Vertical Lift Network: Technical Workshop

Nunsmere Hall, Oakmere, Cheshire
10-12 April 2015

Edited by A. Filippone, N. Bojdo & G. Barakos

10th April 2015

Welcome

UK Vertical Lift Network: 1st Technical Workshop

Taking a Snapshot of the Academic Research in Vertical Lift

Ref. Number: VLN.W1

Date: 10th – 12th April, 2015

Location: Nunsmere Hotel, Oakmere, Cheshire

Welcome to the **1st UK Vertical Lift Network Technical Workshop**.

The recently established UK Vertical Lift Network (www.ukvln.net) aims to bring together the UK research community on vertical lift. Inspired by similar events taking place outside the UK, and the past glory of the Burn helicopter meetings in Scotland, this first Technical Workshop is a chance for students and researchers to present their work on a wide range of related subject areas. This event will allow the UKVLN to obtain a snapshot of today's research in the rotorcraft and vertical lift areas and use this event to mark its launch as an EPSRC Network.

The workshop programme is based around contributions from the following VLN Themes:

- Operations & Handling
- Environment
- Aerodynamics
- Power plant
- Flight Mechanics
- Dynamics

Each presentation slot is 25 minutes; 20 minutes presentation time followed by 5 minutes of Q & A. Additional time over the weekend has been allocated to open discussion on matters such as collaboration or funding opportunities, to allow this event to work as a forum for ideas and future ambitions.

This book of abstracts will be provided to all attendees at the event; an electronic copy is also available on request (13mb) from Nicholas.Bojdo@manchester.ac.uk.

We hope you enjoy the event!

Antonio Filippone, George Barakos, Nicholas Bojdo

The 1st Annual UK Vertical Lift Network Technical Workshop

Nunsmere Hall Hotel, Oakmere, Cheshire

10-12 April 2015

UK Vertical Lift Network

Final Programme

Friday 10th April

10.00 - 15.00	VLN Meeting			
15.00 - 15.20	**Keynote**	Antonio Filippone	MAN	*Introduction to the VLN Activities*
15.20 - 15.45	**Aerodynamics 1**	Dan Poole	BRI	*High-Fidelity Simulation of Vortex Generators for Tiltrotor Aircraft Wings*
15.45 - 16.10		Richard Green	GLA	*The Clean Sky CARD project: wind tunnel measurements of a model helicopter rotor and fuselage drag*
16.10 - 16.25	Coffee			
16.25 - 16.50	**Powerplants**	Fakhre Ali	CRA	*Multidisciplinary Design and Optimisation of Conceptual Rotorcraft Powerplants:*
16.50 - 17.15		Nicholas Bojdo	MAN	*Helicopter Environmental Engine Protection: Progress and Challenges*
17.30 - 19.30	Dinner			

Saturday 11th April

09.30 - 09.50	Coffee			
09.50 - 09.55	**Opening Remarks**	Antonio Filippone	MAN	
09.55 - 10.20	**Flight Mechanics**	Kevin Ferguson	GLA	*Study of a Coaxial Compound Helicopter flying Mission-Task-Elements*
10.20 - 10.45		Clement Crozon	LIV	*Coupled CFD/Flight Mechanics method for SHOL*
10.45 - 11.00	Coffee			
11.00 - 11.25	**Aerodynamics 2 / Operations & Handling**	Daniele Zagaglia	GLA	*Experimental investigation of the aerodynamic interaction between a helicopter and ground obstacles*
11.25 - 11.50		Giulia Chirico	LIV	*Helicopter wake interaction with ground obstacles*
11.50 - 12.15		Yaxing Wang	LIV	*Simulation of helicopter and wind turbine wake encounters with light aircraft*
12.15 - 14.00	Lunch			
14.00 - 14.25	**Aerodynamics 3**	Massimo Biava	LIV	*Adjoint-based optimisation methods for rotorcraft blades*
14.25 - 14.50		Mark Woodgate	LIV	*Implicit Unstructured Methods for fuselage CFD analysis*
14.50 - 15.15		Antonio Garcia	LIV	*Tilt-rotor CFD using the Helicopter Multi-Block solver*
15.15 - 15.30	Coffee			
15.30 - 15.55	**Dynamics**	Djamel Rezgui	BRI	*Non linearities in Rotating Blade Dynamics*
15.55 - 16.20		Vasilis Pastrikakis	LIV	*Simulation of helicopter rotors equipped with Gurney flaps*
16.20 - 17.15	**Open Discussion / Close**		ALL	
17.30 - 19.30	Dinner			

Sunday 12th April

09.30 - 09.50	Coffee		
09.50 - 12.15	**Open Discussion / Walk**		
12.15 - 13.30	Lunch		
13.30 - 14.00	**Closing Speech**	Antonio Filippone	MAN

BRI - University of Bristol
CRA - Cranfield University
GLA - University of Glasgow
LIV - University of Liverpool
MAN - University of Manchester

The Vertical Lift Network: An Introduction

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The vertical lift network (VLN) was funded in 2013 as the central forum to develop and consolidate all the research on rotorcraft systems within the United Kingdom. This network builds on long-established expertise built on research in several inter-connected areas, from aerodynamics to flight mechanics, from acoustics to flight simulation. Over the years, the rotorcraft expertise has been fragmented, due to short-term funding and other factors. More recently, there has been a revival of ideas, thanks to advent of active rotors, tilt-rotors, fast compound helicopters, fan-in-wing vehicles, unmanned air vehicles, quad-rotor systems. These vehicles share some commonality – the vertical lift capability. However, they bring new challenges in the analysis, design and flight control. Therefore, rotorcraft may be facing one of the biggest technology challenges since the development of the first practical helicopter. It is recognised that no single academic institution has expertise and test facilities to take on many of the complex projects required by the industry.

The network builds on a comprehensive partnership among the key academic institutions in the UK, and important segments of the industry, including the Ministry of Defence. The Aerodynamics Growth Partnership reported that the "UK's future competitive success will depend on its ability to stay at the leading edge on four key areas of technology". One of these areas is advanced aerodynamics. This initiative clearly demonstrates the importance of research in aerospace engineering. A number of large international programmes such as CleanSky2 provide a platform for multi-disciplinary research. So does the Aerospace Technology Institute (ATI), which has already funded, among other things, a consolidation of the experimental infrastructure. This includes the commissioning of a national experimental rotor rig that is aimed at replacing facilities decommissioned several years ago.

This presentation will give an overview of the aims of the network; it will review some of the funding available schemes, and will attempt to address strengths and opportunities in all the areas of vertical lift. This VLN workshop is the first of an annual series for the EPSRC-funded network.

High-Fidelity Simulation of Vortex Generators for Tiltrotor Aircraft Wings

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I. Introduction

In forward flight the lift of a tiltrotor aircraft is provided by conventional wings. However, due primarily to structural issues, these wings are of small span, and so low aspect ratio, and also very thick to allow sufficient internal volume for the drive mechanism to the tip-mounted and hinged rotors. This results in a highly loaded wing that is particularly susceptible to stall and buffet , so boundary layer control is critical and, hence, upper surface flow control devices are an important consideration. A wide variety of flow control devices and systems can be fitted to control separation but by far the most common methods are passive schemes, with vortex generators (VGs) a conventional approach. These involve small flat plates normal to the surface, usually rectangular in shape, inclined to the freestream flow.

