PIV/Phased Array/Far-field Noise Measurements of a Low-Noise Top-Mounted Propulsion Installation for a Supersonic Airliner

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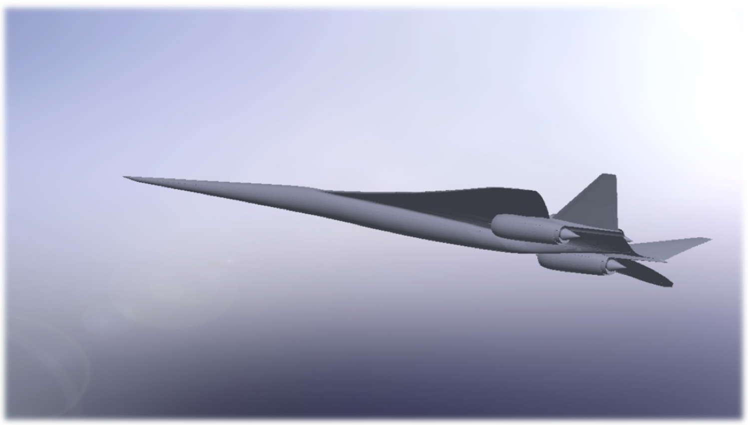
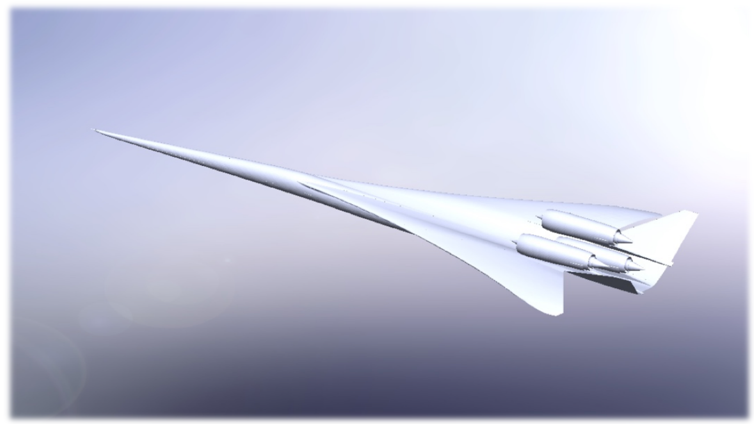
Motivation

- From low-boom concept to low-noise concept.
- No longer an optimized low-boom design after propulsion mod, but a demonstration piece for major change in architecture for landing/take-off noise.
- Key noise reduction concept: Source relocation and shielding



