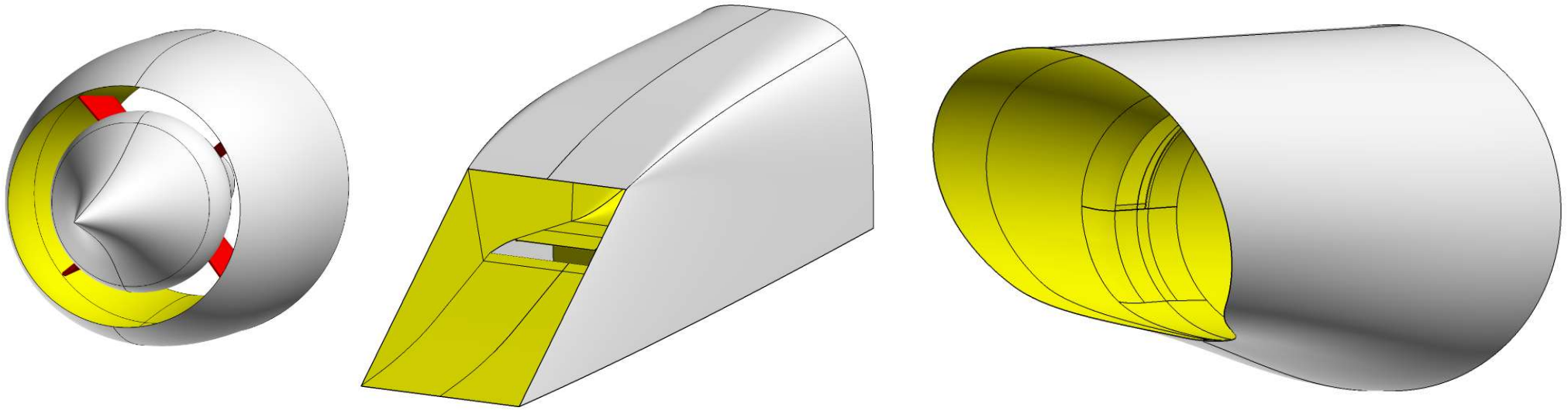




Supersonic External-Compression Inlets for Mach 1.4 to 2.0

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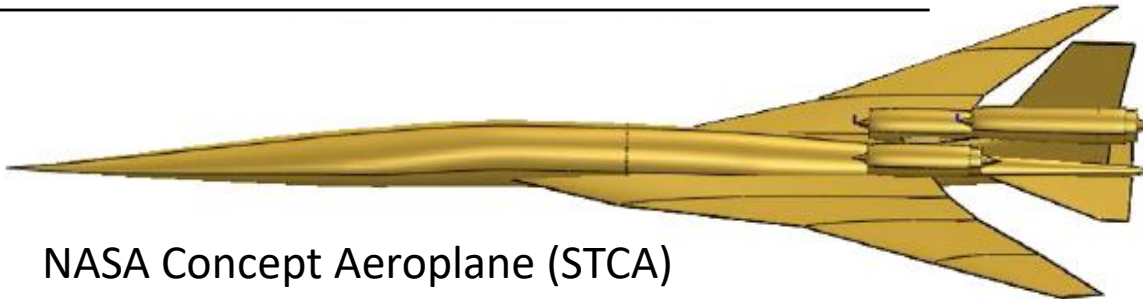
NASA Commercial Supersonic Technology



- Commercial supersonic flight for cruise in the range of Mach 1.4 to 2.0.
- The propulsion system (inlets, engines, and nozzles) is an important sub-system.
- The focus of this paper is on the inlets.
- Design of the inlet requires:
 - Flow conditions approaching the inlet
 - Dimensions and flow rate at the engine face



M_0	h_0 (ft)	W_{C2} (lbm/s)	M_2
1.4	50000	413	0.663
1.7	55000	383	0.581
2.0	60000	353	0.514

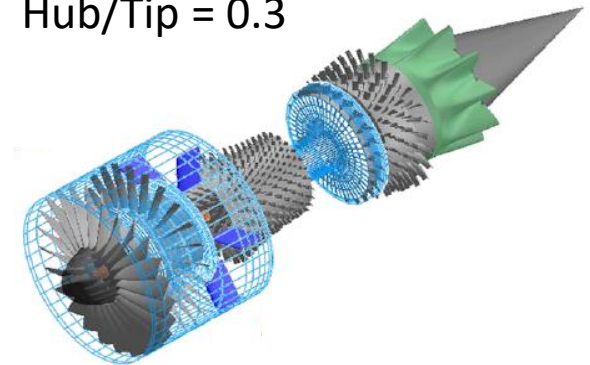


NASA Concept Aeroplane (STCA)
AIAA-2020-0263, Berton, et al.

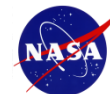
NASA STCA concept turbofan

$D_2 = 43.5$ inches

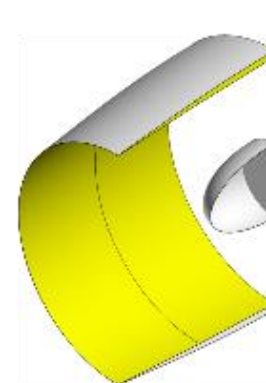
Hub/Tip = 0.3



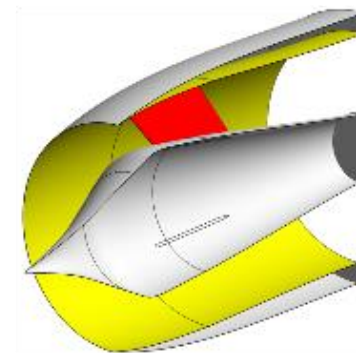
Inlet Types



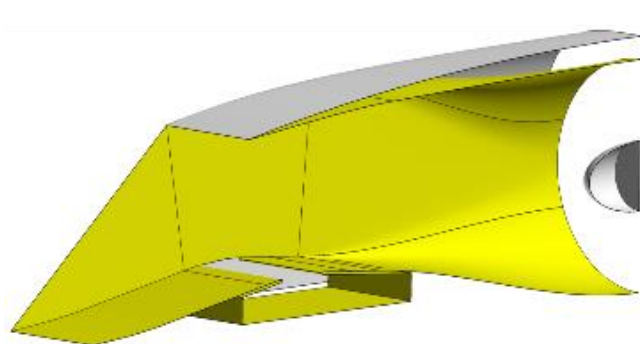
- Consider external-compression inlets.
- Consider five inlet types.
- Consider cruise at Mach 1.4, 1.7, and 2.0.
- Objective of the study was to compare and contrast inlet size and performance over the range of Mach numbers and inlet types.
- Methods were computational.



