



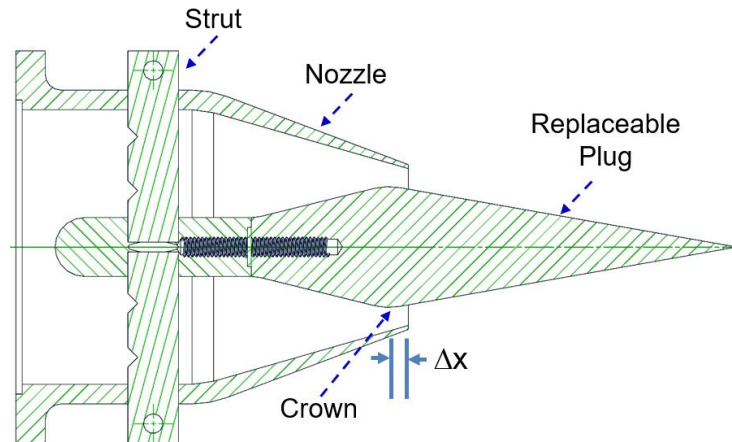
Study of a plug nozzle for supersonic aircraft concepts

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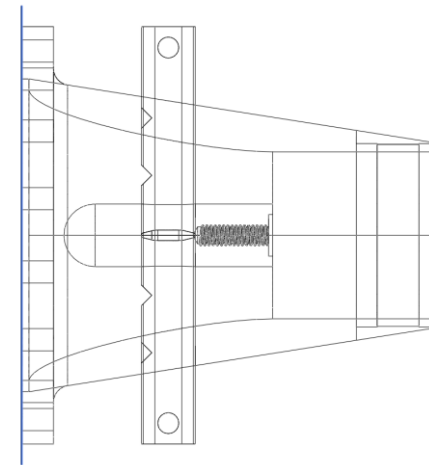
30th AIAA/CEAS Aeroacoustics Conference
Rome, Italy
4-7 June 2024

In support of NASA's Commercial Supersonic Technology (CST) Project

- A plug nozzle is a candidate for supersonic aircraft concepts in a NASA Project
- This is a fundamental study with focus on the external plug for noise and thrust
- Earlier results with a **convergent cowl** presented at previous meetings
(AIAA 2022-2828 and AIAA 2024-2305)



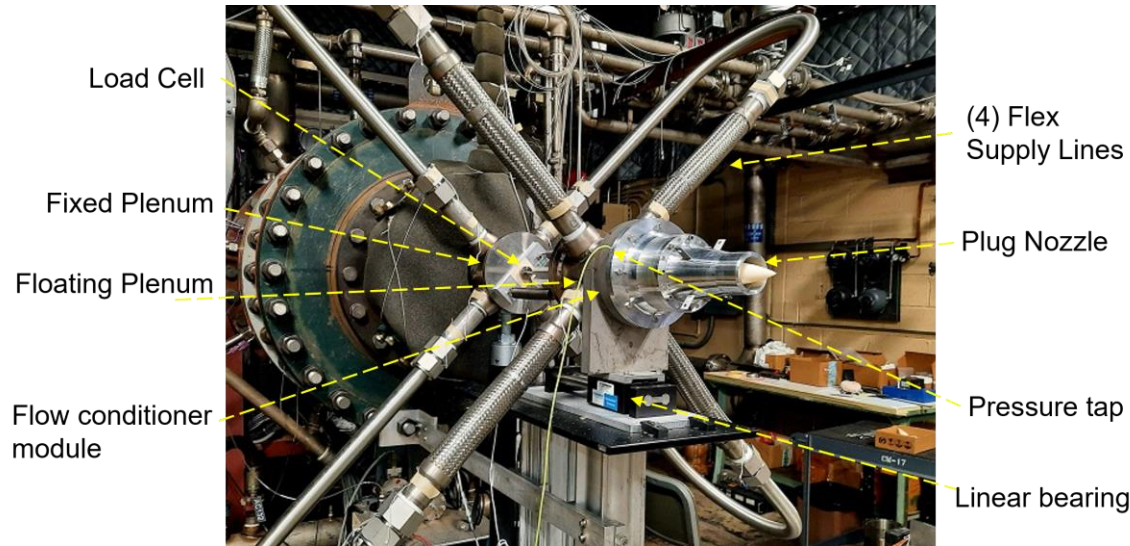
Convergent cowl (nozzle)



New cylindrical cowl

- Because of boattail drag concern, a **cylindrical cowl** is adopted now
- This paper presents noise, flow and thrust data for various plugs with a model of the new plug nozzle.

