VLN 2nd Annual Workshop

Book of Abstracts

Shrigley Hall, Macclesfield, 9-10 May 2016

Nicholas Bojdo & Antonio Filippone

May 2016

UK Vertical Lift Network: 2nd Technical Workshop

Many thanks for the presentation titles and abstracts submitted to the 2nd UKVLN Technical Workshop. This workshop is part of the activities of the Vertical Lift Network, an initiative funded by the EPSRC. This workshop is a unique opportunity for academics and post-graduate students to show their research. The previous event was held at Nunsmere Hall, near Chester, and consisted of 14 presentations on different research areas. Similar events have been held in the past at other locations and proved always very popular with the rotorcraft research community.

The programme for these two days consists of 14 presentations (as in the previous year) in areas such as computational and experimental aerodynamics, computational fluid dynamics, aeromechanics, flight dynamics, blade dynamics, design and blade manufacturing.

Six Universities are represented, along with some of our industrial colleagues from AgustaWestland. Our research is still dominated, one way or another, by aerodynamics. Applications are varied and include blade aerodynamics, wakes, wake encounters, propellers, tilt-rotors, fuselage and airframe.

The purpose of this workshop is not limited to the presentation of on-going research; it is also a forum to exchange views and promote new ideas in a relaxing environment. It is hoped that stronger cooperation will follow, and new inter-disciplinary areas of research will flourish.

Nicholas Bojdo and Antonio Filippone
The University of Manchester
7th May 2016

The 2nd Annual UK Vertical Lift Network Technical Workshop

Shrigley Hall Hotel, Cheshire

09-10 May 2016

UK Vertical Lift Network

BAT - University of Bath
BRI - University of Bristol
CRA - Cranfield University
GLA - University of Glasgow
FIN - Finmeccanica Helicopters
LIV - University of Liverpool
MAN - University of Manchester
VLN - UK Vertical Lift Members

Final Programme

Monday 9th May

12.00 - 13.00	Lunch			
13.00 - 15.30	VLN Meeting		VLN	*VLN Meeting VLN.14*
15.30 - 16.00	Coffee			
16.00 - 16.15	**Keynote**	Antonio Filippone	MAN	*Introduction to the VLN Activities*
16.15 - 16.45	**Aerodynamics 1**	Dave Cleaver	BAT	*Unsteady Aerodynamic Loads and Their Control through Mini-tab Actuation*
16.45 - 17.15		Antonio Garcia	GLA	*Aerodynamic and Optimisation Study of Tiltrotor Blades*
17.15 - 17.45		Byungkwon Jung	BRI	*Investigating the Autorotational Performance of Scaled Samara Rotor in Forward & Vertical Flight*
17.45 - 18.30	**Plenary / Discussion**		ALL	*Open Questions Meeting*
18.30 - 20.00	Dinner			

Tuesday 10th May

08.45 - 09.00	Coffee			
09.00 - 09.30	**Aerodynamics 2**	Richard Green	GLA	*Progress with GARTEUR AG22 experimental work at Glasgow University*
09.30 - 10.00		Paul Mullen	FIN	*Rotor blade aerodynamic analysis and design*
10.00 - 10.30		Mark Woodgate	GLA	*Towards Real Time Wake Computations using Lattice Boltzmann Method for Flight Dynamics Simulations*
10.30 - 11.00	Coffee			
11.00 - 11.30	**Dynamics / Manufacturing**	Robert Dibble	BRI	*Helicopter rotor blade modal tuning using internal preloads*
11.30 - 12.00		Samuel Furtado	MAN	*Design and Manufacture of Composite Blades for Rotorcraft Applications*
12.00 - 12.30		Augustin Gaxiola	BRI	*Pitch link-induced beam bending-twist coupling and its use in vibration-based rotor health monitoring*
12.30 - 13.30	Lunch			
13.30 - 14.00	**Aerodynamics 3**	Xiao Liu	BRI	*Turbulence Budget Analysis for Serrated Airfoils*
14.00 - 14.30		Giulia Chirico	GLA	*Propeller Computational Aeroacoustic Analysis*
14.30 - 15.00		Dan Poole	BRI	*Adaptive Surrogate-Based Optimization of Vortex Generators for Tiltrotor Wings*
15.00 - 15.30	Coffee			
15.30 - 16.00	**Flight Mechanics**	Jack Stockford	CRA	*Aeromechanics and Rotorcraft Vehicle Design activities in the Department of Aerospace Science at Cranfield University*
16.00 - 16.30		Paul Scott	LIV	*Development of a Modelling and Simulation Environment to Support Helicopter Operations to New RN Vessels*
16.30 - 17.00	**Open Discussion / Close**		ALL	*Open Questions Meeting*

Unsteady Aerodynamic Loads and Their Control through Mini-tab Actuation.

D.J.Cleaver, N. Chiereghin, D.J. Heathcote, S. Bull and I. Gursul
Department of Mechanical Engineering, University of Bath

Rotorcraft blades are subject to unsteady aerodynamic effects due to the plunging motion created by blade flapping, the pitching motion created by cyclic control input and torsional bending, the rowing motion created by lead lag and also gusts or unsteady freestream inputs. All of these components combine to create an extremely unsteady aerodynamic scenario. The majority of these unsteady inputs will have a frequency related to the rotor frequency. For aerodynamic purposes this is non-dimensionalised as the reduced frequency $k = \omega b/V$, with values in the range k =0.05 to 0.2 classified as unsteady and values above k = 0.2 classified as highly unsteady. As reduced frequency is a function of local velocity it varies massively across the rotor however typical values for 75% span are up to 0.2 placing rotorcraft firmly in the range of unsteady aerodynamics.

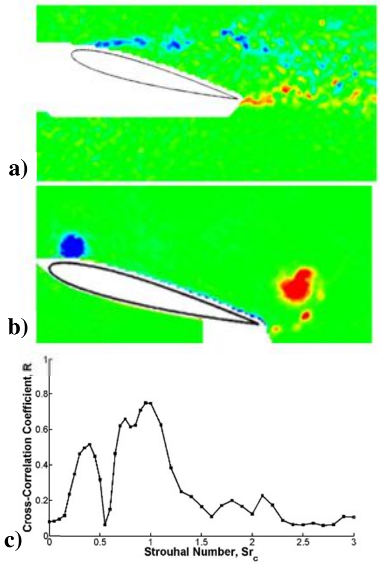

Figure 1: a) Instantaneous vorticity for a stationary airfoil, b) phase-averaged vorticity for a plunging airfoil and c) increasing coherency with increasing frequency.

Previous measurements [1] have shown that the time-averaged lift for a plunging airfoil at post-stall angles of attack generally increases with Strouhal number / reduced frequency. This increasing lift with increasing frequency is associated with increasing coherency of the leading and trailing edge vortices, see Figure 1. Local optima are observed in both time-averaged lift coefficient and coherency, measured through velocity cross-correlation at two spanwise points, at the natural vortex shedding frequency, its sub-harmonic and harmonics, see Fig. 1c.

Measurements to be presented at the workshop will give more detail on the unsteady aerodynamic forces for quasi two-dimensional airfoils. These unsteady measurements will include the effect of reduced frequency, amplitude and angle of attack. Figure 2 shows preliminary data for α=0º in the form of amplitude and phase lag of the lift signal. Included is a comparison to the classic Theodorsen prediction for small-amplitude oscillations of an airfoil. The agreement between experiment and Theodorsen prediction is generally good for all amplitudes. Rather surprisingly the agreement in lift amplitude is proportionally better at large amplitudes than small. Measurements to be presented in the workshop show that the agreement between experiment and Theodorsen is maintained to surprisingly high, even post-stall, angles of attack. This information is important for predicting the unsteady loads on both fixed-wing and rotary-wing aircraft.

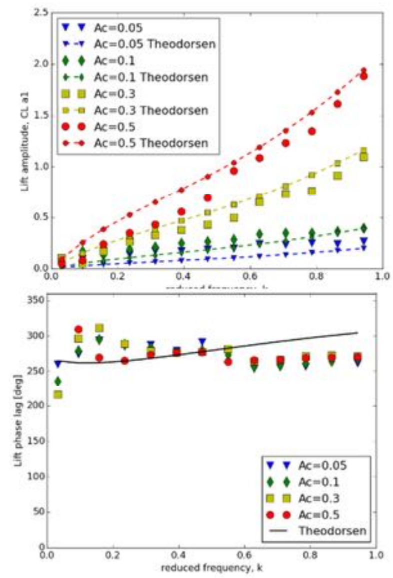

Figure 2: Amplitude and phase-lag of lift compared to Theodorsen function.

