10th EASN Virtual International Conference on

Innovation in Aviation & Space to the Satisfaction of the European Citizens

2 - 4 SEPTEMBER 2020

Book of Abstracts

Table of Contents

Clean Sky Thematic Projects: where the Bottom-Up meets the Top-Down (PART I)

Session Chair: Dr. Jean-Francois Brouckaert, Clean Sky Joint Undertaking

Low-emission kerosene combustion with the Lean Azimuthal Flame combustor concept

P.M. de Oliveira, A. D'Anna, G. de Falco, M. Sirignano, N. Noiray, L. Miniero, D. Fredrich, A. Giusti

Developing combustors that reach simultaneously low NOx and low particulate emissions has been one of combustion engineering "Holy Grails" and various concepts have been proposed over the years to achieve this. In this paper, the "Lean Azimuthal Flame" combustor concept, which is based on the "MILD" or "Flameless" combustion mode, is presented and the progress in turning this concept into a realistic kerosene combustion system is described. Results of this multi-lab integrated project so far include an experimental and computational study of a new kerosene LEAF burner, the design of a high-pressure variant, and associated fundamental research on the underlying canonical problems that include single droplet combustion in vitiated air, spray in vitiated cross-flow, and laminar flame measurements focusing on NOx and nanoparticles that allow the development of new chemical schemes.

CHAIRLIFT: Compact Helical Arranged combustoRs with lean LIFTed flames

Antonio Andreini

The main objective of the Session ChairLIFT project is to assess an innovative combustor concept capable to achieve an ultra-lean, low NOx, operation of future engines. With this combustion concept the requirements of ACARE Flightpath 2050 regarding NOx emissions will be fully satisfied. The concept comprises two novel features: The first is to adopt “low swirl” lean lifted spray flames which feature a high degree of premixing and consequently significantly reduced NOx emissions. Inherent characteristics of such flames are the strongly reduced risk of flashback and a reduced susceptibility to thermo-acoustics instabilities compared to conventional swirl stabilized flames. However, such lifted flames bear the risk of lean blow out at some operating conditions. As second novelty of the Session ChairLIFT concept an alternative approach to standard flame piloting is proposed, enabling a further reduction of NOx emissions. Stable and safe operations of the combustor are ensured by the interaction of adjacent flames in circumferential direction within the annular combustion chamber. This requires tilting of the axis of the flames relative to the axis of the machine. This design is called Short Helical Combustor (SHC). The research is supported by a dedicated multisector test rig and by a set of numerical investigations based on state of art methodologies as well as innovative approaches. To explore further NOx reduction capabilities of the concept, an advanced LBO active control is also studied by combining ion sensor probe and plasma assisted combustion. An overview of the project status and of the most recent findings will be given in this contribution.

Impact of stationary and transient factors on the formation of NOx in stimulated flames

Dmytro Dolmatov, A.V. Kukurudza, S.V. Epifanov, S.M. Nyzhnyk

The article contains the results of numerical and physical researches of atmospheric pressure hydrocarbon-air and hydrocarbon-air-oxygen flames, affected by modulated discharge (arc, high frequency spark and corona types). The influence of such factors as: flow speed oscillations and unevenness, small blunt bodies, discharge parameters and its changing, oxygen injecting and its position etc. has been studied. According to obtained results, the both high-temperature and high speed mechanisms of NO formation in primary and secondary combustion zones can be accelerated or

suppressed by discharge free electrons with specific energy. The key free radicals and ions concentration fields can be shifted in favor of NOx-suppression electrochemical mechanisms by low energy discharge(s) in the zones with relatively rich concentration of alkyl radicals.

RAPTOR: Research of Aviation PM Technologies, mOdelling and Regulation

Ayce Celikel

A number of recent studies have both illustrated the possible impact of aircraft engine emissions on Particulate Matter (PM) concentrations in and around airports and have identified local air quality and public health concerns for airport workers and adjacent communities. To help address these concerns and fill gaps in knowledge RAPTOR has brought together a wide range of expertise to provide insights and new understanding on the impact of aircraft PM emissions. Funded through Clean Sky2 Joint Undertaking and EU Horizon 2020 and working closely with other related projects RAPTOR will deliver an ambitious programme of work comprising three connected and interdisciplinary workstreams.

Our underpinning line of research is a coherent overview of the current state-of-the-art research efforts regarding measurement, modelling and health impacts of aircraft engine emissions as a source of PM. Working alongside linked projects, including AVIATOR, these efforts will specifically identify uncertainties, gaps and interdependencies. Our aim is two-fold: firstly, to provide input into a European roadmap for aircraft engine PM regulation, measurement, modelling and future technology adoption; and secondly, to provide a framework to assist policy makers and stakeholders including EASA and the EU in developing future regulation, policy and guidelines.

Our second line of research will both utilise historic data and a series of combustor rig experiments to support improvement of current CAEP/11 non-volatile Particulate Matter (nvPM) standards. By generating a wide range of nvPM number and mass concentrations and size distributions a novel Rich-Quench-Lean combustor rig will be utilised accommodating simultaneous measurements from two ICAO compliant nvPM systems towards better definition of system-to-system variability. We will also quantify the uncertainty in reported nvPM Emission Indices (EI), associated with, fuel composition, drift, calibration and limit of detection whilst investigating the adoption of size measurements. This work is critical to assess potential correction methodologies, to assist the development of a more accurate prediction of aircraft engine exit nvPM, and to provide a better understanding and confidence in derived aircraft engine EI nvPM. The outcomes of this work will be important for the dispersion modelling community in narrowing some of the uncertainties inherent in the modelling of nvPM concentrations in and around airports.

Our third line of research will provide a more nuanced understanding of the potential impact of ultrafine PM emitted from aircraft engines on health outcomes. We will do this by firstly reviewing the literature to form an understanding of toxicity of key pollutant components within aircraft engine plumes. We will then use particles collected during the combustor rig experiments to assess the oxidative potential as marker to predict toxicity of freshly generated and aged aircraft PM and relate to these to the better understood effects of other PM sources, such as road traffic PM.

Our intention is to bring these three lines of research together to provide contextual evidence and advice to the regulatory community in developing future EC guidance and standards.

HiMT: A Human Factors approach for multimodal collaboration with Cognitive Computing to create a Human intelligent Machine Team

DORMOY Charles, ANDRÉ Jean-Marc, PAGANI Alain, MINASKAN Narek

During a flight, pilots must master complex situations, while facing increasing system complexity due to the amount and type of information available. As part of the Horizon 2020-funded programme Clean Sky 2, Co2Team (Cognitive Collaboration for Teaming) pursues the idea that a system based on artificial intelligence can effectively support the pilot using cognitive computing towards single pilot operations. To create collaboration between the pilot and the intelligent agent, an innovative bi-directional communication paradigm and an intelligent allocation of roles and tasks are needed, based on the concept of keeping "pilot in the loop". In this way, it is possible to benefit from the most effective pilot skills, such as decision making, to achieve flight objectives and guarantee a maximum level of safety and better acceptability. In our state of the arts, we examined the different human factors identified in the literature that are involved in the integration of an intelligent agent for cockpit operations with all that this implies in terms of complexity.

We considered that the Human intelligent Machine Team (HiMT) will operate in a cockpit and will therefore deal with the automated systems of the aircraft. We examined the advantages and weaknesses of automation of the avionics and how Cognitive Computing could address them or help manage them. We then became interested in the interactions between man and machine and how these interactions would be with a Cognitive Computing Teammate (CCT). The aim being to form a hybrid HiMT, we studied the different aspects of multimodal communication in order to keep the most familiar way of collaboration for the pilot (i.e. Human-human). And it is through this bi-directional multimodal communication that this pilot-intelligent agent collaboration will be possible. Because this team will operate in a fast-evolving, risky and uncertain environment with high level of responsibility in terms of safety issues, the cultural effect and context on communication in a small-group was considered, based on what is already applied, such as Crew Resource Management and how to adapt it to a HiMT.

We addressed one further interesting issue: teaming from a cognitive point of view, for each individual and as a team. Team cognition is a dynamic team activity inextricably linked to context that applies to the team (i.e. shared mental model). This implies that the CCT must also be equipped with the ability to deduce certain elements from a real situation (i.e. theory of mind).

The use of AI does not escape the need for mutual trust between the pilot and the CCT, nor from the trust the team will establish in the avionics. Therefore, we explored how trust is built and maintained at the right level, to avoid under and over trust. We examined decision making and risk management to understand how the CCT may assist the pilot, using the same schemas as the human, and avoiding some cognitive bias. By taking human factors into account, the power of human-machine symbiosis can be enhanced. Pilot and CCT collaborate by doing what they do best. Co2Team is in line with the vision of Horizon Europe's CleanSky programme with the use of the CCT, which could serve as an intermediate step towards opening avionics to the open world and intelligent unmanned aircraft.

Clean Sky Thematic Projects: where the Bottom-Up meets the Top-Down (PART II)

Session Chair: Dr. Jean-Francois Brouckaert, Clean Sky Joint Undertaking)

Agent based model to improve Flight Crew performance through enhanced cockpit perceptual variables

Miquel Angel Piera

The decision-making process is an important part of an aircraft operation. The pilot monitors the aircraft systems, environment, communication, and other elements involved in the operation. The crew is involved in a decision-making process in situations that affect the operation of the aircraft. When a pilot decision is required, a logical choice is selected from a set of available options that reflects the needs and mitigates the situation.

In Multi-Crew Operations (MCO), the decision-making process is carried out by both pilots. However, in Single-Pilot Operations (SPO), this capability is reduced due to the lack of the redundancy in the decisions input and confirmation by a second pilot. Additionally, in single-pilot operations the pilot's situation awareness may be suboptimal, affecting the perception of situations that emerge from the aircraft operation and its environment, the comprehension of their meaning, and the projection of their future.

Modern aircraft are equipped with warning and alerting systems for the early detection of various aircraft system failures and malfunctions or non-normal conditions. These events are often assessed by on-board assistance systems such as Airbus' Electronic Centralized Aircraft Monitor (ECAM) or Boeing's Engine-Indicating and Crew Alerting System (EICAS). E-PILOTS solution envisage to provide support to aircraft operations by improving the quality of the pilot's situation awareness and decision-making process, using cognitive computing to identify situations where such support might be needed. Data-driven models are complemented with knowledge-based models to elaborate the right information that should be provided to the pilot, as well as how and when it should be provided, taking into account their workload levels.

The supporting system has been designed to support the decision-making process performed by the pilot while including external agents (other pilots or ATC) and variables of the environment (traffic, scenery, weather, airline, crew, on-board systems). The decision-making process is abstracted based on Endsley's model of Situation Awareness, in which the task/system factors are driven by a sequence of steps performed in a recurrent process.

HARVIS: Cognitive assistant in the cockpit

Antonio RodríguezVázquez, Stefano Bonelli, Géraud Granger

HARVIS project is developing a cockpit digital assistant concept able to partner and support the pilot to support anticipating needs and make decisions in complex scenarios. The impact of the cockpit assistant concept will be assessed under the two following use cases: (1) Go around decision under unstable approach and (2) Diversion to alternate airfield after an emergency. Both demonstrators are being developed in the context of Project HARVIS (www.harvis-project.eu).

Use Case 1. Non Stabilized Approach: During the high workload phases of the flight such as the approach, the PF has the support of the PM for the trajectory monitoring and the Go Around decision. Nowadays, 97% of Non-Stabilized Approach (NSA) are continued until landing going against Standard Operational Procedures (SOP), therefore, an assistant solely based on SOP will potentially lead to conflicts with PF decisions. Moreover, the PM is aware of what the PF is doing and can decide if a trajectory deviation announce is relevant or not according to the situation. Our assistant will provide support for monitoring and go around decision making. For the Go Around decision making support assistant, our innovative approach is to use expertise from a large number of pilots on many relevant scenarios to classify human judgement on real flight trajectories instead of relying on rules like SOP. Relevant segments of NSA based on Flight Data Recordings (FDR) and operational constraints will be presented on a web interface displaying parts of the flight deck for the pilots to give their judgement about the necessity to go-around or not. Thanks to this labelling, an assistant will be trained to recognize these situations and will provide real time support to decision-making. For the trajectory monitoring task usually done by the PM, we intend to use an eye tracker in order to check if the single pilot is looking frequently at the deviating parameters in order to reduce the announcements to the minimum. We intend to run non-stabilized approach simulation and compare the behavior of a single pilot with a single pilot supported by our assistant.

Use Case 2. Aircraft Dynamic Rerouting: Diversion is often required after system failure, medical emergency, or just for weather phenomena (dense fog, storms, etc.) in the approaching. During regular operation if a diversion is needed the pilot in command and first officer discuss on the multiple options they have and try to find out the one they think is the best. The AI assistant will take into account characteristics of nearby airports, METAR at destination, and facilities to take care of passengers, among other factors. It may then consider several options, assess the risks and benefits of each one, and finally inform the pilot accordingly. In this scenario, the digital assistant takes care of the Options and Risks in a FORDEC procedure. HARVIS is committed to develop a use case demonstrator for the arrival rerouting. Two technical challenges are contemplated: Firstly, the collection of a relevant and representative dataset to train the AI from real flights and secondly, to develop the proper human-machine interface between the virtual assistant and the pilot for a satisfactory experience.

UNIFIER19: Conceptual design of a nearzero emission and cost-efficient regional air mobility solution

David Eržen, Fabrizio Oliviero, Lorenzo Trainelli

In the European Union, communities without adequate transport infrastructures are struggling to attract investments and create jobs due to the lack of connectivity to major urban areas, that can offer better and more diverse busines opportunities. Providing enhanced mobility infrastructures to those communities is one of the major challenges in the implementation of Europe's Flightpath 2050 vision, that envisages that virtually all EU citizens shall reach any continental destination in less than four hours, door to door, by the year 2050.

It turns out that in Europe there is a sparse, underused small airport network, that could provide communities with a new mobility solution without overwhelming burdens for new ground infrastructures.

UNIFIER19 investigates a new aircraft concept for passenger and cargo transportation on short and very-short haul routes, to be used in two flavors: the microfeeder and the miniliner services. The microfeeder service is intended as a hub-to-spoke air transportation service, used to feed major airports from smaller cities and open country territories. The miniliner is intended as a point-to-point air transportation service, used for inter-city commuting and to connect open country territories.

The conceptual design loop starts by considering all possible combinations of aero-propulsion systems and hybrid-electric architectures, in the quest for the best possible candidate solution. A special focus is placed on the combination of liquid hydrogen fuel cells and batteries as energy source. Recently, hydrogen-based powertrains are enjoying a major boost for usage in transportation since, they represent a most environmentally friendly solution.

In the conceptual design loop (Figure 1), two metrics are introduced to rank candidate solutions: i) the emission index, aimed to capture the combination of CO2 emissions, NOx emissions and acoustic emissions; and ii) the success index, which aggregates estimations on development, certification and production costs, maintenance complexity, and operating costs to ensure future commercially successful operations. In this way, the loop will yield not only an environmentally friendly, but also cost-efficient air mobility solution to be further developed in the preliminary design process.

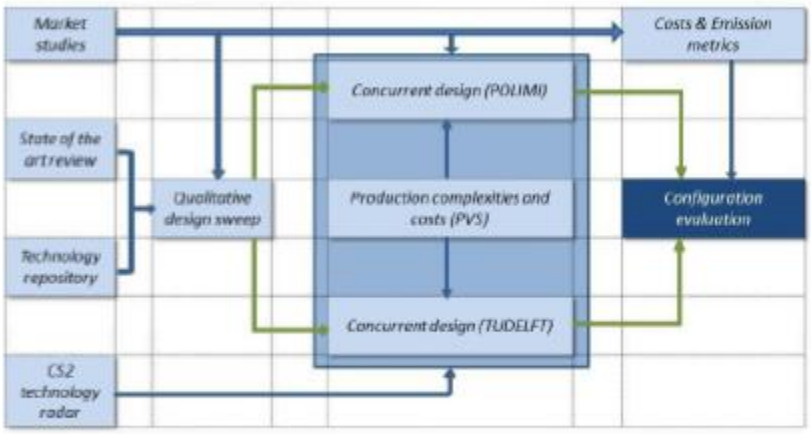

Figure 1. UNIFIER19 conceptual design workflow.

Both microfeeder and miniliner services are conceived as key components in the future development of a more connected European transportation network through enhanced, environmentally sustainable regional air travel. The new community-friendly short-haul airliner may drastically enhance connectivity in territories with inefficient ground transportation services to major airports or between towns, enabling Europe's Flightpath 2050 vision.

UNIFIER19: Methodologies for the initial design studies of an innovative communityfriendly miniliner

Lorenzo Trainelli, Carlo E. D. Riboldi, Alberto Rolando, Francesco Salucci

The UNIFIER19 – Community Friendly Miniliner project is a research effort in response to the Clean Sky call H2020-CS2-CFP09-2018-02, focused on the conceptual design of a near-zero emission CS23 commuter aircraft conceived for the enhancement of the mobility of European citizens. This vehicle, capable to exploit the potential of the wide European small airport network, is seen as a key enabler of the Flightpath 2050 vision, including the ambitious policy of a 4-hour door-to-door travel duration for virtually all destinations in the EU.

This design activity involves several highly innovative aspects, stemming from the ambition to achieve an environmentally friendly and, at the same time, cost-effective solution for short haul regional transportation. This brings into play dedicated market studies envisioning future services for hub-feeding ("microfeeder" role) and inter-city commuting ("miniliner" role) based on the UNIFIER19 commuter aircraft. As this market segment is not developed, a fundamental preparatory task involves the estimation of the potential passenger demand. This is considered crucial to the sensible determination of some of the most important top-level aircraft design requirements, namely payload, mission range, take-off and landing distances, cruising speed.

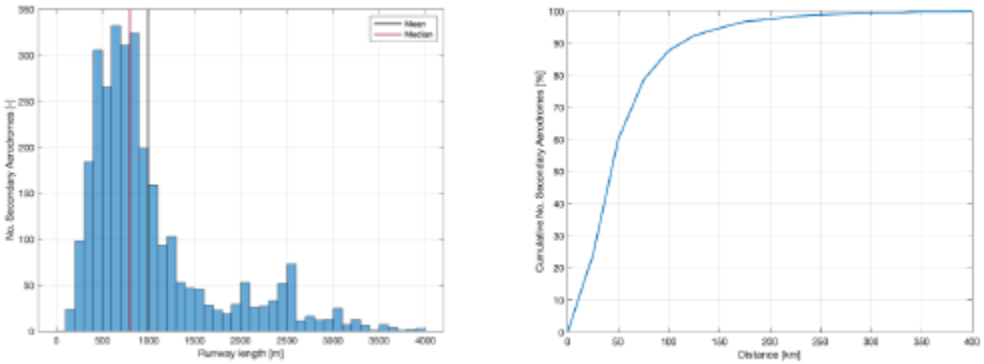

Figure: European secondary aerodrome statistics.

The demand estimation process starts from the analysis of the effectiveness of the existing ground transportation in European countries and the analysis of the potential aerodrome network supporting a vast number of candidate air routes. Example outcomes of such preparatory studies are depicted in Figure 1: in the left diagram, the distribution of field length for secondary airports and airstrips is depicted; in the right diagram, the distribution of the minimal distance between such aerodromes is shown. These results point out the opportunity for a very-short haul service supported by relatively short runways.

The next step involves the determination of the potential demand based on the advantage – according to some predefined criteria, such as time saving – provided by an air transportation service as a substitute of ground-based transportation means. This leads to the definition of a catchment geographical area for each of the candidate air routes connecting secondary aerodromes between them or to hubs. This entails the estimation of the number of potential travelers and of the number of aerodromes involved.

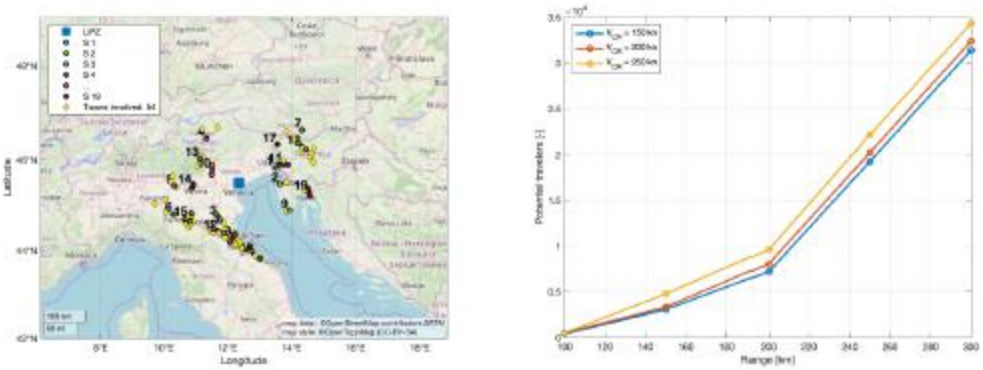

Figure 2. Potential demand for a microfeeder service for Venice International Airport.

Figure 2 provides an example of such studies for the case of a feeding service to the Venice International Airport, Italy, for the case of a commuter capable to take-off in 800 m. In the left diagram, the 54 towns served with a population over 20,000 are depicted (yellow diamonds) together with the 19 secondary aerodromes constituting the network (circles), corresponding to a maximum trip distance of 200 km and a cruising speed of 200 KTAS; in the right diagram, the potential demand is shown as a function of the maximum trip range and cruising speed. The paper provides examples of multiple scenarios for hub-feeding and inter-city commuting services in various European countries.

In addition, further elements of the preliminary studies devoted to the technology survey and the design framework are addressed. Specifically, requirements related to the usage of hydrogen and batteries in a zero-emission configuration for the aircraft powertrain are considered, considering their impact on the airframe design, the aerodrome infrastructure needs, and the operational scenario.

HECARRUS: Hybrid ElectriC smAll commuteR aiRcraft conceptUal design

Vasilis Gkoutzamanis, Christos Nasoulis, Giorgos Protopapadakis, Anestis Kalfas, Mavroudis Kavvalos, Dimitra-Eirini Diamantidou, Smruti Sahoo, Konstantinos Kyprianidis, Panagiotis Tsirikoglou, Ndaona Chokani

Aircraft electrification is seen by the global community as a major leap towards the necessary rethinking of flight, to attain specific environmental targets set by Flightpath 2050 for CO2, NOx and noise reduction. Small Air Transport (SAT) is characterized by the great potential to improve the environmental footprint of aviation, if electric and hybrid-electric technologies are employed in the regional, compact-air-travel aircraft of the future. In this framework, the project HECARRUS funded by the Clean Sky 2 Joint Undertaking aims to develop and integrate the conceptual design of a 19-passenger aircraft, based on hybrid-electric propulsion configurations with a targeted Entry-Into-Service of 2030. To achieve its ambitious goal and proceed to a next step such as the detailed component design and experimental demonstration, the HECARRUS approach is built upon five main objectives, each covering one step of the value chain. Initially, the project focuses on the design and performance evaluation at sub-component (sub-systems including compressors, turbines etc.) and component (gas turbine, battery, electrical machines, heat exchangers etc.) level. The second main objective delves into the integration of components at the systems' level towards developing the entire propulsion system. The aim here is to

identify all the associated challenges and opportunities that arise through the interaction of the individual systems when it comes to the level of multi-disciplinary frameworks. The third main objective of the project consists of research at the aircraft level including aircraft aerodynamics and structural disciplines. The fourth objective's purpose is to investigate the overall environmental impact of the under-studied aircraft by also including a research on the components' Life Cycle Analysis (LCA), to identify the main drivers that determine such approach when considering a hybrid-electric architecture. The last main objective intends to pave the ground for the future exploitation of the proposed design and ensure the communication of benefits and dissemination of project results.

Considering the proposed methodology of the project, its goal is to provide an integrated, 'full-loop' framework resulting in the conceptual design of the aircraft. The framework is based on already existing platforms of physics-based simulation and optimization, properly modified and further developed to match the purposes of the commuter aircraft. The scope is to provide mission level optimization of the proposed radical configurations, for state-of-the-art components integrated in the hybrid propulsion system. With a focus on the sizing and performance of the key propulsion components, aircraft structure and aerodynamics, the project aims at full design space exploration for various hybrid-electric propulsion configurations that are currently at low Technological Readiness Levels (TRL). The scope of this research contains detailed component design in key subcomponents of the powertrain such as fan/propeller, heat exchanger and wing structure design. The main achievements of the project so far can be summarized in the following:

- Analysis and reviewing of state-of-the-art technologies of each component of the powertrain used in the field of alternative propulsion architectures of the future. The concepts are examined in terms of efficiency, technological readiness level (TRL), potential applicability on the commuter aircraft along with emerging challenges and opportunities.
- Identification and trade studies of Top-Level-Aircraft-Requirements (TLARs) including mission profile, range and passengers along with an analysis of the CS-23/FAR-23 airworthiness regulations available by the European Union Aviation Safety Agency (EASA) and Federal Aviation Regulation (FAR) correspondingly, for this type of aircraft.
- Generation of a 'pool' of aircraft concepts based on all possible hybrid-electric propulsion architectures for the commuter aircraft. The process is followed by a technology and opportunity down-selection based on a qualitative assessment where the most promising candidates have qualified for the next level of quantitative analysis including aircraft sizing.
- Aircraft conceptual sizing including proper modifications to match the hybrid-electric propulsion system architecture and coupling with automated design creation procedure via Python scripting in an open source software. This step also includes aircraft centre of gravity calculation along with static margin and trim analysis.
- Propulsive powertrain establishment of the individual modules that will constitute the base for the full-design optimization loop. These include the thermal engine (engine sizing and performance), the electrical machines (sizing and performance of motors/generators), batteries (for a range of specific power), thermal management system and power distribution and conversion.

Clean Sky Thematic Projects: where the Bottom-Up meets the Top-Down (PART III)

Session Chair: Dr. Jean-Francois Brouckaert, Clean Sky Joint Undertaking

GLOWOPT: A novel approach to minimize the climate impact of next generation aircraft

Kaushik Radhakrishnan

With commercial aviation growing at an impressive pace it is imperative to rethink the ways in which aircraft are designed and operated in order to lower the impact of aviation on climate change. Analysing the climate impact of aviation requires the consideration of interactions between aircraft, routings and atmosphere. In aircraft design optimization studies, normally operating costs, but also fuel burn or maximum take-off mass are used as objective in the cost functions. Designing the aircraft for minimum fuel burn directly contribute to a reduction of CO2 emissions. However, more than 50% of the climate impact from aviation arises from non-CO2 effects which are largely independent from CO2 emissions and their climate impact depends on the atmospheric state and background concentration.

Hence it is essential to consider these non-CO2 effects when developing climate optimized aircraft designs. Without considering the relevant route-network and typical operating conditions, the current aircraft design process is decoupled from their environmental performance. The objective of GLOWOPT approach is to develop Climate Functions for Aircraft Design (CFAD), which will enable a common interface between the aircraft design tool, climate model and global route network. These climate functions will constitute an easy-to-use tool which can be integrated into the existing aircraft synthesis workflows without high adaptable effort. By minimizing these CFADs in aircraft design optimization process, a design solution can be synthesized with lower climate impact while considering the operating regime and the relevant market segment. This work will present an overview on the GLOWOPT approach and methodology and give insight into some initial project results.

GLOWOPT: Climate optimization of aircraft operations and design: A review and implications on modelling requirement

Kathrin Deck, Volker Grewe, Feijia Yin, Irene Dedoussi, Roloef Vos, Pieter-Jan Proesmans, Florian Linke, Kaushik Radhakrishnan, Malte Niklay, Benjamin Lαhrs, Katrin Dahlmann, Sigrun Matthes

Aviation is a highly necessary transport sector in our modern society. It guarantees mobility on a short- and long-range spectrum and is still a growing sector. However, aviation also contributes significantly to the anthropogenic climate change via CO2 and non-CO2 effects.

One possibility to reduce the climate impact of aviation would be to optimize the aircraft at the design level. Another possibility is to optimize the operations, e.g. to avoid climate sensitive regions in the ight route. To derive modelling capabilities, we review the climate impact of aviation with a focus on climate optimization of aircraft operations and design. The overall climate impact of aviation based on CO2 and non-CO2 effects is analyzed under consideration of contrails and different emissions like CO2, NOx, and H2O. The connection to the related temperature change is shown via the climate sensitivity for each species. An overview over the most common climate metrics, including radiative forcing, global warming potential, global temperature potential, and the average temperature response is given to find the most

suitable climate metric for aircraft design purposes. During previous studies within various projects, e.g. WeCare, REACT4C, and ATM4E, climate optimization strategies for aircraft operations were investigated. The aircraft routes regarding the ight path or altitude can be adjusted regarding climate considerations, also in dependence on the current weather situation. In these projects, climate change functions and algorithmic climate change functions were developed which could potentially facilitate the climate optimized routings. The aircraft design for climate optimization di_ers from the approach to optimize the design for reduced cost or reduced fuel burn. For the climate impact, ying slow and low is benefficial which was shown in the project CATS, but this is not reected in the current aircraft design. Therefore, previous studies propose redesigned aircraft. The relation between climate, aircraft operations and aircraft design is used to point out the requirements for modelling resulting from that. The focus is on the connection between climate and operations on one side, and on the connection between climate and design considerations on the other side. Currently, the model capacity for aircraft design does not support the climate optimized design. Therefore, deriving climate functions for aircraft design is highly important which will be one of the main goals in the Clean Sky 2 project GLOWOPT (Global-Warming-Optimized Aircraft Design).

RHEA: Robust by design ultra high aspect ratio wing and airframe

Ali Elham, Rolf Radespiel, Marco Fossati, Rafael Palacios, Anne Gazaix, Koen Artois

The efficiency gains offered by ultra-high aspect ratio wings are key to increase the sustainability of air travel as the volume of passengers continues to grow. However, a fully viable and deployable solution has not yet been proposed due to technological, certification and operational limits, which are mainly due to complex aeroelastic behavior and constraints from both manufacturing methods and airport infrastructure.

Robust- and sustainable-by-design ultra-high aspect ratio wing and airframe (RHEA) is a Clean Sky 2 project centred around the idea that future-generation aircraft with ultra-high-aspect-ratio wings is conceivable with forward-looking technologies and physics-based multidisciplinary analysis and optimization approaches. Critically, RHEA will introduce a paradigm shift towards robust design methods, inherently built with a quantitative management of uncertainties in both operating conditions as well as model predictive capabilities. The project will also introduce a number of carefully selected technologies into the aero-structural design process of novel aircraft configurations. Multidisciplinary designs optimization of representative aircraft will address short-range, medium range and longrange missions. The project is collaboratively done by Technical University of Braunschweig (Germany), University of Strathclyde (UK), Imperial College London (UK), IRT Saint Exupery (France) and German-Dutch Wind Tunnels (Netherlands).

U-HARWARD: a THT Project Aiming at Ultra High Aspect Ratio Wings Advanced Research and Designs

Sergio Ricci

There is a world-wide need for improved fuel-efficient and environmentally friendly aircraft designs; however, the rate of improvement in performance of conventional aircraft configurations (via improved aerodynamics, composite structures and better engines) is reducing to a marginal level. Consequently, there is a need to explore the benefits of novel aircraft architectures to provide a step-change in fuel

efficiency; this need has been identified by ICAO, FLIGHTPATH2050 and CLEANSKY2 initiatives in Europe and also NASA, with challenging goals set for reductions in CO2, NOx and noise by the year 2050.

Historically, the most significant improvements in jet aircraft efficiency have been related to improvements in the propulsive term associated with the development of high-bypass-ratio turbo fan engines. Most recently, the extending use of high-strength composites promise so to increase the weight fraction. Finally, configuration changes such as increased wingspan can lead to improve L/D. However, it must be pointed out that integrated nature of the aircraft design means that few substantive configuration changes can be made without incurring some multidisciplinary trade-offs. For example, increasing the wingspan can lead to an increase of wing weight.

Luckily, the same integrated nature of aircraft design could represent a great opportunity: indeed, significant improvements can come from configurations that can simultaneously exploit aerodynamic, control and structural advances to improve efficiency. Furthermore, in most cases the multidisciplinary approach is the only one that could guarantee a net improvement in global efficiency. It is the case of Natural Laminar Flow (NLF) that could be obtained by an aggressive combination of Manoeuvre (MLA) and Gust Load Alleviation (GLA) technologies that hold the potential to greatly improve both the weight and aerodynamic terms in the Breguet equation.

U-HARWARD project, in response to the call JTI-CS2-2019-CFP10-THT-07: Ultra-High Aspect ratio wings, will consider the use of innovative aerodynamic and aeroelastic designs in a multi-fidelity multi-disciplinary optimal design approach to facilitate the development of Ultra-High aspect ratio wings for medium and large transport aircraft. A conceptual design study, building on the current state of the art, will perform trade-off studies to determine the potential gains of different wing configurations, including strut-braced and folding wingtip wings, and loads alleviation concepts, in terms of aerodynamics, weight, noise, fuel-burn and range. Scaled model wind tunnel tests will be used to validate parametric variations in the aerodynamic and acoustic characteristics. Starting from a reference aircraft, the preliminary design of the best candidate configuration will be completed, and the estimated gains validated using high fidelity tools and a larger scale aeroelastic test. The consortium is composed by six partners, i.e. Politecnico di Milano, the coordinator, IBK-Innovation GmbH & Co. KG, University of Bristol, Office National d'Etudes et de Recherches Aérospatiales, Institut Supérieur de l'Aéronautique et de l'Espace and Siemens Industry Software SAS.

INFRA-CA3ViAR Rig: Experiments on combined intake-fan aerodynamics in the propulsion test facility (PTF)

Friedrichs, Eggers, Harjes, Frantzheld, Brunow, Grubert, Seume, Gößling

The technological challenges to achieve the mid- and long-term goals for reduced emission in the aviation sector are requiring working on all systems and subsystems of future aircraft. For the overall drive system this basically covers the fields of energy storage and energy conversion while the latter typically splits into mechanical (shaft) power generation and thrust generation. The conversion from shaft to thrust power (propulsor) of future drive system requires high mass flows and low jet velocities to increase the propulsion efficiency. This basically means propeller and fans of high diameter but lower pressure rise and low speed. While a ducted fan does offer significant advantages for noise emission and flight speed

compared to a propeller, the intake and nacelle have to be designed shorter and slimmer to reduce its drag which makes the aerodynamic interaction with future fans more sensitive.

The Institute of Jet Propulsion and Turbomachinery at TU Braunschweig is operating the Propulsion Test Facility (PTF) - a large scale lab capable of conducting combined experiments of intake and fan aerodynamics. The purpose is the examination of coupled fan-intake interactions to better understand and characterize the sensitivity of such coupled future systems and to generate high-fidelity experimental data for validation of numerical methods for the intake flow up to the Aerodynamic Interface Plane (AIP).

The PTF represents a 2,4m x 2,4m atmospheric wind tunnel (Eiffel-configuration) combined with a fan test rig. Wind tunnel blowers allow for low speed headwind conditions corresponding to Ma=0,2, while the fan drive provides 2MW power to drive single-stage fans up to approx. 0,65m diameter. The special feature of the PTF is an additional closed-system crosswind duct, equipped with individual blowers and allowing for pure crosswind conditions above 35kts if operated without headwind. Combining headwind and crosswind generates a low speed AoA-condition for the intake and fan.

To especially investigate to intake-fan coupling effects, aspirated intakes being fully de-coupled from the fan (ASI-configuration) can be investigated and well as intake-fan coupled configuration (INFRa-configuration).

The presentation covers the validation of the PTF ASI configuration based on the LARA nacelle setup which was tested and analyzed against existing experimental and numerical data investigated in the early 1990s at the ONERA F1 wind tunnel. The results of the validation experiment show the Reynolds influence on the inlet peak Mach number between the ONERA F1 and PTF experimental data for identical boundary conditions based on Mach number and crosswind. Within the validation test campaign, also the separation and reattachment effect leading to a hysteresis when varying crosswind as well as intake mass flow has been confirmed. This phenomenon still has no fully established theoretical basis for understanding the aerodynamic behavior.

For coupled experiments the design of the INFRa setup will be shown, which allows for integration of UHBR-like designs of a future low pressure-rise fan. The reference rig setup is a titanium alloy fan, which is currently under construction and planned for commissioning stating mid 2021. In addition to that, the CA3ViAR project currently designs another fan stage for integration into the same rig but based on Carbon Fibre Reinforced Polymers (CFRP) instead of titanium alloys, providing another design space to address especially the aeroelastic behavior. Using the INFRa and CA3ViAR setup, the wind-tunnel capabilities of PTF and the instrumentation and flow visualization techniques which will be presented allow for a comprehensive range of high-fidelity experimental investigations and also open test case reference data for the research community.

CA3ViAR: a step forward towards modelling and testing aerodynamic and aeroelastic instabilities experienced by Low Transonic Fans made of composite material

Nicola Paletta, Vecchio E, Seume J, Gößling J., Amer M., Friedrichs J., Eggers T., Russo S., Natale N.

Driven by economic as well as ecological requirements, airplane operators and thus manufacturers invest continuously in reducing the fuel consumption. Regarding the engines, a way to further reduce the fuel consumption is the increase of propulsive efficiency, which directly depends on the difference between engine outlet velocity and flight velocity. This led to the development of Ultra High Bypass Ratio (UHBR) engines equipped with larger fans having a reduced pressure ratio as well as reduced speed.

Such new propulsors, equipped with larger fans, do come with significant challenges from aerodynamic and structural perspective. The higher engine-BPR does increase the required operating range of the fan by moving especially Take-Off and Approach closer to the part power limit of the fan and therefore reducing its stall-margin and increasing the flutter risk. In parallel, the increased fan diameter is driving the intake design, with significant implications on drag and airflow inlet distortion at the Aerodynamic Interface Plane (AIP) during off-design and cross-wind. Beside these increased aerodynamic requirements, the fan itself has to be reduced in weight, leading to application of lighter and stiffer materials, such as Carbon Fibre Reinforced Polymers (CFRP) instead of more conventional titanium alloys, providing more design degrees of freedom in terms of "customized" stiffness and inertia distributions along the blade-span. This implies the need of developing more reliable and accurate methods for aerodynamic, aeroacoustic and aeroelastic design of engine fans.

The main aim of the CA3ViAR project is to design an Open-Test-Case Fan that experiences instability mechanisms which are representative for UHBR fans of civil aircrafts, and to perform a comprehensive experimental investigation to measure aerodynamic, aeroelastic and aero-acoustic performance in a wide range of operational conditions. Experimental tests will be performed in the Propulsion-Test-Facility (PTF) of the Institut für Flugantriebe und Strömungsmachinen (IFAS) of Braunschweig, Germany.

The CA3ViAR project, coordinated by IBK, is targeting several objectives. The design of the Low-Transonic Fan (LTF) is led by the Technische Universität Braunschweig (TUBS) with support from DREAM (an Italian SME) in terms of aerodynamic shaping as well as from Leibniz Universität Hannover (LUH) and IBK in terms of aeroelasticity and aeroacoustics. The LTF test article, to be mechanically designed by IBK and manufactured by using Carbon Fibre Reinforced Polymers by specialized subcontractors, is being conceived to be operated close to aerodynamic and aeroelastic instabilities during wind tunnel operations. Requirements for the test article integration are provided by TUBS, responsible of WT instrumentation and operations. The execution of the experimental tests aimed at measuring fan instabilities (e.g. stall, flutter, etc.) is performed by TUBS with support from LUH.

The last technical phase of the project is the calibration and the eventual validation of aerodynamic, aeroelastic and aeroacoustic models according to WT test data acquired in the PTF. This work gives an overview of the CA3ViAR project and presents the status of technical activities devoted to the design of the composite LTF. More in particular, the aerodynamic design of hub profile, fan and stator blades will be presented along with the first set of preliminary aeroelastic analysis. The strategy adopted to drive the structural design is presented and discussed. The aim is to target an optimal fan rotor stability map, by starting with the first pre-predictions based on the analysis of reduced frequency, bend to twist ratio and acoustic wave propagation, to finally perform the actual high-fidelity flutter analysis taking into account aerodynamic viscosity and compressibility effects. First analyses aimed at characterizing the aeroacoustic performance complete the overview on the current status of LTF design activities.

Clean Sky Thematic Projects: where the Bottom-Up meets the Top-Down (PART IV)

Session Chair: Dr. Jean-Francois Brouckaert, Clean Sky Joint Undertaking

CATANA: Composite Aeroelastics and Aeroacoustics

Christoph Brandstetter

There is increasing evidence that today's turbojet technology is limited by instabilities arising from non-linear coupling between aerodynamic, aeroelastic and aeroacoustic phenomena. These multi-physical processes are going to become even more important in future architectures, which utilize Ultra-High-Bypass Ratio and lightweight composite fan designs to reduce greenhouse gas emissions and noise. However, enormous knowledge gaps currently exist concerning these processes and the resulting stability boundaries. In the talk, the fundamental problems of aeroelastic and aeroacoustic interactions and particularly the occurrence in low-speed composite fans will be addressed. Based on specific examples, the challenges even for state-of-the-art computational methods to capture the relevant phenomena will be discussed, revealing the necessity of representative test-cases for validation.

To overcome the current lack of relevant test cases, and to promote the development of efficient and quiet concepts, a comprehensive research programme is carried out in Project CATANA (Composite Aeroelastics and Aeroacoustics) in collaboration between Ecole Centrale de Lyon and the Von Karman Institute for Fluid dynamics. The programme will provide an open-test-case fan stage and employ unprecedented instrumentation to perform extensive investigations into the nature of multi-physical instabilities. The carbon-fibre fan stage is currently being developed at Ecole Centrale de Lyon and will be aerodynamically and structurally representative of near future low-speed fans. Multi-physical experiments are planned which allow transient investigations with synchronous measurements of aerodynamic, structure-dynamic and acoustic phenomena. The research concept combines complementary measurement systems and enables the detection of interactive mechanisms where individual systems are insufficient. To improve the coherence of the aeroelastic results, a study on structural mistuning and intake geometry will be carried out to understand and quantify the sensitivity of occurring instability mechanisms. The database will be completed by a detailed structural analysis of the stage providing modal characteristics of the rotor blades, including structural damping under rotation with the ambition to provide a reference benchmark for the international research community. In the talk, the project, its specific objectives and the planned experimental campaigns together with a available numerical results will be presented.

VENUS: Investigation of Distributed Propulsion Noise and its Mitigation through Wind Tunnel Experiments and Numerical Simulations

Roberto Camussi, Alessandro Di Marco

Distributed Electric Propulsion (DEP), is one of the propulsion configurations that, taking advantage from the Distributed Propulsion concept, is believed to exploit the benefits of electrical engines to drastically reduce fuel consumption and emissions. In the framework of the topic JTI-CS2-2018-CFP10-THT-08, the proposal VENUS will have the objective to understand the physics behind the aeroacoustics of DEP through a deep theoretical, experimental and numerical study. Appropriate numerical procedures for DEP noise assessment will be set-up and experimental data-set obtained in dedicated wind tunnel tests, will

be used both as experimental DEP noise validation reference and for providing support to the identification of the main parameters affecting DEP noise. Technologies for DEP noise reduction will be studied as well and tested experimentally. From the technical standpoint, the VENUS consortium will support the model design, manufacturing and integration by realizing a representative test article for WT parametric aeroacoustic tests, able to allow for configuration changes, in terms of engine-wing and engine-engine installation configurations, and to test the selected noise mitigation technologies. The consortium will develop methods and tools enabling a concurrent aerodynamic and aeroacoustic design of DEP configuration aircraft. The final step will consist in the experimental-numerical assessment of the numerical models. As a practical achievement, the study will support the design of a new regional aircraft configuration, in terms of wing and engines' installation, to target a DEP which is optimized in terms of aerodynamic and aeroacoustic performance. It is pointed out that all the produced models, data and documents will be open access for other institutions, with the objective to establish an "open test-case" for the whole European scientific community, unique in the aircraft design landscape.

SilentProp: Experimental and numerical investigations on acoustic propagation and noise abatement for distributed aircraft propulsion

Dimitrios Chronopoulos

Distributed Electric Propulsion (DEP) is particularly attractive from a noise reduction perspective since the induced high frequency noise is associated with: i) increased atmospheric absorption benefiting citizens and ii) improved structural shielding benefiting passengers as well as citizens. SilentProp specific objectives are:

- Performing an inclusive testing campaign within a modern and large anechoic wind tunnel configuration. Comprehensive measurements for a wide range of experimental and operational parameters will be delivered for quantifying interactions when adjacent propellers are operating within a DEP system.
- Developing a seamless and efficient numerical methodology for providing near field and far field numerical noise computations for DEP configurations nominally identical to the ones experimentally tested. A reduced surrogate modelling approach will also be delivered for accelerating the subsequent optimization procedure.
- Experimentally and numerically assessing the effectiveness of established, as well as novel noise suppression technologies including propeller phase blocking for directional sound cancellation and poroelastic, metamaterial and adaptive liners in a variety of configurations. Noise structural shielding by the aircraft structures will also be quantified to evaluate induced disturbance for citizens, as well as passengers.

SilentProp will directly contribute to the CS2JU vision of drastically reducing aircraft induced community noise. This will be achieved by delivering key technological advancements to the European aerospace sector that will eventually facilitate the optimal multidisciplinary design and social acceptance for DEP configurations. The Consortium will advance the understanding of key noise aspects involved in DEP systems, enabling initial evaluation of the overall noise level produced for a wide range of DEP designs, as well as provide substantiated appraisal of the efficiency of several noise mitigation means.

ACONIT: Actuators for Surge Control in Gas Turbine

Antoine Dazin, Pierric Joseph, Francesco Romano, Quentin Gallas, Julien Marty, Gérald Aigouy, Marcel Stößel, Reinhard Niehuis

This contribution is to be presented in the Clean Sky Thematic Topics Session Surge and rotating stall are unstable flow phenomena which can occur in aeronautical compressors operating at low flow rate. They represent serious concerns for flight safety as their arising can lead to some dramatic accidents. Consequently, the engine manufacturers and users introduce safety margin to avoid that surge and rotating stall set-in the compression stages of the engines they consequently deprive the machine from its higher-pressure ratios and higher efficiencies. An improvement of the socalled 'surge margin' can directly allow to have a beneficial impact on the engine weight by reducing the number of the compressor stages and thus on its Specific Fuel Consumption. The present European financed project focus on the extension of the stable operating range of axial compressors by controlling the flow at compressor blade tip thanks to fluidic jets blowing at the machine casing. The final goals consist of reducing the surge margin by postponing the stall onset. More specifically, the objective of the ACONIT project is to design, manufacture, and test actuators for flow control to integrate in an aircraft engine. The actuators must, therefore, fulfill aeronautics requirement in order to increase the Technology Readiness Level (TRL) in this domain. To do so, the first objective of the work is to improve the knowledge of the flow physics of an efficient flow control system by joint numerical and experimental analyses performed in a low speed, single stage axial compressor. The results of these analyses will be used to derive the fluidic specifications for a high TRL actuator and control system. These specifications will be the basis for the design and manufacturing of amplified piezo-electric actuator prototypes whose fluidic and operational performance will be precisely evaluated before manufacturing final actuators to be integrated in a full-scale jet engine test vehicle. The performance evaluation will be carried out in an environment with vibrations and controlled level of temperature. With extensive engine tests, the actuator performance will be evaluated in terms of Surge Margin Improvement, as well as in terms of energy balance between the induced consumption and the engine performance improvements. Our project consortium gathers a SME (CEDRAT TECHNOLOGIES,), two academic institutions (Bundeswehr University Munich and Arts et Metiers Institute of Technology) and a Research Center (ONERA). It therefore includes skills ranging from internal flow analysis in turbomachineries, to flow control and actuators design, manufacturing and characterizations by testing supported by CFD. The project duration is from March 2020 to September 2023 and is thus at its very beginning. The aim of the present paper is to provide an overview of the global strategy and its main steps.

Aerodynamic Analysis & Design (PART I)

Session Chair: Prof. Christian Breitsamter, Technical University of Munich, Germany

Design of a Morphing Leading Edge for use as a High Lift Device for a Regional Aircraft

Conchin Contell Asins, Volker Landersheim, Jens-David Wacker, Seiji Adachi, Sonja Arnold-Keifer, Michael May

Morphing technologies can provide a significant contribution for reduction of noise and fuel consumption for future aircrafts. In the framework of the European Aviation research programme Clean Sky 2, a design for a morphing leading edge was developed, which allows for simultaneous increase of wing chord and camber to adapt the airfoil to different airspeed conditions. The design under investigation has a sliding contact at the bottom, whereas the upper surface is continuous with variable camber. In contrast to classical high lift devices, the lift coefficient can be increased without adding sources for turbulences at the upper wing surface.

CFD analyses have been performed in order to quantify the aerodynamic performance of the designed morphing leading edge. Furthermore, a design concept both for the skin and for the actuation system is presented. The skin is designed using carbon fiber reinforced plastics (CFRP). In order to achieve both the required stiffness and flexibility, a customized, non-constant layup is developed. Its feasibility for the high deformations occurring during morphing is demonstrated by means of both numerical analysis and experimental material tests. The electro-mechanical actuation system is designed to completely fit inside the morphing leading edge with even considering space for other subsystems. Besides the design space also weight, mountability and flight safety considerations are taken into account. Altogether, an application for a morphing system is analyzed in this paper, various design challenges are highlighted and appropriate solutions for these challenges are discussed.

Methods of analyzing isolated and ducted fixed-pitch propellers under non-axial inflow conditions

M. Cerny, J. Faust, C. Breitsamter

Most propellers for UAVs are designed solely for axial inflow conditions although they may experience highly yawed inflow conditions during horizontal flight. To improve the aerodynamic efficiency, a better understanding of the flow-fields is demanded. Therefore, an isolated and a ducted small-scale propeller is operated at a wide range of inflow angle.

Aerodynamic Design and Optimization of Propellers for Multirotor

Witold Klimczyk

This work presents a methodology of designing a propeller used in large Unmanned Air Vehicle (UAV). Starting from low-fidelity Blade Element (BE) methods, the design is obtained using evolutionary algorithm driven process. Realistic constraints are utilized, including minimum thickness required for stiffness, as well as manufacturing ones- including leading and trailing edge limits. Hence, the interactions between propellers in hex-rotor configuration, and their influence on structural integrity of the UAV are investigated. Unsteady Reynolds-Averaged Navier-Stokes (URANS) are used to obtain loading on the propeller blades in hover. Optimization of the propeller by designing a problem-specific airfoil using

surrogate modeling-driven optimization process is performed. The resulting blade reduces power required for hover by around 7%. Potential improvements to the presented methodologies are described, which can further improve the efficiency.

Study on a twin-fuselage transport airplane model in a low speed wind tunnel

Evgeny Pigusov, V. Chernousov, A. Krutov

Over the years, Central Aerohydrodynamic Institute (TsAGI, Russia) has been studying on twin-fuselage aircraft concepts for different purposes. This paper represents a variant of twin-fuselage aircraft designed for container transportation on busy regional lines. The obvious advantage of the twin-fuselage transport aircraft (TFTA) is a significant (more than twice) reduction of the maximum bending moments on wing, compared to a conventional single-fuselage aircraft of the scheme. As a result, with the same payload, the airframe weight will be less than for single-fuselage aircraft. In addition, the longitudinal dimensions of the TFTA will be smaller with constant total volume of cargo holds. The separation of freight volume between two fuselages provides more comfortable and faster cargo loading and unloading operations.

In comparison with two single-fuselage aircraft, a twin-fuselage analog with the same total payload has a 9% lower take-off weight that allows using three engines instead of four, and simultaneously reduces its purchase value approximately by 11.4%. The researched TFTA variant is a tri-engine transport aircraft intended for transportation a wide range of cargo weighted 40 tons at a distance up to 3000 km with speed 700-740 km/h. The aerodynamic configuration has the two fuselages distributed under high-wing, and a " TT " - shaped tail. The experimental study results of the TFTA model at cruising configuration in a low-speed wind tunnel T-102 TsAGI are presented. The research purpose was determination of the aerodynamic characteristics of the TFTA model without engines and assessment of the twin-fuselage layout impact on control surfaces efficiency. The effect of installing an external cryogenic fuel tank under the wing between the fuselages of the model was considered too. The studies were carried out at a flow velocity V=50 m/s (Reynolds number Re=1000000), in the range of angles of attack from -6 deg to +20 deg and sideslip angle from -20 deg to +20 deg.