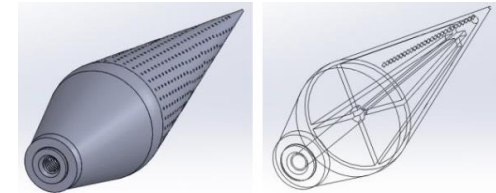
Experimental Facility



Jet facility with thrust apparatus



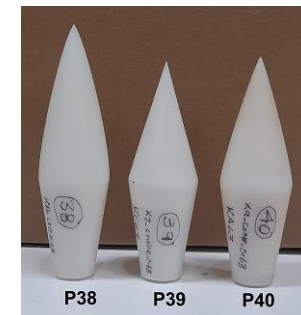
Conic plugs



Porous plugs



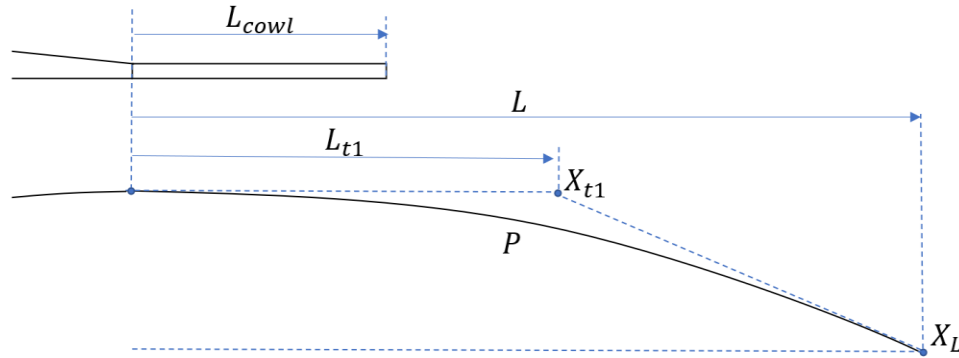
Cowl lip extension



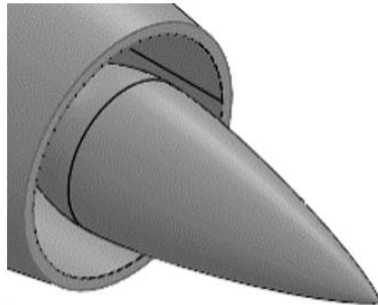
Optimized plugs

Plugs from numerical optimization study

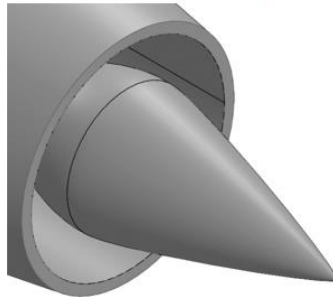
Korth AIAA Paper 2024-1776



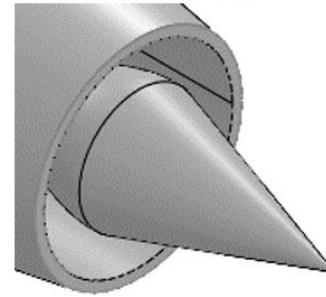
LTO Optimized (P38)



Performance Tradeoff (P40)



Cruise Optimized (P39)



SPL spectra at 90°, schlieren and limited thrust data

$M_j = 0.6 - 1.67$ (NPR = 1.28 – 4.7)

(NPR $\approx 2 \Rightarrow$ 'LTO')

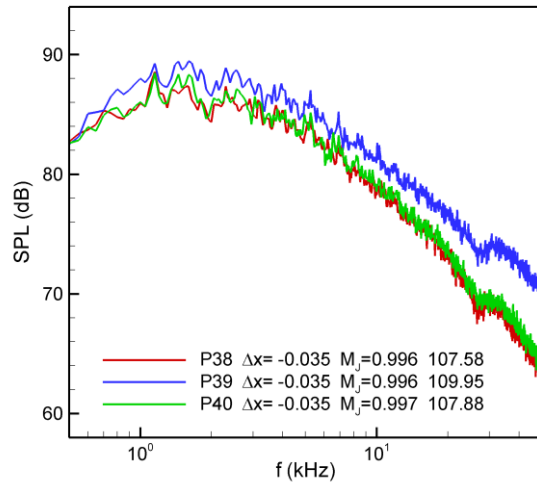
NPR $\approx 4.7 \Rightarrow$ approaches 'Cruise')

Unheated flow, Static tests (no external stream)

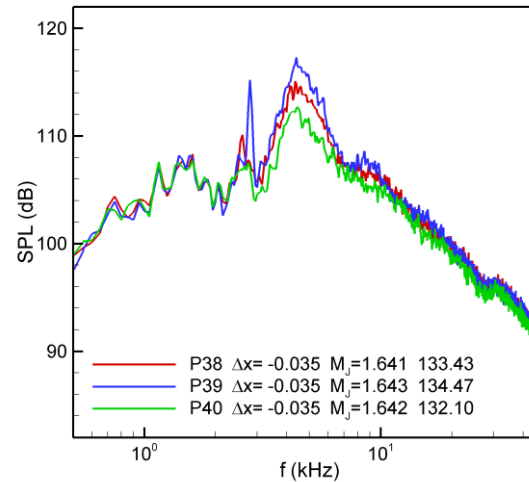
Noise and flow from the 3 optimized plugs



