9.17 Supersonic PIV Measurements on a Space Shuttle Model

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Table 9.21. PIV recording parameters for transonic flow above a NACA0012 airfoil.

Recording geometry	light sheet swept 15° from normal to the stream
Maximum cross-plane velocity	$U_{\text{max}} = 585\,\text{m/s}$
Maximum in-plane velocity	$V_{max} = 130\,\text{m/s}$
Field of view	$870 \times 380\,\text{mm}^2$
Interrogation volume	$20 \times 10 \times 4\,\text{mm}^3$ $(H \times W \times D)$
Observation distance	1.8 m – 3.2 m
Recording method	dual frame - single exposure
Recording medium	CCD 1386 × 1024 px
Recording lens	$f = 35\,\text{mm}$, $f_{\#} = 2.0$ and 50 mm, $f_{\#} = 1.2$
Illumination	two Nd:YAG laser[a] 250 mJ/pulse
Seeding material	oil droplets ($d_{\text{p}} \approx 0.3\,\mu$m – $0.5\,\mu$m)

[a] frequency doubled

Before the Space Shuttle could return to flight after the loss of Columbia, NASA was required to validate the computational fluid dynamics (CFD) codes that it uses to predict the trajectories of debris that may be shed from the vehicle during launch. To meet this and other requirements, NASA conducted two tests of a 3% scale model of the Shuttle ascent configuration in the NASA Ames $9 \times 7\,\text{ft}^2$ Supersonic Wind Tunnel (9 × 7 SWT). In these tests, Dual Plane Particle Image Velocimetry (PIV) was used to measure the three components of velocity upstream of the Orbiter wings where debris shed from the External Tank (ET) would be convected downstream. The measurements were made in four cross-stream vertical planes located at different axial positions upstream of the Orbiter and above the ET. The measurements were made at

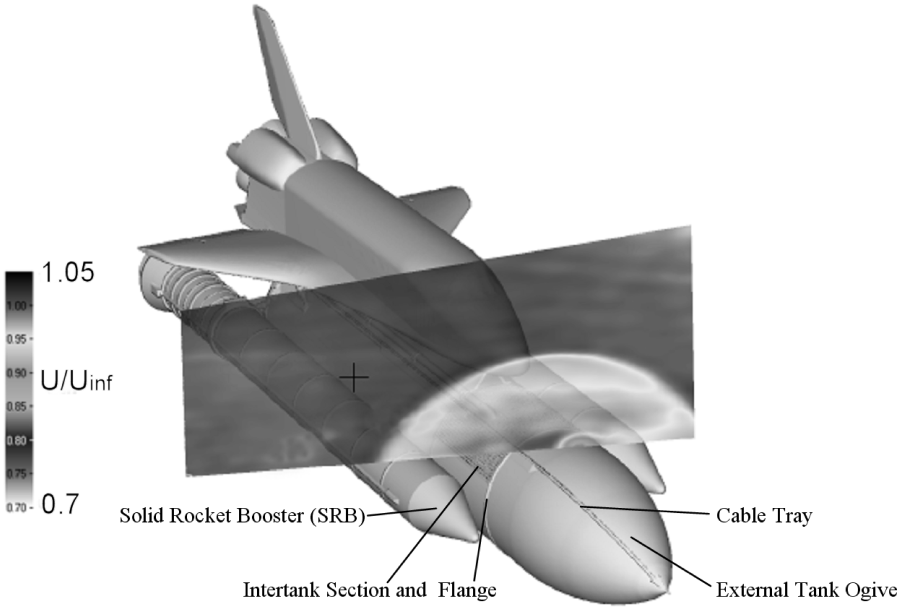

Fig. 9.83. Sample plot of normalized axial velocity in the most upstream measurement plane $Ma_\infty = 2.5$, $\alpha = 0°$, $\beta = 0°$.

two Mach numbers (1.55 and 2.5) over a range of model attitudes. The high stream velocity necessitated the use of the dual plane technique. These measurements revealed a complex network of interacting shock waves and a region of turbulent, separated flow on the ET just upstream of the Orbiter-to-ET attach point ("bipod"), where foam broke loose during Columbia's final flight. Figure 9.83 shows average axial velocities in the most upstream measurement plane for a typical case. Higher spatial-resolution measurements were made in a single vertical plane in the separated-flow region above the Intertank section of the ET. More than 7000 samples were acquired at a single test condition to allow computing turbulence statistics. Figure 9.84 shows a plot of the overall velocities measured at this position.