Aerial Stability of an In-Flight Water Scooping System

Mario Verhagen, Huub Timmermans, Wouter van den Brink

Given operational restrictions of current firefighting aircraft, a novel concept is proposed within SCODEV. Launched within the Horizon 2020 Fast Track to Innovation framework, SCODEV considers a novel system that refills an aircraft's water tanks during low altitude flight. This system provides significant benefits with respect to current technological platforms used for firefighting purposes. The novel scooping system consists of a hose and a scoop that penetrate the water surface during low altitude flight. Water enters the scoop and is raised up to the aircraft via the hose. This system is designed such that it can be installed in existing cargo aircraft. Though posing major benefits as compared to current firefighting aircraft, the design of such a novel scooping system poses significant challenges. This paper delves into the unique design aspects related to this novel scooping system. This includes devising unique handling and stability requirements for this system, and subsequently designing the system to meet desired performance metrics. With respect to the hose, aeroelastic behavior and stability are analyzed. Results, in terms of hose shape and stability, are shown for variations in operating speeds and hose length. Constant and uniform

inflow conditions are considered herein. For the scoop, aerial stability analyses have been performed using MSC Nastran. The scoop is designed to maintain a stable and desired orientation with respect to the oncoming airflow. The analyses presented herein consider system shape and behavior during reel-out and during level flight, till the onset of water ingestion. Maintaining a desired hose shape and a given scoop orientation is a paramount prerequisite for scooping to commence. Additionally, the system needs to be stable during reel-out and inflight, returning to a stable position and orientation in time. Focusing on system prerequisites that allow for initiation of water ingestion, this paper does not consider system response during water ingestion. The scoop and hose analyses have been substantiated by means of helicopter flight tests. Here, hose and scoop stability, hose shape and scoop orientation are compared to analytical results. When the scoop and hose are tested separately, behavior is in good agreement with simulation predictions. For the coupled system, scoop behavior differs from analytical predictions. This highlights the need to consider the coupled system in the simulations, instead of analyzing both components separately.

The dependence of the speed of sound in the Earth's atmosphere on its density and the correction of Mach's number

Vladimer Kirtskhalia

In the modern theory of sound, its speed in the Earth's atmosphere depends only on temperature and does not depend on its density (height). The report shows a significant dependence of the speed of sound on the density of the atmosphere and, consequently, the need to correct the Mach number, which plays an important role in determining the aerodynamic parameters of aircraft.

Aerodynamic Analysis & Design (PART II)

Session Chair: Prof. Dragan Kozulovic, Hamburg University of Applied Sciences, Germany

Cooling System Design for the Internal Combustion Engine of a BWB UAV Prototype

Thomas Dimopoulos, Stylianos Dimitriou, Pericles Panagiotou, Kyros Yakinthos

The current study presents an analytical design methodology for a compact thermal management system of a high-power density rotary engine. The engine is a part of a fixed wing, tactical Blended-Wing-Body (BWB) Unmanned Aerial Vehicle (UAV) prototype that has been developed for the aerial delivery of cargo and lifesaving supplies. The methodology developed is based mainly on a low-fidelity thermodynamic model and high-fidelity Computational Fluid Dynamics (CFD) modeling. The results are validated against dedicated windtunnel experiments. The overall methodology is divided into two distinct segments, the design of the heat exchanger (HEX) and the sizing of the inlet ducts. The low-fidelity thermodynamic model is based on 0D and 1D textbook methods and well-established formulae found on the existing literature. The thermodynamic model is used for the calculation of the geometrical characteristics of the HEX. The high-fidelity CFD modeling is employed to yield a more detailed investigation of the flow field around the HEX and provide information about whether the airflow velocity requirements, for the 0D and 1D model, are met. Additionally, the detailed CFD simulations assist the design of high-efficiency inlet ducts, in order to secure optimal airflow around the HEX and engine compartment. Using the proposed methodology, a functional HEX prototype is designed and manufactured, as a proof of concept, in order to be thoroughly examined on a test rig in laboratory conditions. Multiple experiments are conducted in a variety of inlet temperatures and airflow velocities, for the validation and fine-tuning of the overall proposed design methodology. The study concludes with the final HEX design, as well as an analysis of its integration aspects on the tactical BWB UAV prototype.

Aerodynamic and stability analysis of a VTOL flying wing UAV

Chris Bliamis, Ilias Zacharakis, Pavlos Kaparos, Kyros Yakinthos

The stability analysis of an aerial vehicle is an integral part of its design procedure. It is of even greater importance in the case of tailless aircraft, which are prone to stability issues. In the present study, the aerodynamic and stability characteristics of a Vertical Take-off and Landing (VTOL) fixed wing Unmanned Aerial Vehicle (UAV), designated as MPU RX-4, are investigated. The MPU RX-4 has a flying wing layout and is capable of performing, both conventional flights, like a regular fixed wing aerial vehicle, as well as vertical hovering, like a multicopter, adapting on different operational demands and achieving rapid field deployment. In this study, the MPU RX-4 preliminary design phase is presented and the aerial vehicle's aerodynamic performance, as well as, its stability and control behaviour are assessed using both semi-empirical correlations, specifically modified for lightweight flying wing UAVs, and Computational Fluid Dynamics (CFD) computations. These correlations are employed to estimate the non-dimensional aerodynamic coefficients for various flight conditions (e.g. cruise, loiter, maximum speed, etc.) of the MPU RX-4 flight envelope. Furthermore, the correlations are validated with dedicated CFD analyses in order to assure their level of accuracy. Finally, the MPU RX-4 stability and control derivatives, and the required control surfaces deflection for steady level flight are computed, in order to assess its overall aerodynamic performance and flight characteristics.

Energy approach to transonic flutter and LCO with shock waves movement

Svetlana Kuzmina, Fanil Ishmuratov, Oleg Karas

The paper briefly describes the main features of the mathematical model of aerodynamic forces in transonic flow. It is based on Euler equations solution in various approximations, including the effect of viscosity by using the boundary layer theory and viscous-inviscid interaction. Elastic deformations of the structure are described by vibration equations in modal coordinates. Algorithms for calculating and visualizing the aerodynamic work distribution in various forms are developed for the mathematical model used. The solution of three dynamic aeroelasticity problems is considered.

2D optimization of a Small Horizontal Axis Wind Turbine blade using flow control techniques

Charalampos Papadopoulos Pavlos Kaparos, Zinon Vlahostergios, Dimitrios Misirlis, Kyros Yakinthos

In this work, the optimization of the efficiency of a small horizontal axis wind turbine (SHWT) blade segment is presented. Typically, SHWT have a radius of 1.5 to 3.5 m and a hub height of around 10-15 m from the ground. SHWT operate in a relatively small Reynolds numbers range (up to 1 – 1.5x106) and are installed inside the atmospheric boundary layer. This operational environment is characterised by volatile and turbulent air flow, making the flow over the blade prone to separation. In order to counter this flow behavior, a set of flow control techniques is introduced and studied. These techniques control the flow, either passively, solely by the inclusion of blade add-ons, or actively, by adding energy to the boundary layer. More specifically, two passive flow control techniques and one active flow control technique are modelled and tested on a wind turbine blade segment. The passive techniques implemented in this study are based on the use of vortex generators and tubercles. Vortex generators are small vanes attached vertically to the lifting surface and are widely used in aerospace applications with varying degrees of success. Tubercles are sinusoidal modifications of the blade's leading edge. This is a novel flow control technique. The original concept has been inspired from the characteristic flipper of the humpback whale (Megaptera Novaeangliae). Regarding the active flow control technique, a dielectric barrier discharge (DBD) plasma actuator (PA) is used, a technique that adds momentum on the local flow, close to the blade's surface, by ionizing the air. The complexity and impact on the blade aerodynamic efficiency for each technique are evaluated and presented. The results from this comparison show that flow control techniques can offer a considerable benefit to SHWT by improving their critical performance efficiency factor, which is the lift-to-drag ratio.

Mesh-Diverging Inviscid Adjoint Solutions

Carlos Lozano, Jorge Ponsin

This paper describes a surprising problem encountered in the numerical solution of the Adjoint Euler equations. The basic result presented here is that two and three dimensional numerical adjoint solutions to the Euler equations have a value at and near the surface of wings and airfoils that depends strongly on the mesh density and which does not converge as the mesh is refined. The purpose of this paper is to characterize this problem and offer insights as to the possible explanation of this unusual behavior.

Artificial neural networks in panel method for solving aerodynamics

Dmitry Strelets, Kataev A.A., Khrustalev A.L.

The authors proposed an experimental panel method combined with an artificial neural network to solve the problems of aerodynamics with minimum computational power consumption and high accuracy. A software solution based on the proposed method has been created. A comparison with experiments and other existing solutions has been made. The proposed method is intended for solving aerodynamic problems in systems of multi-criteria optimization, as well as in related problems. For example, solutions to the problem of strength and aerodynamics in the associated wing of a civil aircraft.

Aerodynamic Analysis & Design (PART III)

Session Chair: Prof. Dragan Kozulovic, Hamburg University of Applied Sciences, Germany

Steady and Unsteady RANS Modeling of Wake Effects and Grid Resolution Requirements in a Low-Pressure Turbine Cascade

Alexander Führing, Dragan Kozulovic, Christoph Bode, Matthias Franke

Due to relative motion between rotors and stators in aircraft engines, periodic wakes are present in downstream blade rows, which exert significant influence at flow loss and engine efficiency. To quantify and reproduce this influence, a low-pressure turbine cascade is computed using steady and unsteady RANS methods in the flow solver TRACE by DLR and MTU Aero Engines. A thorough grid study is carried out and various aspects of grid resolution requirements are investigated for the setups and considered performance metrics respectively. A steady state transition model extension that has been developed and published by the authors is applied to the cascade flow at a number of operating points and validated with experimental data while being compared to the unsteady results as well as the steady state results without the wake effect extension. Further, a variation of wake-related parameters is carried out while discussing the effects modeled in the unsteady setup as well as the ability of the two steady state setups (with and without wake extension) to capture the trends identified by the unsteady results. A sufficiently accurate reproduction by the wake model extension enables steady simulations of the inherently unsteady effects in the aerodynamic design of the turbine, which results in an enormous reduction of computational time and effort.

Development of a Cargo Airdrop Modeling Method for a Tactical Blended Wing-Body UAV

Dimitios Mitridis, Nikolaos Mathioudakis, Pericles Panagiotou, Kyros Yakinthos

In this work, the development of a cargo airdrop modeling method is presented for a fixed-wing tactical UAV. The UAV, which is being developed in the framework of the DELAER UAS project, is based on the Blended-Wing-Body layout, and its mission is to deliver cargo and lifesaving supplies to remote Greek territories and the Aegean Sea, via airdrop. At first, a simplified kinematic model is developed, to describe the trajectory of the cargo. Then, the critical airdrop parameters, such as aerodynamic drag and the effect of wind gusts, are identified and added to the model. Based on this model, an analytical methodology is proposed, conducted in several simulation loops. In each loop, the cargo mass, release height, drop velocity and wind gust speed are the main variables. The results are given in a form of scatter plots, depicting the simulated cargo airdrop positions around an actual target location, with respect to release height, drop velocity and wing magnitude. The main conclusion is that, an optimal relative to the aerial vehicle, wind direction can be computed and chosen during the mission in order to provide the best air drop accuracy.

Multidisciplinary wing concept for aircraft preliminary design purposes

Pavel Hospodar, Armad Drabek

In this paper, an aerodynamic and wing structure is investigated by low-fidelity methods. Bell-shaped lift distribution was rediscovered in the last decade as a perspective alternative to traditional wing design. This leads to lower aerodynamic drag than elliptical lift distribution for a given lift force and root bending

moment. Root bending moment is used as a surrogate model of wing structure weight. It is relatively raw simplification introduced by Ludvig Prandtl to estimate the weight of the spar as a main part of the wing structure. For a more accurate wing weight estimation, the main parts of the wing are dimensioned under CS-23 regulation in this work. The design procedure starts with defining the elementary parameters of the wing shape (chord/twist distribution, wingspan). After geometry generating a non-linear lifting line is used to calculate aerodynamic characteristics for all regime, determined from the flight envelope. The dimensions of a spar, ribs and skin are calculated in the next step of the procedure for given bending moment, load and torque moment distribution. The structure of the wing is assumed as a two-spar, manufactured by aluminum. A target of design is to find out the shape of the wing for given weight. The solution is verified by CFD calculation.

A CSM-CFD methodology applied to the design of a cryogenic WT mode

S. Russo, J. Kirchner, G. Graumann, S. Adden, N. Paletta

The Aero-structural coupled analysis presented in this work represents an important part of the PRODIGE project, whose main purpose is the prediction of aerodynamics and hinge moment loads at high Mach numbers (>0.8) and flight Reynolds number. More in details, this methodology supports the design activities of the cryogenic wind-tunnel (WT) model to be tested in the European Transonic Wind tunnel (ETW). The need to implement such a kind of analysis comes from the requirement to take into account the “pure aeroelastic effect” during experimental tests and need to understand the effect of the WT model flexibility on the control surface load prediction, prior to and in parallel with the balance design. CFD evaluations are performed on the whole model, while a static Fluid-Structure-Interface (FSI) procedure is set up and, only, applied to the wing and aileron of the model. The FSI cycle is made of two blocks: a CFD evaluation part and a CSM evaluation part. Both modules are coupled within an iterative loop, where information are exchanged between them. For a given aerodynamic input (M, Re, speed of sound) and an initial null deformation data file, the CFD module performs a series of operations including the generation of a computational grid on the actual geometry CAD file and the CFD evaluation of the current flow field. Then the surface pressure distribution on the wing is transferred to the CSM module. The CSM module translates the wing surface pressure distribution into a load condition according to the aeroelastic input data (dynamic and total pressures) and evaluates the new deformed shape which represents the output of the CSM module. About this step two approaches, are considered:

1. “UBS” Approach (i.e. Undeformed Basic Shape): the new pressure distribution is always applied to the undeformed shape of wing and aileron;
2. “DBS” Approach (i.e. Deformed Basic Shape): the pressure difference between the actual cycle and the previous one distribution is applied to the actual deformed shape of wing and aileron. A new CFD evaluation is performed and the cycle is stopped until the aerodynamic forces convergence criterion is met. The convergence criterion consists in the comparison between the current aerodynamic forces (i.e. CL, CD and CM) and the previous FSI iteration computed forces. If the percentage change of the aerodynamic forces is within a pre-defined tolerance, the loop is stopped; otherwise the surface pressure distribution on the wing is passed to the CSM module for another iteration.
3. The aerodynamic conditions that are considered in the CSM-CFD analysis are the most critical for the WT model and are represented by a high Mach number (>0.8) and flight Reynolds number. Two angles of incidence are taken into account, i.e. the lowest value (α=-3°) and the highest one (α=6°). The test

case is represented by the configuration in which the aileron is at its maximum positive and negative deflections. Results will be compared in terms of global aerodynamic forces and pressure coefficient distributions. Moreover, the new deformed shapes derived from the application of both approaches will be compared with the original one.

A CFD study on the strut Interference on a regional aircraft wind-tunnel model

S. Russo, J. Maoeller, J. Alderman, N. Paletta, S. Adden, L. P. Ruiz-Calavera

The aim of this paper is to investigate the aerodynamic interference effects of typical devices supporting aircraft models during wind tunnel tests by means of steady RANS simulations of the flow field. It is well known that their shape could strongly affect the aerodynamic flow field around the model with significant consequences on the accuracy of the measured data and several studies were undertaken in the past decades to determine this effect for numerous configurations and flow velocity. Steady RANS simulations of the flow field are performed to predict the interference produced by two models of strut having an elliptic shape: (a) one with a pitch mechanism external to the model (used for testing in the RUAG Large Low Speed Wind Tunnel Emmen in Switzerland – LWTE) and (b) the other with a pitch mechanism located inside the model (for testing in the ONERA F1 wind tunnel in France. In the strut with external pivot, the pitch change mechanism is located in the strut and the pivot point is outside the model. The strut follows the WT model for α and β changes and the model and the strut rotate together. Conversely, in the case of internal pivot, the pitch change mechanism is located inside the model and the pivot point coincides with the origin of the reference frame. The strut follows the WT model at β changes but not for α changes. For this reason, for α changes the model rotates and the position of the strut remains unchanged, conversely, for β changes, the model and the strut rotate together. A clean cruise configuration of a scaled model of a regional aircraft is considered and both power-on and power-off conditions (i.e. without simulation of propeller effects) are considered. The strut interference is analyzed in terms of global force and moment coefficients in the body axes system and comparisons of pressure coefficient distributions. To identify the corrections to the experimental data in terms of global forces, the strut effect is evaluated as the difference between the configuration with and the configuration without the strut at the same geometrical angle of incidence and sideslip. With this work, an interpolation surface or a fitting surface are derived from numerical data that better represents the difference between results with and without the strut, for each aerodynamic coefficient. These surfaces are important to study the variation of the interference with the angle of incidence and the angle of sideslip and, moreover, to check the effect of the strut in conditions that are not simulated through CFD or calculated experimentally. Moreover, results will be compared in order to highlight the differences produced by the presence of the two models of strut on the flow field in different conditions.

Reliable Method of Aerodynamic Analysis using Computational Fluid Dynamics and Scaled Models in the Development Process of a Very Light Airplane

Aleksander Olejnik, Adam Dziubiński, Lukasz Kiszkowiak

In past decades, a massive improvement of computational fluid dynamics (CFD) methods and the rapid increase of computational resources made it possible to simulate a lot of phenomena appearing during the flow of fluid around objects. In following paper, a reliable method of aerodynamic analysis using both CFD and scaled models in the development process of a Very Light Airplane have been presented. A method of preparing a numerical model of an airplane and the aerodynamic analysis methodology have

been shown. A numerical calculation using finite volume method implemented in specialized software were performed. What is more important, to perform the aerodynamic tests in wind tunnels, scaled models of an airplane have been prepared using the modern and fast manufacturing technologies, including 3D printing and CNC machining. Research was done for various airplane configurations. Some phenomena according to propeller influence on aerodynamic and stability properties of an aircraft have been recognized numerically. The results have been shown in the graphs form of aerodynamic force and moment components as function of angle of attack. During research, an influence of particular structural parts of an airplane on aerodynamic characteristics have been analyzed. The qualitative results of a flow around the aircraft body have been presented in form of parameter distribution maps on the airframe surface have been shown. Visualization of pressure distribution have been extended with path lines visualization of the flow. The research described in the paper is an example of professional and innovative approach to the subject matter.

R&D Research in the Field of Aeronautics & Air Transport: ASuMED, CENTRELINE, ECOCOMPASS, JETSCREEN, PASSME overview presentations

Session Chair: Mr. Vladimir Cid-Bouriè, Innovation and Networks Executive Agency (INEA)

CENTRELINE: Latest Progress in TRL 3 Research on Fuselage BLI Propulsion

Arne Seitz

Novel propulsion technology and propulsion-airframe integration play a key role in enabling aviation's long-term sustainability. Significant improvements of vehicular propulsive efficiency may be expected from wake-filling propulsion integration via Boundary Layer Ingestion (BLI). The EU H2020 project CENTRELINE aims at maximising these benefits under realistic systems design and operating conditions[1]. The project is dedicated to demonstrating the proof of concept (TRL 3) for the most straight-forward approach of applying BLI to the aircraft fuselage – the so-called Propulsive Fuselage Concept (PFC). Therefore, all the main challenges associated with a PFC aircraft configuration are tackled in a methodical manner: Extensive aero-numerical simulation activities are undertaken together with low-speed experimental test campaigns of the overall aircraft configuration and the BLI fan, in order to develop a thorough understanding of the aerodynamic effects of 360° fuselage BLI. The evaluation of the aero-structural design integration of the PFC aircraft including the BLI propulsive device is based on high fidelity finite element analyses performed for the most critical load cases defined by the CS-25 certification rules. The overall power plant system featuring a turbo-electric power train for the fuselage fan drive is elaborated including high-end finite element methods for the mechanical, magnetic and thermodynamic computation of the involved electric machinery. Consistent solutions for a best and balanced systems design integration at the overall aircraft level are developed under the careful consideration of multi-disciplinary aspects. In a rigorous multi-disciplinary benchmarking exercise, the final PFC aircraft design is evaluated against a conventional aircraft configuration featuring similarly advanced technology level. With the project approaching its completion, a number of key result are ready to be presented and an outlook towards the final conclusions expected from the project can be provided: The technology application case in the wide-body market segment[2] will be motivated. The developed thrust-drag book-keeping scheme for fuselage BLI propulsion integration[3] will be reviewed. The results of the 2D aerodynamic shape optimisation for the bare PFC configuration[4], i.e. the integrated fuselage and nacelle bodies, will be discussed. The work - flow followed for the aerodynamic validation testing will be explained

[1] Seitz, A., Peter, F., Bijewitz, J., Habermann, A., Goraj, Z., Kowalski, M., Castillo Pardo, A., Hall C., Meller, F., Merkler, R., Petit, O., Samuelsson, S., Della Corte, B., van Sluis, M., Wortmann, G. and Dietz, M., "Concept Validation Study for Fuselage Wake-Filling Propulsion Integration" Paper-ID 0382, 31st International Congress of the Aeronautical Sciences (ICAS), 09-14 September, Belo Horizonte, Brazil, 2018.

[2] Peter, F., Habermann, A., Lüdemann, M., Plötner, K., Troeltsch, F., Bijewitz, J. and Seitz, A., "Definition of the CENTRELINE Reference Aircraft and Power Plant Systems", in: Deutscher Luft- und Raumfahrt Kongress 2020, Aachen, Germany, 1-3 September 2020.

[3] Habermann, A.H, Bijewitz, J., Seitz, A., Hornung, M., "Performance Bookkeeping for Aircraft Configurations with Fuselage Wake-Filling Propulsion Integration", CEAS Aeronautical Journal, published online, 2019, https://doi.org/10.1007/s13272-019-00434-w

[4] van Sluis, M. and Della Corte, B.,"D3.03 Final PFC Aircraft Aerodynamic Design and Performance", Delft University of Technology, CENTRELINE Public Deliverable Report, 2020.

and basic descriptions of the experimental setups for the overall aircraft wind tunnel testing[5] as well as the BLI fan rig testing[6] will be provided. Key insights obtained from the numerical and experimental work thus far will be summarised. These include aircraft aerodynamic properties along with flow profiles determined at the aerodynamic interface plane of the BLI fuselage fan[7], as well as fuselage fan aerodynamic design and performance results for the obtained inflow distortion patterns[8]. The discussion of results includes the architectural concept and systems integration for the turbo-electric power train[9] [10], the involved electric machinery pre-design[11], as well as design and performance implications on the main power plants[12]. Conceptual design solutions for the mechanical and aero-structural integration[13] of the BLI propulsive device will be highlighted. To round off, key heuristics deduced for PFC conceptual aircraft design will be presented[14] together with an assessment of the fuel burn benefits for PFC aircraft against an advanced conventional aircraft for an entry-into-service in 2035.

Acknowledgement: *This paper is based on the work performed by the CENTRELINE project consortium comprising Airbus, Bauhaus Luftfahrt, Chalmers Tekniska Hoegskola, MTU Aero Engines, Politechnika Warszawska, Rolls Royce, Delft University of Technology, University of Cambridge and ARTTIC. The CENTRELINE project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 723242.*

Results of the ECO-COMPASS EU/China project and an outlook on future research topics for the introduction of ecocomposites to aviation composite structures

Jens Bachmann, Xiaosu YI

The project ECO-COMPASS started in April 2016 under Horizon 2020 and aimed to bundle the knowledge of 19 partners from China and Europe to develop ecological improved composites for the use in aircraft interior and secondary structures. With a duration of three years the cooperation deepened the general relationship between both continents. Bio-based reinforcements, resins and sandwich cores were

[5]Della Corte, B. and van Sluis, M., "D3.1 Specification of Wind Tunnel Model Design and Test Campaign Plan", Delft University of Technology, CENTRELINE Public Deliverable Report, 2018.
[6]Castillo Pardo, A., "D3.04 Specification of Fan Design and Rig Test Campaign Plan", University of Cambridge, CENTRELINE Public Deliverable Report, 2018.
[7]Della Corte, B., van Sluis, M. and Rao, A. G., "D3.02 Results of the Overall Configuration Wind Tunnel Testing", Delft University of Technology, CENTRELINE Public Deliverable Report, 2020.
[8]Castillo Pardo, A. and Hall, C. A., "Aerodynamics of Boundary Layer Ingesting Fuselage Fans", Aerospace 2019, 6(12), 126; https://doi.org/10.3390/aerospace6120126.
[9]Wortmann, G., "D4.04 Electric Machinery Preliminary Design Report", Siemens, CENTRELINE Public Deliverable Report, 2018.
[10]Merkler, R., "D4.05 Power Plant Integration Concept for Electric Generator", MTU Aero Engines, CENTRELINE Public Deliverable Report, 2020.
[11]Biser, S. Wortmann, G., Ruppert, S., Filipenko, M., Noe, M. and Boll, M., " Predesign Considerations for the DC Link Voltage Level of the CENTRELINE Fuselage Fan Drive Unit ", 9th EASN International Conference on Innovation in Aviation & Space, Athens, Greece, 3-6 September 2019
[12]Zhao, X., "D4.03 Power Plant System Final Design and Performance Characteristics", Chalmers University of Technology, CENTRELINE Public Deliverable Report, 2020.
[13]Goraj, Z., Kowalski, M. and Goliszek, B., "Optimisation of the loading structure for Propulsive Fuselage Concept", ISABE-2019-24193, 24th ISABE Conference, Canberra, Australia, 22-27 Sep 2019.
[14]Seitz, A., Habermann, A.H., van Sluis, M., "Optimality Considerations for Propulsive Fuselage Power Savings", Proc IMechE Part G: Journal of Aerospace Engineering, published online, 08 April 2020, https://doi.org/10.1177/0954410020916319

developed and optimized for their application in aviation. Furthermore the use of recycled carbon fibres to increase the mechanical strength and multifunctional aspects of bio-composites were evaluated. In order to withstand the special stresses in aviation environment, protection technologies to mitigate the risks of fire, lightning and moisture uptake were under investigation. An adapted modelling and simulation enabled the optimization of the composite design. Electrical conductive composites for electromagnetic interference shielding and lightning strike protection were under investigation in ECO-COMPASS as well. The cooperation included the exchange of knowledge and materials in order to optimize the development eco-composites. A preliminary Life Cycle Assessment (LCA) was carried out. The aim of the presentation at the EASN-CEAS conference is to give an overview of the project results and it is special background with the collaboration of Chinese and European partners. Furthermore, the consortium identified gaps and challenges. Recommendations for future research topics related to bio-based and recycled materials for aviation composites will be given. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 690638 and the Special Research Plan on Civil Aircraft of Ministry for Industry and Information of the People's Republic of China (MIIT) under Grant No MJ-2015-H-G-103.

JETSCREEN - JET Fuel SCREENing and Optimization

Bastian Rauch

High Sustainable Aviation Fuel (SAF) pricing relative to conventional fuels is an issue that is limiting the SAF deployment as well as limited availability of sustainable feedstocks. As a consequence, SAF production capabilities and financing required for the upscaling are still missing. While frameworks like CORSIA are aiming to reduce the price difference, there is an ongoing need to develop and approve a variety of fuel production pathways that tap into the utilization of a broader range of resources, while bringing additional advantages as increased performance, cost competitiveness and reduced pollutant emissions. However, substantial investments are needed to seek approval for such new alternative fuel production pathways under the ASTM D4054 international standardization process. Fuel specifications were developed empirically and based on conventional crude oil. However, since the first approval of a synthetic aviation fuel in 1998 (in UK Defense Standard 91-91, Issue 3), increasing experiences were made with the utilization of fuels from other origins. The knowledge and tools to assess fuel effects grew significantly with the formalization of the approval process of new pathways in ASTM D4054 and the approval of 5 pathways by ASTM (D7566). During the approval processes and in accompanying scientific projects factors influencing the operability & safety as well as influencing the added value & performance benefits were identified. These new tools can now be used to initiate the streamlining/rationalization and significantly de-risking the approval of new fuel production pathways. In consequence, this will reduce the cost and timescales of the deployment of new fuels significantly. Furthermore, in the mid-term perspective alternative fuel specification can be challenged for:â€¢ blending ratios higher than the current limits of <50% to fully maximize the impact of value-added sustainable aviation fuels in terms of CO2 and non-CO2-impact, and, â€¢ allow a wider scope of blend materials which have benefits in yield, production costs and reduction in environmental impact of production and processing.

PASSME: The Schiphol Innovation Way of Working

Max Davidse

Royal Schiphol Group (RSG for short) has the goal to 'Connect your world', with the ambition of creating the world's most sustainable, high-quality airports. This ambition calls for extensive innovation efforts and

requires the pursuit and implementation of creative solutions. Dating back to the dawn of flight, Schiphol Group has been a leader of the aviation community and our employees see themselves as innovators. In order to push the aviation industry forward, it is imperative to keep exploring (disruptive) opportunities that challenge the status quo. To make this possible, we formed a central Innovation Hub, which has since started to coordinate and accelerate long-term transformational & disruptive innovation projects. In order to maximise our innovation output, we are continuously evolving our own way of working, which helps us make sense of our rapidly changing world. To look beyond the horizon, we distinguish three types of innovation that help us navigate the uncertainty ahead. Earth: Incremental innovations. Improvements to day-to-day challenges, executed in well-understood steps. Expanding our current reality. Moon: Transformational innovations. Fundamental changes to the workings of existing value chains. Exploring an achievable future, we can envision. Mars: Disruptive innovations. Introducing new value chains or operating models. Exploring a distant future, we can't even envision yet. On top of this, we focus our efforts on various themes, which we call innovation families, ranging from the development of an autonomous airside to realising a true multimodal hub. Our innovation way of working specifically includes collaborations. We believe we can accelerate innovation by cultivating collaborations with startups, knowledge institutes and corporate partners, to help create the world's most sustainable, high-quality airports.

R&D Research in the Field of Aeronautics & Air Transport: UHURA Project Session

Session Chair: Dr. Jochen Wild, German Aerospace Center (DLR), Germany

Unsteady High-Lift Aerodynamics - Unsteady RANS Validation An Overview on the UHURA Project

Jochen Wild

The project UHURA is focusing on the unsteady flow behavior around high-lift systems and will first time deliver a deeper understanding of critical flow features at new types of high-lift devices of transport aircraft during their deployment and retraction together with a validated numerical procedure for its simulation. UHURA performs detailed experimental measurements in several wind tunnels to obtain a unique data set for validation purposes of Computational Fluid Dynamics (CFD) software, including detailed flow measurements by Particle Image Velocimetry (PIV) and other optical measurement technologies. Advanced CFD methods promising significant improvements in the design lead time are validated against this database to obtain efficient and reliable prediction methods for design.

Hybrid RANS-LES simulation of a deflecting Krüger device

Song Chen, F. Bagheri, S. Wallin

Laminar wing technology for reducing the fuel consumption and environmental impact requires new leading-edge high-lift devices. One solution is to introduce a Krüger device deployed from the lower wing surface leaving the upper surface undisturbed. During the deployment, the aerodynamic performance becomes critical with large unsteady separation behind the device. The aerodynamics of high-lift systems on transport aircraft still poses high challenges on the capabilities of numerical simulations, and accurate prediction of the deployment of a Krüger device is yet beyond the state-of-art. In the H2020 project UHURA, CFD capabilities, as well as validation experiments, are addressed. Unsteady RANS computations, the industrial state-of-art today, is known for its limitations for accurately capturing unsteady massively separated turbulent flows independent of the choice of turbulence model. Hybrid RANS-LES methods are better suited by resolving the large non-equilibrium turbulence motions which are contributing to the dynamic interaction between the turbulence and aerodynamics. The smaller scales within the attached boundary layers as well as the sub-grid scales in the LES zones are more in statistical equilibrium and are more easily modelled using unsteady RANS. Still, scale resolved computations are excessively computational expensive when simulating slow processes such as the deployment of a high lift device. In a pre-study, before the final definition of the experimental setup, it has been shown that such hybrid RANS-LES simulation of a complete deployment cycle is actually affordable within a few days of computation time on a standard CPU cluster by carefully optimizing the computational setup like meshing strategy, time integration, numerical scheme and turbulence model. The movement is accommodated by mesh deformation and remeshing. Since the distances between the different moving structures are small, the remeshing must be made very frequently. We are using scripted automatic meshing with Pointwise where only a local zone around the deployed device is remeshed. Important for an efficient LES resolution (best resolution per CPU time) is a large structured zone in the wake of the device where the cell size and aspect ratio is kept constant. The optimization of the computational setup was made for a fixed position of around 90 degrees with a massive separation zone. The influence from mesh resolution, time step, spanwise width, numerical schemes as well as turbulence models were carefully assessed by turbulence energy spectra and two-point correlations at numerous locations. The feasibility of a simulation of a

complete deployment cycle of 1.2s was then demonstrated by using Spalart-Allmaras DDES. See the attached figure and also the link https://www.youtube.com/watch?v=FctYbzYjY2M.

Acknowledgments: *The project leading to this publication has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 769088.*

A dynamic Immersed Boundary method for moving bodies and FSI applications

Francesco Capizzano, T. Sucipto, P. Iannell

The document describes the CIRA and IBK collaborative research during the UHURAEU project whose aim is characterizing the dynamic unsteady flow due to the deploy-ment of a Krueger high-lift device at approach/landing conditions. Both numerical andexperimental activities are considered in the project. The present work is devoted to the comprehension of the unsteady phenomena during the Krueger motion by means of a coupled fluid-structure interaction (FSI) approach. In particular, the CIRA in-house Im-mersed Boundary (IB) code SIMBA[15] is extended to treat moving bodies and dynamic mesh refinements with the aim of simulating compressible and viscous flows around moving/deforming objects. Firstly, the rigid body motion feature has been validated by simulating well-known benchmarks available in literature[16]. The basic idea considers the motion of Lagrangian bodies through an inertial Eulerian Cartesian mesh. Differently from classic moving-mesh approaches, the Cartesian cells do not move in space but rather they observe the solid walls crossing themselves. A moving least-square procedure (MLSQ) is used to build up a dynamic discrete forcing similar to that of Vanella et al.[17] and De Tullio et al.[18]. Secondly, CIRA and IBK developed a proper interface for coupling the IB method with a structural solver in the framework of a partitioned approach. In particular, the shared platform drives the solution sequence and allows exploring different coupling strategies[19]. The final aim is to simplify and automatize the study of complex flows whose characteristics strongly depends on the structural dynamics of moving objects. Indeed, the extreme loads generated by the Krueger deployment represent challenging issues for the design of efficient solutions. The final applications deal with the FSI simulations of two differenthigh-lift devices[20] during their respective deployment phases[21].

Progress towards simulation of Krueger device motion with Lattice Boltzmann Methods

Jorge Ponsin Roca, C. Lozano

The numerical simulation of the deployment/retraction of a high-lift Krueger device poses numerous challenges regarding physical and numerical modelization. The flow has to be computed in presence of large, enforced motions, which requires the use of unsteady solvers in combination with special meshing

[15] F. Capizzano, L. Alterio, S. Russo, C. de Nicola, A hybridRANS-LES Cartesianmethod based on a skew-symmetric convective operator, Journal of Computational Physics 390 (2019) 359–379.
[16] F. Capizzano, Report on extension of in-house immersed boundary method SIMBA to treat moving bodies and FSIcoupling, UH-11-D22.7-CIRA, UHURA Project(2020).
[17] M. Vanella, E. Balaras, A moving-least-square reconstruction for embedded-boundaryformulations, Journal of Computational Physics 228 (2009) 6617–6628.
[18] M. de Tullio, , G. Pascazio, A moving-least-squares immersed boundary method forsimulating the fluid-structure interaction of elastic bodies with arbitrary thickness, J.Comp. Physics 325 (2016) 2001–225.
[19] T. Sucypto, S. Adden, Report on FSI-interface methodology, UH-11-D22.6-DLR, UHURA Project (2020).
[20] J. Wild, Geometry release DLR-F15-3eRef, UHURAcoordination memorandum, UH11-CM02-DLR, DLR (2018).
[21] J. Wild, Final shape of DLR-F15-LLE Krueger flap for wind tunnel testing, UHURAcoordination memorandum UH-31-CM12-DLR, DLR (2020).

techniques (chimera, etc). Likewise, the presence of large turbulent separated flow areas downstream of the Krueger device during a significant fraction of the device motion is to be expected. Such large, unsteady separation is expected to affect significantly the flow over the rest of the elements.

The main option nowadays to simulate the deployment of the Krueger device is to use URANS solvers, a technology that has been in use for decades now and is well validated for steady attached and/or weakly separated flows. On the other hand, massive flow separation occurs during significant parts of the motion, and the limitations of URANS for this type of flows are well documented. It may thus be worth exploring and assessing alternative methods that may offer different physical (e.g scale resolving turbulence modelling) and/or numerical models. In this context, the Lattice Boltzmann Method (LBM) has some particular features that make it an ideal candidate for this problem, such as:

- It is intrinsically unsteady
- It has very low numerical dissipation/dispersion errors, which makes it ideally suited for joint use with high-fidelity turbulence models such as LES
- Its underlying adaptive Cartesian octree mesh approach and handling of wall boundary conditions, which are particularly well suited for complex and/or moving geometries
- Its high computational efficiency, even though the time step advancement is limited by the explicit stepping nature of the time integration method.

In this paper we describe the knowledge and experience gained during the first phase of the UHURA project using a Wall Model LES-LBM based commercial software to simulate the unsteady aerodynamics of the Krueger device motion.

R&D Research in the Field of Aeronautics & Air Transport: "Aviation sustainability: ACACIA – ALTERNATE – CLIMOP – GREAT common session"

Session Chair: Dr. Jordi Pons-Prats, CIMNE, Spain

ACACIA: Improved understanding on aviation's climate impact

Sigrun Matthes, Klaus Gierens, Robert Sausen & ACACIA Project Team

Non-CO2 emissions of aviation may impact climate as much as aviation's carbon dioxide (CO2) emissions do. However, the impact the non-CO2 effects, comprising e.g., ozone and methane induced from NOx emissions, together with contrails, or the indirect aerosol effects, is associated with much larger uncertainties. The research project ACACIA (ADVANCING THE SCIENCE FOR AVIATION AND CLIMATE) explores the climate impacts of non-CO2 effects which show a strong dependence on atmospheric conditions and synoptic situation; hence they depend on location and time of aviation emissions. While CO2 and non-CO2 effects in general introduce a warming effect for climate change, some indirect effects might result in a relatively large cooling. In January 2020, the EU Aeronautics project ACACIA started. It has four aims for scientifically based and internationally harmonised policies and regulations for a more climate-friendly aviation system. (1) We will improve scientific understanding of those impacts that have the largest uncertainty the indirect effect of aviation soot and aerosol on clouds. (2) We will identify needs for international measurement campaigns to constrain our numerical models and theories with data and we will formulate several design options for such campaigns. (3) Putting all aviation effects on a common scale will allow providing an updated climate impact assessment. Uncertainties will be treated in a transparent way, such that trade-offs between different mitigation strategies can be evaluated explicitly. This helps our final aim (4) to provide the knowledge basis and strategic guidance for future implementation of mitigation options, giving robust recommendations for no-regret strategies for achieving reduced climate impact of aviation. Apart from the indirect aerosol effect with its very large uncertainties, ACACIA will as well reconsider the effects of gaseous aviation emissions, in particular of NOx, on atmospheric chemistry and the resulting climate effects. Weather conditions for potentially large aviation climate impacts will be identified. Novel field experiments will be designed to close knowledge gaps and to allow proof of concepts for climate-optimal routing.To this end, ACACIA brings together research across scales (from plume to global scale), from laboratory experiments to global models, and it proceeds from fundamental physics and chemistry to the provision of recommendations for policy, regulatory bodies, and other stakeholders in the aviation business. ACACIA will cooperate with international partners, both research institutions and organisations. Additionally, ACACIA seeks for synergies with EU partner projects: ALTERNATE (Assessment on aLTERNative AviaTion fuEls development), ClimOp (Climate assessment of innovative mitigation strategies towards operational improvements in aviation), and GREAT (GREener Air Traffic operations).

ACKNOWLEDGEMENTS: This project ACACIA receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 875036.

ALTERNATE: Assessment on Alternative aviation fuels development

Jordi Pons-Prats, Gustavo Ionso

It is widely accepted that the use of sustainable fuels, with a Life-cycle carbon footprint substantially smaller than the present fossil-origin kerosene, is the most promising and probably the only short-medium time measure allowing the aviation industry to reduce its emissions, helping to reach 2015 Paris Agreement targets. During the last 10 years, many tests have been done with different drop-in organic products with high level of success. Present commercial aircraft engines are certified for using a mix of up to 50% of some of these new products. More additional research is still going on the convenience of developing new feedstocks and on their potential climate change impact. The International Civil Aviation Organization (ICAO) is now discussing the best way to standardise the Life-cycle Analysis (LCA) of the most readily available products and what is the best certification procedures. This process is needed in order to apply CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation), approved in October 2016, intending to stabilize international aviation carbon dioxide (CO2) emissions at 2020 levels. However, none of those new organic-origin fuels has proved the means to be produced in an economically competitive way versus fossil kerosene. It is generally accepted that some type of incentive mechanism needs to be implemented to make sustainable fuel attractive for the airlines in addition to the CORSIA and European Trading System provisions. As the result of this Chinese and European cooperation proposal, some possibilities appear for a wider aviation sustainable fuel utilisation, considering both technical and economic areas, including the possible use of more feedstocks and production pathways than the existing ones. New fuel candidates will be evaluated in this project according to improved modelling methods, considering LCA optimization, climate change effects and technical and economic consequences of their use.

ClimOp: Climate assessment of innovative mitigation strategies towards operational improvements in aviation

Carlo Abate , K. Sutopo, B. Ohlenforst, J. Middel, V.S.V. Dhanisetty, B.F. Santos, F. Yin, P. Rao, F. Linke, C. Weder, I. Ozkol, B. Başpınar, T. Roetger, E. Branchini, C. Abate, S. Gottofredi, V. Grewe, S. Matthes

The ClimOp project aims to investigate which operational improvements have a positive impact on climate, taking CO2 and non-CO2 effects into account. As a first step, ClimOp has identified preliminary Key Performance Indicators (KPIs) and Operational Improvements to mitigate the impact of aviation on climate. A preliminary list of promising operational improvements includes, for example, the climate-optimised operation for the airline network, the climate-optimised trajectories, the operational and infrastructural measures on the ground, the operational measures at a regulatory level and so on. The set of KPIs will be used to evaluate and rank the selected OIs by considering quantitative (environmental, technical, operational, safety, economical) and qualitative aspects (human performance and social acceptance). Then ClimOp will quantify the impact these measures have on climate, through detailed modelling of the climate response to different contributions from aviation emissions.

Subsequently, the feasibility, effectiveness, and impact on aviation stakeholders of the proposed operational improvements will be validated with the representatives of all actors in the aviation industry, such as airlines, airports, passengers and ANSPs.

GREAT: Greener Air Traffic Operations

Abdellaoui Rabeb, Finke Michael, Temme Marco-Michae

Addressing environmental challenges, especially global warming, is more than ever a must for the community. This matter is becoming an increasing priority at reginal and global level. Europe has made commitments to reduce the aviation environment footprint; hence it is contributing to climate change, increasing noise, impacting local air quality and consequently affecting the health and quality of life of European citizens. The air traffic in Europe is growing and expected to continue increasing significantly in the future in order to cope with the growing demand for mobility and connectivity. A long-term effect on the environment from aviation sector, mainly caused by aircraft noise and exhaust gases (especially CO2, nitrogen oxides NOx and methane), make it a clear target for mitigation efforts. The future growth of aviation shall go hand in hand with environment sustainability policies. Therefore, studies and research are being conducted in Europe exploring possible optimization of the aircraft technologies as well as air traffic management operations. The international project project "Greener Air Traffic Operations" (GreAT) is launched in line with this perspective. Given the close interdependency between flight routing and environment impact, optimization in flight trajectory design and ATC operations are an appropriate means to reduce the emissions in short- and medium-term time frames. Flight trajectories are influenced on the one hand by environmental and aircraft parameters, and on the other hand by ATC driven parameters, like route length or usable altitudes. During flight execution, re-planning on board of an aircraft using the Flight Management System (FMS) enables to compute a greener trajectory considering dynamic effects at the tactical level, like changes in the weather situation. To hence the efficiency, it is necessary that this trajectory is flown as planned, even under the actual traffic situation controlled by ATC, which is often not the case today. This project will be conducted in cooperation between Chinese and European partners. The overall objective of this cooperation is to reduce the fuel consumption and gas emissions during "gate-to-gate" flight phases. The main focus is to develop and assess environment-friendly air traffic operational concept, adaptive airspace, green trajectory optimization technologies, and supporting avionic systems. Evaluation campaigns between the European partners and in combination with the Chinese partners through cross evaluations are planned to validate the proposed concept and prove the potential of such approach in significantly reducing the aviation's impact on climate change.

Hybrid-electric flight (PART I)

Session Chair: Prof. Andreas Strohmayer, University of Stuttgart, Germany

Foundations towards the future: FUTPRINT50 TLARS, an open approach

Ricardo Reis, Francisco Palazzo, Carlos Ilário, Evert Windels, Dominik Eisenhut

The Top-Level Aircraft Requirements for an up to 50 PAX Hybrid Electric Aircraft with Entry Into Service circa 2035 – 2040 will be presented.

This class of aircraft embodies already some similar challenges to larger class aircraft in technology, operation and future regulations. It is thus at the right spot to drive technology, regulations and operational developments in order to accelerate cleaner flight technologies based on propulsion electrification

FUTPRINT50 TLAR aim to be reference foundation for the development of specific themes handled in the project but also drive the open collaboration model adopted by FUTPRINT50. Current and future scenarios will be presented for this class of aircraft, from which the TLARs were derived. Considerations on future implications learned during the project will be discussed, has the future work in progress for a conventional reference with EIS in Y2040, to serve has comparison against the FUTPRINT50 HEA proposal.

Development of top-level requirements for regional aircraft based on the needs of the Russian market

Maksim Ovdienko, A.N. Varyukhin, B.G. Nesterenko, A.V. Vlasov, V.V. Klochkov, A.E. Karpov, E.V. Varyukhina

Nowadays, the share of regional flight traffic is amounted to about 10% of all air transport network in Russia. It notes, in the first place, that regional aircrafts in Russia are focused on providing public transport accessibility of small remote settlements are located in the conditions of ill-developed land transport infrastructure and carry out different types of aviation tasks on behalf of various branch of economy. These points to the fact that regional aviation in Russia is focused on problem market areas such as Northern, Siberia and the Far East regions, which have the highest costs at a low level of paying capacity. In these regions, regional aviation has the highest social significance, because it is the only one means of ensuring transport accessibility.

The paper includes the analysis of current conditions and development trends of the interregional air transport system of Russia for the period after 2030 until 2035 years. In addition, the structure and volume of commercial flight traffic performed by the regional aircrafts are analyzed. Also, an assessment of operational requirements and an analysis of the technical excellence of commercial regional aircrafts are carried out. An assessment of the environmental requirements for this class of aircraft was carried out on the basis of ICAO standards.

This resulted in obtaining the mission requirements for advanced regional aircrafts of two types of passenger capacity range: 35-40 and 65-70 pax. The main difference in mission requirements between Russian and European markets for 35-40 pax aircraft is that it should have the range of 1,500 km and the ability to take off and land from unpaved runways, as well as the ability to convert the cabin into a cargo-

passenger one. Similarly, for the 65-70 pax aircraft, which should has a cruising speed about 800 km/h, a range up to 3000 km and the possibility of operation from class G airfields.

Selecting figures of merit for a hybridelectric 50 seat regional aircraft

Nicolas Moebs

As the impact of climate change is becoming more imminent, the aviation industry strives to engineer solutions for greener air travel. In order to heavily reduce emissions, new aircraft configurations and technologies like hybrid-electric aircraft concepts are investigated. In the course of the aircraft design process for a new hybrid-electric aircraft, a number of configuration alternatives have to be assessed. In addition, new propulsion concepts have to be compared to a conventional reference aircraft. These comparisons are carried out by the means of suitable figures of merit, adapted to the reference mission.

The presentation will give insight into the process of identifying suitable figures of merit for a 50-seat hybrid-electric regional airliner, which was carried out in the EU-funded project FutPrInt50. Coming from a thorough perspective, a down selection leads to a graspable number of parameters which are categorized in regard to the environment, to airline desirability, and to the introduction of hybrid-electric aircraft. Those figures of merit, like emissions and operating costs, are gathered in an objective function which can support an overall evaluation of the aircraft design. This offers a detailed, yet transparent assessment of the various designs. The application of the proposed figures of merit methodology will be shown with the evaluation of different energy management strategies on selected mission profiles.

Operator Technology Impact Simulator - assessing innovation from operator perspective

Yorick Teeuwen

Abstract - The research performed shows the impact of new aircraft technologies on aircraft operators in terms of cost-revenue potential and climate impact. A novel coupling of aircraft physics, cost-revenue modeling, and climate modeling has been realized. The traditional multidisciplinary design approach of aircraft has therefore been augmented with climate and cost-revenue aspects. The addition of revenue management and climate impact to the aircraft design space allows for new insights into the design drivers. The climate modeling takes into account the operational usage of the aircraft and allows for assessing Aviation Induced Cloudiness with the Average Temperature Response selected as a climate metric.A number of case studies have been performed that show the broad implication of novel propulsion techniques. Hybrid electric, boundary-layer ingesting aircraft have been assessed as well as aircraft that employ hydrogen combustion in gas turbine engines. The analysis shows the implication of these technology on the physical aircraft design e.g. effect on take-off mass. In addition, the operational characteristics are exposed that will determine for example the ticket price. Optimization on the routing of the aircraft to balance fuel burn and the climate impact is possible.

Hybrid electric distributed propulsion overall aircraft design process and models for general aviation

Juan Pablo Ruscio, Joël Jezegou, Angel Gomez Pacheco, Paul Laonet, Raquel Alonso Castilla

In the frame of the European objectives in terms of CO2 emissions, the aeronautics is looking for a technological rupture to achieve them, in particular, the aircraft design domain pursuits this through the research of innovative architectures. One of these innovative configurations currently being explored

includes the hybrid electric energy source (thermal/electric) for Distributed Electric Propulsion (DEP) architecture.

This Paper details a code developed to size a general aviation aircraft at concept level, by only defining its top-level requirements and the main architecture parameters. The code can manage both conventional and hybrid power source as well as concentred or distributed propulsion architectures in order to allow the user to evaluate and compare the feasibility and benefits respectively of these innovative architectures.

This code is a branch of the code "FAST" (Future Aircraft Sizing Tool for CS 25 type) held by ONERA/ISAE-SUPAERO, but now through this work, it's expanded to CS 23 with hybrid electric energy source and distributed propulsion system. Through this paper the models used for the concept aircraft sizing loops are described but putting special emphasis on the distributed propulsion aerodynamics and wing mass estimation. These detailed models mentioned were tested with the NASA X-57 configuration giving promising results.

Hybrid-electric flight (PART II)

Session Chair: Prof. Andreas Strohmayer, University of Stuttgart, Germany

Power control system for a lightweight electric aircraft

Fedor Zagumennov, Varyukhin Anton N., Ivanov Grigory S., Zhuravlev Denis I., Zakharchenko Victor S.

This article describes the development and the key features of lightweight electric aircraft power system. The overview includes the internals of main power control units and propulsion system rigging, hardware parts selection guide and fail-safe features in hardware and software of the aircraft.

The propulsion system includes lightweight solution utilizing BLDC motor with a propeller as a main thrust generator, and a control system, which consists of IGBT 3-phase bridge and control system, as well as a special optical-insulated throttle controller. Main power control system automatically starts up an aircraft modules and provides all the necessary information coming from the sensors. All key components in the aircraft are connected using CAN interface.

To create a strong protection against surges and electric interference, special cabling and interfacing aspects between several systems of a lightweight aircraft are described. Part of the article provides a future extendibility, versatility and economical concepts.

Optimal Control of the Energy Management of a Hybrid Electric Helicopter for Urban Air-Mobility

Teresa Donateo, Claudia Lucia De Pascalis, Luciano Strafella, Antonio Ficarella

In the last decade, aircraft propulsion electrification has been earning an increasing interest due to several benefits that it could bring, especially in terms of fuel saving and emissions cutback. While technological enhancements are mandatory to make pure- and hybrid-electric power systems viable for heavier applications, such as commercial and cargo planes, particularly concerning electrical energy storages, these concepts find perfect fit in one of the today's emerging aviation markets that is the urban air-mobility, also known as on-demand or air-taxi operations. Urban air-mobility is enabled by vertical take-off and landing capability, while the short-range requirements suggest it as a good candidate for the application of non-traditional powertrains. In this study, a helicopter for air-taxi operations is considered to be equipped with a hybrid electric drivetrain, where a turboshaft engine and two electric machines fed by a lithium ion battery contribute to the total rotor power. A gearbox is included to sum the individual contributions and the recharge-mode is enabled for battery. In previous works, some of the authors developed a simple but thorough modelling approach for the electric patch of the power system described above that was validated by means of both experimental data from literature. In this investigation simulation results from the Gas-turbine Simulation Program (GSP) commercial environment were used to develop and validate the turboshaft model. Furthermore, three different energy management strategies defined a priori were tested in the previous work, finding interesting margins of fuel saving under certain operating conditions and battery aging. This study aims at exploring more in depth the important role of the energy management in the fuel economy of this application. The offline optimal control method called Dynamic Programming is used as benchmark to be compared to the results from an online optimal control known as Equivalent Consumption Minimization Strategy. One of the main features of the hybrid-electric technologies is their higher degree of freedom with respect to the conventional systems. Properly designed energy control strategies, together with proper components size, represent the key for a deep exploitation of the benefits that these advanced concepts can introduce.

