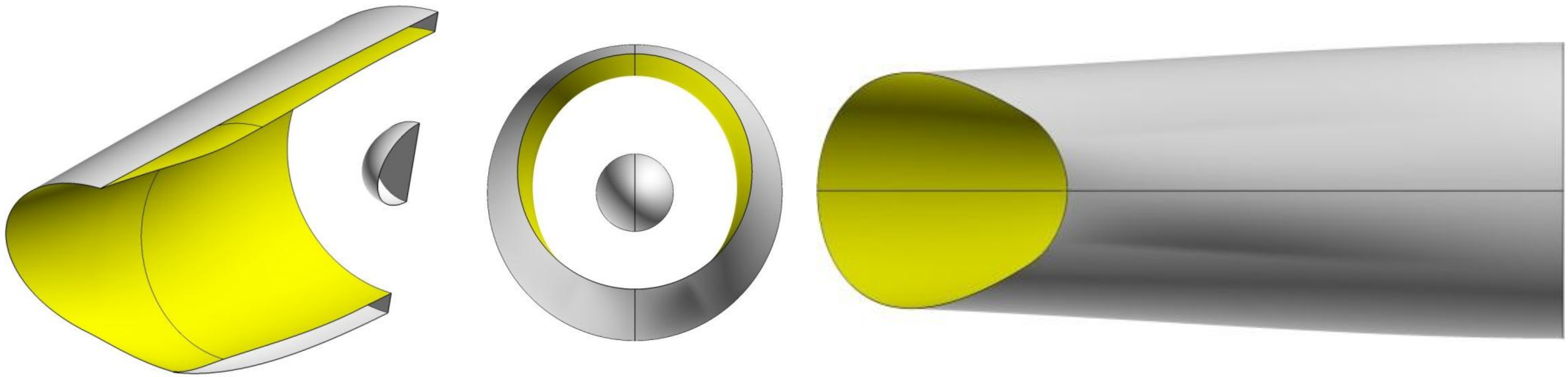

Enhanced Performance of Streamline-Traced External-Compression Supersonic Inlets

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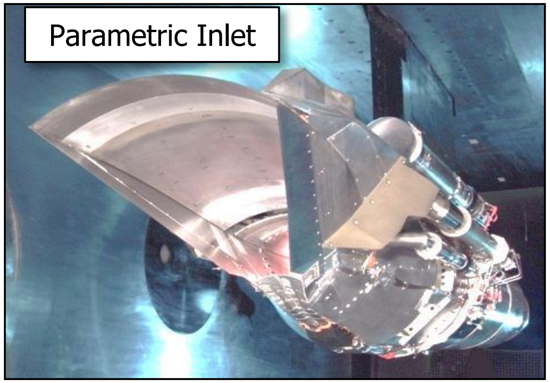
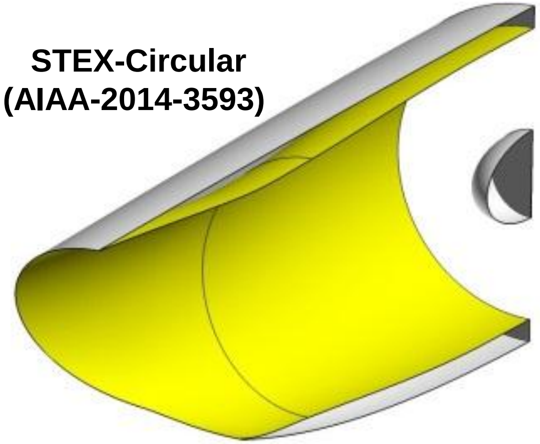
Streamline-Traced External-Compression (STEX) Inlets

- A supersonic, external-compression inlet involves the spilling of subsonic flow past a terminal shock located about the cowl lip.
- Streamline tracing involves defining a compressive, supersonic parent flowfield and tracing streamlines through that flowfield to obtain an external supersonic diffuser.
- Techland Research, Boeing, and NASA explored the streamline-traced external-compression Parametric Inlet for Mach 2.35 (2005).
- The Aerion Corporation has explored the use of streamline-traced external-compression inlets for their Mach 1.6 supersonic business jet.
- Slater (AIAA-2014-3593) provided a methodology designing streamline-traced external-compression (STEX) inlets and compared their performance to traditional two-dimensional and axisymmetric inlets (further details on the next slide).
- NASA is exploring the use of STEX inlets for efficient, low-boom supersonic cruise about Mach 1.6. Potential benefits of STEX inlets:
  - *3D inward isentropic turning reduces cowl drag.*
  - *No centerbody or struts with wakes.*
  - *No corner flows.*
  - *Subsonic spillage and exterior shocks can be "directed" to reduce external disturbances and sonic boom.*
  - *Flexibility of capture shape may improve integration with the aircraft.*



STEX-Circular (AIAA-2014-3593)

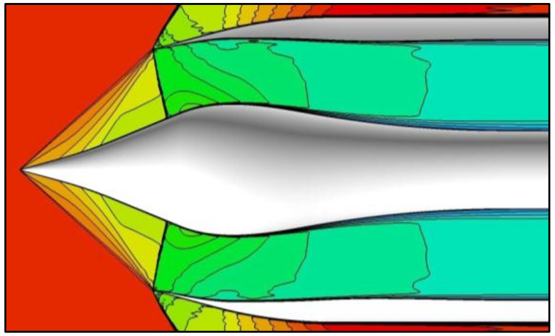


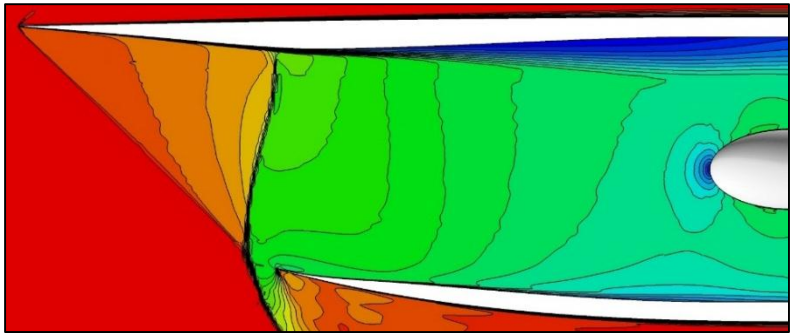
Streamline-Traced Inlet Design Study (AIAA-2014-3593)

- Inlet design conditions are consistent with current interest for commercial supersonic transport aircraft.
- Used SUPIN to design and size the streamline-traced inlets and generate 3D grids for CFD analysis.
- An axisymmetric spike inlet was also designed and analyzed to provide a reference inlet performance.
- Summary of 2014 Study:
  - The STEX inlet was 45% longer and had 25% greater surface area than axisymmetric spike inlet (with no struts), which correlates to inlet weight. Added length and area could be beneficial for acoustic treatment.
  - The STEX inlet had a total pressure recovery of 0.95 with 2.4% spillage at critical condition compared to 0.98 and 0.5% spillage for the axisymmetric spike.
  - The STEX inlet formed a low-momentum region at the top of engine face resulting in higher distortion.
  - The cowl wave drag of the STEX inlet was 16% of that of the axisymmetric spike inlet.
  - External sound pressures of the STEX inlet were “directed” with RMS values 38% of those of spike inlet.

