Complex Flow Separation Pattern on Transonic Fan Airfoils Revealed by Flow Visualization

Modern turbofan engines employ a highly loaded fan stage with transonic or low-supersonic velocities in the blade-tip region. The fan blades are often prone to flutter at off-design conditions. Flutter is a highly undesirable and dangerous self-excited mode of blade oscillations that can result in high-cycle fatigue blade failure. The origins of blade flutter are not fully understood yet. The latest view is that the blade oscillations are triggered by high-frequency changes in the extent of the partially separated area on the airfoil suction side. There is a lack of experimental data describing the separated flow characteristics of modern airfoils for transonic fans.

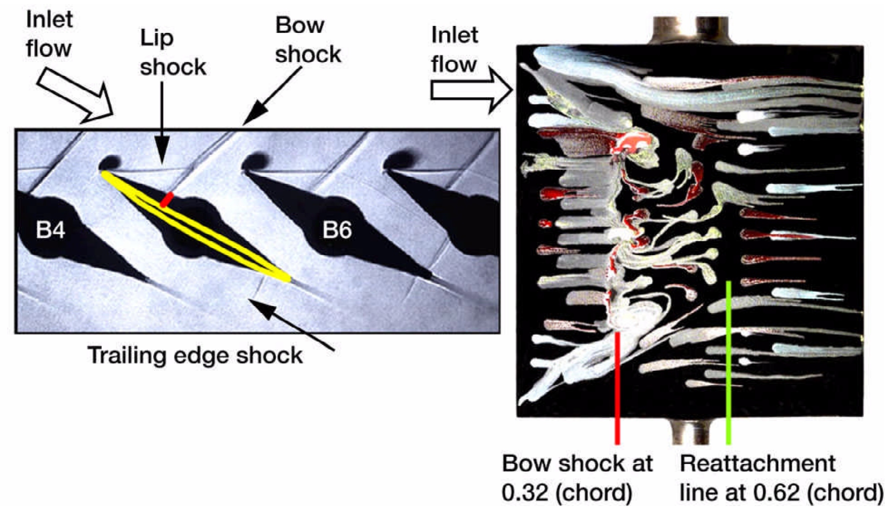
It is very difficult to determine the presence and extent of the separated flow zone from only static pressure measurements on the airfoil surface. Therefore, two visualization experimental techniques were used to determine flow behavior on the suction side of an airfoil:

1. Surface flow visualization using dye oils
2. Shadowgraph flow visualization

Surface flow visualization techniques are based on a dye being smeared over the surface by flow. Droplets of colored oil are deposited on the test surface, and the facility is started. Requirements for reliable surface flow data are a very short facility startup time and a dye-oil mixture of suitable viscosity in conjunction with small dye-oil marks on the test surface. The tests were carried out in the Transonic Flutter Cascade Facility at the NASA Glenn Research Center. Data were acquired for steady-state conditions at a high flow incidence of 10°.

For a subsonic inlet Mach number of 0.8, the flow exhibits a large separated region that starts immediately at the leading edge and extends, at midspan, down to 52 percent of the blade chord. The separation pattern for a low supersonic Mach number of 1.18 is completely different as seen in the picture on the right. First, starting from the leading edge, the flow is attached to the blade surface down to approximately 32 percent of the chord. Then, there is a separated flow region in which air moves in the direction against the inlet flow. Finally, at 62 percent of the blade chord, the flow attaches back to the blade surface. The adjacent shadowgraph (left) helps depict this complex flow pattern. The excellent agreement of these two methods is clearly demonstrated here.

The experimental results are being used to verify computational code. The prediction of flow separation for the supersonic inlet conditions agrees qualitatively with experimental results. It appears that the separation bubble in the calculations starts closer to the leading edge than is seen in the experimental data.



Surface flow pattern for supersonic inlet flow; Mach number of inlet flow, 1.18. Left: Shadowgraph of cascade (side view). Right: Surface flow visualization of blade B5 (top view).

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