Thermal management for a hybridelectric 50 seat regional aircraft

Ricardo Reis, Francisco Palazzo, Carlos Ilário, Ricardo Gandolfi, Walter Affonso, Nicolas Rodio, Timoleon Kipouros, Panagiotis Laskaridis, Andrei Chekin, Yury Ravikovich, Nikolay Ivanov, Leonid Ponyaev, Dmitry Holobtsev

Electric/hybrid-electric aircraft – E/HEA – incorporate new systems, which demand am integration level higher than classical architectures. Higher power systems, electrical transmission, batteries or fuel cells, distributed propulsion… all introduce new heat sources and dynamics that have to be accounted for and regulated. The latent opportunity to explore synergies among these systems need the development of new models and coupling with MDO toolchains. Also, an understanding of the implications into operations and trade-offs is critical to ascertain and validate gains at the aircraft level. This presentation will provide a review of state-of-art for an up to 50 PAX class E/HEA, main opportunities, issues and trade-offs identified by FUTPRINT50 regarding Thermal Management System. A discussion of road ahead, regarding development of capabilities to support the design of TMS during the project will be brought to the fore, showcasing the open approach of FUTPRINT50 to be driven by open collaboration in order to accelerate the Entry Into Service of this type of aircraft.

Safety and Certifiability evaluation of Distributed Electric Propulsion Airplane in EASA CS-23 category

Joel Jezegou, Umair Sufuan

Distributed Electric Propulsion (DEP) is one of the unconventional airplane architectures of interest in the quest for decreasing aviation environmental footprint. This configuration integrates strong and innovative couplings between systems and aircraft design disciplines. To address limitations of the traditional approach for certification and of the associated means of compliance when certifying innovative products, the European Union Aviation Safety Agency (EASA) issues in 2017 a novel certification philosophy that relies on high-level objective-based safety requirements. In this context, this paper presents a safety and certifiability evaluation of DEP airplane in EASA CS-23 category, with a methodology for aircraft-level safety assessment during preliminary design, a certification gap analysis with regards to existing means of compliance, and some proposals to clear the certification path for DEP configuration.

Hybrid-electric flight (PART III)

Session Chair: Prof. Andreas Strohmayer, University of Stuttgart, Germany

Wing conceptual design for the airplane with distributed electric propulsion

Pavel Hospodář, Nikola Zizkovsky, Jan Klesa

Most of the small airplanes are designed for relatively long-range. However, several studies show the typical purposes of the thin-haul airplane have a much shorter range (around 200 NM). The urban air mobility concept also assumes a shorter range flight profile to ensure city-to-city on-demand transport as a supplement to vertical take-off and landing (VTOL) airplanes, that will focus on traveling in the city. For those reasons, an aerodynamic and structural wing design for short-range is presented. A distributed electric propulsion (DEP) is used to increase aerodynamic efficiency. In this work, a ten seats Ae270 aircraft is used as a case study. The new design uses existing fuselage, tail and turboprop engine, only wing is completely redesigned. The cost function for the design procedure consists of two parts. The first one is aerodynamic efficiency, which has a primary impact on fuel consumption and the second one is the weight of the wing. Lifting line theory with blade element momentum theory will be used to design a wing geometry with DEP. Optimal geometry is also verified by CFD simulation. The second part of the cost function is the weight estimation of the wing. This is done by the design of elementary wing parts (spars, ribs, and skin) under CS-23 regulation. The wing is assumed as full-aluminum with two spars. The main goal of this optimization is to redesign the wing for a given range and save fuel as much as possible. For that reason, a hybrid-propulsion system in different configurations is investigated.

Effects of an innovative distributed propulsion system on a regional aircraft wing configuration

Giovanni Andreutti, M. Minervino, G. Mingione

Wingtip-mounted propellers installed can decrease the wing induced drag by weakening the wingtip vortex by the propeller slipstream. Due to weight and size this solution is not applicable for classical thermal engine, but could become appealing when hybrid/electrical propulsion is used. The purpose of this paper is to investigate the aerodynamic effects of non-conventional propulsion installation on a regional aircraft. In order to obtain results within reasonable accuracy margin and keep the computational time low, three different methodologies are integrated. High-fidelity CFD simulations are used to provide detailed aerodynamic information for lower-fidelity methods tuning and to increase the physical understanding. Advanced panel code simulations, tuned with CDF results, make possible to extend coverage of the design space without exceeding a computational time compatible with preliminary design activities. Simplified theoretical formulations, based on the previous methodologies analyses, furnish influence trends for the major configuration parameters.

Innovation Design Analysis of the Optimal Aerodynamic Adaptive Smart Structures for Disk-Body Hybrid Electric Solar Aircraft and Airship Concepts

Leonid Ponyaev, Yury Ravikovich, Michail Kuprikov

The innovation complex Design Analysis of the find any Optimal Aerodynamic Structure Concept with Adaptive Smart Systems as change facility of the Geometry Shape Surface by the Integrate Disc Wing-Body Hybrid Electrical Solar Aircraft and Airship for decrease Weight, Power and Fuel Sources are very actually today and focus for International EC INEA Green Ecology Air Transportation R&D Program as

named the FUTPRINT50. The Universal Digital Optimization Method of Aircraft CAD Design focus to the goal of Minimum Weight-Drag-Stability layout from the virtual mass center is given, which allows us to obtain the Aircraft layout from the conditions of the decrease Full Flight Operation E-Mobility Time and Low Cost for the Short Take Off and Landing (STOL) request with High Angle Flight Trajectory and Compact Infrastructural Constraints in the Terminal Slot Configurations of the Modern City Airports Infrastructure and IATA/ICAO Ecology Zero Toxic & Noise Regulation.

Set-based design for hybrid-electric: a decision-making approach

Timoleon Kipouros

During the development of a hybrid-electric aircraft the design space is considerably large, the constraints due to the interactions between the different sub-systems are very hard to satisfy, the maturity level between the different key technologies varies, and all these aspects are expressed under uncertainties. In FUTPRINT50 we aim to extend the pre-design Multidisciplinary Design Optimisation (MDO) capability to become an efficient, collaborative set-based design process, able to cope with all the aforementioned challenges. We will follow the set-based design paradigm and will enhance it with machine learning algorithms that will enable uncertainty quantification, modelling and propagation by synthesising and connecting datasets across disciplines and technologies. Interactive visualisation of multidimensional data will further expand the capabilities of the method that will be offered in the form of a software platform suitable to expose and analyse multi-technology trade-offs. In this presentation, preliminary results will be presented and discussed. These will include the technical challenges to develop such capability, but also communicating the first findings from the exploration of key technologies that will enable a hybrid-electric aircraft to market by 2040.

Analysis of efficiency of commuter airliners with hybrid electric propulsion

A.N. Varyukhin, V.S. Zakharchenko, P.S. Suntsov, D.Ya. Rakhmankulov, M.A. Ovdienko

The efficiency analysis of commuter airliners up to 19 passengers with different type of hybrid electric propulsion systems is presented. The turboprop aircraft L-410 is chosen as a prototype with a maximum take-off weight of 6600 kg and 19 passengers, and cruise speed 275 km/h. For this aircraft we developed a conceptual design and calculated characteristics of a promising turboprop engine. These data we use for the efficiency assessment of the aircraft with the conventional turboprop propulsion system.Here we consider a parallel and a series hybrid propulsion system, and an all-electric propulsion system. All results we compare with results for the conventional turboprop with advanced engines.The efficiency analysis based on a multidisciplinary approach shows that all-electric aircraft for 19 passengers with the same maximum take-off weight will have flight range only up to 150 km for 2030-time period (conventional turboprop with the same weight has flight distance up to 850 km).The series hybrid propulsion system considered here consists of one turbogenerator that is the main power source for two electric motors rotating propellers. Batteries provide additional power to the electric motors at take-off and climbing. Such a propulsion system provides 20% fuel consumption decrease for 2030-time period with approximately the same flight distance. Also the advantage is the less cost of the hybrid propulsion system with only one turbogenerator in comparison with conventional. The parallel hybrid propulsion system considered here consists of two hybrid turboprop engines with electric machine integrated into the gearbox. Batteries supply electric power to these electric machines at take-off and climbing. This allows to decrease the power and weight of gas-turbine part. But unfortunately such a propulsion system does not provide fuel economy in comparison with conventional turboprop propulsion.

New generation of hybrid aircraft structures (PART I)

Session Chair: Dr. Alexander Shanygin, Central Aerohydrodynamic Institute (TsAGI), Russia

Novel hybrid layouts for composite civil airframes based on UD structure concept

M. Zichenkov, A. Shanygin

In the present work the results of the investigations of hybrid structures of the new generation are presented. It is shown that metal-composite hybrid airframes based on unidirectional (UD) composite layouts integrated with supporting elements (protective skin, titanium details) give a number of potential benefits in weight saving and increasing safety. Principles and methods of development of metal-composite structures of the new generation are presented and substantiated both for conventional and non-conventional aircraft concepts taking into account state-of-art level of manufacturability of design solutions. The hybrid structure is characterized by a considerable transition (attachment) zones, integrating both composite and metallic elements. For substantiation of effective application of such structures the results of weight analysis are presented, including detail analysis of joints and attachments for:

- fuselage section of a long haul aircraft;
- wing longeron of a regional aircraft.

For each of the structures the comparative weight estimations are performed and strength margins for both suggested structure layouts and the conventional analogues are defined.

Study of impact resistance of thin-walled hybrid metal-composite rods

A. Chernov, E. Dubovikov, N. Guseva, I. Mareskin, A. Shanygin

The current research includes the results of numerical investigation of impact resistance of thin-walled composite parts of the hybrid (metal-composite) rod. Several variants of the multilayers protection, which was developed in TsAGI, were studied by FEM analysis. The impact resistance of protected composite part was investigated as function of the mass of the protection. The results of the current research was used for study of the synergy effect of an interaction of the rod and the protection system. This effect is used for designing of the lightweight truss structures of the prospective airframes.

Investigation of prospective structure of high aspect ratio strut-braced wing for regional aircraft

E. Dubovikov, D. Fomin, I. Mareskin, Y. Mirgorodskiy, D. Vedernikov

To provide economic efficiency and competitiveness on world market, civil aircraft must have the best aerodynamic characteristics, minimum weight of structure (for providing strength standards) and low cost. The considered variant of layout for regional aircraft with high aspect ratio strut-braced wing is one of the main trend in aviation that can improve aerodynamic characteristics of the wing and reduce weight of the structure. In this article, investigation of selection of rational layout for prospective structure of high aspect ratio strut-braced wing for regional aircraft is presented. In case of this investigation were performed determination of design loading cases for allowable flight regimes, strength finite-element model (FEM) was created and rational layout was investigated. The design loading cases were defined based on numerical aerodynamic scheme by using method of discrete vortices. Strength FE model is

formed on the basis of the specified geometrical parameters of wing box and strut. Investigation of rational layout with minimal weight was performed with the following constraints:

- Margin of safety Rst≥1,
- Margin of buckling skin R0≥0.4,
- Margin of buckling panels and strut Rpan/strut≥1.

In this work hypothetical regional aircraft with three variants of aspect ratio wing (λ=11.7, 15, 20) is considered.

400 different variants of the wing with different parameters of the strut were considered. The rational variant of layout (parameters of wing box, strut and position of attachment point of strut on wing, geometrical parameters of strut and material of wing box and strut) was obtained.

Investigation of damage evolution on micro level in CFRP laminates using high frequency acoustic microscopy and acoustic emission

E. Morokov , T. Ryzhova, E. Dubovikov, I. Gulevsky, Y. Petronyuk, V. Levin

High sensitivity of composite laminates to impacts and climatic factors, their fragility and difficult character of internal stress-strain state are caused by presence of multiple stress concentrations at microlevel, leading to occurrence and growth of microcracks in resin and subsequent degradation of strength characteristics of composite laminates while in long-term operation under mechanical loading and climatic factors.

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.

In this work step-by-step damage evolution in orthogonal laminate under three-point bending test has been studied by numerical model and high frequency acoustic microscopy and acoustic emission. The results demonstrate emergence and growth of micro-cracks in resin under the different stages of quasi-static loading.

Parametric investigation of strength of domestic aircraft structure using the models based on the doublet lattice method

D. Vedernikov

Regional aircrafts have less shape sizes relatively to long haul aircrafts. However, they have a number of features, which are vital for preliminary design stages. Short time of cruise flight is the main of these features. Due to this reason, geometry parameters of a regional aircraft configuration, which are defined by cruise flight conditions, have no strict “aerodynamic” constraints. Consequently, aircraft designers should solve multidisciplinary problem having a large number of design variables. An implementation of composite materials increases amount of design variables to a greater extent.

This work illustrates methodology of strength analysis of composite structures at preliminary design stages, which are allow to reduce labor-intensiveness of parametric investigations of structures with variation of external geometry.

Multilevel approach to strength analysis of aircraft structures is used in this work. Main feature of this approach is simultaneous solving of strength problem using nested, parametric numerical and analytical models. This approach was developed and validated in TsAGI within the framework devoted to strength analysis of aircraft structures with non-conventional configurations and structure layouts.

One of the nested models, in this methodology is a numerical parametrical model based on the doubled lattice method. This model is used for quick analysis of flight loads, applied to aircraft structure as well as solving aeroelasticity and balance problems.

Within the frame of validation of proposed methodology, parametric investigations of strength of domestic aircraft with MTOW 14500 kg were carried out. For this aircraft, dependencies of weight of the structure were obtained from the following set of parameters:

- Wing aspect ratio
- Wing twist
- Wing Sweep
- Strength and buckling constraints
- Parameters of structure materials

The obtained results can be useful for developers for estimation of the economic efficiency of civil aircrafts.

New generation of hybrid aircraft structures (PART II)

Session Chair: Dr. Alexander Shanygin, Central Aerohydrodynamic Institute (TsAGI), Russia

Development of Numerical Tools for Optimization of Lightweight Details Based on Mechanical Metamaterials

S. Belikov, I. Kondakov

Application of modern Additive Manufacturing methods makes it possible to develop and create the new generation of structure elements, based on mechanical metamaterials – architectured meso-structures (corresponding to the dimensions of 10-3 – 10-4 m)

Structure elements based on mechanical metamaterials can be classified as following:

- Lightweight details
- Harmonizing details
- Controlled-shaping details (smart-structures)

Lightweight details from metamaterials are a type of lighten variants of the corresponding details made of “solid” material. Application of porous metamaterials in low-loaded zones of such details gives an opportunity to save weight, keeping the required strength properties.

Harmonizing details make it possible to realize smooth transition in the zones of attachments of two details, made of materials having drastically different stiffness properties (e.g. metal-plastic/composite). For instance, in a typical metal-composite joint, in the zone of direct contact between metal and resin of composite material, there is a significant different between strength characteristics of metallic and composite parts of the joint, that leads to appearance of local concentrations and thus to failure. Application of an interim element made of metamaterial allows to realize smooth transition of loads and avoid failure of resin.

Metamaterials can be used for creation of so-called Smart-structures. The main principle of operation of such structures is control of their form change under certain external loads.

In the present work the investigation of lightweight type of structure elements is carried out. It is shown that optimization of internal structure of such details is a very labour consuming task, and its solution requires development of specific operative tools. For strength analysis and optimization of details based on mechanical metamaterials, the two-level method was proposed and realized. Within the method, at the first level the strength properties of metamaterial cells and calculated, and at the second level optimization of the details is performed using FE-model, where each cell of metamaterial is modelled by a single FE. On the basis of the developed method, test optimization investigations were carried out for a several typical details, using equivalent strength principle. Convergence of the optimization results was shown, as well as high correlation with the results, obtained by topology optimization methods.

2D-material based devices in aeronautics and aerospace: from modeling to experimental results

Session Chair: Prof. Patrizia Lamberti, University of Salerno, Italy

2D materials in field effect electronic devices and sensors

Antonio Di Bartolomeo

Two-dimensional materials have been widely investigated for new electronic devices and sensors, owing to the tunable bandgap and mobility, the strong interaction with light, the easy formation of van der Waals heterojunctions, the mechanical strength, and the chemical stability. We fabricate back-gate field-effect transistors with nanosheets of MoS2, WSe2, PdSe2, PtSe2, or GeAs to investigate the effects of light, electron irradiation, gas pressure, and temperature. We show that light and electron irradiation cause photoconductive and photogating effects. We exploit electron irradiation to reduce the Schottky barrier at the contacts and improve the 2D-material/metal interface. We correlate the gas adsorption energy to the hysteresis observed in the transistor transfer characteristics and use gas pressure to control the polarity of the devices, highlighting how these features can enable selective gas sensors. The dominant n-type behavior in a high vacuum and the sharp-edge geometry enable field emission current, which we extensively characterize under different conditions. We use 2D materials to propose a new field emission transistor. We investigate the temperature dependence of the electrical conductivity and we report a temperature-dependent conductivity anisotropy as well as an anomalous peak in the 2D carrier, that we interpret as the manifestation of a 2D conduction phenomenon in multilayer nanosheets.

Highly stretchable PDMS matrices for graphene-CNT piezoresistive sensors

Filomena Piscitelli, Maia Laura Lo Gatto, Gennaro Rollo, Giovanni Filippone, Marino Lavorgna

Future aircraft will possess adaptive capabilities, from supervised morphing to active deployable subcomponents, and self-sensing properties for auto-inspection. All these functionalities are promising but challenging and a crucial role is played by the development of smart materials for integrated sensing networks. The use of innovative sensors is essential for morphing and deployable applications where non-conventional properties are requested, i.e., very large deformations (>10%) and durability into harsh environmental conditions (temperature range -50 ± 80 °C, RH up to 100%, severe pressure excursions).

Conventional strain sensors, such as foil strain gauge, Fiber Bragg Grating and semiconductor strain sensor, show some limitations, for instance in terms of weak deformation ability and small measurement range (<2%) that hinder the utilization in high stretching conditions . Moreover, the strain sensor should also be able to conformably attach onto irregular non-planar surfaces and should also deform with the flexible structures without deteriorating its sensing function. Apparently, the conventional strain sensors often are not practical in such conditions . Hence, for all these reasons, the future strain sensors, among the other things, shall be highly stretchable, resistant to harsh environmental conditions, and highly sensitive. In this contest, the effort of the present work was to design and synthetize a highly stretchable polymeric matrix, Polydimethylsiloxane (PDMS) based, prepared with simplified and not expensive methods, large scale applicable, lowly viscous which guarantees a homogeneous dispersion of the conductive fillers, affine to carbon based conductive fillers, namely graphene and carbon nanotubes (CNT), and finally, solvent free. Therefore, in order to reduce costs, make the product large scale applicable, and have a low viscosity, semi-industrial polymeric precursors at low molecular weight and

solvent free, were employed to prepare the PDMS matrix. The polymeric precursors consist in PDMS with olefinic terminal groups and silanols. The hydrosilylation reaction, which takes place, was catalyzed by the Pt-1,3-Divinyltetramethyldisiloxane catalyst. Additionally, with the aim to assure a good affinity of the conductive fillers, part of the PDMS oligomers was substituted with Diphenylsiloxane-Dimethylsiloxane copolymers having phenyl lateral groups. Finally, the polymeric matrix and the corresponding nanocomposites were prepared by using magnetic stirring and casting.

It was found that the ultimate deformation of the polymeric matrices was high (deformation ~70-80%) only slightly reduced after the addition of the fillers, e.g., from 80 to 65%. The addition of two different conductive fillers acts in a synergistic way, therefore it was found that the percolation threshold of the combined fillers is largely lower than the percolation threshold observed with each of the selected fillers. The SEM images of nanocomposites show a good dispersion and a strong adhesion between the matrix and the conductive fillers. Finally, the electrical measurements highlighted that the hybrid nanocomposites with graphene and CNT show piezoresistive behavior, for which the resistance follows the applied deformations changes. However, a little drift in the resistance signal was detectable.

Effect of non-covalent functionalization of graphene-based nanoparticles on the local electrical properties of epoxy nanocomposites

Marialuigia Raimondo, Maria Rossella Nobile, Carlo Naddeo, Liberata Guadagno

In this study, we propose a non-covalent π-π interaction between graphene nanoparticles (G) and a pyrene-based molecule (py). The proposed modification has proven to be a winning solution aimed at safeguarding the graphene's notable electronic properties, while promoting a more effective nanofiller dispersion attributable to a decrease in viscosity with consequent improvement of the rheological properties of the formulated nanocomposites. Tunneling Atomic Force Microscopy (TUNA) analysis was carried out using G-py weight percentages both below and above the Electrical Percolation Threshold (EPT) to investigate the electrical behavior of the conductive nanodomains of the epoxy/graphene systems. In particular, for the lowest concentration equal to 0.1wt% of G-py, in most of the sample domains, no electrically conductive paths are observed, while for the highest concentration equal to 1wt% of G -py, the presence of a conductive network at the nanoscale level with efficient adhesion to the interface indicates that the sample is above the EPT. The possibility to detect low currents also for the sample at lower concentration (0.1wt%) confirms the good electrical performance of the nanocomposites and, consequently, the successful performed functionalization. The electrical results are in perfect agreement with the rheological ones. In fact, the inclusion of a functionalized G-py amount of 0.5wt% caused the decrease in the complex viscosity of the unfilled epoxy resin, while instead, the same quantity of unfunctionalized G resulted in an increase of its viscosity. This aspect is of crucial importance from the industrial point of view since the use of non-covalently functionalized G-py allows to considerably simplifying the steps of the preparation process of the nanocharged epoxy samples, thus potentially favoring also the impregnation of the plies of carbon fiber fabrics. The non-covalent modification significantly improves the thermal stability of the graphene-based nanoparticles, also determining an increase in the oxidative thermostability of the formulated nanocomposites.

Studies on novel way for realizing an epoxy coating for Aerospace applications

Federico Micciulla, A. Cataldo, C. Cencetti, A. Sorrentino, R. Cossi, S. Bellucci

Composites, and in particular nanocomposites, are widely used in several fields for different applications, due to their interesting and unique engineered properties: lightness, shape mouldability, thermal and electric conductivity, isolator, fire retardant, electromagnetic shielding, high mechanical properties. In the aerospace field these materials are more and more used (popular) due to the incredible properties they showed about an important reduction of the structural weight of the aircraft and increasing the the payload weight. A large variety of nanomaterials are used as filler into several different matrixes with the purpose of combining their excellent properties with the properties of polymeric matrixes[22] [23] [24] [25]. Nanocomposites have high performances and low cost per kilo/load. In this study we analysed the behaviour of epoxy matrix (Epikote 828) filled with carbon nanostructures. The idea is to create a specific coating for different purposes, such as electromagnetic shielding, high moisture resistant, fire retardant, high mechanical performance. In the past we already studied electrical and thermal properties[26] and electromagnetic shielding capability of this coating. Further, we correlated the electromagnetic properties to ageing effects[27]. All these studies suggested us to focus our attention on lateral size and thickness of GNPs. The GNPs used in our studies are synthesized by means of exfoliation process into Next Group's Laboratory at Frascati National Laboratories INFN. Following a low cost and green process which uses commercial intercalated graphite and very short time to expand the graphite, with an excellent yield. Starting from the Adam G, Kelly et al paper we decided to use different common alcoholic drinks, as whisky, grappa, rum, and bi-distilled water as medium for liquid phase of exfoliation of the GNPs. These ones can help the exfoliation and the homogeneity dispersion. For these studies we used a special machine, PR-1 Nano - Premixer from THINKY Corporation, designed to achieve high effective and reproducible highly reproduce dispersion of nano-materials such as CNTs, while operating in safety by

---

[22] Hongbo Gu, Chao Ma, Junwei Gu, Jiang Guo, Xingru Yan, Jiangnan Huang, Qiuyu Zhang, and Zhanhu Guo3, â€œAn Overview of Multifunctional Epoxy Nanocompositesâ€•, Journal of Materials Chemistry C, Iusse 25, Volume 4, pp 5890-5906, 2016

[23] Maureen A. Boyle, Cary J. Martin, and John D. Neuner, Hexcel Corporation, â€œEpoxy Resinâ€•, ASM Handbook Volume 21, Composites (ASM International), pp 78 - 89 (12), 2001.

[24] C. R. Cabrera, F. A. Miranda, Advanced nanomaterials for aerospace applications, Pan Stendford Publishing, 2015.

[25] L. Guadagno, M. Raimondo, V. Vittoria, L. Vertuccio, C. Naddeo, S. Russo, B. De Vivo, P. Lamberti, G. Spinelli, V. Tucci, â€œ Development of epoxy mixtures for application in aeronautics and aerospaceâ€• RSC Advances 4 (30), 15474-15488, 2014.

[26] S Bellucci, C Balasubramanian, F Micciulla, G Rinaldi, â€œCNT composite for aerospace applicationsâ€• Journal of Experimental Naoscience, 2 (3), 193-206, 2006.

M Potenza, A Cataldo, G Bovesecchi, S Corasaniti, P Coppa, S Bellucci, â€œGraphene nanoplatelets: Thermal diffusivity and thermal conductivity by the flash method AIP Advances 7 (7), 075214, July2017.

E Ivanov, H Velichkova, R Kotsilkova, S Bistarelli, A Cataldo, F Micciulla, S Bellucci, â€œRheological behavior of graphene/epoxy nanodispersions, Applied Rheology, Volume 27, Issue 2 pp 12, 2017.

[27] NI Volynets, DS Bychenok, AG Lyubimov, PP Kuzhir, SA Maksimenko, SA Baturkin, A Ya Klochkov, M Mastrucci, F Micciulla, S Bellucci, â€œShielding properties of composite materials based on epoxy resin with graphene nanoplates in the microwave frequency rangeâ€• Technical Physics Letters 42 (12), 1141-1144, 2017.

Fatemeh Ravari, Abdollah Omrani, Abbas Ali Rostami, Morteza Ehsani, â€œAgeing effects on electrical, morphological and mechanical properties of a low viscosity epoxy nanocompositeâ€•, Polymer Degradation and Stability, Volume 97, Issue 6, , Pages 929-935, June 2012.

F Micciulla, P Ulpiani, A Cataldo, S Bistarelli, S Bellucci, â€œAgeing effects on composite nano carbon based materialsâ€• International Semiconductor Conference (CAS), 37-42, 2017.

keeping the sample into an enclosed container. The dual-sonic technology (patented) irradiates the high-speed rotating container from the bottom and the side of the ultrasonic bath. Rotating the container at an angle of 45Â° causes convection in the materials so the entire sample is treated. The analysis showed a reduction of GNPs dimensions (lateral size and thickness) and a different homogeneity of suspension with alcoholic solution and GNPs. We have found a scale of efficiency: not all the alcoholic solutions have given a good performance in the GNPs dispersion, as shown in figure 1. b) GNPs dispersion into different Alcoholic solutionsThe suspensions were tested by the analytical centrifuge LUMiSizer LS651 which measures instantaneously the extinction of transmitted light across the full length of the samples using the STEP-Technology (Space and Time Extintion Profiles). The enhanced optical system of the LUMiSizer enables to detect particles and droplets velocity distributions for creaming and sedimentation phenomena and performs particle sizing (ISO 13318-2). The measurements showed a reduction of lateral size of GNPs, as reported in the following table

Sample Name 10%≤ in nm 16%≤ in nm 50%≤ in nm 84%≤ in nm 90%≤ in nm

- GNPs Ethanol 1870 2493 3668 5789 8387
- GNPs MoroloGrappa 222.9 370.1 734.4 1458 1710
- GNPs Lagavulin Whisky 43.1 46.66 81.25 472.1 701.2
- GNPs – Bacardi Rum 42.14 44,47 73.46 199.0 297.6[28]

Tolerance analysis of a GFET transistor for aerospace and aeronautical application

Vincenzo Tucci, Patrizia Lamberti, Monica La Mura, Francisco Pasadas

Graphene is the two-dimensional (2D) allotropic form of carbon that can be obtained by exfoliation from graphite or by chemical vapor deposition (CVD) from gases. It is an atomically thin crystalline film formed by sp2-hybridized carbon atoms arranged in a honeycomb structure [1]. Due to its unique electronic structure favoring high carrier mobility, graphene is considered a promising material for use in high-speed electronic devices in the post-silicon electronic era [2]. Thanks to its atomic thickness and capability to sustain high density current, graphene can push the miniaturization of electronic systems towards achievements impossible for standard semiconductor technology. These characteristics allow the of high-performance instruments with low power consumption, small volume, and reduced weight with respect to traditional semiconductor devices. Furthermore, graphene high resistance to radiation and extreme temperatures makes the development of graphene-based electronics a key-enabling technology for aerospace, defense and aeronautical applications. Nevertheless, achieving uniform device-to-device performance is still a challenge, and these fields require high reliability components. Therefore, despite experimental research into graphene-based electronic devices has rapidly increased, in order to think about their use in such scenarios many critical issues remain to be solved such as their reproducibility with guaranty and identical performances against possible variations of different nature.In the present work, a model capable to take in to account physical characteristic linked to the production process of a Graphene Field-Effect Transistor (GFET), basic component of all analog and digital electronic systems, is exploited to perform a tolerance analysis of the characteristic parameters (max oscillation frequency, voltage gain, trasconductance, output resistance and Ion/Ioff ratio) of a GFET common-source amplifier.

[28] Adam G Kelly, Victor Vega-Mayoral, John B Boland and Jonathan N Coleman, â€œ Whiskey-phase exfoliation: exfoliation and printing of nanosheets using Irish whiskeyâ€• 2D Materials 6(4) 2019.

Experimental results of cosmic radiation tolerant bolometers based on 2D metastructures

Patrizia Lamberti, Polina P. Kuzhir, Yuri Svirko

The development of tunable THz sensors capable to operate in space will be reported. The sensors are based on the perfect absorber of the THz radiation that employs graphene and other 2D materials. In particular, the case of five layers of Graphene/PMMA heterostructures fabricated by chemical vapor deposition (CVD) and put onto the SiO2 substrate will be considered as possible bolometer useful to detect cosmic rays (Fig. 1a). In order to evaluate the reliability of the bolometer, the effect of the ion bombardment on the PMMA/graphene sandwich electromagnetic response in THz range is investigated by employing TEMP-4 pulse ions accelerator capable to produce ion beams of carbon and hydrogen (70% and 30%, respectively) guided by a family of magnetically isolated diodes (Fig. 1b). The case of 2 and 4 pulses will be considered and compared with the pristine device by means of SEM image analysis (Fig. 1c-1e). The experimental results performed on THz measurements as well as Raman characterization support the outstanding radiative resistance of CVD graphene at irradiation by 80 ns 290 keV providing 1.5 * 1012 atoms per cm2. THz wave transmission before and after irradiation demonstrate the degradation of first and second layers of graphene in sandwich structure. This is result of high energy extraction in short period in first and second layers of PMMA, that cause heating of layers and following macroscopic consequences (melting, bubbles). Nevertheless, cosmic irradiation on geostationary orbit (GEO) canâ€™t cause such temperature effects because GEO proton flux is in many orders less. Electron flux on GEO is not dangerous for structure due to small energy extraction. All negative influence of proton irradiation on structure can be totally neglected by using additional plate with thickness ~ 10 Âµm which protect structure from protons.

From Sensors to FMS

Session Chair: Dr. Cezary Szczepanski Warsaw Institute of Aviation, Poland

Review and selection of commercially available IMU for short period of time inertial navigation

Krystian Borodacz, Szczepański Cezary

The overall attainable performance of various types of inertial sensors is known and available in the literature. Despite the fact that inertial technology has been developing rapidly in recent years, not all of them are available out of the shelf. Whatâ€™s more, selection of the suitable sensor is not a trivial task. Some guidelines can be found in manufacturer's technical notes and white papers, however, focusing on its own inventory.The presentation will cover review of inertial sensors currently available on the market as well as guidelines for the selection of devices, based on the achievable position/attitude estimation accuracy. Emphasis will be placed on the use of inertial navigation systems in a short period of time, such as in the case of tactical missile or navigation during GPS outage, which is feasible with most of available sensors.

Simulation and Testing of Flight Stabilisation System Using Trimmers in the Longitudinal Channel

Cezary Szczepanski, Mariusz Krawczyk, Albert Zajdel

The new flight stabilisation system, using the trimmers, dedicated to the light aeroplanes has been designed and developed. Application of only the trimmers for the flight control allowed to achieve the satisfactory aeroplane's flight stabilisation result. Such a system has been built and tested in the Hardware-In-the Loop (HIL) stand. The detailed model of the turboprop trainer PZL-130 "Orlik" dynamics of flight has been applied in those tests.

The stabilisation system regulator has been designed with the use of Simulink package, applying the Model-Based Design attitude. The software code generated in such a way has been implemented into the hardware demonstrator platform (servomechanisms) and tested with the use of the HIL stand. Thanks to that, we could initiate the tests of the designed flight stabilisation system in the longitudinal channel in the very beginning phase of the development process. Also, we could eliminate the expensive and time-consuming development of the specialised testers dedicated to that system.

The results of the tests in automatic mode and with the participation of the test pilot have been presented and discussed. They allow confirming the feasibility of active stabilisation of the aeroplane's flight in a longitudinal channel using only the trimmers. The proposed system also fulfils some of the requirements for the autopilots for GA aeroplanes.

Simulation and Testing of Flight Stabilisation System Using Trimmers in the Lateral Channel

Cezary Szczepanski, Mariusz Krawczyk, Albert Zajdel

The new flight stabilisation system dedicated to the light aeroplanes has been designed and developed. Stabilisation result has been achieved only by the application of the trimmers. Such a system has been built and tested in the Hardware-In-the Loop (HIL) stand. The detailed model of the turboprop trainer PZL-130 "Orlik" has been applied.

The stabilisation system regulator has been designed with the use of Simulink package, applying the Model-Based Design attitude. The software code generated in such a way, has been implemented into

the hardware demonstrator platform (servomechanisms) and tested with the use of the HIL stand. Thanks to that, we could initiate the tests of the designed flight stabilisation system in the lateral channel in the very beginning phase of the development process. Also, we could eliminate the expensive and time-consuming development of the specialised testers dedicated to that system. The results of the tests in automatic mode and with the participation of the test pilot have been presented and discussed. They allow confirming the feasibility of an effective stabilisation of the aeroplane's flight in the lateral channel with using only the trimmers. The proposed system also fulfils some of the requirements for the autopilots.

Sensors for UAVs dedicated to agriculture

Cezary Szczepanski, Purushotaram Raja

The Unmanned Aerospace Vehicles (UAV) entered their development stage when different applications became real. One of those application areas is agriculture. The agriculture and construction currently follow energy as the top industries in the world UAV market. Within the next four years, India is to become the third world UAV biggest marketThe UAVsâ€™ elements and modules are comparatively easy to acquire, so many of the potential users plan to build such vehicle themselves. That paper aims to help them to choose the right sensors for agricultural purposes. For that sake, the overview of the types and application areas of on-board sensors will be presented and discussed. Some conclusions and suggestions should allow readers to choose the right sensors for their individual purposes and budgetary limitations.

A concept of an automatic flight control system capable of aerobatic flight

Tomasz Rogalski, Paweł Rzucidło, Jacek Prusi

The paper reviews and in some way concludes authorâ€™s previous works touching problems of automatic flight control during aerobatic maneuvers. The nature of the maneuvers and the range of changes in flight parameters during their execution limit the possibility of using classic autopilot systems, as well as the possibility of obtaining accurate information about the exact both 3-D position and spatial orientation of the aircraft. The article presents an alternative approach to the design of automatic aircraft control systems that can be applied in the discussed cases, to guide the aircraft along an aerobatic flight trajectory. Selected aerobatic maneuvers are discussed from the perspective of the flight mechanics and pilot in correlation with the structure of control algorithms and the method of verifying their operation in simulation tests.

Non-Destructive Testing and Structural Health Monitoring of Aircraft structures (PART I)

Session Chair: Prof. Elena Jasiuniene, Kaunas University of Technology, Lithuania & Prof. Dr. Marco Ricci, University of Calabria, Italy

Sensing devices with a sigmoidal sensing characteristic to simplify data interpretation and enhance robustness in Structural Health Monitoring

Helge Pfeiffer, Sevilia Sunetchiieva, Michael Stamm, 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 sensors showing an sigmoidal response curve depending only on one outer parameter that is related to a certain damage threshold. They usually rely on phase transitions, crack phenomena or related physical principles. 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, moisture ingress in composite materials as well as detection of ice in the tanks of airplanes.

Non-destructive Evaluations of Composite Adhesive Bonding with Data Fusion

Bengisu Yilmaz, Elena Jasiuniene, Abdoulaye Ba, Huu Kien Bui, Gerard Berthiau

This work aims to declare the importance of post-processing and data fusion in the case of non-destructive composite-adhesive bonding evaluations. In the previous study, adhesively bonded composite-epoxy single lap joints have been investigated with immersion ultrasonic NDT and induction thermography [1]. Bonded structures with artificial debonding defects have been investigated. Two different inclusion types have been selected: brass as electrically conductive and polyolefin copolymer release film as non-conductive materials for artificial debonding. Experimental data has been pre-processed for data fusion application by several steps: noise reduction, coordinate matching, registration, interpolation, and normalization (Figure 1). Then, the feature matrices for ultrasonic and thermography inspection have been obtained. These matrices have been used as source in basic and statistical data fusion algorithms. The defect detection performances of advanced non-destructive testing techniques as well as data fusion algorithms have been evaluated quantitatively. In conclusion, it is shown that data fusion can increase the detectability of artificial debonding in the case of electrically conductive inclusion, whereas ultrasonic NDT outperforms the induction thermography and fusion results for non-conductive defect detection. This

research is funded by NDTonAIR project from the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant No. 722134 [29].

Integration and evaluation of a meander-shaped fiber-optical sensor in GFRP coupons

Andreas Preisler, Friedrich Wolf-Monheim, Athanasios Dafnis, Kai-Uwe Schröder, Wolfgang David, Paul Zandbergen

Due to their good strength-to-weight and stiffness-to-weight ratio, structures made of carbon-fiber and glass-fiber-reinforced plastics (GFRP) are attracting more and more attention also in non-aviation sectors. The possible formation of internal damage and its difficult detection thus simultaneously increases the need for structural health monitoring (SHM). In this case especially fiber-optic sensors possess an enormous potential. Due to their fiber-shape and the possibility of a quasi-continuous measurement along the fiber, they enable a wide range of measurement and placement possibilities.

In the previous work, the so-called zero-strain direction was derived for a particularly efficient damage detection. For a well-defined load case, the longitudinal strain (due to external loading) and the transverse strain (due to lateral contraction) cancel each other out in this direction. A significant amount of measured strain is thus directly related to the presence of damage. In order to enable comprehensive monitoring, the previous work proposed the use of a meander-shaped sensor layout (see attached Fig. 1): measuring points in longitudinal direction provide loads monitoring while distinct measuring sections in zero-strain direction are used for SHM.

In the present work, the proposed meander-shaped sensor layout is integrated inside unidirectional GFRP coupons. Further samples without a sensor and samples with a straight sensor-fiber were also manufactured as a reference. The influence of the sensor on the static strength and stiffness is then examined in a test campaign using a three-point bending setup. In addition, the functionality of the meander-shaped sensor layout is validated.

Air-coupled ultrasonic measurement of inplane elastic properties of a non-uniform MICA paper

Justina Sestoke, R. J. Kazys, R. Sliteris

MICA is a naturally occurring mineral, based on a group of silicate minerals composed of varying amounts of aluminium, potassium, magnesium, iron and water having thin sheet-like or plate-like structure with different composition and physical properties. MICA's unique properties as a thin, durable insulation material with excellent electrical resistance make it ideally suited for a variety of aerospace applications. MICA composites contribute to interior aircraft equipment such as parts of the galley, cabin, black boxes or data recorders in planes. The black boxes or data recorders, aircraft flight recorders are the crucial recording devices. MICA's flexibility as an insulating material will help ensure that the black box is fully compliant with manufacturing standards.

The tensile strength of the MICA is very low, therefore it is reinforced according to the product with some backing like glass cloth or polyethylene film. According to a manufacturer most important parameters of the MICA paper are density, tensile strength, porosity, humidity and uniformity of elastic properties. On-

[29] Yilmaz, B.; Ba, A.; Jasiuniene, E.; Bui, H.K.; Berthiau, G. Comparison of different non-destructive testing techniques for bonding quality evaluation. 2019 IEEE 5th Int. Work. Metrol. Aerosp. 2019, 92–97, doi:10.1109 / MetroAeroSpace.2019.8869692.

line measurement of those parameters, especially of elastic properties and thickness during a manufacturing process are not solved up to now.

The objective of this work was development of an ultrasonic contactless measurement method suitable for on-line measurement of spatially non-uniform elastic properties of MICA paper.

For solution of this problem we proposed to exploit a subsonic A0 mode ultrasonic guided wave and to measure its velocity. The elastic properties were found from the measured ultrasound velocity. Ultrasonic guided waves in the MICA sample were excited by a contact and air-coupled PMN32%PT strip-like piezoelectric transducers operating in the frequency range 43 - 48 kHz. The normal displacements of the A0 mode guided wave were picked up by the POLYTEC laser interferometer. Propagation of guided waves in the MICA sample was simulated by a finite element modelling. In order to separate the sub-sonic A0 mode from the direct ultrasonic wave propagating in air we proposed to use the 2D spatial-temporal filtering of the recorded B-scans. This method is based on exploitation of different propagation velocities of those waves. From the 2D filtering follows that in the MICA sample propagate two A0 modes with different phase velocities - c1=98 m/s and c2=117 m/s at 47 kHz, which correspond to two regions with clearly different elastic properties. The experimental and simulation results revealed that the proposed method is suitable for measurement of spatially non-uniform elastic properties of the MICA paper.

Development of Air-Coupled ultrasound Guided wave numerical model in COMSOL Multiphysics

Aadhik Asokkumar

Numerical simulation in research is mainly used in order to gain insight into the functioning of a system and to understand the system at a fundamental level. Finite Element method (FEM) being one of the methods in the realm of numerical simulation is used for this research where a geometry of the problem is broken into small finite number of nodes and the physical phenomenon to be studied is solved in form of partial differential equations. In case of guided wave inspections, such FEM enables one to understand the mode conversion, the interaction of the guided waves with the geometry and with the modelled artificial defects without the influence of external factors during an experimental investigation such as effect due to temperature, noise during data acquisition, etc,. This research presents the development of an air-coupled guided wave Finite Element (FE) model created by using the acoustic-solid interaction module in a commercial FE-solver COMSOL Multiphysics where the pressure acoustics equations and solid mechanics equations are coupled to generate the air coupled guided wave. The specimens used for the numerical model is 3.2 mm thick Quasi-Isotropic Glass Fibre Reinforced Plastic (GFRP) plate and two Aluminium 2024 plates 1.6mm each are adhesively bonded with epoxy resin of 0.24mm thick. This numerical FE model of Air-coupled investigation is performed based on the parameters obtained from theoretical dispersion curves. The specimens were investigated with 300kHz single element flat Air-Coupled transducer model. The results from numerical simulation are verified experimentally.

Delamination detection in composites using non-linear vibro-acoustic modulation

Tommaso Seresini, Christ Glorieux, Helge Pfeiffer, Martine Wevers

Composites cover a significant role in modern aircrafts manufacturing, for both structural and aerodynamic component they are becoming more and more often the materials of choice. Novel non-destructive techniques capable of an early and reliable detection of the defects and damages which might arise in composite components are needed to increase the efficiency of the maintenance process. In this contribution, the non-linear elastic response of the defects is exploited as defect signature. The approach

followed is to excite a multifrequency ultrasonic excitation and to measure the vibration spectrum over the sample, using scanning laser vibrometry. Non-linear features, mostly sidelobes, are the indication of the defective region. The accuracy of this technique is compared with state-of-the-art techniques and future development to full-field methods are described.

Non-Destructive Testing and Structural Health Monitoring of Aircraft structures (PART II)

Session Chair: Prof. Elena Jasiuniene, Kaunas University of Technology, Lithuania & Prof. Dr. Marco Ricci, University of Calabria, Italy

Investigation on Low Velocity Impact Damage identification with Ultrasonic techniques under different sensor network conditions

A. Beligni, F. Cadini, C. Sbarufatti, M. Giglio, N. Cimminiello, P. Salvato, E. Monaco, F. Romano

This work resumes the results achieved accomplishing the Work Package 2.1.1.10-02 in the European project AirGreen 2 within the Clean Sky 2 programme, dedicated to the evaluation of the Structural Health Monitoring (SHM) diagnosis robustness when single/multi sensor failures occur. Direct or indirect damages due to foreign object impacts on aeronautical structures, represent a major concern. The problem potentially intensifies with the adoption of composite materials, especially due to Barely Visible Impact Damage (BVID). This damage is the upper limit of Category 1 of damage (EASA AMC 20-29), that includes permissible defects caused in manufacturing or low energy impact damage (induced by tool drops, runway or ground debris, hailstones) that are not detectable by the standardised and current visual inspection technique and that have substantiation data showing ultimate load is retained for an aircraft structure's life span.In this context, understanding whether an impact event gives rise to delamination or debonding is highly desirable in view of the optimization of the maintenance strategies and, at the same time, of the safety margins associated to the operation of the structures. One possible method to achieve this goal is that of integrating damage monitoring systems within the vehicle architecture itself. By doing so, in fact, the enhanced structural health state awareness allows the implementation of Predictive Maintenance philosophies and the possibility to detect damage with size/severity and indentation smaller than the BVID currently applied by design and certification,In this work, a simple and a stiffened carbon fiber panel are subjected to Low Velocity Impacts using falling masses to generate a structural damage. A sensor network made of Piezoelectric elements (PZT) allows the application of Ultrasonic techniques, to monitor the damaged structure and calculate signal related features called Damage Indexes (DIs). The DI capability to first detect the damage and then also localize it and quantify its extent is then thoroughly investigated, with specific reference to: (i) effect of signal averaging through acquisition repetitions, (ii) effect of reduced sensor network configurations and (iii) effect of sensor faults. The combination of each performance allows to select the most promising DIs for real applications.The project leading to these results has received funding from the Clean Sky 2 Joint Undertaking under the European Unionâ€™s Horizon 2020 research and innovation programme under Grant Agreement nÂ° 945548 - GAM-2020-REG-H2020-IBA-CS2-GAMS-2019.

Development of Eddy Current based inspection system for detection of defects in Carbon fibre

Ian Nicholson, Vicki James, P. Ian Nicholson, Chris Silva, Chris Smith, John Hans, Nelly Fernandez, Abbas Egbeyemi, James Sexton, Mo Missous, Joseph Dobson

The use of composite materials in aerospace manufacture is accelerating fast, with the most modern aircraft in the world's fleet now made of more than 50% composite materials. Carbon fibre is in many ways the ideal material for aerospace construction, being less dense, and with a greater stiffness-to-weight ratio, compared to traditionally used material such as aluminium. However, Carbon fibre can suffer from hidden cracks that stem from manufacturing defects or heavy stress.

Eddy Current (EC) is a widely used non-contact inspection method for Non-destructive Testing (NDT) in aluminium aerospace structures and is popular as a fast and reliable method of detecting surface flaws. However, the signal can be hard to interpret in components of complex geometry, and it only works effectively on conductive materials. Carbon fibre is 1000x less conductive than aluminium, so EC NDT for composites is challenging due to the poor sensitivity and limited signal bandwidth of traditional eddy current sensors.

This paper presents the latest work-in-progress by the CFLUX consortium for the design and development for a new Carbon fibre inspection system. The goal is to use a new magnetic Hall sensor with a 5µm2 sensing element based on a proprietary GaAs epitaxial structure and that offers greater sensitivity compared to traditional sensors used in EC techniques. Initial results are presented using both conventional EC sensors and a newly developed probe head that combines a solid-state sensing element with an excitation coil. A system demonstrator is being developed where the probe head will be scanned over the component geometry by a six-axis robotic arm with the view to facilitate repeatable measurements for complex geometries.

Optimising Design for Inspection

Session Chair: Prof. E. Jasiuniene, Kaunas University of Technology, Lithuania & Prof. R. Pullin Cardiff University, UK

Acoustic based Structural Health Monitoring of Aircraft Structural Testing

S. Grigg, M. Pearson, C.A. Featherston & R. Pullin

Structural fatigue testing of aircrafts is of paramount importance for the aviation industry in order to understand how damage will grow through the life of an aircraft. This testing is performed on both small components and full scale structures. Larger tests are performed over long periods of time, where after a given number of cycles the structure is deconstructed and assessed for damage through Non-Destructive Testing (NDT) methods, such as phased array scanning. Where damage is detected, the part is repaired or replaced, and testing is allowed to continue. The identification of these failures allows engineers to specify maintenance procedures for in-service aircrafts. This process of full inspection is slow, costly and only identifies problems at inspection intervals, rather than when damage occurs.

Structural Health Monitoring (SHM) aims to detect damage as it develops within a structures. In large scale testing strain gauges are used to detect unexpected changes in strain, often the product of damage. These provide significant information to engineers, however are limited in their ability to identify damage and costly to install. Alternative SHM approaches have been shown to effectively locate the presence and growth of damage, this information would enable engineers to better understand when and how damage is occurring. Additionally, it may be possible to reduce the need for full inspections of the structure, by performing smaller inspections & repairs when required.

As part of an industrially funded project three acoustic based techniques are being investigated, Acoustic Emission (AE) monitoring, Acousto-Ultrasonics (AU) and Audible Acoustics (AA). The aim of this work is to investigate their applicability for real large scale aircraft structures. The results of preliminary testing will be presented, where the techniques were able to identify the presence of damage on a range of tests. The design of a large-scale demonstrator is also presented, which will be manufactured and tested with the aforementioned techniques.

Failure analysis of ATR 72 tow bar – opportunity for re-design for inspection

Ivana Atanasovska, Dejan Momcilovic

The safe towing of aircraft is an important part in aviation security. Failures during the towing and parking related operations are not so rare due to bad working circumstance, human error, etc. Tow bars are simple but very important elements, for towing aircrafts on airports all over the world. This paper describes failure analysis of accident during towing of regional ATR 72 aircraft. During towing of ATR 72 aircraft sudden fracture of shear pins caused that tow tractor goes into one and airplane ATR 72 into other direction. As a result, the airplane crashed on the empty tanker truck and severely deformed nose in this ground damage incident. Design of failed tow bar key elements and of susceptibility to corrosion was discussed in this paper.

Failure analysis unveil the several key elements that lead to fracture of shear pins: outdated design of tow bar, improper maintenance and non-regular towing of aircraft. Combination of reduction of load capacity of shear pins induced by corrosion and impulse overloading caused premature fracture of the shear pins

and damage of ATR 72 aircraft. As a result of presented analysis the remedy was initiative for detail inspection of existing tow bars and redesign or purchasing the new ones. The results are presented.

A case study on ultrasonic guided wave inspection of aerospace components – is 'in-situ' feasible?

Damira Smagulova, Vykintas Samaitis, Mastan Raja Papanaboina, Elena Jasiuniene

Guided wave structural health monitoring (SHM) of aerospace components is often hindered by dispersion, anisotropy and presence of multiple modes. Numerous methods are being developed to solve the issues caused by complex structures, non-uniform spatial properties of the materials and intricate guided wave signal analysis. Usually, the inspection approaches are being developed in the isolated laboratory environments focusing on one or two aspects of entire system with no clear guidelines for benchmarking of proposed technologies. The underlying assumption, that proposed methods should behave similarly in situ is not necessarily verified.

In this contribution, we discuss results obtained through a few years of research in guided wave structural health monitoring. Following a series of inspections, we present different methods to analyse and estimate footprints of the defects in complex guided wave signals; and parametric studies to evaluate sensitivity of influential parameters for defect detection and positioning in SHM systems. Discussing the results and variety of practical issues encountered, we debate the feasibility of moving from isolated environments to inspection of aerospace components in-situ.

