

Refinement of Supersonic Inlets for Mach 1.4 to 2.0

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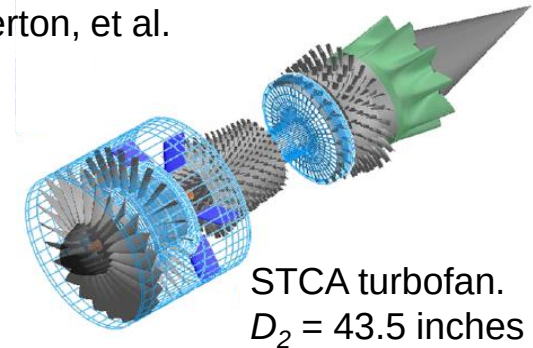
Introduction

- Explore design factors and performance of inlets for commercial supersonic aircraft.
- Mach 1.4, 1.7, and 2.0.
- Set of isolated, external-compression inlets.
- Supersonic Technology Concept Aeroplane (STCA)
 - Mission defines freestream.
 - Concept engine defines engine-face diameter and flow rates.
- Refinement of AIAA-2023-4016.
- Off-design inlet performance.

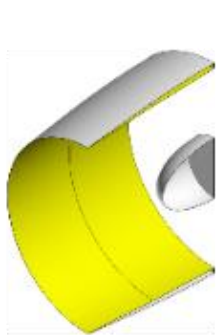


NASA Supersonic Technology
Concept Aeroplane (STCA).
AIAA-2020-0263, Berton, et al.

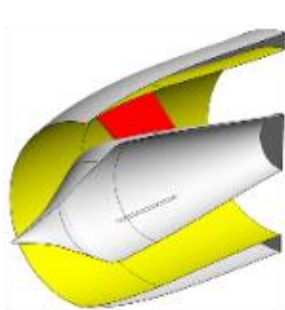
M_0	h_0 (ft)	W_{C2} (lbm/s)	M_2
1.4	50000	413	0.663
1.7	55000	383	0.581
2.0	60000	353	0.514



