Investigation of the Orthogonal Blade-Vortex Interaction

3rd Interim Report

by

J.M. Early* & R.B. Green†

Department of Aerospace Engineering
University of Glasgow
Glasgow
G12 8QQ
Scotland

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* Research student
† Principal Investigator

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J.M. Early, R.B. Green

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Department of Aerospace Engineering
University of Glasgow
Glasgow
Scotland
G12 8QQ

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The following report details the current investigation into the behaviour of the vortex core axial flow during the BVI, highlighting the salient features promoted by the interaction. The feasibility of acquiring PIV and pressure data simultaneously for the orthogonal BVI has also been examined.

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Abstract

The following report details the current investigation into the behaviour of the core axial flow during the BVI, highlighting the salient features promoted by the interaction. The feasibility of acquiring PIV and pressure data simultaneously for the orthogonal BVI has also been examined.

1 Experimental Investigation of the Orthogonal BVI

1.1 Measurements of the axial flow component of the Isolated Vortex

By positioning the digital camera downstream of the working section in order to capture the progression of the vortex core, it is possible to obtain information pertaining to the axial flow component of the convecting three-dimensional vortex produced by the vortex generator. All previous particle image velocimetry studies of the orthogonal blade-vortex interaction have concentrated on the effect of the interaction on the vortex core, with information about the effect of the interaction on the axial flow extracted from this data. By considering the axial flow in the isolated vortex, it has been possible to compare the measurements obtained through the particle image velocimetry system with previously acquired hot wire anemometry results. The maximum velocity of the isolated vortex obtained through the PIV study compares well with the previously obtained value of $0.6*U_\infty$ (Doolan et al., 1999).

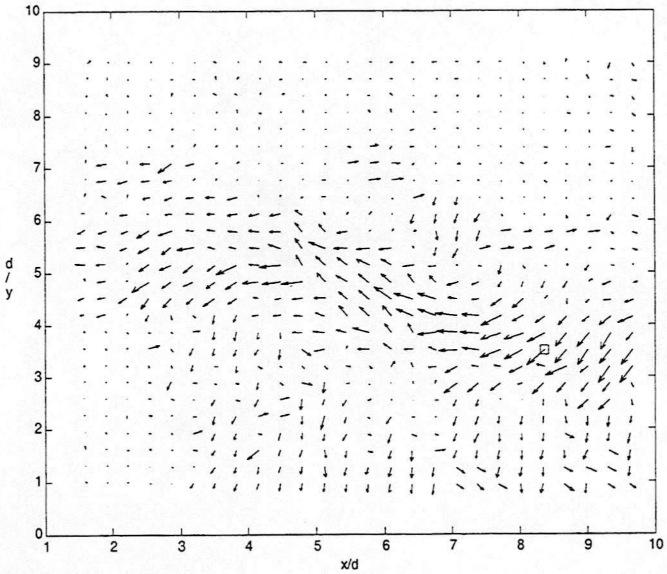

Figure 1 : Vortex Axial flow of the Isolated Vortex

One of the most striking features of the axial flow component is the curvature in the velocity vector map. The trajectory of the convecting vortex is known to be highly curved, and this observed curvature within the flowfield would be indicative of this feature of the trailing vortex. As the lightsheet was positioned within the wind tunnel working section where the stationary blade would usually be situated for the modelling of the interaction, the observations made about the vortex core at this location indicate that the vortex core axial flow is in the plane of the lightsheet, rather than cutting through it. This would support previous modelling of the experimental setup for this interaction, that the approach angle of the vortex at this location is nominally orthogonal as is essential for the correct modelling of this interaction.

These results obtained from the isolated vortex case may then be used for comparative purposes to isolate the effects of the orthogonal blade-vortex interaction upon the vortex core axial flow.

