APPLICATION BRIEFS FROM FLUENT

EX228

Injection into a Supersonic Stream

FLUENT 6.1 is used in this example to predict the behavior of an under-expanded jet, injected into a supersonic free stream flow. Different one- and two-equation turbulence models are compared for their ability to best predict this type of flow. To make the comparisons, wall pressures for a range of injection pressure ratios are compared with experimental results.

In this 2D example, an under-expanded jet penetrates through a turbulent boundary layer and expands into a supersonic cross flow. The slot through which the jet passes is located 228.6 mm from the leading edge of the plate, and the slot width is 0.2667 mm. The flow behavior is studied for injection ratios (P_{jet}/ P_∞) of 8.74, 17.12, 32.44, and 63.50. At the supersonic flow inlet, pressure conditions are used with a static pressure (P_∞) of 3145 Pascals and freestream Mach number (M_∞) of 3.5. Four different turbulence models are used in the simulations: the realizable k-ε model with enhanced wall treatment, the standard k-ω model, the SST k-ω model, and the one-equation Spalart-Allmaras model. The freestream inlet turbulent kinetic energy is specified as 15.97 m^2/s^2 (assuming a turbulence intensity of 0.005) and the specific dissipation rate (ω) is specified as 113,035 s^{-1} (obtained by equating molecular viscosity and eddy viscosity). At the slot inlet, sonic pressure and temperature conditions are specified with turbulence quantities of $k = 100$ m^2/s^2 and $\omega = 5 \times 105$ s^{-1}.

When the jet passes through the slot and into the supersonic cross flow, a complex flow pattern develops. A prominent feature is a Mach disk that forms as a result of the coalescing of compression waves (Figure 1). Upstream of the Mach disk, a bow shock forms as the jet blocks the passage of the supersonic flow. The boundary layer separates, resulting in a separation shock, which intersects with the bow shock. Upstream of the jet, between these shock boundaries and the plate, a recirculation zone is created with primary (PUV), secondary (SUV) and tertiary (TUV) upstream vortices. The jet reattaches downstream and encloses a recirculation region containing primary (PDV) and secondary (SDV) downstream vortices. A recompression shock is formed as a result of this reattachment. This type of flow field is of particular interest in supersonic combustors and thrust vector control systems.

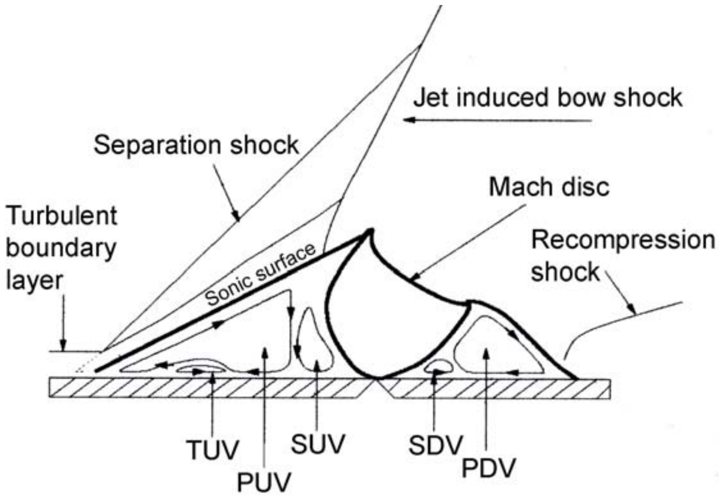

Figure 1: A diagram of the flow features

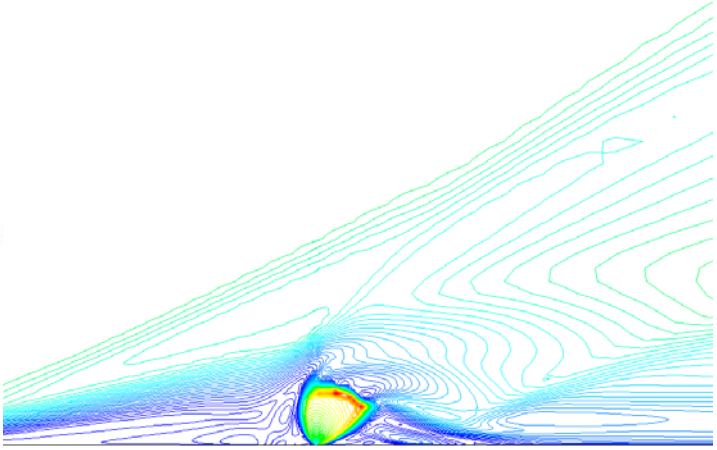

Figure 2: Mach number distribution for $P_{jet}/ P_\infty = 63.50$ as predicted by the k-ω SST model

