Off-Design Analysis of Axisymmetric External-Compression Supersonic Inlets for Mach 1.4 to 2.0

John W. Slater
NASA Glenn Research Center
Cleveland, Ohio, USA

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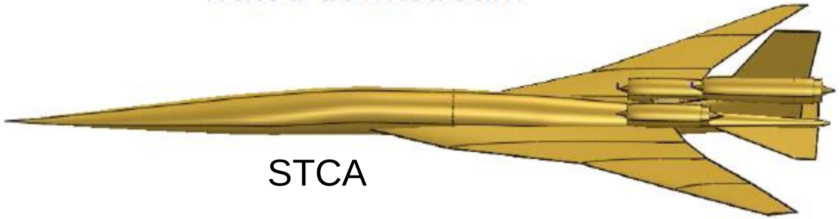
Introduction

Commercial supersonic flight for Mach 1.4 to 2.0

Requires an efficient propulsion system

Focus is on the design and analysis of the inlet

- Flow conditions approaching the inlet
- Dimensions and flow rate at the engine face



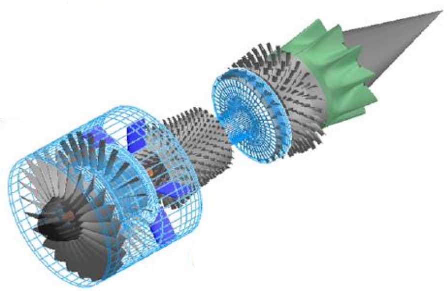
STCA

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

Consider axisymmetric spike inlets isolated from the aircraft

Examine off-design performance of the inlets including low-speed conditions involving an auxiliary intake.

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

Model of the Axisymmetric Spike Inlet

Geometry model with multiple geometric and aerodynamic design factors.

One to three stages for the external supersonic diffuser.

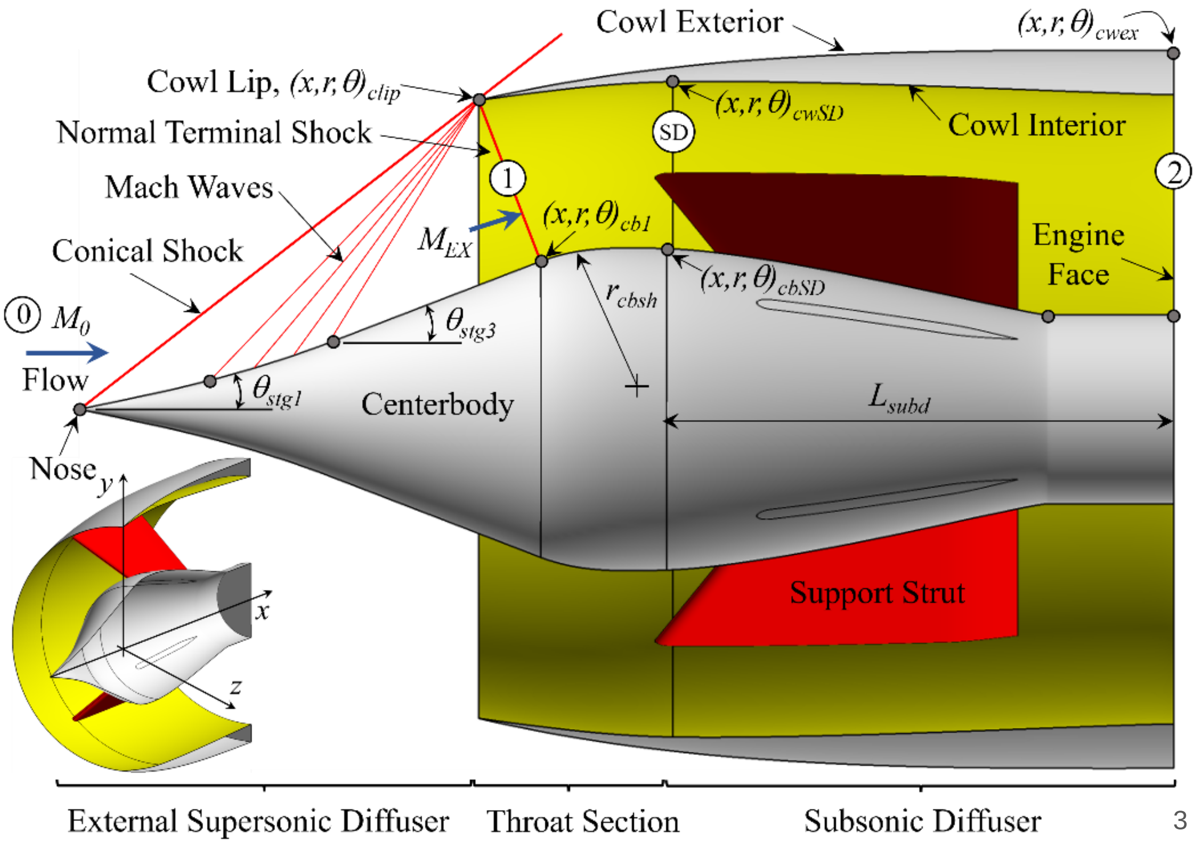
Cowl lip aligned with flow.