The second aspect under consideration is not only prediction of these loads but also their control. Previous measurements [2] have shown that mini-tabs (small ~1%c tabs protruding normal to the surface) are a viable method of controlling lift in steady-state scenarios. Locations near to the trailing-edge are preferable for low angles of attack, locations near the leading-edge are preferable at high angles of attack, and a 'spoiler' location, around 60%c, is effective across a wide range of angles. New measurements will investigate the effectiveness of mini-tabs for controlling loads in unsteady scenarios.

Preliminary measurements shown in Figure 4 for α=0º show that the effectiveness of the mini-tab decays in-line with Theodorsen's prediction for this angle. Further measurements to be presented in the workshop will give more detail and show how this behaviour is effected by angle of attack. This work is supported by Airbus and EPSRC.

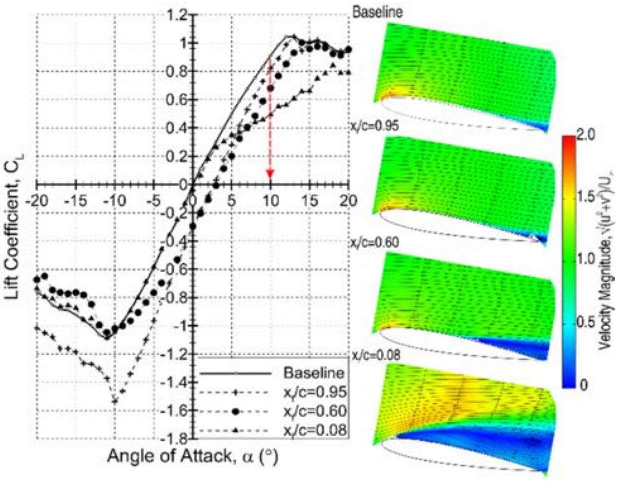

Figure 3: Lift coefficient and associated PIV at α = 10° for a mini-tab of height *h*/*c* = 0.02.

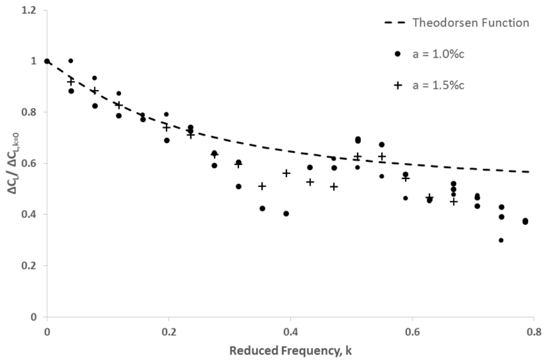

Figure 4: Mini-Tab Effectiveness as a function of reduced frequency.

[1] Cleaver, D.J., Wang, Z., Gursul, I., Visbal, M.R., 2011. Lift Enhancement by Means of Small-Amplitude Airfoil Oscillations at Low Reynolds Numbers. AIAA J. 49, 2018-2033.

[2] Heathcote, D.J., Gursul, I., Cleaver, D.J., 2016. An Experimental Study of Mini-Tabs for Aerodynamic Load Control, 54th AIAA Aerospace Meeting. AIAA, San Diego, AIAA 2016-0325.

Aerodynamic and Optimisation Study of Tiltrotor Blades

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This work investigates the aerodynamics of tiltrotor blades using CFD. Once confidence in the method is established, optimisation of the blade twist and tip shapes was also attempted. The optimisation procedure is based on an adjoint method coupled with a high-fidelity aerodynamic model, within the HMB3 CFD solver. The aim is to enhance the aerodynamic performance for the full-scale XV-15 tiltrotor blade by finding the optimal twist and tip shape distributions, for helicopter and airplane mode configurations. The optimisation objective was to maximise, independently, the Figure of Merit and the propeller efficiency, keeping constant the thrust coefficient. Regarding the shape parametrisation employed, seven control points were used located uniformly along the spanwise of the rotor, which is reproduced by means of a Bernstein polynomial distribution. It was found that a higher performance is obtained for the whole C_T range if compared with the baseline rotor blade, where the Figure of Merit was increased by 3% and the propeller efficiency up to 2% (see Figure 1 and Table 1).

Collective	Baseline Blade			Optimal Blade		
(degrees)	$\mathbf{C_T}$	$\mathbf{C_Q}$	η	$\mathbf{C_T}$	$\mathbf{C_Q}$	η
26^o	0.00222	0.000915	0.819	0.00227	0.000906	0.846
28^o	0.00503	0.001942	0.874	0.00504	0.001905	0.893
28.8^o	0.00615	0.002367	0.877	0.00614	0.002316	0.895

Table 1: Comparison of the thrust, torque, and propeller efficiency computed for the baseline and optimal XV-15 rotor blade in airplane mode configuration. $M_{tip} = 0.54$, $Re_{tip} = 4.5 \times 10^6$, $\mu = 0.337$, $\Theta_{75} = 26^o, 28^o$, and 28.8^o and $k-\omega$ SST turbulence model was employed.

REFERENCES

[1] J. S. Light. “Results from an XV-15 Rotor Test in the National Full-Scale Aerodynamics Complex”. In: *Proceedings of the Fifty-Third American Helicopter Society Annual Forum*. Virginia Beach, Virginia: AHS, 1997.

[2] F. F. Felker, M. D. Betzina, and D. B. Signor. *Performance and Loads Data from a Hover Test of a Full-Scale XV-15 Rotor*. NASA TM–86833. Sept. 1985.

[3] M. D. Betzina. “Rotor Performance of an Isolated Full-Scale XV-15 Tiltrotor in Helicopter Mode”. In: *Proceedings of the American Helicopter Society Aerodynamics, Acoustics, and Test and Evaluation Technical Specialist Meeting*. San Francisco, CA: AHS, 2002, pp. 1–12.

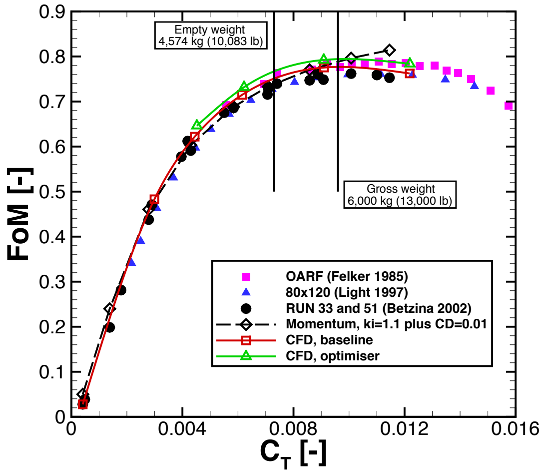


Figure 1: Figure of Merit versus thrust coefficient computed for the baseline (square symbols) and optimal (triangle symbols) for the full-scale XV-15 rotor blade in helicopter mode. Experimental data [1, 2, 3] is also shown for comparison. $M_{tip} = 0.69$, $Re_{tip} = 4.95 \times 10^6$, $\Theta_{75} = 3^o, 5^o, 7^o, 10^o$ and 13^o and $k-\omega$ SST turbulence model was employed.

Investigating the Autorotational Performance of Scaled Samara Rotor in Forward & Vertical Flight

Byungkwon Jung, Supervisor: Dr Djamel Rezgui

Why Study Samara Seeds?

Samara seeds or maple seeds are nature's most efficient fliers – they can create twice the lift compared to translating wings. This extra lift comes from the leading edge vortex (LEV) – a tornado like vortex that sits on top of the leading edge, to give a region of low pressure. Realising this potential, numerous Samara inspired UAVs are being made like the SAMURAI designed by Lockheed Martin. [1] But UAVs tends to be much bigger than a Samara seed and operate in a more versatile flight conditions and this naturally bring us to the question of "Does scaling up the natural Samara seed degrades its aerodynamic performance?" and "How does the scaled Samara rotor perform in autorotation in the forward flight regime?"

So far, Lentink has successfully constructed a 3D velocity field around various seeds when auto-rotating and found that the shape of the LEV depended on Reynolds number (Re) and the stability with the Rossby number (Ro) (Fig.2) (2). Also Yasuda tried to understand the aerodynamics of Samara by building models. He found that the thick leading edge, surface roughness was critical for low descent and high rotational speed (3).

