9th EASN International Conference
European Aeronautics Science Network
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Booklet of Abstracts
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Digital twin of the rotor-shaft of a light weight electric motor during aerobatics loads

*Robert Goraj*

Airworthiness considerations regarding a shaft of an electric motor are presented. A fatigue lifetime prediction analysis based on one step load spectrum is performed during high cycle fatigue. Time dependent normal and shear stress components are estimated using a high-fidelity digital twin built in Siemens PLM Nx Nastran as a finite element model (FEM). Linear and centrifugal acceleration as well as gyroscopic moment, motor torque, propeller thrust and thermal loads are taken into account. The equivalent cyclic degree of utilisation and a safety margin against the slip of a press-fitted shaft to rotor hub connection is estimated.

Next Generation Product(ion)..!? Manufacturing Turbomachinery Components in a Digital Environment

* Sascha Gierlings*

The trend of a higher digitalization in industry is heavily promoted since several years. By now, however, most of the successes that have made it to the factories are usually limited to optimized logistic chains - even though the huge potentials of using a fully networked infrastructure down to the manufacturing process in the machines is considered self-evident. This presentation intends to present methods and examples of how to better understand and learn from what is actually happening on the shop floors through data, and how data has to be step-by-step processed into information in order to gain benefits for the product throughout its value chain.

Data analytics case studies in the maintenance, repair and overhaul (MRO) industry

* Maurice Pelt, Konstantinos Stamoulis, Asteris Apostolidis*

The aircraft maintenance process is often characterized by unpredictable process times and material requirements. This problem is compensated for by large buffers in terms of time, personnel and parts, resulting in higher costs. Data analytics seems to be a promising way to tackle the problem of unpredictability in MRO by unleashing valuable information from the massively growing amount of data. An applied research project was organized across 25 case studies for eight different aviation MRO companies. The main research question is: How can SME MRO’s use fragmented historical maintenance (and other) data to decrease maintenance costs and increase aircraft uptime? The Cross Industry Standard Process for Data Mining (CRISP-DM) methodology provided a structural guideline for organizing activities. A representative selection of the case studies reflect the MRO companies and typical challenges they face and can be grouped into 3 categories of data mining approaches, presented here with their corresponding results:

1. Visualization
   Case: Development of KPI’s and dashboards to identify maintenance tasks that are executed long before they should be performed according to the maintenance instructions. This information was used to optimize maintenance planning in an airline MRO organization.

2. Statistical Data Mining
Case: The prediction of the remaining useful tire lifetime based on six input parameters and using regression algorithms. This led to better replacement planning in an airline MRO company.
Case: The accurate prediction of required man hours for either planned or unplanned MRO tasks (findings) by automated selection of forecast algorithms and distribution functions. This was implemented in a maintenance tool for a SME MRO company.

3. Machine Learning

Case: The identification of the main factors related to low lead-time accuracy of a component maintenance organization. Thirteen parameters and combinations were visualized and analyzed with statistics and machine learning methods.
Case: The prediction of whether a certain component will need maintenance or not. The prediction accuracy of seven machine learning methods using nine input parameters was evaluated, with the resulting recommendation to add more external data.
Case: The analysis of free text maintenance records using automated natural language processing (NLP). A dashboard was implemented for an airline MRO organization that automatically triggers alerts and extends the appropriate investigation.

Furthermore, the current project led to the following extra findings and recommendations for implementing data mining in the Aviation MRO industry:

a. Clearly, aviation maintenance companies are underutilizing the potential of data, due mainly to a focus on compliance rather than prediction. The availability of external data from airline operators, suppliers and OEM’s was hampered by confidentiality and ownership issues. Time-consuming data preparation work was often needed to make the data quality acceptable.

b. In many case studies the prediction accuracy is compromised by the lack of relevant inputs. For example, sensors are missing to measure certain characteristics that are related to the failures of the components in an aircraft. Another explanation is the relatively small sample size of similar events due to the wide variation in components and maintenance tasks.

c. Data visualization is a natural starting point in data analytics and has proven to be very useful for MRO companies as they start data mining. Next is prediction and machine-learning. Each problem needs to be approached with the most suitable and less complex method to address the corresponding objective. Focused applications that target real problems obtain the best results.

d. Correlations were often investigated. However, it is more powerful to measure parameters that have a causal relationship with defects. Companies should combine data-driven models with expert and failure models to create higher prediction accuracy.

e. The human factor is very important in data mining in MROs. Companies should introduce data scientists into their organization. It is equally important to train operational management and mechanics, because they generate the data and use the new information sources to improve their work.

All these DM case studies highlight the prospects for optimized and sustainable MRO processes. Overall, the ‘Data Mining in MRO’ process optimization research project delivered promising proofs of concept and pilot implementations. It created valuable insights and recommendations about the feasibility and effectiveness of modern data science techniques at medium-sized aviation maintenance companies.

Energy Efficiency in Aeronautic Production through Industry 4.0 Implementation
Miguel Angel Castillo
This contribution includes Aernnova approach on Industry 4.0 for energy efficiency. This approach develops and integrates, throughout the value chain of parts and production units, from the design to the supply and manufacturing process in the production plant, a tool to improve the energy efficiency:

- seeking an improvement in the sustainability of the processes,
- aiming to reduce the use of material and energy resources,
- reducing the environmental impact in terms of waste and emissions.

The new monitoring tool is developed to enable observation of the environmental impacts of the processes and / or operations, depending on the different variables defined for their control. This monitoring tool will make possible to measure the evolution of sustainability on a continuous basis of the modeled manufacturing process. This tool enables:

- to implement a plan for the continuous improvement of the energy performance of the pilot plan, through an energy management system module
- to make a more efficient and sustainable consumption of the raw materials necessary for the manufacture of the components.
- to identify the most efficient productive equipment.

There is a need to study the manufacturing processes and operations. This is carried out to identify the parameters that regulate the manufacturing processes functionalities and the generation of environmental impacts.

From the collection of data on the parameters defined by the studies described before, and their analysis, those parameters that have a direct influence on environmental impacts will be identified. Then, the relationships between key productive parameters and environmental impacts are concluded.

**FASTEN: EU-Brazil cooperation in IoT for manufacturing. Embraer use case**

*Ricardo J.N. dos Reis, Flávio Diniz; Rosana Yamasaki; Luciana Mizioka; Gléverson Lemos; Marta Quintães; Ruben Menezes; Flávio Amadio; Rita Sousa; Daniel Vieira; Miguel Furtado; Narciso Caldas*

FASTEN is an H2020 project under a bilateral call UE-Brazil. Embraer is a global aerospace company, with manufacturing and assembly lines in Europe, Brazil and USA. FASTEN aims to advance IoT and IoT enabled applications to support Industry 4.0 concepts, namely in the area of automation and additive manufacturing. The project results will be demonstrated through two pilots: one in Brazil, lead by a ThyssenKrupp use case, and the other in Europe, at Embraer facilities in Portugal. The project results for the Embraer use case will be presented, with emphasis on bilateral collaboration gains provided by exploiting common frameworks for development, open architecture and future opportunities for exploitation.

**Collaborative Augmented worker and Artificial Intelligence in Zero defect Manufacturing environment**

*Michele Sesana, Abdulrahman Moussa*

The industry 4.0 paradigm is carrying several technologies in the factory. The H2020 QU4LITY project is investigating the role of the human worker in new highly automated zero-defect manufacturing environments and which is the level and way of collaboration with the Artificial Intelligence in controlling production parameters, quality of products manufactured and collaborative real-time troubleshooting of emerging production misalignment.
The first technological trend analysed is the eXtended reality technologies (encompassing Virtual reality, augmented reality and mixed reality) which are changing the way in which people perceive the digital world having this fully digitalised and connected in to digital twin for fidelity in replicated environments or connected to the physical element of the factory (machineries, equipment/robots, products, etc.). Augmented Reality is quickly progressing, Gartner in the 2018 version of the famous Hype cycle 2018 moved it after at the bottom of the “Trough of disillusionment” and ready to get more mature getting back to expectation and really moving to a more maturity to be widely adopted. In particular AR is progressing in maturity of wearable devices like the Microsoft HoloLens which will have a new major upgrade on the second half of 2019.

The second technological trend is Artificial intelligence which is one of the most disruptive classes of technologies, which is expected its Widespread in 2019 and will become more widely available due to cloud computing, open source and the “maker” community. The technology is changing the way in which data is managed passing from a passive collection of data, to active reacting IOT system analytics and moving towards more and more sophisticated intelligent systems which understand the context in the factory and predicting possible defects and providing prescriptions to the factory itself including both equipment and workers.

The QU4LITY project address the thematic of zero-defect manufacturing like aerospace from different perspectives. The focus of this paper is to define a system by which the augmented worker wearing an Augmented Reality connected headset can collaborate with the shopfloor Artificial Intelligence to better and timely support the goal of zero product.

**An IIoT-based architecture for decision support in the aeronautic industry**

*João Basto*, *Narciso Caldas*, *Roberto Vita*, *Romão Santos*, *Symone Alcalá*

Nowadays, industries deal with a necessity to improve their performance, either due to market demand or to the technological forces driven by the Industry 4.0 growth. This paper aims to design a reference architecture for decision support of manufacturing systems, using real-time monitoring, dashboards, simulation and predictive analytical tools. This architecture integrates critical equipment, manufacturing and corporate systems through an Unified IIoT Cloud Platform.

A real case study on the aeronautic industry illustrates the viability of this architecture to enhance productivity, predict equipment failures and bring agility to react to unexpected events. In this case study, data from robotic resources’ sensors is read in real-time and stored in a database. The monitoring tool displays the current status of the sensors and the predictive tool uses the data to calculate a probability of failure for the robot. When this probability reaches a certain threshold, the simulation tool is triggered to evaluate the impact of the disruption in the system’s productivity. In order to capture the current state of the manufacturing system, the simulation uses data from the corporate systems of the factory.

The results from all the tools are displayed online, so that each operator can access in their own devices.

**Digital Transformation in Aeronautics through the ICARUS Aviation Data and Intelligence Marketplace**

*Fenareti Lampathaki*, *Michele Sesana*, *Dimitrios Alexandrou*

While drifting all industries, the digital transformation wave aspires to generate ‘connected’ aircraft and passenger experiences in aviation. Despite its technological sovereignty, the aviation ecosystem from
airlines and airports to OEMs and MRO providers is in fact not resting on its laurels, but is almost unanimously invested in some way into a digital transformation strategy. At the same time, data is nowadays at the heart of the disruptions occurring across the economy, with aviation stakeholders aggressively investing in harnessing their data as critical corporate assets to drive strategic insights, improve operations, and support faster aircraft turnaround and predictive maintenance timings. Over the past years, various ambitious initiatives to mine and exchange data within closed ecosystems of aviation stakeholders at the same level have emerged (e.g. Skywise between Airbus and airlines) yet there is still little data diffusion and sharing across the plethora of the broader aerospace-related stakeholders. In this context, the paper will focus on the ICARUS platform that leverages aviation data to help companies and organisations (whose operations are directly or indirectly linked to aviation) to simultaneously enhance their data reach, as well as to share / trade / enrich their existing data sources and intelligence, in order to gain better insights into their status quo. In support of the Industry 4.0-inspired quest for data-driven digital transformation, ICARUS offers a set of unique offerings to 1st-tier (e.g. airports, airlines, aircraft manufacturers, etc.) and 2nd-tier (e.g. OEM suppliers, MRO providers, GDS providers, etc.) aviation stakeholders, including: (a) end-to-end data security allowing to encrypt and check-in data through an on-premise environment, (b) trusted data sharing for creating, signing and validating smart data contracts in an immutable manner to acquire aviation-related data, (c) advanced access control to regulate access to the privately owned data assets through declarative authorization policies, (d) secure and private analytics space for designing and executing analytics and “applications” in private sandbox environments, spawn on demand, (e) intuitive data exploration in order to find, understand and explore aviation-related data, and (f) effortless data linking that aims at curating, mapping and linking the privately owned data assets with external data based on a common data model. In the paper, the ICARUS benefits, challenges, limitations and lessons learnt regarding digital transformation in the aeronautics industry in particular will be discussed.

Industry 4.0 in Aeronautics: challenges and experiences in EU-funded projects

Sergio Gusmeroli, Ricardo Reis, Roberto Sanguini, Michele Sesana, Fabio Floreani

The fourth industri revolution (Industry 4.0) is a term coined in 2011 in Germany to indicate the full adoption of Cyber Physical Systems in Production. The new Industry 4.0 Smart Factory would then be able to support the Internet of Things and the Internet of Services. Since that time and following the World Manufacturing Forum editions, the Industry 4.0 concept has evolved in two main directions: one the one side it is now encompassing not just the production of physical goods, but is also the whole value chain of products including pre- and post-production phases; on the other side, new characteristics have been added to the CPS concept including e.g. “make to order” manufacturing, product service systems and sustainable human centric workspaces.

Since then several National and Local initiatives have been undertaken in order to maximize the dissemination of the industry 4.0 Mantra and fiscal incentives, proof of concepts, pilots and pre-commercial Lighthouse plants have been developed in several EU Countries.

The adoption of Industry 4.0 in real life production systems has always seen aeronautics in a leading edge position, as pioneer for digital transformation and business model innovation. Large manufacturing enterprises in the aeronautics have understood since the very beginning the disruptive innovation of Industry 4.0 technologies and new derived business models (such as servitisation and remote maintenance). Moreover, ecosystems of SMEs in the aeronautics value chains have followed the Large Manufacturers in their Digital Transformation in terms of Products, Processes, Platforms and People.
EU-funded projects (and specifically H2020 projects) are playing a key role in the technology maturation of Industry 4.0 technologies and in their full adoption by industry. In this paper we are going to present two Industry 4.0 experiences grown up in two distinct cross-industry H2020 projects: the former (more in line with the original definition of Industry 4.0) addresses the CPS-isation of production plants by Industrial IOT devices and platforms and is located in Evora Embraer production plant (FASTEN project); the latter implements the human-centric workplace paradigm by realizing a VR / AR training and maintenance system for helicopters in the Leonardo helicopter Training Academy in Sesto Calende (FITMAN project). Results achieved and experiences gained are collected and assessed in order to provide guidelines and recommendations for further replication of this Industry 4.0 solutions in other industrial sectors and manufacturing contexts.

Linked Data Architecture for Assistance and Traceability in Smart Manufacturing

Adrian Singer, Ken Wenzel, Marko Friedemann

Traceability systems and Digital Assistance solutions are becoming increasingly vital parts of modern manufacturing environments. They help tracking quality-related information throughout the production process and support workers and maintenance personnel to cope with the increasing complexity of manufacturing technologies. In order to support these use cases, the integration of information from different data sources is required to create the necessary insights into processes, equipment and production quality. Common challenges for such integration scenarios are the various data formats, encoding and storage solutions, software systems, technologies and interfaces that are involved in the acquisition, transmission, management and retrieval of the necessary data. Nowadays, there is no generic approach that would be able to address the individual challenges for the adaptation and integration of a given number of systems and components, let alone for keeping track of the inevitable changes in heterogeneous systems.

This paper proposes a system architecture based on Linked Data with related web services as a basis for modular and independent assistance software. Where applicable, data is represented using linked-data concepts while semantics of production data and descriptive information are represented as ontologies. The proposed concept is illustrated with examples from the manufacturing domain like maintenance on forming machines, data analysis and traceability.
PARE: Perspectives for the Aeronautical Research in Europe - Women’s value(s) in PARE project


In order to support the achievement of the ACARE 23 Flightpath 2050 goals, it is of paramount importance to trigger strong collaboration between various European stakeholders. This is precisely the main aims of the project PARE (Perspectives for Aeronautical Research in Europe), an EU-funded project started in Nov. 2017. Along its 3 years of implementation, PARE will create a series of three yearly reports (YR) with the goal to assess information on the perspective for aeronautical research in Europe, covering the progress of the 23 Flightpath 2050 goals and related issues. Moreover, the YRs will provide appropriate recommendations to the decision-making authorities to support specific actions aimed at overcoming the possible gaps still existing towards the accomplishments of the FP goals. During the first year, the project developed roadmaps for each of the 23 Flightpath 2050 goals, indicating the evolution from 2000 to 2015 (historic factual basis); the progress expected over the next decade; the remaining gap to be covered in 2025-2050.

In addition, PARE retains a permanent focus on gender issues and provide the best advice on how to increase the participation of women in aeronautics. Several members of PARE have relevant experience in addressing gender issues in the aerospace sector, and they have participated in initiatives on gender issues in the past and intent to continue to do so in the PARE project. The recommendations for future actions stress the importance of involving women at all levels and dimensions of aeronautics research and in STEM. It is worth to be mentioned that one of the Flightpath 2050 goals states that “Students are attracted to careers in aviation”, whereas today the situation is rather unbalanced between men and women. A schematic view of the role of PARE with respect to the 5 ACARE challenges is summarised in Figure.

TRA Visions: Transport Research Arena 2020

George Smyrnakis, Ioannis Ergas

The European project TRA VISIONS 2020, supported by the European Commission, invites both junior and senior researchers from all over Europe to submit their scientific papers for smart, sustainable and integrated transport and mobility of people and goods to the competition. TRA VISIONS takes place every two years and awards prizes to young and senior researchers for innovative concepts and transport solutions throughout Europe.

Open Science in Aeronautic and Air Transport Research: Why Bother?

Martin Spieck, Diana Penzien, Tina Klages, and Martin Maga

Open Science is the concept to make scientific research as transparent and accessible as possible. The approach bases on “cooperative work and new ways of diffusing knowledge by using digital technologies and new collaborative tools”.
The term “Open Science” serves as an umbrella for many manifestations, or instantiations, of open scientific activities. Open in this context means that anyone can access, use, modify and distribute all different aspects of scientific research. There are numerous classifications available that structure Open Science into its various elements, depending on the field of science, the background of the researchers, and the objectives and the specific requirements of the application. One of the most widely used breakdown structures is often referred to the Six Principles of Open Science: Open Access, Open Data, Open Source, Open Methodology, Open Peer Review and Open Education, with the idea that these six elements represent the main steps of the scientific process. Other approaches contain elements like Open Infrastructure, Open Notebook, or Citizen Science.

Relevance to AAT Research

Open Science is one of the three policy priorities of the current European Commissioner for Research, Science and Innovation, Mr Carlos M.F. Moedas. As a part of the European Commission’s Digital Single Market initiative, Open Science shall reshape the entire research cycle, “from the inception of research to its publication”.

Of course, this long-term strategic aim of the Commission also relates to aeronautic & air transport (ATT) research. EC-funded AAT research, however, does not end with publication. Among other goals, one major objective is to strengthen and maintain the competitive edge of Europe in an increasingly contested market of high strategic and economical relevance.

Not astonishingly, the AAT research community has so far met the concept of Open Science with little interest and enthusiasm. After all, continuous research, technology development and innovation is one of the main pillars on which the success of this high-tech sector is funded. Some particularities and special conditions and features of aeronautic and air transport are seen as an additional obstacle to Open Science, such as the long lead times and high up-front investment costs, technical demands at the border of feasibility in combination with increasing pressure on costs, and rigorous certification requirements.

On the other hand, Open Science offers a significant potential for improvement to strengthen the efficiency of AAT research and to support Europe’s competitiveness on the market. It would be negligent to simply brush aside any attempt to purposefully implement elements of Open Science just because it might break with cherished habits and convenient routines.

Objective and content of the paper

The paper aims to serve as a starting point for a more thorough and intense discussion of the kind and characteristics of Open Science the aeronautic and air transport sector needs to unlock the potential, avoid possible downsides of an inappropriate openness, and last not least comply with the Commission’s long-term strategy in a way that suits the needs, requirements and interests of all actors in the European AAT research landscape. It may be added that the scope and possibilities of Open Science go well beyond the first applications which are already underway, e.g. in the field of Open Access.

The paper consists of four main parts:

1. A brief general introduction to Open Science, an outline of the European Commission’s strategic objectives, and some success stories from other sectors to show not-so-evident advantages of the concept.
2. Historic and more recent examples of activities in AAT research and technology development where some of the principles of Open Science had already been employed – even though the term had not been coined then – and what we could learn from those.

3. An overview of pain points and bottlenecks which have to be overcome in order to allow for wide-spread implementation and application of Open Science to the benefit of the European aeronautic and air transport sector.

4. A description of potential enablers, drivers and accelerators for unlocking the potential Open Science can offer for AAT research.

The paper closes with a suggestion for the next step in the comprehensive process to shape an Open Science which is compatible to and supportive of effective future AAT research in Europe.

**Be Open: Open Science in transport research**

*Afroditi Anagnostopoulou, Maria Boile*

The current technological advances and the rapid development of new collaborative tools have endorsed an on-going transformation of transport research enabling research information sharing. This systematic change of transport research covers a wide range of aspects and the BE OPEN “European forum and observatory for OPEN science in transport” project aims to create a common understanding on the practical impact of Open Science and to identify and put in place the mechanisms to make it a reality in transport research. Openness, transparency, fairness, reproducibility of science are key areas around which BE OPEN will seek to establish the ground rules for the transport research communities, ultimately establishing a community of transport research organizations willing to work on the basis of a commonly agreed “Open Science Code of Conduct”. The novelty of the project is to contribute in implementing Open Science approaches in transport research enabling stakeholders to share and use all available knowledge at an earlier stage in the research process. Specifically, BE OPEN targets the promotion, regulation and standardization of Open Science in transport research through (i) developing a framework of common understanding for realizing Open Science services that will provide technical interoperability, data and information interoperability and legal interoperability; (ii) developing the TOPOS forum and observatory for different stakeholders to support an evidence based dialogue; (iii) providing a roadmap and concrete guidelines for operationalizing Open Science services and guide key actors on how to adopt and adapt Open Science services in their research workflows; and (iv) designing a Code of Conduct for adopting them considering the main legal and security issues for their implementation. This opening up of science and research is expected to lead to a European community of transport research stakeholders willing to work together and speed up the path from research to innovation and promote citizen’s engagement in the scientific process.
The climate impact of hypersonic transport  

Grewe, V., Hauglustaine, D., R. Valoroso, J. Emmerig

Some innovative high-speed aircraft configurations have now the potential for an economically viable high-speed aircraft fleet. They make use of unexploited flight routes in the stratosphere, offering a solution to the presently congested flight paths. Those flights have also to ensure a minimum environmental impact, e.g., in terms of emitted greenhouse gases and their climate impact. Here we are investigating the climate impact of hypersonic configurations and compare those to an adequate reference subsonic configuration. While subsonic aircraft emit at tropopause altitudes (roughly 10-12 km) hypersonic configuration emit above 25 to 30 km, hence deep into the stratosphere, where atmospheric lifetimes are substantially larger and emitted species accumulate in the atmosphere. We consider a large range of emissions and effects, which include CO2, H2O, H2, NOx, and particulate emissions, and regard effects on atmospheric changes of CO2, H2O, O3, CH4, and contrails.

Aero-Propulsive and Flight Control System Analysis of the STRATOFLY Hypersonic Cruiser  

Marco Marini, Pietro Roncioni, Roberta Fusaro, Nicole Viola

The STRATOFLY project, the last one of a series of projects co-funded by the European Commission in the last fifteen years, is a highly-multidisciplinary project combining technological and operative issues for hypersonic civil aircrafts and aiming to study the feasibility of high-speed passenger stratospheric flight. Technological, environmental, operational and economic factors, that allow the global sustainability of new air space’s exploitation, are taken into account, drastically reducing transfer time (i.e. antipodal flights in less than two to four hours), emissions and noise, and guaranteeing the required safety levels. The main project objectives are to refine the design and the concept of operations of the LAPCAT-II MR2.4 vehicle, and to reach the ambitious goal of TRL=6 by 2035 for the concept, considering that the crucial technologies of STRATOFLY vehicle may represent a step forward to reach the goal of future reusable space transportation systems.

The reference configuration for the STRATOFLY project is the LAPCAT-II MR2.4 vehicle (see Fig. 1) which has a length of 94 m, a wing-span of 41 m, a GTOW of 400 tons and carries 300 passengers. The configuration is a waverider aeroshape with a dorsal mounted combined propulsion system, i.e. a merging of six Air-Turbo-Rocket (ATR) engines, operating from take-off to Mach=4÷4.5, and a Dual-Mode-Ramjet (DMR) engine operating from Mach=4.5 to the cruise target Mach=8.

The reference flight trajectory is Brussels-Sydney with a hypersonic cruise at Mach 8 and 32÷33 km altitude, with a distance flown of about 18700 km and a flight duration of about three hours.

The aero-propulsive characterization of the STRATOFLY vehicle along the whole flight reference mission, with an assessment of aero-propulsive balance, mechanical, inertial and thermal loads, and vehicle’s trimming in the different phases of flight, is the main topic of the present paper. Moreover, the on-going evolution of the STRATOFLY vehicle aeroshape will be described in detail, in particular focusing the attention on the design and analysis of flight control system, i.e. the sizing of ailerons/elevons and vertical
tail, and the refinement of the DMR intake design with the adding of rounded leading edges, optimized to reduce locally the aerothermal loads while keeping the same DMR intake’s performance.

The final paper will contain some meaningful results in terms of aerodynamic database with the last version of control surfaces and performance of the DMR intake in terms of pressure recovery factor, captured air mass-flow and thermal loads on its leading edges.

**Analysis of the Thermal and Energy Management System for STRATOFLY MR3 Vehicle**

*R. Fusaro, N. Viola, D. Ferretto, M. Marini*

One of the major challenges that is currently faced by the designers of hypersonic civil transportation systems is the definition of adequate thermal and energy management strategies to be adopted to withstand very high temperatures, heat fluxes and heat loads all along the mission. Many research activities on this topic envisaged subsystems and technologies optimized to perform thermal protection, control and management issues. Conversely, the current trends in hypersonic speed transportation design are going towards the development of multi-functional subsystems highly integrated in the vehicle, whose working points are the results of multidisciplinary optimization processes. In this context, within the research activities carried out in the framework of LAPCAT-II, ATLLAS-II and HIKARI projects, ESA developed the concept of TEMS, the Thermal and Energy Management Subsystem. This is a clear example of an innovative multifunctional subsystem combining together the management of thermal loads and the electric power generation and supply, making benefits of liquid hydrogen boil-off, that is usually considered a drawback. The high level of innovation, the complexity of the TEMS and constituent components, the low maturation levels of the technologies as well as the integration on-board the reference vehicle needs to be furtherly investigated in order to confirm the technical feasibility of the concept. The TEMS is conceived to use the boil-off vapors coming from the evaporation of the LH2 within the tanks as main cooling means for the cabin, the powerplant and the air-pack of the Environmental Control System (ECS), being finally injected in the combustor of the engines. Moreover, the high-pressure liquid hydrogen is used to drive a dedicated turbine providing mechanical power to the devices of the TEMS itself, producing enough power margin for the other on-board subsystems. Tanks and cabin are in fact highly integrated in a bubble-structure architecture, which characterize the overall internal configuration of the wave-rider.

This paper aims at presenting the application of this concept to the reference vehicle of the STRATOFLY project, funded by the European Commission, under the framework of Horizon 2020 plan, with the aim of assessing the potential of this type of high-speed transport vehicle to reach TRL6 by 2035, with respect to key technological, societal and economical aspects. Main issues of the project are related to thermal and structural integrity, low-emissions combined propulsion cycles, subsystems design and integration, including smart energy management, environmental aspects impacting climate change, noise emissions and social acceptance, and economic viability accounting for safety and human factors. After a short introduction pointing out the main challenges related to thermal management of a hypersonic vehicle, Section II describes the main features of the STRATOFLY MR3 reference vehicle as well as the reference trajectory, i.e. the antipodal Brussels-Sydney route. Then, Section III focuses on the design and sizing of the Thermal and Energy Management Subsystem for the STRATOFLY vehicle whilst Section IV describes the way of working of the TEMS subsystem in the different operating conditions expected all along the mission. Eventually, main conclusions are drawn and technical and operational challenges for the integration of this subsystems on-board the vehicle are discussed.
STRATOFLY MR3 vehicle design and subsystems integration

R. Fusaro, N. Viola

The worldwide incentive to reconsider commercial high-speed transport urges Europe to quantitatively assess the potential of civil high-speed aviation with respect to technical, environmental and economic viability in combination with human factors, social acceptance, implementation and operational aspects.

As eluded in previous studies, with special reference to those carried out in the European framework, some innovative high-speed aircraft configurations have now the potential to assure an economically viable high-speed aircraft fleet. They make use of unexploited flight routes in the stratosphere, offering a solution to the presently congested flight paths while ensuring a minimum environmental impact in terms of emitted noise and greenhouse gasses, particularly during stratospheric cruise. Only a dedicated multidisciplinary integrated aircraft design approach could realize this, by considering airframe architectures embedding the propulsion systems as well as meticulously integrating crucial subsystems. In this context, starting from an in-depth investigation of the current status of the activities, the STRATOFLY project has been funded by the European Commission, under the framework of Horizon 2020 plan, with the aim of assessing the potential of this type of high-speed transport vehicle to reach TRL6 by 2035, with respect to key technological, societal and economical aspects. Main issues are related to thermal and structural integrity, low-emission combined propulsion cycles, subsystems design and integration, including smart energy management, environmental aspects affecting climate change, noise emissions and social acceptance, and economic viability accounting for safety and human factors.

This paper aims at describing the current status of the STRATOFLY MR3 vehicle concept. For this reason, the Introduction summarizes main goals and challenges of the H2020 STRATOFLY project, especially focusing on the main design challenges and their connection with both technical and operational challenges.

Section II is dedicated to the description of the external vehicle configuration. STRATOFLY MR3 external layout is the results of iterations based on a waverider design methodology targeting the optimization of the overall vehicle efficiency in cruise condition at Mach 8. Attention is also devoted to Empennages and control surfaces design and sizing that need to guarantee the stability and controllability in both low-speed and high-speed regimes. In this context, the optimization of air intake and nozzle with the airframe is tackled, providing indications on how to couple aerothermodynamic and thermal issues to properly select values for leading and trailing edges rounding radii.

Then, Section III focuses on the internal vehicle layout, reporting the main results of the design and sizing of the main on-board subsystems. Special attention is devoted to the design and integration of Passenger Compartment, Cryogenic Propellant Subsystem, Propulsive Subsystem, Landing Gear and Thermal and Energy Management Subsystem. The validation of the vehicle concept is provided in Section IV where the fulfillment of the main operational requirements such as the capability of covering antipodal routes, is related to the expected technological improvements.

Eventually, main conclusions are drawn and suggestions for next steps are provided.
Main Challenges and Goals of the H2020 STRATOFLY Project

Nicole Viola, Roberta Fusaro, Bayindir Saracoglu, Christophe Schram, Volker Grewe, Jan Martinez, Marco Marini, Santiago Hernandez, Karel Lammers, Axel Vincent, Didier Hauglustaine, Bernd Liebhardt, Florian Linke, Christer Fureby

The worldwide incentive to reconsider commercial high-speed transport urges Europe to quantitatively assess the potential of civil high-speed aviation with respect to technical, environmental and economic viability in combination with human factors, social acceptance, implementation and operational aspects.

As eluded in previous studies, with special reference to those carried out in the European framework, some innovative high-speed aircraft configurations have now the potential to assure an economically viable high-speed aircraft fleet. They make use of unexploited flight routes in the stratosphere, offering a solution to the presently congested flight paths while ensuring a minimum environmental impact in terms of emitted noise and greenhouse gasses, particularly during stratospheric cruise. Only a dedicated multidisciplinary integrated aircraft design approach could realize this, by considering airframe architectures embedding the propulsion systems as well as meticulously integrating crucial subsystems. In this context, starting from an in-depth investigation of the current status of the activities, the STRATOFLY project has been funded by the European Commission, under the framework of Horizon 2020 plan, with the aim of assessing the potential of this type of high-speed transport vehicle to reach TRL6 by 2035, with respect to key technological, societal and economical aspects. Main issues are related to thermal and structural integrity, low-emission combined propulsion cycles, subsystems design and integration, including smart energy management, environmental aspects affecting climate change, noise emissions and social acceptance, and economic viability accounting for safety and human factors.

This paper aims at summarizing the main challenges and goals of the STRATOFLY project, highlighting the steps forward with respect to the past European Projects and underlying the next planned goals.

Thus, after a short introduction, Section I depicts the background and the heritage from which STRATOFLY project is moving further. In this context, special attention is devoted to the latest achievements of the LAPCAT-II project with special emphasis on the MR2.4 reference configuration. Then, Section II reports synthetically the main challenges of the STRATOFLY project, clearly listing the main objectives of the research activities. Section III describes the integrated multidisciplinary design methodology developed to support the design of innovative, complex and highly performance vehicles. The integration of simulation and CAD modelling as validation methods since the very first design steps is stressed. Complementary Section IV and Section V summarize the main achievements of the project as far as the technological and operational sides are concerned. Indeed, from the pure technical and technological perspective, the key enabling technologies currently under investigation are described with special emphasis on Propulsion and Propellant Technologies, Thermal Protection and Management Technologies and Innovative Structural Configurations. As far as the operations are concerned, some preliminary results related to Pollutant and Noise emission reduction, business case and economic feasibility, and human factors are presented. In this context, several safety-related issues can be considered: from the propellant handling procedures to the risk related to possible out-of-nominal procedures.

Eventually main conclusions are drawn with an indication of the next activities to be carried out in the project.
Analysis of Combined Cycle Propulsion System for STRATOFLY Hypersonic Vehicle Over An Extended Trajectory

Ali Can Ispir, Pedro Goncalves, Bayindir Saracoglu

Hypersonic civil aviation becomes significant by enabling extreme short flight durations for long-haul routes and using unexploited flight altitudes. STRATOFLY project, funded by European commission and is a continuation of former EC projects such as LACAT-I and II, ATTLAS I and II, FAST20XX, HIKARI, HEXAFLY, HEXAFLY-INT., aims at developing the European hypersonic vehicle concept. The aircraft concept is planned to be flew at 35 km flight altitude with Mach 8 cruise speed by using an air breathing combined cycle propulsion plant. Combined-cycle engines designed for hypersonic vehicles provide extended flight operation regime at subsonic, supersonic and hypersonic flight conditions. The plant under investigation consists of two different type of engines: There are six air turbo rockets (ATR) operated from take-off to high supersonic velocities and dual mode ramjet/scramjet (DMR) engine propelling the vehicle at hypersonic cruise conditions. ATR engines consist of two parts; fuel regenerator system and turbo engine. Fuel regenerator is vital for cycle reliability and self-sustainability of the system because it is responsible to heat pick-up from heat source such as combustion chamber walls to provide enough enthalpy increase for fuel turbine. The fuel turbine must drive air compressor and fuel pump to keep thrust level. There is a trade-off between the heat pick-up capacity and the turbine component complexity. The DMR engine is settled in the middle of propulsion duct and started to operate at supersonic speeds to contribute to acceleration. After cruise speed of Mach 4.5, ATR engines shut down and the cruise requirements is fulfilled by only DMR engine which works in both ramjet and scramjet mode depending on flight condition.

In the present study, 1D transient thermodynamic simulations of combined cycle propulsion plant have been conducted between cruise speeds from Mach 0 to 8 in Ecosimpro software platform by using the European Space Propulsion System Simulation libraries. The air-turbo rocket part of the engine is optimized in terms of maximum engine performance and minimum overall weight for low speed part of the trajectory while the supersonic combustion in DMR engine is investigated in terms of ignition, combustion chemistry and fuel – air mixing, modeled by using analytical and empirical expression. The optimized engine parameters are achieved by coupling Ecosimpro software with an optimizer tool namely Computer Aided Design Optimization (CADO) framework developed by the von Karman Institute.

High speed air travel: safety and legal challenges of future spaceports and aerodromes

Roberta Fusaro, Nicole Viola, Tom Walker

The worldwide demand for commercial high-speed transport is pushing the scientific community to both reconsider and assess the benefits and the risks posed by civil high-speed aviation. However, it is not just the technical challenges and risks, and their interface with operational and human factors, which require assessment. Environmental, social acceptance and economic viability issues are all matters which require urgent consideration. In this context, in order to guarantee the possibility of operating these transportation systems on a daily basis, safety and legal aspects deserve special attention. Indeed, the current lack of a specific regulatory framework is a potential 'showstopper' for future high-speed civil transport. Starting from these considerations, this paper aims at providing an overview of the main safety and legal challenges of high-speed transportation systems and to describe the current developments on the legal and regulatory side. In particular, the main goal of this paper is to highlight the way in which the design of the spaceplane may create safety issues at ground level (e.g. cryogenic propellant handling and storage, risk of explosion, etc…). The expected safety and legal assessment will have a general validity
covering a wide range of high-speed transportation systems. However, for the sake of clarity, a specific case study is used as reference and as an example throughout the paper, namely: a point-to-point vehicle, able to transfer 300 passengers at a time, covering antipodal routes, flying at Mach 8 in the stratosphere. In Section I, the main goals of the research activity will be presented. In this context, an overview of the currently on-going initiatives aiming at defining a proper regulatory framework will be introduced. Then, Section II will provide a thorough description of the high-speed vehicle here considered as reference as well as of its typical mission profile, paving the way for the discussion about the main safety challenges posed by high-speed vehicles in Section III. Safety will be considered in its broadest sense, encompassing the vehicle reliability concept, the safety of passengers on-board, the risk for people living in areas overflown during the mission as well as all the on-ground personnel and people living or working in areas close by the launch and landing locations. Focusing on the spaceport/aerodrome, the main sources of risk explored will relate to the handling, transportation and storage of the dangerous chemical reactants used to propel these spaceplanes. Thus, Section IV will focus on the safety issues imposed by the selection of specific propellant. In particular, the case of cryogenic liquid hydrogen will be investigated in detail. Section V will focus on the legal and regulatory aspects in more depth. Taking the case study, it will explore a hypothetical series of incidents/mishaps, providing an opportunity to examine potential causes and their legal consequences for those involved, to include: designers, manufacturers, ground operations operatives and passengers/flight participants. The case study will be examined from the UK perspective (through both EU-derived law and the emerging principles under domestic legislation and the new Space Industry Act 2018) and explore whether a robust regulatory framework can simultaneously promote both innovation and safety in high-speed air and space travel. Eventually, preliminary conclusions will be drawn and suggestions for the development of future regulatory frameworks will be outlined.
Exploration and optimization of a Blended Wing-Body concept featuring distributed electric propulsion with gradient optimization techniques

Alessandro Sgueglia, Peter Schmollgruber, Emmanuel Benard, Nathalie Bartoli, Joseph Morlier

In the past years, air traffic has continuously increased, with an impact on the emissions level. Thus it has become a major issue for the aeronautical field to face its responsibilities and seek for solutions to lower its environmental footprint. Research is focusing on the study of unconventional aircraft: among all the possible solutions that can be found in literature, hybrid propulsion is a possible solution to reduce emissions. In particular, the results from the NASA N3-X show that the most promising results are achieved when distributed electric propulsion is mounted on a BWB configuration. Indeed, thanks to the larger area, the benefits of DEP are enhanced by this configuration, which has also more empty volume available for the electric devices and a naturally high aerodynamic efficiency. Also, this configuration is mainly indicated for the use of BLI devices, since the portion of boundary layer ingested is increased because of the larger surface subject to this phenomenon.

This work presents a new framework for the sizing of a BWB featuring distributed electric propulsion, based on the integration of the sizing tool called FAST (Fixed-wing Aircraft Sizing Tool), developed at ISAE-Supaero and ONERA, within OpenMDAO, an optimization code developed at NASA Glenn Research Centre.

Thanks to the efficient gradients calculation offered by OpenMDAO, the new framework performs the sizing and the optimization of the proposed configuration with low computational cost, making it suitable for conceptual design exploration. The selected use case for this configuration is a typical short and medium range mission, considering 150 passengers; an entry into service in 2035 is foreseen.

To understand the characteristics of this aircraft, performances are evaluated against an A320Neo, resized to match the 2035 hypothesis, for different sets of parameters.

Finally, once that the best geometry is selected, some mission optimizations are carried out in order to understand the sensitivity of the concept with respect the mission profile, defined by the thrust rating of the two energy sources for each aircraft phase.

Parallel hybrid electric propulsion architecture for single aisle aircraft - powertrain investigation

Jos Vankan, Wim Lammen

This paper presents an investigation of the fuel- and energy-saving potential through the introduction of several hybrid electric propulsion (HEP) and more electric aircraft (MEA) systems on single aisle aircraft. More specifically, for an A320NEO aircraft the following main electric systems are considered: electric motors, batteries and power electronics for parallel HEP, electric components for replacement of the main pneumatic and hydraulic non-propulsive systems like environmental control system and actuators, and electric power transport and supply. The power sizing of the electric components, as well as their mass effects on overall aircraft mission performance are evaluated by system modelling of the aircraft, turbofan and the considered electric components. It is found for the considered aircraft and missions that the fuel
saving potential of parallel HEP systems alone is very limited or absent. Typically the combination of HEP and MEA technologies shows potential for improved energy efficiency due to synergies of the involved systems and their operation. System evaluations indicate potential, in comparison to the reference A320NEO aircraft, of approximately 14% reduction of trip fuel and 11% reduction of trip energy for short haul missions of about 800nm.

Electric Skydiving Aircraft
Richard Glassock, Warren Williams, Tibor Glesk, Michael Galea

Electric air transport propulsion systems are being developed by most leading aerospace manufacturers, including recreational and small commuter segments as well as traditional large corporations, due to increasing urgency for compliance with future emissions and energy reduction targets such as defined by ACARE. Initial deployment on smaller scale aircraft is proceeding with many new pure-electric powered light and sport aircraft emerging in the market. For example, the 2-seater types, Pipistrel ‘Alpha Electro’ (currently available) and the Bye Aerospace ‘Sunflyer 2’ (scheduled for commercial release during 2019) are finding strong market interest. These electric aircraft have many excellent features including reduced direct operating costs and reduced emissions of CO2, NOx and Noise. The next phase of aircraft propulsion electrification will step up to small commercial passenger and utility aircraft up to 19-seat capacity.

This paper provides an introduction to several new hybrid and electric propulsion concepts for commercial aircraft with a focus on the skydiving application. Skydiving is a popular aviation sport throughout the world with continuous popularity involving hundreds of thousands of people and approximately 1000 centres worldwide, the United States Parachute Association alone recorded 36,770 members at the end of 2014. The potential for development for this application is attractive due to the duty cycle of the mission profile, and the commercial operating fuel costs of the skydiving aircraft operation. Further, the legacy types in use are well suited for near term application of pure-electric propulsion and can lay the foundation for longer range hybrid-electric systems with alternate fuel sources in clean-sheet and retrofit developments.

Air Race E: Electric Racing Aircraft
Richard Glassock, Jeff Zaltman, Louis Flanagan

The University of Nottingham and Air Race E are creating a prototype Formula 1 Air Racing aircraft which will use pure-electric propulsion. The project forms part of the University’s £13m Beacons of Excellence program, which addresses responses to global challenges including sustainable travel. The project will harness developments of new materials, components and technologies aimed at the whole field of electric aerospace propulsion. Air Race E is committed to pushing technology for speed, performance and power management to provide a platform for development and promotion of cleaner, faster and more advanced electric propulsion for civil aerospace applications. This paper details the progress on the retrofit of a Cassutt III air racing aircraft with an electric motor, power electronics and battery system.

Design of distributed propulsion system for general aviation airplane
Nikola Žižkovský, Pavel Hospodář

In this paper, a small airplane is redesigned by using a distributed electrical propulsion (DEP) system. The design procedure is focused on the reduction of fuel consumption reducing in cruise regime with take-off/landing parameters constraints.
In this case, a one third wing area compared to an original airplane is used. Take-off distance and minimum airspeed for landing is achieved by distributed propellers mounted on the leading edge of the wing. These propellers induce velocity on the wing and thereby increase local dynamic pressure, thus the required lift force can be reached with smaller wing area. Moreover, the distributed propellers are assumed as folded in cruise regime to minimize drag when the main combustion engine provides sufficient power. It is a kind of an hybrid power system, where distributed propellers are electrically powered and combustion engine, located in the front of fuselage, is designed for cruise regime. The required power of DEP system in the take-off/landing regime is provided from a battery, while those are charged in cruise regime or at ground.

The weight of batteries, engines, electrical controllers and fuel are assumed in the optimization procedure which is using response surface optimization. Design of propeller and their characteristics are computed by Blade element momentum theory and the propeller-wing interaction is calculated by lifting line theory in a non-linear form. It offers a design of multi-propeller wing with high lift devices. Optimatimal configurations are compared with results of CFD calculations for main regimes (take-off, cruise and landing).

Electric motor-glider powered by a hydrogen fuel cell stack

P. Czarnocki, W. Frączek, K. Drabarek, M. Dudek, A. Raźniak, M. Rosół, T. Miazga, G. Iwański, M. Nikoniuk

The current outcomes of the AOS-H2 electric motor-glider project are presented. The AOS-H2 electric propulsion system (EPS) consisted of an electric motor, proton exchange membrane fuel cell (PEMFC) stack, two hydrogen tanks, an auxiliary polymer-lithium batteries set, (APLBS), and an energy management system. The selection of the electricity supply source would depend on the power and energy demands during the mission. The power demand during run-up and climbing is significantly higher than that for a horizontal flight. Since the power density of HFCS is smaller than that of Li-polymer battery, the selection of the HFCS as a main energy source for the first two stages of the mission was not justified and to save hydrogen and assure possibly long flight time needed for the PEMFC stack flight tests the APLBS was installed. The estimated power demand for the run-up and climbing was about 40 kW, while for horizontal flight just 10 kW under the assumption that the propulsion system would assure climbing rate of 1.5 m/s for 5 min. and about 1 hour level flight. Another purpose of the APLBS was to assure smooth energy management. The APLBS consisted of 96 Li-polymer KOKAM cells, each of 16 Ah capacity, assuring 400 V maximum voltage at full charge and 320 V minimum voltage. The minimum voltage was adequate to assure stable operation of the electric motor at maximum rotational speed 2000 rpm in a wide range of the battery charge state. The number of cells had been selected to provide sufficient energy storage, estimated to be equal to 5.6 kWh, and power input of 30 kW for 5 min., (run-up and climbing - 2.5 kWh), and horizontal flight, in case of the PEMFC stack failure, (10 kW for 15 min.) The line-to-line peak electromotive force of permanent magnet AC motor EMRAX 268MV equalled 230 V at 2000 rpm. The 10 kW PEMFC stack consisted of two 5-kW modules connected in series. Gaseous hydrogen to power it was compressed to 300 bars and stored in two composite containers of a total capacity of 24 Ndm3.

Wing-Propeller Interaction

Nikola Žižkovský, Jan Klesa

Paper describes the effect of the distributed electric propulsion system (DEP) on the aerodynamic characteristics of the airplane wing. Using CFD simulation is described the influence of the wake of the
propeller on the wing for various ratios of the propeller diameter to the wing chord. Unlike the normal case of wing-propeller interaction, periodic boundary conditions are used, i.e. a rectangular wing with infinite span with propellers installed periodically its span is considered. A wind tunnel experiment will be used to verify the calculations. Propeller thrust is set to compensate for airplane drag in horizontal flight, i.e. equal to the wing segment drag, which is increased by the corresponding part of the expected drag of other parts of the airplane. The increase of the drag was determined by the aerodynamic design of a generic airplane with DEP. The benefit of the work are the input data usable for the conceptual design of the airplane wing with DEP.

**An application of ECMS strategy to a Wankel Hybrid Electric UAV**

*Teresa Donateo, Claudia L. De Pascalis, Antonio Ficarella*

In the last decade, concepts of power systems electrification have earned an increasing interest due to their several benefits, such as higher power-to-weight ratio, reliability, compactness, and quietness with respect to the conventional configurations, and, above all, pollutant emissions cutback. In a battery-based hybrid electric system, the environmental-cost benefit derives from both the fuel burning and the electricity production whose contributions have to be considered at the same time when the design process is faced. In a previous work, the authors considered a parallel hybrid electric power system for a tactical Unmanned Aerial Vehicle (MALE-UAV) including a Wankel engine as thermal converter and a permanent magnet electric motor powered by lithium batteries. A hybridization factor of 0.3 (defined as the ratio between the nominal power of the electric machine and the total installed power) was found with a coarse optimization of thermal and electric contributions to the propulsion at each of the segments of 720 seconds in which the flight-path was split up into. In fact, it allowed a 9.4% saving of the fuel mass burned throughout the mission (or, alternative an improvement of endurance of 12%) while maintaining Mpay equal to the baseline configuration’s and increasing MTOW of 10.7%. Starting from this optimal configuration, we address here the topic of a refined optimization of the energy management strategy, i.e. the contribution of the battery to the required power in each segment. In particular, we apply the Equivalent Consumption Minimization Strategy (ECMS) with the goal of minimizing fuel consumption while fully depleting the energy stored in the battery from the beginning to the end of the mission. In the ECMS approach, well known in the automotive field, a local optimization is performed at each time step in order to find the power split between the two converters (engine and motor) that ensure the minimum of the equivalent fuel consumption with the constrain that battery state of the charge follows a desired path. This equivalent fuel consumption is calculated as the sum of the actual fuel consumption, depending on the engine operating point, and an equivalent amount associated to the usage of the battery. This strategy is based, therefore, on the usage of an equivalent factor “s” that needs to be optimized in order to assure the depleting of the battery over the mission. In this investigation, two nested optimizations are performed: one external optimization of the equivalence factor “s” over the whole mission and one internal, finding the best combination, at each segment, of the power delivered by the two converters (thermal and electric) that minimizes the equivalent fuel consumption which is dependent on the value of “s” in the external-loop iteration. The final goal is to find the optimal value for “s” that minimizes the environmental-cost of the aircraft along several flight-paths. To this, the optimized value of the equivalent factor is applied to different mission profiles to check the robustness of the proposed method.
Wing Tip Propeller-Technology Testing with UAS - Concept of Pod and In-Flight Measurement System

Dominique Paul Bergmann, Jan Denzel, Ole Pfeifle, Michael Schollenberger, Andreas Strohmayer

Electric and hybrid-electric propulsion systems are an important technology for the development of future propulsion systems in aviation. Furthermore, the leap in technology that results through advanced electric motors with the high efficiency ratio combined with a compact and light weight design enables new propulsion arrangements and aircraft configurations. This facilitates an effective integration of wing tip propellers with respect to the use of positive aerodynamic effects to increase flight performance and thus reduce emissions. In the project ELFLEAN (Electric wing tip propulsion system for the development of energy-efficient and noise reduced airplanes) the effects of wing tip propellers are investigated to estimate their impact on future aircraft performance. The UAS e-Genius-Mod - a 33.3% scale model of the electric aircraft e-Genius of the University Stuttgart, Institute of Aircraft Design - will be equipped with wing tip propellers to investigate them in relevant environment and to assess the impact on aircraft level.

In order to identify the effects expected by the wing tip propellers (e.g. drag reduction, lift increase) the UAS is equipped with an in-flight measurement system to validate the numerical results of a CFD investigation. In order to be able to make a statement about the impact on the overall aircraft system, a scaled platform with known similarity requirements to the full-scale is used. The contribution will give a brief overview of the nacelle concept and thrust-measurement system design.

Assessment of Aircraft Surface Heat Exchanger Potential

Hagen Kellermann, Mirko Hornung

Research for next generation commercial aircraft is driven by ambitious goals to reduce the aircraft’s environmental impact such as the European Commission’s Strategic Research and Innovation Agenda (SRIA) that targets a 75% reduction in CO2 emissions by the year 2050 compared to the year 2000. A big contributor to achieve those targets is the propulsion system. Novel propulsion concepts with intercoolers or bottoming cycles are currently under investigation to further reduce the specific fuel consumption. Another promising approach seems to be a higher electrification of the on-board systems or even the propulsion system. Examples are the more electric aircraft or electric propulsion systems, whose electric components generate heat. Many concepts result in higher thermal loads of the systems. Conventional cooling concepts require ram air and heat exchangers placed in the airflow path and thus

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1 Advisory Council for Aviation Research and Innovation in Europe, Strategic Research & Innovation Agenda - Volume 1, Brussels: Aerospace and Defence Industries Association of Europe, 2017.
induce drag. Another option is to use existing aircraft surfaces for heat transfer to ambient. These structurally integrated heat exchangers may be beneficial for both weight and drag of the thermal management system because no additional components such as the ram air heat exchanger are required and no components are installed in the flow path. Additionally, heat rejection to the aircraft's boundary layer may lead to drag reductions. The aim of this paper is to investigate the heat sink potential of available aircraft surfaces. For that purpose, a thermodynamic model of a surface heat exchanger covering existing aircraft surfaces is developed in this study. A scalable geometric model of a tube and wing type aircraft with podded engines is derived with a semi-empirical approach. It is used to analyse the impact of aircraft size and available portions of the total surface area. Various dependencies of for example surface temperature, incoming radiation and surface enhancements such as riblets are considered. The ambient conditions differ at each operating point. The study evaluates steady state heat transfer performance in pre-defined sets of Mach number, altitude and ISA deviation. They reflect typical operating conditions of commercial aircraft namely Take-Off, Top of Climb, Cruise and Taxi, which are relevant sizing points for the thermal management system. The results of this paper will quantify the potential of the aircraft's skin as heat sink. Future projects on advanced propulsion concepts can use the results to account for the total amount or a fraction of the system's waste heat.

Design and Development of Hybrid-Electric Propulsion Model for Aeronautics

Emma Frosina, Luigi De Petrillo, Davide Lauria, Adolfo Senatore, F. Curreri, G. Saccone, G. Di Lorenzo, C. Pascarella

Nowadays, worldwide environmental issue, associated to reduction of pollutant and greenhouse emissions are gaining considerable attention. Aviation sector contribution to the whole CO2 released accounts to around 2%, but it is expected to grow in the next future due to increase of demand. Probably, combustion engine design and fuel efficiency have already reached their optimum technology level and only a breakthrough as hybrid-electric propulsion could be able to satisfy the new international more demanding requirements. However, an improvement of the technology readiness level of hybrid-electric propulsion is strongly necessary and many operational and safety challenges should be addressed. In the work here reported, a hybrid-electric model was designed and developed for general aviation aircrafts, by means of the Mathworks® Matlab – Simulink 1D/0D simulation environment. Both thermal and electric energy storage units, transmission systems and power management devices were considered and the overall performances were evaluated during cruise phase and a conventional training mission, characterized by several run (lap) “touch-and-go”. Furthermore, an innovative mathematical methodology was implemented for battery pack discharge profile interpolation. Finally, reliability and accuracy of the new proposed model were evaluated through comparison with the commercial Siemens AMESim® software and an average bias only equal to 5% was achieved.

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Effect of heating rate on micro-formability of Ti6Al4V alloy under an electrical field

Kunlan Huang, Yi Yang, Jie Wang, Yi Qin, Jian Liu

With the rapid development of micro-electro-mechanical systems and micro-system technology, a high requirement is taken out for the micro part manufacture technology, which gives a chance of development for the micro-forming technology. Ti6Al4V offer a combination of good mechanical properties and high temperature properties that render it attractive material for automotive, aerospace and military applications. In this article, a novel micro plastic forming technology was introduced for the forming of Ti6Al4V micro-gear. It is found that the Ti6Al4V micro-gear can be achieved from a Ti6Al4V bar under the electric AC current at 1200°C. When the heating rate increasing from 5°C/s to 40°C/s the formability of Ti6Al4V micro-gear gradually improved. Scanning electron microscopy (SEM) was performed on the deformed specimens to reveal the microstructure. The results showed that the phase transition is the critical mechanism of the superplastic of Ti6Al4V under the electric field.

Cutting force prediction in orthogonal turn-milling of Inconel 718

Felusiak Agata, Chwalczuk Tadeusz, Wiciak-Pikuła Martyna, Madajewski Marek

Machining of materials such as Inconel 718 is inefficient from a both – economic and technological point of view. New, more efficient machining methods of milling are presented nowadays. One of them is turn-milling. This method can be an alternative to conventional turning. However, the kinematics of this process is not thoroughly analyzed, and there are only a few works concerning force analysis during milling of hard-to-machine Ni-based materials. The paper presents the model of turn-milling process for force estimation under various cutting conditions. Cutting speeds, depth of cut and feed values were investigated and its influence on cutting forces values, stiffness and deflection of both, tool and workpiece.

Springback prediction of micro W-bending using support vector machine and BP neural network

Xiaoyu Liu, Xiaolong Lu, Yijun Du, Shiping Zhao

Accurately predicting and effectively controlling of the springback of micro W-bending is evidently important to improve its dimensional accuracy and forming quality. For the first time, micro W-bending is taken as the research object. The research on the springback prediction of micro W-bending was carried out using support vector machine and BP neural network respectively. Firstly, the experimental design method based on the I-optimal criterion was proposed to test the four factors (foil thickness, gain size, punch frequency and punch displacement) affecting the forming accuracy, and 56 sets of data were obtained. Secondly, support vector machine was used to predict the springback of micro W-bending. Afterwards, 40, 8 and 8 sets of data were employed for training, validating and testing the BP neural network, respectively. Finally, the prediction results obtained by support vector machine and BP neural network were compared from the aspects of prediction accuracy, reliability and stability. It is showed that support vector machine can predict the springback with high accuracy, which could be used to control and forecast the springback of micro W-bending, providing references for the design and evaluate of the bending accuracy of the W-shaped micro-bent parts.
Critical cooling of aluminium blanks for hot stamping

Jie Zhao, Yi Qin, Yankang Tian, Wenlong Chang, Daniel Melville

Aluminium alloy has been increasingly used in aerospace and automotive industry due to the trend of lightweight and carbon emission reduction. Particular interests are drawn and many research efforts have been made in the hot stamping process for aluminium sheet due to its potential for mass production. However, there are still significant challenges to form ultra-high strength aluminium alloy with large, complex geometry while maintaining low manufacturing-cost. The hot stamping process for forming steel components has been established in the industry for many years, and facing the recent trend to convert to aluminium production line with minimum effort. Due to the different materials characterisation, an intermediate fast cooling process is desirable between heating and forming of the high alloy aluminium such as AA7075, in order to improve its formability, enhance the forming tool life and increase the productivity. In this work, the critical cooling for hot stamping aluminium alloy and its effects on the formability of high strength aluminium have been reviewed, which contains the principle of material behaviour and how the cooling affects the material properties, as well as a comparison of different cooling technologies with a view of industrial application, including its set-up and maintenance cost. The outcome from this work can be used to guide process designs and volume production solution of hot stamping aluminium alloy sheets.

Laser metal deposition additive manufacturing for high-value components in aerospace

Quanren Zeng, Yankang Tian, Wenlong Chang, Jie Zhao, Yi Qin

Laser metal deposition (LMD) is a prospective enabling additive manufacturing techniques which could directly construct geometrically-complex and near net-shape metal components by depositing powders or filaments on the substrate layer-by-layer. With its merit characteristics such as more design freedom, less manufacturing constraints, flexible product customization, shorter time to market and lower overall production cost, LMD easily finds its applications in direct manufacturing or remanufacturing of the high-value critical parts for the fields of aerospace, automotive and biomedical engineering.

However, controlling the quality consistency of the deposited components and understanding the internal mechanism of the deposition process are still the main challenges which prevent the LAM technique from growing to its full potential in the aeronautics and aerospace related manufacturing. The manufacturing-related variables for LMD process are so many and to some extent interactive; the suitable LMD processing parameters are usually in a comparatively narrow range. To overcome these problems, this research proposes to establish an integrated numerical model, which considers the powder dynamics, heat transfer, and liquid/solid interface, solidified geometrical deformation and deposited mechanical property. The popular metal-powder-based AM technologies focusing on the DED process was first reviewed. The metal powder blown process was then simulated to investigate how the powders being injected into the molten pool. The liquid/solid interface on the molten pool during the solidification was also analyzed. The numerical model and corresponding experiment could help give an insight of the relevant physics of the LMD process and finally facilitate the realization of high quality deposited components with better consistency by using optimized processing parameter sets. The research will be particularly useful for production of the geometrically-complex and functionally-reliable components that with higher demanding requirement in the aeronautics and aerospace.
Development of anti-icing micro texturing structures on Titanium alloy by a nanosecond laser

Wenlong Chang, Yukui Cai, Fei Ding, Quanren Zeng, Xichun Luo, Qin Yi

In the aerospace industry, the safety of aircraft is paramount. Titanium alloy is the most common safety material in aerospace due to its light weight, high strength and high corrosion resistance. Another issue which is vital to the safety of aircraft in flight is preventing the build-up of ice on the surface of the aircraft or on any of its mechanical parts, hydraulics, sensors or powerlines. During a flight water vapour can catch on the surfaces of an aircraft and because of the altitude quickly form ice which is extremely hazardous. Current solutions include the use of superhydrophobic surfaces which repel the build-up of water which could turn to ice but these are complex to make and tend to have relatively short lifespans. This research tested using high precision nanosecond laser machining on a titanium alloy to create an effective superhydrophobic surface in order to achieve a cost-effective solution for the aerospace industry. A serial of experiments were undertaken on a high precision nanosecond laser machine and the results demonstrate that the laser machined titanium alloy with micro structure is potentially a superhydrophobic surface and it delays freezing time by 25% without any chemical adjustment.

Research on Titanium Alloy Material-TC4 Grinding Technology in Aeroengine

Chao Zhang, Tianbiao Yu; Jiashun Shi; Xue Sun; Zhelun Ma; Zixuan Wang

Titanium alloy materials mainly refer to titanium alloys, titanium-aluminum intermetallic compounds and titanium-based composite materials. They have excellent properties such as low density, high strength, good oxidation resistance and creep resistance, and have broad application prospects in the field of aeroengines. Grinding is an important method for efficient and precise machining of titanium materials, and good machining accuracy and surface quality can be obtained. Titanium alloy materials are typical difficult-to-machine materials. If the traditional grinding wheel is used for processing, not only the production efficiency is low, the grinding quality can not be guaranteed, and the service life of the grinding wheel is also reduced. Therefore, in view of the above problems, a new process and a new method suitable for grinding titanium alloy materials are proposed in this paper. In this paper, based on the traditional ceramic bond cBN grinding wheel formula, the original group distribution ratio and the addition of nano materials are used to improve the grinding performance of the grinding wheel, optimize the grinding wheel preparation process, and improve the grinding efficiency of the grinding wheel. Service life. The main research contents are as follows:

(1) The performance test results of the common binder spline show that the addition of nano-Al2O3 and SiO2 can improve the performance of the ceramic bond. However, the amount of nanomaterials should not be too high, which easily leads to a decrease in the performance of the ceramic binder.

(2) On the basis of the previous section, the addition of nano rare earth lanthanum oxide and nano rare earth yttrium oxide, the performance of the ceramic spline has been further improved. The comparison experiments show that the addition of nano-cerium oxide is more conducive to the improvement of the comprehensive performance of ceramic binder.

(3) A grinding experiment was conducted on a titanium alloy material - TC4 for aero engines. Experiments show that under the same processing parameters, the grinding quality of nano bond grinding wheel is significantly higher than that of ordinary ceramic bond grinding wheel. Whether it is the surface roughness after TC4 grinding or the surface grinding of the workpiece, the nano bond grinding wheel performs excellently.
Experimental research on machining micro holes of DD5 nickel-based single crystal superalloy by spiral microelectrode

Yao Sun, Yadong Gong, Fantao Meng

Micro circular and heteromorphic holes are widely used in the aerospace industry, and the fabrication of micro holes with high efficiency, surface quality and good machining accuracy is an important and urgent problem to be addressed. Attention has been paid to fabricate micro holes by spiral microelectrode instead of cylindrical electrode and edge cutting electrode. Firstly, the spirals microelectrode with the diameter less than 200µm is obtained with low speed wire electrical discharge machining method. Then, the micro holes are fabricated on DD5 nickel-based single crystal superalloy by spiral microelectrode, and the effects of machining parameters on machining time, surface quality and roundness error are discussed.

Material removal mechanism of three-dimensional ultrasonic vibration assisted polishing

Tao Yu, Tianbiao YU, Tianqi Zhang, Jiashun Shi, Fanwei Meng

Components with smooth and ultra-smooth surfaces have been playing a crucial role in the field of aerospace. In order to obtain smooth and ultra-smooth surface, the academic and industrial fields have proposed various sorts of methods for polishing. Among those methods, the ultrasonic vibration assisted polishing (UVAP) possesses many advantages including high processing efficiency, high accuracy and low cost, more importantly, it having huge application potential during the processing of hard and brittle materials. This paper is focusing on solving the existing problems caused by the traditional and 1D UVAP methods such as poor material removal rate (MRR), inhomogeneous surface morphology, high roughness. Therefore, we propose a novel method of using 3D UVAP method and establish accurate mathematical model to precisely calculate the MRR. Through the introduction of ultrasonic vibration to the polishing process, it can change the motion trail, status and distribution of abrasive particles to promote the increase of MRR, reduce the surface roughness value and optimize the surface morphology. Based on the analysis of the effects of the contact between polishing pad and component surface, the material removal method, abrasive particle type and working status, as well as the parameters such as amplitude, frequency and particle size on polishing process, the prediction mathematics model is established in assistance of 3D ultrasonic vibration to calculate the MRR. Abrasive movement trajectory simulations, impact and scratch simulations and UVAP experiments results suggest that the MRR and accuracy of 3D UVAP are obviously better than 2D ultrasonic vibration assisted and traditional methods. Furthermore, the experimental results are in good agreement with the calculated MRR by prediction model.

Experiences with a systematic framework for simulating laser-assisted manufacturing process

Jun Hong, Quanren Zeng

Nowadays, difficult-to-machine materials, e.g. Ti alloys, Ni-base superalloys and ceramics, have been receiving ever-increasing demand in aerospace and sportmotor industry due to its high toughness, high wear resistance and ability to retain high strength in the high temperature working environment. Laser-assisted machining (LAM) process provides an innovative way to dealing with difficult-to-machine materials by preheating & softening the workpiece surface and being followed with the conventional machining. This research proposes a proof-of-concept framework to systematically simulate the LAM process. The python scripts were developed under the proposed framework to make it easy to import, extract, process and export the 2D/3D geometry of components. It also allows to adjust the essential
Electroforming of Large-Scale Nickel Structures for Leading-Edge Energy, Aerospace and Marine Applications

Eleni Andreou, Sudipta Roy, Niall Mannion, Steve Wainwright,

Additive manufacturing (AM) processes are expected to contribute significantly to the rapid transformation of the industrial landscape in the future. Although the deployment of AM processes can be an expensive, their use opens the way for significant reduction of production time as well as expense, rendering high-volume production feasible even for the cases of challenging product design. In addition, significant reduction in industrial waste can be achieved and optimisation of the supply chain can be incorporated.

Electroforming is an electrochemical additive manufacturing process. Some of the strengths of this process include the high energy and resource efficiency coupled with low power consumption. However, as current techniques rely on traditional chemistry and processing methods, utilisation of nickel electroforming remains a specialist activity.

Electroforming’s boundaries can be pushed further through leading-edge electrochemical engineering. For example, an in-depth investigation of electrolyte chemistry can help to achieve desirable deposit properties, whilst raising metal deposition rates. Deeper investigation on electrolyte agitation and reactor analysis can provide information on process parameters that affect the properties of final electroformed products. Based on such data, optimised reactor and process designs are possible through state-of-the-art modelling techniques using specialist simulation software.

Our team aspires to bring the electroforming process to the forefront of AM by opening new horizons for precision manufacturing and overcoming limitations which have rendered specific products “impossible to manufacture” up to this day.

Additive Manufacturing of Heterogeneous Structures by Cold Spray Deposition

Sara Bagherifard, Asghar Heydari Astaraee, Stefano Monti, Jan Kondas, Reeti Singh, Alberto Collela, Mario Guagliano

Heterogeneous materials obtained through embedding coarse grains inside a matrix of nano grains or vice versa, are expected to exhibit tailored mechanical properties particularly regarding the combination of strength and ductility. Additive manufacturing is an attractive way to fabricate this class of materials; however, the commonly used laser based additive manufacturing technologies, which mainly rely on layer by layer powder melting and solidification, are quite limited in this case due to the high thermal input that will alter the crystalline structure of the nanograined material.

In this study, we have used the additive manufacturing potential of cold spray deposition technology (based on kinetic energy rather than on thermal energy) to fabricate free standing samples of a CuCrZr alloy using different volume fractions of coarse and ball milled nano grained powder particles. The process parameters were optimized to obtain depositions with minimum porosity and high cohesive strength. The
deposited samples were characterized regarding mechanical strength, microstructure, porosity, microhardness and residual stresses to identify the effect of the volume fraction of each powder as well as patterning approach on their performance.