Linear Mach number diffusion through the internal ducting.

Four support struts.

Key factors: M_{EX}, r_{cbsh}, L_{subd}

NASA Supersonic Inlet Design and Analysis (SUPIN) Tool.



Computational Methods

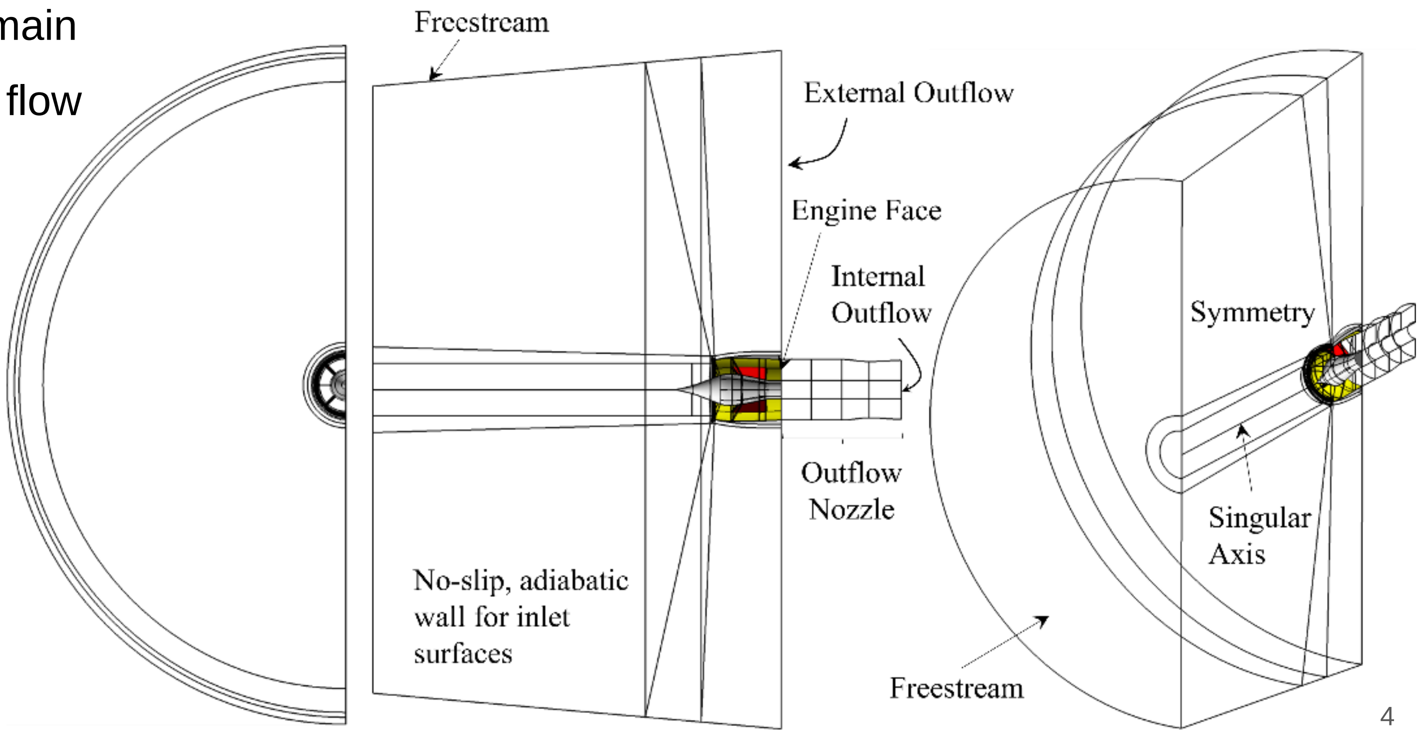
Isolated axisymmetric spike inlet

Half of inlet for flow domain

Outflow nozzle for inlet flow

Wind-US CFD Solver

- Multiple blocks
- Structured grids
- Steady RANS
- SST turbulence



Inlet Performance

Inlet Performance Metrics

- Inlet flow ratio, W_2/W_{cap}
- Total pressure recovery, p_{t2}/p_{t0}
- Cowl wave drag, C_{Dwave}
- Size and weight of inlet, S_{inlet}/A_{cap}
- Total pressure engine-face distortion (SAE 1420) indices, DPR/P and DPC/P

Optimization of inlets considers effect of inlet performance metrics on the aircraft range:

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

Table 2. Effect of inlet performance metrics on aircraft range.