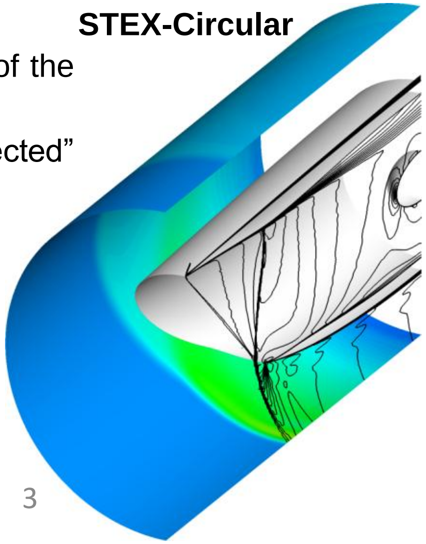
Inlet Design Conditions	
Inflow Mach number, M_L	1.6
Altitude, h_0	40,000 ft
Engine-Face Diameter, D_2	3.0 ft
Engine-Face Mach Number, M_2	0.52

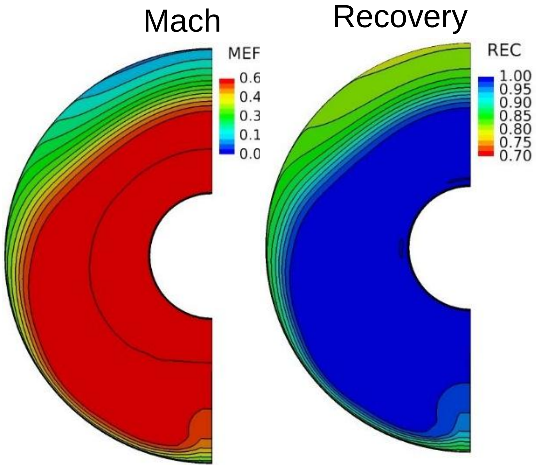
Axisymmetric Spike





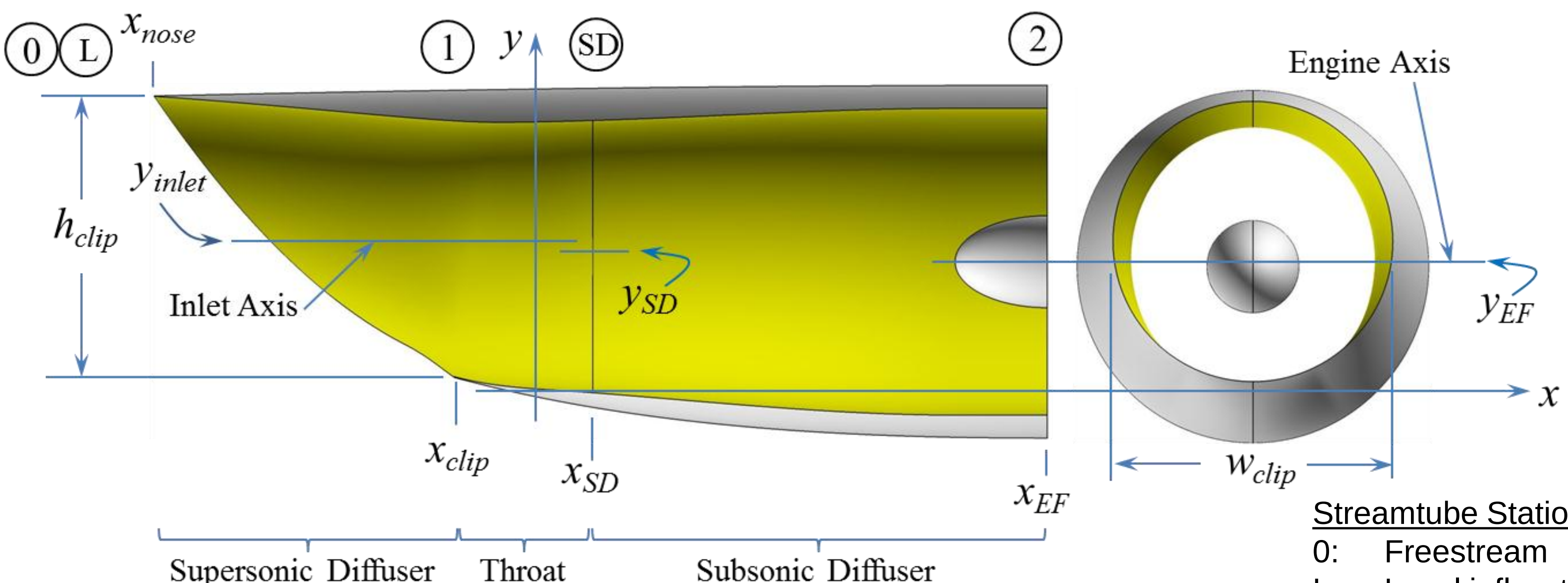
STEX-Circular





Enhancements for the Current Design Study

- The current design study explores four enhancements for STEX inlets with the goal of increasing total pressure recovery and reducing total pressure distortion.
- The four enhancements are:
  1) Switch to a parent flowfield that naturally contains a leading edge oblique shock and a strong oblique terminal shock that results in subsonic outflow.
  2) Explore the design space of varying lengths of subsonic cowl lip displacement "cut-out" and subsonic cowl lip incidence angles.
  3) Explore off-setting the engine face axis with respect to the inlet axis.
  4) Explore the use of porous bleed.

