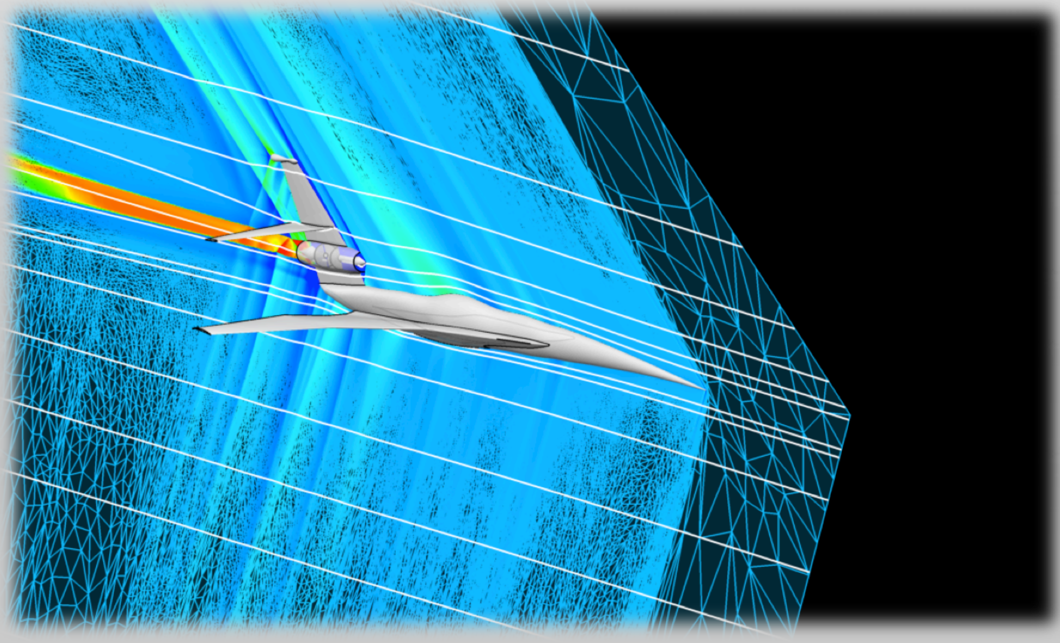
Inlet Trade Study for a Low-Boom Aircraft Demonstrator

Christopher M. Heath & John W. Slater
NASA GRC – Cleveland, OH

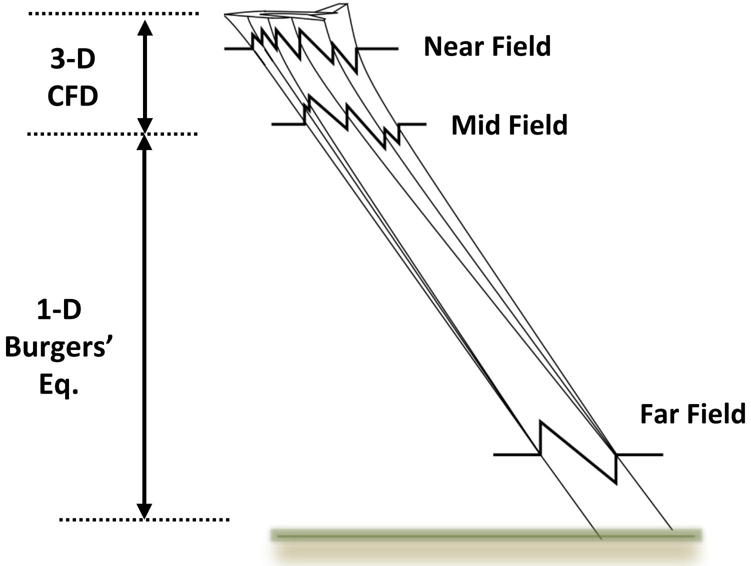
Sriram K. Rallabhandi
National Institute of Aerospace – Hampton, VA



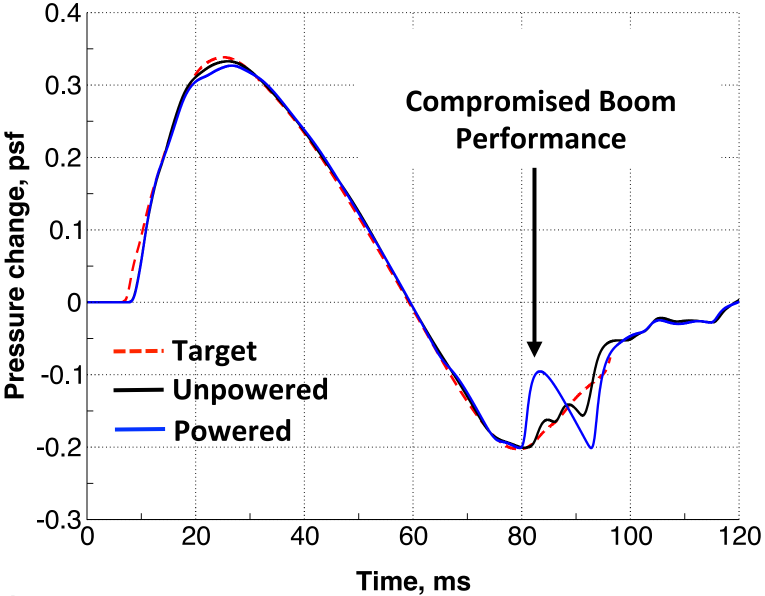
AIAA Aviation Conference
Washington, D.C.
June 13-17, 2016

Research Motivation

Overland sonic boom challenges supersonic aircraft viability.



