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The Collaborative Development of New CFD Methods Adapted for Tilt Rotor Aircraft in the HiPerTilt Project

Florent Dehaeze[1]
Leonardo Helicopters, Yeovil BA20 2YB, UK

Christian B. Allen[2]
University of Bristol, Bristol BS8 1TR, UK

and

George N. Barakos[3]
University of Glasgow, Glasgow G12 8QQ, UK

Following new requirements for CFD tools regarding tilt rotor aircraft, Leonardo Helicopters, partnering with the Universities of Bristol and Glasgow and Innovate UK, launched the HiPerTilt project, aimed at designing and validating new methods adapted to new aircraft. It was also required that these methods should be compatible with conventional helicopters. The project, focusing on both the airframe and the rotor aerodynamics, was split in five work packages, and the main achievements are described in this paper. The new methods have proven efficient and adapted for use in industrial processes. The strong cooperation between the partners, associated with the expertise of the partnering Universities, was one of the key factors contributing to the success of the project.

I. Introduction

Following the development of tilt rotor aircraft in Leonardo Helicopters, a need for new, adapted, Computational Fluid Dynamics (CFD) methods in Leonardo Helicopters arose. Due to the lowering cost of computing power, and the progress of CFD methods, it is now possible to perform more complex simulations in shorter times. This advancement highlighted the need for a review of CFD requirements for future aircraft, as well as additional capabilities that could be exploited in the design process to make it more efficient. Furthermore, all developed methods were required to be useable for both tilt rotors and conventional helicopters.

The increased interest in tilt rotor aerodynamics research is not limited to Leonardo Helicopters. A series of European research programs focused on this particular problem, with NICETRIP (1) being the latest. These experiments provide a strong validation database.

Given the improvements of CFD, Leonardo Helicopters considered that a strong use of CFD method would be the most cost-effective approach to develop efficient aircraft. Since CFD methods were not currently developed and qualified for tilt rotor aircraft, a new project was required to bring these to an industrial use.

To solve this particular issue, Leonardo Helicopters decided to team up with the University of Bristol and the University of Glasgow. Both Universities have a long-standing relation with Leonardo Helicopters, and the HMB CFD code (2), developed by the University of Glasgow, has been used in Leonardo Helicopters for more than 10 years.

The presentation and paper will describe the project’s main goals, and its structure allowing these to be reached. Main achievements are then highlighted, together with the exploitation of obtained results and conclusions for future collaborative projects.

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[1] R&T Programme Lead – University Research and Aerodynamics, Box 266.

[2] Professor, Department of Aerospace Engineering, MAIAA.

[3] Professor, CFD Laboratory, School of Engineering, MAIAA.

II. Work Breakdown

HiPerTilt, a 4-year long project, started in April 2013, and was supported by Innovate UK. The work planned for the partnering universities was completed by end of March 2016, by which time all their main goals were reached. The main project aim was to develop and implement new design and optimization tools specifically adapted for tilt rotor aircraft.

It was decided to split the work in the project into five work packages, as shown in Figure 1. The first three work packages aimed at improving the understanding, prediction and optimization of the aerodynamics of the airframe, while the last two work packages focused on the rotor aerodynamics.

Work package 1, performed in Leonardo Helicopters, aimed firstly at validating the CFD methods for the simulation of a tilt rotor airframe, and the optimization of the airframe to reduce the drag. Work package 2 focused on the validation of the CFD simulations by running a wind tunnel test campaign, aiming at validating the CFD methods developed in Work Package 1. Work Package 3, performed by the University of Bristol, aimed at developing their own optimization techniques, and adapt them to the specific requirements associated with the development of tilt rotor wings, as well as improving the simulation of vortex generators for the wing, optimizing their location. Work Package 4 looked at the development of CFD methods for the design and validation of tilt rotor aircraft. It was performed by Leonardo Helicopters and the University of Glasgow, in a close cooperation. The work covered the validation of multiple CFD methods for the simulation of tilt rotors, before focusing on rotor design and optimization approaches, and a study on acoustics methods. Work Package 5 focused on the more complex CFD simulation: the University of Glasgow used the HMB solver to simulate a full tilt rotor aircraft in flight, while Leonardo Helicopters carried out a study of the Vortex Ring State (VRS).