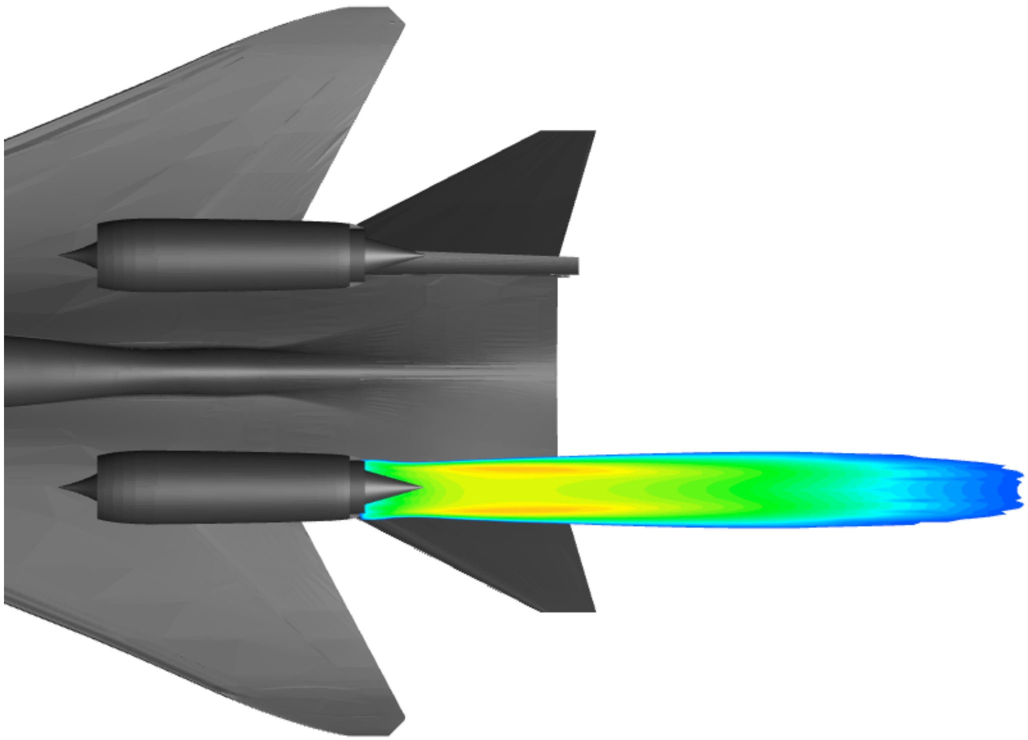
NASA/Lockheed LM1044
Low-Boom Concept



NASA LM1044/TMP
Quiet Top Mounted Propulsion Concept

Conventional nozzles, underbody installation

Observer view

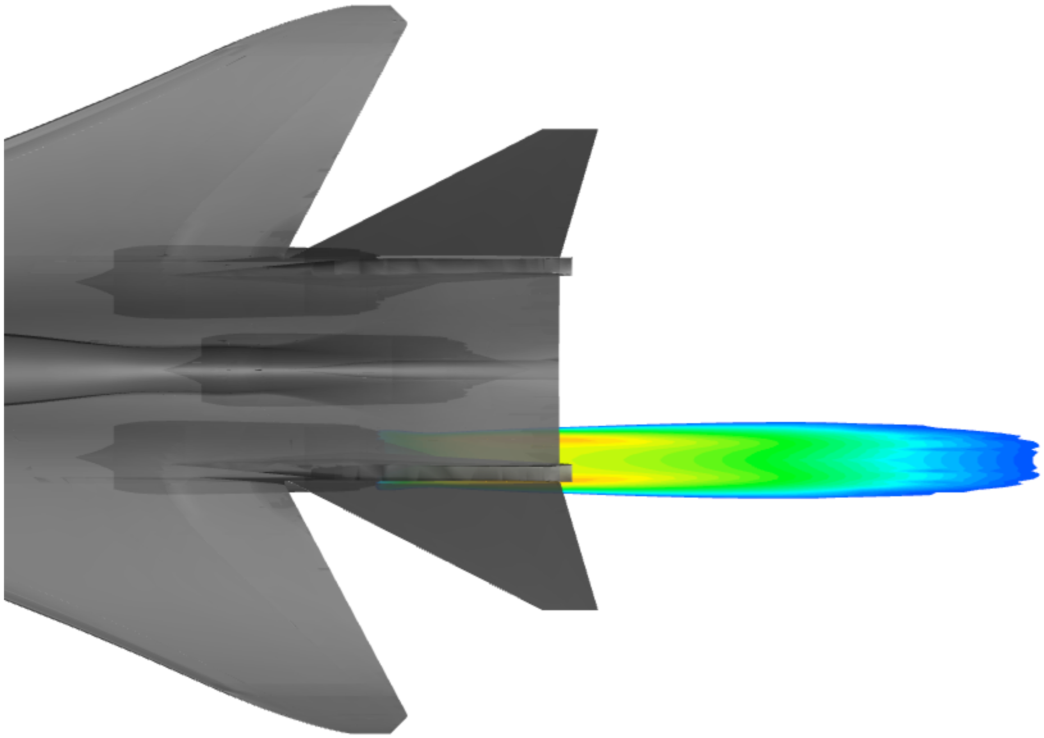


Noise sources

Conventional nozzles
Conventional installation
—*Too loud for commercial airports.*

