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Contents

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1. Keynote speeches

The Clean Sky 2 Fast Rotorcraft Initiatives: where are we today and where to next?

The Airbus Helicopter's RACER compound helicopter and the Leonardo Helicopter Division's NEXTGEN CIVIL TILTROTOR initiatives are breaking new ground in taking new technology and innovative solutions towards the stage of flight demonstration under their co-funded projects through the Clean Sky 2 Joint Undertaking [as part of the EU's Horizon 2020 Framework Programme for Research and Innovation].

These two innovative flying vehicle configurations will bridge the gap in performance [payload, range and speed] between traditional helicopter configurations and fixed wing alternatives: bringing superior mobility solutions to some key markets served by the current rotorcraft fleet, but also potentially opening up entirely new markets looking for the marriage of VTOL capability and the cruise performance of a fixed wing aircraft.

In this update the progress so far will be shown, highlighting some key technical challenges and the innovative approaches the teams working with the two lead manufacturers are implementing. Some thoughts on new steps beyond this new State of the Art, possibly under renewed collaboration in the next Framework Programme will be given and the forum is welcomed to engage in an exchange of ideas.

Ron van Manen (TU Delft Aerospace Engineering, 1987) started his career at KLM Engineering & Maintenance before joining British Airways in a senior manager role. In 1998 he returned to KLM E&M as VP Business Development and in 2003 he joined QinetiQ in the UK as Programme Director Civil Aeronautics directing its contract research and development projects with industry, UK Government and EU, including several assignments in support of UK government transport, climate, science and technology policy. In 2008 he was appointed MD Aerospace Consulting, spanning QinetiQ's research, engineering and test services in aeronautics.

In 2011 he joined the Clean Sky JU as Technology Evaluation Officer. In 2012 he was tasked with coordinating the preparation of the Clean Sky 2 Programme: the largest aeronautics research programme ever launched and now running under H2020; involving €4bn of total investment. In September 2013, he was appointed Programme Manager [acting] for Clean Sky 2, to coordinate the Programme's successful launch, a position that was confirmed in October 2014 after the formal launch of the Programme.

Training enhancement for the Defence Helicopter Command – The power of visionary needs analysis

For a helicopter training organisation there is always a challenge to ensure its Flight- and Aircrew is trained efficiently and effectively, using optimal training media in an affordable manner. Military training organisations not only train for safe and efficient operations, but also for combat readiness. Military helicopter operations abroad lead to highly experienced Flight- and Aircrew for a small set of operations and conditions, but they may not be able to maintain full combat readiness. The Defence Helicopter Command (DHC) of the Royal Netherlands Air Force (RNLAF) is in the process of a major training system revision, including the acquisition of simulators. This presentation provides an overview of the key ingredients for the approach implemented, which was developed by NLR in cooperation with DHC and JIVC (Joint Command Information management).

Blueprints for idealised qualification training (initial qualification, mission qualification) and currency training are defined, applying modern instructional principles, as far as accepted by the Flight- and Aircrew community. The idealised syllabus initially does not even consider whether a training sortie should be live or simulated.

Maj. Roland (Wally) Blankenspoor, Defence Helicopter Command, Royal Netherlands Air Force, started his military career in 1990 in Breda. He became a Platoon Commander in the Army in the 11th Air Mobile Brigade. In 1997 he started his flying career with the Air Force. He was trained to become an Apache Pilot.

After deployments to Djibouti (2), Afghanistan (6) and recently Mali (1) Major Blankenspoor is now Head of Crew Training and Simulation in the Dutch Defence Helicopter Command based at Gilze-Rijen Airbase. With a total of more than 4000 flying hours, being Flight Instructor and Weapons Instructor Roland is one of the most experienced helicopter Pilots of the Royal Netherlands Air Force.

Anneke Nabben has fifteen years of experience in instructional design and research in aviation. Anneke has a Master of Educational Science and worked for KLM and Airbus before she joined NLR in 2010. As senior training expert she is responsible for a variety of projects for civil and military aviation organizations related to training needs analysis, training concept design, training development and enhanced use of training media, including selection and development these media.

Aviation challenges for the Global Energy Market

This presentation is about the challenges to support and enable Shell's current and future operations through safe, secure and efficient aviation solutions in a competitive environment. Our aim is to enable sustainable, routine and reliable aircraft operations, whilst capable of adopting new technology for business advantage. This requires amongst others engagements and collaboration within the wider aviation industry to enable future growth prospects, well-considered aircraft certification standards, and robust Safety Management Systems with effective learning from incidents.

Shell's commercial airline exposure is approximately 558,000 passenger flights in an industry that is regulated by the highest standards. However, Shell's contracted aircraft do not enjoy the same regulatory protection as airlines with significant national variation and regulatory gaps. A significant higher overall Global Energy Market accident rate for helicopters reflects this difference. Continuous improvements are required for the prevention of accidents through improved helicopter design, enhanced operations procedures, and aspects of training and maintenance.

Tony Cramp was appointed as Shell's VP Aircraft and Managing Director Shell Aircraft in May 2016. With Shell since in 2003, he has global experience in working with aircraft operators supporting oil and gas operations, undertaking assurance, air accident investigations and providing specialist advice to Shell's extensive business stakeholder group. Championing initiatives to enable safe and efficient operations in some of the most diverse and challenging environments, he has work closely with OEMs on aircraft design specifications and represents the Company on several industry and national regulatory bodies. Prior to joining Shell, he served 19yrs in the Royal Navy as a helicopter pilot and instructor, commanded a Naval Air Squadron and a Warship and served as the media spokesman for overseas military operations

Alrik Hoencamp works as Advisor Air Transport Safety for Shell Aircraft. With Shell since in 2015, he has global experience in working with aircraft operators supporting oil and gas operations, undertaking assurance, air accident investigations and Remotely Piloted Aircraft Systems (RPAS). He graduated from the Empire Test Pilots' School as Flight Test Engineer, holds a PhD in aerospace engineering from Delft University of Technology and has extensive experience in helicopter flight testing and certification of synthetic training devices, including Helicopter-Ship Qualification Testing.

Alrik is a member of the Vertical Flight Society (since 2007).

The Electric VTOL Revolution

More than 100 electric vertical take-off and landing (eVTOL) announced concepts are being studied around the world, with several advanced prototypes already conducting impressive passenger-carrying flights. Companies like Uber, Airbus, Bell, Joby and Kitty Hawk are competing to develop the hardware, software and regulatory framework to provide all-electric intra-city air shuttle services at very low cost and low noises, with zero tailpipe emissions within the next 5-10 years. In addition, hybrid-electric VTOL aircraft designs promise larger payloads, longer-range and higher cruise speeds. This presentation will discuss the promise and progress of electric VTOL aircraft.

Mike Hirschberg assumed the duties of the Vertical Flight Society Executive Director on June 1, 2011, after 20 years in the aerospace industry, primarily in vertical flight. As the Executive Director, he is responsible for the execution of the strategic direction set by the Vertical Flight Society Board of Directors. Mr. Hirschberg was previously a principal aerospace engineer with CENTRA Technology, Inc., providing technical and program management support for over 10 years to the Defense Advanced Research Projects Agency (DARPA) and Office of Naval Research (ONR) on advanced aircraft and rotorcraft concepts. Prior to this, Mr. Hirschberg worked from 1994 to 2001 in the Joint Strike Fighter (JSF) Program Office, supporting the development of the X-32 and X-35 vertical flight propulsion systems. Mr. Hirschberg holds a B.S. in Aerospace Engineering from the University of Virginia (1991) and a M.E. Mechanical Engineering from Catholic University of America (1996). He completed a Master of Business Administration at the Virginia Polytechnic Institute & State University (Virginia Tech) in 2013.

EASA Rotorcraft Safety Strategy

European Helicopter industry is facing one accident per week and one fatal accident per month. The trend is not significantly improving over the last 10 years. In a more visible and connected world, this level of accident is not sustainable anymore.

EASA has launched an initiative to develop a rotorcraft safety strategy aiming at reducing the number of accident by 50% in the next 10 year. This strategy will not only focus on Airworthiness, but will try to tackle some key areas such as Safety Culture, Operations, Airmanship, Training and technology. Within this last pillar, research can play a leading role in improving helicopter safety. Key aspect of the rotorcraft safety strategy will be highlighted and presented during this key note speech.

David Solar started his career in Dassault Aviation as a development engineer on the F7X program.

He was the appointed as Falcon Customer Technical Manager addressing round the clock customer support of the Dassault Civil fleet from the Falcon 10 to the Falcon 900EX Easy.

He joined EASA in 2006 as a Large Transport Aircraft Project Certification Manager. He leads projects such as 777F, 787, A380, MRJ and A400M among others. In 2012, he was appointed Large Transport Aircraft Section Manager and Deputy Head of Large Transport Department.

In September 2017, he was nominated as Acting Head of Rotorcraft Department.

The danger of speed instability below minimum power; A forgotten problem?

Flying at low speed on the approach, both rotary and fixed-wing aircraft are susceptible to speed instability. Below minimum drag (or power depending on the type of propulsion), while the natural dynamics (e.g. phugoid mode) might be stable, when a pilot or an automatic system controls the vertical flight path with elevator or cyclic, the dynamics change and a new, speed, mode emerges that can be driven unstable by increasing pilot gain. This 'problem' was discovered on fixed-wing aircraft in the first decade of aviation but theory to predict its behaviour, and explain the underlying physics, came much later. The theory was extended to rotorcraft by the author. Nevertheless, accidents continue to occur all too frequently because of this adverse aircraft-pilot-coupling (APC); to the point where it seems appropriate to question whether pilot training properly addresses the risk to safety associated with this dangerous problem. The presentation will describe the theory for this APC and examine three accidents that involved speed instability on the approach; one involving a fixed-wing aircraft, the other two involving helicopters. A question arises from this as to whether the pilot community has a proper grasp of the fundamental aeronautical science behind this APC? It is hoped that the presentation will stimulate discussion around this question.

The wonder of flight led **Gareth Padfield** to study aeronautical engineering at the University of London, later learn to fly both aeroplanes and helicopters and gain a PhD in flight dynamics at Cranfield College of Aeronautics. His career has been spent in the aviation industry, government research and in academia and has involved all aspects of flight dynamics - flight testing, modelling and simulation, flying qualities and flight control. He has held senior management and leadership roles in Government service (Chief Rotorcraft Scientist, DERA) and Academia (Head of School of Engineering, Liverpool).

Gareth is research-active in his current role as Emeritus Professor of Aerospace Engineering at The University of Liverpool where he also supports staff and students in their endeavours. He operates a consultancy company, Flight Stability and Control, undertaking a variety of specialist projects for the aviation industry, and has delivered short courses in Europe, North America and Asia.

Gareth is a Chartered Engineer, a Fellow of the Royal Academy of Engineering and the Royal Aeronautical Society. He is an honorary member of the American Helicopter Society's

Modelling and Simulation and Handling Qualities Technical Committees and he has served on the UK's Defence Scientific Advisory Council.

2. Technical papers

#
Paper title
Author
Co-author(s)
Abstract

3

A rugged fiber optics monitoring system for helicopter rotor blades

Luigi M. Bottasso (Leonardo Helicopters)

Giuseppe Sala, Paolo Bettini (Politecnico di Milano); Paolo Tagliabue, Franco Corbani (Optical Sensing Technolgies)

Emilio Platini, Andrea Guerra, Andrea Anelli (Leonardo Helicopters)

Health and Usage Monitoring (HUM) and Structural Health Monitoring (SHM) technologies play an increasingly important role in aerospace applications, for example in support to fleet maintenance and for test and development purposes. We describe the design, manufacture and integration of an advanced blade strain monitoring system for the tail rotor of the AW139 helicopter. The goal was two-fold: to demonstrate the feasibility of a rugged rotor-based interrogation system and the practical embedding of Fiber Bragg Gratings (FBG) sensors within composite rotor blades. This task required careful study of the optimal fiber path within the constraints of the blade composite structure and the ply stacking sequence. A temperature compensation method was developed to decouple thermal strain. An integrated interrogation-communication system housed in a dedicated beanie was developed with the capability to withstand the harsh high-g environment of a rotor hub. In order to avoid the need for slip rings for power and data transfer between fixed and rotating frames, the interrogator was designed as a self-contained unit equipped with batteries and wireless data transmission capability. This rugged monitoring system offers cleaner aerodynamics and longer sensor life compared to traditional strain gauges and represents a stepping stone towards the development of future fiber-based HUM with photonics chip interrogators.

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Impact scenarios for collisions with Unmanned Aerial Vehicles and their consequences to rotorcraft

Florian Franke

Michael Schwab, Alexander Engleder, Uli Burger

(Technische Hochschule Ingolstadt)

This paper presents different impact scenarios for collisions between rotorcrafts and small unmanned aerial vehicles (sUAV) as well as the corresponding consequences. As the popularity and number of sUAV in the airspace increases continuously also increases the risk of a collision between unmanned and manned aircraft. Possible impact scenarios are defined within this paper based on bird strike data. Up to now, there are no relevant data for the collision with a sUAV. But sUAV are similar in size and mass to birds and due to this, bird strike data can be used to determine impact load cases and locations. EASA's suggestion of drone sizes will be adapted for the collision with rotorcrafts. Furthermore, the structure of a drone is described. A drone consists of at least four main parts, the battery, motors, structure and payload. Each of these components represents another threat and these are evaluated on the basis of their risk potential. The FAA penetration equation and further penetration equations are used to describe analytical the threat of a drone strike to a helicopter. The final analytic results are rated by engineering judgement due to uncertainties in the analytic approaches. Based on these results, a test- and simulation program is developed to fully characterize the threat of a drone strike to manned rotorcraft. The main results are that a drone strike poses a greater danger to rotorcraft than to commercial airliners. Impact tests need to be performed to fully characterize the threat and will be done in further research activities.

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Dynamic extendable chord for improved helicopter rotor performance

Dong Han (Nanjing University)

Kelong Yang (Nanjing University), George N. Barakos (University of Glasgow)

Extendable blade sections are investigated as a method for reducing rotor power and improving helicopter performance. A validated helicopter power prediction method, based on an elastic beam model is utilized. The static extendable chord can deliver a rather small power reduction in hover, and significant power savings at high speed flight, however, the cruise power is increased. In hover, the active chord is best deployed in the middle part of the blade, and just inboard of the tip at high speed flight. The increase in chord length can leads to power savings at high speed flight but the benefits decrease in other speeds. The 1/rev dynamically extendable chord can lead to an overall power reduction over the speed range of a helicopter. The best deployment location is the blade tip, which is different from the statically extendable chord. It is best extended out in the retreating side and retract back in the advancing. The power reduction by the 1/rev dynamically extendable chord

increases with the increase in the length of the chord extension and take-off weight of the helicopter. Generally, a lower harmonic extendable chord can save more power than one actuated at higher harmonics. The dynamic chord can reduce more power than the corresponding static chord.

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Orthogonal vortex-rotor interaction: impact on rotor controls, blade flapping, thrust and power

Berend G. van der Wall (DLR)

Rotors of vertical take-off and landing vehicles (main rotor, tail rotor, and propeller) are often subjected to interaction with vortices from other lifting devices. Interactions with vortices whose axes are essentially parallel to the rotor plane of rotation are widely investigated and understood, especially with respect to blade-vortex interaction (BVI) phenomena. Interactions of rotor blades with vortices oriented normal to the rotor disk were rarely investigated and this article focuses on this type of interaction, including the vortex impact on power required by the rotor. It is a fundamental study that is intended to contribute to future flight dynamics investigations.

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Real time flight dynamics model identification of tilt-rotor aircraft

Wu Wei (Nanjing University)

An improved real time identification method for tilt-rotor aircraft flight dynamics modeling is developed in this paper. A general parametric flight dynamics model which can be used for online identification purpose in all 3 flight modes is established, and an unideal noise model is also built in order to minimize the influences to the identification accuracy caused by measurement noise. An adaptive model structure identification algorithm is established by introducing local accuracy criteria, so that the time variant optimal model structure can be obtained in real time. A weighted recursive least squares algorithm is established for parameter identification, and a time variant weighting matrix is designed to provide best numerical performance of the identification procedure at any time. A comprehensive nonlinear flight dynamics model of a sample tilt-rotor aircraft is used to build a numerical simulation platform and identification results of the sample aircraft in fixed wing mode, helicopter model as well as transition mode are obtained based on simulation flight test. Finally, the flight dynamics model of an unmanned tilt-rotor aircraft in helicopter mode is identified by using the real flight test data. The identification results show that the real time identification method for tilt-rotor aircraft developed in this paper is effective, efficient and robust.

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Shipboard landing period based on dynamic rollover risk prediction

Binh Dang-Vu (ONERA)

While SHOLs (Ship/Helicopter Operating Limitations) provide acceptable wind velocities and orientation and ship motion limits, limited attention has been given to the real-time determination of windows in which ship motions are likely to be safe for helicopter landings and deck handling operations. Existing operational systems developed to indicate periods of quiescence usually combine a specific set of ship motions into a scalar quantity, e.g. an energy index. The contribution of the present paper is to associate forbidden landing windows with the conditions of a control departure when the helicopter landing gear touches the deck of the ship. Among the well-known losses of control, dynamic rollover is particularly critical and hard to recover. A method to determine shipboard landing periods based on dynamic rollover risk prediction is proposed. The objective is to reduce the helicopter hover time and to provide the pilot with a safe go-ahead signal to start the hovering descent to the deck. A simulation tool has been developed, capable of modelling the complex interactions in the dynamic interface between ship and helicopter. Simulation results as well as sensitivity analysis with respect to uncertainties are presented.

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Aerodynamic investigation of rotor / propeller interactions on a fast rotorcraft

Ronan Boisard (ONERA)

During the past few years, different concepts of fast rotorcraft have appeared. Most of them rely on additional propellers (usually one or two of them) to ensure the propulsive force at high speed in order to be able to slow down the main rotor rotating speed. On such configuration, the propellers are in strong interaction with the main rotor wake which affects their performances and the aircraft maneuverability. The present work numerically investigates the aerodynamic of the rotor / propeller interaction on rotorcraft similar to the Racer from Airbus Helicopters. By using two different levels of modeling it is shown that at high advance ratio, a simple free wake model is perfectly able to give most of the interaction effects, while in hover, a full CFD unsteady computation may be necessary to capture all the unsteadiness of the interaction. This paper also outlines the different behavior of the propeller while it is fully inside the rotor wake or out of if, and therefore the need for a precise control of the rotorcraft in the transition between hover to fast forward flight.

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An extensive helicopter Ground Vibration Test: from pretest analysis to the study of non-linearities

Christopher Ciavarella (Airbus Helicopters Deutschland)
Martijn Priems (Airbus Helicopters Deutschland); Yves Govers, Marc Böswald (DLR)

The Ground Vibration Test (GVT) is one of the key milestones in the characterization of an aerospace structure, allowing to describe its structural dynamic behavior. Moreover, a helicopter GVT is associated to additional challenges deriving from the rotorcraft architecture, such as a high modal density and non-linear phenomena. In this paper, these challenges are treated by presenting the extensive H145 GVT campaign carried out in June 2017 by AHD and DLR, from its conception to the first analysis of results. Starting from a H145 FE model, the pre-test analysis began with the selection of target modes from the initial numerical modes set based on modal participation and energy considerations. An optimal sensor distribution was also achieved as results of the implementation of sensor placement metrics like the Normal Displacement Method and sensor elimination methods based on MAC analysis. An extensive description of the testing methods and procedure is as well documented, from the use of a dedicated test rig to the excitation of the structure by means of several exciter constellations using different force levels in order to assess non-linear behavior and therefore identify the structural variability. After data acquisition, the efficient post-processing performed using DLR correlation tool allowed the identification of modes family and the creation of a modal model. In the first analysis of results, modal identification has shown the validity of the pre-test analysis by identifying more than 40 modes for the first helicopter configuration and exhibiting an excellent data quality. Comparison between two H/C configurations has given also a first sample of how structural variability can influence the modal layout. Furthermore, focus has been put on the identification and analysis of non-linear phenomena, proving how non-linear behavior can affect significantly the H/C dynamic response and the modal identification. Finally, a comparison between FE and test results for one H/C configuration has been performed, allowing an objective evaluation of the predictive capability of current FE models. On this basis, the path for future works in the field of FE modal updating and structural optimization is clearly defined.