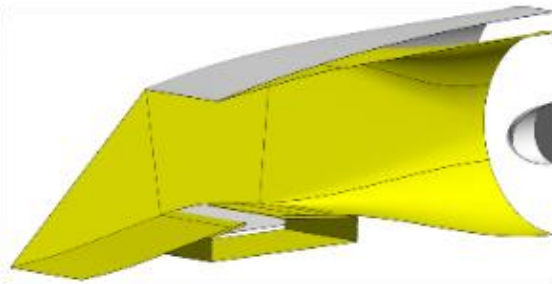
STCA turbofan.
 $D_2 = 43.5$ inches



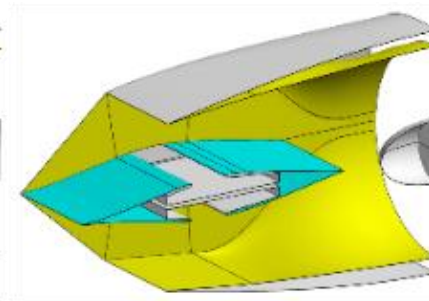
Axisymmetric
Pitot Inlet



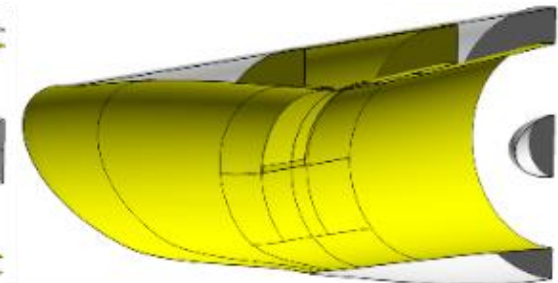
Axisymmetric
Spike Inlet



Two-Dimensional Inlet

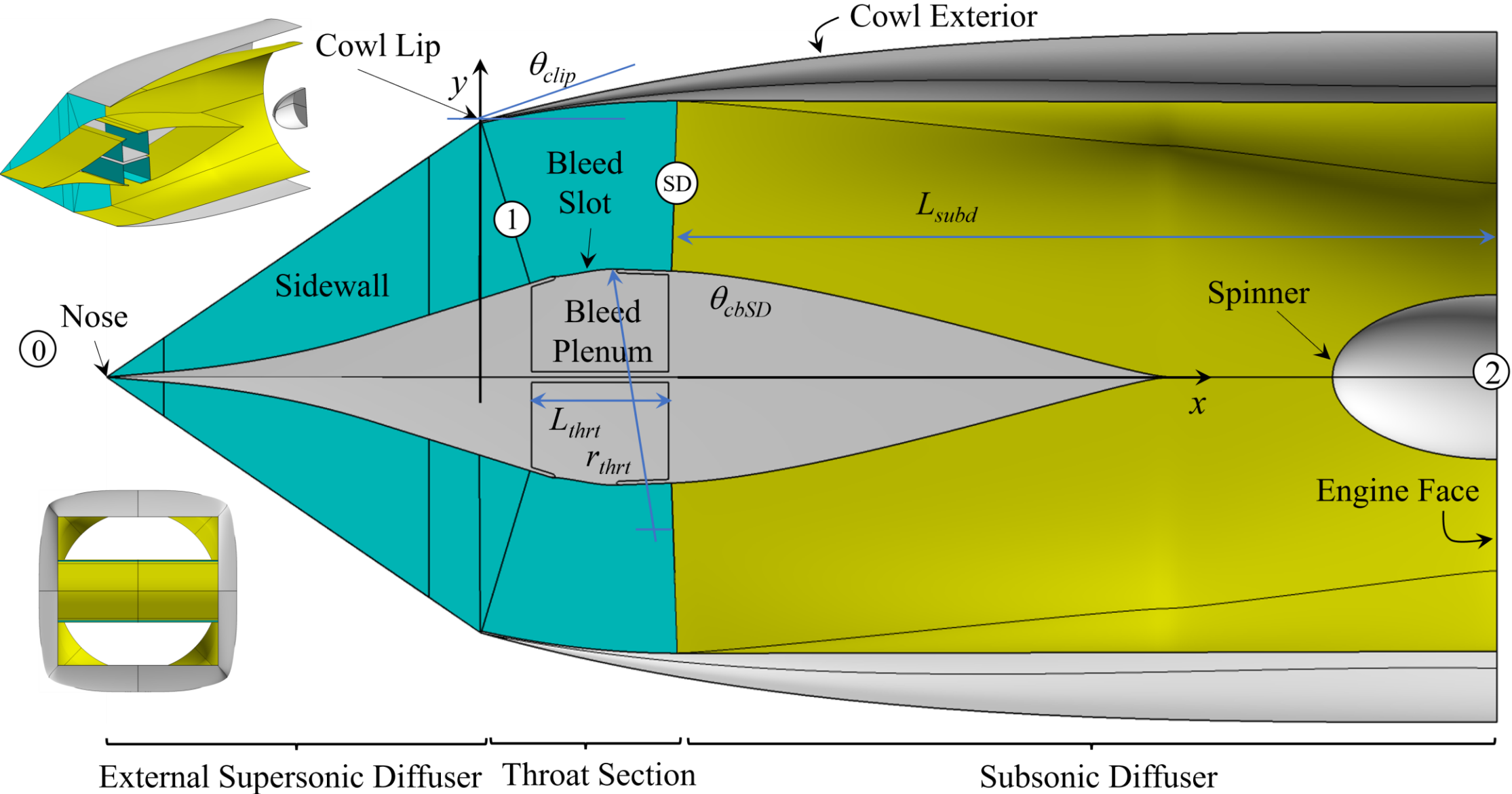


Two-Dimensional
Bifurcated Inlet



Streamline-Traced Inlet

Geometry Model of Two-Dimensional Bifurcated Duct Inlet



Computational Methods

- NASA Supersonic Inlet Design and Analysis (SUPIN) Tool
 - Input consists of geometric and aerodynamic design factors.
 - Uses analytical, empirical, and numerical methods.
 - Computes flow rates, total pressure recovery, and inlet drag.
 - Uses planar constructs to generate inlet surfaces and CFD grids.
 - Available to US persons at the NASA Software Catalog (software.nasa.gov)