The results indicated the capacity of cold spray technology to be used as an effective method for additive manufacturing of heterogeneous materials. The material characterization data indicated the importance of ball milling and cold spray process parameters on the mechanical performance of the depositions.
Large-Scale high-lift Morphing Wing of A320 type, based on Electro-Mechanical Actuators and Shape Memory Alloys

A. Giraud, B. Nogarede, Y. Bmegaptche-Tekap, M. Carvalho, D. Harribey, C. Nadal, J.F. Rouchon, M. Braza

Aerodynamic Performance of an A320 type morphing wing in the transonic regime

P. Flaszynski, R. Szwaba, P. Doerffer, Jean-Baptiste To, N. Simiriotis, A. Marouf, J.F. Rouchon, M. Braza

Electroactive morphing effects in the aerodynamic performance of a cambered A320 wing by means of time-resolved PIV

M. Carvalho, C. Nadal, D. Harribey J.F. Rouchon, M. Braza

High-Fidelity Numerical simulation of a morphing A320 wing in subsonic speeds and sensitivity evaluation

N. Simiriotis, A. Marouf, K. Diakakis, G. Tzabiras, F. Kramer, F. Thiele, M. Braza

Aerodynamic performance increase of a morphing A320 wing with high-lift flap by means of Hi-Fi CFD approaches

A. Marouf, N. Simiriotis, J.B. Tô, Y. Bmegaptche, M. Braza

Multi-point sensing by dynamic pressure measurements through Bragg grating applied in the SMS project

J.B. Paris, A. Kitouni, V. Lamour
Overview of the FLEXOP H2020 Project

Bálint Vanek, Sebastien Blanc, Gertjan Looye, Gernot Schneiderbauer, Christos Koimtzoglou, Roeland de Breuker, Mirko Hornung, Andres Marcos, Florian Schültke

The FLEXOP project is about developing multidisciplinary aircraft design capabilities for Europe that will increase competitiveness with emerging markets, particularly in terms of aircraft development costs.

A closer coupling of wing aeroelasticity and flight control systems in the design process opens new opportunities to explore previously unviable designs. Common methods and tools across the disciplines also provide a way to rapidly adapt existing designs into derivative aircraft, at a reduced technological risk (e.g. using control to solve a flutter problem discovered during development). The goal will be achieved by:

• improving efficiency of currently existing wing, by increased span at no excess structural weight, while establishing modifications by aeroelastic tailoring to carry the redesigned derivative wing;
• developing methods and tools for very accurate flutter modeling and flutter control synthesis, to enable improved flutter management during development, certification, and operation, enabling to fly with the stretched wing at same airspeed as the baseline aircraft;
• validating the accuracy of developed tools and methods on an affordable experimental platform, followed by a scale-up study, demonstrating the interdisciplinary development cycle. Manufacturers will gain cost efficient methods, tools and demonstrators for enhancing aircraft performance by integrated development of flutter control and aeroelastic tailoring.

These inter-disciplinary capabilities will improve the design cycle and the Verification & Validation process of both derivative and new aircraft. Better control of development and certification costs can be achieved if these capabilities are used to address problems early in the design process. Flight test data will be posted on the project website to provide a benchmark for the EU aerospace community. The project’s results will serve as a preliminary outlining of certification standards for future EU flexible transport aircraft.

FLEXOP Work Package 1 - Aeroelastic Tailoring Methods for Wing Design And Preliminary Design of a Subscale Flying Demonstrator

Franz-Michael Sendner, Roeland de Breuker, Gernot Schneiderbauer, Wolf Krüger, Martin Herring, Mirko Hornung;

Beside the elaboration of methods for designing aeroelastic wing structures, the performed work in WP 1 included the basic requirements engineering, mission design, as well as conceptual & preliminary design of the subscale demonstrator aircraft. By the application of the developed methods and principles on three different, interchangeable wings for the demonstrator, a base for evaluation and verification was created.

Starting with the requirements engineering phase, flight mission profiles, aeroelastic testing demands, safety and crashworthiness aspects for the subscale, unmanned demonstrator were collected and analysed. Based on these requirements, the conceptual aircraft design was approached in the following
phase. Studies in wing sections, planform and 3D lofting were executed to define a suitable aerodynamic base line design.

Starting with this geometry definition, three different wing structural concepts were elaborated: The Wing-0 design represents a state-of-the-art wing structure. The stiffness of the structure is designed to avoid the occurrence of instable aeroelastic phenomena within the given flight envelope. The design method of the wing-1 radically focusses on light-weight structural design. Intentionally, the natural flutter boundary range within the targeted flight envelope of the demonstrator. By the means of a closed sensor-actuator control loop, flutter should actively be damped and suppressed up to the envelope boundaries. The iterative design loop is depicted in Fig.1 (Attachments). The resulting preliminary FEM model is shown in Fig.2 Attachments).

The design method applied to the third wing design (wing-2), as illustrated in Fig.3 (Attachments), was based on the principle of passive load alleviation in flight. In contrast to the wing-1 design, separation of flight envelope boundaries and aeroelastic instabilities is purely provided by the aeroelastic properties of the wing without active dampening systems. In parallel to the wing design, a detailed numerical modelling was performed to simulate the aeroelastic behaviour of the wings to test. Besides conventional FEM/DLM and FEM/VLM analysis, structure coupled CFD-CSM analysis was run to evaluate pitch moment characteristics and aerodynamics close to flow separation (shown in Fig.4 (Attachments)).

Fuselage and empennage conceptual design studies, as shown in Fig.5 (Attachments), were performed with aiming on minimum drag while providing sufficient flight dynamic stability margins for remote pilot control. The propulsion system modelling was integrated into the conceptual design, to optimise the configuration for the defined reference mission. A detailed mass breakdown and -tracking for correlation of the demonstrator inertias with the aeroelastic models was assured.

Finally, a preliminary design of a flying demonstrator with three sets of wings with different aeroelastic properties was developed. Design and modelling methods for flexible aeroelastic tailored wings were elaborated. Meeting the requirements was ascertained by testing in a numerical mission simulation environment.

**Assessment, Validation, and Scale-Up Issues related to the FLEXOp**

*Sebastien Blanc, Balint Vanek*

The FLEXOP project partners within WP4 have developed tools and methods for scaling up the project results to a full-scale derivative aircraft, which takes advantage of advanced flutter control results in addition to aeroelastically tailored wing structure.

Validation of developed tools for flutter management and aero-elastic tailoring using the flight test demonstrator developed and manufactured in WP3 have been flight tested in the project as part of WP4. Attainment of the project goals, using the developed methods and tools for design of a derivative aircraft with extended wing-span (scale-up task) providing 7% fuel efficiency improvement or 20% payload increase at a 50% reduction of development and certification costs, will be discussed also within the talk.
Building and Testing a Flutter Management Demonstrator within the FLEXOP H2020

Sebastian Koebel, Franz Sendner

The FLEXOP project aims at researching flutter suppression methodologies for high aspect ratio wings of transport aircraft. To test and validate the methodology, three wings of seven meters wingspan were designed to be tested on an unmanned aircraft, which design as well as the building and integration process was organized in work package 3 (WP3) and is the scope of this work. The wings are geometrically identical but show different flutter behaviours: A stiff baseline wing that does not show flutter within the flight envelope, an aeroelastic-tailored wing and a wing that requires active flutter suppression to allow flight in the entire envelope. The aircraft design resembles a transport aircraft, yet features design peculiarities such as a turbine on top and airbrakes to provide the dynamics required to reach speeds necessary for flutter tests in visual line of sight conditions, a rescue system and several data links for control and command purposes. The component selection comprises custom developments such as the flight control computer and interrogators for fibre-optical sensors as well as conventional off-the-shelf components for remote controlled aircraft. For ensuring safety the demonstrator was designed and integrated carefully, as well as components, subsystems and systems continuously tested as the system’s complexity increased. Special focus was put on systems’ failsafe behaviours. The demonstrator is complemented by a Ground Control Station that serves monitoring and guiding purposes as well as a hub for communication between the external pilots, the demonstrator and air traffic control. Besides practical technical solutions to facilitate efficient operations such as good accessibility of connectors and switches, routines like check-lists and communication patterns had to be developed and implemented by operator training.

Flutter Prediction and Control Design Methods within the FLEXOP H2020 Project

Andres Marcos, Bálint Vanek

The FLEXOP consortium, within the lifespan of the project have significantly advanced the methodology and tools related to aeroservoelastic modelling, analysis and control design tasks. Within the presentation the advances in study methods and tools for flutter modelling, prediction and control design up to a level ready for industrial consideration will be summarised. In addition the developed tool-chain for highly accurate mathematical modelling of flutter phenomena and subsequent flutter controller synthesis will be detailed. Followed by solutions for design systems for flutter prediction. In addition the design of basic flight control laws for the flight demonstrator and the subsequent flutter control laws for the -1 wing aircraft will be detailed.
Comparison of Reactive Flow Simulations for a LOX/CH4 Multi-element Rocket Engine

Ainslie D. French, L. Cutrone, A. Schettino, M. Marini, F. Battista, P. Natale

This study details the reactive flow simulation of a LOX/CH4 Multi-element rocket engine. The work has been conducted within the framework of the HYPROB-BREAD project whose main objective is the design, manufacture and testing of a LOX/LCH4 regeneratively cooled ground demonstrator. Numerical simulations have been carried out with both commercial software and CIRA software developed in house. Two sets of boundary conditions, nominal and experimental have been applied from which a code to code validation has been effected with the former and a code to experiment validation with the latter. The results presented include both flow data and heat fluxes as well as parameters associated with engine performance and indicate excellent agreement with experimental data.

A Discrete-Time Kalman Filtering Method for Launch Vehicle under Parametric Modelling Uncertainty

Adrian-Mihail Stoica

The paper presents a discrete-time Kalman type filtering problem for discrete-time linear systems with parametric modelling uncertainties. A stochastic model with multiplicative noise both in the state and in the output equations is used to represent the system with uncertain parameters. The solution of the filtering problem is a Kalman type filter whose gain is determined by solving the optimization problem resulting from the coupling between the filter and the stochastic system with multiplicative noise. It is proved that this optimal gain results by solving a trace minimization problem with constraints expressed in terms of a system of matrix inequalities. The filtering approach is illustrated by a case study aiming to estimate the states of the pitch dynamics of a space launch vehicle.

Cold Start XNAV Feasibility for Deep Space Navigation

Octavian Thor Pleter, Cristian Emil Constantinescu

XNAV (navigation base on milliseconds X-band pulsars) is rapidly approaching a maturity level fit for real space mission deployment. Recent space missions (NASA SEXTANT experiment on board ISS and Chinese XPNAV-1 pulsar characterization mission) will allow fast adoption of the technology for missions beyond Earth orbit. Various flavors of XNAV configurations are possible (absolute, incremental, relative, diverse degrees of data fusion with other data sources etc.) but the most studied are incremental and relative XNAV implementations, with quite a few proposed algorithms addressing various use cases in development. Instead the paper will concentrate on the requirements for a fully autonomous in-flight cold start of an absolute timing and positioning XNAV system. Several scenarios are considered. The most probable use for such an algorithm is a full spacecraft reboot in which case some knowledge about current trajectory is available. A more difficult problem is an almost zero knowledge start (the only assumption is position in our solar system). The paper ends with the general case of zero knowledge (cold start for the position somewhere in our galaxy) and a discussion about a truly galactic navigation system.
A reactive control system for a partially guided small sounding rocket

Constantinescu Cristian Emil

Most small sounding rockets are unguided vehicle. Stability is solved aerodynamically using fins and/or rapid spinning and trajectory is determined by the azimuth and elevation of the launch pad with the rocket usually flying a gravity turn. Access to upper atmosphere usually require two or three stages and the presence of fins on the upper stages impose a penalty on the stability of the launcher in first stage configuration.

The paper presents the modification made to an existing launcher suggested by the need to add dead weight for stability when flying small payloads. By eliminating the fins from the second stage and using an RCS for active stability and control of the upper stage several opportunities arise: the aerodynamic configuration is simpler and the stability of the first stage improved, $C_d$ is reduced a bit, non-gravity turn evolutions are possible and special payload requested attitudes (mainly orienting a camera towards ground) are conceivable. The added mass of the RCS system practically replaces the balancing weight and the removed fins, and the overall performance even improve. Of course, this require a new OBC with enhanced sensors and new navigation and flight control algorithms.

COTS based GNSS Receiver with Precise Point Positioning for CubeSats

Alexandru Pandele, Costel Cherciu, Marius Trusculescu, Claudiu Dragasanu

The paper presents the work towards developing a COTS based GNSS receiver and integrating Precise Point Positioning algorithms to facilitate close proximity operations for CubeSats in formation flying and during docking or rendezvous maneuvers. We initially present the driving requirements identified for these types of missions. Besides fitting a standard CubeSat, the receiver has to weigh less than 0.3 kg, consume less than 5 W and be multi-frequency and multi-constellation. Next, follows the identification of a commercial off the shelf GNSS receiver that can be easily customized to fit the basic requirements of a GNSS space receiver and on which Precise Orbit Determination (POD) algorithms can be implemented.

For the start of the activity three commercial receivers were selected as proposed candidates to be traded off regarding the degree to which they fulfill the requirements, the degree of openness and of manufacturer support. A COTS microcontroller shall be then selected to control the operation of the COTS receiver. We then expand on the proposed general architecture of the system from COTS modules to their integration philosophy, with a discussion on the means of delivering the correction factors to the receiver. PPP corrections are expected to be delivered either via ground stations or via the geostationary satellite based commercial services. The PPP algorithms are to be implemented on the microcontroller, which will also try to maximize the availability of a precise PVT solution by incorporating a neural network fed by an orbit propagator and the PPP algorithm. The neural network shall estimate a precise position whenever PPP corrections are not available. The training of the neural network shall be done on the ground, allowing for a small footprint on board. A preliminary design of the hardware and the planned qualification plan is concluding the work.
A Reduced Order Model Based On Large Eddy Simulation of Turbulent Combustion In The Hybrid Rocket Engine

Sterian Danaila, Dragos Isvoranu, Alina Bogoi and Constantin Leventiu

A combined method of large eddy simulations for non-premixed combustion in a turbulent boundary layer coupled with proper orthogonal decomposition of instantaneous velocity, pressure and temperature fields is developed in order to obtain a reduced order model.

First we investigate a channel turbulent reacting flow using Large Eddy Simulations (LES) technique. This physical model is pertinent to internal flows inside the hybrid rocket engines. The regression process at the wall of the solid propellant is modeled by either constant mass flow rate or variable mass flux of the major combustible species of the fuel grain pyrolysis in order to identify the behavior of turbulent structures in vicinity of the wall. HTPB/O2 has been considered as fuel/oxidant pair. The turbulence-combustion interaction is based on a combination of finite rate/eddy dissipation model applied to a reduced chemical mechanism with four reactions. The LES numerical results are analyzed with respect to RANS simulations and with other reference data. The second part of the paper refers to the derivation of a Reduced Order Model (ROM) for the same problem. ROMs are used to obtain fast and accurate results, needed in the areas of flow control and design optimization algorithms. The Proper Orthogonal Decomposition (POD) is a powerful tool employed to obtain a Reduced Order Model for the unsteady flow field. In order to achieve that, the eigenmodes of the flow are computed from several snapshots of the instantaneous fields uniformly spaced and the most energetic ones are used to set up the Reduced Order Model. Two cases of interest are analyzed in this paper: constant and variable regression rate of the fuel grain. In both cases, the flow and thermal fields obtained with ROMs are compared with the ones obtained from the full simulation and analysis on the number of modes required to achieve the desired accuracy is presented.

Versatile Microlauncher Using Solid Propulsion and Minimal Guidance Scheme

Florin Mingireanu, Marius Stoia Djeska, Nicolae Jula

In this work we are proposing a configuration for a micro-launcher (ML) which is dedicated for launching micro and nano satellites (MNS) since, nowadays, there is a clear demand for using small satellites in order to reduce mission costs and thus there is an increasing need for launching capabilities for MNS. Having masses from 1 kg up to 50-100 kg, a wide range of tasks can be performed by these small and cheaper satellites. To keep acceptable the overall mission costs, to reduce the delays and to increase the reliability and availability, a need of a specialized launch service aimed at MNS market is becoming more and more stringent. Hence, the main criteria for designing the ML are the cost, mobility and availability.

Without fulfilling these 3 requirements any ML remains in the realm of academic or institutional state funded study. The architecture proposed in this paper is a 3 stage ML using solid rocket motors (SRM) for all 3 stages. The tools used are an internal ballistic code with extending modelling capabilities for SRMs and a code for the 3-DOF exterior ballistic for the accurate simulation and optimization of the trajectory. The interior ballistic code uses a simple but precise 0-D model taking into account erosion/hump and two phase flow effects and also the level set method for an improved prediction of the burning surfaces with complex geometries. The 3 DOF model uses within its inputs the outputs from the interior ballistic model and predicts accurately the trajectory and global performances of the ML. The numerical results obtained by coupling the codes show that with a take-off mass of 6 tones the proposed micro-launcher can place a
10 kg payload into a 400 km altitude circular sun-synchronous orbit. The SRMs are chosen because they allow the fulfillment of mobility requirements while also driving down the cost by minimizing the number of persons and infrastructure needed to operate the launcher. At the same time the SRM option increases ML’s availability. A minimal guidance scheme is implemented with no active guidance on 1st and 2nd stage. The ML is launched from a 70 degrees inclined launch pad using gravity turn for the 1st and 2nd stage flight; 1st stage uses aerodynamic stabilization and 2nd stage uses spin stabilization. The 3rd stage uses direct-cosine-matrix based (DCM) attitude control with no rolling and orbital injection being performed based on pre-programmed data.

Robust control design for micro launcher nonlinear dynamics

Ene Costin

A linear quadratic regulator (LQR) is designed to control the pitch angle of the linearized longitudinal/lateral dynamics affected by uncertainties for a micro launcher. The gain margin and phase margin will be maintained above the imposed limits of 6dB and 30deg for the nominal system and for the considered uncertainty amount. This design is then augmented with a Kalman estimator to account for the unmeasured states and also for noise affecting the measured states and the input command. Finally, the design is applied to the nonlinear longitudinal dynamics of the micro-launcher and two simulation scenarios are performed.

Improving GNSS Positioning of Satellites using Artificial Neural Networks

Sergiu-Stefan Mihai, Dan Selaru, Miheea Ion, Alexandru Pandele, Mugurel Balan

Small and nano-satellites have a very limited energy budget and their precise positioning capacity is limited in time as positioning sensors are, in general, power demanding. In this context, the article aims to present a comparison between the positioning results of a power demanding Precise Point Positioning (PPP) algorithm and the ones provided as the output of a low-power consumption Artificial Neural Network (ANN). The data that is to be processed with PPP and AAN consists of GNSS measurements. In order to validate the results we compare the outputs with a valid set of data containing the real positions and velocities, which will be referred to as control data. The novelty of this article consists of the ANN architecture, which is designed to better exploit information coming from both an Orbit Propagator (OP) and GNSS measurements. The idea behind the OP is to estimate the Earth-orbiting satellite’s position and velocity at any moment in time. Its main disadvantage comes from the finite precision of the machine that performs the computations. Thus, numerical errors accumulate in time and the estimation becomes less and less accurate. Simultaneously, the GNSS measurements alone are not sufficiently precise to allow complex orbital maneuvers such as inspection and controlled flight formation, giving only approximations of the actual satellite’s position and velocity. The ANN is trained to compensate for the errors that the OP and the GNSS receiver intrinsically have. Two main approaches are to be tested, considering that the OP gives estimated positions and velocities with a sufficiently large frequency, as follows: (i) the GNSS data is queried at the same frequency with the OP; this approach is expected to give satisfactory results, because the estimation can be improved faster by the ANN, having constant available GNSS data. (ii) the GNSS data is acquired at a much slower frequency; the challenge for the ANN is now to better improve the predictions with limited GNSS readings. Theoretical aspects regarding the development of the ANN and its training phase are, too, described in the current paper, followed by the comparison with the control data which reveals the performance of PPP algorithms and ANN.
Notes regarding the Modeling of the Angle of Attack

Laurentiu Moraru

Numerical integration has become routine for many decades and so has become the numerical integration of the aircraft’s equation of motion. Many numerical algorithms have been used in flight dynamics and the applications of the basic numerical methods to flight simulation have been included in textbooks for a long time. However, many design and/or optimization algorithms rely on analyzing large amounts of simulated data, so analytical algorithms that can provide expedite estimations of the fast varying parameters have been reevaluated. The current paper discusses approximate analytical solutions for the angle of attack. Two types of such solutions are discussed. The first model considered originates in the classically linearized equations of motion. The second model discussed was obtained by simplifying the nonlinear equations of motion using an order magnitude analysis. The two models are compared against numerical results, provided by classical numerical integration algorithms. Their validity and limits are discusses. Comparisons are made between sensitivity analysis based on the approximate analytical models and on the numerically integrated equations.

Sensitivity Analysis on the Aeroelastic Static and Dynamic Stability of Slender Launchers and Missiles Using a Reduced Order Model

Marius Stoia-Djeska, Florin Mingireanu

The present study concerns with the development of an aeroelastic model with a reduced number of degrees of freedom for aeroelastic analysis of slender launchers and missiles. The model is useful in the preliminary design phase and it allows an efficient investigation of the aeroelastic stability boundaries of such very high-speed vehicles. The structural dynamic model of the booster and rocket system is based on a beam-like model with the thrust acting as a follower force. The aerodynamic forces are calculated using the piston theory and/or a supersonic unsteady potential method. The aeroelastic model is used for parametric aeroelastic stability analysis considering variations of the mass and inertial properties of the vehicle and variations of the thrust. The results of the work are the aeroelastic model for aeroelastic static and dynamic stability analyses and the method for the identification of the sensitivities of the stability margins of the rocket during the entire flight time.

Flexible Model for Micro-launcher Dynamics

Teodor-Viorel Chelaru, Valentin Pana, Alexandru Iulian Onel, Tudorel-Petronel Afilipoae, Andrei Filip Cojocaru, Ionut Cosmin Vasile

The paper presents aspects regarding flexible model used for describe the dynamics of the three stages micro-launcher. This work analyzes two types of elastic oscillations, transverse and longitudinal. By the hypotheses adopted, the flexibility problem will be reduced to a group of equations that will be attached to the rigid body model with six degrees of freedom, thus obtaining an elastic model for the launcher. The results analyzed will be the flight parameters the launcher, with the influence of the elastic modes considered. The novelty of the paper consists in highlighting the influence of elasticity on the launcher control problem.

Wind Influence on Micro-launcher Dynamics Model

Teodor-Viorel Chelaru, Valentin Pana, Alexandru Iulian Onel, Tudorel-Petronel Afilipoae, Andrei Filip Cojocaru, Ionut Cosmin Vasile
The paper presents aspects regarding wind influence in model used for describe the dynamics of the three stages micro-launcher. This work analyzes two types of perturbations, uniform wind and atmospheric turbulence. For atmospheric turbulence a dedicated linear model based on characteristics correlation functions will be developed. This will be attached to the rigid body model with six degrees of freedom. The results analyzed will be the flight parameters of the launcher, with the wind influence. The novelty of the paper consists in dedicated wind models developed and their influence on the launcher control problem.

**ADCS design for CubeSat satellites**

*Valentin Pana*

This paper addresses the problem of designing the attitude determination and control system (ADCS) of a CubeSat type satellite. The proposed architecture aims at obtaining the desired performance by selecting the appropriate control procedures for different operating conditions. The challenges imposed by the limited resources makes the development of a multi-control algorithm even more important. The proposed design is tested through numerical simulation conducted in MATLAB/Simulink.
**TEST-Inn: Test-Innovative Load Application Monitoring Systems**

*J. Zurbitu, I. Urresti, D. Cruz, Y. Essa, F. Martín De La Escalera*

The objective of this proposal is to overcome the conventional experimental set-up commonly used in structural testing as the proposed for measuring the torsional and bending stiffness of the HLFC Leading Edge configurations by experimental testing. Conventional instrumentation for measuring displacement, like LVDT contact sensing elements; or for stress measuring, like strain gauges or punctual data obtained from fiber Bragg grating, will be replaced for several newfangled solutions in order to develop a new and an innovative monitoring system for the qualitative and quantitative assessment of stress-strain events during structural testing such as overloads, defects appearance or even defect growth. For uniform load application, improved innovative technology will include, a combination of direct uniform load application, with an emerging technology probed successfully for others applications, capable to apply uniform loads for complex tunable elastic strains based on SMA (Shape Memory Alloys). This issue will allow control the deformation process as decided for torsion bending of wanted strain case. For the innovative monitoring system, classical punctual and contact strain measurement, will be replaced by a combination of novel SHM (Structural Health Monitoring) sensors in order to qualitative and quantitative assessment of stress-strain during structural testing. Four emerging technologies will be previously proved in laboratory for ensuring a properly performance during the test. These technologies will include elements for the first damage detection; the identification and quantification of stress-strain events, overloads and hot-spot point with non-contact measuring elements; the quick overall deformation measurement for FEM correlations; and the continuous strain measurements for internal areas or areas difficult to be instrumented with other techniques. All of these with the objective of ensuring an efficient, high quality testing that reduces the product development time risk and cost.

**AUFOVER: Automation Formal Verification**

*Tomáš Kratochvíla*

The goal of the Automation Formal Verification (AUFOVER) project is to develop automated formal verification tools and integrate them seamlessly to the industrial process, mainly for Aerospace and open source. The approach is to use both human & machine-readable requirement standards, mature university tools based on formal mathematical methods, and incorporate of these tools into the commercial processes for software verification. Since there is no best formal verification tool and even experts cannot guess which will deliver the best results for given requirements and system, our approach is to deploy many tools and let them compete on distributed verification servers.

The tools that will be developed or improved within the project: Verification Server, Verification Server Client Application, Scmock Plugins, DIVINE, Symbiotic and Testos. At the end of the project, it is expected to demonstrate the benefits of integration of formal verification into the project partner’s software development lifecycle. AUFOVER is a project funded by the Technology Agency of the Czech Republic by Epsilon programme.
DEPART2050: Environmental and Mobility Benefits Of Coaxial Compound Rotorcraft Configurations

Calum Scullion, Stavros Vouros, Devaiah Nalianda, Vassilios Pachidis, Alf Junior, Gianluigi Misté, Jos Stevens, Edward Rademaker, Ernesto Benini, Nico van Oosten

The requirements for the next generation of civil rotorcraft include increases in flight speed, range, capacity, and operability, whilst simultaneously reducing fuel burn, gaseous, and noise emissions. Fast rotorcraft constitute a promising concept towards achieving these requirements. They are intended to “bridge the gap” between conventional helicopters and fixed-wing aircraft by combining the benefits of vertical take-off and landing (VTOL) with high-speed forward flight capability. The focus of this presentation is to introduce the DEPART2050 project, which is part of the TE for Clean Sky 2. DEPART2050 aims to quantify the improvements that may be accrued through replacement of conventional helicopters with fast rotorcraft. A case study is presented wherein the predicted performance of a generic twin-engine compound configuration with a stiff coaxial rotor system and pusher propeller is compared with a conventional helicopter.

The presentation introduces a holistic simulation methodology utilised for the assessment of performance (fuel consumption), environmental (gaseous and noise emissions) and socio-economic impact (mobility, connectivity, and productivity). Utilising the proposed methodology, a comprehensive physics-based rotorcraft performance simulation model is employed to model flight performance. This is coupled with a zero-dimensional engine performance analysis module and a stirred-reactor combustor emissions model. These individual models are incorporated within an elaborate mission simulation framework. The mission results obtained for realistic four-dimensional operational scenarios demonstrate significant performance, emissions and mobility benefits, arising from the introduction of the configuration within the future fast rotorcraft fleet.

DIGESTAIR: Chemical composition and potential biomethane production of waste generated on board

Enrique Aymerich, Jon Garcia-Aguirre, Tamara Fernandez-Arevalo

Airlines are a big source of food waste. According to the International Air Transport Association, airlines produced 5.2 million tonnes of waste in 2017, and the figure is set to double by 2030. While the statistic includes a host of disposable products, around 20% is directly linked to the food service and other 20% to packaging plastic waste. An additional important source of waste is wastewater from toilets. Although some airlines have initiatives in place to reduce food-related waste, more sustainable waste management practices are needed. The EU-funded project DIGESTAIR is investigating the use of anaerobic digestion – microorganisms breaking down food waste in the absence of oxygen, removing pathogens and producing methane at the same time – to further improve onboard waste management (Figure 1). If successful, it will significantly reduce the environmental impact of passengers and will allow a much competitive management of Category 1 waste generated at international flights. The DIGESTAIR solution will be transferable to other sectors like cruisers and sea transport.

Biogas technology or anaerobic digestion technology has been used globally and successfully for decades, with primary applications for large-scale, high-tech commercial systems in Europe and small-scale, low-tech “household scale” systems in developing countries. However, the application of AD technology in an aircraft environment requires research and innovation efforts since no attempts are documented up-to-
date in the sector of aviation. The baseline for designing the anaerobic digester prototype in DIGESTAIR project will be a two stage system where methane production and acidification are carried out separately (Figure 2). The latter is an improved design that is applied at full-scale both at mesophilic and thermophilic temperature for sewage and food waste treatment, which can help solving the problem of fast acidification of food waste and avoiding the subsequent inhibition of methane production. This work will present a brief summary of DIGESTAIR project, as well as the preliminary results obtained in the first research part, related to the characterization of waste generated on-board, including their methanogenic potential production.

**DoDo: DOor to Door**

*Marco Cappella*

The General Aviation (GA) aircrafts can be considered as the next logical step in the natural progression of innovations in the people transport system. This wide branch of today aviation framework stands as an important turning point in the future personal mobility thanks to a significant reduction in transfer times and therefore a significant improvement in the quality of life. The vehicles belonging to the GA segment are usually small planes most of which are considered as light aircraft (LA) or ultralight aircraft (VLA). In the Europe there are about 50,000 small motor planes and about 200,000 aircraft of the LA and VLA categories of which about 13,000 in total in our country. Italy, thanks also to its geographic conformation, is one of the countries with a high potential for spreading this type of vehicle to meet the needs of short-distance trips within the Regions, the so-called "door to door" trips. Due to the high costs of the equipment and the certifications required for their installation on board, the pilots of the GA aircraft are penalized in terms of information relating to the surrounding traffic, hazard weather, and more generally information necessary for a safer conduct of the flight during all its phases: pre-flight, ground movement and flight. Nowadays, there are several applications available on the market for mobile devices (such as smartphones and tablets) that can support pilots during one or more flight phases, but none that can guarantee continuity of service during all phases of flight. Often these applications exploit exclusively the GSM signal for communication with the ground servers from which they obtain the information to be shown to the user. The problems of coverage of the GSM signal in some locations and, above all, beyond a specific level of flight are well known. The "Door to Door" (DoDo) project aims to create a low-cost product for GA pilots that does not require the installation on board of any additional system to support GA users during all the following characteristic phases of the flight:

- **Flight planning** - the system will allow you to calculate the optimal route starting from the declared departure airport or the current aircraft position until the destination airport. This calculation will consider different flight limitations such as segregated areas and adverse weather conditions.
- **Taxi-out / Taxi-in** - thanks to the digitalization of the maps of airports and airfields allowed to GA operations, the pilot is supported during taxiing operations from the parking area to the runway and vice versa:
  - projection of the position of the aircraft with respect to the map in use
  - calculation and visualization of the trajectory on the ground
  - visualization and identification of possible taxiway connections
  - display and identification of parking areas
- **Climb/Descent phase** - DoDo will be designed to require the least possible number of interactions to the pilot during climb and descent. The transition from the specific functions of the ground
phases to those specific to the route phase based on specific flight parameters of the aircraft will therefore be automated. For IFR flights, where available, the procedures for take-off and / or approach (SID, STAR) these procedures will be shown to provide support to the pilot.

- Route phase - the APP will provide support to the pilot in terms of adherence to the planned route and all other relevant aeronautical information that will allow to increase his/her Situation Awareness and consequently flight safety.

All the flight phases listed above will be supported by a communication infrastructure based, in addition to GSM signal, on satellite signal. The pilot will in fact have a SATCOM device, completely independent and integrated with the personal mobile device (and with the DoDo Mobile App) which will guarantee coverage even in the absence of GSM signal. The pilot can therefore count on a continuity of service that could be very important in emergency situations (e.g. receiving weather alerts, sending SOS). DoDo represents the first step of the deployment of a wider range of services to support the general aviation users during each operation they daily perform. These services will soon be available on the market as part of Flight Applications (FLAPP) suite powered by NAIS.

**GRECO: Manufacturing Technology and Tooling Development for Continuous Manufacturing Preform Cutting and Compaction with Dry Fiber Composite Material**

*Miguel Angel Castillo*

The manufacturing of dry fiber preforms is an essential part of the composite parts manufactured out of autoclave. In Aeronautic Industry, looking for highly integrated parts, out of autoclave processes use carbon fiber dry layers which are distributed in “rolls” by the raw material providers. Therefore, the base material needs to be cut considering the geometrical and fiber orientation requirements, and afterwards conformed in multiple layers structures, compounding a preliminary geometry (before the resin is added) which is called perform. Then, this preform will be compacted in a hot forming tool and trimmed following the final part geometry, prior to entering to the curing process, where resin will be added and the part come out in its final form. This trimming is partially due to the manufacturing process particularities, which is done with extra length in the dimensions of the piece, in order to avoid trouble due to lack of precise cutting of the layers.

This project objective is to optimize the manufacturing process for dry fiber preforms, by developing, manufacturing and integrating innovative tooling which will improve the cutting of dry fiber layers, and at the same time, build multiple layers looking forward to a multi-cut process, speeding up the manufacturing process and augmenting regularity, repeatability and overall product quality. There are technology development lines that generate notable advantages to the aerospace industry, through the fulfillment of the following specific, technical and strategic objectives:

- Reduce the manufacturing time of a preform, diminishing the costs
- Upgrade the perform in terms of quality, thanks to the better cutting technology and procedure of the layers
- Optimize the usage of material, generating less waste
- Improve receptivity of the process

GRECO project has several relations to current Clean Sky 2 projects in which Aernnova is involved. In particular, there are links with ITD Airframe OUTCOME, where Dry Fiber is used to manufacture parts in
two different work packages. Being complicated structures, with high number of layers, several curved surfaces and complex geometry, the interconnection between the Greco project and the OUTCOME project is very significant.

**Drilling and Sanding with a Multipurpose Mobile Dual-Arm Robot**

**Urko Esnaola, Hector Herrero, Jose Luis Outon, Ivan Villaverde, Arkaitz Urquiza, Enrique Gil, Brigida Corta, Iñaki Gomez, Manuel Peña, Korbinian Muenster, Maximo Roa**

During the assembly of an aeronautic structure it is typical to drill several parts and perform painting preparation operations as shown in the following figures. Such applications are of great interest to be automated especially due to the repetitive and strenuous nature but are withheld by the unstructured environment which is often reconfigured to accommodate different product variants. The system being presented automates both operations to be performed by one multipurpose dual-arm mobile robot. The robot navigates to a work-area, takes the required grippers and performs the operation. After the operation is finished it releases the grippers and navigates to the next working station. The main technologies to be integrated are navigation and artificial vision. **Navigation:** The navigation of the first prototype of the MRP is composed of standard 2D laser-based navigation. Several implementations available as packages of ROS have been configured, tested and fine-tuned for the MRP. This 2D navigation is used as base system for global and local navigation. **Artificial Vision:** Drilling templates are detected based on CAD models of the object. This is illustrated in 2. The detection pipeline contains the following steps:

- Acquisition of images and pointcloud data with the rc_visard sensor.
- Initial segmentation. When information from the process is available, such as in the drilling operation, an adapted pipeline can reduce the complexity of further processing steps. In this case, the skin of the wing where the drilling operation is performed is a large flat surface, which can be easily segmented from the pointcloud. The largest dominant plane is selected and the corresponding points are removed from further processing. The cluster of points representing the template is then selected, and an initial pose estimation is performed through the computation of the COM and axis of inertia of the cluster.
- Final alignment. For this step, the information coming from the image stream of rc_visard cameras is used. The edges are extracted from the image, and also the edges from the initial pose are rendered, thus leading to two silhouettes of the template over-imposed on the image. The edges are then aligned to improve the detection accuracy.

Drilling process is ready and being tested to ensure the quality of the riveting. The artificial vision system is being tested with different templates in different lighting conditions to ensure the robustness of the system. The navigation system is being tested in different environments with a variation of obstacles to ensure safety and robustness of the system. The sanding system is being tested in different types of surfaces. The system is in a TRL4 stage. Development is being done to increase the TRL to level 6 until Autumn 2019 in TECNALIA. After, 12 month of testing are planned in AERNNOVA until Autumn 2020. This development is being done in the EU Project THOMAS. THOMAS received funding from the European Union’s H2020-EU.2.1.5.1. - Technologies for Factories of the Future under Grant Agreement number 723616.
MULTIDRILL: New Multi-Material Drilling Conditions

Miguel Angel Castillo

The drilling operation is fundamental for Aerospace Industry since the riveting is the most important method approved to joint structural parts. The aircrafts have thousands of holes in their constructions and therefore this operation is the greatest contributor of quality problems in the final assembly line. For this reason, the industry is working to develop new Electric Drilling Units (EDU) to substitute the current pneumatic ones. These new drilling machines are now getting into the market but they do not have the best integration with the drilling tools since the commercial tools in the market are not design for these variable drilling conditions. This project pretends to develop the best combination between drilling tools and new portable machines (EDU). This project objective is to develop new multi-material drilling condition (feed and revolutions per minute, r.p.m ), drilling tools materials and cutting geometries more adequate to use in conjunction to new drilling machines. These electric drilling portable units (EDU) allow the programming of the cutting condition according the stacking to be drilled. This develop will bring two clear advantages to the aerospace industry.

- To reduce the time needed to drill the multi-material aerospace structures (composite, metallic aluminium, titanium and hybridations)
- To improve the final quality of the holes
- To reduce handwork in this operation
- This project is related with the Clean Sky 2 topics:
  - The strategic topic titled: “Wing and Tail Unit Components Multifunctional Design and Manufacturing (including out of Autoclave composites)”, id. JTI-CS2-2014-CPW01-AIR-02-02
  - The strategic topic titled: “Specific Design and Manufacturing of fuselage rear end and engine supports”, id. JTI-CS2-2014-CPW01-LPA-01-04

Aernnova is Core Partner in these topics in which is developing new composite technologies, designing, manufacturing and assembling different lightweight structural components for the different demonstrators of the ITD and LPA.

Two-Component Epoxy sel-Healing Adhesive throught The Incorporation of “All In One” Microcapsules

Raquel Rodriguez, Haizea Villaverde, Sonia Flórez

Self-Healing materials have been proposed as an emerging method of improving the efficiency of materials and aeronautic systems by offering a means for self-repair concepts. Self-healing technology has been developed and recently applied to composites, coatings and adhesives, to extend the effective life-span of them, to reduce the maintenance needs and costs, while improving the damage tolerance and reliability of structures. One of the most widely exploited self-healing routes to date employs the use of microcapsules and a catalytic curing agent, the general concept is based on the development of microcapsules which contain a healing agent inside. Being understood that when these microcapsules are distributed and embedded in a polymeric matrix and a crack is made, at least one microcapsule is broken. Therefore, its healing agent is released and mixed in the crack area with the catalyst, allowing the
polymerization of the healing agent into a solid polymer that fills the crack by capillary forces and repairs it. One of the biggest disadvantages for self-repairing systems based on microencapsulation is the random distribution of the catalyst and the difficulty to find and react with the healing agent. Therefore, one of the main challenges to improve microcapsules self-healing strategy is to control catalyst location. “All in one” self-healing microcapsules can be considered as a real alternative. These microcapsules are entirely self-contained, both the healing agent and the catalyst are held on the same capsule and isolated from each other, therefore the healing system is more controlled. This work has focused on the development of a two-component epoxy adhesive with improved properties in terms of prolonged service life and thus more reliable. For that, “all in one” microcapsules (self-contained) vs conventional system (microcapsules + catalyst) has been assessed. Said microcapsules have been synthesized by suspension polymerization, and the concentration and nature of the encapsulated self-repairing agent, the nature of the catalyst in terms of repairing efficiency have been analyzed. Efficiencies up to 116% have been achieved after applying a defined healing cycle.

**INTELLICONT: Automating Loading and Locking of New Generation Air-Cargo Containers**

*Georgios Bolanakis, Konstantinos Machairas, Konstantinos Koutsoukis, Athanasios Mastrogeorgiou, Michael Loupis, Evangelos Papadopoulos*

Air cargo handling has experienced tremendous growth over the past decades. However, the most essential components, the air-cargo containers or unit load devices (ULDs), have not followed the same evolution as the aircraft structures and systems, and remain as an open field for further technological advancements. In the meantime, the introduction of autonomous mobile robots and automated guided vehicles has already simplified and accelerated the procedures in fields related to transportation and logistics, especially in complex environments such as warehouses, distribution centers and even hospitals.

As far as upgrading the current air cargo handling systems is concerned, the main challenges include the automation of the existing cargo handling procedures, the reduction of the weight of the aircraft permanently installed hardware used for transport and locking, the improvement of flight safety by enhancing the container fire/smoke detection and suppression system, the optimization of the loading/unloading logistics and the reduction of maintenance requirements. Those challenges can be addressed by incorporating state-of-the-art solutions in the design and development of a new intelligent lightweight aircraft cargo container that can be transported autonomously in and out of the aircraft, be locked/unlocked autonomously in predefined places, detect and suppress fire, and transmit valuable sensory data to the pilot at all times. In particular, the CSL team focuses on the design and implementation of a novel self-moving holonomic robotic platform (RP) allowing seamless motion of the ULDs inside and outside the aircraft’s cargo compartment while enhancing them with self-locking and monitoring functionalities. The main tasks of the RP include the autonomous movement of ULDs with more than one tone of mass, avoiding at the same time environmental obstacles such as the gap between the cargo loader and the aircraft’s cargo compartment, and aligning with the locking positions with high accuracy before triggering the restraint mechanisms. Moreover, high energy efficiency and long-running times have to be achieved while providing backwards compatibility features for older aircrafts.

Here, an outline of the main results up until now will be presented, involving the main design features of the RP, the selection of the appropriate actuators and other key electrical components, such as motor
drivers and the Battery Management System (BMS). Important issues regarding motion control, path planning and localization techniques will be discussed also. Relevant information will be introduced on the specifications of the selected central control board, as well as its integration with the motor drivers, smart sensors and other peripherals with the Robot Operating System (ROS). Finally, designs for the autonomous locking system incorporating manual release capabilities will be presented.

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**IRON: Feasibility Study of Innovative Regional Turboprop**

*S. Corcione, V. Trifari; D. Ciliberti; V. Cusati; P. Della Vecchia; F. Nicolosi*

In-depth market analysis of the regional and commuter aircraft segment has revealed that nowadays the increase in oil price, the huge growth of air transport traffic, and the increasing attention to the aircraft environmental footprint has led to considerable interest of specialists in new configurations of regional and commuter transport aircraft. Furthermore, the major airlines in this segment demand a replacement for several hundred heritage airplanes, currently in service around the world, in the 20-150 seats categories, as many are now reaching the end of their useful commercial life. As drafted by the Advisory Council for Aeronautics Research in Europe (ACARE), major environmental targets can be resumed as follow:

- in a short term to achieve 50% reduction in CO2, 50% reduction in perceived noise and 80% reduction in NOx by 2020 relative to year-2000 aircraft.
- in a long term to achieve in 2050 technologies and procedures able to allow 75% reduction in CO2 emissions per passenger kilometer to support the ATAG target (i.e. Carbon-neutral growth starting 2020 and 50% overall CO2 emission reduction by 2050) and 90% reduction in NOx emissions. A reduction of the perceived noise emission of flying aircraft by 65%.

Regional aircraft are playing an increasing role in the evolution of the airline operations. For many years, this growth has been faced by a wide adoption of regional jets (RJ). Despite the RJ success, turboprop (TP) engines are 10-30% more efficient than jet engines in cruise conditions. Is it possible to fill the gap between RJs and TPs adopting new technologies or innovative aircraft configurations? Nowadays several research works are focused on the investigation of new regional platforms that cope with ever more stringent performance, costs and emissions requirements. Innovation, in the regional TPs field, can come from improved power plants (e.g. open rotors, low noise propellers design, etc.), innovative materials and from unconventional aircraft concepts (e.g. Box-Wing, Strut-Braced Wings, Blended Wing Body, Three-Lifting Surfaces, etc.). This paper is framed within the Innovative turbopROp configuratioN (IRON) project that complies with the European Union topic JTI-CS2-2015-CPW02-REG-01-03 (Green and cost-efficient Conceptual Aircraft Design including Innovative Turbo-Propeller Power-plant) as part of the Clean Sky 2 program for Horizon 2020. The topic leader, Leonardo, and several core-partners are involved into the project. CIRA (Italian Aerospace Research Centre) is the coordinator of this project.

The project focuses on the feasibility study of an innovative turboprop regional configuration with 130 pax, which is supposed to be competitive with respect to short/medium haul regional jets. The aircraft configuration is an innovative layout with low wing and rear-mounted engines installed at the horizontal
tail-plane tip. Aerodynamics target provided by Leonardo Company are very challenging aiming for a cruise efficiency (lift/drag ratio) of about 18 at Mach number equal to 0.64 and at a cruise altitude of 30kft, and relatively high maximum lift coefficients: 2.4 and 3.0 for take-off and landing respectively. The paper will be an overview of the results achieved through two loops of design from July 2016 to June 2019 by Design of Aircraft and Flight technologies (DAF) research group of the University of Naples Federico II.

Within the IRON project, two different design loops with increasing level of complexity and fidelity, have been already accomplished, aiming to assess the design through numerical simulations, and experimental validations. DAF group has been involved in the preliminary design, aerodynamic analysis, performance evaluation, Direct Operating Costs (DOC) estimation and Multi-Disciplinary Optimisation of this innovative regional platform, and it has also performed a preliminary wind tunnel test campaign. Several aircraft configurations have been investigated and compared with respect to a possible conventional turboprop layout. Among the analysed configurations, the best solution has been identified in a three-lifting surfaces layout, which well complied with Top Level Aircraft Requirements, Aerodynamics, Weight and Balance and Performance. Dedicated activities dealing with high-lift devices design, tail planes sizing, and complete aircraft aerodynamic analysis have been accomplished by means of numerical medium and high-fidelity analyses. Several criticalities dealing with aerodynamics interferences of a three-lifting surfaces have been highlighted, carrying out some useful information into designing of such an aircraft configuration. Finally, a comparison with a reference regional jet (Airbus A220) has been performed in terms of performance, DOC, Block-Time and Block-Fuel.

Powered wind tunnel tests setup of the IRON innovative turboprop aircraft

Danilo Ciliberti, Vincenzo Cusati, Pierluigi Della Vecchia, Salvatore Corcione, Fabrizio Nicolosi

The research work is framed in the Innovative turbopROp configuration (IRON) project that complies with the European Union topic JTI-CS2-2015-CPW02-REG-01-03 (Green and cost-efficient Conceptual Aircraft Design including Innovative Turbo-Propeller Power-plant) as part of the Clean Sky 2 program for Horizon 2020.

The actual innovative turboprop configuration, which has been shown in several exhibition partnered with Clean Sky 2, is a three lifting surfaces aircraft with rear-mounted, propeller-driven engines. In order to validate the stability and control characteristics previously evaluated with numerical simulations in prop-on conditions and to expand the results of wind tunnel tests in prop-off conditions, powered wind tunnel tests have been planned by the end of 2019.

To enable thrust similarity between the full-scale aircraft and its 1:25 scaled model, a scaled engine deck has been assumed, which set the motor and propeller requirements. The electric motor LMT 2280/40 LK, manufactured by Lehner Motorentechnik, has been chosen to match torque and power at the required RPM with high efficiency. The propeller had to be designed from scratch, since there is no commercial product available that comply with the required propeller coefficients: the propeller should rotate between 5000 and 10000 RPM, at high advance ratios between 1.5 and 3.2, providing a maximum thrust of about 10 N with a max power of 400 W, and must have a diameter of about 15 cm (about 1:25 scale).

The propeller has been designed with XROTOR and the results were checked with RANS simulations with a moving reference frame technique. The design flow chart shows the logic followed in the design process, which includes airfoil selection and optimization as well as a structural evaluation of the stress and
deformation of a single blade. The best propeller seems to be a six-bladed rotor with a high solidity ratio, resembling a marine propeller. Such a geometry is due to the required thrust with a limited RPM number and diameter size. To comply with both cruise and climb conditions, two couples of propellers, designed for different operating points, have been considered.

As concern the wind tunnel tests, the acquisition data system available at UNINA low speed wind tunnel facility will be upgraded and extended with a control system for the electric motors. A special stand will be built to allocate the electric motors close to the tailplane of the aircraft model, but without contact to avoid vibrations of the model and to measure separately the thrust of the engine and the drag of the airframe. The support system will enable moving the motors to keep their relative position as the aircraft model will change angle of attack and sideslip.

**MIB: Modular Iron Bird Abstract - Equipment Test Lab**

*Mauro Borrelli, Sergio Cotecchia*

The Modular Iron Bird (MIB) is a research project funded by the Campania Region (Italy) for developing a modular laboratory to verify the Flight Control System equipments and/or electromechanical actuators prior their installation on small civil aircrafts or UAV. The project has led by Protom Group SpA with the collaboration of the University of Campania “Luigi Vanvitelli”.

The project aims to offer to the small-medium aeronautical companies a flexible test tool to qualify stand alone FCS equipments or to qualify their interfaces before the installation into the aircraft, reducing the risks linked at that latter critical step. So MIB shall be capable to reproduce all the interfaces necessary to simulate the real behaviour of the A/C zones where the equipment or the actuator to be installed in (i.e. the structural stiffness and the electrical interfaces). The full size Iron Birds are complex test tools necessary to verify and qualify the equipments of fly-by-wire aircrafts or of unmanned aerial vehicles and are basic to simplify the process to gain the permit to fly of a prototype. These tools are very costly and for this reason can be used only by big aeronautical companies because justified by the market prize of the new aircraft. Instead the medium – small ones cannot sustain those costs, forcing them to perform the tests at level of benches and when the first prototype of the aircraft is ready. That implies the risk to develop a new equipment without performing significant and realistic development engineering tests waiting for the flight test campaign of the new aircraft. The risk is to discover potential not compliances very late respect to the development schedule, causing an increase of the project costs and delaying the company planning. Sometimes the increase of costs had been the cause of the cancellation of the program. In other cases, the absence of a reliable and affordable testing tool to mitigate the development risks pushed the small companies to renounce at the implementation of equipment upgrades, renouncing, at the same time, to increase the competiveness of their aircraft on the market.

The target of the modular Equipment Test Laboratory is to make available on the market a tool to simulate the flight controls actuators and electronics of medium-small aircrafts, allowing the related aeronautical companies to take the benefits from the development testing on a realistic little iron bird, as well as the big companies are doing since decades using big and costly iron birds.

MIB is equipped with the following systems: a Test Management System, the Structural Boxes, a programmable Active Loading System, a Data Acquisition System, the Human Interface, the Electrical System, the Hydraulic Generation System, to generate the hydraulic power and to feed the Hydraulic
Cylinders. The modular Equipment Test Laboratory core is a modular Basic Element, that employs: a Wing Box with the related Control Surface, an hydraulic actuator, all the sensors necessary, the Loading System, the Data Acquisition System and the human interface.

The MIB Basic Element has been designed to be used in a single stand alone test. The modularity is completed by the possibility to assemble together more Basic Elements to simulate the actuation of a complete control line (i.e. the roll control) or of a complete a/c. Then the above Basic Element will be fully replicated or partially replicated (i.e. only the structural box to joint two complete Basic Elements) and joined using structural splices in order to simulate the complete aircraft. The MIB project will be concluded verifying by test the proper functioning of the modular Equipment Test Laboratory. This task of the project could be performed testing a flight control system actuator developed under Clean Sky 2 COSTAR project, as already informally anticipated to Airbus Helicopters during the Annual Review Meeting held on May 2018, or testing an off-the-shelf electromechanical actuator.

**SAT-AM: Superhydrophobic coatings as anti-icing systems for small aircrafts**

*Filomena Piscitelli, A. Chiariello, D. Dabkowski, L. Di Palma*

Typically, the presence of tiny pieces of ice or supercooled liquid water in the clouds, which remains liquid below zero and suddenly turns to ice after the impact with the aircraft surfaces, are the main sources of ice deposition during a flight. The presence of ice on surfaces alters the airflow over the wing and tail, and then reduces the lift force that keeps the plane in the air. This potentially causes aerodynamic stall, a condition that can lead to a temporary loss of control of the aircraft. In order to prevent or reduce the ice formation, or, alternatively to remove it once formed, anti-icing and de-icing systems are usually adopted. Currently the most largely used systems are thermal and pneumatic types. In details, the thermal system melts the ice accretion or prevent the ice from forming by application of heat on the protected surface of the wing. The heat is generated by the hot air "bled" off the jet engine into piccolo tubes routed through wings, tail surfaces, and engine inlets. The spent bleed air is then exhausted through holes in the lower surface of the wing. Similarly, the electro-thermal systems use resistive circuits buried in the airframe structure to generate heat when a current is applied. The heat can be generated continuously to protect the aircraft from icing, or intermittently to shed ice as it accretes on key surfaces, the latter being generally preferred due to the lower power consumption. Instead, the pneumatic de-ice boot consists of a rubber sheet bonded to the leading edge of the airfoil: when ice builds up on the leading edge, an engine-driven pneumatic pump inflates the rubber boots, and then the ice is cracked and should fall off the leading edge of the wing. Additionally, some innovative systems are being developed, e.g., the electro-mechanical deicing systems which uses a mechanical force to knock the ice off the flight surface; the weeping wing system, which releases a glycol-based chemical onto the wing surface through small orifices; or, finally, the hydrophobic surfaces which repels water. In some cases, the combination of a traditional icing protection system and the superhydrophobic/icephobic coatings is a strategic instrument to reduce energy consumption, essential especially for small aircrafts. In the last decade a huge literature concerning the development of superhydrophobic and icephobic coatings able to delay the ice formation, or reduce the ice adhesion strength once formed, has been produced. Shared strategy is to create surfaces with low surface free energy and, contemporary, micro-nanoscopic rough structures. In this contest, this paper focuses on the development of a superhydrophobic coating as anti-icing system for small aircraft, which cannot spend energy for traditional anti-icing/de-icing systems. In this regards, it was demonstrated that there is a strong correlation between the water wettability and the ice adhesion, therefore, ultrahigh rec
angle, typical of nanostructured superhydrophobic surfaces, means low ice adhesion strength. Subsequently, if supercooled liquid water freezes when impacts to the solid surface of aircraft, the resulting ice can be shed, taking advantage of external forces, such as gravity or aerodynamic forces, to overcome ice-surface adhesion forces.

In the last decade, several works have been dealt with the development of superhydrophobic/icephobic coating to reduce the ice adhesion or the ice accretion, most of them employing complex synthetic conditions, e.g., etching and high temperature, complex fabrication techniques, and are often limited by the substrate type and geometry that can be successfully coated.

The effort of the present work is to develop a superhydrophobic coating for metallic substrates having low roughness and find out a simplified and not-expensive method to prepare and apply the coating on the aircraft surfaces. The new formulated superhydrophobic coating consists of nanostructured layers able to generate hierarchical micro/nano structured roughness, and, contemporary, reduce the surface free energy, which, as previously declared, are the two main factors useful to make a surface superhydrophobic. This work is being developing in the framework of the Clean Sky 2 ongoing SAT-AM (More Affordable Small Aircraft Manufacturing) project, whose main goal is the development of new technologies for future small aircraft allowing to fly with low fuel consumption, low noise level and in its life cycle will need minimal quantities of the raw material.

**SPAIN: A New Concept of Insulation Package For A Small Turboprop Aircraft**

*Massimo Viscardi, Giuseppe Bizzarro, Valerio Maria Porpora, Giuliano Di Paola, Edoardo Aubry*

Control of interior noise levels in aircraft has been a significant research area over the last two decades; mainly turboprop vehicles have been largely studied. The reason is that, the turboprops, are more fuel efficient than jets on shorter, slower routes but present a strong potential for unacceptably high structure-borne noise levels in the aircraft fuselage. These high noise levels would require very efficient fuselage sidewall transmission loss at a propeller blade passage frequency in the range of 150 to 300 Hz. To meet these technical requirements in terms of internal noise reduction, the use of insulating materials between interior trim panels and the fuselage is required. Within the Clean Sky 2 – SPAIN project, a new concept of insulation package has been developed with reference to the Evektor EV55 aircraft; the new concept approach uses an innovative acoustical blanket configuration to be attached to the interior trim panel rather than to the fuselage. This configuration allows, in concept, a faster access to wiring and an easier replacement of the blankets, when needed.

The methodological process is based on a Vibro-acoustical numerical Finite Element approach, to evaluate the Sound Pressure Level (SPL) at passenger ear level. In the preliminary work phase, the CAD model of a fuselage section has been created representing the typical features and dimensions of an airplane for regional flights; the mesh has been built on it considering different materials and properties to obtain the best representation of the real in-flight condition. To estimate the aerodynamic load caused by the blade passage, operative in-flight sound pressure level has been analyzed in a reverse engineering approach; as a result, the equivalent pressure distribution over the fuselage exterior has been computed.

On the basis of the target of the study, different materials and possible stratifications have been experimentally studied in terms of acoustic properties and performances. Also relative complex impedance parameters have been estimated. Also experimental evaluation of the Transmission Loss has
been performed at Trim panel level. Equivalent impedance characteristics have then been implemented within the FEM model, by the use of Frequency-Dependent Acoustic Absorber Element and a predictable model has been created to evaluate interior noise. Through this numerical tool it has been possible to evaluate the best configuration and optimize the blanket choice to obtain the target SPL reduction considering different fuselage location, acoustic cavity and target weight of the complete insulation package. The innovative sound insulation package has then been realized and experimentally tested both at coupon and component level as a preliminary stage toward the in-vehicle installation and testing.

DECOA: New Effective and Environmentally Friendly Technologies for Metallic Aircraft Fuselage Parts

Alexandra Karanika, Nikolaos Vourdas, Anastasios Makrikostas, Theofanis Plagianakos

Operational considerations, societal concerns, REACH regulations and ACARE targets are creating a growing demand for the development of new effective and environmentally friendly manufacturing technologies. From an operational point of view, materials used in manufacturing of airframe components need to become lighter, more resistant against corrosion, cheaper and more eco-compliant. These components may include the wing, the fuselage and the cockpit structure. From an environmental and societal point of view, it will be necessary to reduce the aviation footprint, through aircraft performance improvements (weight/drag reduction and versatility) and an eco-friendly life cycle, including a significant decrease of hazardous materials during manufacturing. ACARE targets and REACH regulations should be also fulfilled. Within the frame of all the above mentioned needs and targets, Hellenic Aerospace Industry (HAI) is participating in Clean Sky2: ecoTECH* seven years core project (2016-2022). The goal of this research is aiming on the development of new Surface treatments anticorrosive technologies which are totally Cr free, applied on new high formable, lighter and more corrosion resistant Ali-Li alloys.

In this work, the presented activities are focused on Thin Film Sulphur Anodization (TFSA) process, including also a newly developed Cr free sealing step and the application on a 4th generation AA2060 T8E30 alloy which is investigated regarding mechanical properties and formability, and avoiding heat treatment by the airframer. The environmental benefits coming from the development of these technologies are performed by the elimination of hazardous compounds, the weight saving coming from the use of lower density materials, the further lightening of the structure out of alloys with improved mechanical properties and the energy saving from avoiding the heat treatment process, necessary during usual parts forming like rolling, bending and stretch forming. In addition, the TRL increase of the combined technologies will be proved by the ground testing of a representative fuselage panel.
Linked Data Architecture for Assistance and Traceability in Smart Manufacturing

Adrian Singer, Ken Wenzel, Marko Friedemann

Traceability systems and Digital Assistance solutions are becoming increasingly vital parts of modern manufacturing environments. They help tracking quality-related information throughout the production process and support workers and maintenance personnel to cope with the increasing complexity of manufacturing technologies. In order to support these use cases, the integration of information from different data sources is required to create the necessary insights into processes, equipment and production quality. Common challenges for such integration scenarios are the various data formats, encoding and storage solutions, software systems, technologies and interfaces that are involved in the acquisition, transmission, management and retrieval of the necessary data. Nowadays, there is no generic approach that would be able to address the individual challenges for the adaptation and integration of a given number of systems and components, let alone for keeping track of the inevitable changes in heterogeneous systems. This paper proposes a system architecture based on Linked Data with related web services as a basis for modular and independent assistance software. Where applicable, data is represented using linked-data concepts while semantics of production data and descriptive information are represented as ontologies. The proposed concept is illustrated with examples from the manufacturing domain like maintenance on forming machines, data analysis and traceability.

A multi-disciplinary design optimization of the passenger service unit in the aircraft cabin

Mara Fuchs, Christian Hesse, Jörn Biedermann, Jörg Fuchte

This paper is focussed on showing the first results of a multidisciplinary design optimization (MDO) of the passenger service functions in the cabin. Therefore, both the placement of the components and the dimensions of the passenger service unit (PSU) are varied. In order to modify the parameters, the individual components of the PSU are generated as objects using model based systems engineering. As a result, the information is stored in each object and can be used for the evaluation. In particular, the focus will be on passenger comfort and safety regulations. Collectively, this paper shows some possible variations for the arrangement of the PSU elements and discusses and compares the results obtained as well as possible future developments of this work.

Sustainability Driven Product Development in Aviation

Christine Thiede

To meet environmental concerns, many companies pursue eco-innovation. In doing so, eco-design is probably the most popular and applied approach to integrate environmental aspects into design and innovation processes. To implement eco-design, enterprises commonly use the standardized and well known approach of Life cycle assessment (LCA). The integration of environmental aspects in early stages of the design processes enable potentially high influences on the final product, while the influence is steadily decreasing the later the aspects are integrated. While product and project costs and risks are traced and monitored regularly, the implementation of environmental aspects does not match to daily work of engineers and innovators. To have an appropriate and embedded approach that fits the needs of
companies and is integrated in the daily business, Altran developed its approach for “Sustainability Driven Product Development”. Based on LCA, Altran conducts an integrative life cycle assessment (iLCA) that includes a life cycle costing (LCC) as well as an environmental life cycle assessment (LCA). The integrated LCA (iLCA) results in different life cycle scenarios that are built and evaluated in different iterations during the full development process, that build the basis for decision-making within crucial phases of the innovation process. This approach ensures an optimized way of developing new or disruptive technologies by considering technical, economic and ecologic perspectives. Resulting in a model that covers all relevant aspects, risks and parameters that impact the objectives of the product or process. This model is capable to show qualitative interdependencies between specific parameters in order to highlight relationship amongst them and allows identifying environmental hot spots, as well as (associated) costs and risks. Merging the iLCA and risk management results in deeper understanding of the overall product and process system to provide better project or product steering during the innovation process.

**Blockchain as a smart bridge between disconnected IT systems**

*Vincent Ackenhausen*

In the scope of AutoKAB (LuFo), a proof of concept of a Digital ecosystem of Chatbots connecting multiple organizations and their toolkits through a permissioned blockchain network is developed and investigated. It aims to automate the execution of cabin customization processes and multi-organizational data sharing within the aviation supply chain. Within this digital ecosystem, chatbots should be used as intelligent assistance systems that can perform redundant tasks. These include tasks such as simple (cross-organizational) status queries. Another key aspect of the digital ecosystem is the integration of toolkits, such as the G Suite, which are used for collaborative and decentralized processing of various common file formats (for example, creating, reading and editing documents). A blockchain serves as a secure "bridge" for the transfer of data across the entire process chain (cross-organization – single source of truth), through which chatbots can be triggered. This work provides insights and learnings from the finished development work until now as well as the according conclusions for the way forward.
An introduction to the Future Sky program

Bruno Sainjon

Future Sky (FS) is a Joint Research Initiative of the Association of European Research Establishments in Aeronautics (EREA) devoted to preparing key technologies and capabilities for a green and seamless air transport in Europe. Within Future Sky EREA promotes joining forces with the European industry and universities to design a new air transport system allowing environmentally friendly, smooth and efficient air vehicles and associated mobility. Green and seamless air transport is to be thought as a key element for the most far-reaching goals of Flightpath 2050. Striving for a substantial increase in performance, safety, competitiveness, and acceptance, Future Sky aims at promoting maximum air mobility while making the highest demands on technologies as well as vehicle, system and operation design. The overall Future Sky program is subdivided into six topics, each of them called “Future Sky Theme” and focusing on different aspects or challenges on track to the future air transport system:

1. Future Sky Theme 1: SAFETY – The population of a Future Sky will be denser and definitely more diverse than it is today. For this, new safety rules, regulations, measures, and standards have to be developed and validated together with the development of technologies aiming at high level of safety.

2. Future Sky Theme 2: QUIET AIR TRANSPORT – Reducing the noise impact of aviation is more critical than ever for the public acceptance of air transport system, both because health issues are now acknowledged to be at stake and because new challenges are emerging (Urban Air Mobility, Supersonic aircraft). The issue must be addressed thoroughly with experts in social sciences and urban planning beyond core researches on reducing noise at source through noise reduction technologies and low-noise vehicle designs.

3. Future Sky Theme 3: ENERGY – Aside from quietening air transport, greening is the second major challenge for future vehicles and power plants. Green and seamless air transport will require new propulsive concepts and technologies as well as new energy sources (drop-in or non-drop-in fuels, electrification) as an alternative to fossil energy sources.

4. Future Sky Theme 4: URBAN AIR MOBILITY: This emerging new mode of transportation will provide on-demand mobility in high density as well as remote areas, regional seamless mobility, and efficient and environmental friendly manned and unmanned passenger and cargo transportation as set out by Flightpath 2050. This new FS Theme can be seen as a contribution to the reduction of road traffic congestion.

5. Future Sky Theme 5: SECURITY FOR AVIATION: Nowadays, the security is a crucial international and societal challenge which faces a growth of the diversity security threats and the development of autonomous systems which increases dramatically the complexity of the threat management. Studies need to be carried out to determine the best measures for protection and the most appropriate reactions to develop appropriate, efficient and consistent solutions against the present and future aviation threats.
6. Future Sky Theme 6: CIRCULAR AVIATION: The increasing environmental awareness within the European society is challenging the aviation sector to intensify its efforts towards a greener, cleaner and more sustainable aviation, by reducing its environmental impact in terms on consumption, waste and emissions connected to all aviation activities and operations. The principles of circularity, or circular economy, shall provide a framework to re-evaluate the complete, cradle-to-cradle, life cycle of each aspect of aviation, enabling the transition to circular aviation.

Future Sky seeks to rally the available but so far scattered capabilities to tackle the major longer-term challenges of Flightpath 2050. For this reason main feature of this program will be the coordination, as far as possible, of research establishments’ efforts in the field of aviation research in Europe. EREA believes institutional cooperation of European research establishments is the best guarantee to ensure medium and long term technology development beyond the scope of top-down approach in SESAR and Clean Sky JUs. In Future Sky national research establishments develop and pursue roadmaps covering at least a period of seven years addressing the complete air transport system and tackling research gaps not fully covered by the national institutional research programs.

Renewed Prospects for research on Quiet Air Transport in EREA’s Future Sky
Laurent Leylekian

This presentation will introduce the renewed views of the Association of European Research Establishments in Aeronautics (EREA) on “Quiet Air Transport” for its flagship research programme named Future Sky. Future Sky endeavours to make possible a green and seamless transport at the Horizon 2050. In this regard, aviation noise is a broad matter of concerns challenging the European leadership on aviation, its economic competitiveness and the highest living standards that the EU ambitions to achieve for its citizens. In the past few years, intensive research has been led both at the European level and at national levels to address this issue. These research projects were mostly streamlined further to the so-called balanced approach recommended by the ICAO. Though such projects proved to be bring very valuable outcomes, the engaged effort must now be upgraded.