	p_{t2}/p_{t0}	C_{Dwave}	*Weight*
Metric Δ	-0.01	0.01	0.10
Range Δ	-32	-41	-17
LBSS	0.9470	0.0930	16.64

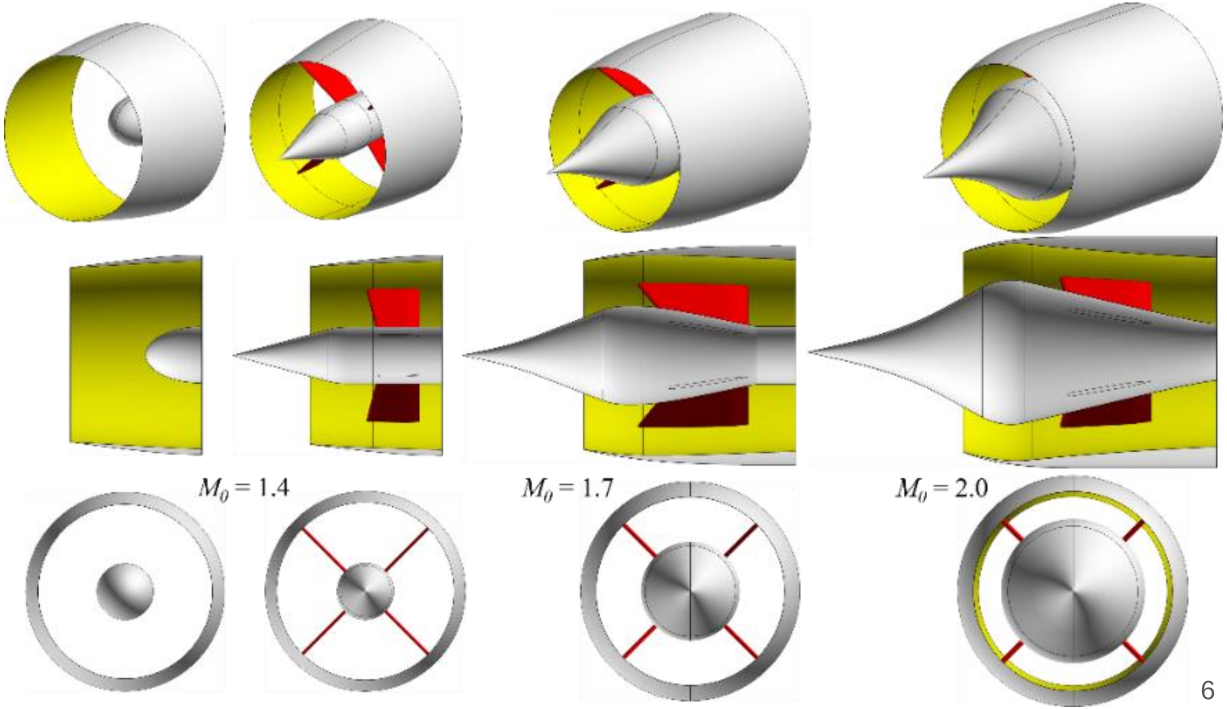
[10] D N Bowditch, R E Coltrin, B W Sanders, N E Sorensen, and J. F. Wasserbauer, "Supersonic Cruise Inlets," *Aircraft Propulsion*, NASA SP-259, November 1970.

Optimized Inlets

Used design-of-experiments (DOE) and response surface modeling (RSM) to statistically analyze variations in the design factors (M_{EX}, r_{cbsh}, L_{subd}) and arrive at “optimized” inlets.

Added axisymmetric pitot inlet for reference.

Higher Mach required greater turning and length.



