Investigation of the Orthogonal Blade-Vortex Interaction

2nd Interim Report

by

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Steps towards the implementation of a stereoscopic particle image velocimetry (PIV) system for the investigation of the orthogonal blade-vortex interaction are described. The accuracy of the 2D PIV system has been reassessed in the light of the greater accuracy demands of stereo PIV. The improvement to the perceived quality of the PIV vector map from a discrete window offset algorithm was investigated, and it was observed that significant improvements were made in the critical vortex core region.

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Abstract

Steps towards the implementation of a stereoscopic particle image velocimetry (PIV) system for the investigation of the orthogonal blade-vortex interaction are described. The accuracy of the 2D PIV system has been reassessed in the light of the greater accuracy demands of stereo PIV. The improvement to the perceived quality of the PIV vector map from a discrete window offset algorithm was investigated, and it was observed that significant improvements were made in the critical vortex core region.

1. Introduction

One of the mechanisms for noise generation and high impulsive loading on helicopter tail rotor blades is the orthogonal blade-vortex interaction (BVI). Here the vortex wake from the main rotor is skewed backwards by the oncoming flow, and the tail rotor blades cut across the vortex core; in the limiting orthogonal case the local vortex axis is normal to the plane of the blade. As opposed to the distinctive blade slapping sound of the parallel blade-vortex interaction, the orthogonal interaction is often characterised by a 'bubbling' sound. An understanding of the mechanism of the orthogonal BVI is essential if adverse vibration effects are to be reduced and quieter helicopters be developed.

The current research project is to perform an investigation of the orthogonal BVI using a stereoscopic PIV technique, to follow on from the previous USARDSDG-UK sponsored study. This interim report describes the progress with the implementation of the stereoscopic PIV system. In addition data from the previous USARDSG-UK sponsored study was reassessed given the improvements made to the 2D PIV analysis method at Glasgow. This is important as the stereo decomposition involves taking the difference between two PIV vector maps. Given the known difficulties of performing PIV in concentrated vortex cores any improvement to PIV accuracy in vortex cores is worthwhile.

2 Development of the stereoscopic PIV system

The Scheimpflug mounts have been completed and the camera and mounting system is currently being tested. The mounts as built have been found to be easily adjusted to meet the required Scheimpflug condition, but during familiarity tests the significant challenge has been aligning and setting the two cameras to the same magnification and on the same region of interest. The difficulties are essentially due to by poor user access to the wind tunnel working section. However it is a case of adopting up procedures so that adequate calibration can be guaranteed and that the camera mounting system is not disturbed once the calibration procedure has been completed. These procedures are currently being developed based upon experience with using the system in situ.

3. Reappraisal of accuracy of PIV

The stereo decomposition process essentially detects differences between the two PIV vector maps. The signal to noise ratio must be large enough so that the measured difference is due to the out-of-plane contribution to the individual planar velocity fields measured by the PIV system. PIV is well known to be sensitive to spatial noise, however, so a successful stereo decomposition places heavy demands on the accuracy of the basic planar system. Vector map accuracy depends not just on the accuracy of an individual vector, but on the fidelity of the whole vector map. An individual correlation based particle displacement measurement might be accurate to one-tenth of a pixel, for example, but the data should not be treated as true velocity data until it has been determined that it was the result of particle displacement due to the velocity field and not simply a poor local signal. This problem has attracted much attention, and all the popular methods tend to examine the fidelity of the vector map as a whole by comparing a velocity vector with its immediate neighbours. Green et al. (2000) developed a highly localised velocity field validation technique, the Forward-Reverse Tile Test (FRTT), which is useful for improving individual velocity vector fidelity at the PIV correlation level. It was observed that the technique is particularly useful in regions of poor seeding, and will improve the performance of the post-processing vector map validation methods referred to above. As part of other research efforts at Glasgow using PIV improved analysis methodologies have been included in the PIV analysis system. One of these is the discrete window offset (Westerweel, 1997), which improves the accuracy of measurement, subject, of course, to later validation. It was appropriate to examine the effectiveness of the method on orthogonal BVI data from the previous USARDSG sponsored study (Early et al., 2001).