Therefore, if the main focus remains reducing noise at source for airliners, the scope of research for aviation noise must be enlarged. For traditional aircraft, improving noise reductions technologies through incremental research is still demanded but efforts leading to disruptive low noise aircraft designs must be pursued and even reinforced as the 2050 objectives are probably unreachable without such designs. In addition, the specific but growing concerns about forthcoming Urban Air Mobility and Services (UAMS) must be addressed comprehensively, i.e. in a process in which noise at source should be envisaged in trade-offs with other issues (safety, pollution, energy) in an overall quest for sustainable ATM models. For this new UAMS as for conventional aviation, noise should ideally be handled comprehensively, taking into account the overall noise endured by the neighbours of airports considered as intermodal hotspots. Last but not least, new developments to reduce carbon emissions for aircraft should be developed in coordination with aircraft noise reduction strategies. In this regard, notions such as annoyance, social acceptance, compensation or related health issues must also be embraced beside technology. In particular, the recent release of a critical report of the World Health Organization (WHO) about aviation noise turned more than ever noise into a top-priority health issue.
The Future Sky Safety program

Michel Piers, Lennaert Speijker

As one of the largest EU-funded programmes in aviation safety research ever, the Future Sky Safety (FSS) programme is strengthening the coordination of the vast amount of air-transport safety research and innovation across the EU and has created new cooperative safety research projects in which the leading European researchers take on key safety challenges together.

For example, a project on runway excursions developed algorithms and monitoring techniques for reducing the risk of runway veer-offs. Validated in large flight test experiments, these tools can be used by both airlines and flight data monitoring software developers. Also, the program has developed a prototype of a Risk Observatory, integrating risk models from various industry domains (Aircraft design, ATC, aviation oversight, etc.), allowing the monitoring on Total Aviation System Risk and what-if analysis of the impact of safety interventions. Furthermore, starting with a pan-European safety culture survey of 7239 European pilots, FSS-developed guidance on advancing the safety management of organisations which has already been adopted by a major European airport. Another important result is the development of the Human Performance Envelope (HPE), a new concept for cockpit operations and design. Through flight simulation, researchers have demonstrated how the HPE approach can contribute to safeguarding human performance in emergencies. In another project, researchers tested the fire resistance of advanced composite materials. This work has demonstrated the potential of geo-polymers to vastly improve the fire-safety of aircraft cabin materials. This presentation will provide an overview of the background and content of the program as well as the main results.

Future Sky Circular Aviation Theme

Ligeia Paletti

Circular Aviation is the Future Sky theme promoted by the Association of European Research Establishments in Aeronautics (EREA) and addressed to tackle the multitude of environmental challenges faced by aviation in its path to become fully sustainable.

The commitment from European institutions towards sustainable transportation, together with a growing environmental awareness in the European society, requires the development of appropriate, efficient and consistent solutions to reduce the present (and future) environmental footprint of aviation, without impacting economic growth and limiting the movement of passengers and freight.

Insofar sustainability activities in aviation mainly referred to reducing greenhouse gases emissions and fuel consumption from operations. Though essential, such approaches cover only part of the lifecycle of an aircraft, and only a limited amount of the overall energy consumption and emissions related to aviation. Recently, sustainability has also approached aspects related to production and manufacturing. Yet, most aspects related to end-of-life solutions, maintenance and (most of) operations and production of aircrafts and airports have been neglected in the life cycle analysis.

Circular economy principles can enhance the already ongoing research activities and industrial implementations of more sustainable solutions in aviation, by expanding their current fields of application (from local to global), by initiating new solutions aiming at achieving a greater impact and by reassessing the overall aircraft lifecycle (from cradle to cradle) based on more comprehensive criteria and indicators. Within the Circular Aviation framework, the development and implementation of sustainable and circular solutions in a broad range of research topics are inspired, stimulated and supported, from design, material selection and manufacturing to operations, and from life cycle analysis methodologies to recyclability and other end-of-life considerations.
Future Sky Urban Air Mobility (FS UAM)

Christian Eschmann

The aim of Urban Air Mobility (UAM) is to improve the efficiency of cargo and passenger transport urban and inter-urban systems, to relieve the congestion on roads and to enable fast motion of goods and persons. Taking into account the costs and the value of time saved by airborne solutions, UAM will offer attractive alternatives at an urban, suburban and inter-urban level. Therefore, the goal is to shift a part of short and medium distance passenger car trips as well as short and medium distance cargo transports to small aircraft and innovative air systems. In summary, UAM sets out three main objectives: on-demand mobility in high density as well as remote areas, regional seamless mobility responding to Flightpath 2050 goals, and efficient and environmentally friendly unmanned cargo and piloted/autonomous passenger transportation. In this context and promoted by the Association of European Research Establishments in Aeronautics (EREA), the joint research initiative of Future Sky Urban Air Mobility will focus on the topics Aircraft Technology Advancement, Autonomy, Traffic Management, Strategies for Mobility, as well as Public Acceptance and Environment.
Low frequency sound transmission into buildings and induced vibration due to sonic boom

Finn Løvholt, Karin Norén-Cosgriif, Joonsang Park, Jörgen Johansson, Arnkjell Løkke, and Christian Madshus

Sonic boom can cause rattling and whole body vibration that can perceived by humans due to its high level low frequency sound spectrum. The perception of such vibration may further lead to human disturbance and annoyance. Here, we present a study quantifying how the low frequency sound due to a sonic boom enter buildings and causes vibration into the construction. The first part present results of previous field measurements of sound transmission loss and vibration in lightweight buildings. The second part concerns numerical simulations of sound transmission and vibration. A European building style screening study is used to define the building type study cases, which is in turn combined with a broad set of sonic boom transmission loss simulations for the selected types of buildings. Based on the simulations, we conclude that a wide range of construction properties needs to be taken into account to determine the low frequency sound transmission and vibration. It was found that the construction details (stiffness, mass, and mounting) of the outdoor wall, the indoor floor, and the windows were important in controlling the transmission loss and the vibration. However, other aspects such as the room dimensions and presence of openings and open ventilation were equally important. In particular, presence of small openings and ventilation can largely increase the sound pressure indoor. While the modelling focussed mostly on the sound transmission into single rooms, we also carried out a brief investigation of the excitation of global shear vibration modes in multi-storey buildings. It was found that such modes might possibly be perceived by humans too, but this needs to be investigated further. This work is conducted within the EU H2020 RUMBLE project.

Sensitivity of sonic booms to parameters of atmospheric turbulence

Roman Leconte, Jean-Camille Chassaing, François Coulouvrat, Régis Marchiano

Sonic boom propagation in a turbulent atmosphere has been modeled in two dimensions using a numerical solver (software FLHOWARD) developed by Sorbonne Université and CNRS and specifically developed for this purpose. To a quiescent and isothermal two-dimensional atmosphere is superposed a random synthetic velocity field with homogeneous and isotropic statistical properties satisfying a von Kármán energy spectrum. Using the "random field generation method", the flow velocity turbulent field is governed by three independent parameters: a random matrix, an intensity parameter and a scale parameter (turbulence integral scale). Sensitivity of sonic boom propagation to these last two physical parameters (also supposed to be random variables with a uniform distribution) is quantified for three types of boom of same amplitude but different initial shapes: an ideal N-wave, a measured boom (NASA data for F-18) and a "low" boom (C25D mock-up) with increased rise time. In order to reduce the number of simulations compared to a Monte-Carlo approach, study is performed within the generalized chaos polynomial (gPC) framework. Various convergence tests have been performed to define the optimal discretization and gPC order. Stochastic evolution of selected metrics along a 1 km distance are investigated. Random defocusing and focusing areas are observed, as already observed in the literature. Moreover, the uncertainty of sonic boom metrics with regard to turbulence parameters is also shown to vary with distance, with zones more certain and zones more uncertain. Study also indicates that zones of
focusing/defocusing and zones of certainty/uncertainty are not simply correlated to one another. However, uncertainty is shown to globally increase with distance, but is reduced for a reduced boom compared to an N-wave. Further analysis shows that sonic boom metrics are generally more sensitive to turbulence intensity, though in zones of highest uncertainty, sensitivity to integral scale gets comparable or even higher than sensitivity to turbulence intensity. [Institut Jean Le Rond d’Alembert, Sorbonne Universite and CNRS. Work realized for the European project RUMBLE. PhD of Roman Leconte is also cofunded by DGA]

To the issue of evaluating sonic boom overpressure and loudness

Andrey Kazhan, Igor G. Bashkirov, Victor V. Kovalenko, Vladlen S. Gorbovskoy, Vyacheslav G. Kazhan, and Sergey L. Chernyshev

At present, in the world there is a growing interest in the development of a new generation of supersonic passenger aircraft. One of the main problems of creating such aircraft is to ensure both an acceptable sonic boom level and high aerodynamic characteristics in the supersonic cruising mode. This requires the development of reliable methods for obtaining the near field under the plane with taking into account the influence of the boundary layer, calculation of overpressure signature on the ground and evaluation of sonic boom loudness. In this work four variants of the equivalent body of revolution of minimum sonic boom with different nose sharpening were investigated for an aircraft weighing 19 tons in supersonic cruising flight at Mach number of 1.7 and altitude of 15.5 km using the software package for solving the Reynolds-averaged Navier-Stokes equations (RANS) ANSYS CFX. A macro for calculating the overpressure signature on the ground for the distribution of disturbances in the near field under the aircraft and a program for evaluating the sonic boom loudness in various metrics were developed. Computational mesh verification of the results was carried out, the obtained overpressure signatures were compared with theoretical data and calculation results from the software package for the integration of complete system of Euler equations by finite-difference method X-CODE. The effect of the sharpening of the nose part on aerodynamic drag and sound boom characteristics was shown. The work was done in the interests of the international project RUMBLE (RegUlation and norM for low sonic Boom LEvels).

Design of sonic boom simulators for low boom perception studies

Léo Cretagne, Carlos Garcia, François Coulouvrat, Jacques Marchal, François Ollivier, Stephan Töpken, Steven van de Par

One of the main objective of RUMBLE European project is to quantify accurately the correlation between low sonic boom exposure and human response in representative situations (« ecological validity ») for the European citizens. Noise and vibration dose to response relationships, including the probability to awake during night sleep, are needed to inform policy, establish standards and develop protection concepts in order to reduce the impact in communities and therewith decrease the overall annoyance of supersonic transportation noise. To reach this objective before a new generation of supersonic aircraft with reduced boom is developed, two low boom simulators have been built as part of the project. The first one, developed by University of Oldenburg (Germany), is a pressure chamber with a volume of less than 10 cubic meters. It is driven by two 18 inch speakers that are mounted in a door towards a neighboring room, which acts as the loudspeaker enclosure. Due to the small size of the pressure chamber, low frequency sound from a few Hertz to 50 Hz can be reproduced without the disturbing influence of room modes. The influence of room modes at higher frequencies is reduced by absorbing material on the walls and the
tilted ceiling. In addition, a platform for the reproduction whole-body vibration can be installed in the chamber for the investigation of the multi-modal perception of low sonic boom.

The second one has been developed by Sorbonne Université and 3rd party CNRS so as to insonify with a low boom an already existing house from University campus in Saint Cyr l'Ecole (France) in Paris metropolitan area. To our knowledge, this is the first time such type of high-fidelity boom reproducing system is specifically designed to adapt to an existing habitation house. To reproduce the low frequency part (< 100 Hz) of the signal, which conveys most of the sonic boom energy, six electromechanical subwoofers have been assembled and installed outside the selected test house, just in front of the window frame of one ground floor room. The system is completed by a loudspeaker for reproducing higher frequencies. For both simulators, characteristics of pressure and vibration fields will be detailed, and further perception studies will be presented.
Evaluation of Variable Pitot Inlet Concepts for Transonic and Supersonic Civil Aviation

Stefan Kazula, Marcel Mischke, Paul König, Klaus Höschler

Variable inlets have the potential to reduce aircraft drag, allowing for increased efficiency and faster flight speed compared to aircraft with rigid inlets\(^9\). Furthermore, compared to 2-dimensional variable inlets, which are currently utilised in supersonic aviation, circular axisymmetric variable inlets can provide an airflow of higher uniformity to the aero engine’s compressor system. Therefore, variable pitot inlets could allow for a shorter length and thus decreased weight, potentially enabling supersonic commercial aviation. Several research studies concerning circular variable inlets with adjustable lip and duct geometry have been conducted\(^{10,11}\). However, this technology has not made its way into service yet. A potential lack of safety and reliability is one explanation for this, as the additional function ‘adjustability’ leads to an increased complexity of the inlet system.

For this reason, within the scope of a feasibility study for circular variable inlet concepts, the methodological development process is combined with the safety assessment process in aviation according to Aerospace Recommended Practices ARP 4754A\(^{12}\). Previous publications addressed:

- the development of first concept groups for circular variable inlets, e.g. geometry adjustment by movement of rigid segments, deformation of elastic surface material or boundary layer treatment\(^{13}\)
- the application of the safety methods Functional Hazard Assessment (FHA), Fault Tree Analysis (FTA) and Common Cause Analysis (CCA), as well as subsequent design adaptations\(^{14,15}\)
- the integration of ice detection and protection systems for circular variable nacelle inlet concepts\(^{16}\) as well as
- the identification of ideal inlet geometries in terms of drag and flow uniformity for different flight speeds up to Mach 1.6\(^{17}\).

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\(^{13}\) Kazula S, Höschler K. A Systems Engineering Approach to Variable Intakes for Civil Aviation. 7th European Conference for Aeronautics and Space Sciences (EUCASS), Milan, 2017.
This paper describes the selection of the ideal group of variable inlet concepts by utilising results of these system safety analyses, integration studies, aerodynamic investigations and further studies.

First, the tasks and requirements of inlets, the trade-off in inlet design, as well as the variable inlet concept groups are introduced. Afterwards, suitable concept evaluation methodologies and criteria are selected and presented. Subsequently, the different concept groups are analysed and evaluated regarding economic, functional and safety requirements. This evaluation allows for the identification of the most suitable group of concepts for variable inlets. These concepts will be refined in further detailed studies to achieve Technology Readiness Level 3 (TRL3).

The selection of the most suitable concept group at an early stage of the product development allows for a more detailed investigation during the following phases of the development process, potentially leading to an improved safety and operating efficiency of the final variable inlet concept. This could enable the technology of variable inlets for civil aircraft and consequently assist to achieve the ambitious ecological, safety and economic goals for future commercial aviation.

**Parametric Design Study on Aerodynamic Characteristics of Variable Pitot Inlets for Transonic and Supersonic Civil Aviation**

*Stefan Kazula, Mark Wöllner, David Grasselt, Klaus Höschler*

The aviation industry is constantly striving to improve efficiency, reduce emissions and increase travel speed, while ensuring safety and reliability\(^\text{18}\). One way to achieve these goals is to improve aero engines and their integration into the aircraft. Currently, aero engine inlets are designed as a trade-off concerning aerodynamic requirements. Many studies concerning inlets are dealing with the aerodynamic design of the ideal trade-off geometry\(^\text{19, 20}\).

By implementing a variable inlet geometry, it is possible to avoid flow separation due to crosswind and incidence during take-off and climb conditions up to Mach 0.3, while ensuring maximum efficiency at high speed cruise. A reason for not implementing variable inlets in subsonic aviation yet, may be the low benefit in this range of speeds, as the improvements in aerodynamic efficiency may not compensate the increased complexity and weight.

Variable pitot inlets for transonic or even supersonic business applications up to Mach 1.6 could have bigger benefits than those for subsonic aviation\(^\text{21}\). Several aircraft manufacturers are conducting research on ambitious programs concerning supersonic business jets for the future. Compared to the variable non-circular two-dimensional inlets of all earlier applications, a circular variable pitot inlet could achieve much lower drag and provide air of higher uniformity to the compressor system, enabling shorter inlets, and thus less weight as well as improved integration into the aircraft. However, it must be considered that the ideal lip and duct geometry of a pitot inlet for supersonic operation differs significantly from that of a

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\(^{19}\) Luidens RW, Stockman NO, Diedrich JH. An approach to optimum subsonic inlet design. ASME. Turbo Expo: Power for Land, Sea, and Air, Volume 1A: Gas Turbines, 1979.


subsonic pitot inlet. Hence, knowledge of the ideal geometries for the relevant flight phases is necessary to develop and evaluate concepts for variable inlets.

This paper introduces an approach to determine ideal macroscopic inlet geometries for circular variable aero engine inlets in transonic and supersonic civil aviation. The trade-off in aerodynamic inlet design and inlet evaluation parameters are presented. The development and the validation of an aerodynamic model for the respective diverging flight conditions are introduced, compare Fig. 1. The advantages and limitations of the presented approach are addressed. The dependencies of inlet drag and efficiency from geometric inlet parameters at flight speeds of Mach 0.95 up to Mach 1.6 are identified by means of a parametric design study. This way, ideal geometries for variable pitot inlets and their potential range benefit of variable inlets are determined.

**Tailless Configuration for a New Generation SST**

*Catalin Nae*

This work is a continuation for the work performed within the ATLLAS-II Project aimed for a new generation supersonic transport aircraft. Here the focus is on the assessment of the tailless configuration concept, where significant advantages may be envisaged if this approach is to be combined with a flight dynamics unconventional strategy. The demands of high performance characteristics have led to aerodynamically unstable aircraft configurations. A tailless supersonic aircraft is by definition an unstable aircraft that can be flown only with the aid of a flight controller (i.e. in a closed loop). Increased maturity of key technologies for the dynamics of sustainable supersonic flight makes possible development of a new generation of supersonic aircraft where disruptive technologies will play a key role. In this paper we assess the benefit of the tailless configuration in terms of weight savings (17%) and we introduce the concept of dynamic configuration control for the new SST design (tailless) where we achieve control using dynamic allocation of mass. This is highlighted mainly for spin recovery control, with extensions towards more complex dynamics. Some preliminary wind tunnel tests results are also presented for our reference configuration in order to justify the potential benefits, together with development strategy including fluidic controls for a tailless SST.
Assessment of the Performance of a Cruise Missile Wing Depending on Design Parameters at Various Flight Conditions  

**Burak Erturk, Yavuz Yaman**

The design of a cruise missile wing is a multidisciplinary work, since the wing has to provide enough aerodynamic forces while being structurally safe. In order to meet the design requirements and achieve a successful design, several parameters of the wing need to be investigated at various flight conditions. In this paper, lift forces and flutter speeds are obtained for different wing geometries, at various altitudes and speeds. The design of experiments is constructed by changing the several variables of the wing to have better understanding of the effect of design parameters. The aerodynamic analyses for predicting the lift force are performed by using FLUENT and the aeroelastic analyses for the determination of the flutter speed are conducted by using ZAERO package programs. At the end, results are utilized using the response surface methodology.

Study of Aero-Thermal Effects of Different Heat Boundary Conditions on Optical Side Window in Hypersonic Flow  

**Chun-Chi, Li**

Under hypersonic flow environment, the optical side window of optical guidance missile triggers aerothermal heating effects that create high heat and cracks in optical windows, leading to optical windows failure. This study adopted computational fluid dynamics to compare the effects of two types of thermal boundary conditions (i.e., adiabatic and heat flux conditions) on the surface temperature of an optical side window at a flight speed of Mach 6, simulated altitude of 20–60 km, and under a transient detached eddy simulation (DES) turbulence model. The simulation results revealed that after a flight time of 60 seconds, the surface temperature of the optical side window was 100–200 K cooler in a heat flux condition compared with that in an adiabatic condition. This temperature range approximated more closely to that observed in reality. At an altitude of 20–40 km above sea level, the surface temperature of the optical side window exceeded the safe working temperature of 500 K, indicating that the optical side window requires a cooling mechanism. When the flight altitude exceeded 50 km or more, the surface temperature of the optical side window was less than 500 K, suggesting that no cooling mechanism is necessary.

Design and Optimisation of Flat-Upper-Surface Airfoil  

**Cezary Galinski, Magdalena Gronowska, Wiencezyszlaw Stalewski**

Technology of photovoltaic cells and lithium batteries is being developed rapidly. As a result, attempts to build solar High Altitude Long Endurance (HALE) airplanes are more and more frequent. In the future such airplanes may appear very useful for the economy because they may replace geostationary satellites in several applications for a fraction of cost. Unfortunately, data on altitude effect on photovoltaic cells and batteries performance are not easily available. Moreover, acquisition cost of cells is still high. Therefore HALE airplanes design is expensive and risky. Incorrect components selection could result in the project failure. Therefore, a tool for inexpensive testing of cells is needed. Small and very light unmanned aerial
vehicle (UAV) can be used for this purpose. It could fly as high as envisaged HALE airplane with small number of cells and batteries providing valuable information on them. The weight of such an experimental UAV could be minimized because long endurance would not be required. Wings of this UAV should allow for installation of various types of photovoltaic cells including rigid ones. Therefore it would be advantageous to apply an airfoil with as large as possible flat upper surface. The flat upper surface would be also useful in the case of flexible cells since they usually tolerate deflection in one direction. Attempt to bend the cell in two directions simultaneously may result in the permanent damage. Unfortunately high altitude airplanes have to be very light. Moreover, they need wings with very long aspect ratio. As a result, significant bending can be expected along the wing span. This bending could destroy cells previously bended along the wing chord in order to follow the shape of an airfoil. Unfortunately airfoils with flat upper surface are not frequently present in airfoils catalogues. Therefore an attempt was undertaken to design an airfoil with 75% of its upper surface being flat. The research was focused on maximization of lift to drag ratio and power factor assuming low Reynolds numbers conditions since it was designed for small UAV for photovoltaic cells testing.

Proposed presentation and paper will contain description of design methodology, design assumptions and obtained results. Moreover, experiment envisaged to verify the design will be described as well. Therefore the wind tunnel and a semi-span model used for this experiment will be presented together with obtained results. The model has exactly the same structure as envisaged structure of UAV, so flexibility of the wing will be taken into account. This wing structure will be also described.

Optimization of the three-segment aerofoil arrangement based on wind tunnel tests and numerical analysis.

Wojciech Grendysa, Bartosz Olszański

The aim of the activity described in this paper is to find new and optimal configuration of a classic and well known three-segment wing aerofoil. Based on the geometry and characteristics of the well-known and proven in flight wing aerofoil, the authors analyse the possibility of achieving a higher lift force coefficient by changing the position of the slot and the flap. The authors used both, computed fluid dynamics method (CFD) and wind tunnel tests, to investigate variable space and to find the best configuration of wing aerofoil segments. CFD methods were used for preliminary optimization while wind tunnel tests yielded certain results that allowed to determine the optimal position of the wing aerofoil segments. As a result of our work, a new slot - wing - flap geometry was developed. This geometry is based on the well-known aerofoil and allows to obtain a lift force coefficient equal to 3.9 in the landing configuration. The obtained value of the lift force coefficient is 12% higher than the initial one.

The research described in this paper was conducted on behalf of aircraft Production Company and its results will be applied in a newly designed aircraft. The original value derived from our activity is a procedure based on optimization methods, CFD methods and wind tunnel tests, which allows to determine the optimal slot - wing - flap arrangement that improves performance.

Numerical Investigation of Mutual Interaction between a Pusher Propeller and a Fuselage

Marcin Figat, Paulina Piątkowska

This article presents the numerical analysis of the aerodynamic impact of the fuselage on the propeller performance in the pusher configuration and the propeller impact on the flow around the fuselage. The main aim of the presented investigation was to find the magnitude of the interaction between the
propeller and the fuselage. This effect was evaluated by the analysis of the change of the fuselage drag and the propeller thrust according to the change of the propeller's geometry and its performance. All obtained results allowed to prepare the methodology for choosing the best propeller geometry for the aircraft in the pusher configuration. A power unit configuration mounted on the fuselage may be designed in the tractor or the pusher configuration. Both of them have many advantages and disadvantages. The impact of the fuselage on the propeller in the tractor configuration is rather low. However, this configuration makes the fuselage longer, which increases the drag and generates possible problem with CG position. The pusher configuration allows to obtain a better CG position because of the engine position. It allows to reduce the fuselage length and its friction drag. The main disadvantage is that the flow around the propeller is disturbed by the fuselage. It significantly changes the propeller efficiency and the available thrust. On the other hand, the propeller parameters significantly influence on the drag force generated on the fuselage. As mentioned above, during the investigation the different propeller geometry was analyzed. First of all, the change of the blade pitch and the propeller radius was tested. Computation was made for numerous flight conditions and propeller rotation rate. The main result was finding the best suited propeller, which is satisfactory for the new designed aircraft in the pusher configuration. Moreover, the relation between propeller and fuselage in the pusher configuration was found. Especially it was found the change of the propeller thrust caused by the fuselage and the change of the fuselage drag caused by propeller.

**Design method of a distortion gauze for testing the boundary layer ingesting fan**

*Adam Sieradzki, Tomasz Kwiatkowski, Michał Rajek, Grzegorz Krysztofiac, Paweł Ruchala, Borys Łukasik*

Global trends aim at reducing emissions of pollutants, thus boundary layer ingesting (BLI) propulsions attract more and more attention. Therefore, N+2 generation aircraft with propulsors mounted at the aft of the aircraft are gaining in popularity. The boundary layer is formed on the fuselage before entering the fan. Due to significant difficulties of performing experimental tests of BLI engines with full-size aircraft, distortion gaizes are one of the methods to provide the appropriate air velocity profile at the inlet. This paper focuses on the method of designing the above mentioned gaizes which are not well described in the world literature. In the first stage of the presented method single orifices of different sizes were calculated using CFD methods. The connection between their size and gauze resistance coefficient was found and this allowed to model the distortion gauze using porous media. An iterative approach was used to design the gauze that meets the requirements. Experimental tests demonstrated that the produced distortion gauze allows to obtain a velocity profile similar to the desired one. This indicates the great potential of using presented approach in further research on the boundary layer ingesting propulsions. It gives an opportunity to reduce substantially both the costs of experimental research and the time required to design a distortion-tolerant fan.

**Comparison of aerodynamic characteristics provided by wing with bell shaped lift distribution and generalized wings**

*Pavel Hospodář, Armand Drábek*

In this article different wings are computed by low and high-fidelity methods to compare their aerodynamic characteristics. Thanks to the unusual properties of the wing with the bell-shaped lift distribution, several general geometrical variants of the wings were calculated and their results are presented in this work. Three general wings are assumed and their geometry is defined as rectangular, trapezoidal and elliptical. Airspeed, total lift force, shape of airfoil and root chord are defined, and bending
moment is assumed as a surrogate model for wing weight. The goal of optimization is minimization of aerodynamic drag. Then two different wing geometry were designed to reach bell shaped lift distribution. First one is twisted tapered wing and second ones is untwisted wing with specified chord distribution. As a design tool a nonlinear lifting line is used to optimize having wing and result is compared with CFD. Both computational methods are validated with wind tunnel measurement.

**Nonlinear Vortex Lattice Method for Stall Prediction**

*Hasier Goitia, Raúl Llamas*

The stall behavior of an empennage is a crucial and conditioning factor for its design. Thus, the preliminary design of empennages requires a fast low-order method which reliably computes the stall behavior and which must be sensitive to the design parameters (taper, sweep, dihedral, airfoil, etc.). Handbook or semi-empirical methods typically have a narrow scope and low fidelity, so a more general and unbiased method is desired. This paper presents a non-linear vortex-lattice method (VLM) for the stall prediction of generic fuselage-empennage configurations which is able to compute complete aerodynamic polars up to and beyond stall. The method is a generalized form of the van Dam algorithm, which couples the potential VLM solution with 2.5D viscous data. A novel method for computing 2.5D polars from 2D polars is presented, which extends the traditional infinite swept wing theory to finite wings, relying minimally on empirical data. The effect of the fuselage is modelled by a cylindrical non-penetration surface and removing the inner lifting surfaces, which successfully models the spanload distribution of the exposed surfaces. The deflection of control surfaces is possible through the input of the 2D polars. Though a complete validation is still required, the method has been compared to CFD and WTT results, showing an acceptable degree of accuracy for the preliminary design of empennages.

**Evaluation of vortex-blade interaction utilizing flow feature detection techniques**

*Nuno Vinha, David Vallespin, Eusebio Valero, Valentín de Pablo, Santiago Cuesta*

The extraordinary growth in computational capabilities over the last few decades has enabled the numerical simulation of massive and complex flow problems with high accuracy. Not surprisingly, Computational Fluid Dynamics (CFD) has become a crucial tool in the design of pioneering aircraft engine architectures, such as Counter-Rotating Open Rotor (CROR) engines. Noise and performance requirements lead the design process from a very early stage, thus requiring deep investigation of the acoustic and aerodynamic behavior. Monitoring the trajectory of the vortices generated at the tip of the front rotating blades is of critical importance to understand and prevent vortex-blade interaction with subsequent stages, as this non-linear flow topology strongly influences the aerodynamic performance and acoustic footprints of the engine. This manuscript follows a flow feature-based approach to visualize and track these coherent structures, for the particular case of CROR. It starts by evaluating the suitability and performance of four typical Region-based (RB) vortex detection criteria, which delimit rotating flow regions, and one Line-based (LB) method that allows the reconstruction of the imaginary center lines of the vortices. Then, two new methodologies are introduced that improve the original assortment of seeds required by the tested LB method, as they increase the probability of the selected seeds to grow into a tip vortex line, providing faster and more accurate answers during the design-to-noise iterative process. This research was funded by the European project AIRUP (Airbus-UPM European Industrial Doctorate in mathematical methods applied to aircraft design), under grant agreement number FP7-PEOPLE-ITN-608087.
On a novel technique for hypersonic vehicle control

Mitridis D., Bliamis C., Panagiotou P., Yakinthos K.

A novel control technique which utilizes active shock bumps (SBs) as a form of control device is investigated for hypersonic aerial vehicles. The SBs deflect to create shockwaves on-demand, at specific locations around the aerial vehicle. As a result, a force is applied on the aerial vehicle, which in turn is used to provide the necessary moment for pitch and roll maneuvers. In this work, a preliminary aerodynamic analysis of the SB device technique is made by means of CFD. For this purpose and because of the large corresponding Reynolds numbers of the flow into consideration, the Euler equations in their 2D formulation are solved. A parametric investigation is carried out, by examining the effect of key parameters, namely the Mach number (M) and the device deflection angle (δSB) on the generated force acting on the vehicle, serving as a proof of concept. Using a dedicated Kriging interpolation method, the resultant force is presented as a function of the Mach number together with the device deflection angle, on three-dimensional charts, where the effect of each parameter is shown (force-Mach-deflection maps). Furthermore, a preliminary feasibility study is performed, including a kinematic analysis and some key material considerations. Additionally, a kinetic analysis is also conducted to secure the dynamic rigidity of the actuating mechanism by providing also an initial estimation concerning the weight and the basic geometrical parameters of the SB mechanism components. Finally, a system feasibility study is conducted to investigate its potential benefits or drawbacks, compared to conventional hypersonic aircraft control systems.

Multi-objective surrogate model based optimization of the small aircraft engine air-intake duct

Przemyslaw Drezek

Aviation industry is constantly striving for more efficient design processes in respect of optimal time, human and computational resources utilization. This implies a need for application of an approximation techniques enabling for fast responses generation with maintained level of results quality. This study focuses on an advancement of aerodynamic shape optimization process of a small aircraft engine intake system by introduction of a surrogate modeling step into the design loop. The multi-objective metamodel-assisted optimization is carried out in order to reduce pressure losses along the engine intake duct and increase flow homogeneity at the engine compressor intake plane. Latin Hypercube Design method is utilized in order to sample the design space. A set of initial samples is generated with usage of a commercial Computational Fluid Dynamics (CFD) Reynolds-averaged Navier-Stokes (RANS) code – ANSYS CFX. The ensemble of samples is further used to train a Kriging based surrogate model. The Efficient Global Optimization (EGO) algorithm basing on the Expected Improvement (EI) function is employed to gradually increase the metamodel prediction quality by usage of sequential sampling technique. Finally, the optimal point predicted by the Kriging surrogate is validated against the high-fidelity model with usage of the CFD code. The final conference paper will present an application of the above-mentioned methodology to the design process of the I-31T aircraft turboprop engine intake system. Proposed Kriging-based optimization workflow will be utilized in order to improve pressure losses and flow homogeneity in the engine air-intake duct.
Scaling of Helicopter Rotor Slipstream in the Ground Effect

Pawel Ruchala, Adam Dziubinski, Malgorzata Wojtas, Wit Stryczniewicz, Romana Ratkiewicz-Landowska, Kazimierz Szumanski

An unsteadiness of pressure, in a helicopter rotor slipstream, may bring a significant problem during operation from the elevated heliports, as the oscillating slipstream acts on the heliport plate and causes vibration of building’s structure (Mejssner 2011). However, still it is an unappreciated issue, discussed mainly in the literature focused on the brownout, e.g. (Nathan and Green 2008), (Ramasamy, Potsdam, and Yamauchi 2015). In this case researchers usually neglect the loads acting on the ground. On the other hand, investigations of interaction between the rotor slipstream and helicopter’s surroundings, e.g. (Gibertini et al. 2015), (Dziubiński 2016), are often limited to a time-averaged case. Investigation of pressure oscillation of the slipstream IGE may be conducted using scaled rotors. However, as the rotor slipstream is a complex, unsteady and aperiodic flow, it is necessary to obtain a way of scaling the rotor to achieve required similarity. The paper presents investigation of two 2-bladed rotors, located on the height of 1.0 radius above the ground. The ‘full-size’ rotor has its diameter of 7.9 m and revolution speed of roughly 450 RPM. The ‘scaled’ rotor has diameter of 0.71 m and revolution speed of 2100 RPM. Results of pressure oscillation captured on the ground underneath the rotor in both cases will be presented in the paper. The presented work is aimed on obtaining a set of nondimensionlized coefficients, which enable a transfer of results of experiments performed with a scaled rotor into a full-scale case. Currently the investigation of the ‘full size’ rotor is completed and the investigation of the scaled rotor is ongoing. It is planned to complete this part of the test till the end of June, 2019.

The concept and methodical assumptions for the development of a dynamically scaled aircraft model (unmanned or passenger aircraft)

Aleksander Olejnik, Robert Rogólski, Jarosław Milczarczyk

The article describes the concept of a scaled model and its application in the process of real aircraft prototyping. Computer simulations of aerodynamic flows are commonly used in the design of aircraft. Numerous data on the characteristics of an airplane can be obtained using tunnel tests. To get complete information in extreme or unstable conditions, dynamically scaled models are tested. The scaled model is a reduced model of the real airplane which have specific qualities similar to real aircraft qualities and these relations are strictly defined with characteristic similarity numbers (factors). The article presents methodology for determining scale factors in relation to geometric, aerodynamic and structural properties (mass, stiffness) of the aircraft. The methodology will be presented on the example of the concept of unmanned aircraft designed in Faculty of Mechatronics and Aerospace of the Military University of Technology (Warsaw, PL). The estimation of scale factors of the scaled model with respect to selected similarity features will be presented. In particular, the requirements and difficulties related to the determination of the dynamic similarity coefficients will be shown, due to the fact that the mass distributions and stiffness of the scaled-model structure differ significantly from their analogous features related to the real airplane. The aim of the article is to present the methodology developed by researchers from MUT. The method of estimating scale factors of the scaled model with respect to selected similarity features will be demonstrated here. The results obtained will be used then to dimensioning the selected structural component.
Investigations of the Vortex Ring State on a Helicopter Main Rotor Based on Computational Methodology Using an URANS Solver

Wienczyslaw Stalewski, Katarzyna Surmacz

Computational investigations of the Vortex Ring State (VRS) on a helicopter main rotor have been conducted. The VRS phenomenon is a condition of powered flight that occurs most frequently during the vertical or nearly vertical descent of rotorcraft. The characteristic feature of the VRS is a torus-shaped vortex around a rotor. The occurrence of this extensive vortex structure is a dangerous phenomenon that usually causes sudden decrease of main-rotor thrust, finally leading to increase of the rate of descent and vibration level, disturbances of a helicopter balance, deterioration of manoeuvrability and loss of power.

The investigations presented in the paper, have been conducted based on computational methodology developed and implemented by the Authors. The methodology is based on coupling of several computational models of Computational Fluid Dynamics and Flight Dynamic. The approach consists of calculation of unsteady aerodynamic forces acting on the flying rotorcraft by simultaneous solution of the Unsteady Reynolds-Averaged Navier-Stokes (URANS) equations, the equations of motion of the helicopter as well as the equations describing Fluid-Structure-Interaction phenomena especially important in rotorcraft flight, e.g. blade flapping. In the developed and applied methodology, flow effects caused by rotating blades of main and tail rotor, are modelled based on the Virtual Blade Model (VBM) approach, where real rotors are replaced by volume-discs zones influencing the flow field similarly as rotating blades. Time-averaged aerodynamic effects of rotating blades are modelled using momentum sources placed inside the volume-disc zones. The intensities of momentum sources are evaluated based on the Blade Element Theory, which associates local flow parameters in the blade sections with databases of 2D-aerodynamic characteristics of these sections. In addition to the VBM method, two UDF modules are used to the simulation of helicopter flight: the module responsible for modelling of all kinematic aspects of the flight and the module gathering the momentary aerodynamic loads and solving 6 DOF-Equations describing a motion of the helicopter seen as solid body. Using the described methodology several transient phases of a helicopter flight in vicinity of the VRS boundaries have been simulated. These simulations concerned typical flight scenarios usually leading to the VRS occurrence. When it has happened, the simulations have been continued aiming at escaping form the dangerous flight state. It has been conducted through appropriate changes of helicopter flight controls. The Figures attached to the abstract present the VRS phenomenon, the occurred during the 60-degree descent flight at velocity 8 m/s. The presented streamlines visualise extensive vortex structures around the helicopter main rotor. The velocity-magnitude contours show that higher velocities of flow occur only in proximity of the helicopter, which is typical for the VRS.

Comparison of numerical predictions of the supersonic expansion inside micronozzles of micro-resistojets, using different propellants

Maria Grazia De Giorgi, Donato Fontanarosa; Antonio Ficarella

In the field of small satellites, the design of micro-propulsion systems for attitude control, formation flying and high-accuracy pointing capabilities represents a crucial concern due to the requirements for small thrust forces, ranging between micronewtons to some millinewtons, and high specific impulses. In this regard, micro-resistojets represent an attractive option. Among this class of micro-propulsors, vaporizing liquid microthrusters (VLM) and cold/hot gas microthrusters can satisfy all propulsive requirements with a reduced overall complexity, while still meeting mass, volume and power constraints. Compared to
cold/hot gas microthrusters, VLMs can store the propellant in low pressure and light weight fuel tank, even though with increased complexity and a higher consumption of the electric power to be spent for the evaporation process. One of the main issues of both VLMs and cold/hot gas microthrusters is the strong penalty in the micronozzle efficiency due to the growth of the viscous boundary layer inside the micronozzles, enhanced by the micro-scale and the rarefied gas condition. In this context, the present work will provide a numerical investigation of the supersonic flow inside a planar micronozzle configuration under different gas rarefaction conditions. Two different propellants will be considered, namely water vapor and nitrogen, which relate to their use in VLMs (the former) and cold gas microthrusters (the latter), respectively. Furthermore, two different numerical approaches will be implemented and compared, i.e. the typical continuum Navier-Stokes with partial slip assumption at walls and the particle-based Direct Simulation Monte Carlo (DSMC) technique.

Advanced Multi-level Hybridized Optimization Methods Coupling Local Search Deterministic Algorithms and Global Search Evolutionary Algorithms

Z. Tang, X. Hu, J. Periaux

Efficient optimization methods coupling a stochastic evolutionary algorithm with a gradient based deterministic method are presented in this lecture. Two hybridized methods are compared: one is a stochastic/deterministic alternate algorithm (1), the other is a stochastic/deterministic embedded algorithm (2). In the alternating algorithm, stochastic and deterministic optimizers are performed alternately as follows: several individuals are randomly selected from the previous population, and sent to the deterministic optimizer, then the locally improved individuals are inserted to form from the previous population a new one for the global stochastic optimizer. In the embedded hybridized optimizer, the stochastic and deterministic software are run in parallel independently, the coupling between them is that the deterministic optimizer operates on a randomly selected individual from the non-evaluated evolutionary population, then its new individual is re-injected into the population. Complementary to this hybridized approach, a multilevel approximation is introduced, via a low fidelity flow analysis and coarse parameterization to perform a search on large population size at the lower level, and then followed by a high fidelity flow analysis with refined parameterization used at higher level. After an acceleration analysis of the hybridized optimization on mathematical functions without constraint (Camel, Schwefel, Shubert, Shaffer ...), the new approach is successfully applied to the real life problems such as the aerodynamic high fidelity shape design optimization of the fore-body of an hypersonic air breathing vehicle at flight conditions, \( Ma = 8.0 \), angle of attack \( \alpha_f = 0^\circ \) and altitude \( H = 30 \text{km} \) with Euler flow analysis. Two objectives functions are considered: (a) total pressure recovery maximization and (b) Mach number at the inlet of scramjet minimization. The numerical results obtained with the hybridized optimization combining local and global search are presented and discussed. It is concluded that this multi-level hybridized approach is more efficient that simple GAs in terms of CPU cost and design quality.
Computational complexity of flight planning algorithm for free routing airspace

**D. Rzonca, G. Dec, S. Samolej, A. Majka, T. Rogalski**

Free Routing Airspaces are currently used in several European countries. Creation of a software for automated flight planning for General Aviation in such an airspace, considering restricted areas and weather phenomenas, is not a trivial task. In the paper computational complexity of suitable flight planning algorithm is discussed and a new airspace model is presented.

**Trajectory Control during Aerobatic Flight**

**Tomasz Rogalski**

The paper presents some aspect of automatic flight through some selected aerobatic maneuvers. The paper presents simplification assumptions, control systems structure, control algorithms, data fusion algorithms allowing the control system to automatically guide the aircraft along maneuver trajectory. There are presented some calculations leading to the draft controllers’ parameters, results achieved during simulations referred to real flight data.

**Multi-Criteria Decision-Making in Planning Aircraft Trajectory in Free Route Airspace**

**Leszek Rolka, Grzegorz Drupka, Alicja Mieszkowicz-Rolka**

This paper presents a hybrid approach to determine optimal aircraft trajectory in accordance with the concept of Free Route Airspace (FRA), which is aimed at achieving higher efficiency of air traffic management in the European airspace. This is important due to increasing air traffic density and growing number of flights. In contrast to the currently applied procedures of air traffic management, the idea of FRA consists in giving more flexibility to the airspace user with respect to choosing trajectory between entry and exit points in the considered airspace. We assume that the airspace is modeled as a cluster of unity cells. Every cell is characterized by a record of suitable parameters. The process of finding optimal trajectory is divided into two stages. In the first stage, we select an initial subset of trajectories which have a low value of distance between the entry and the exit point. In the second stage, additional criteria are taken into account, such as complexity of trajectory, cost of the flight, and travel comfort. For obtaining the final solution of the multi-criteria decision-making problem, we apply a modified TOPSIS method, using different combinations of weights for the considered criteria. The presented approach will be illustrated by a case study.

**Landing control verification using airplane simulation model**

**Piotr Ciecinski, Jacek Pieniazek**

The last phase of flight, an approach, is most safety critical in whole flight. Near ground flight decrease time margin of correcting actions necessary to avoid danger caused by an erroneous pilot or autopilot action and also caused by external disturbances. The control accuracy demand is higher and finally the approaching airplane should be at correct location and it should have proper state before touchdown. Additional, more accurate than necessary to cruise and take off, measurement systems are used during approach phase of flight (e.g. ILS, DGPS). The phase of the last moment in the air and the first contact with
the ground is the verification of control correctness. The area of the proper locations at this moment is limited by the dimensions of the runway and depends on the class of an airplane. The approach phase which leads airplane to runway looks rather simple as setting: appropriate elevator deflection, control of thrust level, necessary to obtain demanded flight slope and control roll angle at zero level. But in the case of disturbances, like wind, turbulence and most demanding wind shear, pilots or controllers continuously correct airplane motion and state. The form of these disturbances not only increase requirement of accuracy but also more sophisticated control methods are necessary. Limited size of runway and also motion of runway, when the subject of search concerns aircraft carrier, increase additionally demanded control accuracy. After an approach manoeuvre or sequence of manoeuvres (flare and touchdown) is applied. As a result an airplane suspension become on the ground. The suspension endurance is limited so the forces which are the result of remaining vertical speed should not be too high. Subsequent phase is drive of the airplane on the runway. Main difficulty is a necessary change of the structure of the controllers and initial high speed of on-ground motion. Some incorrect control actions, and also delayed actions, may result in danger. The reliability of automatic landing control system should be proved in various conditions before it would be used in real flight. Some real test flights are possible to be executed with assistance of an emergency human pilot, but only if all control sequences are easily detectable and we ensure that, final manoeuvrers are correct. In the case of strong disturbances and preliminary verification of emergency procedures in flights are too dangerous itself. The solution is the simulation test using airplane motion model not only for flight modelling but also with appropriately accurate suspension model which gives possibility to evaluate on ground motion.

In the Department of Avionics and Control of Rzeszow University of Technology an experimental airplane MP02A Czajka is a basis for in-flight experiments with measurement devices, measurement systems and control systems. Authors developed model of MP02A considering non-linear aerodynamics with ground effect, wind and turbulence influences, rigid body dynamics, characteristics and dynamics of engine with propeller, and also model of suspension. The last part includes friction model of wheels and stiffness of undercarriage legs.

This model and developed methodology gives possibility to verify different concepts of control algorithms and also they give possibility to test real controllers before in-flight using HIL (hardware in the loop) methodology.

The suspension model in simulation is important for investigated subject. Although many research concerns accuracy of the approach the most critical part of touchdown is rarely considered.

**Route difficulty and estimated length assessment used for emergency destination evaluation**

*Piotr Grzybowski*

When there is urgent need of defining emergency destination for flight diversion key factors for defining such destination are route length and its difficulty. In such case, when evaluating possible destination, exact information on route to it is only needed, when with limited time constrains for delivering answers, routes to all potential destinations can be calculated. For case where time constrains for such calculations cannot be met better strategy is to define set of possible solutions "U", then create subset "A" of destinations where definitely one should not go, and to choose most promising destinations from complement set "A'". Only for those most promising destinations exact route calculation should be performed. This paper presents methods for assessing routes created in order to define such destinations.
They were developed in order to reduce calculation load when dealing with problem of definition of routes from start to multiple possible destinations while avoiding obstacles, prohibited areas which can occur en-route, but without time consuming route calculation process. Within scope of this paper criterions for defining route difficulty were presented as well as methods for delivering estimated lengths of routes.

**Flight Reconfiguration System - emergency system of future**

*Piotr Grzybowski, Ewelina Szpakowska-Peas*

Development of future avionic systems leads to definition of new functions which have not been available in aviation so far. One of such function is automatic handling of emergency situations by aircraft systems. Currently aircraft pilot is responsible for handling of such situations. Motivation for development of such systems is mitigation of risk related with pilots health issues in single pilot operation. For this reason for commuter aircrafts as well as airliners a crew of minimum 2 pilots must be kept. Well equiped aircraft can perform automatic landing, but for such landing destination place must be defined by pilot. Time constrains in case of health issues are strict and often flight plan diversion must be made in order to deal with crisis onboard. This paper presents general concept of Flight Reconfiguration System (FRS) developed within scope of Clean Sky 2 COAST project. FRS is system enabling automatic diversion management of flight for emergency situation onboard by means of: defining set of possible emergency destinations in case of pilot incapacitation, defining routes to them, finding best option from set of possible emergency destination with use of multi criteria decision methods, execution of diverted flight with use of autopilot, while informing other airspace users on crisis onboard. Assumptions, problems occuring during developments of such systems and tests are presented within this paper.

**How many RPAS can be safely integrated in non-segregated airspace?**

*Javier Pérez-Castán, Fernando Gómez Comendador, Alvaro Rodríguez-Sanz, Rosa M. Arnaldo and Jaime Torrecilla*

The forthcoming integration of Remotely Piloted Aircraft System (RPAS) is one of the complex challenges for aviation. Europe draws to allow operating RPAS and conventional aircraft in non-segregated airspace by 2025. This demanding prospective entails a thorough analysis of the different aspects involved. The RPAS integration in non-segregated airspace cannot imply an increase of the safety levels. This paper assesses how the RPAS integration affects safety levels. The goal is to regulate the number of RPAS that can jointly operate with conventional aircraft regarding conflict risk. This approach benchmarks a Calculated Level of Safety (CLS) with a Target Level of Safety (TLS). Monte Carlo (MC) simulations quantifies the TLS based on schedules of conventional aircraft. Then, different combinations of conventional aircraft and RPAS provide different CLS. MC simulations are performed based on probabilistic distributions of aircraft performances, entry times and distribution of route movements. The safety levels are based on a conflict-risk model because the primary metrics are total conflict time, ratio of exposure time and number of conflicts. The methodology is applied to one flight level of en-route airspace. The results provide restrictions to the number of RPAS that can jointly operate with conventional aircraft. Particularly, the CLS is quantified for four conventional aircraft and MC simulations provides the combinations of conventional aircraft and RPAS that fulfil the CLS. The same number of RPAS than
conventional aircraft shows an increase over 200% total conflict time, 80% ratio of exposure time and 60% number of conflicts.

**Air Traffic Management Based on 4d-Trajectories: Requirements and Practical Implementation**

*Alvaro Rodriguez-Sanz, Cecilia Claramunt Puchol, Fernando Gómez Comendador, Javier Pérez-Castán, Rosa Arnaldo Valdés, Francisco Serrano Martínez and Mar Najar Godoy*

**Background:** The current Air Traffic Management (ATM) functional approach is changing. Both SESAR (Single European Sky ATM Research) and NEXTGEN (Next Generation Air Transportation System) support the four-dimension (4D) trajectory implementation within the new concept of Trajectory Based Operations (TBOs). The application of the 4D-trajectory operational concept in the future ATM system will impose on aircraft the compliance of very accurately arrival times over designated checkpoints. These time-constraints are called Time Windows (TWs).

**Objectives:** The first goal of this work is to review the operational concept of 4D-trajectories, by initially developing an analysis of basic requirements for their implementation in the field of Communications, Navigation and Surveillance (CNS/ATM) systems and then by investigating their management in the future ATM framework. The second goal of this work is to analyse a 4D-trajectory evolution and degradation, to define and introduce the necessary corrective measures. The work will also include a feedback controller to emulate the actions that air traffic controllers (ATCOs) and pilots may take to satisfy the constraints imposed on TWs. This TW tracking controller will be designed to reach a predefined target while satisfying specific operational state constraints.

**Methodology:** To obtain the TWs, 4D-trajectories are modelled using a point mass model and the EUROCONTROL’s BADA (Base of Aircraft Data) methodology. The variability of parameters that influence the definition and development of 4D-trajectories is appraised stochastically through Monte Carlo simulation, by considering different scenarios and several checkpoints. Then, a causal model (based on a Bayesian Network approach) allows us to evaluate the impact of variations in fundamental parameters over the established checkpoints. Furthermore, we develop a model to evaluate potential ‘malfunctions’ of a 4D trajectory, based on the Multi-State Systems (MSSs) reliability theory. 4D-trajectories can be understood as complex MSS that rely on environmental, internal and usage conditions. This is a natural extension of the classical binary-state evaluation: trajectories present different performance levels and several failure modes (a degradation range). The operational reliability assessment, using Monte Carlo simulation and random processes (Markov) methods, offers a framework to predict how probable is for the trajectory to enter a degraded state. After having assessed the relationships and interdependencies between the factors that affect a 4D-trajectory, as well as the degradation suffered by the 4D-trajectory along all flight phases, we focus on defining the relationships between 4D-trajectories and other concepts and systems of the future ATM framework, and the needs that it will require for its application. The purpose is to collect the requirements and conditions associated with the implementation of 4D-trajectories, detailing the main tools, programs and ATM/CNS systems that must be deployed. After that, we appraise how 4D-trajectories must be managed and planned (negotiation, synchronization, modification and verification processes). Finally, we propose the degradation tolerances and conditions, under which 4D-trajectories must be updated. These restrictions are validated with real flights using the EUROCONTROL’s NEST tool, comparing its initial flight plan and their actual flight. Moreover, we suggest when the updating process should take place by ATCOs or pilots. Initial results (validated at an intra-
European route) show that for the aircraft type Boeing B737, the proposed TW model can control the time tolerance within less than 27 seconds along the passing checkpoints of an en-route segment.

Contribution: The main contribution of this work is the provision of a holistic vision of the systems and concepts that will be necessary to implement the new 4D-trajectory concept efficiently, thus enhancing performance. We also propose tolerance windows for trajectory degradation, to understand when an update is necessary and the conditions for pilots and ATC to provide this update. 4D-trajectories will improve traffic synchronization, while its adequate management will potentially ease conflict resolution. These are cornerstones in future airspace operational environments.

**GICS, a new concept to enhance in-flight safety and security of commercial aviation**

*Marc Lesturgie, Hian Lim Chan, Sylvain Azarian*

This paper presents a new concept of aircraft tracking based on a LEO constellation of small satellites, each of them carrying receiving and transmitting devices in order to check the integrity of the ADS-B (Automatic Dependent Surveillance - Broadcast) positioning information and proceed with a non-cooperative independent localization of the aircraft, if a flight anomaly comes out. To do so, on side of the conventional ADS-B processing, authors propose to add a multilateration process and two active radar modes, able to perform a finer and reliable localization of the aircraft, as well as a first information on the nature of the flight anomaly. The paper deals with a preliminary system analysis, although underpinned by some illustrations of existing sensor technologies, already or nearly operational in space. The concept has been patented.

**An Efficient Aircraft Path Planning Method at Free Route Airspace**

*Andrzej Majka, Jowita Pawluczy, Tomasz Rogalski*

As a response to the growing problems of Air Traffic Control (ATC) and Air Traffic Management (ATM) in Europe are solutions which are being developed, tested and implemented within the frames of the SESAR program. One of the proposed solutions is to change the concept of ATM and ATC, allowing for planning and performing flights between a defined entry point and a defined exit point, with the possibility of routeing via intermediate (published or unpublished) waypoints, without reference to the air traffic services (ATS) route network, subject of course to availability. This concept can be implemented in properly prepared airspace called Free Route Airspace (FRA). The necessity to take into account many factors at the stage of making a flight plan in the FRA means that without the tools supporting the person preparing such a flight plan, the task can be challenging. Also, the use of all the potential benefits of a new method of planning and executing flights may not be possible. Therefore, it will be necessary to use systems supporting the preparation of flight plans in the FRA space. Big airlines can purchase commercial systems that are already available on the market today, which are too expensive for smaller users. The paper presents the concept of an efficient algorithm for planning the optimal route of flight in the FRA, based on the airspace model in the form of a graph. Such an algorithm can be used in automated flight planning systems, available for non-commercial users (General Aviation) or smaller aviation companies (e.g. Business Aviation, Remotely Piloted Aircraft Systems). Use of such a system allows taking into
Aircraft Trajectory Control and Management

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A Multi-Dimension Weighted Graph-Based Aircraft Path Planning at Free Route Airspace

Andrzej Majka, Jowita Pawluczy

Among the most critical problems currently faced by air transport, it can be distinguished the impact of aircraft on the natural environment and the rising costs of air transport. One of the possibilities to improve this situation is better fit of the aircraft path to the characteristics of currently used transport aircraft, taking into account all the requirements and limitations that exist in airspace and environmental influences. It was reflected in the research tasks carried out under the SESAR program. The efforts to minimise the impact of aircraft on the natural environment are implemented, among others, through appropriate shaping of aircraft routes characterised by minimal fuel consumption or minimal emission of harmful substances. However, optimised routes must take into account the conditions that existed in the airspace (prohibited zones, restrictions, weather hazards, etc.). The work presents a method that allows taking into account the conditions and limitations that exist in the airspace through the appropriate selection of multi-criteria weights on the edges of the graph modelling the airspace.

Determination of the flight trajectory in terms of emission and fuel consumption minimisation

Michał Kuźniar, Małgorzata Pawlak, Andrzej Majka

Air transport is in an intense phase of development. In projects such as SESAR (which aims to develop and implement a modern ATM system), attempts are made to plan the flight of the aircraft so that the operation is more economical and environmentally friendly. As part of this project, the authors undertook research into determining the model for determining fuel consumption and pollutant emissions in the engine's exhaust. In the development of this model, it is possible to determine the route of passage in terms of minimum emissions an minimum fuel consumption. The article presents the methodology for determining fuel consumption and emissions of these pollutants for the longest stage of the flight - the cruise phase. First, the thrust required for the flight of the example aircraft was determined, and then the values of engine confidence and specific fuel consumption were calculated. In addition, it was necessary to specify Emission Indexes (EI) for CO, NOx, HC and CO2 for the cruise phase, based on known such indexes for LTO. The implemented model was used to determine the best route between two airports (Rome - Athens, length of the cruise phase of 1000 km). In the research, the Dijkstra algorithm was used to determine the route. The fuel consumption as well as the total emission of harmful and toxic compounds for a given route were determined and the trajectory with the most favourable parameters was selected.

The performance model of the light unmanned aircraft for the purpose of simulations of the departure and arrival procedures execution in controlled air traffic

Daniel Lichoń, Andrzej Majka, Marek Orkisz
The performance model of the light unmanned aircraft was presented in this work. The main goal was to build the model accommodated to the aircraft take-off mass below the mass present in manned aviation. The additional goal was to minimize the input data required for the identification of the complete aircraft and flight parameters. The topics of the model include a synthesis of aircraft geometry, aerodynamics characteristics, mass and balance, propeller-driven power unit characteristics, flight performances. The input data include the key parameters of the aircraft, i.e. take-off mass, wing surface loading, power loading and other required. The unmanned aircraft technical data are identified by using analytical and statistical methods. The flight performance model is based on flight mechanics of the steady-state flight. This include airspeed polar in symmetrical and asymmetrical flight, range and endurance, the profile of climb and descent, the profile of the take-off and landing. The model built is destined for the research in the integration of the light unmanned aircraft in the departure and arrival procedures of controlled aerodromes. Currently, on the European level, there is an on-going program of integration of the unmanned aviation in the uniform (non-segregated) airspace. One of the aspects is the integration of the Remotely Piloted Aircraft Systems (RPAS) in controlled air traffic including the Standard Instrument Departure and Arrival procedures (SID and STARs). This integration aspect treats manned and unmanned aviation equivalently thus the RPAS shall be able to execute the existing procedures which were designed for manned aircraft. For the light RPAS, the identification of the performance characteristics required to fulfill the SID and STARs procedures become significant. The proposed model-based simulations allow correlating of the light unmanned aircraft characteristics with the execution of controlled flight procedures. Selected simulation results of procedures execution were presented in this work. The expected further step is the validation of the model by using the real-time flight simulator and (or) experimental flights of the available unmanned aircraft.

Modeling and validation of the reference departure and arrival procedures in the context of integration of the unmanned aircraft in controlled air traffic

Daniel Lichoń

In this work, the models of Standard Instrument Departure and Arrival procedures (SID and STAR) was built. It was focused on preparing the reference procedure shapes which will be used in the researches in the integration of the Remotely Piloted Aircraft Systems (RPAS) in the uniform airspace. The SID and STARs describe the flight path which connects the en-route airspace with the aerodrome runway threshold. The procedure is composed of a nominal track, tolerance area, minimum obstacle clearance, climb and descent gradients, procedural manoeuvers. Moreover, the procedure shape is dependent on the navigational aid used. For the SID procedures, the reference model of straight departure and turning departure was built. The navigational aids in these models include GNSS and VOR. For the STAR procedures, the reference models of approach with the use of GNSS, VOR and ILS navigational aids were built. The approach models contain the manoeuvers of straight approach, approach with turn, reversal turn, racetrack and missed approach. The reference procedures shape was based on the International Civil Aviation Organization (ICAO) procedure design guidelines and statistics of the parameters of existing procedures. The statistical parameters concern the flight altitude, segment length, climb and descent gradients. The models of reference procedures were implemented in the form of points with geographical coordinates and altitude. This allows using the models in simulations of manned and unmanned flights in
SID and STARs. The validation of reference procedures built is intended by means of test flights with the use of available flight simulator of General Aviation manned aircraft considering the SID and STARs are designed for manned aviation.
Formation of new architecture of boron based composite powders under effect of concentrated light for nano-enabled composites

Lina L. Sartinska, Yevgen Voinich, Izabella Timofeeva, Tarik Eren, Anatoly Efimov, Olena Fecenko, Gennady Frolov

Nanocomposites are the materials of twenty-first century. Possibility of combining desired properties, nanocomposites are expanding their potentials in aerospace applications and in future space missions. Due to mechanical, thermal, electrical, chemical and biodegradable properties of boron nitride and low weight requirements boron nitride based nanocomposites are the most perspective for using for aerospace applications. Therefore, considering boron based composite powders of new architecture produced under effect of concentrated light in optical furnace for aerospace applications will increase the spectrum of properties of nano-enabled composites.

Concentrated light heating of an optical furnace has number advantages such as high heating and cooling rates, versatility and ability to adjust temperature profile along each axis, maximum operating temperatures and environmental adaptability. Moreover, high-flux optical furnace presents a one of cleanest energy sources available for the nanotechnology and this technique is appropriate for both conducting and non-conducting materials.

Transformation of boron nitride and boron powders with 25 wt. % indium, aluminum, copper, iron or nickel added in flow of nitrogen was considered. It was demonstrated effect of temperature distribution and temperature gradients within an experimental camera on architecture, phase composition and other properties of obtained powdered materials. Presence of catalyst in boron nitride powder during transformation under effect of concentrated light promotes formation of nanostructures.

Formation of new architecture of nanostructures can be explained in framework of “gaseous model” which was based on an evolution of the bubble during heating in an optical furnace. Burst of these bubbles results in graphene-like and nano-petal structures formation. The stepwise transformation of bubbles of appropriate chemical composition leads to nanotubes formation because of their pulling by heated gases upwards. Fullerene-like particles can also have complicated “fish-eye” (“core shell”) structure in the result of segregation of transparent BN shell with H3BO3 layer on the surface around crystalline InN.

Nanopowders prepared in an optical furnace under concentrated light heating has complicated gradient or layered structure. According Raman, AES and FTIR study the surface of all powders is composed of BN. XRD disclosed pure amorphous boron inside particle. Gradient transformation pure boron to BN in the framework of one particle as well as layered nanostructure was observed by TEM study.
Disbond detection of adhesively bonded metal to composite joints using different ultrasonic techniques  

**Smagulova Damira, Jasiuniene Elena**

Adhesively bonded metal to composite structures are widely used in aerospace, energetic, automotive, and other industries. Disbonds are common defects in these structures. However, disbond detection is a challenging task due to different properties of materials, which causes complexity of distinguishing difference in results of inspection of defected and good bonds. Therefore, disbonds are hardly detected or not detected at all. The objective of this investigation is to detect debonding in metal-composite joints using different ultrasonic techniques, compare the results, evaluate complexity and make analysis to increase probability of defect detection. Different objects made of adhesively bonded aluminium to CFRP, steel to CFRP/GFRP were investigated using pulse-echo contact and immersion techniques, 3.5-5 MHz phased arrays and 10-15 MHz focused transducers. Different parameters of ultrasonic wave were calculated theoretically and compared to experimental results, transmission and reflection coefficients were evaluated, multiple reflections analysed and phase of the echo from good and defected bond has been investigated. Factors affecting the disbond detection were taken into account, spectral analysis and signal post-processing for better defect interpretation performed. As a result, disbonds were detected by analysing subsequent reflections from good/defected bond and selecting the one with a higher difference in amplitudes.

Techniques for PZT transducers integration with composite structures for enhanced Structural Health Monitoring capabilities  

**Krzysztof Dragan, Neha Chandarana, Michal Dziendzikowski, Marina Shevtsova, Fedir Gagauz**

Application of guided waves excited by a network of PZT transducers integrated with a given structure is one of the promising approaches to Structural Health Monitoring (SHM). The performance of a SHM system based on PZT network is a vast area of research including: technology of sensors manufacturing and optimization of their working parameters, development of dedicated electronic units or signal processing methods which would allow for reliable structure assessment. One of the factors which may have significant impact on damage detection capabilities of SHM system based on PZT transducers as well as its durability is technique of sensors integration with a monitored structure.

For composites, beside the possibility of the transducers attachment to a surface of an element, also immersing of PZTs into their internal structure is possible. In the paper three different techniques of sensors integration with CFRP composite structures are presented and the influence of PZT transducers embedding on mechanical properties of the structure is assessed. Furthermore capabilities of structure monitoring is compared for the different techniques of sensors integration. In particular comparison of the efficiency of structure integrated sensors in debonding or impact damage detection as well as damage propagation monitoring with use of acoustic emission signals propagation is delivered in the paper.

Possible application of Rayleigh wave scattering for the surface-treated structural elements characterization  

**Sergey Gartsev, Bernd Köhler**
Surface engineering is widely used during the design of high-performance elements of jet engine. Few of the most common methods for enhancing the fatigue properties are shot peening, roller burnishing and laser shot processing. The improvement is obtained through restriction of the surface crack appearance through inducing of compressive residual stress layer. Up to the moment, only laboratory NDT and destructive methods are being utilized for monitoring the treatment intensity, which determines the exact improvement of the expected lifetime. In this work we aim to expand the application field of ultrasonic NDE, suitable for the in-field inspection. Characterization of metal surface treatment intensity with ultrasound requires a knowledge of local material attributes. In particular, residual stress characterization with surface acoustic waves (Rayleigh waves) or bulk waves demands an awareness on the local nonlinear elastic properties. Stress state of material is linked with elastic wave propagation velocity variation through acoustoelastic constants/third-order elastic constants (AEC/TOEC), which tend to alter in a treatment area, and therefore have to be measured on-site.

In this contribution several experimental works for the determination of AEC/TOEC for bulk and surface waves for Inconel 718 and Titanium 6246 alloys are compared, as well as new measurement results for different material states (annealed, plastically deformed and surface treated) are presented. In addition, new method for the in-situ local TOEC determination through simultaneous excitation of several waves is proposed and numerical simulation results are shown. Obtained results became a basis for experimental proof, which is a work in progress.

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Reducing complexity in Structural Health Monitoring by Percolation Threshold Sensors

**Helge Pfeiffer, Sevilia Sunetchiieva, Martine Wevers**

Sensing principles for interrogating the structural integrity in an aircraft are frequently operating in a quasi-linear mode. However, although quasi-linear-sensing is a prerequisite for versatile, high-end devices in applications where only one or two thresholds are monitored, other concepts could provide more appropriate solutions. An interesting alternative is offered by percolation threshold sensors that are characterized by a sharp sensor response depending only on one outer parameter that is related to a certain damage threshold. Moreover, the sensor response usually ranges over many orders of magnitude and in this way it is an ideal tool to filter out baseline variations and thus, the probability of detection is superior with respect to many other technologies.

In the literature, there are a couple of highly non-linear sensing devices reported and partly even used in operations, such as the alarm wires in bleed air systems for aircraft providing information on overheat, or crack propagation gauges in fatigue testing. The presentation given is providing an introduction into this field in a more systematic way and provides a couple of recent applications, such as the detection of corrosive liquids in aircraft (Boeing 737-500, Boeing 747-400), detection of hydraulic liquids and fuel as well moisture ingress in composite materials.

**Structural health monitoring system for moisture ingress detection in sandwich composite structures**

**Sevilia Sunetchiieva, Helge Pfeiffer, Martine Wevers**
Aircraft innovation includes involving improving the efficiency of air structures by utilizing new materials in order to be more durable and lighter. The percentage composite usage in recent airplane designs has reached more than 50% by weight which goes hand in hand with a reduction of fuel consumption. At the same time the Maintenance, Repair and Overhaul (MRO) requirements for composites are very different from those applied to metals which lead to new NDT procedures, including a still pending lack of trained staff and certification issues. Honeycomb sandwich materials are widely used in aircraft structures. Some of them play a significant role in the flight control process, like rudders, elevators, and winglets which need to be appropriately maintained in a long run. Despite the thickness of the core including the metal meshes, sandwich composites are still relatively light and have a relatively high flexural strength. The most common purpose of manufacturing sandwich structures is to achieve the highest stiffness at minimum total density (average). However, the water ingress problem is very prevalent for these structures with even greater danger of corrosion if the core is made of aluminum honeycomb and/or adhesive bond degradation (node and skin-to-core). Moreover, structural damage (node bond failure) could occur in the structure during normal flight operations due to repeated freeze-thaw cycles of trapped standing water (in liquid or vapor state). Here, we aim to monitor the water ingestion by percolation threshold sensors integrated into monolithic and sandwich composite structures, addressing the challenges of sandwich composite manufacturing process, e.g. high pressure and temperature, its quality and data acquisition. The percolation threshold sensor is based on the collapse of a conductive particles network in a randomized lattice structure. The presented SHM system finally is validated on lab scale and it is robust to environmental changes and sensitive to moisture ingression. Part of the research leading to these results has received funding from the European Community’s Seventh Framework Programme [FP7/2007-2013] under grant agreement n°212912 and the “NDTonAIR” project (Training Network in Non-Destructive Testing and Structural Health Monitoring of Aircraft structures) under the action: H2020-MSCA-ITN-2016-GRANT 722134.