Conventional nozzles, top-mounted installation--shielding

Observer view

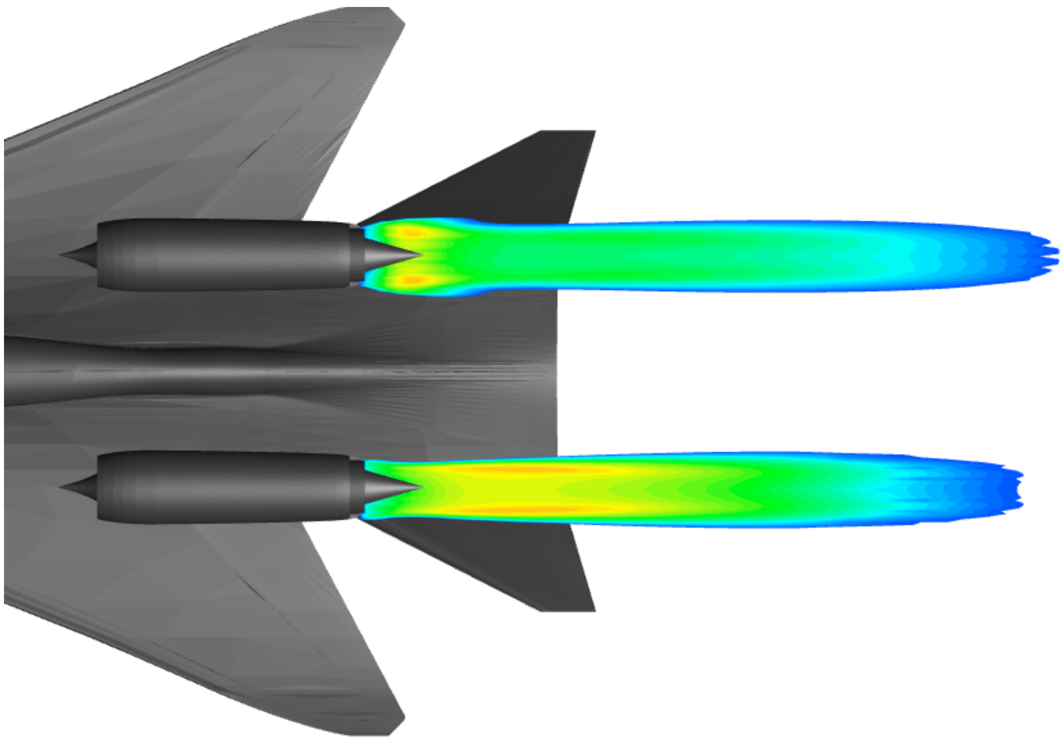


Noise sources

Conventional nozzles
Top-mount installation
—*Appreciable noise reduction.*

Modified nozzles, underbody installation

Observer view



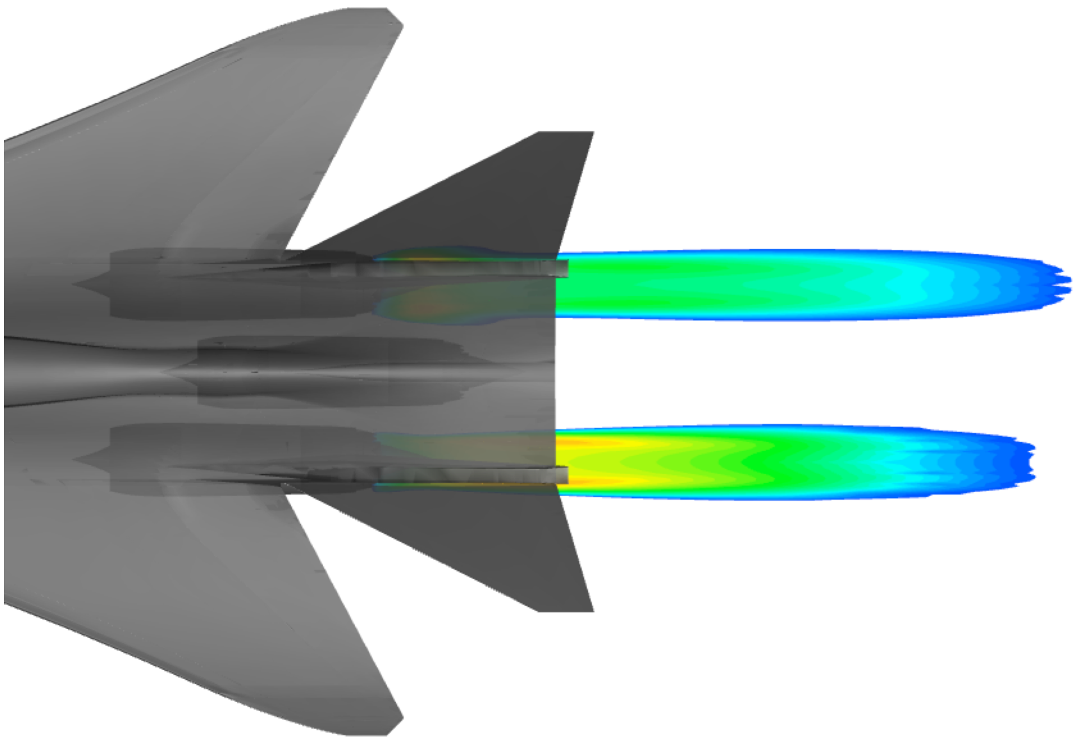
Noise sources

Chevron nozzles
Conventional installation
—*Shift source distribution.*

Conventional nozzles