It is necessary to understand the physics that the VGs are introducing into the flow. The intention of this work is to quantify the effects of vortex generators on the flow around a representative tiltrotor aerofoil, with particular attention being paid to the analysis of the shear layer; metrics are developed detailing the association of the VG design with flowfield variables. This is done within a computational environment initially, and detailed flow analysis tools are developed to quantify vortex generator effects.

II. Simulation Approach and Initial Results

The modelling of the vortex generator and resulting flow is not a trivial task; the suitable capture of the physics requires high fidelity solvers and high density numerical meshes. However, this is merely the first stage of the work. The primary purpose of the research concerns the simulation of numerous VG configurations, in order to assess the optimal design considerations. The simulation approach uses structured meshes which are produced using a transfinite interpolation approach. Flow solutions are been obtained using OpenFOAM[a] to solve the RANS equations. To demonstrate the software, initial simulations, involving a VG on an aerofoil, are undertaken at a Reynolds number of 9 million, and a Mach number of 0.2 on a NACA 6 series aerofoil. The 3D mesh extends to 100 chords farfield and contains 1,522,496 cells. The set-up of the problem and simulation results are shown in figure 1.

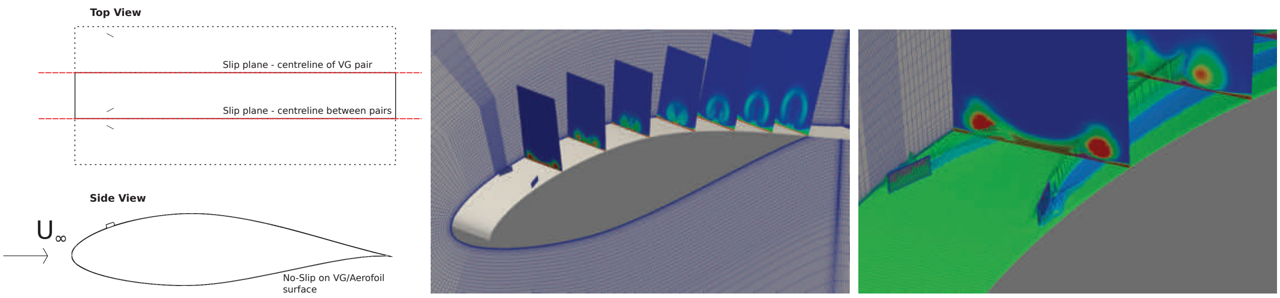

Figure 1: Problem set-up and initial results

III. Ongoing Work

The quantification of the effects of flow around a tiltrotor-like aerofoil with vortex generators has been considered using high-fidelity simulations. The work presented at the workshop will expand on the initial simulations presented and detail approaches developed for the design of the vortex generators. Particular attention if to be paid to the design using metrics developed to quanitify the effects of the VG on boundary layer properties.

III.A. Acknowledgements

The authors would like to thank David Tring and Nigel Scrase of AgustaWestland, for their support of and contribution to this work. The financial support, via the HiPerTilt project, of AgustaWestland and Innovate UK (Technology Strategy Board) is also gratefully acknowledged.

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[a] `http://www.OpenFOAM.org/`

The Clean Sky CARD project: wind tunnel measurements of a model helicopter rotor and fuselage drag

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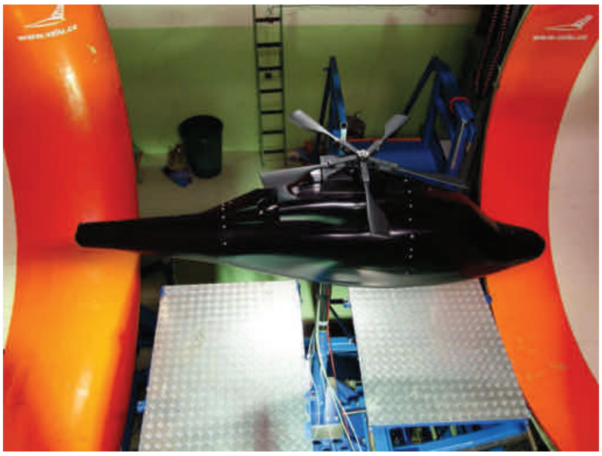
It is well known that helicopters have high aerodynamic drag compared to fixed wing aircraft. While the fuselage and rotor blades can be designed to be as aerodynamically efficient as possible, the complex aerodynamic environment of the rotor system and associated interactions can lead to a higher overall drag than otherwise expected. High drag compromises the endurance of the helicopter, and presents an additional operational expense. Furthermore combustion emissions need to be reduced, and the high drag of a helicopter presents a challenge to this goal. Any attempt to reduce the drag of the helicopter must address the aerodynamic environment of the rotor hub and the fuselage area around the rotor hub. Research projects to investigate helicopter drag reduction under the EU Clean Sky Green RotorCraft Research Programme reflect this need, and this paper presents results from the CARD project (Contribution to Analysis of Rotor hub Drag reduction) conducted in collaboration with the ARA (UK), VZLU (Czech Republic) and Airbus Helicopters (France). While analysis of the helicopter aerodynamics is a significant challenge for computational fluid dynamics, a wind tunnel experiment to validate designs and provide research data must be able to separate out the various contributions to the drag due to the rotor components and the fuselage. Thus the goal of the CARD project was to perform wind tunnel tests of a representative helicopter configuration to obtain rotor system and fuselage drag data. The presentation will describe the experiment and data analysis, and present sample results of drag data.

Figures

(a) Model in wind tunnel



(b) Sample results

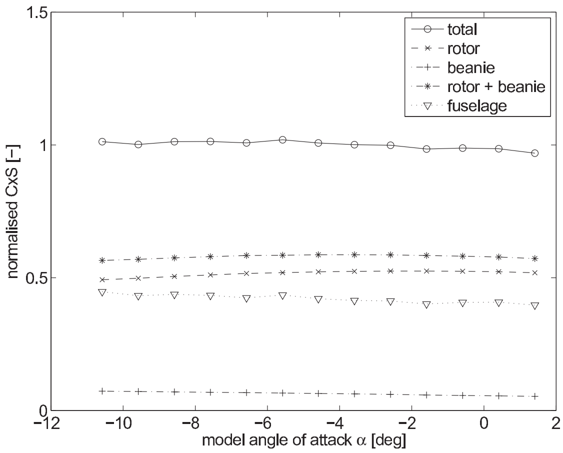


Figure 1: CARD model in the wind tunnel and sample test data. Model shown in frame (a), the rotor rotates clockwise, and the wind tunnel flow is from right to left. The beanie and rear engine pylon fairing have not been fitted, and the blade stubs and flexure sleeves can be seen. The platform below the tunnel is removed prior to testing. Frame(b) shows normalised $C_x S$ data as a function of angle of attack for cruise at advance ratio 0.383, showing total model $C_x S$ and the individual contributions of the rotor, beanie and fuselage.

Multidisciplinary Design and Optimisation of Conceptual Rotorcraft Power plants: Towards High Fidelity Engine Design Optimisation

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The acquisition of a robust and cost-effective product design prior to manufacturing of prototypes is of prime importance to any industrial activity to ensure its competitiveness and marketability. The rotorcraft industry is no different. In today's highly dynamic and competitive aerospace industry there is profound emphasis placed on reducing the rotorcraft through-life-cycle costs in conjunction with maintaining its compliance with increased performance, safety and regulatory standards. These underpinning design prerequisites introduce enormous design challenges for the rotorcraft designers and they are often exposed to conflicting design requirements in an effort to support concurrently both the rotorcraft operational and environmental performance. The increased use of multidisciplinary high-fidelity simulation framework within the engine conceptual/preliminary design stage has been identified as an enabling technology for overcoming the significant challenges of designing sustainable future rotorcraft designs.

