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In Application

Unmanned Air Vehicle Design through Fluid-Structure Interaction Investigations

R. Bleischwitz et al, Experimental Fluid Mechanics Research Laboratory, University of Southampton, UK

Introduction

Particle Image Velocimetry (PIV) and Digital Image Correlation (DIC) are optical measurement techniques that can simultaneously be deployed for the study of advanced Fluid-Structure Interaction (FSI) phenomena such as aeroelasticity [1]. The non-intrusive, full-field nature of these techniques lends itself to the investigations that have previously been experimentally unavailable due to their complexity. One such example is the investigation of bird flight mechanisms, which are highly optimized processes that can yield valuable insights into the design of nature-inspired wing designs of the future. In particular, new designs of Unmanned Air Vehicles (UAV) using biologically inspired membrane wings can be based on the understanding of the dynamics of bat flight, as provided by combined PIV and DIC measurement data. Such data can reveal the interactions that manifest during flight, between deformations of the thin membrane wings and the fluid flow around the structure.

Experimental Setup

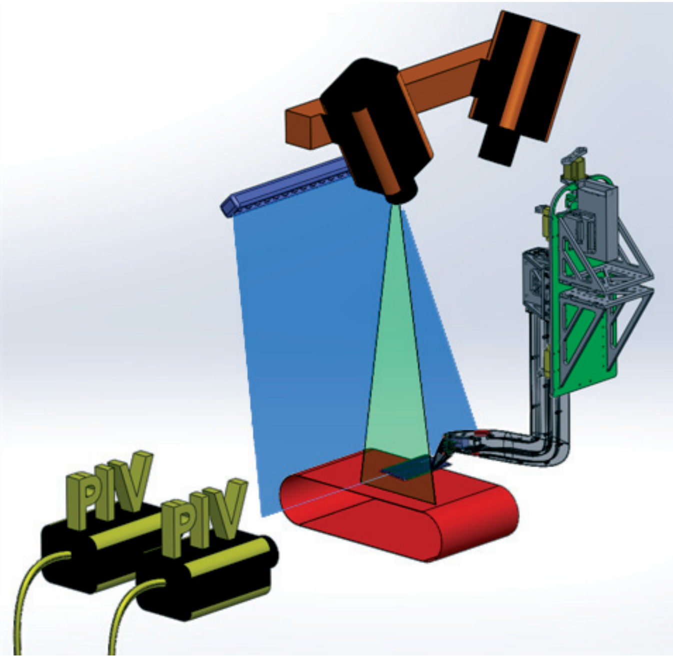

Figure 1: *Experimental setup*

An experimental facility for the investigation of thin membrane wings was designed at the Experimental Fluid Mechanics Research Laboratory within the University of Southampton. This facility, comprising of an open circuit wind tunnel, was instrumented with two high-speed cameras and a high-speed laser for performing time-resolved PIV measurements at a rate of 800 Hz, as well as two high-speed cameras and blue LED illumination for acquiring 3D DIC images of the membrane wing. The two systems were synchronized using a LaVision Programmable Timing Unit device, which allowed for synchronized measurements to be performed, while the use of green bandpass filters on the PIV cameras, and blue bandpass filters on the DIC cameras, facilitated simultaneous data to be acquired without the influence of secondary light sources on the two systems respectively.

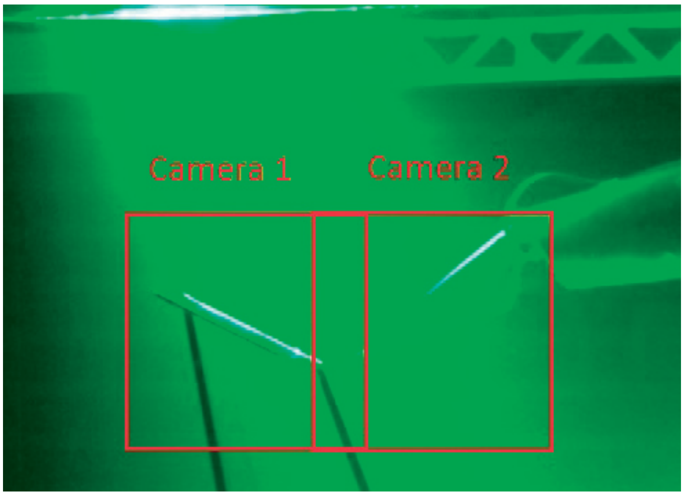

Figure 2: *PIV fields of view of two cameras in a side-by-side arrangement*

Two PIV configurations were considered throughout the measurement campaign, with a side-by-side arrangement configured for recovering the streamwise 2D velocity field over an enlarged field of view (FOV) as illustrated in Figure 2, and a Stereo-PIV arrangement setup that produced spanwise 3D velocity data downstream of the wing position. Furthermore, the experimental facility was instrumented with load cell sensors that were monitoring the total lift and drag acting on the wing.