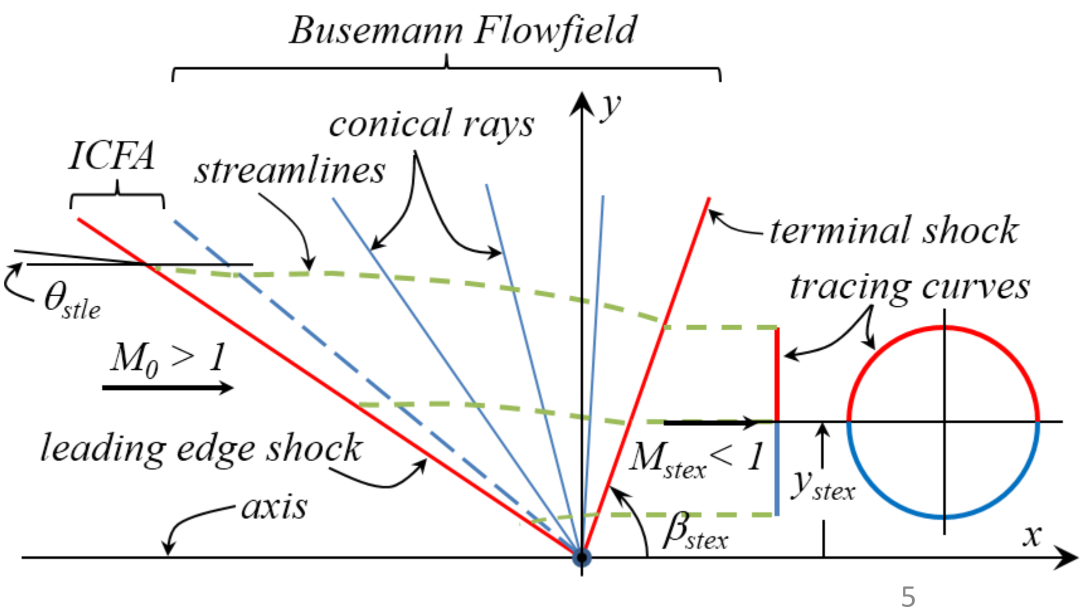


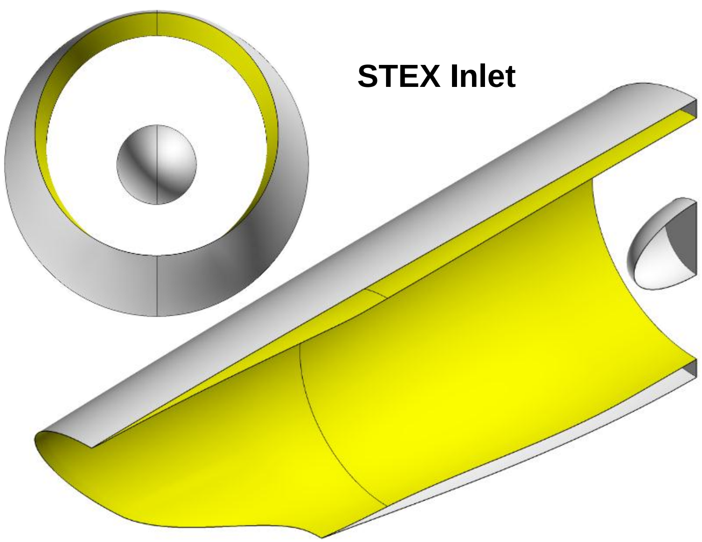
<u>Streamtube Stations</u>

0: Freestream
L: Local inflow to the inlet
1: Cowl lip
SD: Start of subsonic diffuser
2: Engine face

Otto-ICFA-Busemann Parent Flowfield (AIAA-2015-3700)

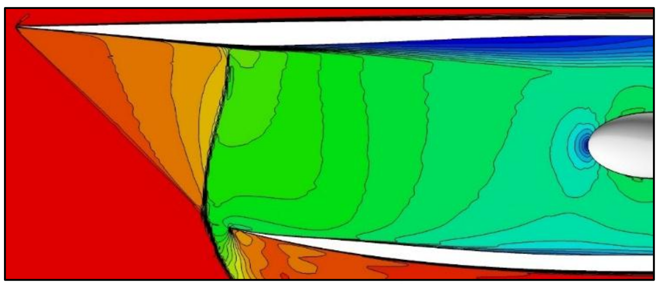
- An improved parent flow field was used that combined an internal conical flow (ICFA) that created a leading-edge oblique shock with an axisymmetric Busemann flowfield that has a strong conical exit shock.
- Specifications are the inflow (M_0), leading edge angle (θ_{stle}), and outflow (M_{stex}) Mach numbers. Inflow is supersonic. Outflow can be subsonic or supersonic.
- A tracing cross-section shape is established using super-ellipses, which allow circular, elliptical, and rectangular shapes through the values of its parameters.
- The tracing cross-section is placed within the outflow of the Busemann flowfield.
- Points on the tracing cross-section are traced upstream along streamlines of the Busemann flowfield.
- Imposing an off-set of the tracing cross-section from the axis of the Busemann flowfield created a leading edge for the inlet that was swept back.
- We use M_0 = 1.6, θ_{stle} = -5.0 degrees, and M_{stex} = 0.90 (for Mach ahead of terminal shock of 1.27).

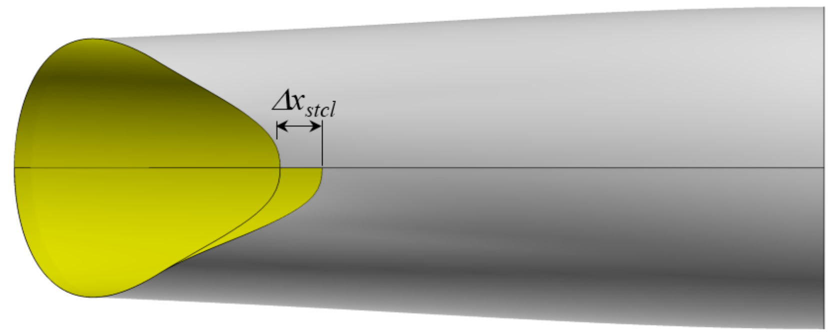


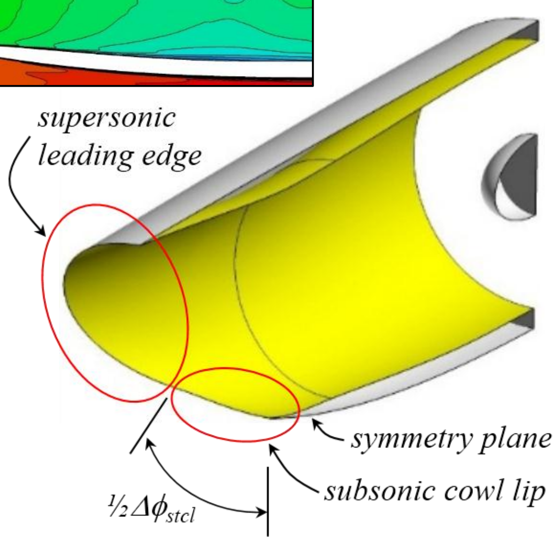


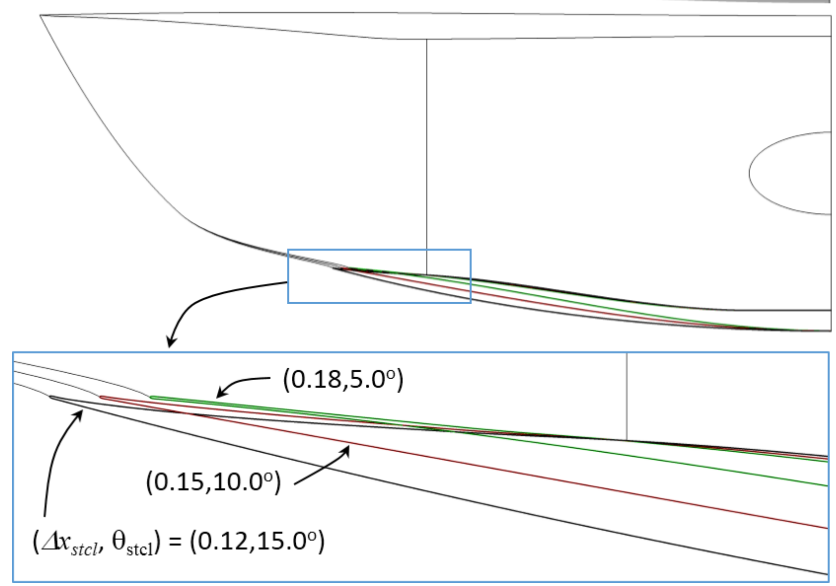
Subsonic Cowl Lip Factors

- The subsonic cowl lip is that portion of the leading edge that encounters the subsonic flow downstream of the terminal shock.
- The subsonic cowl lip is formed by blending a profile at the symmetry plane with the profile of the supersonic leading edge at the bounds of a circumferential span.
- $\Delta\phi_{stcl}$ is the circumferential span ($\Delta\phi_{stcl}$ = 120 deg).
- Δx_{stcl} is the axial displacement and allows for increased subsonic spillage. (Δx_{stcl} = 0.0, 0.12, 0.15, 0.18 normalized by the engine-face diameter).
- θ_{stcl} is the angle-of-incidence. (θ_{stcl} = 0, 5, 10, and 15 deg).