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Unsteady aerodynamic interaction between rotor and ground obstacle

Jian Feng Tan (Nanjing University)
Yi Ming Sun, Tian Yi Zhou (Nanjing University), George N. Barakos, Richard B. Green (University of Glasgow)

The mutual aerodynamic interaction between rotor wake and surrounding obstacles is complex, and generates high compensatory workload for pilots, degradation of the handling qualities and performance, and unsteady force on the structure of the obstacles. The interaction also affects the minimum distance between rotorcrafts and obstacles to operate safely. A vortex-based approach is then employed to investigate the complex aerodynamic interaction between rotors and ground obstacle, and identify the distance where the interaction ends, and this is also the objective of the GARTEUR AG22 working group activities. In this approach, the aerodynamic loads of the rotor blades are described through a panel method, and the unsteady behaviour of the rotor wake is modelled using a vortex particle method. The effects of the ground plane and obstacle are accounted for via a viscous boundary model. The method is then applied to a “Large” and a “Wee” rotor near the ground and obstacle, and compared with the earlier experiments carried out at the University of Glasgow. The results show that the predicted rotor induced inflow and flow field compare reasonably well with the experiments. Furthermore, at certain conditions the tip vortices are pushed up and re-injected into the rotor wake due to the effect of the obstacle resulting in a recirculation. Moreover, contrary to without the obstacle case, the peak and thickness of the radial outwash near the obstacle is smaller due to the barrier effect of the obstacle, and an up-wash is observed. Additionally, as the rotor closes to the obstacle, the rotor slipstreams impinge directly on the obstacle, and the up-wash near the obstacle is faster, indicating a stronger interaction between the rotor wake and the obstacle. Also, contrary to the case without the obstacle, the fluctuations of the rotor thrust, rolling and pitching moments are obviously strengthened. When the distance between the rotor and the obstacle is larger than 3R, the effect of the obstacle is small.

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Drivetrain influence on the lead-lag modes of hingeless helicopter rotors

Felix Weiss (DLR)
Christoph Kessler (DLR)

Structural couplings between the flexible main rotor and the flexible drivetrain of the Bo105 helicopter are investigated by numerical simulation. For this purpose, the rotor hub constraint $\Omega = const.$ is dropped and a drivetrain model, consisting of discrete inertia elements and intermediate flexible elements, is connected to the hub. By use of the multibody-software SIMPACK, the coupled rotor-drivetrain system is linearized and the Eigenmodes are compared to those obtained with a constrained rotor hub. The drivetrain has a significant influence on the shapes and Eigenfrequencies of the collective lead-lag

modes. While the first collective lead-lag Eigenfrequency is raised by the finite drivetrain inertia, the second is lowered due to drivetrain flexibility. To assess the influence of modeling inaccuracies on the observed couplings, the study is complemented by a sensitivity analysis. Rotor blade mass axis offset, blade pitch (causing elastic coupling) and blade precone angle have only weak influence on the coupled modes. In contrast, variations of drivetrain inertia and stiffness strongly affect the Eigenfrequencies of the coupled rotor-drivetrain modes.

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Master minimum equipment list (MMEL) / engine Time Limited Dispatch (TLD) on helicopter

Matthias Hatzak (Airbus Helicopters Deutschland GmbH)

The certification regulations published by Joint Airworthiness Authorities (JAA), European Aviation Safety Agency (EASA) or Federal Aviation Administration (FAA) require that all equipment installed on a helicopter must be operative in compliance with the airworthiness standards and the operating rules. However, the rules (e.g. in JAR-MMEL/MEL or CS-MMEL) permit the publication of a Minimum Equipment List (MEL) where compliance with certain equipment requirements is not necessary in the interests of safety under all operating conditions. Experience has shown that with the various levels of redundancy designed into helicopter, operation of every system or installed component may not be necessary when the remaining operative equipment can provide an acceptable level of safety. Hence helicopter utilization is improved and more convenient and economic air transportation for the public is provided thereby. In order to enable the aircraft operators to establish their individual MELs, the Master Minimum Equipment List (MMEL) is developed as a basis for the MEL by the type certificate holder of the respective aircraft as part of the Operational Suitability Data (OSD) and approved by the competent authority. The MMEL includes those items of equipment related to airworthiness and operating regulations and other items of equipment which the competent authority finds may be inoperative and yet maintain an acceptable level of safety by appropriate conditions and limitations. Special attention has to be paid if engine related items shall be implemented in the MMEL. As engines have their own type certificate (TC), engine related parts cannot be directly implemented in the aircraft MMEL by the aircraft manufacturer. To implement these items, a “permission” given by the engine manufacturer is needed. To have this permission officialised, the competent airworthiness authority has to approve it in the TC. To obtain the approval, a “Time Limited Dispatch” (TLD) approach needs to be performed for failures leading to redundancy failures in the engine control system. For failures not leading to redundancy failures, the “classical” MMEL approach can be conducted. The compliance demonstration is based on the list of relevant failures leading to redundancy failures in the engine control system. These failures have to be justified by appropriate means, e.g. fault tree analyses, taking into account that one failure has already occurred. For the TLD approach also new analysis methods need to be applied taking into account the requirements of the certification specification for engines (CS-E). Airbus Helicopters performed this approach as the first helicopter manufacturer in the world successfully in a joined approach together with the engine manufacturer.

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A physics-based approach to Urban Air Mobility

Patricia Ventura Diaz (NASA Ames Research Center)
Seokkwan Yoon (NASA Ames Research Center)

High-fidelity Computational Fluid Dynamics (CFD) simulations for multi-rotor vehicles have been carried out. The three-dimensional unsteady Navier-Stokes equations are solved on overset grids employing highorder accurate schemes, dual-time stepping, and a hybrid turbulence model using NASA’s CFD code Overflow. The vehicles studied consist of small to medium sized drones, and bigger vehicles for future Urban Air Mobility (UAM) applications. The performances for different con1gurations and rotor mounting are calculated in hover and in forward flight. Understanding the complex flows and the interactions between rotors and with other elements will help design the future multi-rotor vehicles to be quieter, safer, and more efficient.

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New technologies to enhance rotorcraft crash safety

Akif O. Bolukbasi (The Boeing Company)

Crash safety of rotorcraft can be significantly enhanced using several new crashworthiness technologies under development. These technologies include actively controlled subsystems such as external airbags, crashworthy seats, landing gears, and crash load limiting elements for the transmission and rotor systems. These actively controlled subsystems can be integrated at the rotorcraft system level using an Active Crash Protection System (ACPS) that can sense an impending crash event and control the subsystems to enhance occupant crash safety. This paper presents the results of research and development efforts for various actively controlled crashworthy subsystems and their integration at the rotorcraft system level. The paper also addresses the potential benefits of these crash safety technologies using the Crashworthiness Index (CI) as a metric. CI scores calculated for deploying the new crashworthiness technologies individually and as an integrated system are also presented and compared to rotorcraft without these technologies.

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Height–Velocity diagram analysis of a Variable Speed Rotor helicopter

Xufei Yan (Nanjing University)
Cheng Chi, Renliang Chen (Nanjing University)

This paper applies optimal control method to study the effects of variable speed rotor (VSR) on the helicopter Height–Velocity (H-V) diagram in one engine inoperative (OEI) situation. Taken UH-60A as a sample helicopter, a flight dynamics model and the optimal control method applied are validated against the flight test data. The low-speed H-V diagram in OEI and the landing procedures at three key points (High hover, Knee and Low hover points) of the H-V diagram in OEI are investigated under different rotor operating speeds. Results indicate that the reduction of rotor operating rotation speed will cause the area of H-V diagram in OEI gradually shrink at first, and then expand rapidly. The rotor operating speed corresponding to the minimum area of H-V diagram in OEI is a little higher than that corresponding to the minimum required power. A reasonable rotor operating rotation speed not only effectively reduces the helicopter required power, but also improves the landing performance in OEI.

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Helicopter vibrations: a major comfort improvement through Seat SARIB® implementation

Christian Buxel (Airbus Helicopters (Germany)
Anne-Claire Chapuis-Desplanques; Julien Guitton (Airbus Helicopters France); Thomas Manfredotti (Dynalya)

In response to current vibration regulations and driven by the wish to further improve the comfort on helicopter seats, Airbus Helicopters and its partner Dynalya have seized the opportunity to develop a mechanical anti-vibration device called “Seat SARIB®”. This passive device is fitted at the interface between the floor and the seat and is dedicated to the vertical b/rev vibration filtering on the entire nominal frequency range of a rotorcraft and it is independent of the passenger weight. The system offers a vibration attenuation of more than 10dB while only adding only 2-3kg of weight per seat. The development, tuning and testing of this system are detailed in this article, as well as the certification methodology deployed in order for our customer to benefit from this new comfort improvement. The Seat SARIB® has been certified by the European Aviation Safety Agency (EASA) in October 2017 for the cockpit seats of the Airbus H145 rotorcraft.

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Detecting planetary gear bore crack

Wenyi Wang (Defence Science and Technology Group)

Since 2009 there have been two fatal crashes of the Super Puma helicopter caused by fatigue cracks propagated from the bore of the planetary gear in the main transmission gearbox. The bore crack propagated through the gear rim causing the planet gear to breakup, which consequently destroyed the integrity of the transmission gearbox. For helicopter safety, it is imperative to develop methodologies for detecting such faults and to implement this capability into helicopter Health and Usage Monitoring Systems (HUMS). In this paper, a method is proposed to detect and track the propagation of a planetary gear bore-crack based on planet gear Synchronous Signal Averaging (SSA) and residual signal enveloping. The method has been initially validated using the vibration data generated from a small industrial planetary gearbox test rig with a notch inserted in the bore of one of its planetary gears. Results from this test show that the planetary gear bore notch is detectable with two different notch sizes using the residual signal of the composite planet SSA signal under three different load conditions. Furthermore, the diagnostic capability may be achievable using the squared envelope of the SSA residual signal, where the respective meshing of the defective section in the planet gear with the ring and sun gears are individually identifiable. Further bench testing will be conducted in the small test gearbox and in a full-scale Bell-206B helicopter main rotor gearbox with a very fine spark-eroded initial notch defect inserted in the bore of the planetary gear. The objective is to initiate a real fatigue crack from the bore notch and propagate the crack. The vibration data generated in this test will be used to further validate the proposed method.

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A Hybrid Navier-Stokes / viscous vortex particle wake methodology for modeling maneuver loads

L. S. Battey (Georgia Tech)
L. N. Sankar (Georgia Tech)

Maneuvering flight and high-speed flight are critical design points in any rotorcraft’s operating envelope. These conditions give complex flow phenomena, creating high stresses and vibrations. To accurately predict the flow properties over the relatively flexible rotor blades, coupling between computational fluid dynamics (CFD) and computational structural dynamics (CSD) is required. In this work, GT-Hybrid, a hybrid wake rotorcraft CFD code that is coupled to DYMORE, is used. A vortex particle method has been implemented, in place of the existing lattice wake methodology. Selected UH-60A maneuvering flight conditions; being two diving-turn and pull-up maneuvers, are simulated using the vortex particle method. Results are

compared qualitative with those using the traditional wake method and available experimental data; indicating that using the vortex particle method gives similar or better results. Additionally, computational efficiency is improved by using the vortex particle method and time savings exist in every simulation.

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The potential of technologies to mitigate helicopter accident factors – status update and way forward

Jos Stevens (NLR)
Joost Vreeken (NLR)

Technology is not high on the list of most important accident / incident factors, as it is merely the lack of technology that may have led to an accident. However, technology provides a variety of solutions that can (directly or indirectly) address the identified safety issues and contribute to prevent various types of accidents or to increase survivability. In mid-2014 the Specialist Team (ST) Technology, under the aegis of the European Helicopter Safety Team (EHEST) concluded that 15 'highly promising' technologies jointly could potentially mitigate 11 of the top 20 helicopter safety issues, that five technologies were highly promising for three or more safety issues, and that there were three safety issues for which no potential promising technology have been identified. The current European Plan for Aviation Safety (EPAS) 2018-2022 includes an action to 'promote technologies that will provide helicopter safety benefits', which action is attributed to the European Safety Promotion Network Rotorcraft (ESPN-R) as successor of the EHEST initiative. In light of this action the questions arose what is the current status of those 'highly promising' technologies, how can this EPAS action be targeting the right technologies, and what could be a viable way forward. This paper presents an update regarding the status of the 15 identified 'highly promising' helicopter technologies. All of these have progressed towards a higher Technology Readiness Level (TRL) with various solutions being available on the market and being employed. Some additional safety enhancing technologies have been identified that in recent years either have been developed or became available on the market. Furthermore the paper lays the foundation for the aforementioned EPAS action by distilling safety concerns for the period 2012-2016 from the EASA Annual Safety Report 2017. For various types of operation the key risk areas have been identified, which then have been translated into technical and/or operational and/or human factors safety issues. Technological developments can help mitigate those safety issues. Finally it recommends the way forward for the EPAS action. This is not only based on the lessons learned from the former ST Technology, but also on other initiatives that have come to light. Various helicopter industry-wide (trade) organisations have developed programmes, including technical solutions, guidance material and training. And EASA concentrates on rulemaking tasks, research projects and safety promotion. It is recommended to:

- Assess whether specific technologies that are being used in Offshore operations can equally be adopted in other Commercial Air Transport and/or Specialised Operations;
- Identify for which technical, operational and human factors related safety issues the application of technologies might be useful;
- Explore the possibilities to develop a proactive approach to enable an early focus on safety benefiting technologies for future safety concerns through assessing the potential type of accident and contributing factors, not only for current but also for future operations, and the development of an associated and periodically updated roadmap.

It is the intention that these recommendations will be addressed by a new ST Technology.

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Complementary use of black-box and physics-based techniques in rotorcraft system identification

Susanne Seher-Weiß (DLR)
Johannes Wartmann (DLR)

Accurate linear helicopter models are needed for control system development and simulation and can be determined by system identification when appropriate test data are available. Standard methods for rotorcraft system identification are the frequency domain maximum likelihood method and the frequency response method that are used to derive physics-based linear state-space models. But also the optimized predictor-based subspace identification method (PBSIDopt), a time domain system identification method that yields linear black-box state-space models, has been successfully applied to rotorcraft data. As both methods have their respective strengths and weaknesses, it was tried to combine both techniques. The paper demonstrates the successful complementary use of physics-based frequency domain methods and the black-box PBSIDopt method in the areas of database requirements, accuracy metrics, and model structure development using flight test data of DLR's ACT/FHS research rotorcraft.

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Development of improved rotor blade tip shape using multidisciplinary design analysis and optimization

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Tip shape optimization of rotor blade is performed to improve hover performance and to reduce required power and forward flight noise by using multidisciplinary design analysis and optimization framework with ModelCenter. The blade tip above radius of 93.5% is optimized from the Light Civil Helicopter being developed in Korea. The single sweep tip is slightly good at hover performance and forward flight noise. The single sweep tip is superior to approach noise and dynamic load of pitch link in particular. It is inferred that the single sweep tip is the optimal solution. The optimal design is analyzed in noise condition using CSD/CFD coupling method to validate results from MDAO process. The single sweep tip shape has lower noise level than baseline.

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Improved Mars Helicopter aerodynamic rotor model for comprehensive analyses

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The Mars Helicopter is part of the NASA Mars 2020 rover mission scheduled to launch in July of 2020. Its goal is to demonstrate the viability and potential of heavier-than-air vehicles in the Martian atmosphere. Ultimately, it aims to bridge the resolution gap between orbiters and the rover as well as allow access to otherwise inaccessible regions. The low density of the Martian atmosphere and the relatively small-scale rotor result in very low Reynolds number flows. The low density and low Reynolds numbers reduce the lifting force and lifting efficiency, respectively. This paper describes the generation of the improved Mars Helicopter aerodynamic rotor model. The goal is to generate a performance model for the Mars Helicopter rotor using a free wake analysis, since this has a low computational cost for design. The improvements in the analysis are two-fold and are expanded on from two prior publications. First, the fidelity of the simulations is increased by performing higher-order two-dimensional time-accurate OVERFLOW simulations allowing for higher accuracy aerodynamic coefficients and a better understanding of the boundary layer behavior as well as its transient features. Second, a version of the model is generated to duplicate the exact testing conditions in the 25–ft. diameter Space Simulator at the Jet Propulsion Laboratory, which allows for better correlation of rotor performance figures. Previous work correlated performance with that test, but did not consider the higher temperatures in the experiment compared to those of the Martian atmosphere. The higher temperatures in the experiment are expected to give conservative performance estimates, as they give rise to an increase in speed of sound and decrease in observed Reynolds numbers.

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Identification and selection of rotorcraft candidate models to predict handling qualities and dynamic stability

Johannes Wartmann (DLR)
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Current frequency-domain system identi1cation methods require an open-loop experiment design for data collection to identify one model of a vehicle. This makes open-loop system identi1cation for unstable systems like rotorcrafts challenging. The optimized Predictor-Based Subspace Identi1cation method also estimates accurate models from closed-loop data. In this paper, a parameter study is conducted to identify a set of bare airframe models of the ACT/FHS research rotorcraft using this subspace method. A selection method is introduced to chose appropriate candidate models from the identi1ed set. The selected candidate models differ slightly in terms of the model invariants and are all a valid approximation of the rotorcraft dynamics. Consequently, the selected candidate models can be used to predict the possible properties of the system and their uncertainties. Here, the candidate models are employed to estimate the dynamic stability and handling qualities of the ACT/FHS bare airframe and two control system of the ACT/FHS research rotorcraft.

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HOPLITE - A conceptual design environment for helicopters incorporating morphing rotor technology

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The SABRE project has been initiated under the EU's Horizon 2020 programme for development of blade morphing technologies for helicopter rotors. The project targets reductions in fuel burn and NOx emissions of up to 5-10% through the use of morphing rotor blades. A new design tool for rotorcraft, HOPLITE, is being developed to investigate the effects of rotor morphing on engine emissions and fuel burn. HOPLITE uses low-fidelity models for quick and reasonably accurate force and

power calculations for major components of the vehicle. The main rotor is modelled using the Blade Element Method, and accounts for changes in blade shape due to rotor morphing and other geometrical modifications. Additionally, a robust fuselage parameterization method, and an equation based engine model have been incorporated in HOPLITE to include the impact of rotor morphing on the design of the helicopter as a whole. The main argument behind the development of HOPLITE is to combine various low-fidelity methods, such that quick design assessments can be performed for various purposes, and, simultaneously, have sufficient fidelity to capture changes in blade shape due to rotor morphing. Actuator disk models can perform a quick analysis, but are unable to match the required level of fidelity. In comparison, traditional CFD simulations or experimental campaigns will be cost and time intensive. Hence, there is a need for a new tool. Due to a multidisciplinary and modular approach used by HOPLITE, it can be used for a wide range of tasks, such as design space exploration and optimization. Furthermore, it can be used in conjunction with high fidelity methods. This paper describes the current work done towards the development of various modules of the tool, theoretical aspects of engine, fuselage and rotor modelling, and initial results obtained during development and testing of individual modules. Theoretical aspects of conceptual design capabilities of the tool have also been briefly described in this paper. Future work will involve development and integration of conceptual design functions in HOPLITE for conventional helicopters, and expansion of these algorithms to non-conventional rotorcraft designs.

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Flight testing and analysis of helicopter gas turbine engine performance – a multivariable approach

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Helicopter performance flight-testing is an expensive activity that requires efficient testing techniques and appropriate data analysis for good performance prediction. Regarding the flight testing techniques used to evaluate the available power of a Turboshaft engine, current methodologies involve a simplistic single-variable polynomials analysis of the flight test data. This simplistic approach often results in unrealistic predictions. This paper proposes a novel method for analyzing flight-test data of a helicopter gas turbine engine. The so-called 'Multivariable Polynomial Optimization under Constraints' (MPOC) method is proven capable of providing an improved estimation of the engine maximum available power. The MPOC method relies on maximization of a multivariable polynomial subjected to both equalities and inequalities constraints. The Karush-Khun-Tucker (KKT) optimization technique is used with the engine operating limitations serving as inequalities constraints. The proposed MPOC method is implemented to a set of flight-test data of a Rolls Royce/Allison MTU250-C20 gas turbine, installed on a MBB BO-105M helicopter. It is shown that the MPOC method can realistically predict the engine output power under a wider range of atmospheric conditions and that the standard deviation of the output power estimation error is reduced from 13hp in the single-variable method to only 4.3hp using the MPOC method (over 300% improvement).