Frequent meetings were held between the involved partners on all tasks, on a monthly basis when possible, benefiting from video conferencing facilities when travel was difficult to organize. For the tasks requiring more exchanges; various placements at Leonardo Helicopters were offered to the researchers of the universities; allowing for better communication between the partners, and a more efficient integration of the developed tools into the company’s operating procedure. Longer visits from engineers from Leonardo Helicopters, when required, also ensured a deep understanding of the new technologies and tools developed within HiPerTilt.

III. Results from the HiPerTilt Project

In this section, the work performed in HiPerTilt will be described, work package by work package.

A. Work Package 1

The first step in the development of new optimization approaches for the airframe was the validation of the CFD software in use in Leonardo Helicopters: Fluent™ (3), AeroFOAM (4) and HMB (2). Four airfoils were selected for this test, representative of tilt rotor wing airfoils. All solvers gave satisfactory results, especially Fluent™ and HMB. The former was selected for further work, due to the experience of staff members working on the project.

The next step was the validation of Fluent™ for the simulations of the whole aircraft. The ability of CFD to predict both the drag and the separated areas was tested, using the ERICA airframe (tested in the NICETRIP project (1)) and a simplified AW609 airframe (datum case). The drag prediction on the ERICA airframe compared well, as shown in Figure 2, with only a slight difference in the prediction of the onset of stall, which could be linked to the fact that the wind tunnel and the model support were not simulated. The propagation of the flow separation at the wing trailing edge, and along the span at high incidence was then studied on the datum airframe. Due to the influence of this flow separation on the aircraft performance and buffet, it was decided that the geometry optimization should focus on delaying the onset of this flow separation.

The next step was the development of an optimization approach for the wing aerofoil, before optimizing the airframe. The main objective of the wing aerofoil optimization was to reduce the drag of the datum wing, while taking into account the constraints linked to tilt rotor wings. A genetic algorithm based optimizer was developed, and separate optimizations of the flaperon and the whole aerofoil were undertaken. In both cases, improvements were achieved at high incidence, and the stall was delayed. The focus of the optimization was then shifted to the parts of the airframe that were shown to have a strong influence on the onset of the stall on the wings: the wing/fuselage junction and the shape of the actuator fairing at the wing/nacelle junction. The surfaces to be optimized were parameterized in Altair HyperMesh™ (5). The optimization of the surfaces enabled the delay the onset of stall and the associated high increase in the drag. Overall, the fully optimized design was able to reduce the drag of the airframe in cruise condition, as well as delay the stall, as shown in Figure 3. The onset of buffet, created by the trailing edge separation on the wings, was also significantly delayed.

B. Work Package 2

A new database for the validation of CFD solvers for tilt rotor wing aerofoil will be generated. A wind tunnel test performed at the Aircraft Research Association (ARA) in Bedford, UK, in the Transonic Wind Tunnel, in February 2017. The aerofoil will be tested at speeds covering Mach 0.2-0.6, and various incidences. This test will also allow the quantification of the effect of the vortex generators on the lift, drag and trailing edge separation. The various CFD solvers will also be validated against this new database. The paper will outline the experimental approach as well as show key features from the results.

C. Work Package 3

The first part of the work of the University of Bristol focused on aerofoil optimization (6). Two methods of aerofoil parameterization were developed during the project: Singular Value Decomposition for full aerofoil optimization and Radial Basis Functions for the optimization of part of an aerofoil (such as a flap). A gradient based optimizer and a gravity based global search method were tested. OpenFOAM (7) was used to determine the aerofoil polar. The resulting optimization, taking into account inputs from Leonardo Helicopters regarding the constraints, was able to reduce the drag at cruise conditions, as shown in Figure 4. The trailing edge separation was delayed at higher incidences, meaning a delayed onset of buffet.