Air Traffic Management (ATM) & Airports

Session Chair: Prof. Octavian Thor Pleter, University Politehnica of Bucharest, Romania

Enhanced cockpit avionics systems for greener aviation

Patrick Delpy, Thierry Maret

Worldwide air traffic (notwithstanding current COVID crisis) is constantly growing, leading to bottlenecks in airspace management and capacity, short term pre-tactical measures for avoiding saturations of some sectors, and more and more tactical interventions from ground controllers for traffic management sake.On the airborne side flight planning and crew mission execution is mainly supported by a few avionics products, namely Flight Management System (FMS), and connected communication means and displays.Environmental sustainability and socio-economic impact mastering call for planning and mission execution enhanced means to provide anticipation and control solutions.To cope with these challenges, in the frame of CleanSky 2, and SESAR2020, european research programmes, Thales has prototyped and matured a number of solutions (ECO functions, What-If analysis capabilities, Permanent Resume Trajectory) gathered in an extended FMS concept covering both standard avionics FMS and Open World pilot aids for enlarged assistance. Main identified driving capabilities improving environmental impact, safety and reduce crew workload during the flights stem from airline customer feedback. They are:

- Continuity of operations, from ground preparation to flight execution in the cockpit, from managed mode to vectored situation during flight
- Flight optimization assistance, for normal and abnormal situations, taking into account an enlarged set of environmental data (weather for instance)

A brief description of these solutions balancing the three pillars of safety, operability and greener impacts will be given. Their qualitative impacts with regard to environment, mobility and competitiveness, and overall safety will be stressed. Overall quantitative budget analysis with respect to CO2 induced reduction and operating costs lessening will be detailed in terms of hypotheses and results at airline and global traffic level. Remaining barriers to reach Perfect Zero CO2 Waste aircraft trajectories will be evoked.

Applying Machine Learning Modeling to Enhance Runway Throughput at A Big European Airport

Guillaume Stempfel, Victor Brossard, Antoine Bonnefoy, Mohamed Ellejmi, Vincent Trêve, Ivan de Visscher

One of the factors limiting busiest airport's runway throughput capacity is the spacing to be applied between landing aircraft in order to ensure that the runway is vacated when the follower aircraft reaches the runway threshold. Today, because the Controller is not able to alwaysanticipate the runway occupancy time (ROT) of the leader aircraft, significant spacing buffers are added to the minimum required spacing in order to cover all possible cases, which negatively affects the resulting arrival throughput. The present paper shows how a Machine Learning (ML) analysis can support the development of accurate, yet operational, models for ROT prediction depending on all impact parameters. Based on Gradient Boosting Regressors, those ML models make use of flight plan information (such as aircraft type, airline, flight data) and weather information to model the ROT. This paper shows how it can be used operationally to increase runway capacity while maintaining or reducing the risk of delivery of separations below runway occupancy time. The methodology and related benefits are assessed using three years of field measurements gathered at Zurich airport.

Impact of Weather Conditions on Airport Arrival Delay and Throughput

Álvaro Rodríguez-Sanz, Javier Cano, Beatriz Rubio Fernández

Weather events have a significant impact on airport arrival performance and may cause delays in operations and/or constraints in airport capacity. In Europe, almost half of all regulated airport traffic delay is due to adverse weather conditions. Moreover, the closer airports operate to their maximum capacity, the more severe is the impact of a capacity loss due to external events such as weather. Various weather uncertainties occurring during airport operations can significantly delay some arrival processes and cause network-wide effects on the overall Air Traffic Management (ATM) system. Quantifying the impact of weather is, therefore, a key feature to improve the decision-making process that enhances airport performance. It would allow airport operators to identify the relevant weather information needed and help them decide on the appropriate actions to mitigate the consequences of adverse weather events. We present a methodology to evaluate the impact of adverse weather events on airport arrival performance (delay and throughput) and to define operational thresholds for significant weather conditions. We use a Bayesian Network approach to relate weather data from meteorological reports (METAR) and airport arrival performance data with scheduled and actual movements as well as arrival delays. This allows us to understand the relationships between weather phenomena and their impacts on arrival delay and throughput. The proposed model also provides us with the values of the explanatory variables (weather events) that leads to certain operational thresholds in the target variables (arrival delay and throughput). We then present a quantification of the airport performance with regards to an aggregated weather-performance metric. Specific weather phenomena are categorized through a synthetic index, which aims to quantify weather conditions at a given airport, based on aviation routine meteorological reports. This allow us to manage uncertainty at airport arrival operations by relating index levels with airport performance results. Our results are computed from a dataset of over 750,000 flights on a major European hub and from local weather data during the period 2015-2018. We combine delay and capacity metrics at different airport operational stages for the arrival process (final approach, taxi-in and in-block). Therefore, the spatial boundary of this study is not only the airport but also its surrounding airspace, in order to take both the Arrival Sequencing and Metering Area (ASMA) and potential holding patterns into consideration. We introduce a new approach for modelling causal relationships between airport arrival performance indicators and meteorological events, which can be used to quantify the impact of weather in airport arrival conditions, predict the evolution of airport operational scenarios and support airport decision-making processes.

Advanced Passenger Movement Model Depending On the Aircraft Cabin Geometry

Marc Engelmann, Tim Kleinheinz, Mirko Hornung

The aircraft cabin is steadily becoming a more important focus for both aircraft manufacturers and airlines, as it is the most prominent aspect of an aircraft that passengers get in contact with during a commercial flight. In regards to this, the boarding performance of an aircraft plays a key part in the customer experience and enables cost saving potential by reducing the turnaround time at the airport. An important focus of today's aircraft operational research thus is the boarding procedure and possible options for a reduction in boarding time as well as an increased passenger comfort throughout the process. Therefore, the boarding process is assessed in the LuFo research project "AdVanced Aircraft CONcepts" (AVACON). Regarding the aircraft cabin, the project contains the boarding performance assessment of all aircraft iterations created in the different design iterations. This is achieved using the open-source passenger flow simulation PAXelerate. It is developed by Bauhaus Luftfahrt as a boarding

assessment tool, giving fast and easy results for the boarding performance of both conventional and novel cabin layouts.
As the goals of the project go beyond the existing modelling capabilities and level of detail of PAXelerate regarding the passenger movement, a novel methodology was both created and implemented into PAXelerate and is now introduced in the scope of this publication. Improvements to the model include the development of a method capable of describing the passenger walking speed in dependence of the surrounding objects, their proximity as well as the location of other passengers within the cabin.
The newly developed model is validated using the AVACON research baseline aircraft and an Airbus A320 and then applied to an altered version of the Airbus A330 with a modified aisle width and overhead bin position. Furthermore, the model is used to assess the impact of regulations potentially imposed due to the COVID-19 pandemic. As the model is capable of defining a minimum distance to preceding passengers, a boarding assessment with a minimum distance of between 1.5 and 2 meters between passengers or a vacant middle seat is performed for an Airbus A320. This highlights the potential effects of such a regulation on boarding processes and thus the turnaround as a whole.
The validation results prove the feasibility of the new model as boarding times remain nearly constant compared to real world data and the previous model implementation. The application of the new model for an extended aisle width delivers boarding times reduced by up to 3%, highlighting the effect of geometry changes to the simulation outcome. Concerning the COVID-19 assessment, boarding scenarios enforcing a safe distance of 1.75 meters between passengers during boarding deliver a 67% increase in boarding times, whereas a combination of the safe distance with vacant middle seats leads to an unchanged result compared to the reference scenario.
The integration of the newly developed model empowers PAXelerate to simulate a more detailed boarding process and enables a better understanding of the influence of cabin layout changes to the aircraft's boarding performance. This allows for the identification of critical aspects of a cabin layout such as a local narrowing of the aisle and therefore gives cabin designers the opportunity to tackle potential issues in an early design phase.
In general, the potential for a swifter boarding process by changing aspects of the cabin layout may enable airlines to quicken the turnaround process with lower effort. Passengers on the other hand may feel less congestion during the boarding procedure as potential bottlenecks can be removed in advance. Lastly, the results of this paper also highlight potential paths for future improvements of the design of the AVACON project's next aircraft iterations and their respective cabin layout.

Numerical implementation and validation of the simulation models of reference SID and STAR procedures for the RPAS integration research

Daniel Lichoń

This work is a continuation of the elaboration of reference models of Standard Instrument Departure and Arrival (SID and STAR) procedures for the research in the integration of Remotely Piloted Aircraft Systems (RPAS) in non-segregated airspace. Previously, the reference shapes of SID and STAR were done based on statistics of existing procedures (published in Aeronautical Information Publication, AIP) and International Civil Aviation Organisation (ICAO) procedure design guidelines. In this work, the reference SID and STAR were numerically implemented creating the simulation models for the Fast Time Simulation (FTS) environment. Considering the AIP charts and ICAO guidelines describe the procedures in total distances, heights and gradients it was necessary to transform the units into the geographic coordinate system. First, the transformation functions were elaborated. These functions create points, lines, arcs and surfaces using latitude, longitude and altitude units. In the next step, the procedural nominal flight track is generated using the runway threshold and axis as the origin. Finally, the procedural tolerance area is

generated around the nominal flight track. The “Matlab” software was selected for the FTS simulation environment. The implemented models of SID and STAR can interact with simulation models of RPAS. This allows to perform the FTS simulations of procedural flights for different RPAS configurations and wind conditions. Additionally, the validation of SID and STAR models was done by a series of test flights of manned aircraft using the “X-Plane 11” flight simulator.

Tactical Runway Scheduling for Demand and Delay Management

Alvaro Rodriguez-Sanz, Pablo López Cózar, Javier A. Pérez-Castán, Fernando Gómez Comendador

Airports are limited in terms of capacity. Particularly, runways can only accommodate a certain number of movements (arrivals and departures) while ensuring safety and determined operational requirements. In such a constrained operating environment, any reduction in system capacity results in major delays with significant costs for airlines and passengers. Therefore, the efficient operation of airports is a critical cornerstone for demand and delay management of the whole air transportation system. Runway scheduling deals with the sequencing of arriving and departing aircraft at airports such that a predefined objective is optimized subject to several operational constraints, like the dependency of separation on the leading and trailing aircraft type or the runway occupancy time. Scheduling arrivals and departures at runways is a complex problem that needs to address diverse and often competing considerations among involved flights. In the context of the Airport Collaborative Decision Making (A-CDM) programme, airport operators and air navigation service providers require arrival and departure management tools that improve aircraft flows at airports. Airport runway optimization, as the main element that combines airside and groundside operations, is an ongoing challenge for air traffic management.The objective of the runway scheduling problem is to find a sequence of aircraft operations that ensures an effective runway usage, reduces delays and fulfils the required operational constraints, given uncertain aircraft availability at the runway. However, the planning algorithm needs to be implemented in the real world, where input data (as the estimated time of arrival/departure of an aircraft) face disturbances or changes over time. In this work, we study the runway scheduling problem at a tactical phase, to consider traffic deviations from the initial planned schedule. By considering real airport performance data with scheduled and actual movements, as well as arrival/departure delays, we present a robust model together with an optimization algorithm, which incorporates the knowledge of uncertainty into the tactical operational step. Our approach transforms the planning problem into an assignment problem with side constraints. The coupled landing/take-off problem is solved to optimality by exploiting a time-indexed (0, 1) formulation for the problem. The Binary Integer Linear Programming (BILP) approach allows us to include multi-criteria and multi-constraints levels and, even with some major simplifications, provides fewer sequence changes and target time updates, when compared to the usual approach in which the plan is simply updated in case of infeasibility. Thus, the use of robust optimization leads to a protection against tactical uncertainties, reduces delays and provides more stable operations.Our model has been validated with real data from a large international European airport in different traffic scenarios. Results are compared to the actual sequencing of flights and show that the algorithm can significantly contribute to the reduction of delay, while adhering as much as possible to the operative procedures and constraints, and to the objectives of the airport stakeholders. Computational experiments performed on the case study illustrate the benefits of this arrival/departure integrated approach: the proposed algorithm significantly reduces weighted aircraft delay and computes efficient runway schedule solutions within a few seconds and with little computational effort. It can be adopted as a decision-making tool in the tactical stage. Furthermore, we present operational insights regarding demand and delay management based on the results of our work.

Noise Prediction and Control Strategies

Session Chair: Prof. Massimo Viscardi, University of Naples "Federico II", Italy

Vibro-Acoustic Response Analysis and Experimental Validation of a Turboprop Insulation Package

Giuseppe Bizzarro, Massimo Viscardi, Valerio Maria Porpora

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 that 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 have 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 Trasmission 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.

Laser scanning vibrometry technique for the damping assessment of new structural multifunctional epoxy resin for aerospace

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

The increasing demand for more advanced materials, particularly in the aerospace field, has led to the development of carbon-fiber-reinforced composite manufactured employing different kinds of nanoparticles. The reinforcement with Carbon Nanotubes (CNTs) allows the modulation of several characteristics of the composite, which becomes suitable for more extreme operating conditions. Furthermore, the incorporation of CNTs in polymeric matrices of composite materials allows them to be

electrically conductive, and hence suitable for developing self-responsive/self-protective materials characterized by a combination of properties strongly requested for replacing the traditional composites. In addition, the potential detection of specific electrical properties is useful to develop self health-monitor composites subjected to damages under static and/or dynamic loads. Furthermore, the introduction of an elastomeric phase into the resin is very effective for improving the damping properties of the material. Laser scanning vibrometry, is a very useful technique to assess, following vibrational loads, the damping capacity of a material and it has been used in this paper to assess the damping capacity of an epoxy specimen containing embedded both a rubber phase and CNTs. The obtained results are encouraging and motivate the research towards future developments of this kind of multifunctional materials.

Boundary Element Method for the acoustic improvement of aircraft headrests made with electrospun mats

V. Giannella, F. Branda, J. Passaro, G. Petrone, M. Barbarino, R. Citarella

This work illustrates the development of Passive Noise Control (PNC) improvements of aircraft headrests to enhance the acoustic comfort for passengers.

Two PNC improvements were designed to reduce the Sound Pressure Level (SPL) perceived by passengers of an aircraft during the flight: the first was based on the optimization of the headrest shape, whereas the second was based on the adoption of a high absorbing material made of headrest fabric. In particular, a Silica/Polyvinylpyrrolidone (PVP) woven non-woven mat was produced through an in-house made electro spinning apparatus and its acoustic performances measured to obtain the related sound absorption coefficient.

Boundary Element Method (BEM) models were built up to evaluate the acoustic performances of different headrest configurations in terms of shape and covering textile. A spherical distribution of monopole sources surrounding the headrests was considered as acoustic load, in such a way to recreate a diffuse acoustic field replicating the cabin noise perceived by passengers during cruise conditions.

The impact of the two PNC improvements on the SPLs perceived by passengers was estimated, envisaging also some general guidelines useful to design advanced headrests from the acoustic viewpoint.

Clean Sky building synergies with the regions: Innovation and Technologies created in the European aeronautics regions

Session Chair: Dr. Christos Vasilakos, Clean Sky Joint Undertaking

MIB project: Modelling and control of a Modular Iron Bird to test movable surfaces actuators of aircraft

Massimiliano Mattei, Luigi Emanuel di Grazia, Egidio D'Amato, Immacolata Notaro, Mauro Borrelli

The scope of the Modular Iron Bird (MIB) project, funded by the Campania Regional Council, is to design and develop a modular iron bird to test actuators of movable surfaces to be mounted on different kinds of aircraft. The project has the scope of offering to medium size aeronautical companies a tool to verify and qualify components. An iron bird allows engineers to simulate and analyze the behavior of the most critical aircraft aeronautical components, as actuators of movable surfaces, landing gear, on board computer, etc. The technical complexity and huge cost to build such an iron bird, often force small and medium size aeronautical industries to execute tests directly on prototypes. However, this may result in a long and expensive modification to the overall aircraft design, extending also certification times. A modular and reusable iron bird can reduce costs, permitting an early identification of defects and/or design mistakes. The novelty of MIB is the ability of the system to be adapted to different kinds of aircraft (UAVs, general aviation, regional aircrafts). A modular active load generation system is based on a customizable flight dynamics simulator ("Flight Controller and Aircraft 6 DoF real time Simulation" block in Error! Reference source not found.), able to compute hinge moments on movable surfaces on the basis of the inertial, geometrical, and aerodynamic characteristics of the aircraft subject of the test. A Test Planner has the role of defining the maneuver to be simulated for testing in terms of desired positions of the control surfaces or reference signals to the aircraft flight controller. The calculated hinge moments are then reference inputs for a hydraulic load generator ("Actuator for load applications" block in Error! Reference source not found.) controlled in closed loop on the basis of force estimation based on force and pressure measurements. Another control loop to be accounted for in the test planning is that one encharged of controlling the aerodynamic surface position via the aircraft movable surface servo-actuator. One of the critical factors in designing the system is the interaction between the two control loops, i.e. position control and force control. In particular, the design of the load control system must reject the action of the position controller driven by the aerodynamic surface actuator. In principle force control needs to be faster than position control. The proposed paper will present a dynamic modelling of the whole system shown in Error! Reference source not found., and the design of both force and position controller. With reference to a general aviation aircraft, in Error! Reference source not found., a preliminary result of the system response in the presence of a scenario where, at time 0, a constant force of 5000N is requested to the force controller and a position of 0.05m is requested to the actuator position, is shown. Starting from a 0.00 m position, the position error slowly tends to zero regardless the constant force applied by the load actuation system. On the other hand, force is kept nearly constant, regardless the rotation of the aerodynamic surface. Error! Reference source not found. shows the result of a preliminary numerical simulation obtained with the aircraft flight simulator generating reference forces in the loop. The test planner provides a reference signal to the position controller of the aerodynamic surface actuator (Error! Reference source not found.a). Force control signals exhibits some overshoot due to the system dynamics and controller tuning (Error! Reference source not found.b) which is one of the point that will be deeply investigated.

CRO2 project overview

Alain Toufine

The CRO2 project[30] deals with both the aircrafts' parts repair & maintenance and the Additive Manufacturing by metal powder Directed Energy Deposition[31]. In aeronautical domain repairs is a major issue to improve the current way of manufacturing's, to reduce operation losses and to avoid waste of costly and strategic raw materials. By focussing on low critical structures in TA6v Titanium as air bled piping's, CRO2 proposes a pre-industrial development to rebuild lost shapes and functions. Mechanical and metallurgical characterisations have being performed on manyTA6v DED AM samples. Results give behaviours and properties near and even greater than those obtained by forging, roll forming or casting, as well in static and fatigue domains. To demonstrate the CRO2 solution robustness in comparison to welding current process, aircraft environmental qualification tests at hight temperature and pressure have being successfully realised on thin representative pipping's.

Design challenges in the joint research project RACER

Adrian Gaz, Katrin Mayrhofer

The Demonstrator project RACER is part of the Innovative Aircraft Demonstrator Platform (IADP) Fast RotorCraft of the European Research Program Clean Sky 2 (Fig. 1). The aim of Fast Rotorcraft Platform is to develop new VTOL formula in order to fill the mobility gap between conventional helicopters and airplanes. RACER is the first flying demonstrator within a joint European research project. The project is developed under the Coordination of Airbus Helicopters Group within a European partnership. Within the RACER community, INCAS, as the Consortium Leader (RoC), is responsible for the Airframe Advanced Design and CETIDA, the R&D Center of Romaero, manufacture and assemble the main fuselage, as well as the Upper Deck, Stub Wing and Fuel Drop Test Specimens. This project will be developed until TRL 6 (flight tests). The paper highlights:

- the main technologies applied to the technical solutions that led to new basis for design and execution processes of the RACER helicopter fuselage
- Means of Compliance (MoC) for a new helicopter configuration
- Documentation PtF (for safe for flight according a flight condition approval plan)
- Test Specimens for systems assessments

The presentation associates state of the art processes, innovative solutions with necessary infrastructure, control and testing methodologies. The open architecture from the Airframe point of view could provide the flexibility to add the necessary means of fixation of different devices requested by the mission needs and also the possibility for easy modification of the existing provisions without having a significant impact on the main structure. Challenges which had to be achieved will be described in the paper, such as weight targets, structural detailed layout and substantiation (static and dynamic).

Innovative manufacturing in the joint research project RACER

Catalin Moisoiu, Katrin Mayrhofer

[30] *CRO^2: **C**ost **R**epair **O**verhaul **O**ptimization*

[31] *DED AM : Directed Energy Deposition Additive Manufacturing*

The Demonstrator project RACER is part of the Innovative Aircraft Demonstrator Platform (IADP) Fast RotorCraft of the European Research Program Clean Sky 2 (Fig. 1). The aim of Fast Rotorcraft Platform is to develop new VTOL formula in order to fill the mobility gap between conventional helicopters and airplanes. The Core-Partner (CoP) roles (RoC, Romanian Consortium) and responsibilities are Design, Structural analysis (INCAS) and Manufacturing (Romaero) of the Airframe, therefore the tasks and the WPs in which, completely or partially, the CoP will work are (Built to Spec). The presentation associates state of the art processes, innovative solutions with necessary infrastructure in the frame of manufacturing challenges:

- Risk Management
- Building Philosophy Optimization
- Identification of LLI
- Procurement Plan
- Standard Parts harmonization and Tooling availability

The main areas in which the new technical solutions have been developed and integrated are:

- Hybrid structure assemblies (composite-metal)
- Composite panels manufacturing technologies
- Process Qualifications

Innovative processes applied to the fuselage structure developed in RACER project

Dorin Barsan , Adrian Gaz

The paper highlights the main technologies applied to the technical solutions that led to new basis for design and execution processes of the RACER helicopter fuselage. The development of the fuselage structure includes additional activities that are supported by INCAS within a complementary project called RoRcraft CompAct in order to:

- select innovative materials and technologies for developing a wide range of aerospace products as result to the development of the helicopter fuselage;
- perform complex numerical simulations;
- execute advance ground testing – dynamic tests (Additional);
- increase the level of technical expertise and training capabilities for the next generation of specialists in aeronautics structures;
- develop new methods for validating technical solutions through specific testing;

The presentation associates state of the art processes, innovative solutions with necessary infrastructure, control and testing methodologies and workforce training developed in other relevant projects. The main areas in which the new technical solutions have been developed and integrated up to the industrial level are:

- Hybrid structure assemblies (composite-metal)
- Experience in composite panels manufacturing technologies
- Simulation and testing methods for hybrid structures
- Modern collateral technologies

The implemented innovative processes aim to increase the safety in operation in conditions of low costs and environmental protection.

Contributions to Clean Sky 2 FRC IADPs and SAT

Session Chair: Dr. Marika Belardo CIRA, Italy

On the wing design of NGCTR-TD

Belardo M., Diodati G., Beretta J., Paletta N., Giuliani V., Orlando S., Ariola P., Graziano M., Pezzella C., Di Palma L.

This work is focused on the wing design workflow of the innovative composite wing of the Next Generation Civil Tiltrotor Technology Demonstrator, one of the Fast Rotorcraft Integrated Aicraft Demonstrator Platforms foreseen in Clean Sky 2 Program. The T-WING project is aimed at designing, manufacturing, qualifying and flight testing the new wing of the NGCTR-TD. The present paper presents how the project Consortium, under the leadership of Leonardo Helicopters, performed all the necessary steps to achieve the Critical Design Review of the wing. The wing of a tiltrotor poses a series of challenges which are peculiar of this type of aircraft, capable of take-off and landing like a helicopter and performing like a fixed wing aircraft turbo propeller during cruise flight. In particular, besides the assessment of safety with respect to strength and buckling capability under loads, for this peculiar aircraft, requirements such as aeroelastic stability (flutter and whirl flutter) and crashworthiness may have a tremendous impact on the wing design itself. In addition to the above, the NGCTR-TD wing is designed to yield high lift and low drag which is optimized to improve downwash impingement in helicopter mode (Hovering), by means of the introduction of two surfaces, an outboard flaperon and a large (almost one half chord wise extension) morphing surface which rotates downwards in helicopter mode to reduce the wing area beneath the rotors.

This translates in a very challenging design of the wing, since it has to assure a global stiffness (flexural and torsional) compatible with aeroelastic stability, with fuel capacity (mission) and with all the systems installed inside the wing box. Accessibility requirements, bladder fuel storage, segregation, make the design even more challenging. To undertake all the above contrasting requirements, at the minimum structural mass, TWING consortium has operated a design work flow to accomplish Critical Design Review which foresaw the following main steps, which main results are shown in the present paper.

- Preliminary sizing and optimization based on simplified models (strength, buckling, stiffness)
- Preliminary Flutter analyses based on stick beam structural model
- Stress analysis based on coarse FEM (Strength and buckling) and mitigation of negative MoS
- Digital Mock Up update based on the results of the stress analysis and upgrade of mass distribution
- Structural optimization of the composite parts with respect to strength and buckling
- Tuning of bending and torsional stiffness by local reinforcements to accomplish flight mechanics and whirl flutter stability
- Flutter analyses based on 2D finite elements structural model of wing and moveable surfaces
- Detailed stress and buckling analyses based on a finer mesh FEM
- Emergency conditions analyses (Crash and Ditching)
- Update of Digital Mock Up based on all analyses results and on functional and systems interface requirements

A brief look on the main results achieved so far is presented.

- Development of a highly integrated composite wing structure.
- Development of a compact structural wing box, since almost half of the wing chord-length is dedicated to the moveable surfaces.

Requirements, design strategy, methodology and main steps followed to achieve the composite wing design are presented. The main driving requirements have been expressed in terms of dynamic requirements (e.g. limitations on natural frequencies), aeroelastic requirements i.e. compliance with European Aviation Safety Agency (EASA) CS-25 and CS-29 Airworthiness Requirements), structural requirements (e.g. target wing structural mass, strength, buckling), functional requirements (e.g. fuel tanks, accessibility, assembly & integration, etc.) and wing preliminary loads. Based on the above-mentioned requirements, the first design loop is performed by targeting an optimal wing structure able to withstand preliminary design loads, and simultaneously with stiffness and inertia distributions leading to a configuration free from flutter within the flight envelope. The outcome from the first design loop is then used to build a global FEM, to be used for a multi-objective optimization performed in ALTAIR OPTISTRUCT environment.

Preliminary studies of flight sensoring for loads and aeroelastic parameters estimation of the NGCTR-TD wing

Cardozo Andrés, Beretta Jacopo, Paletta Nicola, Adden Stephan, Belardo Marika, Chiariello Antonio, Di Palma Luigi

The paper presents the preliminary analyses carried out to estimate the accelerometers and strain gauges optimal configuration for the in-flight natural modes and internal loads identification of the NGTCTR-TD wing. The optimal accelerometers' configuration has been achieved with the aeroelastic model by taking into account the modal displacements of the targeted natural modes, requirements of space availability and accessibility. A further analysis has been set up to estimate the acceleration peak on the wing by using a continuous turbulence model with a von Karman power spectral density. The optimal strain gauges' configuration has been achieved as a subset of an initial layout by using the Skopinski methodology, where quality ratios and percentual errors lead to the identification of redundant and irrelevant measurements. This approach aims to recover the flight loads on the wing from an optimal set of strain measurements during flight. The present work has been a numerical study. A verification of the final Load Evaluation Matrix (LEM) has been performed using a set of validation load cases.

Clash analysis of main landing gear door using advanced nonlinear finite element analysis

Antonio Chiariello , Salvatore Orlando, Pasquale Vitale, Mauro Linari, Raffaele Longobardi, Luigi Di Palma

The paper presents analysis and method adopted to predict the behavior of AIRBUS-RACER helicopter Main landing gear doors, installed on Karman zone between wing and fuselage. To achieve the required smoothness and flushness of external aerodynamic surface, the door panel has been designed as CFRP flexible multi body parts linked together with a dedicated engineered metallic mechanism. The architecture is made of a fixed fairing connected on Main Landing Gear (MLG) wheel and movable panel indirectly connected to the retraction actuator. Both parts come in contact during the latest closure steps of MLG and kept preloaded, to ensure the required smoothness and prevent the door opening. The dynamic phenomena, is a complex numerical problem dependent on: mutual stiffness, contacts history and aerodynamic deformations. The authors propose a quasi-static resolution by using of non-linear Finite

Element method based on multi-steps MSC Nastran SOL-400 analysis. An appropriate contact algorithm has been used to fully represent the complete kinematics during the door engagement under inertial and aerodynamic loading. The main result is the identification of a robust method to support engineers during the aerodynamics and structural strength analysis of a complex transient field.

Optimization of vibration levels of a main landing gear composite door for highspeed rotorcraft

Maurizio Arena, Antonio Chiariello, Martina Castaldo, Luigi Di Palma

One of the main crucial issue affecting the structural safety of propeller vehicles is the propeller tonal excitation and related vibrations. Propeller rotation during flight generates the main vibrating sources depending upon its rotational angular velocity, number of blades, power at shaft generating aircraft thrust and blades geometry. Generally, the higher energy levels generated are confined to 1st Blade Passing Frequency (BPF) and its harmonics; while additional broadband components, mainly linked with the blade shape, the developed engine power and the Turbulent Boundary Layer (TBL), also contribute to the excitation levels. The vibrations problem takes on particular relevance in the case of composite structures. The laminates in fact exert damping levels generally lower than metallic structures where the cutoffs due to the greater amount of joint elements allow for dissipating vibration energy. The prediction and reduction of aircraft vibration levels are therefore significant considerations for conventional propeller aircraft now entering the commercial market as well as for models currently being developed. In the Clean Sky 2 framework, the present study focuses on a practical case inherent in AIRBUS-Racer program which aims to design and develop a multi-tasking fast rotorcraft. The paper defines a FE based procedure for the characterization of the vibration levels of a main landing gear composite door with respect to the expected operating tonal loads. A parametric assessment has been carried out to evaluate the principal modal parameters of the landing gear-door assembly in order to achieve the reduced vibration levels. Based on the FE analysis results, the influence of the extra-damping, location and number of ballast elements has been investigated with respect to failure scenarios of the kinematic line opening the study towards aeroelastic evaluations. Further experimental ground test results will serve as a validation database for the prediction numerical methods representative of the composite door dynamic response.

Experimental Investigation of damage detection on structures with FSW junctions

Sorrentino Assunta, Chiariello Antonio, Di Palma Luigi, De Fenza Angelo

A Structural Health Monitoring system for damage detection is proposed in this paper. The Probability Ellipses method (PE) is a non-destructive method based on measurement of Lamb waves. This method starts from the calculation of a global index called Damage Index (DI), that represents a way to measure how much critical is the related sensing-path (actuator-sensor). In other words, the DI is bigger when the damage is closer to the sensing-path. Moreover, the DI increases when the damage severity grows.

The work is being developed 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 to be employed in the development of next generation of small aircrafts (following CS/FAR-23). The Friction Stir Welding (FSW) is one on the technologies studied in SAT-AM to reduce error and manufacturing cost. Preliminary experimental investigations of the ET method, applied to structures with Friction Stir Welding (FSW) junctions, are illustrated.

Aluminium panels of different thickness were joined with FSW technique and a damage was produced in the junctions. The structures were instrumented with piezoelectric devices, used as both actuators and

sensors. The Lamb waves were acquired on both undamaged and damaged configurations and the PE method was applied to identify the damage position.

Tailored design assessment for the CFRP wing of the Next Generation Tilt Rotor supported by virtual allowable test method

F. Starace, S. D. Orlando

The design and development of an innovative composite wing for the Next Generation Tilt Rotor (NGCTR), requires a hectic proceeding of subsequent phases as well as a suitable optimization procedure, as the vehicle includes the critical issues of an aircraft and a helicopter both. An extensive set of design guidelines representative of the actual industrial requirements has been introduced to avoid ply drop and difficulties in manufacturing. A former design optimization procedure seeks to define all composite parameters, such as the laminate thickness and stacking sequences, which are fundamental to the initial wing sizing considering the worst wing-loading case and environmental condition. Briefly, the optimal design attempts to find the framework layout that minimizes the structural weight of a composite wing, while satisfying a series of design constraints. Enhancement of the aeroelastic stability is selected as an objective in the upper-level optimization, performed to derive stiffness and inertia requirements. Furthermore, the failure envelope and the performance of a tailored composite material have been evaluated in a virtual test lab as final purpose. Basically, the certification of composite material requires analysis as well as tests at coupon level of the testing pyramid to generate robust design allowable values. The multibatch experimental data for the certificated CFRP complement the virtual test results to save cost and optimize material use earlier in the design process. Benchmarking the experimental-numerical test results allows to assess the statistical reliability of the proposed method.

LABOR Project Session

Prof. Pasquale Chiacchio, University of Salerno, Italy

Clean Sky 2 - REG IADP Overview and links with AIR ITD

Vittorio Ascione, Vito Perrupato, Rossella Valiante

A presentation by Leonardo Aircraft during the 10th EASN Conference will give a brief overview of the Regional IADP (REG IADP) and its main links with the Airframe ITD (AIR ITD) in the frame of the Clean Sky 2 Programme.

Innovation in manufacturing and assembly automations matured in the AIR ITD with contributions of dedicated Projects selected through the CS2 Call for Proposals instrument finds a direct application in achieving one of the major REG IADP deliveries: composite fuselage full-scale integrated on-ground demonstrator. Such presentation includes the following topics:

- High Level Plan for Clean Sky 2,
- The REG Team,
- Work breakdown Structure,
- Interfaces with other SPDs,
- Major Demonstrators,
- Automation from AIR ITD to REG IADP.

New concepts for a robotized cell for the assembly and control of composite fuselage panel component

Matteo Nisi, D. Massa, A. Bruni, C. Cristalli

According to the Global Market Forecast 2018-2037, there is a strong need to increase productivity in the aviation industry and, to this end, all manufacturers are investing in order to reduce the production costs and increase their efficiency in particular in the construction processes of aeronautical components and their assemblies. Robotics is a key technology, but current commercial robotic systems for assembling aeronautical structures are usually using automatic systems with large payloads, large dimensions and large investments. The LABOR project (www.labor-project.eu) aims to overcome these obstacles in the automation of some critical assembly operations, proposing a new approach. The proposed technological strategy consists in the adoption of two medium size robots which, based on real time measurements, adapt to the environment in which they operate and to the operations to be performed, integrating quality control systems for the assembled components. The cell is equipped with a dedicated vision system that is adopted to guide the processing in a self-adaptive way (thanks to the real-time scanning of the components) and to check the quality of the components, in order to guarantee a high standard of the process.

The operations that the cell can perform automatically are as follows: referencing of the robot working area on the basis of the recognition of geometric features of the parts to be coupled (edges, holes, etc.); "one shot" drilling and countersinking operations; automatic control of the holes; installation and sealing of the connection units, plus their correct installation control including the "flushness"; reporting. Furthermore, it is possible to have activities in co-working with operators such as insertion and removal

of temporary connecting parts, application of sealant by interposition, removal of metal burrs on the edge of the holes.

The project started in March 2018 as part of the European Clean Sky 2 research program with Leonardo S.p.A. as Topic Manager and now, after the competition of the assembly of the cell, the tests on real panels started. The installation of the LABOR cell and the demonstrations are scheduled at the Leonardo S.p.A. site of Pomigliano.

Collaborative robotized assembly of composite fuselage panels

Gaetano Lettera, Ciro Natale

Human-robot collaboration (HRC) task represents one of the major area of exploration for the aerospace manufacturing sector. Intervention of the human operator is required in several phases of the assembly process, e.g., dismantling for deburring of hybrid metal-composite structures. Therefore, suitable safety measures have been taken to prevent injury of the workers. Besides standard safety procedures and countermeasures established by the current regulations as ISO 10218-1/2 and ISO/TS 15066, a novel work space monitoring approach based on multimodal sensing has been developed for the LABOR workcell, with the aim to maximize the system productivity and preserve operator safety at the same time. Achieving such conflicting objectives is challenging: on one hand, a perception system is needed for monitoring human presence reliably, on the other hand, suitable control algorithms are needed to be devised to select the proper robot behaviour for keeping a high level of productivity during the collaborative activity, i.e., reducing at a minimum the number of robot stops during the assembly process.

Robot deployed Laser-Ultrasonic NDT system for large aircraft structures

Vicki James, Dave Carswell, J Riise, P. Ian Nicholson, Norbert Huber, Martin Gärtner, Bernhard Reitinger, Edgar Scherleitner, Peter Burgholzer, Norbert Graf, Jon Phipps, Dave Burns, Ciro Incarnato

The mandatory Non-Destructive Testing (NDT) by the aerospace industry for both present and future generation hybrid aircraft using thick composite structures poses many challenges for traditional inspection techniques. Laser Ultrasonic testing (LUT) deployed by a robot for inspection of modern aerospace composite components shows good promise. It is a non-contact method offering the possibility of fast scan times without the need for couplant. This paper presents the latest work-in-progress for the design and development of the system developed by the ACCURATe consortium. ACCURATe is an ongoing H2020 CLEANSKY 2 part funded project to develop a laser ultrasound based NDT system prototype for fast and contactless testing of large carbon fiber reinforced polymer (CFRP) aircraft structures.

The approach is based on a non-contact laser generated and detected pulsed ultrasound technique with delivery of both the laser ultrasound excitation and detection pulses through flexible optical fibres. The backscattered light from the lasers is also collected into a fibre. The measurement head, which contains the two beam outputs and the light collection optics is raster scanned over the surface by a 6-axis robot arm. The excitation and detection lasers are based on diode pumped Nd: YAG lasers, which enable a low profile casing with low weight and very long lifetime with little maintenance and high nominal scanning speed of 400Hz. For the demodulation of the ultrasonic waves, a two wave mixing interferometer (B-TWM) is used. The robot arm is mounted on a rail and raster scans the laser head system over the part surface, and moves in increments along the track to inspect the whole component.

The system has recently been used to scan a reference panel, specially created for the project. This panel has 125 artificial flaws, which were created by insertion of alien materials into the layers of the FRP before infusion and cure of the panel. The panel also has regions where viscoelastic material is present, and regions with differences in thicknesses and composition. The latest test results are presented.

TOD – Thermoplastics on Doors: Development of full scale innovative composites doors, surrounds and substructure for Regional Aircraft Fuselage barrel on-ground demonstrators

Sofia Sampethai, Antonio Miraglia, Francesca Felline, Ciro Rocco, Alessandro Ceresa, Umberto Raganato, Miguel Zavala, Bertrand Flipo, Georgios Liaptsis, Jonathan Riise, Xiaofei Cui, Minghui Wu

Thermoplastic composites can reduce cost and save weight in airplane structures. Currently on the market there is no thermoplastic door available for commercial aircraft. The overall goal of TOD project is to demonstrate and validate the manufacturing process of thermoplastic door components, induction welding assembly process, additive manufacturing and metallic parts of door mechanism, metallic and thermoset parts of surrounding structure of the passenger and service door of an aircraft The impact associated with the activities performed in TOD project is related with the following:

- Use of thermoplastic materials and the development of out-of-autoclave manufacturing processes, which are drivers of manufacturing cost reduction and of manufacturing rate increase. These technologies are projected to 75% energy savings over standard autoclave processing
- Minimum 15% weight reduction on structural components as doors. Recent thermoplastic composite studies already demonstrated the substantial weight reduction that can be obtained by combining automated production processes and thermoplastic materials. Specifically, in aircraft related components, an approximate 10% weight reduction of the torsion box of the tail has already been achieved using thermoplastic composites.
- Reduction of Recurrent Cost considering the conception of an adaptive and smart manufacturing equipment to:
  1) Increase production flexibility
  2) Decrease the full line tools cost
- Reduction of waste and scrap by 10% by working directly at the defects root cause with a multidisciplinary approach thru the sensors for in-line monitoring directly connected to the manufacturing equipment
- Significant eco-impact reduction through the component's and aircraft's life-cycle: the reduction of energy usage during manufacturing of thermoplastics, combined with the light-weighted parts will contribute to the reduction of CO2 emissions during both product manufacture and operation
- TOD addresses a key issue of extensive use of out-of- autoclave composite with aerospace relevance. The R&D work will generate new scientific knowledge as well as new technologies, and thus strengthen the European positions in this field.

TOD project has received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement number 821192.

SPARE project: Improvement of continuous compression moulding process for the production of thermoplastic composite beams

Riccardo Angiuli, Federica Dell' Anno, Leonardo Cosma, Umberto Raganato, Alessandra Passaro

In recent years, thermoplastic matrix composites have seen an increasing interest from the research and development sector due to the versatility of use and the wide potential in sectors such as automotive, aeronautics and transport.

Furthermore, the thermoplastic matrix allows the use of simpler, faster and automatable production cycles and joining systems. As part of the SPARE project, the continuous compression moulding process (CCM) was upgraded using as numerical simulation, monitoring via infrared thermography and induction welding.

Thanks to these innovations, the CCM process can ensure savings in terms of production costs, reduction of waste and a higher level of automation, the proposed work will illustrate the activities carried out during the project. The numerical simulation was used to analyze the heating process and verify its uniformity in order to identify the best configuration to obtain uniform heating, infrared thermography, on the other hand, was used to continuously monitor the temperate of the laminate at the entrance and exit of the compaction zone and to measure the process temperature and the degree of uniformity.

Finally, at the end of the production process, a tool was developed for the induction welding of the laminates for the construction of complex beams with a T or H cross section.

R&D Research in the Field of Aeronautics & Air Transport: SLOWD Project Session

Session Chair: Mr. Francesco Gambioli, Airbus, UK

Sloshing Induced Damping in Vertically Vibrating Systems

Joe de Courcy, Lucian Constantin, Brano Titurus, Tom Rendall, Jonathan Cooper

All aircraft are subject to a range of loading throughout ground and ight operations, which ultimately dene the sizing and weight of the aircraft structure. Active and passive loads alleviation technologies provide an approach to reduce dynamic loads arising from atmospheric gusts and turbulence, leading to a more fuel-ecient aircraft design. Within the H2020 SLOW- D project, fuel sloshing is being considered as a method for alleviating loads in aircraft wings via an increase in e ective damping. Recent work has considered the transient response of a vertically vibrating, single degree of freedom system coupled to a rectangular liquid-lled tank. This research revealed identiable dissipation regions in the free vibration responses characterised by their own distinct equivalent damping ratio values. It was observed that the response characteristics were dependent on the ll level and excitation size. Free surface displacement has been extracted from high-speed camera footage during the chosen sloshing regimes, which are representative of a decaying parametrically excited uid. A uid-structure coupled numerical model based upon smoothed particle hydrodynamics showed good agreement with the experimental damping behaviour and identied free-surface motion. This work aims to further analyse the free-surface response of the numerical solution with specic focus on determining the source of previously observed discrepancies such as the presence of the undesired travelling longitudinal wave. The detailed analysis of the discrepancies between the model and experiment is then used to introduce an improved numerical formulation.

Experimental study of the damping effects on a SDOF sloshing tank

Jon Martínez Carrascal, Leo Miguel González Gutiérrez

It has been reported that the sloshing force acting on the aircraft fuel tanks dampens wing vibrations but the complexity of the fluid-structure phenomena of the problem demands further investigation. The work presented aims to define an experimental methodology in order to derive the sloshing force acting in a Single Degree Of Freedom (SDOF) system that undergoes similar accelerations when compared to the ones found in the real wing. A preliminary test campaign has been carried out at the Model Basin Research Group Sloshing Laboratory of the UPM in Madrid, Spain. The objective of this experimental campaign was to quantify the damping effect due to fuel slosh in a decaying test of a partially filled tank.A Froude scaled tank is tested for vertical sloshing study confirming that the liquid presence increases the damping in the system and second that the sloshing-induced force is composed of an intertial and dissipative term. Finally, this study also shows that the phase-shift between the sloshing force and position measurements is a key factor in sloshing-induced energy dissipation.

Advances in Reduced Order Modelling for Linear and Nonlinear Sloshing

Marco Pizzoli, Francesco Saltari, Franco Mastroddi

This activity aims at providing new Reduced Order Models (ROMs) for linear and nonlinear sloshing by means of Linear Frequency Domain (LFD) approach and Neural Networks (NN). The development and exploiting of ROMs addressed to sloshing phenomena occurring to aircraft structure is one of the topic in

the H2020 European project SLOWD. Linear sloshing has often been accounted by means of the so called equivalent mechanical models (EMM), that are limited to simple tank geometries, like vertical cylinders and rectangular tanks. First, we provide a generalization of such EMM by means of LFD approach obtained by computational fluid dynamics unsteady simulations. A rational function approximation of LFD allows for obtaining new state space formulation identical to EMM but generalized for any kind of tank shape. In this modelling, the hypothesis of rigid tank can be overcome by considering tank possible deformations.

However, this modelling is limited to the study of little perturbation of the tank, and there is no way to describe vertical sloshing that for little perturbation is negligible. High vertical acceleration of the tank can trigger Rayleigh-Taylor instability, and the subsequent chaotic flow causes the dissipation of a large amount of energy. To this end, an Input/output approach based on Neural Network is used to model vertical sloshing by using as data provider an equivalent mechanical model of vertical sloshing represented by a bouncing ball. The parameters of such EMM are fitted with experimental sloshing data provided by partners of Technical University of Madrid. Both models, i.e. LFD and NN, have been included in a simulation environment for closed loop fluid structure interaction showing promising performances.

Proper Orthogonal Decomposition and Wavelet Analysis of Sloshing Flows

Tiziano Pagliaroli, Francesco Gambioli, Francesco Saltari, Jonathan Cooper

Generally, interior hydrodynamics and its coupling with structural dynamics are non-negligible processes in the design phase of aerospace systems. A deep knowledge of the nature of this coupling would ensure greater effectiveness in passive vibration control, in modelling and subsequently in the design phases. In this article we propose a data analysis procedure based on POD decomposition and wavelet transform applied to time–resolved images of liquid within an enclosure. The purpose of the technique is to highlight fluid-dynamic modes in space and time and to verify their coupling with the structural dynamics. The technique has been applied for the first time to monitor the free oscillations of a beam coupled with a water tank under transitional regime: from chaotic flow to the sloshing regime. The main result was that the content of the images is very informative and can be used for quantitative analysis. As the main outcome the modal components (spatial and temporal) related to the hydrodynamics are extracted by using these novel techniques. As a second but still interesting result, some components present in the time trend of the POD coefficients are perfectly correlated with the accelerometric time series. These findings led to correlate the effective damping of the cantilever oscillation to the chaotic regime in the hydrodynamic field.

Investigating the Impact of Non-Dimensional Fluid Properties on Violent Sloshing by means of High Fidelity Volume of Fluid Simulations

M. Wright, A.G. Malan, F. Gambioli

The modelling of fluid free surface interaction within tanks, as seen in violent sloshing, is an area of interest within the aerospace industry as the movement of fuel within the wing fuel tanks is of importance to the design process of aircraft. This paper is concerned with fluid slosh where the tank excitation direction is normal to the liquid-gas interface. It proposes the use of high-fidelity Volume of Fluid Computation Fluid Dynamic Code (Elemental®) as a method to perform a sensitivity analysis into the effects of specific non-dimensional numbers in two-phase fluid flow on violent sloshing interactions. As part of the SLOWD European Union Horizon 2020 Project prototype test campaign as performed by the Airbus Protospace Lab (Filton, Bristol UK) a non-dimensional analysis of fluid properties impacting slosh

damping and corresponding sensitivity study aims to provide insight for the future scaled experiments as part of the continuing project. Employing Elemental® CFD Code as a high-fidelity simulation tool the impact of the selected non-dimensional numbers is quantified for the expected natural excitation frequency of a single-aisle airliner wing.

Prediction of energy dissipation in violent sloshing flows by Smoothed Particle Hydrodynamics

Salvatore Marrone, Javier Calderon, Jon Martinez, Matteo Antuono, Andrea Colagrossi

In the framework of the H2020 SLOWD project the damping effect of violent fuel sloshing on the dynamics of wings subjected to wind gusts is studied. In fact, if accurately evaluated fuel slosh can be taken into account to reduce the design loads on aircraft wing structures. To this aim Computational Fluid Dynamics (CFD) can be used along with physical models to assess the amount of mechanical energy dissipated by the liquid during its sloshing motion. This represents a quite challenging task for CFD tools, the flow being extremely complex due to violent impacts and intense fragmentation of the air-liquid interface. Among the different numerical methods, the Smoothed Particle Hydrodynamics (SPH) can be a good candidate for such a problem due to its meshless Lagrangian character, which allows to accurately resolve the evolution of liquid interfaces, and its intrinsic conservation properties.

Notwithstanding that, the SPH approach to the problem suffers from some numerical issues which need to be carefully addressed before tackling the problem at hand. To this aim in the present work new models are described and applied to the SLOWD sloshing problem. The focus of the analysis is on the energy balance of the mechanical system, i.e. the oscillating tank and the sloshing liquid. In this first stage of the project the motion of the tank is imposed, the fully coupled system being addressed in a more advanced stage of the project.

The study shows that single phase simulations confirm that the presence of liquid in the tanks attached to flexible structures introduces a damping effect that can be numerically measured in terms of energy dissipated by the fluid.

R&D Research in the Field of Aeronautics & Air Transport: ENABLEH2 Project Session

Session Chair: Dr. Vishal Sethi, Cranfield University, UK

Enabling Cryogenic Hydrogen-Based CO2-free Air Transport (ENABLEH2)

Bobby Sethi

Liquid Hydrogen (LH2) has the potential to completely decarbonise civil aviation. At the moment this is a minority view within the industry, mainly due to the anticipated higher costs. But considering heightened environmental awareness emissions taxation scenarios, and the sheer necessity of transformation, the cost of transition will be relatively modest for such a fundamental, long-term solution. Flightpath 2050 targets very ambitious emissions reductions, relative to year 2000. It will be extremely challenging to meet these targets with carbon-based fuels, despite large research efforts on disruptive airframe and propulsion technologies, even when coupled with improved asset and lifecycle management procedures. Even if we were able to meet these targets, this would not be sufficient for a fully sustainable future for civil aviation, particularly considering the rate at which other sectors are decarbonising. ENABLEH2 is providing thought leadership through revitalising enthusiasm in LH2 research for civil aviation by maturing key technologies to achieve zero mission-level CO2 and ultra-low NOx emissions, with long term safety and sustainability.

The key technologies being researched and matured are H2 micromix combustion and fuel system heat management. As part of the overall technology evaluation, a suite of models is being developed to evaluate LH2-fuelled aircraft with respect to energy efficiency, emissions, life cycle CO2 and costs, for potential fuel price and emissions taxation scenarios. The benefits and economic viability of LH2 will be quantified relative to best-case scenario projections for Jet A-1, Biofuels and LNG. ENABLEH2 is also generating best-practice safety guidelines for LH2 at aircraft, airport and operational level and will also deliver comprehensive roadmaps for the introduction 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 industry advisory board. A brief introduction of the presentations for the session will also be provided namely:

1. Progress in Ultra-Low NOx Hydrogen Micromix Combustion Research in ENABLEH2
2. Development of fuel and heat management systems for liquid hydrogen powered aircraft
3. Control and Assessment of Hydrogen Explosion Hazards on Aircraft and Airports – ENABLEH2 laboratory studies and large scale release consequence modelling
4. Evaluating and roadmapping hydrogen propulsion in the ENABLEH2 project
5. Low risk technology proposals for early adaptation of LH2 on board civil aircraft – implications of hydrogen fuel tank gravimetric efficiency assumptions on overall aircraft design.

Progress in Ultra-Low NOx Hydrogen Micromix Combustion Research in ENABLEH2

Xiaoxiao Sun, Bobby Sethi, Pierre Gauthier

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 NOx 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 NOx 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 NOx 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 NOx 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.

Development of fuel and heat management systems for liquid hydrogen powered aircraft

Carlos Xisto, Isak Jonsson, Tomas Grönstedt

The presentation describes the recent developments in the design of the fuel and heat management systems for liquid hydrogen powered aircraft within the H2020 project ENABLEH2. The fuel distribution system main task is to deliver the right amount of hydrogen to the combustion chamber at an adequate pressure. This requires the usage of fuel pumps, valves, insulated piping, and a fuel control system to adjust the fuel flow for a given engine rating. Moreover, since liquid hydrogen is stored at cryogenic temperatures (-253C), it also requires the integration of heat exchanger technology to increase the fuel temperature up to a state where it can be efficiently mixed with air and combusted. The combination of hydrogen high specific heat with cryogenic temperatures results in formidable cooling capacity that can be explored by compact heat-exchanger solutions. Concepts that use existing engine aero-surfaces located after rotating turbomachinery are currently being investigated a Chalmers University of Technology.

A recently commissioned facility to investigate the potential benefits of a compressor flow cooling heat rejection system will also be discussed. The test facility comprises a vertically mounted low-speed 2.5 stage compressor designed to operate continuously at rotor mid-span chord Reynold number up to 600,000, which is representative of a large-size future geared turbofan engine. Detailed aerothermal studies at TRL4 will be conducted to calibrate in-house design methods for radical core integrated heat exchangers. The facility is driven by a 147kW electric drive at a nominal speed of 1920 RPM. Traverse access is included in two 18-degree sectors for all the rotor-stator interfaces. At the upstream plane of the compressor outlet-guide-vane, four independent access traverse systems are included for a 360-degree access. Downstream, an ABB robot arm with a U-shaped probe mount provides full volume probing access in the exit compressor duct.