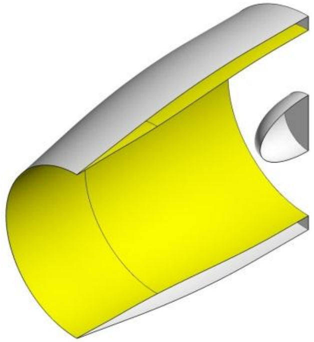




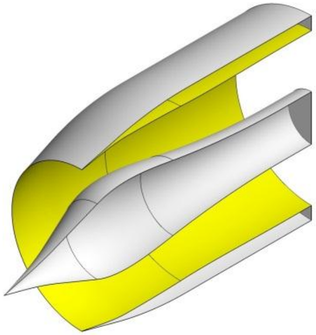
SUPIN Supersonic Inlet Design and Analysis Tool

- SUPIN (SUPersonic INlet design and analysis code) is being developed as a computational tool for supersonic inlet design and analysis.
- Modes of SUPIN usage:
  1) *Generate the inlet geometry from explicit input factors.*
  2) *Perform design operations to size the inlet and compute performance.*
  3) *Perform aerodynamic analysis of a specified inlet geometry (TBD).*
- Guiding ideas for SUPIN:
  - Construct the inlet geometry using design factors (parameters) and simple planar constructs to facilitate inlet design and optimization studies.
  - Ability to estimate inlet performance (flow rates, total pressure recovery, and inlet drag) in a matter of second for propulsion system studies.
  - Consider traditional inlet types (pitot, axisymmetric, 2D), as well as, more advanced inlet concepts (streamline-traced).
  - Create surfaces for visualization and prototyping (Plot3D and STL).
  - Generate CFD surface and volume grids (Plot3D).
  - Keep coding and interfaces simple (Fortran 90).

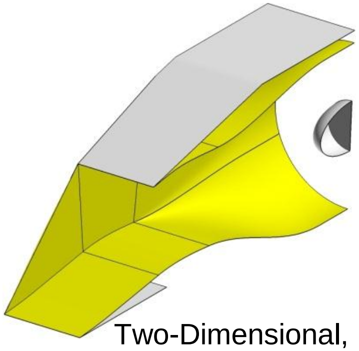
SUPIN is a research code under development, but it is available for Beta testing.



Axisymmetric Pitot Inlet



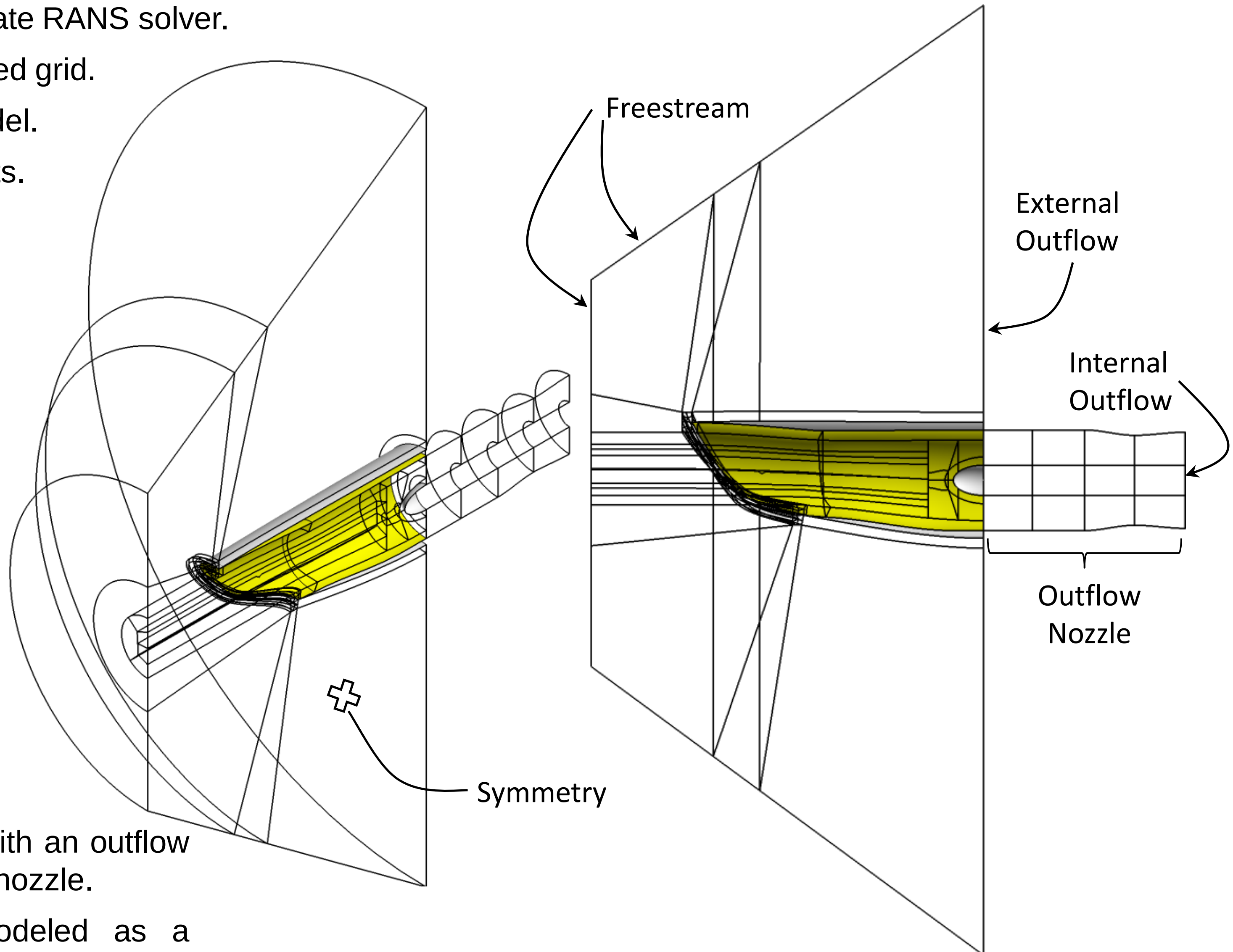
Axisymmetric, Outward-Turning Spike Inlet