Finally, the University of Bristol focused on the simulation of vortex generators (8), and optimized the spacing, placement and shape of the vortex generators on a NACA64(4)-421, which is representative of the thick airfoils used for tilt rotor wings. Both rectangular and trapezoidal vortex generators were assessed. The drag could be decreased at cruise conditions, compared to the current design of vortex generators for the AW609, and the obtained optimized design is shown in Figure 5. Furthermore, various vortex generator source models were tested, to reduce the cost of CFD simulations of airfoils with them.

D. Work Package 4

The first step was the validation of the currently used aerodynamics methods for the specific simulation of tilt rotors: the free-wake panel method ADPanel (9), and the CFD solvers HMB (2) and Fluent™ (3). Leonardo Helicopters used the rotor of the XV-15 (10) as a reference for the current work; this rotor is the only tilt rotor freely available in the open literature. This choice was also influenced by the freedom to share and compare the results with the University of Glasgow's own simulation, without any restriction on both sides. Meanwhile, the University of Glasgow performed their own validation of the HMB solver, using the XV-15 rotor, as well as the comprehensive database available for the S-76 rotor (11) (as shown in Figure 6Figure 6), and the JORP propeller, demonstrating the use of HMB for simulating rotors and propellers. This was completed by a comparison with the NICETRIP database later in the project, once it became available. All developed methods were validated, as shown in Figure 7 and this exercise in Leonardo Helicopters also proved an opportunity to train young engineers in the use of the various available aerodynamics methods. The University of Glasgow also interfaced HMB with BENP (12), the acoustics prediction tool in use in Leonardo Helicopters. This led to a new capability in Leonardo Helicopters, to couple the use of HMB and BENP. In order to decrease the dissipation of acoustic waves in the flow field, the University of Glasgow also developed and implemented higher-order schemes, aiming at improving the tonal noise acoustic field in the vicinity of the rotor.

The main task in Work Package 4 for Leonardo Helicopters consisted of developing a new approach for optimizing tilt rotors (13). The XV-15 rotor was chosen as a reference for this study, and the aim of the optimization was to improve the hover figure of merit and propeller efficiency, while keeping geometrical constraints imposed on the original aircraft. A new aerofoil optimization method was applied, using a gradient-based Adjoint Optimization Method, developed by the University of Glasgow (14), and a multi-point objective function. The newly generated airfoils were then used for an optimization of the blade sweep, twist and chord, using the ADPanel panel method, and the results were validated using a CFD simulation with HMB, showing a clear improvement in both hover at high thrust, and aircraft mode at all speeds, as shown in **Figure 8**. The University of Glasgow also performed a demonstration of the Adjoint Optimization Method on a full XV-15 rotor, proving that this optimizer could be applied to a full rotor directly, as shown in **Figure 9**. Future work will also cover a further study of the effect of the blade sweep, and the blade anhedral.

E. Work Package 5

The University of Glasgow demonstrated HMB on a complete tilt rotor aircraft in all possible configurations, using the NICETRIP geometry. Simulations at various experimental test points corresponding to all three flight phases (hover, cruise and transition) were selected and run with HMB (2), as shown in **Figure 10**. The Chimera mesh approach was selected, and actuator disks simulating the effect of the rotor were used in some simulations, to assess their effect of modeling the rotor rather than simulating it. The obtained results compared well with the experimental data from the NICETRIP project (15), and the whole aircraft have been successfully tested at Leonardo Helicopters to assess the possibilities this new capability will offer.

Finally, the Vortex Ring State (VRS) was studied in Leonardo Helicopters (16). This flight condition is important for tilt rotor aircraft design and defining the conditions in which it may occur, to prevent the pilots reaching such conditions, is an important part of the flight tests of a new aircraft. The early definition of the condition in which VRS occurs ensures that critical flight conditions are avoided during the flight test phase. Simple momentum theory based models were tested to predict the onset of VRS, and a new methodology to assess the location of the VRS area in the flight domain was devised. Finally, the HMB and Fluent™ CFD software were assessed for the simulation of rotors in VRS, using multiple approaches to evaluate the best way to simulate this case. Both solvers produced similar results, predicting a high variation of the loads in the VRS region.