Propagated Ground Signature*



Current State-of-the-Art:

- Adjoint-based shape optimization to match low-boom signature
- Isolated inlet, engine core, nozzle design and subsequent integration

Drawbacks:

- Low-boom optimization neglects propulsion effects, sacrifices inlet/airframe performance & TSFC to meet low-boom objective
- Research shows introducing propulsion effects into a pre-optimized airframe pressure signature can compromise low-boom performance

*Wintzer, M. et. al., AIAA Paper No. 2015-1045.

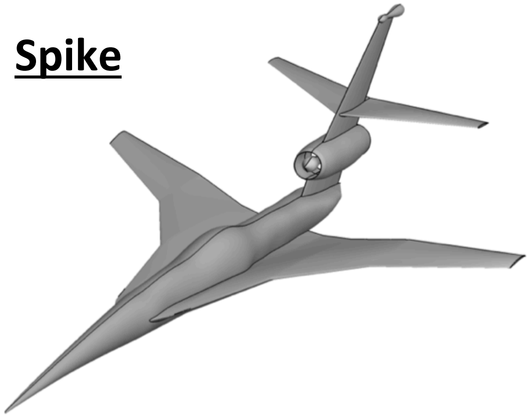
Research Objectives

1. **Quantify installation effects on inlet/engine performance.**
2. **Quantify installation effects on airframe/sonic boom performance.**

Approach:

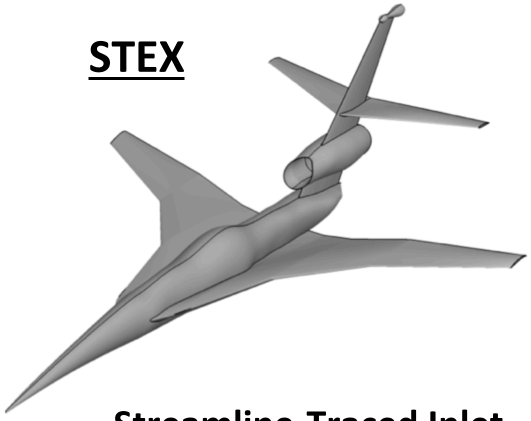
Compare isolated vs. installed performance of two inlet types on aerodynamically tailored low-boom **reference*** airframe.

Government Ref. Vehicle – Config. 25D



Spike

Axisymmetric Spike Inlet



STEX

Streamline-Traced Inlet

***Ref. vehicle designed w/Euler adjoint-based shape optimization to achieve under-track loudness <76.4 PLdB. Wintzer, M. et. al., AIAA Paper No. 2015-1045.**

Problem Definition – Single Pt. Design

Reference Cruise Pt.

- 55K-ft std. day alt.
- Mach no. = 1.6
- C_L= 0.065, $\alpha \approx 3.25°$
- 21K lb cruise weight

Government Ref. Vehicle

Estimated Reference GE-F404-402 Conditions

Inlet

- $W_2 = 51.2$-lbm/s
- $P_{t,2} = 6.1$-psi
- $T_{t,2} = 590$-deg R

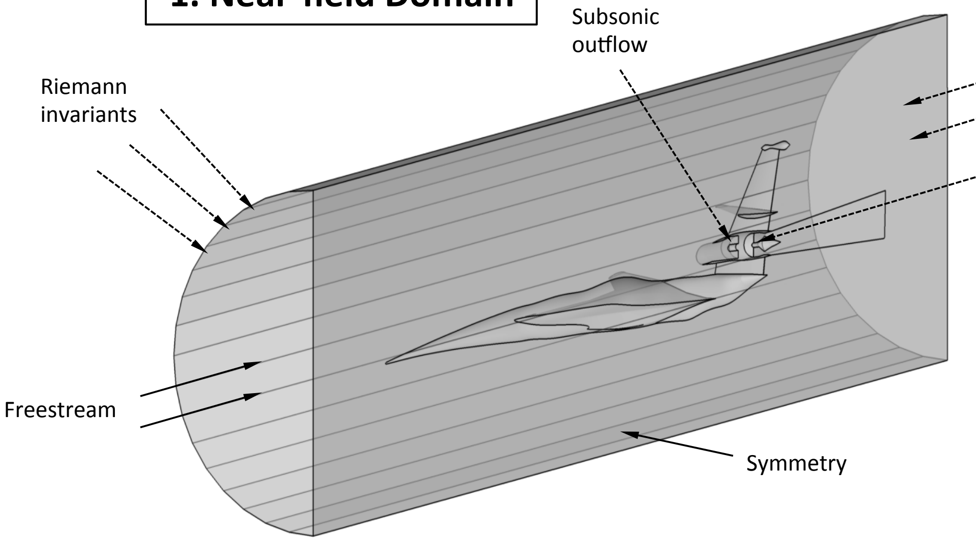
Nozzle

- $W_6 = 52.6$-lbm/s
- $P_{t,6} = 21.4$-psi
- $T_{t,6} = 2852$-deg R

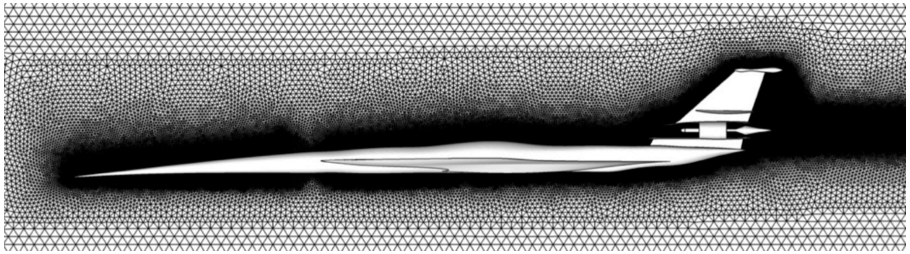
- TSFC = 1.53-lbm/lbf-hr
- $F_{net} = 4487$-lbf