Critical Flow Solution for Inlets at Design Mach

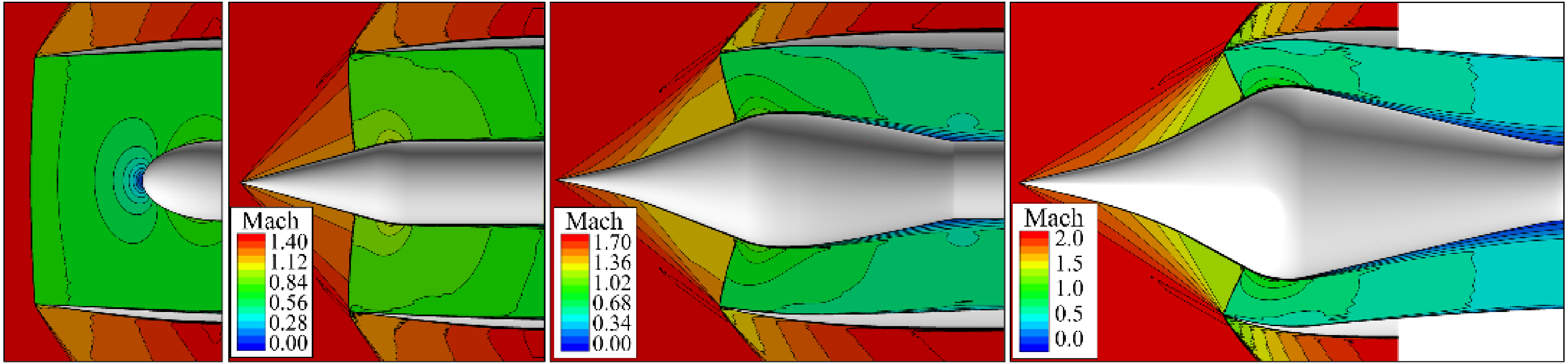
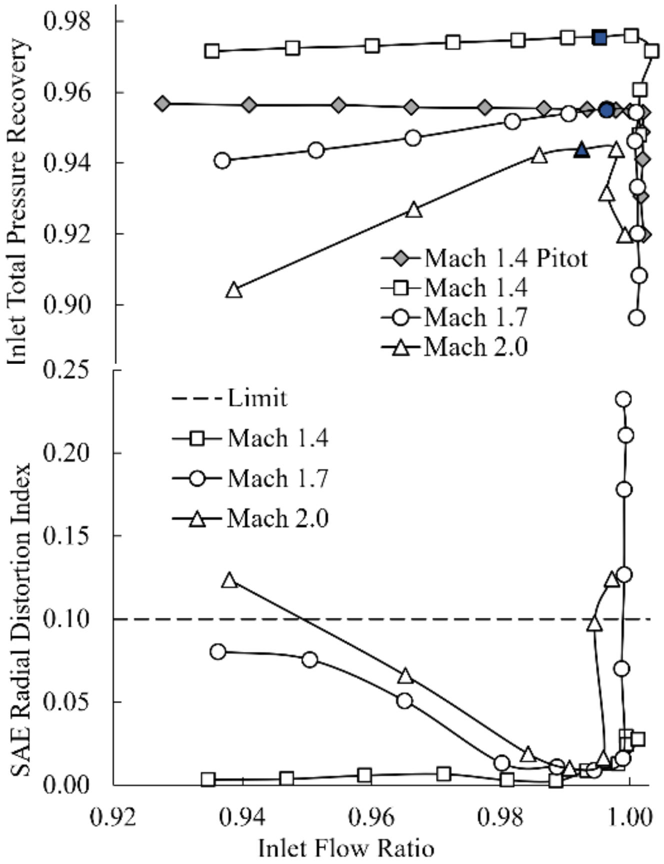
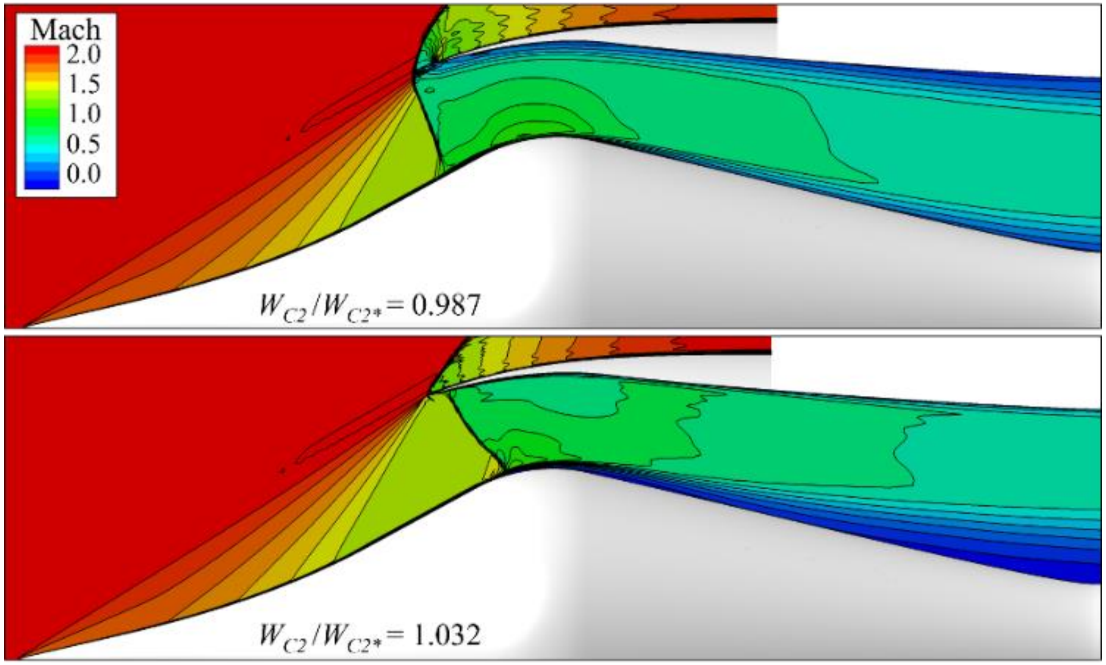


Table 5. Performance metrics for the inlets at the cruise design condition.