IV. Exploitation and Dissemination

The HiPerTilt project allowed all partners to have a deeper understanding of the specifics of tilt rotor aircraft aerodynamics. The newly developed tools, taking into account industrial requirements, have already been used in Leonardo Helicopters, and will also be applied to future tilt rotor aircraft being developed, such as the demonstrator in Clean Sky 2. Furthermore; all the software developed in HiPerTilt were also designed to be applicable to conventional helicopter simulations. The understanding of CFD capabilities in Leonardo Helicopters was also improved, particularly in the case of complex flows, thanks to the VRS study.

The project also improved the visibility of the partnering universities, who used the opportunity to publish their work in many renowned conferences. The developed tools can also be reapplied in other domains, such as fixed wing aircraft, or even wind turbines. The project also helped developing a privileged link between Leonardo Helicopters and the Universities of Bristol and Glasgow.

V. Conclusion

The HiPerTilt project allowed Leonardo Helicopters to develop and validate its CFD tools for the simulation of tilt rotor aircraft, as well as develop its engineer’s skills in their use. The participation of the Universities of Bristol and Glasgow, using Leonardo Helicopters’ guidance, allowed for the upgrade of the current tools and the development of new ones, reaching the current state of the art. These tools were then integrated in optimization procedures that have since been applied to the design of current and future tilt rotor aircraft within the company. Furthermore, they were developed since the beginning of the project to be also applicable to standard helicopters, rather than strictly focusing on tilt rotor aircraft.

To reach a high level of compatibility between the software developed in the universities and the company requirements, a strong cooperation between all partners was developed. The constant exchange of information between all partners was key to the success of the project, and will be used as a basis for future cooperation, each partner having a better understanding of the others’ requirements and methodology.

Acknowledgements

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References

1. *Experimental Validation of Tilt-Rotor Aerodynamic Predictions.* **Decours, J., et al.** Southampton, UK : s.n., 2-4 September 2014. 40th European Rotorcraft Forum.

2. *Framework for CFD Analysis of Helicopter Rotors in Hover and Forward Flight.* **Steijl, R., Barakos, G. N. and Badcock, K.** 8, 2006, International Journal for Numerical Methods in Fluids, Vol. 51, pp. 819-847.

3. **ANSYS.** *ANSYS Fluent.* s.l. : http://www.ansys.com.

4. **Cassinelli, Carlo and Thomopoulos, Alexandros.** *AeroFOAM Validation for Fuselage Aerodynamics Applications.* s.l. : AgustaWestland Technical Note MULJ0000K004 Issue A.

5. **Altair.** *Altair HyperMesh.* s.l. : http://www.altairhyperworks.co.uk/.

6. *Optimal Domain Element Shapes for Free-Form Aerodynamic Shape Control.* **Poole, Daniel J., Allen, Christian B. and Rendall, T.** Kissimmee, Florida, USA : s.n., 5-9 January 2015. 53rd AIAA Aerospace Sciences Meeting .

7. **OpenFOAM Ltd.** *OpenFOAM.* s.l. : http://www.openfoam.org.

8. *Optimization of Vane-Type Vortex Generators for Tiltrotor Wings using Computational Fluid Dynamics.* **Bevan, Rhodri, et al.** San Diego, California, USA : s.n., 4-7 January 2016. 54th AIAA Aerospace Sciences Meeting, AIAA SciTech.

9. *Development of a Multi-Processor Unstructured Panel Code Coupled with a CVC Free Wake Model for Advanced Analyses of Rotorcrafts and Tiltrotors.* **d'Andrea, A.** Montréal, Canada : s.n., 29 April-1 May 2008. 64th Annual Forum of the American Helicopter Society.

10. **Maisel, M.D., Giulianetti, D.J. and Dugan, D.C.** *The History of the XV-15 Tilt Rotor Research Aircraft: From Concept to Flight.* s.l. : NASA SP-2000-4517, 2000.

11. *Hover Performance Predictions for the S-76 Main Rotor Blade.* **Jimenez Garcia, Antonio and Barakos, George N.** Kissimmee, Florida : s.n., 2015. 53rd AIAA Aerospace Sciences Meeting .

12. **Agusta Relazione.** *100-95-057 Rev.A* .