NPR $\approx$ 1.89

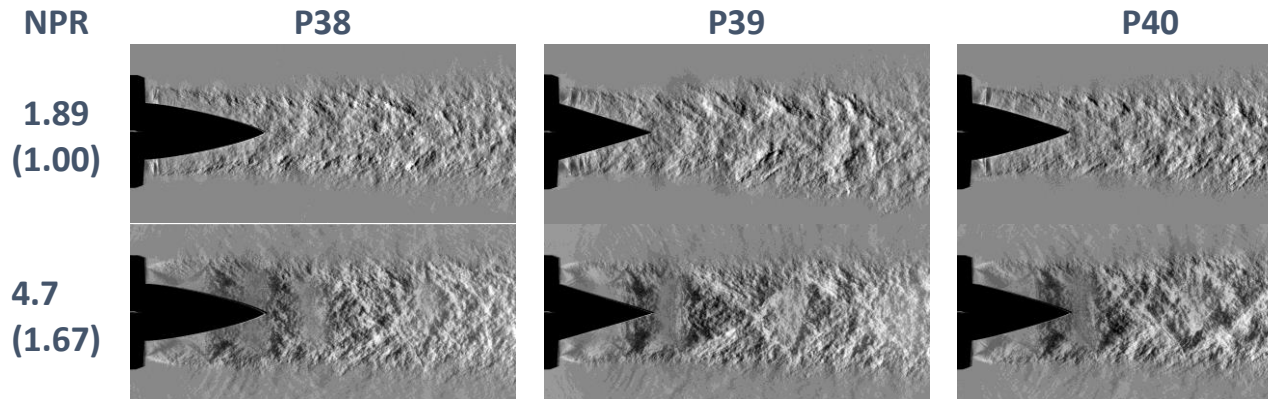


NPR $\approx$ 4.6



P38 = 'LTO'
P39 = 'Cruise'
P40 = 'Compromise'

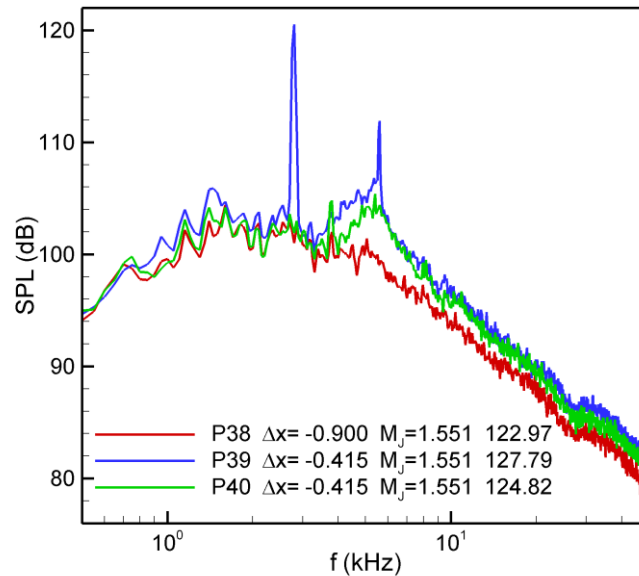
SPL spectra at $\theta \approx 90^\circ$ for three optimized plugs; $\Delta x = -.035''$.



Schlieren images of flows for the three plug cases.

Noise and flow from the 3 optimized plugs

With crown locations as indicated; $M_j = 1.55$, NPR = 4



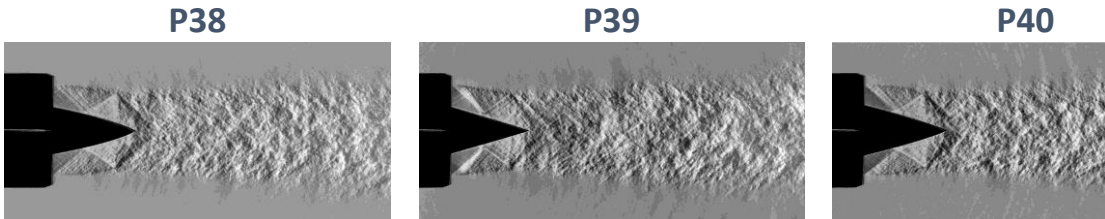
P38 with $\Delta x = -0.90''$

P39 with $\Delta x = -0.415''$

P40 with $\Delta x = -0.415''$

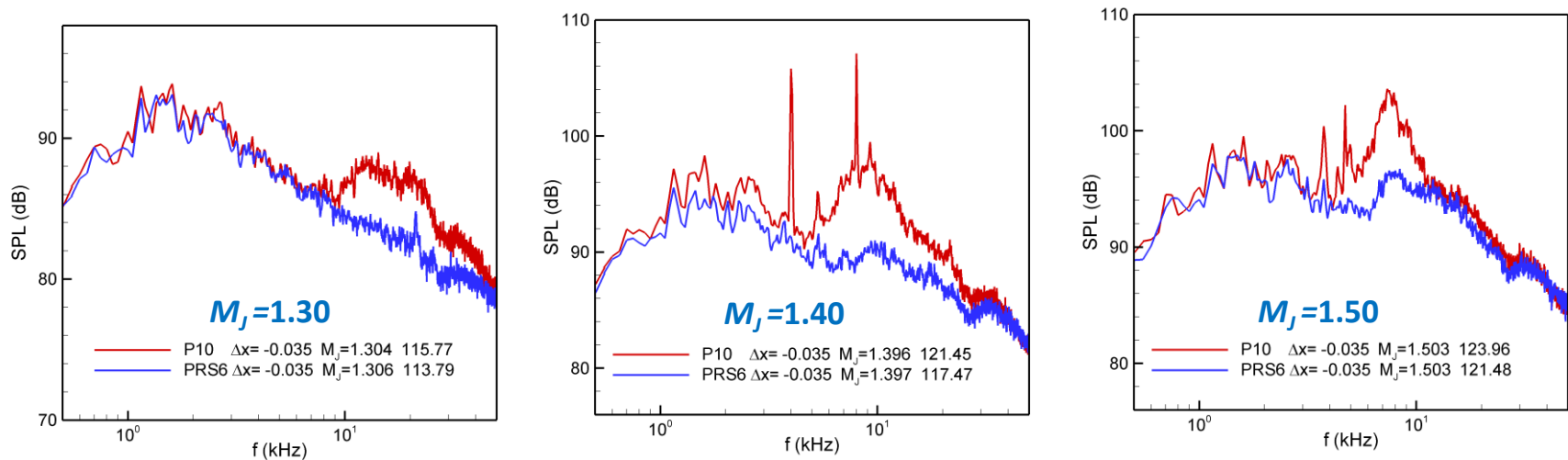
SPL spectra at $\theta \approx 90^\circ$ for three optimized plugs