M_0	ft²	SUPIN				Mil	CFD			
	A_{cap}	W_2/W_{cap}	M_2	C_{Dwave}	p_{t2}/p_{t0}	p_{t2}/p_{t0}	W_2/W_{cap}	M_2	C_{Dwave}	p_{t2}/p_{t0}
1.4	9.15	1.000	0.667	0.0442	0.979	0.973	0.993	0.667	0.0451	0.976
1.7	9.96	1.000	0.582	0.0611	0.960	0.949	0.995	0.584	0.0630	0.955
2.0	11.47	1.000	0.509	0.0859	0.958	0.920	0.991	0.518	0.0978	0.944

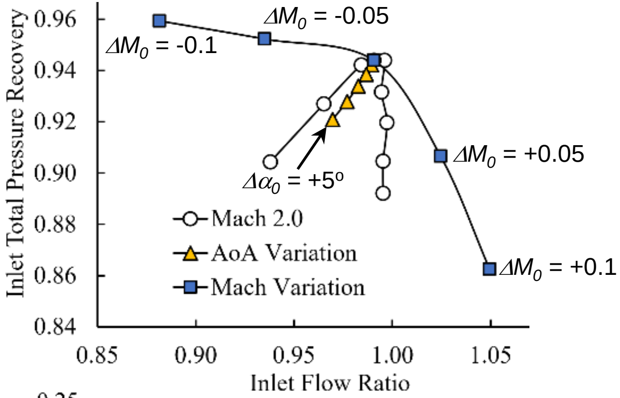
Variation in Inlet Flow Ratios at Design Mach

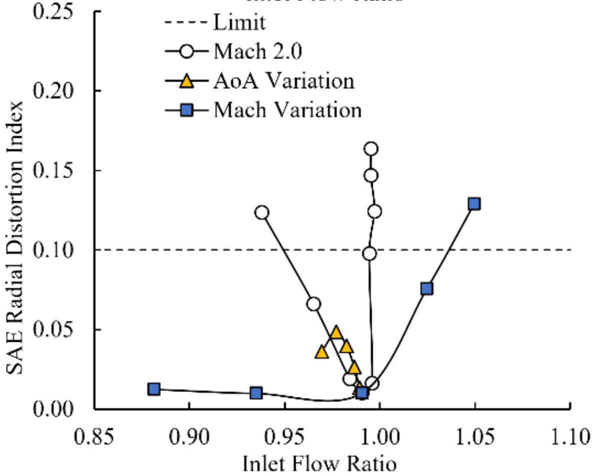




M_0 = 2.0 Inlet

Variation of Mach and Angle-of-Attack





M_0 = 2.0 Inlet

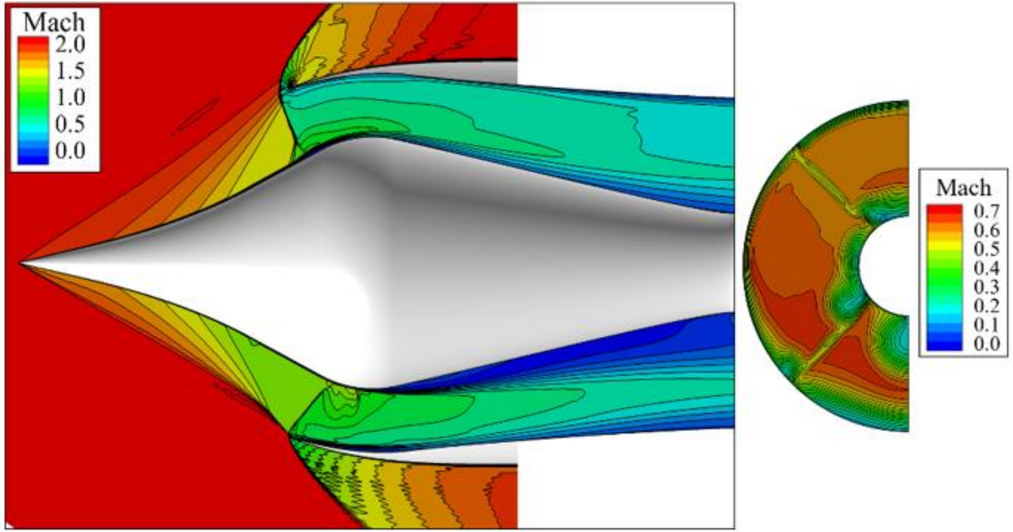
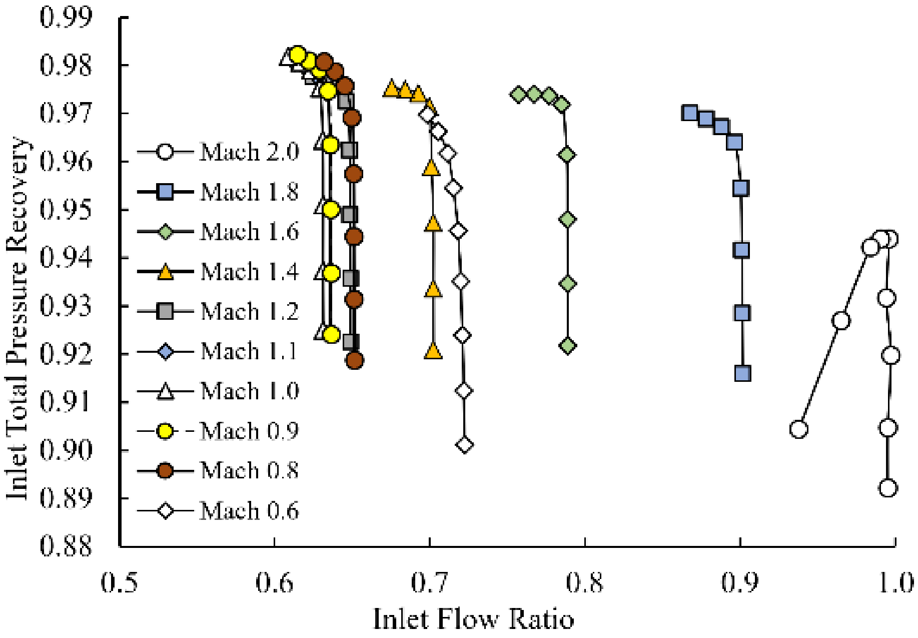