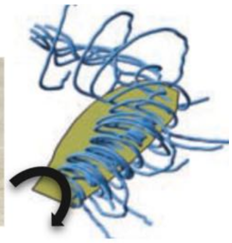
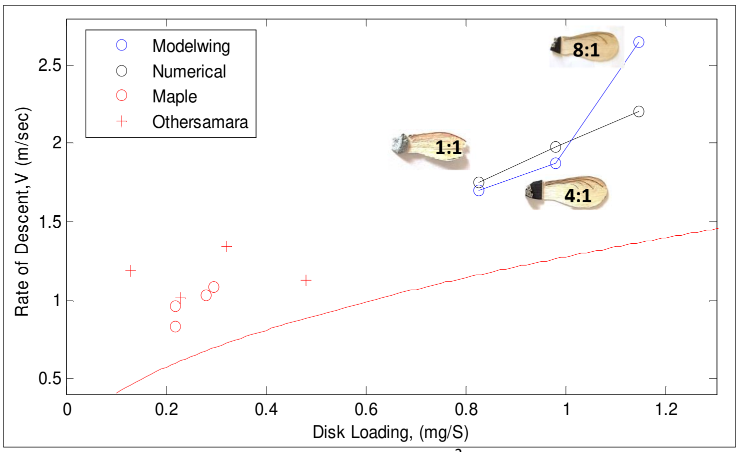


Figure 1 (left): Photo of a Samara seed
Figure 2 (right): Flow visualisation of streamlines calculated from the 3D velocity field using DPIV (2)

But some questions remains unanswered. The aim of this research is to explore the yet unknowns – Investigating the performance of Scaled Samara rotors in forward and vertical flight.

Scaled Samara Seed Performance in Vertical Descent

To investigate the effects of scaling, single bladed Samara rotors, based on Blume maple seed, were built to a scale of 1:1, 4:1, and 8:1. The Samara rotor was built using balsa wood and all the assets that constituted to the 'extra lift' and stable LEV of the natural Samara were imitated to its best.
To measure the performance of the single bladed Scaled Samara rotor, a drop test was conducted. The rate of descent and rotation speed of the autorotating scaled Samara rotor were measured as an indicator of its performance. Alongside the experiment, a numerical analysis of the scaled Samara rotor was made. It combines the momentum and blade element theory to predict the performance of autorotating rotors, if LEV was still attached. For the 1:1 and 4:1 blade models, the difference in the rate of descent between the balsa Samara wing and numerical prediction was very small (2.9% and 5% respectively). This suggested that at these small scales, effective LEV was still present. However, when the Samara blade size increased up to 30cm in span (8:1 scale), the rate of descent of the rotor suddenly increased dramatically, giving a difference of 17%. The rotation speed for the Balsa blade also fell to an extremely low rate reflecting its under-performance. This might indicate that the LEV became unstable or separated resulting in a degradation of aerodynamic performance. But it is conclusive, if the LEV is lost once it reaches 8:1 scale as other factors may be responsible for performance degradation. Work still remains.



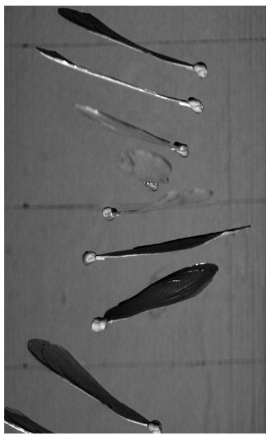


Figure 3 (Left): Rate of descent (m/s) versus Disk loading (N/m^2) for basalt wood scaled model wings, numerically solved scaled wings and the Natural samaras. The red line indicates the minimum rate of descent at optimal state of operation.
Figure 4 (Right): High speed camera image for 4:1 scale balsa wood artificial Samara

What are the future work?

Manufacturing a more representative scaled Samara rotor still remains as a task. Forward flight testing of Samara rotor has already been conducted, but, a way of better controlling the pitch and the flap angles of the rotor blades must be devised for further progress.

Reference

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2. Lentink, David, et al. "Leading-edge vortices elevate lift of autorotating plant seeds." *Science* 324.5933 (2009): 1438-1440.
3. Yasuda, Kunio, and Akira Azuma. "The autorotation boundary in the flight of samaras." *Journal of theoretical biology* 185.3 (1997): 313-320.

Progress with GARTEUR AG22 experimental work at Glasgow University

R.B. Green, M. Giuni, D. Pickles
University of Glasgow, UK
and
D. Zagaglia, Polimi, Italy

Abstract

GARTEUR AG22 concerns rotor wake interactions with ground obstacles. Experimental work at Glasgow has included tests to measure obstacle surface pressure, rotor loads and moments, rotor disc inflow and rotor wake velocity field and flow visualisation. These experiments have been completed, and the major results will be presented.

Two sets of experiments were performed, and in each case the obstacle was a regular cuboid with the side dimension equal to the rotor diameter. A 1m diameter, 4-blade rotor was used to determine rotor loads and pitching and rolling moments, and this system was also used for inflow measurements using laser Doppler anemometry (LDA) in a plane slightly above the rotor disc plane (see figure 1). A smaller, 0.3m diameter, two blade rotor was used for the surface pressure measurements and for particle image velocimetry (PIV) measurement of the rotor wake. A ZOC pressure scanner was used to sample surface pressures on the obstacle upper surface and on the vertical wall directly opposite the rotor, and stereo PIV was employed at various planes parallel and normal to the vertical wall.

Tests were conducted with the rotor axis at various positions relative to the obstacle centre, and with the rotor disc at various heights above the ground. Significant rotor in-plane moments were observed at certain positions of the rotor relative to the obstacle, and rotor in-flow was observed to be affected by the obstacle also. PIV identified clear recirculation zones, and roof and wall surface pressure indicated significant pressure loading dependent upon relative rotor position. The presentation will outline the test matrix, and present sample results of note from the tests performed.

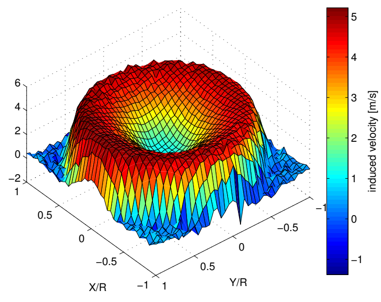

Figure 1: LDA survey of inflow to rotor disc

Rotor blade aerodynamic analysis and design

P. Mullen, F DeHaeze, A. P. Daniel

Finmecannica, UK

Over the past 3 years, AgustaWestland has been working on the collaborative research project call HiPerTilt. The main objective of this project was the development of computational tools for tiltrotor aerodynamic analysis and design. This presentation will use the HiPerTilt work achieved on the Rotor Aerodynamics contribution to go through the computational tools used in Rotor Aerodynamics and how they are used in the design and analysis process. This will involve CFD validation using test data, blade optimisation, discussion of the challenges of tiltrotor blade design and CFD analysis of complex airflows in the form of vortex ring state."

Towards Real Time Wake Computations using Lattice Boltzmann Method for Flight Dynamics Simulations

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Computational fluid dynamic methods have become increasingly sophisticated and accurate over the past 20 years, however they are orders or magnitude too slow for real time flow computation and so, analytical models or simplified aerodynamic models are still used for real time computations.

There are a number of methods to represent vortical wakes in real time flight simulations. The first is to use an analytical model or a set of velocity vectors in tabular form. A second method for real time simulation is obtained by reducing the computational cost of the calculation by using a low fidelity free wake model. Lastly, using a high fidelity simulation to build a database which is accessed in real time. This was achieved through the use of a data compression scheme via mesh simplification and the use of kd-trees for fast data queries. Recently Khan, *et al.* [1] demonstrated the use of the lattice Boltzmann method, implemented on a graphic processor unit (GPU), running real time simulations for indoor environments.

The Lattice Boltzmann Method (LBM) solves macroscopic fluid dynamics problems and sits at the boundary between the molecular and continuum views. The LBM uses the discrete Boltzmann equation to simulate flow using the Bhatnagar-Gross-Krook (BGK) collision model to calculate the flow of the fluid across a limited number of particles and directions. The LBM is an explicit numerical scheme with only local operations which has leant itself to optimisation on both CPU and graphics processing units (GPUs). The disadvantages of the LBM is that its limited to low Mach numbers with non-trivial implementations of the boundary conditions. However both these drawback are not an issue when just considering wake calculations.