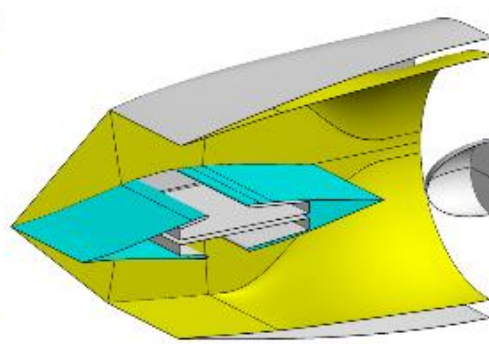
Axisymmetric
Pitot Inlet



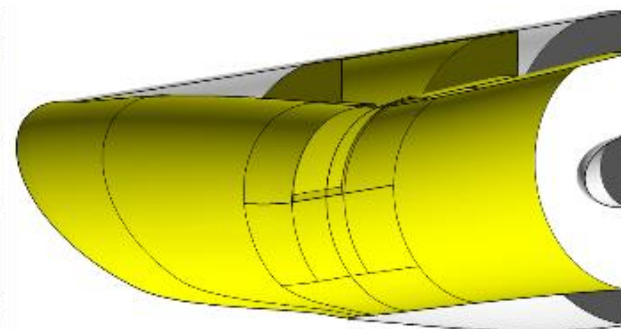
Axisymmetric
Spike Inlet



Two-Dimensional Inlet



Two-Dimensional
Bifurcated Inlet



Streamline-Traced Inlet

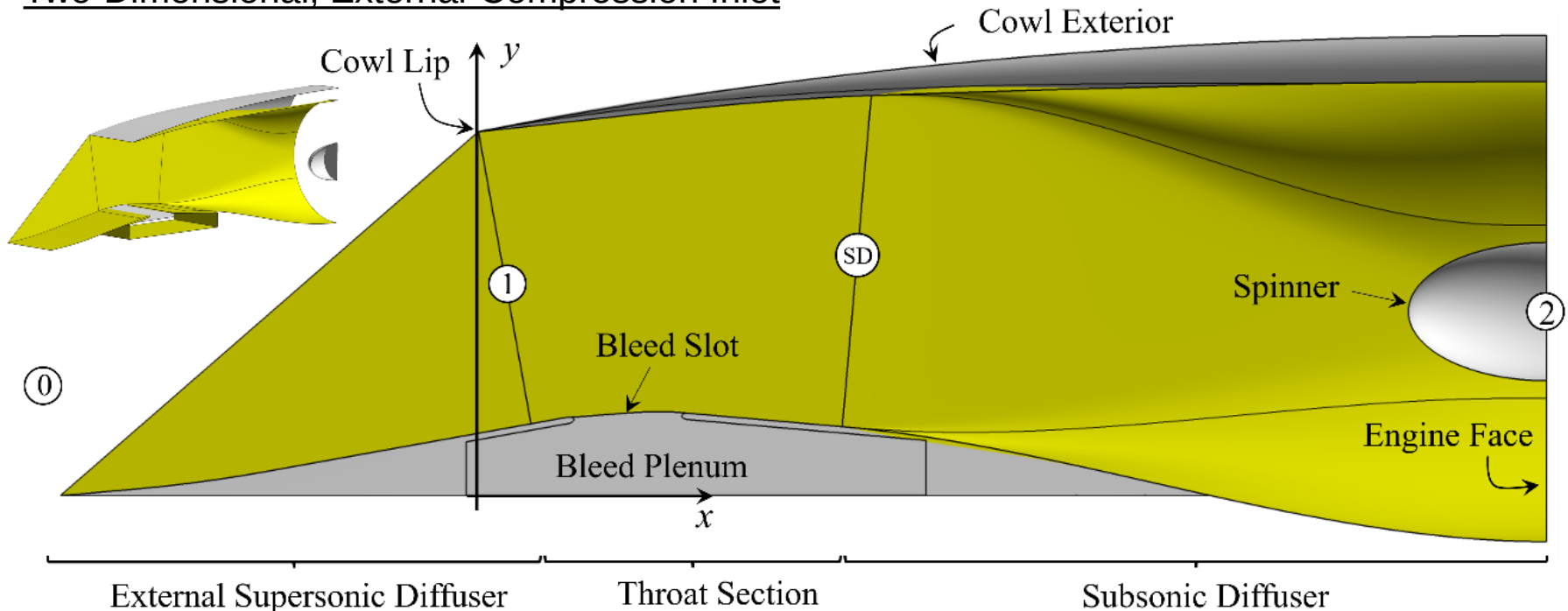
- NASA Supersonic Inlet Design and Analysis Tool (SUPIN)
 - Specify geometric and aerodynamic design factors for the inlet design problem.
 - Uses mostly planar constructs to form inlet geometry.
 - Uses algebraic, empirical, and numerical methods to size an inlet and compute inlet performance in terms of total pressure recovery, flow rates, and drag.
 - Creates surface and CFD grids.
 - Available to US persons through the NASA software catalog (software.nasa.gov).
- Wind-US Computational Fluid Dynamics (CFD) Solver
 - Uses multi-block, structured grids with 15-30 million grid points.
 - Solve steady-state Reynolds-Averaged Navier Stokes (RANS) equations.
 - Menter SST turbulence model.
 - On-design simulations involved matching the engine-face corrected flow rate (W_{C2}) by adjusting the throat area of the converging-diverging outflow nozzle.

Inlet Components



- Main inlet components are the external supersonic diffuser, throat section, and subsonic diffuser ending at the engine face.
- Stations through the inlet define interfaces between components and locations of quasi-one-dimensional properties for the inlet flow model.

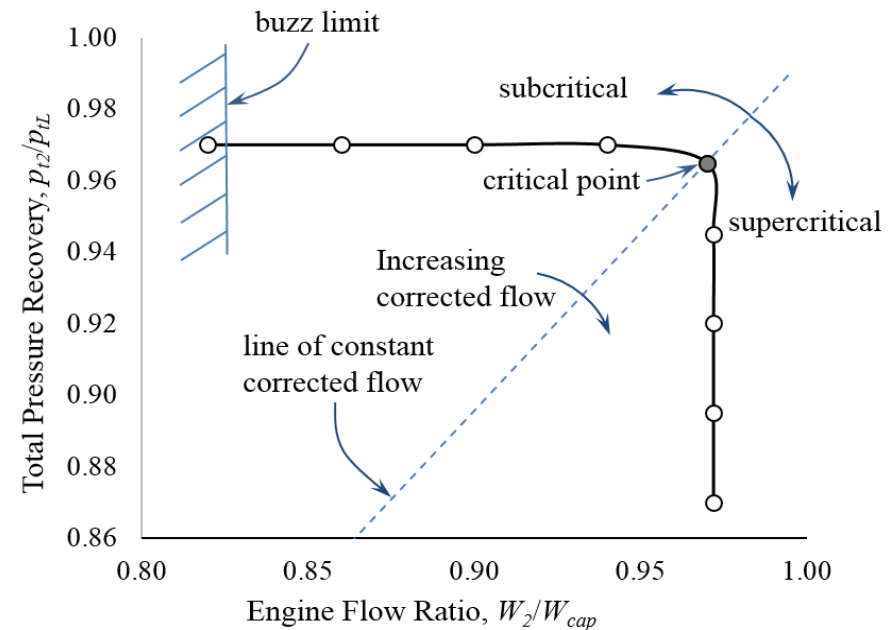
Two-Dimensional, External-Compression Inlet