NPR=4
 $M_j=1.55$

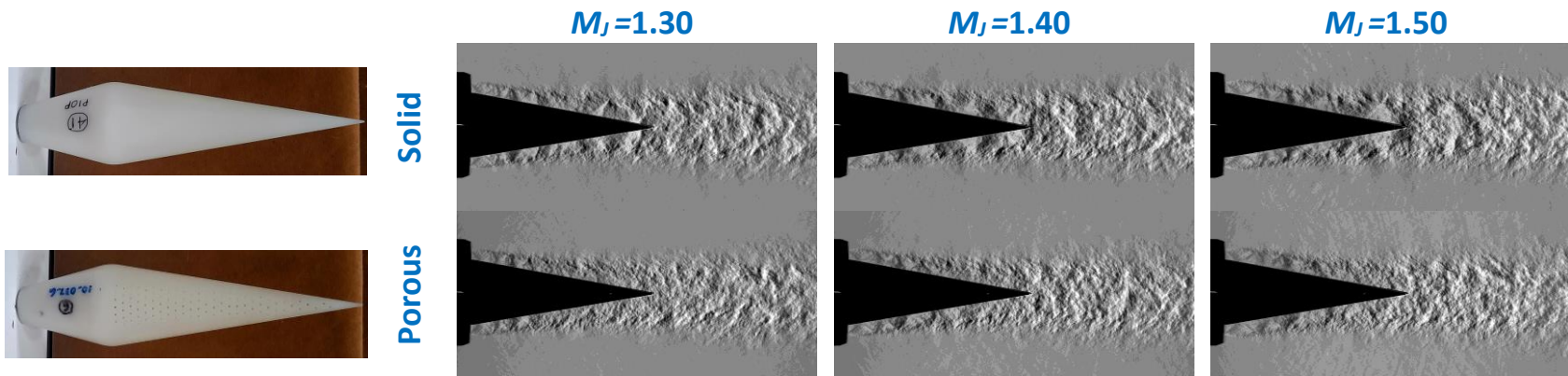


Corresponding schlieren images.

Plug porosity effect on noise and flow 10° conic case



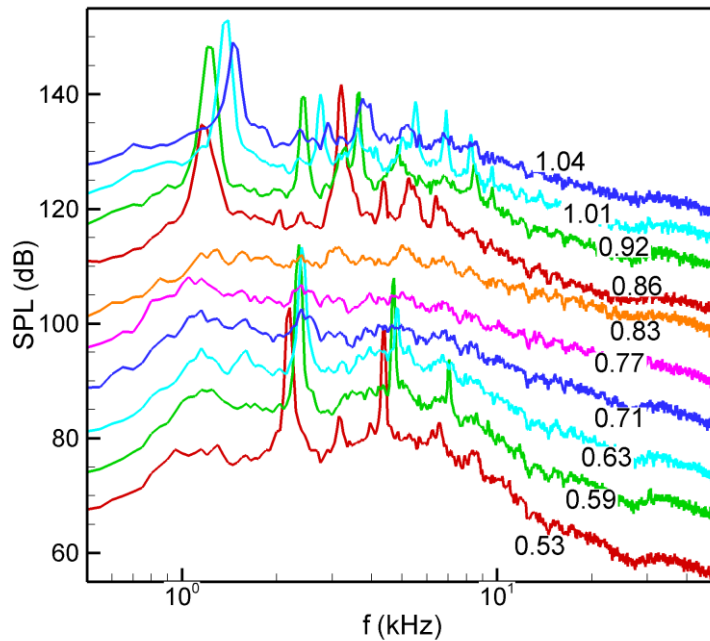
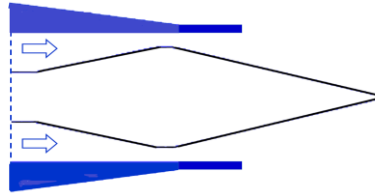
SPL spectra at $\theta \approx 90^\circ$; **Red line: solid plug**, **Blue line: porous plug**