Two-Dimensional, Single-Duct Inlet

STEX Inlet CFD Analysis

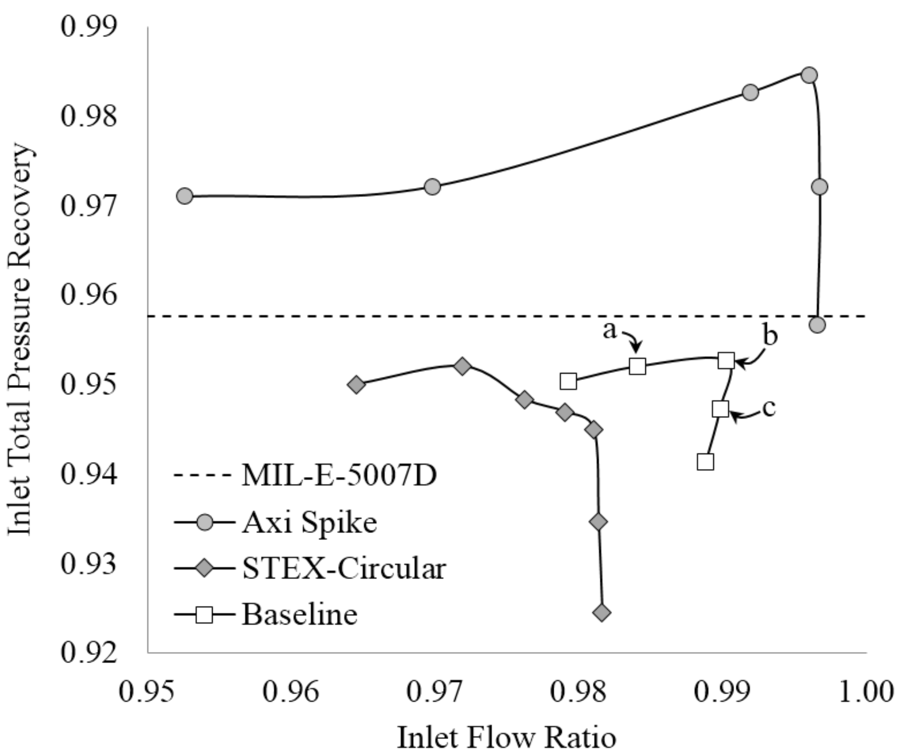
- Wind-US, steady-state RANS solver.
- Multi-block, structured grid.
- SST turbulence model.
- 2-6 million grid points.
- $\Delta y^{+}_{1} \approx 1$ to 2.

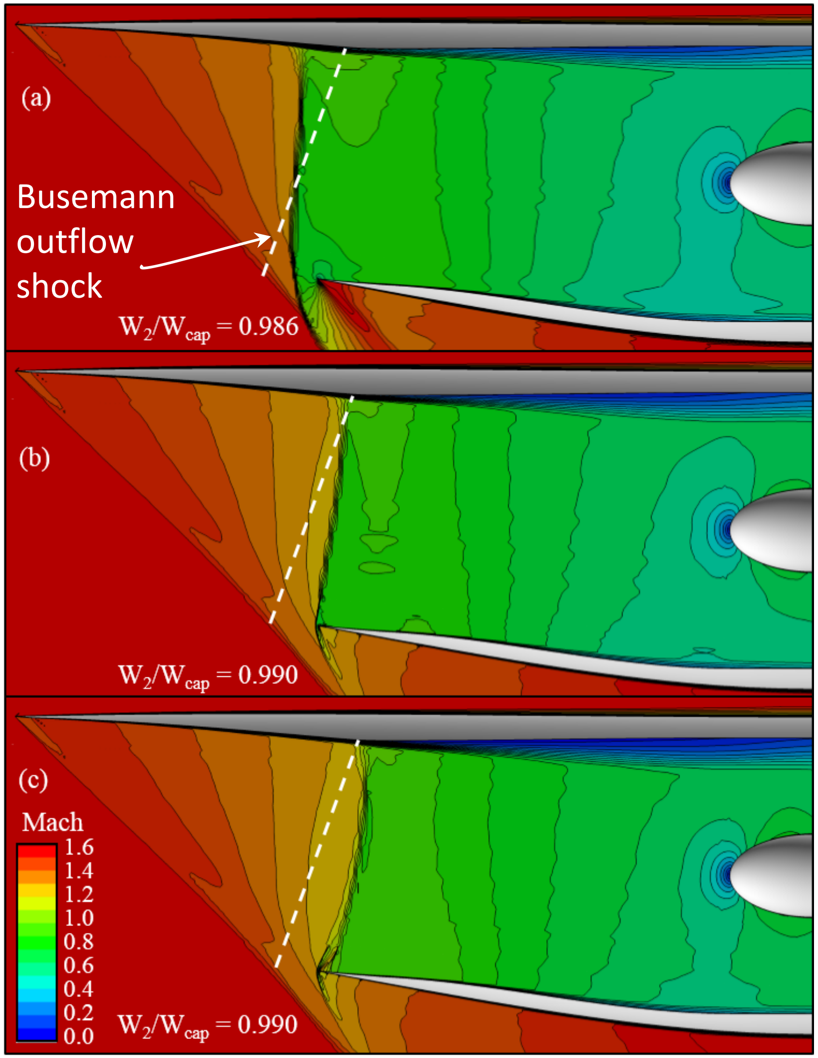


- Outflow is modeled with an outflow converging-diverging nozzle.
- Porous bleed is modeled as a boundary condition over a specified bleed region.