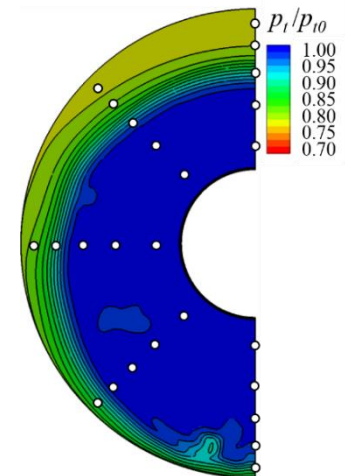
Inlet Performance



- Flow rates:
 - $W_{spillage}/W_{cap}$, W_{bleed}/W_{cap} , W_{bypass}/W_{cap} , W_2/W_{cap}
- Engine-face total pressure recovery (p_{t2}/p_{t0}).
 - Total pressure losses are due to 1) shock waves, and 2) viscous dissipation.
 - Characteristic “cane” curve relates total pressure recovery with the engine flow rate.
- Inlet Wave Drag
- Engine-face total pressure distortion
 - SAE ARP 1420 40-probe rake.
 - Interpolation of CFD solution onto the rake.
 - Radial distortion indices (DPR/P).
 - Circumferential distortion indices (DPC/P).



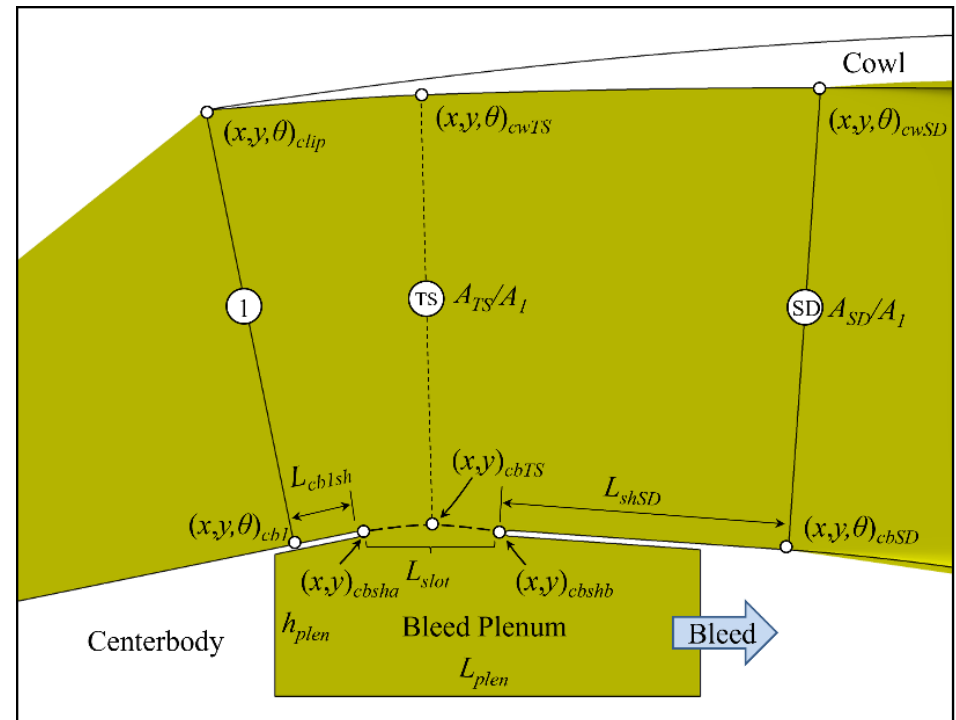
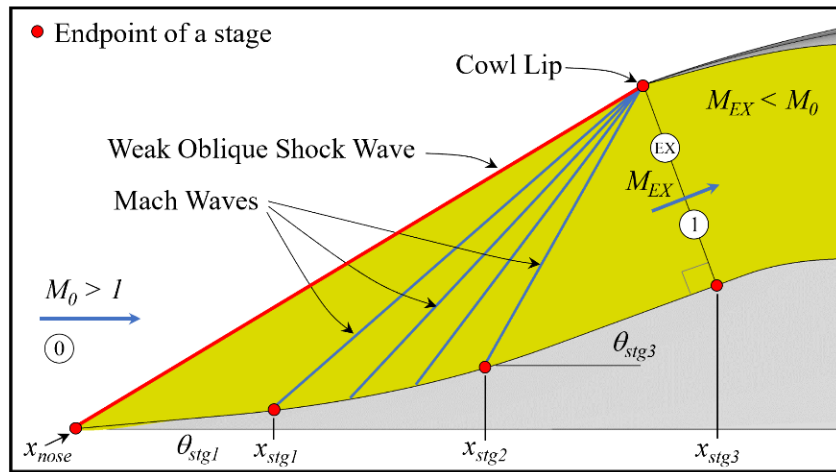
40-probe rake



Modeling of Inlet Components



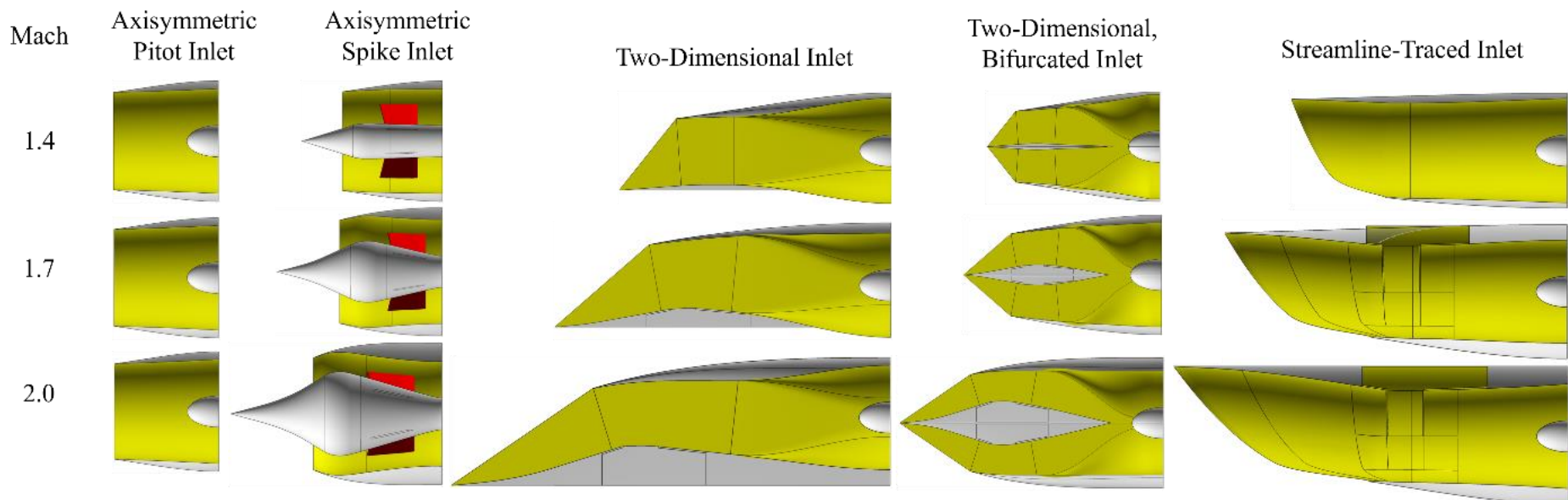
- The external supersonic diffuser, throat section, and subsonic diffuser are modeled within SUPIN using geometric and aerodynamic design factors.
- Details are within the paper.