Active and passive damage monitoring in composites using embedded piezoelectric sensors

**Neha Chandarana, Kanokporn Tangthana-umrung, Marina Shevtsova, Fedir Gagauz, Krzysztof Dragan, Michal Dziendzikowski, Constantinos Soutis**

Reliable damage detection and monitoring of composite materials is necessary in facilitating their widespread use in the aerospace industry. The use of active and passive ultrasonic methods is widely accepted for the detection of damage in composites. The anisotropic nature of composites makes identification of different damage mechanisms, such as matrix cracking, delamination, and fibre breakage, more complex to predict and to analyse. The layered structure of composites lends itself to the integration of sensors, which can be used for damage monitoring. Piezoelectric disc sensors are particularly attractive, due to their low cost, small size, and ability to be used for both the transmission and reception of guided waves. Guided waves can be excited in the structure by two main methods: (i) passive acoustic emission waves, emitted when the structure undergoes a change in response to loading, (ii) active guided waves, transmitted within a network of sensors for on-demand structural health assessment. In the present work, two carbon fibre/epoxy composite laminates are instrumented with piezoelectric disc sensors, embedded at different through-thickness levels. Glass fibre envelopes isolate the sensors from the surrounding conductive material. Passive and active methods are used to detect and locate damage arising as a result of impact, and progressive damage during flexural loading. A comparison is made between the datasets obtained from embedded and surface mounted sensors, to assess their ability in detecting the damage.
Non-destructive Testing and evaluation for carbon fibre epoxy bonded laminates using ultrasonic measurement techniques

Jaishree Vyas, Bengisu Yilmaz, Elena Jasieniune, Rymantas J. Kazys

The significance of composite materials is highly recognized in aerospace industry with high performance, lightweight, and environmental compatibility; however, conventional joining technologies such as mechanical fasteners limits their applications and disturb integrity of the materials. Hence, adhesive joint is preferable assembling technology for the aerospace composite structures due to their homogenous load distribution, high strength to weight ratio, ability to join dissimilar materials and complex structures. The lack of knowledge in bonding quality with non-destructive testing techniques limits adhesive joint applications to secondary load carriers. The objective of the study is to evaluate the capability of non-destructive ultrasonic testing techniques to determine voids and debonding in bonded structures. This comparative evaluation of two different techniques was done using air-coupled focused transducers and focused acoustic microscope transducers from which air-coupled transducers are built at Ultrasound research institute, KTU Kaunas, where two carbon fibre samples of different disbonds were investigated. At low frequency of 450 kHz through transmission air-coupled technique gives the approximation of defect made by artificial deboding with release film and the brass inclusion at the interface. As a result, we can observe from post processed high resolution C-scan images that, the difference in perfect bonds and disbonds can be clearly identified. The high frequency focused acoustic microscope transducers of 50 MHz pulsed echo, immersion technique passed-down to assess the irregularity of interface reflection based on the shape feature extraction in the time and frequency domain. Additionally, the change in ultrasonic amplitude and phase delay has been observed from A-scan signals for both the techniques. As an outcome the air-coupled technique is capable to the defect allocation due to acoustic impedance in air whereas acoustic microscope transducers provides the size proportion of delamination and disbonds present in the samples.

The detection of melting ice in fuel tanks by acoustic emission

Michael Stamm, Helge Pfeiffer, Johan Reyneart, Martine Wevers

During the daily aircraft operation, water accumulates in fuel tanks by condensation and contaminated fuel. While the “free water” potentially leads to microbial corrosion and the misreading of fuel meters, freezing water can harm the internal structure of the fuel tank in a high degree resulting in potentially hazardous situations for passengers, crew members and ground personnel. The draining procedure is performed to remove liquid water from the fuel tank during daily maintenance. A reliable, low-cost and easy-to-use detection method for melting ice could optimize this process. Such a method should enable the detection, location and quantification of melting the ice inside the tank after landing. Previous experiments showed that acoustic emission (AE) is capable to detect melting ice including the start and end of the melting phase.

Advanced experiments in a custom-made temperature controlled chamber provided data that contain information about the acoustic activity of melting ice and its dependence on external parameters like heating rate and contaminants. During the melting, a characteristic pattern of acoustic activity was measured which allows the estimation of the start and end of the melting and suggests a linear correlation between the total number of acoustic events and the amount of melting ice. Promising results potentially leads towards an easy to handle AE monitoring facility for melting ice in complex systems where only the acoustic signal provides sufficient information about remotely located ice.
Towards ultrasonic stimulated thermography as a standard aircraft maintenance tool

Michael Stamm, Tommaso Seresini, Helge Pfeiffer, Johan Reynaert, Christ Glorieux, Martine Wevers

During the daily aircraft operation, several person-hours are spent to inspect specific aircraft structures on “cracks and loose, missing or sheared rivets”. In certain areas, the in-flight vibrations and high stresses require frequent inspections in accordance with the manuals provided by the aircraft manufacturers. The current inspection methods are visual inspections and Eddy current inspections. However, both require highly trained personnel and many staff hours when inspection big areas. One alternative is ultrasonic stimulated thermography (UST) that use ultrasound and infrared cameras to visualize the heat production caused by friction of loose rivets. This technique allows fast and full field inspections and delivers results that are easy to interpret. The presented work explores the need for new inspection methods for loose and sheared rivets and compares nowadays inspection methods with ultrasonic stimulated thermography. Experiments in the laboratory as well as on real aircraft structures in the hangar demonstrate and benchmark the feasibility and limitations of the aforementioned approach.

New Criterion for Aircraft Multiaxial Fatigue Analysis

Tetiana Maslak, Mykhailo Karuskevych, Łukasz Pejkowski

Damage Tolerance principle considers the problem of aircraft fatigue monitoring crucial as never before. The complexity of analytical and experimental estimation of aircraft components fatigue life is determined by the irregular character of the load’s sequence, a huge number of stress concentrators, multiaxial stress state, etc. The fuselage skin is subjected to the simultaneous action of external and internal loads: pressurization, bending, twist. For the wing structural members, the stresses caused by the bending and twisting considered as dominant. As a result of the action of mentioned loads normal and tangent stresses act in the bearing components. Proposed early multiaxial fatigue criteria are aimed to reduce the complex multi axial loading to an equivalent uniaxial loading. These criteria cover different categories of metals but taking into account the wide variety of constructional materials, modes of loading, environmental conditions, etc., the instrumental structural health monitoring looks a reasonable alternative or at least a strong complement to existing multiaxial fatigue analysis procedures.

The new criterion has been proposed as a result of multi-scale levels study of metal surface transformation under fatigue. The discussed investigation deals with covered by pure aluminum alloy D16AT (so-called alclad alloy). Being plastic metal, the pure aluminum cladding layer responds on loading by the formation of the surface deformation relief. Due to the possibility to observe signs of microplastic deformation (extrusions, intrusions, persistent slip bands) aluminium and some of its alloys which may be used for cladding are considered to be persistent slip bands type materials. The same phenomenon has been observed on the western analogous of D16AT alloy designated as 2024-T3. Both D16AT and its analogue 2024-T3 are widely used for manufacturing the aircraft skin. The multi axial experiments were conducted on the Instron 8874 Axial-Torsional Servo Hydraulic Fatigue Testing System. For the selection of the
loading regimes, the real operational stresses in the components made of aluminium alloys have been considered.

Summarizing data obtained at the new cycle of deformation relief study under multiaxial loading – torsion and axial, in-phase loading, and out-of-phase loading it can be concluded that extrusion/intrusion criteria can be applied for multiaxial fatigue damage estimation. Comparison of the distribution of stresses performed by the Finite Elements Stress-Strain analysis and distribution of surface relief intensity has shown a strong correlation. The introduction of additional directions of stresses at the multiaxial loading leads to the evident changes of surface morphology. Relief exhibits the appearance of additional directions of slip and characterized by a bigger rate of saturation.

The direct surface relief monitoring is possible for alclad aluminium alloys and for some metals (PSB-metals), which exhibit persistent slip bands extrusion/intrusion structures under fatigue. For less ductile metals the application of attachable fatigue sensor made of PSB-metals is a perspective way for aircraft and other engineering structures structural health monitoring. The multiaxial fatigue indicator might be manufactured in the shape of a micro cruciform specimen with geometry optimized for required sensitivity by Finite Elements Methods.

Advanced signal processing tools for helicopters’ future Health and Usage Monitoring Systems (HUMS)

Konstantinos Gryllias, Alexandre Mauricio, Linghao Zhou, Mathew Greaves, Wenyi Wang, David Mba

Health and Usage Monitoring Systems (HUMS) have been developed in order to monitor the health condition of helicopter drivetrains, focusing towards early, accurate and on time fault detection with limited false alarms and missed detections. Among other systems, the Main GearBox (MGB) is the heart of the drivetrain, reducing the high input speed generated by the engines, in order to provide the appropriate torque to the main rotors and to other auxiliary systems. HUMS are mounted on helicopters aiming to enhance the operational reliability and to support maintenance decision making, in order to increase the flight safety keeping in the meanwhile the overall maintenance cost low. Currently used HUMS seems to have reached their limits and the need for improvement has been recently highlighted by the post-accident analysis of the helicopter LN-OJF, which crashed in Norway in 2016. The aim of this paper is the application and further extension of recently proposed advanced cyclostationary based signal processing tools for the accurate detection of faults in helicopter gearboxes. The methodologies are tested, evaluated and compared with state of the art methods on datasets captured during experimental tests under various operating conditions on helicopter gearboxes, including a Category A Super Puma SA330 main planetary gearbox.
Dynamic Response & Damage Characterization of Impact in Composite Structures Through Non-Dimensional Parameters

*Andreas P. Christoforou, Ahmet S. Yigit*

The dynamic response characterization of impact in composite structures under low-velocity impact is achieved using three non-dimensional parameters and the normalized impact force. The relationship between the normalized maximum impact force and the non-dimensional parameters are presented in a graphical form and are used to predict the type of response a priori. It is demonstrated that, for constant impact energy, the response varies according to the impactor and structure characteristics, influencing the type and extent of damage. It is expected that the methodology will minimize the experimental matrix associated with impact testing, as well as provide insight into impact commissioning tests for composite structures.

Development of Composite Propeller Blade model for High Velocity Impacts on Aircraft Fuselage using Finite Element Analysis

*Vasilis Votsios, Esteban Martino-Gonzalez, Jorge López-Puente*

An Open Rotor blade failure and release event can result in a high energy impact on an aircraft fuselage that can reduce the strength of the structure and challenge the safe continuation of the flight and landing. This work highlights the development of a numerical approach and methodology in order to improve the assessment of the damage predictions of a composite propeller blade impact against the fuselage of an aircraft and be able to estimate a minimum thickness of shielding for the full protection of the airframe. A number of dynamic simulations were carried out, from rigid up to deformable and frangible projectiles at different angles of incidence, varying the material and the thicknesses using ABAQUS Explicit. The FE models for blade and target were calibrated and validated separately allowing to capture the right behavior and failure modes. Impact tests of partial blade fragments against stiffened composite panels were correlated with simulations and the obtained results show a good agreement regarding deformations and delaminated area. Finally, a full blade FE model was generated and used for the fuselage impact numerical analysis. This was done within the frame of the Open Rotor project funded by Clean Sky European research programme.

A Strain-Rate Dependant Micromechanical Finite Element Model for High-Velocity Impacts on Laminated Composite Plates

*Dimitris K. Siorikis, Christos V. Nastos, Dimitris A. Saravanos, Esteban Martino Gonzalez*

Fiber-reinforced polymer matrix composites are increasingly applied in structural aerospace components. In spite of the many attractive characteristics, laminated composite materials suffer in foreign object impact loading, such as impacts of small hail stones, engine blade fragments, bird strikes, runway debris, and so forth. The impact damage caused by foreign objects may significantly reduce the residual strength of the composite structures. In general, impacts of composite structures are highly complicated structural dynamic phenomena involving complex nonlinear interactions between the impactor and the target.
structure. Yet, the analysis of high-velocity impacts is further complicated by the development of extensive mixed-mode damage in the composite laminate and the non-negligible strain-rate effects on the constitutive material behavior. Motivated by the need of developing a modeling tool for the simulation of CROR blade impacts, and also by the shortage of impact simulation methods in terms of strain rate treatment, the current work presents the development and validation of a multi-scale finite element model, which incorporate a rate-dependent constitutive model and a micromechanics model. The multi-scale finite element model, includes a micromechanics analysis scale based on the composite material model of Chamis\textsuperscript{22}. The inclusion of micromechanics enables the synthesis of composite properties using constituent material models and input properties at the fiber/matrix level. Consequently, strain-rate effects are modeled at the matrix level, using a rate-dependent constitutive model, developed by Goldberg\textsuperscript{23} \textsuperscript{24}. Additionally, the micromechanical model enables improved calculation of microstresses and failure prediction at the fiber/matrix scale, and improved representation of damage effects on the updated composite properties. Finally, the incorporation of the micromechanics model reduces the amount of required material characterization testing required to model composite plies of various fiber volume ratios and laminates of various fiber architectures. The numerical and experimental studies on the topic are further focused on carbon fiber (IMS-65) polymer (RTM-6) composites, which are extensively used in aerospace industry. A series of woven carbon/epoxy plate specimens impacted of steel ball impactors of high velocities and energies reaching and exceeding the ballistic limit (m=110 g, v=60-100 m/s, E=200-500 J) are investigated. The presented numerical results are also supported by experiments conducted on fabricated composite plates on a high-velocity impact test bench, composed of a high-velocity impact gun and hi-speed videos. Ultimately, key impact simulation results, such as the ballistic limit and induced impact damage, are correlated with representative experimental results, and important conclusions are provided regarding the impact behavior and the validity of the proposed modeling assumptions.

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The Road Map for Analysis of Composite Helicopter Engine Cowl Against Bird Strike

\textit{Efthimios Giannaros, Athanasios Kotzakolios, George Sotiriadis, Vassilis Kostopoulos}

The constant requirement of aerospace industry to enhance the structural efficiency have being driven to the usage of high-performance composite materials. However, the composites are prone to damage occurred by high moving objects. This vulnerability can result extensive damage or even structure perforation which will eventually degrade its post-impact residual strength. A significant impact threat in aerospace industry, and mainly in helicopters due to low-altitude high speed flights, is the bird strike. Vital flight operating systems can be damaged leading to fatal accident. In January 2009 at Louisiana, Sikorsky S-76C helicopter was crashed, and 8 people died. A 1.1 kg red-tailed hawk fractured the windshield and


\textsuperscript{23} Goldberg RK. Strain Rate Dependent Deformation and Strength Modeling of a Polymer Matrix Composite Utilizing a Micromechanics Approach. 1999

inserted to the engine fuel control system causing a sudden engine power loss. It was proved that the main factor of accident was that the windshield was not certified to bird strike requirements.

Regarding to airworthiness requirements, the helicopters are divided to two main categories A. Small rotorcrafts and B. Large/Transport rotorcrafts. The airworthiness code CS-27 is applicable to small rotorcrafts with maximum weight of 3,175 kg or less and nine or less passenger seats. In the CS-27 regulation, no birdstrike requirements are defined. On the other hand, large rotorcrafts should be certified according to airworthiness code CS-29. According to CS-29, the rotorcraft must be designed to assure capability of continue safe flight and landing or safe landing after impact with 1 kg/2.2 lbs bird when the velocity of rotorcraft is equal to VNE or VH at altitudes up to 2,438m (8,000 ft). VNE and VH are the never-exceed velocity of rotorcraft and the maximum speed in level flight at maximum continuous power respectively. Additionally, it is mentioned that the compliance to CS-29 must be shown by tests, or by analysis based on tests carried out on sufficiently representative structures of similar design.

The current work develops and proposes an experimentally validated methodology for the numerical prediction of composite sandwich panel behavior to bird strike, targeting to the reduction of the cost of experimental and certification campaigns required for its design. More specifically, the road map from the quasi-static material characterization tests of cowl CFRP faces to the numerical prediction of cowl panel damage by bird impact is provided.

**Impact Damage on Al-Alloys and Composite Materials for Aircraft Fuselage Usage**

*M.A. Gomes, J.P. Sousa, R.J.B. Rocha, L.M.P. Pina*

Impact resistance is a key requirement for materials used in airframes, particularly fuselage materials. Aluminum alloys have been the material of choice but in recent years developments in composite materials technology render this very attractive for that application. Both aeronautic grade 2024 Al alloy and several composites, laminate, sandwich and hybrid Al-laminate, intended to benchmark further composite materials being developed in an on-going project, have been produced and impact tested under a wide range of velocities. Low speed impacts were performed on a drop-weight device following ASTM D7136M standard whereas for high velocity ones a compressed air cannon was used. Projectiles were hardened steel spheres, Ice spheres or cylindrical-spherical indenters, with masses ranging from several grams up several Kg. The resulting damage was characterized by X-ray radiography or UT C-scan imaging. Possible correlations between impact characteristics and resulting damage are discussed. Although for Al alloys this is reasonably straightforward for composite materials there is a clear need for a better understanding of the damage mechanisms possibly with the help of improved numerical modeling.

**Simulating of Bird Strike on Aircraft Laminated Glazing**

*Natalia Smetankina, Alyona Malykhina, Dmytro Merkulov*

Bird strike is one of the most important concerns about safety in the aviation industry. According to the data of the International Civil Aviation Organization (ICAO), 42,508 cases of aircraft-bird collision were registered within 2001 to 2007. In 66% of these incidents, such collisions damage the aircraft, with three incidents being the cause of air disasters. The most frequent aircraft damages are as follows: puncture holes and dents in the cover of wings, airframe and aircraft engine inlets; destruction of the canopy windscreens and deformation of compressor or fan and turbine blades. Statistical data show that the annual number of aircraft-bird collisions is growing. In 1990, just 1,793 cases of civil aircraft-bird collisions
were registered, whereas in 2015, the number of incidents soared to 13,800. The total annual losses (direct and indirect) in the global aviation industry due to collisions with birds exceed US$3 bln.

Hence, all modern aircraft structures are designed with account of likely collision with birds. Thus, aviation standards in force require that the aircraft construction would allow the crew to conclude the flight safely after collision with 1.81 kg bird. The bird strike resistance of engines should also meet special requirements. These requirements were introduced following in-depth analysis of statistical data on observed aircraft-bird collisions with birds of different species. They characterize the averaged parameters (the mass) of birds that most often strike an aircraft.

In the majority of cases, the bird-resistant elements of an aircraft structure are designed based on experimental data. Theoretical analysis of the bird resistance of aircraft structural components calls for developing special methods for their strength design to account for bird strikes.

A method for analysis of the strain-stressed state of laminated airplane glazing at different operational factors is presented. The method includes a technique for strength analysis of the laminated airplane glazing at the bird impact, and a technique for analysis of superfluous pressure. The model of laminated glazing is based on the refined theory of the first-order accounting transverse shear strains, thickness reduction and normal element rotation inertia each layer. The mathematical model of pressure impulse authentically reproducing bird impact is based on the experimental researches. The analytical solution of the problem about deformation of laminated glazing under bird impact superfluous pressure is obtained by using the immersion method and reduced to integration of systems of the integral-differential singular equations. The response of laminated airplane glazing elements on bird impact and superfluous pressure. Theoretical results are in good agreement with experimental data that allows recommending the method for working out new airplane glazing elements.

**Dynamic Response of Basalt Fiber - Reinforced Polymer (BFRP) Composites under Drop-Hammer Tests**

*Farid Abed, Zin Mehaini*

Fiber Reinforced Polymer (FRP) bars are deemed to be one of the best solutions to the corrosion dilemma associated with steel reinforcement. This paper presents an experimental study on the behavior of Basalt FRP bars subjected to impact loading. Dynamic tests were conducted on eighteen BFRP bars of 17 mm and 20 mm diameters (B17 and B20) using the drop hammer test procedure. Different loading rates were achieved through varying the weight of mass and height of fall. The paper evaluated the maximum stresses attained by the BFRP bars at various loading rates. As the loading rate increased, the B20 bars reported a higher strength value. However, the B17 bars showed a slight drop in the strength with the increase of the loading rate, which requires further investigation. The crushing was observed to be most prominent in the top part of the bars where the bars exhibited a conical shape after failure.
Mechanical Characterization of Ti6Al4V processed by EBM

**C. Pirozzi, S. Franchitti, R. Borrelli, L. Di Palma, A. Chiarrello, A. Faraguti**

Electron Beam Melting (EBM) is one of a few AM technologies capable of making full-density functional metallic parts realized from raw materials in the form of powders. EBM utilizes a high-energy electron beam, as a moving heat source, to melt and solidify, by rapid self-cooling, metal powder and produce parts in a layer-building fashion.

In particular, the ability of direct fabrications of metallic parts can accelerate product designs and developments in a wide range of metallic-part applications, especially for complex components, e.g., fine network structures, internal cavities and channels, which are difficult to make by conventional manufacturing means.

In the field of aerospace industry it is crucial for quality certification purpose that the material used in the manufactured part is qualified and validated through an accurate characterization in order to make sure that the component meet the requirements set by the specific application.

In this work a mechanical characterization of Ti6Al4V produced by EBM has been carried out. Tests have been performed on different material conditions in order to investigate the effect of post processing as machining and hot isostatic pressing on mechanical behavior. Results have been compared with standard mechanical performance values of Ti6Al4V processed by conventional manufacturing processes.

Residual Stresses and Springback Predictive Model

**Federico Martin de la Escalera, Yasser Essa and Daniela Herrero**

The use of composite materials within the aeronautical sector, acquires a great relevancy. One of the manufacturing processes most used with this type of materials is RTM or resin transfer molding.

In the present work, the manufacturing process by RTM is studied in a leading edge which incorporate a laminar flow. It consists of a hybrid structure, in which the composite-titanium connection has been carried out through an adhesive union. One of the essential stages of this manufacturing process is the curing process. During this process, stresses accumulate inside the manufactured part and cause displacements of the final geometry when the mold is removed (phenomenon known as springback). After the simulation, the results of residual stresses and the final distortion are obtained. The aim of this analysis is to evaluate these results and to correlate the model with experimental data. This work are developed under the frame of Clean Sky 2 Wp 141 CS" LPA

Hail Impact Model for Hybrid Laminar Flow Control (HLFC) Structure

**Federico Martin de la Escalera, Essa Yasser, Miguel Angel Castillo**

Weight and fuel reductions are key factors in the increase of composite materials in aeronautical structures. Hybrid laminar flow control (HLFC) is considered as an active drag reduction system. A delay in the boundary layer transition from laminar to turbulent flow can be accomplished applying suction over the first 10–20% chord position. Design of HLFC leading edge and its damage behaviour against hail impact
represents a significant engineering challenge for design and simulation. Different materials are used; carbon fibre composite and micro-perforated titanium to produce adequate suction. Simulation of composite damage mechanisms are complex due to heterogeneity and anisotropy. Additionally, laser drilled titanium simulation has to consider damage micro-mechanisms of the tiny holes of the leading edge.

The uses of current finite element codes are limited in the direct modelling of hail impact against micro-perforated weakened materials. The main obstacles are due to the dependence of the size of micro-perforated holes and localized damage on the mesh element size and alignment. The present study aims to represent a novel application for cohesive elements to model micro-perforated titanium. The implemented model could successfully simulate what it could be called “zipper failure mode”, predicting micro-perforated titanium behaviour. Energetic method is explored, where the breakage line is predefined before the impact. The different advantages and disadvantages are discussed, and the impact of the parameters involved. Correlations between numerical and experimental tests have been carried out. Results demonstrate that the simulated HLFC model is similar to the experimental one giving required confidence for engineers. This work has been developed under the frame of Clean Sky 2 CS2 LPA.

**Numerical Modelling of Aerospace Structure Subjected to Lightning Strike Phenomenon**

*Federico Martín de la Escalera, Yasser Essa; Ignacio Briones*

The lightning strike is an important issue to be taken into account in modern aircraft designs, having high percentage in composite materials. Composites possess a clearly worst behaviour compared with metallic structures against Lightning strike phenomenon, due to their low electrical and thermal conductivities. The aim of this paper is to illustrate the development of numerical models simulating this phenomenon. Lightning strikes produce direct and indirect effects. The focus of the current study is set on direct effects, namely: “overpressure”, due to a supersonic acoustic shock wave; “magnetic forces”, due to high current areas around attachment point and “heating and burning”, due to joule effect. Specifically, it has been developed a numerical model that allow estimating the interlaminar damage areas, where the resin is decomposed and sublimated, i.e. the delaminated area. This work has been limited to investigate the joule effect because it has clearly the most important influence on the size and shape of the produced damaged area. The contribution of other factors, overpressure and magnetic forces, are discarded in this study, due to its less importance on the damaged area.

Creating a reliable tool to assess the damaged areas, allows saving cost in the composite structure certification process. It will also help to decide what will be the most critical cases to be tested and throw out the less critical ones.

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**A+ Glide Forming: A new automated process for stringer manufacturing**

*Jordi Brufau Redondo*

New composite airplane structures are made out of panels with stringers for reinforcement, either frames or ribs. The typical fuselage stringers are omega sections, while T stringers tend to be used in the wings. Stringers are usually long, narrow parts. Fuselage stringers can measure between 4 and 12 meters in...
length; wing stringers up to 40 meters in a large airplane. A+ Glide forming technology has been developed to form long and curved stringers from flat, full thickness pre-preg layups made on Automated Tape Lay-up (ATL) or Advanced Fiber Placement (AFP) machines. This innovative technology can be used to form curved stringers with different sections, lengths, thicknesses and curvatures using a single machine that accepts different tools.

A+ Glide forming allows form complex geometries parts, that cannot be made using the current technologies such as press forming or hot drape forming and is less labor-intensive and timing consuming than ply-by-ply methods. A+ Glide forming is a continuous process, which allows forming in only one shoot a full thickness part. One single machine can be used for many different stringers, only a new tool and a new stack are needed to manufacture an additional geometry with the same machine.

**Mechanism study of dynamic hardening process on ground aerostructure workpiece’s surface topography**

*Shichao Xiu, Cong Sun, Xiangna Kong*

Grinding is a multiple-field coupled process, which generates much heat in the aerostructure workpiece’s material removal process. Once the workpiece’s surface temperature reaches the microstructure transformation point, the dynamic hardening accompanies with grinding process inevitably, which may result in differences of ground workpiece’s surface quality. Based on the above, this paper proposes a mechanism study of dynamic hardening process on the workpiece’s surface topography. Firstly, the dynamic thermal-mechanical for the grinding force and grinding temperature are solved sequentially. Secondly, the workpiece’s microstructure transformation is considered as well. Afterwards, a novel model on workpiece’s surface topography based on dynamic hardening process and multiple grits’ trajectories is established accordingly. Finally, the influence mechanism is further testified by the grinding hardening experiments. The results show that the dynamic hardening process can influence the hardness distribution in both spatial and temporal field. Thus, the ground workpiece’s surface topography can be affected by the dynamic spring-back due to different hardness distributions accordingly. Meanwhile, the analyzed results can be a reference for aerostructure manufacturing industries with grinding hardening technology.

**Research on circular thin-walled parts fabricated in additive manufacturing using laser engineered net shaping**

*Liaoyuan Chen, Tianbiao Yu, Yu Zhao, Jiashun Shi, Zhe Liu*

In the aerospace industry, the forming precision, microstructure and mechanical properties of the circular thin-walled parts are higher than those of conventional industrial parts. Due to the laser cladding additive technology, in the forming process of the annular thin-walled parts, the overlapping areas between the layers are prone to concave and convex defects. As the deposition progresses, the uneven defects become more and more obvious without the proper control. It is easy to cause the dimensional accuracy of the round thin-walled parts to decrease, and at the same time affect the microstructure and mechanical properties of the overlapping area. In view of the above problems, a process for manufacturing a circular thin-walled member by using a helical additive is proposed. By optimizing the pitch of the laser cladding head during the scanning process, a circular thin-walled part with excellent topography and uniform microstructure distribution was obtained. The microstructure of the part was observed by a 3D laser electron microscope, and the Rockwell hardness inside the cladding layer was measured using a MH-500.
micro-hardness tester. The results show that the surface of the formed part is flat, the inner circle size is less than 5%, the outer circle size error is less than 3%, and the wall thickness is stable at about 2 mm. The microstructure of the layered joints in the forming area is small. The grain is fine, the structure is dense and uniform, and the overall hardness of the part remains stable. Therefore, the spiral printing of the circular thin-walled parts can improve the surface roughness of the part, overcome the step effect, reduce the cracks and pores existing at the overlap between the layers, and reduce the residual stress, thereby improving the service life of the part. The manufacturing process of laser cladding annular thin-walled parts provides a preliminary theoretical reference for practical applications in aerospace and other fields.
Scaled model experiments of the ditching phase

Emanuele Spinosa, Silvano Grizzi, Ivan Santic, Alessandro Iafrati

Water entry tests of scaled models with horizontal velocity and dynamic variation of the pitch angle have been carried out with the aim of achieving a deeper understanding of the phenomena taking place during the aircraft ditching phase. These tests also help to build up a database for the validation and development of the computational tools to be used in the design and certification of aircraft at ditching. Experiments have been performed at the Wave and Towing tanks of the CNR INM. The former allows a horizontal velocity of 5 m/s in both heading and following wave conditions. The latter allows a horizontal velocity of 12 m/s in calm water conditions. The vertical-to-horizontal velocity ratio is in both cases 1.5/40=0.0375.

Three different fuselage shapes have been used by varying the transverse and the longitudinal curvatures. All shapes are analytically defined so that the data can be distributed for validation. Three test conditions have been considered:

- Drag tests in calm water at different attitudes, pitch angles and horizontal speed.
- Water entry in calm water with pitch angle variation starting from the impact time: 6° to 4° and 6° to 8°.
- Water entry at 6° pitch in calm water as well as in heading and following waves, with the fuselage descent synchronized to exactly impact a wave crest, face or trough.

The fuselage movement is provided by two linear servo-actuators, which have a feedback control on their linear speed. The actuators are computer-controlled and can provide the desired vertical fuselage trajectory and pitch angle variation. The fuselage is connected to the moving vertical struts using two multi-component load cells, which measure the normal and tangential forces (with respect to the fuselage longitudinal axis) during the water entry. Pressure probes are installed in the impact area, and the position and the pitch angle are recorded real-time using an optical tracking system. Results are presented in terms of forces and pressures. For some cases, comparisons with the high speed ditching tests are also presented to highlight the effects of the scaling.

This project has received funding from the European Union’s Horizon 2020 Research and Innovation Programme under grant agreement No 724139 (H2020-SARAH).

A fully-nonlinear potential flow model for aircraft ditching applications

Alessandro Del Buono, Alessandro Iafrati

A fully nonlinear, potential flow model for the descriptions of the hydrodynamics of water entry is presented. The problem is formulated in terms of boundary-element representation of the velocity potential and the time evolution is described by a mixed Eulerian-Lagrangian approach: the velocity potential is assigned on the free surface by integrating the unsteady Bernoulli’s equation, whereas its normal derivative is assigned on the body contour. In order to reduce the computational effort, a simplified model, based on finite element method, is adopted for the thin jet developing along the body. The model is able to describe the detailed flow evolution and to evaluate the pressure distribution and
the total hydrodynamic force acting on the impacting body. It has been validated in the case of constant velocity water entry of two dimensional sections and water entry of axisymmetric cone with imposed motion.

This model is further developed within the H2020-SARAH project with the aim of using it as a lower-fidelity tool for the aircraft ditching problem. With respect to other approach, like Modified Logvinovich Model or the Generalized Wagner, both extremely efficient in providing an accurate predictions of sectional forces, the proposed model, being fully nonlinear, provides more accurate estimates of the pressure distribution at the spray root, which can be significant when modelling the fluid-structure interaction. Due to the smoothly curved aircraft sections, a flow separation model based on a kinematic criterion is developed to retrieve the unknown flow separation point. In order to describe the 3D flow generated by the water entry of the fuselage, the two-dimensional solver is embedded in a 2D+t approach where the 3D problem is approximated by a 2D problem in the transverse plane in an earth-fixed frame of reference, with the shape of the impacting body changing in time.

Some validation studies have been made for the vertical water entry problem of the fuselage and they will be presented.

This project has received funding from the European Union’s Horizon 2020 Research and Innovation Programme under grant agreement No 724139 (H2020-SARAH)

**Aircraft Ditching Simulation with ditch**

**Thomas Rung, Micha Überrück, Philip Meier**

Impact loads on the fuselage that occur during ditching of aircrafts are an important issue in aircraft engineering and homologation. In order to predict reliable loads on the fuselage during the water impact, the 2D+t simulation method ditch has been developed\(^{25}\) and improved.

Since the simulation of the ditching process is actually performed a couple of hundred times to analyse and optimize the behaviour of each aircraft, both, the predictive accuracy and the numerical efficiency are crucial. The employed procedure can be executed in near-to-real-time and is conceptually divided into two main parts, i.e. a motion model and a load model. To reduce the effort, the aircraft motion is restricted to three degrees of freedom, i.e. horizontal and vertical movement and pitch angle. Load contributions are considered for the fuselage, wing, engines and horizontal tail.

Ditching loads are dominated by hydrodynamic loads on all (wetted) components. Moreover, aerodynamic loads on the (unwetted) wing and tails as well as engine thrust forces are considered. Fluid forces generally consist of normal and tangential forces due to pressure (& buoyancy) or friction, and loss of components can be modelled. Hydrodynamic impact forces follow from augmented Karman\(^ {26} \) and Wagner theories\(^ {27} \) which are able to capture issues of multiphase flows (cavitation, ventilation) as well as wave induced aspects. Aerodynamic forces can optionally consider ground effects. As loads can effect

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global and local fuselage deformation, a fluid structure interaction module has been integrated into ditch. The latter mimics load changes due to deformations and globally deforms the loaded aircraft during runtime.

The presentation will briefly discuss the rationale of the computational approach and present a few validation and application examples that were performed under the aegis of the SARAH project funded by the European Union Horizon 2020 research and innovation program under the grant agreement No 724139.

**Prerequisites for the accurate prediction of hydrodynamic impact loads in mesh-based ditching simulations**

*Maximilian Müller, Matthias Haupt, Peter Horst*

The emergency landing on water, also referred to as ditching is an important element of aircraft certification. Novel mesh-based simulation methods that incorporate both the fluid and the structural field as well as their two-way interaction, open up a promising way to model ditching in full scale. This study addresses the simulation of the fluid field, with a particular focus on the prerequisites for the accurate prediction of the hydrodynamic impact loads. The dynamic response of the aircraft structure is determined by those loads. Thus, their correct computation is an indispensable requirement for fully coupled, full-scale ditching simulations. By using the two-dimensional model problem of the vertical impact of a circular rigid cylinder, two major influencing factors on the prediction of the hydrodynamic impact loads are investigated: the sharpness of the air-water interface and the compressibility of the water. It is shown that a sharper air-water interface leads to a more accurate load prediction. However, improving the interface sharpness by merely increasing the mesh-fineness leads to a significantly increased computational effort due to the Courant number limit $C_0 < 1$ that is imposed by the Volume-of-Fluid (VoF) method used in this study. This is remedied by employing a geometric VoF method that reconstructs the air-water interface within each mesh cell, leading to an improved load prediction and simultaneously reducing the required mesh fineness. The influence of the water compressibility is investigated by solving the model problem with the compressible Navier-Stokes equations. The results demonstrate that the effect of compressibility influences the load prediction and must therefore be considered in ditching simulations. Based on the findings obtained for the model problem, the ditching of a rigid realistic fuselage geometry with a dominant horizontal velocity component is analysed. This is done by using both a geometric VoF method and a compressible flow solver. The computed pressure history at predefined pressure probe locations is compared to experimental reference data. All simulations exhibit smaller pressure peaks compared to the experiment. This indicates that a compressible flow solver employing a geometric VoF method is needed to accurately predict the hydrodynamic impact loads in ditching simulations while keeping the computational effort manageable, thus making the fluid simulation model feasible to be incorporated in a fully-coupled ditching simulation.

**Novel energy absorbing concepts for ditching scenarios**

*Jendrik Seiler, Stephan Adden*

One goal of the SARAH project is the improved comprehension of structural responses to ditching loads. In a controlled ditching event, the area of impact of the aircraft is known as well as the environmental conditions and flight parameters. While other research efforts are made to improve the computational
accuracy and effectiveness of the impact calculation and fluid behaviour, opportunities for improved safety can also be found on the structural side.

During ditching impact, a specific area of the underside of the aircraft experiences crash-like loading. These conditions are usually not a primary concern during the aircraft design phase. However, with better understanding of the roles the various structural components possess in such an event and how they individually behave, optimizations can be developed to reduce the risk of structural failure leading to water ingress and a reduced floatation time. Since ditching is a rare event, special considerations are required to minimize the impact on space and weight of any modified or additional components.

For this purpose, a generalized nonlinear FE-model of a wide body airliner fuselage was developed and subjected to ditching impact loading. The individual behaviour of different structural components was evaluated which allows careful selection of parts which are prone to damage in such an event and could therefore benefit from strengthening. Furthermore, different concepts for specialized energy absorption elements, which are either added to the structure or replace existing elements are implemented and compared to the default case.

**SARAH: Increased Safety and Robust Certification for Ditching of Aircrafts and Helicopters**

*Stephan Adden*

SARAH is concerned with establishing novel holistic, simulation-based approaches for the analysis of aircraft and helicopter ditching. It is composed from a consortium of experts from OEM industries, experienced suppliers of simulation technologies, established academic and research institution and supported by representatives of the certification authorities. Results of SARAH are expected to support a performance-based regulation and certification for next generation aircraft and helicopter configurations and to enhance the safety of air transport as well as to foster the trustworthiness of aviation services.

Aircrafts and helicopters often travel above open waters and thus have to prove a safe water landing under emergency conditions. This is particularly true for fixed-wing aircrafts certification, but also for helicopters as they are strongly used to support marine tasks (e.g. serving offshore wind-parks, supporting S&R actions etc.). The specific challenge for the design of airborne vehicles is to minimize the risk of injury to persons on board during the whole water landing and to give chance for safe evacuation of the occupants. Accordingly, the motion of the aircraft/helicopter along with the forces acting on the structure is studied for controlled water impact during the design phase of an aircraft. SARAH is addressing these topics in a holistic way both concentrating on delivering simulation means as well as experimental results to validate methods. The overview presentation will show the activities and the progress made so far.

**Development of structural fuselage models for numerical analysis of aircraft ditching events**

*Malte Woidt, Maximilian Müller, Matthias Haupt, Peter Horst*

The SARAH project is concerned with simulation-based approaches to the analysis of aircraft ditching. One approach within the project is a high fidelity, fully coupled fluid-structure interaction simulation of a modern wide-body transportation aircraft landing on water. The simulation will cover the impact phase of the ditch event.

For such a simulation the deformation state of the fuselage need to be computed. As the fuselage will most likely not remain in a completely undamaged state during the ditching event, geometrical and material non-linearities need to be included.
Experience from barrel drop tests show, that damage phenomena of fuselage structures are highly localized and therefore very fine grained FE models are needed to simulate the damage behaviour directly. Especially for big fuselage sections the computational effort is too high, as also the time step size shrinks with the elements for explicit simulations.

To tackle these problems different reduced order damage models were successfully developed in the past. In this work such a model should be assessed for ditching simulations. The model captures elastic deformation with a classical FE element model and damage phenomena with special macro-elements that are placed at damage-prone locations. The local damage behaviour of these elements is computed with local high granularity FE models under simplified loading conditions. A semi-automatic process for placing the elements and extracting relevant loading conditions is shown.

To validate the results a generic fuselage structure is defined and models are built in different granularities and different damage models. A short fuselage barrel is simulated during a vertical impact on water and on solid ground. As the considered fuselage section is relatively small very fine-grained models can be used to assess the reduced order models in coarser models.

**SARAH: Some outcomes contributing to Helicopter ditching**

*Séverin Halbout, Jérémy Ohana, Benjamin Bouscasse, Angélique Jullien, Yoann Jus*

SARAH, Increased Safety & Robust Certification for ditching of Aircrafts and Helicopters, is a European research program addressing some aspects of the ditching in order to increase the safety of crew and passengers. Airbus, helicopter division, is one of the main OEM industry implied in this project. Among the results of SARAH it is expected to support performance-based certification and design guidelines for helicopters. Helicopters often travel above water and thus have to prove a safe landing under emergency conditions. The specific challenge is to minimize the risk of injury to passengers and to enable safe evacuation. The kinematic and the integrity of the helicopter depend on the forces acting on the structure. This aspect of the subject is one of the main focus: predict loads during such a non-linear and hazardous event. As a consequence a large effort consists in improving or optimizing tools to reach this prerequisite. One of the specificity of ditching of helicopters is the presence of inflatable floatation system. The experimental campaign led at Ecole Centrale de Nantes with a generic mock-up allowed to obtain some preliminary results of correlation with simulations using DFEM and semi-analytical approaches.

Touching the end of the project it is the occasion to highlight the main outcomes foreseen from the focus on development tools to the largest view of the operational and performance based certification.

**Experimental testing of helicopter ditching in waves, from specifications to tests**

*J. Ohana, B. Bouscasse, A. Merrien, S. Haquin, L. Davoust, M. Abu Zarim, S. Halbout*

The purpose of the experiment is to evaluate a set of forces, displacements and deformations acting on a helicopter and its floaters during an emergency ditching, with the objectives being to create a database for the validation of numerical high fidelity CFD codes but also to be as representative as possible of realistic scenario. The tests were performed at the ocean wave tank of Ecole Centrale de Nantes both in calm water and in waves with a scaling of 1/3.4. The experiment is designed in the framework of the H2020 SARAH project. The helicopter was accelerated on a large sliding structure developed for this specific purpose. The mockup consists in several parts, the floaters (two sets of 4: rigid and inflatables), the cabin, a junction piece (which is changed to vary heel, trim, and yaw at impact) and a trolley (which is
going down the slider). At model scale, the helicopter built in aluminium weighs around 350 kg, with a maximum horizontal velocity at impact over 8 m.s and a maximum wave height tested of 1 m. Measurements are performed though 3 piezoelectric load cells under the fuselage, placed in the front, the middle and the back of the cabin. Additional load cells are dedicated to measure the loads given by the floats on the sponsons and on the cabin, and on the girths linking the floats to the fuselage themselves. The presentation will focus on the path from the specifications to the actual testing, the technical choices and feedback about the learning experiences.

Development of a novel Thermoplastic based composite material by In-Situ Consolidation Automated Fiber Placement process
Marco Barile, Leonardo Lecce, Vincenzo Iannone, Giuseppe Barile

This work resumes the results achieved until today in the ongoing European project NHYTE, deriving from the development of an innovative thermoplastic composite prepreg material aimed to guarantee a reliable and repeatable production process for next generation aerostructures, highly integrated and green.

In general, taking into account that the main issue in fabrication of thermoplastic composites structures is in the affordability of the production process, the NHYTE approach by means of In-situ consolidation Automated Fiber Placement technology would eliminate autoclave consolidation cycle by applying an amorphous bonding concept to aerospace grade thermoplastic based composite materials. As consequence of this development a significant reduction of energy consumptions and overall manufacturing cost flow (Out of Autoclave process) is expected.

This paper deals with the promising results emerged from the mechanical and physical testing (ILSS, DSC, Microscopy, etc.), carried out, at lamina and coupon level on the new thermoplastic material fabricated by Novotech, with the technical support of Leonardo and Cetma.

NOVOTECH, acting as Coordinator, presents this paper on behalf of all Partners of the project.

The activity was carried out in the frame of the NHYTE project, a Research and Innovation Action funded by the European Union’s H2020 framework programme, under Grant Agreement No 723309.

A New Objective Function For The Optimization Of An Aeronautic Structure With Regard To The Component Quality, The Life Cycle Costs And Environmental Performance
Ch.V. Katsiropoulos, Sp.G. Pantelakis

The assessment of cost and environmental footprint for producing an aircraft component is nowadays a common practice. In this context Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) are used. In addition, meeting the quality of the component, in terms of predefined quality features like eg. critical mechanical properties etc., is a non negotiable demand. Yet, in most cases a quality increase is associated to an increase of cost and in several cases also to an increase of the environmental footprint and vice versa. Therefore at the stage of the design optimization of a structure environmental footprint, cost and quality need to be considered not as independent design objective functions but as interrelated ones.

In the present work, a novel objective function for the optimization of aircraft structures with regard to quality, cost and environmental footprint is introduced. The proposed objective function accounts for cost analysis (LCC) based on the activity based costing model, life cycle analysis (LCA) based on the ReCiPe
method involved and quality analysis realized through a mechanical testing study for the definition of the critical mechanical properties for the structural part under consideration. The terms of the proposed objective function are considered to be cumululative. Hence its maximum value is considered to be optimal. The abovementioned concept has been applied to compare several materials, manufacturing processes and recycling scenarios for a typical aeronautical composite part. The implementation of the proposed concept was made for several composite materials.

To this end, cradle-to-cradle Life Cycle Analysis (LCA) and Life Cycle Costing (LCC) models were developed and implemented for the case of a fuselage panel production. For the LCA the ReCiPe method was chosen to model the environmental impacts of different materials and processes by using open LCA software. Representative environmental midpoint impact categories used to characterize the overall environmental performance are: Climate change, Ionizing radiation - human health, Land use, Ozone depletion, Resource depletion – water and Terrestrial eutrophication etc. The LCC was carried out using the Activity Based Concept modeling method. The materials considered have been Carbon Fiber Reinforced Epoxy and Carbon Fiber Reinforced PEEK (PolyEtherEtherKetone). The manufacturing techniques compared were the conventional autoclave process and the well established Automated Fiber Placement (AFP) process, both very popular for aeronatics applications. The considered recycling scenarios included mechanical recycling and pyrolysis as they are currently the most widely used. The selected quality features were evaluated through mechanical as well as DSC tests.

The results of the study pointed out that producing the panel by using carbon fiber reinforced thermoplastic composites and involving Automated Fiber Placement (AFP) as the manufacturing process is the optimal route both in terms of environmental and financial efficiency. Furthermore, the product quality of the thermoplastic AFP case is almost similar to the expected high valued behavior of the autoclave option, thus outlining it as the overall preferable solution. It is noticeable that even though the environmental and financial efficiency of the scenarios including thermoplastic composites as the material of choice is impaired from both the high embodied energy and raw material cost of PEEK, the high degree of automation and hence the reduced cost and energy required overlap the abovementioned impair. The result is expected to be further enhanced if the scenarios investigated account for potential benefits arising from the recyclability and the improved reusability of thermoplastic matrices as compared to thermosetting ones; yet these aspects have not been part of the present work.

**Induction welding process simulation of thermoplastic materials**

*Panagiota Polydoropoulou, George Lampeas, Spiros Pantelakis*

The induction welding technology implemented on advanced thermoplastic composites for aircraft structures will reduce the environmental impact of aviation by reducing the emission during production process as well as by reducing energy consumption [1]. The induction welding process combines the melting of the joining materials due to the generation of eddy currents into the composite plates which are in contact, caused by a coil generating an alternating electromagnetic field as well as the pressure enforcement by a consolidation roller [2–6]. When an electric current is induced into composite materials, three mechanisms occur simultaneously leading to heating: i) heating by Joule losses along the fibers; ii) heating by contact resistance at junctions between fibers and iii) heating by dielectric hysteresis at fiber junctions, where fibers act as a capacitor when are separated by a layer of thermoplastic resin [7].
In this work a model simulating the induction welding process of thermoplastic materials is developed. The material is a hybrid PEEK composite sandwiched between amorphous PEI films. The addition of amorphous PEI films aims at the reduction of the required melting temperature below the melting temperature of the crystalline phase of PEEK (at least 380°C) [1].

Acknowledgments
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References
AIRPOXY: Thermoformable, Repairable And Bondable Smart Epoxy Based Composites For Aero Structures

*Nerea Markaide*

With strong growth rates of 13% in the aero sector and forecasts that demands could be doubled by 2032, carbon composites (CC) are under the spotlight. CC production requires a quick ramp-up that needs to be based on robust materials & processes, and a solid manufacturing supply chain, where higher production rates and cost reductions are essential.

The aim of AIRPOXY is to reduce production and maintenance, repair & operating (MRO) costs of CC parts in aeronautics, by introducing a new family of enhanced thermoset composites that preserve all the advantages of conventional thermosets, while showing new unprecedented features such as Re-processability, Reparability and Recyclability. This new generation of 3R composites are obtained by using dynamic hardeners which create reversible crosslinks in the cured epoxy resin. Once the 3R composite has been produced, the dynamic chemical bonds of the cured resin can be reshuffled under determined external stimulus, such as temperature or the exposure to a specific chemical agent. For these reasons the 3R composites are easily re-processable, repairable and recyclable.

The AIRPOXY consortium has established various specific objectives. Thus, thermoforming processes previously unthinkable for thermosets are being adapted for 3R composites, in order to reduce manufacturing cost of CC parts by 35% vs autoclave, reducing processing times from hours to minutes. Faster/cheaper repair technologies in combination with structural health monitoring (SHM) are also being studied in order to reduce significantly MRO costs. Additionally, it is expected that welding process adapted for 3R composites will reduce CC bonding costs by up to 50%. Supporting tools such as simulation and life cycle assessment/ life cycle costing/ human health risk assessment (LCA/LCC/HHRA) will be applied from the early stages of design.

The project started in September 2018 and will conclude in February 2022 with the validation of the developed technologies in industrial environments. For this purpose, two demonstrators of aerostructures will be produced: a sub-component of a fan-cowl formed by a longitudinal stiffener, transversal stiffener and skin, and a sub-component of a leading-edge formed by a nose and two webs.

AIRPOXY relies on a multidisciplinary consortium of 11 partners from 6 countries: inventor and formulator of 3R composites (Cidetec), key technology providers (IVW, Eurecat, Coexpair, University of Ioannina and Altair), aircraft components manufacturers (Eire, Idec and Sonaca), standardization experts (UNE) and aeroconsultancy (Arttic), supported by a strong advisory board (Airbus, Leonardo, Huntsman, SGL and EREA).

Semi-Finished 3R Material Manufacturing And Thermoforming Of 3R-Composites

*Stefan Weidmann, Alaitz Ruiz de Luzuriaga, Andreas Krämer, Christian Goergen, Peter Mitschang*
High production rates and short cycle times are essential for an efficient manufacturing of high performance components made of carbon fiber reinforced polymer composites (CFRPC). Additional production requirements are robust materials and robust processes. Aim of this study is to reduce production and maintenance, repair and operations (MRO) costs of CFRPC-parts in aeronautics by introducing a new family of enhanced composite materials using an epoxy based vitrimer matrix polymer (3R composites). At room temperature, vitrimers are fully cross-linked like thermosets, at temperatures above glass transition temperature (Tg) they are deformable like thermoplastics due to dynamic covalent bonds. When heating vitrimers, the covalent bonds detach and re-crosslink when cooling. If the vitrimer is deformed during re-crosslinking, this change in shape is retained after cooling. Vitrimers have advantages of conventional thermosets as high stiffness, chemical resistance and a low tendency to creep. Simultaneously, they have properties like multi-reformability, weldability and recyclability at higher temperatures. Montarnal et al. presented the first vitrimer in 2011 [1, 2, 3, 4, 5]

Three possible processing methods for manufacturing of 3R composites parts will be presented: First, the manufacturing of flat semi-finished parts using the RTM process. The approach for the formulation of the 3R matrix polymer as well as the process design and execution of the RTM process will be described.

Second, a processing concept for part manufacturing in thermoforming will be presented. Due to the specific reshaping mechanisms of 3R composites, a completely new process approach comparable to the well-known thermoforming of thermoplastic composites has to be developed. This primarily concerns the temperature management and referring exposure times in order to enable the vitrimer to reorganize the dynamic bonds. First guidelines will be presented which describe how to achieve good thermoforming results.

Third, the continuous compression molding process (CCM) is introduced as an alternative manufacturing method to RTM to produce flat semi-finished products. Single prepreg plies of completely as well as partially cured 3R composites are stacked one above the other and processed by applying consolidation pressure and temperature at the same time, resulting in continuous 3R composite sheets.

As a first result, the investigation shows that manufacturing of fiber reinforced vitimer semi-finished sheet in RTM as well as CCM processing is possible. Thermoforming of these new materials show complete different processing performance compared to thermoplastic composites.

### Bonding Strategies For Dynamic 3R-Composites

**Alaitz Ruiz de Luzuriaga, Arrate Huegun, Alaitz Rekondo, Stefan Weidmann, Diego Calderón, Antoine de Fontgall, Emmanuel Detaille**

Mechanical fastening is still the state of the art joining method for primary aerospace structures. One key technology for the future development of composite aircraft structures is a suitable joining technology. In this sense, adhesive bonding is one of the most promising alternative joining technologies enabling new disruptive structural concepts allowing the uniform distribution of stresses and strains across bonded joints.

According to the aerospace industry, adhesives have to meet better technical specification together with tougher environmental and safety criteria to fully replace mechanical joints. In this context, the creation of covalently bonded structures can help by potentially removing the need for abundant rivets and fasteners.

As an alternative, thermoplastic composites offer the possibility of effective joining of composite parts through the rapid, reliable and cost effective welding technologies. However thermoplastic composite cannot replace thermoset composites in many applications.

In an approach to solve all above described limitations, AIRPOXY project opens the possibility to develop breakthrough bonding technologies based on a novel 3R (repairable, reshappable, recyclable) thermoset resin. 3R resin presents reversible dynamic bonds that enable a series of smart properties creating a new generation of composites and adhesives while showing unprecedented features once the resin is completely cured such as reprocessablity, reparability and recyclability (3R).

3R resin enables the development of 3R welding and adhesive bonding creating covalent bonds with composite structures allowing load transfer across the entire bonded area. In this work we present two different approaches to obtain highly efficient chemically bonded composite parts:

- **3R adhesive bonding:** in AIRPOXY project standard composite substrates will be replaced with 3R substrates and standard adhesive with 3R adhesive, so that the whole bonding is based in 3R resin. Due to dynamic exchange of chemical bonds during curing of the adhesive whole element will be fused into a single element improving the performance of the joint.

- **3R welding:** due to the presence of dynamic bonds into the surface of different elements, in AIRPOXY project, the welding of totally cured 3R composites will be done. As a result of 3R welding, recombination of dynamic bonds will occur which will permit the disappearance of the interface between two substrates, allowing the uniform distribution of stresses.

### Implementation of Structural Health Monitoring (SHM) techniques for the evaluation of repairing on 3R polymers & composites

**Alkiviadis S. Paipetis, Georgios Foteinidis, Maria Kosarli, Kyriaki Tsirka**

Polymer matrix composites have a vast amount of applications in the aeronautics due to their low weight to strength ratio. A significant disadvantage of advanced thermoset epoxy polymers and composites is their poor fracture toughness while also their repair can be proved time and money consuming. An efficient repair process can now be achieved with a novel thermoset resin which is Re-processable, Repairable and Recyclable (3R). The 3R properties are due to the reversible crosslinking in the cured
thermoset resin. The repair process of the 3R resin has been evaluated in detail during this study using several Non-Destructive Techniques (NDT), i.e. Impedance Spectroscopy (IS), Electrical Resistance Change Method (ERCM) and Acoustic Emission (AE), in an attempt to develop an efficient Structural Health Monitoring (SHM) protocol. SHM is a vital tool for damage detection and prevention of high value composite structures. Among SHM techniques, the ones that relate the electrical properties to the mechanical response and/or the durability of the structure are of great interest due to the sensitivity of the electrical properties to internal degradation. In detail, this study utilized IS, ERCM and AE simultaneously with mechanical tests at i) matrix level, ii) composite level and iii) modelled structures level in order to evaluate the knockdown effect between conventional and 3R specimens. Moreover, the knockdown effect of 3R specimens was assessed before the introduction of damage and after the repair process. In this case, the differences in the signature profiles of 3R specimens were evaluated before and after repair and specific indicators in each indirect method were correlated with the repair efficiency values measured by the mechanical tests.

**Supporting Tools To Technical Advance In The Early Stages Of Design**

*Jose Jorge Espí, Abderrahmen Aridhi, Maria Sedó, Mireia Mesas, Frederic Clarens, Juan Pedro Berro, Bilal Bendjeffal*

The development of methods and tools to support the advancement in scientific and technical solutions has emerged in recent years in order to assist decisions that allow to avoid extra efforts due to the common traditional “trial and error” approach. At the same time, new challenges in terms of environmental protection have also engaged to adopt decisions having into account that climate protection needs to remains as a primer driver in the development of the aviation sector.

AIRPOXY, will recover all current requirements through an integrated approach where LCA (Life Cycle Assessment), LCC (Life Cycle Cost analysis), HHRA (Human Health Risk Assessment) and numerical simulation of manufacturing process will work together in order to demonstrate and support the development of thermoformable, repairable and bondable smart epoxy based composites for aero structures.

Regarding LCA and LCC the planned cradle-to-grave studies will focus on the assessment of the benefits and drawbacks related to the environmental and economic impact of the new processes focusing on three aspects of the life cycle: product manufacturing, use phase, and recycling stages. Special attention will be pay on the production of the new 3R resins, sheet manufacturing by RTM and thermoforming, bonding, repair and benefits for the recyclability.

HHRA Human Health Risk of the production process of the new 3R resin will be assessed using standard methodologies and most up-to-date toxicity values. Study will be based on the exposure of the receptors (workers) to the chemicals and their toxicity.

The numerical simulation of manufacturing process (thermoforming and bonding) can improve the quality of final products as well as reduce the material waste. That means that numerical simulation can impact the components LCA and LCC. Focusing on thermoforming, some methods to better describe the interaction between plies have been investigated. Smooth particle Hydrodynamic approach are used to represent the resin present in the interface which produces an “adhesion” force. For the material itself, two parallel approaches are carried on: firstly a hypoelastic material for fabric modelling is developed in
a user material framework on Altair Radioss, secondly a hybrid approach modelling separately the fabric (with standard material law) and a new viscoelastic thermal dependent material for the resin. For bonded and repaired structures, a method will be developed to take into account the presence of these new interfaces to be able to predict correctly the part performances. The simulation driven manufacturing allow us to reduce cost and energy through process optimization and quality improvement of produced components.

By considering all stated before, the final aim will be double. On one hand, to being informed about technical, environmental, economic and safety requirements during key stages, in order to take informed decisions and optimise it following the Eco-design principles. On the other hand, to obtain objective data to support performance in order to increase the impact of the project and support the further implementation of the technologies as the AIRPOXY solutions reach higher TRLs.
HARVEST: Hierarchical Multifunctional Composites With Thermoelectrically Powered Autonomous Structural Health Monitoring For The Aviation Industry

Paipetis S. Alkiviadis, Gergidis L., Barkoula NM, Tzounis L., Tsirka K.

A huge amount of the energy produced globally is dissipated as waste heat, with the transport sector being the major contributor to this unutilised energy, since only 20% of the fuel's energy ends up as useful energy. Aeronautics structures represent typical examples of high energy usage with low efficiency, where almost 75% of the energy produced during combustion is lost in the turbine or engine coolant in the form of heat. To address this issue, HARVEST proposes the development of Advanced Multifunctional Carbon Fiber Reinforced Composites (CFRCs) as efficient lightweight structures widely used as structural components in the aviation industry.

Significant amounts of this lost energy can be recovered by thermoelectric generator (TEG) materials/structures which permit the direct conversion of thermal to electrical energy. A TEG is typically used for energy conversion through the Seebeck effect \( S = \Delta V / \Delta T \), or in other words the TEG is producing electrical voltage when subjected to a temperature gradient. In the aircraft environment, temperature differences can be found in various locations (i.e. between the interior & exterior during flights, near turbines, at the leading edge).

In view of the above, HARVEST has set several objectives associated with the i) development of biomimetic hierarchical TEG-enabled CF reinforcements by R2R deposition of nanoparticle (NP) based inks aiming at a Seebeck Coefficient of \( S > 50 \mu V/K \) for p-doped and \( < -40 \mu V/K \) for n-doped structures; ii) manufacturing of Smart 3R (Repairable, Reprocessable, Recyclable) nano-modified polymeric matrices with self-sensing and self-repairing capabilities, containing different amounts of carbon NPs and/or traditional inorganic thermoelectric particles; iii) enhancement and optimization of the TEG performance using advanced analytical and numerical tools to simulate materials performance at a range of length scales; iv) manufacturing of TEG-enabled laminated multifunctional composite structures with optimised number of p-n serially interconnected laminae and evaluation of multi-functionality and TEG performance at laminate level; v) design, development and integration of an electronic system (software & hardware) responsible for managing the energy harvesting, structural health monitoring (SHM) data accumulation and transmission, during the implementation of the multifunctional materials in structural components; and vi) manufacturing of two Aeronautics Demonstrators and validation of the multifunctional capabilities under operational simulated environments.

Advanced Thermoelectric Concepts For The Aviation Industry

Lazaros Tzounis, Kyriaki Tsirka, George Karalis, Christos Mytopoulos, Anastasia Polymerou, Alkiviadis S. Paipetis

Due to the finite supply of fossil fuels, an increasing demand for alternative energy resources has evolved. Thermoelectric (TE) materials are one potential candidate for thermal energy harvesting, due to their
ability to convert waste heat into electricity via the well-known Seebeck effect. We present herein different synthetic protocols towards efficient TE inks based on organic materials (PEDOT:PSS and SWCNTs), inorganic crystals (Te nanowires - NWs) and hybrid inks consisting of polymer/ inorganic crystal mixtures. The ultimate objective is to develop carbon fiber (CF) hierarchical reinforcements using the developed TE p- or n-type inks in a printing/ deposition process with a p- or n-type semiconductor character.

Namely, p-type SWCNT ink of SWCNTs(0.2g):SDBS (0.5g) has been fabricated in 100ml of DI water with electrical conductivity \( \sigma = 1.87 \times 10^4 \) S/m and \( S = +34\mu V/K \). Accordingly, -n-type SWCNT ink using Polyethylene imine (PEI) as n-dopant, SWCNTs(0.2g):SDBS (0.4g):PEI (6g) exhibited \( \sigma = 1.98 \times 10^4 \) S/m and \( S = -38\mu V/K \). Hybrid inks of organic/ inorganic TE nanoparticle crystals as TE inks have been prepared using SWCNTs and PEDOT:PSS mixed with TeNWs in order to i) deploy the high Seebeck arising from the inorganic nanocrystals and the high electrical transport/ conductivity from the conductive polymer or CNT medium, ii) the final nanocomposite TE material will reserve the \( \Delta T \) upon being exposed to temperature gradients due to the phonon scattering by the nanocomposite inherent numerous interfaces, and iii) the organic material (CNT or PEDOT:PSS) will induce flexibility to the final TE films as well as protection of the TE nanocrystal from oxidation (thermostability) upon operation as a TE material. The optimum formulation were found to be by weight \([\text{Te(ink)}] 2 : [\text{SWCNT(ink)}] 1 \) with \(4.7\pm0.2\text{mV @ } \Delta T=100\text{K} \) and \(132\pm8\text{Ohm at } 2.5 \text{ cm interelectrode distance (Te NW ink at 30mg/ml)} \). On the other hand, the optimum hybrid PEDOT:PSS based ink was \([\text{Te(ink)}] 1 : [\text{PEDOT:PSS(ink)}] 2 \) with \(5.6\pm0.1\text{mV @ } \Delta T=100\text{K} \) and \(163\pm12\text{Ohm at } 2.5 \text{ cm interelectrode distance.} \)

Upon coating CF T-700 that exhibit inherently an n-type TE behavior with a Seebeck coefficient \( S= -4.35 \) \( \mu V/K \) and an electrical conductivity \( \sigma = 1.14\pm0.03\times10^5 \) S/m \((2.7 \text{ Ohm @ } 2.5 \text{ cm interelectrode distance})\) with TeNWs ink, a hierarchical morphology arrived with a voltage output of \(-7.9\pm0.7 \text{ mV @ } \Delta T=100\text{K} \) with room temperature resistance of \(70\pm3 \text{ Ohm (@ an interelectrode distance of 2.5 cm)} \).

It is envisaged that the hierarchical TE reinforcements will be the TE building block elements that can be serially interconnected with alternating p- / n- or p- / p- towards TEG-enabled structural CFRP laminated composites widely used in the aviation industry.

**Reshapeable, Repairable And Recyclable Thermally Conductive Epoxy Resin**

**Arrate Huegun, Nadir Kchit, Alaitz Rekondo**

Thermoset resins are the most widely used resins in fiber reinforced composite manufacturing due to their high thermal stability, good rigidity, hardness and resistance to creep and solvents. In particular, epoxy resin systems offer strong adhesive properties as well as chemical resistance and toughness. However, once a traditional thermoset composite is formed it cannot be reshaped, repaired neither recycled due to its permanently cross-linked structure. In order to solve such limitations, a novel 3R (Reshape-able, Repair-able and Recyclable) epoxy matrix was developed by Odriozola eta al. which is based on dynamic covalent bonds.

The 3R epoxy resin shows mechanical properties equivalent to traditional epoxy counterpart, but additionally presents: (i) good reprocessability of postcured composites by thermoforming, (ii) reparability of delamination and micro-cracks by applying heat and pressure in the damaged part, and (iii) recyclablility
by matrix chemical dissolution with specific reagents or by grinding and mechanical processing into second generation composites.

The aim of this work is to develop a novel 3R epoxy resin with enhanced thermal conductivity to be implemented in thermoelectric generation (TEG) enabled composites within HARVEST project (www.harvest-project.eu). As any typically polymer resin, 3R system is a good thermal insulator and presents very low thermal conductivity. Therefore, here the addition of nanofillers such as carbon nanotubes (CNT) and carbon black (CB) into the resin has been explored in order to facilitate the heat transportation in the system.

**Damage monitoring of composite structures via electrical measurements: recent activities and open issues**

*Michele Zappalorto*, PA Carraro, L Maragoni, M. Quaresimin

Damage monitoring is a fundamental aspect in the design process of composite structures where high reliability is required without negatively affecting the life-cycle costs of the part. In advanced structural applications, parts made of composite materials are subjected to static and cyclic loads, leading to a progressive damage and degradation of the mechanical properties. In addition, parts may be subjected to impacts, which are in most of the cases difficult to be detected by visual inspection. Structural health monitoring (SHM) provides a continuous inspection of the part, so that these typologies of damage can be detected since the earliest stages, and preventive actions can be taken to reduce operational costs, downtime, and to generally increase the reliability of the structure. Within this frame, electric potential-based methods have been widely investigated in the literature. Their effectiveness in monitoring the stiffness reduction due to fatigue loads and, more generally, the damage accumulation has been successfully proven. In this context, an innovative and promising solution for damage monitoring is the use of an electrically conductive CNT modified matrix, which provides the material with multifunctional properties such as an increased interlaminar shear strength, and electrical conductivity also when fibres are insulating. In addition, CNT modification of CFRP increases the out of plane conductivity, enhancing the damage sensitivity of the material. In a number of recent works[1], the authors explored the capability of Electrical Damage Monitoring (EDM) carried out Mode I opening tests on DCB specimens made of CNT modified CFRPs, monitoring the variation of the electrical resistance due to the growth of a delamination. Experimental results showed that electrical resistance change can be used as a quantitative parameter to estimate the presence and the extent of the delamination with a great degree of accuracy.