- Wind-US Computational Fluid Dynamics (CFD) Solver
 - Uses multi-block, structured grids.
 - Solves the steady-state Reynolds-Averaged Navier Stokes (RANS) equations.
 - On-design simulations involved matching the engine-face corrected flow rate (W_{C2}).

Inlet Performance Metrics

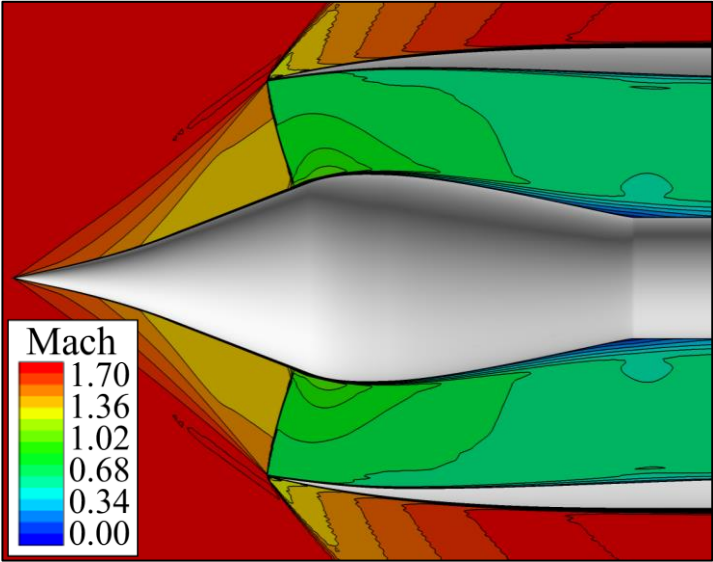
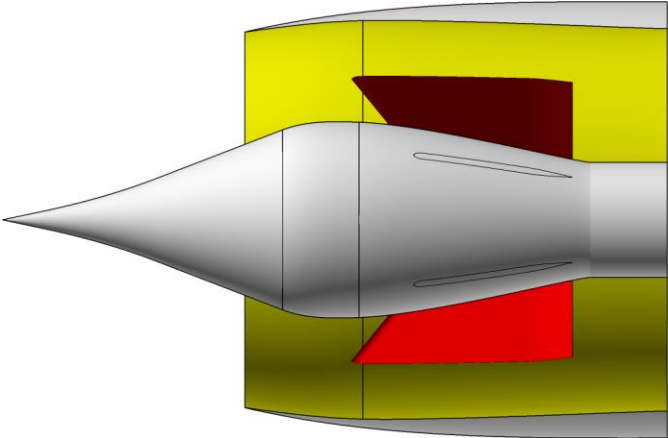
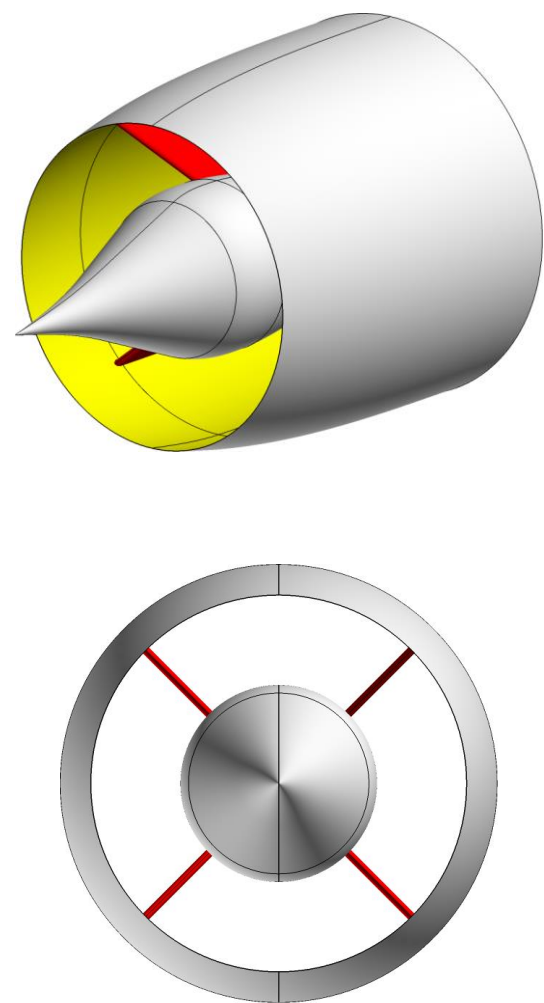
- Flow rates: $W_{spillage}/W_{cap}$ W_{bleed}/W_{cap} W_2/W_{cap}
- Engine-face total pressure recovery (p_{t2}/p_{t0}). Establish the “cane” curves.
- Inlet wave drag (C_{Dwave})
- Engine-face total pressure distortion
 - Interpolate CFD solution onto a 40-probe rake
 - SAE ARP 1420 methods. Radial (DPR/P) and circumferential (DPC/P) indices.
- Combine influence of metrics through estimation of effect on aircraft range:

$$\Delta R = \Delta R_R + \Delta R_D + \Delta R_B + \Delta R_W$$

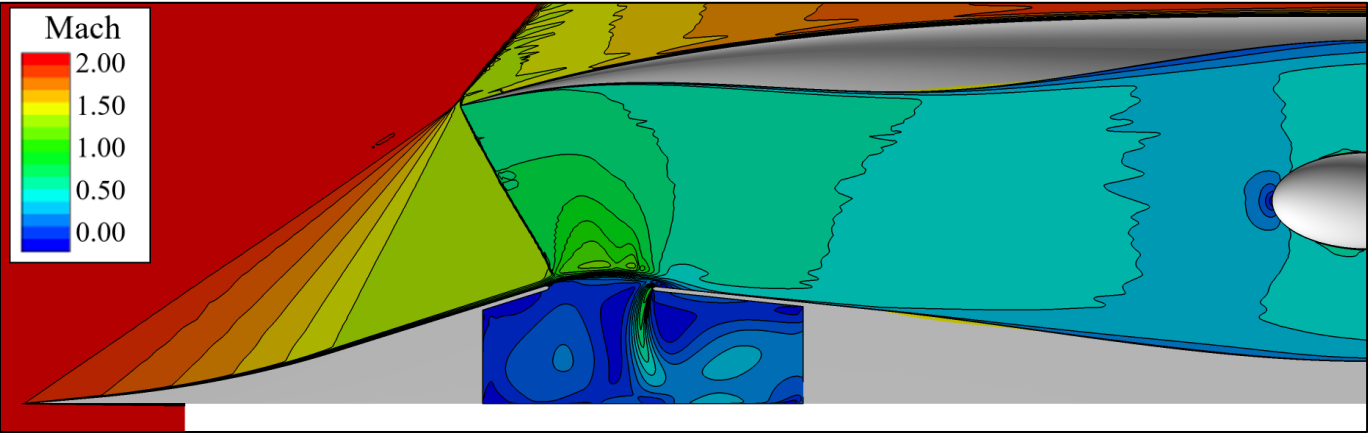
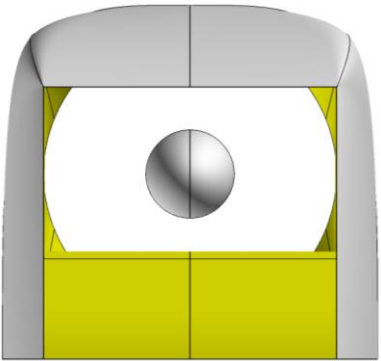
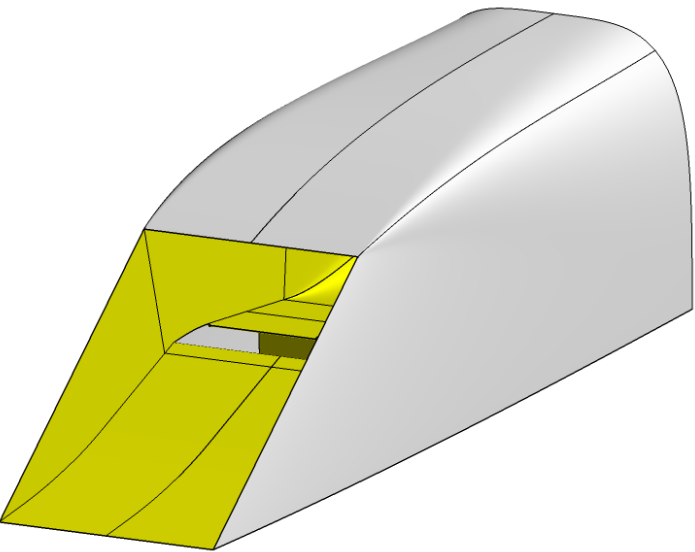
	p_{t2}/p_{t0}	C_{Dwave}	W_{bleed}/W_{cap}	<i>Weight</i>
Metric Δ	-0.01	0.01	0.01	0.10
Range Δ	-32	-41	-23	-17
LBSS	0.9470	0.0930	0.0	16.64

Based on 1970s Mach 2.5 aircraft with a turbojet engine.