Figure 1 shows the parallel speedup which shows a drop off at the higher number of cores is due to that fact that the memory bandwidth is saturated, and adding more cores does little to improve the overall performance. as well as the effect of lattice spacing on a counter-rotating vortex pair on the baseline 101×201 lattice vs a finer 201×401 lattice.

Acknowledgements
The work was funded as part of the embedded CSE support project eCSE05-04 with use of the UK National Supercomputing Service ARCHER, and the West of Scotland Computing service ARCHIE-WeSt are all gratefully acknowledged.

References

[1] M. Amirul Islam Khan, Nicolas Delbosc, Catherine J. Noakes, and Jonathan Summers. Real-time flow simulation of indoor environments using lattice boltzmann method. *Building Simulation*, 8(4):405–414, 2015.

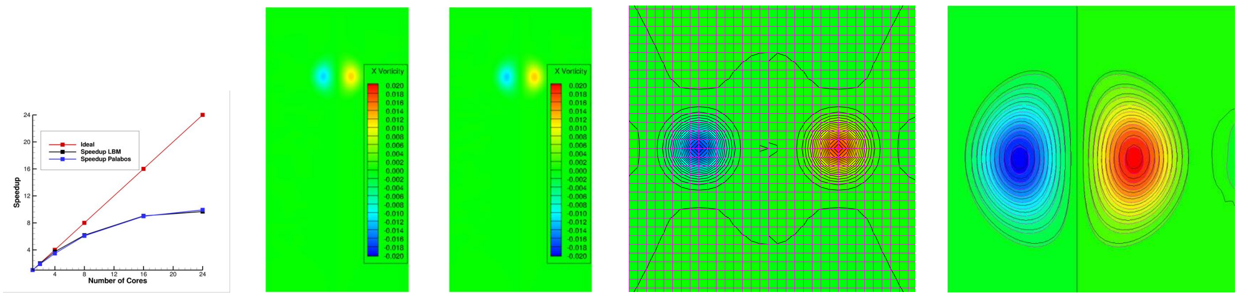

Figure 1: The parallel sppedup curve and comparison between the the baseline, black contours, and fine lattice, purple contours, for the counter-rotating vortex pairs.

Helicopter rotor blade modal tuning using internal preloads

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Abstract

To avoid resonance of a helicopters rotor blades the rotor's speed is limited to a very narrow range or even a single value. However there are a multitude of benefits from having variable speed rotors which include: improved performance; reduced noise and increased rotor, transmission and engine life. To harness these benefits there must be no resonance across the entire range of desired rotor speeds. Existing methods for vibration control are unsuitable as they perform well only in a very narrow frequency range or require significant power input and infrastructure that are not suitable for the harsh environment of the rotor.

It has previously been shown that adjustable mode softening affects can be used to predictably alter the dynamics of a simple redundant structure. This research explores the use of this concept in rotor blades to avoid resonance in centrifugally stiffened blades. The ability to alleviate resonance through prescribed mode softening would go partway to solving the dynamics problem associated with variable speed rotors. The aim is to create a method for adaptive vibration control which would alter the blade's natural frequencies to ensure sufficient separation from the varying excitation frequencies.

A simplified case of a non-rotating, high aspect ratio, transversally vibrating beam with an internal cable to provide preloading was used for the initial concept test. The system was kept simple to increase the speed and ease of the experimental and modelling process as well as to mitigate more complicated effects from coupling, rotation or a more intricate experimental setup.

The experiment and model correlated well and showed that the concept was indeed applicable to a blade like structure. The model was therefore extended to include the effects of rotation allowing for the modelling of a flapping rotor blade to be completed.

The MBB Bo 105, Westland Lynx and Westland 30 are aircraft which, due to their vastly differing roles and capabilities, are a diverse representation of helicopters in service. A Blade Element theory model for variable speed rotors was used to quantify the available performance benefits which could be achieved if variable rotor speed was permitted. The model also provides information on how much variation in rotor is required for these benefits to be realised.

The dynamics model and blade data for these aircraft were used to evaluate their potential for resonance avoidance using the aforementioned method by calculating how the natural frequencies changed with applied preload. The lower modes were shown to be the least responsive to preloading but adequate separation could be achieved without requiring loads that would buckle the blade or necessitate excessively heavy actuators.

Design and Manufacture of Composite Blades for Rotorcraft Applications

Samuel C. R. Furtado[1], Clara Frias[1], Adam Joesbury[1], Antonio Filippone[2], Nicholas Bojdo[2], Constantinos Soutis[1]

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[2]*School of Mechanical, Aerospace & Civil Engineering, University of Manchester*

Abstract

Rotorcraft blade design and manufacturing presents several challenges. Many aerodynamic and mechanical/manufacturing constraints are found. The mechanical design and manufacture must provide components capable to generate the required aerodynamic profile whilst simultaneously fulfilling other requirements (e.g. level of noise and comfort, fuel consumption and other special applications capabilities).

In the present work, instrumented tilt rotor and helicopter blades were designed and manufactured to be used for wind tunnel tests. The aerodynamic design was constrained by the wind tunnel capability (dimensions of the test section and wind speed) and by the rotor head design loads. The rotors are Mach-scaled, i.e. are designed to operate at rotation speeds that yield the same tip Mach number as in the full-scale flight. Another constraint is the design thrust, which was required to not exceed 2.5 KN and 3kN for the helicopter and the tilt rotor blades, respectively. The final geometry is given by a trim condition of zero net thrust ($T = 0$).

The key requirement that constrained the blade mass and moment of inertia was the maximum permissible radial hub load, which was set at 15 kN. This constraint was quite a challenge, as a balance was fought between achieving the desired blade profile for the design thrust and tip Mach number, accommodating sufficient shell thickness to not exceed material yield stresses in bending and torsion, and keeping the mass and radius of gyration low enough to remain within the centrifugal load limit. To facilitate control of design a constraint chart was constructed, based on a simple dynamic relationship between the rotor blade mass, radius of gyration and centrifugal load. A *lumped mass approximation* was used for these calculations.

An additional requirement is that of internal instrumentation (strain gauges), demanding that the blades have hollow cross-sections. Using the lumped mass approximation, an initial 'target' weight was set, eventually yielding the optimal solutions presented in Figure 1. This proved to be a simple yet effective approximation, as the blade design went through several design iterations, in particular to in the design of the root attachment.

In order to keep the weight low, a composite material was considered for the aerofoil and D-spar skins, while aluminium was selected for the metal root attachments. As can be seen in Figure 1, the thinner aerofoil section of the helicopter blade was not fitted with a D-spar for increased stiffness as such a solution became impractical for such a thin aerofoil. To meet the stiffness requirement, a different lay-up of the composite skin was considered (different ply orientation and higher number of plies).

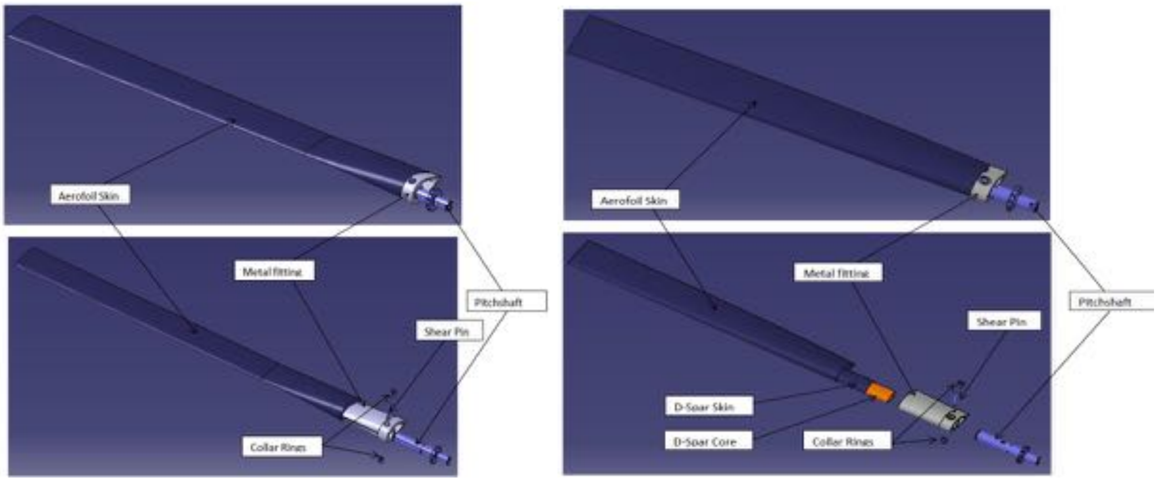

Figure 1: Blade design solutions: Helicopter (left); Tilt rotor (right).