Control and Assessment of Hydrogen Explosion Hazards on Aircraft and Airports – ENABLEH2 laboratory studies and large-scale release consequence modelling

Paul Holborn, Claire Benson, James Ingram

Over the next few decades air travel is predicted to grow significantly and based on current fuel type, International Civil Aviation Organization (ICAO) project emissions from aviation are estimated to be seven to ten times higher in 2050 than in 1990. At the same time emissions from other sectors such a power and ground based transportation are projected to fall. The use of liquid hydrogen (LH2) as a fuel can potentially enable civil aviation to deliver zero CO2 and NOx emissions and offer a long term sustainable solution. There are, however, safety concerns.

In relation to LH2 systems on aircraft, even small leaks/releases into confined spaces can have serious consequences. In addition to making systems as reliable as reasonably possible it is probable that additional measures will be required to reduce the explosion risk which may include measures such as ventilation, inerting, explosion venting, ignition source control, etc. To facilitate design/evaluation of such measures the ENABLEH2 project is currently conducting research to experimentally quantify a number of key flammability parameters under simulated high altitude conditions.

With regards to airports, LH2 storage and re-fuelling systems, the main safety concern is with potential accidents/failures resulting in large LH2 releases. To examine the consequences of large releases the ENABLEH2 project is using FLACS Computational Fluid Dynamics (*CFD) modelling* to simulate the potential hazard effects following an accidental LH2 leak, including the extent of the flammable LH2 clouds formed, magnitude of explosion overpressures and pool fire radiation hazards for a range of scenarios. These include airport LH2 storage leaks, aircraft LH2 tank rupture/failure and a LH2 leak occurring during aircraft refueling operations.

This work reports on the current status and findings of the ENABLEH2 laboratory and FLACS modelling work in support of aircraft and airport safety.

Evaluating and roadmapping hydrogen propulsion in the ENABLEH2 project

Anders Lundbladh, Andrew Rolt, Devaiah Nalianda

In the early phases of technology development, the formulation of product requirements must be integrated with selection of technologies. In ENABLing cryogEnic Hydrogen based CO2 free air transport (ENABLEH2) the project consortium is attempting to develop key propulsion technologies for a high subsonic speed airliner fueled by liquid hydrogen. Due to the large impact the required fuel system and tanks has on the airframe, it was necessary also to select and characterize a number of aircraft as well as its operation and required infrastructure. The thus developed models serve as platforms to derive requirements on the propulsion system. Further, the models serve as tools for comparative evaluation and optimization of propulsion system technologies in terms of energy use, environmental impact and operational cost. In the course of ENABLEH2 the technology readiness for aircraft and infrastructure will reach levels of one (basic principles) and two (concept) whereas some aspects of the fuel system and combustion system will be brought to level three (proof-of-concept). In the 2030s these technologies could be brought to level six (demonstration in relevant environment), which is the industry benchmark for start of commercial product launch and development. This would allow a hydrogen aircraft to enter service between 2040 and 2050. To develop a roadmap of hydrogen technology the project consortium has been extended with an advisory board composed of representatives from engine manufacturers, airframers and aviation organizations. Eleven technology areas and an integrating activity were identified in the first round as necessary to complete the development goals. The areas include the required elements of the propulsion system, aircraft configurations, air and ground operation, infrastructure, the direct environmental effect of the aircraft and the extended impact of the air transportation system. The presentation will provide an update of the models of the selected aircraft configuration and a description of the first iterated version of the technology development roadmap.

Low risk technology proposals for early adaptation of LH2 on board civil aircraft – implications of hydrogen fuel tank gravimetric efficiency assumptions on overall aircraft design

Jon Huete, Devaiah Nalianda, Pericles Pilidis, Bobby Sethi

Given the continued growth of civil aviation, introduction of new propulsion technologies, aimed and optimised specifically for lower climate impact, are necessary. However due to high investment levels and safety critical aspects of the technology inherently associated with aviation, the process of technology adaptation is complex and expensive. Creative solutions are therefore necessary to scale down investment and complexity, while accelerating the transition of the aviation industry towards a dramatically lower environmental footprint. This presentation is based on recent research undertaken to explore design options that may be considered while adopting a low risk / high pace approach in conceptualising a civil aircraft that could use hydrogen as fuel on board to achieve zero CO2 emissions at mission level. The research presented initially introduces the possibility of designs based on advanced conventional (currently in service) aircraft designs to achieve this goal. The work utilises well-established analytical methods to identify and optimise successful combinations of aircraft components, which are based on existing aircraft (primarily used on medium and long range routes) to eventually present novel design variants.In order to cater for the utilisation of hydrogen as a fuel, the work assumes the storage of liquid hydrogen in special cryogenic tanks. Due to the specific storage requirements of cryogenic fuel (in terms of pressure and low temperatures), these tanks are heavier and significantly more complex in terms of integration requirements, when compared with conventional fuel (kerosene). A special metric termed

as the Gravimetric efficiency is frequently used to assess the suitability of a tank design in the context of the design of the overall aircraft. This efficiency, essentially being the ratio of the fuel carried on board to the overall weight of the fuel system (a sum of the fuel, tanks and associated accessories), when assumed has a significant effect on overall aircraft design, and hence weight and performance. The focus of this presentation is to therefore discuss the overall design process adopted for the study, and to demonstrate and highlight the critical effects of tank gravimetric efficiency assumptions on aircraft design. Finally, based on the design philosophy adapted and an assumed gravimetric efficiency of 0.45, preliminary results of the design exercise are finally presented for three aircraft variants. These include configurations for medium range (350+ passengers and a range of 3,300 nm), long range (300+ passengers and range of 4,800 nm) and an extra-long range variant (200+ passengers and range of 5,600 nm).

R&D Research in the Field of Aeronautics & Air Transport: HOMER Project Session

Session Chair: Prof. Dr. Andreas Schröder, German Aerospace Center (DLR), Germany

HOMER - Holistic optical metrology for aero-elastic research

Andreas Schröder, Benjamin Leclaire, Bas van Oudheusden, Ludovic Chatellier, Christian J. Kähler

The H2020 HOMER project is developing advanced optical metrology techniques and methodologies for testing in (industrial) wind tunnels and achieving breakthrough research on aerodynamics and aero-elasticity in order to increase the understanding of unsteady flows around air vehicles and wings, the related load distributions and induced dynamical forces around and within the exposed structures. Furthermore HOMER will produce benchmark numerical and experimental data sets which are ideally suited for comparison with and validation of advanced coupled CFD-FEM/CSM codes which are recently under fast development for flows coping with the problems of unsteady Fluid Structure Interaction (FSI). A main aim of HOMER is the development of advanced experimental methods that enables the delivery of volumetric flow field and dynamic surface deformation data in a holistic manner needed for a better understanding of unsteady flows and aeroelastics. Such experimental data are required for validation and development of improved numerical tools including FSI simulation that will be used e.g. for innovative and lightweight aircraft design with improved energy efficiency and environmental performances. The state-of-the-art of experimental analysis techniques approach the above problems by splitting the system into fluid and structure parts, where distinct methodologies are available that characterize the fluid motions (Particle Image Velocimetry (PIV) and Lagrangian Particle Tracking (LPT)), the related loads (pressure taps, pressure sensitive paint, pressure from PIV/LPT) and the structural deformation and modes of vibration (Digital Image Correlation, advanced point tracking, strain gages, accelerometers). Coupling of the above techniques has been achieved during the project at high complexity of the scaled (flexible) model instrumentation and installation. As a result, techniques allow crossing the information from fluid and structure diagnostics. The ambitious objective is set to obtain the experimental data that will close the dynamic FSI equations: the unsteady Collar triangle of forces. The HOMER project consortium consists of seven partners from four European countries, two from national research agencies, three from academia and one SME. The structure of the project and an overview of the goals and aims of the five work packages will be presented together with an insight into some important project results and developments from the first project period.

Numerical benchmarks for assessment of fluid-structure optical metrology and data assimilation algorithms

Benjamin Leclaire, Andrea Sciacchitano, Andreas Schröder

In the H2020 HOMER project, a workpackage is dedicated to the development and performance assessment of processing tools for fluid-structure optical metrology. This includes approaches for fluid (e.g. Lagrangian Particle Tracking, LPT) and solid (e.g. Digital Image Correlation, DIC) characterization, as well as data assimilation (DA) algorithms, which allow to augment the capability of these techniques, for instance in terms of spatial or temporal super-resolution, and in model estimation. Research efforts within the workpackage also pertain to the development of associated uncertainty quantification (UQ) methods, in order to allow assessing confidence in the final experimental results.

A central tool in the optical metrology community to help derive and assess such approaches is the use of synthetically generated data, mimicking as best as possible actual data that would have been obtained experimentally. Within the HOMER project, a dedicated fluid-structure simulation was performed, considering a turbulent flow over a moving panel. Flow has been resolved using Large Eddy Simulation (LES), while a realistic motion of the panel, obtained from preliminary structural dynamics computations, has been prescribed by use of the Arbitrary Lagrangian Eulerian method. From this high-fidelity simulation, synthetic LPT and marker images have been generated by computing the trajectories following the fluid (resp. solid) motion of randomly located particles (resp. markers). In this contribution, after a presentation of this benchmark generation, and of its links and relevance with experiments performed within the project, we will detail how the result processing can help characterize the performance of the algorithms, by introducing the quantities examined for assessment. This will help understand the goals and stakes of the fluid-structure estimation approaches derived within HOMER. Also, we will introduce the 1st LPT and DA challenge, which has been derived from the present benchmark, by considering the simplified case of a fixed panel. This ongoing international competition, whose results will be presented November 19-20, 2020 in Paris during the 3rd CFD for PIV workshop (http://cfdforpiv.dlr.de/), will help provide current status of the state-of-the-art in the domain of LPT and DA methods for advanced flow characterization.

Addressing the aero-elasticity problem for MAVs

Hortense Laeuffer, Daniel Diaz, JeanChristophe Dupré, Pascal Doumalin, Jean-Claude Grandidier, Marco Gigliotti, Frédéric Pons, Laurent David, Ludovic Chatellier

Micro-air vehicles (MAVs) operate at low to very low Reynolds numbers, at which conventional thrust and lift devices show poor performance. At such regimes, alternative flight solutions can be derived from the understanding of insect or small birdsâ€™ flapping flight, in which efficient aerodynamic and aero-elastic strategies have been developed. Addressing the aero-elasticity problem for MAVs requires a thorough understanding of the response of the wing structure to the fluid, structural, and inertial loads taking place in Fluid-Structure Interactions (FSI) phenomena, namely, closing the Collar triangle. In order to do so, this study focuses on the behavior of a flexible polymer wing operating in flapping flight conditions. The first step of the study consists in the characterization of the material and its mechanical behavior. soft material – polyurethane – has been selected in order to cast the flexible wing, which behavior is strongly dependent on time and sensitive to water adsorption and ageing. Tensile and creep tests were performed on tensile specimens in water, along with a quantification of the swelling due to water adsorption. Results show that the behavior is stable at room temperature (no risks of rubber-glass transition) and remains elastic for strains below 5% of elongation. However, swelling induces an increase in volume up to 1.5% with moisture and ageing results in a 10% decrease in the Young's Modulus after three weeks spent in water. These conclusions bring two constraints for performing reliable experiments, i) modelling swelling and stiffness variations, ii) tailoring the FSI experiment to limit the effect of long immersion times on the material properties.The flexible polymer wing is then subjected to a periodic flapping motion in a water tank at Re=10Â³ to mimic the behavior of micro-aerial vehicles. Both solid and fluid optical diagnostics are conducted to track the three-dimensional fluid motion and the structure's displacements, in order to educe the fluid, inertial and structural forces during the flapping cycle. The influence of the wing deformation on the flapping flight performances are then compared to the baseline case of a rigid wing.This project has received funding from the European Union's Horizon 2020 research and innovation

program under grant agreement No 769237 HOMER "Holistic Optical Metrology for Aero-Elastic Research".

High Speed Air Vehicles (PART I)

Session Chair: Dr. Nicole Viola, Politecnico di Torino, Italy &
Dr. Catalin Nae, INCAS - National Institute for Aerospace Research, Romania

Dynamic Control for Tailless High-Speed Aircraft Configuration

Catalin Nae

It is a basic fact that the demand of high performance characteristics has led to aerodynamically unstable aircraft configurations in part of all of their regimes in the flight envelope. Although unstable aircraft can be flown only with the aid of a flight controller (i.e. in a closed loop), determination of the aerodynamic characteristics of the basic aircraft (i.e. of the open-loop plant) is still of primary interest in the advanced design in order to achieve airworthiness compliance. However, Increased maturity of key technologies for sustainable high speed/supersonic flight makes possible development of a new generation of design and optimization tools extending current philosophy with respect to the stable aircraft. However, this conceptual design and optimization is very different, since this is performed without traditional knowledge base and validation history, and, most important, when morphing and/or dynamic mass allocation is considered. A tailless high speed aircraft optimized configuration is a major challenge for current airworthiness regulations. Basically the vertical stabilizer provides stability in yaw to conventional aircraft and the size of the vertical tail of multi-engine aircraft is driven by the need to counteract the yawing moment due to a failed engine. However, no dedicated maneuverability capabilities in high speed/supersonic regimes is needed for transport a/c due to the very high loads, so vertical tail is mainly needed for take-off and landing and/or special maneuvers. Also, if one takes into account that it is heavy, with strong Impact on structural systems and/or space allocation requirements, major interference problems in high speed/supersonic regimes and wetted surface problems (e.g. thermal protection), than we make a strong case introduction mature technologies like blowing flaps/surfaces, morphing structures and real time internal mass transfers as possible solution for new dynamic stability and control.

From direct analysis using 6 DOF model for the coupled motions, we define the strategy to control a new design (tailless configuration) able to achieve anti-spin from combined morphing (forcing the inner wing down relative to the spin axis and avoid tilting the outer wing down) and generating gyroscopic “cross-couple” inertia effect to terminate the spinning motion using real time mass dynamics allocations. A reference configuration is used as starting point, so that a derived optimized tailless configuration is than assessed. Some reference aerodynamic data is provided from work performed in an EU project, where a dedicated wind tunnel test program was performed. Extending this database using theoretical models is part of the current presentation. Also, based on a proposed internal mechanical structure and system architecture, innovative dynamic mass allocation mechanisms are introduced, so a first set of results are presented for the dynamic characteristics of a tailless SST. In this presentation we conclude with respect to the real benefit and various implications from proposed methodology with respect to a future SST able to meet dynamic stability requirements. New generation high speed aircraft configurations should be based on such key technologies in the optimization process having the power to demonstrate benefits and change current airworthiness regulations.

STRATOFLY H2020 MR3: CAD Design Overview

Enrico Viola, N. Viola, D. Ferretto, R. Fusaro

This paper aims at presenting the last updates of the configuration of the STRATOFLY MR3 vehicle, a hypersonic airliner capable of cruising at Mach 8, currently under development in the framework of the Horizon 2020 STRATOFLY Project. Major improvements of the current vehicle configuration encompass the external skin up-scaling, the redesign of empennages and control surfaces, detailed design of air-intake leading edge and integration of main subsystems and of the preliminary structural elements.Starting from an already well-defined baseline and outer mold line, inherited from previous EC-funded project (LAPCAT I-II, HEXAFLY, HEXAFLY-INT, etc..), the STRATOFLY team has recently performed a scaling up of the entire model mainly to guarantee the possibility to implement a double wall architecture without reducing the internal flow-path of the engine and to better accommodate crucial on-board subsystems. Details on the trade-off for the selection of the up-scaling factor will be reported.Then, special attention will be devoted to the design, trade-off and implementation of control surfaces which had to be re-designed according to specific parameters of maneuverability yield by the aerothermodynamic and stability analysis performed by CIRA. With respect to the initial baseline configuration, a new version of the flaperons, two independent ones per each wing, and of the V-tail rudders were designed and analysed. In addition, an utterly new concept of the nozzle flaps was developed in order to obtain sufficient static and dynamic stability throughout the mission, from subsonic to supersonic and hypersonic speed regime. In fact, aerodynamics analyses underlined that the present control surfaces configuration would not allow the aircraft to be trimmed effectively, hence an increment in the control surfaces effectiveness was required. These new nozzle flaps are capable of moving upward only and they reach a maximum angle of extension of 20 degrees. The re-introduction of canard (all movable surfaces) is on-going as well. Another important area of improvements relates to the detailed design of the air-intake leading edge. In order to implement solutions that allows the vehicle to sustain the heat fluxes which the aircraft undergoes throughout the mission phases, a new system of liquid metals heat pipes have been designed and implemented. The heat pipes run parallel to the x-axis of the aircraft, were implemented on both the upper and lower leading edge of the inlet. More specifically on the upper leading edge are implemented 40 heat pipes with spacing of 4 centimeters, in order to withstand higher temperatures (T=1800 C), while on the lower leading edge just 20 heat pipes are implemented with spacing equal to 40 centimeters since the temperatures are slightly lower in this area (T=1400 C). The currently implemented concept has been developed after a set of iterations with the aerothermodynamics experts. Scope of this endeavor was to enable the aircraft to fly at high speed without suffering from high temperatures problem at the inlet, which has been preliminarily identified as the more critical area. Many feasible concepts were envisaged at the very beginning, but eventually the solution with double-wall co-axial pipes made by Nichel and Potassium has been adopted and implemented.Finally, the paper will also provide an overview of the main integrated subsystems, such as the cryogenic tanks, the passengers deck, the landing gear and the major structural components.

Advanced propulsion cycle design and analysis for STRATOFLY MR3

Bayindir Saracoglu

Modern aviation ecosystem pushes the industry to develop new airplanes which fly faster and cleaner without compromising efficiency. In this perspective, hypersonic aviation can address such needs by

reducing the flight time an order of magnitude for the long-haul routes. European Commission funded STRATOFLY project aims at developing a hypersonic aircraft which cruises at Mach 8, carries 300 passenger and flies at stratospheric altitudes as high as 35 km. The propulsion system stands for the most critical component for such an ambitions flight mission. In order to be economically viable and ensure reusability, the vehicle should be powered by air-breathing engines through the complete flight trajectory. This new aircraft concept, called STRATOFLY MR3, will be propelled with a combined cycle power plant composed of six air-turbo rocket (ATR) and a dual-mode ramjet / scramjet (DMR) engine. The ATR engines are used to take-off and accelerate the aircraft to supersonic speeds from the idle. Then the DMR engine kicks in ramjet mode to provide extra thrust to contribute the acceleration of the vehicle further up to Mach 4-4.5. Finally, the ATR engines are shut down and DMR engine, in scramjet mode, provides the required thrust to achieve hypersonic speeds and power the aircraft at nominal cruise conditions. Hydrogen is used as the single fuel throughout the entire flight duration for both ATR and DMR engines of STRATOFLY MR3. Detailed thermodynamic analysis and optimization of the engine components are required to ensure seamless operation of the propulsion system. There are strong interdependencies amongst various elements of the engine. Heat regeneration from the exhaust stream through fuel system is essential to drive the turbo components. Therefore, the optimization of the heat-exchangers located around the combustion chamber and the propulsive nozzle has been accomplished in conjunction with sizing of turbomachinery parts as well as throttling conditions of both engines throughout the complete ascend trajectory of the vehicle. Figure 1 clearly shows the complexity and the interactions between different engines and engines components on a simplified schematic of the combined cycle power plant of MR3. The current work aims at summarizing the efforts devoted to optimize the engine components and their working conditions for an extended flight trajectory from the take-off till hypersonic speeds.

STRATOFLY MR3: analysis of operational procedures for a high-speed aircraft

Oscar Gori, N. Viola, R. Fusaro

This presentation aims at displaying a thorough analysis of the Concept of Operations and operational procedures for the STRATOFLY MR3 vehicle, a Mach 8 waverider aircraft, currently under investigation in the field of the Horizon 2020 STRATOFLY MR3 Project. The development of proper operational procedures comes as a result of a multidisciplinary study. This study is performed in order to identify which solution could guarantee the best compromise among different fundamental aspects: safety, environmental emissions, noise, cost, etc. Specifically, in this context, special attention devoted to the vehicle performance during specific operational procedures, such as take-off and landing phases. The STRATOFLY MR3 vehicle is supposed to operate within existing airport infrastructures, and the compliance of take-off and landing requirements from current existing airports shall be guaranteed. The evaluation of required take-off and landing distances and the comparison with the present airport runways shall be performed. Moreover, from a general perspective, the conformity with the present regulations and safety levels required for the subsonic transport aircraft shall be evaluated. Main operational challenges related to vehicle performance in airport proximity and during the whole mission shall also be taken into account. In addition to that, operational procedures will be defined in an attempt to reduce the environmental impact on ground (attenuation of sonic boom) as well as on the atmosphere (reduction of pollutant emission and greenhouse gases mitigation). Moreover, the set of requirements related to human factors shall also be considered, focusing for example on the limitation of the acceleration loads. Eventually, when it is not possible to satisfy the requirements, an analysis of the changes required in the operational procedures shall be considered. As it happened for the Concorde, the list of changes for the operational

procedures will constitute a solid technical basis for the negotiation of ad-hoc operational procedures to be adopted for the in-coming future high-speed vehicles.

High Speed Air Vehicles (PART II)

Session Chair: Dr. Nicole Viola, Politecnico di Torino, Italy &
Dr. Catalin Nae, INCAS - National Institute for Aerospace Research, Romania

Sustainability Key to Reinventing Commercial Supersonic Flight

Andreas Hardeman, Dr Lourdes Maurice

The 2020 Covid-19 global pandemic has shocked the aviation system to its core, reminding us first hand what the loss of this economic engine can do to the world's economies and societies. But the crisis also presents an opportunity in that it can be leveraged to create new capabilities and outlooks. Supersonic aviation can be part of that future in a sustainable manner. While fuel efficiency and noise performance have continuously improved for subsonic aircraft, similar gains have not yet been realized to benefit civil supersonic aircraft development. However, advanced computational designs, propulsion systems, materials, and route optimization have convinced a new generation of supersonic OEMs and entrepreneurs, including Boom, that the economic and environmental challenges that once plagued Concorde can be successfully overcome.Boom's ultimate goal is to make high-speed air travel accessible to millions of passengers per year. Projections of business-class airline demand suggest a total market of 1,000 to 2,000 commercial high-speed aircraft operating on more than 500 primarily transoceanic routes that benefit from speeds twice as fast as today's aircraft. Current technology allows for a supersonic airliner that is economically viable at business-class fares. Boom is dedicated to driving down fares on future aircraft, making the fastest ticket the most affordable.Given the increased awareness of aviation's environmental impact, bringing a new aircraft to market in the 2020s requires a careful focus on sustainability. To win public acceptance high-speed aircraft manufacturers and operators will have to proactively engage to address stakeholder concerns and focus on integrating sustainability solutions across their business strategies. Boom is the first commercial OEM to build sustainability into its aircraft programs from day one, meaning that sustainability considerations form an integral part of every aspect of the production process. A sustainability commitment to cover every step in the aircraft development cycle, from design and test through in-service operations and end-of-life recycling is seen as the key to successfully reinventing commercial supersonic flight in the years ahead.

Climate Impact of Hypersonic Transport

Volker Grewe, Emmerig, Johannes, Hauglustaine, Didier, Cohen, Yann

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, and NOx, and regard effects on atmospheric changes of CO2, H2O, O3, CH4, and contrails.

Hypersonic Airbreathing-Propelled Vehicles

Marco Marini

After an introduction to high-speed airbreathing propulsion systems, their motivations and the main technical advantages and drawbacks of the different systems (ramjet, scramjet, combined with more conventional turbojets) with respect to the flight application and targets, the paper is devoted to a historical description of the scenario of hypersonic airbreathing-propelled vehicles, either from an international point of view either from an European point of view, starting from the first hypersonic flights of US North American X-15 at the end of 1950s till the last technology development projects co-funded by the European Commission in the last fifteen years.The paper will focus on the main characteristics and aero-propulsive performance of this kind of aerospace vehicles, giving in some cases interesting details about the disciplines involved in the design: aerodynamics and aerothermodynamics, propulsion, flight mechanics, guidance navigation and control, materials, structures, thermal protection systems, thermal energy management, avionics, in-flight experimentation, strategies to reduce pollutant and noise emissions in both landing and take-off cycle and cruise cycle, and to improve the overall aircraft efficiency.USA were undoubtedly the driving nation in the development and flight testing of hypersonic airbreathing-propelled vehicles, but during the last two decades Europe has matured competencies in the design of hypersonic vehicles equipped with airbreathing propulsion by means of several EU-funded projects, allowing to some state members (and European Space Agency) to play important roles (Germany, France, Italy, Belgium, United Kingdom, etc.). As a results, two European hypersonic flight demonstrators should fly in the next years, thus allowing to demonstrate the technical feasibility of concepts and technologies for hypersonic flight, and to increase the TRL of some breakthrough technologies suitable for future high-speed civil transportation systems.

Hypersonic and suborbital vehicles integration in air traffic

Marc Vales, Marie-Christine Bernelin, Christophe Giraudeau

The anticipated operations in the higher airspace represent an emerging market like for the early days of aviation where providing rules, including structural procedures regarding traffic and operations management, is now considered as the key enabler of this international business dedicated to quicker connection of people worldwide. Hypersonic aircraft, trans-atmospheric and suborbital new type of vehicles, and new type of operations generate also service needs and related technologies in order to fairly and safely manage air traffic. The paper will give an overview on expected types of vehicles and operations, phases of flight, nominal and non-nominal situations with respect to traffic management environments, raising related open points and technology gaps to overpass.

Integration of high-speed operations into the European ATM network

Dragos Tonea

A safe, efficient and secure integration of high-speed operations into the European ATM network is essential to ensure operational and social acceptance. Traditional ATM systems have been designed to manage sub-sonic aircraft through a raft of tools - operational procedures, CNS capabilities, data-processing systems, etc.-deployed either at national or regional level. Europe has moved towards a region-wide network centric approach in areas that require a trans-national approach and has identified several network functions deployed seamless in the European airspace that ensure a region wide approach towards: planning, disruption and crisis management, scarce resource management and

infrastructure monitoring. Incorporating new airspace users, including high-speed operators, will require strategic decisions allowing the European ATM network to develop the necessary capabilities needed to ensure sustainable growth, minimise the environmental impact and interface with non-aviation actors such as space agencies at operational level. A new level of integration and interoperability must be considered to ensure that increasing number and frequency of high-speed operations are met with sufficiently robust capabilities that allow for High-speed operations, including commercial space launch/re-entries and hypersonic flights will pose distinct challenges in areas such as management of non-nominal scenarios (e.g. debris protection for major aviation flows), arrival/departure integration with sub-sonic aircraft, air defence, etc. The interface between the European air traffic management network and the space traffic management systems will have to be considered with a view to address safety and security challenges whilst ensuring growth perspectives for the European industry.As high-speed operations are emerging in various regions of the world, the European ATM network needs to change and adapt to operational scenarios that have not been considered in the traditional aviation context. Operational procedures and system capabilities need to be adapted to meet these new requirements in a manner that ensures scalability, flexibility and adoption of digitalisation and automation. All elements of the ATM system, including airspace design, infrastructure such as CNS or airports/spaceports, have to be evaluated as regards the suitability to accommodate high-speed operations.in a manner that does not disproportionately affect the performance of the existing European ATM network.Fair and equitable access to airspace, contingency management and integration between ATM (Air Traffic management) and STM (Space Traffic management) systems are key priorities for a safe, efficient and secure integration of high-speed operations in the European ATM network.

Aerostructural Materials (PART I)

Session Chair: Prof. Roberto Pantani, University of Salerno, Italy

Understanding the Role of Graphene on the Moisture Absorption in Graphene/polymer Nanocomposites

Faisel Almudaihesh, Haya Alfaris, Perminder Sangha, Rhys Pullin, Mark Eaton

Composite materials such as fibrous/polymeric composites are attractive materials for applications in the aviation industry due to their excellent strength and stiffness to weight ratios as well as their capability to resist corrosion. In aerospace, materials are exposed to extreme environments such as moisture absorption, pressure variation and impact. It is therefore essential to understand their behaviour under these conditions. Many studies have been carried out to understand the role of moisture absorption on the performance of fibrous composites. More recently, nanocomposites have attracted interest from the aerospace sector for their potential to enhance the mechanical properties and further reduce weight. Examples include the addition of graphene in the resin matrices of the Airbus A350 horizontal tail leading edge. This study focuses on understanding the role of adding graphene to epoxy resin on the moisture absorption behaviour. Specimens with pure epoxy resin, epoxy resin with functionalised graphene, and epoxy resin with unfunctionalised graphene were manufactured and exposed to 90°C purified water for 30 days. The flexural and tensile properties were observed for both unaged and aged specimens. Figure 1 presents the mass change due to moisture absorption, and Figures 2-3 present the observed mechanical properties for all unaged and aged specimens. Lower mass change values are observed for graphene enhanced specimens as compared with pure epoxy resin which indicates that graphene could act as potential barrier to moisture ingress. Despite the lower mass gain observed the properties of the nanofilled resins exhibit a larger reduction in properties following water absorption. It is hypothesised that this effect is correlated to moisture degradation at the interfacial graphene/polymer regions leading to potential reduction in stress transfer.

Stress relaxation of thermal stresses developed in the curing cycles of carbon fibers-epoxy laminates

Alfonso Maffezzoli, Francesco Nicassio, Francesca Lionetto, Gennaro Scarselli

The effect of the curing cycle on the thermal stresses developed in a composite laminate is strictly related to the final shape of a composite part, a key feature for its acceptance and further assembly operations. However, stress relaxation, either during cooling from curing temperature, either at room temperature can play a key role on the final shape of composite laminates. The stress relaxation behaviour of carbon fibre reinforced composites for aeronautical applications, exposed to elevated temperatures at a constant strain level, has been studied and modelled, accounting for the anisotropy of these materials. In particular, specimens, cut with an off axis angle of 90° and from +45° from AS4/8552 laminates cured in autoclave have been tested. The time dependent shape change behaviour has been also observed adopting a [0/90] non-symmetric lay-up, are characterized by two stable curved shapes, so being bistable. The curvature changes of rectangular bistable plates were monitored at room temperature by a laser scanner system over a time span of ten days. These changes were ascribed to the relaxation of thermal stresses over time. Anisotropic stress relaxation behavior was then studied looking at the matrix dominated properties, such as the transverse modulus in accelerated high temperature experiments. Then, a simple viscoelastic

model was proposed together with a Finite Element Analysis of the distortion arising from laminate cooling at the end of high temperature curing processes. Room temperature and high temperature stress relaxation data were correlated leading to a deeper understanding of the basic mechanisms underlying the shape change of composite laminates.

Supramolecular chemistry applied to structural materials

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

In the field of aeronautical structures, one of the current challenges is to produce multifunctional composites that meet many of the typical requirements needed for structural materials, such as good electrical conductivity and high impact damage resistance. Many approaches have been proposed to achieve this target and, among these, the strategy based on supramolecular chemistry turned out to be one of the most interesting and successful. This work proposes the use of carbon-based functionalized nanofillers that, dispersed in a structural epoxy matrix, are able to confer electrical properties and self-healing ability to the matrix, due to their ability to establish supramolecular non-covalent interactions with the host environment. This ability makes the nanofillers capable of generating a composite material with high potentiality to meet industrial requirements, as highlighted by the performed characterizations.

An extensive mechanical test campaign on nanocrystalline materials for aviation and space applications

Panagiotis Bazios, Konstantinos Tserpes, Spiros Pantelakis, Nikolaos Michailidis, Konstantinos Katakalos

Nanocrystalline metals have attracted considerable interest over the past two decades due to their unique mechanical properties, which are highly sensitive to their microstructure[32] [33]. Due to several barriers for producing big quantities of this class of materials, such as the thermodynamic instability because of the Gibbs free energy monotonic reduction, experimental test campaigns for the investigation of mechanical properties of nanocrystalline materials remain up to now limited. In a recent research project[34], sufficient quantities of Tungsten-Copper, Tungsten-Aluminum and Titanium-Aluminum nanocrystalline alloys were produced allowing for an experimental test campaign. The Tungsten-Copper and Tungsten-Aluminum alloys are attractive for space applications, such as irradiation shielding at space enviroment, while the Titanium-Aluminum alloys are used on primary parts of aircraft and space vehicles. In this work, a mechanical test campaign has been performed including compression, hardness and nanoindentation tests. The mechanical tests were supported by SEM/TEM analyses to obtain information about the influence of the nanocrystalline material features, powder sizes and volume fractions of the alloying elements on the material's microstructure and its resulting mechanical behaviour. The effects of porosity on the mechanical behaviour have been accounted for. The experimental results of this work were compared with the corresponding experimental results of the microcrystalline counterparts of the alloys.

[32]Kumar, K., Van Swygenhoven, H. and Suresh, S. (2003). Mechanical behavior of nanocrystalline metals and alloys. Acta Materialia, 51(19), pp.5743-5774.

[33] Meyers, M., Mishra, A. and Benson, D. (2006). Mechanical properties of nanocrystalline materials. Progress in Materials Science, 51(4), pp.427-556.

[34] ICARUS (2016) Innovative Coarsening-resistant Alloys with enhanced Radiation tolerance and Ultra-fine-grained Structure for aerospace application. Project's Public Final Report, Grant agreement No. 713514, Funded under European Union's Horizon 2020 research and innovation programme

The results underline the potential of nanocrystalline materials for being implemented in space and aircraft structural applications.

Comparison between Selective Laser Melting and Conventional Maraging Steel in Corrosion-Fatigue Performance after various surface and heat treatments

Apostolos Arvanitidis, Fotis Kazelis, Emmanouil Bouzakis, Homero Castaneda, Nikolaos Michailidis

Among the additive manufacturing methods developed, selective laser melting (SLM) has attracted the major interest. SLM can deliver very good manufacturing quality by optimally adjusting production parameters for a specific alloy. This adjusting could affect the grain structure, phase formation, microstructure, roughness and porosity, compared to conventionally manufactured parts. Among them, the surface integrity, such as distorted subsurface microstructure and roughness are determinant of the functional life, especially in a corrosive environment. The present study highlights and compares the fatigue life of maraging steel 18Ni-C300 with a superior strength and toughness, between conventionally manufactured specimens from a rolled bar and different post-treated SLM-fabricated specimens of the same geometry. The post-treatments refer to surface polishing, shot peening and heat treating. Experiments were performed in corrosion free and in a 3.5% wt. NaCl aqueous solution. Metallography, microscopy, surface scanning, FEM and hardness measurements were employed to help understand the results obtained. There is a clear superiority of the wrought material both in pure fatigue and in corrosion-fatigue, because of its dense and homogeneous microstructure, as well as its lower resulting surface roughness compared to the SLM. The as received SLM specimens, due to the distorted microstructure and more dominantly the higher roughness, has an inferior fatigue and corrosion-fatigue performance that acts positively in neutral environment with combination of shot peening and polishing, because of the imposition of residual stresses and improvement of surface integrity. On the contrary, shot peening has a negative impact in a corrosive environment. Heat treatment does not seem to have a positive effect in high stress fatigue life, however, increase the endurance limit.

Aerostructural Materials (PART II)

Session Chair: Prof. Roberto Pantani, University of Salerno, Italy

Finite element analysis of shot peening applied to case-hardened Aeronautical gears

Asghar Heydari Astaraee, Sara Bagherifard, Mario Guagliano

The mechanical/metallurgical performance of aeronautic case-hardened gears is occasionally enhanced by the application of shot peening treatment to evade fatigue damage. Prediction of the effects of shot peening parameter selection on the induced residual stresses and surface morphology would be much more convenient by the application of modeling and simulation. This research is intended at proposing a 3D finite element (FE) model of the shot peening process on carburized gears to predict induced residual stresses and surface roughness using commercial FE program Abaqus. A simplified but yet an intelligent approach is introduced to integrate the interaction of shot stream and gear tooth geometry by varying the angle of shot impact. Local gradient material properties were modeled using inverse modeling and hardness-based approaches. The first approach was accomplished by conducting experiments and FE modeling of indentation tests to inversely capture the gradient material behavior. The second approach relied on the conversion of the local hardness to the stress-strain response using an empirical relation. The results show that the proposed model can fruitfully predict the induced residual stresses and surface roughness. The significance of the proposed model is discussed based on the results of different modeling approaches.

Detection of the diffusion properties of the encapsulated health-monitoring agent in advanced protective coatings: A solid-state NMR study

S. Orfanidis, M. Raimondo, L. Guadagno, I. Palazzo, E. Reverchon, 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 aeronautical and naval industries [1]. The real challenge in aerospace is to find an efficient mechanism that can monitor the structural parts and also leading to an extended life cycle of the structure. Structural Health-Monitoring (SHM) methods are needful for controlling the structural integrity of aeronautical components. In this work, a new multifunctional coating is described. It is based on green paint containing dispersed microcapsules filled with a fluid health-monitoring agent (HMA), which is composed of the bifunctional epoxy resin DGEBA, the reactive diluent BDE, and the chromophore (Solvent Red 242). The HMA agent is also capable of repairing the damaged paint through crosslinking reactions. When damage occurs, the chromophore solubilized in the fluid health-monitoring agent is released in the damaged region allowing the visualization of the zones interested from the damage.The chemical composition chosen for the health-monitoring agent is also able to promote healing reactions. In particular, this study focused on the rheological behavior of the health-monitoring agent (HMA) after the damage occurs. The examined structure of this scenario is a protective coating formulation consisting of the Aerowave 3003 epoxy primer and Curing Solution 6007 with dispersed health-monitoring microcapsules. The two-dimensional solid-state proton Nuclear Magnetic Resonance (1H NMR) advanced spectroscopic technique and especially DT2 experiments (Diffusion-T2 relaxation time) have proven to be a successful approach to characterize the rheological behavior of the health-monitoring agent (HMA) by simulating the operation environment, in order to determine the diffusivity

of the encapsulated HMA, thus allowing quantitative investigation of the crosslinking reactions in the hosting matrix after the active agent comes out of the capsules.

Meshfree Methods of Airframe Stress Analysis

Nikita Kalutskii, Leonid Firsov

Present-day meshfree methods of numerical computer analysis of structures have been analyzed in this article. Principal mathematical ratios used in meshfree methods have been provided. Building of a shape function, one of the principal problems of the meshfree method, has been discussed, and an algorithm for the building of a shape function by using polynomial basis functions has been proposed. The algorithm developed has been tested on solving an elementary problem. The Conclusion section of this article contains solution results of a practically important problem of mechanical stress concentrations in a typical aircraft stringer. Comparative analysis of the accuracy of the results obtained by the conventional FEM and the meshfree method proposed has been conducted.

Low-velocity impact response and compression after impact assessment of carbon fibre/epoxy composites containing Diels-Alder reaction mechanism based self-healing agent in electrospun form

Athanasios Kotrotsos, Anna Geitona, Stavros Tsantzalis, Vassilis Kostopoulos

Fiber reinforced polymer composite materials (FRPs) are leading candidates as component materials to improve the efficiency and sustainability of many forms of transport due to their lightweight, high specific-strength and stiffness nature. However, a primary limitation of composites is their susceptibility to micro-damage, the poor interlaminar strength and fracture toughness that make them prone to delaminations during the service life. Based on these, it is necessary to consider new concepts in operations and maintenance domain since aluminiun (traditional utilized material in aeronautical applications) has different nature if compared to the polymer composites. To meet the need for reduction of maintenance cost an innovative robotized inspection and repair concept is required together with smart designs and new hybrid multifunctional material concepts. This challenging situation acted as an inspiration for seeking of new repair methods (further to the typical scarfing and stepping that used in composites); cheaper and applicable at the early stages of damage evolution.

An emerging approach called “Self-healing (SH) materials” has been proposed but not yet been applied to commercial composites. This smart technology aims to in-situ and autonomously damage repair and thus to lead to extension of the effective life-span of composite structures. SH of composites promises to mitigate the importance for detecting damage and to reduce the frequency of scheduled inspections. SH technologies could extend the service life and reliability of epoxy resins and composites. Based on literature, a typical way to classify SH systems is as: (a) autonomous (extrinsic) and (b) Non-autonomous (intrinsic). Non-autonomous SH seems to be the most promising approach for SH composites as specific reversible bonds will be introduced into epoxide networks. This approach allows the healing to be unlimited as no chemicals are consumed as in the case of autonomous SH mechanism (capsule- or vascular-based network). Bis-maleimides (BMIs) exhibit healing functionalities on polymer level due to their thermally reversible nature and present resin-type behavior. In the current investigation, BMI SH resin in electrospun form, based on Diels-Alder reaction mechanism was integrated into high performance aerospace carbon fibre reinforced plastics (CFRPs) as interleaves. Interleaves made by electrospinning are considered to be promising in the material science field, including aerospace composite structures.

Electrospinning process is relatively simple and scalable. Based on these, the effect of electrospun BMI resin as self-healing agent (SHA) into CFRPs is assessed. More precisely, reference and BMI modified CFRP samples having [45/0/-45/90]2S stacking sequence, with similar fibre volume fractions have been tested under low velocity impact (LVI) and compression (prior LVI, after LVI and after healing activation) tests. According to experimental results, it was shown that after LVI tests all material sets exhibited comparable damage resistance taking into consideration C-scan inspections while compression prior LVI revealed no knock-down effects due to the incorporation of the SHA. Finally, after healing activation the SHA was able to fully restore the damage area into the composite structure and to improve the residual compression characteristics.

Investigation of different failure modes of a plate under differing impact conditions

S. Kalapis, A. Dafnis, K.-U. Schröder

Aerostructures such as panels are widely used in aircraft structures due to their beneficial weight to stiffness ratio. Plates in particular are prone to lateral forces that occur during impact. Such impact events are caused by falling tools, bird strikes, collision of objects and many more. In general, the mass ratio of plate and impactor is considered one of the main drivers of failure modes. Two types of impact are distinguished: an impact with a large mass and an impact with a small mass. The former results in plate bending, which is similar to a quasi-static load, while the latter is characterised by high peak loads followed by plate vibration. Depending on the type of impact, the plate tends to fail in different ways: With quasi-static loading, failure is more likely to occur due to bending and membrane forces, while with high peak loads, the plate tends to fail due to shearing.To avoid damage, such endangered plates are designed heavier and more robust than necessary. With better understanding of impacted plates, their design process can be enhanced. Within the presented work a semi-analytical investigation of plate impact is presented. A simply supported plate, which is hit by a sphere, is studied. Various variables such as impact location, velocity of the impacting sphere, plate and sphere dimensions are considered and varied. To study the effects of the different variables in an impact event, the plate behaviour is considered linear, that means without consideration of shear and membrane forces. To verify the semi-analytical approach, a code to code approach is carried out comparing the solutions with a commercial FE-solver.

Icing of Aircraft Structures

Session Chair: Prof. Liberata Guadagno, University of Salerno, Italy

Numerical procedure for electothermal anti-icing system simulation coupling interal thermal analysis and external multi-phisyc code

A. Carozza, F. Petrosino, G. Mingione

The present work has the aim of coupling two codes developed in CIRA, one able to perform icing simulations and another one capable to simulate the performance of an electro–thermal anti-icing system in an integrated fashion. The classical tool chain of icing simulation (aerodynamics, water catch and impact, mass and energy surface balance) is coupled to the thermal analysis through the surface substrate and the ice thickness. In the present approach, the ice protection simulation is not decoupled from the ice accretion simulation, but a single computational workflow is considered. Validation results obtained on benchmark test cases from NASA database will be detailed as well as comparison with numerical results from other authors.

Application of different Lagrangian Particle Tracking techniques for water impingement

F. Petrosino, D. De Rosa, G. Mingione

In the framework of icing on aircraft study, the first phenomena to investigate is the impingement of water droplets on the surfaces of aircraft. Numerical approaches are usually implied to support the experimental testing and to provide fast responses when designing ice protection systems. In order to compute the impingement efficiency we need to follow the water particles presents in the air flow field, from their starting positions to the hitting positions on the surfaces of an aircraft. This can be done using two approach: Eulerian approach that means fix the observation volume and solve the transport equation of the water inside the main air flow, Lagrangian approach that means follow each water particle solving the equations of motion for the particle interacting with the main air field. In CIRA both approaches are developed and implemented in 2D and 3D tools, validated trough literature and experimental test cases. In this work we focus on the use of lagrangian approach. A comparison between Lagrangian model implemented in CIRA software Multi-Ice[1] and in open-source framework OpenFOAM[2], has been made. The robustness of the methodology and the accuracy of the approach are discussed. The method is applying to classical two- and three-dimensional test cases for which experimental data are available in literature. The results are compared with experiments and also using different numerical aerodynamic solutions.

Film heating for anti-icing applications

F. Petrosino, P. Catalano, G. Mingione

Usually cooling film are used on engine turbine blade for blade cooling. In GTRE proposal heating film is proposed to heat blade to increase ice protection effectiveness.

A short literature survey has been performed to identify a model for the simulation of heating film. Only model for cooling have been found in literature, therefore it is proposed to identify a model to be implemented in CIRA Multi-Ice ice accretion code.

Simulations of Two-Phase Flows over Aircraft Surfaces to Determine the Droplet Collection Efficiency

Strelets D. Yu, Zhuchkov R.N., Kozelkov A.S., Pogosyan M.A., Galanov N.G

This work deals with simulations of two-phase air/water droplet flows over aircrafts. It represents one of the steps in aircraft icing simulations and is relevant for flight safety. We demonstrate that the Lagrangian approach, although more natural from the standpoint of mathematical modeling, is computationally more expensive as applied to real-life aircraft engineering and certification. The Eulerian approach is not as good at resolving the details of all the physical processes taking place in the multi-phase flows, but it delivers adequate results fast enough for practical applications.

New Aircraft Anti/de-Icing Technologies

Luigi Vertuccio, Fabiana Foglia, Roberto Pantani, Salvatore Russo, Generoso Iannuzzo, Liberata Guadagno

Icing is a crucial problem for aircraft flight. Some aircraft parts are more vulnerable than others. Ice accretion during the flight occurs most of all on the leading edge of an aircraft wing (see Fig. 1) and usually covers only 2% of the wing chord, with the thickness of the ice layer being about a few centimetres [1]. However, even an ice layer of a few centimetres thickness at the key parts of the aircraft may cause flow separation and destroy lift, increase drag and reduce the maximum lifting capability; determining in the worst cases the decrease of engine performance and stability [1-4]. Wing ice management falls into two broad categories: anti-icing (ice prevention), and de-icing (ice elimination or mitigation). Most technology focuses on de-icing, operating on the assumption that some ice is going to form on a wing and works to get it off before it becomes problematic [5]. Here a new efficient strategy applicable for activating anti or de-icing function is discussed. It is based on shapeable flexible graphite-based foils that can be directly placed between the plies of the composite material. The feasibility of the de-icing performance is demonstrated through a series of experiments and the results indicate that the developed method could be a very promising electrical heating strategy able to maintain lightness, efficiency in the de-icing performance, and reduction in the environmental impact of de-icing polluting fluids.

Advanced Manufacturing Technology for Aeronautics (PART I)

Session Chair: Dr. Jie Zhao & Prof. Yi Qin, University of Strathclyde, UK

Simulation of the Rolling Process of the GH3536 Thin-walled M-profiled Crosssection Sealing

Ring Zhiyu Xiang, Hongwei Li

Special-shaped cross-section sealing rings of superalloy with a large diameter and a thin wall are the key components, which guarantee high efficiency and good working performance of aero-engines. However, its structural characters together with the hard-to-deform characters of superalloy material make the forming difficult at room temperature. Multi-pass rolling is usually adopted. In order to maintain a steady and precise process of the M-profiled cross-section sealing rings without defects like wrinkling or crack, the key problems lying in the design of forming pass and the determination of processing parameters should be properly handled. To this end, the 4- and 7-pass rolling processes are designed by synthetical bending radius method. Then, the corresponding finite element models are established. With the models, the influences of forming pass on forming quality are studied. The result shows that in the 4-pass process the bending deformation characters appear while the drawing deformation retains in the 7-pass process. The bending deformation benefits the wall thickness reduction rate and the parallelism of the formed ring. Subsequently, with the 4-pass process, the influences of processing parameters, such as feed speed of rollers, friction coefficient and rotary speed of the mandrel, on forming quality are analyzed. The results provide a guidance for the precise and high-quality rolling of the GH3536 thin-walled M-profiled cross-section sealing ring.

A study of the forming quality of Ni-based superalloy conical-cylindrical parts under complex strain path by deep-drawing spinning

Gangfeng Xiao, Zeyu Ling, Qinxiang Xia, Yilong Zhang

Conical-cylindrical parts wildly used in gas turbine and aero engine are generally made of Ni-based superalloy. But the work-hardening effect of the Ni-based superalloy is serious. An advanced method of manufacturing conical-cylindrical parts was proposed, where the conical blank was obtained by shear spinning, and then the deep-drawing spinning was adopted to form the final geometry based on the conical pre-formed blank after solution heat treatment. Wrinkling and fracture defects occur easily due to the serious work-hardening and the complex strain path. The finite element model of the deep-drawing spinning was established based on the Abaqus software. The distributions of stress and strain under different strain path were analysed. The results show that the wrinkling occurs and the stain distribution is concentrated in the middle of cylindrical wall under linear strain path by single-pass deep-drawing spinning. The forming limit is significantly improved and the strain distribution is more uniform under complex strain path by multi-pass deep-drawing. The maximum tangential tensile and compressive stresses, which are the main reason to result in wrinkling and fracturing, are both located on the opening end of the spun workpiece under complex stain path. The influences of the process parameters, such as the roller feed rate f, the space between each pass p and elevation angle of first pass θ0, on the defects were also studied experimentally. The results show that the fracture defect can be eliminated by increasing f and p; and the wrinkling defect can be eliminated by increasing θ0. The conical-cylindrical parts with high dimensional accuracy can be obtained under the process parameters of f=0.8mm/s, p=5mm and θ0=40°.

Numerical Study on the Forming Rules of 6061 Aluminum Alloy Complex Tubes in Incremental Tube Forming

Danni Bai, Pengfei Gao, Yukun Li, Mei Zhan

The integral multi-bend aluminum alloy tube with varying diameter and wall thickness is widely used as the oil transportation and load-bearing component in the aviation and aerospace fields. Due to the complex shape and variable geometrical parameters, it is difficult to form such complex tubular products using the conventional bending processes. The incremental tube forming (ITF) process combines the advantages of spinning and flexible bending, which provides an effective way to realize the rapid forming of such complex components. During ITF process, the tube billet undergoes complicated uneven deformation in the spinning and bending sequentially due to the characteristics of continuous and local loading deformation. Moreover, the deformation in spinning step will greatly affects that in the later bending process. These characteristics make the ITF a complicated forming process with coupling effects of multi-factors and easy to produce the wrinkling, crack, cross-section distortion and other defects. In order to deepen the understanding of ITF characteristics, the ITF of a 6061 aluminum alloy tube with 90° plane bending shape is studied in this work. First, the finite element model of ITF is established and verified. Based on the established finite element model, the evolution of stress and strain field during forming process is obtained and analyzed. Especially, the influence of spinning forming on flexible bending process is clarified by comparing to the pure bending forming. Then, through the virtual orthogonal experiment, the influences of key forming process parameters, such as feeding speed, rotary speed and bending tool speed, on wall thickness variation and cross-section deformation are obtained and a set of optimized process parameters are determined. The results will provide guidance for the high-performance and integral forming of complex tubes through ITF process.

Micromechanical Modeling of Deformation and Damage Heterogeneity of TA15 Titanium Alloy with Tri-modal Microstructure

Mengyan Fei, Pengfei Gao, Zhenni Lei, Mei Zhan

Tri-modal microstructure is composed of equiaxed α (αp), lamellar α (αl) and transformed β matrix (βt), which has become the desired microstructure of titanium alloy owing to its potential for excellent comprehensive mechanical properties. However, the complex microstructure morphology and property differences of three constituent phases may lead to complex mesoscopic deformation and damage evolution, which will significantly affect the macroscopic mechanical properties. Thus, it is necessary to reveal the heterogeneous features of mesoscopic deformation and damage evolution of tri-modal microstructure. To this end, a representative volume element (RVE) model considering the deformation and damage behavior of each constituent phase was established. Firstly, the key techniques of micromechanical modelling, including the geometric extraction of real microstructure and boundary condition, etc., were solved. Then, the Hollomon hardening model and the Gurson-Tvergaard-Needleman (GTN) damage model were used to describe the hardening and softening behavior of each constituent phase, respectively. The key parameters in hardening and damage model were determined by calibrating the RVE simulation stress-strain curve with the experimental one. Then, the micromechanical model of tri-modal microstructure was established. Based on that, the mesoscopic deformation characteristics and damage evolution rules of tri-modal microstructure were revealed. It is found that the plastic deformation in αp and the αl are larger and the void volume fraction are higher than that in βt. Moreover, the void

volume fraction in αl begins to increase first and the growth rate is high, which makes the αl be the key constituent phase that affects the mechanical properties of tri-modal microstructure.