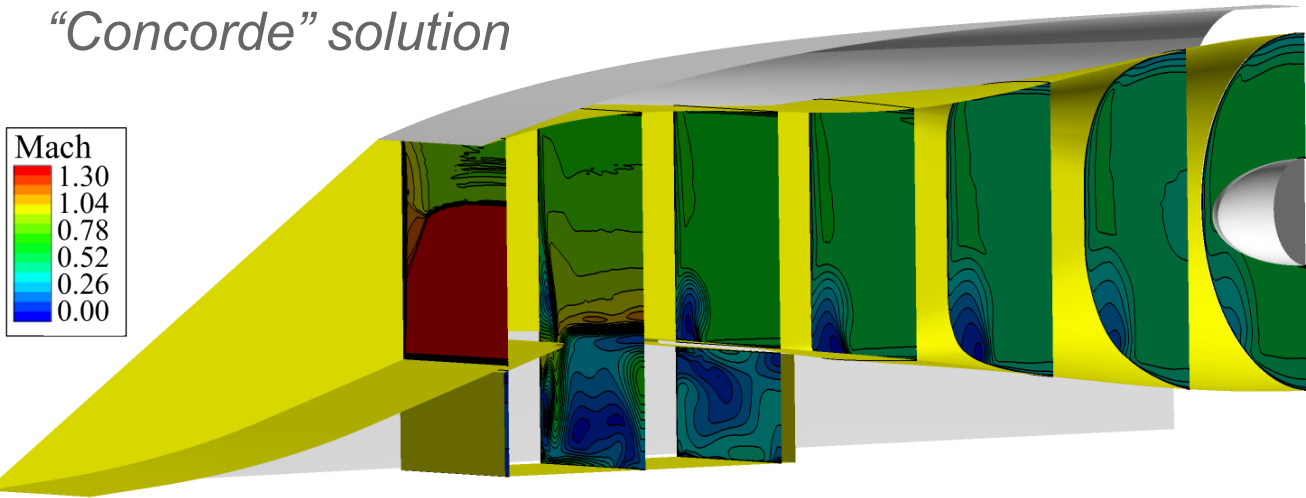
Mach 1.7 Axisymmetric Spike Inlet



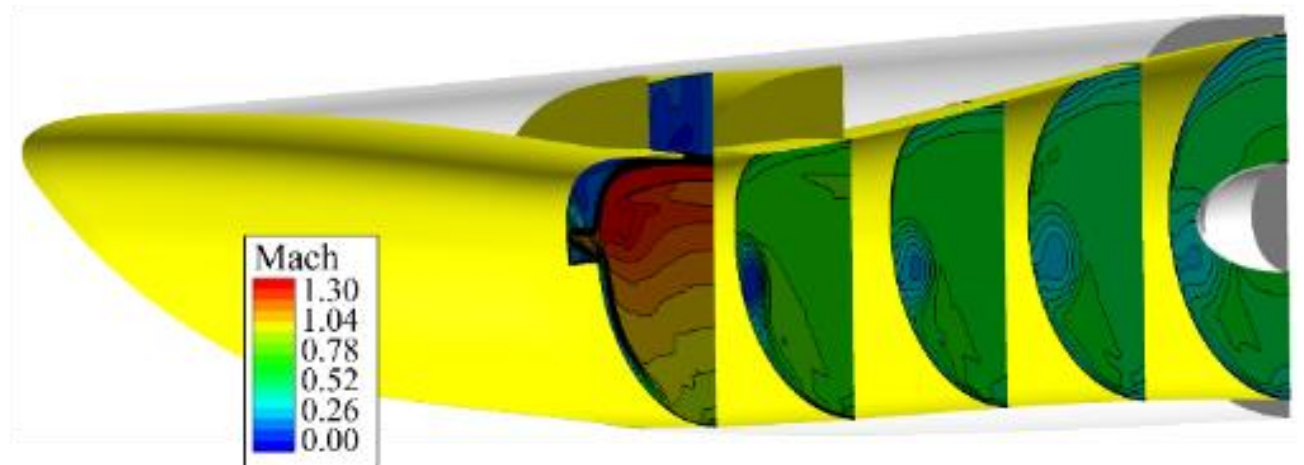
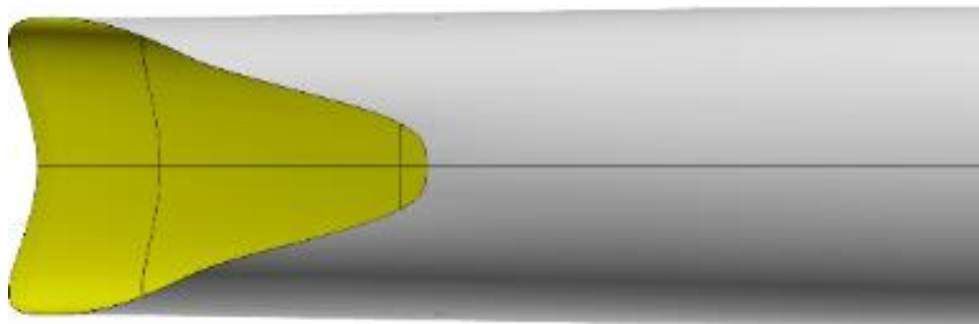
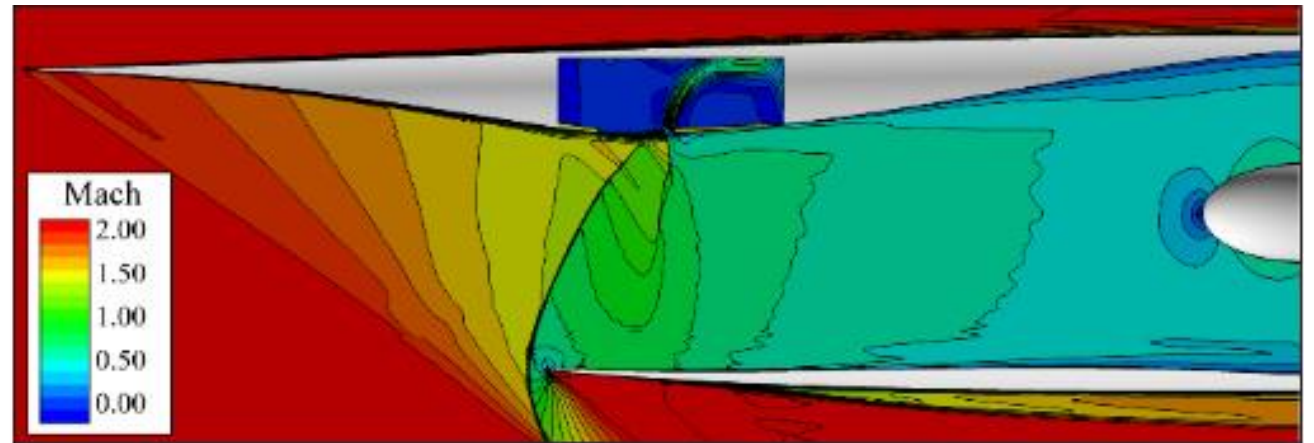
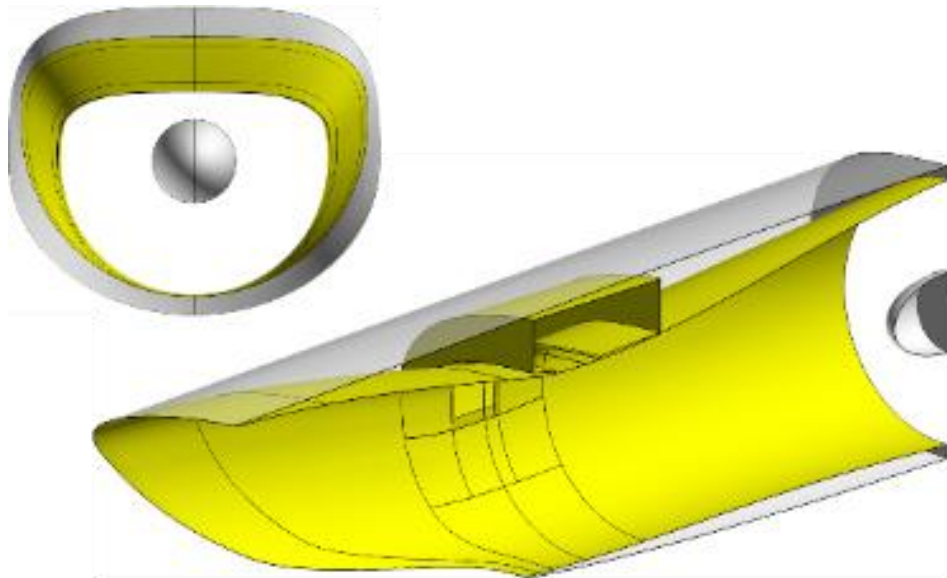
Mach 2.0 Two-Dimensional Inlet