Solution Overview

1. Near-field Domain



2. Compute Performance



3. Optimization Problem

Minimize:

$$\left(C_L - C_{L,target}\right)^2$$

Subject to:

$$0 < \alpha < 5$$

$$-1 < \delta A_7 < 1$$

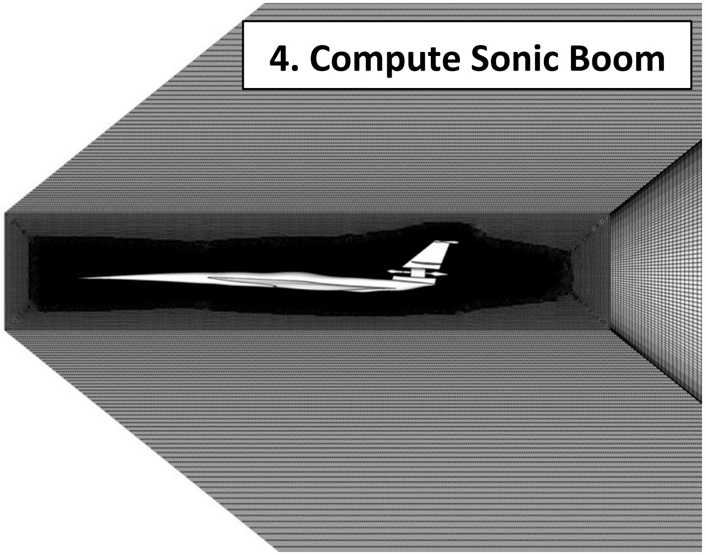
Such that:

$$F_{net} = D_{net}$$

Angle of Attack

Nozzle Throat Area

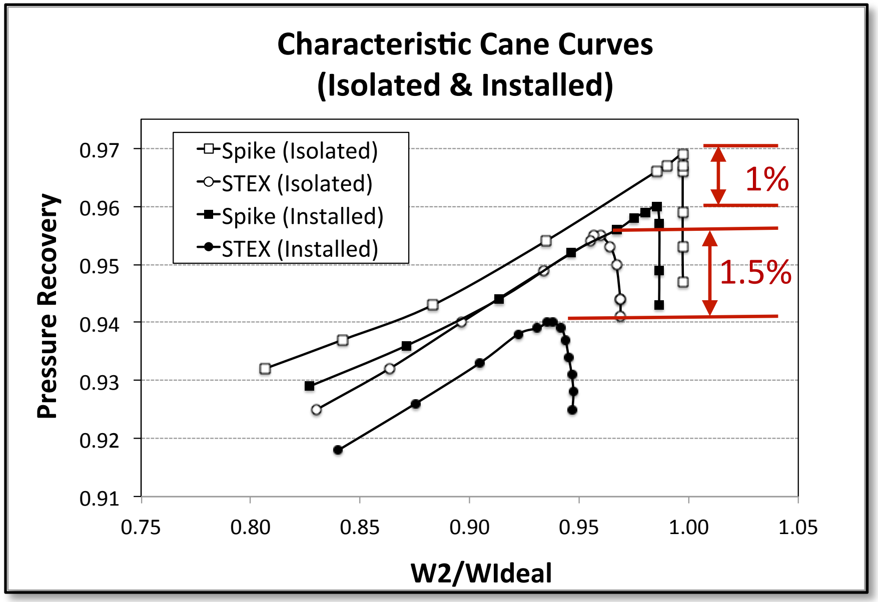
4. Compute Sonic Boom



Process & Tools

Computational Steps
1. Parameterize airframe geometry (ESP).
2. Design & size custom inlets (SUPIN).
3. Integrate inlet/airframe geometry (ESP).
4. Discretize surface geometry (Pointwise).
5. Discretize volume w/plume sourcing (AFLR3).
6. Compute RANS vehicle performance (Fun3D).
7. Compute inlet rec. & adjust ref. engine cycle. (NPSS)
8. Balance vehicle forces using adjoint-based optimization (Fun3D/SNOPT).
9. Generate sonic boom grid (Inflate).
10. Perform sonic boom RANS analysis (Fun3D).
11. Extrapolate mid-field signatures to ground and convert to perceived loudness (sBOOM).