The main purpose of the internal instrumentation is to capture the blade mode shapes. To achieve successful implementation of the strain gauges required the blades to be manufactured in two separate halves and bonded together after being instrumented. In each blade set, the strain gauge placement was required to be identical, so as to maintain consistent weight distribution and avoid the generation of unwanted forces/stresses in the rotor head. Figure 2 presents the Helicopter blades strain gauges placement and wiring.

Figure 2 - Helicopter blades strain gauges placement and wiring.

By using composites materials, the weight requirement is fulfilled, allowing the wind tunnel constraints to be met. Additionally, the composite materials provide bigger design flexibility, enabling the designer to 'tailor' some material properties in accordance with the requirement. However, the manufacturing and instrumentation presented several challenges, especially due to small sizes presented in this case.

Keywords: Rotorcraft blades design; Rotorcraft blades manufacturing; Rotorcraft blades instrumentation; Composite materials blades; Wind tunnel test.

Pitch link-induced beam bending-twist coupling and its use in vibration-based rotor health monitoring

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Helicopter blades and those substructure mechanisms that are integrated in the main rotor are very important because they directly influence helicopter control, performance and stability. As these systems begin to accumulate damage, the structural dynamics of the main rotor and its substructures progressively changes. Examples of such damage include failures such as pitch link wear, composite matrix cracking and delamination, and many others. As a countermeasure, the development of the Health and Usage Monitoring Systems (HUMS) is explored by many industries and researchers.

The main motivations behind this research is to experimentally validate and demonstrate the modelling approach suitable for the dynamic analysis of the blades with the coupled bending-twist type deformations. The focus of this work is the study of the Pitch Links (PLs) and their influence on the blade bending-twist vibrations. The PL-blade modal interactions are studied as a potential basis for the vibration-based health monitoring. In this study, the measured and computed Frequency Response Functions (FRFs) and their sensitivity to the changing conditions are studied on the chosen benchmark structures.

Initially, C-channel aluminum cantilever beam is studied experimentally. The measured data are used to develop the validated the mathematical model. A coupled bending-torsion vibration of the beam is described by the governing set of Ordinary Differential Equations using the classical Euler-Bernoulli beam theory. The resulting model is solved as the Boundary Value Problem in the frequency domain using the collocation method. Then, the *advanced beam* (AB) structures are developed. The two machined solid aluminum beams which feature the elastic flapping and flap-twist root hinges are studied. An *adjustable pitch link substructure* is also developed and used to induce the bending-torsional dynamics. A series of experiments were completed by changing the tightening torque in the PL. A maximum torque represented the “heathy” conditions and the reduced torque levels produced the damage cases. These results are aimed to provide the insight into the characteristic influences of the PL substructure on the beam (blade) vibration modes.

The computational framework is successfully correlated with the measured FRF data and used to interpret the modal dynamics of the C-channel beam. The experimental data collected during the PL-AB tests indicate the frequency region of interest with the bending-twist modes which are sensitive to the PL

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health. The ongoing activities are aimed at the AB model development with the variable PL stiffness effects.

Turbulence Budget Analysis for Serrated Airfoils

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ABSTRCAT- This paper concerns the application of trailing serrations as a passive flow control technique for aerofoil wake turbulence mixing enhancement. It has been shown that the use of trailing-edge serrations for aerofoils can lead to significant reduction of the turbulent kinetic energy in the aerofoil near wake region [Fig.1, Fig.2], implying the possibility of significant reduction of blade vortex interaction noise in rotor blade systems, rotor-stator configurations or contra-rotating propellers, *etc*. This paper is mainly concerned with the physical mechanism of the turbulent kinetic energy reduction, particularly at pre-stall angles of attack, where maximum aerodynamic performance is obtained. Two aerofoils are considered in this study, a symmetric (NACA 0012) and an asymmetric (NACA 65(12)-10) aerofoil with different types of trailing-edge serrations. To investigate the turbulence budget within the wake region, 2D Particle Image Velocimetry measurements were carried out to obtain the different components of the turbulence budget, namely turbulence diffusion, production rate, viscous diffusion and dissipation rate. Also, to better understand the turbulence decay, RANS CFD results will also be provided. It has been observed that the TKE decay depends greatly on the type of serration and the behaviour of the flow around the serrations and within the serration valley.

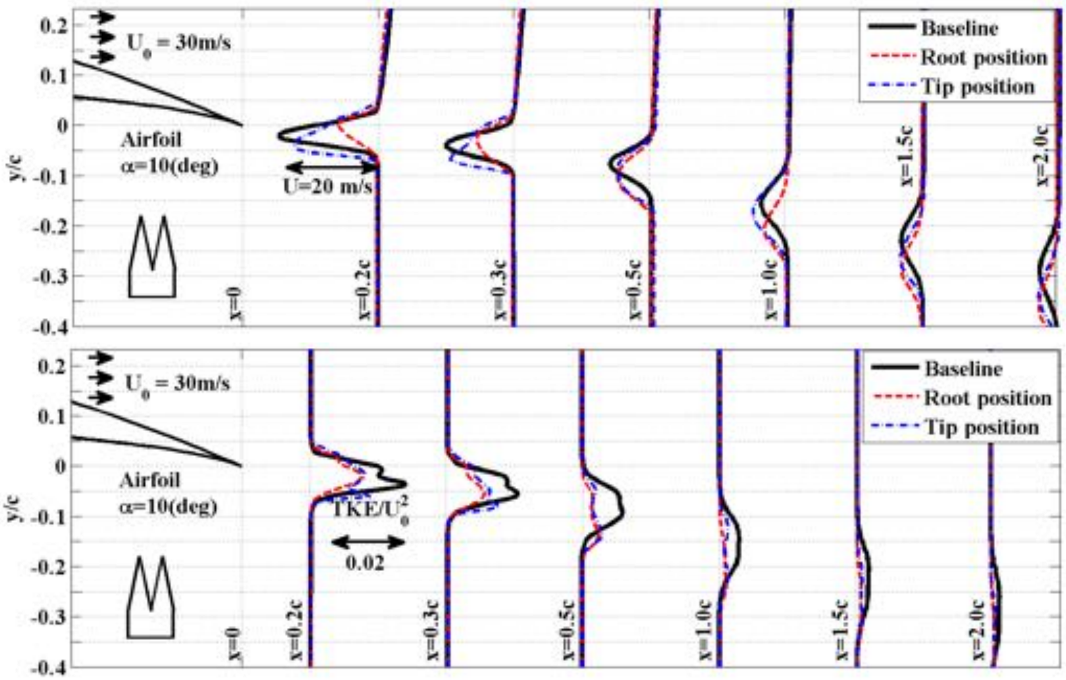

Fig. 1 Wake turbulent kinetic energy for NACA 65(12)-10 aerofoil at α= 10˚.

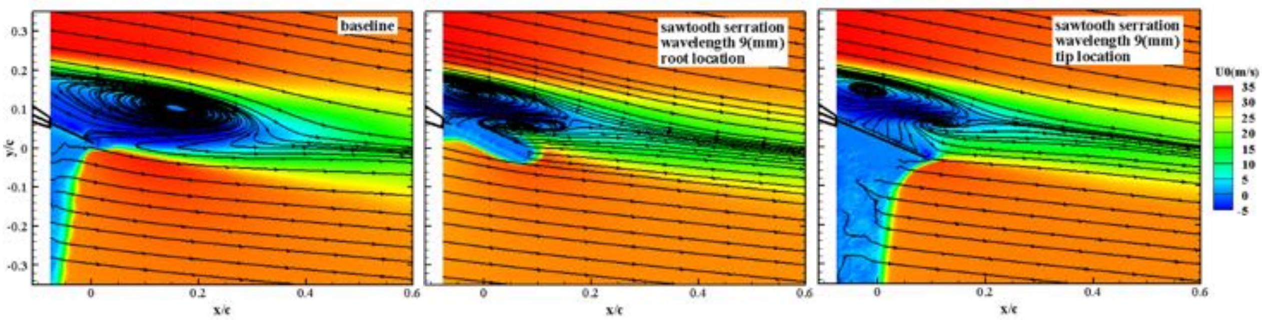

Fig. 2 Velocity contours from PIV for NACA 65(12)-10 aerofoil at α= 15˚.