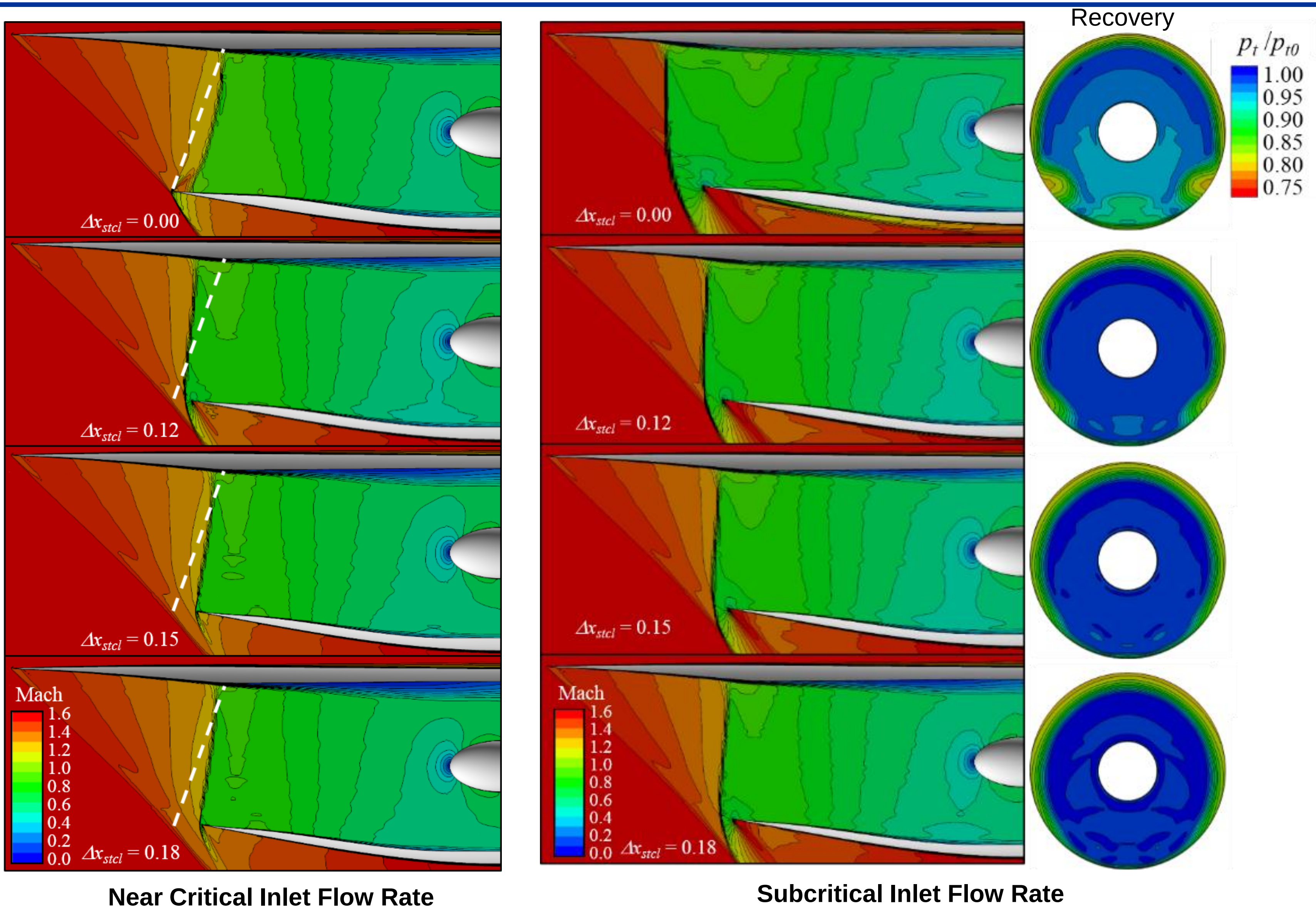
Baseline Inlet

- $(\Delta x_{stcl}, \theta_{stcl}, y_2) = (0.15, 10, 1.05)$.
- Engine face was moved downward until the top of the subsonic diffuser had no streamwise turning.
- Characteristic "cane" curves show total pressure recovery (p_{t2}/p_{tL}) with respect to inlet flow ratio (W_2/W_{cap}).
- Baseline inlet reduces spillage, but recovery is similar to previous STEX-Circular inlet.



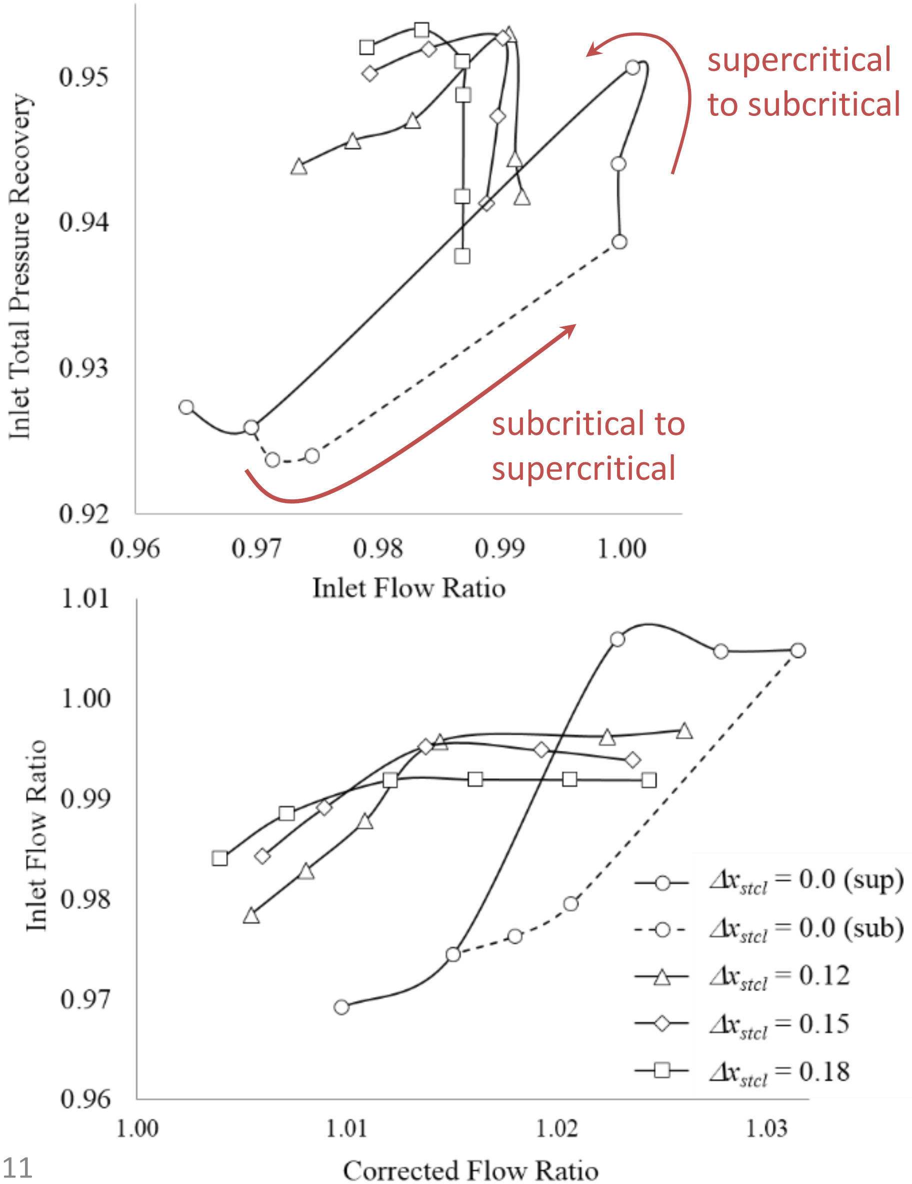


Effects of Cowl Lip Displacement



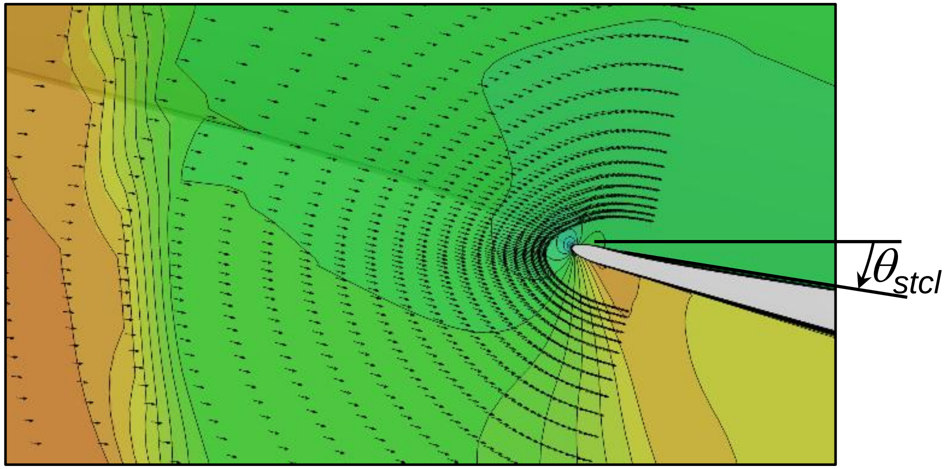
Effects of Cowl Lip Displacement (Δx_{stcl})