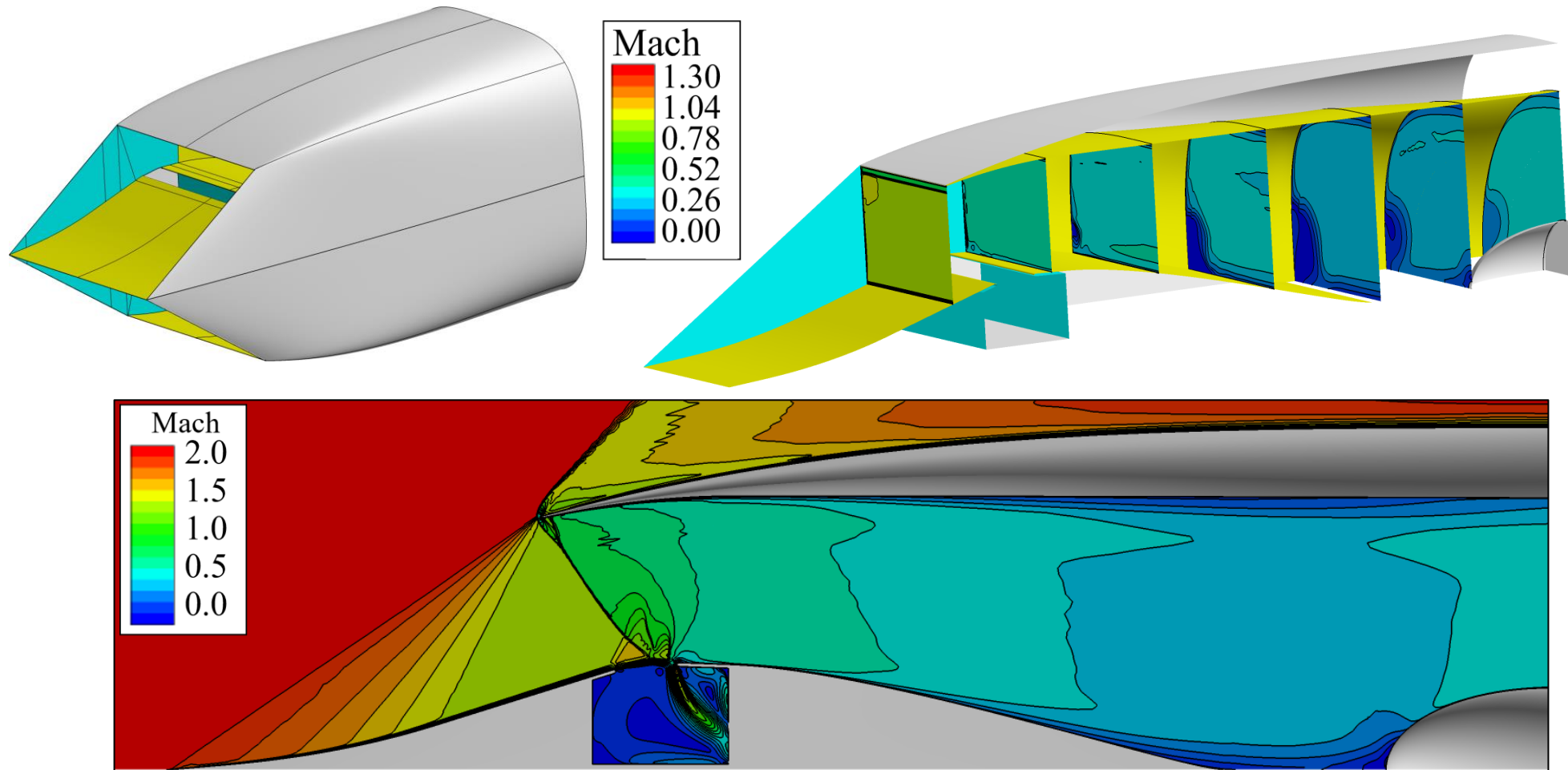
"Concorde" solution



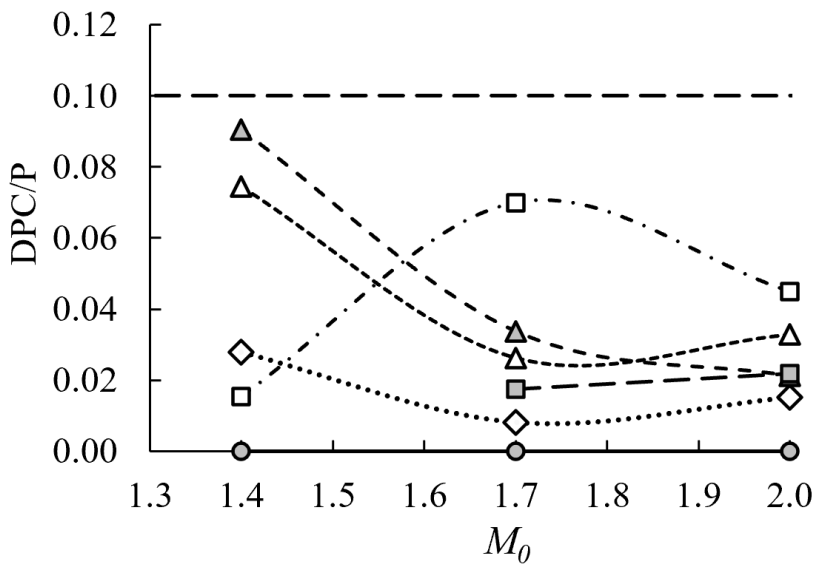
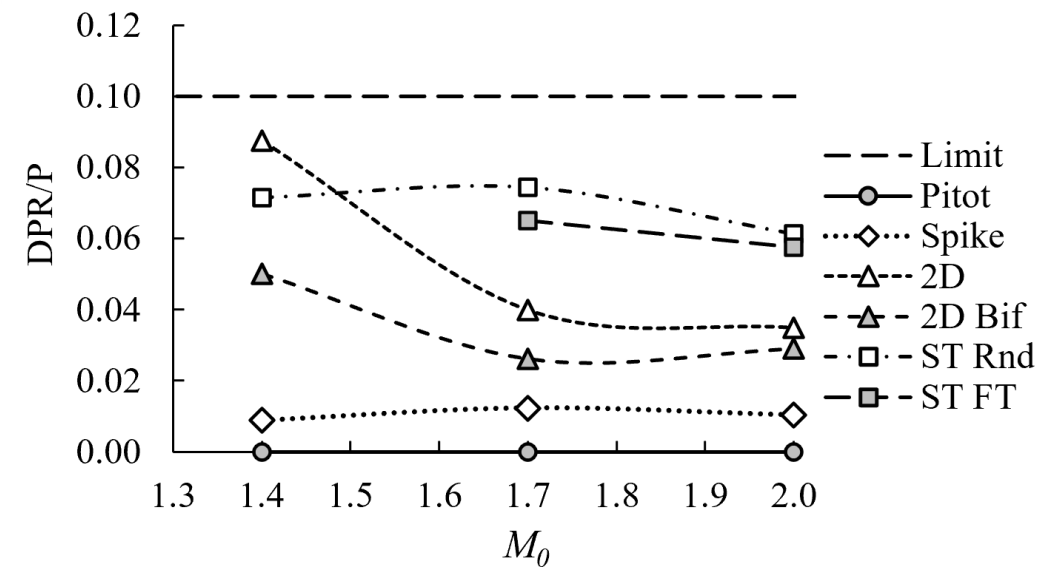
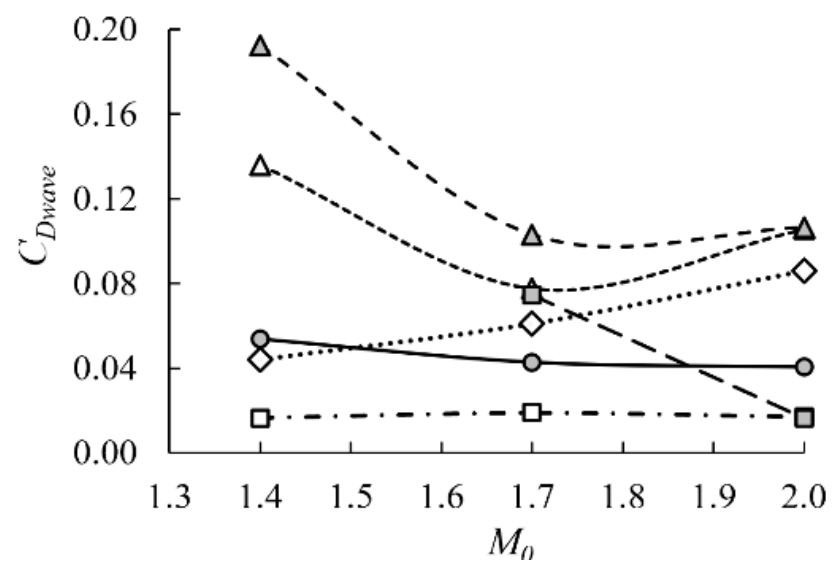
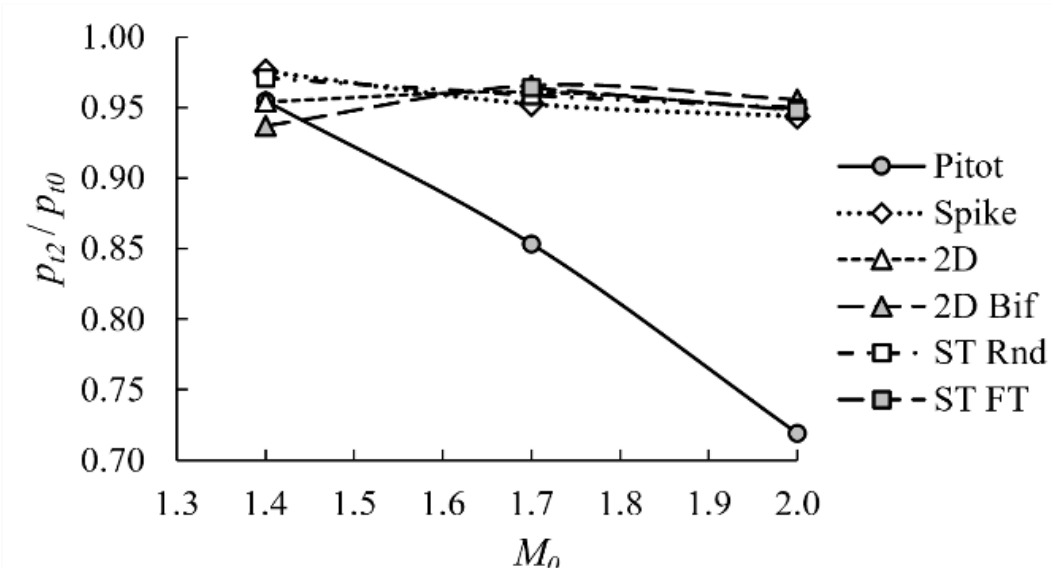
Mach 2.0 “Flattop” Streamline-Traced Inlet