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**Advanced Monitoring Techniques For Mechanical Testing Of Cfrp**

*Martin Gurka*, Vitalij Popow, Benjamin Kelkel

In order to determine material properties of anisotropic continuous fiber-reinforced polymers, such as stiffness and strength, usually quasi-static tensile tests are carried out, in which the test specimen is subjected to a controlled load until failure. Because of the small strain and brittle failure mechanism, observation of damage progression (e.g. transverse matrix cracking), exact localization of the failure on
the test specimen or observation of final failure is not possible. The sample often breaks down into many small fragments. In order to get a deeper understanding of the failure behaviour and to optimize the material and the design of the specimen, additional characterization of the damage progress under load by various non-destructive test methods is often applied. This contribution gives a short overview and focusses on the combination of methods, such as acoustic emission (AE) and infrared thermography (IRT) in order to get additional information during quasistatic mechanical testing.
Investigation and Characterization of Electrospark Deposited FeCoCrNiNb0.5 High Entropy Alloy coatings on AZ31B magnesium alloy

Lian Yong, Zhang Jin, Ji Xianda, Ma Minyu, Han Dong, Liu Chang

A computed numerically controlled electrospark deposition (ESD) system was applied to produce high entropy alloy (HEA) coatings on AZ31B magnesium alloy. An ESD electrode was manufactured from a FeCoCrNiNb0.5 HEA cast ingot. The ESD process parameters including voltage, capacitance, frequency and moving speed of electrode were investigated systematically. It is shown that process parameters have interactive effects on the coating features and there is an optimum condition for achieving a sound coating. A dense coating with low as-deposited surface roughness was prepared under properly selecting parameters. The electrospark deposited coating had an excellent sliding wear resistance and corrosion resistance attributing to the continuous and protective FeCoCrNiNb0.5 HEA coating.

Multifunctional Bio-inspired Integrated Thermal Protection Structures: Design, Numerical Simulation and Selective Laser Melting Fabrication

Kaijie Lin, Prof. Dongdong Gu

With the development of high-speed vehicles, more complex geometries, such as lattice structures and bio-inspired structures, have been introduced into the design of integrated thermal protection (ITP) structures, aiming to enhance the thermal protection and load bearing performances. Additive manufacturing holds high flexibility in processing and enables more complex designs, which is suitable for the fabrication of complex ITP structures. In this work, inspired by the structures of plant stems, a series of ITP structures with different gradient hollow designs was proposed and manufactured by selective laser melting (SLM). The thermal and mechanical behavior of those bio-inspired ITP structures were investigated by numerical simulation. To verify the accuracy of the numerical simulation results, Ti6Al4V components with different structures were fabricated by SLM. Thermal conductivities and compression properties of those SLM-processed components were experimentally measured. Results revealed that the gradient designs greatly influenced the thermal and mechanical performance. The gradient structure with larger hollow tubes near the top and bottom plates and smaller hollow tubes in the center possessed the best thermal insulation and load-bearing capacities. The underlying mechanism was analyzed through the combination of numerical simulation and experimental observation.

The State Of The Art On The Coatings Prepared By Cathode Plasma Electrolytic Deposition

Jin Zhang, Shuguang Zhang, Chenxu Liu, Ruonian Ji, Yedong He, Chen Quan, Peng Wang, Shunjie Deng, Deren Wang

Cathode plasma electrolytic deposition (CPED) technology has recently gained significant attentions due to its capability to considerably enhance surface properties. By CPED technology, coatings can be prepared on the substrates of non-valve metals, and the compositions can be adjustable by altering the components of the electrolytes. In this paper, the development of CPED technology with our researches on the CPED prepared coatings were introduced. Firstly, the advantages and disadvantages of the CPED technology were showed. Then several methods to change the discharge properties were introduced for preparing
coatings on larger area surface. The deposition mechanism and electrical breakdown mechanism were studied, including the establishment of gas-coating dielectric model, the regulating and controlling of the coating structures. The structures and properties of the metal coatings (such as Ni, Co, Cr), alloys coatings (such as Ni-Cr), and ceramic coating (such as Al2O3, ZrO2) and composite coatings (such as Pt-Al2O3, PTFE-Al2O3, Al2O3-La2Zr2O7) were investigated. At last, the energy consumption and environmental friendliness of the CPED technology was analyzed, and the major problems and the potential development of the technology were summarized.

**Challenges And Opportunities On Nano-Enabled Multifunctional Composites For Aerostructures**

*Andrea Araujo, D. Vale, P.N. Pappas, N. Koutroumanis, R.M. Santos*

The demand for carbon fiber reinforced polymer (CFRP) composites increased for highly demanding industries, in particular in aerospace applications, due to their high strength-to-weight ratio, stiffness and corrosion resistance. In fact, the substitution of traditional metal materials for CFRPs on aircraft structural parts provides weight reduction and fuel economy, in combination with advantages on the manufacturing process of complex integrated components. Nevertheless, CFRPs face challenges regarding their relatively weak out-of-plane properties that may lead to the mechanical failure and reduction of their lifetimes, promoted by delamination or matrix cracking. In the past years, the opportunity emerged for the use of carbon-based nanoparticles as a secondary reinforcement for CFRP multi-scale composites, able to introduce additional toughening mechanisms, such as crack bridging, crack pinning, void growth of the matrix and crack deflection. Furthermore, the formation of a conductive network promoted by the homogeneous dispersion of the particles in the epoxy resin is known to improve the interfacial properties between the fibers and the matrix, and to enhance the mechanical and electrical properties of the final material. In this work, different types and loads of two-dimensional (2D) particles from the graphene family, graphene nanoplatelets (GNPs) and reduced graphene oxide (rGO), were dispersed into an epoxy matrix using a high-shear calendaring equipment. The dispersion conditions were optimized by changing the gap width between the rolls and the rotational speed of the rolls. The rheological, electrical and optical microscopy experiments were performed to access the influence of the nanoparticles geometry and surface chemistry on the nanocomposites properties. The results demonstrated that the particles were well dispersed in the matrix. Afterwards, pristine and modified resin containing 0.089 wt. % rGO and 2.14 wt. % GNPs were used to produce pre-impregnated materials with carbon fiber volume fractions between 57 and 61 %. Double cantilever beam (DCB) tests were performed to determine the interlaminar fracture toughness (GIC) of the CFRP composites produced. GIC results denoted a 17.4 % increase for CFRPs containing 0.089 wt. % rGO and an impressive enhancement of 98.4% with the addition of 2.14 wt. % GNPs.

**The Effect Of Corrosion Micro-Environment On Deadhesion And Electrochemical Behavior Of Coated Metal**

*Jin Gao, Chao Li, Xiaogang Li*

Based on the failure behavior of well-coated steel under different adhesion mechanisms and coating systems, micro-probe technology and ion chromatography were used to detect such corrosive medium as chloride ions, pH and oxygen concentration in the micro-environment. The interactive effects of different micro-environment factors on the failure behavior of coating and metal interface were analyzed by localized electrochemical techniques such as SKP, LEIS and SECM to show the mechanism of the effect of
micro-environment factors on deadhesion of coated metal and under-film corrosion, and further reveal the interaction mechanism of deadhesion and under-film corrosion.

**Electrolytic Plasma Polishing On Light Alloys And Additively Manufactured Surfaces**

*Nicolas Laugel, Allan Matthews, Aleksey Yerokhin*

Electrolytic Plasma Polishing (EPPo) is a finishing method allowing the smoothing, deburring, cleaning and polishing of metallic surfaces. An electrolytic technique, its application is largely independent from piece geometry. Moreover it makes use of benign electrolytes which permit easy, safe handling and waste disposal, and requires limited material removal for a given target roughness.

These characteristics align remarkably well with the advantages and shortcomings of additive manufacturing. Some of the tools created to develop the EPPo of additively manufactured surfaces of AISI 316 stainless steel will be presented, such as a characterisation of roughness discriminating between surface features at different length scales. The main challenges and opportunities inherent to the approach will be overviewed, and specific focus will be brought on its application to light alloys commonly used industrially.

**Assessing The Reinforcement Mechanism Through Nanoindentation Mapping Data Of Nanoenhanced Composites**

*Elias P. Koumoulos, Geoge Konstantopoulos, Costas A. Charitidis*

Carbon fibre reinforced polymer composites (CFRPs) are continuously gaining attention in aerospace and space applications; in particular, multi-scale reinforcement with nanoadditives. Carbon nanotubes (CNTs), graphene, Carbon nanofibres (CNFs), and their functionalized forms are often incorporated in interactive systems to engage specific changes in the environment of application to a smart response. Structural integrity of these nanoscale reinforced composites is assessed with advanced characterization techniques with the most prominent being nanoindentation testing. Nanoindentation mapping grid protocol enables the characterization of the interface in a statistical manner and the correlation of nanoadditive reinforcement, revealing aspect ratio correlation to interfacial properties. This is accomplished by evaluating the results with a clustering algorithm in relation to the physical problem with a representative character (train and test); the statistical character of nanoindentation is therefore proved as a key factor to provide next step unsupervised data analysis of the tested specimens and recognize the type of (nano)reinforcement.

**Acknowledgements**

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**Application Of Modified Carbon Plastics In Advanced Units Of Aviation And Aerospace Structures**

*Iryna Husarova, Xiao Ying Li, Olha Romenska, Oleksandr Litot, Yana Liang*

Thanks to the high mechanical properties and small density, carbon plastics on specific strength excel all known materials. For this reason, they belong to the prospective materials, applied in frame structures of
aerospace industry and aviation. Currently, strong global interest is shown to all-composite propellant tank structure, which is a thin-walled structure, consisting of composite flange, cover and pressure shell. When selecting materials for a composite tank, the main criterion to be low weight with the obligatory compliance with impermeability, strength and resistance to propellants requirements, considering multiple “pressurization - depressurization” cycles of propellant operational pressure. Therefore, during manufacturing of a propellant tank it is rational to apply with maximum of strength carbon-plastics.

Carbon plastic strength enhancing is possible with improving of carbon fiber adhesion and epoxy matrix. Toward this goal different methods of carbon filler surface treatment by incorporation of new or activation the existing functional groups are used. The prospective type of filler surface treatment with the purpose to modify chemical and physical structure of top layer is plasma treatment. Lately, a new type of plasma treatment – active screen plasma (ASP), is being actively developed. This method of treatment is of indisputable interest for modifying carbon fibers surface. One of the advantages of ASP treatment is the components floating potential, which allows treating of insulating materials.

In this paper, based on experimental values of physic-mechanical properties of carbon-plastic, made of fiber, modified by ASP treatment at University of Birmingham (UK), the all-composite propellant tanks were designed from pristine and modified carbon fiber.

Based on structural analysis results, it was discovered that strength of the tanks, made of modified carbon fiber, was by 12% higher, at the same time the strength margin for the tank, made of pristine carbon fiber was 1.32 and for modified one was 1.47.

Experiential-theoretical activities on strength definition of all-composite propellant tanks have shown, that application of carbon fiber, modified by ASP treatment, is prospective for frame structures in aerospace industry and aviation.

The study was carried out under Horizon-2020 Grant Agreement №685844 (H2020, MODCOMP Project).

**Improved IFSS of active screen plasma treated CFR composites**

*Xiaoying Li, Yana Liang, Hanshan Dong*

Carbon fibres (CFs) are leading reinforcements in composite materials in aerospace industry because of their excellent mechanical performance to weight ratio. However, the weak fibre/matrix interfacial adhesion and hence low interfacial shear strength (IFSS) limited the wide application of the materials.

Plasma surface treatment of carbon fibres has been proved to be an efficient way to overcome this weakness. To this end, an innovative plasma surface engineering technology based on active-screen plasma treatment (Figs. a, b) has been developed to activate and multi-functionalise HTA40 carbon fibre surfaces. Systematic surface characterisation of the modified CFs was carried out using SEM, AFM, XPS, contact angle and tensile strength measurements. It has been demonstrated that the plasma treatment can increase surface roughness, remove weakly bonded layers, alter their surface chemistry and enhance their wettability. Push-out tests (Figs c, d) were used to measure the fibre-matrix interface share strength in uni-direction carbon fibre-reinforced composites and the results provided the evidence of very much improved carbon fibre/ polymer matrix interfacial bonding strength of active screen plasma treated CFR composites over pristine CFR ones.
Towards High-Performance Carbon Fibre Reinforced Composites - A Novel Plasma Surface Engineering Approach
*Hanshan Dong, Yana Liang, Xiaoying Li*

Carbon fibres are leading reinforcements in composite materials but the weak fibre/matrix interface adhesion becomes a barrier to further increase in the mechanical properties of composite materials. To this end, some new plasma surface engineering technologies have been developed at Birmingham Surface Engineering Research Group to multi-functionalise carbon fibre surfaces. This talk will start with the recent development of innovative plasma surface engineering technologies. The potential of these new plasma technologies will be demonstrated by way of plasma activation and functionalisation of CF surfaces through increasing their surface roughness, removing weakly bonded layers, altering their surface chemistry and enhancing their wettability.

Improving carbon fibers / epoxy resin composite for Aerospace structural applications by functionalization
*Alberto Tagliaferro, Mauro Giorcelli, Salvatore Guastella Xiaoying Li, Yana Liang, Hanshan Dong*

In recent years, composite materials have been extensively used in Aerospace structural applications. Among different materials proposed to improve composite performance, carbon fibre reinforced polymers are one of the most common. As a polymer matrix, epoxy resin is widely used. The composites based on epoxy resin/carbon fibres became of interest as they show up to the mark impact damage properties. The performances of epoxy resin/carbon fibres composites are influenced not only by the intrinsic characteristics of the reinforcement (carbon fibers) or by the polymer matrix used (epoxy resin) but also by their physicochemical properties of their interface that affect adhesion. In order to increase polymer-fibres adhesion, carbon fibres surface modification is a well-recognised process. In this work we compare different surface modifications techniques with the aim to improve the adhesion between carbon fibres and epoxy resin. In particular, we focus on the plasma functionalization of carbon fibres. Plasma surface modifications have been performed using three different techniques: Atmospheric Pressure Plasma (APP), Low Pressure Plasma (LPP) and Active Screen Plasma (APP). Their functionalization grade will be investigate using XPS technique. Other complementary analysis as FESEM and Raman will be reported in order to investigate morphological and structural changes due to the functionalization process.
Enableh2 - overview presentation

Vishal Sethi, ENABLHE2 consortium

Flightpath 2050 very ambitiously targets 75% CO$_2$ and 90% NO$_x$ emissions reductions, relative to year 2000. It is highly unlikely that these targets will be met with carbon containing fuels, despite large research efforts on advanced, and in many cases disruptive, airframe and propulsion technologies, even when coupled with improved asset and life cycle management procedures. LH2 has long been seen as a technically feasible fuel for a fully sustainable aviation future yet its use is still subject to widespread scepticism.

ENABLEH2 is a recently launched European H2020 R&I project which will revitalise the enthusiasm in liquid hydrogen research for civil aviation. It will demonstrate that switching to hydrogen is feasible and complements research into advanced airframes, propulsion systems and air transport operations. Combined, these technologies can more than meet the ambitious long-term environmental and sustainability targets for civil aviation.

ENABLEH2 is maturing critical technologies for LH2 based propulsion to achieve zero mission-level CO$_2$ and ultra-low NO$_x$ emissions, with long term safety and sustainability. The project includes experimental and numerical work for two key enabling technologies: H2 micromix combustion and fuel system heat management. These technologies are being evaluated and analysed for competing aircraft scenarios; one advanced short-medium range aircraft and one long range aircraft, both featuring distributed turbo-electric propulsion systems. The study will include mission energy efficiency and life cycle CO$_2$ and economic studies of the technologies under various fuel price and emissions taxation scenarios. ENABLEH2 will also deliver a comprehensive safety audit characterising and mitigating hazards in order to support integration and acceptance of LH2.

This introductory presentation for the ENABLEH2 session will provide overviews of the strategic importance and expected impacts of the ENABLEH2 project, the overall work scope and partners and the role of a dedicated ENABLEH2 industry advisory board. A brief introduction of the subsequent presentations for the session will also be provided namely:

4. Integration of Cryogenic Hydrogen Fuel and Propulsion Systems for Commercial Aviation
Hydrogen – Enabling A Safe Fuel: “Safety Challenges And Opportunities For Lh2-Fuelled Aircraft And Supporting Infrastructure”

*CM Benson, JM Ingram*

A radical solution is needed to harmonise the conflicting drivers of increasing need for air travel, and the need to reduce global emissions and pollution. One proposed solution is hydrogen propulsion as hydrogen produces no carbon dioxide, and can produce little or no nitrogen oxide. High profile events, such as the Hindenburg disaster, have resulted in negative associations with hydrogen, but where used in transport & energy industries, with safeguards in place, hydrogen can have a similar level of safety to other fuels. However, managing this fuel and maintaining the impressive aviation industry safety record will require significant work.

The Enabling Cryogenic Hydrogen-Based CO$_2$-free Air Transport (ENABLEH2) project has therefore, made safety a cornerstone to ensure safety on-site (for experimental work) and in design processes. In order to assess the safeguards that may be needed, and the gaps in our current knowledge and technological ability, the project has a designated safety work package that, as well as safety management, comprises of several major analysis areas including:

1. Liquid hydrogen systems hazard analysis
2. Small scale experimental work to define fundamental hydrogen behaviour in low pressure, low temperature conditions
3. Modelling of large-scale liquid hydrogen dispersion and release scenarios
4. The assessment of hazards related to hydrogen use as airports

The presentation will show the project plan, and demonstrate the achievements so far, including preliminary hazard analyses liquid hydrogen use in combustion and fuel management systems, and at airports.


*Askin T. Isikveren*

Although the use of Liquid Hydrogen (LH2) as a chemical fuel and as an energy carrier for propulsion/non-propulsive systems would secure CO$_2$-free emissions during aircraft operation, emphasis must be placed upon increasing the overall vehicular efficiency of any aircraft design concept. Such a focus will ensure a minimum amount of LH2 will be needed in meeting the year entry-into-service 2050 operational requirements as defined in the European Commission Horizon 2020 ENABLEH2 Project. By virtue of aircraft sizing cascade effect, a minimum amount of LH2 would then pave a way forward in maximising the extent of operating economics reduction and facilitate further improvements in both NO$_x$-emissions and aircraft external noise. In order to further amplify overall vehicular efficiency improvement, aircraft conceptual design ideas should also take stock of potential synergies afforded by hybrid/electric solutions; whether architectures are hybrid-electric or turbo-electric in nature.

The technology evaluation activity for ENABLEH2 involves a multi-faceted array of tasks. Ultimately, the goal is to undertake a critical appraisal exercise using the Techno-economic Environmental Risk Assessment (TERA) evaluation platform, which is considered to be suitable for multi-objective, multi-
disciplinary assessments and trade-off studies. The TERA work will involve estimating life-cycle CO₂-emissions as well as predicting corresponding operating costs associated with use of LH2 for commercial aviation. In order to establish some semblance of robustness of the final design candidates a number of different fuel prices and emissions taxation/fees scenarios will be examined as well.

The sequence of tasks that constitutes the ENABLEH2 Project technology evaluation activity is itemised as follows:

1. Suitable for Short-to-Medium Range (SMR) and Long-Range (LR) operations, down-selection of aircraft morphology, integrated systems including implementation of LH2 fuel storage, fuel system heat management, and, Micro-mix combustion technologies developed by the ENABLEH2 Consortium all tempered by serious considerations given to safety;
2. Generation of “best-and-balanced” sized aircraft outcomes based upon the down-selected SMR and LR concepts defined in Item 1;
3. Declaration of reference aircraft based upon the premise they shall operate using JET-A1 / Drop-in Bio-fuel / Liquid Natural Gas (LNG) fuels only; and,
4. Undertake technology and scenario evaluation studies that will serve to compare and contrast the relative attributes of the sized SMR and LR aircraft concepts to each of the JET-A1 / Drop-in Bio-fuel / LNG fuelled references.

In view of the time planning adopted for ENABLEH2, Items 1 and 3 are scheduled to be completed by the time of the 9th EASN International Conference on Innovation in Aviation and Space. Accordingly, this presentation will initially review the variety of aircraft morphological and integrated systems candidates comprising the concept cloud delivering SMR and LR operations. Thereafter, engineering logic and rationale (based upon mostly qualitative arguments) will be offered in justifying the chosen design solutions. Information will also be offered about the attributes and characteristics of the final sized JET-A1 / Drop-in Bio-fuel / LNG based reference aircraft. To round off, some discussion will take place regarding future work: sized outcomes for the down-selected SMR and LR aircraft concepts; and, the all-important benchmarking and assessment studies associated with each.

Integration Of Cryogenic Hydrogen Fuel And Propulsion Systems For Commercial Aviation

Isak Jonsson, Hamid Hamidreza, Adrew Rolt, Tomas Grönstedt, Boddy Sethi

The rapid growth in air traffic requires more attention to be paid to its environmental effects, in particular CO₂ and NOₓ emissions and their relation to global warming. Therefore, it is crucial to find alternative fuels that can make drastic cuts in these emissions and so liquid hydrogen (LH2) is being considered as a replacement for conventional oil-based Jet-A fuel. Although chemically bonded hydrogen is abundant, hydrogen production is nowhere near what would be needed to serve the aviation sector. To put it in perspective, the world’s largest electrolysis plant could not keep a single Airbus A380 flying, and the total world production would only be enough for two large airports. To ramp up hydrogen production is a great challenge, but it does have some economic credibility as hydrogen production cost is not far off from Jet-A production cost even at today’s oil prices. It is reasonable to believe that with increasing oil prices and the benefits of large-scale hydrogen production, this gap can be closed. Thus, sustainable global aviation may be achieved in the long term by using hydrogen, while electrically driven aircraft may be developed.
for short range flights. To quantify the relative merits of hydrogen, electrical and conventional propulsion, conceptual aircraft design studies are presented in a comparative way.

Compared to the Jet-A, LH2 has a higher heat of combustion (approximately 2.8 times) which in turn theoretically reduces the fuel weight to a third. On the other hand, LH2 has a much lower density than Jet-A (approximately one tenth). This means that for a fixed amount of energy, more storage volume is required for LH2 which in turn makes the aircraft body larger. Moreover, due to the extremely low storage temperature (approx. 20 K @ 145 kPa), LH2 tanks require careful insulation increasing their complexity and complicating their supporting structures. These major differences to Jet-A create lots of challenges for aircraft configuration, fuel systems, propulsion systems, safety and overall performance. Amongst all of the technical challenges, the cryogenic fuel container requires special attention. In this perspective, its size, location, material, insulation thickness, mechanical structure and safety must be addressed carefully. Moreover, to improve the performance of the propulsion system while using cryogenic fuel, various concepts for advanced engine cycles must be considered. These may lead to the introduction of additional components such as pre-cooling and intercooling heat exchangers for the engines’ compressor air to benefit from the cryogenic fuel’s properties. The presentation will review various heat management concepts using LH2 as a heat sink and show how these will be systematically investigated in the ENABLEH2 project.

The development of a modelling environment coupling a cryogenic hydrogen fuel system and a turbofan performance is also described. Key parameters for the design process are established using sensitivity analysis and parameter variations. Conventional gas turbine simulation software frequently uses a successive execution of component performance calculations during the design process, leading to a good starting point for off-design iteration. However, having separate paths of information flow for the fuel system and the gas turbine makes maintaining causality in the model a challenge and requires good numeric methods. This paper summarizes some lessons learned in developing the simulation tool. Linking external software for the modeling of cryogenic hydrogen is also discussed. Tabulation and interpolation software usually used for gas turbine simulations is based on either direct interpolation in tables or storing pre-computed interpolation coefficients. These approaches are shown to be inadequate when operating close to the critical point of the working fluid, so means to link external fluid-properties software such as REFPROP are described.


*Xiaoxiao Sun*

Kerosene has relatively narrow combustion stability limits. This leads to problems with lean blow out and combustion instabilities when reducing flame temperatures to implement low NOx emission combustion technologies. Hydrogen is a promising candidate fuel in this context as it has much larger stability limits and therefore lean combustion is possible without approaching lean blow out limits. Micromix (diffusion) combustion enables superior fuel and air mixing without the risks associated with premixing thereby reducing maximum local flame temperatures leading to ultra-low NOx emissions.

Within the ENABLEH2 project there is a dedicated work package which comprises complementary experimental and numerical research to mature hydrogen micromix combustion technology.
The work is split into the following three phases:

Phase 1 - Injector array studies to:

1. Assess the predictive capabilities and evaluate validate hydrogen combustion models in state-of-the-art CFD tools namely ANSYS, STAR-CCM+ and AVBP
2. Perform a design space exploration study to identify preferred injector designs and spacing that have the potential to deliver the lowest NO\textsubscript{x} emissions without compromising other combustor performance and operability criteria.

Phase 2 - Multi-Injector Full Annular Combustor Segment Studies at more representative combustor inlet conditions

Phase 3 - Sub-Atmospheric Altitude relight studies

The overall objectives are:

1. To deliver an optimized hydrogen annular type micromix combustor design that provides 90% reductions in landing and take-off cycle and mission NO\textsubscript{x} relative to Y2000 technologies.
2. To demonstrate that the hydrogen micromix combustor design satisfies design and operational requirements including; satisfactory stability (over a wide range of fuel to air ratios), combustion efficiency (≥99.5%), optimum pressure loss, satisfactory thermoacoustic behaviour, acceptable durability, acceptable outlet radial and circumferential temperature distributions, altitude relight capability, size and weight constraints.
3. To quantify the extent to which NO\textsubscript{x} emissions and thermoacoustic instabilities can be further reduced, combustor outlet temperature distribution further customised and liner durability improved by customising the fuel flow for each injector in the micromix injector-array.
4. To perform a thermoacoustic risk assessment of a representative combustor under real engine conditions.
5. To deliver validated analytical combustor design and reduced order NO\textsubscript{x} emissions prediction models for the technology evaluation studies

This presentation will provide an overview of the case for hydrogen micromix combustion, details of the planned work in ENABLEH2 and a summary of the achievements and main results to date.

Benefits Of Enableh2 Numerical And Experimental Hydrogen Micromix Combustion Research For The Gas Turbine Industry

Dr. Pierre Q. Gauthier

Power generation is experiencing a fundamental global transformation: energy requirements will no longer solely rely on fossil fuels but will increasingly move towards renewable energy sources. All the main Energy sector players are taking a leading role in driving and shaping the transition to a decarbonised energy mix, which is in line with the EU’s 2050 goal of a climate neutral economy.

Today, gas turbines, which mainly run on natural gas, are core components of Europe’s energy system.

Gas turbines play an important role in the energy mix as they deliver on-demand, reliable and efficient power and heat, independently of weather conditions. This technology will be of even higher value in a carbon neutral energy system based on variable renewables, which will need constant available power.
The gas turbine sector supports the decarbonisation of the EU energy system by offering solutions which will convert a large variety of renewable energy fuels and progressively replace natural gas.

To delivering technologies that can operate with a renewable gas, such as hydrogen, the Energy industry must rely on fundamental research and innovation work, such as ENABLEH2, to provide:

1. Insight into the types of flames and combustion regimes required to minimize harmful Nitrogen Oxide [NO\(_x\)] emissions when burning hydrogen.
2. Valuable flame and emissions data, at Gas Turbine operating pressures and temperatures, to further improve
   a. The design Space knowledge required to create new ultra-low NOx combustor concepts, or to retrofit existing engines
   b. The Numerical tools used to assist in the design and analysis of these system

Without this valuable technical knowledge, along with economic viability and safety assessments, the Energy industry would solely have to rely on expensive and time consuming engine tests to mature the technologies required to transition Gas Turbine operation to higher and higher hydrogen content fuels.
Robustness Analysis Of Cfrp Structures Under Thermomechanical Loading Including Manufacturing Defects

Martin Liebisch, Georgios Balokas, Benedikt Kriegesmann, Tobias Wille

Carbon fibre reinforced plastics (CFRP) show superior weight-specific properties compared to metals. However, the structural behavior is more complex when exposed to thermomechanical load conditions, for instance in engine, turbine or battery environments or in space applications. The properties of CFRP decrease with increasing service temperature due to the temperature-dependency of their plastic matrix system. Yet, within current industrial design processes, temperature limits are defined with high conservatism. Therefore, additional load carrying capabilities at higher temperatures, before complete loss of mechanical performance, are not exploited. This study is presenting an enhanced analysis process for robust composite design by considering temperature-dependent material behavior, effects from manufacturing deviations and uncertainties from thermomechanical loading conditions.

A sequential finite element (FE) analysis strategy is utilized to assess the mechanical performance of a structure under thermal load conditions until glass transition temperature. The current investigations use nonlinear temperature-dependent material models to account for the corresponding stiffness and strength reduction. Based on the thermal load conditions and the structural concept, different temperature distribution will occur within the part and therefore, thermal expansion results in varying development of structural deformation and stress. Moreover, the temperature field causes locally decreased material properties. Evaluation of forces, stresses and strains allows assessing the structural performance. Inherent material uncertainties, local property knock-down resulting from fibre-placement defects and deviations of thermal load conditions are introduced to analyze the structural robustness. The work focuses on the analysis strategy and describes the approach of material modelling and applied uncertainties. Finally, results of the presented methodology are shown for a thin-walled stiffened CFRP structure.

Sucohs Project – Sustainable Cost Efficient High Performance Composite Structures Demanding Temperature Or Fire Resistance

Tobias Wille

Due to their high weight specific mechanical properties, fibre reinforced composite materials are increasingly utilized for high performance primary structures within aircraft wing and fuselage components. Yet, further exploitation is often limited due to rather high material and manufacturing costs including post-processing, concessions and rework. Additionally, very conservative engineering allowables are currently applied in order to account for uncertainties arising from manufacturing as well as operation phase. Further significant weight savings are expected for new structural components that are currently made from metals e.g. by reason of combined high thermal, mechanical or fire loading that cannot be bared by state of the art composites.
In order to maintain the leadership of the European aeronautics, the European funded project SuCoHS is investigating potential weight and cost savings in expanding the use of composite materials in areas of demanding thermal conditions (temperature and fire).

In particular, SuCoHS envisions new structural concepts with novel multi-material composites to provide high robustness against thermal, mechanical and fire loading. These developments also cater for high production rates, providing a cost competitive manufacturing process at minimum material and energy consumption, while reducing the requirement for visual inspection or rework. New solutions for structural health monitoring are considered within the structures to enable condition-based maintenance taking into account actual loading and structural conditions.

The paper will provide insight into the project objectives as well as present the detailed concept and methodology for their achievement. Moreover, first technological developments of the project will be analysed.

Acknowledgment: This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 769178.

**Properties And Structure Of Cyanate Ester/Polyethersulfone Composites**

**Lyaysan Amirova, Markus Grob, Christian Brauner, Fabian Schadt**

Cyanate ester resins are currently used for many important applications such as high-temperature adhesives and advanced composite matrices in the aerospace and automotive industry. A unique combination of properties such as high temperature stability and chemical resistance, low moisture uptake and low dielectric constant in the cured state, as well as low viscosity in the uncured state (lowest viscosity of all high temperature resins) has led to their use in low-volume high-performance applications. However, their widespread use is unfortunately limited in many applications by their inherent brittle behavior due to their high cross-linked densities. The incorporation of thermoplastics into such networks has emerged as a promising approach, especially when high values of elastic moduli and glass transition temperature are required. The most common thermoplastic tougheners are Polysulfones (PSF), Polyetherimides (PEI) or Poly-ethersulfones (PES). The process of phase separation during cure of the thermo-set/thermoplastic blends is essential to generate the toughened thermosets.

The aim of the present work in the frame of the EU Project “Sustainable Cost Efficient High Performance Composite Structures demanding Temperature or Fire Resistance” (SuCoHS) was the investigation of molecular weight, functionalization and content of PES on the morphology and phase separation behavior as well as on thermal and mechanical properties of cyanate ester composites. In this work phenol novolac cyanate ester was used as a matrix and PES with various molecular weights and different functionalizations were used as tougheners.

It was shown that mixtures with 5 and 10% of low molecular weight hydroxyl terminated PES show dispersed spherical domains with a diameter of approximately 3 µm. Mixtures with 15 and 20% of PES possess a dual phase morphology with bigger particles of about 5-10 µm. Fracture surface investigations demonstrated crack pinning and crazing toughening mechanisms. At the same time, high molecular weight hydroxyl terminated PES forms co-continuous thermo-plastic phases leading to sedimentation. This causes a reduction in glass transition temperature of the composite to the value of Tg of PES.
same effect was observed for the PES without end hydroxyl groups. Nevertheless depending of the content and molecular weight of PES, the drop of the storage modulus at the PES glass transition temperature can be insignificant, which allows to consider such systems as suitable for high temperature applications.

SENB analysis showed that incorporation of 20% of PES leads to 132% improvement in fracture toughness. Based on the obtained results of thermal and mechanical properties of the investigated composites the optimal content of the toughener for further research was estimated.

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Cure Monitoring Of High-Temperature Resins For Enhancing The Manufacturing Of Advanced Composites

*Nikos Pantelelis, W. Gerrits, R. Klomp-de Boer, A. Johnston, S. Wilson, A. McKibbin, C. Brauner, F. Schadt, L. Amirova, M. Grab*

The resistivity and temperature of a reactive resin have been successfully used for sensing resin arrival and provide online viscosity and the glass transition temperature for various thermoset resins in the whole range of composites [1, 2, 3]. In this paper, the Optimold system was employed to measure the curing of a BMI/CF and of CyanateEster/CF composites at higher temperatures. The measured resistance and temperature are post-processed online to provide useful resin properties such as viscosity, gelation, degree of cure and glass transition temperature. The investigations in the lab showed the high potential of the monitoring system and the good correlation between the resistance, the degree of cure and the Tg. On-going development within the EC-funded SuCoHS project has correlated these measurements with viscosity and Tg for automating a significant part of the production of advanced composites for high-temperature aerospace applications.

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References


Thermoplastic Particle Toughening Of Carbon Fiber / Cyanate Ester Composites

*F. Schadt, M. Grob, C. Brauner, L. Amirova*
Carbon fiber reinforced Cyanate ester composites are of interest for structural aerospace applications because of their high strength, stiffness, high thermal properties, superior adhesion, and low moisture absorption. Cyanate ester polymers absorb less water at saturation than epoxy, Bismaleimide (BMI), and Polyimide resins. However, due to their high crosslink density, Cyanate esters are inherently brittle and therefore exhibit low fracture toughness. This is the major draw-back limiting their use in structural applications.

It is known that adding thermoplastic polymers to highly crosslinked thermosets is an effective strategy to increase the fracture toughness. However, distributing the thermoplastic polymer homogenously in fiber reinforced applications presents a great challenge.

The aim in this study within the framework of the EU Project “Sustainable and Cost Efficient High Performance Composite Structures demanding Temperature and Fire Resistance” was to investigate the influence of thermoplastic distribution in Cyanate ester - carbon fiber reinforced composites and the resulting change in mode I fracture toughness and glass transition temperature (Tg).

The studied composite was created from Toray T800 carbon fibers and Phenol Novolac Cyanate ester resin with a Tg of 405 °C. Two thermoplastic powders were tested in concentrations between 5 % and 15 % as toughening agent, Phenoxy with a Tg of 92 °C and Polyethersulfone with a Tg of 225 °C.

The thermoplastic powders were distributed with two approaches. The first approach was interlayer toughening for which powder was spread on the surface of the prepreg. The second approach was to disperse the thermoplastic powders in the resin before prepreg production.

All manufactured laminates were examined using microscopy imaging and tested using a double cantilever beam test. The Tg was measured with a dynamic mechanical analysis.

The scanning electron micrographs revealed that the thermoplastic distribution is much more homogeneous, when dispersed in the resin before prepreg production compared to when spreading it on the prepreg surface. This is attributed to a very low resin flow during the curing process, which does not transport the high thermoplastic concentration from the interlayer into the plies.

The thermoplastic distribution is also reflected in the mode I fracture toughness where samples with a thermoplastic rich interphase showed a higher fracture toughness compared to samples with a homogeneous thermoplastic distribution. The addition of Phenoxy did not decrease the Tg of PT-30 at any concentration, which is linked to a very small particle morphology and a strong chemical bonding. Adding Polyethersulfone decreased the onset of Tg to 240 °C. Based on these promising investigations the optimal content of thermoplastic type, content, and distribution is evaluated for further research.

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Technology Of Ground Vibration Testing And Its Application In Light Aircraft Prototyping

Michał Szcześniak, Aleksander Olejnik, Robert Rogólski, Stanisław Kachel

The article describes the vibration measurement technology used for light aircraft and the application of results in the prototyping process. The aim of this type of research is to determine the frequencies and resonance natural modes of aircraft or its structural components. Ground Vibration Testing is an essential dynamic structural test necessary to carry out before the aircraft certification. This test is usually performed on the finished aircraft example at the final stage of the prototype development. Special measuring equipment is used to carry out this type of tests.

The system located at the Institute of Aviation Technology in Military University of Technology is used for contact vibration measurements and is used to provide data collected from real objects and to integrate them into the simulation process. The system consists of a multi-channel LMS SCADAS analyzer, a set of piezoelectric accelerometers, shakers, amplifiers, impedance heads and a computer with the Test.Lab Software. The analyzer has a wide range of applications - from acoustics and vibration techniques to modal analysis using multiple channels, aircraft ground vibration testing, and high-performance tests.

The aim of the article is to present the methodology of performing Ground Vibration Testing in order to find resonant modes and to estimate characteristic modal parameters. Using the dedicated apparatus in relation to the actual construction of tested aircraft, properly prepared in terms of mass distribution, rudders deflection stiffness and proper support, key vibration characteristics corresponding to resonant points can be determined. It is worth noting that not only fully equipped aircraft can be tested, but also isolated elements (e.g. one wing) or empty airframe structures. This is important because it allows you to verify some aeroelastic properties at an earlier stage of prototyping. This means that the use of resonance tests carried out at the final stage of aircraft design also applies to earlier stages of the prototyping process. As examples of the use of vibration measurements in various stages of the prototyping process, three examples are presented. An isolated strut-braced wing from of the light patrol aircraft OSA, airframe structure of light jet FLARIS LAR, and an aerial target drone in the maximum mass configuration for flight ATD JET-2. Then will be presented examples of the results of tests carried out. In the following, the application of the received data for the calibration of numerical models and flutter calculations will be presented. At the end, observations and conclusions will be drawn out in the context of the results obtained.

Design And Optimization Of A Scaled Down Composite Wing Model For Aeroelastic Wind Tunnel Testing

Spyridon Kilimtzidis, Vassilis Kostopoulos, Dimitrios E. Mazarakos, Athanasios Kotzakolios

In this paper, the aeroelastic similarity between a Full Scale (FS) wing structure and a scaled down wing (SC) model for wind tunnel (WT) testing has been investigated. The Full Scale wing was developed by Leonardo Aerospace company for future turboprop aircraft applications. The aerodynamic shape, the structural frame (low fidelity finite element model) and the operational requirements of the FS wing were provided from Leonardo. The Scaled Wing model was further proposed for the WT testing. The SC model preserves the aerodynamic shape and follows the aeroelastic similarity laws of the FS wing. Using the aeroelastic scaling laws and the Buckingham-π theorem, a scaled low fidelity finite element model,
equivalent to the FS was developed, including all the scaled aeroelastic data (testing conditions, inertias, masses etc.) for the WT model. The SC low fidelity finite element model was dynamically matched to the FS wing and was further used for the structural optimization of the 3D WT model. Composite materials such as UD IM7, SIGRAPREG fabric were the primary selection for the 3D WT model. Following the application of the aeroelastic scaling laws, the 3D WT model has the same structural behavior as the scaled low fidelity finite element model. The 3D WT wing was modeled with 2D shell elements and the NASTRAN Finite element model was further optimized in order to succeed similar structural characteristics using a genetic algorithm. Four different structural layouts were investigated considering criteria such as the structural integrity, the scale similarity, the manufacturability and the manufacturing cost. The optimization process results are discussed regarding their feasibility. As the SC model is set under WT testing conditions, an additional static/dynamic aeroelastic analysis was performed securing the normal operation under the Wind Tunnel environment. The WT composite wing was modeled with Doublet Lattice panels for the aerodynamic calculations and shell elements for the structural components. The aerodynamic panels and the structural mesh were coupled using the infinite plate spline method in order to secure the correct load transfer. MSc FlightLoads was used for both static and dynamic aeroelastic analysis investigating the divergence and flutter points of the 3D scaled WT model. The proposed methodology is part of the CS-2 GRETEL project where an aeroelastic composite wing was delivered for morphing technologies testing in ONERA Wind tunnel facility.

Dielectric Barrier Discharge Plasma Actuator for Load Alleviation and Instability Control in a Compressor Cascade

Antonio Suma, Maria Grazia De Giorgi, Antonio Ficarella

The increasing diffusion of aeronautics and aerospace devices and the enhanced ecological sensitivity has brought to a more efficient design of aerodynamic surfaces. The request for increasing efficiency has driven researchers and aircraft/aeroengine manufactures towards new designs of lifting surfaces, targeted to minimize weight and maximizing the aerodynamic performance, bringing to have turbomachinery blades - as well as wing and helicopter rotor sections - feature increasingly long and slender shapes.

Long and slender shape enhances suffering to self- and flow-induced vibration. As a consequence, the risk of fatigue and flutter phenomena is dramatically enhanced. In order to wholly benefit from these new designs, the aforementioned aerostructural feasibility problems must be solved.

The application of fast-response actuation systems, as the dielectric barrier discharge plasma actuator, has already demonstrated the capability of reducing the unsteady loads on the aerodynamic profiles under unsteady flow conditions.

Dielectric barrier discharge plasma actuators (DBD-PAs) are constituted by a pair of asymmetric metallic electrodes, separated by a dielectric layer, and fed by a high voltage high frequency signal. The DBD effect results in an electrohydrodynamic body force (EHD) directed from the exposed towards the encapsulated electrode.

Dielectric barrier discharge plasma actuators dimensions can change from millimetres to centimetres, bringing to strongly different power output, and allowing an easy location on a wide range of baseline geometry, requiring also only small differences from the original aerodynamic profile.
Moreover, other important advantages are that the actuation intensity of these devices can easily change by modifying the frequency or the amplitude of the electric signal applied and that they have a high frequency response, allowing an extremely fast time response actuation.

The generated force acts on the flow, next to the airfoil surfaces, increasing the kinetic energy of the boundary layers of the flow and increasing the turbulence too. So, to simulate the DBDs, a force field is applied next to the trailing edge with the idea to reproduce the additional momentum source produced by the DBDs.

The goal of this study is to make a numerical examination of the impact of DBD on the cascade unsteady loads, with the aim to reduce the amplitude of the loads, the phase shift between flow and loads and to increase the stability of the devices. The simulations will reproduce a cascade in which blades have a pitch motion with different phases between each other.

The analysis will involve the evaluation of the mean value, standard deviation, imaginary part of the first coefficient of Fourier series and hysteresis curve of both lift and moment coefficient of the NACA 0012 airfoil. Moreover, in order to evaluate the stability of the device, the static and dynamic pitching stability coefficient will be analyzed.
Evaluation Of Research Initiatives On The Problem Of Reducing The Air Transport Noise Rate In Accordance With The Tasks Of Flightpath 2050 Goal 9

S. Dmytryiev, V. Loginov, M. Mitrahovich, K. Doroshenko

The review was made on technical solutions to reduce noise level in engines of power plants of Ukrainian and foreign companies. The review of world current state of the problem on noise reduction in air vehicles and aircraft power plants points out onrush of technologies to reduce acoustic emission of air transport. In the study it is stated consolidation of review results of research initiatives as for “Flightpath 2050, goal 9: “In 2050 technologies and procedures available allow a 75% reduction in CO\textsubscript{2} emissions per passenger km and a 90% reduction in NO\textsubscript{x} emissions. The perceived noise of flying aircraft is reduced by 65%. These are relative to the capabilities of typical new aircraft in 2000” in European Union and interacting countries.

The review on priority of projects directed to solve the problems of air vehicle acoustic reduction proceeding from Strategic Research and Innovation Agenda (SRIA) of ACARE was presented. One of the main directions of research within Flightpath 2050 (goal 9) is a rational integration of airframe parts of an air vehicle and power plant in order to improve fuel and acoustic emission.

The results of estimation on research initiatives as for the problem to reduce noise of turbofan and turboprop GTE were grounded according to programme Flightpath 2050.

There were presented analytical forecasts for prospects of achieving ACARE Flightpath 2050 (goal 9) for PD-14 engine (ODK-Aviadvigatel JSC, Perm, Russia), engine family of Rolls-Royce (London, UK) as well as DREAM project (FP7). On the grounds of the analytical data it is determined that by 2050 it is foreseen further development of electrical airplanes, and Open Rotor engines coming to a new level, which are characterized by higher efficiency compared to bypass engines with a high bypass ratio (m=50...70). It was marked that design of aircraft with distributed electrical power plant could essentially influence the solution of the problem to reduce noise of power plants in future.

New Tailor-Made Sizing Strategies For Recycled Carbon Fibres To Improve The Mechanical Properties Of Polymeric And Cementitious Composites

Claudia Aguilar, Cristina Li

The performance of any composite material is strongly linked to the adhesion between the host matrix and the reinforcing fibre. Recycled carbon fibres are especially problematic, as they commonly possess less than a quarter of the available surface oxygen compared with virgin fibre [1], leading to reduced adhesion. The CUSTOMISIZE project will improve the interfacial adhesion between recycled carbon fibre (rCF) and polymers (thermoset and thermoplastics) and cementitious matrix to obtain composites with enhanced strength, toughness and environmental stability in comparison with state of the art rCFs.

The proposed strategy is the development of specific sizings for different matrices through the incorporation of coupling agents along the fibres (mats, non-woven and chopped tow). These coupling agents will act by different mechanisms (covalent bond, hydrogen bond, Van der Waals interactions...) to create active points on the CF surface. New approaches, such as Steam Water Thermolysis (SWT), the use
of Polyhedral Oligomeric Silesquioxanes (POSS) or Plasma Treatments (Atmospheric or Vacuum), will be used as a novel sizing base to increase rCF-matrix interfacial adhesion. Current sizing technologies (bath coating or spraying) with specific binders for each matrix will also be explored.

The specific sizing will be developed for non-woven mats and chopped tows of recycled carbon fibres. The improved rCF reinforcements will be used to produce new composites with cementitious and polymeric matrices (PU, epoxy resin, PEKK and PPS). The transformation process of thermoset composites will be achieved through the use of Resin transfer Moulding (RTM). In addition, to validate thermoplastic composites, manufacturing techniques such as compression moulding and injection moulding will be used. A complete characterization of the new composites will be undertaken, in order to ensure an enhanced interface between the filler and the matrix.

The CUSTOMISIZE project aims to bring a second life to carbon fibre that has been condemned to landfill or low-end applications that will span all stakeholders involved in the associated production chain: material suppliers, recycling industries, final part manufacturers, as well as end-users (aircraft industries).

**Global Trends In Aeronautical Environmental Field And Their Real Impact**

*Ivo Jebacek*

The article describes main global trends in aeronautical environmental fields focused on the greenhouse gases. Kyoto protocol was signed in 1997 and global emissions grow up. Not in EU but in global world. Does this mean that technologically more advanced countries are shifting environmental issues to less developed countries? Therefore, the question is what can bring the current efforts to apply into every technological work the environmentally friendly materials or structures, or to support and develop battery powered aircraft. The article confronts two views. On the one hand, efforts to minimise emissions and, on the other hand, strong global interests of multinational corporations, whose goal is nothing more than the profit growth and sales.

**vliesRTM – Reuse Of Carbon Fiber Waste In Composite Structures**

*Fabian Albrecht, Philipp Rosenberg, Felix Behnisch, Kahtarina Heilos, Marcel Hoffmann*

Due to their outstanding mechanical properties, composite contribute a high amount to the weight reduction of moving masses. Especially in the production of continuous carbon fiber reinforced composites, high-quality waste in the form of short fibers is produced. The recycling of this waste holds a high potential due to the cost and high energy consuming production of fibers. In order to investigate the recycling of this high-quality waste, the Fraunhofer Institute for Chemical Technology (ICT) together with the Saxon Textile Research Institute (STFI) ensures a completely consideration of a value-added chain from recycled carbon fibers through the semi-finished product up to the rCFRP. In addition to the optimization and identification of interactions between nonwoven production and consolidation, the project includes the mechanical characterization of composites produced in both the Resin Transfer Molding (RTM) and Wet Compression Molding (WCM) processes. The results show that production waste can be reused in nonwovens. Efficient manufacturing and infiltration of various nonwovens made out of rCF was demonstrated. The achieved material properties of the structural rCFRP are promising.

**Airscraft Composites recycling: turning waste into products**

*Mario Malinconico, Maurizio Avella, Antonio De Falco*
New opportunities for CFRP recycling come from a process of cold emulsification into a thermoplastic matrix of grinded composites from production scraps or aircraft dismantling. The obtained materials can be moulded into slabs or pellets for injection moulding. The obtained shaped items have interesting mechanical and aesthetic properties which make them attractive for furniture application. Moreover, being thermoplastic, they can be further recycled for successive lives.
Study Of Repair Efficiency Of A Self-Repaired Microcapsule Based Composites Via 1h Nmr Spectroscopy

S. Orfanidis, M. Kosarli, A.S. Paipetis, M. Fardis, G. Papavasilliou

Polymer composites have gained increasing use over the past several decades, displacing traditional materials such as metals. The range of applications is wide due to their extraordinary strength and stiffness properties, especially in aerospace and naval industries [1]. An imperfection or vulnerability may initiate degradation in the material, which can eventually evolve into a critical damage. For this purpose, the next generation of polymeric composite materials have the ability to repair themselves, through self-healing functionalities, which can be either extrinsic or intrinsic [2], [3].

This study is focused in extrinsic microcapsule based self-healing systems, which are capable of large damage volume repairs, where the healing agent can be infused to extended damaged area. Specifically, urea-formaldehyde (UF) microcapsules containing an epoxy healing agent [Epikote 828 & 5% ΕΡΑ (ethyl phenylacetate, C9H10O2)] were synthesized and as a catalyst of the healing agent aluminum triflate was used. 1H NMR spin-lattice (T1) and spin-spin (T2) relaxation times measurements were used in order to design and synthesize the optimal self-healing system and to quantify self-healing performance. In addition, dynamic two dimensional 1H NMR diffusion-relaxation (D-T2) and T1-T2 measurements were employed to examine the behavior of both the capsules and the composite at various temperatures, by simulating the operation environment (-50/+50°C), in order to determine the diffusivity of the encapsulated healing agent at different temperatures, and understand how the healing process may take place when damage occurs, for example during a flight.

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Design Of Supramolecular Carbon Based Self-Healing Systems For Structural Application

Elisa Calabrese, Liberata Guadagno, Luigi Vertuccio, Carlo Naddeo, Giuseppina Barra, Marialuigia Raimondo, Andrea Sorrentino, Wolfgang H. Binder, Philipp Michael, Sravendra Rana

This paper focuses on the design of self-healing systems based on non-covalent reversible interactions. In order to obtain nano-composites with integrated self-healing ability and improved electrical conductivity, Multiwall Carbon Nanotubes (MWCNTs) have been covalently functionalized with chemical groups able to act as hydrogen bonding acceptors and donors at the same time (MT and MB, shown in Figure 1). The functionalized nanotubes have been incorporated in the percentage of 2.0% by weight in an aeronautical epoxy resin suitably modified for enhancing the toughness. Infrared spectroscopy has highlighted the
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increase of hydrogen bonding signals in the formulated samples. Self-healing efficiency has been evaluated through continuous dynamic flexural deformation. Electrical and mechanical results highlight the potentiality of the formulated materials to act as multifunctional structural materials.

Detection Of Electrically Conductive Paths By Tunneling Atomic Force Microscopy (Tuna) In Self-Healing Aeronautical Resins

Marialuigia Raimondo, Carlo Naddeo, Luigi Vertuccio, Leila Bonnaud, Philippe Dubois, Wolfgang H. Binder, Andrea Sorrentino, Liberata Guadagno

Local electrical properties of different structural epoxy resins (EP) filled with carbon nanotubes (CNT) modified through a covalent (CCNT) and non-covalent (NCCNT) approach were assessed by means of Tunneling Atomic Force Microscopy (TUNA). The incorporation of 1 wt% of functionalized CCNT and NCCNT in the epoxy matrix markedly affects the conductive behavior of the formulated nanocomposites EP+1%CCNT and EP+1%NCCNT resulting in an abrupt insulator-to-conductor transition, thus safeguarding the effective charge transport in the conductive pathways at nanodomain level, due to an optimal functionalized nanofiller dispersion. The ability of TUNA technique to detect low currents of fA order demonstrates the intrinsic electrical conductivity of the samples. In this work, the CNT functionalized through covalent and physical bonds in the cross-linked resin turned out to be powerful in determining strong interfacial adhesion between nanofiller-matrix and in dispersing the carbonaceous nanoparticles in the matrix. The interactions that the functionalized CNT establish with the matrix have found to be capable to impart self-healing efficiency to epoxy formulations through supramolecular assembly. Besides, the role of the matrix-filler interphase was found to be decisive in increasing the mechanical, thermal and electrical properties of the final nanocomposites. The results prove undoubtedly that the formulated materials, specifically designed to fulfill structural aeronautical requirements, can pave the way for new multifunctional applications.

Damping Assessment Of New Multifunctional Epoxy Resin For Adaptive Structures

Giuseppina Barra, Liberata Guadagno, Luigi Vertuccio, Maurizio Arena, Massimo Viscardi

Adaptive structures are capable of perceiving changes in their own “state”, in the environment in which they work. The frontiers in this sense are really wide mainly aimed at improving their performance and to meet different design requirements regulating the life of each component. In this challenging context, the realization of innovative materials capable of being “multi-functional” is undoubtedly a viable cutting edge solution. The aim of this work is the exploitation of new nanofilled polymeric composites, integrating electrical conductivity properties with durable structural-mechanical functions (multifunctional materials) and high damping capacity. The introduction of carbon nanotubes to epoxy composites gives very interesting electrical properties so that they can be used in extreme operating condition as structural health monitoring systems (piezoresistivity) in air. For adaptive aerospace structures is also important to consider the possibility of extra-damping of vibrational energy and the toughness of the material. At this purpose, the addition of a rubber phase in the epoxy matrix has been considered. For these systems, the measured damping is much higher than what is observed in traditional composite materials. The combination of the elastomeric phase with the addition of carbon nanotubes increases the dissipative phenomena within the resin so that the damping of the material globally increases.
Design of strain sensors for damage monitoring based on different epoxy systems loaded with carbon nanotubes

P. Lamberti, L. Egiziano, G. Spinelli, V. Tucci, L. Guadagno, L. Vertuccio

This paper focuses on the optimization of the piezoresistive performance of different epoxy formulations incorporating MWCNTs. Samples with different amount of CNTs in epoxy matrices have been prepared and tested. Morphological investigations, performed at low weight percentages of MWCNTs, highlight that the nanofiller forms isolated islands in the matrices without interconnections between them. The value of the electrical conductivity of the resulting nanocomposites is very low since the filler content is below the Electric Percolation Threshold (EPT). Near or beyond the EPT, the CNT form interconnected paths. The nature of the epoxy formulation and curing process affects the cross-linking density of the systems and hence the mechanical performances and the value of the EPT. Due to these morphological features, microscale alteration of the distance between CNTs result in changes of the electrical conductivity of the sample. These variations are easily detectable by means of electrical measurements allowing a non-destructive sensing of the strain or possible damage in the material. A very relevant result is the applicability of the thermosetting filled formulation either for diagnostic function in structural aeronautical panels or in automotive components.
Multifunctional Polymer-Based Composite Materials with Weft-Knitted Carbon Fibrous Fillers

Bezsmertna V., Mazna O., Kohanyiy V., Vasilenkov Y., Bilan I., Shevtsova M., Stavychenko V.

Carbon fibers (CFs) together with high values of physical and mechanical properties are characterized by the interesting complex of electrophysical parameters which make it possible to create new multifunctional materials on the base of them. However, the high damageability of carbon fibers during textile processing, especially for high-strength CFs from PAN-precursors, essentially restricts their using for production of multifunctional materials. The production technology of reinforcement filler for polymer based composites with weft-knitted structure had been proposed. In such reinforcement filler high-strength CFs from PAN precursors (wefts) were laid in a knitted fabric as straight continuous yarns, so in such case these CFs are not twisted by knitting machine to form the loops. Various kinds of chemical and inorganic fibers can be used as base yarn in this case, in particular glass fibers, aramid fibers, carbon fibers from hydrate cellulose and etc.

Properties of multifunctional polymer-based composite materials with weft-knitted fillers are depended from fiber composition, relative content of weft and base yarns, scheme filler stacking (1D, 2D and 3D composites).

The results of physical and mechanical tests had shown that for structural composites it is possible to create weft-knitted filler with the content of high strength carbon yarns up to 95 % and use the reinforcement schemes where the most part of high strength CFs is situated along the direction of applying of mechanical loads during their exploitation.

The electrical conductivity of weft-knitted fabrics shows the strong anisotropy along high-strength fibers in comparison with looped rows, depending on the direction of high-strength carbon fibers (weft),. Combined carbon-glass fabrics can be used as heating elements.

Investigation of shielding properties of polymer based composites reinforced by weft-knitted fabrics showed the possibility of using them as shielding materials with the ability to absorb electromagnetic radiation.

Computation Of Mechanical, Thermal And Electrical Properties Of CNT /Polymer Multifunctional Nanocomposites Using Numerical And Analytical Models

Konstantinos Tserpes, Vasileios Tzatzadakis

In the present work, the mechanical, thermal and electrical properties of CNT/polymer nanocomposites are computed using numerical and analytical models as functions of material parameters (CNT aspect ratio, CNT waviness, presence of the interphase) and processing factors (CNT volume fraction, formation of agglomerates and the number and arrangement of CNTs in the agglomerates). The computation is performed using representative unit cells (RUCs) of CNT agglomerates. The RUCs are solved numerically using the FE method and analytically using the Mori-Tanaka method. At the same time, homogenization is applied in the RUCs. The results from the parametric study reveal that the considered parameters and
factors govern the reinforcement effectiveness and, under specific combinations, might counterbalance the multifunctionality of nanocomposites.

**Tensile strength of pre-bond contaminated scarf composite bonded repairs by thermal degradation and de-icing fluid**

*Elli Moutsompegka, Konstantinos Tserpes*

In the present work, the effect of pre-bond contamination scenarios related to repair processes on the tensile strength of scarf composite bonded repairs is investigated. The composite substrates were scarfed with a ratio of 1:17 by milling and subjected to thermal degradation and to a combination of thermal degradation and two different concentrations of deicing fluid contamination before bonding procedure. In all contamination cases, one of the adherents was contaminated while the other one was intentionally left in a reference state replicating the real-life application of repair patches. For the single thermal degradation scenario, the contaminated samples presented a higher failure load than the reference samples, which is attributed probably to chemical changes inside the matrix material. However, the beneficial effect of this contamination is not present in the combined contamination cases. The results revealed that the combined contamination with thermal degradation and de-icing fluid has a negative effect on the mechanical performance of the scarfed repair joints, reducing the failure load. Additionally, after the tensile tests, the failure surfaces were examined in order to accurately assess the causes of adhesive bond failures. The thermal degraded repairs presented an increased cohesive failure type which is consistent with the increase in the failure load. Finally, the combined contamination caused increased substrate failure mode designating a deleterious impact on the composite adherents.

**Mechanical behavior of multiphase composites with randomly located particles**

*P. Papanikos, N. Zacharopoulos*

Multiphase materials are generally used due to their beneficial combination of mechanical, physical, and electrical properties compared to their constituent elements. In the past, numerous theoretical approaches have been proposed to predict these properties based on the properties of the constituent elements. Reinforcements could be continuous in the form of fibers, or discontinuous in the form of particles or whiskers. The prediction and estimation of overall mechanical properties of random multiphase composites are of considerable interest to engineers in many science and engineering disciplines. In this work both analytical and numerical tools are used to evaluate the effective elastic moduli and strength of these materials, focusing initially in two-phase and three-phase materials containing uniformly and randomly distributed spherical particles. The work is further extended to account for failure initiation both in the matrix and the matrix/particle interface. In general, the results of this investigation suggest that randomness has a small effect on elastic moduli but significant effect on strength, both interfacial and matrix failure. Furthermore, for the three-phase materials, an optimization study is carried out to design materials with specific stiffness and strength. This is based on the selection of “optimum” materials for the particles and appropriate volume fractions. This study uses both analytical expressions and three-dimensional finite element models.

**Production and mechanical characterization of a novel bio-based structural adhesive**

*Konstantinos Tserpes, Vasileios Tsatzadakis*
In this paper, a novel bio-based structural adhesive is produced and characterized by tension tests and single-lap shear tests. The bio-based adhesive mixture comes in three parts: the bio-based epoxy resin, the environmentally friendly hardener and a reactive diluent. The bio-based epoxy resin is produced from epichlorohydrin which is based on glycerin while the environmentally friendly hardener and the epoxy diluent are based on cardanol. Composition of the bio-based structural adhesive comprises seven steps. For the formulation of the adhesive, the equivalent weight of epoxy mixture (EEW) is essential to be determined. Once the EEW is determined it is important to calculate the PHR and the stoichiometric ratio for the mixture. Subsequently, the resin and the diluent are mixed in vacuum and afterwards the hardener is added into the mixture, also in vacuum. All products must be in a proper stoichiometric ratio. Once mixed thoroughly and degassed completely the adhesive is ready to be applied on the molds to produce dog-bone coupons and on adherents to produce bonded specimens. The bonded specimens were cured at 80°C for 6 h and post-cured at 120 Celsius for 8 h. DSC tests, tension tests and single-lap shear tests have shown very promising results for the processing and the mechanical performance of the bio-based adhesive.
Multidisciplinary And Multifidelity Exploration Of A Medium Range Blended Wing-Body Transport Aircraft

Alessandro Sgueglia, Luca Cerquetani, Larissa Cristina e Cunha Lima, Diana About Kharoub, Pablo Rodriguez Otero, Harleen Kaur, Paolo Traverso, Alexander Lejon, Emmanuel Benard

To cope with the more stringent environmental goals, the Blended Wing-Body has been largely studied in the past years: the integration of propulsion system, payload and passengers within a single lifting surface allows to reach value of lift-to-ratio that exceeds 22.

Despite these great advantages, it presents some drawbacks, mainly related to the structural design and the stability. In literature, the study of the different aspects of a BWB has reached a mature point, but at this stage the exploration of the interaction between disciplines is poorly explored. Also, most of the works rely on high fidelity methods. This approach can be useful for a detailed design or a better assessment, but it is unfeasible for the conceptual design stage, in which a quick answer is needed to evaluate performances of a concept and have a first clue of its feasibility.

To face this problem, ISAE-Supaero and ONERA set up a research strategy for the Blended Wing-Body concept, aimed to use high fidelity methods for assessing the error of the methods used at conceptual design (like the Vortex Lattice Method for the aerodynamics, or mass surrogate models for evaluating the structural weight). This multifidelity approach involves all the key disciplines in aircraft design: aerodynamics, structure, propulsion. Stability and security issues, concerning the evacuation time, are considered too. A common reference geometry is used throughout all the work. The results of these analyses have been lately used into FAST (Fixed-wing Aircraft Sizing Tool), which is a sizing tool, developed at ONERA and ISAE-Supaero, for the conceptual design of large passenger aircraft. Thanks to this code, a first performance analysis has been conducted, and the results are compared with the A320 Neo, that has the same requirements as the ISAE-Supaero and ONERA BWB.

Lightweight UAV For Emergency Medical Service – Synthesis Of The Layout

Tomasz Goetzendorf-Grabowski, Jacek Mieloszyk, Marcin Figat, Andrzej Tarnowski, Bogdan Hernik

This article presents the innovative UAV project for emergency medical services. Designed UAV combines VTOL characteristics that are vital to perform such an emergency medical mission with fast forward flight capability that is also crucial in case of such mission. The main purpose of the designed UAV is to deliver the necessary medical package to the place where access is difficult and estimated arrival time of conventional ambulance is too long. The cost of the support of such UAV could be significantly lower than in case of medical helicopter, which is not necessary in some cases. Designed UAV can be also used for fast delivery of essential medical substances (e.g. blood).

The selection of the configuration was the first and crucial step of the design. After analysis of many different copter configurations together with selected crash reports analysis, the coaxial quadcopter configuration crossed with conventional airplane was selected. All power units for VTOL capability are electric and they are doubled for redundancy purposes, while maximum T/W is about 2.0. Such configuration allows to sustain a stable flight (vertical phases) in case of one motor failure. Two versions
of the vehicle are designed: fully electric (power units for the forward flight and VTOL are electric) and mixed where forward flight unit is a small piston engine.

The final layout was the result of conceptual investigation and preliminary research, MDO and trade-off analysis, in which as many aspects as possible were considered. The main problem was to meet the VTOL capabilities, relatively long range and endurance, expected payload (3 kg) and the requirement not to exceed 25 kg of MTOW. Paper presents the design process from initial requirement to the final configuration accepted to be manufactured.

**Numerical Multidisciplinary Optimization Of Aircraft With Flight Dynamic Stability Constraints**

*Jacek Mieloszyk*

Classical approach to conceptual and preliminary design in aerospace sciences reaches limits. To go further and achieve better, competitive results use of optimization methods becomes mandatory. The trend is clearly visible in professional software for simulations equipped with optimization tools, which was not standard just decade ago.

The article shows an example of design and optimization of VTOL aircraft with innovative approach with use of constrains from flight dynamics. The object of the optimization is VTOL aircraft, which has to satisfy number of constrains and fulfil performance requirements. Although, it is conceptual design faze, to obtain reliable results for such a complicated object as VTOL aircraft, it has to be sufficiently well modelled. The numerical optimization includes analysis of aerodynamics, mass estimation and flight dynamics.

The design has basic utility requirements for payload weight and size, which force strict requirements for power needed for vertical flight and for size and masses of the vertical propulsions system. Due to the flight law regulations it was also assumed that the total weight for flight cannot exceed 25kg.

Utilizing these basic assumptions initial technical requirements were defined and numerical optimization conducted for the VTOL aircraft.

**UL-39 Albi II – A New Generation Development**

*Theiner Robert, Brabec Jiří*

The UL-39 Albi university's all-composite ultralight aircraft project, powered by a piston engine and ducted fan, continues at the Department of Aerospace Engineering at Faculty of Mechanical Engineering CTU in Prague and its partners ZALL JIHLAVAN airplanes, s.r.o. and LA composite, s.r.o. by developing its new generation. The article is a follow-up to a contribution from 2017, where the entire genesis of the first prototype was described. The introduction summarizes the experience of the prototype operation (service) and analyzes the deficiencies that required a major redesign of the propulsion unit. Aspects leading to the choice of another propulsion unit arrangement and changes in the ducted fan stage, inlet duct and channel, outlet channel with cooling bypass and nozzle are described. Subsequently, changes in airframe and systems are described, whether they are associated with propulsion unit reconstruction or resulting from operational experience. The fuselage of the airplane has undergone a fundamental and dominant change. The paper describes not only structural changes leading to the reduction of the width of the fuselage and its wetted area, the change in the engine mounting and installation or the arrangement of transmissions of the primary control, but also the technology of production of composite parts leading to weight reduction. Following the changes in the fuselage design modifications of the wing
(mainly high lift devices) and modification of the horizontal tail are described. At the end changes of airframe, engine and avionics systems are also described and there is a plan of further development, which should ultimately lead to the commercialization of the project.

**CFD Analysis of Selected Distributed Propulsion Concepts for an Inverted Joined Wing Airplane**

*Klimczyk Witold, Dziubinski Adam*

This paper addresses the aerodynamic performance of a joined wing aircraft with distributed propulsion. A few concepts for replacing single pusher propeller were considered. Firstly, a row of five small engines located either in front of, or behind the rear wing. Secondly, a mixed configuration, involving a combination of three small engines at the rear wing added to the main, central one, representing a hybrid configuration of piston and electric motors. Analysis of feasibility of these concepts was performed, which in case of propellers behind the wing called for addition of wing skids. Calculations aimed to find the effects of distributed propulsion on the overall aerodynamic performance were carried out using Computational Fluid Dynamics (CFD). Hence, detailed analyses and comparisons were made, to reveal, that only in case of pushing distributed propulsion there is some improvement in overall aerodynamic performance.
Test Facility To Investigate Plume-Regolith Interactions

Konstantinos Kontis, Craig White, Hossein Zare-Behtash, Takahiro Ukai, Jim Merrifield, David Evans, Ian Coxhill, Tobias Langener, Jeroen Van den Eynde

For both sample return and in-situ analysis missions it is vitally important to understand the physical phenomena related to the propulsion subsystem and terrain interactions during landing of the spacecraft. The plumes of the retro-rockets will cause erosion and chemical contamination to the celestial body’s surface which will affect the landing manoeuvres and measurements of the regolith in the vicinity of the landing site. Due to the chemical composition of the plume gases, contamination of the soil needs to be minimised. Furthermore, the generated regolith dust clouds and the reflected plume flow can affect the spacecraft force and torque balance as well as posing problems for the proximity navigation equipment and sensitive external surfaces.