These multidisciplinary simulation frameworks are generally referred to as Multidisciplinary Design Analysis and Optimization (MDAO) frameworks and are often comprised of several representative sub-systems level computational/numerical models to represent a system level modelling fidelity. The advantages arising from their effective implementation are twofold, (i) efficient and rapid exploration of design space, (ii) enabling sound understanding towards the influence of design requirements on the feasible solutions. These advantages enable the designers to optimize a particular design configuration to a high level of refinement, and make informed decisions before accepting a particular design on to the next phase of the development process.

This research presentation will aim to present an integrated rotorcraft conceptual design and analysis framework, deployed for the multidisciplinary design and optimisation of conceptual rotorcraft power plants in terms of operational performance and environmental impact. The proposed framework comprises a wide-range of individual modelling theories applicable to rotorcraft flight dynamics, gas turbine engine performance and weight estimation as well as a novel physics-based, stirred reactor model for the rapid estimation of gas turbine gaseous emissions. A Single-objective and Multi-objective Particle Swarm Optimizer is coupled with the aforementioned integrated rotorcraft multidisciplinary design framework. The combined approach is applied to the multidisciplinary design and optimization of a reference Twin Engine Light civil rotorcraft modelled after the Airbus Helicopters BO105 aircraft, operating on representative mission scenario.

Through the implementation of a single-objective optimization strategy, optimum engine design configurations are acquired in terms of mission fuel consumption, engine weight and gaseous emissions at constant technology level. Multi-objective optimization analyses are carried out in order to quantify the optimum interrelationship between mission fuel consumption and gaseous emissions. The acquired optimum thermodynamic cycles are subsequently deployed for the design of conceptual regenerative engines for rotorcraft, targeting improved mission fuel economy, enhanced payload-range capability, as well as reduced environmental impact.

Helicopter Environmental Engine Protection: Progress and Challenges

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Helicopters are required to operate in a range of environments, as part of their capability remit. In particularly dry and arid climes, the helicopter's downwash may disrupt the loose sediment bed upon which it is to land, causing a dust cloud that engulfs the whole aircraft (Fig. 1). Inevitably, during the mass-flow heavy operations of take-off and landing, the engine ingests large quantities of particulate. Without some form of protection, the engine's life can be reduced to as little as 25 hours[1].

Figure 1: An RAF Merlin creates a 'Brownout' dust cloud whilst landing in Afghanistan[2].

Environmental Engine Protection for helicopters comes in three main forms, each with their own unique method of removing particulate. In this contribution we will briefly describe the development of these devices, and summarise how they have become a ubiquitous and vital feature on modern helicopters. They are known as Engine Air Particle Separators (EAPS), and are commonly grouped into three categories: vortex tube separators (Fig. 2); inlet barrier filters; and integrated particle separators. They achieve varying degrees of efficacy, and in the design of each device a compromise must be met between minimising an inherent pressure loss and maximising separation efficiency. The present work describes new methods to quantify this performance, as carried out in the Environmental Protection group at the University of Manchester.

The presence of EAPS prevents the helicopter requiring premature engine overhaul, and is often advertised as 'fit-and-forget' technology. However, in reality the best performing EAPS devices require constant monitoring. Vortex tubes are known to become clogged with grass and may even become detached from their housing, while inlet barrier filters accumulate a surface cake that exacerbates the pressure loss over time leading to a lack of useful power. Their presence can also lead to poorer engine performance in forward flight due to an absence of ram recovery. Despite the absence of such problems for integrated particle separators, their separation efficiency cannot match that achieved by vortex tubes and barrier filters.

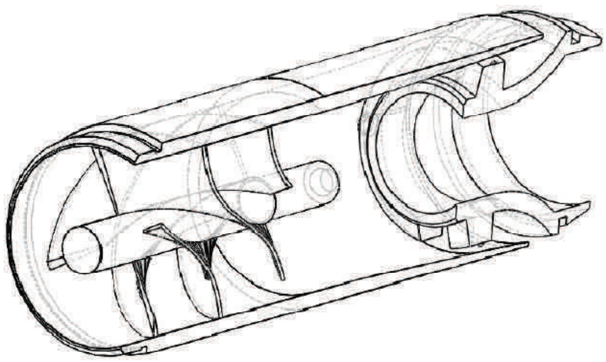

Figure 2: Cutaway of a single vortex tubes, showing swirl generator and exit core. Several hundred as arranged in parallel to make up the complete vortex tube ‘pack’.

None of the three devices achieve an efficiency of one hundred percent, which means the engine will encounter contamination, albeit in a reduced form. If it reaches the engine, the particulate attacks the engine at a number of locations: erosion at the compressor blades; wall glazing in the combustor; and deposition in the turbines. The degree of damage is dependent on the particulate type, which can vary from location to location depending on the local geology. For example, deposits found in damaged T700 engines operating in Iraq were found to contain a much greater proportion of magnesium and calcium silicates with a lower melting point to highly eroded and wind-sorted quartz in Afghanistan[3]. In this presentation we discuss ongoing work at the University of Manchester inresearching such variables to understand the cost and benefit of damage prevention of helicopters in harsh environments.

References

[1] P. Stallard, “Helicopter Engine Protection,” *Perfusion*, vol. 1997, no. 12, pp. 263 – 267, Jul. 1997.

[2] Sgt Steve Blake RLC and UK Ministry of Defence, *RAF Merlin Helicopter Creates a “Brownout” Dust Cloud Landing in Afghanistan*. 2012.

[3] J. L. Smialek, F. A. Archer, and R. G. Garlick, “The chemistry of Saudi Arabian sand - A deposition problem on helicopter turbine airfoils,” in *24th International SAMPE Technical Conference*, 1992, Vol. 24, p. 63.

Study of a Coaxial Compound Helicopter Flying Mission-Task-Elements

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The compound helicopter design could potentially satisfy the emerging requirements placed on the next generation of rotorcraft. The resurgence of interest in the compound helicopter is partly due to the recent successful flight tests of the Sikorsky X2, with Sikorsky planning future testing of the Sikorsky S-97 aircraft. The Sikorsky S-97 aircraft is envisioned to be a multi-role vehicle that can satisfy the demands of the US Army's operational requirements. The main benefit of the compound helicopter is its ability to reach speeds that significantly surpass the conventional helicopter. However, it is possible that the compound helicopter design can provide additional benefits in terms of manoeuvrability. This study features a conventional helicopter and a compound helicopter. The conventional helicopter features a standard helicopter design with a main rotor providing the propulsive and lifting forces, whereas a tail rotor provides the yaw control. Due to the interest in the Advancing Blade Concept, the compound helicopter configuration featured in this study consists of a rigid coaxial rotor with thrust compounding supplied by a propeller. The idea behind the rigid coaxial rotor (or the Advancing Blade Concept) is that the lift potential on the advancing sides of the rotors discs is realised in high speed flight. In high speed flight, the two rotors provide significant rolling moments around the rotor hub as the advancing sides of the disc produce much greater lift than the opposing retreating sides. However, the overall hub rolling moment trim is achieved as the upper and lower rotors provide rolling moments equal in magnitude but in opposing directions. The vehicle also includes a propeller, mounted at the rear of the aircraft, to offload the coaxial rotor of its propulsive duties. This study investigates the manoeuvrability of these two helicopter configurations using inverse simulation. The results predict that a compound helicopter configuration is capable of attaining greater load factors than its conventional counterpart, when flying a Pullup-Pushover manoeuvre. In terms of the Accel-Decel manoeuvre, the compound helicopter configuration is able of completing the manoeuvre in a shorter time than the conventional helicopter, but at the expense of greater installed engine power. The addition of thrust compounding to the compound helicopter design reduces the pitch attitude required throughout the acceleration stage of the manoeuvre.