Conventional installation

Nozzle Modifications + Shielding

Observer view

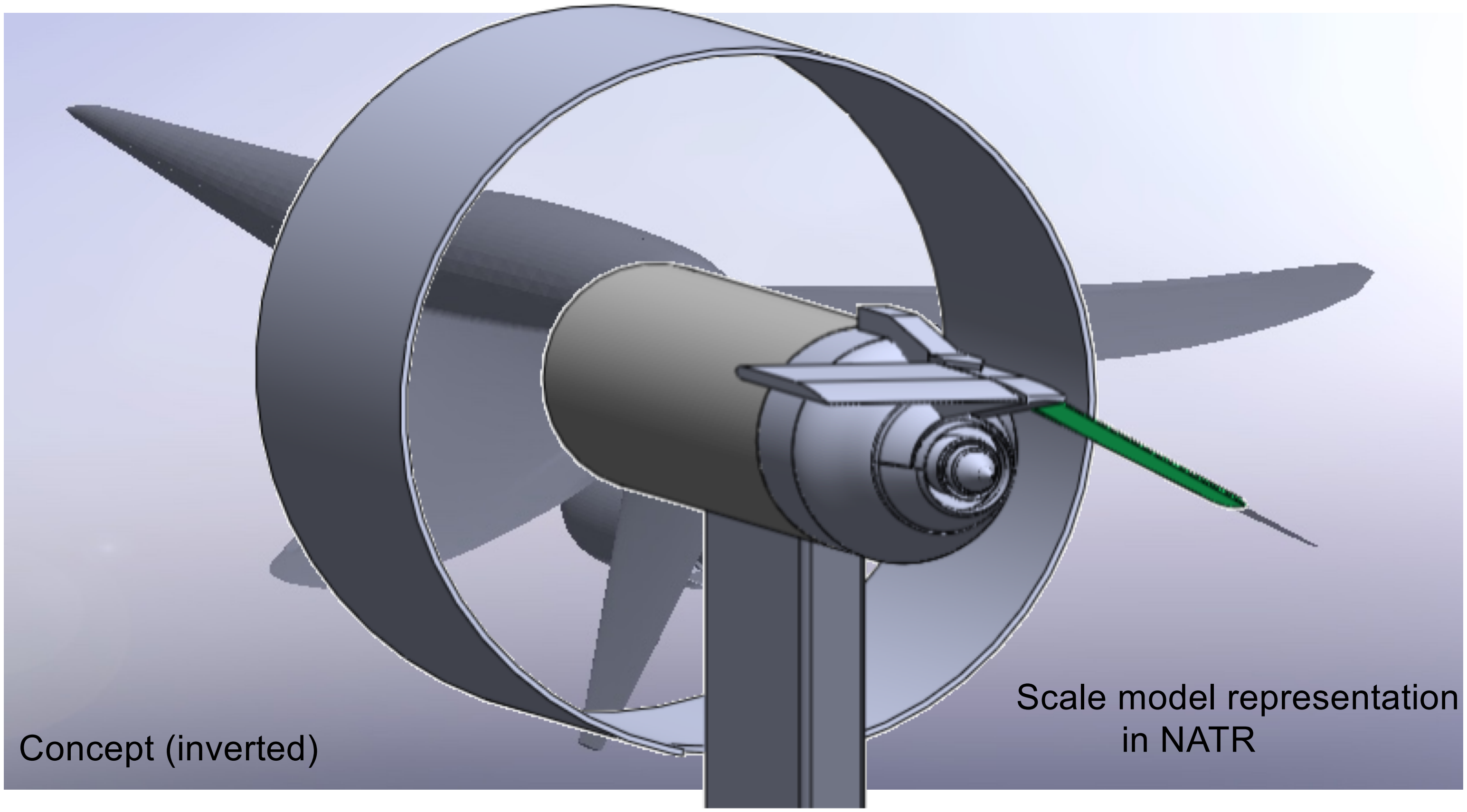


Noise sources

Chevron nozzles
Top-mount installation
—*Quietest design.*

Conventional nozzles
Top-mount installation

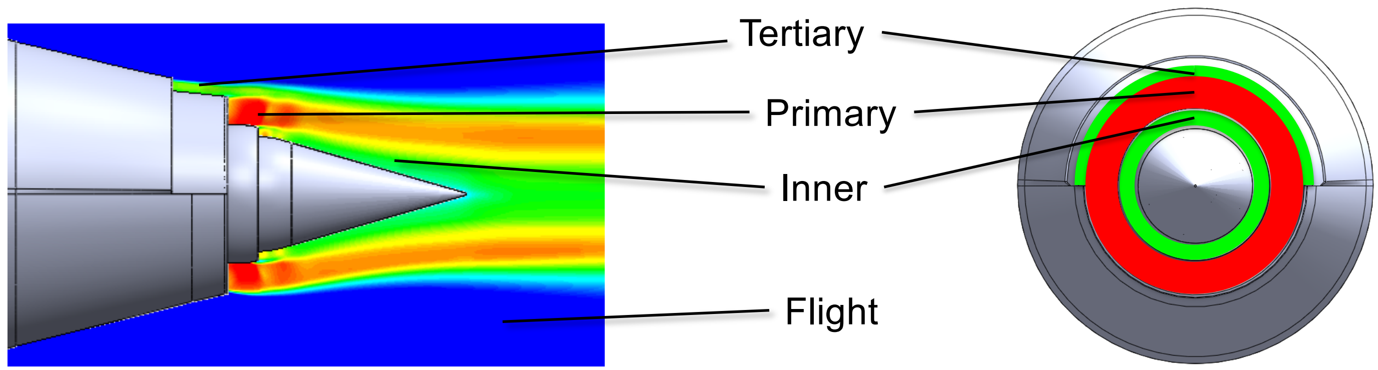
From Concept to Test Article



Test articles—Nozzles

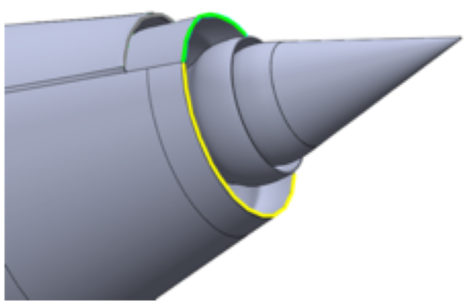
- Nozzles
  - Inverted velocity nozzle with 180° tertiary stream