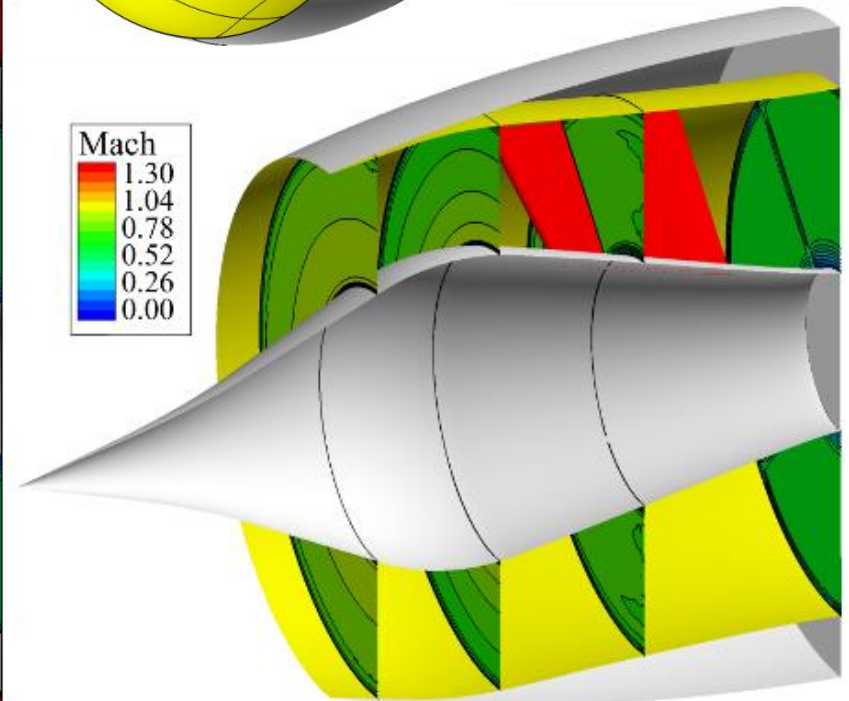
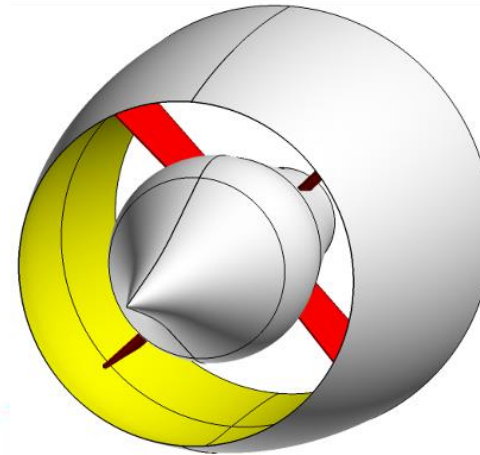
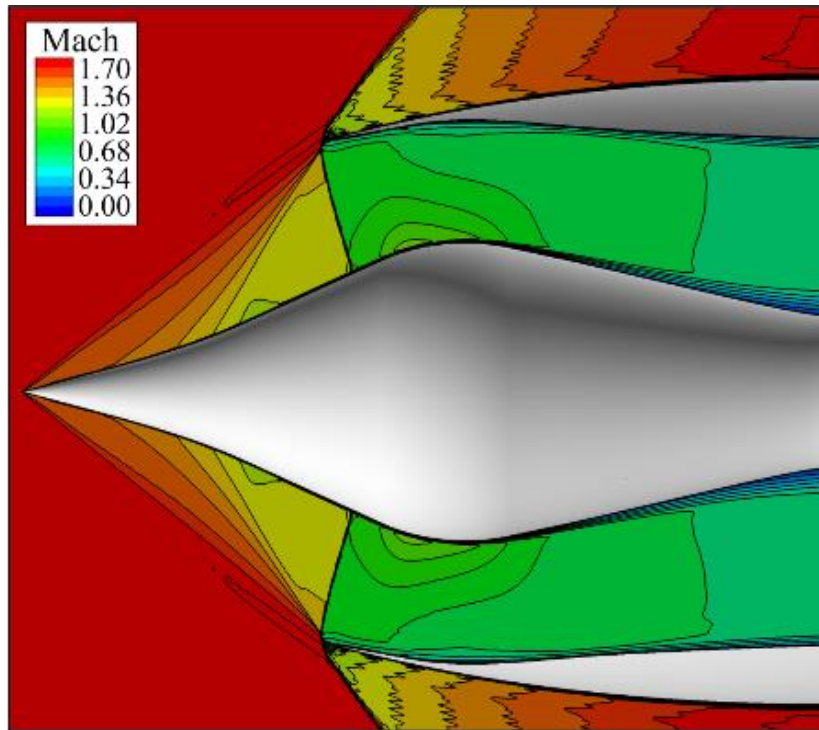
The Fifteen Inlets