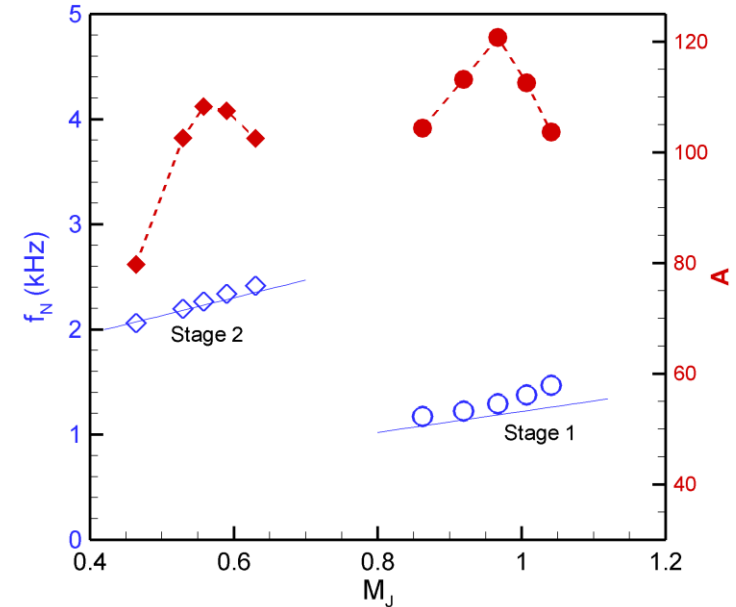
Schlieren images of flows for the 10° conic plug solid vs. porous

Characteristics of transonic tones with plug nozzle

10° conic plug (solid) with crown at $\Delta x = -1.625''$



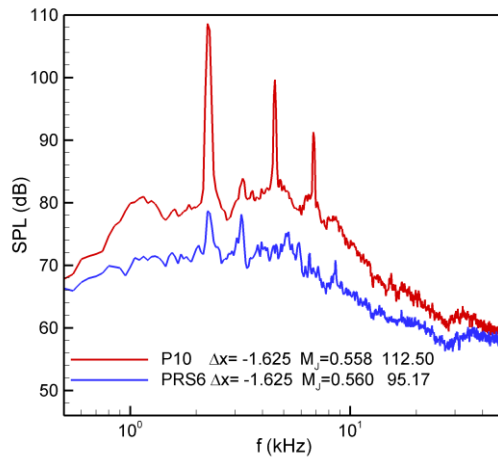
SPL spectra at different M_j



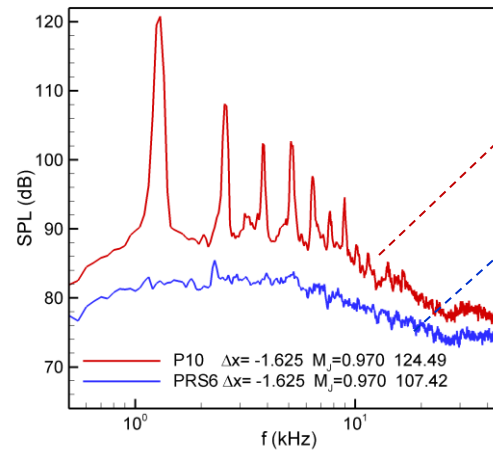
Tone frequency and amplitude versus M_j

Solid blue lines: from correlation
Equation based on round C-D nozzle data
(Zaman et al., JFM 2002)

Effect of plug porosity on x-tone and EBBN



(a)



(b)

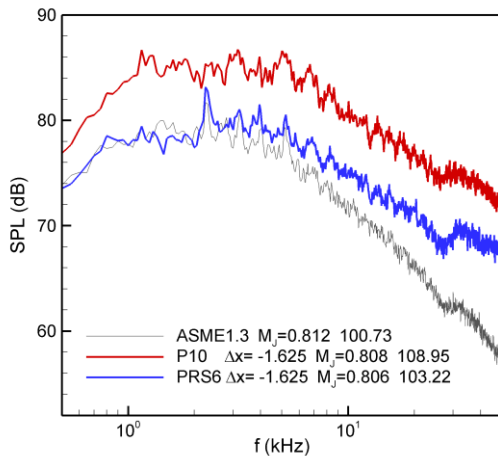
Solid (P10)



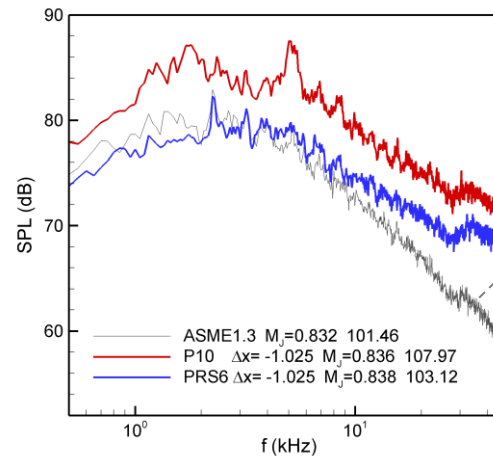
Porous (PRS6)



Effect on transonic-tone



(c)



(d)

