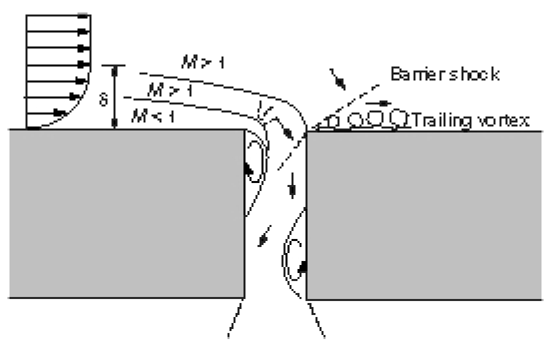
Bleed Hole Flow Phenomena Studied

Boundary-layer bleed is an invaluable tool for controlling the airflow in supersonic aircraft engine inlets. Incoming air is decelerated to subsonic speeds prior to entering the compressor via a series of oblique shocks. The low momentum flow in the boundary layer interacts with these shocks, growing in thickness and, under some conditions, leading to flow separation. To remedy this, bleed holes are strategically located to remove mass from the boundary layer, reducing its thickness and helping to maintain uniform flow to the compressor. The bleed requirements for any inlet design are unique and must be validated by extensive wind tunnel testing to optimize performance and efficiency.

To accelerate this process and reduce cost, researchers at the NASA Lewis Research Center initiated an experimental program to study the flow phenomena associated with bleed holes. Knowledge of these flow properties will be incorporated into computational fluid dynamics (CFD) models that will aid engine inlet designers in optimizing bleed configurations before any hardware is fabricated. This ongoing investigation is currently examining two hole geometries, 90° and 20° (both with 5-mm diameters), and various flow features (see the following figure):

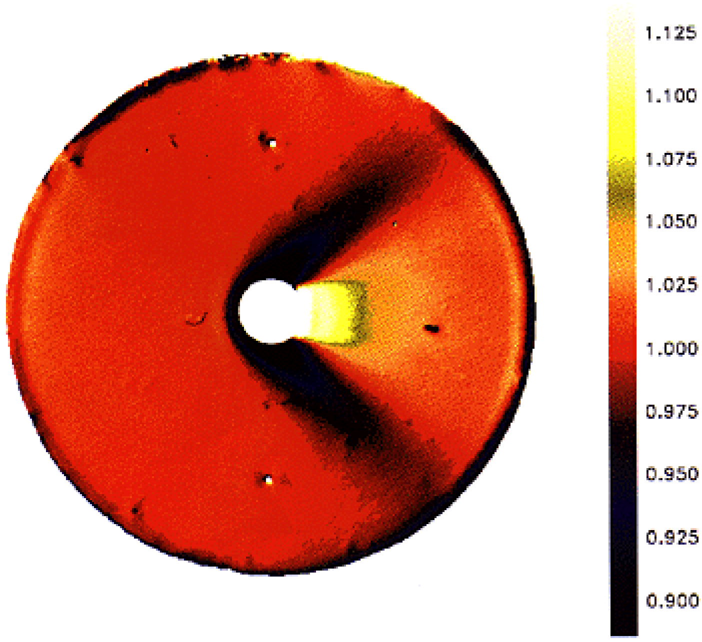
- The shock structure in and around the hole
- Multihole interaction
- Slant hole flow misalignment
- Orifice scaling relative to the boundary layer thickness
- Flow separation inside the bleed orifice
- The vortex structure around the hole



Flow in the vicinity of a 90° bleed hole. Boundary layer thickness, d.

The tests are being conducted in NASA Lewis' 15- by 15-Centimeter Supersonic Wind Tunnel, which is an open-loop, continuous-flow facility. Mach number variation is provided by interchangeable, fixed-geometry nozzle blocks. The tunnel can be run subsonically from Mach 0.2 to 0.8, and supersonically at discreet Mach numbers of 1.67, 2.0, 2.5, and 3.0.

To date, several of these areas have been investigated. For both 90° and 20° holes, pitot and five-hole probe surveys downstream of single bleed holes revealed an oblique barrier shock originating from the back lip of the hole. Pressure sensitive paint applied to the wall indicated flow expansion and compression regions in the vicinity of these orifices (see the figure below).



Normalized surface pressure ($P_w/P_{w,0}$) at Mach 2.5 in the vicinity of a 90° bleed hole.

For the 20° hole, alignment with the local flow direction was found to be critical for supersonic Mach numbers. The misalignment of a slanted hole fabricated in a rotatable plug was varied between 0° and 30° at Mach numbers of 0.60, 1.67, and 2.50. For each angle, a mass flow survey was taken for plenum pressures varying between full bleed and no bleed. It was found that at Mach 2.50 as little as one degree of flow misalignment resulted in a drop in mass flow through the orifice. The lower Mach number test showed similar behavior; however, mass flow hindrance proved less severe.

In inlet applications, holes are arranged in fields, each on the order of two to three diameters away from neighboring holes, so a two-hole interaction for this type of arrangement was studied. Two 90° holes with the rotatable plug geometry were located two diameters from each other: one hole was at the center of the plug and the other was offset from the center. The plug was then rotated between 0° (holes lie in a plane normal to the flow direction) and 90° (holes lie in a plane parallel to the flow direction). Mass flow surveys were again taken for each angle. As with the 20° misalignment experiment, sensitivity to location increased with Mach number. However, although shallow orientations resulted in a drop in the flow coefficient, at angles above 50°, the flow coefficient improved. This shows the potential for multihole configurations to exhibit more efficient bleed properties than their single-hole counterparts.

Continuing research is being conducted to study various other phenomena. As air enters a

90° hole, it separates from the hole wall, creating a blockage throat that hinders the hole's performance. Flow-visualization experiments using oil trace techniques verified this feature; however, flow-field measurements in the hole are yet to be recorded. Surveys of the trailing vortices created by bleed holes are also planned, as well as studies of the problems and benefits of bleed hole scaling.

Bibliography

Bodner, J.P.; and Greber, I.: Experimental Investigation of the Effect of a Single Bleed Hole on a Turbulent Supersonic Boundary-Layer. AIAA Paper 96-2797, 1996.

Davis, D.O.; Grimes, M.; and Schoenenberger, M.: Effect of Flow Misalignment and Multi-Hole Interaction on Boundary-Layer Bleed Hole Flow Coefficient Behavior. Prepared for the 1996 International Mechanical Engineering Congress and Exhibit, ASME, Nov. 17-24, 1996.