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Results

Several test runs were considered for this experimental investigation, with the membrane wing being operated in ground-effect (GE) at various ground clearances (from 1% to 200% chord length). The acquired PIV and DIC data was then processed using **DaVis**. By recovering the membrane oscillations from 3D DIC measurements, and using this information as a guiding master for the various test runs, it was possible to phase-average the two PIV planes (spanwise and streamwise), into a single cycle, as illustrated in Figure 3. This allowed for membrane-induced flow oscillations to be uncovered in the wake, even at locations one chord length downstream of the wing trailing edge. Furthermore, Proper Orthogonal Decomposition (POD) analysis was used to correlate between the frequency content of the membrane oscillations and that of the flow structures.

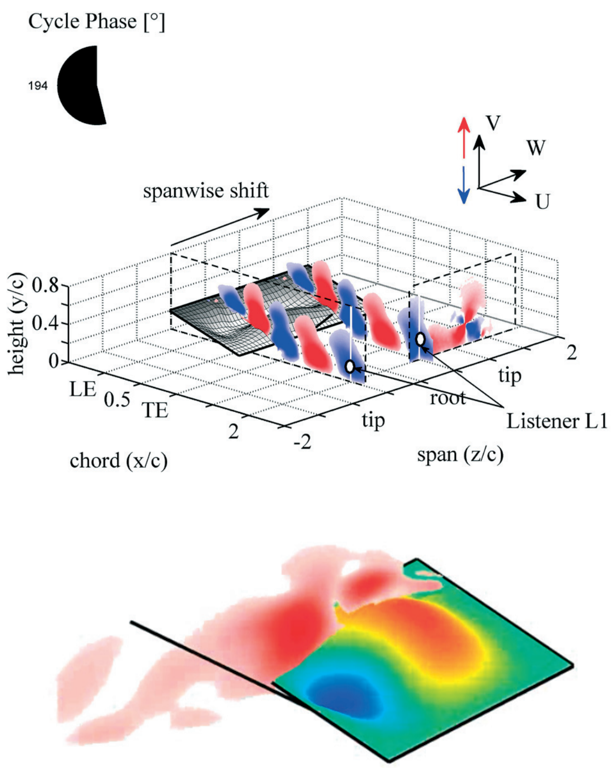

***Figure 3**: Results of membrane wing oscillations (top) and fluid flow vorticity (bottom)*

Conclusions

The insights provided by deploying combined PIV and DIC measurements, led to the development of an innovative UAV design [2] (as seen in Figure 4), that operates in Ground Effect conditions using flexible membranes. A prototype developed at the University of Southampton has already been successfully tested in a wind tunnel as well as over water, with promising results.

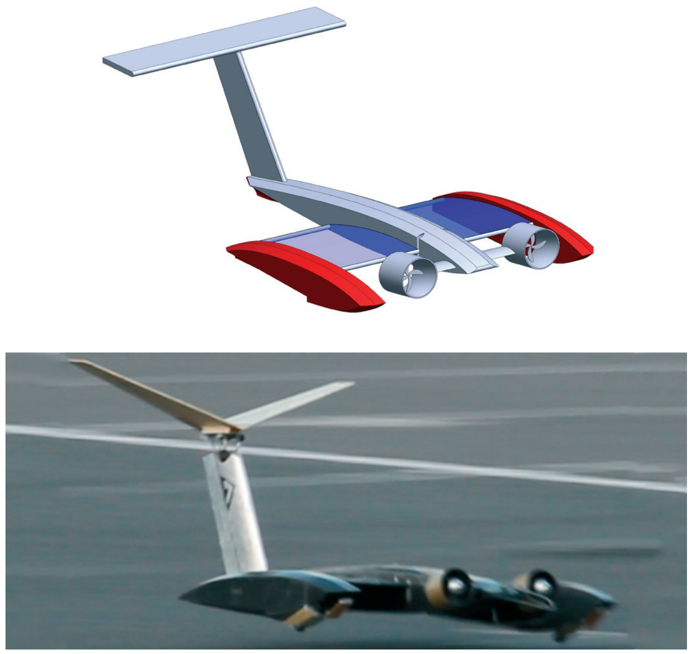

***Figure 4**: UAV design (top) and prototype testing (bottom)*

For more information please see [1] L. Marimon Giovannetti et al., Fluid-Structure Interaction Measurements of Flexible Aerofoil Sections (LaVision Application Note) and [2] The Guardian news article Is it a bird? Is it a bat? No, it's the future of drone technology (available at https://www.theguardian.com/science/2016/feb/18/is-it-a-bird-is-it-a-bat-no-its-the-future-of-drone-technology). (c) Guardian News & Media Ltd

LaVisionUK Ltd
2 Minton Place / Victoria Road
Bicester, Oxon / OX26 6QB / United Kingdom
E-Mail: sales@lavision.com / www.lavisionuk.com
Phone: +44-(0)-870-997-6532 / Fax: +44-(0)-870-762-6252

LaVision GmbH
Anna-Vandenhoeck-Ring 19
D-37081 Göttingen / Germany
E-Mail: info@lavision.com / www.lavision.com
Tel. +49-(0)551-9004-0 / Fax +49-(0)551-9004-100

LaVision Inc.
211 W. Michigan Ave. / Suite 100
Ypsilanti, MI 48197 / USA
E-mail: sales@lavisioninc.com / www.lavisioninc.com
Phone: (734) 485 - 0913 / Fax: (240) 465 - 4306