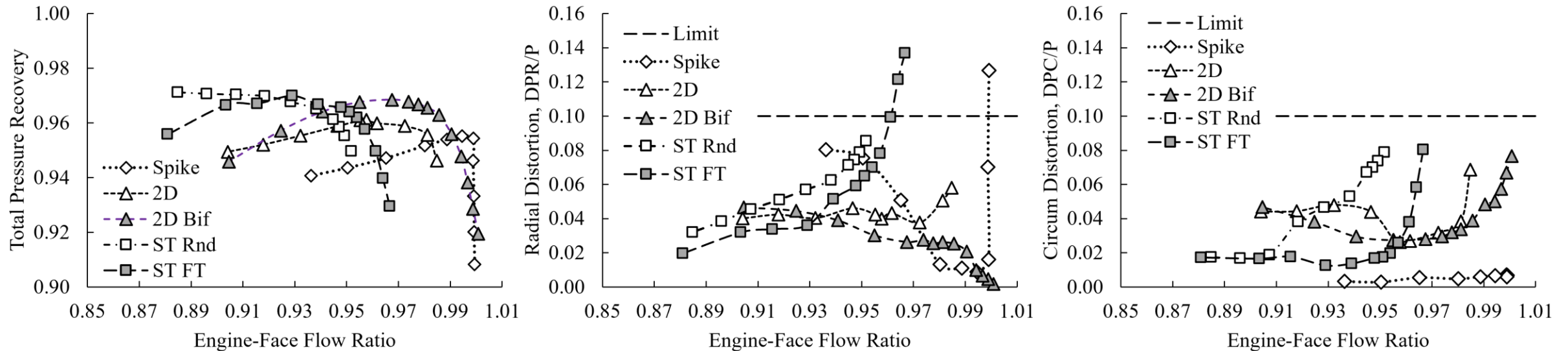
Mach 2.0 Two-Dimensional Bifurcated-Duct Inlet



