PARTICLE IMAGE VELOCIMETRY FOR EVALUATING THE FORMATION OF SEPARATION REGIONS BEHIND A WALL MOUNTED HUMP

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ABSTRACT

Presented here is a study of the dynamic formation and oscillation of the separation bubble present behind a wall mounted hump. The test article is used as an analog for the suction side of a low pressure turbine vane operating at low Reynolds Number. The operating envelope of compact air breathing engines is constrained by flow separation under adverse pressure gradients [1]. High fidelity CFD was run on the model to evaluate both steady behavior of the separation bubble as well as unsteady growth from stagnant conditions and response to oscillating pressure fields. Particle Image Velocimetry (PIV) conducted at 2kHz is used to evaluate the predictions of these CFD studies as well as extrapolate to cases that were not simulated. Two operating regimes are considered in the PIV study: a sudden discharge of flow and an oscillating pressure field. The sudden discharge case is used to simulate the separation bubble formulation from stagnant flow conditions to steady state. The oscillating case is used to scale up to the unsteady flow operation of relevant turbine stages. For the oscillating velocity field an upstream valve is controlled at 5 Hz to induce oscillations on the free stream flow. The dynamic response of the separated flow region under such circumstances is monitored with PIV. In addition to the baseline geometry, passive flow tripping is introduced in an attempt to reduce the size of separation regions. Experiments are set-up in a highly modular blow-down wind tunnel facility [2] specifically designed to allow full optical access at the Purdue Experimental Turbine Aerothermal Lab (PETAL).

METHODOLOGY

A frequency-doubled (532 nanometer) diode-pumped Nd:YAG laser is used to create doublet pulses at 2 kHz with an energy of ~1.5 mJ per pulse. Mineral Oil particles are produced by a high output nebulizing smoke machine and have a mean diameter of .5 micron. Seed particles are introduced upstream of the wind tunnel settling chamber so that they can mix completely into the bulk flow and be observed in the separation region. Particle images are taken with a Photron Sa-Z Fastcam capable of acquiring 1 megapixel images at 2 kHz. After data acquisition, images are processed in LaVision Davis to create transient 2D velocity vector fields. Using these velocity fields, progression of flow separation and reattachment points over time can be measured, as well as the overall size and intensity of the separation bubble. PIV data can be synchronized with surface pressure data taken simultaneously to allow for richer understanding of the transient flow data.

RESULTS AND DISCUSSION

- Figure 1 shows the test domain and representative flow structure. The wall mounted hump can be seen with a separation point after the crest of the hump followed by a long separation bubble and eventually a flow reattachment point
- Figure 2 shows CFD simulations of the test article with response to a sudden pressure increase representing the opening of a wind tunnel supply valve. The separation bubble can be seen to increase in size at each time increment. This growth rate measurement is the target of the PIV test campaign
- Figure 3 shows particle images taken in the recirculation zone of the wall mounted hump. Data taken at 2 kHz over 5 second intervals will be processed to find velocity vectors and determine separation and reattachment locations

- Anticipated results:
  - Measurement of steady flow separation and reattachment points at unit Reynolds Numbers from 100,000 to 1800000 per meter
  - Analysis of separation bubble growth and fluctuation with response to sudden flow discharge and oscillating free stream velocity
    - Comparison to CFD predictions
  - Analysis of effect on separation growth and overall strength with introduction of passive flow tripping

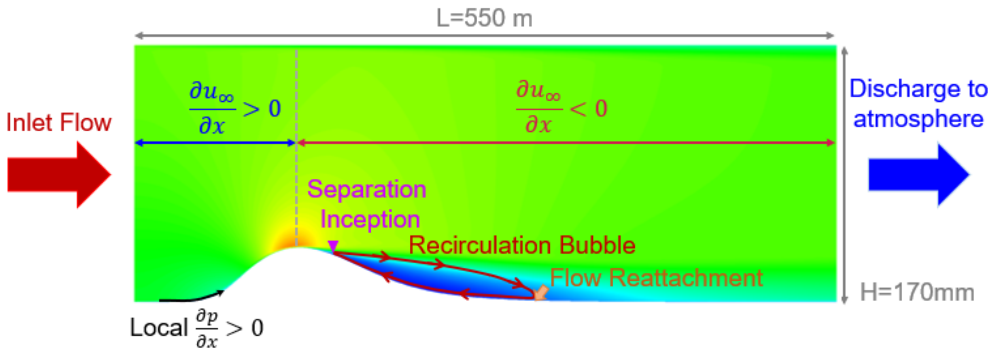

Figure 1 Layout of CFD test case showing dominant flow features

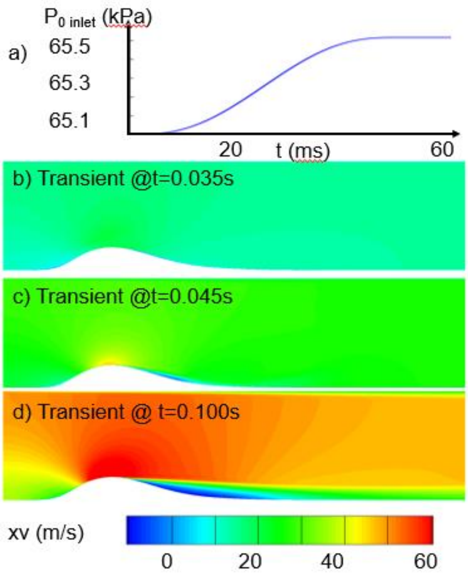

Figure 2 CFD simulation showing growth of separation bubble after sudden pressure increase

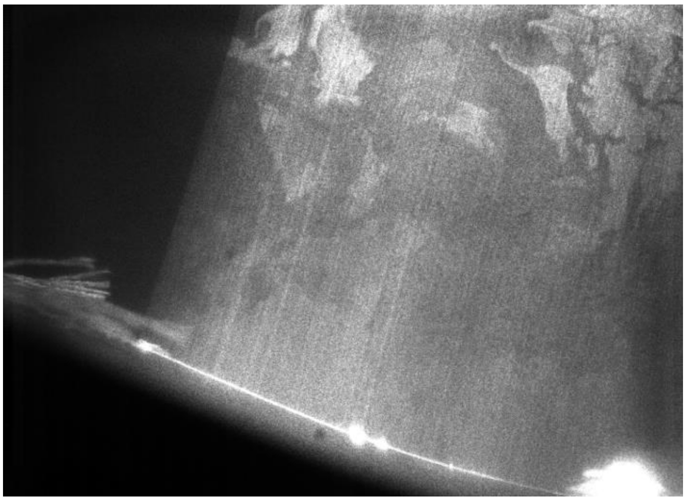

Figure 3 Particle Image in Recirculation Zone

REFERENCES

[1]Saavedra Paper- not published yet

[2] Paniagua G., Gonzalez Cuadrado D., Saavedra J., Andreoli V., Meyer T., Meyer S., Lawrence D., 2016, "Experimental turbine facility for optical and surface aero-thermal measurements in turbines". Proceedings of the ASME Turbo Expo 2016. Paper GT2016-58101. https://doi.org/10.1115/GT2016-58101 . ISBN: 978-0-7918-4982-8. Seoul, Korea. June