Engine cycle:
1.4 < NPRprimary < 2.6
1.6 < NTRprimary < 2
1.7 < NPRinner < 1.9
1.2 < NTRinner = 1.25
0 < Mflight < 0.35

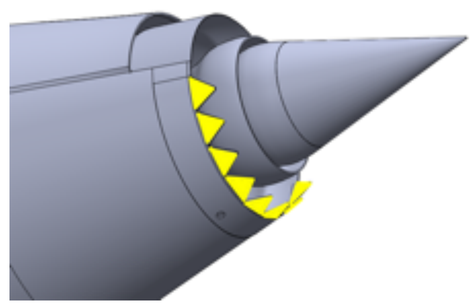


- Lip treatments

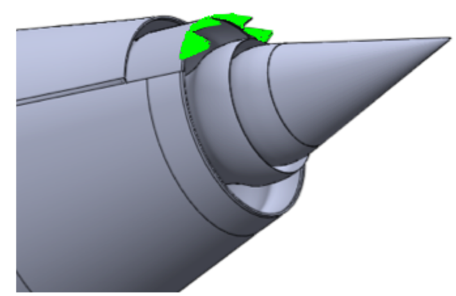
Baseline



Primary-flight

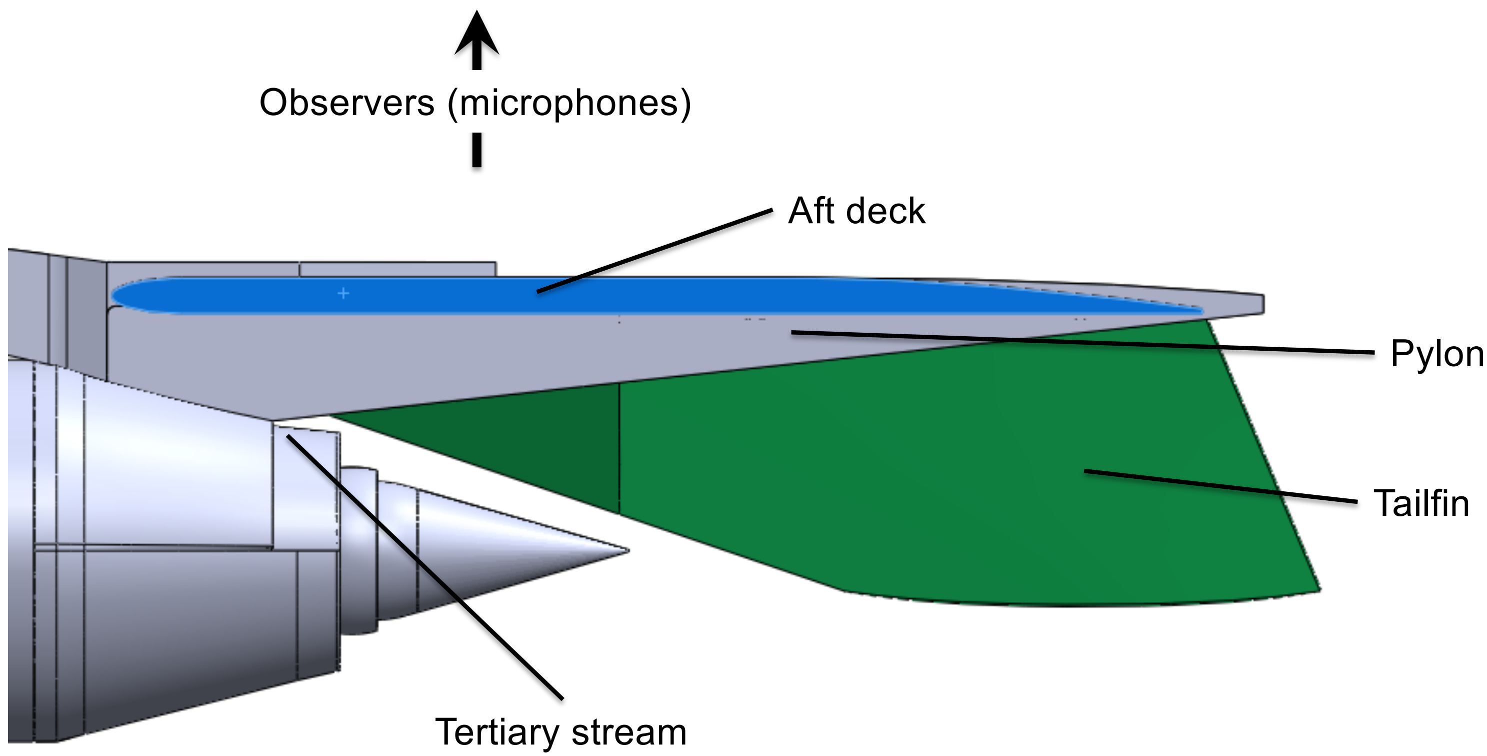


Primary-tertiary



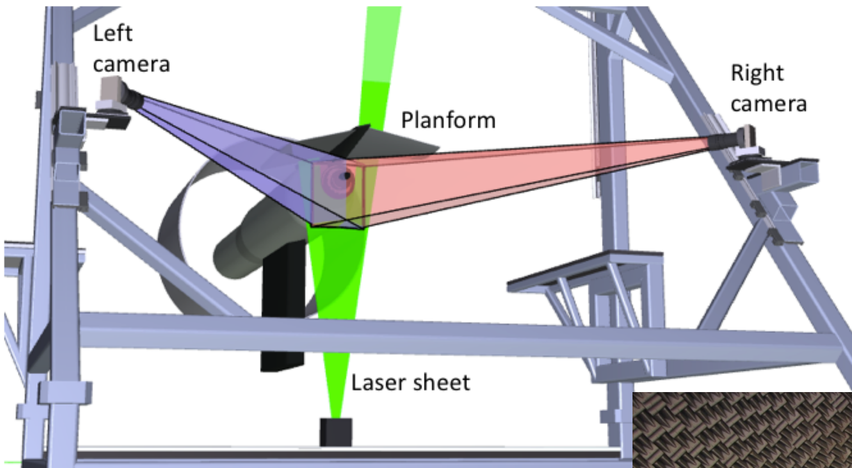
Test articles—Planform

- Planform

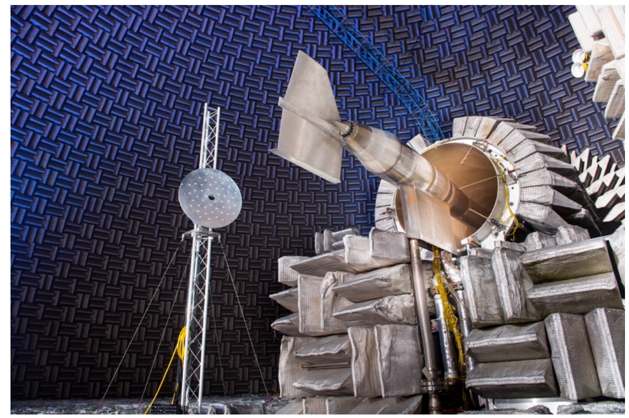


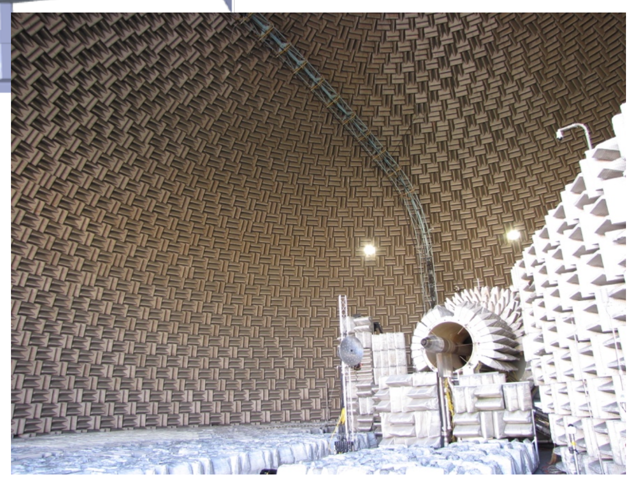