Coupled Flight Dynamics and CFD - Demonstration for Helicopters in Shipborne Environment

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Shipborne take-off and recovery tasks are common in helicopter missions and require the aircraft to manoeuvre in a confined and turbulent area. To ensure safe operation, Ship/Helicopter Operational Limits (SHOL) need to be determined through expensive and time-consuming at-sea trials, repeated for each specific Aircraft/Ship combination and over a range of wind strengths and directions. Accurate numerical simulation of manoeuvring helicopter would permit to: (1) build more realistic simulation tools, (2) predict potentaial extreme loads on the airframe, and consequently help design, and (3) support the trials by simulating the most dangerous manoeuvres ahead of the flight.

In the context of this work, a 6-DOF Helicopter Flight Mechanics (HFM) solver was developed that implements simplified aerodynamic models along with a trimming method and a pilot model. HFM is capable of simulating a wide range of manoeuvres for different helicopters. It is a multi-body dynamics solver that implements the Euler's equations of motion for rigid bodies to calculate the trajectory of the aircraft from the loads calculated on the rotors and fuselage. HFM is directly coupled into the CFD framework of HMB2 and the estimated loads are substituted by the loads calculated via CFD. The HFM/HMB2 solver is used here to carry out high-fidelity simulations of a manoeuvring helicopter. Realistic models of the Sea King helicopter and the Halifax-class frigate are used to simulate a typical Royal Navy ship/landing manoeuvre.

Figure shows the position of the helicopter during the manoeuvre performed without the presence of the ship and demonstrates that the pilot model is able to maintain the helicopter attitude while following the prescribed trajectory; a descent in this case. Figure shows the flowfield around the ship and helicopter at the beginning of the coupled simulation. The Linear Integral Convolution (LIC) method is used to highlight the flow features.

Acknowledgements

The support of this project by the AgustaWestland Liverpool Advanced Rotorcraft Center is gratefully acknowledged. The authors would like to acknowledge the use of the Chadwick and N8 High Performance Computing (N8 HPC) centres for the CFD computations.

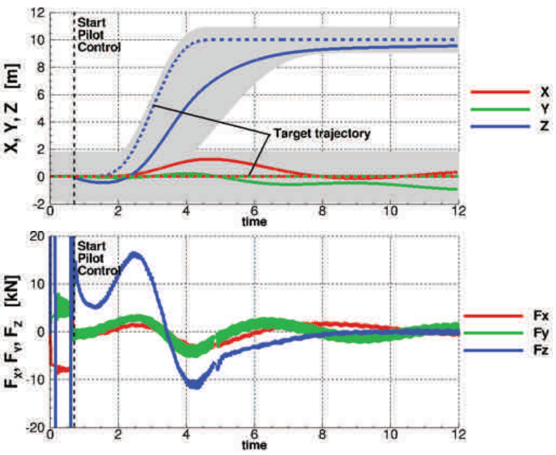

Figure 1: Position of the helicopter and global loads during the isolated descent manoeuvre.

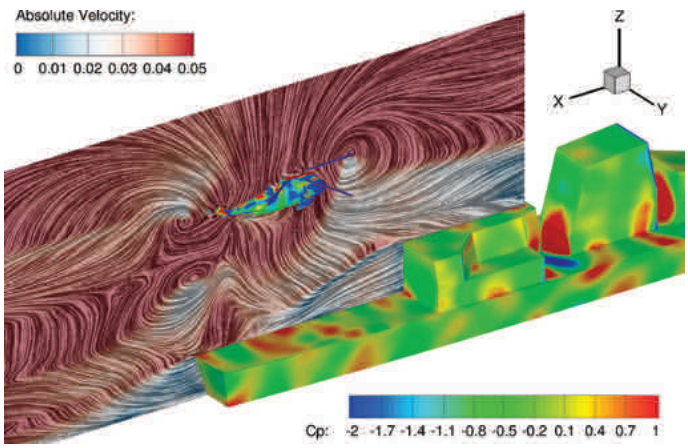

Figure 2: LIC visualisation of the initial flowfield before the coupled manoeuvre.

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Experimental investigation of the aerodynamic interaction between a helicopter and ground obstacles

Daniele Zagaglia

Visiting PhD student, University of Glasgow
PhD student, Politecnico di Milano

in collaboration with:
R. Green, M. Giuni – *University of Glasgow*
G. Gibertini, C. Parolini, A. Zanotti – *Politecnico di Milano*

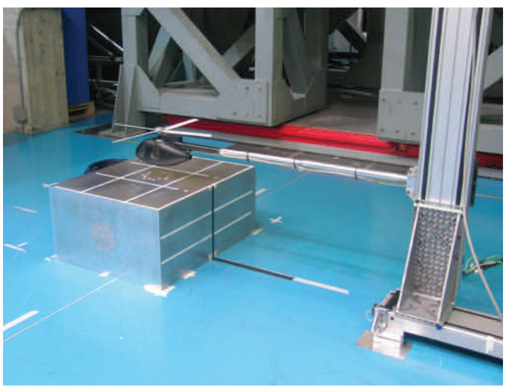
Helicopters, due to their capability of managing hovering flight, are highly exploited in missions within confined areas. The aerodynamic interaction between the rotor-induced wake and the surrounding obstacles generates, on the one hand, high compensatory workload for the pilot and degradation of aircraft performance, on the other hand unsteady forces which can stress the structure of the obstacle.

The GARTEUR Action Group 22 *"Forces on Obstacles in Rotor Wake"*, comprising several universities (Politecnico di Milano, University of Glasgow, University of Liverpool, NTUA) and reasearch institutes (CIRA, DLR, ONERA, NLR), originates from the idea to promote activities which could contribute to a better understanding of such fluid-dynamics phenomena.

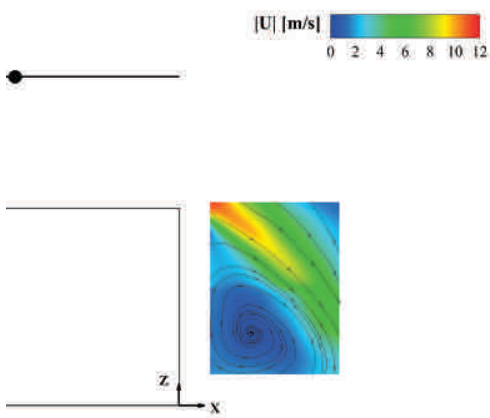
The preliminary activities carried out at Politecnico di Milano were meant to produce an experimental database for the study case of a helicopter model (rotor and fuselage) in proximity to an obstacle in not-windy conditions (the wind tunnel campaign beign postponed to the next year). The assembled test rig (Figure 1a) consists of a helicopter model with fixed blades ($D = 0.75\ m$, $\theta_c = 10°$), connected to a horizontal pylon that can be moved by a system of two traversing guides. The helicopter model was powered by an on-board electric motor, and the loads acting on the rotor were measured by means of a 6-components balance. The obstacle was a 1m x 0.8m x 0.45m cuboid, courteously made available by DLR. Steady (average values) pressures on the obstacle walls were measured through several pressure taps on the building. Moreover 2D PIV surveys were carried out in some relevant configurations.