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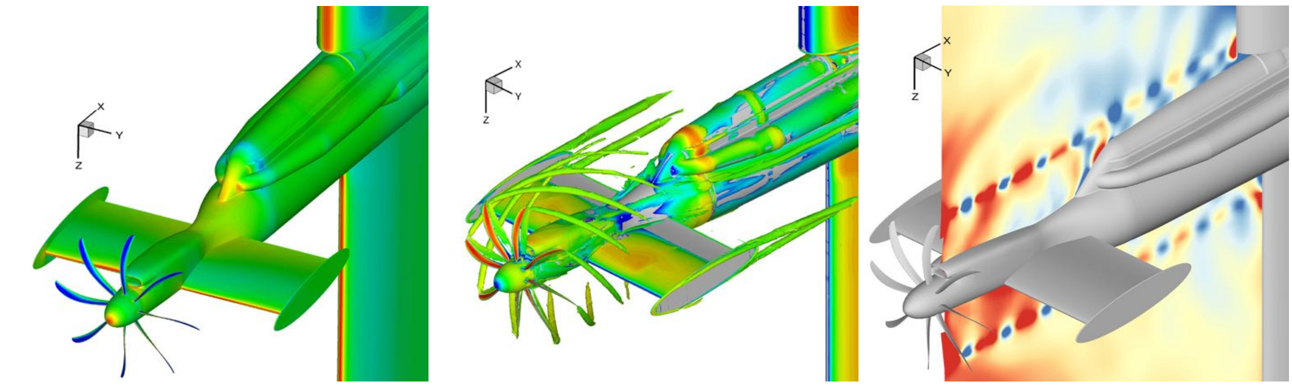
UK Vertical Lift Annual Technical Workshop
"Taking a Snapshot of the Academic Research in Vertical Lift"
9-10 May 2016.

Propeller Computational Aeroacoustic Analysis

Giulia Chirico * and George N. Barakos †

High efficiency, combined with high-speed, make turboprop aircraft the most convenient choice for short-distance flights. However, because of the propeller noise characteristics, improvements are needed to comply with new noise environmental certification requirements. Within this context, Dowty Propellers promoted the *IMPACTA* project: IMproving the Propulsion Aerodynamics and aCoustics of Turboprop Aircraft. The project aims to further improve propeller efficiency and reduce the emitted noise, thus to have a cleaner and quieter airplane. Wind tunnel tests and CFD simulations were performed during the project to study novel designs and the propeller-airframe interaction effects. In particular, innovative blade geometries and propeller configurations have been identified to reduce and/or modify the propulsion acoustic spectra. The Baseline design consists of eight blades, swept back and with thin sections. Besides this, two hub geometries have been analysed with staggered and unequally-spaced blades. Two different blade geometries, an off-loaded tip blade and a low noise blade, are also considered.
This work focused on the numerical aerodynamic and acoustic study of the IMPACTA propeller. Simulations were carried out using the CFD solver HMB3.
Steady computations using RANS for the isolated Baseline blade were first performed at cruise and climb conditions. The equivalent unsteady pressure signal was computed to study the tonal noise and the Sound Pressure Level has been analysed at different locations on a fictitious fuselage. The noise spectra have also been compared with those of the two different hub designs. Tones at the Blade Passing Frequency and its multiples are clearly visible and harmonics corresponding to half of the BPFs appear in the latters, thus increasing the smoothness of the sound. The broadband noise was also estimated using Proudman's method.
Numerical simulations of the scaled wind tunnel model, including nacelle, intake and a stub wing, were also carried out. The experiments carried out by ARA[1] allow a validation of the flow solver. Isolated and installed results will be compared to analyse the noise characteristics of the whole propulsion system. Finally, the propeller installed on a high-wing aircraft, similar to the Fokker 50, is also simulated to explore potential scaling methods of the results obtained at wind tunnel conditions.



(a) Pressure coefficient distribution averaged over one full propeller revolution.
(b) Wake visualisation via isosurfaces of non dimensional Q criterium colored by axial velocity.
(c) Acoustic pressure visualisation on the propeller centreline plane.

Figure 1: IMPACTA wind tunnel model, Baseline propeller design at cruise conditions and 4387 RPM. Numerical results of HMB3: URANS closed by the k$-\omega$ SST turbulence model.

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Adaptive Surrogate-Based Optimization of Vortex Generators for Tiltrotor Wings

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I. Introduction

Tiltrotor aircraft wings have a small span and a high thickness, for both structural resasons and 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.

To understand and quantify the effects of VGs, simulation using a computational fluids dynamics (CFD) method is often employed. However, the modelling of VGs by conventional CFD approaches poses difficult issues in capturing the vortex and its convection downstream. These simulations often require high-quality, fine numerical meshes on geometries where the size of the flow control device is orders of magnitude smaller than the global object, hence are expensive. The high cost of these simulations tends to make CFD-based design, and in particular, numerical optimization prohibitively expensive. However, the design of VGs is important and too large of a VG can provide a large cruise drag penalty, while too small can lead to an ineffective device. This paper considers the optimization of VG via an adaptive surrogate modelling approach, where the number of expensive CFD simulations are minimized, allowing a wide exploration of the design space and therefore effective design of the VG.

II. Surrogate Framework

II.A. Simulation and Meshes

The simulation approach uses structured meshes which are produced using a transfinite interpolation approach with local stretching and rotation to create the VG goemetry. Flow solutions are obtained using OpenFOAM[a] to solve the RANS equations. The mesh used in this work is shown in figure 1 . The aerofoil used is the NACA 64(4)-421 section with a 0.4% chord blunt trailing edge

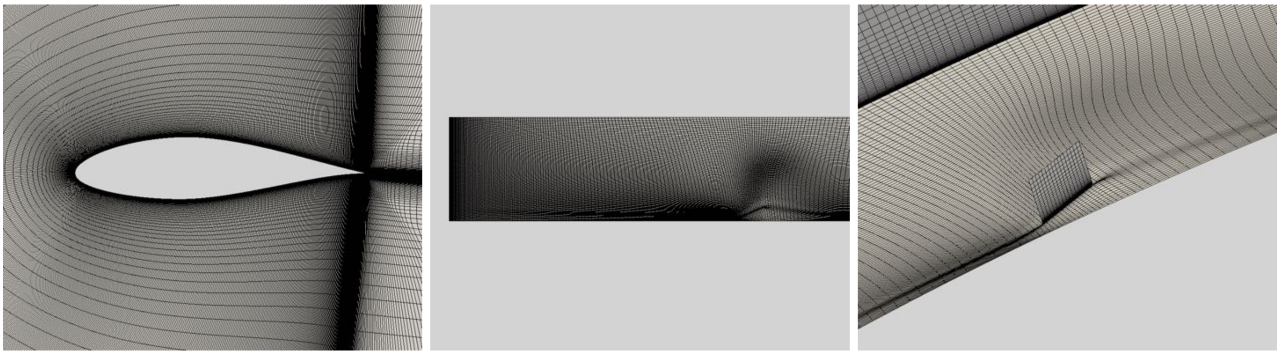

Figure 1: Structured mesh around VG

II.B. Problem Considered

Eliminating early onset buffet on tiltrotor wings is the overall objective. The flow condition considered is $C_L = 1.3$, which is a loading that induces a large separation region and therefore buffet. The objective function (equation 1), against which to design the vortex generators, is chosen to balance the design objective of reducing separation with the common objective of reducing drag.

$$J = C_D + kS \tag{1}$$

The VG length (l), VG aspect ratio (AR), VG setting angle relative to freestream (θ), VG chordwise location (c) and the spacing ratio (s) are the design variables.