An upper surface interaction case was chosen for this, with the laser sheet 3.5mm away from the maximum thickness point of the interacting blade. Figure 1 shows the basic PIV analysis (the mean u-component has been removed to show the vortex flow). There is clearly a cluster of poor vectors of large magnitude in the upper right corner of the image, and others elsewhere. Erroneous vectors of lower magnitude are present elsewhere, and in the vortex centre some non-physical effects are clearly present. The same raw data was analysed using the PIV method including the discrete window offset method, figure 2. The number of large magnitude errors has clearly been redcued, while there are fewer clearly erroneous low magnitude values elsewhere. The vortex core contains fewer poor quality data points. When a coherence based post-processing method is applied (Noguiera et al., 1997) and the same tolerance level is set, 21 data points are corrected after the basic PIV analysis, while only 8 are corrected after the discrete window offset analysis. Figures 3a and 3b show the coherence post-processed velocity vector maps and streamline plots for the basic PIV analysis, and figures 4a and 4b show the same plots for the post-processed discrete window offset data. The nature of the orthogonal BVI over the blade upper surface causes vortex core shrinkage and an inflow to the vortex core. In the immediate core region the previous study (Early et al., 2001) revealed a curious divergence pattern, which suggested that the upper surface interaction is not simply a reversed lower surface one and underlined the need for good quality data for the behaviour of the vortex core jet velocity component during the interaction. In this context the streamline plots of figures 3b and 4b are interesting. Each of the two streamline plots show the streamlines spiralling in towards the vortex centre. However in figure 3b there is a large 'hole' of about 20mm diameter indicating that the streamlines could not cross a surface around the vortex core (the hole could be filled with streamlines if streamline seeding points were set within the hole). In figure 4b the hole is still present but its diameter is much smaller at approximately 10mm. It may well be that there is a physical effect present at the centre of the vortex that generates an outflow similar to that observed in the lower surface interaction, but this outflow would have to be very weak and highly localised. However the significant changes to the streamline flow field in the vortex core region as a result of using a method of improved accuracy tends to suggest that the PIV system does not have the sensitivity to sufficiently resolve all the details of the upper surface interaction in the vortex core itself. Improvements have been gained by adopting the better PIV analysis technique, so when stereo decomposition has been performed there will be greater confidence over larger areas of the vector map. The area immediately around the vortex core may require special treatment. It is noteworthy that the raw images for this analysis were obtained using poor quality video camera lenses. The new lenses available to the PIV system are virtually distortion free within the resolution limits of the cameras, and sharp focussing across the entire field of view is easily achieved. This will provide further improvements to the accuracy of the PIV study of the orthogonal BVI.

4. Research plans for remainder of contract period

The emphasis of the work now is on tightening up the calibration procedures for the stereo PIV. Testing of the orthogonal BVI will commence as soon as confidence in this has been gained.

5. Administrative actions (staffing)

No additional administrative actions regarding staffing have taken place within the period covered by this report.

6. References

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Noguiera, J., Lecuona, A. & Rodriguez, P.A. (1997) 'Data validation, false vectors correction and derived magnitudes calculation on PIV data' Meas. Sci. Tech., 8, pp 1493-1501

Westerweel, J., Dabiri, D. & Gharib, M. (1997) 'The effect of a discrete window offset on the accuracy of cross-correlation analysis of digital PIV recordings' Exp. Fluids, 23, pp 20-28

Figures

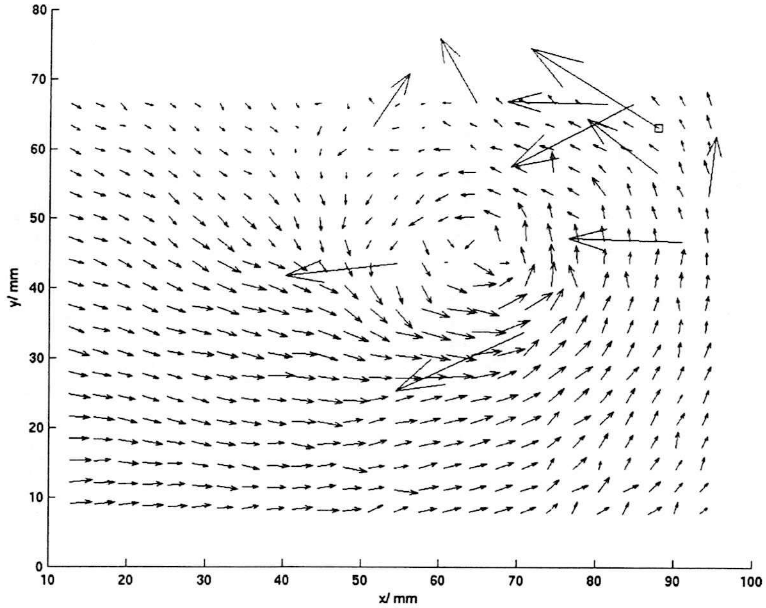

Figure 1 Basic PIV analysis with FRTT of upper surface orthogonal BVI case. The blade leading edge is at x=30mm.ThePIV analysis tile size is a 32 pixel square. No filtering (apart from the FRTT scheme) has been applied.