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Experimental studies of non-stationary aerodynamic characteristics of a helicopter airfoil oscillating in the pitch

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The article presents the results of experimental studies of non-stationary integral and distributed aerodynamic characteristics one of the helicopter airfoil in stationary and non-stationary modes. The stationary mode is a fixed airfoil in a uniform steady airflow. The non-stationary mode is an airfoil oscillating in the pitch in a uniform steady airflow. The investigations were carried out in the vertical, closed-circuit TsAGI wind tunnel with an open test section. The tests were carried out at Reynolds numbers Re = 270,000 and 540,000; at reduced frequencies from 0.06 to 0.26. A particular feature of the research was the use of two methods for determining aerodynamic characteristics, namely: a direct method of measuring forces using balance and calculating forces by integrating the pressure distribution along the chord. The obtained results are compared with each other, their satisfactory agreement in the stationary mode is shown. Another feature of the research was the analysis of pulsations of forces and pressures on the airfoil surface. In particular, using the wavelet analysis, a phenomenon called "frequency explosion", specific of dynamic stall of the flow, is demonstrated.

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Numerical investigations of the aerodynamics and handling qualities of a helicopter flying across a wind turbine wake

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The present paper illustrates the outcomes of a research activity carried out by CIRA and the Delft University of Technology in the framework of the GARTEUR HC/AG-23 action group. This activity has been aimed at investigating, from the aerodynamic and handling qualities point of view, the problem of a Bo105 helicopter rotor crossing, in low-speed level flight, the wake of an NREL 5MW wind turbine (WT), in the presence of atmospheric boundary layer (ABL). A crossing flight path orthogonal to the WT axis, and located two WT rotor diameters downstream to the WT disk, has been selected. Three different flight altitudes, with respect to the WT hub, and two flight directions, L2R and R2L, have been investigated. The aerodynamic simulations have been carried out by using a BEM methodology and by applying a decoupled interactional procedure specifically conceived for the purpose. The rotor blades have been assumed fully rigid. The simulations have shown that the encounter of a uniform side wind or a WT wake with a helicopter rotor, locally alters the velocities acting on the helicopter rotor blades, in magnitude and/or direction, because of the WT axial and radial changes in velocity deficit; the presence of the WT blade tip vortices; the

presence of the ABL; the WT wake swirl. These velocities modify the helicopter rotor blade sectional effective angles of attack, which, in turn, change the blade loads, generate flapping angles and alter the rotor forces and moments. Compared to the flight inside a uniform side wind, the crossing of a WT wake produces important rotor rolling and pitching moments, the thrust increases while the torque decreases. The flight altitude has only moderate effects. Regarding the handling qualities, the paper has considered the ADS-33 pitch and roll attitude quickness parameters and has shown that when the WT wake approaches the helicopter from left to right (L2R) this results in an increase in the quickness that pilot needs to command. The analysis of the results has concluded that, for a WT rotor and helicopter rotor both counter-clockwise rotating, a pilot experiences a greater workload during the L2R crossing of the WT wake, but also that this situation is transient in nature and the pilot needs to command it only momentarily.

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Low order multidisciplinary optimisation of counter-rotating open rotors

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A recent renewed interest in CROR propulsion demands the need for suitable design and analysis tools. As an unconventional propulsion system, a multidisciplinary analysis should be made at the preliminary design stage in order to fully evaluate a designs suitability across a number of domains. To address this, this contribution presents a number of low order models ideally suited for the preliminary design stage. Low order models for the evaluation of aerodynamic, acoustic and structural performance are presented. Following this, a multi-objective optimisation is carried out. Suitable objective functions are presented to evaluate the performance over a number of flight phases. Using these, a number of designs are presented for take-off only, cruise only, and combined take-off and cruise. These designs are shown to be of greater performance with respect to a baseline design. The work presented highlights the potential of the low order models and optimisation routine as a preliminary design and analysis tool for CROR propulsion.

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Low-order aeromechanics of tilt-rotor helicopters

Wesley Appleton (University of Manchester)

The conversion corridor represents the safe region of flight for tilt-rotor aircraft during the transition between helicopter and aeroplane mode. A low-order rotary-wing model has been established and validated throughout the conversion corridor, showing good agreement with experimental data. Furthermore, the equations of motion for longitudinal flight have been derived and solved to determine the conversion corridor boundaries with the results correlating well with published data. The largest discrepancy was observed at the lower boundary which indicated a downwash model of the rotor wake over the wing was required. Additionally, from a trimmed flight perspective, it was found the tilt-rotor aircraft had transitioned from helicopter to aeroplane mode by the approximate shaft angle $\gamma = 60°$.

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Aerodynamics of single and multiple rotors hovering inside a square tunnel

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Flight performances of hovering single and multiple rotors inside tunnels are studied. Following the wide spread of applications of the multiple rotor type drones, possible observation and search inside tunnels are under investigations. With constraints of the surrounding walls in a narrow tunnel, there is concern that the downwash caused by the hovering rotors may circulate around the aircraft and the flight performance may be severely deteriorated. In this numerical simulation study, a single rotor and a hexa-rotor UAV are placed inside straight square tunnels with various width. It is found that when the gap between the rotor tip and the wall is less than two diameters of the rotor, the hover performance is severely degraded.

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Vibration reduction analyses using individual blade pitch controls for lift-offset rotors

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Do-Hyung Kim (KARI); Sanghyun Chae (KARI); Ye-Lin Lee (Chungnam National University); Jeong-In Go (ADD)

This work attempts to reduce the hub vibratory loads of a lift-offset rotor using IBC (Individual Blade pitch Control) in high-speed forward flight. As a lift-offset rotor for the present study, the rigid coaxial rotor of XH-59A compound helicopter is considered, and CAMRAD II is used to predict the hub vibration and rotor performance. Using the IBC with a single harmonic input at 200 knots, the vibration index of the XH-59A rotor is minimized by about 62% when the 3/rev actuation frequency is applied with the IBC amplitude of 1° and control phase angle of 270° (3P/2°/270°); however, the rotor effective lift-to-drag ratio is reduced by 3.43%. When the 2/rev actuation frequency with the amplitude of 2° and control phase angle of 270° (2P/2°/270°) and the 3/rev actuation frequency using the magnitude of 1° and control phase angle of 210° (3P/1°/210°) are used in combination for the IBC with multiple harmonic inputs, the vibration index is reduced by about 62%, while the rotor effective lift-to-drag ratio increases by 0.37% at a flight speed of 200 knots. This study shows that the hub vibration of the lift-offset rotor in high-speed flight can be reduced significantly but the rotor performance increases slightly, using the IBC with multiple harmonic inputs.

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Development of integrated avionics functions for external situation awareness in civil helicopter missions

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Providing a consistent perception about the external situation to the helicopter flight crew can greatly enhance awareness, simplify mission and contribute to a safer operating environment. This paper focuses on the HELIONIX® external situation awareness functions including SVS, HTAWS, DMAP integrated in the HELIONIX® avionics suite of Airbus light and medium helicopter platforms. First, a background of CFIT incidents that motivated the development of the external awareness functions is presented. The context of civil helicopter mission is then described to identify the needs regarding external awareness under different operations. Thereafter the main capabilities of the SVS, HTAWS and DMAP functions along with their HMI concept are explained. Finally, some aspects about a standardised common development and certification approach are highlighted. Due to the awareness functions being fully embedded in the cockpit multi-function displays, a coherent and consistent HMI concept as well as cost, weight and space savings are achieved while answering the needs of civilian helicopter missions.

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Twist morphing of a hingeless rotor blade using a moving mass

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This paper presents a new concept of morphing by changing the twist of a composite blade through the movement of a mass near the tip of the blade. The mass is moved in the chordwise direction which then modifies the centrifugal force near the tip of the blade. The blade is tailored with composite materials and hence coupling is introduced. By moving the mass in the chordwise direction, a variable bending moment is produced which is the result of the offset between the point mass centrifugal force and the shear centre of the blade section. This bending moment will be transferred to the composite spar, and then through the bend-twist coupling of the composite layup, a variable torsional moment will be induced. This variable torsional moment changes the twist distribution of the blade. The dynamics of the rotating composite blade is modelled by using the geometrically exact fully intrinsic beam equations and the point mass is considered as a non-structural concentrated mass which has offsets with respect to the beam reference line. It is found that by moving the mass in the chordwise direction, the twist distribution of the blade changes. The rate of twist change completely depends on the bend-twist coupling and also the point mass magnitude and location. Finally, the effect of sensitive morphing parameters on the rotating frequencies of the Bo105 main rotor blade is determined.

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Eigenmode distortion as a novel criterion for motion cueing fidelity in rotorcraft flight simulation

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Eigenmode distortion (EMD) is a novel methodology developed to study the degradation of perceived vehicle dynamics as a result of motion cueing algorithms (MCA's) applied in rotorcraft flight simulators. This paper briefly introduces EMD and subsequently describes its application in a pilot-in-the-loop experiment conducted on the SIMONA Research Simulator at Delft University of Technology. The experiment considers a precision hover task performed by two test pilots in three different motion cueing conditions. Each of the evaluated conditions is devised such to best reproduce one of the vehicle modes (pitch/heave subsidences and phugoid) simulated using an independently developed, three degree-of-freedom, longitudinal, nonlinear model of the AH-64 Apache helicopter. The experiment yielded a number of interesting results. For example, the mode participation factors (MPFs) computed using recorded model states showed that the unstable phugoid mode dominates the overall dynamic response in all conditions evaluated. Also, based on the relative distribution of MPF's across the three motion conditions, some indication of a change in pilot control behaviour as a result of motion cues (or lack thereof) was exposed. Finally, subjective pilot ratings suggest that the motion cueing condition optimized for the pitch subsidence mode is preferred, even though this is not the dominant mode in the vehicle's response. The condition corresponding to the heave subsidence mode (i.e., only vertical motion cues) is appreciated least.

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Towards a European helicopter noise calculation method

Marthijn Tuinstra (NLR)
Jos Stevens (NLR); Nico van Oosten (Anotec Engineering); Herold Olsen (SINTEF)

Helicopter noise is strongly dependent on flight conditions, exhibiting in addition a pronounced directivity, complicating noise modelling. In land-use planning, the current best practice stems from fixed-wing aircraft and follows a Noise Power Distance approach that is unsuitable to include these features. The European Commission commissioned the development a novel helicopter noise model to be eventually part of a public "European Environmental Model Suite for Aviation". The model embodies a helicopter noise calculation method based on the current state-of-the-art. A clustering strategy has been used to represent the European helicopter fleet, thus avoiding the need for performing noise measurements on all types of helicopters. The method uses an empirical source model, with noise hemispheres to faithfully describe the noise directivity pattern. Emission characteristics of a helicopter type are described by a set of hemispheres measured for a range of conditions within the flight envelope. Atmospheric propagation effects are accounted for to evaluate the noise hindrance experienced on-ground. The latter is based on established public models for atmospheric propagation, ground reflection and surface impedance.

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Rotor airfoil aerodynamic design method and test verification

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Good airfoil design is a prerequisite for high performance rotor design. In order to establish the rotor airfoil design method and verify the wind tunnel data, this paper developed an efficient multi-objective and multi-constraint optimization design system for rotor airfoils, which is based on high-precision CFD analysis. And using OA309 as the baseline rotor airfoil, the CRA09 optimized rotor airfoil was designed successfully. Combined with the foundation of high-precision rotor airfoil stationary test technology, the CRA09 and OA309 rotor airfoils were tested in the S3MA high speed wind-tunnel of ONERA and the FL-21 high speed wind-tunnel of CARDC. Results indicate that, multi-objective and multi-constraint optimization design method developed in this study is reliable; CRA09 optimized airfoil provides better stationary performance than OA309 airfoil, in terms of maximum lift coefficient and lift over drag ratio.

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Evaluation of a slung load control system for piloted cargo operations

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Helicopter operations with externally slung blades are highly demanding for the flight crew. Without having a direct view on the load, the pilot requires assistance from an additional crew member for load handling to achieve operational requirements (e.g. precise load positioning). An automatic load stabilization and positioning systems for cargo operations has been designed with the aim to reduce pilot workload, damp load pendulum motion and to improve the load positioning performance. This system uses the concept of load-motion feedback to the rotor control. To avoid degradation of Handling Qualities (HQs), as found in previous investigations, a function has been developed that monitors pilot control inputs. Dependent on the amplitude and duration of pilot control stick deflection, the feedback signal for slung load damping is blended between two different gain sets. One set provides improved HQs during piloted control and one set provides good load damping when the pilot is passive. A further novel aspect is the evaluation of an automatic load control system using a Translational Rate Command as method of helicopter control. A piloted simulation study has been conducted using this advanced load control system with automatic load stabilization and positioning. Three test pilots evaluated the system in different control law configurations using a Mission Task Element simulating an external load cargo operation. HQs and pilot workload were evaluated using the Cooper-Harper Rating Scale and NASA Task Load Index respectively. The results of the study show that improved HQs in combination with improved task performance can be achieved with the advanced slung load control system.

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The development of a European helicopter noise model

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No international consensus yet exists on a method for helicopter noise contour calculation for land-use planning. An intermediate approach is recommended in the Environmental Noise Directive (END) to model helicopters in a similar manner as fixed-wing aircraft. This method however, lacks the capability to capture the complex nature of helicopter noise adequately. The European Commission commissioned the development a helicopter noise model to be part of a public European environmental model suite for aviation. A helicopter noise calculation method was defined based on the current state-of-the-art, which was subsequently implemented in a software prototype (NORAH). Through dedicated flight test campaigns noise hemispheres were established for eight helicopter types, covering the noise relevant regions of the flight envelope. Based on these noise databases the noise emission of 70% of the helicopters flying in Europe can be represented in the NORAH model.

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The Tilt-Quadrotor: modelling and attitude stabilization

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This paper presents the study on a new type of aircraft, the Tilt-Quadrotor. This multirotor platform differs from classical quadrotors by having four servo motors that tilt two of its four rotors, in two different directions each, allowing the horizontal motion to be executed without tilting the platform. The derived Tilt-Quadrotor model is explained and implemented in a simulator. LQR controllers are designed for attitude and altitude stabilization, and validated in simulation. An approach based on the linearized model is implemented experimentally in a PixHawk autopilot, achieving the stabilization of all three attitude angles of a Tilt-Quadrotor prototype.

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Extensive analysis of hardover and trim-runaway failures on TLUH mathematical model based on CS-29 requirements

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Flight control systems improve the handling qualities of helicopters based on their allowable control authority. However, in limited authority helicopters the control systems do not have high number of redundancy. Therefore, in the event of a flight control system failure a pilot must safely recover from the failure scenario. In such a case, the pilot should have enough time to react and recover back to the original flight condition. During the certifications process of a helicopter, failure scenarios should be demonstrated with piloted simulations and flight tests. Piloted tests consume too much time to analyze all the flight conditions that include control system failure. Therefore, desktop based simulation analyses can be conducted to determine the worst case regime and to obtain a statistical database related to control system failures. In this paper failure and actuator module that has been implemented is presented. Using implemented modules with an in-house development tool, actuator failure cases on TLUH based on Certification Specifications for Large Rotorcraft and Advisory Circular (CS/AC-29) are conducted. Results of the analyses are given in the final section. Results obtained from the piloted simulations conducted in system integration laboratory are compared with the results obtained from desktop based simulations.

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Dynamic simulation of a rotorcraft hybrid engine in Simcenter Amesim

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This paper assesses a series hybrid propulsion system utilizing a recuperated gas turbine configuration. An adapted engine model capable to reproduce a turboshaft engine steady state and transient operation is built and used as a baseline for a recuperated engine. The recuperated engine presents a specific fuel consumption improvement of more than 15% at maximum continuous rating at the expense of surge margin which is reduced. An Oil and Gas (OAG) mission of a Twin Engine Medium helicopter has been used for assessing the hybrid configuration. The thermo-electric system brings a certain level of flexibility allowing for the recuperated engine to operate for high take-off weight cases. If envisioned 2025 technology is considered the fuel benefit of the series hybrid recuperated configuration for the OAG mission is in the range of 5%. The integrated system models (gas turbine, electric and heat exchanger systems) are built in Simcenter Amesim, a system modelling platform allowing for both steady state and dynamic simulation.

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Investigation on loss of Tail-Rotor Effectiveness of helicopter with ducted fan tail rotor

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The loss of tail rotor effectiveness (LTE) means steep loss of yawing stability in particular flight condition due to the reduction of tail rotor performance. In this study, numerical analysis is conducted to investigate the LTE characteristics of the ducted fan tail rotor. The complete helicopter configuration (main rotor, ducted fan tail rotor, fuselage, and empennage) is simulated to obtain the mechanism of wake interaction for a range of whole crosswind angle, from 0° to 360°. It is confirmed that both the main rotor wake and port wing wake are immersed within tail rotor disk by the suction force of tail rotor. The main rotor wake rotates in the opposite direction to the tail rotor, and it contributes to the improvement of thrust. The port wing wake works oppositely. As the flow entered from the front side, both magnitude and vibration of thrust are increased due to the broad influence of the main rotor wake. Nevertheless, direct impingement of wakes is prohibited by the structures of tail rotor system, and also substantial wake of tail rotor prevents re-entering of tip vortex. Consequently, the ducted fan tail rotor maintains acceptable thrust variation in comparison with the open type tail rotor.

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Helicopter engine air intake icing wind tunnel certification test

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Korea Aerospace Industries LTD (KAI) contracted the Netherlands Aerospace Centre (NLR) to support an Icing Wind Tunnel (IWT) test campaign with the Korean Utility Helicopter KUH-1 engine air intakes aimed at substantiating the compliance with the applicable military regulations for flight in icing conditions. The icing wind tunnel test was performed in the Large Climatic Wind Tunnel (CWT) at Rail Tec Arsenal (RTA) in Vienna, Austria. The test set-up included a full-scale production engine cowling complete with electrothermal anti-icing system and it was installed on a mock-up of the aircraft upper fuselage. The production cowling was used to ensure an exact match and conformity of the thermal properties of the part. To aspirate the engine intakes, NLR designed a dedicated Engine Mass Flow System (EMFS) that simulates the airflow through the engine air and cooling intakes. Two separate industrial radial fans were installed to individually control the mass flow through the engine air intakes and cooling inlets. A continuous mass flow measurement was provided for both channels by anti-iced Pitot-static probes that were calibrated against orifice plate measurements performed prior to the icing test. The tunnel test conditions were scaled for altitude effects by matching key similarity parameters. The test airspeed was based on either Reynolds number scaling or Weber number scaling, depending primarily on the static air temperature. Inter-laminate and surface temperature measurements and observed ice shapes compared favourably with artificial and natural icing flight test results obtained with the same intake configuration. The IWT testing supplemented the flight test results by providing more stable icing conditions with control over drop size, and covering the corner points of the icing envelope.