On-Design Inlet Performance

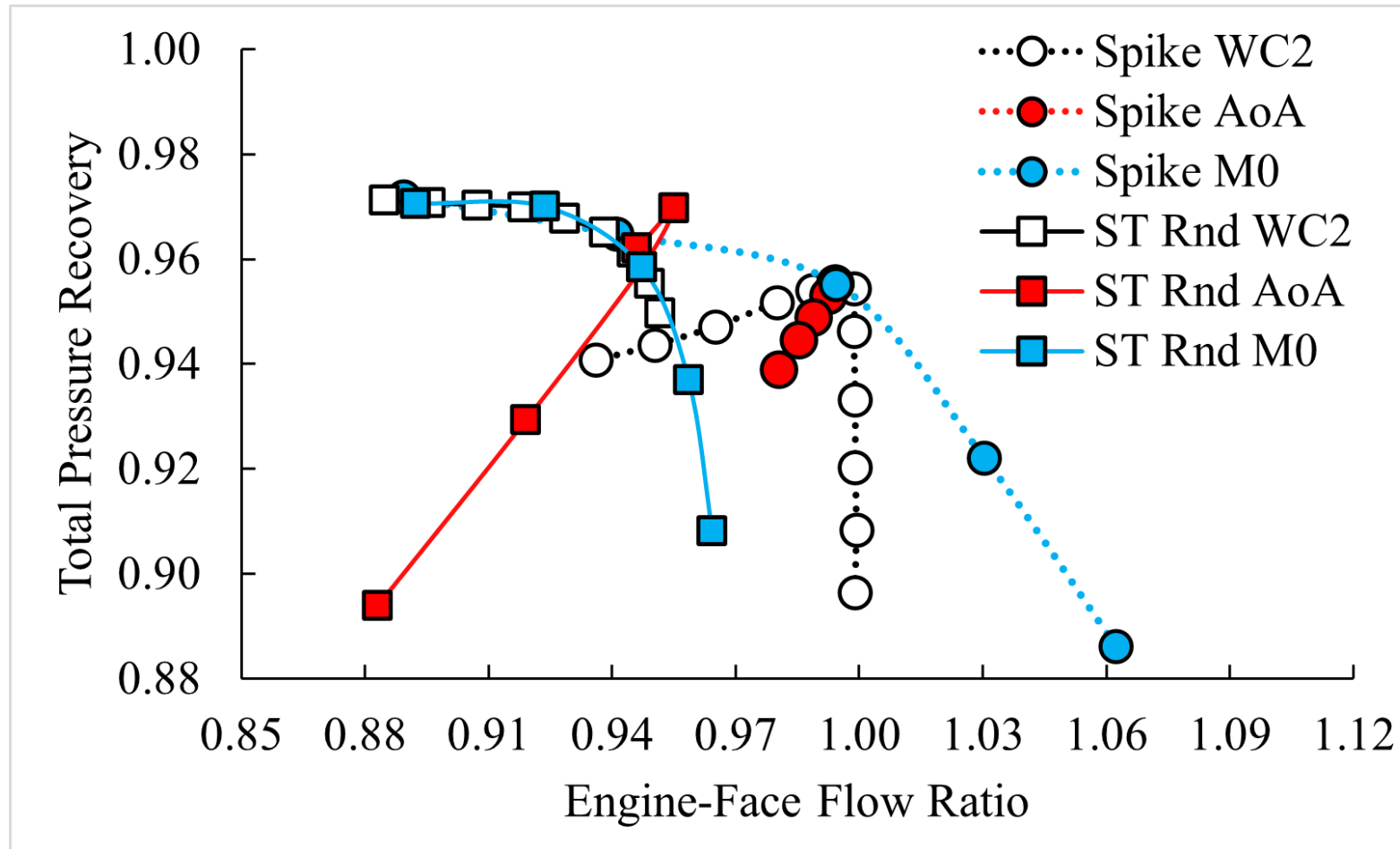


Inlet Performance with Inlet Flow Ratio for Mach 1.7



- Characteristic “Cane” Curves
- Variations in inlet flow ratios reflect bleed and spillage.
- Similar “roll-off” of recovery for inlets, except for the round streamline-traced inlet.
- Acceptable distortion, except for some radial distortion at supercritical conditions.

Variation in Freestream Mach (M_o) and Angle-of-Attack (α_o)



- Streamline-traced inlet shows greater angle-of-attack variation than the axisymmetric spike inlet.
- Shielding of inlets by a wing or fuselage would limit variations due to angle-of-attack.

Range Increments for the Inlets at On-Design Condition

M_o	Type	ΔR_R	ΔR_D	ΔR_B	ΔR_W	ΔR
1.4	<u>Axi-Pitot</u>	25	166	0	108	299
	<u>Axi-Spike</u>	103	196	0	96	396
	2D	23	-234	0	-18	-229
	2D-Bif	-32	-458	0	-32	-523
	ST Round	76	322	0	-37	361
1.7	<u>Axi-Pitot</u>	-300	206	0	108	14
	<u>Axi-Spike</u>	41	127	0	21	189
	2D	-29	54	-72	-60	-106
	2D-Bif	79	-41	-31	-72	-65
	ST Round	37	235	-69	-99	103
	ST Flattop	54	260	-52	-146	116
2.0	<u>Axi-Pitot</u>	-730	209	0	108	-413
	<u>Axi-Spike</u>	-10	-20	0	10	-20
	2D	5	-49	-115	-150	-309
	2D-Bif	27	-55	-104	-99	-231
	ST Round	8	305	-115	-132	65
	ST Flattop	2	361	-111	-176	76

Lower drag really helps.

2D-Bif is an improvement over 2D inlet.

Larger and heavier inlets get penalized.

Conclusions

- Similar levels of total pressure recovery are likely regardless of inlet type.
- Total pressure distortion seems manageable.
- Streamline-traced inlets offer low wave drag but are larger and heavier.
- Shielding would be recommended for streamline-traced inlets and 2D inlets to limit adverse angle-of-attack variations.
- For Mach 1.4 and 1.7, axisymmetric spike inlets seem to be the best choice.
- For Mach 2.0, streamline-traced inlets become more favorable.
- For Mach 2.0, a strong terminal shock and bleed are recommended for 2D and streamline-traced inlets (Concorde solution).