A fast simulation strategy for flow spinning: adaptive octree mesh refinement algorithm based on dualmesh method

Zhuolei Zhai, Yunda Dong, Mei Zhan, Zhipeng Shi, Xiaoguang Fan

Flow spinning is one of most popular plastic forming processes to product large-scale thin-walled cylindrical metal tubes through continuously local loading of rollers on the workpiece. The process is characterized by small local plastic deforming zone and large rigid (undeformed or deformed) zone and their continuous transformation. To reproduce accurately these deformation characteristics, considerable all-hexahedral fined mesh elements are needed in the previous finite element simulation (FES) for the process, and the simulation is extremely low efficiency. For improving the FES efficiency, a local mesh and data reconstruction method was put forward based on octree refinement method and dual mesh method. In the proposed method, an all-refined mesh is used as a storage mesh (SM) to save and transmit detailed data during simulation, and a computation mesh (CM) is frequently applied to refining and coarsening the mesh with rollers' motion by means of standard refinement template. This procedure makes it feasible to only retain fined mesh in the deforming zone and form transitional mesh. To keep consistent between CM and SM, an appropriate remapping algorithm is employed to hold the continual computation during frequent data remapping. By comparison, nodes only need a simple shape function interpolation (SFI), whereas Gauss points require some extra indirect patch recovery technique such as radial basis function (RBF) interpolation and super-convergent patch recovery (SPR) to make sure the feasibility of SFI. Using the local mesh reconstruction method, the element number of the FE model for the flow spinning will be fewer than that of the traditional model at least an order of magnitude. Thus, the CPU time based on the local mesh reconstruction method will probably reduce up to 60% comparing to the traditional one. This study will promote the efficient application of FES in localized plastic forming processes.

Effect of Rise and Fall Rate on Dwell Fatigue Behavior of Titanium Alloys

Pandi Zhao, Songlin Shen, Mei Zhan, Zebang Zheng

Dwell fatigue of titanium alloys has been a concern to the aerospace industries since it was first recognized in the 1970s. It has been shown that the stress distribution through the soft-hard grain combination, which is argued to be crucial in the facet crack nucleation, increased significantly during the stress hold period. The effect of rise and fall rate of each loading cycle on the load shedding phenomenon has been investigated using a rate- and lengthscale-dependent crystal plasticity model. Both equiaxed α and α-β lamellar microstructures have been considered. The rise rate can significantly affect the peak stress in the hard grain at the onset of dwell period. Although the rise rate is different, the peak stress in the equiaxed microstructure reaches the same maximum and stable value within 80s during the stress hold, which means that the effect of rise rate is eliminated when the dwell period is longer than 80s. The residual peak stress after each cycle is also a function of the fall rate. A higher fall rate lead to a higher residual stress in the hard grain, which is argued that may cause the quick failure of the alloy. The sensitivity to the rise and fall rate of the lamellar microstructure with different β-lath widths and α-variants has also been detailed analyzed. The key mechanism with respect to the effect of rise and fall time on load shedding in titanium alloys is the time constant associated with the process of thermally activated dislocation escape.

Characteristics of Mechanical Properties of a Near-α Titanium Alloy with Tri-Modal Microstructure

Yili Gong, Pengfei Gao, Zhenni Lei, Mei Zhan

Excellent combined mechanical properties have always been the target to pursue during the manufacture of titanium alloy components, especially in the high-end aviation and aerospace industries. Tailoring microstructure to satisfy the request on mechanical properties has become an important subject. The tri-modal microstructure consisted of equiaxed α, lamellar α and β transformed matrix has been reported to possess a possibility to reach the excellent combination of strength-ductility-toughness properties. However, the microstructure parameters must be well designed to obtain excellent combined properties. Thus, we have investigated the tri-modal microstructure features and its grain-scale deformation characteristics. Based on that, we systematically studied the integrated mechanical properties of tri-modal microstructure. Utilizing the microscopic digital image correlation technology, the grain-scale strain heterogeneity of tri-modal microstructure during uniaxial tensile were deeply explored. On these bases, the dependence of strength and plasticity of tri-modal microstructure on the microstructural parameters was studied. Meanwhile, the damage tolerance properties, i.e., low-cycle fatigue (LCF) property and fracture toughness were also investigated. For the LCF property, we analyzed the cyclic stress response behavior, deformation in fatigue crack tip plastic zone and fracture features. With respect to the fracture toughness, the damage distribution features, and crack propagation path characteristics were revealed. Subsequently, the relationship between damage tolerance properties with tri-modal microstructural parameters was also investigated. At last, the tri-modal microstructure parameters were optimized to obtain superior combined mechanical properties.

Advanced Manufacturing Technology for Aeronautics (PART II)

Session Chair: Prof. Zebang Zheng, Northwestern Polytechnical University, China & Prof. Yi Qin, University of Strathclyde, UK

Simulation on dynamic recrystallization of magnesium alloy by cellular automaton method coupled with adaptive activation energy and matrix deformation topology

Sibing Wang, Wenchen Xu, He Wu, Ranxu Yuan, Xueze Jin, Debin Shan

In order to analyze the dynamic recrystallization (DRX) behavior of Mg alloys, the cellular automaton (CA) model of DRX coupled with adaptive activation energy and topology deformation was established successfully to simulate the entire DRX process of AZ61 Mg alloy during hot compression. The results indicate that the recrystallization grains firstly nucleated at the grain boundaries of initial microstructure, where the dislocation density reached the critical value, and the DRX process was characterized by repeated nucleation and finite growth of the recrystallized grains. The simulation results incorporating adaptive deformation activation energy were close to the experimental ones since the activation energy influenced the nucleation rate and thus the recrystallization process. In addition, the simulated DRX process as well as microstructure evolution was in good accordance with the experimental ones, indicating the reliability of the CA model proposed in this study.

FE simulation of isothermal forging for 7075 aluminium alloy diffuser

Chunju Wang, Leilei Wang, Bin Guo

Deform-3D finite element simulation software was used to simulate the isothermal forging process of 7075 aluminium alloy. Two sizes, three blank shapes and two forming schemes were compared. The equivalent strain, material flow and coordinate grid in the forming process were simulated and analyzed. The simulation results show that for the diffuser studied in this paper, the bigger the blank diameter is, the better the material filling in the lower die. The ring billet is advantageous to material flowing inward and outward along the radial direction, avoiding folding and other defects. In order to better shape the micro groove, two-step forming method is adopted, which is conducive to the flow filling of materials, and the forgings with good forming quality are obtained, and the streamline of forgings is more uniform. The experimental results show that the diffuser forgings fabricated based on this simulation process have good size, high mechanical properties and meet the requirements of use.

Investigation on Electrically-Assisted Rolling Process of Surface Texture for Drag Reduction

Shaoxi Xue, Zhenhai Xu, Chunju Wang, Baosheng Liu, Debin Shan and Bin Guo

Surface texture is employed for drag reducing in the aviation and aerospace, which have a positive effect on boundary layers of flow. Several studies have found that the triangular shape has better effect on drag reduction. In this paper, micro structure of drag reduction surface was analyzed and fabricated from the point of view of simulation and experiment. The effects of roll gap, thickness of sheet and different interval and size of triangular shape on the forming results of surface texturing sheets were studied. The simulation results indicate that the forming full profile needs a small roll gap. With the increase of thickness of sheet, the forming height is greater, flatness of sheet is better in the same condition. The increases of interval and size improve the forming height and are benefit for forming result. The current is introduced into the forming process. The electrically-assisted rolled surface texture sheet shows greater

forming profile and better flatness. It is concluded that the electrically assisted roll process is a promising way of forming surface textures on metal sheets.

On Unsteady Flow Analysis of a Round Spike Blunt-Nose Afterbody in Mach 6 Flow

Ashish Vashishtha, Shashank Khurana

An aerospike, in front of a blunt body, has largely been deemed as a key passive control device for effectively reducing the wave drag and aerodynamic heating associated with high-speed flows. In addition, it has been reported that the presence of a spike brings in unsteadiness in the form of oscillation and pulsation to the flow characteristics. Past researchers, having investigated mainly the aerothermodynamic coefficients, have hinted towards the suppressing of such oscillations with the use of a round nose spike over a sharp spike, though a thorough and a concrete result is yet to be established together with offering a detailed explanation of the flow physics and its dependence on the spike's geometric characteristics (length-to-forebody diameter ratio, L/D).

Numerical investigation has been carried out using axisymmetric Navier Stokes laminar flow solver at hypersonic Mach number 6.0. A round-tip spike with flat face cylindrical afterbody have been simulated for spike length ratios of L/D = 0.5 −2.0, with spike diameter to forebody diameter of 0.1. The behavior and subsequent control of flow pulsation for a round (hemispherical) spike with varying L/D ratio has been established in the full paper.

Additive Manufacturing – New Potentials for Aviation

Ina Ludwig

Additive Manufacturing (AM) allows for lightweight design, functional integration, a large material diversity and small batch quantities. The potential for AM in aviation is therefore enormous and will continue to grow in the future. In order to strengthen the technology implementation of AM, the Fraunhofer IAPT covers the entire process chain of several additive technologies. Within each technology topics such as quality assurance, design automation and process optimization are covered as well as material developments and post-processing for metals and polymers. In research projects like the Horizon 2020 project Bionic Aircraft, a bionic feature design catalogue for the L-PBF process has been developed to enable the perfect design structure for each application. In combination with the increase in process stability and energy efficiency of the process by up to 35 %, the technology is ready for industrial use. By reducing the weight of aluminium components a lower CO2 footprint can be achieved.

Design of a composite aircraft nose wheel for a regional aircraft

Jens-David Wacker, Conchin Contell Asins, Dominik Laveuve, Andreas Büter

Innovative approaches for lightweight design of components can contribute significantly to reduced fuel consumption and emissions of future aircraft. Within the framework of the European Aviation research program Clean Sky 2, an innovative design of an aircraft nose wheel for the A320 is developed using carbon fiber reinforced plastics (CFRP) in order to demonstrate a weight reduction potential of 30% compared to more traditional designs.

Aircraft wheels are conventionally made of forged aluminum alloys and represent highly stressed components, which have to endure static, dynamic, and thermal loads that occur during different phases of aircraft operation. Taking into account these challenging load cases as well as space, installation, and safety requirements, different geometrical design principles for the wheel are analyzed in a concept

phase. Furthermore, innovative solutions for the integration of bearings as well as joints and seals are presented. Within the detailed design phase, force and moment resultants, which occur during 360° rolling of the wheel, are evaluated in order to define a suitable laminate layup. Also, failure analysis of the composite components and experimental validation of the joints are performed via FEA and tests on bolted single lap shear specimens, respectively. In addition to structural analysis, the concept developed for manufacturing the complex wheel geometry via resin transfer molding (RTM) using carbon non-crimp fabrics is presented and an outlook on the future manufacturing and testing of wheel specimens is given. In the present paper, the methodical approach of the development process and the final detailed design of the composite aircraft wheel are presented. Various design challenges are highlighted, and the solutions developed to meet them are discussed.

Robotized Assembly and Inspection of Composite Fuselage Panels: the LABOR project approach

Ciro Natale, P. Chiacchio, M. Caterino, C. Cristalli, M. Fera, G. Lettera, M. Nisi

Within the H2020 Clean Sky 2 private-public partnership for research and demonstration of advanced technologies for regional aircraft with the LEONARDO Aircraft leadership, the LABOR project "Lean robotized AssemBly and cOntrol of composite aeRostructures" aims to bring further the level of automation of an assembly and inspection line for composite fuselage panels.

The project started in March 2018 and targets a Technology Readiness Level (TRL) 7 – System prototype demonstration in operational environment, over a 36-month period, for a complete work cell with two cooperative robots that can safely operate in coexistence with human workers.

Most of the existing solutions exploiting robots for automated assembly of aeronautical structures adopt quite heavy and big robots equipped with large, usually multi-functional end effectors, which mainly execute drilling operations. The LABOR project proposes a lean and flexible automated solution, which combines the use of two small-medium size robots and smart tools integrated into multiple end effectors equipped with a quick tool changer. The proposed technology implements all steps of the assembly process, i.e., drilling, sealing, fastener insertion, and inspection operations (of both holes and fasteners).

The work cell includes a rotative assembly jig to hold the panels, two 6-axis robots mounted on the two sides of the panel, each one mounted on a linear axis along the panel longitudinal axis, and three custom end effectors developed to execute all the assembly and inspection operations.

The robot work cycle is fully cooperative: a 3D vision system mounted on the internal robot localizes the panel with high precision and guides the external robot to drill and inspect the hole, seal it and finally install the rivet. During the drilling phase, the proper countersinking force is ensured by the internal robot which suitably clamps the hybrid stack-up to be drilled. The first external robot tool is composed of the drilling tool and a 2D inspection tool. As the drilling tool needs to work with different tips, a tool holder warehouse has been developed. Through a quick tool changer, the external robot can install the fastening and sealing tool. The fastener warehouse has been also realized, with the aim of storing fasteners. Indeed, the LABOR cell is able to handle fasteners with different geometries (diameters and lengths of different fastener models).

A challenging objective of the LABOR project is the implementation of human-robot collaboration (HRC) tasks, a major area of exploration for the aerospace manufacturing sector. The intervention of the human operator is required in several phases of the assembly process. Therefore, suitable safety measures have

been taken to prevent injury of the workers. Besides standard safety procedures and countermeasures established by the regulations, a novel workspace monitoring approach based on multimodal sensing has been developed during the project, with the aim to maximize the system productivity and preserve operator safety at the same time. Achieving such conflicting objectives is challenging: on one hand, a perception system is needed for monitoring human presence reliably, on the other hand, suitable control algorithms are needed to be devised to select the proper robot behaviour for keeping a high level of productivity during the collaborative activity, i.e., reducing at a minimum the number of robot stops during the assembly process. The HRC module developed for the LABOR cell leverages machine learning techniques based on multimodal perception and a novel sensor fusion algorithm, which merges depth and thermal data for human tracking, as well as a fuzzy control logic to detect the proximity and the speed interaction between human operators and robots in real time. The application of this new work paradigm, where some phases of the working cycle involve both the human and the robot, arises new research questions about the ergonomics and, more in general, the human comfort. LABOR demonstrated the improvement of ergonomic indices that can be guaranteed from the execution of heavy operations by the robots. In detail, using a digital twin approach, LABOR numerically validated the goodness of the working postures during the normal working cycle execution, in compliance with the international standards for the adoption of robots in production environments as ISO 10218-1/2 and ISO/TS 15066.

The LABOR solution saves major equipment costs, reduces the whole production time, improves efficiency rates and flexibility, it is easy to maintain while keeping quality standards of the assembly and allows robots and humans to share the same workspace. Indeed, rather than exploiting expensive external metrology systems to align big-size robots and the assembly jig, adaptive alignment solutions, as well as the design of integrated smart tools, are adopted to contain the overall cost while guaranteeing the required accuracy, as well as allowing ease of maintenance and programming. An intuitive Human Machine Interface has been developed in order to guarantee an easy programming phase of the cell, powered by a distributed architecture. In particular, each specific tool and component (i.e. robot, drilling unit, 2D vision tool, etc. …) has its respective embedded system in order to simplify the insertion of new components in the system.

Regarding flexibility, most of the automatic assembly machines currently adopted in the aeronautic industry are tailored for a specific part to assemble, e.g., wing, fuselage, vertical or horizontal stabilizer. Whereas, LABOR proposes a robotized solution that could be exploited, with minimal adaptation, to the assembly of different parts, especially in terms of material and partly of geometry.

The required average time for manual assembly operations per single hole, i.e., drilling, countersinking, sealing, riveting, cleaning, deburring, and inspection, on a CFRP and thermoplastic compound panel, using 9 mm grip fasteners, is around one minute. The target cycle time for the LABOR robotized cell is 30 s per hole (excluding fastener inspection), which means a reduction of about 50% with respect to the manual operation.

The prototype will be installed in Pomigliano D'Arco (Italy) at the Leonardo Aircraft plant.

Session 40: Advanced Manufacturing Technology for Aeronautics (PART III)

Session Chair: Dr. Jie Zhao & Prof. Yi Qin University of Strathclyde, UK

Nanosecond laser micro-structuring of epoxy painting surfaces adhering to an aluminum alloy

Wenlong Chang, Xichun Luo, Yi Qin

The painting materials and their thickness coated on the airframe of an aircraft would affect the overall weight of the aircraft as well as effectiveness of the protection of the airframe. Epoxy is one of the most popularly used painting materials widely used in the aviation industry for the airframes, and capable of providing a high resistance to chemicals, has less color fading and lower attendance to oxidation. It does not break down easily and adheres onto Aluminum alloys well. At the same time, avoiding icing on the epoxy paintings at different flight altitudes and/or in high latitude countries is essential. In this study, a series of micro-structure patterns were created on the Epoxy painting surfaces using high-precision nanosecond laser machining. These micro-structures are of superhydrophobic characteristics that lead to an improvement of the anti-ice and anti-fog capability and render self-cleaning and water-adhesion reduction functionalities. For the cases investigated, the optimal processing parameters for creating superhydrophobic surfaces on the Epoxy painting material have been found to be: 2W of the Laser power, 100 kHz of frequencies, 10 um of pitch size and 15 um of spot size. Icing experiments have also been conducted, in order to confirm the performance of the micro-structures created as well as to establish the delays of the freezing time. The results showed that the best superhydrophobic surface could delay the time of freezing by 28%, comparing to those with normal epoxy painting surfaces without artificially created micro-structures.

Redundancy Optimization in Robotized Assembly of Aerostructures

Federica Storiale, Enrico Ferrentino, Pasquale Chiacchio

Aerospace production volumes have increased over time, so automated and robotic solutions have been progressively introduced in the aeronautic assembly lines in order to achieve high quality standards, high production rates, flexibility and cost reduction. Drilling, riveting, sealing, coating, painting and material handling are the most recurrent operations. The majority of them are executed by complex ad-hoc machines and high-payload robots, yet a high number of drilling and riveting operations are manually performed, especially in regional aircraft lines where the required positioning accuracy is higher than what common industrial robots can achieve. In this context, the LABOR (Lean robotized AssemBly and cOntrol of composite aeRostructures) project aims to increase the level of automation of the current assembly process of fuselage parts, by means of a lean, reliable, easy to maintain and flexible solution, while guaranteeing quality of the assembly and compliance to time constraints. In order to provide adaptability in many different situations and geometry of the fuselage panels, the robotic cell is composed by two medium size cooperating robots supporting interchangeable tools to perform the required operations of drilling, sealing, riveting and inspection. Robots are characterized by six degrees of freedom and are mounted on external translational axes allowing the movement along the length of the panel. However, carrying and re-orienting the needed tools and exerting an adequate thrust force, while respecting the required tolerances and accuracy, could be challenging for this type of robots: large and geometrically-complex tools limit the mobility, while slippage phenomena may arise during interaction with the panel. Considering each robot translation along the panel axis, an additional degree of freedom is available with respect to the six required by position and orientation constraints, so that the system is kinematically

redundant. The objective of this work is to exploit the augmented dexterity arising from redundancy to satisfy other requirements and constraints, besides the end-effector task. In particular, optimal joint-space trajectories are planned to improve the stability of the interaction between the robot and the panel and to increase the overall safety of the system, while meeting the assigned cycle time. The proposed solution is based on a dynamic programming algorithm, which is able to compute optimized trajectories, minimizing or maximizing a cost function of interest and, at the same time, satisfying additional constraints required by the specific task or by the robotic system itself. The computation time is controlled through a suitable parametrization of the algorithm, so as to ensure compliance with the available planning time. In the use case considered in this work, the kinematic redundancy is parametrized with the linear axis, and joint displacements are minimized to avoid unnecessary movements. At each stop, the stiffness of the working pose is maximized, while self-collisions and collisions with the panel are avoided. Experiments are performed in a simulation environment, where the optimal trajectories are executed, highlighting the resulting performances and improvements with respect to non-optimized solutions.Acknowledgments: This work has been funded by the European Commission under the Clean-Sky 2 project LABOR (GA n. 785419), with Leonardo S.p.A. as Topic Manager.

Pilot prototype production line for the hot-forming of aluminium alloy sheets with fast contact-cooling and multipoint tooling

Song Yang, Jie Zhao, Yankang Tian and Yi Qin

As lightweight materials, Aluminium alloys are popularly used in many industry sectors, including Aerospace/Aeronautics industry. Nevertheless, due to the poor formability of high strength aluminium alloys, there are still significant challenges to the conversion of the Aluminium sheets into complex geometries. Hot stamping technology has been used intensively for the forming of the engineering components from Aluminium sheets which helps to reduce the forming force requirements and the springback incurred due to the forming, while the structural integrity and impact safety are maintained. However, hot stamping of high strength aluminium alloys still encounter some problems that are associated largely with the forming of complex shapes, forming die conditions as well as the high productivity requirements, being reflected particularly by the restriction to relatively low forming-limits and hence, to the achievable component-forms. At the same time, although intermediate cooling has been introduced to the hot stamping of Aluminium alloys as a means of addressing the constraints to the forming limits, either the cooling rates achievable to-date such as air/spray cooling were still too low, or the designs of fast-cooling were not viable for production environment applications.

The effort made in The University of Strathclyde is to address the issues raised above by developing a prototype pilot production line that combines the hot stamping of Aluminium alloys and fast contact-cooling. The forming is effected by a multi-point tooling with a view to adding flexibility of the test trials in relation to the different shapes/features without need to make different sets of solid dies. The intermediate cooling with high cooling-rates are achieved with a contact-cooling system developed recently in the University of Strathclyde. The pilot line also integrates a heating facility and a control system.

With this pilot line, the Aluminium sheets heated up by the electrical furnace are subjected to the intermediate cooling prior to the loading into the multi-point tooling for forming. Different cooling rates, such as 50 0C/s and 100 0C/s, have been tested, and their effects on the forming limits for different component-forms investigated. AA6082 sheet blanks with 1.0mm thickness were used as the raw

materials; several square cups with different depths were formed; and the temperatures of the sheet blanks were monitored during the tests through a built-in monitoring system.

The tests conducted so far demonstrated that the integration of fast contact-cooling into a production process is feasible and its associated cost could be relatively low. It also demonstrated that introducing a high-temperature forming configuration into a multi-point tooling forming process is feasible, which extends the existing process capabilities. The test results showed that proper cooling rates, which are achievable easily with the facility developed, could improve form limits of the high strength aluminium alloys greatly, although, in general, the higher the cooling rate, the better results are obtained. At the same time, the fast-cooling configuration designed could, potentially, lead to significant process-time saving, due to the extremely short cooling time involved.

Full details on the forming process chain and the pilot line will be reported in the full paper submission, and further tests on different component-forms and different types of the materials will also be conducted.

Numerical and experimental investigation into laser-metal-deposition based additive manufacturing with Inconel 718 powder

Yankang Tian, Quanren Zeng, Andreas Reimer, Yi Qin

Inconel 718 is widely used for manufacturing aerospace/aeronautics components due to its superior properties at elevated temperatures. However, it remains a challenge to the manufacture of those components with this material without sacrificing some of the material properties and manufacturing cost, especially when complex shapes are to be achieved. At the same time, additive manufacturing with laser metal deposition (LMD) is of a capability that could well address the challenge mentioned here, namely, high degree of freedom for design and manufacture, especially when complex shapes are to be dealt with. Nevertheless, the development of LMD of Inconel 718 for fabricating engineering components is still ongoing, and the focus is particularly placed on the quality control. While the effort still largely relies on experimental trials, lack of effective and efficient modelling tools have hampered the progress in process design and optimisation.

The strategy implemented in the University of Strathclyde is to develop comprehensive understandings of the interactions of the material and process parameters during LMD of Inconel 718 and their relations to the quality of the parts formed. This has been enabled by establishing an integrated numerical model taking into account in-process powder dynamics, heat transfer, liquid/solid interface, part geometric formation via solidification and resulting mechanical properties of the material.

The development of the integrated numerical model was underpinned by an in-depth analysis of the state of the art of metal-powder-based AM technologies and modelling techniques, being focused on the Direct Energy Deposition (DED) process. This was followed by studying powder dynamics when it is injected into the molten pool through which the distribution and deposition of Inconel 718 powder were quantified. The formation of the liquid/solid interfaces around the molten pool during the solidification was then studied. The simulated formation of the deposited geometry was further compared to those obtained from the experiment. The latter also facilitated the conditioning of the numerical model as well as underpinned the process optimisation in which both experiment and numerical modelling were combined.

The effort described above has resulted in an integrated numerical tool and technical details for guiding LMD process design and parameter setting for quality control in LMD of Inconel 718 parts for aerospace and aeronautics applications.

Aeroelastic optimisation of manufacturable tow-steered composite wings with cruise shape constraint and gust loads

Zhijun Wang, DaniÃl Peeters, Roeland De Breuker

In the structural design of aircraft wings, aeroelastic tailoring is used to control the aeroelastic deformation to improve the aerostructural performance by making use of directional stiffness. Recently, tow-steered composites, where the fibre angles continuously vary within each ply, have been proven to have the potential to further expand the advantages of aeroelastic tailoring. This work presents an aeroelastic optimisation framework for the conceptual design of tow-steered composite wing structures, which takes manufacturing constraints, and static and dynamic loads into consideration. Further, in this framework, the jig twist distribution can be optimised to maintain a desired prescribed cruise shape. This not only ensures optimal aircraft performance in cruise flight conditions, but also takes full advantage of aeroelastic tailoring in off-cruise conditions. The framework is constructed by sequentially and iteratively performing 1) aeroelastic tailoring and 2) lay-up retrieval. In the first step, the lamination parameters and thickness of the wing sections are optimised under manoeuvre and gust load conditions. The first step is implemented within TU Delft aeroelastic optimisation tool PROTEUS. Subsequently, in the second step, the stacking sequence, including minimum steering radius constraint, is retrieved. As the lamination parameters obtained before and after the lay-up retrieval step differ, it has to be checked that the aerostructural constraints are still satisfied after the retrieval step. If the constraints are violated, the first step is repeated with a tighter constraint to account for the loss in performance during the retrieval step. Finally, the optimisation process is terminated when all constraints are satisfied after retrieving the manufacturable stacking sequence. To demonstrate the usefulness of the proposed optimisation framework, it is applied for the design of NASA Common Research Model (CRM) wing, of which the objective is minimizing wing mass subjected to aerostructural design constraints, such as aeroelastic stability, aileron effectiveness, material strength and buckling load. The optimisation results provide insights regarding the effect of dynamic loads on the design of manufacturable tow-steered wing structures.

Off-Line-Programming and Inline Measurement for Sealing Automation – Ensuring fully automated sealant application in the industrial aircraft production

Nihat Biyiklioglu, Daniel Ludwig, Sascha Quast, Thomas Schwane

Due to high variety of AC part geometry and bead shapes teaching or off-line-programing for an automation are alongside of the application itself the most important task for the sealing process. The reduction of labour cost by the application should not lead to increased cost for the preparation in reverse. Because for a business case decision not only the invest cost is important, especially the re-curing cost (programming effort) must be reduced. Subsequently, for an efficient production the data input for machinery and also the recognition of the real part and its deviation to the design must be automated as well.

With Brotje´s Soul OLPS software the operator is able to generate the NC program automatically out of the native CAD data. Further the system references itself on the AC part and takes also automatically sufficient measurements on the various AC components. Based on these measurement results the system

compensates the deviation between the design data and the realty. This happens in real time during the sealing application process. Broetje´s Sealing Solution offers a full scale automation for the AC manufacturing and reduces the production cost up to twenty percent.

The development and trend of materials modelling for creep age forming of aluminium alloys

Xi Wang, Yong Li, Baoguo Chen, Zhusheng Shi, Jianguo Lin

Creep age forming (CAF) is technology that combines creep deformation and age hardening into one process for manufacturing large aluminium panel components. Since its invention, it has attracted extensive research interest and has been finding industrial applications such as aircraft wing skin panels. One of the challenges is the prediction of springback during unloading stage of CAF process, which should be compensated in and is important for tool design. Inevitably, materials modelling becomes a hot topic in CAF studies. This paper contains a review on the development and trend of materials modelling for CAF of aluminium alloys.

In the early stage of studies, classic stress relaxation or creep models were employed to link the strain and stress. Later, unified constitutive equations following the power-law or sinh-law were proposed, in which phenomenological hardening is considered. These early-stage models do not contain information on microstructural features and the interaction between creep deformation and precipitation hardening. With further development in understanding of hardening mechanisms involved in CAF, unified mechanism-based constitutive models were developed and had proven their capacity in modelling both creep strain and age hardening evolutions in corresponding research. By introducing internal state variables in the model, the microstructural characteristics, such as precipitation size, solute concentration, and dislocation density, have been introduced gradually by different researchers in rate form to manifest their evolvements during creep ageing. These microstructural related internal variables are considered to have effects on both material hardening and creep deformation during creep ageing, which were adopted in equations for describing yield strength (including precipitation hardening, solid solution hardening, and dislocation hardening components) and macro creep behavior in the unified models. Therefore, the latest unified mechanism-based constitutive models have linked evolutions of microstructures with age hardening and macro creep strain in CAF, which can be efficiently implemented into commercial finite element (FE) software via user subroutines for process simulation and springback prediction, as well as tool shape compensation and optimisation. This review aims to provide perspectives on the current development and future challenges in materials modelling for CAF of aluminium alloys.

Aircraft Design and Propulsion (PART I)

Session Chair: Prof. Michael Weigand, Vienna University of Technology, Austria

Analysis of fuselage skin reinforcements with beam element models in flexible aircraft panels for ditching simulations

Christian Leon Munoz, Bertrand Langrand, Dieter Kohlgruber

In the scope of the aircraft certification process manufacturers must demonstrate the structural response of the airframe to hydrodynamic loading in the case of an emergency landing on water, called ditching. Since full-scale experiments are unaffordable and investigations with sub-scale models are limited in terms of parameter variations, structural analysis and representativeness, experimental campaigns can be complemented by hi-fidelity numerical methods. In combination with a multi-disciplinary aircraft design process chain, ditching of generic aircraft models can be considered in early stages by contributing to the aircraft design process. However, a realistic interaction between the fluid and the aircraft structure is very challenging.

Over the past years the German Aerospace Center (DLR) and the French Aerospace Research Center (ONERA) have been working together to evaluate different aspects of suitable computational methods for ditching simulations. The test cases included detailed analyses of methods to perform Fluid Structure Interaction analyses on rigid and flexible panels [1] as well as first steps towards full aircraft ditching simulations [2] [3]. In the scope of these investigations a generic flexible reinforced panel similarly to an aft lower fuselage section was developed for guided ditching simulations [4]. The structural model is discretized with a classical Finite Element method while the fluid model uses the Smoothed Particle Hydrodynamics (SPH) or the Arbitrary Lagrangian-Eulerian (ALE) method. Subsequently, structure and fluid can be coupled in a multi-model fashion, allowing the definition of convenient time steps for each sub-model resulting in the improvement of the computational performance. Very fine models with stringers and frames discretised using shell elements on extruded cross sections have been used to compute the mechanical behaviour of the reinforced panel [4]. However, this approach may not be transferred to full aircraft fuselage models due to its computational cost. Alternative methods based on models with coarser shell elements and beam elements to represent the structural reinforcements can be used to save computational time. To transfer the modelling method from shell to beam skin-reinforcements a virtual test campaign including linear and elastic-plastic material models for both implicit and explicit calculations was started. Also, the degree of discretization of the structure and different fluid particle densities were considered. The presented paper focuses on the contribution of the use of beam-stiffened flexible aircraft panels for ditching simulations considering different mesh sizes. Ditching computations are performed with different formulations (i.e., ALE or SPH) and with particle densities for the SPH formulation.

Towards Energy-Autarchic Unmanned Aerial Systems (UAS): A Bionic Approach on Solar-Electric, Multi-Vehicle Aerial Platforms for Waterborne Operations

Franz-Michael Sendner

Miniaturization and commercialization in sensors, actuators and flight control systems allow for small size, reduced complexity and low-cost aerial platforms, increasing availability for science, civil and environmental protection. Advancements in autonomous flight of Unmanned Aerial Vehicles (UAVs)

reduce the workload for system operators, shifting resources from vehicle to mission and payload control. Especially in inhabitable, remote or hazardous environments, the utilization of unmanned aerial platforms enables to sense, detect and explore, while separating human beings from threats. However, current commercially available small size UAVs, including vertical take-off designs, require human support for launch, recovery and turn-around. Due to the limited range of these vehicles, this in turn induces human presence close to the theatre of operation. In the following, an alternative approach is proposed: Without human presence on site, a continuous operation of the aerial platform system should be realized via in-situ resource utilization. By a collaborative multi-vehicle architecture, a two-mode operation can be introduced for the individual vehicle: In a wake phase-like mode with full functionalities, mission tasks are executed. A second, sleep-like phase of minimum activity increases efficiency of energy regeneration. Thus, the required individual endurance can be reduced. In consequence, energy storage mass, vehicle size and finally costs should be minimized. As a particularly interesting study case, an aerial sensor and broadcasting platform for waterborne operations is exercised in this paper: Out of the various possible combinations of energy harvesting technologies, swarm organization and vehicle operation schemes, a homogenic system of solar/battery-electric seaplanes is proposed. During the active phase, optical and/ or electromagnetic sensors are operated in flight and processed data is being broadcasted by radio link. During the regeneration phase, vehicles float on the water surface for minimum required power and act as ground relays for increased radio broadcasting range. Thus, a mass and size driving satellite communication module should be avoided. To account for the mutual dependency of system architecture/ -operation and individual vehicle design, an integrated approach is implemented for the feasibility study: Analytical and empirical methods for waterborne aircraft design from literature are implemented. Additionally, historical data on manned and unmanned sea- and floatplanes is analysed. Trends for sizing parameters and performance estimations are derived to develop an initial parametric vehicle model. A time-step based multi-vehicle simulation is implemented. Two representative mission scenarios are studied in detail: An aerial remote detection system for sea rescue and an emergency broadcasting by UAVs. For the assumed mission payloads, a representative multi-day mission is defined and simulated. The impact of solar irradiation fluctuations by overcast and geographical location/season is examined. The sensitivity of system performance regarding data structure, data link and link budget is studied. Strategies to compensate (or utilize) wind and water currents are investigated. Individual vehicle or subsystem failures are modelled. As a result, key parameters of platform system and vehicle designs for the exemplary missions are proposed and discussed. Limitations of the approach, uncertainties in modelling and connected open questions are presented. Finally, an outlook towards the conceptual design of energy-autarchic waterborne UAVs is given.

Mechanism design for a VTOL flying wing UAV

Dimitrios Mitridis, Chris Bliamis, Pavlos Kaparos, Kyros Yakinthos

In the current work, the detailed mechanism design for the transition from vertical to horizontal flight of a Vertical Take-off and Landing (VTOL) fixed wing Unmanned Aerial Vehicle (UAV) is presented. The UAV, which is being developed on the framework of the MPU research project, under the designation MPU RX-4, is a lightweight, all electric driven UAV with a flying wing layout. The MPU RX-4 is capable of performing both conventional flight, like a regular fixed wing aerial vehicle, as well as vertical hovering, like a multicopter, adapting on different operational demands. To achieve that, the development of a robust transition procedure from one flight phase to the other is required. This procedure is based on mechanisms capable of altering the flying characteristics of the UAV. More specifically, these mechanisms

should be designed in order to change the orientation of the thrust vectors from horizontal to vertical and vice versa. MPU RX-4 uses a configuration of three electric motors (two mounted on the canards, and one in the main body) in order to perform both flight phases. Regarding the transition from the hovering phase to the level flight, the two frontal motors have to be rotated from the vertical position to the horizontal, and the rear motor to be nested in its proprietary position, using four external hatches. Ttwo separate mechanisms are designed, one for the canards rotational movement and another one for the extension and retraction of the rear motor hatches. The mechanisms design is performed using analytical kinematic/kinetic calculations for the geometrical sizing of the mechanisms parts (i.e. linkages length, maximum working angels, external loads), constrained by the MPU RX-4 external geometry and structural layout. Furthermore, Finite Element Analyses are carried out for the structural sizing of the mechanism (i.e. internal loads, linkages cross-section, joints sizing). The aerodynamic loads, acting on the mechanisms, are derived from Computational Fluid Dynamics computations performed for the various flight phases (hovering, level flight and transition) of the UAV. Finally, the designed mechanisms are presented as integrated parts of the RX-4 prototype UAV.

Enhancing preliminary aircraft design through operational considerations : a data-driven approach

Sébastien de Longueville, Joël Jézégou, Emmanuel Bénard, Yves Gourinat

Nowadays, digitalisation of aircraft, of their operations and their support became a crucial component for all the market players of the aeronautical industry. This technical field occupies an increasingly significant place, due to the generation of a substantial volume and an extensive variety of operational data. This new trend suggests to take those data into account during early preliminary design steps, in order to include additional considerations during those phases, such as operational criteria, maintenance, added value, development times or certification delays. Those data flows and the results and decisions arisen from their analyses by different algorithms seek mainly to optimize the lifetime, the availability and the Direct Operating Cost of aircraft and systems through the use of means and/or services of health monitoring, advanced maintenance systems or operation support. Recent researches suggest that those data might also be taken into account in early preliminary design phases thanks to digital threads (see Figure 2) and integrated design environments (Figure 3). In the same vein, those data can be used to challenge hard criteria applied during the design and certifications processes, which rely on robust and proven solutions, often based on conservative hypotheses, underlying in certification rules.

This study proposes therefore to investigate how design choices and certification requirements could benefit from data-driven applications, by applying the methodology described below to the to Vertical Tail Plane (VTP). This use case choice is mainly driven by the highly multidisciplinary scope of this subsystem and the important number of conservative assumptions its design process involves. More specifically, it will aim at studying the relevancy of the various safety factors enforced by the regulation authorities for structural components as well as load cases and aerodynamic performances (e.g: minimal speed (1.23xVs1g), gust loads, ...). The origin of those safety factors, as well as the kind of uncertainty they cover is then criticized in order to identify data that would allow reducing the magnitude of those safety margins without impacting safety levels. Finally this study will be combined with a requirement analysis, in order to highlight the dependency effects of the most constraining certification requirements and a sensitivity study of those various safety factors, in order to evaluate the impact of those safety factors on the preliminary design process.

Methodology: This methodology aims at providing decision-support tools regarding overall aircraft design degrees of freedom, as shown on Figure 4. In addition to that, a formal approach of certification and design requirements will be used to identify the impact of the most constraining requirements.

This objective is achieved by completing the following steps:

1) Tree-like modelling of applicable certification requirements, based on a sequential reading of the CS-25.
2) Functional analysis of the Vertical Tail Plane.
3) Requirement inter-dependencies identification and modelling using requirement and property diagrams.
4) Identification of the requirements conservatisms that could be relaxed through a better characterisation of the operational state.
5) Mathematical modelling of those requirements
6) Architectural and functional modelling of the Vertical Tail Plane.

Advanced Materials and Technologies for Compressor Blades of Small Turbofan Engines

Dmytro Pavlenko, Yaroslav Dvirnyk, Radoslaw Przysowa

BACKGROUND: Manufacturing costs, along with operational performance, are among the major factors determining the selection of the propulsion system for unmanned aerial vehicles (UAVs), especially for aerial targets. OBJECTIVES: In this paper, the design requirements and operating parameters of small turbofan engines for single-use and reusable UAVs are analysed to introduce alternative materials and technologies for manufacturing compressor blades such as sintered titanium, a new generation of aluminium and an alloy based on titanium aluminides. METHODS: To assess the influence of intensive plastic deformation on the hardening efficiency of the proposed materials, the alloys in the coarse-grained and submicrocrystalline states were studied. Changes in physical and mechanical properties of materials were taken into account. The thermodynamic analysis of the compressor was performed in a finite element analysis system (ANSYS) to determine the impact of gas pressure and temperature on the aerodynamic surfaces of compressor blades of all stages.

RESULTS: Based on thermal and structural analysis, the stress and temperature maps on compressor blades and vanes were obtained, taking into account the physical and mechanical properties of advanced materials and technologies of their processing. The safety factors of the components were established based on the assessment of their stress-strength reliability. Thanks to nomograms, was confirmed the possibility of using the new materials and the technologies in view of the permissible operating temperature and safety factors of blades.

CONCLUSIONS: The proposed alternative materials and production technologies for the compressor blades and vanes meet the design requirements of the turbofan at lower manufacturing costs.

Aircraft Design and Propulsion (PART II)

Session Chair: Prof. Michael Weigand Vienna, University of Technology, Austria

Conceptual design of a novel Unmanned Ground Effect Vehicle

Charalampos Papadopoulos, Dimitrios Mitridis, Kyros Yakinthos

In this work, a methodology for the conceptual design of a combined Box-wing and Blended-Wing-Body unmanned aerial platform, which exploits the ground effect, is presented. Ground Effect Vehicles (GEVs) are aircrafts or aerial vehicles capable of flying very close to the surface of water areas, being a promising alternative to ships and seaplanes operating in closed seas. In order to exploit the air cushion that is formed underneath, GEVs have low Aspect Ratio wings. Thus, the Blended-Wing-Body (BWB) layout configuration is an appealing choice due to the large available body surface. On the other hand, a tailless vehicle having the BWB layout is facing challenging stability issues, especially in a turbulent and highly volatile environment as the one close to the sea level. Therefore, the addition of the Box wing configuration, namely a continuous-surface nonplanar wing formation with no wing tips, is deemed beneficiary as a way to overcome the stability challenges and eliminate the wingtip vortices. The combination of these two prominent platforms leads to improved aerodynamic performance and eventually, a reduced fuel consumption. The design methodology starts by the estimation of the most important design parameters, such as aspect ratio, sweep angle, and taper ratio, which are continuously refined in an iterative computational framework during the conceptual design phase. In an initial approach, the flight scenario with no ground effect interference is studied, with the use of both analytical calculations and computational fluid dynamics simulations. The results from the conceptual design phase indicate that the UGEV configuration has a considerable potential as an alternative to ships or seaplanes, based on its ability to carry larger payload than seaplanes and deliver it faster than ships.

Conceptual design of an unmanned aerial vehicle for fast container transport

V. Chernousov, A. Krutov, E. Pigusov, V. Zamaraev

The rapid development of technologies in the area of unmanned aircraft systems (UAS) combined with its wide spread in the civil market, indicates the possibility of creating a relatively large unmanned aerial vehicle (UAV) for cargo transportation (maximum take-off weight more than 18 tons). The concept of unmanned flight will improve the efficiency of an airplane with conventional layout. The removal of the crew compartment and associated systems makes it possible to apply advanced layout solutions that refine aerodynamics, reduce the airframe weight, direct operating costs, etc. Certification according to specially developed airworthiness standards for UAV will remove a number of restrictions inherent in manned transport aircraft certified under the FAR/CS-25. This paper presents the conceptual design of a Civil Transport UAS (CITRUS). The CITRUS is intended for fast transportation of commercial containerized loads up to 6 tons with speed 800-850 km/h. The CITRUS is a cargo aircraft with high swept 25° wing and T-tail, with two turbofan engines mounted on underwing pylons. The article provides the basic premises and principles of the new concept. The features of the aerodynamic layout and structures of the CITRUS are described. Estimates of the aerodynamic and take-off and landing characteristics are given.

Multi-Disciplinary Framework for Propeller Blade Design

Andreas Kümmel, Christian Breitsamter

Improved propeller designs are necessary to ensure an eco-friendly and resource-saving operation. The shape optimization of propellers involves different disciplines. The important ones are the aerodynamics, the structural behavior and aeroacoustics of the propeller. To deal with the complex optimization task, a multi-disciplinary optimization framework is developed.

Numerical Analysis of Cyclorotor Aerodynamic Properties in Hovering State

Shawn Cogan, Louis Gagnon

Cyclorotors employ cyclically pitched axial rotor blades to create an extremely maneuverable propulsion system. The pitch angle throughout one rotation is defined so that the resulting angle of attack follows a prescribed function that generates lift. The lift and drag produced is also affected by curvilinear flow, dynamic stall, and induced velocities, all of which affect the pitch angle to form the angle of attack. These factors form complex relationships that are impossible to solve analytically, making it hard to predict a cyclorotor's performance. Here, a numerical model is presented which can be used to predict thrust and power draw of different cyclorotor configurations. Parameters include airfoil, number of rotor blades, rotational velocity, pivot function, fluid properties and Reynold's number. The numerical model builds on previously implemented approximations but focuses on time-efficient calculations so that many configurations may be calculated in an iterative process. In each iteration the parameters can be adjusted according to machine learning or other metaheuristic optimization algorithms to determine an optimal configuration. Previous attempts at determining ideal cyclorotor configurations have largely relied on experimental and analytic models, which can be time consuming or rely on representations that are solvable analytically, respectively.

Aircraft Design and Propulsion (PART III)

Session Chair: Prof. Michael Weigand, Vienna University of Technology, Austria

From FAST to FAST-OAD: An open source framework for rapid Overall Aircraft Design

Scott Delbecq, Christophe David, Sébastien Defoort, Peter Schmollgruber, Emmanuel Benard, Valérie Pommier-Budinger

To face the increasing environmental footprint of commercial aviation, industrial and research efforts have been focusing on exploring unconventional configurations and new propulsion paradigms, mostly based on electric technology. Such explorations require Overall Aircraft Design that has to be performed in an integrated multidisciplinary design environment. Such design environments are often limited to multidisciplinary analysis, adapted for a single aircraft configuration or require an important effort to be mastered. FAST-OAD is a software program developed by ONERA and ISAE-SUPAERO for aircraft sizing analysis and optimization with emphasis on user friendliness and modularity. It is an aircraft sizing code based on multidisciplinary design optimization techniques and the point mass approach to estimate the required fuel and energy consumption for a given set of TLARs. This paper presents the motivations and improvements for moving from the original software program, called FAST to the open source code FAST-OAD based on OpenMDAO.

The performance and emissions of a microturbine and turbofan powered by alternative fuels

Radosław Przysowa, Bartosz Gawron, Tomasz Białecki, Anna Łęgowik, Jerzy Merkisz, Remigiusz Jasiński

In order to reduce CO2 emissions, as well as make use of inedible raw materials from renewable sources, alternative fuels containing biocomponents produced in various technologies are introduced in aviation. However, using biofuels to propel aircraft we are much less experienced than we are at using mineral fuels. Currently, ASTM D 7566 standard allows for seven synthetic fuel production technologies to be used in aircraft turbine engines, including Alcohol-to-Jet (ATJ) and Hydroprocessed Esters and Fatty Acids (HEFA). The purpose of the work is to compare the performance and gas emissions produced from two different jet engines: the GTM-140 microturbine and the full-size DGEN380 turbofan. The engines were powered by blends of Jet A-1 and one of two biocomponents: 1) ATJ and 2) HEFA produced from used cooking oil (UCO) in various concentrations. Data were analyzed in the scope of physicochemical parameters of fuel blends, engine operating parameters and gas emissions. Blends of the mineral fuel with synthetic components were prepared in various concentrations, and their physicochemical parameters were examined in the laboratory. Measurements of gas emissions from the GTM-140 microturbine were carried out in selected operating points using the Semtech DS gaseous analyzer and the EEPS spectrometer. Similar emission measurements were made for the DGEN380 engine in a test cell. Measurements were averaged over 30 seconds, visualised and compared. It was confirmed that the used blends of Jet A-1 and the ATJ and HEFA biocomponent in the range of selected physicochemical properties meet the standard requirements, and there are no contraindications against fuelling gas-turbine engines. The analysis of engine performance parameters showed that the tested blends differ so little from the mineral fuel that their impact on the engine operating parameters is very limited, and their use does not carry the risk of a significant decrease in aircraft performance or increase in fuel consumption. It was also found that increasing the content of biocomponents causes a noticeable increase in the emission of CO and some other gasses (HC and NOx), which should not, however, worsen the working conditions of the ground personnel. By comparing the performance and emissions of a microturbine and full-size engine, it is possible to generalize some results that can only be obtained with a microturbine. This is the case with new alternative fuels, synthesized in quantities insufficient to power large engines. Moreover, the analytical combustion model and statistical methods seem to be suitable for linking the thermophysical parameters of the fuel with the operating parameters and emissions of engines of a basic structure. A more complex understanding of the effects of fuel blends on engine performance and emissions requires more complex engine models, describing, in particular, its combustor and control system.

Generative design case study of a CNC machined nose landing gear for an unmanned aerial vehicle

Ioannis Zaimis, Efstratios Giannakis, Georgios Savaidis

Generative design is a powerful design method, pushing the limits of the industry to new design solutions, inspired from nature's evolution. Using minimum input requirements, the resulting designs can be structurally adequate, weight-optimised and almost production-ready. The main purpose of this paper is to present the different approaches of the standard engineering design and the generative design methods. This is achieved through the case study of a nose landing gear for a prototype tactical unmanned aerial vehicle, intended for low volume production. In the first part of the paper, the conceptual design of the nose landing gear is outlined. Subsequently, during the preliminary phase the stress distribution along the different parts is calculated, based on the classic strength of materials theory and therefore a design

solution is produced. In the second part, a generative study is carried out with a commercially available tool, based on the conceptual parameters previously chosen. Both of these concepts, are studied with industry-standard FEM tools, in order to validate, from a theoretical standpoint, the strength requirements according to STANAG 4671 regulation. The final structure will be manufactured with 3-axis CNC machining, while providing about 25% weight reduction without compromising the structural functionality.

In-Flight Thrust Measurement and Drag Estimation of an Unmanned Propeller Aircraft

Dominique Bergmann, Jan Denzel, Ole Pfeifle, Stefan Notter, Andreas Strohmayer

Electric and hybrid-electric propulsion systems are an important technology for the development of future propulsion systems in aviation. The technology leap achieved with highly efficient advanced electric motors combined with a compact and light weight structure enable new propulsion arrangements and aircraft configurations. This effective integration of distributed propulsion facilitates synergetic effects, improving flight performance and thus reducing in-flight emissions. In order to systematically analyse these effects, a 33,3% scaled version of the e-Genius was designed and manufactured at the Institute of Aircraft Design at the University of Stuttgart and used for test flights in the context of various research projects.

As the aircraft is being used for various flight performance analyses in the field of distributed electric propulsion (currently in the project ELFLEAN), a precise identification of its flight performance is necessary. One of the main challenges is the determination of the total drag of the airplane to be able to identify an exact drag polar in-flight. For this purpose, an on-board measurement system was developed which allows for a precise determination of the thrust of the scaled model and thus permits a direct correlation to the corresponding drag. The system has been tested and confirmed in flight. The article gives a short overview of the installed measuring system and its functionality and shows results of the conducted flight tests.

An overview of the new research infrastructure for rotating labyrinth seals at COMOTI

Bogdan Gherman, Lica Flore, Razvan Carlanescu, Marius Enache

In this article will be described the improved test stand for rotating labyrinth seals that will be developed at COMOTI. The present test rig is able to test only a seal configuration in a simplified environment, (air temperature max.150 oC, labyrinth diameter max. 300 mm, airflow rate max. 0.35 kg/s, pressure max. 9 bars). The newly improved research infrastructure will be able to increase these limits up to: 800oC temperature, 600 mm labyrinth diameter, 10 kg/s airflow rate and 50 bars pressure.The upgrade performed on to this research facility will comprise of a test rig for experimental measurements; a air supply station with two centrifugal compressors; an air cooling tower; a air tank to store high pressure air and an air heater station capable to supply air with 800oC.

Development of a Flight Mechanics Simulation Computer based on a Flexible Aircraft Model for a Regional Aircraft

Simone Malisani, Elisa Capello, Giorgio Guglieri

The changes on aircraft structures and the increased use of advanced and light materials have led to the design of more efficient and flexible aircraft. This implies that rigid body dynamics are no longer sufficient to describe the aircraft behaviour in atmospheric flight. Coupling between structural and rigid body dynamics should be included, due to frequencies of structural modes.

In this work, an analytical method, based on a mixed Newtonian-Lagrangian approach, is used to derive a simplified model of a flexible aircraft,. Moreover, flexible displacements and torsional variables, starting from the Lagrange's equations, are discretized by means of a finite number of generalized coordinates. This approach allows to derive directly a finite-order system of ordinary differential equations, making it less complex and suitable for real time simulation and control law synthesis. The main objective of the proposed methodology is the real-time implementation on a “flyable” hardware, for experimental tests. A simplified low-order model is designed for a regional aircraft, including different masses and flight conditions. Only two symmetrical bending modes and one torsional mode are considered in the flexibility definition. To show the effectiveness of the proposed method, sensors model are also included. Accelerometers on selected wing sections are design to measure the effect of flexibility in terms of bending and torsional deformations. Moreover, an inertial measurement unit (IMU) and a global positioning system (GPS) model are provided.