13. *Rotor Blade Aerodynamic Analysis and Design.* **Mullen, P.** Macclesfield, UK : s.n., 09-10 May 2016. 2nd Annual UK Vertical Lift Network Technical Workshop.

14. *Fully Implicit Discrete Adjoint Methods for Rotorcraft Applications.* **Biava, M., Woodgate, M. and Barakos, G.N.** 2, 2016, AIAA Journal, Vol. 54, pp. 735-749.

15. *CFD Simulations of the ERICA tiltrotor using HMB2.* **Jimenez-Garcia, A. and Barakos, G.N.** San Diego, California, USA : s.n., 4-7 January 2016. 54th AIAA Aerospace Sciences Meeting .

16. *Vortex Ring State Prediction and Analysis.* **Mullen, P. and Bernini, G.** Lille, France : s.n., 6-8 September 2016. 42nd European Rotorcraft Forum.

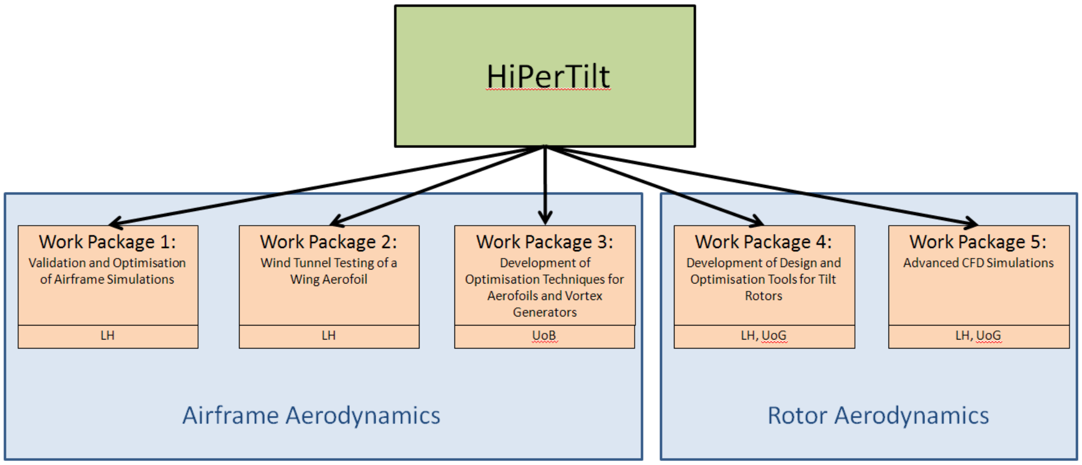


Figure 1. Work Package Distribution in HiPerTilt, describing the partner(s) taking part to each work package

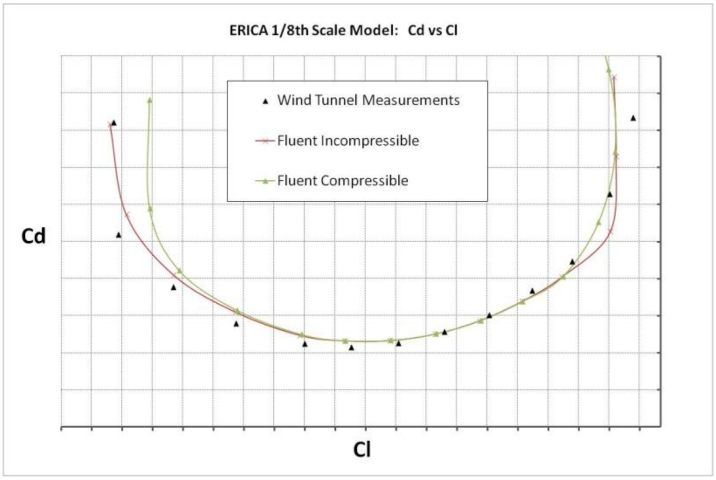


Figure 2. Validation of the “Fluent™” CFD solver for the simulation of the ERICA fuselage.