1.2 Measurements of the vortex axial flow component post-interaction

The persistence of trailing vortices within the operating region of the tail rotor leads to the tail rotor blades interacting with a single vortex several times. It is therefore of importance to fully understand the behaviour of the vortex after a single interaction to determine the nature of any further vortex cutting. Previous studies of the interaction of a pre-cut vortex with an instrumented blade (Doolan et al., 2000) indicated that the interaction proceeds in a similar fashion to the 'clean' interaction case, but greatly reduced in strength. This has led to the proposal that there is a possible re-establishment of the vortex axial and tangential components prior to the interaction, but it is not possible to make any firm conclusions from the available pressure data. Initial studies of the orthogonal interaction within the trailing edge region (Early et al., 2001) indicate that the core undergoes a significant reduction in peak vorticity, but the structure remains coherent, with no evidence of the induced radial flow present, which would be indicative of the re-establishment of the vortex tangential components.

In order to establish the effect of the interaction on the axial flow, the above arrangement considering an upstream view of the vortex was utilised, enabling the features of the axial flow to be examined. By moving the position of the lightsheet away from the trailing edge in stages, the progression of the two halves of the vortex core into the trailing edge region was mapped. Close to the trailing edge, the vortex appears to remain 'split', with two distinct halves of the vortex evident. Observations of the half of the vortex passing into the trailing edge region after passing over the lower surface still shows evidence of the characteristic bulging that is associated with the orthogonal blade-vortex interaction on this surface. As the core passes from the upper surface, the flow appears to be reversed to the bottom of the vortex core, as the fluid is extracted from the surrounding flow in order to re-establish the blocked vortex axial flow. The most interesting point of note is that the vortex core does not appear to be extracting fluid in a symmetric fashion, and the manner in which this occurs would be complementary to the previously obtained divergence patterns for the upper surface interaction, which had displayed a similar asymmetric pattern.

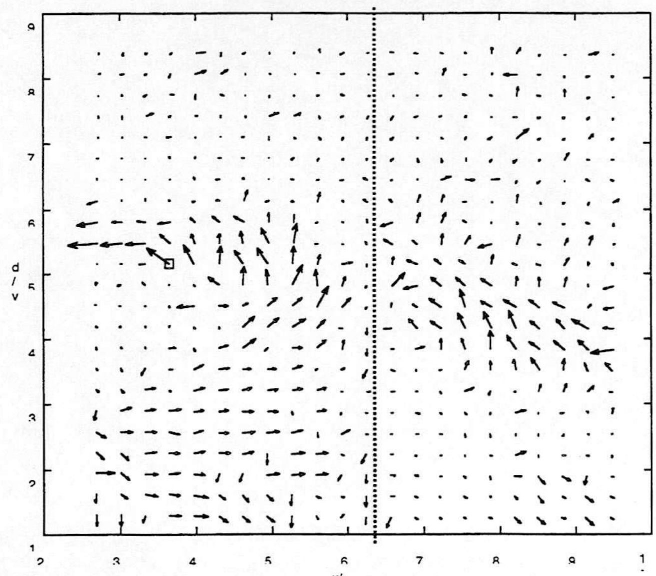

Figure 2: Axial Flow Post-Interaction (21mm behind the trailing edge – trailing edge location indicated with dotted line)

Moving away from the trailing edge, the distortion to the core becomes less evident, but the two halves of the core still remain separated within the velocity vector maps. The velocity of the fluid passing through the vortex core remains comparable to that of the freestream vortex case, and the characteristic curvature of the flowfield due to the trajectory of the vortex still evident. Although the vortex core appears to remain separated post-interaction, there are other possibilities which would explain the obtained results, most notably the re-establishment of the vortex core leading to a 'kink' in the core, and hence appearing as a split vortex within the velocity vector maps.

The examination of the axial flow highlights the highly three-dimensional nature of this flow regime, and the necessity for further examination of the axial flow behaviour through a three-dimensional imaging procedure. It would therefore be necessary to use a technique such as stereoscopic piv to fully examine the progression of the vortex into the trailing edge region.

1.3 Investigation of simultaneous PIV and pressure data acquisition

In order to track the position of the interacting vortex relative to the transducer array for the pressure data acquisition, the PIV system was arranged so as to capture the vortex passing over the leading edge region of the instrumented blade. The blade used for the simulation is instrumented at 78.5% span with a chordal array of 30 minature Kulite pressure transducers, connected to a surface orifice of 1mm diameter. The data is recorded by a BE256 data logger in a single sampling block, with a sampling rate of 50khz. The data logger and software employ an automatic gain adjustment, so that all data is attained at the maximum possible resolution. The height of the blade within the wind tunnel working section may be adjusted so as to ensure that the interacting vortex is passing over the pressure transducers.