Test instrumentation

Stereo PIV



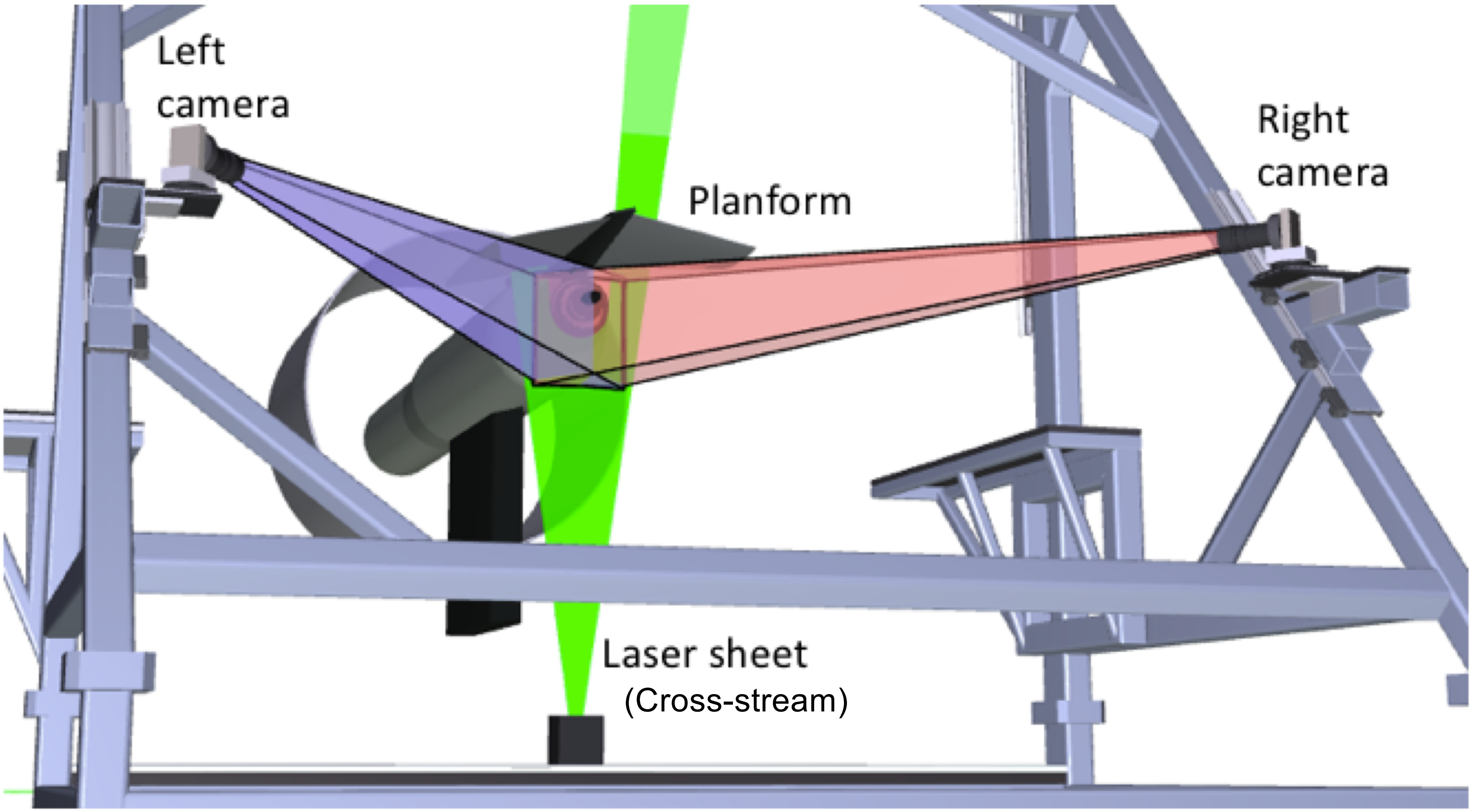
Translating phased array





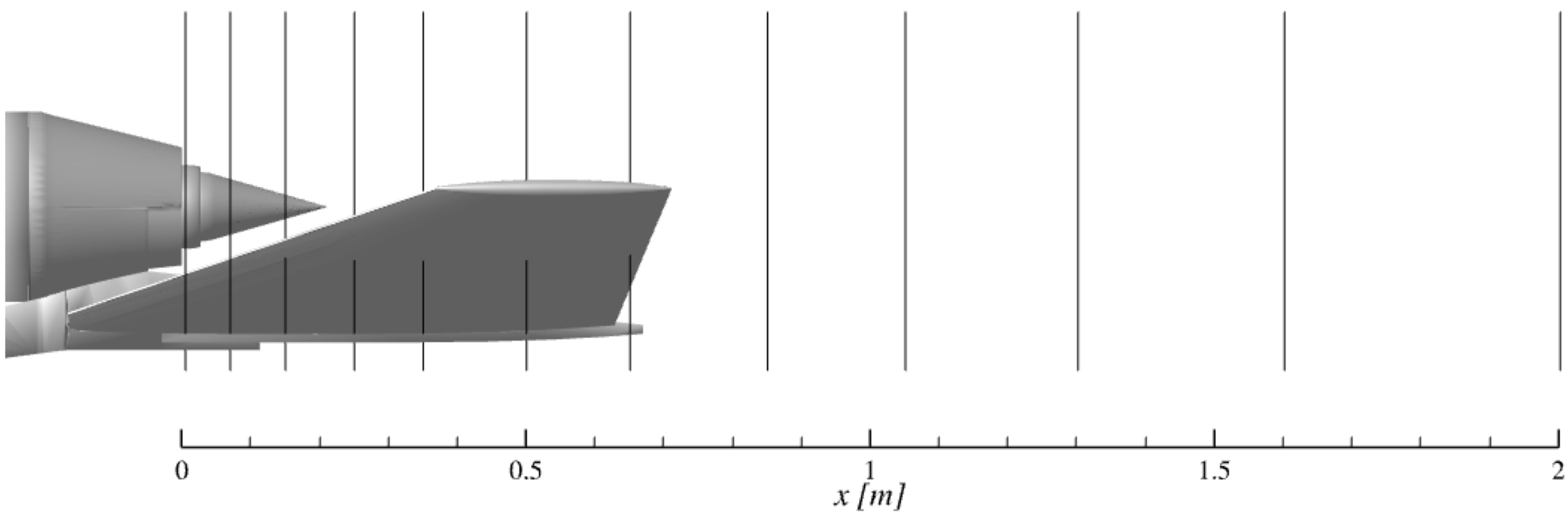
Far-field acoustics

Stereo PIV


Left camera
Planform
Right camera
Laser sheet