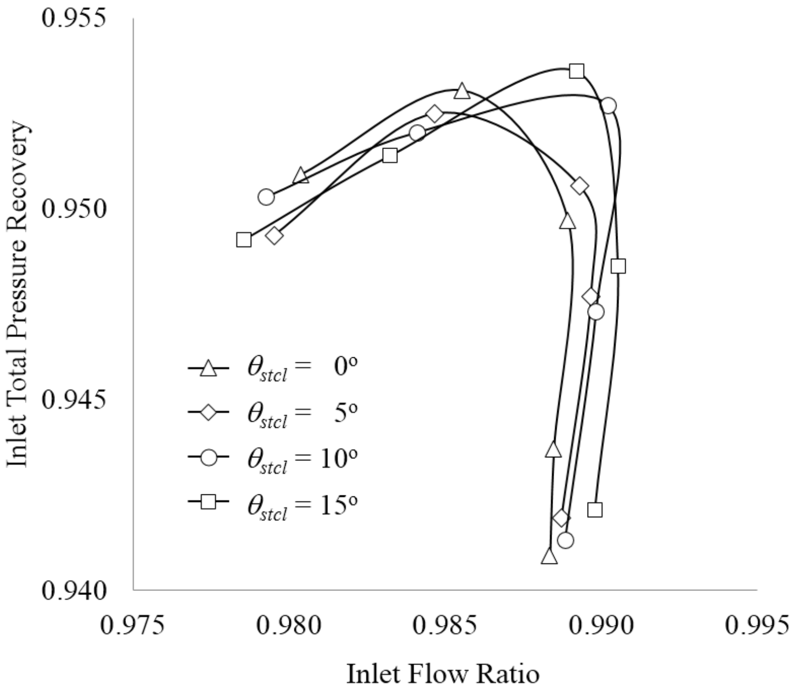
- Greater cowl lip displacement leads to greater supersonic and subsonic spillage.
- Some spillage is acceptable to provide for a smoother characteristic “cane” curve.
- A hysteresis was observed for the case with no cowl lip displacement.
- Cowl lip displacement provides an important spillage mechanism.



Effects of Cowl Lip Angle (θ_{stcl})

- The guiding idea is that cowl lip should be oriented to be inline with local flow angle.
- Higher angles produced a more pronounced "peak" in the characteristic curve.
- Cowl wave drag increased slightly for higher angles due to higher cowl exterior angle.
- Generally, the cowl lip angle did not have a large effect.

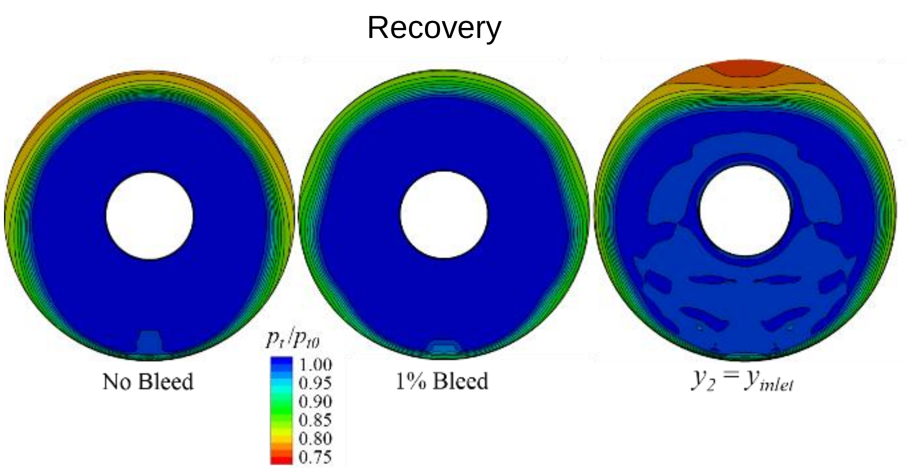


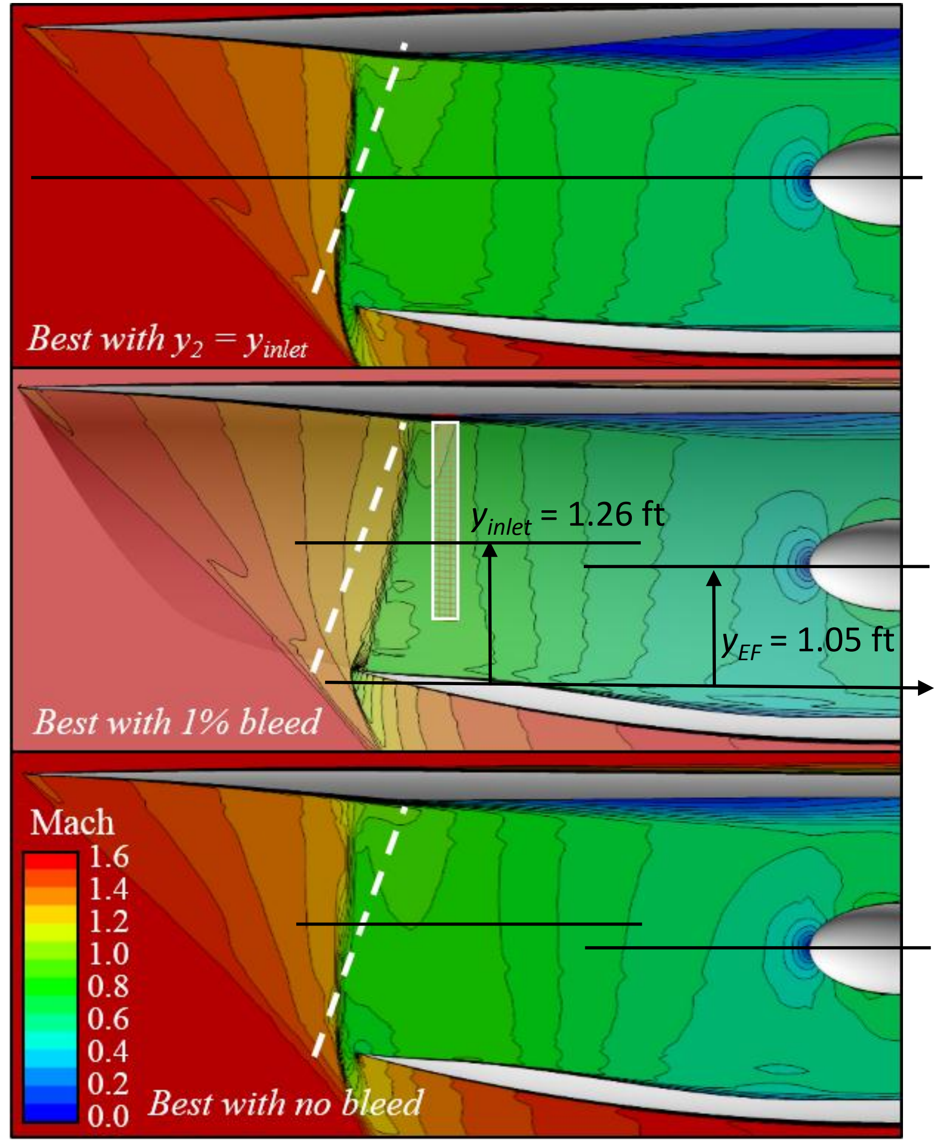


θ_{stcl} (deg)	W_{C2}/W_{C2}^*	p_{t2}/p_{t0}	C_{Dwave}	DIST
0.0	1.0158	0.9497	0.0404	0.2191
5.0	1.0152	0.9506	0.0401	0.2092
10.0	1.0138	0.9527	0.0408	0.1952
15.0	1.0124	0.9536	0.0429	0.1787

