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APPLICATION OF PIV TO THE MEASURMENT OF HIGH SPEED JET FLOWS

FINAL REPORT

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ABSTRACT

The Particle Image Velocimetry, PIV, has been implemented for the investigation of high-speed jet flows at the NASA Langley Research Center. In this approach the velocity (displacement) is found as the location of a peak in the correlation map of particle images acquired in quick succession. In the study, the technique for the correct seeding of the flow field were developed and implemented and the operational parameters influencing the accuracy of the measurement have been optimized.

1. The PIV Technique

The measurement of the velocity field using PIV is based on the ability on accurately record and measures the positions of small tracers suspended in the flow as a function of time. In the study, the technique is used in the cross correlation mode. Therefore the individual instantaneous particle image patterns are kept in separate frames. The time interval between frames (exposures) is appropriately chosen, such that the tracer particles will have moved only a few diameters, far enough to resolve their motion, but less than the smallest fluid macroscale. Thus, information on the local fluid velocity is stored on the recordings for later retrieval. The main advantages of the cross correlation approach are:

a. The displacement is obtained without any directional ambiguity.

b. The correlation peak signal is carries more signal strength, and thus is more immune to noise.

2. Application to High-Speed Facilities

2.1 Seeding

In applications of PIV to the measurement of high-speed flows, the selection and implementation of the proper seeding strategy is a major factor contributing to successful measurements. The seeding particles must be small enough (< 1μm) to ensure minimal velocity lag between them and the fluid stream and supplied in sufficient numbers to accommodate the typically large fluid mass flow rates. Seeding particles must also be efficient light scatterers, to ensure that enough light is scattered in order to expose the recording media.

The particle dynamics must be especially considered in flows with large velocity gradients (shear layers), vortical structures and supersonic flows containing shocks. For accurate high speed measurements the largest particle size needs to remain in the range of 0.5μm.

The choice of the type of particle and the mechanism used for their introduction in the fluid must be carefully considered to minimize particle agglomeration and provide uniform distribution in the fluid stream. In addition seeding particles may be are required to survive high temperatures in heated flows.

The current method for seeding uses a dispersed metal oxide (Aluminum Oxide) as a seed. These particles are good light scatterers, capable of withstanding temperatures on the order of 2200 K and available in powder form consisting of polydisperse sub-micron particles. Although this material does not present a toxic hazard, it is important to minimize inhalation exposure by providing appropriate exhaust collection, and use of personal filtering masks. The principle of operation of the solid particle aerosol generator is based on a fluidized bed re-suspension process. This simple design incorporates a cyclone separator to eliminate large particles and a carrier-gas bypass system.

2.2 Illumination sources

The light detected by the recording media in PIV measurements is that which have been scattered 90° to the incoming laser light. Extremely energetic light sources are required because of the low efficiency of this scattering process, and the small dimension of the scattering particles. The specific amount of laser energy required in a particular situation is a function of tracer type and size, concentration, recording lens aperture and magnification, and on the sensitivity of the recording media (solid state array) at the particular laser light frequency. The timing between laser pulses is the other important requirement. In order to capture two closely spaced images, produced high-speed tracers, i.e. spacing of the order of 100-300μm, the time interval between laser pulses is typically 1 μsec.

Solid state lasers are the only available laser sources capable of satisfying these requirements such as the frequency-doubled Nd-Yag lasers. These laser systems can provide repetition rates from 10-100 Hz and pulse energies up to 0.5J/pulse in the single pulse mode of operation. The operation of these lasers in a double pulse mode, necessary for PIV use, has been a major difficulty. Typically manufacturers only have been capable of providing dual pulse operation with pulse separations in the range from 50-200 μsec. This limited range is obviously insufficient for high-speed PIV usage. A method of solution to this problem is the dual laser configuration. This configuration originally used by Kompenhans and Reichmuth[3] and Lourenco[6] The output of two, orthogonally polarized, frequency-doubled Nd-Yag lasers combined into a collinear beam using a polarizing beam combiner cube. The main advantage of this laser system is that the time separation between laser pulses can be adjusted to fit any value. The difficulties in the usage of such system are due to the stringent alignment requirements to keep the two beams co-linear, and the difficulty of obtaining perfectly similar beams and thus illumination profiles from the two lasers. These factors contribute for decreased correlation between the image pairs.

2.3 Image Acquisition

The technique relies on the ability to detect and record on a solid state camera the images of the seeding particles. At the heart of the Kodak ES 1.0 camera is the CCD interline transfer sensor, KAI-1001 with a resolution of 1008(H) x 1018(V) pixels. Each square pixel measures 9 μm on the side with 60 percent fill ratio with microlens, and a center to center spacing of 9 μm. The camera is also equipped with a fast electronic shutter and outputs eight bit digital images, via a progressive scan readout system, at a rate of 30 frames per second.

The unique feature of the Kodak ES 1.0 camera is its ability to be operated in the "triggered dual exposure mode". Operation in this mode is possible due to the CCD sensor architecture, which incorporates both a light sensitive photodiode array and a masked register array. During the exposure cycle, light is converted to charge in the photodiode area of the array; after exposure, the charge on the photodiode is transferred to the masked area of the array. Using a programming feature of the camera's control electronics, this time setting can be made as small as 1 μsec.

The above described arrangement makes it possible to acquire up to 15 image pairs/sec. The image data acquisition is done using Imaging Technologies ICPCI board, which resides on a single slot of the PCI bus of a personal computer. The computer's CPU is an Intel 300MHz Pentium II with 128 Mbytes of RAM.