The PIV frame grabber signal was passed into the BE256 data logger as the triggering pulse in order to ensure that the recording of the pressure data sample block coincided with the image capture for the PIV system. It is then possible to use the PIV images to examine the exact location of the vortex relative to the array, and examine the properties of the interacting vortex with relation to the pressure variations that it produces over the chord of the blade. This should also help reduce the inaccuracies inherent in the pressure traces due to vortex meander by isolating only those cases where the vortex is interacting directly over the transducer array.

The results obtained are currently being analysed, but the initial testing has shown that it is feasible to run both systems simultaneously, with no apparent damage to the pressure transducers due to the oil/smoke seeding particles evident.

1.4 Confidence level testing of the divergence calculation

As the divergence patterns have been used extensively within the current research in order to examine the mass flux associated with the orthogonal BVI, an assessment of the level of fluctuation within a divergence free velocity field was completed. The fluctuations observed within a freestream flow are $\pm 100\ s^{-1}$, much lower than the divergence levels recorded for the interaction cases. Since the calculation of the divergence is performed in a manner similar to that applied to the vorticity calculation, any irregularities will be in evidence in both sets of data.

1.5 Conferences and Publications

The current work was presented to the Royal Aeronautical Society Aerodynamics Research Conference on 10th April 2001. The paper prepared for this conference is now in review for publication in The Aeronautical Journal.

The abstract submitted for the 4th International Symposium on Particle Image Velocimetry in Göttingen, Germany has been accepted for the conference. A paper is currently being prepared for submission.

2. Research plans for remainder of contract period

The experimental test programme is all but complete, and will be completed in early June. The focus will be upon data analysis so that a clear picture of the physical nature of the orthogonal BVI may be built up. Dr. Green will visit NASA Ames in early July to discuss progress and future possibilities for the work.

3. Administrative actions

3.1 Staffing

No changes in the staffing have been necessary. Ms. Early has continued on the project as the research assistant.

3.2 Conference attendance and journal publication

Ms. Early presented her work at two meetings in April. The first was at an informal meeting at the Burn, Edzell, in Northern Scotland. This is an annual meeting run by University of Glasgow on behalf of UK Universities and Industry associated with rotorcraft. The second meeting was at the Royal Aeronautical Society, London, 10th-11th April. Ms. Early delivered the paper, which was well received. The paper has been reviewed and provisionally accepted for publication in the Aeronautical Journal subject to a couple of minor changes.

The abstract submitted for the PIV '01 meeting in Göttingen, Germany, has been accepted. This meeting takes place in mid September, and Ms. Early will given a presentation on her work. The paper has to be prepared for 1st July.

3.3 Travel

Dr. Green has arranged to visit Dr. Chee Tung and colleagues at NASA Ames on 3rd July 2001.

4 References

Doolan, C.J., Coton, F.N.& Galbraith, R.A.McD (1999) 'Measurement of the Three-Dimensional Vortices using a Hot Wire Anemometer' 30th AIAA Fluid Dynamics Conference, Norfolk, VA

Doolan CJ, Green RB; Coton FN; Galbraith RAMcD (2000) The Orthogonal Blade-Vortex Interaction Experimental Programme at the University of Glasgow.26th European Rotorcraft Forum, The Hague

Early, J.M., Green, R.B. & Coton, F.N. (2001) Flow Visualisation of the Orthogonal Blade-Vortex Interaction using Particle Image Velocimetry, In review for publication in The Aeronautical Journal

Appendices

A. Financial statement

A breakdown of the funds so far used is as follows:

Equipment	£0	
Studentship	£2566	$3638
Consumables	£56	$79
Technician salary	£373	$529
Travel	£107	$152
Tuition fees	£2740	$3886
Total	£5842	$8286
Balance remaining	£5033	$7138