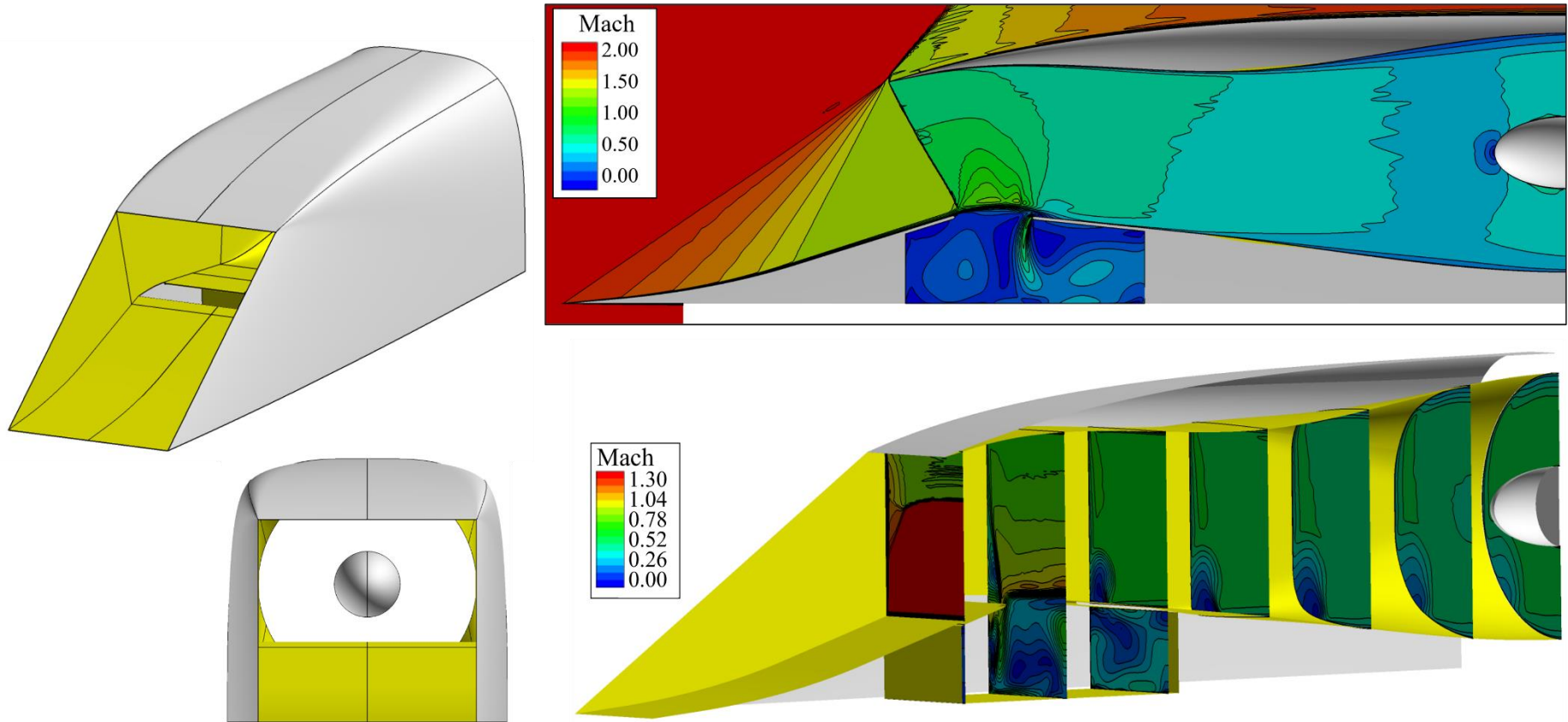
- Three freestream Mach numbers, $M_0 = 1.4, 1.7$, and 2.0 .
- Five inlet types.
- Fifteen isolated inlets designed for the freestream cruise Mach numbers (M_0) and engine face corrected flow rates (W_{C2}).
- Several design iterations were performed, but not formally optimized inlets.
- Performed CFD simulations of all inlets, except for the 2D, bifurcated inlets.



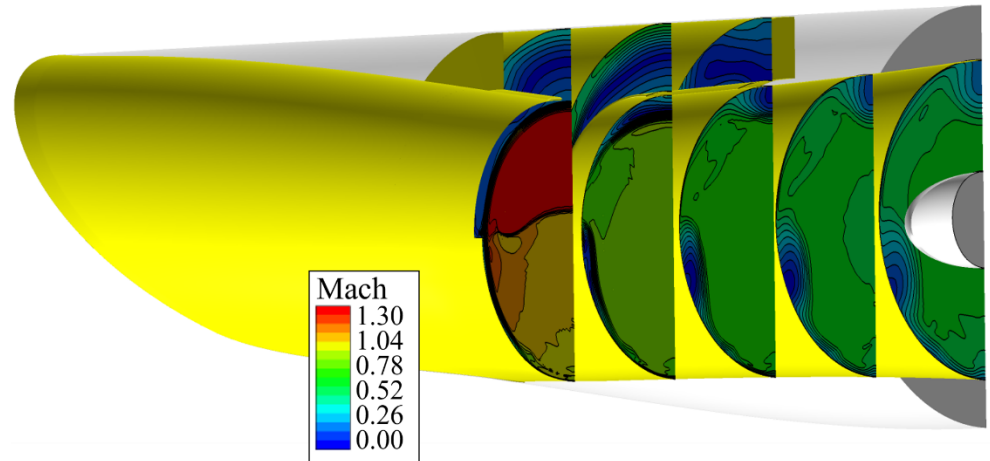
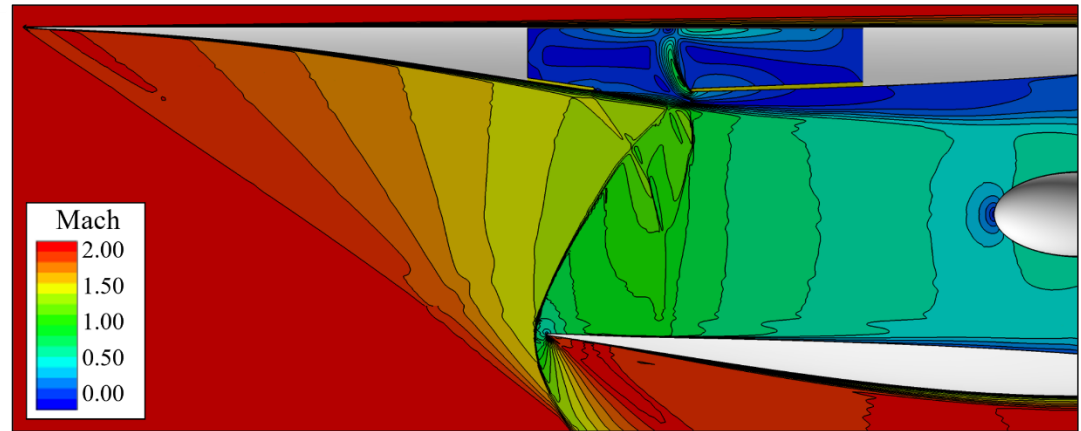
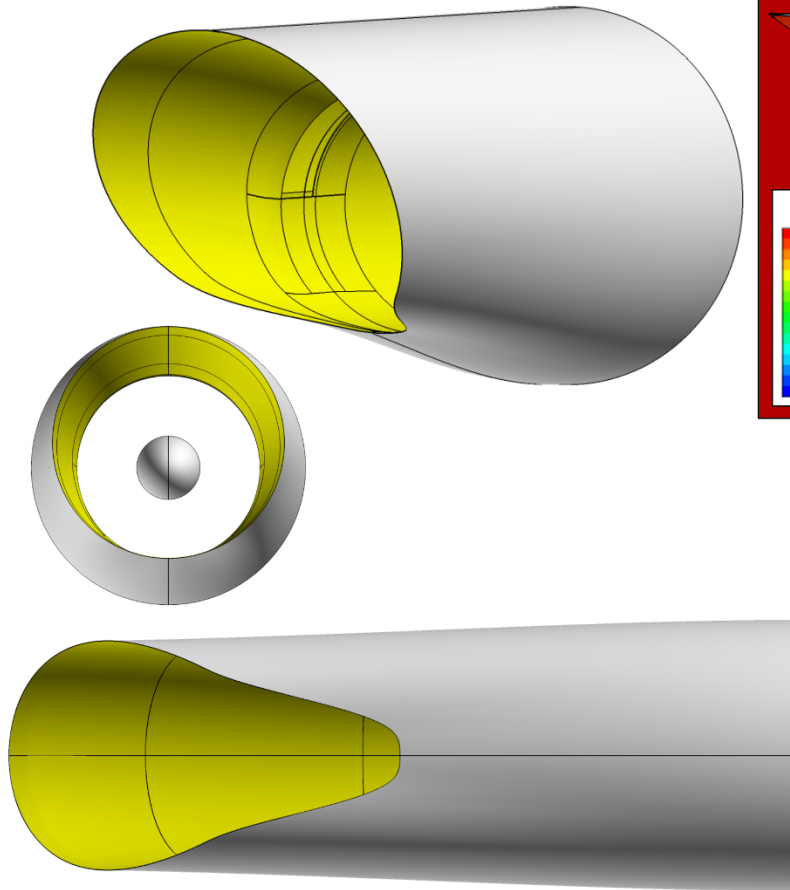
CFD Simulations: Axisymmetric Spike Inlet, $M_0 = 1.7$