The objective of this activity is to investigate the interaction between rocket engine plume and regolith at a fundamental level, in support to all planetary and lunar landing environments such as the Phobos Sample Return mission. These studies are vitally important as the interaction between the hovering and landing plumes with the regolith can have a severe impact on the mission objectives and also the engine performance. To achieve these goals, a dedicated facility, with a total volume of approximately 72 cubic metres, is designed, manufactured, and housed at the University of Glasgow. The volume is split between the test chamber, a 12 cubic metre axisymmetric chamber with access ports, and a 60 cubic metre buffer tank. The purpose of the buffer tank is to keep the pressure rise in the test chamber, during the addition of any mass flow, within an acceptable range.

The facility is designed with two missions in mind. The first case is representative of landing on an airless body, and the second scenario is landing on Mars. Hence, two different mass flow cases which are scaled versions of the proposed thrusters are analysed: a 1g/s mass flow rate, with a nozzle exit Mach number of 6.6 for landing on an airless body, and 18.9g/s with an exit Mach number of 5.84 for landing on Mars. Previous studies of a similar nature have never attempted to match the nozzle exit Reynolds numbers, so in this work the gas is heated in the stagnation chamber to achieve Reynolds number similitude. The gas passing through the nozzle must be heated to 700 K and 1000 K for the Martian and airless body cases, respectively, to satisfy the Reynolds number matching. Strouhal similitude is also important as the motors will operate in a pulsed mode and this means that the heater assembly must also be low volume in order to be able to pulse the scaled nozzles at the required frequencies. To this end, a custom heat exchanger is designed and tested that can heat the pulsating gas from ambient to the desired temperature (e.g. 1000 K) whilst maintaining adequate T90 rise time and T10 decay times for Strouhal similitude (T90: time required to reach 90% of the desired final pressure, T10: time required to go from 100% to 10% of the desired final pressure). The low volume heat exchanger is manufacture through additive manufacturing from a copper alloy (CuNi2SiCr) chosen for its thermal conductivity and mechanical strength.

The results presented will cover the design calculations of the vacuum facility with the added mass flow from pulsating hypersonic nozzles. The methodology behind the specially designed heat exchanger operating at different temperatures, pressures, and frequencies representative of the various landing
Design Of A Multifunctional Composite Structure For Modular Cubesat Applications

Capovilla G., Cestino E., Romeo G., Reyneri L.

CubeSats primary structures are usually made with aluminum alloys, with few examples of lighter CFRP primary structures under study [1]. Power system battery arrays usually occupy 7% to 14% of the spacecraft internal volume that should be available to the payload. The total capacity usually ranges from 9 Wh to 44 Wh. A CFRP structural/battery array configuration has been designed, allowing to integrate the battery array frame in the bus primary structure. The structural/battery array configuration has been developed with the modular, smart tiles design philosophy in the AraMiS CubeSat framework [2]. It is sized as a 1U smart tile, mounted on an external face of the CubeSat. It accommodates two solar cells (figure 1), while the opposite face accommodates power system circuitry. Structural batteries concepts with different degrees of integration, as in [3, 4], are promising technologies especially in the design of future more/all electric battery-powered aircraft [5, 6]. The present design concept has a lower degree of integration and can more easily be implemented. Following a cellular structure concept [7], six commercial 1.8 Wh LiPo batteries have been placed between two CFRP panels and spaced out with CFRP ribs (figure 2). A protection material can be included within the multifunctional structure to protect the batteries from mechanical vibrations and heat fluxes. Compliance with launch mechanical loads has been evaluated as a first step. A simplified analytical approach has been employed to evaluate the maximum transverse displacement due to a variable transversal load factor (figure 3). The optimal configuration has then been studied with a FEM analysis. The structural behavior has been compared with the structural response of a commercial aluminium alloy Cubesat external panel. The structural weight of the CFRP structure is approximately 25 g, slightly inferior to the aluminium alloy counterpart whose weight is 28 g. The results indicate that even with a low degree of structural integration, more volume and mass can be allocated to the payload, with respect to traditional design approaches. The low degree of integration allows to employ relatively cheap and commercial off-the-shelf components. The main FEM analysis results will be presented in the final paper along with pertinent conclusions and future developments.

References


**Multifunctional Load-Bearing Aerostructures With Integrated Space Debris Protection**

*Martin Schubert, Athanasios Dafnis*

In the project multiSat multifunctional composite structures for satellite applications have been developed. Passive functions have been integrated into the load-bearing spacecraft structure by use of suitable materials and components. Sandwich panels have been studied as representative structural parts of a conventional satellite structure and the passive functions include heat transfer, radiation shielding and protection against space debris impacts. Due to their multi-layer character composite materials are suitable for functional integration since each layer can be defined and designed to provide one or more specific functions. Innovative manufacturing technologies such as additive manufacturing allow for the production of new types of sandwich cores which add to the multifunctionality of the structural part. For increased space debris protection the conventional honeycomb core is replaced by 3D-printed aluminium lattice structures, and the sandwich is reinforced by high performance fabrics, which effectively break up and catch impacting debris particles. The concept of a multifunctional structure allows for the reduction of the overall satellite mass and of installation space required for subsystems. Additionally, it opens up new opportunities for highly integrative and standardized production processes and lower total costs and time for manufacturing, qualification and launch. This paper describes the development and design of concepts for multifunctional sandwich panels with increased impact protection capability and presents the experimental results of hypervelocity impact testing with different types of composite sandwich plates.

**PPU For A Small, Low Power And Low Cost EPS**

*Spiridon Savvas, Pavlos Ramnalis, Alexandros Manoudis*

The objective of this paper is to present the design of the Power Processing Unit (PPU) of the Microsatellite Electric Propulsion System (MEPS) currently being developed in an Elegant Bread Board (EBB). High efficiency (> 92%), small size and weight and high reliability are the main parameters that special focus is given.

The MEPS program has been originated by the increasing need to provide a low-cost and low-power Electric Propulsion System (EPS) for small satellites (<300Kg) and finds applications in orbit insertion after launcher separation, orbit maintenance, orbit transfers and deorbiting.

The propulsion system of MEPS consists of three main units: two Thruster Units (TUs) composed of a Hall Effect Thruster and a Cathode, a single Propellant Management and Tank Assembly (PMA/PTA), which performs the regulation of the xenon mass flow rate from the tank to the TU inlet and a single fully
redundant PPU, which provides the necessary power to drive the TUs and the PMA and implements the system control logic.

The PPU designed for the EBB phase has no redundancy, is fully flexible and capable of driving two different TU types (RAFAEL's CAM-200 coupled with RAFAEL's RHHC and SITAEL’s HT100 coupled with SITAEL’s HC1). This paper illustrates the most significant design requirements and aspects on which the design was based and presents the preliminary results obtained from a series of coupling tests on the critical parts developed at Bread Board (BB) level, which constituted the basis for the current design. Last but not least, the current design along with the future development steps of the program that can become the driving point for the successful implementation of an easily adjustable PPU compatible with a wide range of EPSs are also demonstrated.

Spacelidar: Redesigning A Successful Ground-Based System For Space Applications

George Avdikos, Athanasios Baltopoulos, Alexandros Louridas, Antonios Vavouliotis, Dimitris Vlachos

In this paper, we first review the multiwavelength Raman lidar system manufactured by Raymetrics and operated by European Space Agency (ESA). This lidar is a 6-channel system installed in a mobile van and performs mobile on-ground systematic measurements of the aerosols across Europe since 2010. Here, we perform the exercise to setup the requirements and a preliminary design to transfer the design to a Space Lidar system which is directly based on this ESA ground-based system. The system shall be compatible for use on satellite missions and the emphasis is given to specific optical and mechanical components like the laser source and the telescope for use in space. To that purpose, Raymetrics has already run two projects (QOMA 1 and 2, funded by ESA) towards the development of a diode-pumped laser, operating at 1 um. Results of these projects will be presented. Similar results will be presented for CFRP Structures Design and Development (projects implemented by Adamant Composites) which offer a potential solution for lightweight, compact, robust and lidar-tailored telescopes. To this end, nano-enabling technologies on CFRP structures are also evaluated. The first iteration of the requirements and the preliminary design will be presented for first time. The involved entities will present their roadmap for next ESA lidar missions.

Thermal Protection Structures of Reusable Spacecraft, Made of Composite Materials, Based on Ceramic Matrix

Iryna Husarova, Solodkiy, Tamara Manko, Oleksandr Potapov

One of the main problems of reusable spacecraft creation is searching for new lightweight thermal-resistant heat-proof materials for thermal-protection structures that are able to operate under conditions of cyclic heating up to 1200°C. Reinforced ceramics is prospective materials for external thermal-protection panels of reusable spacecraft due to its unique combination of low specific weight, high strength, creep strength, oxidation stability and low thermal expansion coefficient and ability to retain its properties over high temperatures and long period of time. However, the main problem of monolithic ceramics is the fragility, which leads to reduction in effectiveness during operating and complicates the process of assembly of individual elements into the construction. One way to improve the damage resistance is to add a reinforcing phase into a ceramic matrix, which greatly increases the material's fracture toughness.

The composite ceramic in the B-C-Si system has a low specific gravity (<2.9 g / cm³) and presence of oxides B2O3 and SiO2 in the system provides resistance to oxidation and erosion at temperatures up to 1200°C. Moreover, reinforcement of ceramic matrix with carbon fibers makes it possible to achieve high-
performance characteristics, in particular, the crack resistance at 10 MPa•m1/2. It should be noted that the obtaining of high-density reinforced ceramics in the B-C-Si system is successfully realized in the conditions of impregnation of the porous workpiece by the melt of silicon.

The purpose of the work is to create ceramic composites with a density of up to 3 g/cm³ based on boron carbide and reinforced with carbon fibers, and an experimental verification of their functional properties at 1200°C.

Experimental samples of reinforced ceramics of the B-C-Si system with different content of carbon fibers (5, 10, 15, 20% by weight) were made by impregnating a porous workpiece with a silicon melt. The influence of the obtained ceramics reinforcing component amount on the structure, phase composition and physical-mechanical characteristics (hardness, crack resistance) and its thermal stability under cyclic heating conditions (50 cycles) to 1200 °C was determined.

According to the results of the research, it was found that the reinforced composite ceramic in the B-C-Si system meets the requirements of low specific weight (less than 3g/cm³), provides resistance to oxidation and erosion at temperatures up to 1200°C. The content of carbon fibers in the base mixture of more than 10% (by weight) ensures the formation of silicon carbide fibers in the volume of ceramic material and allows achieving high mechanical characteristics, in particular, the crack resistance at 10 MPa•m1/2.

Corner Cube Mechanism (CCM) for MTG: Qualification and Acceptance Test campaign results and lessons learned

Peter Spanoudakis, Philippe Schwab, Lionel Kiener, Gérald Perruchoud, Hervé Saudan, Mathias Gumy, Yves-Julien Regamey

The Corner Cube Mechanism (CCM) of the Infra-Red Sounder (IRS) for the Meteosat Third Generation (MTG) satellites completed an extensive qualification test campaign to show that the high-precision mechanism can meet stringent requirements for operation in the harsh environment of space at geostationary orbit. The Qualification Test Program was performed both at component/sub-system level and at mechanism level.

Qualification and acceptance test campaign results at mechanism level are reported which were performed on the qualification (EQM) and flight models. The critical qualification tests performed on the EQM were the environmental random vibration and shock tests followed by the crucial micro-vibration tests. The remaining qualifications tests for thermal cycling were performed on the PFM. Both the EQM and PFM survived the vibration and shock tests but these events were not the only technical and programmatic challenges that were faced and resolved. With the hurdle of the qualification tests behind the team, the acceptance level tests of the FMs were considered as a repetition and less critical.

The micro-vibration tests on the EQM showed many non-conformances to the specifications which required significant exchanges and clarifications between all partners at all levels. Major results discovered high amplification of CCM resonance modes from induced perturbations from CCS (cryocooler system) harmonics. The solution implemented was mobile mass tuning to shift critical frequencies outside the disturbance bands.

The FM test campaign was hindered from a number of critical anomalies both at sub-system and mechanism level. Upon inspection during integration, the Optical Switch (OS) for the PFM was found with
cracked and abraded outer cable insulation. This required a complete disassembly of both switches and a replacement of all cables followed by a retest of the hardware.

A major setback encountered was just prior to the random vibration tests on the PFM, where it was discovered that a number of critical bolts had loosened despite the fact that they were locked by adhesive. The Nuflon-N anti-friction coating on the bolts was so low that the bolts loosened by themselves! A six-month investigation concluded with the implementation of an IASI heritage sprayed PTFE procedure.

Another obstacle was the discovery of the FM2 OS ruler broken inside the mechanism while the final sequence of the bolt replacement procedure was being carried out. Corrective actions were implemented, the OS ruler was replaced and the hardware re-integrated in the CCM.

The PFM and FM2 performance tests confirmed the previous EQM test results. The maximum lateral deviation for a stroke of 10mm was measured <0.4µm compared to the 2µm specification. Both flight models have been delivered to TAS-F and are one of first flight hardware delivered in the frame of the MTG programme.

Innovative concept of compliant mechanisms made by additive manufacturing

Lionel Kiener, Hervé Saudan, Florent Cosandier, Johan Kruis, Gérald Perruchoud, Peter Spanoudakis

An innovative concept of building compliant mechanisms by additive manufacturing developed at CSEM will be presented. The new geometric possibilities offered by Additive Manufacturing (AM) have allowed us to develop, build and test compliant mechanisms with almost no support structure under the flexure blades. Bringing together CSEM’s experience in the design and development of high performance flexural elements and mechanisms for more than 30 years has opened the doors to new opportunities.

The entire process of acquiring in-depth knowledge and practical experience of a new production method (i.e. metallic Additive Manufacturing) with its new design freedom and associated limitations will be presented. All this work, done at CSEM, allowed us to determine the limits related to the manufacturing of thin, flexible structures used in compliant mechanisms. In this particular context, usual weaknesses attributed to AM processes – such as surface roughness, material porosity & mechanical anisotropy which may become major showstoppers have been taken into account with the development of new strategies to overcome these drawbacks.

The complete redesign for AM of compliant mechanism structures enables CSEM to develop innovative concepts (patent pending) to drastically reduce the need of machining after additive manufacturing. Support structures under flexure blades are thus minimised and the overall process becomes more streamlined.

Moreover, this concept allows us to easily design and produce monolithic cross flexure pivots with interlocked flexible blades.

Thanks to this concept, CSEM is now developing new architectures of Compliant Mechanisms based on Additive Manufacturing (COMAM) for the European Space Agency (ESA) in the frame of a GSTP research project.

The past and current work of design, 3D printing and testing on several compliant mechanisms will be presented. These demonstrators will be used as use-case for future high-precision and harsh environment applications such as cryogenic and space.
Titanium solar metallurgy - Earth and Space

Jaroslav Kovacik, Natália Mináriková, Štefan Emmer, Peter Šugár, Jana Šugárová, Barbora Ludrovcová, Amro Al-Qutub, Khaled Al-Athel, Jose Rodriguez, Inmaculada Cañadas

The experimental results for solar metallurgy and solar powder metallurgy of titanium on Earth are reviewed based on experimental works. Most of them were performed at Plataforma Solar de Almeria Spain using solar furnaces SF5 and SF40. As starting material HDH titanium powder prepared from titanium sponge was used. It was observed that the time to achieve melting point is very short when concentrated solar power used. It is expected that the obtained results will be similar in space. The current state of the art of solar furnaces is extrapolated to Moon, Mars and asteroids solar furnaces. Finally, necessary changes in solar furnaces for space metallurgy are discussed.
Identification Of The Flight Performance Of The E-Genius-Mod

Jan Denzel, D. P. Bergmann, O. Pfeifle, A. Strohmayer

Unmanned aeronautical systems play an increasingly important role in flight testing and in the field of scaling effects analysis. The basic requirement for this is a careful identification of the corresponding parameters for flight performance and the flight mechanics of the initial system.

The e-Genius-Mod system, which was recently put into operation, was characterized and identified with regard to its flight performance in view of the subsequent integration of various propulsion systems. The important parameters of the system were already calculated during the design process and verified in corresponding flight tests. Among other things, an appropriate wing profile was developed in order to adapt the polar curve of the aircraft as precisely as possible to the requirements for later measurement flights.

This article highlights the approach to flight tests and their evaluation. An outlook on further flight tests is given. The aerodynamic modification of the system with regard to the ELFLEAN project will also be considered.

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Study Of Unmanned Aerial Vehicles’ Flight Capabilities In The Aspect Of Minimising The Threat To Civil Aviation

Mirosław Nowakowski, Andrzej Szelmanowski, Andrzej Pazur, Edyta Franczuk, Wojciech Paterek

The article discusses the issues related to adaptation to the civil aviation requirements of flights performed in Poland by military unmanned aviation vehicles (UAV). The basic flight parameters of the selected flying objects, built at the Air Force Institute of Technology, constituting air targets (classically driven SMCP-JU “Komar”, SMCP-WU “Szerszeń” and jet ones “Jet” and “Jet-2” with a programmed flight route) and unmanned aviation vehicles implementing combat missions (surveillance “HOB-bit” with an electric drive and “Atrax C” of vertical take-off and landing in the X4 flight configuration with 4 propellers and X8 with 8 propellers) were presented. The unmanned aviation vehicles’ flight capabilities were discussed in the aspect of using the automatic flight control system to minimise a threat to civil aviation.

The selected test results of computer simulation for a numerical model of the “HOB-bit” unmanned aviation vehicle, the aim of which was to determine its flight capabilities, and in particular, resistance to the introduced flight disturbance in the form of sudden, pulse elevator and rudder deflection, were presented. The results of the experimental verification of flight capabilities necessary to show the dynamic stability were also presented. It was indicated that the simulation tests simplify the automatic flight control system programming and reduce a threat to civil aviation.
Towards Surrogate-Based Aero-Structural Design Optimization Of An Unmanned Aerial Vehicle

Jan-Niclas Walther, Francesco Torrigiani

In order to be able to assess also unconventional aircraft configurations, aircraft designers need to take into account physics-based analyses even during the early design stages. This highly multidisciplinary task requires the contributions and expertise of several different disciplinary specialists. This also applies to unmanned aerial vehicles, where improvements in performance yield a tactical advantage.

In this paper, a partitioned design optimization process is presented, for the OptiMALE UAV configuration, originally introduced during the AeroStruct project [1] and was further investigated during the AGILE project [2]. The optimization will couple panel method aerodynamics and structural sizing to find the design with the maximum range. The process is set up in a modular fashion, using common data models as interfaces. The initial design is provided in the Common Parametric Aircraft Configuration Schema (CPACS) [3, 4], and serves as common input for the disciplinary model generators.

The multidisciplinary analysis (MDA) process itself is implemented in Python as a Gauss-Seidel fixed point iteration, using comprehensive interfaces to the disciplinary analysis tools. The structural analysis and sizing is performed on a beam and shell model. For the aerodynamic analysis, a 3D potential method for subsonic flow applying the Green’s function method to the small perturbation potential flow equation after Morino [5] has been implemented.

The loads resulting from the converged MDA are used as inputs for a sizing optimization of the wing structural components using Lagrange [6]. Finally, a mission simulation is performed using the updated massed to yield the range of the design.

The optimization will be implemented in two steps. First, a design of experiments is performed on the wing design variables. Kriging [6, 7] is used to construct a metamodel from the DOE results, which provides gradients for a subsequent gradient-based optimization.

References
Stability Study And Flight Simulation Of A Blended Wing Body Unmanned Aerial Vehicle

Thomas Dimopoulos, Periklis Panagiotou, Kyros Yakinthos,

The main directions of aeronautical research in recent years are Unmanned Aerial Vehicles (UAVs) and the investigation of layouts alternative to the conventional aircraft layout, consisting of a distinct fuselage, a wing and the empennage. One of these alternatives is the Blended Wing Body (BWB), where the fuselage has an aerodynamic shape, blends smoothly into the wing and contributes to lift production. This platform significantly increases the aircraft’s lift/drag ratio, minimizing drag-related energy losses during flight, while increasing internal payload volume.

The Laboratory of Fluid Mechanics and Turbomachinery, in the Department of Mechanical Engineering of AUTH, are involved in the design and development of a BWB platform UAV (1), combining the two most cutting-edge trends of aeronautics. This design is part of the DELAER research project, concerning an aerial platform capable of delivering humanitarian aid to isolated islands and remote areas of Greece, rapidly and at low cost. The DELAER project is a cooperation between academic and industrial institutions of Greece, coordinated by the LFMT.

The layout of the UAV, is under the code name RX3. The layout eliminates the empennage, compromising the aircraft’s controllability and stability. In conventional layouts, the aircraft’s rotation about the Y axis (pitch) is governed by the elevator(s) located on the horizontal tail, while its rotation about the Z axis (yaw) is governed by the rudder(s) located on the vertical tail(s). As these components are eliminated from the RX3, the need to incorporate their functions to the new layout arises, so that the stability demands, applying to aircraft of similar size and mission profile, are covered. In particular:

- The wing control surfaces, which conventionally function as ailerons, can either be deflected in counter-direction to act as ailerons, or in the same direction to act as elevators.
- The flaps on the winglets, positioned at an angle from the wing plane, can either apply a force on the Y axis to act as rudders, or apply a force on the Z axis to act as elevators.

Customarily in aeronautics, an aircraft’s stability behavior is expressed by the stability derivatives (2). This approach simplifies the equations of forces and moments, linearizing them with the small disturbance theory. Thus, the effect of disruptions to the aircraft’s equilibrium (changes in velocity, angle, angular velocity or acceleration) can be determined. Regarding conventional aircraft, an established methodology to calculate stability derivatives exists (3), based on empirical and experimental results, codified into charts.

However, this methodology cannot be fully applicable on a BWB layout aircraft, as it heavily relies on the geometric and aerodynamic properties of the empennage. This paper describes how the methodology was modified for the design process of the RX3, in order to apply to its layout. In particular:

- Vertical tail contributions were calculated based on the winglets, as they incorporate the vertical tail’s functions.
- Horizontal tail contributions in lateral stability were completely ignored, as they assume that the empennage acts as a secondary wing in the lateral direction, which is eliminated from the BWB.
- Horizontal tail contributions in longitudinal stability were calculated considering the wing’s geometrical properties and the aerodynamic properties resulting from flap deflections. These
were calculated with low fidelity methods, including analyzing two-dimensional sections of the wing with the panel method (XFLR5), and validated through CFD.

The stability derivatives of the RX3 were calculated based on these assumptions. Afterwards, they were used:

- For the description of the aircraft’s behavior with automatic control methods (transfer functions).
- For the comparison of the aircraft’s behavior to that of similar aircraft
- For the visualization of the aircraft’s flight, using flight simulation software.

Acknowledgements
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Numerical 3d Study On The Influence Of Spanwise Distribution Of Tubercles On Wings For UAV Applications
Papadopoulos Charalampos, Katsiadramis Vasilis, Yakinthos Kyros

In this work, a 3D numerical study on the influence of the spanwise distribution of tubercles for UAV applications is presented. The humpback whale (Megaptera novaeangliae) has a characteristic flipper, with a spanwise scalloped leading edge, creating an almost sinusoidal shape, consisting of bumps called tubercles. Since the early 2000s, when Dr. Frank Fish first noticed these bumps on the leading edge of the humpback whale’s flipper, many scientific papers have been published, regarding the effect of these protuberances, as a means of passive flow control. His early experimental research showed a great potential in enhancing the 3D aerodynamic characteristics of a wing. The majority of the existing experimental results concern 2D (full-span) models and are accompanied with substantial loss in lift and increase in drag in pre-stall region. On the other hand, 3D (full-span) models have displayed a better overall aerodynamic behavior (increased lift and moment, but also decreased drag). At a Reynolds number of 500,000 – 1,000,000 (based on the mean chord of the flipper), tubercles act as virtual fences, introducing a pair of counter rotating vortices that delays the stall of the flipper, a phenomenon that the whales use in order to perform sharp turns and catch their prey, while swimming. The above mentioned Reynolds number range is the same as the operational Reynolds number for typical Unmanned Aerial Vehicles (UAV). In order to assess the influence of the tubercles installation on UAV wings, a full 3D computational study is carried-out, with the use of CFD tools, that at a first phase are validated and calibrated with available in the literature experimental data. Then, computations are performed, for different spanwise turbercles distributions, including a distribution similar to the whale’s flipper. The results show that there is a noticeable potential on controlling the flow on the wings of a UAV operating
in a Reynolds number range between 500,000 and 1,000,000 (based on UAV’s wing mean chord), which can lead to an aerodynamic performance and efficiency increase.

OGN Trackers As Open Alternative To ADS-B And TCAS For Small Airplanes And Autonomous UAVs

*Miroslav Červenka*

With the extensive advancement of both manned and unmanned air traffic the air traffic controllers are with rising frequency becoming reluctant to grant clearance to enter airspace under their supervision to crafts of all categories not equipped with ADS-B transponders. These transponders, however, are costly devices that many aircraft owners cannot simply afford. This consequently results into situations where pilots decide to fly tightly along the border of such airspaces causing significant increase in traffic density in these areas or plainly to fly under the radar with low ground altitude across the airspace, thus lowering the margin for error when encountering technical or meteorological difficulties. The Open Glider Network has originally been designed as dense mesh of interconnected ground receivers to track sailplanes on their cross-country flights. The OGN-equipped gliders carry an on-board tracking device that transmits virtually all the information like the ADS-B transponders and as such could be used as equal and fully-functional cost-effective drop-in replacement. Provided the air traffic controller workplace is equipped with just a regular internet-connected computer, or alternatively, own on-premises based receiver station for higher robustness, the staff can observe such traffic even more comfortably than they currently do on the secondary radar monitors. Furthermore, the OGN units can receive data from other transmitters in vicinity, analyze positions, predict trajectories and detect potential close proximity or collision courses. This can give the pilots or the UAV’s control systems the chance to execute evasion maneuvers in order to avoid impending collision. In this paper the ground network infrastructure, design of the transceivers and the overall benefits of OGN technology for air traffic surveillance, guidance and safety is described in detail.

Aerodynamic moment characteristics of tandem-scheme aircraft

*Iulia S. Kryvokhatko*

In the beginning of XXI century aerodynamic scheme “tandem” (with comparable areas of forward wings and back wings) became widespread among UAVs and small piloted aircrafts. Its aerodynamics has specifics caused by inevitable wing-wing interference that includes flow downwash and upwash from forward wings on the back wings. This affects total lift coefficient and moment characteristics that concerns stability of aircraft and is of high importance.

Analytic method was developed by author; CFD (with Ansys software) and experimental test (in certified wind tunnel AT-1 at Antonov Company) were performed for determination of the aerodynamic characteristics of tandem-scheme UAV model.

Pitch static moment can be found only with correct average downwash angle calculation and so back wings’ lift coefficient. Classic analytic method (by Prandtl) is considering wingspan ratio, height and stagger. Proposed method is able to take into account wings’ dihedral angles and sideslip angle as well. For simple cases both methods show the same results. It’s preferable to achieve minimal balancing losses for maximal lift-drag ratio angle of attack.

Yaw static moment depends on wings’ dihedral angles stronger than for traditional scheme. Dihedral angles of forward/back wings creates destabilizing/stabilizing yaw moment. So winglets on forward wings decrease directional stability as well, but on back wings increase it greatly. Generally tandem-scheme aircraft does not face any problems with yaw stability.
Roll static moment dependence differs from the one of traditional aircraft. Forward and back wings’ interference results in roll static stability increasing for low sideslip angles, but after $\beta=5\ldots10^\circ$ it rapidly decreases. This kink at roll moment graph was predicted by proposed analytic method and was observed in wind tunnel test results. Nevertheless, such an effect was not detected by CFD method based on RANS solving. For explanation the position of tip vortices of forward wings should be considered. Till both forward vortices are situated inside the span of back wings the additional rolling stability is provided. At some sideslip angle ($\beta=6\ldots8^\circ$) one forward tip vortex intersects tip section of back wing. At higher sideslip angles it decreases rolling stability. CFD method indicates that both tip vortices of forward wings are situated between vortices of back wings at least up to $\beta=20^\circ$ that is physically wrong.

Conclusions. Aerodynamic interference between forward and back wings significantly affects pitch and roll moments of tandem-scheme aircraft. Directional stability is decreasing by dihedral angle of forward wings and winglets on them, but is increasing by the same factors for back wings. In narrow range of sideslip angles the interference increases roll stability. Vortex system of tandem-scheme aircraft at sideslip angle is modelled incorrectly by modern CFD methods (solving RANS) that ignores important effects in moment characteristics. So for this purpose it`s reasonable to use proposed analytical method following by wind tunnel test.
Recent Advances In Fuselage Wake-Filling Propulsion Integration

Arne Seitz

In order to reduce aviation’s environmental footprint and to enable aviation's sustainable growth in the long-term, the exploration of breakthrough technological advancements is crucial. Great potential for significant contributions to achieving these goal settings is expected from novel propulsion systems and their more synergistic integration with the airframe. A particularly strongly impact in terms of an improved overall vehicular propulsive efficiency may be realised through the localised ingestion and re-energisation of the viscosity induced low momentum wake flow of a wetted body via Boundary Layer Ingestion (BLI), also known as wake-filling propulsion integration. The positive effect of wake-filling on propulsive power requirements has long been known from the field of marine propulsion, but is also applicable to airborne systems. The "ConcEpt validatioN sTudy foR fusElage wake-filling propulsioN intEgration" (CENTRELINE) project [1], funded by the European Union as part of the Horizon 2020 Framework Programme is dedicated to performing the proof-of-concept and initial experimental validation of a highly promising approach to wake-filling propulsion integration - the so-called Propulsive Fuselage Concept (PFC). The CENTRELINE PFC features a turbo-electrically driven propulsive device at the aft-fuselage that entrains and re-energises the fuselage boundary layer flow in order to directly compensate the viscous drag effects in the fuselage wake field. For large commercial aircraft, the share of viscous and form drag typically ranges between 60–70% of the total drag in cruise. Approximately half of this share can be attributed to the fuselage body, making it the most interesting airframe component to be utilised for the purpose of wake-filling propulsion integration. With its single boundary layer ingesting propulsor, the CENTRELINE PFC realise fuselage wake-filling in the most straightforward way while intrinsically offering the full fuselage wake-filling potential (360° installation). The present contribution presents an overview of the latest results and findings from the ongoing multi-disciplinary, multi-level collaborative research activities performed in CENTRELINE. This covers the CFD analysis-based aerodynamic design refinement work supported by low speed wind tunnel and rig testing of the overall PFC configuration [2] and the BLI fuselage fan [3], as well as the design elaboration of the PFC turbo-electric power train [4], the FEM analysis-based aero-structural design efforts [5-6], and, the multi-disciplinary aircraft design integration and optimisation work [1,7]. Supported by the work-in-progress detailed design and analysis activities, preliminary aircraft level design and performance results will be presented for the PFC and benchmarked against advanced conventional reference technology.

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Optimality Considerations For Propulsive Fuselage Power Savings

**Arne Seitz, Anais Luisa Habermann, Martijn van Sluis**

Novel propulsion systems and their synergistic integration with the airframe are expected to play a key role in pursuing aviation’s challenging long-term sustainability targets. The recuperation of aircraft skin-friction-induced flow momentum via Boundary Layer Ingesting (BLI) propulsion – the so-called wake-filling propulsion integration – is considered to be technological enabler for strong improvements in overall vehicular propulsive efficiency. Long known from the field of marine propulsion, the positive effect of wake-filling on propulsive power requirements is also applicable to airborne systems [1-7]. The most interesting airframe component for wake-filling propulsion integration is the fuselage due to its large share of aircraft overall viscous drag. The most straightforward way of tapping the full fuselage wake-filling potential (360° installation) can be realised through a single BLI propulsor encircling the fuselage aft-body, also known as Propulsive Fuselage Concept (PFC) [8]. A first multidisciplinary design study of a PFC systems layout for large transport category aircraft was performed as part of the EU-FP7 DisPURSAL project [9]. During the ongoing EU-H2020 CENTRELINE project, the PFC proof-of-concept and initial experimental validation is pursued [10]. In both projects, preliminary CFD simulation-based PFC aeroshaping and power train conceptual elaboration have been performed for a wide-body aircraft application scenario featuring a standard payload capacity of 340 passengers. The PFC aircraft configurations in both
cases, feature two underwing podded power plants together with the aft-fuselage BLI fan. While in DisPURSAL the fuselage fan was powered by an independent third gas turbine engine, the CENTRELINE fuselage fan is powered through turbo-electric offtakes from the wing-mounted main engines.

The present paper discusses optimality constellations for PFC aircraft design under special consideration of different fuselage fan power train options. In particular, optimality with regard to the split of shaft power between the fuselage fan and the underwing main fans is investigated. Therefore, the cruise power saving potentials of PFC aero-designs developed during DisPURSAL as well as preliminary design solutions from CENTRELINE are presented and analysed. The power savings are expressed in terms of the Power Saving Coefficient (PSC) initially proposed by Smith [3]. The studied PFC designs cover broad ranges of key design parameters such as fuselage fan size, longitudinal positioning and design pressure ratio, as well as, the split between fuselage fan and overall fan shaft power. Starting from a purely aerodynamic viewpoint with ideal inner efficiency of the propulsion system and no weight implications considered, the scope of the PSC analysis is systematically increased by incrementally adding realistic losses in the BLI propulsor power train and component weight implications. Finally, the PSC optimality is parametrically analysed against variations in fuselage fan power train efficiency, systems weight impact and fuselage-to-overall aircraft drag ratio in cruise.

The aerodynamic data basis of the analysis is formed by 2D-axisymmetric RANS-CFD simulation results of the bare PFC configuration, i.e. the fuselage body including the aft-fuselage propulsion system, performed for typical cruise conditions at zero angle of attack. The CFD results from DisPURSAL refer to simulations performed by ONERA using the “elsA” software [11], while the CENTRELINE-specific CFD results have been produced by TU Delft using ANSYS Fluent®. In order to map the CFD simulation-based aircraft properties to the PSC metric, a compact analytical approach is formulated in the paper. All assumptions necessary in order to apply the presented evaluation approach are introduced and discussed. This includes explanation of the employed system efficiency definitions as well as the drag/thrust bookkeeping standards. Together with the methodology and analysis results, the paper provides basic cruise drag breakdowns of the DisPURSAL and CENTRELINE reference aircraft together with the CFD-computed drag and fuselage fan disk force values for selected PFC design cases.

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Definition of the the CENTRELINE reference aircraft and power plant systems

**Fabian Peter, Julian Bijewitz, Anaïs Habermann, Kay Plötner, Arne Seitz, Florian Troeltsch**

Within the CENTRELINE project, the proof of concept of the Propulsive Fuselage Concept (PFC) with an entry into service year of 2035 will be demonstrated. The content of this paper describes the activities in Task 1.1 “Application scenario and reference aircraft” as part of the first work package in the EU H2020 project CENTRELINE [1]. In order to assess the PFC concept under realistic design and operational conditions, a well-suited application scenario is required. For the PFC environmental benchmarking
against the targets defined by the European Strategic Research and Innovation Agenda (SRIA) [2], a sound baseline representing typical year 2000 standards is necessary. An analysis of the air traffic demands and aircraft market segment trends for a target propulsive fuselage aircraft entering the market in the year 2035 is presented, showing the market forecast and a very strong influence of the intercontinental traffic between Europe and Asia. Broad potential for an application in 2035 is identified for a design mission with 340 passengers and 6500 nm range. A suitable set of top level aircraft requirements is compiled, based on an existing aircraft design with best possible data availability and similarity concerning the design mission requirements. This aircraft was determined to be the Airbus A330-300 equipped with Rolls-Royce Trent 700 series power plants. For a fair comparison, an appropriately stretched model of the A330-300 is deduced and the maximum take-off weight increased, in order to match the 2035 design mission. The resulting configuration represents a suitable year 2000 reference (R2000) including a propulsion system suitable for SRIA benchmarking purposes. As an enabler for a sound comparison of the PFC aircraft, a realistically advanced technology scenario for the year 2035 reference aircraft (R2035) is developed. Both reference aircraft are a key part in the CENTRELINE technology assessment process. The R2035 reference aircraft is derived from the R2000 by insertion of advanced conventional technologies and family concept considerations are taken into account. A shrink baseline and a stretch version of the R2035 are designed, which share common components and an advanced propulsion system featuring geared turbofan engines with ultra high bypass ratio in excess of 16 together with correspondingly advanced component technologies. In results, the R2035 baseline design has a block fuel reduction for the design mission of over 20% compared to the R2000 aircraft.

**Experimental and Computational Analysis of Model Support Interference in Low Speed Wind Tunnel Testing of Fuselage Boundary Layer Ingestion**

**Biagio Della Corte, Andre Augusto Viviani Perpignan, Arvind Gangoli Rao, Martijn van Sluis**

Experimental simulations of aircraft models in wind tunnel is a complex endeavour, especially in terms of applying wind tunnel corrections for accurate thrust to drag bookkeeping. The current paper discusses some of the practical aspects of wind tunnel testing encountered during the experimental investigations of an aircraft model using boundary layer ingestion being investigated within the EU supported Centreline project, at the Delft University of Technology

One of the main uncertainties during the testing is caused due to the interference between the model support and the aircraft model. Usually, when aircraft model are experimentally tested, the support is placed at the aft, since the areas of interest are typically on the fore, such as the effect of control surfaces, or simply the measurement of forces of the entire model. However, the study of the fuselage boundary layer ingestion shifts the interest to the aft. The configuration related to the present study has a propulsive device located at the aft of the fuselage that aims at evaluate the effect of the BLI propulsor on the fuselage and vice-versa in order to quantify the wake energy in such configurations. Therefore, the model support cannot be placed at the aft and any other position will create a certain degree of flow disturbance in the area of interest. In the current experiments, the support needs to be positioned approximately at the half of the fuselage’s axial length, orthogonally, due to structural reasons. In order to quantify and minimize the interference between the model and its support, RANS CFD simulations were performed to evaluate how and to which extent the support interferes with the flow at the investigation plane where BLI is supposed to take place. After a comparison between CFD and experimental data of the baseline geometry was performed for validation and further understanding of the interference, modifications on
the geometry were computationally tested. The variations in the interference drag and the flow distortion for different supports were compared and analysed. The results show that interference and distortion in the flow field can be reduced to some extent by modifying the geometry of the junction between the support and the model, by placing a dummy support with the same geometry placed diametrically opposed to the support.

This work was conducted within the CENTRELINE project, which has received funding from the European Union’s Horizon 2020 research and innovation programme under Grant Agreement No. 723242.

**Sizing of hybrid-electric propulsion systems**

*Stefan Biser, Guido Wortmann, Swen Ruppert, Alexander Zakrzewski, Mykhaylo Filipenko, Mathias Noe, Martin Boll*

The optimal configuration of a hybrid-electric propulsion system is not necessarily the result of an optimization of its single components without their interdependencies. For example, minimizing the mass of an electric machine by enhancing the electric current density results in an increased cooling effort and thus higher weight of the cooling system.

So far, it is computationally expensive to optimize the drive train’s composition while at the same time proving the component’s feasibility. To realize this for a large bandwidth of power classes and mission profiles, analytical models of the components are developed which describe the scalability of physical properties by considering the requirements of the whole system.

Here we present how this approach has been used to optimize the fuselage fan drive unit for the hybrid-electric aircraft design of the CENTRELINE project.

Part of this work was conducted within the CENTRELINE project, which has received funding from the European Union’s Horizon 2020 research and innovation programme under Grant Agreement No. 723242.
ACASIAS overview

J. Verpoorte, H. Schippers

The goal of the EU Horizon2020 ACASIAS project is to reduce the environmental impact of aircraft by improving aerodynamics and reduction of the weight of the aircraft. ACASIAS is an acronym for Advanced Concepts for Aero-Structures with Integrated Antennas and Sensors.

The ACASIAS project brings together numerous partners from aircraft industries, research institutes and SMEs. The partners have complementary skills, high-level knowledge and technologies to solve multidisciplinary issues concerned with the development of four innovative aero-structures with additional functionalities:

1. A novel fuselage panel for the integration of an opto-electronically steerable Ku-band antenna for satellite communication;
2. A smart fuselage panel with integrated sensors and actuators for reduction of cabin noise that will enable the integration of new and efficient but noisy propulsion systems;
3. A smart winglet with an integrated VHF communication antenna;
4. A smart fibre metal laminate fuselage panel that integrates a GPS patch antenna and a VHF slot antenna.

These innovative structures will replace protruding antennas and large radomes for the installation of satellite communication antennas. The fuselage panel with integrated sensors and actuators for reduction of cabin noise will enable the integration of new and efficient but noisy propulsion systems.

The novel ACASIAS structures with embedded functions will certainly reduce the fuel consumption of future aircraft and will thus reduce CO2 and NOx emissions by aircraft and will, therefore, make aviation more sustainable in the future.

The ACASIAS project is now 2 years underway. This overview will present the innovative structures and will address the benefits of the structural integration of antennas.

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Integration of VHF and GNSS antennas in a Fibre Metal Laminate fuselage panel

Y. Konter, C. Heuts, C. van Hengel

This paper will outline aspects, outcome and prospects of full integration of two types of antennas into a representative fuselage panel of aircraft, from an antenna design perspective. Full integration in this respect means making the antenna function an integral part of the structure that fulfils a load-bearing function. Conventionally, antennas are installed as separate components onto the exterior of fuselages. Thus, they will produce aerodynamic drag by protruding into the airflow over the fuselage skin during
flight. Conformal integration of antennas into the fuselage skin will smooth the fuselage skin, and therefore minimize aerodynamic drag. The protruding antennas are conducting structures on which electric currents flow. These changing electric currents induce electric and magnetic fields (electromagnetic waves). Fibre Metal Laminate (FML) is a composite aircraft construction material, consisting of metal layers that are bonded with fibre layers and resin to form a cohesive laminate. Since the core fibre layer within the laminate is electrically insulating, exciting the metal layers with an RF voltage could create electromagnetic fields and thus the layers could act as an antenna. Especially (stacked) patch antennas, e.g. as used for GNSS reception, could be well implemented in FML. Instead of using the metal as a radiating antenna, a slot could be used as an antenna. By exciting the slot with a changing voltage, the slot will also radiate electromagnetic fields. The slot antenna is actually the complement of a dipole antenna. A slot antenna could be used for VHF communication. Research and investigation has been undertaken for this subject in order to respond to the demand and wish of aviation industry for more energy efficient aircraft. The focus has been to use the mechanical properties of FML and combine these with the functional needs of antennas, whilst not disturbing the fuselage exterior. To this end, two types of antennas are considered: a stacked patch GNSS antenna and a VHF slot antenna. The designs enable integration within an aircraft fuselage skin. These antennas are used for different applications in terms of operating frequency and direction of radio wave propagation. The paper will not only describe the design, but also discuss the characteristics thereof that led to the ultimate design; such as limitations and constraints found, and compromises and mitigations taken. Initial simulations and breadboard tests showed promising results that will be validated during antenna performance testing.

Towards application of flexible printed circuit boards into aircraft structures

Victor Lung'aho, Philip Johnston

Flexible printed circuits (FPC) can be used to replace electrical wiring interconnect systems in order to save weight, save space, and improve electrical performance. Improved Harness Technology (IHT) is a patented process, developed by Trackwise, that provides the ability to create multi-layer FPCs of unlimited lengths. These flexible circuits can be used as a replacement for the conventional wire harness.

Flexible printed circuit boards can be manufactured at thicknesses lower than 50um. A bundled wire harness with a large diameter can instead be converted into a flat plane of interconnects. This flat, planar nature of flexible circuits makes them suitable to be bonded and/or embedded within the structure they are mounted on, be it wall or chassis.

The ACASIAS project benefits from the characteristics described above, with low weight and the planar nature important factors required within the aerospace industry.

An FPC antenna was designed and manufactured as part of the ACASIAS project for the development of a smart winglet with structurally integrated notch antenna. The performance was tested and verified against simulated results. The advantages of this antenna include:

- Full flexibility - allowing the notch structure to be as complex as possible as the FPC will confirm to any shape.
- Lightweight – Multiple material choices available for FPC manufacture. Total thickness of less than 0.2mm.
Open ended design – The IHT technology allows for any antenna design to be implemented to a high degree of accuracy of copper planes (±0.02mm).

Alongside the FPC notch antenna, the flexible circuit technology was also used in the development of power and data transmission lines for a smart active acoustic lining panel. Sensor and actuator test lines, with various shielding arrangements, have been designed and manufactured for communication and power transfer. Previous test coupon experiments have found that the capability to produce such low weight, low thickness and high flexibility circuits bodes well with the requirements of integration into structures.

The ability to control the build and uniformity of the flexible printed circuit, allows interconnects to be designed for any specified characteristic impedance. Testing by IMST GmbH has shown flexible circuit transmission lines to be suitable at the frequencies required and research and testing still continues to reduce losses and improve signal quality of flexible transmission lines.

Data transmission along flexible printed circuits is being used in the smart acoustic panel and the redevelopment of the notch antenna structure. For the notch antenna structure, designing and testing of a ‘feed line’ is ongoing. The ultimate aim will be to produce a complex multilayer antenna with the feedline as one piece to reduce the losses and interference that would be observed by using a connector.

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Remote Sensing for a Lining Integrated Active Structural Acoustic Control System

Malte Misol, Stephan Algermissen

In the framework of the EU project ACASIAS an aircraft sidewall panel (lining) with structurally integrated actuators and sensors is developed. Each lining has a digital unit which samples the sensor signals, performs filtering operations and supplies the actuators with control signals. The whole system makes up an active structural acoustic control system aiming at the reduction of low-frequency multi-tonal aircraft interior noise. The novelty of this approach compared to past implementations of active noise control (ANC) systems in aircraft is its modularity. Each so-called smart lining is autonomous in the sense that it processes only structural sensor data from its own integrated sensors. The use of external microphones for error sensing is avoided because this conflicts with the modularity of the smart lining. Hence, one important design task is the replacement of the physical error microphones by the integrated structural sensors and an acoustic filter (observer) running on the digital unit. This method, which is called the remote microphone technique for active control, has never been applied to an aircraft interior structure so far.

The detailed design of the smart lining module comprises several steps which are taken within work package 3 of the ACASIAS project. Experimental data of an aircraft typical double panel system is captured in a sound transmission loss facility. The system is excited with a loudspeaker array placed directly in front of the fuselage structure. Different acoustic load cases are used for the definition of the sensors and the actuators. A multi-tonal excitation with high sound pressure level is relevant for the actuator dimensioning and a broadband excitation with multiple independent sound sources is relevant for the sensor definition.
19 accelerometers are mounted on the lining and 20 microphones are placed in front of it. All sensor signals are sampled simultaneously for deterministic and broadband load cases. The lining is equipped with two inertial mass actuators which are used for the active control. Measured frequency response functions of actuators at 39 positions are used for the optimization of the actuator locations. The measurement data is also used for the derivation of an observer and for the simulation of a smart lining with remote microphones.

In this contribution, the steps undertaken for the detailed design will be described and simulation results of the noise reduction performance of the smart lining with remote microphones will be presented.

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Towards a Lining Integrated Active Structural Acoustic Control System

Stephan Algermissen, Malte Misol, Alexander Kokott, Thomas Haase, Kai Gonet, Victor Lungaho

For future aircraft counter-rotating open rotor (CROR) engines are a promising technology to reduce their CO\textsubscript{2} footprint. Since the contribution of CROR engines to the cabin noise is higher than for jet engines, new strategies for the reduction of noise transmissions for frequency bands below 500 Hz are necessary. Active structural acoustic control (ASAC) systems are capable to reduce sound transmission of lining structures in this bandwidth. Sensors measure the vibrations of the lining to estimate its sound emission into the cabin. Based on these signals a controller calculates force signals for actuators on the lining. The actuator forces change the vibration behaviour of the lining in order to reduce its sound emission. For the realization of such a system in a real aircraft, manufacturing and maintenance issues have to be addressed.

Within work package 3 of the EU project ACASIAS an aircraft lining with an integrated ASAC system is developed. The size of the lining is app. 1300 x 1690 mm\textsuperscript{2} (W x H) and it is simply curved. The radius of 2980 mm makes it relevant for a twin-aisle aircraft like the Airbus A350. The focus of research activities lies on the integration of components and the industrial manufacturing process of the lining. The components to be integrated are sensors, actuators and the corresponding wiring. A concept is proposed where each actuator and sensor is encapsulated in a kind of insert. The inserts smoothly integrate into the manufacturing process of the lining while they protect the actuators and sensors from humidity, dust, etc. The maintenance aspect is covered by the option to change each actuator or sensor upon insert level. The integrated wiring of the lining is left unaffected during an actuator or sensor replacement since connectors in each insert allow a nearly tool-free assembly/disassembly.

In this paper the progress of work package 3 is presented at a detailed design review (DDR) stage. Finally, the lining will be manufactured and equipped with a full ASAC system. Experiments will be conducted in the acoustic transmission loss facility at the DLR.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 723167.

Integration of a Ku-band satcom antenna array in a composite fuselage panel

J. Verpoorte, M. Martinez
The main objective of the ACASIAS project is to contribute to the reduction of energy consumption of future aircraft by improving the aerodynamic performance through conformal and structural integration of antennas that are normally protruding. This paper deals with the conformal integration of an electronically steerable a Ku-band antenna for satellite communication, which does not require anymore a protruding radome.

In the ACASIAS project a novel composite stiffened orthogrid fuselage panel is developed for integration of Ku-band SATCOM phased array antenna tiles. The Ku-band antenna tiles to be integrated are based on the antenna tiles that were developed in a previous FP7 project called SANDRA. In the SANDRA project the focus was on the functional performance of the antenna tiles. In the ACASIAS project the focus will be on the integration of the antenna tiles in a fuselage panel, taking into account integration aspects like thermal control and lightning protection. Structural aspects of the composite fuselage panel will be presented. The ribs of the orthogrid will be made of Carbon Fibre Reinforced Plastic (CFRP), while the skin will consist partly of CFRP and Glass Fibre Reinforced Plastic (GFRP). The GFRP skin is necessary to enable the electromagnetic radiation from the antenna underneath it.

A complete array of 24 antenna tiles will be designed and manufactured. However, not all tiles will be real antennas. Some tiles will only have passive components (with heating resistors) and will not operate as an antenna. The thermal behaviour of these dummy tiles will be representative for the real antenna tiles with active electronic components producing heat. The antenna tiles will have built-in cooling solutions.

The radiation pattern of the array antenna will be determined by the layout of the antenna tiles and the separation between the antenna tiles. Too large a separation may introduce grating lobes in the radiated pattern. Therefore the thickness of the ribs of the orthogrid has to be taken into account in the design of the antenna array. In addition, the influence of the material of the ribs on the radiation pattern has to be taken into account. The CFRP ribs of the orthogrid are conductive. In the design of the antenna elements and antenna tiles the conductivity of the ribs will have to be taken into account, especially under scanning conditions of the antenna. The skin of the fuselage panel above the antenna tiles is transparent to enable the electromagnetic radiation by the antenna. Therefore the complex permittivity of the GFRP material will be determined to assess the transmission, reflection and absorption properties of the GFRP skin for Ku-band waves.

The lightning protection for the antenna will be applied in two stages: The antenna elements will have both stacked patches grounded using a connecting via in the centre of the patch. In this location the grounding via will have no influence on the electromagnetic performance of the antenna element. In addition some kind of lightning diversion will be added to the non-conductive GFRP skin. The influence of the lightning diverters on the performance of the satcom antenna will be taken into account in the design.

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The importance of advanced characterisation in various stages of modern manufacturing

Amin Azar, Spyros Diplas

In recent decades, significant improvements have been achieved in developing advanced characterisation and testing of materials at the lab scale based on spectroscopic and imaging techniques. Advances in manufacturing such as production digitisation via additive manufacturing and the need to accelerate product upscaling, necessitate the development of in-situ, in-/on-line and real time characterisation methods. In this presentation we will show a few examples that emphasise the importance of advanced characterisation in controlling digitised manufacturing processes. The examples will highlight the necessary synergy between lab-based and industrial scale characterisation in achieving process and product optimisation.
Estimation Of Performance Parameters Of Turbine Engine Components Using Experimental Data In Parametric Uncertainty Conditions

Radosław Przysowa, Khustochka Oleksandr, Sergey Chernysh, Sergiy Yepifanov, Ugryumov Mykhaylo

Gas Path Analysis and matching turbine engine models to experimental data are inverse problems of mathematical modeling which are characterized by a parametric uncertainty. It results from the fact that the number of measured parameters is significantly less than the number of components’ performance parameters needed to describe the real engine. In this conditions, even small measurement errors can result in a high variation of results, and obtained efficiency, loss factors etc. can appear out of the physical range.

The current methods of engine model identification have developed considerably to provide stable, precise and physically adequate solutions. In this work, an estimation method of engine components’ parameters based on multi-criteria identification is presented, which provides stable estimations of parameters and their confidence intervals with known measurement errors. A priori information about the engine, its parameters and performance are directly used in the identification procedure. The mathematical basis for this approach is the fuzzy sets theory.

The paper presents new methods for setting a priori information about the engine and its performance in view of fuzzy sets, forming objective functions and scalar convolutions synthesis of these functions to estimate gas-path components’ parameters. The last method is based on W.R. Ashby’s Law of Requisite Variety, on A.N. Kolmogorov’s Mean Value Concept and on the Maximum Likelihood Principle. The distance between two multidimensional samples of experimental data is characterized by Student’s and V.I. Romanovsky’s statistics. This helps structure preferences of Decision Maker for multi-criteria estimation tasks in determined (MV) and stochastic (MH) formulations.

The comparison of the proposed approach with traditional methods showed that its main advantage is high stability of estimation in the parametric uncertainty conditions. It reduces scattering, excludes incorrect solutions which do not correspond to a priori assumptions, and also helps to implement the Gas Path Analysis at limited number of measured parameters.

We discuss the challenges related to different tasks for which the method can be used: matching thermodynamic models to experimental data, Gas Path Analysis and also adapting dynamic models for the needs of the engine control system.

Optimal Propeller Selection By Means Of Pareto Sets

Svatomir Slavík, Jan Klesa

Selection process of the propeller for short take-off and landing (STOL) category aircraft is described. The aim is to achieve the highest possible performance with fixed propeller. The requirements are following: high maximal horizontal and cruise speeds, short take-off, high rate of climb and fixed propeller. These requirements are contradictory and so Pareto sets were used in order to find the optimal propeller.
The method is applied for a family of geometrically similar propellers that are suitable for 73.5 kW (100 hp) piston engine designed for ultralight category aircraft with maximal take-off weight 472.5 kg. The propellers have from two to eight blades, blade angle settings from 15° to 40° and diameter from 1,1m to 2,65m. Pareto frontier is designed for each couple of parameters and the optimal propeller is selected according to these results. For comparison, the optimal propeller selection from the propeller family by means of a standard single-optimal process based on the speed power coefficient cs is also used.

Using of Pareto sets leads to considerable performance increase for the set of contradictory requirements. So, high performance power system with low price (fixed pitch propeller) for STOL category aircraft can be designed. The described method can be used for the propeller optimization in similar cases.

**An Influence Of Shroud Design Parameters On Static Stress State Of Blade Assemblies**

*Kyrylo Savchenko, Anatoliy Zinkovskii, Romuald Rzadkowski, Radoslaw Prsysowa, Vadym Kruts*

Reduction of blade vibration is an important task in high-performance turbomachinery in order to avoid the risk of blade failures during the engine operation. One of the most efficient methods of the blade vibration reduction is the use of structural damping, through shroud coupling, underplatform dampers, and blade-disc joints. In the case of shroud coupling, the main attention in the design is directed to modeling and determination of the influence of contact interaction between the shrouds on the stress state of blade assemblies.

In this study, the structural analyses of the blade assemblies were carried out using the finite element method to determine the influence of design parameters of shroud couplings on the static stress state in a turbine rotor blades. In these analyses, both centrifugal force and high temperature caused by the gas flow were considered.

Two blade rings, one that included the blades which have a zigzag pattern, and the second that has a slant shroud coupling were used to perform the computational analyses. An angle of inclination of the shroud contact surfaces with respect to the rotor rotation axis was selected as the design parameter.

Based on the calculation results it has been found that irrespective of the type of the shroud coupling, the values of the contact pressure and the stresses in the shroud increase with the angle of inclination of the contact surfaces.

Also, for the slant shroud coupling, the stresses increase in the blade airfoil portion with the increase of angle of inclination of the contact surfaces, while for the zigzag shroud coupling the contact stresses decrease with the increase of this angle.

It was concluded that the zigzag shroud coupling causes the increase in static stresses when compared to the slant coupling.

**F100-PW-229 Engine Fault Detection Based On Real Time Data**

*Ioannis Templalexis, Vasileios Kolios, Ioannis Templalexis, Ioannis Lionis, Manolis Antonogiannakis, Petros Kotsiopoulos*

Gas turbine engines, exhibit very high maintenance costs. Moreover, in the case of aero applications, an in-flight engine incidence shall by all means be avoided, a condition that drives total maintenance costs even higher. A measure in favor of balancing these costs is to monitor continuously the variation of engine performance data recorded during flight, establish methods to deduce useful information regarding the
engine “health” status and, as a result, take appropriate actions to maintain a good engine operating condition. The current work presents such a method tailored on the “F100-PW-229” engine that is operated by the Hellenic Air Force as the propulsion system of the “F-16 block 52M” aircraft. CEDATS and MS Excel were the computational tools used for the current engine performance study. CEDATS is a software developed for the engine users. It provides basic data trend monitoring functions and engine fault warnings. It is well known that there is always space for improvement for such health monitoring tools since there are cases where engine operating faults are not captured. Within the frame of the current work, a data post-processing method on the engine performance data time series was applied using MS Excel, in order to raise early warnings of an uncaptured compressor operating fault.

**High Temperature Combustion Oxidation Mechanisms Control And Refinement**

*D.A. Dolmatov*

The various mechanisms of high temperature slow and intermediate hydrocarbon oxidation processes have been researched. There were studied and described several crucial points for thermal, oxygen and excited particle stimulation methods success.

The advanced methods of flame structure, speed and species profile for high temperature combustion chambers of gas turbine engines were developed. There are presented the results of numerical studies of stimulated flame with increased speed of key oxidation mechanisms and additional combustion mechanisms with decreased flame length and reduced pollutant emission level.

The proposed methods are applicable for several types of existing and new developing gas turbine engines with high temperature of combustion for increasing combustion chamber performance and decreasing of nitrogen oxides emission level.

**Determination Of Serviceability Limits Of A Turboshaft Engine By The Criterion Of Blade Natural Frequency And Stall Margin**

*Yaroslav Dvirnyk, Dmytro Pavlenko, Radoslaw Przysowa*

The work aims to improve the accuracy of maximum serviceability limits’ evaluation for helicopter engines operating in a dusty environment. The paper analyses the health and performance of 12-stage axial compressor of the TV3-117VM/VMA turboshaft. Forty engines have been inspected to study the process of dust erosion. For each stage, the dimensions of ten blades are measured and averaged. In total, 4800 blades have been inspected and analysed to model the wear process.

A high coefficient of cross correlation (R> 0.856) is observed between the degree of wear of the blades of the stages 2-12, which is the result of the homogeneity of the processes leading to wear. The corresponding value of the correlation coefficient for 1st stage blades does not exceed 0.4. The blades of 1st and 6th stages are exposed to the maximum wear. The nature of damage to the blades of these stages is different.

Given the tight correlation between the dimensions of the blades of the stages 2-12, it is possible to estimate the degree of wear of blade of any stage using regression analysis. In this case the value of wear of the peripheral chord of the 6th stage blade is used as an independent variable. Functions of wear of the blade profile of 2nd to 5th and 7th to 12th stages from the degree of wear of the blades of the 6th stage are approximated by the linear dependence.
The regression analysis of maintenance data has been used to model the wear of blade chord of the 6th stage, which is the polynomial function of the operating time and dust concentration.

Compressor blades of the modern gas turbine engines are characterized by a thin profile and relatively low rigidity, therefore, oscillations represent a major danger to them. The evaluation of the maximum serviceability limits of blades on the criterion of detuning their natural vibration frequency from potentially dangerous harmonics was carried out on the basis of numerical modal analysis using ANSYS software.

Based on the Campbell diagram, the potentially risky modes of blade vibration which may enter the resonance excited by harmonics related to the uneven flow of air stream, are determined for all the compressor stages. The reduction of the chord profile of the 1st-stage blade in the tip part by 4.2 mm contributes to the appearance of resonance due to the coincidence of one of the modes of natural oscillation with the 30th harmonics, where 30 is the number of vanes of Inlet Guide Vanes and 3rd stator stage respectively.

As a result of gas dynamics calculations of the compressor, it has been found that as the degree of blade erosion increases, the value of air pressure ratio in the compressor and the air flow reduces, which affects compressor maps and the stall line. Operation of the TV3-117 turboshaft in a dusty environment leads to a compressor stall margin decrease by 15 - 17% due to the wear of the blade chord in the tip section of the 6th stage by 6.2 mm. Such a loss of stall margin indicates the appearance of a permanent stall at 770 ... 790 flight hours.

As a result of the comprehensive study of the TV3-117 axial compressor, the guidelines to maintenance and repair organisations concerning the maximum serviceability limits of turboshaft engines operated in a dusty environment are developed.

**Dynamic performance simulation and control of an aeroengine by using NARX models**

*Maria Grazia de Giorgi, Antonio Ficarella*

Dynamic aero-engine model plays a key role in the design of engine control systems. Moreover, modeling of the engine using performance simulations is an important step in the design process in order to reduce costs, decrease accident risks and shortening development period. In the literature, parameters such as engine fan speeds, vibration, oil pressure, oil temperature, exhaust gas temperature (EGT), and fuel flow are used to determine performance deterioration in gas turbine engines. In this study, a new model was developed to get information about the gas turbine engine’s condition. For this model the artificial neural network (ANN) method was used in the identification of the most important engine performance parameters.

The study addresses the challenge of setting up robust and reliable NARX models, by means of a sound selection of training datasets and a sensitivity analysis on the neural network parameters.

The data used for model training are time series datasets of several different maneuvers, which have been created using a gas path analysis, to simulate the transient behavior of the engine.

At the end of the study, a network that predicts the engine parameters in transient operations with the smallest margin of error has been developed.
Assessment Of The Shear Properties Of Thermoplastic Composites Using The ±45 And The V-Notched Rail Shear Method

Antonios G. Stamopoulos, Antoniomaria Di Ilio, Luca Glauco Di Genova, Alfonso Paoletti

Composite materials consisting of thermoplastic matrix and glass fibers are catching on both in aeronautics and automotive industry as they comprise a series of advantages regarding their mechanical performance and their recyclability. Nevertheless, some notable drawbacks have been noticed related to the fabrication process affecting their in-plane shear properties. For assessing the in-plane shear behavior of composite laminates, a relatively high number of standards have been proposed. Each of these testing methods appear to have several advantages and drawbacks mostly related to the way the load is applied, the stress uniformity and the applicability to various material architectures. In the present work, the modified V-Notched Rail Shear and the ±45° shear testing methods are applied to short and textile glass fiber reinforced thermoplastics aiming to assess the effect of the fabrication method and the fiber strands direction both at ambient and higher temperature. Consecutively, the results obtained from the two different testing methods are compared revealing a relatively good agreement while, in parallel, the stress uniformity and the local failures observed on the specimens are analyzed.

Arrestment Of Cracks In Plane Extension By Local Rectangular And Semi-Annular Patches

Dimitris Zacharopoulos, Panagiotis Charitidis

Crack stoppers ahead of a crack tip in plane panels under tensile load are analyzed. They consist of rectangular and semi-annular patches placed symmetrically on both sides of the panel and at a finite distance ahead of the crack tip. Depending on this distance, the predicted crack path could remain straight or curve. For sufficiently low local energy intensity, the crack would run straight and arrest at the patch regardless of the other variables. As the local energy intensity is increased, crack would tend to curve and lead to complete fracture of the patched specimens. This is equivalent to moving the patch closer to the crack tip. The test results agree well with the predictions made from the strain energy density theory.

Numerical Evaluation Of Crack Stopping Mechanisms In Composite Bonded Joints Due To The Presence Of Corrugation And Bolts

Konstantinos Tserpes

In this paper, the crack stopping mechanisms in corrugated composite bonded joints and hybrid bonded/bolted joints were evaluated numerically using the cohesive zone modeling approach. For the study, the DCB (double-cantilever beam) and the CLS (crack-lap shear) specimens were modeled. The first two specimens were subjected to static loads and the latter both to static and fatigue loads. The analysis was performed using the LS-DYNA explicit FE code. Fatigue crack growth simulation was performed using an in-house developed user-defined subroutine (UMAT). All FE models before being used have been validated against tests. The numerical results reveal a crack stopping in the corrugated DCB, no crack stopping in the corrugated CLS and a reduction of crack growth rate in the bonded/bolted CLS for both
static and fatigue loads. The methods and the findings of the present study can be used for the design of crack stopping features in adhesively bonded primary composite aircraft structures.

**Mechanical Characterization Of Woven Thermoplastic Polymers For Aerospace Applications**

*T. S. Plagianakos, K. Munoz, D. Saenz-Castillo, M. Mora-Mendias, M. Jimenez, V. Prentzias*

Continuous-fiber reinforced thermoplastic composites are gaining attention in the aerospace industry for exhibiting advantages compared to thermoset composites, such as: Design and manufacturing flexibility including multiple post-forming processes and capability of being processed by a large range of traditional machining methods, fast cycle time and recyclability. As far as their mechanical performance is concerned, their enhanced impact resistance is a very attractive feature for selecting them in demanding lightweight applications. Moreover, in woven ply configurations they yield less anisotropic mechanical properties, which could be desirable in the context of conceptual design.

In the present work an extensive test campaign is performed for assessing the mechanical properties of a high-performance woven carbon-fiber reinforced thermoplastic material. Material characterization has been achieved by conducting static and fatigue tests according to ASTM standards, such as tension, compression, in-plane and interlaminar shear, flexure, open- and filled-hole tension and compression, Mode I, II and I/II fracture. Moreover, the effect of ageing is assessed by measuring mechanical properties after specimen environmental conditioning. Selected test cases have been modelled in commercial FE software by means of linear elastic material properties in order to determine the limitations of such a modelling approach.

The current work has been performed in the context of SHERLOC, a project belonging to the Clean Sky 2 JU. The purpose of the project is to perform a down selection of most advanced composite materials, manufacturing processes and Structural Health Monitoring (SHM) systems that contribute towards a Condition-Based Maintenance. The presented test campaign is part of a comparative analysis and down selection of the materials that will be applied in the regional aircraft fuselage concept developed in Clean Sky 2.

**Green Regional Aircraft, Structural Design And Manufacturing Of Composite Spars For Wingbox Ground Demonstrator**

*Evgenios Louizos, S. Strapatsakis, E. Karachalios, A. Makrikostas*

Aircraft weight reduction is effective for achieving both lower emissions and lower noise on the community around the airports. Development and demonstration of technologies on advanced metallic and composite structures will be envisaged in the future regional aircraft. In particular in the current design approach of composite structures their sizing is based on material mechanical properties that are degraded to account for the negative effects of humidity and temperatures and for foreign objects impacts occurring during the aircraft operation. Monitoring of actual events occurring to each aircraft, which would be made feasible by sensors embedded in the structures, and the immediate maintenance action consequent to damage detection, will allow a different design methodology in which less degradation is to be considered, with a resulting lower weight.
In the present work the structural design and manufacturing of composite Front and Rear spars as parts of a Central Wingbox full scale ground demonstrator is presented.

The current work has been performed in the context of GRA (Green Regional Aircraft), a project belonging to the Clean Sky JU. The objective of the GRA – Low Weight Configuration was to validate and demonstrate the technologies best fitting the environmental goals set for the regional aircraft entering the market in the following years.