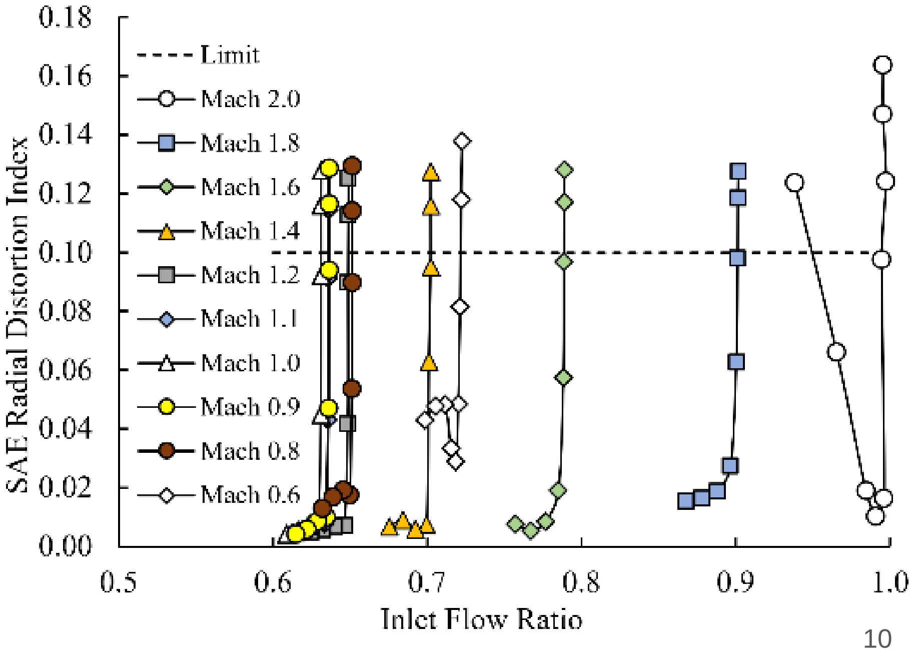
Figure 15. Mach number contours on the symmetry plane (left) and engine-face (right) from a CFD simulation of the Mach 2.0 inlet at the M_0 = 2.0 cruise conditions and at an angle-of-attack of α_0 = 5 degrees.