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Probabilistic approach and inertial tolerancing for H/C ramp-up in production

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The functional Geometrical Tolerance Management is a top-down approach leading to systems specification at each level of the Aircraft assembly, and following the 3 main phases of the Helicopter lifecycle: Design phase, Development phase and Serial life. During Serial life, we shall provide optimized methods and tools matching with quality and production objectives (OTD, OQM, ramp-up) and viewing results format. Since the tolerances are represented by a network, we have defined a format for injecting the results at a given level as input data to the next level. Due to the nature and interconnections of this network, the volume of data to be processed can be significant. So we have implemented an appropriate numerical technique to deal with a continuous influx of measurement data. The objective is to purpose a comprehensible representation of the re-evaluated risks at each stage of the process, i.e.: Initial risks related to the current helicopter definition, Re-evaluated risks related to an aircraft serial number completed with each new measurement of characteristics for this aircraft, Re-evaluated risks related to the observed variability of the product / process at assembly level. Our new industrial model leads to change our approach from a curative model to another model applied to QN process with root cause identification and manufacturing process monitoring allowing deploying preventive and corrective action plan. Behind that our objective is to avoid recurring QN and to switch to a Risk management model by several lever deployments. When a functional geometrical target is too much tight, its cascade of tolerances is at the feasibility limit of production. In this case, Geometrical Tolerancing method loses its benefits. The aim of this paper focus on our process deployment based on the last A/C development in Airbus Heli-copters, presenting the first results, the advantages and drawback for Industrialization & serial phase based on the antitorque brackets integration. The antitorque bracket is the master element of the junction between Main Gear Box and fuselage. The antitorque bracket has tight tolerances due to the stress way and its functional geometrical tolerance cascade. Its manufacture is at the limit of production means. The production of antitorque bracket generates many QN. Each part is going to generate recurring cost and added time of production. To solve this problem, we have chosen to understand what phenomena are in cause and manage non-quality risk with the application of inertial Tolerancing approach. In function of the level of nonconformity calculated, an action plan is defined.

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Design space analysis of an autonomous aerial crane VTOL concept with a detachable airship envelope

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This paper will argue the concept of a logistics autonomous aerial crane type VTOL aircraft capable of being able to optionally attach an airship envelope so that it will contribute to the reduction of the total weight of the aircraft and requires less energy consumption for flight. In order to overcome the disadvantages or airships those are; first the difficulty of operation in gusty condition, and second its massive size of envelope when to rely fully the weight to be afloat solely by the floating gas, this concept is to attach a medium size flotation envelope to save the energy required for the craft to be airborne which will be only used when the weather is mild, and make the powertrain flyable either with or without the airship component. In order to pursuit the reality of this idea, this study will focus on three major issues: the design on the lifting and propulsion system, method to keep the shape of the envelope in health regardless of traveling in speed or under side winds while on ground, and discussion on the weather condition to become the boundary of the usability of the auxiliary airship.

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Estimation of handling quality parameters of a rotorcraft using open-loop linearized and nonlinear flight dynamic models

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Flight dynamic analysis and estimation of handling quality parameters have become important aspects in the design and development of helicopters. This paper presents a detailed analysis of the procedure for estimating the handling quality parameters such as quickness parameter, bandwidth and phase delay. The flight dynamic model used in this study considers rigid flap model for blade structural dynamics, three states dynamic inflow for inflow calculation and modified ONERA dynamic stall model for sectional aerodynamic loads calculation. The applicability of open loop linearized (uncoupled, and coupled) and nonlinear flight dynamic models in estimating the handling quality parameters is studied. For linearized models, only pulse input is used, whereas in the nonlinear model, two different types of input, namely pulse and step inputs, are used to estimate the attitude quickness parameters. The bandwidth and phase delay are calculated from the frequency responses of helicopter attitude in pitch and roll axes, which are obtained from the time response of nonlinear flight dynamic model for the harmonic excitation of cyclic pitch input. The results show that the attitude quickness parameter depends on the duration of input pulse and the nonlinear open system provides attitude quickness parameter which is different from that of the linearised system. In addition, it is noted that linearized flight dynamic models (8x8) cannot be used for bandwidthphase delay calculations, due to their lower order nature.

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Universal geometric transformation method PGT for aircraft design

Alexander Nikolsky (Central Aerohydrodynamic Institute)

The original technique for CAD/ CAE applications of generating aerodynamic shapes is developed. The universal geometric 'parent function/generating functions' transformation method, PGT, is proposed which creates the compact design space covering the entire class of wireframe contours for the design of basic aircraft elements. The wireframe concept is commonly used for surface generation of basic elements of aircraft, such as wing, blade, control surfaces and fuselage. From the one hand it is important to parameterize a wireframe with a reasonable accuracy for CAD applications; from another hand it is important to establish a minimal parameters amount for reaching the accuracy sufficient for CAE design applications. The known techniques of parameterization [1- 7] are based on limited class of functions and not suitable for an arbitrary geometry representation. So it is important to find a universal mathematical formulation to cover the entire set of possible wireframe shapes. Further the basic principles of a new approach are outlined.

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Aerodynamic and flight mechanics analysis of airbus helicopters' compound helicopter racer in hover under crosswind conditions

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Constantin Öhrle; Felix Frey; Manuel Keßler; Ewald Krämer (University of Stuttgart)

In recent years, various helicopter manufacturers increasingly have been focusing on the development of new high-speed rotorcraft configurations, one of them being the compound helicopter RACER of Airbus Helicopters (AH). However, these new configurations encounter new aeromechanic challenges, in terms of aerodynamic interactions, flight mechanics stability, rotor dynamics or aeroacoustic noise emission, to name only a few. In the scope of this work, the behaviour of RACER in hover under the influence of crosswinds from eight different directions is investigated in order to support AH at the de-risking of RACER for this flight condition prior to first flight. Therefore, a multidisciplinary, high-fidelity tool chain for coupled and trimmed aerodynamic simulations of the complete rotorcraft is applied. The presentation of the results is organized in three parts. In the first part, the flight mechanic behaviour is analysed and successful de-risking of ground clearance is shown. The second part focuses on the performance of the main rotor, the lateral rotors and the tail surfaces under wind influence and shows that minimal power is required for headwind. In the last part, an analysis of the engines is performed, with a closer look at the inflow quality to the core engine and the convection of the hot exhaust gases.

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Development and validation of physics based models for ice shedding

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Calculations for ice accretion and shedding are presented for a model scale rotor in hover. The aerodynamic characteristics of the rotor are first computed using a combined blade element-momentum theory. The effective angles of attack, and the local flow velocity are used within the NASA Glenn solver LEWICE to estimate the collection efficiency. The computed collection efficiency and the surface pressure distribution from a panel method within LEWICE are used to estimate the ice accretion over the rotor blades for a selected time interval. Finally, a force balance approach is used to establish shedding events where the centrifugal force over the ice mass exceeds the adhesive forces at the rotor surface and the cohesive forces between adjacent masses of ice. Preliminary comparisons with test data acquired at the Pennsylvania State Icing Research Tunnel are presented. Sensitivity of the ice shedding events to surface roughness, adhesive strength, cohesive strength, and ambient conditions is discussed.

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Load limiting control design for rotating blade root pitch link load using higher harmonic LTI models

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This paper discusses the synthesis of a load limiting controller (LLC) for critical helicopter components that are subjected to significant fatigue loading. The development of a (structural) load limit violation detection and limit protection algorithm using a linear time invariant (LTI) model of helicopter coupled body/rotor/inflow dynamics is described. The developed load limiting controller is evaluated in its ability to limit harmonic pitch link loads and its impact on maneuver performance for a typical longitudinal doublet input.

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Simulation of active flow control actuator using CFD with application to rotor blade vibration reduction

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A computational fluid dynamics (CFD) model is developed to determine the unsteady aerodynamic effects of active flow control implemented by combustion-powered actuation (COMPACT) on a two-dimensional airfoil. Previous work with COMPACT actuators employed pulsed-jet actuation at moderate to high angles of attack to control flow separation and dynamic stall. However, the focus of the present study is to implement actuation in the moderate to low angle of attack range suitable for helicopter rotor vibration control. At low angles of attack, the effect of actuation on the sectional aerodynamic forces of the airfoil diminishes. Therefore, modifications to the COMPACT actuator configuration are considered to enhance the actuation authority for the relevant operating range. Modifications include placing a ramp on the airfoil upstream of the actuator and relocating the actuator near the airfoil trailing edge. These are considered using both CFD simulations and wind tunnel experiments, which are compared to validate the CFD model. Finally, a surrogate-based reduced-order modeling technique is described to address the high computational cost of the CFD simulations. The reduced-order model is used to accurately reproduce full-order CFD results for the unsteady changes in lift, moment, and drag due pulsed actuation on a static airfoil. Furthermore, the results show that the reduced-order model represents a feasible method for representing the unsteady aerodynamic effects of COMPACT actuation. This will be refined in future work and implemented in a comprehensive aeroelastic code for helicopter rotor vibration reduction.

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Correlation of finite state multi-rotor dynamic inflow models with a high fidelity viscous vortex particle method

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Finite state inflow models have been developed from potential flow theory to predict inflow distributions for single rotor configurations. Superposition of velocity or pressure potentials associated with individual rotors has been proposed for arriving at inflow models for multi-rotor configurations. In this study, fidelity assessment of finite state inflow models arrived at using pressure and velocity potential superposition methods for two tandem rotor configurations is considered. Physical wake effects, such as wake contraction and viscous wake dissipation, that are not inherently included in potential flow theory are added to both Pressure Potential Superposition Inflow Model (PPSIM) and Velocity Potential Superposition Inflow Model (VPSIM). In addition, new mass flow parameter formulation for VPSIM is proposed to match with one used in PPSIM. Using this formulation, it is shown that PPSIM and VPSIM have similar steady-state inflow distributions. For model fidelity assessment, the developed finite state inflow models are compared against a high fidelity numerical model known as Viscous Vortex Particle Method (VVPM). Differences in rotors uniform, fore-to-aft and side-to-side inflow components between the models are quantitatively analysed in hover and forward flight. Contour plots of inflow distributions are also provided for qualitative comparison. In addition, effects of inflow distribution and interference velocities on flapping angle predictions are discussed.

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Design of a generic rotor noise source for helicopter fuselage scattering tests

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Alex Zanotti, Giuseppe Gibertini, Luigi Vigevano (Politecnico di Milano), Karl-Stéphane Rossignol (DLR)

This paper deals with the activities conducted in the GARTEUR Action Group HC/AG-24 to address noise scattering of helicopter rotors in presence of the fuselage. The focus of the paper is on the design for a generic “tail rotor” noise source used in the fuselage scattering study. The main design criterion is that the generic rotor noise source should resemble the main characteristics of the tail rotor with clear harmonic components. A two bladed simplified tail rotor model is considered. The performance of the tail rotor model in terms of thrust and torque with respect to the advance ratio is calibrated in the POLIMI wind tunnel. Acoustic measurements of the tail rotor model were tested in the DLR Acoustic Wind tunnel Braunschweig AWB. The results of the rotor performance and the rotor acoustic characteristics are described. The spectral variations resulting from unsteadiness of the source are explored in both with and without wind. The noise characteristics such as the spectral content, sound levels at fixed distances, and the time varying nature of the sound field are discussed.

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A design-centric evaluation of multi-fidelity cost modeling approaches

Robert Scott (U.S. Army Aviation Development Directorate)

A new set of cost-estimating relationships is presented in an application-based assessment activity. The assessment conducts a multi-fidelity analysis of aircraft procurement costs on a selection of vehicles using both legacy models and the newly-development methodology. The study compares the overall accuracy of the different approaches as well as the difference in insight yielded by the respective levels of fidelity. The results of the comparison are examined qualitatively in the context of future aircraft development to infer affordability implications pertinent to contemporary design trends and performance requirements.

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Aero-acoustic analysis with a permeable surface for tip-jet rotor noise characteristics in hovering flight

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This paper presents aero-acoustics in far-field computed by an acoustic analogy code using numerical permeable surfaces for the Tip-jet 80-inch model rotor blade in hovering flight. A chimera grid method is applied to the present simulation to consider the blade motion and moving effects. The permeable surface covering the blade and jet flow is constructed to include the thickness noise, loading noise and the flow noise generated from the shock waves, tip vortices and ejected jet. The Kirchhoff approach is applied to Ffowcs Williams and Hawkings (FW-H) equations to efficient noise prediction in far-field. High speed impulsive noise due to blade tip shock waves and jet flow with large pressure gradient is predicted. Noise characteristics in far-field are investigated with jet flow parameters such as duct inlet pressure and total pressure.

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Rotorcraft Loss of Control In-Flight – The need for research to support increased fidelity in flight training devices, including analogies with upset recovery for fixed-wing aircraft

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A review of the worldwide commercial jet fleet accident data, 2001 – 2010, showed that the largest single factor leading to fatalities was Loss of Control In-Flight (LOC-I). 20 such accidents occurred during this timeframe with over 1800 fatalities [1], highlighting the need for research to investigate the causes of this problem and to develop new regulations and training programmes to improve flight safety. For civil helicopter operations, the need to significantly reduce accident rates has been the focus of the International Helicopter Safety Team (IHST), which was formed in 2005 to address factors affecting the "unacceptable" helicopter accident rate. The Team's mission was to facilitate an 80% reduction in accident rates by 2016. From 2006 to 2011, a team completed a review of 523 U.S. helicopter accidents, from which LOC-I was cited as the main factor in accidents; LOC-I was evident in 217 (41%) of the accidents [2]. Addressing LOC-I for fixed-wing aircraft, the Royal Aeronautical Society's Flight Simulation Group (FSG) 2009 Spring Conference was entitled: '*Flight Simulation: Towards the Edge of the Envelope'*, during which Upset Prevention and Recovery Training (UPRT) was highlighted as a major potential contributor to enhanced aviation safety. During the FSG conference, the International Committee for Aviation Training in Extended Envelopes (ICATEE) was formed to deliver a long-term strategy for reducing the rate of LOC-I accidents and incidents through enhanced UPRT [3]. To achieve this, ICATEE created two streams: the Training and Regulations Stream addressing the development of a UPRT training requirements matrix, and the Research and Technology Stream performing a thorough analysis of the technological requirements for UPRT. Key recommendations from the ICATEE work included better use of existing simulators for training, and aerodynamic enhancements to simulators to include stall characteristics. The impact of the ICATEE work is that their recommendations resulted in a new ICAO publication, "*Manual on Aeroplane Upset Prevention and Recovery Training*" [4]. National Authority regulations have also been impacted, with EASA UPRT requirements expected to be complete by May 2019 and the FAA requiring all Part 121 pilots to be UPRT-trained by March 2020. For the rotorcraft community, an equivalent safety initiative has recently been established. In 2016, the US Helicopter Safety Team (USHST) began the analysis of 104 fatal helicopter accidents (2009–2013) to develop intervention strategies and produce Helicopter Safety Enhancements (H-SE) that would further reduce rotorcraft accident rates. The USHST analysed accidents where LOC-I occurred during basic manoeuvres (e.g., hover, quick stop) and during unsuccessful attempted recoveries from potentially unsafe conditions (e.g., loss of tail rotor effectiveness, settling with insufficient power). Helicopter Safety Enhancement (H-SE) 81 titled, "*Improve Simulator Modeling for Outside-the-Envelope Flight Conditions*" [5] was established to "*improve the accuracy of full flight simulators (FFS)/flight training devices by providing recommendations for developing better mathematical/physics-based models for helicopter flight dynamics*". The goal is to "*achieve more realistic, higher-fidelity simulations of outside-the-envelope flight conditions*" and to examine the "*possible use of simulation for purposes of preventing, recognizing, and recovering from spatial disorientation*". Complementing the H-SE 81 initiative, a rotorcraft simulation fidelity research activity is underway at the University of Liverpool and Liverpool John Moores University [6]. The goal of this work is to establish a rational and systematic engineering approach to flight simulation fidelity enhancement, using physics-based models, linking in with goals of H-SE 81. Whilst rotorcraft operations pose different challenges to fixed-wing operations, drawing on the best practices developed by the fixed-wing safety community could benefit the rotorcraft community by reducing the time to implement new safety regulations and develop new training programmes. The presentation will provide an overview of the critical success factors of the ICATEE work, will report on the rotorcraft fidelity research ongoing in Liverpool, highlighting challenges and opportunities involved in developing simulator-based training for rotorcraft LOC-I scenarios.

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Effectiveness of a computer-based helicopter trainer for initial hover training

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Today, simulators are achieving levels of complexity and cost that are comparable to those of the aircraft they should replace. For this reason, questions have been raised, in both the technical and training communities, on the required level of simulation fidelity for effective pilot training. Computer Based Trainers (CBTs) are not currently considered in regulatory standards, because it has not been proven yet whether they can replace or complement actual flight training hours. The aim of this paper is to better understand to what extent the low-level hover skills developed on a CBT are effectively transferred to a more realistic simulation environment. To achieve this goal, a quasi-Transfer-of-Training (qToT) experiment with task-naïve participants was performed in the CyberMotion Simulator (CMS) at the Max Planck Institute for Biological Cybernetics. Twenty-four subjects, divided in two groups, were trained to perform the hover maneuver controlling an identified model of a Robinson R44 civil light helicopter. The first group (the "experimental" group) was trained in a CBT and then transferred to the realistic setting in the CMS. The second group (the "control" group) received the entire training in the CMS. At the end of the experiment, the two groups were found to show comparable performance. This suggests that, even for the training of low-level flying skills, CBTs may be a valid alternative to high fidelity simulators, if supported by a suitable training program.

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An experimental study on the hover performance characteristics of the coaxial propellers configuration for the drone

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Drone (or Passenger Drone) is one of hot issues in eVTOL industry present. So many companies such as Ehang, Airbus, Volocopter, Uber, Workhorse, etc. release their new concept taxi drone. In near future (within 2030), this taxi drone will enter commercial market and taxi service company (ex: Uber) will start to enter service only if these drones are commercialized. One of this taxi drone is required at the urban air mobility environment. This request compact sized vehicle operated between urban buildings with heavy payload which need to cover passengers. So, several candidate concept of taxi drone such as E-hang 184, Workhorse Surefly introduce the coaxial propellers design. Also, the more heavier payload with given sized vehicle drive these coaxial propellers drone described in figure1 [1] The purpose of this study is to present reliable performance data by experimental studying coaxial propellers configuration and to identify the characteristics of coaxial propellers to be used at the design, production, and verification and performance evaluation. To do this, experimental device was developed that can test at low Reynolds number($Re \approx 3 \times 105$) of coaxial propellers. The experimental device basically constructed the DAQ which can measure torque, rpm, power so that the performance characteristics of the upper and lower propellers can be known. The experiments which composed of the different H/D ratio (0.1~0.8) defined as the ratio of distance of upper / lower propellers divided by its diameter and the different propeller's diameter's ratio were conducted. Experiments were carried out on the coaxial propeller after verifying the calibration. As a result of comparing the values with F.M.(Figure of Merit), it was found that the coaxial propeller of the same diameter showed a constant FM at the H/D ratio(0.2~0.3) and the highest value of all conditions tested was achieved when the diameter of the upper part of the propeller was smaller than the diameter of the lower part confirmed.

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Qualification and certification of special patrol insertion & extraction (SPIE) equipment for military helicopters

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Special Patrol Insertion & Extraction (SPIE) is a type of military operation to rapidly insert personnel in and/or extract personnel from areas where it is not possible to land with a helicopter. The equipment used to perform SPIE operations usually must comply with specifications to ensure adequate performance. Additionally it needs to meet certain airworthiness criteria in order to be certified by the military airworthiness authority. Requirements 27.865 and 29.865 of the civil airworthiness codes provide a useful baseline regarding external loads, which can be adapted to take into account the military operation and environment. This paper discusses the development of the requirements of a qualification and certification programme for a SPIE system to be used on a helicopter. The tests to show compliance with these requirements, both at component level and at system level are discussed as well.

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Simulation of a compound-split transmission for the UH-60

P. Paschinger (Zoerkler Gears)
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Recent studies showed that the variation of the main rotor speed of the Sikorsky UH-60 (Black Hawk) offers the opportunity to reduce the propulsive power demand significantly in some flight states. A possibility to achieve this goal without changing the speed of the two turboshaft engines is the use of a Continuously Variable Transmission (CVT). One possible implementation is a so-called Compound-Split (CS), a special type of power-split transmission. The aim of this study is to present a drivetrain

architecture of this type for the UH-60 helicopter and to show the feasibility by performing simulations in the time-domain. The results show that the transmission system is able to transmit the power in all searched flight conditions and the main rotor speed is kept within narrow limits around the target values.