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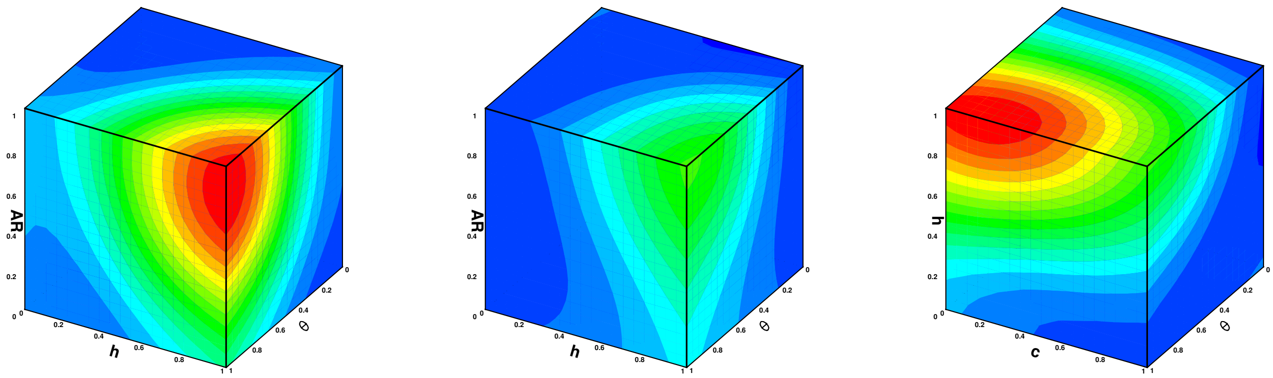
[a] `http://www.OpenFOAM.org/`

II.C. Surrogate Modelling

The surrogate model used in this work is developed around a multivariate interpolation using radial basis functions (RBFs). This interpolation method has the advantage of providing exact recovery of data at the known sites, thus preserving the CFD data at the known sampled points.

An initial set of VG designs are considered and are run in the CFD to obtain the performance of these designs. In this work, latin hypercube (LHC) sampling was used to construct the initial 150 samples. In addition, corners of the sample space were also added as this is important for the surrogate interpolation. Projections of the initial surrogate are shown in figure 2.



(a) Projection at $c = 0$, $s = 0$ (b) Projection at $c = 1$, $s = 0$ (c) Projection at $AR = 1$, $s = 0$

Figure 2: Surrogate model projections (blue represents lower objective, J)

II.D. Optimization and Adaptive Sampling

An optimization approach is required to locate the minimum of the surrogate model an a differential evolution (DE) approach is used. DE is a global optimization approach and can therefore locate the global optimum of the five-dimensional design space described by the surrogate model. Once the minimum is located, this is re-run in CFD to assess the error between the minimum value predicted by the surrogate and the true objective of that design point. An adaptive sampling procedure has been developed and is used if the error is large. The adaptive sampling is used to determine the location of a new sample point, which is at the maximum of the function described in equation 2. This balances three requirements of curvature capture, space filling and optimum locating.

$$C_b = (|\nabla^2 J| + \epsilon)(1 - H)^2 b^3 \tag{2}$$

II.E. Results

The results are given in table 1, demonstrating that separation has been entirely eliminated. Furthermore, the drag of the optimized VG is lower than the clean geometry at this design point, indicating that this is a highly efficient process.

Table 1: Design space results

	J	C_D	Separation	h	AR	θ	c	s
Clean	0.0247	0.0191	11.1%	-	-	-	-	-
Optimized	0.0189	0.0189	0.0%	0.85%	3.64	8.42°	21.5%	5.8

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. An adaptive optimization procedure has been developed and used to design VGs to eliminate a large separation region. The work presented at the workshop will expand on the results presented and detail the approaches developed for the design of the vortex generators.

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.

Aeromechanics and Rotorcraft Vehicle Design activities in the Department of Aerospace Science at Cranfield University

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School of Aerospace, Transport & Manufacturing, Cranfield University

While Cranfield University is involved in academic activities across many rotorcraft disciplines, including design, operation and manufacturing, the focus of the presentation will be on the activities of the Aerospace Science department which focuses on the Aeromechanical Design and analysis of aerospace vehicles. The presentation aims to provide i) a flavour of some of the research activities through a brief description of three current research projects, and ii) a quick presentation on the rotorcraft designs that have come out of the University's flagship Aerospace Vehicle Design activity over the years.

1. Some Current Research Activities

The department is working closely with Airbus Helicopters (in collaboration with BHR Group and Helitune) in an ATI funded programme to design, validate and demonstrate an inflight system for the measurement of dynamic rotor blade deformation. This system requires robust instrumentation system capable of operating in the challenging and harsh environment of a helicopter rotor hub. This will provide the capability to monitor the health of the rotor blades through direct blade shape deformation measurements. Such technology brings benefits to operator and maintainer through continuous in-flight monitoring which results in flight safety, operations and maintenance and contributes towards reductions in point to point travel time.

Existing methods using strain gauges have numerous disadvantages. These range from operational limitations, such as high sensitivity to temperature and precipitation to fundamental limitations, such as the collection of strain data from which shape deformation can only be indirectly inferred. The search for new measurement techniques has been the subject of numerous studies, yet, none of these methods are mature enough to be efficiently used in flight test. The activities within this project focus on (a) the development of a fibre-optic instrumentation for direct shape deformation measurement, as presented in the overview of the proposed system in figure 1, (b) transfer of data between the rotating rotor hub and the airframe and, (c) incorporation within a health monitoring solution. The fibre-optic system uses small diameter fibre-optic cables embedded into the blade surface with a network of gratings and high frequency optical micro sensors.

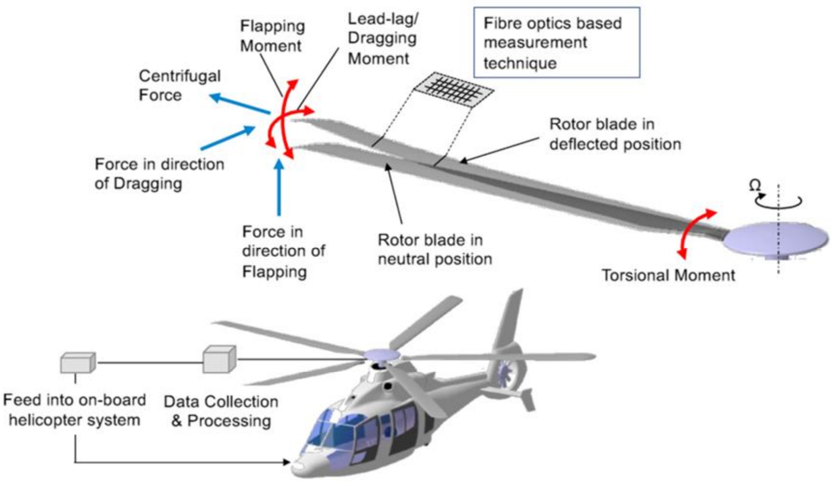
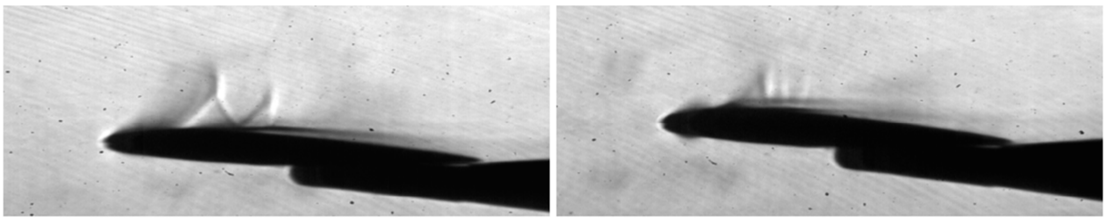


Figure 1: Overview of the fibre-optic, in-flight, blade deformation measurement system.

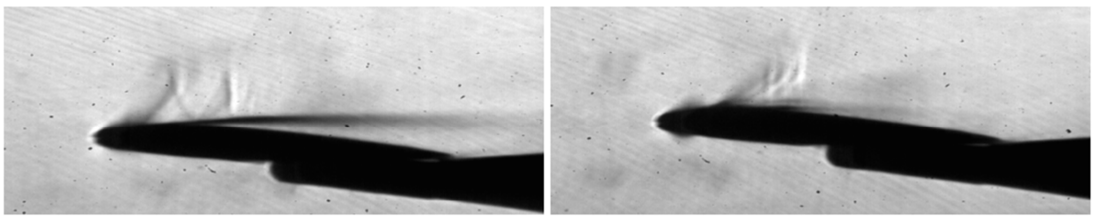
The department is also currently active in the area of low-speed and transonic flow control testing and simulation. In the low speed regime a dynamic stall rig has been constructed with simultaneous pitch and heave capability for the comparative assessment, at relatively small scale (models of chord 12 – 14m, and span of up to 0.5m) with maximum pitch of 40^{o}, pitch/heave frequency of up to 20Hz and a maximum air speed capability of up to 25m/s. This facility, which is currently under test will allow low speed assessment and optimisation of flow control devices in dynamic conditions prior to testing at larger scale in the main NWTF facilities in Glasgow.