Effects of Engine Face Offset and Porous Bleed

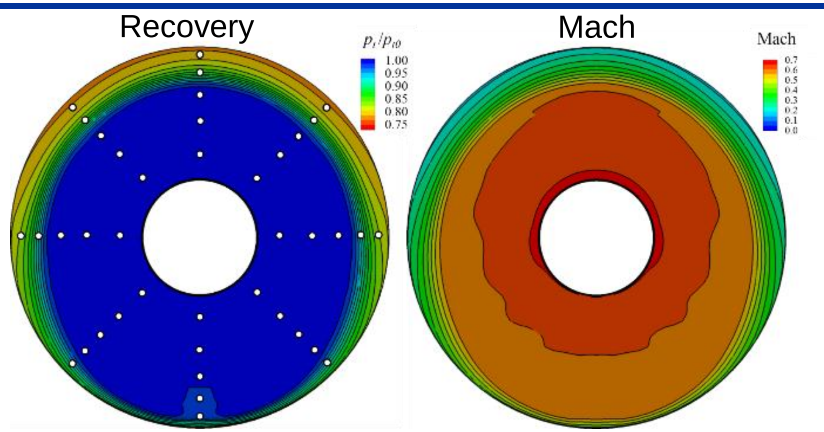
- “Best” configuration used:
  - Δx_{stcl} = 0.15
  - θ_{stcl} = 15 deg
  - y_2 = 1.05 ft
- Placing the engine-face axis collinear with the inlet axis ($y_2 = y_{inlet}$ = 1.262 ft) resulted in an increased growth of lower momentum flow at top of the subsonic diffuser.
- A porous bleed region placed on the top half of the inlet just downstream of the shoulder removed mostly lower-momentum flow.

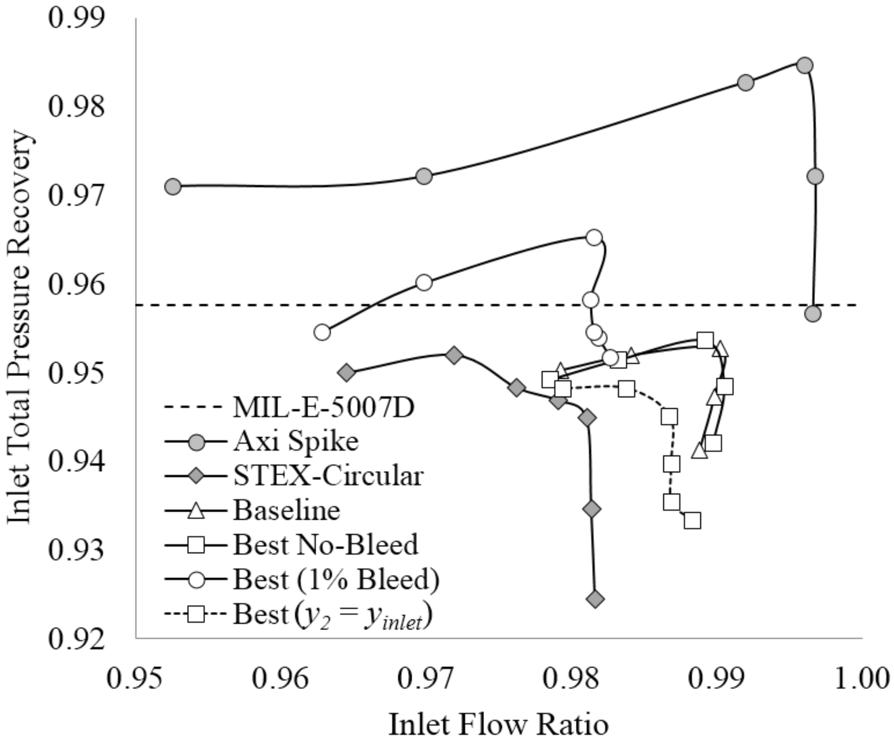


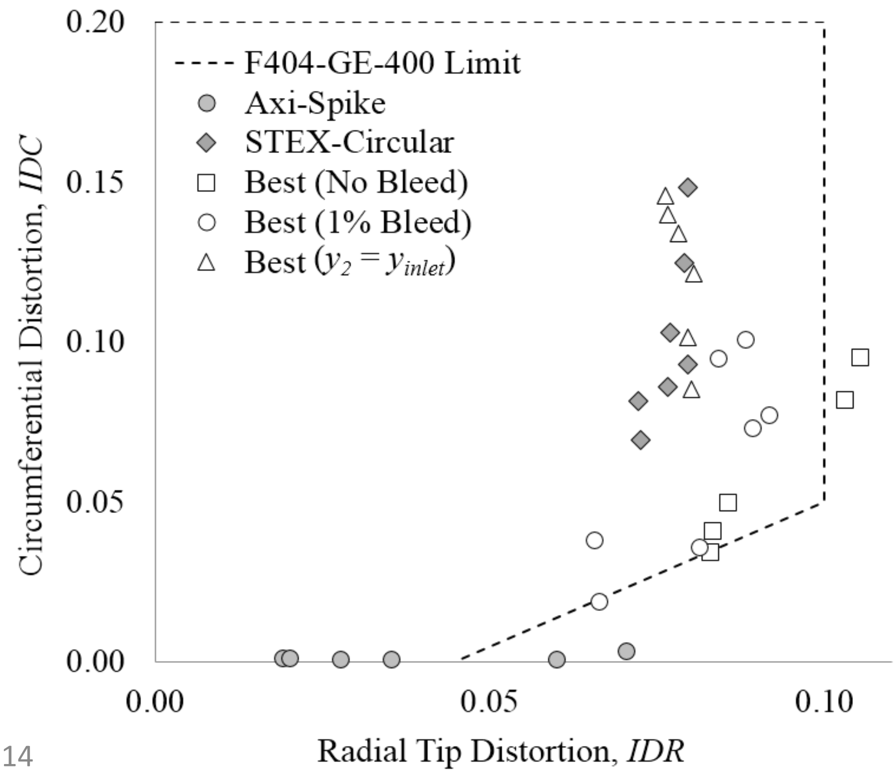


Summary of Inlet Performance

- The characteristic "cane" curves.
- Total pressure distortion descriptors (GE) at the engine face compared to F404-GE-F400 limits.
- ARP 1420 40-probe rake used with probes at centroids of equal areas (white circles on the recovery contour plot).







Summary and Future Plans

Summary:

- The performance of the STEX inlets was enhanced through 1) the use of the ICFA-Otto-Busemann parent flowfield, 2) the proper choices of subsonic cowl lip displacement and engine-face placement, and 3) the use of porous bleed.
- The total pressure recovery was enhanced, but still below that of the axisymmetric spike inlet. However, reduced cowl drag could more than make up the deficit in total pressure recovery.
- The total pressure distortion was demonstrated to be within limits.

Future Plans:

- Continue to explore the influence of various design factors using design-of-experiments (DOE) and optimization methods.
- Perform steady-state and unsteady (DES) CFD analyses of the STEX inlets for on and off-design conditions, including subsonic conditions.
- Explore the integration of STEX inlets onto aircraft configurations. This would include top-mounted inlet configurations.
- Explore sonic boom properties of the installed inlets.
- Explore the use of flow control (bleed, vortex generators, micro-devices) within the inlet to further increase total pressure recovery and decrease distortion.
- Design a wind-tunnel model and perform tests to validate the inlet design.