Inlet Performance Comparison



Similar isolated/installed characteristics

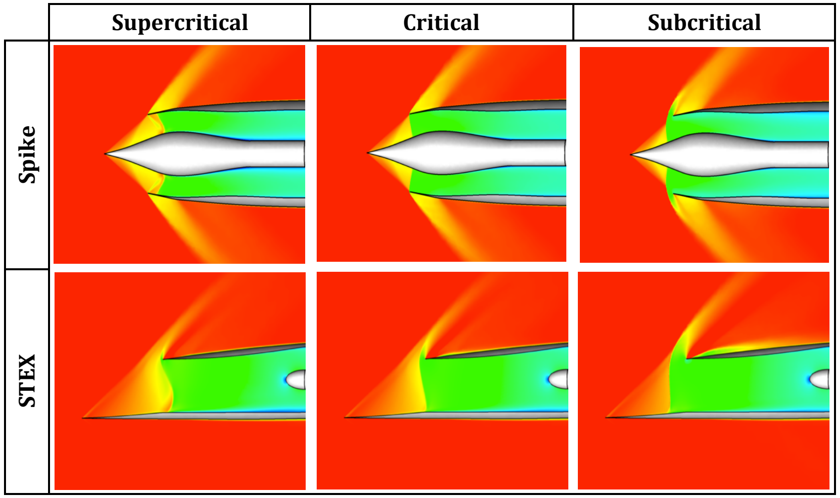
Installed Spike

- Peak recovery declines by ~1%
- ~1% reduction in mass flow rate

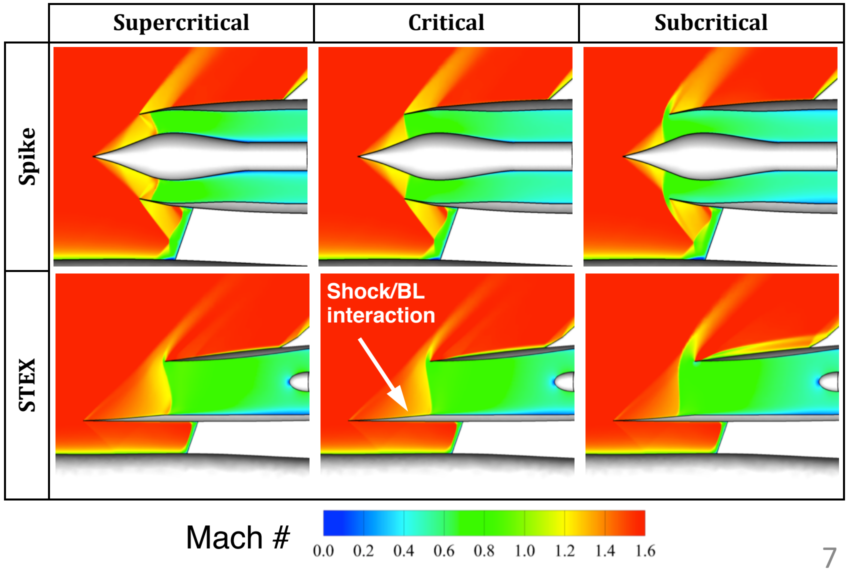
Installed STEX

- Peak recovery declines by ~1.5%
- ~2% reduction in mass flow rate

Isolated



Installed

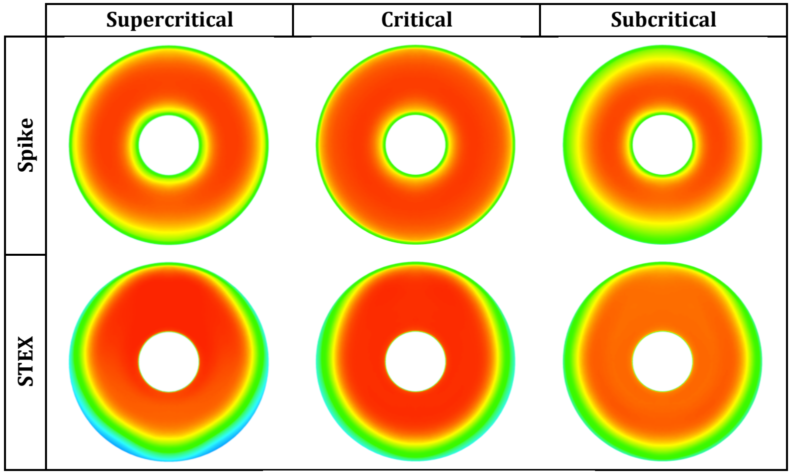


Inlet Performance Comparison @ AIP

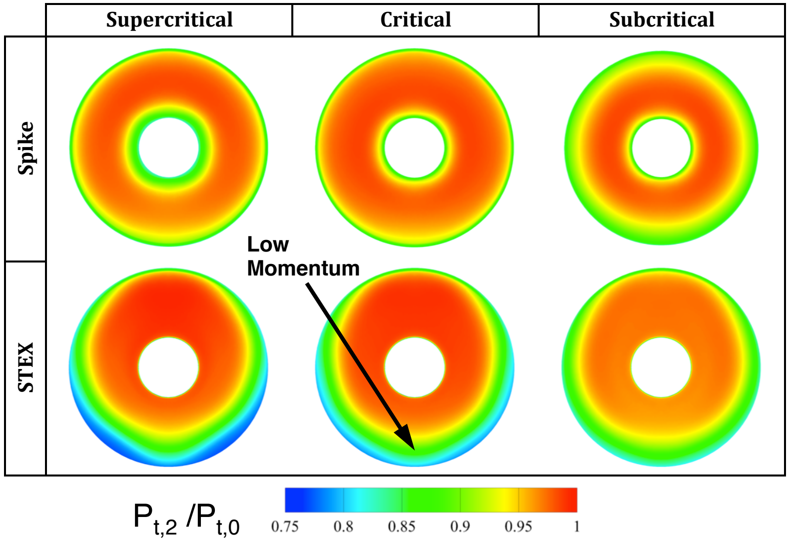
Parameter	STEX	Spike
$P_{t,2} / P_{t,0}$	0.94	0.97
DPC/P	0.0408	0.0075
DPR/P	0.086	0.028

