NASA Ames Wind Tunnel Testing of 3% Shuttle Model

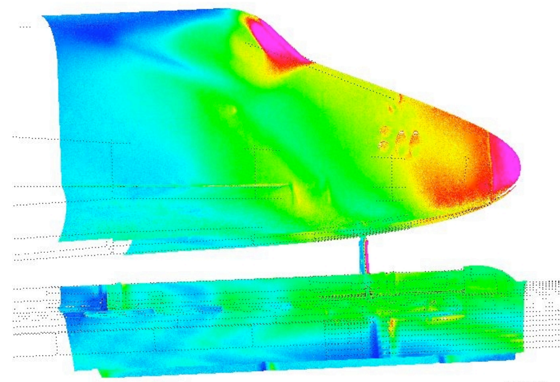
NASA chose the Experimental Aero-Physics Branch at Ames to participate in two wind tunnel tests in support of the Return to Flight (RTF) program for the Space Shuttle. Ames researchers made measurements of the steady and unsteady surface pressures and 3-D flow field velocities using advanced instrumentation developed in-house.

Background

Because of the Columbia tragedy, NASA is planning to remove or modify the foam insulation around portions of the Space Shuttle External Tank (ET). This will change the aerodynamic environment around some important areas of the ET, including the Bi-Pod that attaches the Orbiter to the ET and the main LOX line which feeds oxidizer to the Shuttle's engines. In particular, aerodynamic loads on the LOX line and Bi-Pod could be higher than with the original ET design. NASA tasked the Experimental Aero-Physics Branch with assisting JSC in the planning and execution of two wind tunnel tests of a 3%-scale shuttle model in the Ames 9x7 ft Supersonic Wind Tunnel and in the 16T at AEDC. The model was operated at high Mach number and high dynamic-pressure conditions to simulate the extremes of launch aerodynamics. Steady pressures were measured with Pressure-Sensitive Paint (PSP), unsteady pressures with Kulite transducers, and the off-body flow velocities with Particle Image Velocimetry (PIV).

Test Program

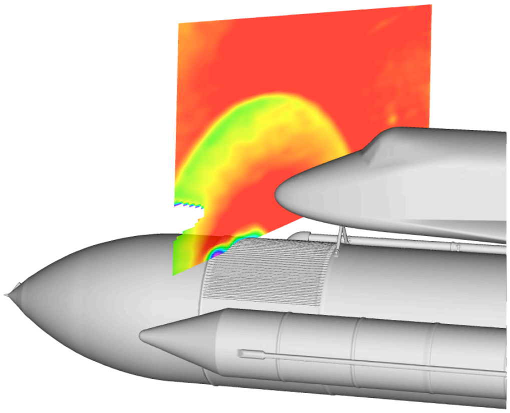
PSP was used to make pressure measurements on the Bipod, LOX line, Orbiter forward fuselage, and PAL ramp areas of the 3%-scale Shuttle model. The data were obtained using a new technique, that of luminescence lifetime measurement, which avoids the need for cumbersome wind-off calibration images. This was the first use of this technique in the 9x7 Supersonic Wind Tunnel. The lifetime technique worked extremely well, showing very good agreement with pressure tap results and resolving the pressures on small components to a degree that would be impossible with conventional PSP techniques. Images were taken over the entire Mach number and model attitude ranges investigated during the test. The images were mapped to a surface grid for



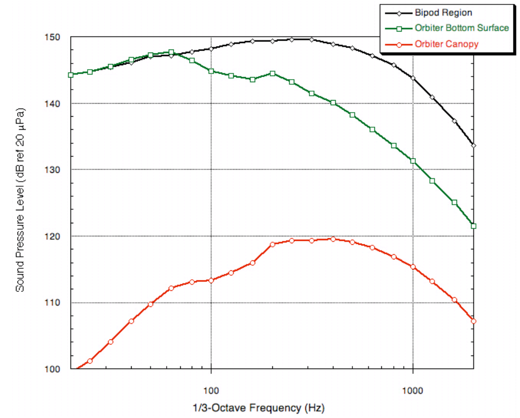
PSP data mapped onto the Orbiter and ET model surfaces. Red indicates high pressure and blue indicates low pressure.

direct comparison with Computational Fluid Dynamics (CFD) results. Most differences between the CFD and PSP results are due either to known variations between the CFD grid and the model, or known errors in the PSP mapping process.

PIV was used to measure all three components of flow velocity in a broad area above the ET, ahead of the Orbiter and in a close-up region just ahead of the Orbiter nose. These measurements are being used to test the accuracy of CFD simulations. CFD is being used to predict the possible trajectories of debris (e.g. foam) that might be shed from the External Tank and must be validated before the Shuttle can return to flight. CFD results at M = 1.55 and 2.5 were in reasonably good agreement with the experimental data, and increase confidence in the general accuracy of the CFD model. The PIV data also revealed significant flow unsteadiness near the Bi-Pod, confirming independent unsteady pressure measurements in this region. This is a significant finding, especially since the CFD used to predict debris transport does not account for unsteady



Plane of PIV data: stream-wise component of velocity contours. The arc in the data shows the velocity change due to the bow shock.



Typical Shuttle noise environment at the surface of the external tank and Orbiter at 3 locations.

effects. These were the first PIV measurements in the 9x7 Wind Tunnel. The PIV team overcame significant challenges, particularly water vapor that condenses in the wind tunnel, obscuring the camera views of the laser light sheet.

The Space Shuttle is designed to withstand very high unsteady surface pressure levels (noise) during ascent. These pressure levels are comparable to the noise experienced 75 ft from a fighter jet at full takeoff power. The Ames acoustics group obtained new measurements to determine the effect of design changes on noise environment levels. These measurements required installation and calibration of new sensors and facility connections. The acquired data also had to be corrected and scaled before undergoing display and analysis. The 25 miniature pressure transducers, each less than 2 mm in diameter, presented a challenge because of their small size, low-voltage output and the long distance between the model and the data acquisition system. The acoustics group met the challenge by designing and building miniature amplifiers that would fit inside the model. The amplifier system was coupled with an existing data acquisition system that was modified for specific RTF requirements. Over 50 GB of data were acquired and previews of the data were provided to the customer in near real-time. The data were then frequency-corrected and scaled to full-scale flight conditions to compare the acoustic environment of the Shuttle with design changes. These measurements improve the understanding of the Space Shuttle unsteady pressure environment by extending the frequency range and spatial coverage of the previous database, and by characterizing the effects of design changes to improve the safety of the program.

These measurements will help to accurately define the structural loads requirements that the Shuttle must meet for safe and efficient operation.

Impact on Return to Flight Program

The complex data returned by these advanced measurement techniques provides a basis for a more detailed understanding of the flow around the Space Shuttle during critical portions of the ascent phase of its flight. Comparison of CFD results with the experimental measurements provides critical validation of the computational technique. CFD validation is a vital part of the overall flow modeling process providing estimates of the aerodynamic loads on critical components as well as to track the possible trajectories of any debris which might be shed from the ET. The flow unsteadiness observed in the Bi-Pod region highlights the fact that this is a sensitive area, where critical Shuttle components are exposed to a highly dynamic flow environment. Thus considerable care is warranted in making sure that the aerodynamics of this part of the Space Shuttle are well-understood.

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