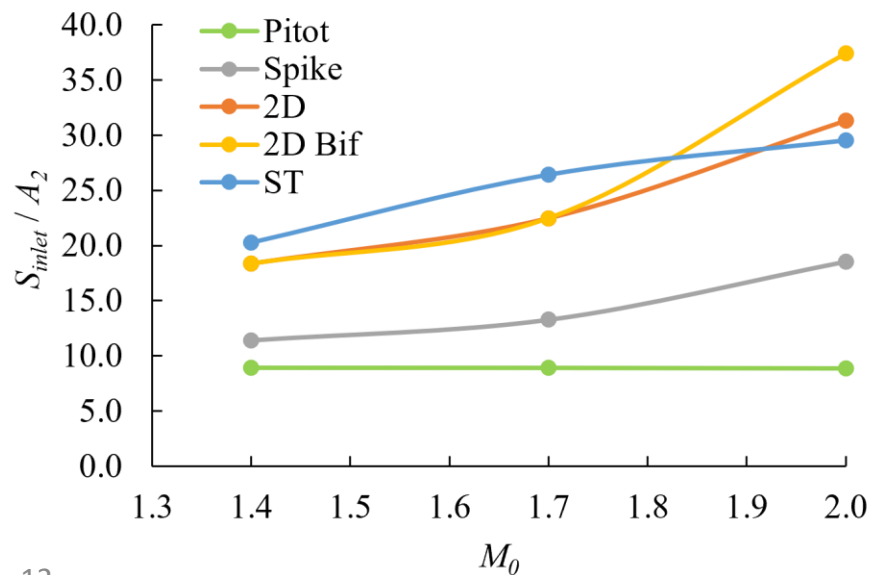
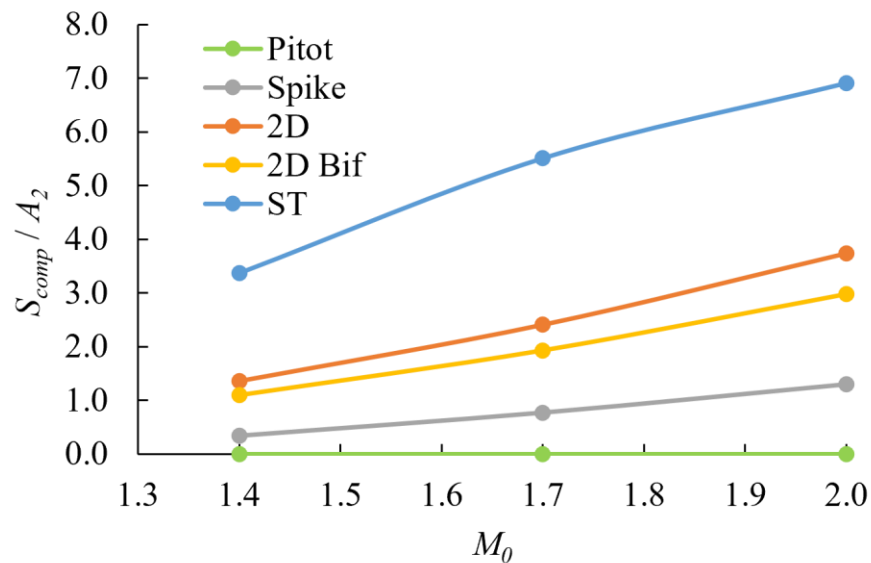
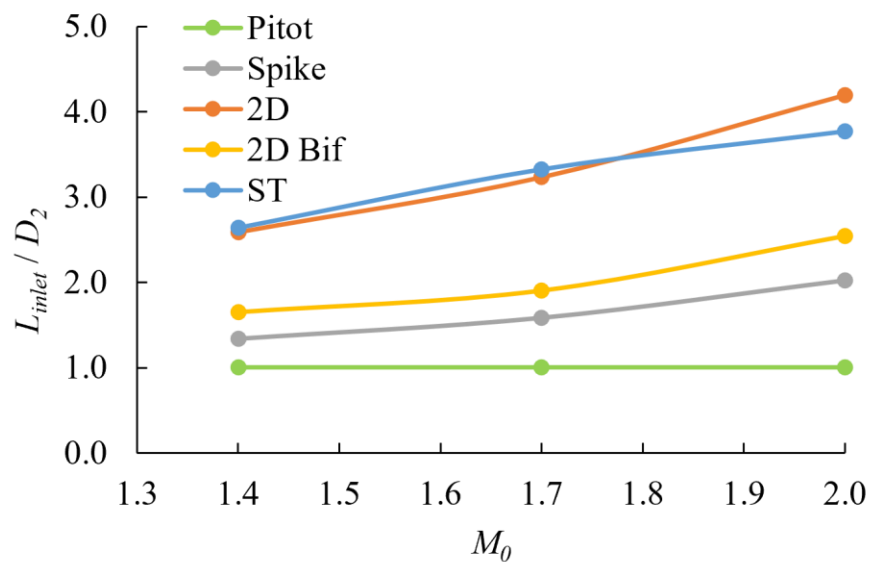
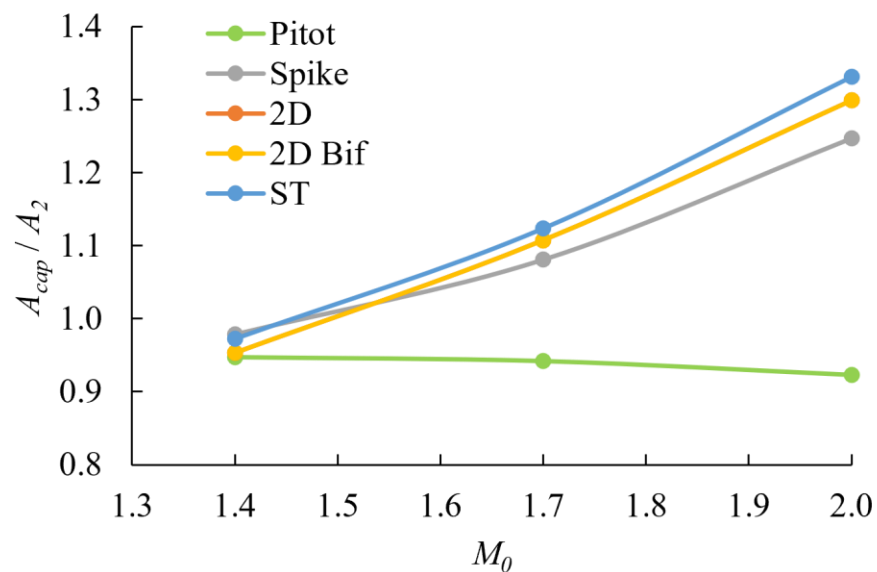
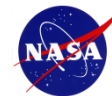
CFD Simulations: Two-Dimensional Inlet, $M_0 = 2.0$