Finally, the hinge moments acting on the control surfaces are evaluated. The hinge moment is calculated as the aerodynamic torque generated on the hinge axis by the variation of the pressure distribution acting on the control surfaces. Therefore, a hinge moment coefficient depending on the geometric data and aerodynamic characteristics of each control surface is defined. The research work presented in this paper is performed within the ASTIB project, which has received funding from the Clean Sky 2 Joint Undertaking under the European Union’s Horizon 2020 research and innovation program under grant agreement CSJU – GAM REG 2014-2015. So, the main focus of this research is the evaluation of accelerations and hinge moments, when a gust occurs. We presently include two models of gust: (1) a discrete gust model, with a “1-cos” shape, implemented following CS-25 regulations, and (2) a continuous gust model based on von Karman theory.

ecoDESIGN and Sustainable Productivity

Session Chair: Mr. Torsten Moll, Fraunhofer-Gesellschaft, Germany

ecoDESIGN and Sustainable Productivity

Torsten Moll

The European aeronautics industry has a large environmental and socio-economic relevance. Its sustainability, productivity and competitiveness will strongly depend on the innovation steps to make economic value and ecologic value come together. Looking at aviation as circular economy, all life cycle phases must be considered closing the loop from end-of-life to material production. Sustainability of materials, processes and resources, efficient manufacturing, lifetime services and the end-of-life challenge will drive the competitive value in the context of environmental services. The presentation provides an overview about the ecoDESIGN Transversal Activity in the Clean Sky 2 programme. This includes an outlook on selected activity domains and demonstrations in scope.

Geometry Model and Approach for Future Blisk LCA

Kilian Fricke, Thomas Bergs

Air traffic is expected to double over the next 20 years and Flightpath 2050 targets to a 70% reduction of CO2 and a 90% reduction of NOx. Optimization of future aircraft engines often is dominantly driven by a focus on the reduction of fuel burn and emissions during operation. To identify additional environmental improvement potential a full Life Cycle Analysis (LCA) shall be aspired also including Materials, Processes and Resources, Manufacture and Production, Lifetime Services as well as Reuse, End-of-Life and Recycling. Core engine components, for example integral rotors, are comprised of high alloys and require complex manufacturing processes. The presentation and full paper will introduce a geometry design model of a compressor blisk which is employed as basis for a future LCA approach focusing on materials, processes and resources as well as manufacture and production. The model is a carrier for challenging manufacturing features such as large blade twist, high aspect ratio and small blade gaps. In addition to the geometry model, a first set of multiple technology scenarios and their process chains will be introduced which will serve as base for a future LCA. The work is part of the Clean Sky 2 Programme (Engines ITD, ecoDESIGN Transversal Activity).

Validation of the simulation tool for environmentally friendly aircraft cargo fire protection system

Arnav Pathak, Victor Norrefeldt, Marie Pschirer

One of the objectives of CleanSky-2 project is to develop an Environment Friendly Fire Protection (EFFP) system (halon free fire suppression system) for the aircraft cargo hold. For this, an Aircraft Demonstrator including the cargo hold has been equipped with a nitrogen suppression system. The demonstrator is located in the low pressure vessel and can thus be subjected to realistic cruise pressure conditions and take-off and descent pressure variations. As a design tool, a zonally refined simulation model to predict the local oxygen and nitrogen concentration distribution in the cargo hold has been developed using the Indoor Environment Simulation Suite (IESS). The model allows for fast transient simulations of the suppression system operation. This paper presents a model validation case of a knock-down during cruise, followed by a holding phase and descent (repressurization of the cargo hold).

Development of SmarT Eco-friendly anticontamination technologies for LAminaR wings

Mireille Poelman, M.E. Druart, T. Sénéchal, J. Palenzuela, G. Glabeke, J. van Beeck, D. Ghysselinckx, F. Bougard, S. Verschaeve, J. Bico, B. Abou, A. Lechantre, B. Martinet, R. Wattiez, A. Laurent, M. Farouz-Fouquet

The aircraft industry is facing issues with the increase of drag directly impacting the fuel consumption of the fleet. Achieving natural laminar flow requires high surface quality. Tiny air flow disturbances at the surface can indeed cause an early transition from laminar to turbulent flow. The accumulation of insect debris on the leading edge of laminar wings has been recognized as one of the most significant operational concerns associated with laminar flow. The main objective of STELLAR is to develop efficient and durable anticontamination coatings and cleaning solutions designed following a deep understanding of the insect residues properties. Hence, STELLAR project seeks to gain insight on the understanding of the biochemical transformation of hemolymph during flight phases and the consequent physico-chemical modification of the surface. In order to meet these goals, the project consortium gathers cutting edge multidisciplinary knowledge and the needed facilities to provide a deep understanding of the contamination issues. This approach has the potential to significantly enhance the current understanding of the key issues and highlight which surface characteristics have the greatest influence on insect residue adhesion. From this approach, new coatings and cleaning solutions will be developed.The knowledge acquired and the solutions developed will be evaluated through large scale tests : tests in wind tunnel which allow simulating extreme conditions occurring during flights, on a test aircraft (short flight tests) equipped with a cameras and sensors (TÂ°, RH, pressure) to monitor all the parameters responsible of real condition contamination and on a commercial aircraft (long flight tests) flighing at higher altitudes and allowing a full validation of the newly developed solutions.As a summary, the project STELLAR aims at producing sustainable solutions to reduce drag on aircrafts and enable laminar flow over time with direct impact on fuel consumption and thus contributes to aviationâ€™s ecological footprint reduction, targeting a 50% reduction of wing friction and up to five percent lower CO2 emission.

Effect of increased recirculation rate on the humidity and CO2 level in the cabin

Victor Norrefeldt, Florian Mayer, Britta Herbig, Pawel Wargocki, Ria Ströhlein, Ivana Ivandic, Lei Fang

In the CleanSky 2 ComAir study, subject tests were conducted in the Fraunhofer Flight Test Facility cabin mock-up. This mock-up consists of the front section of a former in-service A310 hosting up to 80 passengers. In 12 sessions the fresh/recirc ratio was altered from today's typically applied fractions to up to 88% recirc fraction. This leads to increased CO2 levels and to higher relative humidity in the cabin air, as the exhaled humidity by passengers becomes less diluted by fresh, dry air. This paper describes the measured increase of CO2 and moisture level in the cabin air for the different test conditions.

Manufacturing the next generation of aircraft seats: healthier, lighter, costeffective and recyclable

Rudolf Emmerich, Adrian Ortego Novillo, Felix Behnisch, Sergej Illinzeer, Ruben Barriento

To analyse the overall improvement of the environmental performance of an aircraft one must consider all life cycle phases (e.g. raw materials, manufacturing, operation, and end of life). This presentation bases on a collaborative work on efficient manufacturing and testing of aircraft with regard to their environmental benefits. It includes an analysis of innovative technologies for tool localization and status indication, for automated failure localization and an approach towards increased self-testing level of an aircraft during manufacturing. The activity is part of Clean Sky 2 programme.

Aircraft Testing

Prof. Ivo Jebacek Brno University of Technology, Czech Republic

Determination of 1st Buckling and Collapse Loads for Integrally Stiffened Panels by Artificial Neural Network and Design of Experiment Methodology

Selcuk Guzel, Ercan Gurses

Buckling is a structural instability that load carrying capacity of a structural element may suddenly decrease. This sudden change in the load carrying capacity may cause catastrophic failures. Therefore, determination of first buckling and collapse loads of structural elements is essential. FEM analyses and structural testing are used to determine buckling characteristics of a structural element. However, in early design stages, FEM analyses are time consuming and structural testing is costly. In this paper, an artificial neural network tool is used to reduce computational effort to determine buckling loads of integrally stiffened structural panels in early design stages. Artificial Neural Network is a computational tool that can classify and recognize patterns and provide accurate predictions for given inputs by learning from the previous data. Furthermore, it is widely used in the industry for structural purposes such as weight reduction of stiffened panels to reach optimum load carrying capacity, load-displacement relation prediction of different types of columns or design optimization of anisotropic laminated composites. Moreover, the Latin Hypercube Sampling (LHS) methodology is used to reduce the number of required FEM analyses to generate database that artificial neural network is based on. The Latin Hypercube Sampling is a commonly used design of experiment technique for design problems which consist of more than 2 variables. The selected design points are distributed so that they cover all design space but do not intersect with each other. Therefore, the LHS is a useful tool for this study to reduce number of required FEM analyses. Mean errors and fit performance model results are compared to determine accuracy of the neural network results. Finally, accuracy of artificial neural network based on whole design space solutions and based on design points selected by LHS are compared and presented for the first buckling load, collapse load and mass predictions of integrally stiffened panels under compressive loads.

Measurements of deformation, schlieren and forces on an OAT15A airfoil at buffet conditions

Alessandro Accorinti, Tim Baur, Sven Scharnowski, Johannes Knebusch, Johannes Dillinger, Yves Govers, Jens Nitzsche, Christian J. Kähler

Self-sustained shock wave oscillations on airfoils can occur under certain combinations of transonic Mach number and angle of attack due to the interaction between the shock and the separated boundary layer. This phenomenon, commonly defined as buffet, constitutes a limitation for the flight envelope of an aircraft since the unsteady structural loads deriving from the lift fluctuations can significantly reduce its fatigue life. Even though several models have been presented over the last decades [1-4] with the intent to explain the buffet physics and predict its onset, none of them has a recognized general validity and some aspects of this complex phenomenon are still to be thoroughly understood. In order to help understanding buffet physics, a rigid supercritical wing model (OAT15A) is investigated in pre-buffet and buffet conditions by means of a combined application of Background Oriented Schlieren (BOS), Deformation and Force measurements (lift, drag and moment). From the calculation of the rates of the shock movement and of the extent of the boundary layer separation via BOS, the transition from stable shock to buffet will be analyzed in detail. The prediction of buffet onset provided by BOS will be compared with the one from the balance data and numerical results. Moreover, once the buffet is settled, its

frequency deduced from BOS will be compared with the dominant ones extracted from the balance and the surface oscillation/deformation values. The final conference paper will include an experimental database for pre-buffet and buffet flows on the OAT15A wing and will address the influence of the structural properties on the flow development[35].

Development of a prototype test system for certification of curved fuselage panels through experimental validation

M. Jiménez, R. Cabrera, J.L. Armario, E. Graciani, A. Estefani, K. Munñoz, F. París, E. García

A test system for experimental certification campaigns curved fuselage panels has been developed and validated. The system has capability to apply axial, torsional and pressurization loads, representative of inservice loads of curved fuselage panels up to 5m long. This development contributes to reduce certification costs and lead times. The system is aimed to reproduce combined loads, representative of real loading cases of a curved fuselage panel, has been developed. This test machine allows the structural validation of fuselage curved panels up to 5m long to be accomplished. The developed system is able to apply combined mechanical and pressurization loading states under quasi-static and dynamic loading conditions. It has been designed using CAD models and calculated with the aid of Finite Element Models to ensure its integrity. A data acquisition system synchronized with a control system enables real time monitoring of the loads, displacements and pressurization applied as well as the stress-strain states produced on the specimen. The system' performance has been verified and validated by testing dummy specimens specifically designed to this end.

Numerical Methodology for Aerostructures Hail Impact Damage Prediction

D. Ivančević, I. Badurina Žakan, I. Smojver

The two numerical approaches for modelling of soft-body impact in Abaqus/Explicit have been applied in this work at the prediction of high-velocity hail impact damage in aeronautical structures. The applied methods are the CEL (Coupled Eulerian Lagrangian) and SPH (Smoothed Particle Hydrodynamics), while the impacted structure is a metallic slat structure, a typical structural item that is exposed to hail impact.Comparison of the CEL and SPH methods has been performed by impact simulations at a rigid plate, aimed to validate the applied material model [1], and by simulation of the slat structure impact. Validation of the material model has been performed using experimental data [1-3] of hail impacts at a wide range of impact velocities and impactor diameters. The boundary and initial conditions at the slat structure impact have been defined based on the recommendations in FAR25.507. To study the effect of high strain-rates at the damage process in the metallic structure, two material models have been applied

---

[35][1] H.H. Pearcey, A Method for the Prediction of the Onset of Buffeting and Other Separation Effects from Wind Tunnel Tests on Rigid Models, AGARD TR 223, National Physics Laboratory, 1958.

[2] B.H.K. Lee, Oscillatory shock motion caused by transonic shock boundary-layer interaction, AIAA J. 28 (5) (1990) 942–944.

[3] J.D. Crouch, A. Garbaruk, D. Magidov, A. Travin, Origin of transonic buffet on airfoils, J. Fluid Mech. 628 (2009) 357–369.

[4] L. Jacquin, P. Molton, S. Deck, B. Maury, D. Soulevant, Experimental study of shock oscillation over a transonic supercritical profile, AIAA J. 47 (9) (2009) 1985–1994.

in the process. The first is the standard isotropic plasticity model that defines material failure based on the value of equivalent plastic strain. The second constitutive model in the analyses is the Johnson-Cook model that includes the effects of strain rate and temperature on the material failure process.The analyses show that both applied methods result in similar structural response of the impacted slat structure. The simulations have been stable, illustrating robustness of Abaqus/Explicti in these highly nonlinear impact cases. Compared to the CEL, the SPH method is computationally more efficient.

Identification of resonant vibrations of the miniature unmanned airplane with contact and non-contact measuring techniques

Olejnik Aleksander, Rogólski Robert, Szcześniak Michał

The paper describes application of two different vibration measurement methods for identification of natural modes of the miniature UAV. The aim of this type of research is to determine resonant frequencies and modes of aircraft in some required range of frequency values. Special measuring equipment is being used including contact or non-contact techniques. The measuring systems on equipment of the Institute of Aviation Technology (IAT is a subpart of the Faculty of Mechatronics and Aerospace of Military University of Technology) are used to conduct measurements and to provide data collected from testing real objects with possibility to integrate them into the simulation process. In traditional GVT methods a large number of sensors can be attached to the aircraft, which mainly limits the number of free slots in the data analyzer. The weight of sensors and cables is negligible in relation to the mass of the large tested aircraft. But for light unmanned aerial vehicles (especially for mini-UAVs), this could bring a significant mass component in relation to the total mass of the tested object. The aim of the article is to present the methodology of Ground Vibration Testing in relation to two different methods of measuring structure vibrations: the contact method and the non-contact method. Using the dedicated apparatus in relation to the actual construction of tested mini-airplane, properly prepared in terms of mass distribution, rudders deflection stiffness and proper support, key vibration characteristics corresponding to resonant points can be determined. Special measuring equipment was used to carry out this type of tests. A contact method system consists of a multi-channel LMS SCADAS analyzer, a set of piezoelectric accelerometers, electrodynamic exciters, 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 GVTs and high-performance tests. A non-contact method is performed using laser scanning vibrometer Polytec PSV-400 3D. This advanced apparatus is used for non-contact measurement of all kinds of structural vibrations. The principle of operation is based on the separation of the laser beam, one is the reference beam, while the other moves to the vibrating object. The returning beam is captured by the camera and compared to the reference beam. Dedicated software analyzes the collected measurement data and on the basis of it creates animations showing the shape of vibrations of a given object in a wide frequency range. Tests were carried out on the mini-UAV Rybitwa. The drone designed and manufactured in IAT MUT has a classic aerodynamic system with a T-tail and it is made of composite. This is the version equipped with training observation head mounted in front element of fuselage. The article will describe both measurement methods and will present sample results. Some trials of numerical normal mode analyzes with the use of the MSC Software package were presented also. The research goal was to collect similar experimental data from both applied measuring method and to propose correctly adjusted finite element model (FEM) which could give similar values numerically calculated eigenfrequencies.

Implementation of Open Science in Aviation

Session Chair: Dr. Gioia Venturini, SAFRAN Group, France

Use cases towards future Open Science model for air transport

Afroditi Anagnostopoulou, Gabriele Pistilli, Fabio Cartolano, Michela Fioretto, Kristel Palts, Maria Boile

This work aims to provide an overall assessment of scientific production against innovation uptakes in order to propose relevant recommendations for the definition of future Open Science services and infrastructures in air transport mode. A systematic review of current scientific production for air transport is conducted by assessing activity of relevant Technology Platforms and the main influential organizations. Moreover, different positioning is considered based on the attributes and roles of the key actors (i.e. industry, research community, and public authorities) studied. The proposed modelling approach follows a bottom-up mode utilizing scenes, scenarios and use cases that present needs and objectives in terms of services, applications, infrastructure, policies and regulations identifying a general transport condition in air transport area. Representatives of DLR and HUMANIST (i.e. Technology Platforms that stand for Industry sector), of EATEO (i.e. main influential Research Organizations) and of UITP (i.e. public authorities) provided significant input for successfully addressing them. As such, the analysis applied at different planning levels (strategic, tactical and operational) and use cases identified per competence area (i.e. business modelling, environmental area, legal/regulatory area, socio-economic area, technology area and transport planning area). To this end, a systematic assessment conducted in order to i) define the main research trends identified by main actors and clustered per competence area, ii) identify research topics listed in previous research work programmes and grouped per type of resource used, iii) identify gaps (issues not addressed by current research activities) and iv) provide recommendations for future scientific work.

PARE Project Session

Session Chair: Prof. Luiz Manuel Braga da Costa Campos, Instituto Superior Técnico, Portugal

The PARE project and 58 recommendations for aeronautics research in Horizon Europe

Luis Campos, Pedro Serrão, João Oliveira

The main objective of the project PARE (Perspectives for Aeronautical Research in Europe) is to assess the progress made towards the 23 ACARE Flightpath 2050 goals. The methodology takes as baseline the evolution over the period 2000 to 2020 and considers likely or possible evolutionary progress or step changes that could fulfil 2050 targets, identifying cases where gaps exist and suggesting supplementary measures accordingly. The 23 ACARE Goals are covered in Part I of the PARE Yearly Report in five chapters 2-6 following the same grouping: (2) meeting societal and market needs, (3) maintaining and extending industrial leadership, (4) protecting the environment and the energy supply, (5) ensuring safety and security and (6) prioritizing research, test facilities and education.

The Part II of the PARE report has five chapters 7-11 addressing horizontal issues related to ACARE goals, namely: (7) long-range air transport, (8) emerging aviation technologies, (9) cooperation beyond Europe's borders, (10) attracting young talent to aeronautics and (12) increasing the participation of women in

aerospace. These five chapters lead to the formulation of 35 PARE Objectives, supporting the implementation of the 23 ACARE Goals. The ensemble forms a set of 58 Recommendations for Aeronautics Research in Horizon Europe. These 58 PARE Recommendations are summarized in chapter 1, in a concise format consisting of a statement of the recommendation, rationale, relevance, stakeholders and priority rating on a scale of I to IV.

The Part III of the PARE report consists of five chapters 12-16 with detailed case studies including issues that emerged before and during the 3-year span 2018-2020 of the project: (12) prospects for the Chinese aircraft market, including and internal and external influences; (13) the Boeing Middle-of-the-Market Aircraft (MMA), finding the reasons that lead to its later cancellation; (14) the two Boeing B737Max accidents and the consequences of the grounding of the fleet and implications for future aircraft certification; (15) regional and international air transport in the case of the partner airline SATA, covering both the pre- and post COVID-19 period; (16) effects of COVID-19 on aviation, including airlines and lessors, major industry and supply chains, airports and air navigation, maintenance, health and staff issues, government interventions, future consequences and crisis management strategy. The Part IV of the PARE report consists of 3 chapters 17-19 addressing major challenges for the future of aviation, selecting the topics most relevant to the New Green Deal of the European Union, in providing environmentally clean and friendly air transport with increased efficiency, comfort, safety and security: (17) efficient propulsion for low-noise and emissions, (19) decarbonization of aviation by 2050, (20) alternative sustainable fuels. The final chapter 21 includes conclusions in the form of 10 articles accessible to the general public covering the topics of chapters 2 to 11. The whole report is preceded by an Executive Summary presenting in a concise form the main findings and recommendations towards the implementation of the ACARE Goals, PARE Objectives and of the New Green Deal as concerns aviation in the time frame to 2050, starting with Horizon Europe.

PARE analysis of intermediate 2020 goals and of further steps to ACARE Flightpath2050 goals in perfecting environment and energy supply

Oleksandr Zaporozhets, Volodymyr Isaienko, Kateryna Synylo

In recent years the aviation sector has initiated a comprehensive range of measures to mitigate its impact on the environment. To achieve the ACARE Flightpath-2050 goals, step changes in aircraft configuration and operation (including alternative energy sources) will be required (Figure 1) – currently envisaged evolutions will not be sufficient, there is a need a real basket of measures! Such disruptive change will have consequences for all stakeholders: manufacturers, airlines, airports, ANSPs and energy suppliers. The paper describes the current points of the EU civil aviation on a way to FlightPath 2050 Challenge 3 goals, defined in PARE project at pre-final term stage.

In 2050 technologies and procedures available allow a 75% reduction in CO2 emissions per passenger kilometre and a 90% reduction in NOx emissions. The perceived noise emission of flying aircraft is reduced by 65%. These are relative to the capabilities of typical new aircraft in 2000. Besides aircraft movements is expected to be emission-free when taxiing. Air vehicles should be designed and manufactured being recyclable. Europe is established as a centre of excellence on sustainable alternative fuels, including those for aviation, based on a strong European energy policy. Europe is at the forefront of atmospheric research and takes the lead in the formulation of a prioritised environmental action plan and establishment of global environmental standards. The ACARE 2020 Goal for aircraft fuel efficiency is looking reached first

of all in Technology/Operation domain, consequently the goal for CO2 reduction also. Overall fleet efficiency improvement associated with replacing baseline fleet with "imminent" aircraft is 22.0%. Potential reductions in CO2 emissions due to anticipated improvements in ATM efficiency and operational practices - assumed aircraft CO2 emission saving in three main categories (from UK aviation): ATM on 6.3%, APU substitution on 0.3%, Aircraft Operations on 2.1%. Total CO2 emission reduction may be reached on 8-9%. In conclusions there are few current recommendations are formulated for FlightPath 2050 Challenge 3 Goals: 1) Support a broad research effort to reduce aircraft noise (a) at the source (b) through operating procedures and (c) taking into account psychoacoustic effects; 2) Besides struggling with short term solutions to an increasingly pressing noise problem a modest effort should be made towards along-term definitive solution: aircraft in audible outside airport boundaries; 3) To formulate a set of trade-offs between (a) different types of emissions (CO2, NOx, PM and water vapor) in (b) local airports and global cruise flights; 4) Besides struggling with short-term emissions problems put a modest effort towards a long-term definitive solution: the hydrogen powered and electric powered aircraft are among the possible solutions.

Alternative fuels for aviation: possible alternatives and practical prospects of biofuels

Renata Adami, Patrizia Lamberti, Vincenzo Tucci, Liberata Guadagno, Rosa Arnaldo Valdés, Oleksandr Zaporozhets, Pawel Wacnik, Serhat Burmaoglu

Introduction: The successful implementation of the EU Green Deal in aviation depends on the European aeronautics industry's ability to develop new technologies able to face the climate changes. Aviation is considered as one of the most difficult transport sector to decarbonize. One possibility to dramatically reduce emissions within the aviation sector is with low-carbon alternative fuels. Among the analyses carried out within the Horizon 2020 project PARE – Perspectives for Aeronautical Research in Europe, one relevant aspect concerns the possible strategies to reduce emissions within the aviation sector through the use of low-carbon alternative fuels.

Discussion: In order to decarbonize the aviation transport bringing new fuels in commercial flights, several approaches, such as biofuels, electro-fuels, hydrogen, etc. can be exploited. As it concerns the biofuels, a variety of methods to produce renewable hydrocarbon biofuels are available. Renewable hydrocarbon biofuels are similar to their petroleum counterparts and therefore minimize compatibility issues with existing infrastructure and engines. Carbon dioxide captured by growing feedstocks reduces overall greenhouse gas emissions by balancing carbon dioxide released from burning renewable hydrocarbon biofuels. Possible technology pathways explored for the production of renewable hydrocarbon biofuels include hydrotreating, biological sugar upgrading, catalytic conversion of sugars, gasification and pyrolysis. Renewable hydrocarbon biofuels offer many benefits, including: In this paper the main characteristics, potentialities and limitations of the different approaches and recently proposed technologies will be discussed taking into account also the availability, sustainability and costs.

Conclusion: Before biofuels become a real alternative to traditional petroleum fuels, several aspects concerning environmental, economic, safety, ethical, etc. issues have to be deeply considered. For this reason, the involvement of the largest possible assembly of stakeholders is required to keep into account the different perspectives associated to such multi-facet and challenging r-evolution toward the aviation of the future.

Empowering talent: Women in Aviation

Quaiela Costa, Joana Soares, Patrizia Lamberti, Liberata Guadagno, Daniela Geraldes, Filipa Manaia

Introduction: The project PARE – Perspectives for Aeronautical Research in Europe - is a Coordination and Support Action (CSA) supported by the European Commission through the Horizon 2020 Programme. Its main aim is to assess the progress towards the 23 Flightpath Goals established by the Advisory Council for Aviation Research and Innovation in Europe (ACARE) and to propose measures to support their achievement. The PARE project also analyses the skills and human capital needs in the aviation sector, namely the future availability of human resources in sufficient numbers to support the sector's development, together with measures to attract more talent, in particular, by taping the potential for women participation in aviation.

Discussion: The aviation sector seeks to attract and retain women to: face the gender imbalance that generally affects the transports sector; face the current global shortfall in the numbers of qualified employees (mainly pilots, mechanics and top managers that nowadays are still traditionally male-dominated areas); and promote innovation through the combination of different talents in a cooperative and open-minded environment of equality. According to the Social Cognitive Career Theory (SCCT), the academic and career choices of young people are influenced by several factors and form gradually more consciously from childhood and primary school, through teenage and secondary school to adulthood and university. Therefore, interventions should start at an early life stage and consider the four factors from SCCT that help to identify and understand the reasons why students pursue a university course or career: prior experience, social support, self-efficacy and outcome expectation. For women, in particular, it is also fundamental to tackle the existing gender-stereotypes that women are exposed to and to ensure equal employment opportunities and the appropriate labour conditions and practices. This emphasizes the importance and need to implement changes in both the educational and employment contexts that can increase women's interest in the sector. As such, some of them are related with the increase of awareness of science and engineering education and career opportunities, social support and influences in childhood, mentoring relationships, positive experiences in classes, showcasing of female role models, among others.

Conclusion: Greater participation of women in aviation is not only an enlargement of the workforce in numbers, but it is also an enrichment in quality and talent, which are the foundations of inventiveness and competitiveness, on which depend the continuing European leadership in an ever more competitive world with new challenges.

The role of Climate Change Levy schemes in aviation decarbonization by 20250

Valdes Comendator

ICAO 2019 report quantified emissions of the aviation sector over the period 2016-2050 could be between at 56 GtCO2 in a business as usual scenario, and 12 GtCO2 in an optimistic, but unlikely to meet, scenario with technological improvements and 100% of biofuels use. These figures would imply that aviation emissions, between 2016 to 2050, could consume between the 27% and the 12% of the remaining carbon budget to keep global temperature rise below 1.5C above preindustrial levels. Consequently, aviation is being challenged to immediately start to reduce its in-sector emissions, then sharply reduce its CO2 emissions and fully decarbonize toward the second half of this century. Among the analyses carried out within the Horizon 2020 project PARE – Perspectives for Aeronautical Research in Europe, this paper tackles the potential role of Climate Change Levy Schemes in achieving the ambitious objective of aviation decarbonization by the year 2050.

Discussion: The primary rationale for environmental taxation is the externalities argument. By leaving a tax on the pollution-generating activity, the social costs of pollution can be 'internalised' to the agent (who must pay the tax) and the socially optimal level of pollution would occur. Two main impacts of taxing would be analysed in this study. On one side, because of price elasticity, as far as the tax is translated to the user, it is expected to have an impact on demand, aviation markets and emissions. At the same time, the pressure of an environmental taxation can also be a trigger for companies, airlines and manufacturers, to increase fuel efficiency by changing technology, and become a driver for competition.

In this work, authors develop a model to generate CCL marginal tax curves and study its effect on changing demand for air travel and CO2 emision. The model uses a differentiated approach, taking into account the types of aircraft and types of flights, the distance they are operated (short, medium, long range), the nature of the flight - regular, charter, passenger, freight, passenger and express – and different types of air carriers (low cost, traditional, etc…). It also considers price elasticities of demand specific for different markets and for different groups of passengers and cargo operators. Using detailed air transport statistics from past years, global air transport and aircraft production forecasts and the outcome of the previous CCL model and curves, the study will generate medium- and long-term air transport demand, aircraft and CO2 emission forecast.

Conclusion: This analysis gathers analytics and insights to answer how taxing CO2-emissions (Climate Change Levy schemes) will imply significant changes in aviation industry, including aviation demand, industry and markets structure and emission reduction. It aims to answer the following key questions: i) What would a tax mean for the demand in short, medium and long-range flights? ii) Will there be negative growth? iii) Low cost has driven price and demand the last decades. How will this change and how will the sector remain competitive? iv) What will be the impact on fuel efficiency technology improvement and the acceleration of its entry into service?

Electrification of aviation: propulsion onboard and ground systems

Juergen Garche, Martin Schmuck, Stefan Koller

Introduction: The aviation industry is constantly faced with new challenges that drives a steady evolution as well as revolutionary new solutions. The European Commission has set substantial targets in its "Flightpath 2050" [1] guide to be able to meet these challenges, where the electrification of aircrafts is an important measure. The project PARE (Nr. 769220) addresses each of these goals to make a comprehensive assessment of present state but also projections of future developments.

Discussion: Two approaches for electrification in aviation can be observed. The more progressive approach aims the propulsion of the aircraft and the conservative approach aims the successive replacement of hydraulic and pneumatic components by electrical system solution, which is often referred to a more electric aircraft. All-electric aircrafts are powered by electrochemical power sources – ECPS (battery, FC). The flight range of all-electric aircrafts depends besides engineering parameters especially on the specific energy (Wh/kg) of ECPSs. The future developments and also the limits of the specific energy of batteries and fuel cells will be discussed. For the time being as the most promising battery the LIB and as most promising fuel cell the H2 PEMFC are used. Caused by easier fuel logistic and also larger flight ranges Methanol PEMFCs are an option. Caused by a relatively low specific energy the flight range of all-electric aircrafts is limited. Therefore, ECPS-hybrids have been introduced for larger ranges, as solar generator/ECPS (solar powered aircraft) and turbine-generator/ECPS. At solar powered

aircrafts, PV panels act as generator to propel the plane and in parallel to charge the battery for night flights. To have a high panel area the planes have very large wingspans. Also, gas turbines in combination with generators can propel the plane and in parallel charge the battery which propels the plane as well. The turbine can continuously operate within its ideal speed range, which saves fuel and reduces the noise level. Turbine-generators can be used also to propel electro fans directly but with higher CO2 emissions as the turbine-generator/ECPS hybrid. But in both cases several small electric motors could be used, leading to new forms in aircraft design with improved aerodynamics and efficiency. More electric aircraft: Electrical systems replace the conventional hydraulic and pneumatic systems, which suffer often from a lack of reliability and high maintenance costs. The higher electrification leads to reduced weight, greater reliability, lower maintenance costs and increased efficiency and finally to lower emissions. Furthermore CO2 emission reductions are possible also on the airport apron by propulsion of ground systems (z.B. towing tractors, conveyor belt vehicles, container transporters, busses, cars with batteries and fuel cells.

Conclusion: Based on improved parameter of LIBs and PEMFCs the market introduction of small all-electric aircrafts is starting during the next 5 years. For larger aircrafts battery/gas turbine hybrids are under development. Electrification of ground systems on the airport apron also contribute to the CO2 emission reduction.

R&D Research in the Field of Aeronautics & Air Transport: NHYTE Project Session

Session Chair: Dr. Marco Barile, Novotech Aerospace Advanced Technology, Italy

A new approach for the simulation of Induction Welding Process of thermoplastic composite materials for aircraft structures

Panagiota Polydoropoulou, George Lampeas, Spiros Pantelakis, Rosario Dotoli, Francesca Felline and Leonardo Cosma

The induction welding technology implemented on advanced thermoplastic composites for aircraft structures is expected to 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; they are caused by a coil generating an alternating electromagnetic field and the pressure enforcement by a consolidation roller [2–6]. When electric currents are 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].

The material used in this work 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]. In the present work a new approach for simulating the induction welding process of the hybrid thermoplastic material is proposed. For the electromagnetic field of the model, the electromagnetic module of Ansys software has been utilized and the results were embedded to the Ansys Workbench to obtain the temperature field of the composite material. An alternative approach has been adopted using a different Finite Element solver as Msc Marc. In this case, the Maxwell's equations and the heat transfer equation are solved sequentially in the same solver environment for each time step of the simulation. The numerical model is employed to investigate a different experimental configuration including an electromagnetic field intensifier, and it is experimentally validated36. Acknowledgements: This work has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723309, NHYTE Project.

---

[36] 1. NHYTE : New HYbrid ThErmoplastic Composite Aerostructures Manufactured by Out of Autoclave Continuous. Eur. Union's Horiz. 2020 Res. Innov. Program. under grant Agreem. No 723309 2017.
2. Kim, H.; Yarlagadda, S.; Gillespie, J.W.; Shevchenko, N.B.; Fink, B.K. A study on the induction heating of carbon fiber reinforced thermoplastic composites. Adv. Compos. Mater. 2002, 11, 71–80.
3. Sanders, P. Electromagnetic welding: an advance in thermoplastics assembly. Mater. Des. 1987, 8, 41–45.
4. Rudolf, R.; Mitschang, P.; Neitzel, M. Induction heating of continuous carbon-fibre-reinforced thermoplastics. Compos. Part A Appl. Sci. Manuf. 2000, 31, 1191–1202.
5. Ahmed, T.J.; Stavrov, D.; Bersee, H.E.N.; Beukers, A. Induction welding of thermoplastic composites-an overview. Compos. Part A Appl. Sci. Manuf. 2006, 37, 1638–1651.
6. Kim, H.; Yarlagadda, S.; Gillespie, J.W.; Shevchenko, N.B.; Fink, B.K. A study on the induction heating of carbon fiber reinforced thermoplastic composites. Adv. Compos. Mater. 2002, 11, 71–80.
7. Lionetto, F.; Pappadà, S.; Buccoliero, G.; Maffezzoli, A. Finite element modeling of continuous induction welding of thermoplastic matrix composites. Mater. Des. 2017, 120, 212–221.

A holistic design index applied for assessing the suitability of a modified autoclave process to produce a flat skin panel made from a novel hybrid thermoplastic material

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) analyses are performed [1,2]. 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 this frame, a novel holistic design index was introduced in [3]. The Index serves as a decision support tool for the optimization of aircraft composite components and manufacturing processes as well as for the selection of the appropriate manufacturing technique of a component when various techniques are considered as manufacturing options. The criteria involved in the index are quality, cost and environmental footprint functions which are considered to be interdependent.

In the present work, a modified manufacturing process is assessed for the production of a typical aeronautic skin panel made from a novel hybrid thermoplastic material. The process involves a relatively new lay-up technique as a phase of a modified Autoclave process. Moreover, for this application, a novel hybrid thermoplastic material is considered; it is a combination of the semi-crystalline carbon fiber reinforced PEEK (PolyEtherEtherKetone) and the amorphous PEI (PolyEtherImide) in the form of stacked prepreg plies [4]. According to the above mentioned Index the quality is understood as the compliance with certain critical mechanical properties of the component. For simplicity, in the present investigation the ILSS property has been considered to be the only critical mechanical property. To this end, using experimental data the manufacturing process parameters are related to the selected critical mechanical property to derive the Quality Function (QF). Moreover, cradle-to-cradle Life Cycle Analysis (LCA) and Life Cycle Costing (LCC) models were developed and implemented for the case of the skin panel production. For the LCA the ReCiPe method [5] was chosen to model the environmental impacts of different materials and processes by using open LCA software. Cost has been estimated by implementing the Activity Based Concept (ABC) using an in house developed tool. Environmental footprint is assessed by exploiting the ReCiPe method using the 'open LCA' software. The weight factor of each of the above criteria in the decision support tool is calculated by using the Multi Criteria Decision (MCD) method Analytic Hierarchy Process (AHP). The abovementioned concept has been also applied to the classical Autoclave manufacturing technique such as to allow a comparison between the modified process with the conventional Autoclave process.

The results of the study pointed out that producing the panel by using the modified process the quality obtained does not meet the typical constraints set from the aeronautic industry; apart from the reduced ILSS values obtained a significant amount of porosity is observed. On the other hand, the modified manufacturing process exhibit a remarkable increase of both the environmental and financial efficiency. The involved Index has been proved to be sensitive to the criteria set at the design phase thus allowing to meet a justified decision on the suitability of the manufacturing process under consideration.

Virtual testing activities for the development of a hybrid thermoplastic composite material for the Nhyte project

Rosario Dotoli, Antonio Gerardi, Panagiota Polydoropoulou, Alfonso Carpio Rovira

Designing composite structures with a good level of confidence and accuracy requires access to allowables values. The allowables generation is extremely time and cost consuming. In fact, various layups, experimental tests and environmental conditions have to be taken into account for each material to be characterized. Moreover, each test configuration needs many repetitions to obtain a statistical evaluation of the mechanical property.

A robust alternative to reduce the experimental time and costs is the use of virtual allowables calculated and predicted thanks to advanced multiscale simulations. This paper deals with the activities of virtual testing carried out in the European NHYTE Project for the development and characterization of a hybrid thermoplastic composite material for the aerospace sector.

The main aim has been to reduce tests and risk associated with the use of the hybrid composite in aerospace structures. This can be achieved by lowering the probability of failure of primary structures through the use of A-basis or B-basis strength allowables as design values. For this purpose, coupons of the hybrid thermoplastic composite have been accurately analysed using virtual tests. Starting from a micromechanics approach and taking into account the different constituents (PEEK matrix, PEI films and fibre reinforcement), a material model has been implemented; then it has been propagated to different scales until the element level.

For virtual testing to be useful in the certification process, this numerical model has been validated by a synergic approach, correlating the simulation results with the experimental data carried out by Applus+ Laboratory. At the end, it has been possible to demonstrate that the resulting models are an excellent tool to speed up the certification process for complex structures, as required in the Aeronautical industry.

Validation of a novel thermoplastic material concept for the production of primary aerostructures, based on a continuous and highly automated OoA fabrication process

Marco Barile, Leonardo Lecce, Giuseppe Barile

This work resumes the results achieved in the frame of European R&I action NHYTE, deriving from the design and development of a new equipment enabling the production of hybrid aerospace grade thermoplastic material by a continuous consolidation process, the validation of the hybrid thermoplastic material concept and the viability of the fabrication of stiffened composite panels, representative of aircraft structures, by In-situ consolidation with AFP and induction welding process.

The feasibility of the chain of production processes aims at the replacement of aerostructures based on thermosetting composite with those thermoplastic based one, which provide reduced weight of the parts and decreased manufacturing and operational costs. Specifically, reduced weight is obtained through the utilization of a novel prepreg, whose application is made possible and affordable by the performed improvement; manufacturing costs are reduced by lower temperature, reduced energy and simplified processing, as well as improved recyclability; operational costs depends on weight reduction, which determines lower fuel consumption and better behaviour to damage , with reduced maintenance cost.

This paper will be focused on the preliminary technology validation and related benefit assessment emerged from the manufacturing of the first technology demonstrators by means of In-situ consolidation Laser-Assisted Automated Fiber Placement technology to obtain faster manufacturing processes.

The research has been 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.

On the numerical prediction of heating law for PEI-CF/PEEK hybrid thermoplastic composites in a laser-assisted automated fibre placement

Omar Baho, Gilles Ausias, Yves Grohens, Marco Barile, Leonardo Lecce, Julien Férec

The interest of thermoplastic composite materials by using an additive manufacturing out of autoclave is starting to be addressed with success. In this work, an innovative hybrid thermoplastic manufacturing process has been investigated. The new hybrid thermoplastic material consists of carbon fibre (CF) reinforced poly (ether-ether-ketone) (PEEK) prepreg (APC2) sandwiched between amorphous PEI films. By using a laser automated fibre placement (AFP), a laminate is produced by the placement of hybrid prepreg tapes, layer by layer. To realise a part with this process, it is necessary to finalize the part by a step in autoclave to perfect the quality of the welding between layers. One of the objectives of this project is to make parts without defects by avoiding the step in autoclave. The layers of PEI materials must make easier welding between two layers. The temperature history control in tape placement is required to ensure good properties of the part. Indeed, there are numerous parameters influencing the thermal distribution induced in the substrate, such as laser power, incident laser angle, laying speed and compaction force. In order to identify the correlation between these last parameters, an optical-thermal model has been developed. This model involves a new method of ray tracing to take into account the transparent part of the amorphous PEI films. The reflexion phenomenon between the substrate and incoming tape as function of deformation of compaction roller is also considered.

To implement the model, it is necessary to know the optical and thermal properties of the material. The properties of APC2 are known and taken from literature. The properties of the PEI have been measured. Then, the optical properties of the new hybrid material has been established based on the interaction of a laser beam with PEI film and PEEK/carbon fibres. The boundary conditions and the real absorption coefficient of hybrid material are determined from numerical simulations by comparing the thermal model with experimental data.

The machine developed and manufactured at the beginning of the project is now operational to produce hybrid material strips. These strips are cut to obtain coils of tape that are introduced in the AFP machine used in the Novotech research plan to make samples and parts. Thermocouples were implanted in the samples to be able to measure temperature fields in the deposition of layers of hybrid material. The obtained results showed good agreement between FEM predictions and experimental data in terms of the timing and average maximum temperature. After the validation of the model, a process window according to the behaviour of the material has been established. This window provides a heating law according to the process parameters and the configuration of the robot head in order to maintain constant welding temperature in the nip-point process.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723309

Manufacturing process parameters tuning for New Hybrid Thermoplastic Material

Giuseppe Totaro, Marco Raffone, Antonietta Mormone, Francesca Felline

The new hybrid thermoplastic concept patented by Leonardo based on commercial PEEK-Carbon Fiber prepreg with the addition of amorphous (PEI) films allows to obtain a material that can be processed at temperature lower than usual thermoplastic resin processing temperature without any problem concerning the crystallinity. Critical parameters for hand layup followed by low cost autoclave process have been identified to consolidate this new material as well as quality requirements to be used for production of laminates to be used for aerostructures. The activity has been performed by Leonardo with the support of CETMA in order to identify the optimal parameters for autoclave consolidation for flat panels

Induction welding process set up of hybrid thermoplastic composite materials for aircraft structures

Fransesca Felline, Leonardo Cosma, Giuseppe Buccoliero, Silvio Pappada, Rosario Dotoli

In this paper the experimental activities performed to optimize the Induction welding (IW) process parameters to weld the Hybrid composite materials, developed in Nhyte project, are described. The results related to the experimental tests performed to set up the IW process are presented, and prove the technical feasibility of the welding process for joining the Hybrid composite materials (related to the skin) with PEEK/carbon fiber composite material (related to stringer).

In order to evaluate the mechanical properties of Induction welded joints, the results of single lap tests has been presented. The IW process optimization has been performed with the support of a numerical model set up and calibrated with the experimental activities.

Systems / Prognostics / Security (PART I)

Session Chair: Prof. Matteo Dalla Vedova, Politecnico di Torino, Italy

Design of a large wind tunnel for risk assessment on-board Oil & Gas platforms

Domenico D'Ambrosio, Roberto Marsilio, Gioacchino Cafiero, Gaetano Iuso, Anna Chiara Uggenti, Raffaella Gerboni

Oil & Gas offshore installations are complex structures composed of decks (floors) containing piping and process units. The presence of hazardous fluids (flammable and toxic fluids operating under pressure) and the congested spaces are critical characteristics to be considered during the risk evaluation of offshore platforms at any design phase.

Focusing on accidental releases, CFD (Computational Fluid Dynamics) has demonstrated to well suit the simulation of the evolution of a high-pressure gaseous release in such a congested environment and it is now frequently adopted by designers and operators. In the framework of a large project funded by the Italian Ministry of Economic Development, the SEADOG DENERG laboratory has proposed a new approach for consequences evaluation for the risk assessment of offshore Oil & Gas platforms [1]. The approach is nowadays under development and aims at optimising the binomial computational time/accuracy of simulation results. However, as with any theoretical model, after the complete development, an experimental validation will be necessary. The designed experimental setup is a downscaled reproduction of a real size structure, preserving the congestion of spaces, i.e. the key feature of the environment. In particular, the mock-up platform is a 1:10 scale model, with a total of three decks, and it was designed in conformity with existing examples installed in the Adriatic Sea, including volumes, cylinders, and processing units as they can be found on-board. A release system is also included for reproducing an accidental leakage of pressurized methane in the production deck (the intermediate one), where the major number of components is present and the probability of a hazardous release is maximised. Moreover, the choice of supposing this deck as plated is conservative for the partial inhibition of the dispersion of flammable gas due to the wind. Among the three decks composing the mock-up, this is the only one equipped with sensors to capture velocity and concentration of the gas cloud that is formed after the release.

The model is placed in a wind tunnel specifically designed for this project by members of the Fluid Dynamics Group of DIMEAS to create wind speed and flow conditions in similarity correlation to those that can occur in the Adriatic Sea [2]. As an added value, the facility can also be used for a large variety of different scenarios, including aviation and aerospace applications. A typical example could be the testing of micro UAVs in a windy environment. The large dimensions of the test section would make it possible to perform some manouevers and to test autopilot software. The purpose of this paper is the description of the design procedure and of the working characteristics of the wind tunnel. The large dimensions of the model require a proportionally large wind tunnel. This is an open circuit wind tunnel with rectangular open-jet test section, whose dimensions are 6.4x2.5x7.6 m in the spanwise, vertical and streamwise directions, respectively. Air enters the wind tunnel from the external environment through a (6.4x3.6) m opening and it flows through a series of screens and honeycomb layers to abate any residual fluctuations as well as large structures that may affect the flow quality within the test section. Air acceleration is obtained through a 4.6 m long contraction with area ratio equal to 1.44. The contraction ceiling height decreases according to two cubic polynomials ensuring continuity of the second order derivatives. The

equation of the convergent portion of the wind tunnel has been decided based on preliminary simulations. In particular, the choice was deemed to be satisfactory in terms of the flow homogeneity and uniformity within the test section. After the test section, the air stream decelerates flowing through a 4 m long diffuser with 3.6° divergence angle. The flow, which is driven by 10 axial fans disposed in two rows and located downstream the diffuser, is finally exhausted in the environment through an opening in the ceiling. A unique characteristic of the wind tunnel is that the facility has been designed and built inside a large existing room, so that particular arrangements have been devised to fit the various elements in a confined space while maintaining the flow quality.

Numerical simulations have shown that with the adopted configuration it is possible to obtain a (4.5 x 5.0 x 2.0) m3 (length x width x height) rectangular box of uniform and parallel flow in the test section with maximum speed of about 8 m/s (Figure 1). The experimental characterization of the actual flow conditions is currently underway.

Direct method of flexibility and rigidity using Mathcad software

Odhise Koça, Anis Sulejmani, Parid Alimhilli

Static indeterminate structures are difficult structures to solve by hand or using classical methods. They required data and time to solve. New methods for calculating them are Direct Method of Flexibility (DMF) and Direct Method of Rigidity (DMR). These structures, increasingly complex, are finding use in various fields of engineering as well as in the field of aviation and space. So, introducing these methods into aircraft structures, helicopters or space structures is a pretty nice and difficult challenge. An example of this is the structure of a helicopter [1] and through the MDF and DMR methods we determine the internal forces important for other designations. The calculation procedure goes through several stages. The structure and its elements in local and global coordinates are studied, and then we create the matrix of flexibility and rigidity. Through matrix transformations, it became possible to program algorithms for solving both methods in Mathcad software. In conclusion, we have all the graphs of the moment, the shear force and the normal force required for further studies of the structure.

Integration of rule-based 'Expert Systems' on RPAS capable of Specific Category Operations within the U-space: an original mitigation strategy for operational safety risks

Federica Bonfante, Paolo Maggiore, Francesco Grimaccia, Edoardo Filippone, Matteo D. L. Dalla Vedova

The use of RPAS for civil purposes is spreading across Europe and worldwide; Aviation Authorities are working to layout regulations to assure a safe and secure integration of RPAS with manned aircraft across both controlled and uncontrolled (below 500 Feet of altitude) airspaces.Following the identification of a selection of safety risks potentially associated to RPAS Specific Category of operations, an original strategy of risks mitigation focused on rule-based â€˜Expert Systemsâ€™, has been conceived and it is discussed in this work.The article recalls the main components of rule-based â€˜Expert Systemsâ€™ deepening the requirements and highlighting the most critical aspects of â€˜Expert Systemsâ€™ knowledge basis. The work describes the implementation of the rules composing the knowledge basis as statements derived from the safety risk matrix associated to RPAS capable of performing Specific Category operations within the U-space. In addition, the idea of the integration of â€˜Expert Systemsâ€™ as a software module within RPAS functional architecture is presented. Such solution is deemed to be a valuable novelty for future implementations of advanced autopilots capable of recognizing and solving in flight/on ground

operational safety risks to speed up RPAS integration into not segregated airspace and their market development.

Optical fibers applied to aerospace systems prognostics: design and development of new FBG-based vibration sensors

Matteo D.L. Dalla Vedova, Pier Carlo Berri, Paolo Maggiore, Gaetano Quattrocchi

Future generation aircraft systems will be characterized by ever-increasing complexity. In this context, it will be necessary to adopt advanced health monitoring strategies to guarantee a high level of operational safety and system reliability. In this context, Prognostics and Health Management (PHM) is emerging as an enabling discipline for the design and operation of future advanced aircrafts, with a particular focus on Flight Control Systems (FCSs). Intelligent systems with embedded self-monitoring capabilities are nowadays required in order to provide early faults identification and to perform innovative diagnostic and prognostic functions. Such systems may often have to acquire different types of signals; although a virtual sensor approach is possible, it is often necessary to conceive dedicated detection elements. It should be noted that the installation of new sensors can, however, significantly affect the entire system by increasing complexity, weight, costs, and failure rate. A possible solution to partially overcome these drawbacks is the adoption of an innovative type of optical components, i.e. Fiber Bragg Gratings (FBGs); such sensors are minimally invasive and capable of measures with high spatial resolution both in static and dynamic conditions, while adding minimal complexity. Especially in aerospace applications, these components can replace various types of traditional sensors commonly used in structural monitoring, such as strain gauges and accelerometers, but can also support a much more extensive range of system applications, such as mechatronic systems diagnostics and prognostics. This work proposes the first results of an experimental campaign aimed at evaluating and validating various packaging solutions for vibration sensors based on Bragg Gratings (FBG). These results, obtained by the authors by testing different prototypes, were compared with each other, to identify the strengths and weaknesses of the various configurations analyzed, and were validated by comparing them with numerical simulations and experimental measurements performed with traditional sensors (strain gauges and accelerometers).

Diagnostics of Electro-Mechanical Actuators Based Upon the Back-EMF Reconstruction

Pier Carlo Berri, Matteo D.L. Dalla Vedova, Paolo Maggiore, Gaetano Quattrocchi

Electrical systems are gradually replacing the more traditional hydraulic and pneumatic solutions for the transmission of secondary energy for onboard aircraft equipment. Therefore, as described in [1], fault detection and health management strategies properly conceived for electrical devices are becoming a highly relevant topic for research and development in the aerospace disciplines. As highlighted in [2], one of the main problems facing all the fault detection algorithms is the need to manage the uncertainty and accuracy of the available measures. Errors on the measurement of the system's operating parameters, due to the intrinsic precision of the sensors or to the environmental and operational effects, can easily be mistakenly interpreted as faults, as shown by [3] and [4]. A useful solution to overcome this problem would be to identify parameters for diagnostic and prognostic monitoring, which are highly sensitive to incipient faults but, at the same time, are less influenced by operating conditions (external loads, command input, temperatures, etc.). In this paper, as suggested by [5], the authors evaluated the effectiveness of the counter-electromotive force (back-EMF) coefficient as a prognostic parameter. In this regard, however, it should be noted that, unlike other physical quantities characterizing the operation of an electric motor (rotor speed, phase currents, and voltage, local temperatures, etc.), this parameter

cannot be measured directly during system run. Still, it can be obtained indirectly from other motor signals. In this paper, the authors propose an algorithm for real-time reconstruction of the back-EMF coefficient that, as a virtual sensor, merges data provided by different sources calculating the magnetic coupling of the electric motor as a function of the rotor angular position. It should be noted that the proposed strategy uses only the data provided by sensors already integrated into the electromechanical actuator (EMA), avoiding installing additional components. The proposed method was tested by evaluating the back-EMF coefficient reconstruction as a function of some progressive failures typical of EMA motors. Its robustness to external disturbances has been tested by evaluating different actuation commands and operating conditions. As expected, the back-EMF signal shows a marked dependence on the considered failure modes and, at the same time, a suitable insensitivity to the other external factors.