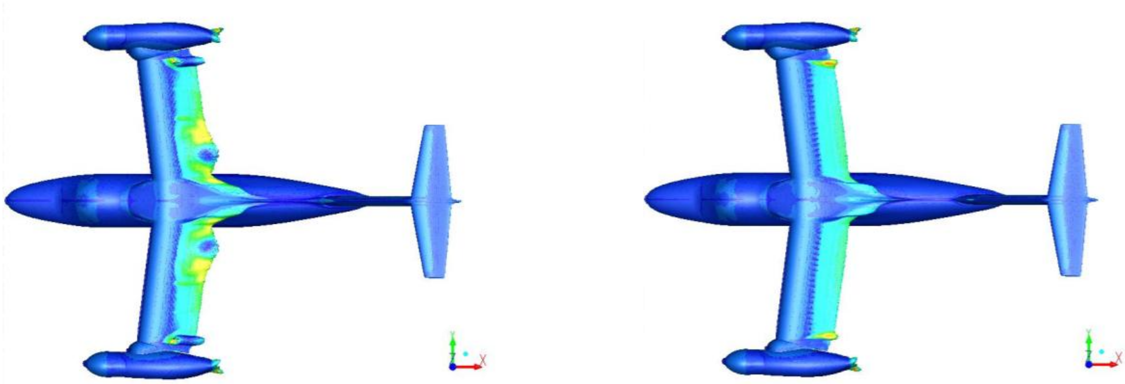


Figure 3: Comparison of the Stalled Areas Between the Datum Aircraft (Left) and the Optimized One (Right).

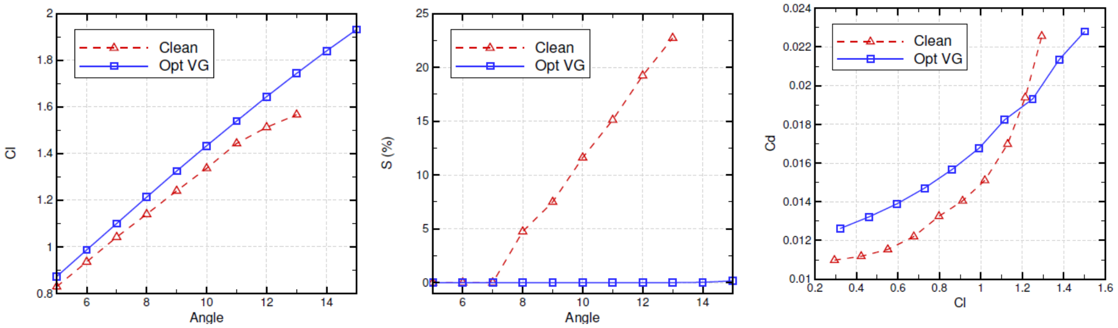


Figure 4: Comparison of the lift and drag coefficient and size of the separated area at the trailing edge between a clean aerofoil and the one with an optimized vortex generator, University of Bristol