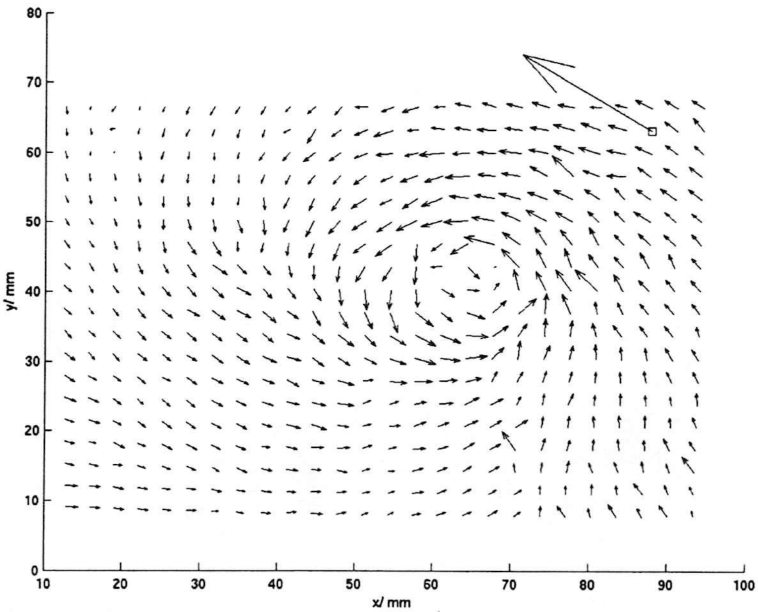

Figure 2 PIV analysis of same raw image data as for figure 1. A discrete window offset scheme has been applied durimg the PIV analysis, while all other parameters remained the same.