Systems / Prognostics / Security (PART II)

Session Chair: Prof. Matteo Dalla Vedova, Politecnico di Torino, Italy

High gear ratio mechanical transmissions for actuators: Simplified models for efficiency under opposing and aiding loads

Pier Carlo Berri, Matteo D.L. Dalla Vedova, Paolo Maggiore, Andrea Manuello Bertetto

Planetary gear drives are widely employed in electrical and hydraulic actuation systems, to adapt a high speed, low torque motor to a low speed, high torque user, within strict weight and volume constraints [1]. During the early design phases of these devices, accurate yet simple simulation models are required to evaluate the performance of a given configuration of the device. Similar models are also useful within diagnostic and health monitoring analyses of existing machines, as a discrepancy between the actual behavior of the physical system and that predicted by its digital twin may be the effect of a damage. This work compares different models available in literature [2-11] for the efficiency of high gear ratio mechanical transmissions; the models are applied to multiple arrangements common for planetary drives, and the results in form of an efficiency map for the transmissions are compared and discussed. The simulations provide different levels of detail, and require different levels of knowledge about the specific architecture of the system. All of them are able to deal with dry friction; additionally, the different behavior of the transmission under the effect of aiding and opposing loads (i.e. loads aligned in the same direction of speed or in the opposite, respectively) is accounted for.

A new simplified fluid dynamic model for digital twins of electrohydraulic servovalves

Matteo D.L. 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 onboard 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 onboard 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.

Observation glide LED lights pilot a visual orientation

Yuliia Kvach

The lights of the light-signal system at the airfield make it easier for the pilot to land the aircraft. The lights are installed in a certain sequence with the necessary light characteristics and color. The light-signaling system should help the pilot to switch from instrument driving to landing visually using light-signaling means. By the location and intensity of the aerodrome lights, the pilot should be able to instantly determine the direction of the runway and the roll of the aircraft.

The light characteristics and the location of the aerodrome lights should be such that in difficult weather conditions the pilot clearly sees the required number of lights of the light-signal system. Each aerodrome light of the light-signal system should be visible within such a horizontal angle so that the pilot can observe when the aircraft is flying, both strictly in the direction of the strip and taking into account the permissible inaccuracy of the output by radio. To visually indicate the glide path of planning and the optimal place to land the aircraft, day and night, the glide path subsystem is used. Glide path lights allow you to visually monitor the position of the aircraft in relation to a given glide path. The development of LED technology has allowed the development of LED aerodrome lighting equipment designs. The use of LED modules in the design of aerodrome lights has several advantages. The most significant advantages of LED aerodrome lights include: low power consumption, instant on and off, vibration resistance, long life, high light quality with a color rendering index in the range of 80-95 and an optimal radiation pattern with the possibility of creating directional light. Of the manufacturers of light-emitting diode LED equipment, we can distinguish the Ukrainian corporation Vatra. In the catalog of elements of light-signaling equipment for light-signaling systems of the aerodrome, glide-beam fire PAPI is presented. PAPI is included in the standard glide path visual display system. The PAPI system consists of four LED lights with a sharp color transition. The glide path system is located to the left of the runway. The glide path system is suitable for servicing day and night flights. The design feature of glidepath fire is a color transition from red to white. The angles of distribution of light rays must be such that the pilot, while approaching, while approaching the glide path, sees two lights white and two red. Located above the glide path, the aircraft pilot sees three white lights during the approach. Located below the glide path, the pilot of the aircraft during the landing approach

sees three red lights. Features of the design of the fire, installation angles of glide lights, difficulties in observing LED aerodrome lights - these factors influence decision-making when making eye contact. In the event of a failure of the light-signaling system, the crew will not be able to establish its location in the air or visual contact may be erroneous. To solve the difficult task of observing light signals from LED light-signal aerodrome lights, a tool using the MatLab interface is proposed. The tool allows you to simulate a fragment of a light-signal picture in conditions of time pressure at the stage of visual piloting. Using the tool, the illumination that is created on the pilot's retina from the aerodrome lights in the MatLab interface is simulated. Modeling the illumination on the retina will allow you to manage risk in order to prevent accidents.

Learning how to escape the unthinkable with virtual reality: the case of pilots' training on emergency procedures

Ioanna K. Lekea, Dimitrios G. Stamatelos, Pantelis Raptis

The focus of our paper is the development of a virtual escape room for pilots' training in flight safety procedures. To this end, we will analyse the first stages towards the construction and evaluation of the scenarios incorporated in our educational escape room made for pilots who fly T-6A Texan II. The first part of our research was carried out in two stages: (a) we studied the flight manual, the boldface procedures and the operating limitations of T-6A in order to write down the procedures set out to be followed in key incident categories (aircraft evacuation, regain control and landing) and (b) we selected the categories of incidents/emergencies to be used as part of our virtual escape room [electronic and mechanical malfunctions, multiple malfunctions (electronic and/or mechanical) immediately after take-off, during cruise and landing]; we also decided how to set up the difficulty level for each incident or emergency scenario and the time which would be available to the pilots, so as to solve the case. Subsequently, we constructed the scenarios that pilots will be asked to solve. In order to evaluate them, we did run various tests: (a) in the cockpit of the aircraft, (b) in the cockpit simulation area as well, and (c) in the form of time-tested scripts to compare methods for efficiency learning the safety procedures and the relevant regulations of the aircraft. We also use questionnaires and interviews to evaluate the realism of our scenarios.

The last stage was the development of the virtual escape room. Given the novelty of our educational approach (training pilots for emergency procedures not in a flight simulator, but through a virtual escape room) and the fact that no other virtual escape room for T-6A Texan II exists, a number of questions had to be answered, such as, whether: (a) we should develop an app for a smart phone, construct an escape box or try to simulate the cockpit as best as possible, (b) we should make trainee pilots' performance known to their instructors, (c) we should give the pilots' the opportunity to collaborate or fly together, at least in some of the scenarios, (d) we should set up a virtual escape room which will be part of the Wing's training procedures or set up a virtual escape room which will be used as an educational tool, but each pilot will decide, if he / she will make use of the virtual escape room or not. We will conclude our paper with comments about future improvements and a timeline on our research progress, as well as on further developing our virtual escape room.

Increased Requirements and Corresponding Power Demand of Allelectric Environmental Control System of Large Commercial Aircraft

Dragan Kozulovic

For many years, engine bleed air together with an air cycle machine and ca. 50% recirculation has been established as standard configuration for environmental control system (ECS) in large commercial airliners (>100 passengers). Due to significant energy saving and operational flexibility, new from-scratch-designed aircraft are expected to shift to all-electric ECS (instead of engine bleed air), as already done in Boeing's Dreamliner. Hence, the present study will focus at all-electric concepts only. The air cycle machine still can be used for cooling purposes, although the energy demand of phase-change concepts is lower. For this reason, both cooling concepts are investigated and compared. Besides the shift to all-electric approach, which is rather beneficial in terms of lower overall power demand and fuel consumption, it is very likely that future aircraft cabins will have to implement completely different air distribution concepts, in order to attenuate or prevent the distribution of pathogenic organisms, e.g. air walls around each passenger seat. Even the recirculation system may be completely omitted. Both aspects lead to considerable increase of fresh air supply and power demand, which is computed in a preliminary manner using thermodynamic and aerodynamic relations. Quantifying these effects, air supply and cooling devices can be sized and the impact at the fuel consumption of future aircraft can be estimated with a first order accuracy.

Systems / Prognostics / Security (PART III)

Session Chair: Prof. Matteo Dalla Vedova, Politecnico di Torino, Italy

The effects of using Virtual Reality technology in a pilot learning training application

Miroslaw Mazurek, Pawel Dymora, Bartosz Kowal, Romana Sliwa

In this study, we focus on some problems related to the usage of virtual reality technology in supporting the educational process. The main goal is to obtain the optimal duration of exposure to virtual reality without the appearance of physiological problems for the user affected the achievement of teaching outcomes. Most of the characteristics of virtual reality software at the same time point out some issues in the areas of technological innovations, especially in the health context. The presented example of the training application in the VR environment shows the effectiveness of VR methods and their possibilities in training aircraft pilots. Teaching involving VR allowed to achieve, on average, as much as 90% correct answers, which in comparison with traditional methods resulted in an increase of 21 to 32.7% of correct answers in comparison with training using VR. The research confirmed that a critical challenge in the context of the broader use of VR in the field of education is to appropriately adapt the learning materials and content to the requirements of the technology. Then, in certain areas, the use of VR is beneficial.

Mini-Multi Interface Box Simulator (MMIBS)

J.G. Doblado Alberto Garcia, Antonio Leopoldo Rodriguez, Maria Angeles Martin Prats, Antonio Barea, Daniel Crespo, Inmaculada Soldado, Guillermo Barrera

Today's military and commercial aircraft avionics and general systems are built around complex networks of intelligent devices. Maintenance and troubleshooting these systems often require access to the data bus or networks connecting the system components. Whether it is on the integration test bench, Final Assembly Line (FAL) or at the Maintenance and Repair Organization (MRO), these tasks are usually performed by means of many expensive, heavy, and intrusive equipment's. The MMIBS (Mini-Multi Interface Box Simulator) is a very compact, portable, multipurpose, lightweight, low-power, and easy-of-use electronics test means intended to improve digital aircraft ground testing and maintenance

troubleshooting. It is capable of perform functional testing and simulating aeronautical equipment through most common aeronautical communication interfaces, such as AFDX, CAN BUS, ARINC 429, MIL-STD 1553, RS-422, RS-232, RS-485, Discrete and Analog I/O and RVDT capabilities. Besides, the system is highly configurable and reprogrammable by means of intuitive Python-based scripting. System is also able to be controlled with an intuitive, user-friendly and dedicated HMI (Human Machine Interface). In this mode, the user can conform a MMIBS WIFI network, allowing multiple MMIBS operating in parallel to cover complex testing scenarios. The MMIBS device integrates all the aeronautical communication and signaling in a volume of 12x12x12cm and weight of 1200g and provides an autonomy of 5 hours. In this way, our solution combines performance, reliability, low maintenance costs, and ease-of-use to support efficient ground maintenance operations.

Model-based strategy and surrogate function for health condition assessment of actuation devices.

Pier Carlo Berri, Matteo D.L. Dalla Vedova, Paolo Maggiore, Gaetano Quattrocchi

Prognostics and Health Monitoring (PHM) is a discipline aiming to determine in advance the Remaining Useful Life of a system. To do so, the operation of the system is monitored and analyzed in search of the early signs of degradation and incipient faults; then, a model for the propagation of faults is employed to estimate the future propagation of faults and evaluate the RUL of the equipment [1, 2]When evaluating the time evolution of faults, a stopping criterion is necessary to determine the RUL. Usually, a simple comparison with threshold is employed, but this is not a reliable method when dealing with multiple faults affecting the system at the same time. Specifically, the combined effect of two fault modes can cause the system not to meet its requirements well before the single faults reach their individual thresholds [3].In this work, we propose a strategy to estimate whether the system with incipient faults is still able to meet its performance requirements with a physics-based model. In particular, the method is applied to aerospace actuators, and performance is evaluated in terms of dynamical response.The model-based algorithm is too slow to be evaluated in real-time, so a Support Vector Machine (SVM) is trained as a surrogate function to speed up the computation. The results and computational times of the full, physics-based model and those of its surrogate are compared and discussed.

A Team Allocation Decision for Aircraft Fleet Maintenance

Duarte P. Pereira, Rui Melicio, Victor M.F. Mendes

ABSTRACT: This paper is about an application for the problem of planning maintenance of a mixed long-range and medium-range aircraft fleet. The problem formalization is of mathematical programming written as a minimizing problem. The decision variables are the allocation of technicians to the maintenance of the aircraft fleet. The required data are the availability of technicians, the working hours needed to accomplish maintenance, the costs due to the daily operation of facilities, and due to the fleet downtime. The problem is a pure linear integer programming solved by the pyomo library calling the GLPK, and for comparison, solved by solvers in the Scipy library as a nonlinear programming problem, relaxing the decision variables to continuous ones. The purpose of the comparison is a discussion about the results and the limitation of using nonlinear programming solvers to emulate the solution of linear integer programming ones.

INTRODUCTION: Airline companies must face the impact of a highly regulated and monitored air transport business settings and regulatory frameworks that impact expressively on the operation, and thus on the

technical and efficiency of the industry [1]. Remains a fact that airline companies that develop a competitive advantage in aircraft maintenance, repair, and overhaul not only have an advantage in terms of fares, but also in a more gainful rotation, shorter lead times, and hangar downtime to improve aircraft availability and lower overall operating cost [2]. Hence, the importance of maintenance, repair, and overhaul in yielding safe and airworthy aircraft is key to business survival, not only by diminishing the probability of incidents, accidents, and augmenting safety, but also by attaining the highest availability and improving efficiency.

Methodology: Maintenance Cost. The Maintenance cost (MC) for each check has four main contributors: the labour cost needed to perform the work of the check (MHC), the cost of materials and services needed to perform the check (MSC), the cost associated to facilities (FAC), the opportunity cost associated to downtime (DC). The MC is stated as follows.

〖MC〗_kc^f=〖MHC〗_kc^f+〖MSC〗_kc^f+〖FAC〗_kc^f t_kc^f+〖DC〗_kc^f t_kc^f (1)

The FAC and DC costs are estimated as a daily cost, thus these costs are dependent of the duration of the check. The FAC cost aggregates the costs associated with the operations and maintenance of the hangars, including for example all the general support equipment, the tools, the hydraulic and pneumatic power supply, maintenance of buildings, heating and lightning. These costs are distributed to each project based on the duration of the check. FAC is the daily cost to have an aircraft in the hangar for maintenance. The DC cost is the daily revenue loss for having the aircraft in the hangar instead of flying paying passengers.[37]

[37] [1] Arjomandi, A., Seufert, J.H., 2014. An evaluation of the world's major airlines' technical and environmental performance. Economic Modelling 41, 133-144.
[2] Alamdari, F.E., Morrell, P., 1997. Airline labour cost reduction: post-liberalization experience in the USA and Europe. Journal of Air Transport Management 3(2), 53-66.

Small Air Transport (SAT) Technologies (PART I)

Session Chair: Dr. Vittorio Di Vito CIRA, Italy

Tactical Separation System for Small Air Transport Vehicles: design advancements in the COAST Project

V. Di Vito, G. Torrano, G. Cerasuolo, M. Ferrucci

Small Air Transport (SAT) is emerging as the most suitable transportation means in order to allow efficient travel, in particular for commuters, on a regional range based on the use of small airports. In this framework, the project COAST (Cost Optimized Avionic SysTem), funded by the Clean Sky JU and started in the year 2016, aims to deliver key technology enablers for the affordable cockpit and avionics, including dedicated technology for Tactical Separation decision support to the pilot. This paper first reports the high-level description of the COAST proposed Tactical Separation System (TSS) and, then, describes the design advancements of the system in the framework of the COAST project. TSS is an ADS-B-based self-separation system aimed to extend traffic situational awareness and to provide the pilot with suggested manoeuvers to maintain the required separation minima. It will constitute an enabling technology for implementation of the separation responsibility delegation to the flight segment (self-separation) in the future SESAR environment, representing a step-forward in the framework of the development of Airborne Separation Assurance Systems (ASAS) for Small Aircraft. The TSS receives consolidated traffic picture (position and velocity of all tracks) from the ADS-B receiver and its own position and velocity from the GNSS receiver. Additional surveillance information, if available, can be also sent in input to the TSS, such as TCAS status, if available. Based on this overall information in input, the TSS performs its main assigned functions, i.e. Conflict Detection and Conflict Resolution. In the paper, a description is reported of the overall TSS architecture and of its concept of operations. Based on that, an overview of each functionality implemented in the TSS is briefly described, namely: Coarse Filtering, Conflict Detection, Severity Assignment, Conflict Resolution and overall TSS Logic. In addition, the basic features of the dedicated TSS HMI are also outlined. In the paper, finally, the achievements reached up to date in the COAST project for the design of this technology and related HMI are reported and the next steps are indicated.

This paper follows the first and introductory one, already presented in the EASN conference 2017 held in Warsaw, with the aim of describing the current status and achieved advancements in the activities addressing the design of the Tactical Separation System in the COAST project.

Advanced Weather Awareness System for Small Air Transport Vehicles: design advancements in the COAST Project

M. Montesarchio, A. Zollo, E. Bucchignani, M. Ferrucci

It is well known that, in the aviation sector, flights are strongly influenced by weather conditions, especially considering small aircrafts. This kind of vehicles, ideal for transportation on regional base, are having an increasing importance in the last decades. In the framework of the COAST (Cost Optimized Avionics SysTem) project, funded by Clean Sky 2, several key technologies are under development for the affordable cockpit and avionics in the area of small aircrafts. One of these technologies is AWAS (Advanced Weather Awareness System) devoted to increase the weather awareness of the pilots, providing on board information concerning monitoring and forecasting of weather hazards having not negligible potential impact on the aircrafts. In this work, the main features of the AWAS system, at the current level of

development, will be presented. In details, the AWAS technology is composed by two applications, namely AWAS on-ground and AWAS on-board, connected each other via a satellite link. The AWAS on-ground is the core of the entire system, devoted to provide on-board synthetic information concerning the weather hazards detected or forecast over an area defined according to the aircraft position. The weather information are extracted from the geodatabase of MATISSE (Meteorological AviaTIon Supporting System), a prototype software developed by the Meteorology Laboratory of CIRA, in which weather data coming from different sources are stored. Data are elaborated in order to identify the polygons enclosing areas affected by weather hazards, along with their associated severity level. For each hazard, only the severity level and the coordinate of polygon vertices are reported in compressed text files, in order to reduce the data to be sent on-board and, hence, allow the usage of a cheap connection for the transmission. The AWAS on-board application, instead, is devoted to provide on-ground the required input information (such as the aircraft position). Moreover, it decodes the text files received by the on-ground application and performs the visualization of weather data in the cockpit, overlapping all the necessary information in the interface specifically designed for the project. Further future developments, aimed to enhance the AWAS general performances, will be also discussed.

This paper follows the first and introductory one, already presented in the EASN conference 2017 held in Warsaw, with the aim of describing the current status and achieved advancements in the activities addressing the design of the Advanced Weather Awareness System in the COAST project.

Jung's theorem application in en-route hazards description

Piotr Grzybowski

The problem of collision avoidance is one of the main tasks of route planning algorithms in civil aviation, apart of the second most common goal which is to make route shortest. When considering multiple hazards that can be encountered en-route, not all have the same impact on the route to the selected destination. Many route planning algorithms (e.g. A*, D*) uses a lot of resources (memory and calculation power) to define the route. They are very efficient in finding the optimal path (e.g. in the labyrinth), yet calculation cost seems a little bit overestimated for application in aviation. Considering the volume occupied by aircraft to available airspace even considering all hazards for flight (e.g. possible collision with terrain or flying into bad weather), the general statement can be made that if there is good weather for flying then airspace volume occupied by hazards is significantly smaller than airspace volume available for flying. The pilots in the decision-making process often tend to group hazards into sets and avoid all set instead of considering each element of such set. For automatization of the process efficient algorithm of the set definition must be hence applied. An effective method to constitute such set for individual elements (such as aircraft) or polygon-described hazards (e.g. no-fly zones) may be by use of the smallest encircling radius. This paper shows the application of Jung's theorem for finding hazard encircling radius and center of such circle for efficient hazard description. Moreover proposed Author's algorithm for the smallest encircling radius has been shown.

Enabling technologies for single pilot operations in in Small Air Transport Vehicles in the COAST Project

V. Di Vito, J. Beran, T. Kabrt, P. Grzybowski, T. Rogalski, P. Maslowski, M. Montesarchio

Small Air Transport (SAT) is emerging as suitable transportation means in order to allow efficient travel over a regional range, in particular for commuters, based on the use of small airports and fixed wing

aircraft with 5 to 19 seats, belonging to the EASA CS-23 category. The affordability of the SAT industry needs to be supported by the availability of new technological solutions allowing reducing the related operational costs while at the same time maintaining the required flight safety levels. In this framework, Clean Sky 2 Joint Undertaking, in the European Union's Horizon 2020 research and innovation programme, funded the project COAST (Cost Optimized Avionics SysTem), which started in 2016 with the aim of tackling this challenge and delivering key technology enablers for the affordable cockpit and avionics, while also enabling the single pilot operations for small aircraft. The project activities cover several technologies and, among them, some selected ones, specifically addressing flight management, are considered in this paper, whose aim is the one of providing an outline of the design and implementation process status reached up to date, emphasizing the obtained results and the work to be done in the future activities expected to be performed in the project. The selected technologies here considered are the ones of tactical traffic separation and enhanced situational awareness, meteorological enhanced awareness, and pilot's incapacitation emergency management. The paper, therefore, focuses on a selected cluster, from the overall framework of the COAST project, of SAT single pilot operations enabling technologies: Tactical Separation System (TSS), Flight Reconfiguration System (FRS), and Advanced Weather Awareness System (AWAS). In the paper, a description is first reported of the overall COAST project approach to the SAT vehicles cockpit design, by providing an overview of the considered architecture and of all the technologies addressed in the project activities, and, then, the description of each of the above-indicated selected technologies is presented (the additional technologies considered in the COAST project are out of the scope of this paper). Based on that, for each of the considered systems (TSS, FRS, AWAS) the status of the design and implementation process is described and the next steps expected to be implemented in the project are outlined.

A Concept for an Integrated Mission Management System for Small Air Transport Vehicles in the COAST Project

V. Di Vito, P. Grzybowski, P. Maslowski

Small Air Transport (SAT) is emerging as suitable transportation means in order to allow efficient travel over a regional range, in particular for commuters, based on the use of small airports and fixed wing aircraft with 5 to 19 seats, belonging to the EASA CS-23 category. In this framework, Clean Sky 2 Joint Undertaking, in the European Union's Horizon 2020 research and innovation programme, funded the project COAST (Cost Optimized Avionics SysTem), which started in 2016 with the aim of delivering key technology enablers for the affordable cockpit and avionics, while also enabling single pilot operations for aircraft in the SAT domain.

In the project, some relevant flight management technologies to support single pilot operations are considered, namely the ones of tactical traffic separation and enhanced situational awareness, meteorological enhanced awareness, and pilot's incapacitation emergency management. These technologies have been subject to a dedicated design and implementation process, based on individual approach where each of them has been considered as independent and dedicated single pilot operations enabling technology.

Nevertheless, during the project execution, it emerged the opportunity to consider proper integration and enhancement of such technologies in order to design a unique Integrated Mission Management System (IMMS). Such IMMS technology has been considered as potential solution to support more

effective and safe management of situations of pilot's incapacitation during the flight, under single pilot operations, and as relevant step forward towards more autonomous aircraft. Based on these considerations, Clean Sky supported and funded proper extension of the COAST project scope, to include the design of the additional Integrated Mission Management System.

This paper, therefore, aims outlining the main concepts implemented by the baseline individual technologies (Flight Reconfiguration System, Tactical Separation System, and Advanced Weather Awareness) already considered in the COAST project and representing the basic building blocks towards IMMS and, after that, aims introducing the IMMS motivations and opportunities. Furthermore, the paper describes the main functionalities expected to be implemented by the Integrated Mission Management System and its high-level expected architecture. Finally, the expected design and implementation process will be also described.

Compact Computing Platform for Future General Aviation

P. Zaykov, J. Beran, P. Axman

In order to achieve the principal goals in the CS-23, such as reduced pilot workload, single-pilot operation, and future airspace integration, the avionics systems shall deliver a leap-change in the computation performance, reduced development and operational costs, and reduced Size Weight and Power (SWaP). In this context, the CS2 COAST project is introducing technologies to address the challenges. In the design of the COAST technologies, the following three aerospace specifics are considered:

- Safety-critical: The growth of small-aircraft commercial operation is expected to be propelled by the level of safety comparable to CS-25.

- Long-term support and maintenance, which might be 30 years and longer. Due to the long-term commitment to customers, the aerospace companies are highly conservative and restrained to adopt new and unverified technologies.

- Aerospace domain is a low-volume market. Therefore, aerospace OEMs rely on COTS components already developed for other higher volume industrial domains (e.g. automotive) and invest into the innovations allowing these COTS components to be utilized in the aerospace domain. In the context of the COAST project, we investigate solutions in the following four technical areas: i) HW architecture that has multiple heterogeneous computing resources yielding superior performance while reliable, ii) RTOS and Software (SW) architecture to provide the necessary abstraction and interface to the underlying HW simplifying interoperability and reuse, and iii) processes and tools to reduce the V&V and to reduce development cost.

Small Air Transport (SAT) Technologies (PART II)

Session Chair: Dr. Vittorio Di Vito, CIRA, Italy

Evaluation of the production results of selected technologies based on cabin part and engine nacelle in the SAT-AM (Clean Sky 2) project

P. Gula, D. Ulma, J. Dudziak, A. Gawlik

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. Demonstrators study 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. The article will cover description of technology development process for the SAT-AM project demonstrators. Comparison of the tested manufacturing methods and indication of the most efficient.

The General Aviation Aircraft Path Planning Method at FRA Airspace Using Multi-Dimension Weights on Graph Edges

Andrzej Majka, Jowita Pawluczy

Currently, within European Civil Aviation Conference (ECAC) area there is a mixed environment implemented: ATS (Air Traffic Service) route network, Direct Routing (predefined DCTs) and Free Route Airspace (FRA). Regardless of the environment in which the flight take place, there is a vast number of existing restrictions and dependencies, which degrade flexibility in flight planning. Therefore, it is hardly possible for airspace user to plan a route in a most convenient manner. The obligation to take into account all conditions and restrictions usually force airspace users to plan longer or more complex routes. This means that the user must plan more fuel and a longer flight than would result from a planned direct route.Although this difficulty applies to all airspace the adverse effects of the current system do not distribute equally. Different user groups such as scheduled and unscheduled airline and cargo traffic as well as irregular but a dense number of a small piston or turbine aircraft belonging to General Aviation are subject to these restrictions to a different degree.Planning flights taking into account the limitations and restrictions make the flight paths far away from their optimal forms. It leads to a reduction in aircraft efficiency, which is greater the lower their performance capabilities are. Therefore, usually the most critical effect occurs for light transport aircraft operating as part of a Small Air Transport (SAT).Large airlines are supported by automated systems allowing to find routes as close to optimal as it is possible. Users of small transport aircraft usually do not have access to such systems because of their very high cost. Flights are therefore planned manually or semi-automatically.The work aimed to develop a flight planning algorithm which would be the base of an aircraft flight planning system in complex airspace, dedicated to light transport aircraft users. The system using the developed algorithm allows planning the flight path in an optimal form, taking into account all the most important restrictions and conditions.The algorithm is based on the Dijkstra method allowing to find the shortest paths between nodes in a graph, which model airspace. By the appropriate selection of multi-criteria weights on the edges of the graph modelling the airspace, the algorithm will allow to take into account restrictions and avoid zones over which the operation of civil aircraft may be restricted.

Small Transport Aircraft Trajectory Management in Emergency Situation

Andrzej Majka, Jowita Pawluczy

Performing a flight by a light transport aircraft is associated with the risk occurrence of an emergency situation. Dangerous situations or emergencies are frequently connected with the necessity to change the profile and parameters of the flight as well as the flight plan. Some serious situations require a change of flight plan and continuation of an emergency flight to the best located airport or other landing field where the emergency landing will be performed. The emergency arrival should be performed along the most beneficial trajectory, taking into account the location of the runway and aircraft as well as the conditions along the arrival route (wind and obstacles). If the flight takes place in populated areas, the emergency trajectory should avoid the most densely populated areas.For larger transport aircraft, special systems are being developed to support the pilot in emergency situations, which are integrated with flight management systems. For light transport aircraft, similar systems can also be developed.The aim of this work was to develop the method used to determine a small transport aircraft flight profile after a dangerous situation or emergency occurs. The presented method also enables determination of the optimal flight trajectory away from the territory of a special protection zone (for example, large populated areas), in the case of an emergency which would disable continuation of the performed flight. The analysis covers only the problem of determining the optimum trajectory, not including the problem of choosing an airport or landing field for emergency landing.The analysed examples are limited to the possibility of an occurrence of an engine system emergency and the further flight continuation along a trajectory whose shape depends on the kind of the emergency. The worked out method can become an element of the on-board system supporting the SAT aircraft pilot in dangerous or emergency situation.

Operational concept for integrating RPAS into terminal airspace

Javier Pérez-Castán, Fernando Gómez Comendador, Rosa María Arnaldo Valdes, Alvaro Rodríguez-Sanz and Jaime Aznar Olmos

Remotely Piloted Aircraft System (RPAS) is a capital issue for the majority of aviation actors nowadays. The integration of RPAS is an extremely demanding task that must be tackled by multiple standpoints: economic, social, technological or environmental among others. U-space is the answer from Europe to design the operation of multiple and different types of RPAS. U-space is a set of novel services designed to support efficient, safe and secure access to airspace, from the very low level to the upper airspace. This paper focuses on the terminal airspace to design the operational concept for the integration of RPAS in conjunction with conventional aircraft and general aviation. This work develops a hierarchical methodology to analyse the way RPAS integration affect crucial factors and tries to bring to the light different issues that can frustrate their integration. First, we focus on detailing the requirements specified by RPAS legislation. Second, all the requirements are gathered into different categories to perform further analysis. The categorisation identifies navigation, communication, surveillance, air traffic management, control, and safety as crucial categories (security is out of the scope of this study). As different airspace users will operate in the terminal airspace, the operational concept considers the possibility of allocating sub-airspace volumes for the operation of RPAS free of interaction with conventional aircraft. This operational concept is applied to the Terminal Control Area of Galicia in Spain.

Advanced Composites for Aerospace Applications: Modeling - Testing - Validation | Adhesion Science & Technology

Session Chair: Prof. Konstantinos Tserpes University of Patras, Greece

The effect of hygrothermal ageing on the bulk mechanical properties and lap-shear strength of the bio-based epichlorohydrin/cardanol adhesive

Vasileios Tzatzadakis, Konstantinos Tserpes

Bio-based structural adhesives face two major challenges with regards to their application to aerospace structures: the low strength and the low resistance to environmental conditions. In the present paper, we have experimentally studied the effects of hygrothermal ageing on the bulk mechanical properties and the lap-shear strength of the novel bio-based epichlorohydrin/cardanol adhesive by conducting tension tests, fracture toughness tests on reference and aged adhesive specimens as well as lap-shear tests on reference and aged metallic and CFRP lap-shear bonded specimens. Moreover, the thermomechanical properties of the adhesive have been characterized through DMA tests. Ageing of samples has been conducted inside an environmental chamber under the conditions of 70 degrees/85%RH until saturation. All mechanical tests have been conducted according to ASTM standards. The glass transition temperature of the adhesive is reduced due to ageing by 7.7%.

Numerical simulation of laser shock-induced composite delamination and adhesive debonding

Kosmas Papadopoulos, Konstantinos Tserpes, Ioannis Floros

In recent years, laser shock processing finds an increasing use in many applications of materials and structures [1]. Indicative applications are the laser shock peening [2], the laser shock stripping, selective delamination in CFRPs, selective debonding in adhesive joints (adhesion test) [3] and non-destructive testing of adhesive bonds [4]. The laser shock experimental process is very complicated and involves many process parameters that might influence the outcome such as the pulse duration and the spot diameter. It is therefore very important to develop efficient and reliable simulation models that can be used for process optimization and virtual testing of laser shock processing.

In the present work, we have developed a numerical model based on explicit finite element analysis to simulate delamination in CFRP materials and debonding in adhesive CFRP joints induced by laser shock. Modeling and analyses have been performed using the LS-Dyna commercial FE software. Delamination and debonding have been simulated using the Cohesive Zone Modeling method [5] while composite damage using the progressive damage modeling method. The model has been validated successfully against tests in terms of back face velocity vs. time data [4]. Using the model, we have studied the effects of the applied pressure profile on delamination, debonding and damage in the composite ply as well as the interaction between composite damage and debonding.

The numerical results for the CFRPs reveal that for the considered pressure profile a delamination of 60% of the laser spot area is predicted in the midplane of the CFRP without any damage in the composite ply. On the other hand, the results for the adhesive CFRP joints reveal that the applied pressure profile has a very strong influence on the debonding area and the damage of composite plies. Therefore, the laser shock parameters need to be carefully selected in order to avoid extensive damage of the composite plies.

When the suitable pressure was applied, the debonding area was almost equal to the laser spot area and the composite ply damage was limited[38].

Comparison of lightning strike damage in bolted and bonded CFRP joints using a coupled electrothermal model

Alexandros Sofianos, Konstantinos Tserpes

Carbon Fiber Reinforced Plastics (CFRPs) are widely used in aeronautical structures. Due to their semiconducting nature of CFRPs, lightning strikes can cause significant damage in aircraft components made from such materials. In CFRP laminates joined by mechanical fasteners or adhesive bonding the damage induced by lightning strikes is a complex multiphysics coupling process. In the present work, in order to study the effects of the different lightning current components on CFRP joints due to the Joule heat flux phenomenon, a coupled electrothermal FE model has been developed using the ANSYS commercial FE code. Two case studies are considered, i.e. a bolted single-lap joint and an adhesively bonded single-lap joint of CFRP laminates. The model is based on the SOLID5 coupled field solid element and applies a non-linear, time-transient analysis. The main input to the model is the thermal-electrical properties of the CFR material which vary with temperature. Three electrical lightning strikes of low, medium, and high peak intensity have been applied according to the SAE ARP 5412 standard. The numerical results reveal the detrimental effect of lightning strike on the bolted joint as the electro-thermal conditions on the bolt facilitated the through-the-thickness degradation of the CFRP material, as opposed to the adhesively bonded joint where the increase of the peak intensity has led to the escalation of the area and penetration of matrix thermal damage (pyrolysis) as well as to the increase of fiber damage (deterioration and ablation). Through static mechanical analysis, the residual joint stiffness has been also predicted.

Buckling analysis of large-scale stiffened composite structures by macromodelling approach

D. G. Stamatelos, G. N. Labeas

A novel engineering approach based on macromodelling principles is developed to enable fast calculation of critical buckling loads of large structural components comprising stiffened composite panels. The main advantage of the present approach is the application of analytical solutions of un-stiffened orthotropic panels in the determination of buckling loads of stiffened panels, by applying an improved smearing approach, which considers the anisotropy introduced by the stiffeners and the compressive load eccentricity with respect to the stiffened panel's mid-plane. The developed macromodelling approach has been validated and it is demonstrated in the sizing optimization procedure of a composite wing aircraft structure.

[38] [1] R. Fabbro, P. Peyre, L. Berthe and X. Scherpereel, Journal of Laser Applications, Vol. 10, pp. 265-279, 1998.
[2] C. Le Bras et al., Metals, Vol. 9, pp. 793, 2019
[3] M. Sagnard, et al., Optics & Laser Technology, Vol. 111, pp. 644-652, 2019
[4] R. Ecault et al, Composite Structures, Vol. 152, pp. 982-394, 2006
[5] K. Tserpes and I. Floros, Fatigue & Fracture of Engineering Materials & Structures, Vol. 42, pp. 1430-1440, 2019

Optimization and strength tests of compressed composite tube as a main element of mechanical flight control system for small aircraft

Wojciech Grendysa

The pushrod type mechanical flight control system is the best choice for small general aviation aircraft. It provides high rigidity, using a simple and low-cost manufacturing solution. The article describes an innovative approach to the design and manufacture of compressed tubes as the main elements of pushrods used in mechanical flight control systems of small aircraft.

The main part of the pushrod, responsible for its stiffness and strength, is the tube connecting its ends. The ability of the pushrod to transfer the load depends on the strength parameters of this tube. The most important parameter, in this case, is the critical buckling force of compression, that a pushrod tube can transfer. This is a well-known fact that the critical buckling force depends on the length of the tube, the stiffness of the applied material and the moment of inertia of the cross-section (according to Euler's formula). In this paper the author proves that it is possible to significantly increase the critical buckling force of a pushrod tube, assuming a constant length, mass, external diameter, and Young's module, only by appropriate shaping of its geometry.

The activities described in this paper include both theoretical considerations and practical research.

In the first part, the author presents the finite element method-based optimization in order to determine the optimal shape of the external pushrod tube geometry. The second part describes the authorial production technology of variable cross-section, composite pushrod tubes, and the results of the strength tests of the manufactured tubes.

The new method of determining the optimum shape of the external geometry and the developed manufacturing technology for composite tubes with variable cross-sections, allowed to reduce the weight of the mechanical control system pushrod tube by approximately 40 percent. Excellent results obtained thanks to the new approach have been confirmed by static tests. The developed methodology has a wide application in all structures where compression thin-walled tubes are used as structural elements.

Finite Element Analysis of Composite Matrix Material with Micro-damage Healing Ability

I. Smojver, D. Ivančević, D. Brezetić

In composite aircraft structures, damage is almost inevitable, and it occurs at several length scales due to the heterogeneous structure of composite materials. Application of materials with self-healing ability can successfully resolve these problems. Therefore, in this work, a constitutive model for modelling of micro-damage initiation and healing phenomena in polymer matrix materials is presented. Materials that are able to heal damage already exist for some time and (Barbero et al., 2005) proposed constitutive model for self-healing composites with extrinsic autonomic healing mechanism. Composite materials with extrinsic self-healing ability contain microcapsules with healing agent, embedded in matrix, which release the healing agent when damaged.The constitutive model proposed in this work utilises a material with intrinsic healing mechanism. Intrinsic self-healing means that the healing phenomenon results from materialâ€™s chemical structure. On the other hand, phenomena such as viscoelasticity and viscoplasticity are not considered in this research due to simplified constitutive model, but which are present in the matrix material in this research. Scalar damage and healing evolution laws are taken from (Darabi et al., 2011) and (Abu Al-Rub et al., 2010), respectively. Parameters of these laws are modified to

describe the behaviour of the matrix material. Damage evolution law used here is strain rate-dependent and able to capture damage nucleation both during the loading and unloading present in simulations of cyclic loading. The concept of nominal, healing and effective configurations is taken from (Darabi et al., 2012). Stress, strain and tangent stiffness tensors in healing and nominal configuration are related by means of strain equivalence hypothesis, what makes the numerical implementation of the constitutive model relatively straightforward. In this initial phase of the research, an advanced ethylene/methacrylic acid (E/MAA) copolymer, DuPontâ„¢ SurlynÂ® 8940 thermoplastic resin, is used as a self-healing matrix material. The healing ability of ethylene/methacrylic acid (E/MAA) copolymer has already been proven for healing of delamination cracks, (Wang et al., 2012). In this experiment, the pure E/MAA copolymer in the form of thin layers was placed between the carbon fibre/epoxy composite plies, thus increasing the fracture toughness of the composite material. Firstly, the proposed constitutive model is developed and validated in Matlab and then implemented into Abaqus user subroutine UMAT. Simple static test cases as well as loading/unloading tests are applied in the validation of the proposed model.The research is carried out in the framework of the ACCESS project (AdvanCed CompositE Selfhealing Simulation), funded by the Croatian Science Foundation (HRZZ).

Conceptual design and parametric structural modeling of a FWAV biomimetic flapping wing

Saiaf Bin Rayhan

Flapping wing air vehicle is the latest technological achievement of the aviation industry, which is still maturing as a miniature of large aircraft before finally achieving the finest development. By mimicking the nature, parametric structural modeling of a flapping wing, made of composite membrane and aluminum alloy support-beam, is numerically investigated adopting commercial FE code Ansys. A flapping cycle is divided by twelve segments, and for each segment maximum stress, first ply failure and deformation is studied. It is found that the fiber orientation angle has the highest impact on the structural properties during a flapping cycle, where improper stacking sequence will cause failure to the wing. Moreover, increasing the ply thickness has a positive impact on the overall structural performance of the model. Finally, appropriate support-beam orientation can further improve the structure by increasing the stiffness and reducing maximum stress significantly without increasing the overall weight of the wing.

Space Technologies

Session Chair: Dr.-Ing. Athanasios Dafnis, RWTH Aachen University, Germany

Drag Control by Hydrogen Injection in Shocked Stagnation Zone of Blunt Nose

Ashish Vashishtha, Dean Callaghan, Cathal Nolan

The main motivation of the current study is to study the high-pressure hydrogen injection as an active flow control technique, in order to manipulate flow-field in front of the blunt nose at supersonic and hypersonic flight regimes. With the right environment in a stagnation zone, hydrogen injection can lead to self-ignition and may cause combustion in deflagration or detonation mode. It can modify the stagnation zone significantly because of interaction of flame and frontal bow-shock, which may provide effective drag control. In the preliminary numerical study, hydrogen with total pressure at 40 bar is injected from the center of the hemispherical blunt nose in hypersonic freestream Mach number 6. The self-ignition of hydrogen and interaction of accelerating flame can cause up to 60 % drag reduction. The final paper will perform the detailed parametric study as well as discuss the time-dependent flow-field modification by hydrogen injection. Extended Abstract with preliminary results is attached with the submission.

High Mach Number Drag Analysis of a Modern Lightweight Launch Vehicle

Ainslie French, Antonio Schettino, Luca Romano

IntroductionThe accurate evaluation of the drag coefficient is crucial to the design of a launch vehicle. For a given configuration, the drag is influenced by the freestream conditions (Mach, Altitude), which are mission dependent. Consequently, when generating the aerodatabase, the Reynolds effects on drag coefficient must be estimated. Moreover, the nozzle exit plume can significantly affect the drag. The goal of the present paper is to analyze these effects in detail on a lightweight launch vehicle being designed by Avio Space, also conducting a drag breakdown on the various vehicle components.DiscussionThis paper presents predictions of pressure and frictional drag on the individual components of the VEGA C Light Launch Vehicle propelled by a solid rocket motor over a hypersonic Mach number range from five to eight at nominal atmospheric conditions associated with the corresponding stage of the ascent trajectory. Both motor-off and motor-on conditions are simulated to isolate the motor-on effects. A preliminary series of simulations were also performed in off-nominal conditions where the Reynolds number was increased and the mass flow rate was decreased and vice versa, in order to examine the effects on drag under more extreme conditions.The CIRA software NExT 3.0 (Numerical Experimental Tool) [1] developed in house was used to conduct these studies. It solves the Reynolds Averaged Navier-Stokes equations including both chemical and vibrational non-equilibrium on structured grids by mean of the finite volume approach. For the present computation both the free stream and the nozzle inlet were modelled as perfect gases by imposing the appropriate physical parameters. The K-Îµ turbulence model was used to account for turbulence effects.A further set of specific simulations were also conducted with the commercial software FLUENT v14.5 [2] as an additional validation of the results obtained over the Mach number range considered.ConclusionsThe results indicate that the differences between the motor-off and motor-on cases in nominal conditions are mainly due to base drag. With the motor-on the base pressure increases thereby reducing the total drag. In the off-nominal conditions, when the Reynolds number is increased there is a reduction in drag, and when the nozzle mass flow rate is decreased there is an increase in drag. Conversely, when the Reynolds number is decreased and the nozzle mass flow rate is increased, the

opposite effect occurs. However, for very low Reynolds numbers, an incipient separation can occur on the first stage, which also influences the drag.In the code-to-code comparison between NExT and FLUENT the results compare very well where minor differences may be explained due to the different turbulence models which were used.

Advanced Design of High Entropy Alloys Based Materials for Space Propulsion (ATLAS), a new project for space propulsion

Mario Guagliano

The development of next generation space exploration propulsion systems requires high temperature materials able to guarantee low density, high strength and ductility, oxidation resistance, good creep properties.

High Entropy Alloys (HEA) are an excellent candidate due to their potential high specific strength and oxidation resistance at high temperatures and have been identified as possible replacement for superalloys in propulsion systems components.

In the present contribution the Research and Innovation Action-H2020 project ATLAS is presented. ATLAS has been recently approved and aimed to take over the present limitations and unsolved issues that limit the utilization of HEA, is presented. through multidisciplinary materials design framework that advances the state-of-the-art of High Entropy Alloys and related materials compounds towards the practical needs (current and future) of the space propulsion industry.

To achieve this ambitious result the following challenges will be addressed: definition of an accurate material property database, design of the HEA, definition of Hybrid/Compound solutions with combination of HEA materials joined to Ceramics and/or Ceramic Matric Composites (CMCs) to create lightweight and temperature resistant functional materials, manufacturing of near-net shape manufacturing and materials integration/joining with Ceramics and CMCs.

To produce the HEA materials and related compounds materials designed within the project two different additive manufacturing processes will be used from the production of coupons and samples to the final full scale demonstration, thus paving the path for the application of HEAs for the new generation of space propulsion.

HERA Mission LIDAR Altimeter Implementation

Nicole G. Dias, Beltran N. Arribas, Paulo Gordo, Bruno Couto, Tiago Sousa, João Marinho, Rui Melicio, António Amorim

In this work we present the design of the optical front end of the LIDAR, its radiometric calculations, optomechanical design and mechanical simulations[39] [1]. LIDAR and rangefinders play an important role in support to spacecraft navigation and are also used as scientific instruments in asteroid exploration. They can be used in mapping asteroids and support spacecraft navigation, from fly by to landing operations. Low mass compact spacecraft missions to asteroids is an increasing trend, including small landing spacecrafts. This fact tends to drive instruments design, namely miniaturization and flexibility maintaining its performance. New compact rangefinder technologies are therefore needed for future

[39] P. Gordo, et all., "HERA lidar instrument development", Proc. 4th COSPAR Symposium: Small Satellites for Sustainable Science and Development, 1-6, Nov. 2019

asteroid missions. HELENA is a time of flight (TOF) altimeter that provides time tagged distances measurements. The instrument can be used to support near asteroid navigation and provides scientific information (e.g. asteroid 3D topography and fall velocity) and also reports the power of the received pulse being possible to calculate the target reflectivity. The LIDAR design comprises a microchip laser and a low noise sensor. The synergies between these two technologies enable the development of a compact instrument for range measurements of up to 20 km with a low power consumption and envelope. LIDAR altimeter has four main blocks, power supply, processing unit, frontend, ToF and opto-mechanics interfaces. The preferred LASER source for HELENA is currently being developed at Faculdade de Ciências da Universidade de Lisboa (FCUL). The laser used as source is a diode pumped, passively Q-switched Yb-Er Microchip Laser targeting a 100 µJ pulse with a full-width half-maximum (FWHM) of 2 ns. The most critical component of the optics front end is the receiver telescope. The receiver telescope has a Cassegrain design. The primary mirror is made of zerodur and has 100 mm diameter. The secondary mirror is assembled on a carbon fibre tripod structure. It is presented below the telescope ray tracing (zemax design). HELENA acquisition modes can be made in BURST or SINGLE Mode; in BURST mode the instrument will output a measurement at a configurable periodicity (maximum 10 Hz). In both working modes HELENA, will also periodically send a housekeeping packet with the equipment health information. On the lowest power consumption mode, IDLE, only housekeeping data is available, and all the frontend are switched off. The unit Engeneering model is currently under manufacturing, it is expected to be completed by December, when tests will be performed to validate its ability to measure the distances up to 20 km.

Session 60: Digital solutions for future aircraft developments (PART II)

Session Chair: Mr. Andreas Koetter ALTRAN, Germany

Using Naïve Bayes Machine Learning approach to evaluate performance on spare parts request for aircraft engines

Antonio Caricato

Aircraft uptime is getting increasingly important as the transport solutions become more complex and the transport industry seeks new ways of being competitive. To reach this objective, traditional Fleet Management systems are gradually extended with new features to improve reliability and then provide better maintenance planning. Main goal of this work is the development of iterative algorithm based on Artificial Intelligence to define the engine removal plan and its maintenance work, optimizing engine availability at the customer and maintenance costs, as well as obtaining a procurement plan of integrated parts with planning of interventions and implementation of a maintenance strategy.

In order to reach this goal, Machine Learning has been applied on a workshop dataset with the aim to optimize warehouse spare parts number, costs and lead-time. This dataset consists of the repair history of a specific engine type, from several years and several fleets, and contains information like repair claims, engine working time, forensic evidences and general information about processed spare parts. Using these data as input, Naïve Bayes models has been built in order to predict the repair state of each spare part for a better warehouse handling.

A multi-label classification approach has been used in order to build and train, for each spare part, a Machine Learning model that predicts the part repair state as a multiclass classifier does. Mainly, each classifier is requested to predict the repair state (classified as “Efficient”, “Repaired” or “Replaced”) of the corresponding part, starting from two variables: the repairing claim and the engine working time. Then, global results have been evaluated using the Confusion Matrix, from which Accuracy, Precision, Recall and F1-Score metrics are retrieved, in order to analyse the cost of incorrect prediction. These metrics are calculated for each spare part related model on test sets and, then, a final single performance value is obtained by averaging results. In this way, the fully probabilistic methods Naïve Bayes models is applied. The accuracy value will be compared in future with other Machine Learning approaches to evaluate performance.

Building Digital Transformation to improve NGCTR design and simulation Michele

Sesana, Alessandro Bardelli

If an airline can predict that when a part is going to fail and to prevent it from happening, extra costs and passenger annoyance during flight can be avoided. Combining flight analytics and sensor data from engines with customer data, airlines can better manage flight disruptions, not to mention missed connections. This is achieved by using data that the aircraft generated during flights through their deep analysis in order to detect possible malfunctions, performing predictive maintenance, anticipating problems before it is raised.

Modern aircrafts are based on a rich set of on board computers supporting many different tasks, capable of recording hundreds of parameters during flight. This allows not only the investigation of problems occurred during flights, such as accidents or a serious incident, but also provides the opportunity to use

the recorded data to predict future aircraft behaviour. This can be done with precise analyses of the recorded data, in order to identify possible hazardous behaviours and developing procedures to mitigate the problems before they occur. Because of the enormous amount of data collected during each flight, two are the problems to be faced: define the appropriate infrastructure in terms of HW platform and the most promising software to identify the segments of data that contain useful information. The objective is to extract for a huge amount of data useful information that can support the aircraft manufacturer to better support their work. Traditional data-mining methods are effective on uniform data sets such as flight tracking data or weather. Integrating heterogeneous data sets introduces complexity in data standardization, normalization, and scalability. The variability of underlying data warehouse can be leveraged using big data infrastructure for scalability to identify trends and create actionable information. The massive availability of data requires complex and performing architecture to support deep analysis on data. Furthermore, data can be so huge that an intelligent support shall be provided by the platform itself, that is, the end user shall be reinforced and guided in the analysis by means of an intelligent support. This can be only achieved by means of the adoption of novel approach to analyse large amount of data and extract useful information (data mining, machine learning, AI).

The ADMITTED Project* has the goal to enable an innovative approach in the development of the NGCTR-TD implementing methods capable to supporting the optimization of flight campaigns and improving design choices, thanks to new insights coming from the massive data analysis and finding innovative algorithms and correlations. Dimensions of a typical flight test data are 3 Flying aircraft prototypes, an average of 10.000 and a maximum of 30.000 parameters, for each flight condition including 600.000 of total flight conditions and the prototypes have as today about 4.000 flights recorded.

Main Objectives of the project are to i)define the most appropriate infrastructure to support large amount of data collected during flights test both in term of HW big data platform and SW toolset to support storing, retrieval, data analysis and ii) to define the best approach to extract useful information from the data recorded according to the identified main purposes; iii) select the most promising techniques to support data analytics supporting computation of prediction or suggestion based on data and iii) the implementation of novel predictive algorithms based on machine learning techniques.

Capabilities of the Regional Cabin Demonstrator as digital twin for a future test mock-up

Andreas Lindner, Victor Norrefeldt

Digital twins are essential for Industry 4.0 and the digitalization of research, development and manufacturing. By now, the models contain more and more information and are already often highly complex systems. However, an important step is to also keep the model as simple as possible in order to reduce computing resources and the associated simulation time. The Indoor Environment Simulation Tool (IESS) is a tool to generate a zonal model from a CAD geometry. It is designed to simulate the indoor climate in a short and also transient time, while still considering all important physical processes (heat conduction, radiation, convection). After the zonal model has been generated, the user can parameterize it specifically to the application and couple it with other models when needed. Here, a new approach is to integrate a thermophysiological model of the human body in order to make statements about the human perception of thermal comfort. This is of particular interest in early development phases in order to assess air conditioning strategies as well as structural or technical adaptions due to thermal bridges or other influences on the cabin climate. In this paper a concept will be presented where the zonal model is

coupled with the thermophysiological model to investigate selected case studies on how thermal comfort in a regional aircraft can be optimized. The cabin model is based on a new type of regional aircraft for which a mockup is currently being built in order to perform subject test at the Fraunhofer Institute in Holzkirchen. The thermal model can thus make statements in advance about how test scenarios should be carried out in order to gain the greatest possible benefit from the test subject study, where the number of different tests is limited.