Figure 2 presents some results for ongoing transonic testing of shock control / separation suppression research at transonic speed, relevant to performance improvement of the advancing side blade tip flows. Here, passive air jet vortex generators are being compared with a clean configuration for a NACA 23012C aerofoil profile at a fixed α=4^{o} pitch at three Mach numbers, demonstrating their ability to reduce the shock extent and suppress boundary layer separation to a much more downstream location. The central sting with 3-component balance, under development will allow force/moment measurement for this application.



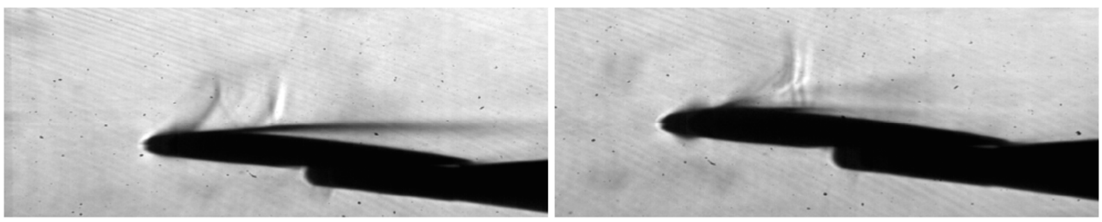
(A) Schlieren pictures of the clean model at $M = 0.73$ and $\alpha = 4°$

(B) Schlieren pictures of the model with air-jets at $M = 0.73$ and $\alpha = 4°$



(A) Schlieren pictures of the clean model at $M = 0.78$ and $\alpha = 4°$

(B) Schlieren pictures of the model with air-jets at $M = 0.78$ and $\alpha = 4°$



(A) Schlieren pictures of the clean model at $M = 0.8$ and $\alpha = 4°$

(B) Schlieren pictures of the model with air-jets at $M = 0.8$ and $\alpha = 4°$

Figure 2: Schlieren flow visualisation images of a NACA 23012C aerofoil model (mounted from a central sting from the lower surface) for 0.73 < M < 0.8 (0.65million < Re_c < 0.7 million) with and without passive air-jet vortex generators (at 15% chord on the upper surface).

2. Rotorcraft Design Activities

Research is currently being undertaken to investigate the design feasibility of turbo-electric propulsion applied to helicopters. This envisages a gas turbine power plant driving an electric generator such that the output electrical power is used to drive the main and tail rotor, without the need for heavy gearing and transmission systems. Once the power plant and rotors are mechanically disconnected, there is potentially a wide scope to alter the configuration of a conventional helicopter. Benefits of such a propulsion architecture may include: weight reductions, performance enhancements, operational flexibility, increased overall system safety etc.

Also, over the past 70 years, since 1946, the teaching of aircraft design at Cranfield has focussed on the practical application of design techniques in a simulated industrial environment. Students are presented with the conceptual design of an aircraft and over the course of their studies they apply what they learn to all aspects of the aircraft's structure, systems and avionics. This presentation details some of those designs studied since 1946, focussing on the aircraft with vertical lift capability, some of which are illustrated in figure 3. These have included conventional helicopter configurations, tilt-rotor aircraft and novel vertical lift airliners in collaboration the Hawker-Siddeley aircraft company in Hatfield.

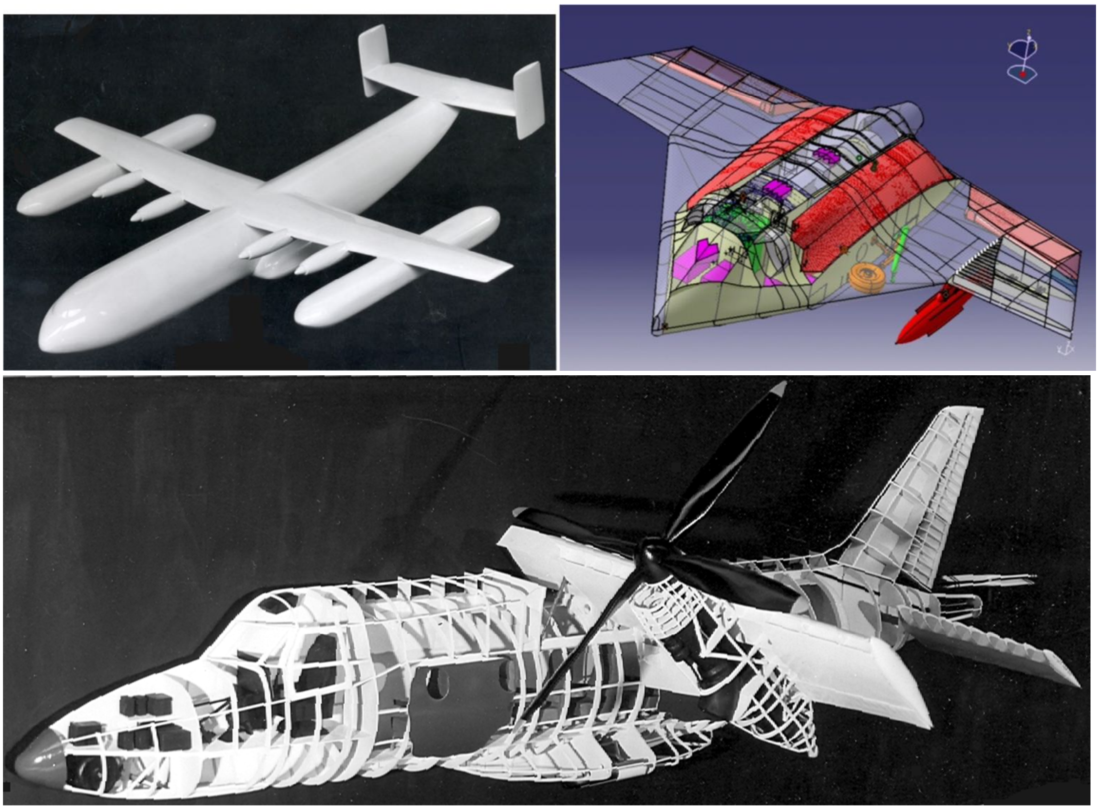


Figure 3: Some of the vertical-lift aircraft configurations examined by the Cranfield University Aerospace Vehicle Design activities.

Development of a Modelling and Simulation Environment to Support Helicopter Operations to New RN Vessels.

Mr Paul Scott, Miss Rebecca Mateer
Flight Science and Technology Research Group
The University of Liverpool

The Flight Simulation and Technology department at the University of Liverpool (UoL) has recently been researching the ship-helicopter operating environment on behalf of BAE Systems. Three PhD students have been working on further understanding the aerodynamics of the Type 26 Frigate and the Queen Elizabeth Class Aircraft Carrier in order to investigate the effects of the Dynamic Interface on helicopter operations to these vessels. The research currently being undertaken is building towards a simulation environment to enable a fully simulated Ship Helicopter Operating Limit (SHOL) for both ships to be developed.

This presentation will report on a range of Computational Fluid Dynamics (CFD) studies that have been undertaken on the Type 26. The studies provide an insight into a number of foreseen issues with the measurement of Wind Over Deck (WOD) conditions by the ship’s anemometers as well as the effect of the ship’s exhaust gases on the safe launch and recovery of helicopters to the vessel. The main anemometers on the Type 26 are positioned on the fore of the main mast structure. Concerns have been raised as to the accuracy of the anemometer readings as a result of design similarities between the Type 26 and Type 45 main mast structure. The Type 45 destroyer has a restricted SHOL as a direct result of poor anemometer placement therefore an aerodynamic investigation has been undertaken to provide an insight into the performance of the anemometers on the Type 26 in their current positioning. Further studies have also been conducted on a proposed aft anemometer that will, in theory, provide more accurate readings for aft WOD conditions. In addition to this, CFD cases have also been computed to analyse the air temperatures around the flight deck of the Type 26 by modelling the ships exhaust efflux. The Type 26 will operate using a Combined Diesel or Gas (CODOG) propulsion system for which the main prime mover will be the ship’s Gas Turbine (GT), supplemented by four Diesel engines. The ingestion of high temperature exhaust efflux from the GT and Diesel engines at the helicopters engine intake can create a hazardous flight condition during launch and recovery. Currently there are no military specifications that define the temperature requirements for helicopter launch and recovery operations and the presentation will demonstrate the challenges of trying to comply with the civil requirements, CAP 437 Standards for Offshore Helicopter Landing Areas.

The presentation will also report on the challenges faced in developing airwakes for the Queen Elizabeth Class Carrier in support of the First of Class Flight Trials (FOCFT).