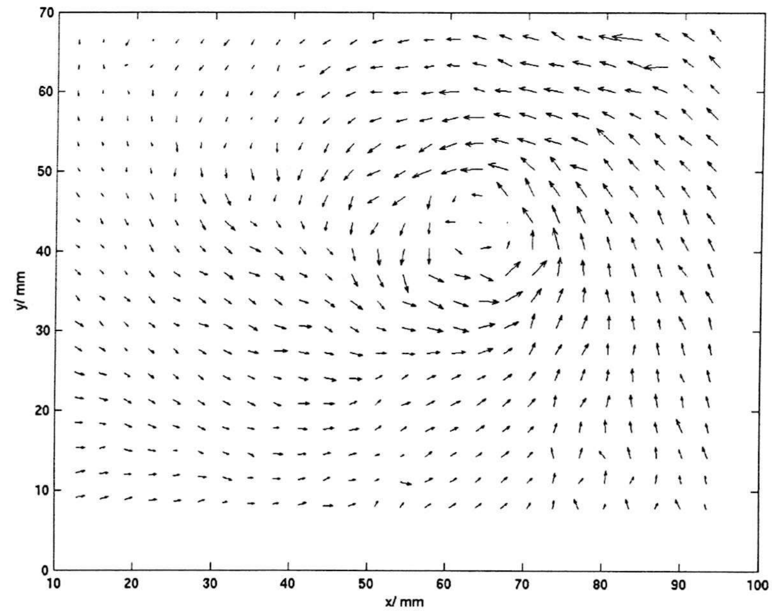

Figure 3a Coherence based post-processing result from vector map of figure 1

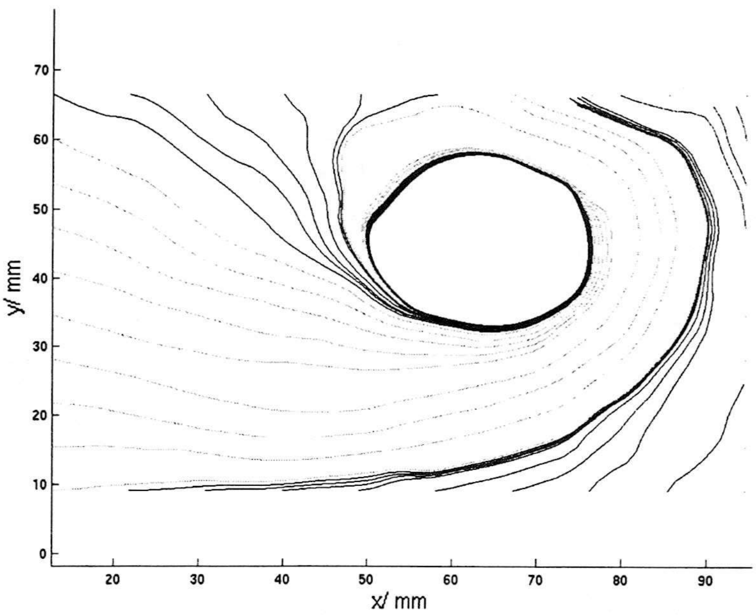

Figure 3b Streamline plot for figure 3a. The streamlines spiral towards the vortex centre due the effect of the blade-vortex interaction. The large hole in the vortex centre is because the streamlines cannot penetrate that surrface.

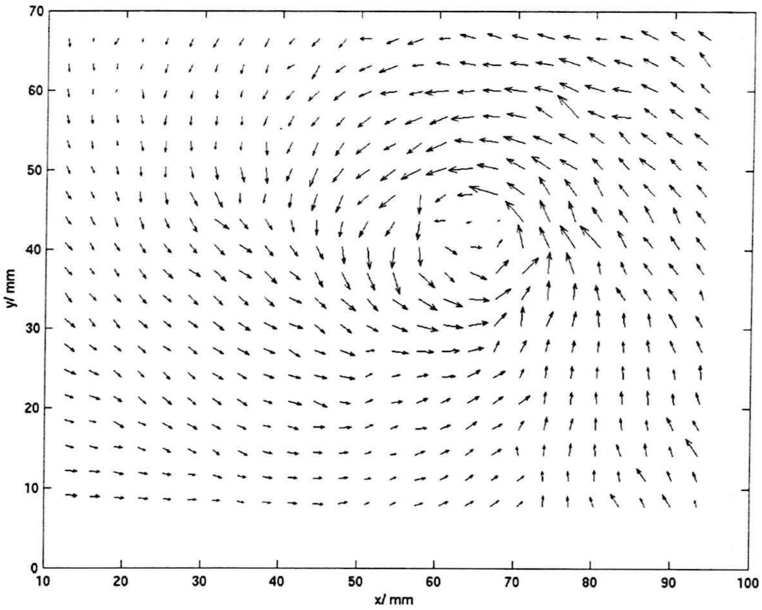

Figure 4a Coherence based post-processing result from vector map of figure 2. The same tolerance level has been applied as for figure 3a.

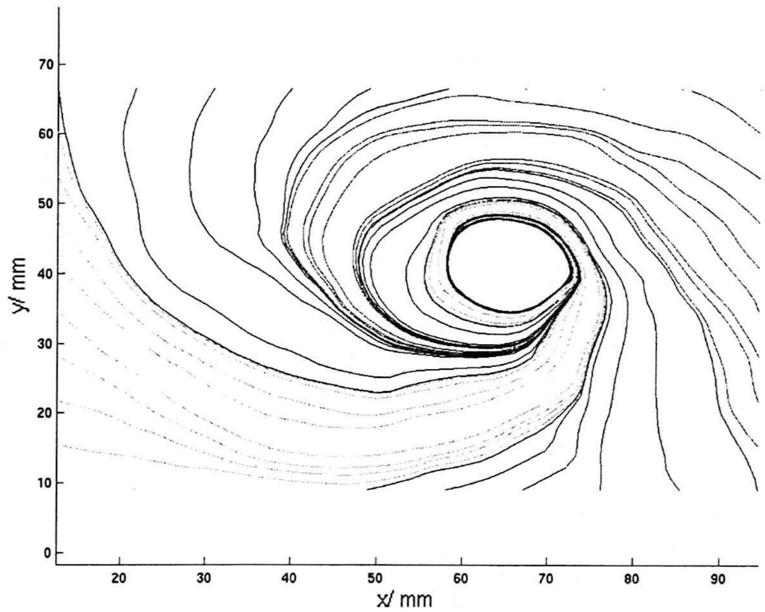

Figure 4b Streamline plot for figure 4a. The streamlines spiral towards the vortex centre due the effect of the blade-vortex interaction. The hole in the vortex centre is because the streamlines cannot penetrate that surface, but note that it is smaller than in figure 3a.

Appendices

A. Financial statement

A breakdown of the funds used during this report period is as follows. The exchange rate of £1=$1.59 was valid on 23rd February 2003.

Studentship + fee		£3467
Consumables and other maintenance of systems		£1404
Technician salary + overhead		£490
Total	£5367	($8523)

Balance remaining **$13048 = £8206**

B. Important property acquired during present report period

No significant property was acquired during the present period.