- Installed spike inlet recovery ~3% higher than STEX recovery
- Both inlets meet SAE ARP radial & circumferential distortion requirements for GE-F404-402
- Spike inlet fan distortion at AIP is significantly lower than STEX inlet distortion

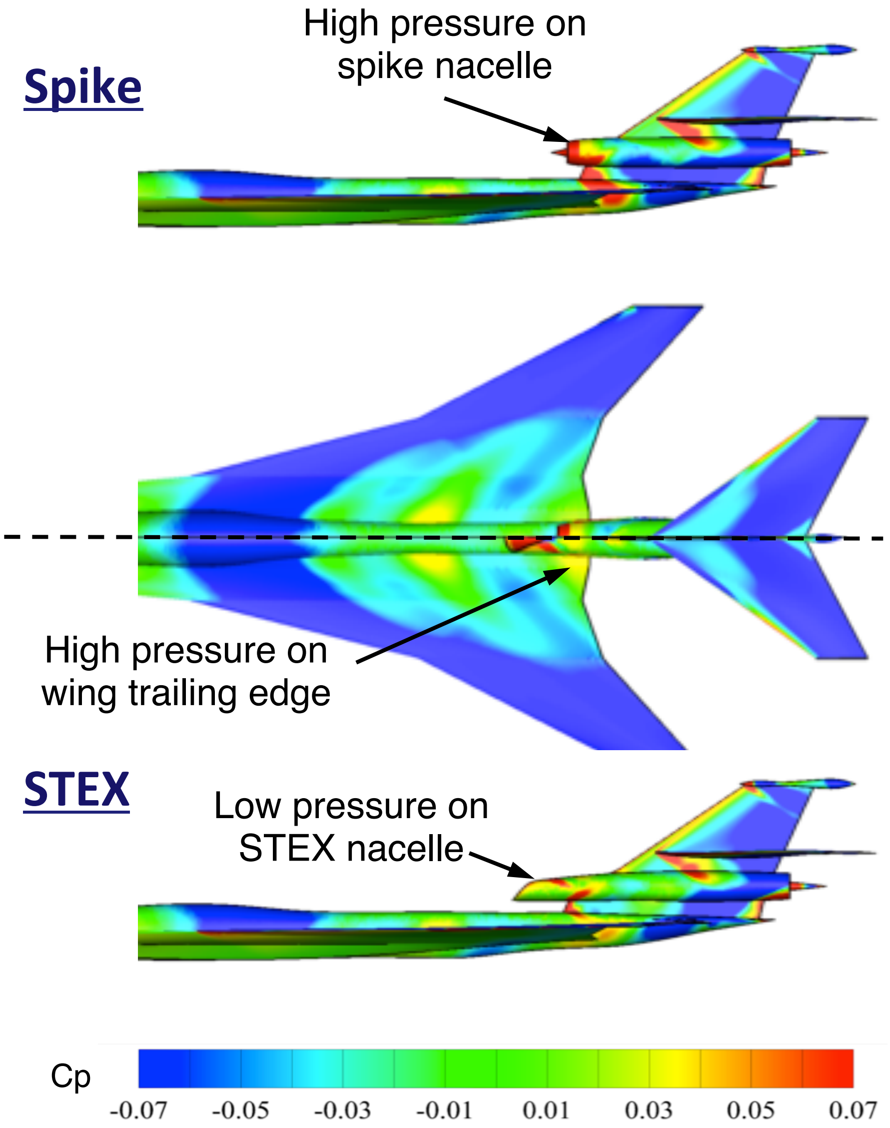
Isolated



Installed



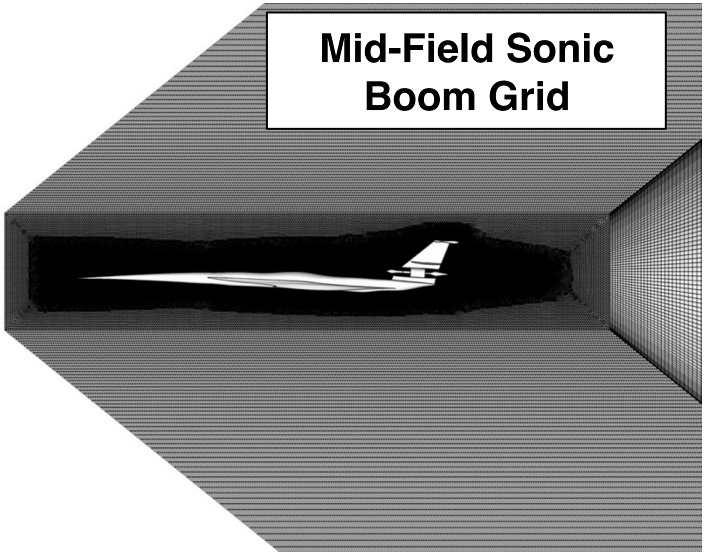