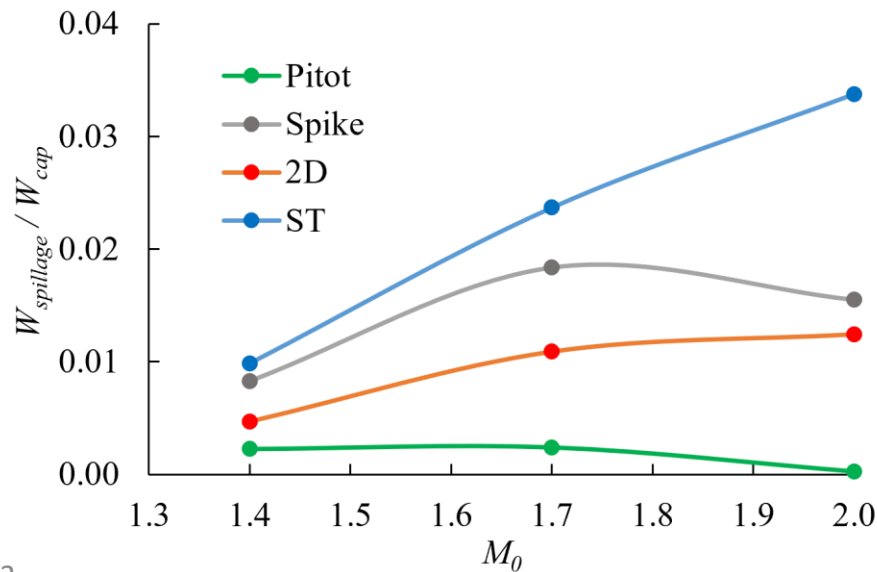
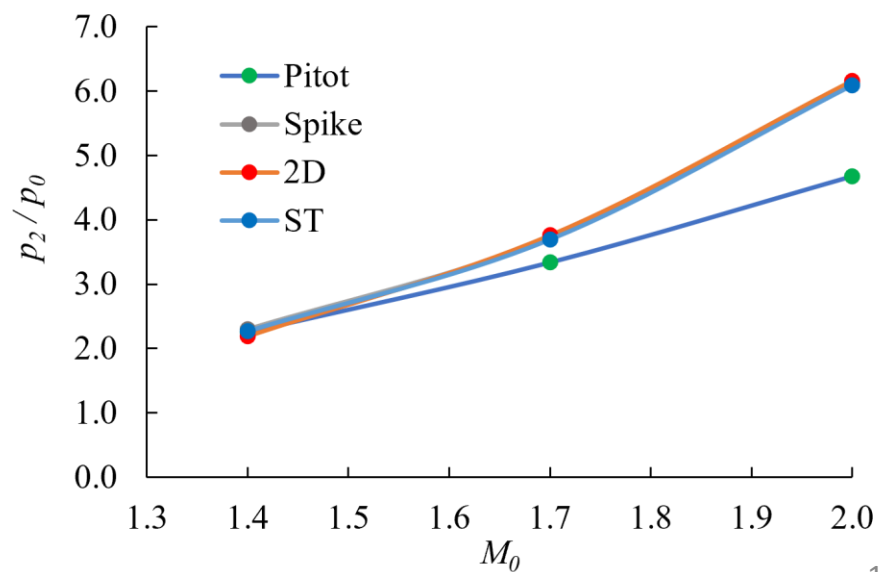
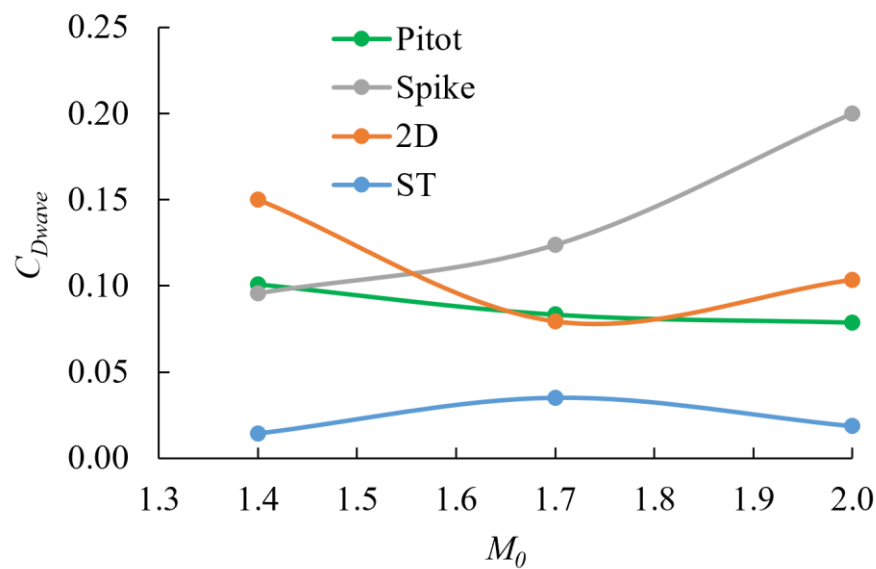
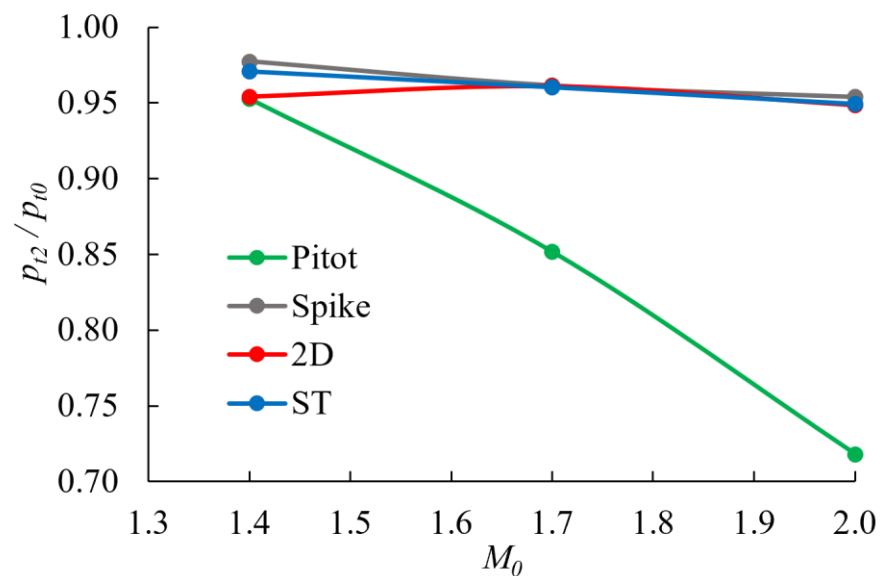
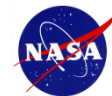
CFD Simulations: Streamline-Traced Inlet, $M_0 = 2.0$