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Experimental research on whirl flutter of tiltrotor aircraft

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The instable phenomenon of the tiltrotor aircraft's whirl flutter is induced from the aeroelastic coupling between flapping of the rotor and bending/torsion of the flexible wing when its flight velocity exceeds the critical speed of the stability boundary. The wind tunnel test using semi-span model is an effective and convincing method to validate the accuracy of analytical methodologies and effect of active/passive control techniques to suppress whirl flutter. A semi-span model was developed and fabricated to conduct tests related to aeroelastic problems of tiltrotor aircrafts. Tests were carried out to ascertain the critical speed of this model with different configurations including rotor/wing tests and rotor/wing/fuselage tests. The stiffness of this model was adjusted to guarantee that whirl flutter would occur in wind tunnel test. Good agreement was shown in the comparison between results of the wind tunnel tests and the theoretical analysis, which indicated that the semi-span model designed in this study and the corresponding theoretical analysis method were capable for studies of whirl flutter problems.

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Experimental study of rotor and ship interference in the absence of ambient wind

YANG Jiong (CARDC)
MA Shuai, WU Jie, WANG Chang, YUE Tingrui, LIU Qinglin (CARDC)

The experimental study and numerical simulation are carried out in this paper which aims at the interaction characteristics of rotor aerodynamic performance under the influence of ship in hovering. Firstly, the position of recirculation region caused by the blocking of the deck rear edge changes obviously when the rotor closes to the deck. The thrust coefficient firstly decreases and then increases, while the pitching moment doesn't change very noticeable. Secondly, the influence of the trailing edge deck can be ignored and the ground effect plays a dominant role when the rotor disc begins to enter the area above the deck. The ground effect significantly enhances with increasing of the projection area of rotor disc on the deck. Finally, the ground effect remains unchanged and the aerodynamic interaction of rotor and the hangar door plays the leading role when the rotor closes to the hangar door. The recirculation region caused by the blocking of hangar door is close to the rotor disk and results in the inflow increase of the rotor disc. The thrust drops sharply and the nose-down pitching moment is increased obviously. The influence of hangar door in two different states is also studied in this paper for the purpose of revealing the flow mechanism of the effect of the hangar door on rotor performance and seeking the effective methods to solve the problem of rotor load mutation.

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Measurement of transient blade passage loads of a coaxial counter-rotating rotor in hover

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This study describes the measurement of transient hub loads and blade deformations due to blade passage in a 1 x 1-bladed, 2m-diameter rigid coaxial counter-rotating rotor system in hover. The experimental results were analyzed and evaluated in combination with a comprehensive analysis model using CAMRAD II. Lower rotor blade deformations were measured using a time-resolved digital image correlation technique. Rotating modal parameters including natural frequencies and mode shapes were identified from measured time histories of rotor blade deformations using the Complexity Pursuit algorithm. Experimentally identified modal characteristics correlated well with numerical results for the first three modes. The numerical model also predicted the vibratory hub and pitch link loads as well as out-of-plane deformations satisfactorily well and within the measurement uncertainties. The 2/rev blade tip displacement due to blade passage was found to be 6% of the mean tip displacement, and the transient blade motion of the lower rotor blade was found to be larger than that of the upper rotor blade. Additional numerical studies on the aerodynamic angles of attack, the inflow velocities from rotor–rotor interaction, and sectional lift distributions over the upper and lower coaxial rotor disks provided further insight into the sources of transient loads due to blade passage. For example, it was found that the angle of attack on the lower rotor induced by the upper rotor had a maximum at 15° azimuth before the blade passage.

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Performance degradation modelling of rotorcraft engines operating in brownout conditions

Matthew Ellis (University of Manchester)
Nicholas Bojdo, Antonio Filippone (University of Manchester)

Rotorcraft engines are subject to significant damage whilst operating in brownout conditions due to the ingestion of mineral particulates. The high pressure turbine is particularly at risk due to the deposition of molten particles on nozzle guide vanes and first stage rotor blades, causing a roughening of the surface and a reduction in efficiency. The rate of damage is non-linear; predicting the evolution of this damage has proven to be difficult given the wide range of contributory factors related to both engine and particulate. A first-order methodology is presented whereby component level losses in high pressure turbine nozzle guide vane efficiency can be translated via surface roughness changes into a performance loss of the whole engine. Component level computational fluid dynamics simulations are combined with an aero-thermodynamic gas turbine model to evaluate reductions in engine performance during brownout operations for two rotorcraft using the same General Electric T700 engine. It is shown that the rate of engine degradation is proportional to the brownout concentration of the particular

rotorcraft. Surface roughness changes alone are shown to be capable of producing up to a 1% reduction in the core mass flow rate and overall engine efficiency. This is demonstrated to occur after only 38 minutes of flight in brownout conditions for the Sikorsky HH-60 'Pave-Hawk' and 120 minutes for the Bell UH-1Y 'Venom'.

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Experimental and numerical aerodynamic investigation of advanced tail boom designs based on optimized thick airfoil profiles

Guillaume Legras (Airbus Helicopters SAS)
David Alfano (Airbus Helicopters SAS)

The current paper aims at validating the aerodynamic performance of several advanced helicopter tail boom concepts answering to different aerodynamic optimization objectives. The flow solver validation has been carried out by comparing the numerical predictions with comprehensive measurement data obtained at the CNAM-IAT Wind Tunnel test facility. The comparison confirmed the accuracy and quality of the optimization results particularly in terms of ranking of the different optimal solutions. In this study, the database is further exploited to assess the capability of the CFD approach using the elsA solver to predict the aerodynamic characteristics of theses optimized shapes.

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Automation of structural cross sectional rotor blade modelling for aeromechanical rotor blade optimization

Bram van de Kamp (DLR)
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It is often difficult to predict the behavior of helicopters, given their complex aeromechanical operating environments. Given these uncertainties, it is often the case that flight tests need to be conducted prior to a design being ”frozen”. To improve the whole design and validation procedure, it is essential that the design freeze (and iterations within) occurs before the expensive and timeconsuming process of building and flying. However, in order to do so, the virtual modelling needs to be more accurate and thus with less uncertainty. The DLR project Victoria (Virtual Aircraft Technology Integration Plattform) with its work package ”Virtual Helicopter” aims to lay the foundation for a next generation comprehensive rotor code to overcome these challenges. Improvement on structural modelling within this code has high potential enhancing the overall development process, regarding time and accuracy. The improvement of rotor blade design is often driven by aerodynamic shape optimization, which means changes in airfoil shapes and sizes as well as their distribution and alignment, to fit different demands. Such changes will always have a major influence on the structural properties, because the inner structure geometry depends on the outer shape. Thus to still maintain an accurate aeromechanical model for the rotor simulation in the optimization process structural properties have to be adjusted. The most common approach is to calculate cross section data for various cross sections over the rotor blade span and feed the information into a beam-based rotor blade model. This is typically done by using approximations and scaling laws e.g., or by reducing the geometry complexity e.g. A high fidelity structural FEM-model will provide higher quality structural data. In general such FEM models are complex and require significant time to setup and process, starting with generating the blades inner geometry with CAD software, then meshing and performing the actual FEM analysis. This is very time consuming and hardly feasibly for an optimization with multiple loops. This paper presents the development of a tool for the automation of this process. The inner geometry is generated in CATIA V. and can handle arbitrary cross section shapes (within reason). Additional parameters and boundary conditions are needed to obtain an inner geometry which is reasonable in terms of its structural integrity. These parameters include the center of gravity, basic spar shaping parameters and the skin thickness. This very accurate geometry model is then passed on to the FEM software (ANSYS). Here a mesh representing the geometry is created and then an analysis with the ANSYS tool SaMaRA is performed. SaMaRA calculates the structural properties of the cross section. The exchange of all data between the different disciplines (e.g. structural and aerodynamic) is performed via CPACS (Common Parametric Aircraft Con1guration Scheme) to ensure data integrity and enable modularity of this structural code. The focus in developing this code was on the quick generation of highly accurate structural data for an aerodynamically driven optimization. The meshing automation in Ansys is not yet finished and in ongoing development. Follow up steps will be the extension of modelling options in terms of the inner structural setup and meshing quality.

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Numerical-experimental correlation of rotor flowfield in ground effect

Claudio Pasquali (Roma Tre University)
Jacopo Serafini, Giovanni Bernardini, Massimo Gennaretti (Roma Tre University)
Joseph Milluzzo, Scott Davids (U.S. Naval Academy)

This work presents the comparison between experimental measurements and numerical simulations concerning the flowfield generated by a helicopter rotor operating in ground effect conditions above an inclined plane. Specifically, the capability of a potential-based, three-dimensional, free-wake aerodynamic solver to simulate in-ground-effect problems is assessed in terms of loads and wake inflow field, showing a good agreement with the experimental data.

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Boundary integral formulations for noise scattered by helicopter fuselage

Caterina Poggi (University Roma Tre)
Giovanni Bernardini, Massimo Gennaretti (University Roma Tre), Claudio Testa (CNR-INM)

The paper deals with a theoretical-numerical comparison among integral formulations for the prediction of noise scattered by moving bodies. Three acoustic scattering integral formulations for the solution of the velocity potential wave equation are considered: a recently proposed linearized boundary-field integral formulation, and two widely applied boundary integral approaches based on Taylor and Taylor-Lorentz transformations. Aim of the work is to highlight their theoretical differences and limits of applicability, while examining their capability of capturing the influence of body motion and corresponding nonuniform mean flow around it on the scattered noise field. Numerical results concern a rigid translating sphere impinged by sound waves emitted by a co-moving pulsating point-source and a helicopter fuselage impinged by noise radiated by main- and tail-rotor.

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Isomorphic spatial visual-auditory displays for operations in DVE for obstacle avoidance

Martine Godfroy-Cooper (NASA)
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Helicopter military missions such as combat search and rescue, medical evacuation and landing on unprepared sites can involve operating in hostile, low-altitude, and degraded visual environments (DVE). These conditions may significantly reduce the pilot's capability to use the natural out of the window (OTW) perceptual cues, increase workload and increase the risk of collision with terrain and natural or man-made obstacles. In modern helicopter cockpits, synthetic vision systems (SVSs) can employ conventional non-conformal two-dimensional (2D), egocentric three-dimensional (3D) conformal symbology (CS) and laser detection and ranging (LADAR)/ radio detection and ranging (RADAR)/ forward looking infrared (FLIR) imagery support guidance and control, especially during operations in DVE. Although 3D CS can decrease pilot workload, it can also produce attentional tunneling (cognitive capture) and may not provide maximally effective depiction of the environment around the helicopter. In this context, it is crucial to develop integrated multimodal interfaces that extend the current operational envelope while enhancing flight safety. Several flight simulator studies have investigated the use of spatial auditory displays (SADs) in combination with spatially and temporally congruent visual displays in tasks as diverse as collision avoidance, intruding aircraft detection, or system malfunction warning. In this paper we propose a novel approach to spatial sonification design based on the premises that perception-based synthetic cueing can increase situation awareness (SA), improve overall performance, and allow mental workload to be kept at operationally effective levels. This paper discusses the development, implementation, and evaluation of a sensor-based augmented-reality spatial auditory display (ARSAD) and its visual analog, an integrated collision avoidance display (ICAD) for all phases of flight. Five UH60M Army pilots participated in a low-level flight simulation evaluating the visual and the auditory displays, alone or in combination in low-visibility.

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Numerical simulation of different rotor designs in hover and forward flight

Thomas A. Fitzgibbon (University of Glasgow)
George N. Barakos, Mark A. Woodgate and Antonio Jimenez-Garcia (University of Glasgow)

This paper presents numerical simulations of different rotor designs using the HMB3 solver of Glasgow University. The PSP blade with a swept-tapered tip, the Langley Baseline blade with a rectangular planform and the Langley BERP blade with an advanced tip shape were studied. Firstly, the three blades were examined in hover. The integrated loads were compared with experiments and show very good agreement for each of the blade designs. The effect of anhedral in hover was investigated and was found to be more beneficial for the BERP-like design, than the other blades. The PSP blade was also simulated in forward flight at three thrust coefficients. The advancing and retreating blade surface pressures were extracted and found to follow experimental data obtained using pressure transducers. The predictions for the simulated cases demonstrate the ability of the CFD method to accurately predict the performance of rotors regardless of planform geometry, or design complexity.

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An experimental investigation of hub drag characteristics on coaxial rotor aircraft

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MingQi Huang, YongDong Yang, Dong Li (CARDC)

A full-scale wind tunnel tests have been conducted to research the hub drag characteristics of combine coaxial rotor aircraft and better understand the aerodynamic interaction between hub and fairings. A hub and fairing drag test was conducted to obtain quantitative drag measurements on multiple fairing geometries, and to get insight into the effect of rotation and the presence of blade stub. There were four interchangeable mid-shaft fairings designed, i.e., optimized fairings F1, F2 based on airfoil and optimized fairing F3, plus a bare shaft(S) for reference. The effect on the hub drag of varying angle of attack, Mach number were investigated. Principal results were that the Mach number had a greater influence on the drag of hub, and the best fairing configuration reduced the drag of coaxial rotor hub by 37%. The test also provided validation data for computational fluid dynamics (CFD), and aerodynamic characteristics for design.

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Modeling and control of lift offset coaxial and tiltrotor rotorcraft

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The US Department of Defense has established an initiative to develop a family of next-generation vertical lift aircraft that will fly farther, faster, and more efficiently than the current fleet of rotorcraft. To accomplish these goals, advanced rotorcraft configurations beyond the single main rotor/tail rotor design must be considered. Two advanced configurations currently being flight tested are a lift offset coaxial rotorcraft with a pusher propeller and a tiltrotor. The US Army Aviation Development Directorate has developed generic high-fidelity flight-dynamics models of these two configurations to provide the government with independent control-system design, handling-qualities analysis, and simulation research capabilities for these types of aircraft. This paper describes the modeling approach used and provides model trim data, linearized stability and control derivatives, and eigenvalues as a function of airspeed. In addition, control allocation for both con1gurations is discussed.

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Human biodynamic models for rotorcraft comfort assessment

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Andrea Zanoni, Vincenzo Muscarello, Giuseppe Quaranta, Pierangelo Masarati (Politecnico Di Milano)

This work shows how different occupant biodynamic modeling techniques are integrated in a rotorcraft design environment and discusses the resulting differences in comfort assessment. Three modeling techniques, that are used for biodynamic characterization, are considered: lumped parameter, finite element and multibody dynamics. These models are identified for the same gender, age, weight and height and then integrated into a virtual helicopter environment with a seat-cushion interface. A generic helicopter model is used to demonstrate the approach. For each of the three techniques, the vertical acceleration levels at the human-helicopter interface, as required by vibration regulations, and at the head are evaluated up to 30 Hz. At a first glance, it is observed that in terms of model set-up the lumped parameter is the easiest to implement. However, the use of lumped parameter models is limited to the population groups that they are identified from, and thus are not as flexible as the finite element and multibody ones in developing biodynamic models for individuals of an arbitrary population percentile. Furthermore, through numerical analysis it is found that the differences are not very significant in terms of accelerations at the interface. Therefore, for comfort related issues, the use of more complex models is not justified, unless complicated comfort assessments other than human interface accelerations are required. On the other hand, the spine dynamic can play a significant role when head acceleration is considered; therefore, when the head-neck health of occupants is considered, the sophisticated finite element and multibody dynamics models redeem their higher modeling cost and computation time.

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Higher-order simulations of interactional aerodynamics on full helicopter configurations using a Hamiltonian strand approach

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Time-accurate numerical predictions of the interactional aerodynamics between NASA's generic ROBIN fuselage and its four-bladed rotor were performed using the recently developed RANS solver HAMSTR. The fifth-order WENO reconstruction scheme, the third-order MUSCL scheme, a secondorder temporal resolution, and the Spalart–Allmaras turbulence model were used. Three-dimensional volume meshes were created in a robust manner from two-dimensional unstructured surface grids using Hamiltonian paths and strands on nearbody domains. Grid connectivity was established between nearbody and background domains in an overset fashion. Two previously researched operational conditions were reproduced, i.e., a near-hover case and a medium-speed forward flight case at an advance ratio of $\mu = 0.151$. The results were compared with various experimental and numerical references and were found to be in good agreement with both. The comparison included the analysis of the rotor wake structure, tip vortex trajectories and strength, steady and dynamic fuselage pressure distributions in longitudinal and lateral directions, and rotor inflow predictions.

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Conceptual design tradeoffs for future single main rotor compound helicopters

Daniel P. Schrage (Georgia Institute of Technology)
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A compound helicopter is defined as a helicopter with an auxiliary propulsion system which provides thrust in excess of that which the rotor(s) alone could produce, thereby permitting increased forward speeds; wings are usually provided to reduce the lift requirement from the rotor system. While there are a variety of different main rotor configurations for compound helicopters, such as single main rotor, coaxial rotor and tandem rotor, we will restrict this generic study to Single Main Rotor Compound (SMRC) Helicopters. A "Sensitivity" Tradeoff Studies approach will be utilized. The Advanced Vehicle Design Synthesis used in Georgia Tech vertical flight design classes is used for Configuration Solution and "Sensitivity" Tradeoffs for potential SMRC helicopter configuration solutions.

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Unified framework for analysis and design optimization of a multirotor unmanned aerial vehicle

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Designing a small-scale multirotor UAV is a complicated procedure that requires multi-disciplinary analyses including rotor aerodynamics, structure, and electric propulsion system. However, owing to the complexity of multi-disciplinary analyses, the design of conventional multirotor UAVs heavily relies on the empirical methods through experimental data or legacy selections. These methods not only lack the firm physical basis for selecting the component, but also are extremely time-inefficient, requiring numerously repetitive experiments. In order to establish a systematic design procedure for multirotor UAVs, the unified design optimization framework, titled as Conceptual Layout Optimization for Universal Drone Systems (CLOUDS), was developed in this study. CLOUDS consists of five multi-disciplinary analysis modules including aerodynamics and electric propulsion system. Utilizing these modules, it can accurately estimate the performance of the system in response to the variation of the combination of components, showing high accuracy of predicting the flight time within 10% deviation. As such, the optimal configuration of multirotors could be designed for a specific mission. Based on the developed framework, correlations between the variables are found using Self-Organizing Maps (SOM) and Analysis of Variance (ANOVA). Additionally, design optimizations were conducted for two hover missions with different time as an example. The optimum design solution was presented by analyzing the optimization results.

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Development of a conceptual design tool for various compound helicopters

Donguk Lee (Seoul National University)
Soomin Jeong, Kwanjung Yee (Seoul National University)

Recent rotorcraft community has suggested various forms of compound helicopters capable of carrying out a high-speed maneuver. These aircraft have disparate aerodynamic characteristics and propulsion system due to their unique way of generating lift and thrust. In view of the unique features, each concept is adapted with a specific mission profile. To provide an appropriate concept for a specific mission, this study developed a comprehensive conceptual design tool for the three concepts, winged helicopter, tip-jet gyroplane, and fan-in-body concept. This design tool enables sizing of the compound helicopters with comparable analysis fidelity, while considering their distinctive propulsion system at the conceptual design phase. With the developed tool, the design optimizations were conducted for six different mission profiles covering various flight range, hover and loiter time. Subsequently, systematic comparisons and analyses were carried out to deduce the most appropriate configuration for each mission.

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A generic ground dynamics model for ground handling evaluations

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Kaan Şansal, Serkan Sağıroğlu, Volkan Kargın (TAI)

This paper demonstrates a generic ground dynamics model for modeling and simulating landing gear systems. Physics based model is developed in MATLAB-Simulink® environment and it is integrated to a non-linear 6-DOF helicopter model which is constructed in an in-house comprehensive analysis code, TAI Originated Rotorcraft Simulation (TOROS). Other than simulating the helicopter motion after touchdown, this model is also capable of trimming the helicopter on ground, which is useful for determining landing and take-off capabilities of a helicopter on either a flat or a sloped surface. This method can show whether the control ranges are adequate or not during the design stage, which is a troublesome task during preliminary design. In this study, slope-landing analyses of a light utility helicopter is demonstrated together with dynamics of a generic landing gear. The effect of ground on non-uniform inflow parameters, which is capable of modelling inclined ground effect, is included into the non-linear mathematical model using a finite state approach. Results show that, finite state ground effect model affected the control margins and main rotor flapping during slope landing and take-off analyses. In addition, rotational degree of freedom is added to the wheel component, which can be utilized not only for trimming and linearizing the helicopter on ground with/without airspeed but also for performing different ground-handling evaluations (e.g. high-speed taxiing, rolling take-off etc.). Moreover, by using this mathematical model, spin-up loads during run-on landings can be calculated, landing distance to full stop can be found and failure simulations (e.g. flat tire) can be performed.