Vehicle Performance Comparison

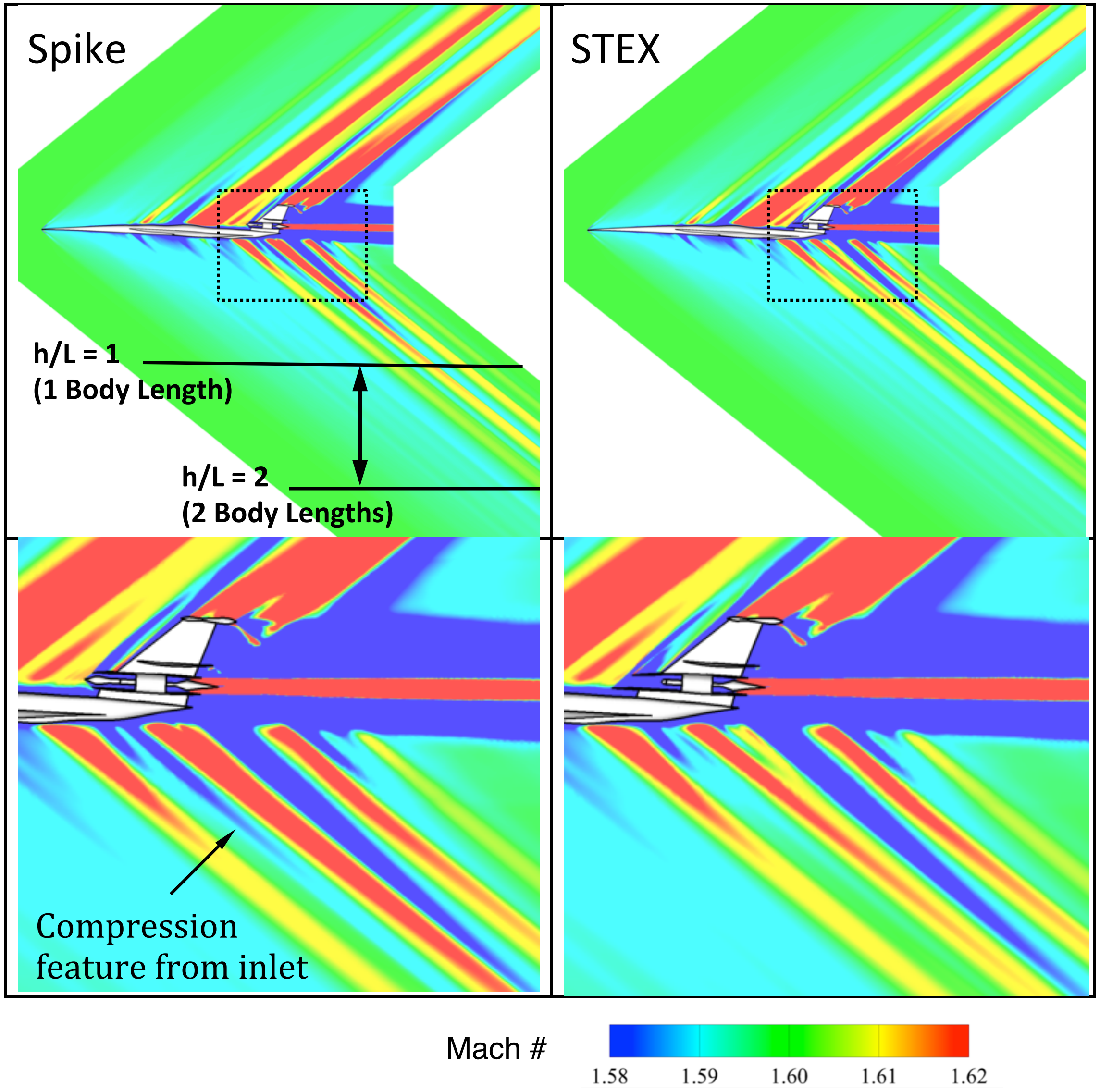


Parameter	Spike	STEX
α (°)	3.26	3.23
Airframe L/D	4.75	4.94
D_{net} (lbf)	4391	4230
TSFC (lbm/lbf-hr)	1.452	1.416
Range	-	+6.6%

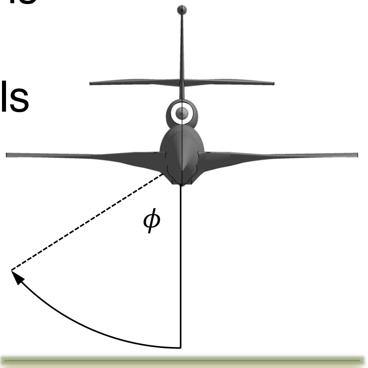
$$Range = \left(\frac{V}{TSFC}\right)\frac{L}{D}\,ln\left(\frac{w_i}{w_f}\right)$$