Figure 9.83 clearly shows the bow shock-wave from the nose of the External Tank (ET). The data are not laterally symmetric because the measurement plane was not perpendicular to the flow (it was yawed 15°). In addition, the cable tray on the starboard side of the ET ogive (figure 9.83) probably induced flow asymmetry. Figure 9.84 shows the shock wave from the flange at the upstream edge of the Intertank. As in figure 9.83, the measurement plane is yawed with respect to the freestream direction. The lower-speed region near the surface is a separation bubble. Turbulence statistics were derived from this dataset.

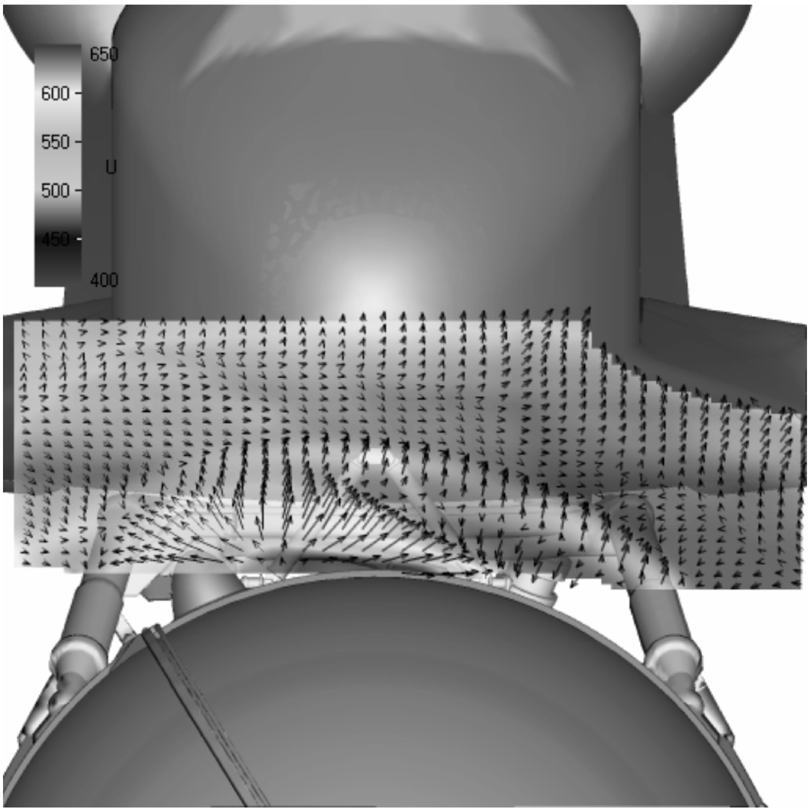

Fig. 9.84. Contours of mean axial velocity with vectors indicating mean spanwise and vertical velocities (m/s). $Ma_\infty = 2.5$, $\alpha = 0°$, $\beta = 0°$.

An adjustable dual-plane laser projection system was required to allow the position of the second plane to be remotely moved downstream during testing operations. This was necessary because the Mach number range was too large to allow a fixed downstream separation of the first and second laser sheets. Each sheet was produced from separate laser heads, with each head providing $250\,mJ$ per pulse. The laser heads were rotated 90° with respect to each other to allow the beams to be combined using a polarized beamsplitter cube. The beam from the second laser was reflected into the cube by a mirror mounted on a high-resolution translation stage. With this arrangement, the separation of the laser sheets corresponded to the readout of the translation stage controller. The plate that supported both lasers and all of the optics was carried by a linear traverse that provided one meter of displacement in the streamwise direction. This traverse permitted remote control of the streamwise locations of the measurement planes.