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Optimisation of differential infrared thermography for unsteady boundary layer transition measurement

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Differential infrared thermography (DIT) is a method of analyzing infrared images to measure the unsteady motion of the laminar–turbulent transition of a boundary layer. It uses the subtraction of two infrared images taken with a short time delay. DIT is a new technique which already demonstrated its validity in applications related to the unsteady aerodynamics of helicopter rotors in forward flight. The current study investigates a pitch–oscillating airfoil and proposes several optimizations of the original concept. These include the extension of DIT to steady test cases, a temperature compensation for long–term measurements, and a discussion of the proper infrared image separation distance. The current results also provide a deeper insight into the working principles of the technique. The results compare well to reference data acquired by unsteady pressure transducers, but at least for the current setup DIT results in an additional measurement–related lag for relevant pitching frequencies.

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Progress in the development of a time-to-contact autorotation cueing system

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Autorotation to landing is a difficult manoeuvre to accomplish successfully in an emergency. During autorotation, it is critical to simultaneously maintain the desired flight path, decelerate the aircraft appropriately, all whilst locating and reaching a safe location to land. This significantly increases the pilot work load in the cockpit. Therefore, there is a clear need to develop a set of pilot cueing and control augmentation technologies that lead to a higher probability of a successful autorotation landing. Tau theory and the associated guides have been shown be of benefit when used to provide guidance cueing in flight, where 'tau' is the instantaneous time-to-contact a surface at the current rate of closure. This article presents a detailed analysis of real autorotation flight data in the tau domain. The findings indicate that the taus of pitch angle and range distance can be modelled as being coupled to intrinsic tau motion guides (constant acceleration and deceleration respectively). Additionally, the article presents the development and analysis of a method to generate deceleration trajectories in autorotation using tau as the basis. A point mass model is used to rapidly evaluate trajectory feasibility and enforce reachability constraints in an autorotative flare. This approach of using a low-order model to evaluate reachability shows promise in terms of both accuracy and runtime guarantees. The tau-based control and tau-based trajectory generation schemes can be combined to create a control augmentation system in which reachable areas are depicted visually to the pilot, and inceptor cues are given to reach a selected desired landing point.

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CFD analysis of helicopter wakes in ground effect

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The paper presents CFD results for the wake of a helicopter flying a low altitude at different advance ratios. The wakes are assessed in terms of topology and velocity magnitudes. The structure of the wake near ground changes rapidly with the advance ratio and its decay appears to be faster than what is suggested by theoretical analyses. The results show clear the potential of modern CFD for use in helicopter safety and highlights the need for detailed surveys of helicopter wakes using full-scale physical experiments.

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Investigation of a helicopter model rotor wake interacting with a cylindrical sling load

Fabrizio De Gregorio (CIRA)
Antonio Visingardi (CIRA), Ranieri E. Nargi (University of Roma3)

An experimental and numerical investigation on a four-blade isolated main rotor in hover condition has been carried out in order to investigate the effect of the rotor downwash on a tethered load. A sling load was located at different positions below the rotor disk in order to evaluate the mutual interference between the rotor wake and the immersed body. A radio controlled helicopter model, largely customized and modified for the scope of the experiment, was used as rotor rig. The sling load was reproduced by a low aspect ratio (l/d=2) cylinder being representative of typical loads as oil drums, water containers or engine canisters. Furthermore, the cylinder flow wake is a well known case largely investigated in literature and a good test case for computational fluid dynamics simulation. A six components balance measured the rotor loads calculating the figure of merit. The cylinder pressure distribution together with the flow field characteristics were also measured. Numerical simulation were carried out by using an unsteady, inviscid and incompressible free-wake vortex lattice boundary element methodology solver for multi-body configurations. The paper reports the main rotor wake characteristics up to 3 radii distance from the rotor plane with and without sling load. The effect of the downwash on the cylinder varying the distance and the changes induced by the presence of the cylinder are discussed.

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Investigation of optic flow, time-to-intercept, and pilot workload during aggressive approach to hover maneuvers

Edward Bachelder (NASA)
Martine Godfroy-Cooper, Bimal Aponso, (NASA), Chris Blanken, Tom Berger (AMRDEC)

This work proposes a novel relationship between pilot workload and optic flow during visual approach-to-land maneuvers. A simulation experiment was conducted at NASA Ames Vertical Motion Simulator (VMS) to evaluate the workload associated with operating two candidate Army Future Vertical Lift (FVL) vehicles: a compound (coaxial-rotor and push-prop) vehicle, and a tilt-rotor vehicle. The UH-60 was included in the evaluation as a baseline reference. Sixteen experienced military pilots flew aggressive visual approaches terminating in a hover while providing Bedford workload ratings in real time. No approach or hover guidance was displayed to the pilot. The out-the-window (OTW) environment (front and chin monitors) was digitally recorded and the optical flow of each video frame computed. Prior work identified a mathematical relationship between pilot workload and the combination of display error rate and stick rate during compensatory tracking tasks. The current work extends this relationship to visual landing approaches, where the pilot is hypothesized to track key optical variables that are available from the OTW scene. Via correlation analysis a set of candidate tracking variables which appears to drive pilot workload is identified: the rate of change of optical flow, and the angle formed between the cockpit glareshield and the intended landing spot. Combined with stick rate these variables are used to generate a Bedford estimate. Actual and modeled Bedford ratings are compared for the compound aircraft (video for the other aircraft will be processed and presented in a

future paper), and performance and workload are compared across the three aircraft. Innovative contributions of this research include: 1) Optical flow from high resolution, high frame rate flight video is computed and analyzed for workload analysis; 2) A modelling technique is developed that produces workload estimates that closely matches actual pilot ratings; 3) A technique based on visual perceptual requirements allows optical flow to be employed in a very simplistic, tractable, yet effective manner; 4) While tau motion theory (i.e. rate of instantaneous time-to-arrive is approximately constant) was roughly observed during the approaches, it appears that tau motion was a result of the pilot adhering to a strategy of minimizing deviation in optic flow rather than being the source of pilot behavior. This preliminary, significant conclusion proceeds from the observation that workload correlated well and was causal with minimizing change in optic flow, but correlated poorly and was often non-causal with changes in tau motion; 5) Using a novel method, Bedford workload ratings were collected in real time without impinging on the flight task, enabling in-situ workload analysis. Lastly, if a pilot has transferred control to automation during an approach in an Optionally Piloted Vehicle (OPV), pilot trust may be higher if he/she observes system behavior that resembles what a skilled operator would produce, i.e., optic flow control.

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An examination of hydrogen fuel cells and lithium-ion batteries for electric vertical take-off and landing (EVTOL) aircraft

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The primary drawback of electric vertical take-off and landing (eVTOL) aircraft is their poor range and endurance with practical payloads. The objective of this paper is to examine the use of hydrogen fuel cells to overcome this drawback through simulation and hardware testing. The paper develops steady state and transient models of fuel cells and batteries and validates the models experimentally. An equivalent circuit network model was able to capture the waveforms and magnitudes of voltage as a function of current, temperature, and humidity. Examination of the results revealed that the transient behavior of batteries and fuel stacks are signi1cant primarily shortly after startup of the fuel stack and at the limiting ranges of high and low power; for a nominal operating power and barring faults, steady state models were adequate. This paper also demonstrates fuel cell and battery power sharing capabilities in an unregulated parallel con1guration as well as in a regulated circuit. A regulating architecture was developed that achieved a reduction in power plant weight. Finally, the paper outlines weight models of motors, batteries, and fuel cells needed for eVTOL sizing, and carries out sizing analysis for three progressively longer on-demand urban air taxi missions. The objective aircraft was sized to carry a minimum of 400 lb payload for an on-demand air taxi-like mission with 5 min hover and 15-60 min cruise at 150 mph. This revealed that for ranges within 75 mi, an all-electric tilting proprotor con1guration is feasible with current technology if high C-rate batteries are available. Either a battery-only or fuel cell and battery hybrid power plant is ideal, depending on the range of the mission. In particular, a 5700 lb gross take-off weight aircraft with disk loading of 11 lb/ft^2 could be sized using a hybrid power plant with fuel cells and 10C batteries to carry a payload of 430 lb for a 75 mi (inter-city) mission. A smaller aircraft of 4000 lb gross weight and a disk loading of 27 lb/ft^2 could be sized using a 6C battery only power plant to carry a payload of 490 lb for a shorter 38 mi (intra-city) mission. Research priorities would depend on target mission duration and range. For any mission beyond 40 miles (or 15 minutes at 150 mph) fuel cells appear to be a compelling candidate. Based simply on performance numbers (cutting-edge numbers proven at a component level but not in flight), ease of re-fueling, high w% hydrogen storage due to the short duration of eVTOL missions, and lack of a compressor due to low-altitude missions, fuel cells appear to far surpass any realistic future projections of Li-ion energy levels. However, for missions less than 40 miles, improving battery energy density is the priority. All mission lengths require improved battery power density to 6-10 C for 150 Wh/kg batteries.

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Determining a safe-distance guideline for helicopters near a wind turbine and wind park

Richard Bakker (NLR)
Peter van der Geest (NLR)

The Netherlands Aerospace Centre (NLR) was tasked to support the (former) Netherlands Ministry of Infrastructure and Environment to define a safe distance guideline for helicopters with respect to wind turbine parks. In an exploratory research, based on a relatively simple analytical wake model, a guideline for safe distance for helicopters is determined that can be used to support helicopter operations near offshore wind turbines and wind farms. The paper discusses the wake model, the safe distance criteria and will also consider the influence of the turbulence intensity, the wind turbine shaft height, rotor diameter of the turbine and the safe distance with regards to a multiple turbines in a wind park. A guideline for a safe distance is determined that could support directives for safe offshore helicopter operations near wind turbines.

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Experimental and numerical investigation of near-field rotor aeroacoustics

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This work presents comparisons between experimental and numerical estimates of near-field rotor aeroacoustics in hover. The experiments took place at the Kazan National Research Technical University named after A. N. Tupolev (Kazan Aviation Institute). A set of rotor blades with NACA-0012 aerofoil sections was used to obtain the sound pressure distribution using a linear array of microphones. It is shown that CFD and experimental results are in good agreement suggesting that the obtained test data can be useful as a validation case for development of CFD tools.

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Experimental investigation of the effects of different helicopter rotor tip geometries on aerodynamic performance and tip vortex characteristics

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In this study, the effects of different tip geometries (rectangular, anhedral, swept-tapered and swept-tapered-anhedral) on the rotor hover performance and tip vortex characteristics are investigated experimentally. A scaled rotor model set-up, instrumented with thrust and torque sensors, is used for aerodynamic performance measurements in hover and a two-dimensional (2D) particle image velocimetry (PIV) is used to obtain the tip vortex characteristics such as vortex trajectory, maximum tangential velocity, and circulation. Although taper+swept and taper+swept+anhedral configurations have the best C_T/C_Q values at lower blade loadings, at higher blade loadings anhedral case has the best performance and an increase of 0.03 figure of merit compared to the baseline. It is observed that different tip shapes change the vortex trajectory, in addition, reduces maximum tangential velocity and circulation significantly. The PIV measurements which were performed at a high blade loading show that there is a correlation between the aerodynamic performance and the vortex strength.

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Wind turbine wakes and helicopter operations: an overview of the GARTEUR HC-AG23 activities

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George Barakos (University of Glasgow), Mark White (University of Liverpool)

The effects of a wind turbine wake on General Aviation and the behaviour of helicopters in the tip vortex of large fixed-wing aircraft has been topic of research in the past years, but less is known about the interactions of helicopters operating in a wind turbine wake. A dedicated GARTEUR Action Group, HC-AG23, consisting of European universities and research institutes was formed to investigate helicopter behaviour in a wind tur-bine wake and to study the consequences for helicopter handling and safety of flight. The activities are structured in work packages addressing wind turbine wake identification, wake experiments and computations, offline and piloted simulations and management and dissemination activities. This paper presents an overview of the partners' activities and provides a short overview of the results that have been achieved in the past three years.

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Predictive maintenance for helicopter from usage data: application to Main Gear Box

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The Main Gear Box (MGB) is a central mechanical unit of the helicopter and is a very highly monitored system. For years, optimizing the maintenance of a MGB is a challenging problem. In this paper we develop a visual method for predicting the future state and aging of a monitored MGB based on the analysis of in-service usage data history. We have collected such data from several aircrafts since three years. Usage data characterize the real usage of in-service aircrafts for internal process and view of operational data for technical event investigation. To deal with such big data, we have applied an exploratory data analysis process focusing on oil pressure and temperature. The corresponding numerical values have been discretized in classes defined by domain experts, from which co-occurence matrices were built for some predefined time windows. The visualization of successive co-occurence matrices turns out to be quite convenient and have been exploited as a decision support tool in monitoring the state of a MGB. We have applied this approach on three different aircrafts and built several videos. As concrete results, we have been able to recover maintenance operations, such as MGB removals, and one known anomaly – registered in maintenance data – from the proposed visualization.

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Evaluation of rotor blade models for rotor outwash

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In this work Computational Fluid Dynamics is used as a tool for rotor outwash evaluation. The paper concentrates on the validation of the method, presents different modelling approaches and concludes with suggestions on the use of the method for detailed simulations of rotor outwash. The required computer resources for the detailed computations of the wake are also discussed.

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Research on vision system for degraded visual environment

Kohei Funabiki (JAXA)
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JAXA (Japan Aerospace Exploration Agency) has been conducting a research project named SAVERH (Situation Awareness and Visual Enhancer for Rescue Helicopter) since 2008. SAVERH aims at inventing a method of presenting suitable information to pilots to support search and rescue missions in Degraded Visual Environment. An integrated system comprising an Helmet--Mounted Display (HMD) and some vison sensors were installed in JAXA research helicopters and series of flight tests conducted to evaluate the benefit of presenting synthetic and sensor images on the HMD. An effectiveness of images presented on an HMD for road following and landing was evaluated through the series of flight experiments. As results, both synthetic and sensor image were effective for recognizing targets, navigation features such as road and terrain.

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Model predictive motion cueing for a helicopter hover task on an 8-DOF serial robot simulator

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Motion cueing for helicopter hover is difficult: small simulators require considerable attenuation, rendering motion cues not useful for stabilization, and large simulators are typically not cost effective. Industrial serial robot-based simulators provide large motion capabilities at a moderate cost, but have two distinct disadvantages. First, they are highly dimensional systems with a non-convex motion space, such that efficient use of the entire space is not trivial. Second, they are typically non-stiff structures with a large mass at the end-effector, resulting in oscillatory dynamical properties. We recently developed a novel Model Predictive Motion Cueing Algorithm (MPMCA) that resolves both problems effectively for prerecorded inertial reference signals. The MPMCA requires an accurate prediction of the future course of the reference inertial signals, which is trivial for prerecorded maneuvers, but not for real-time human-in-the-loop simulations. In this paper, we present a model-based prediction method, which predicts pilot control inputs and the subsequent helicopter response during a helicopter hover simulation in real-time. The method is tested in a human-in-the-loop experiment and compared with the Classic Washout Algorithm. The results demonstrate that the MPMCA is a promising new approach to motion cueing.

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Initial progress in developing a predictive simulation tool to inform helicopter ship operations

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Mark D White and Ieuan Owen (University of Liverpool)

The study presented in this paper is part of the project underway at the University of Liverpool (UoL) to develop a high-fidelity simulation tool that has a predictive capability to inform and support Ship Helicopter Operating Limit (SHOL) trials. The paper reports preliminary progress in developing a desktop based predictive simulation tool that uses a pilot modelling technique to represent the integrated Helicopter Ship Dynamic Interface (HSDI) simulation environment. The approach consists of: a pursuit pilot model, linearized vehicle dynamics, full standard deck landing task, ship motion and equivalent ship airwake turbulence. The tool was initially tested by performing a simplified land-based task for validation purposes. It was then used in HSDI simulations of an SH-60B helicopter operating to a generic single-spot naval frigate. Time and frequency domain comparisons have been made between the predictive tool and piloted simulation flight trials conducted in UoL's Heliflight-R full-motion simulator. It was found that the performance of the predictive tool in maintaining sufficient clearance between the aircraft and the ship whilst rejecting airwake disturbances is well within the desired task performance boundaries. These preliminary investigations show that the tool is capable of representing the dynamics of a pilot in the HSDI environment.

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Cabin safety sensitivity to the mechanical parameters of the main crashworthy stages

Paolo Astori (Politecnico di Milano)
Thiva Ramachandran (Mecaer Aviation Group)

Crashworthy helicopters have energy absorbing concepts introduced into seats, subfloor and landing gears. These stages are always passive systems, usually triggered by a load level, and develop pre-set responses independently from the crash speed. Moreover, the different stages are usually studied as single components, without considering the mutual effects and any possible integration. This study is based on a lumped mass numerical model of a representative, but very simplified, rotorcraft section, including the three crashworthy stages of landing gear, subfloor structure and seat with anthropomorphic dummy. A series of analyses show the advantages, in terms of accident survivability, associated to a seat and landing gear with mechanical characteristics optimised according to varying impact velocities.

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The elevated helipads – study of wind and rotor wash influence for most common configuration types

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Problem of lack of possible places to build new buildings is well known in modern cities. When it concerns helipads, which need large area to be placed and also it have to be carefully checked, how surroundings is influencing on this new construction, the case is even more complicated, because those sites have to fulfil demanding regulations. For hospital helipads it is necessary to have possible quickest way from helicopter to surgery. When area is limited, it is usually necessary to place such construction on a building and such helipad is then called elevated. However no document can provide a strict information, how to place new helipad in its surrounding – only general data is available. Too many factors have to be considered. This is why always a detailed analysis is needed in order to be sure, that flight operations can be done safely. This paper presents the work flow concerning this topic, from regulations to fulfil to results of analysis. Some aspects of different locations and its influence on elevated helipads are discussed. Also details about performing the analysis are presented.

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Embedding intelligent image processing algorithms: the new safety enhancer for helicopters missions

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Over the last two decades, image processing technologies rapidly emerged from the shadows to become one of the most important field of interest in computer science. Although image analysis is a hot topic in the automobile industry and for some aircraft applications (drones, airplane, space probes...), the certification of any vision based autopilot system for helicopter missions remains an ongoing challenge. Indeed, such a system would be required to perform complex missions with a high success rate while possibly facing adverse weather conditions. However the rapid increase of processing power, the development of image analysis algorithms, as well as the miniaturization of high resolution cameras, are allowing new technical solutions for autonomous flight. Facing this new technological deal, helicopters manufacturers can no longer ignore that vision based systems are about to become a key enhancer for versatile rotorcraft missions. Airbus Helicopters is committed to put the safety of its aircrafts at the highest standards. For this purpose, Airbus Helicopters has initiated the development of advanced systems integrating many disciplines like sensor acquisition, scene understanding, situation awareness, and artificial intelligence. As a contribution to this company objective, the EAGLE project (Eye for Autonomous Guidance and Landing Extension) was launched 2 years ago to develop a generic optronic platform facilitating integrations of algorithms for different applications. The system aims to improve safety and reduce the pilots' workload during flights in oil and gas and SAR missions. This paper presents the latest results that have been obtained by Airbus Helicopters and the LIS-lab in the development of a landing platform detector in the frame of this project. We will first introduce the general methodology applied for the determination of the platform position. The approach is hierarchical and based on a collection of hints to determine, refine and validate suitable locations for the presence of a helipad. We will then present the strategy for the selection of regions of interest. The aim is both to determine the right size of portion of the image to be analyzed, and to enable the real-time adaptation of the selection and sequencing of the regions to be explored. This article will then detail the methods used to determine the areas susceptible to contain a landing platform. The algorithm mainly relies on flat ellipse detection as it is the most visible feature of a helipad seen from long distances. An adaption of the Hough transform proved to be the most reliable method in the specific case of very flat ellipses. A validation step using many other properties and visual clues performs the verification of the presence of the helicopter landing platform in the research areas delimited by the obtained ellipses. Having presented the algorithm for the detection of a helicopter landing platform, we will discuss some approaches to increase the system's accuracy, robustness and integrity (detection of failure). In particular, safety and certification considerations are used to select the human-machine interfaces and overall design of the system. A result section will show how this system demonstrated to be capable of detecting landing platforms from a distance of 1500 meters and tracking it without interruption until the landing phase. Last but not least, this paper will introduce an open view of identified image processing technologies continued path for the upcoming years. Our vision of this technological field as a mandatory brand new core competency to be strengthened within Airbus Helicopters, and the way we intend to build up the necessary ecosystem with Airbus' other business units, will be the epilogue of the article.