Vehicle Sonic Boom Comparison

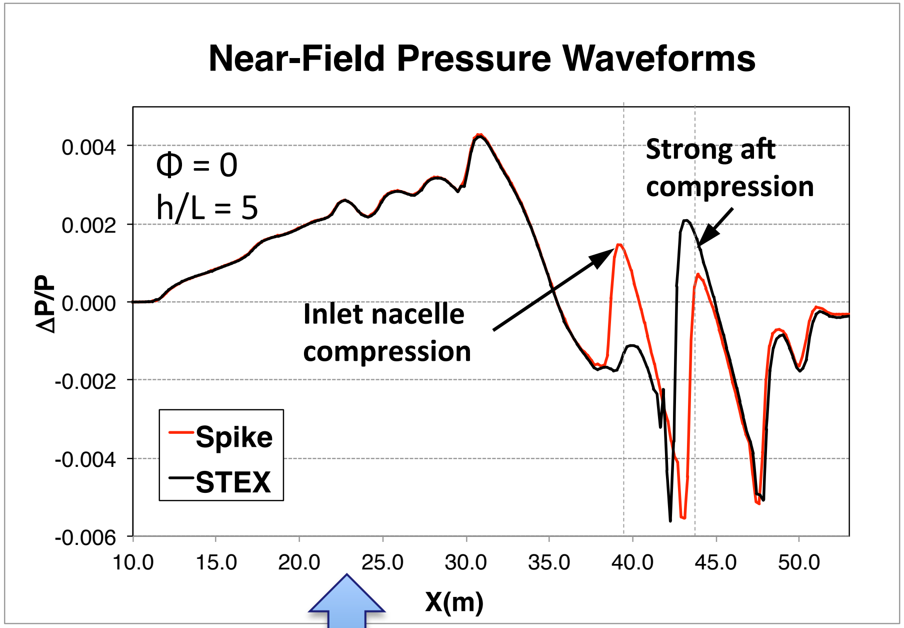




- Mach-aligned extruded prism grid generated using Inflate out to 6 body lengths
- Pressure signals extracted from h/L = 1-5 at Φ = 0°-50°



Mid-Field Pressure Waveform Comparison



Near-Field Pressure Waveforms

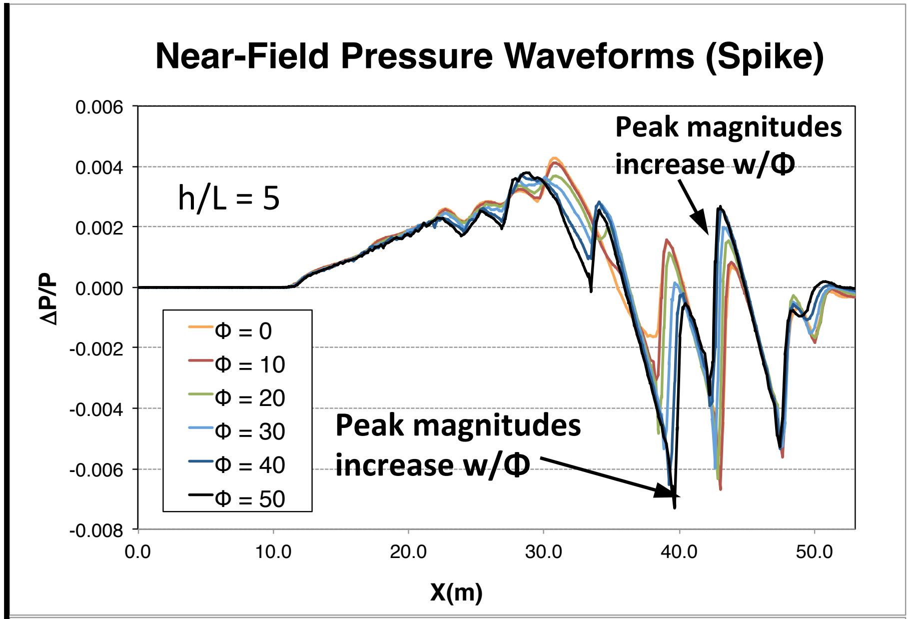
Φ = 0

h/L = 5

Strong aft compression

Inlet nacelle compression

Under-track

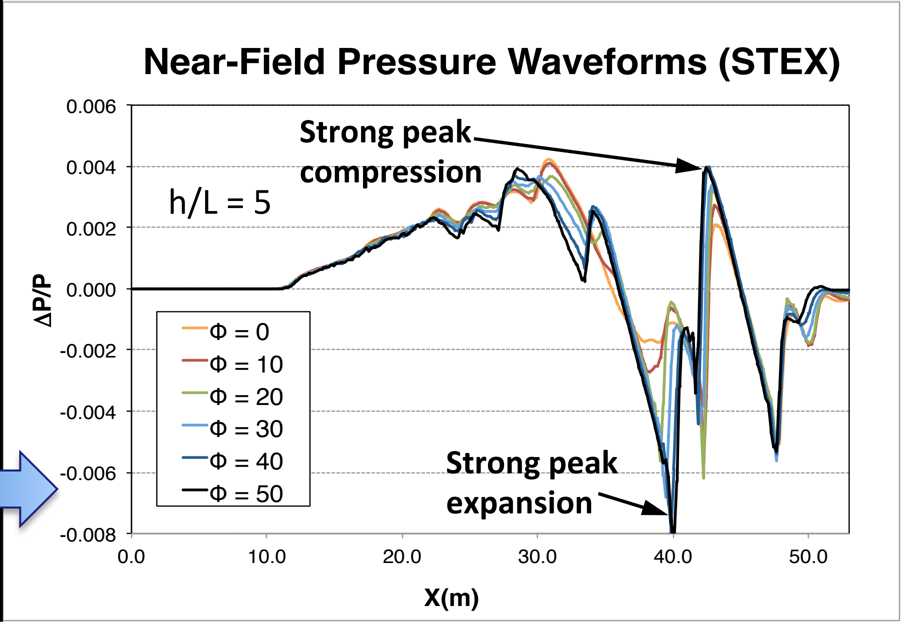


Near-Field Pressure Waveforms (Spike)