A set of measurements with different relative position of the helicopter with respect to the model building were carried out. The analysis of the measured loads allowed a preliminary investigation of the interference effects of the building model on the helicopter performance. A physical interpretation of the flow phenomena occurring was obtained through the analysis of the obstacle pressure measurements and PIV surveys in some relevant configurations (an example is given in Fig. 1b).

A more comprehensive experimental investigation in absence of external wind is being designed at the University of Glasgow. A larger rotor ($D = 1\ m$), with adjustable collective and cyclic pitch angle will be used. The rotor will be mounted on a load cell system so that its trim state can be monitored. The loading on the obstacle will be measured by means of both averaged and unsteady pressure measurements. PIV surveys will be carried out in order to support both the pressure measurement and flow visualizations.



(a) The experimental test rig



(b) Example of PIV survey

Figure 1

Numerical Modeling of the Aerodynamic Interference between Helicopter and Ground Obstacles

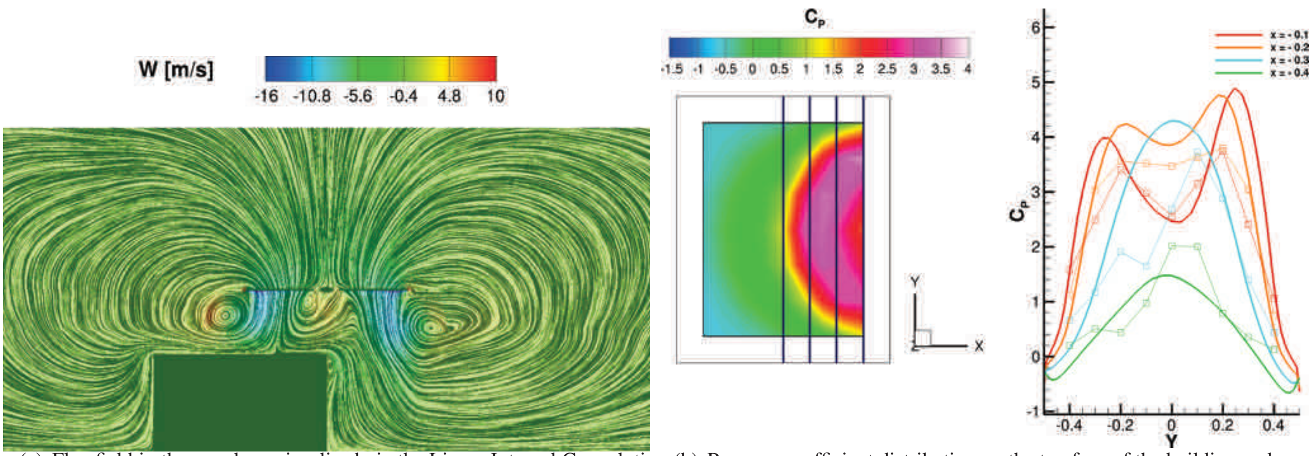
Giulia Chirico *, Luigi Vigevano † and George N. Barakos ‡

Helicopters are usually operating in confined areas and the complex flowfield that develops in windy conditions may result in dangerous situations. Tools to analyse the mutual interaction between rotorcraft aerodynamics and ground obstacles are therefore essential. The GARTEUR AG22 aims to investigate this problem and this work is aligned with their effort. As an example, a helicopter operating in the wake of a building comparable in height to its rotor diameter, has been studied using different aerodynamic models. The final goal is to find the simplest aerodynamic model that captures interactional phenomena so that efficient simulations can be conducted.

Initial simulations have been performed using the Actuator Disk (AD) model, in a uniform or non uniform formulation. This model doesn't capture the details of the rotor wake or flow unsteadiness due to individual blade passing. The Actuator Line technique overcomes these limitations but is computationally more expensive. For this reason, an hybrid technique, the Unsteady Actuator Disk (UAD) has been tested: this method accounts the influence of the rotor blades modelling the global distribution of the rotor loads using a Gaussian function at each time step of the simulation. Simulations accounting for the real blade shape have also been performed, using the sliding planes technique available in the HMB2 CFD solver. The differences between UAD, AD and simulations with resolved blades will be presented, allowing the evaluation of the accuracy of each aerodynamic model.
Moreover, the validity of the superposition principle for combining the building and rotor wakes is also investigated to determine the minimum distance between the helicopter and the building where wake interference is negligible.

The calculations have been carried out using the CFD solver HMB2 of the University of Liverpool. The size of the assembled grids, generated using ICEM, ranges from about 12 million cells, for the AD simulations grid, and 30 million, for full-blades simulations grid.

The wind tunnel tests performed at Politecnico di Milano by Gibertini *et al.* [1] are used for comparisons. Fair agreement has been obtained confirming the validity of the proposed simulation approach.



(a) Flowfield in the xz plane visualised via the Linear Integral Convolution method coloured with the vertical velocity component.

(b) Pressure coefficient distribution on the top face of the building and comparison with the correspondent experimental data [1]

Figure 1: Full-blades simulation for hover with the rotor laying on the building edge at a distance of one diameter above the ground.

References

[1] G. Gibertini, D. Grassi, C. Parolini, D. Zagaglia and A. Zanotti: Experimental investigation on the aerodynamic interaction between a helicopter and ground obstacles. *Journal of Aerospace Engineering*, 2014.

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2015 Technical Workshop UK Vertical Lift Network
April 10 - 12, Cheshire, UK

Helicopter and Wind Turbine Wakes Encounter by Light Aircraft

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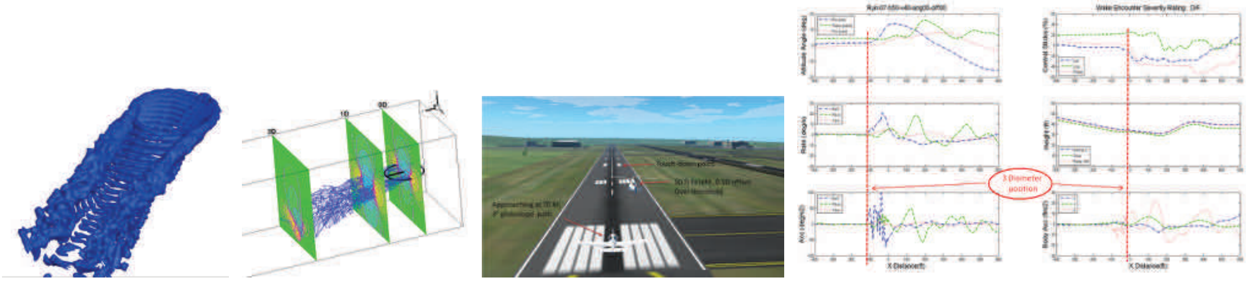
The wake generated by a helicopter could interfere with passing-by aircraft. A number of serious and fatal accidents have so far been happened when light aircraft entered into a helicopter wake resulting in control loss. These accidents often happen near airports where helicopters are in hover-taxi and the encountering aircraft is in a landing or departure procedure, which means that both the helicopter and the fixed-wing aircraft are at low altitude and relatively low speed. This type of wake encounter scenario has its own specific features. And the wake vortices have their characteristic structure, duration and decay.