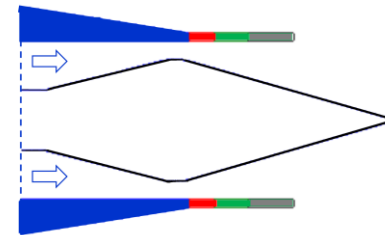
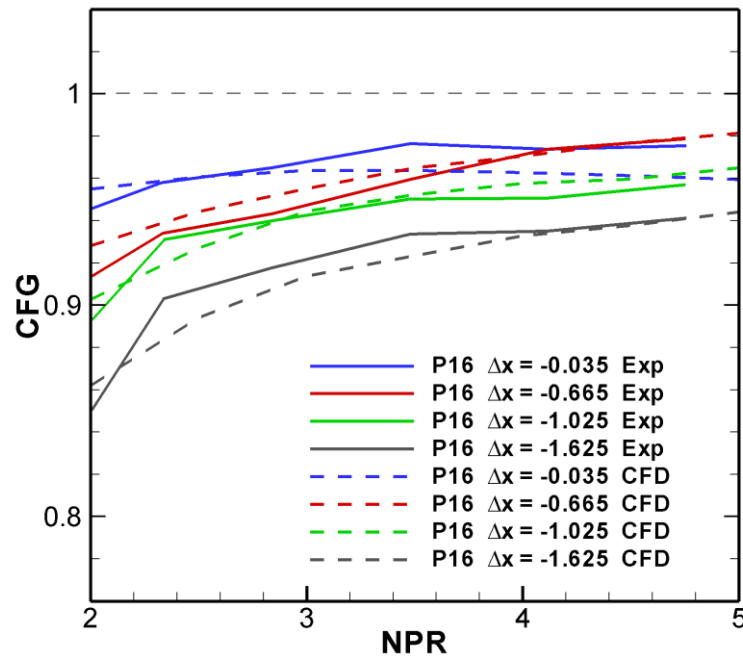
Effect on EBBN

(Zaman et al., AIAA 2010)

ASME 1.3" nozzle

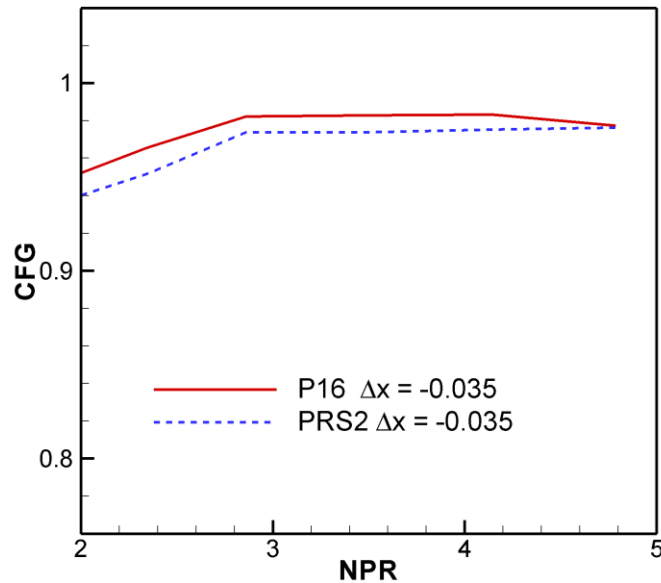
SPL spectra at $\theta \approx 90^\circ$ for 10° conic plug with crown location Δx as indicated

Thrust coefficient results



16° conic plug with different lip extensions.
Solid lines: experiment, dashed lines: CFD.

Thrust loss due to porosity

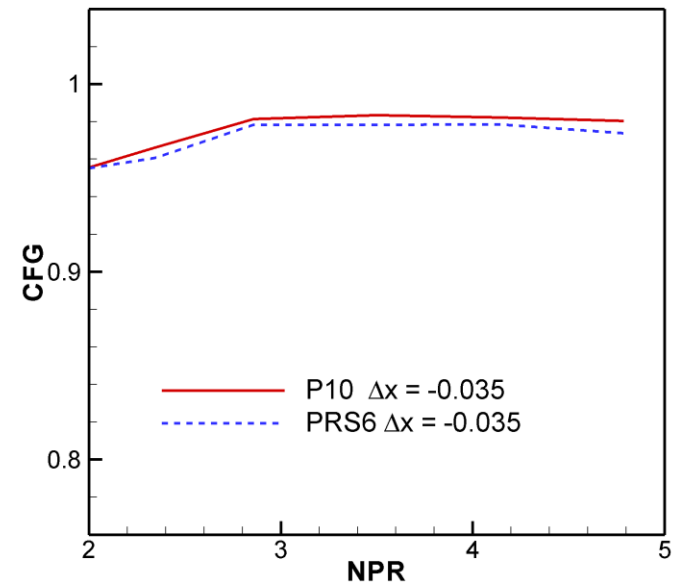


16° conic plug

Red: Solid



Blue: Porous



10° conic plug

Red: Solid



Blue: Porous



Conclusions



Plug optimized for cruise was noisiest over NPR range covered

Compromise shape plug has low noise at LTO

Plug with crown inside can produce x-tones and EBBN at low NPR and screech and BBSN at high NPR

A long porous plug (10° conic) takes out all aberrant noise components while suffering less than 1% loss in CFG

Trends in CFG predicted by simulation are supported by experiment

Further experiments with improved thrust rig under way.