Characteristic Curves over the Mach Range

Inlet performance maps for engine cycle analysis

M_0 = 2.0 Inlet





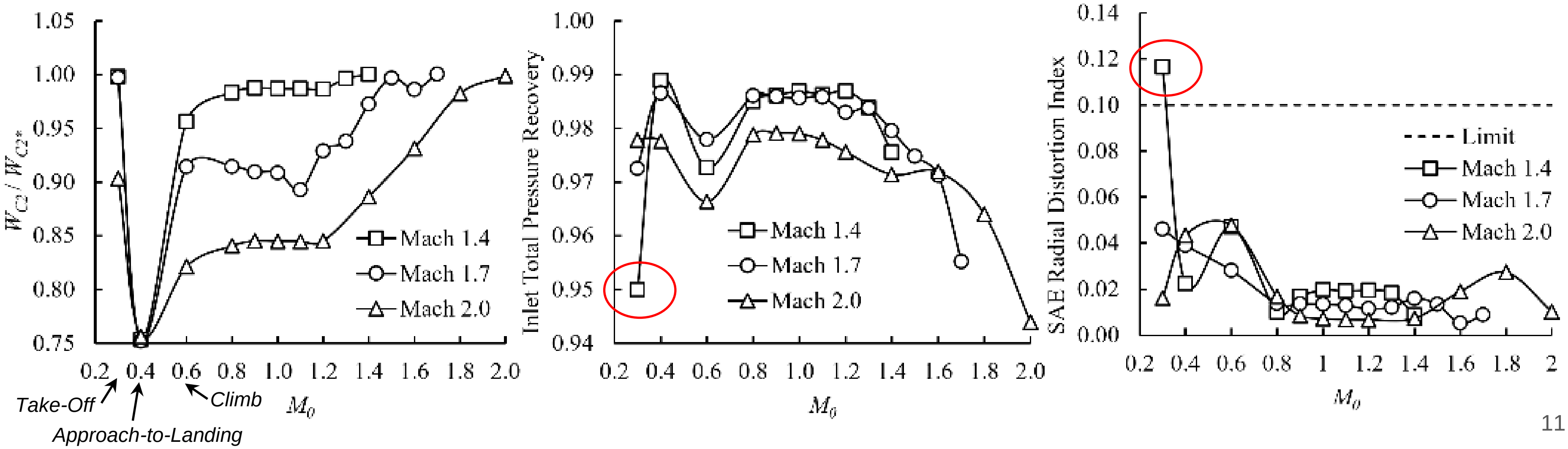
Inlet Operating Points over the Mach Range

Consider desired operating point at each Mach number

Flow “pinch-point” at transonic conditions

Lower throttle at $M_0 = 0.4$ approach-to-landing condition

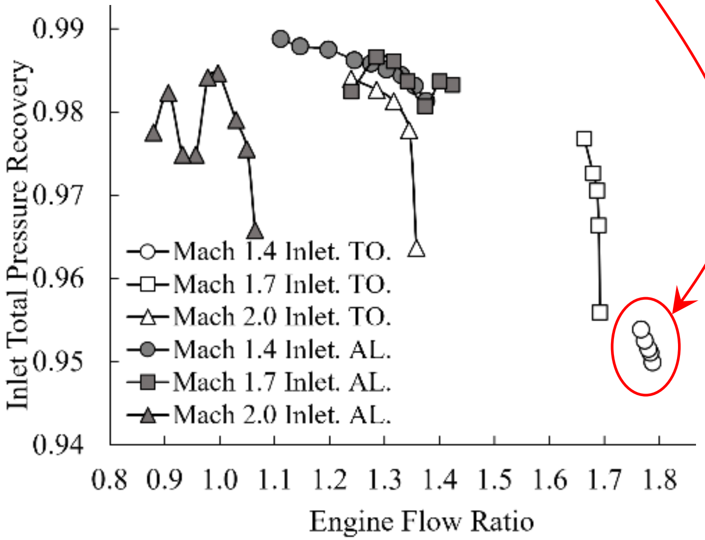
Distortion is low across Mach range



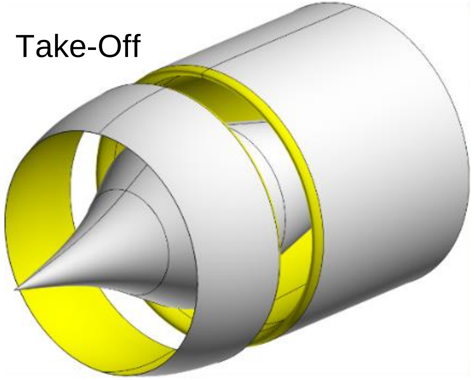
Analyses with Auxiliary Intake

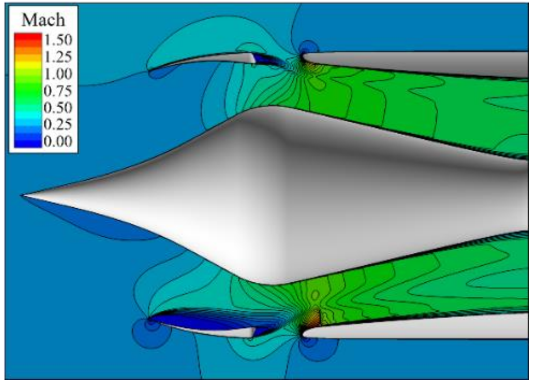
Auxiliary intakes created through the forward translation of the forward portion of the cowl.

Low recovery and excessive distortion for M_0 = 1.4 inlet at take-off.