Different methods of modelling helicopter wakes are presented and compared with available wind tunnel and flight test data. A free wake model was then used to generate the wake vortices of a helicopter hover-taxing over an airport runway. A hybrid wake model, with a wake decay law, was also used to generate the far wake of a helicopter in level flight. The wake induced velocity fields were integrated into an aircraft flight dynamics model and piloted flight simulations were carried out to study a light aircraft encountering a helicopter wake during landing and level flight. It was found that for the current landing wake encounter scenario, the existing wake encounter criteria and severity metrics for the determination of the hazardous distance might not be appropriate if the wake encounter occurs close to the ground. The landing simulation results suggest that for a helicopter in low-speed hover-taxiing (less than 40 kt airspeed), the wake encounter detectable horizontal distance is about three times the diameter of the rotor, which coincides with the current safety guidelines of the Civil Aviation Authority of the UK. The level flight simulations revealed the effects of the vertical separation distance and of the wake decay on the encounter severity.



(a) Free wake model (b) Downwash (c) Flight simulation scene (d) Dynamics of GA aircraft

Figure 1: Helicopter wake model, downwash velocities, sinmulation scene and dynamic responses of aircraft during encounter.

Effect of Active Gurney Flaps on Overall Helicopter Flight Envelope

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This paper presents a study of the W3-Sokol main rotor with Gurney flaps [1], [2]. The effect of the active Gurney is tested at low and high forward flight speeds to draw conclusions about the potential enhancement of the rotorcraft performance for the whole flight envelope. The effect of the flap on the trimming and handling of a full helicopter is also investigated using a generic model built in FlightLab [3].

During hover, the maximum Figure of Merit of the blade did not improve, but at high thrust settings it was enhanced by 6% over the performance of the clean blade. The effect of the Gurney was to pitch the nose of the flapped section down as evaluated with aeroelastic calculations, and it was found that the extra lift of the Gurney in combination with the extra blade twist resulted in an increased Figure of Merit. For further performance improvement a Gurney flap of bigger span was considered, and among different sizes of Gurney the one of 2% of the chord was the most effective. The loading capability of the helicopter was improved by 200Kg, while the hover endurance was increased by 28.8 minutes.

Then, the use of a Gurney flap was put forward to improve the forward flight performance of a helicopter rotor by reducing the stall at the retreating side. The basic idea is that the flap will be actively actuated in forward flight and will be fully deployed in hover flight. The W3 Sokol MRB was used again due to the availability of flight test data as well as the blade shape and structural properties. A carefully designed Gurney flap and actuation schedule proved to be essential for controlling the separation of the flow. Fluid and structure dynamics were coupled in all cases and the rotor was trimmed at two different thrust coefficients. The Gurney proved to be efficient at medium to high advance ratio flights, where the power requirements of the rotor were decreased by up to 3.3%. However, the 1/rev actuation of the flap might be an issue for the trimming and handling of the helicopter.

The current study built on the idea that any active mechanism operating on a rotor could alter the dynamics and the handling of the helicopter. A closed loop actuation of the Gurney flap was put forward based on pressure divergence criterion, and it led to further enhancement of the aerodynamic performance of the rotor. Next, a generic light utility helicopter was built using 2D aerodynamics of the main aerofoil section of the W3 Sokol blade along with a robust controller [4], and the response of the rotorcraft to control inputs was tested. This analysis proved that the 1/Rev actuation of the Gurney did not alter the handling qualities of the helicopter and as a result it can be safely implemented as a flow control mechanism for retreating blade stall alleviation.

A detailed description of the closed loop actuation of the Gurney as well as the analysis of the generic model with and without the flap is given in the paper.

Acknowledgements
The financial support via the IMESCON project, the release of the W3 Sokol main rotor blade geometry by PZL Swidnik, and the use of the computing centre TASK are gratefully acknowledged.

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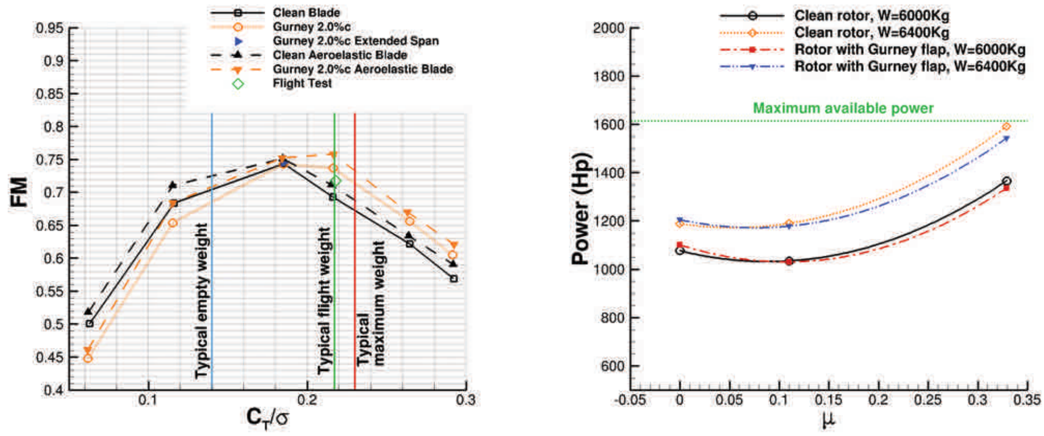
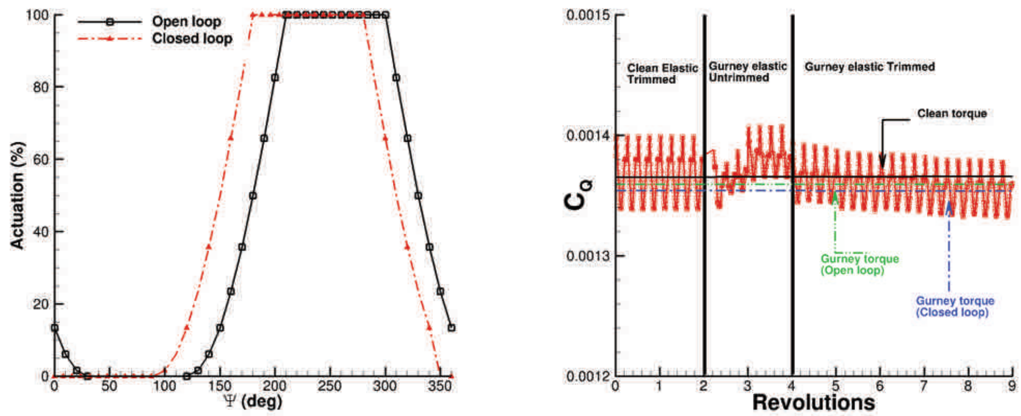


(a) (b)

Figure 1: (a)Figure of merit versus thrust coefficient for the W3 Sokol MRB in hover ($M_{\rm tip} = 0.618, {\rm Re}_{\rm tip} = 3.74 \cdot 10^6, \sigma = 0.0714$), (b) Power requirement for clean W3-Sokol rotor, and rotor with Gurney flap along the flight envelope.



(a) (b)

Figure 2: (a) Gurney actuation schedule comparison against open loop, (b) Torque requirement for closed loop actuation of the Gurney flap.