Thrust coefficient of three optimized plugs (CFD)

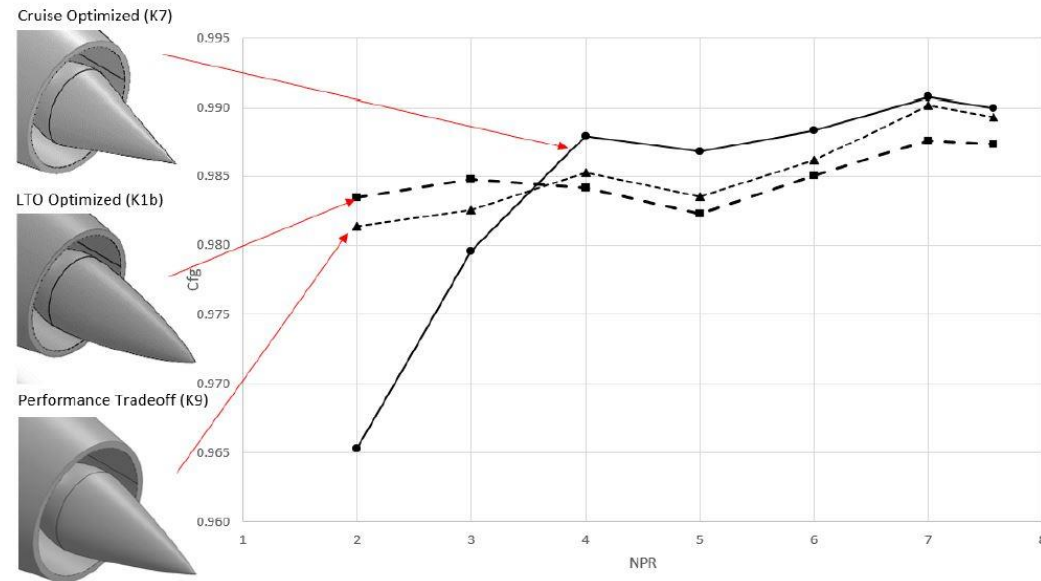
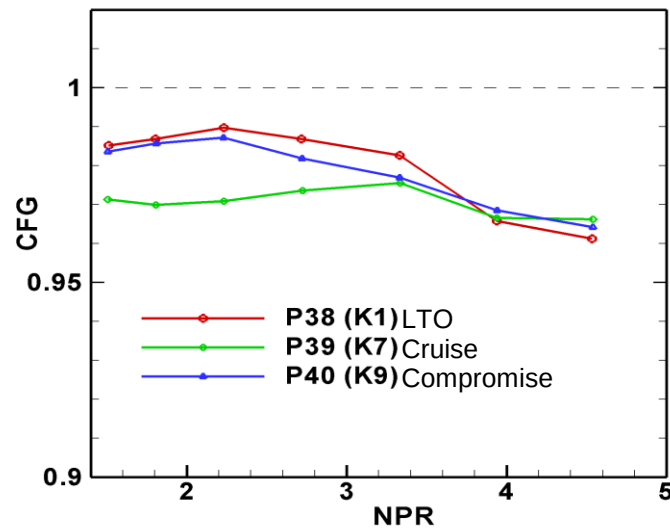