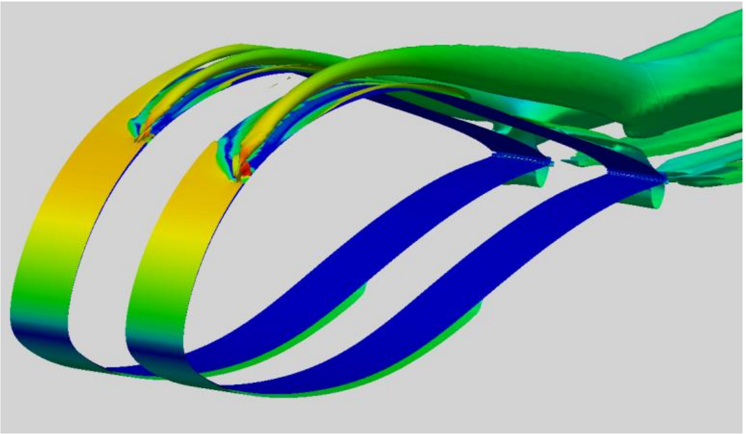
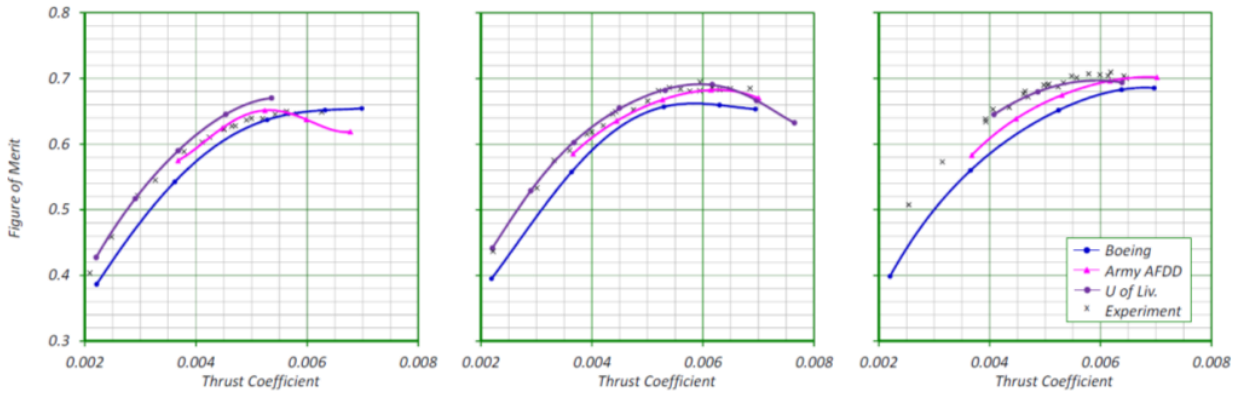
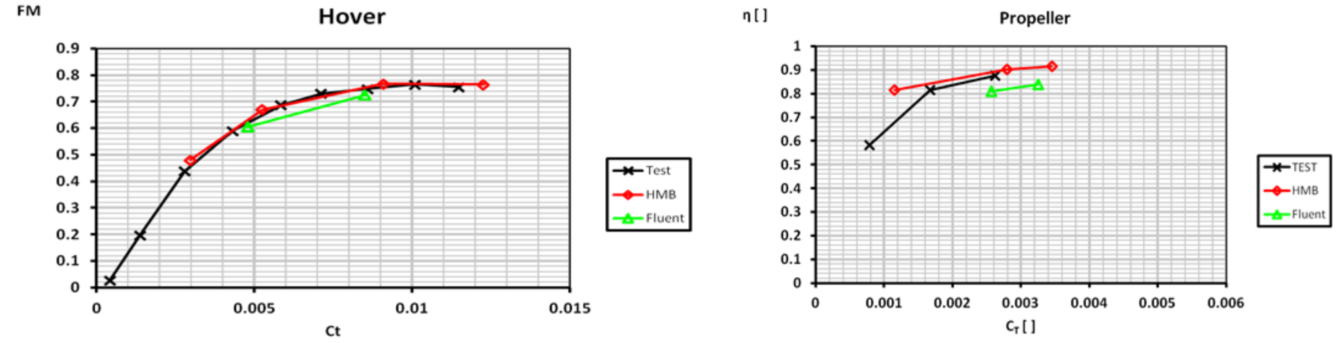


Figure 5: Simulation of two vortex generator configurations for a thick aerofoil, University of Bristol.



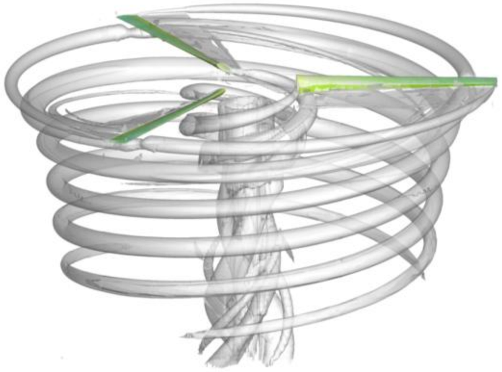
Rectangular tip Swept-taper tip Anhedral tip

Figure 6: Validation of the HMB Solver and Comparison with Other CFD Solver using the S-76 Rotor with multiple tip geometries, University of Glasgow (11).



a. Comparison of the predicted Figure of Merit with Experimental Measurements

b. Comparison of the predicted Propeller Efficiency with Experimental Measurements



c) Isosurfaces of Q-criterion

Figure 7: Validation of the CFD solvers using the XV-15 rotor, (13).