Low weight aircraft configuration has developed the advanced solutions of composite structures with embedded sensors and advanced materials and architectures used to obtain the load carrying capability plus the ancillary functions expected by the different elements of the structure at a weight significantly lower than using current technology.

The relevant technologies that, after the maturation obtained in the first years of the project, have been selected as the most appropriate in terms of benefits and costs for future regional aircraft, have then been demonstrated in full scale ground tests.

**Design, Analysis, Manufacturing And Ground Demonstrator Testing Of Pressure Bulkheads**

*E. Karachalios, E. Carelas, A. Makrikostas, D. Habas*

In the context of the Green Regional Aircraft (GRA) Low Weight Configuration (LWC) domain a Fuselage Barrel Ground Demonstrator (FBGD) has been designed, manufactured and tested on ground.

Part of the FBDG were the two pressure bulkheads that are attached to the ends of the fuselage structure so that pressurization load can be applied during the ground demonstrator test.

In the present work the various steps followed respective to design, stress analysis, manufacturing (including also the tooling) and testing of the pressure bulkheads will be presented.

Two pressure bulkhead parts were manufactured; one of the two bulkheads has also an access door of appropriate dimensions in order to allow for access inside the ground barrel demonstrator during the testing phase.

The bulkhead parts were manufactured by using OoA carbon epoxy pre-pregs (Vacuum Bag Only prepregs), stiffened with honeycomb filled Ω-shaped stringers. Parts were cured in a standard oven with application of vacuum only. A single composite tool was manufactured in order to produce the two bulkheads required. For the bulkhead that requires a door opening cut-out, special provisions were taken into account, locally, so that the respective door part could be produced by using the same tool with minimal modifications. The process for the manufacturing of the composite bulkhead tool was the standard two-step process in which a “male” master model is first designed and manufactured and then a “female” composite tool is produced from the master model.

Design of the bulkheads was performed in CATIA V5, making use also of Composites Part Design (CPD) module for simulating the manufacturing aspects of the work, such as plies layup / draping, flat patterns and final layup integration.
Detail sizing of the parts and respective stress analysis was performed by FEM using MSC/PATRAN/NASTRAN. MSC/Laminate Modeller was employed in order to appropriately account for fibre orientation variations during lay-up operations.

A comprehensive installation of strain gages on test articles, allowed the comparisons between testing and FEM analysis work that will also be presented.

The current work has been performed in the context of Green Regional Aircraft (GRA), a project belonging to the Clean Sky JU.

Enhancing The Translaminar Fracture Toughness With Variable-Axial Composites
José Humberto Almeida Jr, Antonios G. Stamopoulos, Lars Bittrich, Axel Spickenheuer

Given the load-carrying role of fibers in continuous carbon fiber-reinforced polymer (CFRP) composites, the importance of the translaminar fracture behavior for analyzing the damage tolerance in CFRPs cannot be overstated. This work proposes, initially, a framework to optimize the fracture toughness associated with the fiber tensile failure (purely mode I) in a compact tension (CT) specimen allowing curvilinear fibers. The framework is based on the characteristics of the Tailored Fiber Placement (TFP) manufacturing process. The algorithm allows local adjustment of both fiber angle and thickness, which plays a key feature of TFP process, achieved via a smooth placement of the fiber. The objective function is to maximize the mode I energy release rate/mass ratio. The Virtual Crack Closure Technique (VCCT) is employed to model the crack initiation and propagation. Additionally, dry preforms are manufactured via TFP and resin infiltration is performed via resin transfer molding (RTM). Later on, Double Cantilever Beam (DCB) and End-Loaded Split (ELS) tests are carried out to characterize the fracture energies of the composite system used. Key results show that the optimized design, which contains curvilinear fibers and thicker areas at the crack path region, supports a higher ultimate load and greater energy release rate compared to the initial design containing unidirectional fibers (along crack direction) and nominal thickness.

Buckling Solutions Of Stiffened Panels With Varying Degree Of Anisotropy Using The Rayleigh-Ritz Method
D. G. Stamatelos, G. N. Labeas

An energy based solution for calculating buckling loads of partially anisotropic stiffened panels is presented, using a discrete approach for the mathematical modelling of the stiffened panels. The developed formulations extend the Rayleigh-Ritz method and explore the available anisotropic unstiffened panel buckling solutions to interesting cases of anisotropic stiffened panels with varying degree of anisotropy. Moreover, a reference Finite Element (FE) model is developed in order to compare the calculated buckling loads and validate the modelling approach. The assumptions and restrictions of the applied Rayleigh-Ritz method are discussed, such that the limitations of the developed method are identified.

Development Of A Field Repair Procedure For Light Composite Aircrafts
P. Czarnocki, T. Zagrojek, R. Świtkiewicz

The development of a repair procedure for severely damage primary laminate structure of a light aircrafts, e.g. certified in accordance with CS22, is presented. The procedure was developed under the assumption that it would be a field repair carried out by people of average manual skills who had not been trained in
reparis of composite structures. To develop the procedure a typical FG/epoxy laminate glider fuselage was used. The primary objective of the repairs was to restore the original fuselage stiffens, while maintaining possibly low stress concentrations resulting from the repairs. The static tests and FE strength analyses supported the developed repair procedure. To calibrate the FE models the results of previously done static tests were used. Artificial damage of different extents was produced in the fuselage structure and different repair techniques depending on the damage extent were applied, then static tests of the repairs and FEM analyses were carried out. Based on the obtained results finite element procedure was developed which can be implemented in the ANSYS FE code to analyse stress state in the vicinity of the patch and model progressive damage developing at the patch-repaired structure interface for various patch geometries.

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**Dimensionally Stable Laminates Under Thermal Loading And Their Applications**

*Volodymyr Symonov*

There exist many types of structures that are required to have stable dimensions and shape within a wide range of temperatures (thermostable structures). The evident examples of them are reflectors of parabolic antennas, truss structures in space, structural elements of turbine engines, etc. It is known some composite materials have zero or negative thermal expansion coefficients. This specific nature of them allows finding special conditions when the laminate stacking sequence can provide a zero thermal expansion coefficients in one or more directions, which allows the structure being designed to have the same dimensions and shape in a wide range of temperatures.

The article proposes the mathematical expressions for the above noted conditions and provides the examples of thermostable stacking sequences.

As an application of thermostable laminates a thermostable rotating disk is chosen. The mathematical model for such a disk is presented. The model can be used for designing of a thermostable turbine wheel basement. Such a wheel basement can help to reduce the gap between the blades and the outer turbine case what can increase the efficiency of the turbine.

**Lightning And Emc Testing Of A Full Scale Aircraft Cockpit**

*Hugo Tavares, Nelson Matos, Margarida Pinto*

Over the last few decades the role of Carbon Fibre Composites, CFC, has been extended to compose a larger part of modern aircraft materials. The replacement of highly conductive materials by CFC based materials has led to systematic but isolated academic research. This research is typically performed on CFC materials to study either the low frequency high intensity phenomena like lightning, or the low level high frequency phenomena like High Intensity Radiated Fields threats to aircraft platforms. Both areas are important to the evaluation of direct and indirect effects on aircraft platforms and their installed systems. On this paper, an extended electrical test plan is presented, that subjects different CFC materials to low frequency/low intensity/long duration electrical overstress. The goal is to establish long term effects due to low intensity but long duration phenomena on CFC materials and how these affect the electrical and electromagnetic properties of the composites. The variation of electrical conductivity (longitudinal and transversal) to different types of overstress (AC, DC, impulse) is established for different CFC materials to
determine eventual degradation of material electrical and electromagnetic performance. In addition, shielding effectiveness measurements are performed. Finally, electromagnetic simulation models, EM3D, for the estimation of shielding effectiveness of the CFC materials based on the test rig designs used for physical measurements are shown and simulation vs measurement data is compared. As an example, a flanged coaxial test rig model shown below for the evaluation of shielding effectiveness up to 1.5 GHz.

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Mode II Fracture Toughness Of Asymmetric Metal-Composite Adhesive Joints

Panayiotis Tsokanas, Theodoros Loutas, Dimitrios Pegkos, George Sotiriadis, Vassilis Kostopoulos

The present work is a continuation of recent works by the group [1-3]. Here, we experimentally investigate the mode II fracture toughness behavior of dissimilar metal-composite adhesive joints by means of the end-notched flexure (ENF) test. The adhesive joint under study is envisioned to be applied in the hybrid laminar flow control (HLFC) systems of future aircrafts and it consists of a thin titanium sheet and a thin CFRP laminate. Four different industrial technologies for the manufacturing of the joint are evaluated; co-bonding with and without adhesive and secondary bonding using either a thermoset or a thermoplastic composite. First, the vacuum-assisted resin transfer molding (VARTM) technique is employed for the manufacturing of the titanium-CFRP joint. After manufacturing, the joint is stiffened from its both sides with two aluminum backing beams to ensure the non-yielding of the titanium during the subsequent ENF tests. Towards the fracture toughness determination from the experimental data, an analytical model we recently developed [1] is applied, which considers the bending-extension coupling of each sub-laminate of the joint as well as the effect of the manufacturing-induced residual thermal stresses. The load-displacement behaviors, failure patterns, and fracture toughness performances for each of the four manufacturing options investigated are presented and compared. The present work extends our last work [2] in which we study the fracture behavior of the same metal-composite joint by means of the double cantilever beam (DCB) test.

Key words: Metal-composite adhesive joint, fracture toughness, end-notched flexure, strain energy release rate(s), bending-extension coupling, residual thermal stresses

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Optimization of split Hopkinson pressure bar and experimental characterization of 3d woven composite at high strain rate

Bharath Ravindran, George Lampeas

Carbon fibre textile composite has been increasingly employed in engineering applications for high performance, manufacturability and high specific energy absorption characteristic. Composite material have been applied to design energy absorption structures in automobile, aerospace and shipbuilding industries for lightweight and high-performance design [1]. During their service life, the structures undergo complex loading conditions, e.g., dynamic load. High strain rate loading is one of the possibilities in many of such applications. It has always been a case for concern that the mechanical properties of composite materials may be different at high strain rate loading compared with those at quasi-static loading. Thus, for effective use of composite material, it is essential to fully understand the mechanical behaviour under high strain rates and loading conditions.

The present work comprises the further development of the Split Hopkinson Pressure Bar (SHPB) testing technique for the derivation of material data sets at high strain rate and different loading. For this study, a novel three dimensional (3D) woven composite of layer-to-layer architecture manufactured by vacuum assisted resin transfer moulding process in Ulster University is investigated for tension, compression and shear properties under high strain rate testing. The testing device used is the Split Hopkinson Pressure Bar Tensile (SHPB) apparatus installed in the Laboratory of Technology and Strength of Materials of the University of Patras as shown in Fig.1. The specimen geometry is designed to suit the testing facility and to achieve the desired strain rates. 3D woven carbon epoxy laminate was characterized for tensile properties in $0^\circ$ (longitudinal direction), $90^\circ$ (transverse direction) and $45^\circ$ (off-axial direction). Also, the same material is subjected to compression test which is loaded in both $0^\circ$ (longitudinal direction) and $90^\circ$ (transverse direction). A high-speed camera is used for non-contacting deformation measurement technique referred to as DIC is used to conduct the image analysis by means of tracking the displacement field through comparison between the reference images and deformed images to obtain full-field strain distribution and capture the failure mechanisms. The experimental results are analyzed in terms of stress and strain curve, strain rate, failure modes for investigated material system.

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Uncertainty quantification of Digital Image Correlation measurements based on projected speckle patterns

George Lampeas, Ioannis Diamantakos, Siebert Thorsten, Hack Erwin, Patterson Eann

Validation of computational solid mechanics models intended for use in predicting structural integrity is based on the suggestion that validation should be performed using full-field maps of surface strain and / or displacement, as recommended in the recent CEN guideline [1]. Digital Image Correlation (DIC) is a promising full-field measurement technique, which however requires the estimation / quantification of measurement uncertainty before its application in full-field displacement / strain measurements.
The scope of the present work is to propose a simple methodology to determine the DIC measurement uncertainty. The developed methodology is based on the display of un-deformed and deformed speckle patterns on an LCD screen and the measurement of the imposed displacements/strains utilizing a DIC system. Displacements of the displayed speckle pattern can be created either by moving the speckle pattern on the screen or by moving the screen. Deformed speckle patterns are created using results of FE analyses of structures having geometrical and structural characteristics similar to the physical structure to be measured by the DIC system.

The proposed uncertainty quantification methodology comprises a series of successive steps, which are briefly presented hereafter. Initially the Regions of Interest (ROI) of the structure to be tested under appropriate boundary and loading conditions are defined. Based on these, FE models are developed and solved for the calculation of nodal displacements and strains. The FE results are used in the creation of reference (un-deformed) and deformed speckle patterns utilizing appropriate software, such as DantecSPG [3]. The reference and deformed speckle patterns are then directly imported into the DIC software as image files, and displacement / strain fields are calculated by the DIC software. Consequently, the displacement and strain fields which have been previously calculated by the FE and by the DIC software are decomposed using Zernike, Tchebichef or another decomposition basis, and shape descriptors are determined. A comparison of the shape descriptors from FEA and DIC provides the basis for a quantification of the uncertainty related to the speckle pattern creation and DIC calculations, excluding the effect of the other DIC system parts, such as the cameras, lighting, environmental conditions, etc. Finally the reference and deformed speckle patterns are displayed on a high resolution screen, captured and evaluated by the DIC system; and again, compared to the respective displacement and strain fields calculated by the FE resulting in the quantification of the entire DIC system’s uncertainty, according to the CEN guideline data comparison methodology [1].

The above methodology for uncertainty quantification has been successfully demonstrated in the framework of the EU project MOTIVATE [2] for the case of un-deformed and displaced speckle patterns of a flat plate under uniform strain, as well as for a plate with a hole under tension exhibiting strain concentration.

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Numerical Procedure for the Estimation of the Aeroelastic Divergence Limit of a Composite Aircraft Wing using Higher Order Aerodynamics

Kafkas Angelos, Lampeas George

The usage of implicit coupled schemes combining high fidelity aerodynamics and structural mechanics codes in studying static aeroelastic phenomena bears the promise of successfully obtaining static aeroelastic solutions to a wide range of technological fluid-structure interaction problems regardless of the type of geometry, aerodynamic and structural non-linearities (such as those that can be met in advanced composite wing structures). Virtually any structure operating in the presence of fluid can be handled provided the necessary computational resources are available.

This promise however is intertwined with significant challenges. The results from a coupled analysis using high fidelity aerodynamics are obtained in an unintuitive form. Although the detailed flow and structural response is calculated, using these results to determine the divergence limit can be problematic.

An important challenge arises from the inability of the cfd mesh updating and deforming algorithms to successfully handle the very large deformations close to the divergence limit. This leads to the need that the divergence limit be estimated by the closest successful coupled solutions to it in terms of velocity.

Furthermore the time and associated computational cost for each coupled solution renders a high number of solutions at different velocity values highly impractical.

In the scope of the present work a procedure to obtain the divergence limit and an estimation of the numerical uncertainty of this calculation is presented, with the aim of bypassing or mitigating the aforementioned issues.

Given a pre-defined velocity range in which the divergence limit is to be studied, this procedure relies on successive estimations of the divergence velocity based on a Taylor series expansion. The estimations are built around coupled static aeroelastic solutions at successive velocity points. A way to efficiently modify the velocity point spacing during the procedure to reduce the number of required solutions and consequently the computational cost is also studied.

The numerical procedure mentioned above will be applied to the calculation of the divergence limit of a two dimensional airfoil and a high aspect ratio regional airliner composite wing to prove validity of usage in complex static aeroelastic problems.

The presented work has received funding from the Clean Sky 2 Joint Undertaking under the European Union’s Horizon 2020 Research and Innovation Program, GREen Turboprop Experimental Laminar Flow Wind Tunnel Testing (GRETEL) project, under Grant Agreement no. 737671.

Finite element-based design of neutral inhomogeneities

P. Papanikos, M.A. Kattis

The presence of a material or geometric defect in a stressed body causes a local disturbance in the stress field around it. The idea of eliminating such a disturbance was first introduced to mechanics more than 60 years ago for a hole in a stressed elastic plate. It was shown that, if the boundary of the hole is appropriately reinforced, the elastic stress of the perforated elastic plate is the same as without the hole. Then, this idea was extended to the general case of an inhomogeneity embedded in a stressed elastic
medium. In this case, the neutrality is achieved by inserting an appropriate elastically isotropic and homogeneous layer between inhomogeneity and medium. Since then, the design of neutral holes and inhomogeneities in stressed elastic media has attracted the interest of many researchers, both from a practical and a theoretical point of view. In this work, a parametric finite element-based methodology for designing a neutral cylindrical coated inhomogeneity under in-plane normal and longitudinal shear loading is developed. The design parameters considered are the material, shape and size of the coating. Where possible, the results are compared with analytical solutions showing excellent agreement. A discussion on the applicability of the methodology to different engineering applications, from nano to macro scale is also provided.
Aircraft Maintenance Professionals: Stress, Pressure And Fatigue

Nicole Dias, Luis Santos, Rui Melicio

This paper emphasis the environmental and organizational stress, pressure and fatigue induced to aircraft maintenance professionals. Since safety is the main driver of aviation, the environmental and organizational conditions have a direct impact on the performance of the aircraft maintenance professionals. Aircraft crew and Air Traffic Controllers have a theirs schedule and working time table highly regulator by the aviation regulators. The same aviation regulators don’t have the maintenance personal into account, and because of this, the maintenance providers due to the lack of specific regulation can demand extended working timetables to the maintenance staff.

After conducting a survey, it was verified that most of the maintenance personal already committed mistakes on aircrafts most probably due to environmental and organizational stress, pressure and physical fatigue. In the most concerning situations, these maintenance errors were only detected with the aircraft in operation, which is quite concerning regarding the aircraft safety.

The authors also give the possible diagnostics and recommendations, which can be applied to the several industry players and aircraft maintenance personal. These recommendations can be used to create a decision and validation matrix to be used on the field by either aircraft maintenance providers or maintenance staff.

Authors also highlighted the importance of the implementation of a safety culture in aircraft procedures, requirements and control on both aircraft maintenance providers and aircraft maintenance staff.

Towards The Harmonisation Of Just Culture Across Organisations At A Single Airport

Barry Kirwan, Beatrice Bettignies-Thiebaux, Liam Bolger

Organisations at an airport, including the airport authority, airlines, air traffic management, ground handling and other services, must all have a Just Culture policy and system in place, according to EC regulation 376/2014. This is to protect employees and also to promote reporting and learning from safety-related events or hazards. However, there may be differences in such policies and the ways in which they are enacted, including the openness of the culture, the investigation processes, the degree of authentic support from senior and middle management, etc. As part of the H2020-funded Future Safety Sky project, and in collaboration with London Luton Airport (LLA), a Just Culture Framework has been developed which acts as an over-arching Just Culture policy for all companies operating at the airport. This paper will show how this framework was developed and ratified, with input from a number of LLA companies, and will also showcase ancillary information that arose from the work, including a 'Business Case' for Just Culture, and a 'Just Culture Charter for Management.'

Charting The Edges Of Pilot Performance

Barry Kirwan, Matthias Wies, Edzard Boland, Fabian Braun, Rebecca Charles, Jaime Diaz Pineda, Charles-Alban Dormoy, Alia Lemkadden, Nicolas Maille, Jim Nixon, Daniele Ruscio, Carsten Schmidt-Moll
As part of the Horizon 2020-funded programme of work, Future Sky Safety, airline pilots were pushed to the edge of their performance envelope. This was achieved using challenging scenarios in two cockpit simulators: a conventional A320 full motion simulator, and a static advanced touch-screen concept-cockpit simulator. The pilots reported finding the simulations far more challenging than their Base checks. A battery of psychophysiological and behavioural measures recorded each pilot’s individual transition from stable flight towards increasingly difficult abnormal and emergency conditions.

The project relied on the development of a realistic scenario that led us to an enhanced understanding of the factors that drive ‘difficulty’ in the cockpit. This could also be used to understand the challenges of human-machine interface in the cockpit and assist in certification when developing cockpit changes or new cockpit designs and concepts. Simulations testing such new designs could manipulate factors such as stress, workload and situation awareness in order to provide more assurance that the pilots could cope when automation fails or surprises them, for example, or during severely adverse weather conditions. One aim of the project was to better understand the relationship between these factors and performances of the crew.

The first part of this paper outlines the Human Performance Envelope (HPE) framework that was the focus of this study, and the various measures used, and how well they performed. For example, heart rate was more useful and reliable as a measure than the widely used heart rate variability metric. We explain this finding in terms of the dynamic and fast-developing scenarios reflective of real accident situations. Other measures varied in their utility, some measures working well when paired. The studies and simulation exercises within the project have led to the specification of key measures that can track the pilot’s state in real time. To achieve this we employed a new ‘Smart-Vest’ that wirelessly captures a range of electrophysiological measures, as well as eye-tracking and pupil dilation measurement. These measures can be used to define and measure the cognitive and emotive state of the pilot, and these states can be aligned to the HPE concept. Using these measures could provide a way to determine when more support from the aircraft systems might be needed during a complex, deteriorating situation. These results could therefore pave the way for so-called adaptive automation allowing the aircraft to increase the sophistication of communication to the crew.

The studies of the human performance envelope, and what affects it and by how much, has also informed the development of a computerised, competency-based approach for evidence-based training, which is now being tested with a major airline. This new tool is presented in the second part of the paper.

The final part of the article focuses on autonomy in the future cockpit and considers the implications of this research for current considerations of new forms of automation including adaptive automation. We also consider new operational concepts such as Single Pilot Operations or Single Pilot in Cruise, and the use of cognitive computing and artificial intelligence in the cockpit. What is clear from the study is the resilience of human pilots. However, flight crew do occasionally need ‘an intelligent assist’, which could be delivered using cognitive computing. This automation needs to be designed to help rather than override or replace flight crew. The HPE approach can be used to inform when and how this should happen, pulling back pilots from the outer edges of their performance envelope, when pilots may overlook relevant information or when their situational awareness does not take notice of present or upcoming risks. This partnering between intelligent systems and human systems could deliver robust safety and service under all conditions, leveraging the best of human and digital capabilities.
**Implementation Of Advanced Technologies Into Aeronautic Integrated Maintenance Concept - Use Of Virtual Reality In Ground-Floor Training Maintenance Execution**

*Nelson Matos, Pedro Gamito, Joel Ferreira, Luís Oliveira, Margarida Pinto*

Maintenance aviation industry, Repair and Overhaul (MRO) procedures need to keep up with the technological evolution and evolve from the 2D support to the 3D.

The available manuals for learning and training MRO tasks rely much on old 2D drawings and lists of maintenance steps to be performed sequentially, however these are complex actions that require and would benefit greatly from a 3D insight in order to be quickly and comprehensible absorbed. Virtual Reality (VR) apps are potentially a suitable option to turn these procedures closer to reality and, thus, improving competences and skills.

Amongst the several maintenance optimization developments of the AIRMES project, which is cradled in the EU Clean Sky 2 Joint Undertaking programme, the above concept is applied to maintenance execution by developing a VR app to help practitioners in the process of carrying out specific maintenance activities as removing and positioning components into aircraft structures.

The VR app runs on a mobile platform that uses a smartphone and a portable motion capture device coupled with a head mounted device allowing the practitioners to learn and to train onsite on how to proceed with the maintenance operations.

The practitioners will be in an immersive and interactive environment where both the host aircraft structure section with the target component and auxiliary/peripheral systems parts are displayed and in which the 3D component can be removed by virtual hands that emulate, through the motion capture device, the hands of the user (Figure 1 - VR interactive mobile system for aeronautical MRO operations).

The system developed provides a high-level training and reliable information to the technician on the maintenance operations for a dedicated situation and facilitate the identification and execution of the procedure to be applied, improving the time for repair.

**Pragmatic Science? Reflections On The Academic- Industry Interactions In A European Aviation Research Programme**

*Jim Nixon, Colin Pilbeam, Barry Kirwan*

In this article we reflect on the tensions between formal scientific methods and practice based evaluation that we have experienced through the duration the Horizon 2020, Future Sky Safety project.

The Human Performance Envelope project (P6) has deployed a full range of inquiry from larger experimental studies to capturing the view of a small number of experts in simulations. Necessarily, fierce debate has occurred throughout the project as to the methods and scenarios that have given rise to our findings. We suggest that this range of methods is typical of applied human factors research, particularly when considering operational challenges.

In this article we examine the different approaches of stakeholders to research and evidence in this large scale, European aviation research project. We consider their differing requirements and definition of evidence-based findings. We discuss the wider motivations of academics and practitioners in applied, collaborative projects and discuss a variety of scenarios in which these stakeholders both converge and...
diverge. Finally, we present a number of alternative approaches to inquiry beyond the dominant, positivist paradigm and propose ways in which these approaches can be used to bridge the research link between academia and the wider aviation operation.

The Pilot Influence on the Flutter Velocity of the Lightweight Plane
T. Sommer, P. Steinbauer, M. Vilímek, S. Slavík, A. Kratochvil

Flutter of the airplane is a serious problem which is carefully investigated during design and testing both computationally and experimentally. The lightweight plane dynamics is however influenced by pilot, by his muscular transfer function. This study shortly describes results of experimental investigation of pilot's modal characteristics from 1Hz up to 70Hz. Next discusses the pilot influence on modal parameters of longitudinal control route of lightweight airplane. The change is aimed on the natural frequency and damping. This study also discusses the change of flutter velocity with dependence of new modal parameters influenced by pilot. Including a comparison with the current methodology - free and blocked longitudinal control route.

Flight Test of Pilot-Aircraft Haptic Feedback System
Pavel Zikmund, Miroslav Macík, Lukáš Dubnický, Michaela Horpatzká, Ivo Jebáček

This research is focused on an innovative improvement of pilot-aircraft interaction. Haptic devices on a control stick and pedals were designed and tested on a flight simulator before. The purpose of these devices is still warning and guiding a pilot to safe and economic flight regimes. The feedback system mediates airflow data as angles of attack and sideslip to a pilot by haptic way. The paper brings results of the flight test. Qualitative evaluation of the haptic feedback in flight is presented. Reaction time of a pilot in flight and on flight simulator is compared. Benefits of the system are shown on a sideslip during turning. Failure of the haptic feedback system is simulated in order to prove safety of the system.

Human Factors of Collaborative Engineering
Martin Spieck

Aircraft are among the most complex products which are mass produced, which means that they rise highest demands on design processes, integration and system optimisation. One of the key challenges in designing an aircraft, its components and its subsystems is the coordination, cooperation and technical collaboration between all the people who are involved in the development process.

Thus, by inherent definition, technical collaboration is the overcoming of boundaries. Boundaries between disciplines, teams, individuals, organisations, locations, methodologies, and so on. In order to come up with a safe, high-performing and competitive product, the flow of information across these boundaries has to be as smooth, efficient and effective as possible. This applies for technical data, of course: numbers, models, analysis results, measurements, drawings, etc. Very sophisticated methodologies and approaches exist how to establish IT-based frameworks which allow to build and execute interactive and integrative processes and control the flow of technical information.

But however refined and automated these frameworks may be, in the end it is scientists, designers and engineers who define the processes and interpret and evaluate the outcome, and managers who decide upon their results.

And this the point at which the socio-technical factor comes into play.
Socio-technical systems is an approach of systems design that accounts for the interaction between people and technology. The paper concentrates on “human factors” that have an impact on technical collaboration in interdisciplinary aircraft design and engineering.

Reasons for looking into the socio-technical aspects of aircraft engineering

Integrated, cross-cutting computational approaches for interdisciplinary design and engineering have often not delivered the advantage and performance that was expected when they had been introduced. Besides technical problems and other initial difficulties, e.g. in harmonising the workflow, there are also a number of socio-technical issues that arise when trying to establish so radical a concept. Companies in general, and scientists and engineers in particular, tend to be too technology focused when approaching the difficulties on aircraft design while neglecting organisational and especially human issues, [1]-[3].

In aircraft design and engineering, socio-technical issues cannot be seen independently from the other domains of collaboration. The technical and organisational challenges are setting the playing field and the boundary conditions. The people involved – engineers, scientists, managers, etc. – are then acting, and interacting, in this environment.

The “human factors” of collaborative engineering

In this context, the term “collaborative engineering” stands for the principle that a new technical system, i.e. an aircraft or a major component of it, is being designed by the joint effort of various contributors of knowledge, information and creativity.

Technical collaboration in aircraft design has three essential elements: communication, coordination and cooperation:

- Communication is all about the transmission of information between a sender and a receiver.
- Coordination ensures that this information is being transmitted from the correct sender to the correct receiver, at the right point in time.
- Cooperation deals with the environment in which this takes place: it ensures that the legal, administrative and technical conditions, the work flow and the attitude of people involved enable and support the exchange of information.

Collaboration then aims to combine all three elements in such a way that the joint effort of all contributors leads to the best overall result in the shortest time possible.

And in all three of these elements, “human factors” play an important role. Interpersonal relations of team members, typical human behaviour under stress or in complex situations, inherently conflicting objectives which are forced upon individuals or teams, emotions based on personality and past experiences, are but a few examples of these human factors which may have a tremendous impact on the allegedly purely technical challenges of aircraft design, with all its refined software tools, optimisation platforms, network architectures and high-performance IT frameworks.

The impact can be negative, e.g. when typical human interferes with the smooth and efficient execution of a design task, leading to additional work, sub-optimal results or even jeopardising the entire exercise.

But it can also be positive when socio-technical aspects are adequately accounted for, e.g. by applying techniques for intuitive technical insight, for human-centric complexity management, or through fostering emotional commitment in the abstract, highly technical environment of integrated aircraft design.
Contents of the paper
The conference paper will
a. Provide a systematic overview of barriers and bottlenecks for integrated, collaborative aircraft design that are driven, or at least severely affected by socio-technical factors,
b. Propose practices to overcome these barriers and to increase the efficiency and effectiveness in research and industry.

The presented findings base on research performed in the EC-funded research project AGILE (Aircraft 3rd Generation MDO for Innovative Collaboration of Heterogeneous Teams of Experts).

References
Operations Reliability Study Of The Large Aircraft

Paweł Glowacki, Włodzimierz Balicki, Leszek Loroch

Along with the increase in air traffic, the number of reported aviation events also increases. The authors have performed processing of the data contained in European Coordination Centre for Aviation Incident Reporting Systems (ECCAIRS) analyzing large aircraft reliability and safety of their operations, considering events according to ICAO aviation occurrence categories. The airframe systems are the biggest contributor to the total number of reported events have occurred on aircraft MTOM >5700 kg. In the years 2008÷2017 the failures of these systems caused almost 25% of total reported aviation events involved Polish registered aircraft. Bird strikes caused 19% of reported occurrences. Based on the ECCAIRS data, determination of occurrence categories essential for aviation safety was performed with the assessment of their safety risk level. Also detailed airframe systems reliability study was carried out in order to assess the real reason of their failures. Airframe systems faults were assigned to the specific ATA chapters and then to each of their sections. The most frequently occurring defects of each unit of the particular airframe system were identified. Due to the type of powerplant installed, large aircraft were divided into those powered by turboprop and turbofan engines.

The results of this analysis may support the decisions of supervisory authorities in the areas where security threats are most important. They can also help aircraft operators with identification of the airframe units which require special attention.

Preliminary Safety Assessment On System Design Level For Broadband Acoustic Liners

Marcel Mischke, Stefan Kazula, Klaus Hoeschler

Broadband acoustic liner systems that use morphing materials could significantly reduce aircraft noise. No specific description of potential failure modes of these liner systems, as well as guidelines to certify them currently exist. This paper presents the preliminary safety assessment of two innovative broadband acoustic liner concepts according to the Aerospace Recommended Practices (ARP) 4754A and 4761. A suitable Functional Analysis, Functional Hazard Assessment (FHA), Common Cause Analysis (CCA) and Fault Tree Analysis (FTA) have been conducted. Potential failure modes and their severity of the investigated liner concepts have been classified and evaluated for application in engine inlet and bypass duct, highlighting.

In recent decades, several innovations to reduce engine noise, such as the noise-reducing liners in the 1980s, were developed. These rigid acoustic liners works on passive principles and present the state-of-the-art for noise treatment in the inlet and bypass duct of current aero engines. Due to their rigid honeycomb structure, the current acoustic liners can only achieve a narrow-band damping curve. However, the noise emitted by the aero engines has a broad band character. For this purpose, basic concepts and novel structures for broadband damping acoustic liners has been investigated. To evaluate these innovative improved liner structures according to their feasibility in the engine, existing safety guidelines and reliability methods must be analysed and adapted.

The basis for the preliminary System Safety Assessment (PSSA) of the liner concepts is a functional analysis. Thus system function structures of the respective concepts has been developed according to ARP.
4754A. Subsequently, corresponding failure modes of the liner systems are identified, summarised and analysed for different flight phases during a Functional Hazardous Assessment (FHA).

These failure modes provide the input for the Fault Tree Analysis (FTA). Furthermore, a Common Cause Analysis (CCA) has been performed to identify dependences between adjacent systems, external risks and component interactions. In addition, the causes and effects of the failure modes of the acoustic liners with flexible structures can vary depending on the flight phase. Furthermore, the potential failure modes of the new liners were identified and classified according to CS-25.1309. This enables a comparison of both liners concepts with the current liners.

By means of this safety assessment, weaknesses of broadband acoustic liners with flexible foils have been identified. This way, future aircraft could utilize acoustic liners with a broadband attenuation resulting in significantly reduced aircraft noise.

**Preliminary Analysis On An IVHM Approach For Prognosis Of High-Pressure Filters For Hydraulic Power Control Modules Of Helicopters**

*Andrea De Martin, Giovanni Jacazio; Massimo Sorli; Vincenzo Surdo*

The majority of the currently in-service aircrafts makes use of a centralized architecture to provide hydraulic power to the actuation systems employed on board for flight-control, landing gear retraction and steering and other accessory functions. Although some applications of Electro-Hydrostatic Actuators have recently emerged for fixed-wing vehicles, their application is still limited to back-up usage and do not avoid the need of a central hydraulic power unit. Hydraulic Power Control Modules (PCM) are complex devices, where a pump translates the mechanical power provided by the aircraft propulsion systems through the accessory gearbox into hydraulic power; one of the most critical functions of the power unit is to properly filter the impurities and the debris present in the fluid to achieve the long-term functionality of the users under prolonged usage. Unchecked amount of contaminants would represent a severe danger to the integrity of some of the most delicate components of the actuation systems, such as the servo valves, and would cause in time performance degradations by damaging the actuators seals or by scratching the surfaces of the control components. This is especially true for the helicopter applications, where the severe vibratory environment tends to increase the wear rate of the component, hence producing higher amounts of metallic and non-metallic debris. Filters can hence be considered critical to achieve long-term operability of the hydraulic actuation systems. Filtration allows to separate the solid, dangerous particles from the hydraulic fluid by mechanically segregating the debris by means of grids, metallic meshes or porous materials. The segregated material is held inside the filter, which hence tends to clog under prolonged usage. So far, filter substitution follows a scheduled maintenance scheme, aimed at avoiding the possibility of clogging during flight. Practical experience however suggests that this approach tends to be excessively conservative, causing additional costs and unnecessary vehicle downtimes due to the substitution of well-operating filters. The development of novel prognostic solutions to optimize the filter replacement operations would hence provide advantages in terms of cost reduction and system availability. The system under analysis mirrors the typical configuration of a power unit for helicopters; a variable-displacement pump is used to provide flow-rate to the system, comprised of a pressurized tank, accumulators, several relief and control valves and filters on both the supply and return channels. A significant challenge in designing a Prognostics and Health Management system for these systems is the lack of local sensors to measure or infer the circulating flow-rate. We hence propose an Integrated Vehicle Health Monitoring approach, where signals coming from the actuators are used in
conjunction to the information available within the power unit to help in the estimate of the filter clogging status. At first, a dynamic model of the system is presented and discussed, highlighting the importance of the representation of the measure and process uncertainties. Hence, a feature is selected by state-of-the-art metrics and used within a data-driven fault detection system. Prognosis is then achieved through particle-filtering techniques and tested against realistic degradation patterns. Results are then discussed and further development proposed.

**Capabilities Of Diagnosis Of Helicopter Mi24 From The Perspective Of Hums System**

*Andrzej Gębura, Miroslaw Witoś, Miroslaw Zieja, Andrzej Szelmanowski, Andrzej Pazur*

In the kinematic system of airplanes and helicopters there are critical elements of structures on which accelerated symptoms of fatigue use are observed, e.g. in the form of: damage (peeling) of the raceway of the rolling bearing, fatigue undercuts of the gears. The article presents a method for diagnosing a kinematic system based on an on-board generator (state observer). At the beginning, some of the research problems occurring in helicopters, based on their own research data, were approximated. Particular attention was paid to the phenomenon of resonance of rolling bearings and resonance excitation of a pair of gear wheels under its influence. The effectiveness of detection of such resonance phenomena by means of the proposed diagnostic method was presented. The conclusion summarizes the conclusions that the method provides a reliable diagnosis and would be a valuable complement of previously used HUMS. The directions of further research on the development of the diagnostic method were also indicated.

**A New Active Asymmetry Monitoring And Control Technique Applied To Critical Aircraft Flap Control System Failures**

*Matteo Davide Lorenzo Dalla Vedova, Dario Belmonte, Gaetano Quattrocchi*

Asymmetry limitation requirements between left and right wing flap surfaces play an important role in the design of the implementation of the secondary flight control system of modern airplanes. In fact, especially in the case of sudden breaking of one of the torsion bars of the flap transmission line, the huge asymmetries that can rapidly develop could compromise the lateral-directional controllability of the whole aircraft (up to cause catastrophic occurrences). Therefore, in order to guarantee the aircraft safety (especially during take-off and landing flight phase in which the effects of these asymmetries could generate uncontrollable aircraft attitudes), it is mandatory to timely detect and neutralize these asymmetries. The most common architectures of the Flaps Control System (FCS) employ reversible actuators with wingtip brakes and a common Power Drive Unit (PDU), composed by a dual motor type (for operational reliability) located into the aircraft fuselage. The current monitoring techniques generally evaluate the differential angular position between left and right surfaces and, in most the events, they are able to limit the aforesaid FCS asymmetries. This system layout is more economical and efficient than other solutions (for example irreversible actuators or no-back brakes) but in severe fault conditions, and especially in the presence of very high aerodynamic loads, it could cause unacceptable asymmetries compromising the controllability of the aircraft. In this context, the design of advanced flaps actuation systems, based on innovative layouts or improved monitoring and control techniques, can certainly increase the operational performance of secondary flight control systems. In this paper, the authors propose a new active monitoring and control technique capable of detecting the increasing angular error between the different flap surfaces and that, after stopping the whole actuation system, acts on the portion of the actuation line still connected to the PDU to minimize the FCS asymmetries.
A dedicated Matlab-Simulink numerical model, consistent with the FCS architecture proposed by the authors in a previous work, is used to evaluate the performances of the proposed asymmetry algorithm; in particular, its performances are compared with the ones provided by more conventional flap monitoring strategies. The results obtained highlight the merits of the proposed solution and suggest to further investigate its applicability to other FCS architectures.

**Experimental Comparison Of Fiber Bragg Grating Installation Techniques For Aerospace Systems**

*Pier Carlo Berri, Matteo Davide Lorenzo Dalla Vedova, Paolo Maggiore*

Aircraft systems are becoming more and more complex, as they are required to perform multiple functions. For example, smart systems need to be able to self-monitor their working parameters, in order to infer their health status; in addition, they shall be able to adapt their behavior to varying operating conditions and to their own health, modifying their operational envelope in order to improve performances or to maximize their useful life.

All these additional functions require the system to acquire a multitude of measurements; albeit sometimes it is possible to implement virtual sensor techniques, dedicate sensing hardware is usually needed. As a main drawback, the installation of the needed sensors adds up to the total complexity, weight, cost and failure rate of the system.

In this context, minimally invasive sensors can be used to measure the system parameters with high spatial resolution and minimal added complexity. One key technology in this field is the Fiber Bragg Gratings (FBG) optical sensors, used to perform strain and temperature measurements. Those consist in a single optical fiber, with multiple sensitive areas, installed along the monitored system or structure. In aerospace applications, FBG sensors can be used not only to monitor strain and displacements of structural components but also vibrations, loads, stresses and temperatures of various mechanical, electrical or hydraulic equipment.

This work describes an experimental campaign intended to assess and validate several installation techniques for FBGs as strain sensors. Two test benches were developed for different measurement setups. One is intended for creep and repeatability tests of a FBG sensor glued at both ends; the other was used to compare point gluing and continuous gluing techniques on an aluminium beam subject to a bending load. Results are compared with numerical simulations of the structure and measurements performed with traditional strain gauges.

**A Simplified Monitoring Model For PMSM Servoactuator Prognostics**

*Pier Carlo Berri, Matteo Davide Lorenzo Dalla Vedova, Paolo Maggiore, Francesco Viglione*

Electromechanical actuators based on Permanent Magnet Synchronous Motors (PMSMs) are currently employed on various aircraft systems, and are becoming more and more widespread in safety critical applications such as primary and secondary flight controls. Compared to other electrical machines, PMSM offer a high power to weight ratio and a precise control, even near zero speed: this makes them suited for position control and actuation tasks. EMAs offer several advantages over more traditional actuation technologies, in terms of modularity, mechanical simplicity, overall weight and fuel efficiency. At the same time, their basic reliability is inherently lower compared to hydraulic actuators. Then, the use of EMAs for safety critical aircraft systems requires the adoption of risk mitigation techniques to counter this issue. In this framework, diagnostic and prognostic strategies can be used for the health management of the
system, to monitor its behavior in search of the early signs of the most common or dangerous failure modes. In particular, model-based fault detection relies on the comparison of the system response with a reliable simulation model to detect the signatures of faults.

This work proposes a low fidelity model of a PMSM based EMA, intended for diagnostic and prognostic monitoring. The model features a low computational cost, allowing the execution in nearly real-time, combined with a suitable accuracy in the simulation of faulty system operations. This simplified emulator is validated by comparing its behavior to a higher fidelity model, employed as a simulated test bench.

Proposal Of A New Simplified Fluid Dynamic Model For Aerospace Servovalves

Matteo Davide Lorenzo Dalla Vedova, Pier Carlo Berri

In the aerospace field and, above all, in the design and development phases of modern flight control systems, highly detailed computer models are now required, capable of emulating with high accuracy the behavior of the various on-board equipment; at the same time, however, different simplified models are needed, appropriately designed and developed for specific operations such as the optimization of preliminary design and the development of diagnostic or prognostic strategies. As regards the second category of models (i.e. the one related to the topics covered in this work), it must be noted that, having to minimize the computational burden associated with these algorithms, more and more stringent requirements have been conceived requiring developers to implement simplified models able to combine sufficient levels of accuracy and reliability with reduced computational costs.

Despite having a long history behind them, electro-hydraulic actuators are still today a source of criticality in aerospace systems. Due to their sensitivity to various failure modes, the difficulty of identifying such malfunctions promptly and the consequences that these failures can generate in terms of security for the entire system, it is necessary to have correct tools to model and monitor the various components. In particular, it is needed to conceive new dedicated numerical models of the servovalves that control these systems, capable of combining an acceptable computational effort with a satisfying ability to simulate their performance and dynamics.

To this purpose, this paper proposes a new simplified numerical model of the servovalve fluid-dynamic behavior. This numerical algorithm, based on a very compact semiempirical formulation, can take into account in a simplified but sufficiently accurate way several typical behaviors related to the SV spool geometry (e.g. flow leakage between spool and sleeve) and the operating conditions (e.g. variable supply pressure or water hammer).

To evaluate the approximations introduced by this model into a system-level simulation, it has been integrated into a dedicated numerical model simulating a simple electrohydraulic on-board actuator.

The proposed model is compared with a higher fidelity servovalve model, and their accuracy is evaluated both regarding the static pressure-flow characteristic and SM dynamic response.

Hydrogen Leakages In A Congested Aircraft Environment: A Cfd Simulation Method

Anna Chiara Uggenti, Alberto Moscatello, Raffaella Gerboni

The option of using hydrogen as a fuel for propulsion of aircraft has been investigated in the recent past especially in combination with long endurance unmanned mission targets (Helinet, Helios). This application has proved to be challenging mostly due to the low volumetric density of hydrogen, which
needs to be compressed at very high pressures to be confined in the narrow volumes allowed by aircrafts structures. Aerial, as well as automotive, applications of hydrogen pose also the issue of weight for the total storage solution adopted: high pressures may mean thick layers for vessels and consequently high weights for unit of mass of hydrogen stored. Composite materials have helped in reducing the weight but remain tough to be adopted for vessels large enough to store the hydrogen mass necessary for long trips. Liquid hydrogen has only been adopted so far for aerospace applications and just for boosting rather than for endurance.

Instead, hydrogen can be efficiently used for fuelling auxiliary systems on board and for ground services, helping to reduce the environmental impact, also regarding the idling phase. Fuel cells that are supplied with hydrogen can provide the electricity needed by all the auxiliary equipment, from air conditioning systems, to controls and avionics, to lighting and security services.

Although smaller quantities of hydrogen are needed on board to supply only the auxiliaries rather than for propulsion, still there is a need for pressurising the gas and so to have a pressurised feed line that runs into the congested environment of an aircraft where ventilation is anyway usually present.

In view of the experience gained in the oil and gas offshore sector, where flammable and pressurised gases may be released due to failures in the feed lines, we propose an innovative approach to investigate the possible hazards deriving from the use of pressurised hydrogen in aeronautics. Hydrogen releases may happen due to failures all along the lines but, statistically, ruptures are more frequent in lower pressures sections that are potentially less protected. A hydrogen supply line can cover pressures that range from 350 bars of the storage vessel to the nearly ambient pressure when it supplies the fuel cells. This induces to take greater care of possible mid-pressure (10-15 bars) releases and of their consequences.

Ruptures are seldom catastrophic, while more often they are represented by small diameter cracks. The release through these ruptures is supersonic and it soon slows down also due to the scattering with obstacles in the aircraft environment. Modelling of the entire phenomenon is a challenging task for Computational-Fluid-Dynamic analysts as some variables such as pressure, and therefore velocity, have too strong variations throughout the domain. Yet, CFD remains the best tool to predict the dispersion and possibly the dangerous (i.e. above the - very low- flammability limit of hydrogen) accumulation of gas.

Our proposal is to split the phenomenon in two phases and to study them separately with a coupling based on the parameters that are more relevant to describe the evolution: velocity and concentration. First, the supersonic release of hydrogen from the rupture, and the consequent compressible effects, are modelled in a domain that is large enough to contain the deceleration of the gas up to dispersion-like rates: this domain is, however, smaller than the full domain where we wish to study the entire phenomenon. Second, data related to speed and concentration calculated on the surface of this domain are given as boundary conditions for the simulation of the dispersion phase.

Preliminary applications of this method to hydrogen releases from 10 mm hole ruptures at a pressure of 10 bar have provided interesting results especially with the supersonic release phase, that is the most challenging for the CFD simulation due to the intrinsic characteristics of hydrogen as a very light gas. In particular, addressing the supersonic release phase may allow estimating the effect of impact of the jet release onto the first obstacle (in the form of thermal stresses).
The final coupling of the two phases can provide a dispersion pattern within a congested environment that can be validated in field tests, in the same way as it is being done with this method applied to natural gas releases in offshore platforms.

**Design Of A PHM System For Electro-Mechanical Flight Controls: A Roadmap From Preliminary Analyses To Iron-Bird Validation**  
*Andrea De Martin, Giovanni Jacazio, Massimo Sorli*

Literature on PHM systems is mostly focused on the research for novel algorithms or new methodology to isolate a particular fault in a wide range of application fields. Usually the aim of the first type of research is to provide more robust or more accurate RUL predictions, or to lower the required computational effort. The latter is instead often focused on the results achievable through simulated data or through the analysis of data-sets coming from well-prepared experimental campaigns performed under laboratory conditions. Literature on the possible approaches to design and validation of a novel PHM system is however sparse and few contributes can be found. This is especially noticeable in aeronautic applications, where issues like the difficulty of obtaining meaningful in-flight data often puts a cap on the possibility to validate the health monitoring routines developed through simulations or laboratory experiments.

This paper describes a generic framework for the design of a novel Prognostics and Health Management system while making reference to a real-case scenario involving the definition of novel prognostics and diagnostics routines for electro-mechanical flight control systems. At first the literature on the subject is examined and discussed; then the system under analysis is presented and its peculiarities detailed, while the approach to PHM design is described. The proposed methodology for the design and validation of a new PHM system can be roughly divided in four parts: preliminary study, high-fidelity modelling and algorithm definition, laboratory validation of the high-fidelity model and finally algorithm integration and validation within an iron-bird set-up. The paper describes each of these passages, highlighting the most critical aspects, possible difficulties and lessons learnt. Starting with the preliminary activities, a FMECA analysis is performed and a survey of the available sensors is performed. Hence the high-fidelity model and its usage aimed at the definition of the diagnostics and prognostics algorithms is described and its interaction with the laboratory experiments detailed. Finally, the integration of the PHM routines within an iron-bird set-up is discussed; the set-up itself is presented, while critical points and practical issues are highlighted.

**Interactive Flight Crew Manual Procedures based on Failure Scenarios Observed in System Behaviour Simulations**  
*Luboš Janhuba, Miroslav Červenka, Rostislav Koštial*

With rising airborne system complexity and sophistication common division between particular development process like safety assessment, in-flight tests and flight manual definition have begun to blur. Our previously designed integrated algorithm for airborne system safety and reliability assessment utilizing Graph Theory and function-oriented modelling provides a mean, how to investigate system behaviour from the variety of different points of view. Using simulation theory, it is possible to establish a domain of potential operational states (based on items behaviour in time) based on system model developed for safety assessment purposes. Resulting failure scenarios represent possible patterns of occurring failures. This information could serve as a foundation for interactive expert system and identify critical nodes of system. Expert system results are applicable in aircraft maintenance (it could identify
items for inspection), airborne system architecture (in combination with operational data, provides feedback to the system design itself) and especially in flight crew manual procedures development.

Flight manual is typically divided into separate chapters. From system safety point of view, the most important chapters are normal and emergency procedures. These chapters provide specific steps describing how to operate a particular aircraft in various conditions and how to behave in emergency situation. This type of interconnection between system assessment and operational procedures already exists in raw a form. It is essentially fault tree (describing how failures are caused by individual or lower level failure combination) and event tree (defining how to mitigate their effects) combination.

By adapting simulation theory, it is possible to develop interactive failure scenarios (sorted by their relevance) derived from initial conditions in order to quickly obtain most relevant mitigation procedures. Scenario relevance could be in real-time adjusted to the modified conditions of occurring failure. It could help to overcome complicated chain of decision making (Indication - flight crew investigation - response) and decrease flight crew workload.

Interactive AFM based on system behaviour simulation are part of integrated system safety and reliability assessment, which is applicable during each step of aircraft development process. Further, failure scenarios could be used as algorithm for autonomous UAV emergency procedures.

Methodology for analyzing competing options for air management systems at the stage of conceptual design of civil aircraft’s complex of onboard systems

Roman Savelev, Denis Smagin, Tatyana Zyazeva

An analyzing competing options for air management systems undoubtedly is one of the main tasks at the stage of conceptual design. The truth is outcome determines energy efficiency of whole system. The decision about choice of one of the competing options regarding not only the appearance of the system, but also the entire chain of suppliers, the missing parameters for a complex criterion can be replaced by an alternative risk level estimate. The level of efficiency increment is the most important parameter (it takes into account the possibility of improving the efficiency of the option due to its optimization). The value of this parameter will objectively be at vapor cycle due to the wide possibilities to reduce the mass of components and to increase the overall efficiency of the cooling installation. For the air cycle, most of the possible solutions to increase efficiency have already been implemented in the ECS of modern aircraft.

Application SimInTech software for optimization fuel system parameters of the perspective helicopter

Anatoliy Satin, Roman Savelev, Denis Smagin

The possibility of applying optimization algorithms for mathematical modelling of the helicopter fuel system on the example of the advanced helicopter in Russian software complex SimInTech. The results of the fuel system parameters simplest optimization for the nominal operation mode are presented, examples of algorithms for the selection of the parameters of the units are shown.
Operational Readiness Management Of The Integrated Communication System On Board A Military Aircraft

Sławomir Michalak, Andrzej Szelmanowski, Andrzej Pazur, Wojciech Paterek

This paper presents the possibilities and conditions of forming operating capability (readiness) of a ZSŁ1 (Integrated Communications Systems in Polish) with its selected components current serviced at AFIT (Air Force Institute of Technology). A probabilistic approach to the analysis of the issues associated with the determination and prediction of reliability and operating capability of integrated communications systems was discussed, with the use of the theory of operating states and Markov chains. The assumptions to the adopted method of modelling operating states for electronically integrated ZSŁ1 type communications systems were presented. Conditions for the determination of operational readiness and the possibility of forming it on the basis of an IT system were presented based on the obtained results of analytical studies.

On The Use Of AESA (Active Electronically Scanned Array) Radar And IRST (Infrared Search and Track) System To Detect And Track Low Observable Threats

George-Konstantinos Gaitanakis, George Limnaios, Konstantinos Zikidis

The radar has been indisputably the most important sensor in the battlefield, allowing early warning and tracking of air vehicles. Modern fighter aircraft employing AESA fire control radars are able to acquire and track targets at long ranges, in the order of 50 nautical miles or more. However, the proliferation of low observable or stealth technology has contested the radar capabilities, reducing their detection / tracking ranges roughly to one third. This degradation is more severe concerning fighter aircraft radars, since most stealth threats are optimised for higher frequency bands, as in the case of fire control radars. Hence, other parts of the electromagnetic spectrum have been reconsidered, such as infrared radiation (IR). Every aircraft is a source of IR, due to fuel combustion, aerodynamic friction and IR reflection. In this way, a jet fighter can be detected by an IR sensor against the cold background of the sky. Therefore, IRST systems have re-emerged, offering an alternative to the radar. Apart from their capabilities concerning target detection (whether stealth or not), IRST systems also exhibit passive operation, resilience to jamming and better angular accuracy. On the other hand, they are prone to weather conditions, especially moisture, while they cannot measure distance directly, as in the case of the radar. This work explores and compares the capabilities and limitations of the two approaches, AESA radars and IRST systems, offering also some insight to the benefits of sensor fusion.

How To Choose The Right Sensors For UAV Flight Control And Navigation

Cezary Szczepański, Marcin Ciopcia

The article has been dedicated to process of choosing of the right sensors for the navigation and flight control of the UAV. The main effort has been put to screen and compare of commonly used MEMS and GPS sensors, regarding their usability in UAV. Besides a sole technical analysis of the datasheets, authors performed an experiment with several MPU9250 boards in order to compare their output in different operational conditions.
GPS analysis were performed on two modules, manufactured by uBlox, with different applications and the price-points: NEO-M8N and NEO-M8T, with the same configuration at the Standalone mode. Both modules were running simultaneously, side-by-side, for several days collecting position, metric error and delusion-of-precision (DOP) logs. The second part of the article is dedicated to observed discrepancies between those modules.

**Selected Aspects Of MEMS Technology Implementation Into Flight Control Systems**  
*Jerzy Graffstein, PiotrMasłowski, Cezary Szczepański*

The paper presents discussions aimed at analysis of the impact exerted by MEMS technology on automatic flight control systems, especially on research & development activity within this area of engineering art as well as, on avionic systems’ design process. Presented considerations comes from the experience gained by the authors when carrying out several projects in automatic flight control area. As such a definition of area of interest seems to be too wide for the conference paper, presented considerations has been limited to cover only the case of inertial MEMS sensors and potential use of these units in automatic control of the motion of aircraft.

Discussion presented in the paper is illustrated by some simple, but non trivial examples:

- the automatic control of longitudinal motion of an airplane during the approach phase of flight;
- the automatic data recording for monitoring the actual load factors on aircraft structure;
- baro inertial altimeter.

The analysis of potential use of MEMS units in Automatic Flight Control Systems, Stability and Command Augmentation Systems (SCAS) and Navigation Systems leads to the discussion of observability and its role in and impact on the process of system synthesis. Such an analysis is briefly presented with final conclusions on MEMS technology potential within discussed engineering area and possible extensions into other tasks (e.g. the problem of redundancy).

*Ewelina Szpakowska-Peas*

Radar altimeters are elements of avionic equipment capable of measuring the actual height of an aircraft above the surface of the earth. Although, the importance of this information for flight safety appears to be crucial, especially in case of flight performed without ground visibility, radio altimeters are not widely used in small General Aviation aircrafts due to high prices of such kind of equipment. Since 1996 the family of RWL-750M radio altimeters have been developed and manufactured in the Institute of Aviation. An integral structure of the device contains two separate antennas that require for installation a well conducting flat surface on a fuselage, free from protruding elements. Therefore, the application of the radio altimeters is limited to larger aircrafts. Moreover, nowadays the electrical design of the RWL 750M becomes obsolete due to outdated electronic components that are no longer supported or manufactured by suppliers. For these reasons, a novel concept of radio altimeter CRW-13 has been proposed. The new design of the device consists of integral antennas and signal processor for smart digital signal filtering. Hence, it is possible to develop a digital radio altimeter without the previously mentioned limitations.

In the paper the laboratory model of the CRW-13 is presented. A conceptual theoretical framework based on previous version of the altimeter is outlined. Moreover, the results of laboratory and in-flight tests of
the system functionality and performance are presented and discussed within the paper. Finally, this article investigates the functionalities of a new design of the device.

**THE AIRPLANE TRIM SYSTEM - NEW FUNCTIONALITIES**

*Mariusz Krawczyk, Cezary Szczepański, Albert Zajdel*

In 2018 Swedish Språkrådet introduced a new concept of “flygskam”, which means “flying shame” – due to the contribution to humanity’s carbon footprint. Indeed, air travel is responsible for 2 proc. of the global CO₂ emissions and accounts for almost entire carbon footprint in the upper layers of atmosphere, but should it be the reason for restrictions in air transport? Certainly not, especially with regard to long-distance and intercontinental travel. There is hardly any alternative to flying. Therefore the focus should be on developing solutions that rely on renewable energy technologies and on electrical energy.

In case of commercial aircraft, not only the engine, but also the hydraulic system, that actuates flight control surfaces, is indirectly responsible for carbon dioxide emissions. Flaps, slots and airbrakes are used to change the aerodynamic characteristics only during the take-off and landing, whereas rudder, elevator and ailerons are necessary in all the phases of flight. For this reason a control system with three main control surfaces will be subject to further analysis. The aim is finding the answer to the question, what could be done to operate the main control surfaces more efficiently with regard to power consumption. Alternatively an aileron may be substituted by a pair of aileron and spoiler (spoiler reduce the lift of one wing while flying with high speed), or a pair of aileron and flaperon, where a flaperon moves similarly to the aileron but is mounted closer to the fuselage.

It can be assumed in a conventional aircraft that the $I_x : I_y : I_z$ ratio of the principal moments of inertia in a body-fixed coordinate frame, regardless of its MTOW, is as 1:2:3. Moreover, all the aerodynamic moments created by control surfaces arise as a result of aerodynamic forces acting on similar moment arm. If this is the case, why the ailerons, rudder and elevator are of similar area? First, the ailerons have to provide required lateral dynamics and control, hence their area cannot be too small. Second, the main role of the rudder is compensation of the yawing moment stemming from the spiraling slipstream generated by the running propeller, or compensation of the yaw effect of asymmetric thrust in the event of engine failure (in multi-engined aircraft).

In conclusion, energy optimisation in a control system consists in developing an alternative, energy efficient method for control surfaces deflection. For this purpose trim tabs may be used. These tabs counteract aerodynamic forces and stabilise the aircraft. They also compensate the incorrect balance, when the center of gravity moves due to inappropriate aircraft loading or slipstream. Both factors generate additional undesirable moments of force. Trim tabs compensate these moments and reduce the stick force. Technically, tabs are additional small surfaces connected to the primary control surfaces. Deflection of a trim tab causes deflection of a control surface, so that the hinge moments balance each other.

The conducted analysis refers exclusively to aircraft equipped with complete trim system, which consists of aileron, rudder and elevator trimmers, and enables both longitudinal as well as lateral trimming. In particular the idea of expanding the functionalities of trim system will be described and a new functionality of flight stabilisation with use of trimming surfaces will be set forth.
Characterisation Of CFRP-Titanium Local Reinforcement

Fedir Gagauz, Neha Chandarana, Adam Joesbury, Pavlo Shestakov

The use of fibre reinforced polymer (FRP) composites is widely accepted as an approach for reducing aircraft structural weight. However, current design and production trends suggest that FRP composites may never entirely supersede metals due to many reasons, such as their inability to withstand high concentrated loads in mechanical (bolted or riveted) joints because of their low interlaminar and bearing strength. The use of 3D fabric preforms for manufacturing composites is one method of improving the interlaminar strength. It is also possible to produce different fibre architectures in this way. A commonly used approach for increasing the bearing strength of composites in the regions in which fasteners, such as bolts and rivets, would be installed is the inclusion of metal foils within the laminate, resulting in hybridisation of the structure. This is an effective method, but requires the fabrication of composites from discrete fibre layers, such as dry or pre-impregnated materials. In the case of 3D fabric preforms, it is not possible to insert these metallic foils.

A more appropriate method to improve the local bearing strength of 3D woven composites is through installation of metal washers with transverse micropins during the lay-up process. Following this, the composite can be cured; bonding the metal insert in position. There are a number of possible problems that can arise during the manufacture of this type of “locally hybrid” material by resin infusion associated with poor-quality impregnation of the fabric in the region where metal micropins have been embedded, due to tight packing of the 3D-fabric architecture under vacuum. The present work, therefore, will focus on characterisation of the quality of this type of 3D reinforced hybrid composite/metal joint.

Two specimens were manufactured by embedding metal inserts into the surface of 3D-woven carbon-fibre preforms. The hybrid specimens were consolidated with epoxy resin using vacuum-assisted resin infusion. Titanium inserts were used to form these mechanical joints. Two different types of metal washers are considered in this work, with varying thickness (0.25 mm or 1 mm), shape of micro-pins (twisted or untwisted), and arrangement of pins (along the edge of the washer or covering the full surface). After curing, stereoscopic and scanning electron microscopy were used to analyse the effect on fabric architecture of embedding these micro-pins into the 3D preform, as well as to study of the quality (homogeneity) of subsequent impregnation by the resin infusion process.

Novel Carbon Nanotube grafting on Carbon Fibres through Chemical Vapor Deposition: Investigation of epoxy matrix/fibre interface via nanoindentation test

S. Termine, A.F. Trompeta, D.A. Dragatogiannis, C.A. Charitidis

Carbon Fibre Reinforced Polymers (CFRP) conquered the automobile and aerospace industry the last decades. However, new requirements for improved smart properties and functionality arise. The most important aspect in CFRPs is the successful transfer of tension from matrix to the reinforcement, thus functionalization of carbon fibres (CF) surface is a prerequisite. A novel approach of functionalization of
CFs is the in-situ grafting of carbon nanotubes (CNT) onto the surface of the fibres, through chemical vapor deposition. By this approach, the composite becomes multi-functional as CNTs contribute not only to the interface adhesion, but also enhance the electrical conductivity of the composites. In this study, CFRPs where manufactured via Vacuum Resin Transfer Molding (VRTX) process and characterized for their quality by microscopy techniques on their cross-section. At this point, it is important to investigate the effect of in-situ grafting of CNTs onto fibre on the mechanical response of the composite through instrumented indentation technique. Comparing the nanomechanical properties with conventional mechanical testing, as well, will reveal the enhancement of mechanical behavior both in micro- and macro-scale level. Finally, nanindentation will be applied as a tool for studying the local mechanical behavior of the fibre/matrix interface.

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Thermal conductive polymers targeting heat sink applications: Development of polymer / CNT / graphene Oxide nanocomposites

Stefanos Koutsoumpis, Panagiotis Maroulas, Dimitrios Dragatogiannis, Costas A. Charitidis

Thermally conductive polymer composites offer new possibilities for replacing metal parts in several applications, including power electronics, electric motors and generators, heat sinks, thanks to the polymer advantages such as light weight, corrosion resistance and ease of processing. However, obtaining composites having thermal conductivities higher than 4W/mK and usual polymer processability is very challenging at present. The challenge primarily comes from the large interfacial thermal resistance between the filler and the surrounding polymer matrix, which hinders the transfer of phonon dominating heat conduction. We developed nanocomposites base on of High high Density density Polyethylene polyethylene (HDPE) and Polypropylene polypropylene (PEP) with rich in nanofillers of Carbon Nanotubes (CNTs) and Graphene Oxide (GO). The unusually high thermal conductivity makes carbon nanotube (CNT) the best promising candidate material for thermally conductive composites. The synthesisFormulation of nanocomposites is done in two steps: a) pre-mixing CNTs inhot melt mixing using as plasticizer Polyether Glycol or solution mixing polypropylene solution to neutralize the possibility for airborne contamination of CNTsevenly disperse nanoparticles in industrial wise method and b) hot-melting of the nanocomposite. The development of hybrid CNT/GO provides the means for better dispersion of CNTs in the non-polar polymer macromolecules. The impact of CNTs on thermal conductive properties is minor in comparison to the effect on mechanical, thermal and electrical properties. The increase in thermal conductivity will be further pursued in hybrid nanocomposites.

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3D printed CFRPs and micro-composite products by design from recycled resources

Tatjana Kosanovic Milickovic, Willem Van De Steene, Ludwig Cardon, Costas Charitidis
Advances in digital and other key enabling technologies are changing the way of product design, production, commercialization and value generation. By developing appropriate solutions, products should be turned into competitive multi-life products, and at the end of life (EOL) reused in new second life products that can become more competitive than products produced from scratch.

In this direction Repair3D project aims at the development of innovative reclamation and repurposing routes for EOL (both post-consumer and post-industrial) thermoplastic and carbon fibre reinforced polymer (CFRP) components by employing advanced nanotechnology solutions, Additive Manufacturing (AM) and recycled resources, for the production of high added value 3D printed products with advanced functionalities, demonstrating the circular use of materials through multiple cycles of manufacturing/recycling.

Continuous Fibre Additive Manufacturing (CFAM) is based on an innovative CFRPs manufacturing concept applying heavy-duty printer developed to handle composite lay-up forces. Continuous fibres and thermoplastic polymer pellets are fed into a print head which combines them into a well-impregnated composite material right before printing. A full 3D 5-axis lay-up technique is developed to be able to fully tailor fibre direction and thus stiffness and strength of a component. In aerospace, automotive and other applications where high stiffness and strength are required, this CFAM technique could produce strong, stiff and lightweight composite parts also as an alternative to metal products. Based on the preliminary research, triple layer composites with a fibre volume fraction of around 40 vol% and with a decent fibre distribution in the matrix were successfully printed and characterized.

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Effects Of Alternative Fuel On Aircraft Emissions: Results From Recent Flight Experiments

Hans Schlager

Measurements of jet engines emissions are reported for alternative jet fuels from ground and flight tests. The alternative fuels used include various blends of JetA1 with synthetic fuels and biofuels. The flight tests included measurements in the wake of source aircraft in the near-field (~100-200 m) and far-field (~10-20 km) for different fuels, cruise altitudes, power settings and for conditions with and without contrail formation. Alternative fuels contain near-zero levels of aromatics and sulfur which are mainly responsible for the formation of soot particles and volatile aerosols during combustion and in the expanding emission plume, respectively. Aviation-related soot emissions play a crucial role in the formation of contrails. The number of soot particles emitted per kilogram of fuel burnt determines the initial number and size of ice crystals in contrails and thus the radiative properties of aviation-related cloudiness. Emissions of volatile aerosols by aircraft are suggested to alter the radiative properties of liquid clouds in the troposphere.

The ground and flight tests were performed during three campaigns at the NASA Armstrong Flight Research Center in Palmdale, California in 2014, the German Air Base in Manching in 2015 and the USA/NATO Air Base in Ramstein in 2018. All campaigns were conducted in a close collaboration between DLR and NASA. The aircraft involved included the DLR ATRA (Advanced Technology Aircraft) Airbus 320 and Falcon 20, and the NASA DC8 and Falcon HU25. In the campaign in Palmdale also the Canadian NRC participated with a CT133 aircraft. The flights were conducted in restricted air space. The source and measurement aircraft flew race tracks with varying distances, speeds and altitudes. The measurement strategy and main results from the joint campaigns will be presented including the observations that blends with 50% alternative fuel reduce emissions of non-volatile (soot) particles by 30 to 70% at cruise.