h/L = 5

Peak magnitudes increase w/Φ

Peak magnitudes increase w/Φ



Near-Field Pressure Waveforms (STEX)

h/L = 5

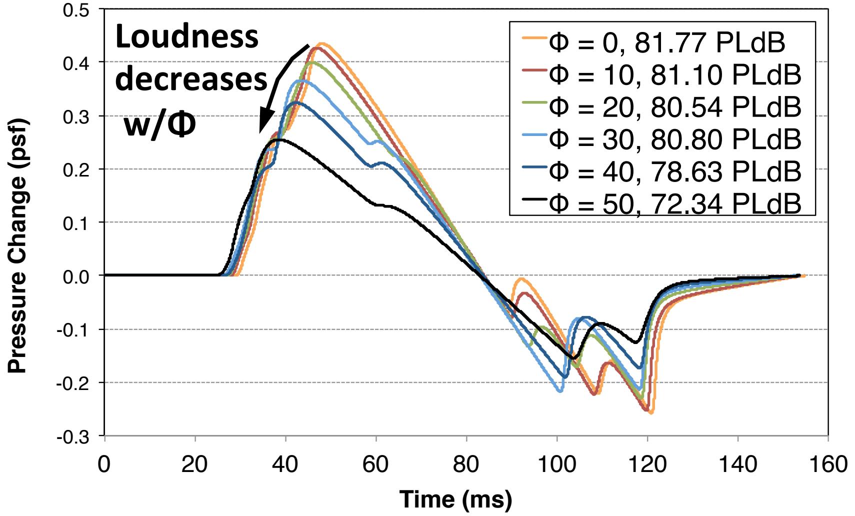
Strong peak compression

Strong peak expansion

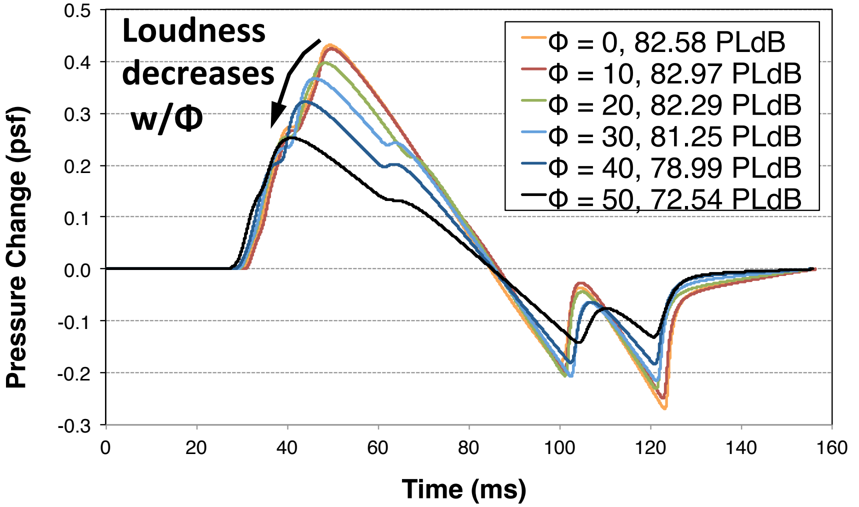
Off-track

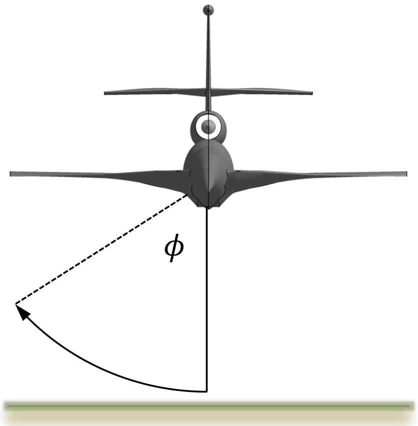
Vehicle Propagated Ground Signature Comparison

Predicted Ground Signatures (Spike)



Predicted Ground Signatures (STEX)





- Under-track loudness higher than original design (~82 vs. 76.4 PLdB)
  - Differing engine geometry
  - Euler vs. RANS (viscous effects)
  - Re-adjusted α to hit target C_L
  - Adjoint-adapted grids vs. geometry refined
- Improvement to sonic boom performance likely recoverable with additional RANS aerodynamic shaping

Conclusions

- Inlet trade study conducted to capture effects of engine installation on inlet performance
- Simultaneously captured the effects of engine installation on aircraft performance AND sonic boom

Conclusions

Spike inlet configuration:

- ~3% higher total pressure recovery
- >70% lower inlet distortion
- ~1% lower propagated ground loudness

STEX inlet configuration:

- Lower external wave drag (~160-lbf)
- ~4% higher vehicle L/D ratio
- ~2.5% lower TSFC
- +6.6% increased range capability

Conclusions

- Integration of a “low-boom” inlet does not automatically guarantee reduction in overall vehicle sonic boom signature.

- Inlet interaction with the vehicle signature plays a much more dominant role.

- Inlet integration should be considered during the conceptual vehicle design optimization process.

Acknowledgements

NASA's Commercial Supersonic Technology (CST) Project

Jon Seidel – Thermodynamic cycle support

Chuck Trefny – Propulsion-airframe integration

Bob Haimes – SUPIN and ESP software integration

John Dannenhoffer – ESP custom parameterizations