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An objective assessment tool (gOAT) of helicopter pilot's performance

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In this research an Objective Assessment Tool (gOAT) is presented. The main idea of the system is to develop a tool that provides more detailed information about the pilots' performance. The gOAT system bases on the Mission Task Elements (MTEs) taken from the Aeronautical Design Standard Performance Specification Handling Qualities Requirements for Military Rotorcraft (ADS-33), and use the data recorded by the flight simulator software. In the ADS-33 document the criteria for tasks are limited and not very complex. The gOAT systems goal is to enlarge the task criteria, so the feedback delivered by the system is wider. That would automatically provide more information and data for postprocessing and evaluation. During simulated flight the gOAT system not only provides an error/deviation compared to the desired pattern, but also has an

"assistant" functionality. The developed system could be used as a tool to improve the current flight skills and performance by giving the cues and tips for pilot. The modular architecture of the system allows to implement additional indicators for the pilot, so the task is done with higher precision.

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SkyFlight mobile: a service to enhance the Leonardo flying experience

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In recent years, the usage of Electronical Flight Bags (EFBs) has significantly increased to assist pilots in their operations. While initially used as a means of storing, updating and consulting the Aircraft Manuals and information necessary for the flight, latest technological developments and the availability of affordable high specifications electronic personal pads, have given to EFBs the ability to perform also a variety of computational calculations, access databases and display real-time data. EFB can have multiple functions. It can store and display important mission data, give the ability to carry out mission analysis and perform calculations for flight performance and weight and balance validation. The management of the flight operations will likely be more and more automated and integrated in all its aspects, from maintenance to flight. In this scenario, in order to maximise the delivered value and to better meet the operational needs, Leonardo, leveraging on its knowledge as the aircraft manufacturer, has developed and is offering services and technologies. With a primary focus on the calculations of aircraft performances and weight and balance, SkyFlight Mobile is the Leonardo Helicopters EFB, delivered as a service to enhance the flying experience. SkyFlight provides the means to evaluate on ground all aspects of the mission, to guarantee a thorough safety assessment and to increase the mission effectiveness. Pilots have SkyFlight application installed on their devices to access the web service. Anywhere, the relevant information and calculations for a mission can be used, fully compliant with the Rotorcraft Flight Manual and the authority's requirements. SkyFlight automatizes the daily operations to reduce the flight crew workload and head-down time, to increase the pilot situational awareness and to optimize costs. SkyFlight has been designed and developed entirely by Leonardo Helicopters, leveraging on its knowledge. In order to keep the pace of modern software applications, a properly tailored Agile methodology has been used, with the aim of delivering quick and continuous updates related to new functionalities and issues identified during the software testing activities. Since the service is meant to be used by the community, the selection of the stakeholders had to take into account some representatives of pilots from the different operations that are meant to be supported. This lead to involving both Leonardo Helicopters Division Pilots as well as a set of specific Customers that demonstrated interest in the evolution of the system (in the Executive and Private transport, Medical and Rescue services, Offshore operations, Security services and Utility). The compliance of SkyFlight with the National Aviation Authorities EFB validation standards, is demonstrated with the evidence of the software testing activities achieved, including User Interface testing, reliability testing, and accuracy testing. The SkyFlight service is designed and developed to enhance the flight experience. Pilots receive value by accessing to the functionalities tailored for their helicopters operations, together with the Leonardo experience, professional skills, systems, facilities, and networks.

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Active vibration control for the Kazan Ansat

Bastian KINDEREIT
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This paper presents a high-level overview of the implementation and the results of LORD's OMNI Active Vibration Control System (AVCS) on Russian Helicopter's Ansat helicopter platform as well as a brief description of principles of the technology. The AVCS is designed so that it can be easily adapted to both existing production aircraft and new aircraft development to actively reduce in-flight vibration levels. Vibration reduction allows for increased crew comfort, reduced equipment fatigue and in certain cases even an increased flight envelope at minimal installation weight versus performance compared to other vibration reduction technologies. The technology is architected with a high degree of modularity to allow it to be adapted to a wide variety of aircraft and customer use-cases. The primary goal on the Ansat was to configure the AVCS to reduce vibration levels at the VIP seats in the aft cabin although cockpit vibration levels were also to be considered. LORD engineers worked with the Russian Helicopters team at the Kazan, Russia facility to integrate and tune the system through simulation and flight test, which resulted in reductions in vibration levels at the VIP seats of up to 84% depending on flight condition. Ultimately, these efforts resulted in two production configurations, which first appeared on a production Ansat in February 2018, making it the first Russian helicopter with LORD's Active Vibration Control technology.

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Reinforcement learning control for helicopter landing in autorotation

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This study presents an application of an actor-critic reinforcement learning method to the nonlinear problem of helicopter guidance during autorotation in order to achieve safe landing following engine power loss. A point mass model of an OH-58A helicopter in autorotation was built to simulate autorotation dynamics. The point-mass model includes equations of motion in vertical plane. The states of the point-mass model are the horizontal and vertical velocities, the horizontal and vertical positions, the rotor angular speed and the horizontal and vertical components of the rotor thrust coefficient. The inputs to the model were chosen to be the rates of change of the horizontal and vertical components of the rotor thrust coefficient. A reinforcement learning agent was trained by a model-free asynchronous actor-critic algorithm, where training episodes were parallelized on a multi-core CPU. Objective of the training was defined as achieving near-zero horizontal and vertical kinetic energies at the instant of touchdown. Training episodes were defined as the autorotative flight from an initial equilibrium flight condition to touchdown. During each training episode, the agent was presented a reward at each discrete time-step according to a multiconditional reward function. Constraints on the rotor angular speed, the rotor disk orientation and the rotor thrust

coefficient were implemented by structuring the reward function accordingly. Reward function was programmed to output a weighted sum of squared vertical and horizontal velocities at touchdown. Majority of the reinforcement signal came from this reward at touchdown, as it is a measure of success for the agent in accomplishing the safe autorotation landing task. The agent consists of two separate neural network function approximators, namely the actor and the critic. The critic approximates the value of a set of states. The actor generates a set of actions given a set of states, sampled from a Gaussian distribution with mean values as output set of the actor network. Updates to the parameters of both networks were calculated by an n-step returns scheme, which accumulates gradients coming from individual time steps into large, once per episode updates to improve training stability. RMSProp algorithm was used for optimization. After training is complete, the agent was tested against different initial conditions both inside and outside of the height-velocity (H-V) avoidance region of the standard OH-58A helicopter at maximum gross weight. Results achieved by the agent indicates that the method is well-suited for guiding the helicopter safely to the ground in a closed loop manner for a large initial condition state space. Controls generated by the reinforcement learning agent were found to be similar to a helicopter pilot's technique during autorotative 2ight. The study demonstrates that a significant part of a helicopterâAZs H-V restriction zone can be reduced using the presented reinforcement learning method for autonomous landing of a helicopter in autorotation.

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Development of a civil light helicopter flight simulator for pilot training

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This paper aims at de1ning the necessary characteristics to develop a reliable and cheap helicopter flight simulator that could be used in flight schools for pilot training. The main contribution is the definition of helicopter dynamics and model parameters that are necessary to reproduce those characteristics perceivable by a pilot in a simulated environment. From this analysis, a physical-based nonlinear helicopter model is implemented. The proposed model description allows helicopter flight characteristics to be modified by changing only few physical parameters, which are readily accessible. The helicopter model is integrated with commercially available off-the-shelf helicopter controls and a Virtual Reality headset to create a cheap fixed-based simulator. The helicopter simulator is then validated through a pilot in-the-loop experiment with five licensed helicopter pilots. Subjective as well as objective metrics are considered for the evaluation. Results suggest that the proposed flight simulator can be effectively used in flight schools to save flight hours for the training of novice pilots. However, for training expert pilots a more complex setup would be necessary, able to provide additional features like the motion cueing.

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Investigation on hovering rotors over inclined ground planes – a computational and experimental study

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The influence of time-varying ground effect (e.g., induced by ship deck motion) or even of static, inclined ground planes (e.g., hillsides) on the flow field and on the rotor inflow in hover is not yet understood. Therefore, experiments and CFD simulations were performed to study the flow field below a two-bladed 0.8 m-diameter rotor in hover over a parallel and a 15 degree inclined ground plane at a height of one rotor radius above the ground plane pivot point. Particle image velocimetry measurements were used to measure the rotor wake, and CFD simulations were correlated to the experimental results. To investigate the flow field, instantaneous, phase-averaged, and time-averaged data were used. The flow field was found to be sensitive to the ground plane inclination angle. It was found that the inclined ground plane reduced the unsteadiness in the flow field. The phase-averaged experimental results were predicted well by the numerical simulation. The computations captured the flow phenomenology well, but underestimated the influence of the inclined ground plane on the rotor inflow.

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Simulation tools for UAV/OPV autorotation performance metrics evaluation

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Under the framework of the US/France Project Agreement (PA) on Rotary Wing Aeromechanics and Human Factors Integration Research, ONERA and AED began to collaborate on helicopter autorotation capability in 2011. In 2017, a new joint task started, dedicated to improving control and guidance capability and defining requirements for implementation on rotary-wing UAV and OPV when operated in autorotation. This three-year program will investigate the enabling systems and technologies from an UAV automatic system to be used in an OPV for autorotation maneuver, thus taking the benefits of a full-automatic system to provide dedicated piloting aid functions. A modeling and simulation framework is proposed for designing, evaluating and testing flight control algorithms for helicopter autorotation flight. A common helicopter model and set of flight controllers have been developed and shared between ONERA and the US Army. Initial studies of the autorotation flare/landing metrics are presented and discussed, with a focus on using these metrics in the future to evaluate purpose-built automated autorotation controllers for UAV/OPV helicopters.

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Development of an automatic system for helicopter approach to a moving vessel

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The paper presents part of the results obtained in the HELIMARIS project (”Modification of an optionally piloted helicopter for maritime mission performance”) led by PZL Swidnik in cooperation with Warsaw University of Technology and CTO. In the paper, development of control algorithms for automated approach of a light single rotor helicopter to the moving vessel is presented. For the purpose of the approach task a Linear Quadratic Regulator (LQR) is used. The model of a helicopter is developed and evaluated in FLIGHTLAB software using flight test data for validation. Developed solutions and cases for approach of the helicopter to the vessel are presented and discussed.

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Mixed-sensitivity H_∞ on-blade control

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In this work, we investigate the use of H_∞ control design for OBC. The designed methods are tested on a hingeless analytical rotor model of the four-blade Airbus EC-145 helicopter with Active Trailing Edge Flaps (ATEF). In order to enable the application of the control methods, system identification tools are applied to extract two-input two-output Linear-Time-Invariant models at hover, 20, 40, 60, 80 and 100 knots forward flight. Such linear approximations are obtained after the rotor is trimmed with zero trailing edge flapping. The vibration reduction strategy is developed using robust control mixed-sensitivity methods targeting the fixed-frame 4/rev vertical force component with 4/rev flaps. The strategy is shown to be satisfactory in the sense that vibration mitigation is obtained with the implementation of a single controller operating for all considered forward flight cases. The vibration reduction was 60% in average in terms of the 4/rev component of the vertical hub force and the vibration reduction scheme is not interfering with the trimming of the rotor.

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Safety, quality and efficiency in flight data gathering

Regine Pattermann (Reiser)
Jos Stevens (NLR)

Safety, quality and efficiency are basic requirements on flight data gathering campaigns. The challenges of meeting all three of them in flight test campaigns planned for the purpose of simulator development are the main subject of the present paper. Specific processes for preparation and conduction of flight test campaigns are discussed according to the challenges of campaigns for simulation compared to those for aircraft certification. A newly developed flight test instrumentation that can be easily adapted for integration in a wide range of helicopter types and fixed-wing aircraft is described. The use of the flight test instrumentation and defined processes lead to convincing results with high safety standards. Thus, the flight test team optimises the process flow allowing the best possible result in terms of quality and completeness of the collected data, with acceptable investment costs for chartering the helicopters. During the data acquisition campaign, the Netherlands Aerospace Centre NLR carried out a substantiation of the data acquisition process through an independent assessment. The goal of this substantiation is to evaluate whether the data acquisition process is capable of delivering accurate data of good quality and is representative of the helicopter type to be modelled.

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Studies on the influence of rotor distance on the efficiency of a coaxial rotor system

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Coaxial rotor systems are of special interest on aircraft with electric propulsion. An experimental analysis of the performance of such a system is described in this paper. Two rotors with identical geometry are operated at an equal rotational speed. The presented test bench allows to measure electrical and force data individually for both rotors. Analyses are conducted in the hover case as well as in a case with an axial incidence flow in a wind tunnel for various rotor separation distances. Efficiency of the rotor system is compared to a single rotor. It is shown that the separation distance of the rotors has a strong influence on the upper and lower rotor individually, although the combined performance is approximately independent in the hover case. In the case with an axial incidence flow, overall efficiency of the analyzed rotor system increases for a smaller rotor separation distance.

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Implementation of aero-elastic capabilities in a LBM flow solver: application to a low-Reynolds rotor for Micro-Air Vehicles

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Micro air vehicles (MAVs) are used both for civil (rescue missions) and military (surveillance, recognition) applications. However the aerodynamic performance of the propeller is known to be lower than for classical large rotors, due to leading edge vortex

occurring at low Reynolds number flows. Such rotors can also exhibits a flexible behaviour due to the material used to build the blades, making the prediction of aerodynamic performance challenging for numerical flow solvers. A potential way to improve the rotor performance is also to take advantage of the flow unsteadiness, by imposing an unsteady forced motion, like a periodic variation of the rotor pitch. There is thus a need to develop aero-elastic capabilities in numerical flow solvers, which is the main objective of this paper. The method relies on the implementation of Fluid-Structure Interaction (FSI) capabilities in a Lattice-Boltzmann flow solver, in order to take advantage of the flexibility allowed by the immersed boundary approach. FSI capabilities are implemented in a monolithic fashion, using generalised coordinates to represent the blade as a flexible beam. Two sets of simulations are performed: a) with a forced motion and b) by coupling the flow with the equation of the dynamics. Results show that a forced motion has a good potential to increase the rotor thrust but significant improvements should yet to be done to reduce the over-power consumed by the forced motion. While dynamic flapping has a negligible influence on the flow, dynamic pitching has the potential to moderately modify the pressure distribution at the trailing edge. However its impact on the rotor performance is weak (less than 0.5% on the thrust).

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Prediction of unsteady aerodynamic loads and wake structure of wind turbine in yawed inflow

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A wind turbine is becoming as one of the most promising and cost-effective renewable energy sources, due to its economic merits and technical maturity. It especially spends considerable time under yawed flow condition during operating time. Under the yawed flow condition, a velocity component parallel to the rotating plane exists, and this leads to skewed wake structures. Because of the skewed wake geometry, the trailing and shed wake vortices unequally expand, and asymmetric inflow distribution on the rotor blades, a strong wake-wake interaction between the hub and tip vortices, and the curled vorticity fields around the rotor area occur. Consequently, the yawing angle causes an azimuthal variation in the aerodynamic loads, thus leading to structural damage to wind turbine components. In the present study, the impacts of the skewed wake on the aerodynamic performance of a wind turbine were numerically investigated and discussed in detail. For this purpose, the nonlinear vortex lattice method coupling with a time-accurate vortex particle method was used. A numerical simulation of the TU Delft and NREL Phase VI wind turbine models was carried out, and predicted results were compared against measurements. The results showed that the aerodynamic loads can be accurately calculated, even for highly yawed flow conditions and complex wake dynamics can be clearly observed.

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Dynamic stall model optimization with CFD and assessment with comprehensive approach for improved blade design

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An enhancement for comprehensive modelling of rotor in forward flight is proposed to enable inclusion of dynamic stall and study characteristic effects on rotor loads and performance in design phase. The characterization of dynamic stall behavior of the selected airfoil on the design is performed with validated CFD analyses. Parameter optimization is performed for the dynamic stall and unsteady aerodynamics model in CAMRAD II, comprehensive analysis tool, to attain maximum similarity with CFD based predictions. Optimized dynamic stall model is then utilized to study rotor loads at dynamic stall dominated flight condition. Using the improved analysis framework with optimized dynamic stall model, the effect of anhedral tip shape on blade loads and stall onset characteristics is studied. It is observed that, anhedral modification to a blade tip combined with dynamic stall phenomena, worsens rotor torsional loads. On the other hand, application of an up-wash twist at tip anhedral region, improves the degraded load characteristics. The aim of this study is practice estimation of dynamics stall characteristics of an airfoil of interest with CFD, optimize dynamic stall model in accordance and investigate effect on rotor loads in the presence of anhedral.

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AH-64 loss of lubrication study: Test of isotropic superfinished AH-64 (Apache) engine nose gearbox without black oxide coating

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Rotorcraft gearboxes are designed to the utmost precision to withstand the tremendous demand and loads required to convert thousands of horsepower and RPM into hundreds of RPM and lift torque. The transmission components and the lubricants utilized incorporate various technologies to enable proper function and longevity. Many of these technologies are “tried and true” over the course of hundreds of thousands of flight hours and decades of real flight experience. As a result, replacement of these legacy technologies requires a tremendous amount of testing and qualification. The US Dept. of Defense conducted a loss of lubrication test of an AH-64 Engine Nose Gearbox (ENGB) with Isotropic Superfinished (ISF) gears instead of the legacy black oxide coated gears. The question addressed in this paper is; will the low Ra value generated by Isotropic Superfinishing lead to scuffing, especially if the Black Oxide Coating is eliminated, and to go deeper, will the gearbox survive the mandatory loss of lubrication test requirements, which is a punishing test designed to simulate a realistic failure scenario within the gearbox. Success for this test is demonstrated by the ability of one gearbox to continue to transmit torque for 60 minutes after loss of lubrication, or of two gearboxes to continue to transmit torque for at least 30 minutes each after loss of lubrication. Upon successful completion of the loss of lubrication test, the gearbox was subjected to a detailed tear-down analysis which indicated no discernable damage occurred to the gear teeth.

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Rotorcraft shipboard landing guidance using MPPI trajectory optimization

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With shipboard launch and recovery operations remaining a challenge, there is a continuing emphasis to determine pilot assist functions in order to reduce pilot workload arising from handling the effects of ship air wake turbulence, random ship motion and degraded visuals associated with this task. This paper is an extension to previous work which investigated the use of Model Predictive Path Integral (MPPI) approach, a stochastic optimal control method, for trajectory guidance during shipboard landing. With the objective of developing a real-time guidance solution, this paper focuses on understanding the effect of the performance measure and parameters associated with the method by using a linear model for prediction and a nonlinear model as a representation of the actual vehicle. First, in continuation with an earlier paper, a simple study is conducted by including yaw attitude constraint during shipboard landing using a six degrees-of-freedom linear model of the helicopter in the MPPI method. Next, a test is conducted where a linear model is used in the MPPI algorithm to predict the helicopter behavior for the entire landing with a nonlinear model serving as the truth model. Lastly, the effect of prediction window on MPPI performance is investigated. The paper concludes with key observations and inferences gained in this study.