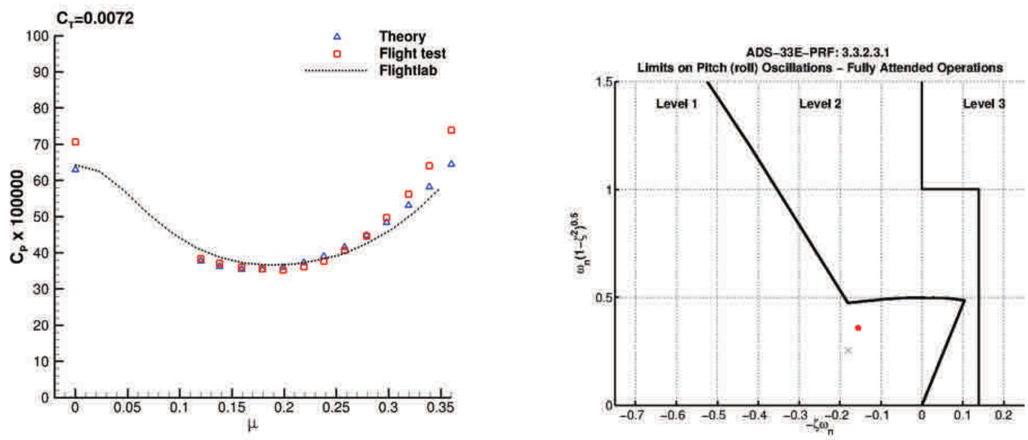


Figure 3: (a) Power coefficient for UH-60 Black Hawk helicopter. FLIGHTLAB model against theory and flight test data [5]. (b) Limits on pitch (roll) oscillations - hover and low speed. Red dot represents the clean rotor, while cross represents the rotor with the active Gurney flap.

Comparison Between Different Grid Methodologies For Rotorcraft Configurations

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Structured, unstructured, or hybrid grids can be used for helicopter CFD. The grids may also use either overset or sliding interfaces to account for the relative motion between components of the helicopter or for reducing the complexity of the mesh generation process. In the literature, established helicopter CFD codes have been used with several types of grids without a clear conclusion as to which mesh type is best for computations. In this paper, the idea of hybrid grids is put forward as an attempt to compromise between accuracy of solution and ease of mesh generation. The basic scheme considered, is to keep structured zones where accuracy is required (e.g. around the rotor blades) or in the rotor wake and use the unstructured parts to alleviate meshing difficulties in regions with complex geometries (e.g. complex fuselage shapes). Of course, the use of hybrid grids brings forward issues related to the solver (that now has to cope with different mesh types) and issues related to communication between different mesh types. This paper presents a systematic comparison of the different meshing techniques and highlights the merits of each one, how they are implemented with a modern CFD solver, and the lessons leant from their use within the HMB solver.

The coupling between the multi-block structured and unstructured domains depends on whether the interface between meshes has an overlap or not, and in the case where the interfaces match on both the multi-block and unstructured domains, then the same surface mesh is used. In general, a Chimera or a sliding mesh interface can also be used.

Figure 1, presents an example for the flow around the ERICA fuselage as obtained using an unstructured mesh. This is one of the several test cases employed during the development of the unstructured method in HMB. Further details on the method, is efficiency, stability and accuracy will be presented during the meeting.

Acknowledgments
The financial support via the HIPERTILT project of the UK Technology Strategy Board and AgustaWestland is gratefully acknowledged.

Figure 1: Processor partition (left) and surface pressure (right) for the ERICA fuselage at zero angle of attack and 0.3 Mach number. Solution obtained using the unstructured mesh method in HMB2.

Numerical simulations of helicopters and tilt-rotors using HMB2 solver

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First, a comparative study of the effect of different tips of the hovering Sikorsky S-76 model main rotor blades is performed using the multi-block HMB2. Rectangular tips with rounded and flat tip-cap, as well as tips with anhedral and sweep are selected for computations. Taking as reference the 60% taper-35° degrees swept tip (baseline), predictions of the rotor performance for a large range of collective pitch is presented. Also, a comparison between chimera and matched grids is shown [1]. It is interesting to note that the results for the anhedral tip broadly follow the swept taper tip trends. The main difference is the higher Figure of Merit (FoM) that is obtained due to the additional off-loading of the tip provided by the anhedral. This is a known effect [2] and is captured very well by the present computations.

Numerical simulations of the full-scale S-76 rotor using the HMB2 solver were also computed, to analyse the Reynolds number on the rotor performance. For this study, a static analysis on the S-76 full-model rotor blade with 60% taper-35° degrees swept tip was performed, at tip Mach number of 0.60.

As a means of comparing the effect of the tip configuration on the S-76 rotor in hover, the hovering endurance in the form of charts has been estimated using both experimental data of [3] and CFD predictions from HMB2. This parameter evaluates the performance capabilities of a helicopter in hover configuration, typically for a range of thrust coefficient from empty weight to maximum takeoff gross weight.

The second part of this work is devoted to numerical simulations of the ERICA (Enhanced Rotorcraft Innovative Concept Achievement) tilt-rotor 1:5 scale model have been performed using HMB2. For this work, an aircraft mode configuration (AC1) of the ERICA tilt-rotor is considered, which is characterised by low speed, and relatively high angle of attack of the aircraft with a large zone of flow separation at the rear part of the fuselage. Visualisation of the flowfield using iso-surfaces of the Q-criterion is shown in Figure 2 and reveals a strong aerodynamic interaction between components.

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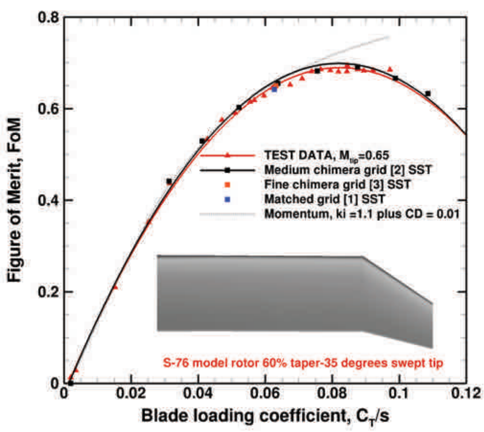

Figure 1: C_T/s versus FoM for the S-76 model rotor with 60% taper-35° degrees swept tip, $M_{tip} = 0.65$, $Re_{tip} = 1.18 \times 10^6$, $\Theta_{75} = 4^o, 5^o, 6^o, 7^o, 8^o, 9^o, 10^o$ and 11^o and SST $k - \omega$ turbulence model.

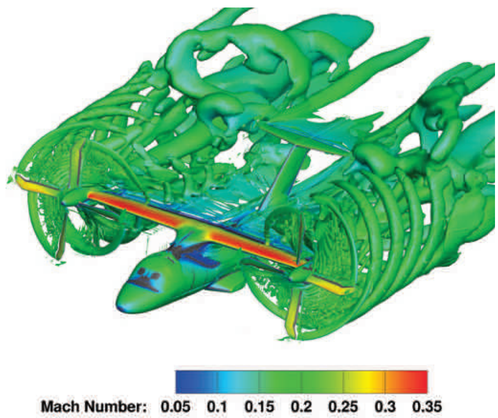

Figure 2: Visualisation of the ERICA tilt-rotor in aircraft mode using Q-criterion of 0.15 coloured by Mach number. $M_\infty = 0.168$, $\mathrm{Re}_\infty = 1.7 \times 10^6$, AoA=10.02^o degrees. The $\kappa - \omega$ turbulence model of Wilcox was used.