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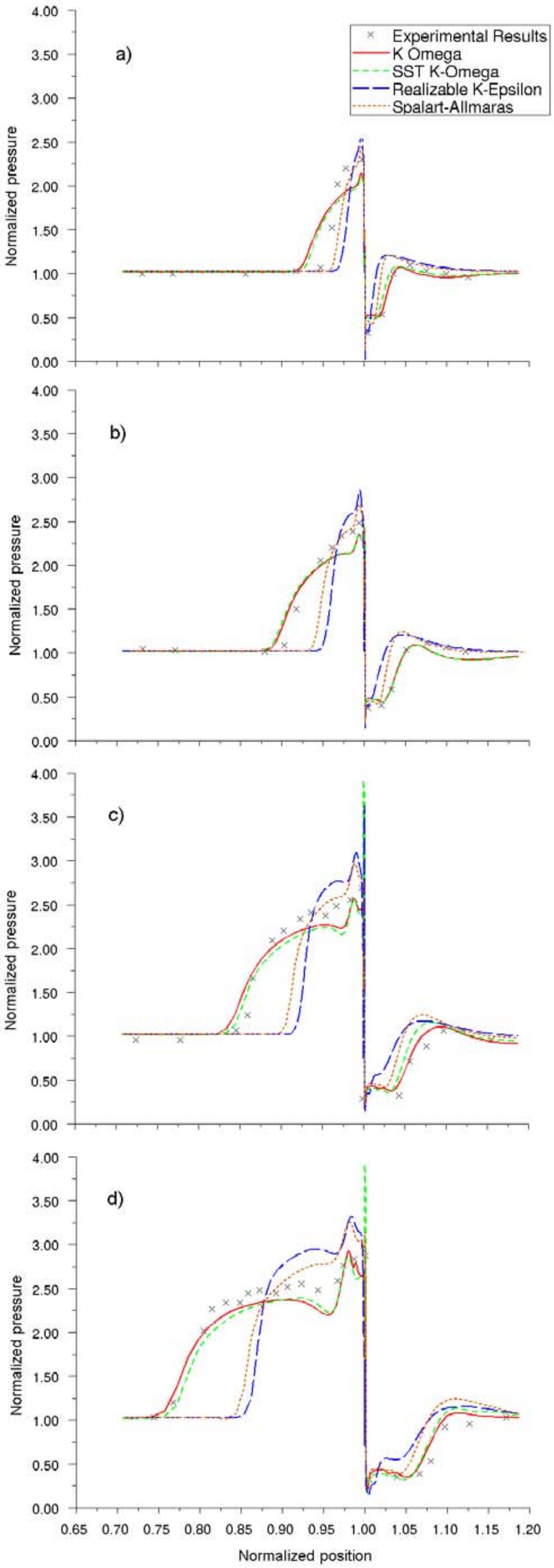

Figure 3: Comparison of wall pressures with experiments for P_{jet}/P_∞ = a) 8.74, b) 17.12, c) 32.44, and c) 63.50

The flow features sketched in Figure 1 can be identified by examining the Mach number contours in Figure 2. The upstream and downstream vortices are well captured. The Mach disk, expanding jet, sonic surface, bow shock, separation, and reattachment shocks can all be clearly identified.

A comparison of experimental results [2, 3] with FLUENT predictions is presented in Figures 3a through 3d, where the x-axis represents the distance from the plate leading edge normalized by the distance to the injection point, and the y-axis represents the wall static pressure normalized by the free stream static pressure (P_∞). In Figure 3a, the predictions downstream of the jet match the experimental results very well, while upstream of the jet, the peak pressure is over-predicted for the realizable k-ε model and under-predicted for the k-ω models. The Spalart-Allmaras model shows the best agreement with experimental data in this region.

As the injection pressure ratio increases, the k-ω models predict the measured values with increasing accuracy, while the realizable k-ε and Spalart-Allmaras models do not (even though they do predict the correct trends). The low Reynolds number effects present in the near wall regions and the downstream recirculation regions are well captured by the two k-ω models. For the highest pressure ratios (Figures 3c and 3d) the k-ω models are far better at predicting the measured behavior than the other models. However, all models over-predict the pressure peak at the injection location.

In summary, the transverse injection of an under-expanded jet into a supersonic stream is studied for a wide range of injection pressure ratios. For all but the lowest injection pressure ratio studied, the k-ω models predict the pressure data much better than do the Spalart-Allmaras or realizable k-ε models.

References:

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2. Clarence, C. F. and Philips, B. S., AIAA J., **36**, No.8, p. 1401-1412, 1998.

3. Sriram A.T. and Matthew, J., 4th AeSI CFD Symposium, Bangalore, 2002.