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A preprocessor for parametric composite rotor blade cross-sections

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Structural helicopter rotor blade optimization comprises classical aeroelastic problems, where the aerodynamic behavior, the structural elasticity and vibrational dynamics have to be studied simultaneously. Since the dynamic and modal behavior is strongly related to the structural properties of the rotor blades, adjusting these properties is essential for an effective optimization. Nevertheless, identifying constraints based on elemental matrices to keep the solution within feasible boundaries is often a protracted and iterative task. In this paper a structural preprocessor for parametric analysis and design of composite beam cross-section is presented. The herein presented definition of the rotor blade topology is deliberately associated to the production of composite rotor blades. Thus, manufacturability is inherent from the geometric layup definition. Using orthogonal projection with corner-style differentiation the cross-section is discretized and processed by the Variational Asymptotic Beam Sectional Analysis (VABS) afterwards. The approach is successfully demonstrated with generic UH-60A composite rotor blade cross-sections.

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Aerodynamic analysis of helicopter in interaction with wind turbine's wake

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Over the last 20 years wind energy has undergone a significant growth. The installation of new wind farms is increasing globally with an average rate (over the last five years) of 10 percent every year. Current commercial wind turbines (WTs) have diameters that range between 90 to 150 meters and their total height exceeds 200 meters. Manufacturer's ambition points towards even bigger turbines with rotor diameters that within the next decade will reach sizes of about 250m. The above development will consequently lead to larger areas occupied by future wind farms. On the other hand, helicopters often execute low altitude flights following trajectories that cross wind farm areas. Furthermore, helicopters are commonly used as transport mean for maintenance staff transportation missions to distant offshore wind farms (as for example in the North Sea where many wind farms have been deployed over the last years). It is therefore foreseen that in the coming years the possibility for a helicopter to fly in interaction with a wind turbine wake will increase. Lack of previous experience or evidence renders safety checks necessary. In this respect of particular significance is to know whether safe passage through or in strong interaction with the wake of an operating wind turbine is possible or in such occasion the turbine should be shutdown. In the present paper, the aerodynamic interaction of a helicopter main rotor with a wind turbine wake is analyzed on the basis of free wake vortex analysis. Helicopter forward flight crossings of wind turbine wakes are simulated using different wake flow models.

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Rotorcraft-pilot couplings: analysis and detection in a safety enhancement framework

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Nowadays, the complexity of high speed civil transport and highly-augmented rotorcraft, has led to an increase in the chances of encountering unwanted unstable phenomena, such as the so called Aircraft/Rotorcraft-Pilot Couplings (A/RPCs) or Pilot-Induced Oscillations (PIOs), whose unpredictability has given rise to a serious problem concerning the safety of a mission. When talking about PIOs, McRuer defined them as "inadvertent, sustained aircraft oscillations which are a consequence of an abnormal joint enterprise between the aircraft and the pilot". However, A/RPCs, these undesirable events associated with the interaction between pilot and aircraft, have become diverse and more complex than those encountered in the past. At the moment, there are different methods available to prevent and detect Cat. I/II A/RPC, but particular interest has recently arisen in this topic for 2ight simulation applications as any enhancement of these tools in order to accurately and objectively predict, detect (in real-time) and alleviate RPCs will be greatly welcomed. One of the main questions to be answered through the

efforts carried out within this work is related to the better detection in real-time of embedded tendencies to RPCs in modern aircraft. To answer this question, initially an assessment of the efficacy of the Phase-Aggression Criterion (PAC), which has been designed a few years ago at the University of Liverpool, will be undertaken either: as a means of alerting the pilot to conditions likely to lead to the onset of a PIO; or, given that the time available for the pilot to counteract may be extremely limited, as a means to assist him/her in alleviating (automatically) the PIO condition itself. Preliminary results from flight simulation trials to explore how best to achieve this will be reported. Moreover, this work will report on the development of PAC boundaries for more highly augmented response types. Furthermore, as classi1ed by McRuer, Cat. III PIO, which is nonlinear in essence, is the most complex one. However, the researches on Cat. III PIO are rare. This paper will reveal some elementary results of Cat. III PIO. Since there is no existing method used for predicting and detecting Cat. III PIO, this paper utilized the characteristics of PIO, such as the amplitude, the oscillation frequency and ultimate tendency of key aircraft response states to judge Cat. III PIO preliminarily. By using this elementary judgment of PIO, we studied the following factors: time delay of pilot input and helicopter main body, actuator position saturation, actuator rate limit and SCAS control authority in triggering PIO. Results show that PIO induced by actuator position saturation, actuator rate limit and SCAS control authority can be regarded as Cat. III PIO as the variation of these factors can be viewed as a kind of transition of effective controlled vehicle dynamics. These kinds of transition can cause a mismatch between the effective controlled vehicle dynamics and pilot control strategy, which is the main cause of Cat. III PIO.

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Modeling and simulation based analysis of a hybrid multirotor unmanned aerial vehicle concept

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The goal of this study is to design a hybrid Unmanned Aerial Vehicle (UAV) having four rotors and a fixed wing, then to model and design a controller for the UAV. Quadrotor is a mechanically simple aircraft to control however its endurance and flight speed is limited. On the other hand, conventional fixed-wing aircrafts have long endurance and flight speed compared to quadrotor UAV. A hybrid UAV is able to take-off and land vertically without a need of landing area. Besides it has high endurance, flight speed, and payload capacity compared to multirotor UAVs. For this reason, a hybrid UAV is decided to be designed conceptually and modelled according to the mission of the aircraft. MH 60 airfoil is chosen for the fixed-wing since it has low pitching moment. Rotor forces and moments of the propellers are found through the blade element and momentum theories. Wind tunnel experiments are conducted in order to verify the results found by the blade element and momentum theories.

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Measurement of rotor blade structural dynamics

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Initial results collected with optical fibre Bragg grating (FBG) strain sensors and with a novel direct fibre optic shape sensing approach during a series of ground vibration tests performed on a rotor blade are presented. A number of key benefits highlight the potential of applying the shape sensing system to complex rotor blade structures: (1) no information of the underlying structure is required to infer the shape and (2) the rotor blade structural characterization can be achieved with only one straight fibre optic cable that is mounted along the length of a rotor blade. An assessment of sensor performance has shown that the results are within 4% agreement with commercially available instrumentation systems. Limitations of the use of FBG based strain gauges are discussed in terms of the dependency of strain measurements on the position of neutral axis.

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Application of parametric airfoil design for rotor performance improvement

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A parametric airfoil design tool, PARFOIL, has been developed in a framework of rotor optimization. The design parameters in PARFOIL include camber and its crest position, thickness and its crest position, leading edge radius, trailing edge camber and its crest position, and boat-tail angle. Upon replacing the standard SC airfoils (SC1095 and SC1094R8) with the advanced RC airfoils (RC(3)-08 and RC(4)-10NL), a sensitivity study with design parameters is performed for UH-60A rotor performance. Camber crest position is found the most influential design parameter. Based on the outcomes in the sensitivity study, new rotor blade configurations are designed and examined for performance improvement. In comparison with the UH-60A standard rotor configuration, it is found that the performance-based best rotor reduces power required by 3.2% in hover, 11.3% at μ=0.3, and 13.6% at μ=0.4. This demonstrates the ability of PARFOIL to produce better airfoils in the design space. In spite of the performance improvements, the pitch link load of the performance-based best rotor shows an increase of about 8.5% from the UH-60A standard rotor configuration for the UTTAS high-g pull-up condition, which indicates the need to consider pitch link load under high thrust condition as a constraint in the blade design process.

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Vibration fatigue analysis of rotorcraft horizontal tail method using finite element

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Aircraft structure are exposed to a combination of wide-band frequency content with harmonic components loads due to the random aerodynamic loading and periodic loading caused by the rotors and transmissions of the helicopter. This situation makes structural analysis to be dynamic in nature. Therefore, the tools of dynamic analysis are applied to study the structures behaviour under these loads. The present work is carried out to determine the fatigue damage accumulated under dynamic loading conditions. The finite element analysis was performed for a helicopter structural element (the Horizontal Tail), which is exposed to the particular combination of wide-band random with sinusoidal vibrations, which is characteristic to the helicopter dynamic environment. The evaluation of the fatigue damage induced by these loads requires the calculation or measurement of the structure's dynamic response in terms of stresses or strains, and the application of the appropriate methodology to this response. In this work, dynamic response was calculated in the frequency domain based on the relations between the power spectral density matrixes of the excitations to that of the responses for a linear system. The transfer matrix that relates the excitation to the responses was evaluated numerically. The power spectral densities of the responses evaluated at specified locations on the structure were used in the determination of the responses.

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Tracking dynamically scaled separating objects during a helicopter wind tunnel test

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A wind tunnel test was made to investigate safe dropping of objects from a helicopter, as might be needed during emergency situations. For a correct simulation of the object trajectory, Froude scaling was used, which also required a proper dynamic scaling of the object mass, center of gravity at mass inertia. A rapid prototyping manufacturing technique was used for the dropped objects. On the dropped objects a unique pattern of fluorescent markers was applied and the position of the individual markers was determined by a Stereo Pattern Recognition technique, using two high speed (500 Hz) cameras. Post-processing of these camera images provided detailed information on the object trajectory and the object attitude angles, which were the prime purpose of the tests. With detailed trajectory data available an attempt was made to derive the aerodynamic forces and moments on the object during its fall. This application requires high accuracy of the trajectory data, which could not be reached with the test setup chosen. The paper presents the test setup and model and then focusses on the trajectory measuring system used, the results obtained and a discussion on how the trajectory measurement accuracy might be improved.

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BladeSense – a novel approach for measuring dynamic helicopter rotor blade deformation

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Technologies that allow accurate measurement of rotorblade dynamics can impact almost all areas of the rotorcraft sector; ranging from maintenance all the way to blade design. The BladeSense project initiated in 2016 aims to take a step in developing and demonstrating such a capability using novel fibre optic sensors that allow direct shape measurement. In this article the authors summarise key project activities in modelling and simulation, instrumentation development and ground testing. The engineering approach and associated challenges and achievements in each of these disciplines are discussed albeit briefly. This ranges from the use of computational aerodynamics and structural modelling to predict blade dynamics to the development of direct fibre optic shape sensing that allows measurements above 1kHz over numerous positions on the blade. Moreover, the development of the prototype onboard system that overcomes the challenge of transferring data between the rotating main rotor to the fixed fuselage frames is also discussed.

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Assessment of the feasibility of an extended range helicopter operational standard for offshore flights

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The accident rate of rotorcraft has improved significantly over the years but at a slow pace, and in any case the number of accident per flight hours is one or two order on magnitude higher than that of commercial aircraft. This could be reasonably related to the inherent higher risk associate with rotorcraft operations. This represent a strong evidence of the necessity to introduce airworthiness operation standards also in the rotorcraft community, as an effective mean to improve safety records, borrowing the experience done in the commercial air transport community with the introduction of ETOPS. In this paper a first proposal of development of a safety standard for helicopter offshore operation is discussed together with the possible support to this development that could be given by the EU H2020 NITROS project.

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Using multibody dynamics for the stability assessment of a new double-swept rotor blade setup

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A new double-swept rotor blade setup has been assessed in frequency domain for both, dynamic stability in terms of ground resonance and aeroelastic stability related to rotor blade and rotor flutter. The blade setup is being developed for a rotor test rig and will be operated under axial inflow. Methodology is based on a multibody system which is coupled with an unsteady aerodynamic model based on Wagner's function and related enhancements for the general motion of an airfoil section considering heave and pitch motion. The simulation model uses modelling techniques for the setup of a linearized model and allows both, the investigation of ground resonance and flutter for the rig with clamped and articulated rotor blades in frequency domain. Numerical results for the two- and four-bladed rotor state dynamic stability for the setup with clamped blades within the planned rotor speed range up to 65 Hz, whilst the setup using articulated blades with lead-lag hinges indicates instability at low scale starting from a rotor frequency of 30 Hz. The aeroelastic assessment shows a small hump in the damping curves for the two-bladed rotor which is found instable at rotor speeds around 20 Hz for both rotor setups. Here, the flutter mechanism has major contributions from the backward whirl mode and flap bending modes. In contrast, the four-bladed rotor configurations do not show flutter.

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Some results of GARTEUR Action Group HC-AG 19 on methods for improvement of structural dynamic finite element models

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The issue of vibration in helicopters is of major concern to operators. This requires close attention to the vehicle dynamics. The ability to faithfully simulate and optimise vehicle response, structural modifications, vehicle updates, the addition of stores and equipment is the key to producing a low vibration helicopter. GARTEUR Action Group, HC-AG14, concluded that helicopter dynamic models are still deficient in their capability to predict airframe vibration. The AG looked at the methods for improving the model correlation with modal test data along with the suitability of existing shake test methods. The helicopter structure tested in AG14 was suspended in the laboratory. However, this is not the operational environment where there are very significant mass, inertia and gyroscopic effects from the rotor systems. Nowadays, modal analysis consists of two principal approaches: experimental modal analysis (EMA) and operational modal analysis (OMA). The EMA evaluates the modal parameters by considering that the excitation and the response of the system are both measurable. The OMA evaluates the modal parameters using only the measured response. The lack of knowledge of the input is replaced by the assumption that the input is a distributed stochastic load, constant in a broad frequency band, e.g. white noise, and uncorrelated in space. This hypothesis, nevertheless, is restrictive in rotorcraft applications, because in these cases the load is characterized by harmonic components, i.e. deterministic signals, originating from the rotating parts. A new action group HCAG19 was formed to study the benefit of using in-flight dynamic data for improving finite element models. Methodologies were assessed to evaluate vibration measurements from flight tests. The objective is to extract modal parameters and demonstrate that the dynamic model can be updated using this data. This paper presents one of the approaches developed by the University of Rome "La Sapienza".

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Actively controlled trailing edge flaps with electromechanical actuation

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The present paper studies Active Rotor Control for helicopters. It is shown that Individual Blade Control (IBC) concept is more preferable for the purposes of rotorcraft vibrations reduction. There described electromechanical pre-prototype actuator and active flap control model test simulator designed by the Mil Moscow Helicopter Plant. Active flap control model and electromechanical pre-prototype actuator test data obtained at the Mil Moscow Helicopter Plant test facilities are provided. The obtained results show that electromechanical actuator of the type could be applied in the active rotor control systems for both existing and future rotorcraft.

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Development of UAV rotor blades using RTM process

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Since 2010, KVE Composites Group (KVE) has been developing Unmanned Aerial Vehicle (UAV) rotor blades (RB). Typically, these rotor blades are developed with limited budgets but still require a sound engineered design to prevent resonance of the rotor system, withstand limit loads and have long fatigue lives. Based on the structural design concept, KVE has developed a cost effective manufacturing process using Resin Transfer Moulding (RTM) to manufacture rotor blades. This single shot technique allows high manufacturing rates and also allows the engineer to design blades with a continuous reinforced leading edge and trailing edge laminate. The process also allows KVE to reliably manufacture blades with integrated balance weights which need only limited balancing afterwards. An important aspect of rotor blade development is the validation of design. KVE has developed in house testing tools for rotor blade characterization and structural testing.

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The conceptual design of auto-rotary mono-wing decelerators (ARMWIND) based on the functionality of maple seeds as an alternative entry-decent-landing system for explorations on Mars

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Within the next years several missions will take place to land scientific payloads on Mars. Most of the upcoming missions will deploy rovers, but also other scientific payloads are to be delivered to the surface. In this regard, one essential technology to master is the Entry-Decent-Landing (EDL). The disadvantages of the existing EDL systems and the Martian environmental barriers might be avoided by the implementation of an auto-rotative descent and landing system. The intended design of auto-rotary EDL system presented in this paper (ARMWIND) is based on the geometry and dynamics of a maple seed. The advantage that this design has is that not only uses the auto rotation EDL system as a decelerator and a gliding tool for increasing the maneuverability during landing but also it takes advantage of the rotation to store energy by converting the kinetic energy of the rotation into potential energy in batteries or springs. This potential energy can later be used to generate the required extra rotational energy for the rotor to produce enough lift for decelerating the payload with near-zero impact velocity or any other possible utilization after landing.

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Airbus Helicopters (AH) Flight Test Safety Management System

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The Airbus Helicopters Flight Test Directorate has developed a specific Flight Test Safety Management System (SMS) and associated concepts and tools. The presentation will provide an overview and the main principles of this SMS and provide some details on issues at stake. The SMS principles of ICAO document 9859 ‘Safety Management Manual’ have been used as guidance material but not found fully adequate for development and certification flight tests performed by a helicopter manufacturer. Additionally, the FAA order 4040.26B ‘Aircraft Certification Service Flight Test Risk Management Program’ was used and also found not fully adequate for some topics. Basically in many cases, development flight tests present a much higher risk than standard aviation operations. For example, even if all possible mitigations based on analysis, computations, simulations, quality checks, ground tests etc. have been taken into account, the first flight of a new aircraft still presents a significant risk level. The typical risks in flight tests (called: Test Risk) could come from a technical side (flight of a new aircraft/concept, installation of a new engine, modification of lifting surface, etc.) or from specific flight test operations not conducted/authorized during certified operations (deliberate engine shut down in critical flight phase, flight above max certified speed, etc.). In addition the “standard” risks (called: Operational Risk) linked to any aviation operations have to be considered. Airbus Helicopters has built a methodology and associated tools to evaluate and rate these two risks for each test flight. The SMS defines the mitigation actions for each type of test, the level of delegation/empowerment to the crew and the associated escalation possibilities depending both on the type of Test Risk level as well as the Operational Risk level. The presentation will clarify the concept behind, which has become a standard for all flight operations within Airbus Helicopters with the aim of making its’ operations even safer.

3. AHS & ARF Best Papers

AHS Best Paper

Avoiding obstacles during approach: DVE-mitigation flight trials and beyond

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Helicopter landings on unprepared sites can quickly become a challenging task. Especially when environmental factors reduce the available visual cues for the pilot, the risk of disorientation increases. Motivated by avoiding accidents during helicopter approaches, a novel pilot assistance system was developed by a workgroup from the German Aerospace Center (DLR) and HENSOLDT Sensors GmbH. The research system combines 3D conformal tunnel-in-the-sky symbology with dynamic path updates driven by a laser sensor. In early 2017, the system was evaluated in flight using DLR's research rotorcraft Active Control Technology/Flying Helicopter Simulator (ACT/FHS). The workgroup was tasked to participate in flight trials with U.S. and Swiss teams during the NATO sponsored flight trials within the scope of the DVE-Mitigation (DVE-M) program. In this program, international efforts in the development of systems for enhanced situational awareness during DVE are supported. The evaluation of the system during the DVE-M trials included approaches which were obstructed by a truck with a 20m high man lift. Four external test pilots participated in the evaluations. Following the positive results obtained during these trials, two further flights were conducted in local scenery at Braunschweig/Wolfsburg airport, including a construction site with a hangar and a crane. Results of these six flights are presented and discussed in detail.

ARF Best Paper

A study of rotor/wing aerodynamic interaction at high speed flight on a compound helicopter

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Yasutada Tanabe (JAXA)

Rotor/wing aerodynamic interaction is considered one of the key technology issues for compound helicopter design. Understanding of the influence on the rotor and the wing aerodynamic characteristics by the aerodynamic interaction is significantly important. This paper describes about the investigation of rotor/wing interaction through a numerical simulation using a rotorcraft CFD solver, rFlow3D, developed at JAXA. A simplified computational model with a rotor and a wing is considered. A rectangular wing model is added to the UH-60A helicopter with the wing size for the original maximum takeoff weight. To investigate the influence of rotor/wing aerodynamic interaction, the isolated rotor and the isolated wing configurations are firstly simulated and then compared to the rotor/wing combined configuration. Two flight conditions at the cruising speed and at the maximum speed are computed. The rotor speed is reduced to 75% RPM at high speed flight condition. The numerical simulation result indicates that the total effective drag of the rotor/wing configuration is increased than the simple summation of the isolated models. The wing lift is reduced by rotor/wing aerodynamic interaction, and the required rotor thrust is increased to keep the same total lift. The sectional normal force on the wing has an asymmetric distribution. The sectional lift is significantly reduced and the sectional drag is increased on the wing side below the rotor advancing side. On the wing side below the blade retreating side, the rotor has much slight effects on the sectional lift and drag on the wing.