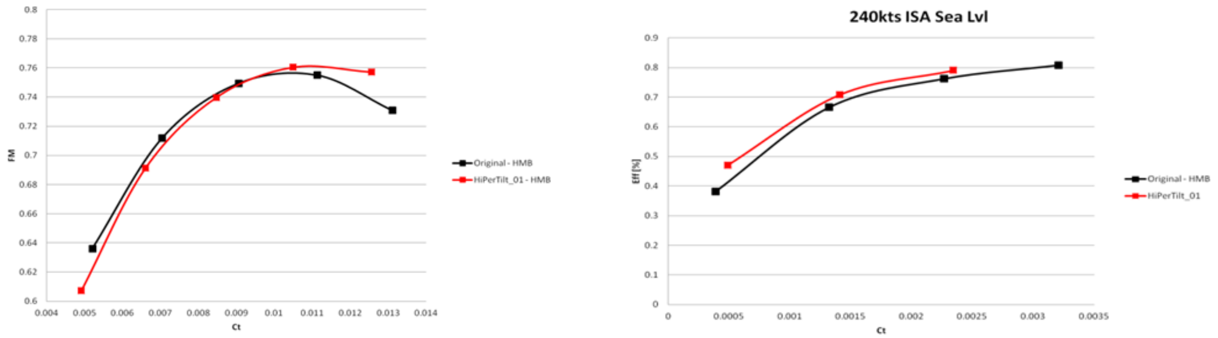


Figure 8. Comparison of the figure of Merit and propeller efficiency of the original and optimized XV-15 rotors.

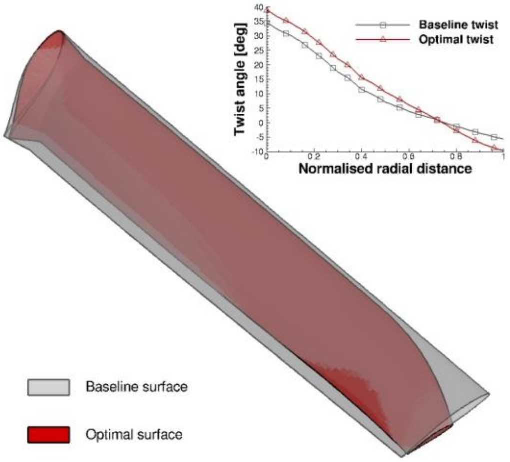
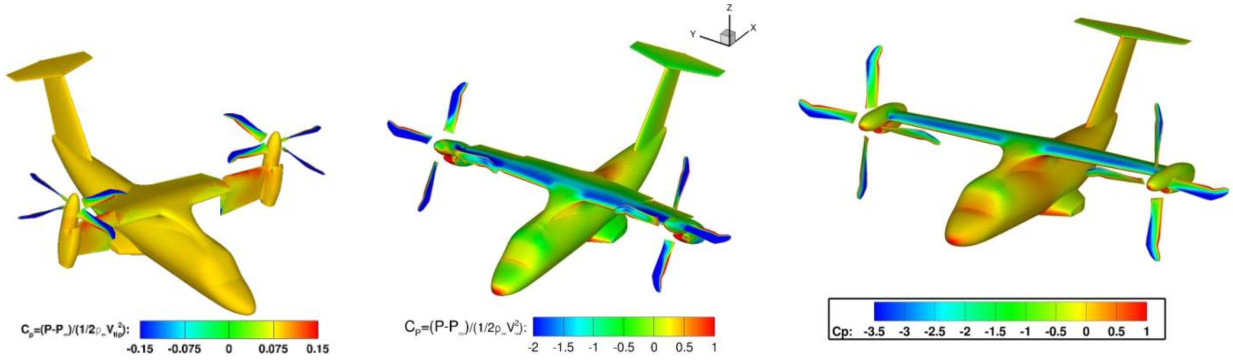


Figure 9. Comparison of the shapes of the original and optimized rotors, University of Liverpool.



a) In Hover **b) In Transition** **c) In Cruise**

Figure 10. Pressure Coefficient Distribution on the ERICA in Various Flight Modes, University of Glasgow (15).