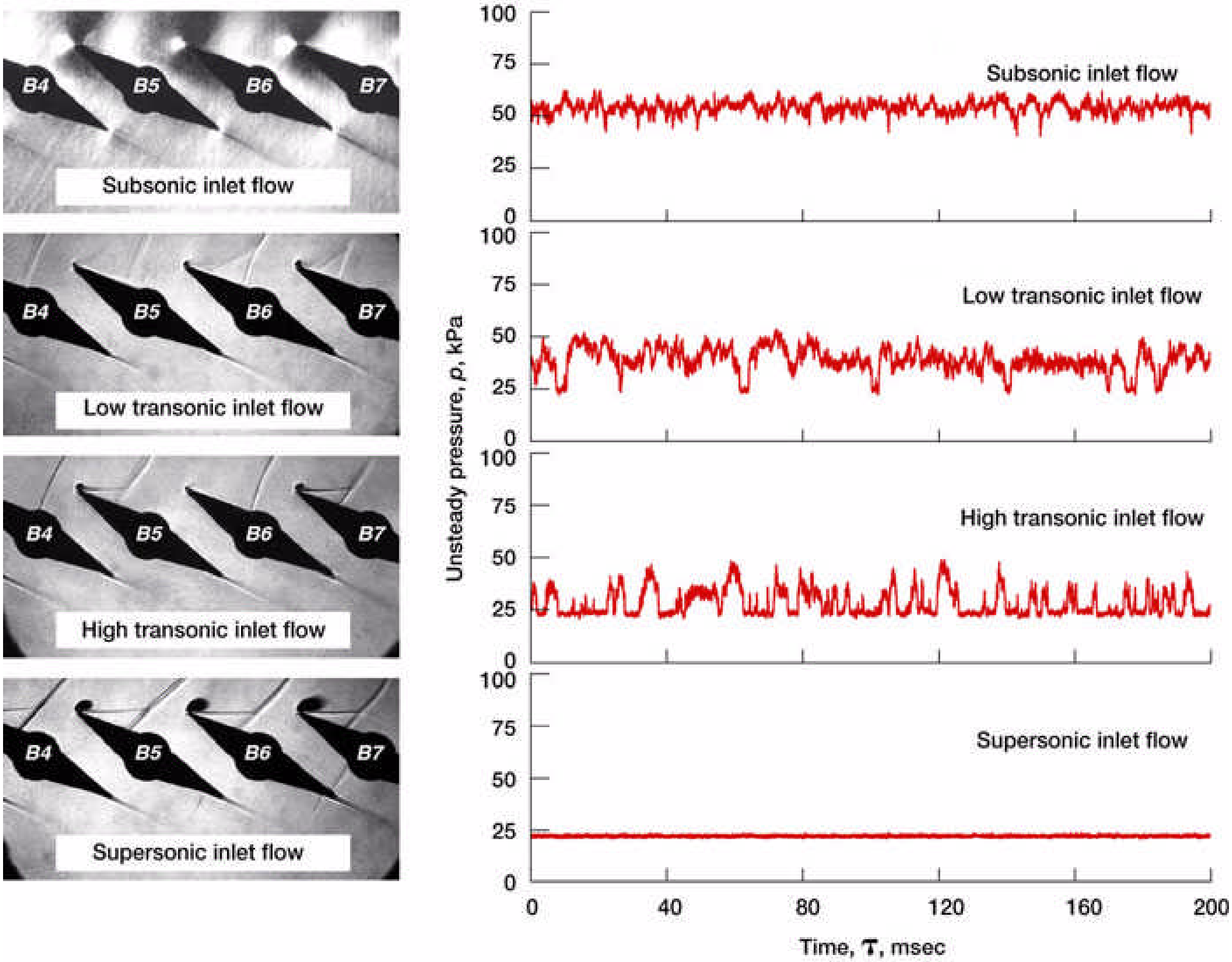
# Fan Stall Flutter Flow Mechanism Studied

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. Experimental data that can be used to clarify the origins of blade flutter in modern transonic fan designs are very limited.

The Transonic Flutter Cascade Facility at the NASA Glenn Research Center was developed to experimentally study the details of flow mechanisms associated with fan flutter. The cascade airfoils are instrumented to measure high-frequency unsteady flow variations in addition to the steady flow data normally recorded in cascade tests. The test program measures the variation in surface pressure in response to the oscillation of one or more of the cascade airfoils. However, during the initial phases of the program when all airfoils were in fixed positions, conditions were found where significant time variations in the pressures near the airfoil leading edges could be observed.




*Fan flow behavior. Left: Shockwave patterns from shadowgraph flow visualization. Right: Time-resolved pressure signal on suction surface past the leading edge. Top row: Subsonic--below Mach 0.90. Middle two rows: Transonic--Mach 0.9 to 1.01. Bottom row: Supersonic--above Mach 1.01.*

Long description : Top row: Shadowgraph view of a cascade of airfoil shapes. Dark lines on the image would indicate the location of a shock wave, but none are present, showing the flow is subsonic. Adjacent is a graph with time on the x-axis and pressure in kilopascals on the y-axis. The graph shows data from a pressure sensor (Kulite) located near the leading edge of one of the cascade airfoils. The pressure varies slightly about the average pressure level. Middle two rows: These are similar to the top row in composition. The shadowgraph photo this time shows that some airfoils in the cascade have clear shock waves attached to them whereas others do not. It is not totally clear, but it appears that shocks are located on every other airfoil. The pressure sensor data graph shows the sensor measuring a higher pressure for a portion of the time and a lower pressure for the rest. The data show that the pressure stays at one pressure level or the other for varying lengths of time. There does not appear to be a pattern as to which pressure is present. The difference between the two pressure levels is approximately 20 kPa. Bottom row: This is also similar to the top row in composition. The shadowgraph picture clearly shows a similar shock wave pattern on each cascade airfoil. There is an oblique wave off the leading edge followed by a stronger wave normal to the airfoil surface before midchord. The oblique wave terminates above the airfoil surface when it meets the normal wave. The pressure sensor data are similar to the pressure data in the top row in that it the pressure vary slightly about the average pressure level. The average pressure is lower than it is for the subsonic inlet flow.

The variations in flow were observed in shadowgraph images of the tunnel flow and were confirmed by high-frequency electronic pressure sensors embedded in the airfoil surface. Prior to shock waves forming on the airfoils, the flow appeared uniform in the shadow-graph figure and in the surface pressure trace from the sensors. These conditions exist for subsonic inlet flow below an inlet flow Mach number of 0.9. After the Mach number was raised slightly about unity to a value of 1.01, supersonic inlet flow was established, the shadowgraph showed a similar shockwave pattern for each airfoil, and again the pressure trace was uniform in time. While the inlet Mach number was in the low to high transonic range (between 0.90 and 1.01), the shadowgraph showed some airfoils with shock waves and some without. Also, the particular airfoils that had shock waves would vary with time. This was confirmed by the data from the sensors as the pressure level randomly alternated between two pressure levels. The lower pressure level indicated the presence of a shock wave and the higher level the absence.

The observed behavior of the cascade experiment could be very useful in the control and avoidance of stall flutter. If this behavior is an indicator or precursor to a fan entering into an area of operation where stall flutter will occur, it can be used in an active control system to control the fan. At this point, however, it is not clear if the observed behavior is common to all current fans, is only observed in this particular airfoil design, or is an artifact of the experimental arrangement. Study of these preliminary observations will continue.

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