Nonlinearity in Rotating Blade Dynamics

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Abstract

The dynamics of rotary wing systems are complex and typically feature highly nonlinear and often unsteadyaerodynamics, as well as aeroelastic influences. In ongoing efforts to reduce noise and vibration, active devices such astrailing edge flaps on the rotor blades are being studied and these devices can introduce further nonlinearities. Therefore,it is important to be able to evaluate the stability of the overall system with a proper understanding of the global nonlinear behaviour. Numerical continuation and bifurcation analysis is well suited to this need, and this paper presents evidence ofthe technique providing a deeper insight into the stability of helicopter rotor systems than the methods typically adoptedin the industry.In this seminar, we present selected examples of rotating blade problems to show how the nonlinearity can manifest itself (see example results in Figure 1). The examples discussed vary from: autogyro rotor instability, helicopter aeroelastic blade stability to nonlinear effects in ground resonance and more. The emphasishere is on the potential for revealing important multiple-attractor dynamics rather than the study of a particular system.The results presented highlight the advantages of the approach used, bothin terms of generating an understanding of local andmore global stability, and in the efficiency in obtaining relevant results as parameters vary.

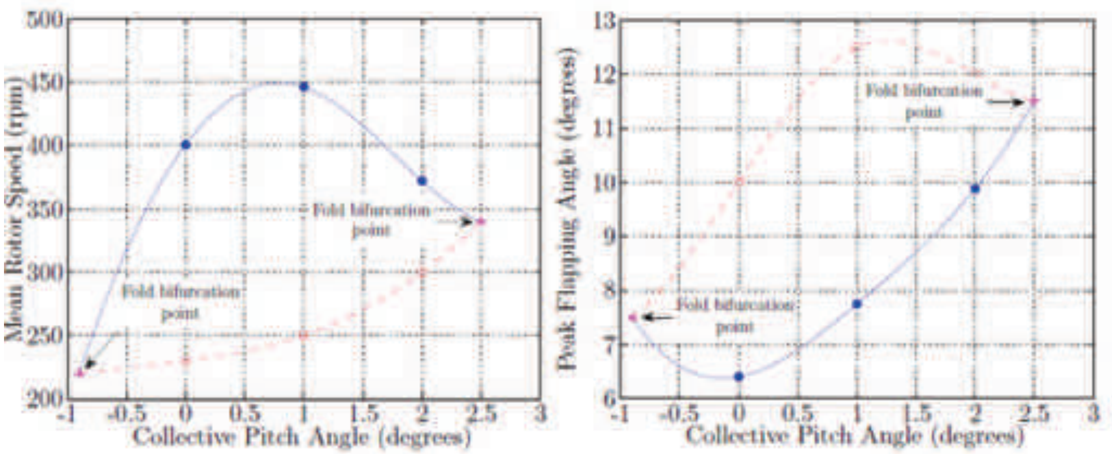

Figure1: Experimental bifurcation diagram showing projections in (a) rotational velocity and (b) flapping angle for an autorotating rotor. The figure shows the existence of both stable and unstable autorotation modes. The solid blue line isa curve-fit through experimental data points (solid blue circles) denoting stable steady autorotation (stable limitcycles). Similarly, the empty red data points and red dashed curve-fit represent the unstable autorotation steadystate (unstable limit cycles).

1st UK VLN Technical Workshop, 10–12 April 2015, Oakmere, Cheshire, U.K.

Aerodynamic Optimisation with Discrete Adjoint Methods

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Gradient based optimisation is an efficient and widely used method for aerodynamic shape optimisation problems, since it minimises the required number of flow solutions. It however requires the flow derivatives with respect to the design variables, which can be extremely expensive to compute when high fidelity CFD is employed. An economic way to obtain the flow gradients with CFD is represented by the adjoint method, which reduces the cost of flow gradients evaluation to about twice the cost of the base flow solution, regardless of the number of design variables. A fully implicit implementation of the adjoint method [1] has been embedded into the HMB2 flow solver of Liverpool and AgustaWestland.

The presentation is aimed at describing the details of the adjoint solver, and of the HMB2 interface with gradient based optimisation tools to solve design problems. The current implementation employs a Sequential Quadratic Programming (SQP) [2] optimisation algorithm, which allows for nonlinear equality and inequality constraints, as provided in the software library NPSOL. It represents the objective function as a quadratic approximation to the Lagrangian and uses a dense SQP algorithm to minimise a quadratic model of the problem. The computational mesh is updated at every optimiser iteration using an advanced deformation algorithm, based on Inverse Distance Weighting (IDW). The optimisation tool chain is demonstrated with 2D aerofoil cases and with a 3D ducted propeller case.

Figure 1 shows the result of the optimisation of a RAE2822 aerofoil in trasnsonic flight ($M = 0.75$) at zero incidence. The original aerofoil (black line) is parametrised using a Bernstein polynomial base and the optimal shape (red line) is obtained by minimising the drag subject to constraints on the lift coefficient ($C_{L,\mathrm{opt}} = 0.42$), the moment coefficient ($-0.12 < C_{M,\mathrm{opt}} < -0.11$) and the thickness at a specified station ($t|_{x=0.33} > 0.13$). The drag is reduced by 30%, and the lift is incremented by 2%.

The method is also applied to a propeller of a lighter than air vehicle (LTV) with high efficiency. It is known that propeller performance can be augmented by enclosing them in ducts, to drive the expansion of their wake and increase the static pressure difference. Accurate design of the propeller twist distribution and of the duct shape requires high-fidelity modelling of the flow, and therefore the use of the adjoint method is necessary to evaluate efficiently the sensitivity of the flow with respect to the design variables. Figure 2 represents, for instance, the surface pressure sensitivity of the ducted propeller for the advance ratio $J = 0.136$ and blade incidence $\beta = 17.2°$ with respect to a variation of the twist at 75% of the blade span.

The importance of flow derivatives is not limited to aerodynamic optimisation. The presentation shall also briefly address other applications of the adjoint method, such as flight mechanics and control.

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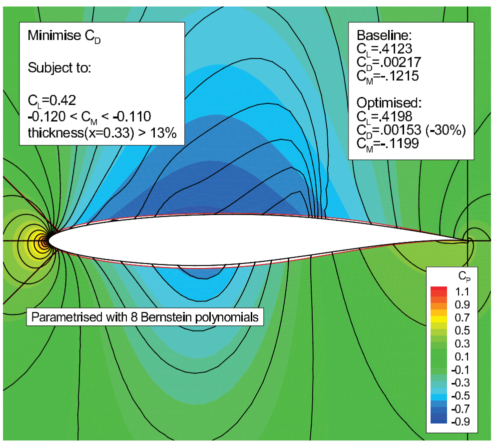

Figure 1: Optimisation of the RAE2822 aerofoil in transonic flight ($M = 0.75$, $\alpha = 0°$).

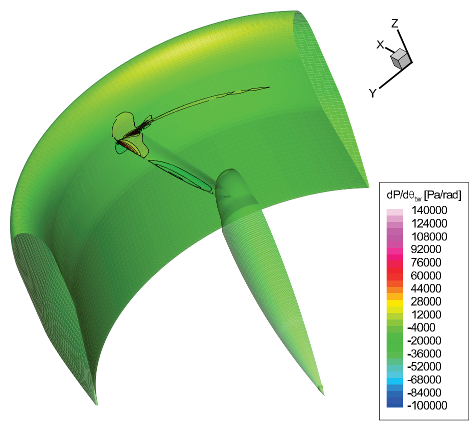

Figure 2: Pressure sensitivity of a ducted propeller with respect to a twist variation ($J = 0.136$, $\beta = 17.2°$).