Fig. 10 SLS operating range performance for candidate nozzles, $M=0.01$

Backup chart 1

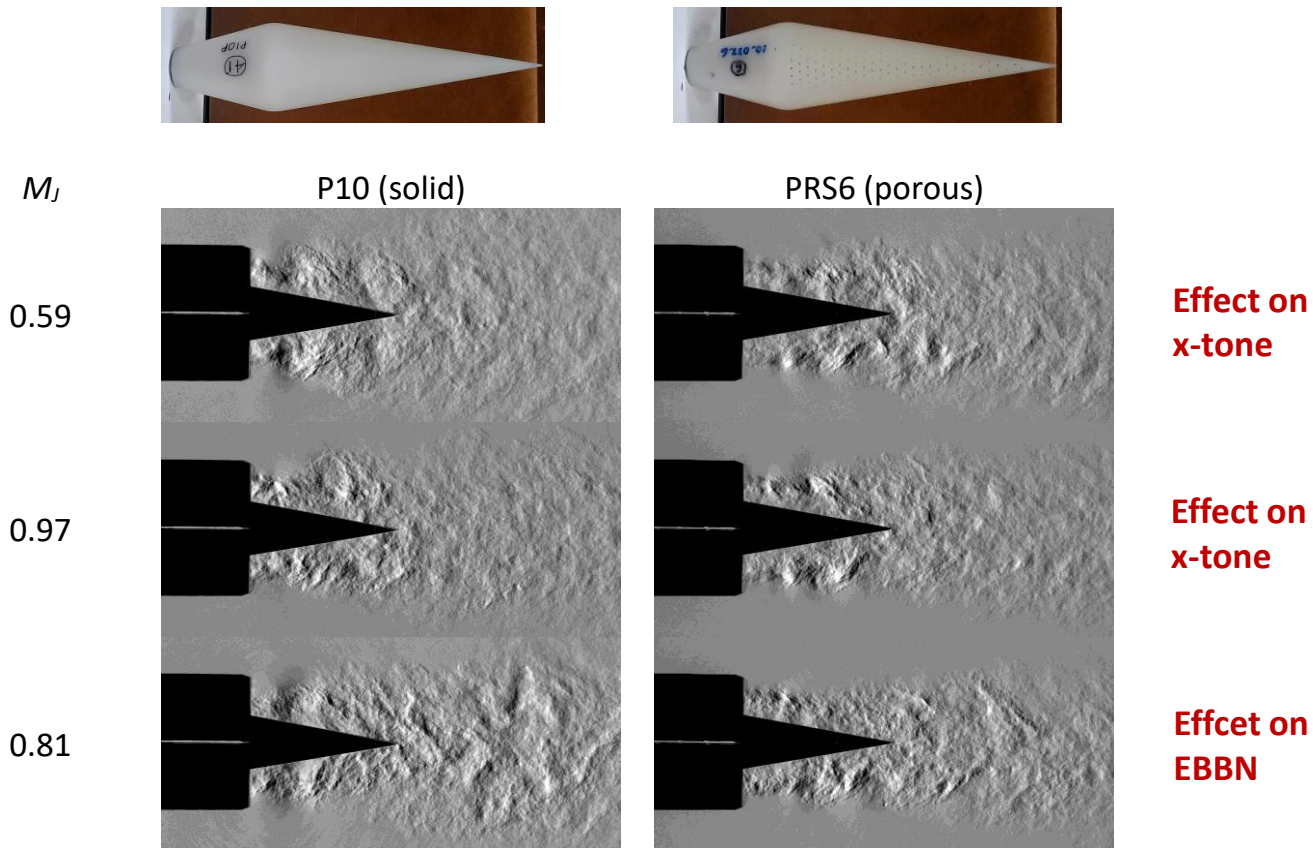
Three optimized plugs CFG data

Plug crown at $x = -0.035$ " for all cases



Backup chart 2

Effect of plug porosity on x-tone and EBBN



Schlieren images on plug porosity effect on x-tone and EBBN.
 10° conic plug $\Delta x = -1.625''$.

Backup chart 3

Plug porosity effect on noise and flow 16° conic case

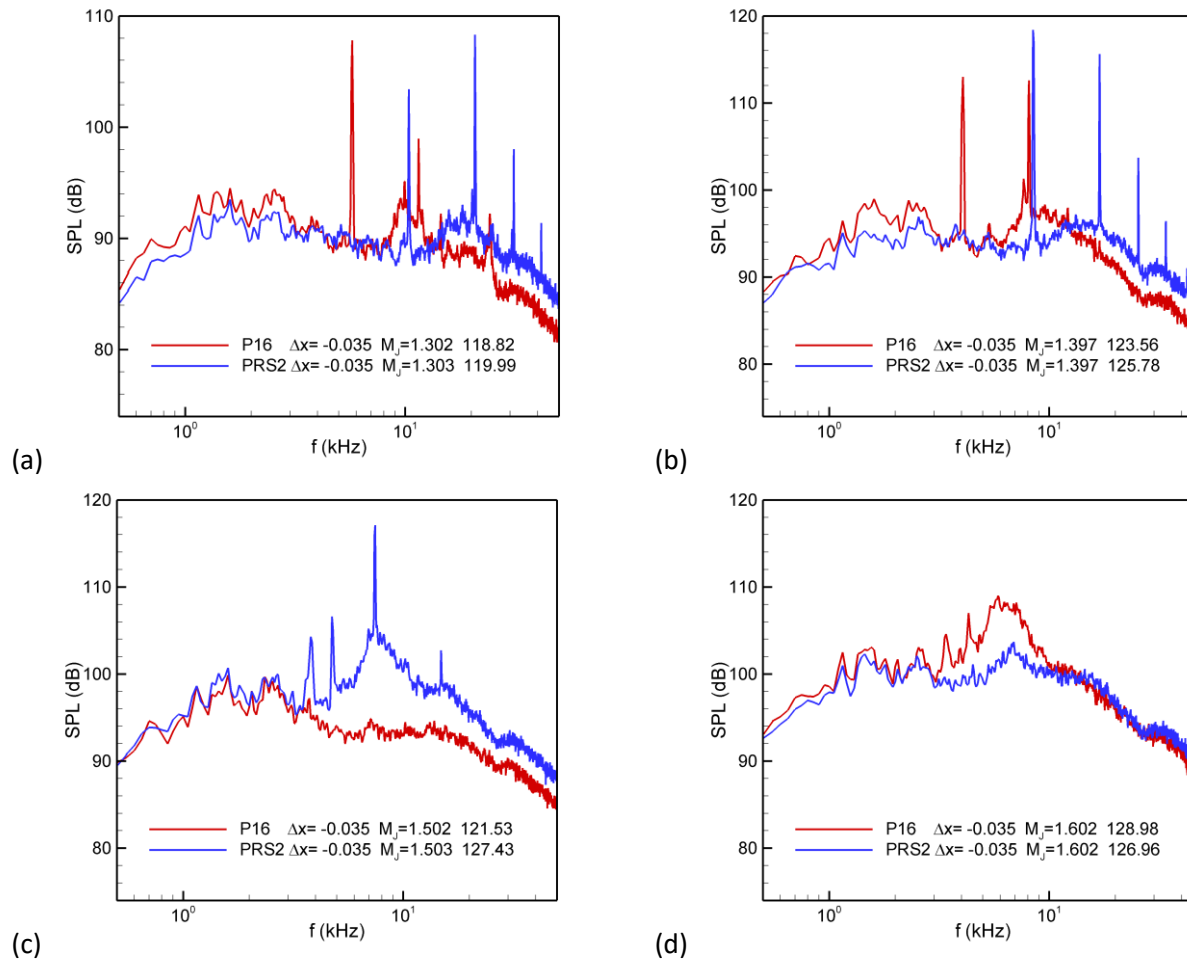


Fig. 13 SPL spectra at $\theta \approx 90^\circ$ for the 16° conic plug showing plug porosity effect. Red lines: solid plug (P16), blue lines: porous plug (PRS2).

Backup chart 4