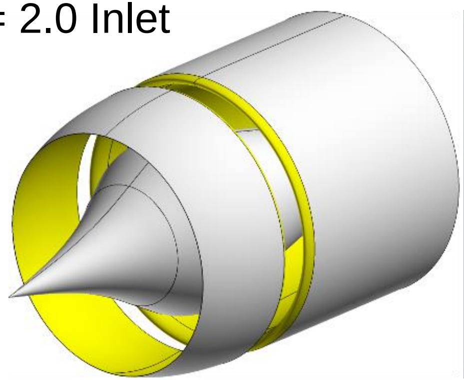
Take-Off

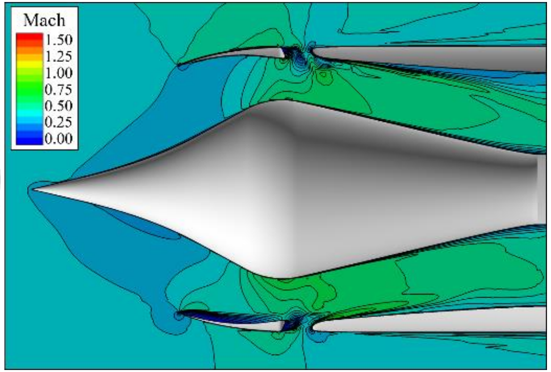




W_{C2}/W_{C2*} = 0.90, M_0 = 0.3, α_0 = 12 deg

M_0 = 2.0 Inlet





Approach-to-Landing

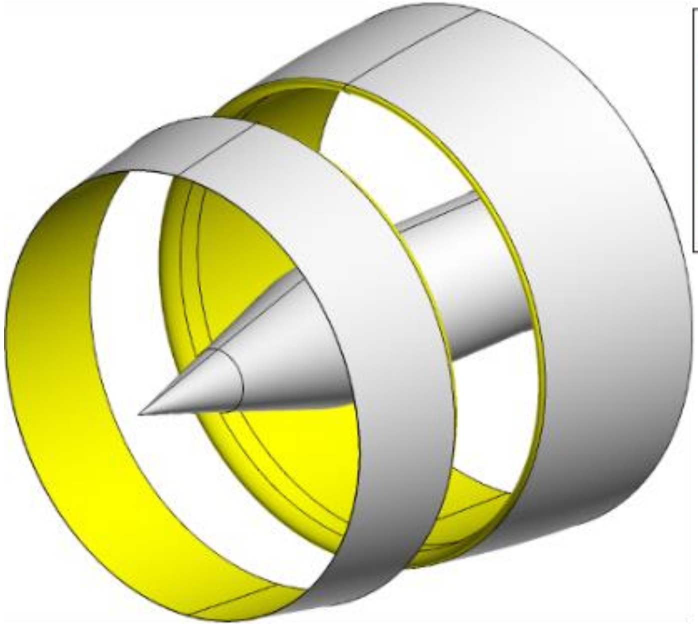
W_{C2}/W_{C2*} = 0.75, M_0 = 0.4, α_0 = 6 deg

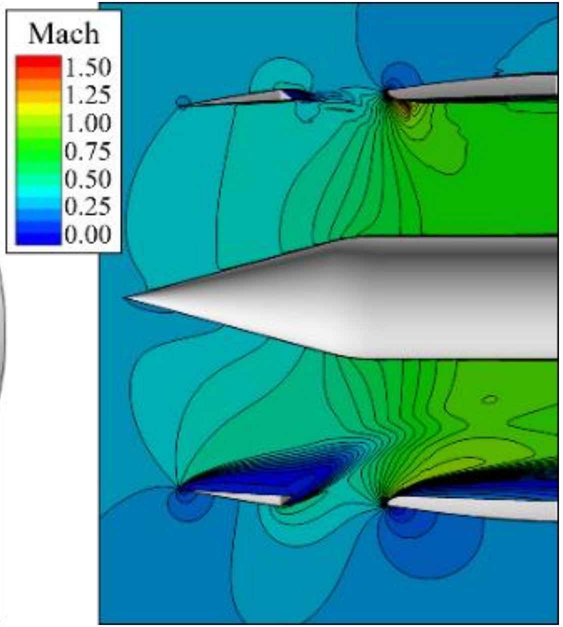
M0 = 1.4 Inlet at Take-Off

Short diffuser results in separation reaching the engine face.

M_0 = 1.4 Inlet

Take-Off





$W_{C2}/W_{C2*} = 1.0$, $M_0 = 0.3$, $\alpha_0 = 12$ deg

Conclusions

DOE and RSM methods were helpful in improving the axisymmetric spike inlet designs.

On-design inlet performance had high recovery and low distortion.

Good inlet performance up to 5 degrees angle-of-attack.

Good inlet performance across the Mach range.

Mostly good performance at take-off and approach-to-landing with auxiliary intakes.

Need refinement of auxiliary intakes (especially for $M_0 = 1.4$).

Need to examine buzz limits and use of centerbody bleed to avoid buzz.

Inlets and results provide information for the design of future commercial supersonic aircraft.