How Large Is The ICAO’s “Carbon Offsetting And Reduction Scheme For International Aviation” Reducing The Climate Impact Of Aviation? – An Ecats Perspective


Aviation serves the global needs for mobility and it is an important economic branch. However, air traffic emissions also contribute significantly to climate warming, though in a very complex way. The emitted species alter the atmospheric composition, the Earth’s radiation budget and eventually contribute to climate change. Importantly, not only CO₂, but also non-CO₂ effects, such as NOₓ emissions, contrails and contrail cirrus contribute to the aviation related climate change. Air transportation shows large annual increase rates reinforcing the aviation’s share to climate change. ICAO started an initiative reducing the climate impact of aviation by implementing the “Carbon Offsetting and Reduction Scheme for International Aviation”. Here, we give a brief overview on CO₂ and non-CO₂ climate effects, discuss how CORSIA will change future emissions and investigating how much this policy actually affects the climate impact from aviation and address future needs in relation to the Paris 1.5°C and 2.0°C climate targets.

Estimating Fuel-Water Dissolution In Conventional And Alternative Fuels

Simon Christie
In an airport operational environment water is ubiquitous, and in spite of rigorous procedures to eliminate it from fuel farm infrastructure it is nevertheless present in all fuel. The quantity of water a fuel can hold at saturation strongly depends on the fuel chemistry, the additive package, temperature and pressure. If more water is present than the fuel can hold, the excess will be present either as emulsion or a separate bulk free water phase, which have potential consequences for maintenance, corrosion and safety.

In this contribution, we report the fuel-water dissolution characteristics for a number of conventional and alternative fuels. Quantitative data as well as temperature response functions for specific fuels are reported. These data are supported by a meta-analysis of literature data to identify common effects, and a comparative analysis with the IUPAC-NIST solubility data series for hydrocarbons with water. The development of generic methods to estimate fuel-water dissolution and the relation with temperature from knowledge of fuel chemical composition is also discussed.

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**Multidisciplinary Preliminary Aero-Engine Design For More Sustainable Flight Missions**

*A. Alexiou, N. Aretakis, D. Kapsoulis, K. Mathioudakis, K. Giannakoglou*

A flexible and extensible modular multi-disciplinary framework has been developed, in order to undertake design space exploration and multi-disciplinary optimization assessments of novel Ultra High Bypass Ratio (UHBR) and open rotor concepts at aircraft mission level.

The framework comprises advanced engine performance simulation modelling capabilities, coupled with turbomachinery component aerodynamic design, flow path and weight estimation as well as aircraft performance, for mission level assessments. Advanced numerical solvers and optimization algorithms are integrated in the framework.

The capabilities developed are used to optimize the design of a UHBR (Ultra High Bypass Ratio) geared turbofan configuration with a Variable Area Nozzle, for short/medium range applications and an EIS of 2025. The objective is to minimize the amount of fuel burn, an objective that leads to both minimum CO$_2$ production and fuel costs. Both single and multi-objective (several missions) optimizations are performed, for representative civil aircraft missions (range from 300 nm to 4000 nm). Based on the technology level assumptions made and the constraints imposed in the design, fuel burn reduction (and therefore CO$_2$ emissions) in excess of 18% are anticipated, compared to conventional current day engines.

The work has been undertaken within Clean Sky 2 project DEMOS, in line with efforts to meet the long term ACARE targets to reduce aircraft CO$_2$, NO$_x$ and noise emissions.

**Reducing Environmental Footprint Of Civil Aircraft Missions Exploiting Free Routing Possibilities**

*D. Katsikogiannis, M. Thoma, N. Aretakis, A. Alexiou, K. Mathioudakis*

The possibility of choosing the flight path of civil aircraft without following strict trajectory definitions, what is known as “free-routing” allows the optimization of flight missions while achieving certain operational targets. Missions can be altered either in terms of the vertical flight profile or the ground trail of the flight.

An approach for optimizing flight mission profiles is presented, taking into account all ambient effects on aircraft engine operation, namely ground pressure and temperature as well as wind direction and
magnitude. The minimization of fuel burn is sought, for flights between specific destinations, with specific time requirements, for executing the missions. Minimizing fuel burn minimizes not only the corresponding cost of fuel acquisition but also the amount of CO$_2$ emitted for the given flight.

Current day capabilities of collecting atmospheric condition data, such as pressure, temperature and wind magnitude and direction are exploited. Short or long term weather forecast data over a geographical area are used in order to choose optimal flight paths.

A mission analysis tool that incorporates the influence of all those ambient factors, without simplifying assumptions, is used coupled with advanced optimization algorithms. Aircraft performance data are drawn from well-established and known databases. Custom built ending models are used for simulating the propulsion features of the aircraft.

The method is validated using various sources of information, such us the predictions of commercially available tools, recordings of publicly available flight tracking software as well as Airline data.

It is demonstrated that the beneficial effect of lower ground temperatures or wind direction can be captured in order to provide fuel burn reduction, by altering the routes of flights between two destinations. Realistic flight cases are used.

Numerical behavior of the algorithms employed is investigated in an effort to assess real-time application capabilities.

**AVIATOR - Assessing aViation emission Impact on local Air quality at airports: TOwards Regulation**

*Víctor Archilla, Gaiska Aragón, Dévora Hormigo, Dave Raper, María Sánchez*

Emissions from aircraft have adverse effects on the air quality in and around airports, contributing to public health concerns within neighbouring communities. AVIATOR will adopt a multi-level measurement, modelling and assessment approach to develop an improved description and quantification of the relevant aircraft engine emissions, and their impact on air quality under different climatic conditions, specifically on non-volatile PM and volatile PM (down to <10 nm), and volatile PM gaseous precursors.

Engine generated particulate matter (PM) and gaseous emissions in test-cell and on-wing from an in-service aircraft will be measured to determine pollutant plume evolution from the engine and APU exhaust. This will provide an enhanced understanding of emitted pollutants, and the scalability between the regulatory test-cell and real-world environments.

AVIATOR will develop and deploy across multiple airports, a proof-of-concept low-cost sensor network for the monitoring of ultra-fine particles (UFP), total PM and gaseous species such as NOx, SOx and VOCs.

**WP2: TEST-CELL ENGINE EXIT AND IN-STACK PLUME MEASUREMENTS:**

The programme of experiments and measurements will be conducted on large modern Rolls-Royce Trent family development engines in the INTA test-cell facility. Long term engine measurements within the test-cell will: i) ensure variability associated with ambient conditions (temperature, pressure, humidity), ii) limit the potential effect of solar radiation on plume evolution, iii) alleviate the impact of cross wind conditions on plume advection. These new insights will provide a better understanding of the potential for in-stack measurements to be used future regulatory purposes.

**WP3: ON-WING ENGINE EXIT AND DOWNSTREAM PLUME WITH APU MEASUREMENTS:**
To establish a better understanding of the evolution of pollutants in the exhaust plume of an aircraft during the LTO cycle, and the impact of climactic conditions (and potentially solar radiance), two distinct test programmes will be conducted during differing seasons (summer and winter). Testing will take place at: i) varying times (day and night), ii) different aircraft axial locations, iii) different engine power levels (LTO cycle) and APU modes. The influence of fuel composition on emissions will also be studied during an alternative drop-in fuel test.

WP4: AMBIENT MEASUREMENTS AND SENSOR NETWORK DEVELOPMENT:
To characterise the pollution burden in and around the airports, transport and impact of emissions from aircraft engines and APU will be monitored in this more complex environment through: i) High-fidelity measurement of ambient air quality at Madrid Airport, ii) low-cost sensors nodes deployment at 3 airports (Madrid, Zurich and Copenhagen).

WP5: MATHEMATICAL AND NUMERICAL MODELLING OF PLUME MICROPHYSICS, CHEMISTRY AND DYNAMICS:
A microphysics and chemical conversion of the plume evolution will be carried out in two phases: i) focus on examining the range of possible background parameter values and concentrations and ii) focus on the modelling on engine emissions. Physical dynamics of the hot and turbulent exhaust of aircraft main engines for different meteorological conditions will also be investigated.

WP6: NUMERICAL POLLUTANT MODELLING AND TRANSPORT IN AND AROUND AIRPORTS:
Dispersion models will be initialized for Madrid and Zurich airports using the estimates and parameterizations developed in WP5 studies and the modelled concentrations of the key pollutants will be compared to those measured in the experimental campaigns at the airports.

WP7: REGULATIONS:
Identification of potential gaps in aircraft engine emissions regulation, using technical evidence and the identification of pathways for bridging regulatory gaps.
Thermo-mechanical Modelling for Directed Energy Deposition

Adrien Doux, Xavier Dugros, Vincent Philippe

Direct Energy Deposition (DED) Additive Manufacturing (AM) processes have great potential to be used as cost-effective and efficient repairing and re-manufacturing processes for aerospace components such as turbine blades and landing gears. The AMOS project intends to connect repair and re-manufacturing strategies with design through accurate DED process simulation and novel multi-disciplinary design optimisation (MDO) methods. The ultimate goal is to reduce aerospace component weaknesses at design stage and prolong their lifecycles.

DED AM process is a multiphysical phenomenon involving high laser power melting powder or wire on a substrate. An experimental heat source has been calibrated using a thermal analysis of IN718 laser and powder AM on a sample part. Residual stresses and final distortion are also computed using thermal field and the evolving part distortion at each increment. Multiple hypotheses have been considered to model the molten pool creation on the Heat Affected Zone (HAZ).

DED Topology Optimisation Study

Adrien Doux, Xavier Dugros, Vincent Philippe

Direct Energy Deposition (DED) Additive Manufacturing (AM) processes enable more resilient life cycle solutions of aerospace components. Multidisciplinary design optimization methods consider the common defects and suitable repair strategies provided by DED systems. It aims to develop a qualitatively understanding of repairing and re-manufacturing potential on new life cycle scenarios by combining life cycle analysis and design optimization methodologies.

An application is performed on a turbine rear frame section provided by GKN Aerospace. Finite element iterative calculations considering two load cases enable to determine the best balance between improving final part stiffness and reducing deposited material volume. A grid pattern with straight stiffeners is defined as design space to be representative of an easy industrialized production. An optimized stiffeners design results from topology optimization. Multiple DED process simulations based on WP3 modelling assumptions are computed on this structure. The impact of several process parameters is evaluated to significantly reduce residual stresses and final distortion.

A Quantitative Model Of Competitive Grain Growth Behaviour In Direct Energy Deposition Fabricated Ti6Al4V

Jinghao Li, Mathieu Brochu, Yaoyao Fiona Zhao

Direct Energy Deposition (DED) technology is now widely applied in the remanufacturing industry, among which microstructure simulation gradually shows its importance and attracts a lot of research interests. Traditional solidification microstructure simulation methods all have their merits as well as drawbacks. The presented research used wire feed DED fabricated Ti6Al4V samples as a benchmark to establish a deterministic microstructure model, named ‘invasion model’. Instead of simulating the grain growth kinetics, this model focuses on the invasion behaviour of grain boundaries by analyzing their tilt angle.
between the adjacent grains. This model is designed to investigate the competitive grain growth behaviour quantitively under the rapid solidification conditions in the DED process. In order to address the difficulties in the microstructure simulation for DED, the databases of grain growth behavior under a rapid and directional solidification condition was established. Thin wall structure samples are fabricated for experimental validation. The crystal orientations of prior β grains are characterized by EBSD reconstruction and compared with the simulation result. The methodology of this model can also be applied to other cases of metal additive manufacturing.

**Measuring Extreme Temperatures In Sand-Grain-Sized Droplets Of Liquid Titanium At Sub-Ms Speed**

*Ole Krarup, Song Gao, Xiaoyi Bao*

A reliable experimental method is needed to determine the temperature at the center of a droplet of liquid titanium and its dependence on the sweep speed and applied power of an industrial laser. The sensor must be robust and fast enough to collect a clear signal before sustaining critical damage in the +2000K environment, while also being so small that it does not affect the thermal dynamics of the d=1mm droplet.

We propose using a commercially available Multimode Silica Fiber and an ultrafast Near Infrared Spectrometer (1 spectrum in < 500µs) to collect blackbody radiation from the droplet’s core. Using Wien's displacement law, the temperature can be inferred from the wavelength where intensity peaks. So far, we have demonstrated that a peak occurs in the expected (1200-1600nm) range when the fiber tip is heated to its melting point by a current arc in a fiber splicer (see supportive material). The integration time is sufficiently fast that dynamics of the melting process can be investigated with good resolution.

Ongoing work focuses on verifying that the temperature measured by the spectrometer is correct. This will be done by placing a high temperature thermocouple in the same environment as the fiber tip and comparing their measurements.

**A State-Of-The-Art Review On Additive Manufacturing Of Inconel Alloy 718**

*Wei Guo, Udisien Woy*

Alloy Inconel 718 (IN718) is optimally engineered to meet the requirements for critical aerospace applications. Its low thermal conductivity, high hardness and work hardening rates makes it especially suited to aero-engine components. However, these advantages are the reasons that IN718 alloys are classed as “difficult to machine” materials. The additive manufacturing (AM) process is an attractive processing route for these otherwise difficult to process superalloys. In particular, enhanced geometric freedoms and the ability to manufacture near-net shape components minimises post-machining requirements. These factors influence the buy-to-fly ratio, which has significantly cost implications for the aerospace industry. This paper provides a state-of-the-art review on the additive manufacturing of IN718 alloys. The requirements for different wire and powder-based additive manufacturing techniques, such as Laser Metal Deposition (LMD), cold metal transfer (CMT) deposition and shaped metal deposition (SMD) are presented. Typical processing challenges due to AM techniques are discussed. In particular, liquation cracking, which is produced at the last stage of solidification via γ/Laves eutectic reaction, is mainly attributed to the constitutional liquation of Laves phase. The typical microstructure, mechanical properties and relative industrial implications of utilising AM for processing IN718 materials are also reviewed in this paper.
The Use Of Affordable Technologies In Manufacturing Of Aircraft Structures For Small Air Transport
On The Example Of Cabin Structure In The Sat-Am Project

Dawid Ulma, Paweł Gula, Jacek Dudziak

The scope of this project complies with the main goals of Small Air Transport of Clean Sky research programme. The project aims to the development of High Versatility and Cost Efficiency. Application of proposed synergy of technology allows to reduce time, cost, weight, numbers of parts which has direct influence on flight performance and finally on reduction of fuel consumption. On the other hand, effective development of the proposed technology increases flight safety. It is the next step in the development strategy of 4 hours door to door journey.

The SAT-AM project provides the development of technologies, as well as synergies between them. Finding maximum affordability for combination tested technologies and synergies between developed technologies will be innovation in the aviation sector. There is main concept of the proposal.

The main objective of the SAT-AM project is to develop technologies for manufacturing lighter and cheaper airframes while their reliability is maintained or increased. Demonstrator will be studied to prove feasibility, synergy and benefits of the selected technologies in comparison to traditionally produced assemblies. Expected technologies should offer high level of flexibility allowing efficient modernisation of airframes production. Technologies to be investigated include:

- Friction Stir Welding (FSW),
- Additive Manufacturing (AM),
- Block Structures (BS),
- High Speed Machining (HSM),
- Composite (CP)

SAT-AM will progress beyond the state-of-art by developing and validating a technology, in which quality, cost production and safety will be linked with the aviation industry.

The Use Of Affordable Technologies In Manufacturing Of Aircraft Structures For Small Air Transport
On The Example Of Composite Nacelle In The Sat-Am Project

Jacek Dudziak, Pawel Gula, Dawid Ulma

Aeroplane structures are exposed to many loads during their working lifespan. Every particular action made during a flight is composed of a series of air movements which generate various aeroplane loads. One rigorous requirement that modern aeroplane structures must meet is that they must be of high durability and reliability. This requirement involves taking many restrictions into account during the aeroplane design process. The most important factor is the structure’s overall mass, which has a crucial impact on both utility properties and cost-effectiveness.

The SAT-AM project provides the development of technologies, as well as synergies between them. Finding maximum affordability for combination tested technologies and synergies between developed technologies will be innovation in the aviation sector.
The “Affordable integration of aircraft components Demonstrator B” is related to the design and modification of the nacelle. The making of a new nacelle with the use of composites, as well as the composite-metal combination, is realized in the project. The nacelle is an element particularly exposed to high temperatures (emitted by the engine) and variable exploitation conditions. That is why special attention must be given to the heating elements, such as the anti-icing installations, as well as the separator which secures the current, the extinguishing system etc. The new element is to be cheaper in manufacturing by 50%, thanks to the use of new technology and the reduction of workload compared to the metal element. Simultaneous talks are in progress with the CAA (Civil Aviation Authority), in order to obtain the permission for land and in-flight tests.

The main goals of the project are to be achieved by the following detailed objectives:

- Development of the selected technologies
- Manufacturing of elements of developed structures
- Assembling of developed assemblies of the airframe
- Evaluation of the production results of selected technologies and indication

**SATS - Small Aircraft Commercial Operation Safety — Distributed Probability Model**

*Bartosz Dziugiel*

Main purpose of the study was to define and build the mathematical model of light aircraft safety dedicated to analyze the probability of accidents related to commercial transport of passenger and goods. The model was used to propose cost efficient and affordable methods to improve the safety of operations executed within the Small Aircraft Transport System (SATS). The methodology was based on definition of the typical mission profile of the SATS aircraft and identification of a set of critical safety issues. The applied methods originated from statistical analysis and theory of probability. Reliability Diagrams theory enabling modelling of Mean Time Between Incident or Accident (MTBIA) was of special importance. The established model was calibrated among other with use of statistical data gathered and processed in the framework of analysis of more than 450 accidents occurred in the United States between 2005 and 2016. The main result of the study was distribution of occurrence of accidents’ initial reasons intensity amongst particular flight phases. Additionally the model had a capacity to provide expected overall system safety level in function of a set of technical and operational specifications of aircraft included into the SATS. It was found from the study that optimal selection of the technical specifications of aircraft fleet as well as operational features of the whole system would improve the SATS safety level even more than 3-fold and increase in the value of MTBIA by more than 200% without significant increase the cost of operation.

**SATS - Small Aircraft Commercial Operation Safety — Distributed Accident Risk Modelling**

*Bartosz Dziugiel*

Main purpose of the study was to define and build the mathematical model of safety of light aircraft. In particular the model was dedicated to analyze the risk and cost of accidents related to commercial transport of passenger and goods by small aircraft and propose cost efficient and affordable methods to improve the safety and reduce the cost of operations executed within the Small Aircraft Transport System (SATS). The methodology was based on SATS distributed probability model extended with accident severity module. Within the scope of occurrence consequences the degree of aircraft destruction, injury and fatality degree among passengers were modelled. The total statistical cost of single accident type was estimated. The study was supported by data acquired from more than 450 accidents occurred in the
United States between 2005 and 2016. The main result of the study was distribution of accidents severity and cost for nearly 30 occurrence types throughout critical flight phases. Additionally the model had a capacity to provide expected overall system safety level in function of set of technical and operational specifications of aircraft forming the SATS. It was estimated that average cost of accident for commercial operation of light aircraft was equal to less than 10 USD per flight hour. Additionally it was found from the study that optimal selection of the technical specification of aircraft fleet as well as operational features of the whole System would lead to significant reduction of that value both through probability reduction as well as by decrease of accident severity. This safety improvement would not result with significant increase the cost of operation.

**Barriers To Development And Challenges For Small Air Transport - Assessment Of The Potential For Change**

*Iwaniuk Andrzej, Piwek Krzysztof*

This paper presents the results of a study which examined the barriers to development and challenges for small air transport (SAT). The concept is seen as an economical alternative to car travel when considering the economic value of a traveller’s time. SAT will be a new component of the European Air Transport System and complementing existing ATS service. It responds to further market segmentation by offering local and regional air transport services at a competitive price. SAT will be a customer-oriented system fulfilling expectations of future travellers which include personalized travel, with individual tailoring of the travelling.

SAT development faces big challenges. A key point is the capability for low cost solutions. The fleet of the SAT might consists of unified and modular families of 4-19 seats fixed wing aircraft, and rotorcraft designed to serve markets with services on diverse and low-density routes. Aircraft configurations should be designed also to fulfil low noise foot print and low emissions. Aircraft propulsion (including electric propulsion) should be optimized for designated mission. Aircraft maintenance and airworthiness should be carried out within a joint system of services. Fleet and transport services management should be net-centric and automated. Future small aircraft should be operated by a single pilot in IMC conditions, may be remotely piloted or in the long term be fully autonomous. Specific avionics for small aircraft is one of the focus for future activities.

A number of works in this area are carried out under Clean Sky2 Small Air Transport - Transversal Activity (SAT-TA). The works are carried out on three levels: ITD Airframe, ITD Engines and ITD Systems. As part of the ITD airframe, the works on the development of optimal and affordable technology for the manufacture of airframe structures are carried out. These are projects: OPTICOMP (Optimized Composite Structures) and SAT-AM (More affordable small a/c manufacturing). Work on the new, more reliable and more efficient turbine engine for the SAT are performed under the engine ITD (MAESTRO). Affordable, modern cockpits and avionics solutions for small aircraft are developed under Systems LTD.

This paper is an attempt to systematic approach to the implementation of SAT concept, an estimation of the scope and coherence of conducted works, and defining development barriers in the field of technics and technology.

Directions of the research and development works and other activities for the effective and effective implementation of the SAT concept were proposed.
The Application Of Thin-Wall Integral Constructions In Aviation In Example Of The Sat-Am Project

**Pawel Balon, Bartlomiej Kielbasa, Edward Rejman, Janusz Szostak**

Aircraft structures are subject to a wide range of loads during operation. Each flight task consists of a series of maneuvers, which generate different types of aircraft load, both as to the value and direction of their operation. The high level of durability and reliability is a strict requirement for today's aircraft constructions. This requirement means that many infrequently contradictory restrictions should be taken into account during the aircraft design process. The most important element here is the mass of the structure which has a decisive influence on both the volatile and technical properties as well as the economical operation. This makes an aircraft one of the most complex products of modern technology. Modern aircraft structures, or more precisely their load-bearing structures, are almost exclusively made as thin-walled structures which meet the postulate to minimize the mass of the structure. Widely distributed are the systems in which the cover is reinforced with longitudinal and transverse elements, providing the system as a whole, the required stiffness and strength. While the local loss of stability of the coverage is permissible under operating load conditions, the exceeding of the critical load levels of the structural skeleton elements (frames, stringers) is practically synonymous with the destruction of the structure. The aforementioned specifies continuous improvement of both design methods and improvement of structural solutions of aviation structures. The development of materials science and the continuous improvement of technological processes is not without significance for the effectiveness of these ideas.

These disciplines allow for constructing geometrically complex integral structures that create the possibility not only of a more rational use of material characteristics, but also by their appropriate shaping, they significantly increase the mechanical properties of the supporting structure. An advantage of the first-rate importance for the application of integral regimes is the economical saving that is gained as a result of the elimination or reduction of assembly operations. Densely ribbed cover elements belong to the category of supporting structure elements that reduce the mass and increase the strength parameters of the load-bearing structure. By reducing thickness of the cover and at the same time introducing densely stiffening longitudinal elements, a structure with considerably higher critical loads can be obtained, and consequently a more favorable distribution of gradients and stress levels, which directly contributes into an increase in fatigue life. This paper attempts to analyze the above-mentioned problem more closely, using the example of a densely ribbed rectangular plate.
Development Of 3D Boundary Element Method For The Simulation Of Acoustic Metamaterials/Metasurfaces In Aero-Acoustic Environment (In Flow) For Next Generation Aero-Engine Applications

Imran Bashir, Charles Courtney, Michael Carley

Low cost airlines have significantly increased the air transport, thus increase in aviation noise [1]. Conventional noise attenuation techniques cannot mitigate civil aviation noise. The aim of this work is to design innovative configurations, which are capable of absorbing, dissipating and redirecting the aeronoise at the source. To achieve this, the light-weight multi-functional acoustic metamaterials and metasurfaces those have already been proven in room acoustics and noise attenuation are being studied to test their performance in flow and modify their design to be suitable for aeronautical applications [2], [3]. Sound propagation through aero-engines which involves moving sources in moving media provides a significant challenge in predicting as conventional methods are not applicable. The work presented here considers the development and re-formulation of existing techniques to incorporate the aeroacoustic environment and to validate results with experimental data. To achieve this, a 3D Boundary Element Method being developed, which is a standard collection technique that can optionally use the Fast Multipole Method (FMM) library of Greengard and Zimbutas [4] to simulate aero-acoustic problems. The sound propagation in mean flow is solved using the Taylor Transformation [5]. In particular, scattering problems are solved by applying Taylor’s transformation to the solution for the total field in the zero-flow case, as in the work of Agarwal and Dowling [6]. Furthermore, the metamaterials are being implemented as an impedance patch, by extracting the characteristic parameters. Non-local boundary conditions are being implemented in 3DBEM, which hales a significant leap in development of simulation method. This will allow a complete implementation of metamaterial as a non-locally reacting impedance patch in aeroacoustic environment. Initial experiments have been carried out inside windtunnel, which show reasonable agreement with 3DBEM predictions. This work is being extended to a wider range of acoustic metamaterials and metasurfaces in order to enhance the controllability and tunability of sound propagation over wide frequency bands in aeroacoustic environments.

References
AERIALIST: an integrated toolchain for the design of metamaterial-based devices in aeronautics

Umberto Iemma

The project AERIALIST (AdvancEd aicRaft-noise-Alleviation devIceS using meTamaterials), funded within the framework of the Breakthrough Innovation topic of the H2020 program, aims at the disclosure of the potential of metamaterials in the development of disruptive devices for the mitigation of aircraft noise. AERIALIST contributes to the identification of the breakthrough technologies to achieve the noise reduction targets foreseen by the ACARE Flightpath 2050. The focus is on the exploitation of the unconventional properties of acoustic metamaterials to modify noise directivity patterns and achieve specific target responses such as scattering cancellation, noise hyper-focusing, and noise trapping. Although targeted to low TRL, AERIALIST is structured in order to guarantee the integration of its achievements in a toolchain cover the entire development process, ad capable to be easily extended to attain TRLs of industrial interest following the evolution of the manufacturing technologies. AERIALIST toolchain is founded onto four pillars: i) the extension of the acoustic metamaterial theory to the aeroacoustic domain and the development of suitable numerical methods to simulate the metamaterial response; ii) the exploitation of the latest additive manufacturing for the realization of sample concepts; iii) the wind-tunnel testing of the selected concepts to validate and assess the metaresponse; iv) the identification of a development roadmap towards higher TRL and integration of devices at system level. The presentation of the project provides an overview of the objectives and a description of the project’s structure. A summary of the results achieved so far is also given, as well as a description of the current and future activities.

An inverse method for design and characterisation of acoustic materials

Huina Mao, Peter Göransson

Noise daily affects a large number of people. The advent of manufacture technology has recently enabled to manufacture materials tailored for specific applications, e.g., acoustic metamaterial in aeronautics and vehicles. In order to design and understand the material properties of anisotropic and viscoelastic structures, an inverse method is proposed. Full field measurements of the 3D displacements under static surface loads are used as targets in the inverse estimation to fit a material model of an equivalent solid to the measurement data. Material properties of different microstructures are characterised and the accuracy of the results are verified in both static and dynamic responses. In addition, novel functional materials are designed and 3D printed based on industry-specific applications. The proposed inverse estimation method provides a possible way to connect the gap between material design and industrial applications.

The influence of additive manufacturing strategies on the performance of acoustic metamaterials

J. Kennedy, L. Dowling, L. Flanagan, H. Rice, D. Trimble

The AERIALIST project aimed to advance the TRL of acoustic metamaterials through the production of several novel material concepts in sufficiently large volume for use in an aeroacoustic wind tunnel test. This work will report on the success of the research which necessitated a variety of manufacturing strategies, including state of the art additive techniques, to produce the metamaterials in the volumes required. The various AERIALIST metamaterial concepts were manufactured through FDM, DLP, SLA and
SLM additive manufacturing techniques. Each of these approaches have their own strengths and weaknesses, the geometric accuracy and surface roughness of the produced parts can have a strong effect on the behaviour of the acoustic metamaterials. Each of the various manufacturing strategies was found to be appropriate for a different metamaterial concept within AERIALIST. This work will report on detailed inspection of the manufactured parts using microscopy and micro-CT scanning. The tolerances of the additive manufacturing have been related to the acoustic performance through impedance tube test results. The results can inform best practice approaches to the manufacturing of acoustic metamaterials for aeroacoustic applications.
Effect Of Aging Condition And Precipitate Coherency State On Corrosion Of Al-Alloy 2024

Gregory N. Haidemenopoulos, H. Mavros, Z. Alhosani, P. Cho, K. Polychronopoulou, H. Kamoutsi

The effect of aging treatment on corrosion mechanisms of Al-alloy 2024 was studied. Aging treatments were applied and the aging conditions were determined according to the evolution of hardness. These conditions were classified as under, peak and over-aged conditions. Corrosion experiments on the aged alloys included Exfoliation Corrosion (EXCO), Electrochemical Impedance Spectroscopy (EIS) and Electrochemical Potentiondynamic measurements. Optical observations based on metallographic and scanning electron microscopy were adopted for the microstructural study of the corroded alloys. The hardness evolution during aging is in compliance with a typical aging curve. In addition, corrosion observations revealed an increasing corrosion susceptibility with the increase of the aging time. Pitting, intergranular and exfoliation corrosion were observed for the under-aged alloys, while a more extensive material loss, involving exfoliation, was observed for the peak and over-aged alloys. The observed corrosion behavior was correlated with the variation of corrosion potential arising from changes of the coherency state of the strengthening precipitates; corrosion resistance decreases as the coherency state of the metastable precipitates decreases from coherent, to semi-coherent and finally incoherent state during aging. Results of the electrochemical measurements are also reported and correlated with the aging behavior. The results of this research will provide a better understanding of the correlation between corrosion-induced hydrogen penetration and trapping in microstructure sites with the coherency of the precipitates.

Microstructural and Mechanical Behavior Of Friction Stir Welded Aa5083-H111 Plates Reinforced With Two Different Ceramic And Carbon Nanotubes Particle Mixtures


Today’s industrial applications are focused on structures with relatively low weight but very high strength with the typical welding methods struggling to achieve that. In the present study the seam of friction stir welded 3 mm thick AA5083 plates was reinforced with two different combinations of ceramic powders and carbon nanotubes (SiC-CNT and SiC-CNT-Al2O3). A comparison study was carried out using means of optical and electron microscopy, energy dispersive spectroscopy, microhardness testing, tensile testing and nanoindentation in order to find out which combination provided the best results.

Study Of Friction Stir Dissimilar Butt Welding Between Thin Plates Of The Aa5754 And The Aa5083 Aluminum Alloys


The aim of our work is the dissimilar welding of thin plates (3 mm thickness) of the AA5754 to the AA5083 via the Friction Stir Welding method. A parametric study was conducted via two sets of experiments in order to achieve sound mechanical bonding between the two alloys. The first set consisted of single pass experiments whereas the second set of multi-pass ones. All the specimens were studied via optical microscopy and the sound looking ones were further examined via microhardness and tensile testing. It
was concluded that the use of two friction stir passes further improved the quality of the weld as both its UTS and elongation were close to the minimum equivalent values of the AA5754 Base Metal.

**Adhesive Strength Characterisation Of Titanium-Composite Joints**  
*Vadim Kruts, A. Zinkovskii, A. Fanleib, K. Savchenko, M. Shevtsova, N. Chandarana*

The use of composite materials in primary aircraft structures, such as the fuselage and wings, represents one of the most efficient methods for weight reduction in the aerospace industry. At the same time, in the mentioned constructions there is still a significant amount of metallic elements. Titanium and its alloys are used commonly in the industry, so it is crucial to develop suitable methods for fabricating hybrid structures that combine the metallic and composite elements, to replace the classic non-detachable joints such as welding and rivets.

In the present study, two types of joints are manufactured and tested: titanium/titanium and hybrid titanium/composite adhesively bonded specimens. The shear strength of the adhesive bond is measured during lap-shear testing. Improvements in shear strength are achieved by the inclusion of mechanical surface treatments prior to bonding. The improved adhesive strength led to a 30% increase in the maximum stress of the joint.

**The Effect Of Adhesive Bonding On The Corrosion Behavior Of Aa2024 Fswed Single Lap Joints**  
*Christina Margarita Charalampidou, Daniel F.O. Braga, Pedro M.G.P. Moreira, Nikolaos.D. Alexopoulos*

Aluminum alloy AA2024 is still the most widely used aluminum alloy in metallic aerostructures mainly due to its high damage tolerance capabilities. Aluminum alloy AA2024, and generally aluminum alloys from the 2xxx series, are considered as non-weldable, as the mechanical properties of the welded joints are decreased significantly. Friction stir welding (FSW) is a solid-state joining technique that has been well documented to the problem of joining high strength Al alloys difficult to weld by fusion welding, such as 2xxx and 7xxx. FSW was found to considerably improve weld properties avoiding problems associated with the conventional fusion welding processes (e.g., solidification cracking and pores). Beyond solid state welding, another joining technology that has shown high potential for disruptive innovation in structural design is adhesive bonding. In order to incorporate the advantages of adhesive bonding and overcome some difficulties (e.g. difficulty in inspecting bondline quality following manufacturing and during in-service life, manufacturing defects during curing, sensitivity to environmental attack and physico-chemical conditions of the substrates) adhesive bonding has been applied in conjunction with other joining methods, resulting in hybrid joining techniques. The broad range of mechanical and chemical characteristics of structural adhesives as well as their ability to bond dissimilar materials allowed the combination with various other joining technologies. In the present work, an effort has been made to weld AA2024-T3 sheets with this high-performance hybrid welding process. Additionally, corrosion damage is essential to the structural integrity of the aircraft structures; hence, the effect of corrosion on the hybrid joint technique of AA2024-T3 was also investigated.

A thermoset epoxy by Huntsman® (Salt Lake City, UT, USA) was used as an adhesive and in between the two sheets for the overlap welded joint. Friction stir welds were produced on an ESAB® (Gothenburg, Sweden) LEGIO 3UL numeric control machine. Adhesive bonded joints and adhesive specimens for mechanical characterization were manufactured in a hot plate hydraulic press, with time, temperature
and pressure adhesive curing control. The parameter window chosen was based on published results, such as and past experience within the work group.

In order to study the effect of corrosion exposure on the hybrid joint specimens, exfoliation corrosion solution (EXCO) was used according to ASTM G34 specification. The surfaces of the specimens were masked with proper insulating material in order to be exposed only at an area near to the weldment. The surfaces were cleaned with alcohol according to ASTM G1 specification and exposed to EXCO for various times. After corrosion exposure, specimens were immediately cleaned according to ASTM G34 specification and subjected to tensile testing in a servo-hydraulic Instron 100 kN testing machine with a grips displacement rate of 2 mm/min. The results of the tensile tests demonstrated that improved tensile behaviour was achieved due to the use of the adhesive. Additionally, the exploitation of the adhesive provides with an anti-corrosion protection to the welding area even after 24 hours of exposure to corrosive exfoliation (EXCO).

Influence of rare earth CeO2 on microstructure and mechanical properties of Ni718 coating containing Ti(C,N) reinforcing phase

Liaoyuan Chen, Yu Zhao, Tianbiao Yu, Jiashun Shi, Zhe Liu

High temperature Ni718 alloy has been widely used in the repair of aerospace parts due to its good fatigue resistance, radiation resistance, oxidation resistance, corrosion resistance and good mechanical processing and welding performance. On the basis of laser cladding of in-situ Ti(C,N) ceramic reinforced phase Ni718 composite coating, different proportions of rare earth element CeO2 were added to the prepared Ni718 composite powder. Coatings that are metallurgically bonded to the substrate are obtained by laser cladding direct manufacturing techniques. The effects of rare earth content on the microstructure of the coating were observed by 3D laser microscopy. The EDS and phase analysis of the coating were carried out by scanning electron microscopy. The effect of rare earth elements on the internal distribution of the reinforcing phase in the coating was studied. Finally, the micro-hardness tester was used to measure micro-hardness distribution of the coating. The results show that the introduction of rare earth CeO2 is beneficial to promote the grain refinement of Ni718 coating with Ti(C,N) reinforcing phase, reduce the generation of cracks, and improve the uniformity of microstructure and micro-hardness distribution of the coating. Thereby improving the service life of the surface repair coating. This paper focuses on the research and analysis of the effect of rare earth elements on the microstructure distribution and micro-hardness of Ni718 coating containing Ti(C,N) reinforcing phase under the direct laser forming process. It provides a preliminary theoretical reference for the practical application of high temperature nickel-base alloy composite coating materials in aerospace and other fields.

Thermomechanical Response of Mg AZ31 at Different Levels of Temperatures and Strain Rates

Farid Abed, Wael Abuaid, Yomna Murad

Magnesium alloys’ mechanical behavior has received increasing attention because of its high strength to weight ratio making them ideal for various industrial applications, such as vehicle components, computers, mobile phones, transportation and aerospace. The objective of this work is to closely investigate the thermo-mechanical properties of magnesium alloy AZ31 at different strain rates and temperatures. Tensile tests are conducted on a 30 mm gauge length MgAZ31 specimens at two strain rates (1.11x10-3 s-1 and 0.28 s-1) at a range of temperatures between 25 ºC and 250 ºC. Digital Image
Correlation (DIC) system was used to calculate the true strain and provide quantitative assessment of the localized deformation response at high levels of deformation. The stress-strain responses of MgAZ31 show that the yield stress as well as the ultimate stress decreases as temperature increases and strain rate decreases. Moreover, the difference between the yield and ultimate stresses at both strain rates increases rapidly as temperature increases. The material shows a significant increase in ductility as temperature increases while the modulus of elasticity remains independent of change in strain rates.

**Corrosion resistance of Al-Cu-Li (2198) alloy for different ageing tempers**

*Nikolaos D. Alexopoulos, Christina M. Charalampidou, Carsten Blawert, Mikhail Zheludkevich, S.K. Kourkoulis*

Al-Cu-Li alloys are increasingly used in aerospace applications due to the excellent combination of reduced weight, high specific strength, good fatigue crack growth performance and improved corrosion resistance [1]. Their improved mechanical properties are often attributed to their complex microstructure and especially the precipitation of several strengthening intermetallic (IM) phases. These phases include δ (Al3Li), θ (Al2Cu), T1 (Al2CuLi) and S (Al2CuMg) [2], with the T1 to be the major strengthening phase. The formation of such IM phases can be accelerated by artificial ageing heat-treatment. However, these precipitates may influence the electrochemical behaviour of such alloys and increase corrosion susceptibility. Corrosion has a deteriorating effect on the aluminium alloys mechanical properties and must be taken into account for the assessment of the structural integrity of aircraft components. Hence the investigation of corrosion mechanisms is of major importance. The corrosion mechanisms of the innovative Al-Cu-Li alloys are not interpreted in the literature. Guerin et al. [3] showed that the fatigue life of aluminium alloy (AA) 2050 presented higher reduction percentage at the T34 state than at T84 where intragranular corrosion takes place. Most of the published articles with regard to the newly developed AA2198 alloy are dealing with weldability, plastic deformation [4], fatigue [5] and fracture behaviour aspects [6].

In the present work, the corrosion behaviour of AA2198 will be investigated through impedance spectroscopy, microstructural analysis as well as mechanical testing and compared against the respective AA2024 for the same tempers. Corrosion kinetics were investigated for the exposure of the alloy to different corrosive solutions e.g. EXCO, 3.5 % NaCl and Harrison’s solution (3.5% ammonium sulphate, 0.5% NaCl) and for various exposure times. Likewise, the corrosion-induced fracture mechanisms are investigated when the material is pre-exposed in different solutions of various aggressiveness (e.g. EXCO or NaCl solutions). Finally, the variance of the tensile mechanical properties and fracture toughness (plane stress critical stress intensity factor) for various artificial ageing times (T3 and T8 also included) is investigated. The effect of corrosion exposure on the already artificially aged specimens is documented in order to investigate the mechanisms for the corrosion-induced degradation.

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**REFERENCES**
A New Approach Of Creating A Finite Element Stick Model For Flutter Analysis

Aleš Kratochvíl

The article describe new approach of creating a finite element stick model for purpose of aeroelasatic or modal analysis of an aircraft structure. By this approach, the control surface properties are merge with lifting surface element as a special degree of freedom (DOF). Thus, there is no need to define a control surface as a separate node with concentrate mass element, torsion springs and kinematic constrains as common. Number of DOF for coordination system is increase from classical 6DOF to 9DOF. A new BAR2 element and concentrate mass element are present, together with aerodynamic element based on strip theory for purpose of flutter analysis. The advantage of this method lies in reducing number of model nodes and reducing of a global matrix order. Quality of results is not affected. The paper also presents a verification example based on flutter analysis of real sports aircraft.

Investigation Of Weight Efficiency Of Implementation Of Composite Materials For Alternative Configurations Of Wing Of Domestic-Airlines Aircraft

Vedernikov Dmitrii

At the present time significant increase of weight efficiency of metallic airframe layouts is a difficult task to be obtained, as the potential for further optimization of metallic structures had been seriously exhausted during a long evolution of metallic airframes. Due to this reason, one of the most actual problem in the area of an aircraft design is the implementation of new perspective materials into the structure layout of aircraft, first of all, composite materials, which have better specific strength properties compared to metal alloys.

Long term experience of implementation of composite materials into airframes confirmed their high efficiency for the elements with low level of loading (fairings, edge-lines, control surfaces, cowls). However, implementation of modern composite materials in the load bearing aircraft structures revealed a number of critical problems of strength and reparability, which decrease significantly weight efficiency of these structure, and raise a question of their using in composite materials in these parts of airframe. Low efficiency of application of composite materials in primary parts of airframe can be a consequence not only of direct reasons (fragility and low strength of modern composite matrixes) but also a consequence of indirect reasons, connected with the errors in aircraft design and selection of non-effective scenarios of providing strength.

In the present work the results of investigations of weight efficiency of a wing structure of domestic airlines’ aircraft (FAR-23/JAR-23) for the alternative configurations and structure layouts, manufactured of metal, composite and metal-composite materials are shown. The main aim of this investigation was the estimation of practicability of implementation of composite materials in the different structure elements and zones of wing for this class of aircrafts. The results have shown that for the same aircraft configuration the application of composite materials may be either effective or not, depending on the structure layout used in the airframe. In the same time, this rule may be violated for another configuration of aircraft. This caused by a lot of factors connected with high sensitivity of strength characteristics of composite structure to the values of design parameters, conditions of operation, storage and service of the aircraft.
Alternative variants of configurations of domestic airlines’ aircraft with maximum take-off weight about 5 tons were investigated. Effectiveness of implementation of different structural layouts was shown, including the following perspective layouts:

- Multi-spar wingbox layout
- Truss metal-composite layout
- Lattice layout
- Bionic layout

The obtained results can be useful for aircraft developers, for solving the problem of assessment of effectiveness of various structural layouts for wing structure.

**Numerical And Experimental Investigation Of Strength Of Composite Unidirectional Rib Layouts Based On Automated Fem Integrated With Module, Supported By Method Of Digital Image Correlation**

*Mirgorodskiy Yuriy*

At the present time, new perspective composite aircraft structures that can more effectively realize the advantages of high-strength carbon fibers are under investigation in strength complex of TsAGI. One of such composite structures is a lattice composite structure, based on load-bearing unidirectional composite elements (ribs). The investigations carried out in TsAGI have shown that the development and creation of this type of structures requires development of new strength analysis methods, as traditional strength analysis methods, effective for metallic structures, turned out to be inefficient for composite rib structures. The main reason is significant topological differences between conventional stiffened skin structures and lattice structures and differences between strength properties of composite materials and metal alloys.

One of the problems of the experimental strength analysis of ribs is the difficulty of adequate control of local stress-strain state based on standard strain gauges due to small dimensions of cross sections of ribs. Accurate determination of local stress-strain state over the rib’s cross section is necessary for the correct analysis of the rib strength, as the ribs in lattice aircraft structures are loaded not only with tension and compression, but also with bending and torsion.

In this paper, the numerical-experimental method for determining the stress-strain state for the ribs of lattice structure is proposed. The method is based on the following principles:

1. Simultaneous computational and experimental strength analysis, performed by a single software module that generates the results of computational and experimental data in a common standard format
2. Using the method of digital image correlation for experimental registration of the deformed state of the surface of ribs
3. Using automated FEM to calculate the stress-strain state of rib

The implementation of these principles for strength analysis of the test specimens (fragments of ribs) made it possible to perform operative solution of the following strength problems:

- Analysis of the global and local stress-strain state of composite rib.
- Validation of calculation methods using test samples (rib fragments).
Reliable certification studies of samples and fragments of lattice structure using a proven methodology.

The paper presents the results of strength analysis of a number of lattice structures/fragments of structures obtained using the proposed method. The effectiveness of this method is shown.

References

Experimental Study Of Impact-Protective Elements For Unidirectional Ribs Of Lattice Composite Aircraft Structures

Ivan Kondakov, Andrey Chernov, Natalya Guseva

Lattice structures based on unidirectional composite ribs is currently one of the most promising directions of research aiming to create lightweight and reliable structure of future aircrafts. Hybrid structure concepts based on lattice layouts have been developed for a number of conventional and non-conventional civil aircraft configurations, giving up to 15-20% weight saving as compared to conventional composite structures based on laminated skin and stiffeners.

One of the most critical problems of load-bearing lattice composite structures is very high sensitivity to impact loads, which is even more crucial than for the laminated composite structures. At the same time, topology of lattice grid makes it possible to create reliable protective system for the ribs, which can be effective in terms of weight expenses.

The present work is dedicated to experimental study of impact-protective elements for unidirectional composite ribs subjected to low-velocity impact loading with energies up to 35-50J.

The specimens-ribs were manufactured using lattice composite technology based on winding manufacturing method. The impact protective elements for ribs consists of special “hats” of various layouts, made of impact-resistant plastic material, wrapped to the rib with strong elastic tape. The tests were made on standard impact-loading machine, using special fixture for correct impact loading of ribs. The fixture was designed and made taking into account the real compliance of the lattice composite structure subjected to impact loading. The compliance was estimated by quasi-static FE simulation on detailed parametrical models of full-scale lattice structures. Before and after impact loading the ribs were controlled using standard and high-resolution NDI methods.

The results of the work have shown that protection of lattice composite ribs against impacts of 30-50J requires additional weight expenses of about 10-30% of grid weight, that can provide overall weight saving for lattice structures not less than 10% (as compared to conventional laminated structures), keeping integrity of internal structure of composite ribs after standard low-velocity impacts.
Numerical Investigation Of Initial Crack Growth In Composite Laminates Under Tension

Evgeny Dubovikov, Alexander Shanygin

Aircraft structures, made from layered fiber reinforced composite materials (composite laminates) allow increasing airframe weight efficiency in comparison with conventional primary metal structures. However, high sensitivity of composite laminates to impacts and climatic factors, their fragility and difficult character of internal stress-strain state do not allow realizing the full potential of high-strength carbon fibers and providing high weight efficiency of composite structures. The specified disadvantages are caused by presence of multiple stress concentrations at microlevel, leading to occurrence and growth of primary destructions (microcracks) in resin and subsequent degradation of strength characteristics of composite laminates while in service. Unfortunately, existing strength criteria do not allow providing long-term strength at designing high-loaded aircraft structures subjected to the influence of impacts and climatic factors without considerable losses of weight efficiency.

For designing the primary composite aircraft structures with high weight efficiency, meeting the requirements of long-term operation, it is necessary to have the reliable strength criteria taking into account occurrence of microcracks, their growth and relation of these processes with strength of the structure. Such strength criteria can be developed only on the basis of the extensive numerical and experimental investigations of strength of composite laminates, including investigations at microlevel. This work is devoted to the first steps for solving this problem.

In the work, the simplified automated strength model of a fragment of composite laminate at microlevel based on the finite elements method (FEM) is offered. The model allows investigating the growth of microcracks arising in the resin in monolayers, orthogonal to a direction of external tensile force, and also transition of microcracks on inter-laminate level.

On the basis of automated strength FEM models of a fragment of composite laminate and the method of reduction of stiffness characteristics of the resin, the scenario of growth of primary destructions at the microlevel is offered and proved. The scenario is confirmed with experimental investigations of composite samples under tension with registration of acoustic emission.

In the work, the dependences of decrease of strength characteristics of composite laminates are obtained as functions of the following parameters: characteristics of resin, angles of orientation of monolayers, volume ratio of fibers in a composite laminate.

As a result of the analysis of stress-strain state of the FEM model of a fragment of composite laminate it is shown that the microcracks in the resin can lead to essential degradation of properties of composite laminate which can be aggravated further under the influence of climatic factors.

Hybrid Structural Layout Of The Wing Box For Small Aeroplane

Lada Aleksandrovna Zudova, Victor Pavlovich Fomin, Konstantin Andreevich Zudov

One of the main ways to increase the weight efficiency of aircraft structures is using the composite materials. However, experience in development of high-loaded aircraft structures shows, that it is possible to increase their weight efficiency on the basis of composite load-bearing elements with unidirectional fiber orientation in lattice, truss, and frame structural layouts. At the same time, conventional structural layout can have high weight efficiency for low-loaded structures, which designed with stiffness criteria.
In this paper, a hybrid structural layout for the wing box structure, formed from several types of structural layouts, is considered. The proposed hybrid structural layout combines lattice-truss structural layout for root high-loaded parts, conventional structural layout for end low-loaded part, and also "transitional" structural layout for middle part of the wing box. In turn, the root part of the wing box consists of lattice composite panels and truss metal-composite spars and ribs.

The paper presents the results of solving the optimization problem on determining the rational location of the "transition" structural layout and the rational values of the design parameters of the wing box for this zone. In frames of the optimization problem, the minimum value of the weight of the wing box structure was determined under the constraints of strength, general and local buckling, technological and geometric constraints.

The best variant of a hybrid wing box structural layout was chosen as a result of the study. This variant meets the constraints, and has the weight benefit compared with conventional structural layout.

References

Novel method for strength analysis of damaged high-loaded composite panel
A. Shanygin, M. Levchenkov

In the paper, the novel engineering method of preliminary estimation of stiffness and strength characteristics of composite high-loaded panel with impact damage of skin is proposed.

The method is based on the use of completely automated parametrical FEM models including special zones, which model impact failure zones. Within the proposed method, the results of FE calculations are refined by the means of correction coefficients, which are calculated using micro- and meso-level parameters, and also the experimental data, obtained in full-scale tests.

The degradation of skin is described by the following parameters:
- coordinates of damage epicenters,
- areas of visible damages,
- ratios of areas of visible damages to the areas of damages detected by NDI.

The efficiency of the method was shown within the validation investigations on the example of the typical hypothetical panel with hat-shape reinforcements, loaded by compression.

Application of the method made it possible a fast and reliable estimation of safety and buckling factors of the damaged panel depending on:
- damage level,
- level of external loads
- boundary conditions.

The method can be useful for designing of advanced composite panels as its application allows to avoid the unreasonable overestimated safety factors for composite structures with impact damages.

In the present paper the dependence of stiffness and strength characteristics of the panel having a single damage has been considered, however, in process of accumulation of the statistical data, the method can
be used for analysis of panels with multiple damages, taking into account an interference of damage zones.
ARTEM: Aircraft noise Reduction Technologies and related Environmental iMpact

Karsten Knobloch

Future aircrafts, anticipated to be introduced between 2035 and 2050, are likely to have different configurations than the current tube-and-wing design with underwing–mounting of the engines. For 2035, the tube-and-wing layout could persist while the engine placement may differ, e.g. being semi-buried in the fuselage. For the 2050 time frame, blended wing-body aircrafts with very high bypass ratio (BPR≥16) may power long-range aircrafts, while regional aircrafts could be powered by hybrid propulsion systems or fully electric systems with distributed thrust generation.

Noise reduction technologies for low-noise 2035 and 2050 aircraft configurations are investigated in ARTEM - a four-year research project started in December 2017. The project takes up innovative ideas and concepts for efficient noise reduction by novel liner concepts, investigates the potential of dissipative surfaces (meta-materials), shielding, and reduction means for various interaction noise sources which are anticipated for novel aircraft configurations. The aim is to develop those “Generation 3” noise reduction technologies to a TRL of 3 to 4.

During the first project period, respective configurations based on blended wing body concept have been designed for short and long-range operations using multi-disciplinary optimization techniques.

For the 2035 time-frame, an acoustic analysis has been performed for a semi-buried (boundary layer ingesting) engine configuration. For various noise reduction technologies, basic principles have been investigated in more depth and parameter studies have been performed.

An overview of the project objectives and technologies will be given with a focus on the first achievements during the initial project phase.

DEFACTO: Disruptive Fuselage Study By Topological Optimization and Additive Manufacturing

Damien Desgaches, Fabian David

STELIA is French aerostructures leader and major worldwide player for design and production of primary structure of aircrafts. STELIA produces every year more than 650 noses and fuselage sections and 6 million elementary parts and panels. For 5 years, STELIA leads research programs dedicated to additive manufacturing technologies.

Stelia Aerospace has produced, through additive manufacturing, a metallic fuselage panel complete with integrated stiffeners. This one-meter-square “self-reinforced” demonstrator panel was robotically produced through an aluminum wire arc additive manufacturing process, and that it represents a “disruptive design”.

Stiffeners are typically attached to panels with fasteners or through welding. Alternatively, panels with integrated stiffeners can be milled from solid metal, but that process leads to substantial material waste.
The parent of the fuselage breakthrough is topology optimization research and technology (R & T) project DEFACTO (DEveloppement de la Fabrication Additive pour Composant TOpologique). Through topology optimization, STELIA R & T designers and engineers have created a fuselage skeleton with strategically placed stiffeners directly 3D printed onto the panel surfaces. Typically, these stiffeners would be affixed to fuselage panels using bolts and screws. By avoiding the need for further components, 3D printed panel stiffeners are less susceptible to weakness, creating a much more stable airplane body.

The aim is to take benefits of additive manufacturing: freedom of conception (no assembly constraint), reduction of production waste (buy-to-fly reduction), and simplification of production process (reduction of assembly).

For manufacturing this demonstrator, Stelia takes into account all operations, from material deposition to part finishing (machining) into design-to-print philosophy.

The main challenge is to prove the viability of additive manufacturing to develop an industrial process which takes account of certification and cost aspects. This one includes no defect in produced part, capability of maintenance and no destructive testing to detect possible crack.

**MMTech: Multiscale and multiphysics numerical modelling for Laser Engineering Net-Shaping process**

_Quanren Zeng, Yankang Tian, Yi Qin, Junyi Lee, Daniel Balint_

Laser engineering net shaping (LENS) is a versatile 3D printing techniques which is not only suitable for depositing geometrically-complex metal components layer-by-layer but also enables fabricate new compositionally graded materials. Generally, the LENS process makes use of the energy-intensive laser melt the substrate and form a melt pool in which the metal powders are injected into and finally solidify tracks/layers as the moving of laser deposition head. Accurate numerical modelling of LENS process is still an obstacle due to the multiscale and multiphysics nature of the process, which at least involves several sub-processes, e.g. powder dynamics, heat & mass transfer, and mechanical deformation. This research aims to establish a numerical model which holistically considers essential sub-processes and factors involved in a practical production, such as incident powder streams, formation of molten pool, variation of G/L/S interfaces and geometry of the finally-deposited tracks/layers. Thanks to the powerful computing capability of HPC, the overall LENS process simulation was firstly realized by interlinking the above-mentioned sub-processes. The project is conducted also in cooperation with the Advanced Manufacturing Research Centre at the University of Sheffield where some of the experimental analyses were performed, and Imperial College London where microstructure evolution analyses were conducted. The developed integrated numerical model will assist in process design and planning for quality control when converting the alloy powders (e.g. γ-TiAl) into engineering products. Applications of both numerical modelling and experimental validation allow the LENS process parameters to be optimised, contributing to the reduction of the production cost, shortening the product development cycle, and also extending the components’ life due to the improved mechanical properties.

**PARSIFAL: Prandtlplane architecture for the Sustainable Improvement of Future Airplanes**

_Frediani Aldo, Cipolla Vittorio_
The paper presents the preliminary design and performance analysis of a civil transport aircraft, based on the so called PrandtlPlane (PrP) configuration, in honor of Ludwig Prandtl, who first studied the aerodynamics of multi-plane lifting systems in early 1920s. The PARSIFAL project aims at enhancing the air transport worldwide in the small-medium ranges where aircraft compliant with the ICAO Aerodrome Reference Code “C” operate, in which the maximum increment of air traffic is foreseen in the next decades. According to such ICAO standard, the PrP developed in PARSIFAL has a wingspan limited to 36m but, if compared to reference aircraft such as B737 and A320 families aircraft, it can improve the passenger capacity from about 200 to more than 300 units. The architectural solutions adopted allow to reduce significantly the turnaround time in the airports and the air pollution at ground level and at cruise level, to improve the safety of flight and the operating costs.

The activities reported in this paper are part of the project “PARSIFAL” (Prandtlplane ARchitecture for the Sustainable Improvement of Future AirpLanes), funded by the European Community under the Horizon 2020 program and coordinated by the University of Pisa (Italy); the other partners of the project are: Delft University of Technology (The Netherlands), ONERA (France), Arts et Métiers ParisTech (France), DLR (Germany) and SkyBox Engineering (Italy)

More in details, the following aspects are briefly faced regarding conceptual design, preliminary design of the baseline configuration and the refinements of the same, and a performance comparison between PrP and reference aircraft. The conceptual design concerns both the fuselage and the lifting system. The preliminary design of the baseline configuration includes aerodynamic studies at low Mach number and in the transonic range through CFD analyses, structural analyses through an automated FEM of the complete aircraft.

The paper deals also with the configuration refinements and further investigations performed in order to optimize the aerodynamic performances during cruise flight, taking the constraints of low speed flight and controllability into account.

Finally, a performance analysis is described and a comparison between PrP and reference aircraft is performed.
Spacefibre Implementation Performance Assessment: Simulation and Traffic Generation At Full Network Load

Vangelis Kollias, Fotis Kostopoulos, Alexandros Panteloukas

SpaceFibre is a next generation of spacecraft on-board interconnection network which is being designed to support the very high data-rates required by sensors like SAR and multi-spectral imagers. SpaceFibre is compatible with the widely used SpaceWire protocol at the packet level allowing existing SpaceWire devices to be readily incorporated into a SpaceFibre network.

The SpaceFibre protocol is designed to support data rates from 1Gbps to 6.25 Gbps per link, much higher than the preceding SpaceWire protocol (which supported link rates of up to 400Mbps per link). This fact introduces to the design of a SpaceFibre interface higher data throughput requirements for each link and presents design performance challenges (avoidance of data flow congestion, flexible data flow architectures), creating the need to refine all architectural and design aspects of the interface in order to be able to satisfy the new protocol’s performance requirements.

In the context of the “SpaceFibre CODEC Evaluation and Breadboarding” project (ESTEC Contract No. 4000124052/18/NL/Cib/fg), TELETEL designed and prototyped a SpaceFibre Network interface board in order to extend its iSAFT protocol validation platform with SpaceFibre capabilities. The new interface board was based on the SpaceWire Network Interface board platform taking advantage of the compatibility between the 2 protocols while at the same time featured key architectural developments in order to support the performance standards set by the new protocol.

This paper presents the performance assessment of the SpaceFibre Network interface board after a validation activity (execution of long-run stress tests with full link utilization on multiple ports) and possible architectural enhancements for future evolutions of the board.

Space Robotics Technologies For On-Orbit Servicing Missions

Iosif S. Paraskevas, Georgios Rekleitis, Kostas Nanos, Olga-Orsalia Christidi-Loumpasefski, Sabrina Andiappane, Evangelos Papadopoulos

A safe and secure space environment is a requirement for all current and future space activities. To contribute to space sustainability, some Agencies and Governments have established or adopted policies to mitigate space debris creation. As a consequence, a new generation of services, namely the On-Orbit Services (OOS), have been envisioned, which indicatively include the replacement of malfunctioned components (using Orbital Replacements Units ORUs), refueling of fuel-depleted satellites, and Active Debris Removal (ADR). To this end, the Control Systems Lab (CSL) in coordination with Thales Alenia Space in France (TASF) implements three key projects.

The first is the European Project EROSS (European Robotic Orbital Support Services), which is co-funded by European Union’s Horizon 2020 research and innovation program under grant agreement N°821904 and part of the Strategic Research Cluster on Space Robotics Technologies as Operational Grant n°7. Its objective is to demonstrate the European solutions for the Servicers and the Serviced LEO/ GEO satellites,
enabling a large range of efficient and safe orbital support services. The project assesses and demonstrates the capability of an On-Orbit Servicing spacecraft (Chaser) to perform rendezvous, capturing, grasping, berthing and manipulation of a collaborative client satellite (Target) provisioned for servicing operations including refueling and payload transfer/ replacement. EROSS embeds key European Technologies by leveraging on actuators, sensors, software frameworks and algorithms developed in previous European Projects. EROSS boosts the maturity of these key building blocks and increases their functionalities and performance in a coherent work program targeting fast and practical deployment of the developed solutions in space. The consortium went into great details in the EROSS concept and the technical operational plan to manage perfectly the risks and complexity of development of such a large system. EROSS wants also to enable extended markets by proposing additional features to cover more complex space robotics operations like orbital servicing of non-collaborative and non-equipped satellites.

Two other programs, where CSL and TASF collaborate, which are considered as important building blocks for OOS, are the ESA’s OBSIdian (On-Board System Identification for Uncertainty Modelling & Characterization) and the ESA’s PRINCE (Passive Mechanical and Rendezvous Interface for Capture After End-of-Life). The main objective of OBSIdian is to develop where necessary and to apply, numerically efficient system identification techniques to space systems, in order to obtain dynamical mathematical models for space systems and control purposes. Beyond applying system identification as first objective, system identification shall be studied in combination with control. The control and identification tasks to be elaborated shall be viewed for increasing system dynamics and architecture complexity. The goal is to enable the use of more complex robotics scenarios in the future for OOS tasks. On the other hand, the main objective of PRINCE is to design and verify (up to TRL 3) a mechanical interface with integrated rendezvous/ navigation aids which enables the safe capture and removal of a non-operational/ non-cooperative satellite for uncontrolled re-entry; hence the focus of PRINCE is the ADR missions.

During this presentation, an outline of the main results up until now will be presented, while the focus will be given to EROSS, which deals with the most critical issues of such missions. In particular, a presentation of the necessary coordinated and impedance control schemes to be used in such missions will be given. Concepts for system identification and how these methods can be integrated in an OOS mission will be shown. Design approaches will be also presented. Finally, details will be given for the CSL’s experimental facility (Space Robotics Emulator – SRE), which will be used in all these three projects.

Large Angle Flexure Pivot development for future science payloads for space applications

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In this development, an innovative design of a Large Angle Flexure Pivot (LAFP) is described. It combines the advantages of flexure mechanisms – no friction, no backlash, no need for lubricant, no wear – while surpassing one of their few flaws, small displacement strokes. These are usually comprised between 10° and 20° for typical flexible angular pivots. The LAFP design exceeds these angular limitations to a range where previously only ball bearings would be adequate. The angular stroke can reach a deflection of 180° (±90°) and can easily meet a lifetime of three millions full cycles. If the stroke is limited to ±70°, infinite operational lifetime is obtained. The LAFP is 120 mm in diameter, 60 mm in length and weighs less than 500 g. A pair of pivots have been sized to carry a payload of 1.8 kg (with interfaces) and offers a low rotational stiffness while ensuring high lateral and transverse stiffnesses. In order to meet future science missions in a cryogenic environment, they can operate in a temperature ranging from -140 °C to +65 °C.
The centre shifts axially or laterally by less than 10 microns throughout the full rotation range. The LAFP is meant to be mounted in pairs, coaxially and with the payload between them. In this configuration it offers an axial displacement of less than one micron. The intended application of the LAFP is to angularly guide an optical component in a space environment.

Extensive FEM analysis has been performed by Heron Engineering (GR) to validate the design at component level and further analyses with the pivots mounted with a representative payload on a test bench for random vibration, shock and thermal cycling environment. In order to test in a cryogenic environment, a custom, large range voice-coil actuator was developed for the project based on the actuator design from the Scan Assembly on MTG. A description of the problems encountered during the manufacturing phase and the solutions implemented will be provided.

A dedicated performance test bench was developed and manufactured to test the pivot characteristics notably the lateral shift using Eddy current sensors. The test bench incorporates a representative dummy payload for mass and inertia and will be used in the frame of the lifetime tests and the TVAC tests. Fatigue test results on Marval X12 specimens validating the WEDM process will be presented followed by the Engineering Model (EM) results for performance and environmental tests. A second test bench for the vibration and shock tests has been manufactured incorporating a simplified launch locking device. As of writing, the pivots are currently being tested in a random vibration environment. Results will be presented.

**OP3C – On board Processing for Compression and Clouds Classification in hyperspectral satellite data**

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Planetek Hellas is industrializing a private-made and patented from the European Patent Office (Patent Classification INV.H04N19/50 G06K9/00 G06K9/62) processing and compression algorithm for hyperspectral images which is installed onboard of satellites carrying corresponding sensors. The product at its final release will be capable of a) Compressing the acquisitions with a 12-22 ratio and b) Classifying the cloud cover of these acquisitions. The result of the products are compressed acquisitions, the cloud coverage mask and a compression structure for direct processing without decompression. The products provide this way to the operator of the satellite, the ability to optimize the down streaming procedure, on one hand by selecting the cloudless images to download and on the other hand by downloading 12-22 times less data (as a result of the compression elaboration). The above leads to significant gains in efficiency such as i) lower volume of transmitted images (only the useful ones, in terms of cloud cover), ii.) less need for storage on-board and flexible acquisition planning, iii.) reduced hardware requirements. These features are disruptive in the industry, since no other solution exists with the same characteristics and allows the drastic satellite operating cost reduction and functionality enhancement. The main users are Space Agencies, Satellite Operating Centers, Satellite manufacturers, Hyperspectral sensor manufacturers.

**High-Performance DSP in Space: R&D with FPGA and DSP Platforms**

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High performance embedded computing in space is becoming a vital prerequisite for future applications, especially those relying on intensive Digital Signal Processing (DSP). Conventional space-grade CPUs are 1-2 orders of magnitude slower than the new application requirements. Therefore, considerable effort is
now being spent on designing new avionics to include hardware accelerators. The Field-Programmable-Gate-Arrays (FPGA) are gaining ground due to various advantages, such as reconfigurability, algorithmic parallelization, performance per Watt, radiation hardening techniques, etc. Our lab is involved in a number of ESA activities related to the use of FPGA and novel DSP chips in space applications. We study all options for leveraging this technology in space and we demonstrate its benefits on specific use cases. We design architectures and accelerate DSP algorithms on a variety of platforms, either Space-Grade or Commercial-Off-The-Shelf, with Single-, Multi-, and System-on-Chip devices.

Our approach relies on sophisticated steps tailored to the needs of each study/problem. We have devised and refined methodologies over time for any methodical survey & benchmarking of platforms towards optimal selection, for testing and evaluation at device and application level, and mainly, for HW/SW co-design with extended profiling, multi-level partitioning, parallel architecture design, and tuning/optimization.

Overall, our work has shown that the FPGAs are currently the best choice for HW acceleration next to a space-grade CPU, because they outperform mobile GPUs and DSP multi-cores, while they also allow for effective hardening even when using their COTS versions. FPGAs provide significant acceleration with limited power consumption, e.g., $P \leq 10$ Watts. Their acceleration can reach $10x$ at system level (HW/SW) vs the latest rad-hard CPUs, or even $100-1000x$ at function level vs the conventional rad-hard CPUs. In this direction, also the latest European BRAVE FPGA/tools are becoming state-of-the-art and competitive to those of very mature vendors. Additionally, compared to the above, novel DSP platforms such as the Intel/Movidius Myriad2 can exchange ~5x performance for ~5x power consumption to provide slightly slower execution with only ~1W, and hence, they could benefit certain mission concepts. FPGAs and novel DSP platforms will become necessary for future on-board processing, e.g., for Vision Based Navigation with high rate & high resolution image processing (in unprepared docking), or for increased autonomy and faster exploration (in rovers), or simply to offload the OBC and serve as an efficient co-processor in Earth Observation missions.