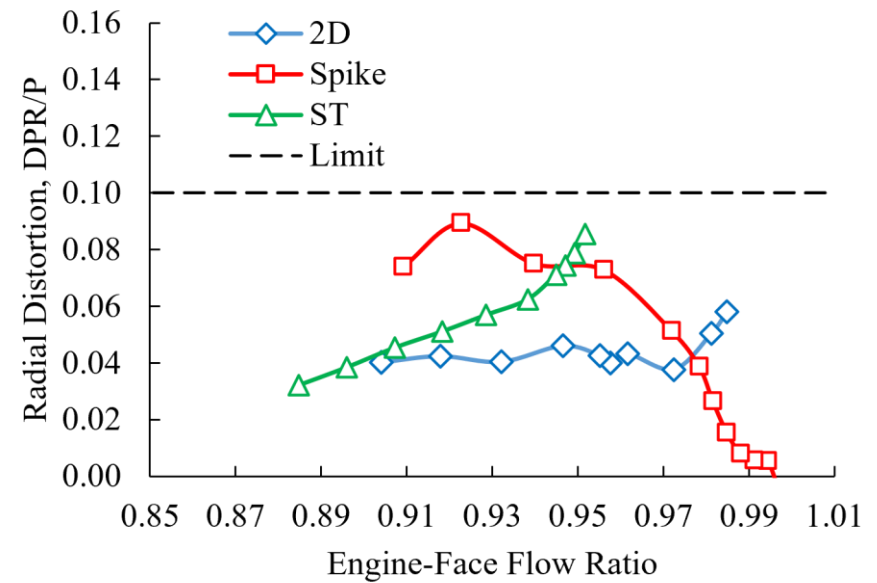
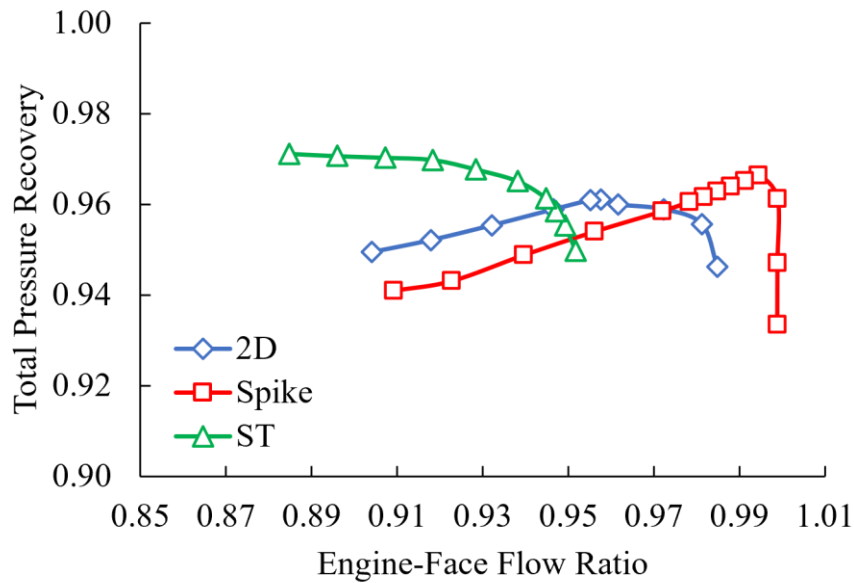
Inlet Size Comparisons



Inlet Performance Comparisons



Inlet Characteristic Curves for $M_0 = 1.7$



Conclusions



- Similar levels of total pressure recovery and inlet pressure ratio regardless of the inlet type (excluding the pitot inlets).
- The lower wave drag of streamline-traced inlets was demonstrated. Axisymmetric spike inlets have lower wave drag than the two-dimensional inlets at $M_o = 1.4$, but greater drag for $M_o = 1.7$ and 2.0 .
- The excessive spillage of the streamline-traced inlets should be examined.
- The axisymmetric spike inlet offers the smallest inlet. The lengths and surface areas of the two-dimensional and streamline-traced inlets are comparable and considerably larger than the axisymmetric spike inlets.
- The characteristic curves indicate stable inlet conditions over $\pm 5\%$ W_{C2} with 3% and 5% throat slot bleed in the two-dimensional and streamline-traced inlets. The axisymmetric spike inlet for $M_o = 2.0$ with no bleed exhibited a buzz behavior in subcritical conditions.
- Axisymmetric spike inlets with no bleed are attractive choice of inlets for the range of $M_o = 1.4$ to 1.7 .
- For $M_o > 1.7$, the two-dimensional and streamline-traced inlets become attractive choices due to lower wave drag and likely need for variable geometry for operation at low-speed and transonic conditions.

Future Work



- Inlets could use some refinement and optimization.
- CFD simulations needed for the two-dimensional, bifurcated inlets.
- Examine off-design inlet performance (angle-of-attack, angle-of-sideslip).
- Examine inlet operation and performance of the inlets at low-speed, take-off, approach-to-landing, and transonic conditions.
- Examine the use of auxiliary inlets for low-speed operation.
- Consider noise originating from the turbofan engine and its propagation through the inlet.