(Cross-stream)

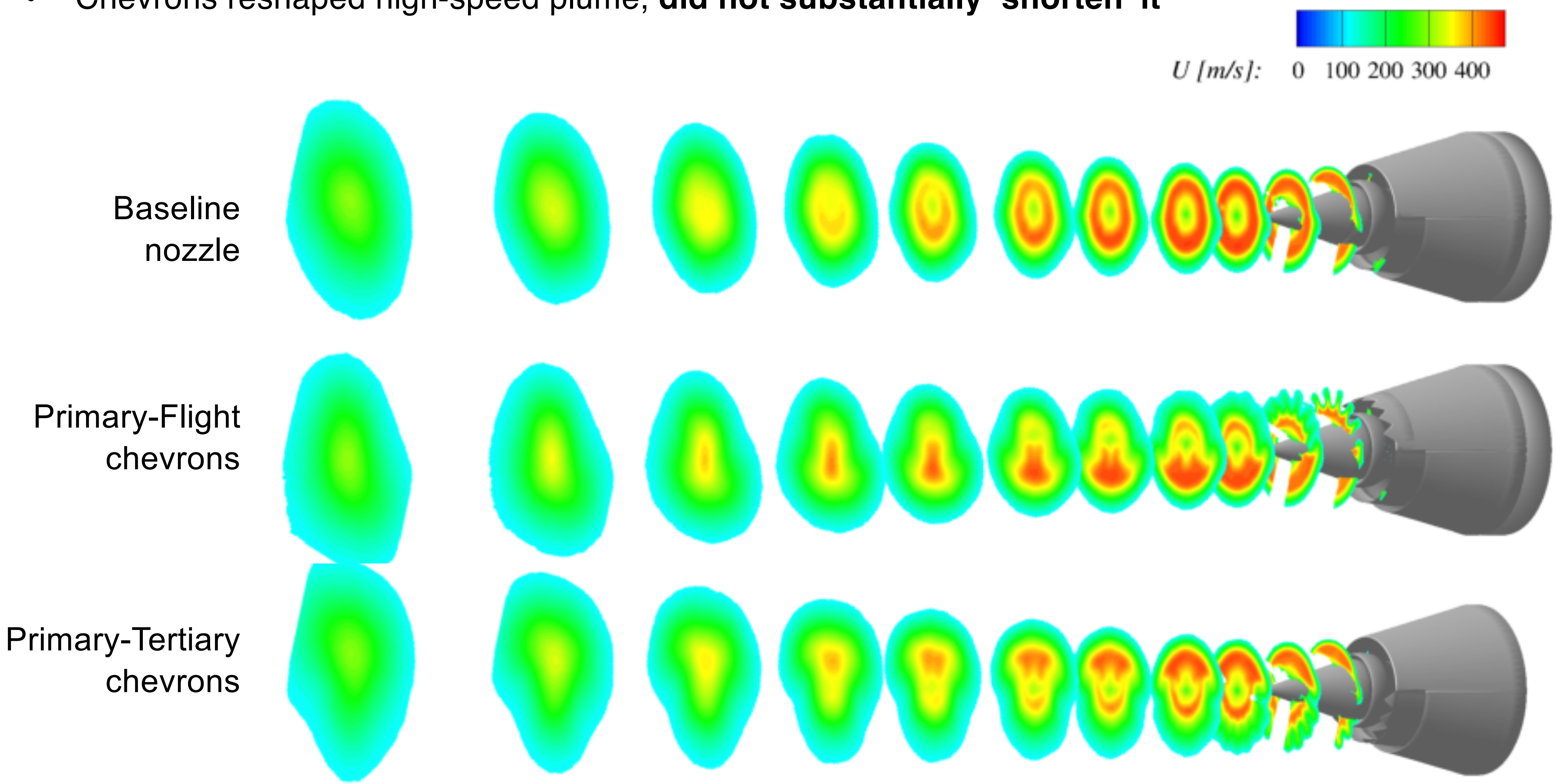
PIV measurement locations

- Axial locations measured relative to baseline primary nozzle exit.
- Visual blockage (lightsheet, one or both cameras) significant near nozzle.



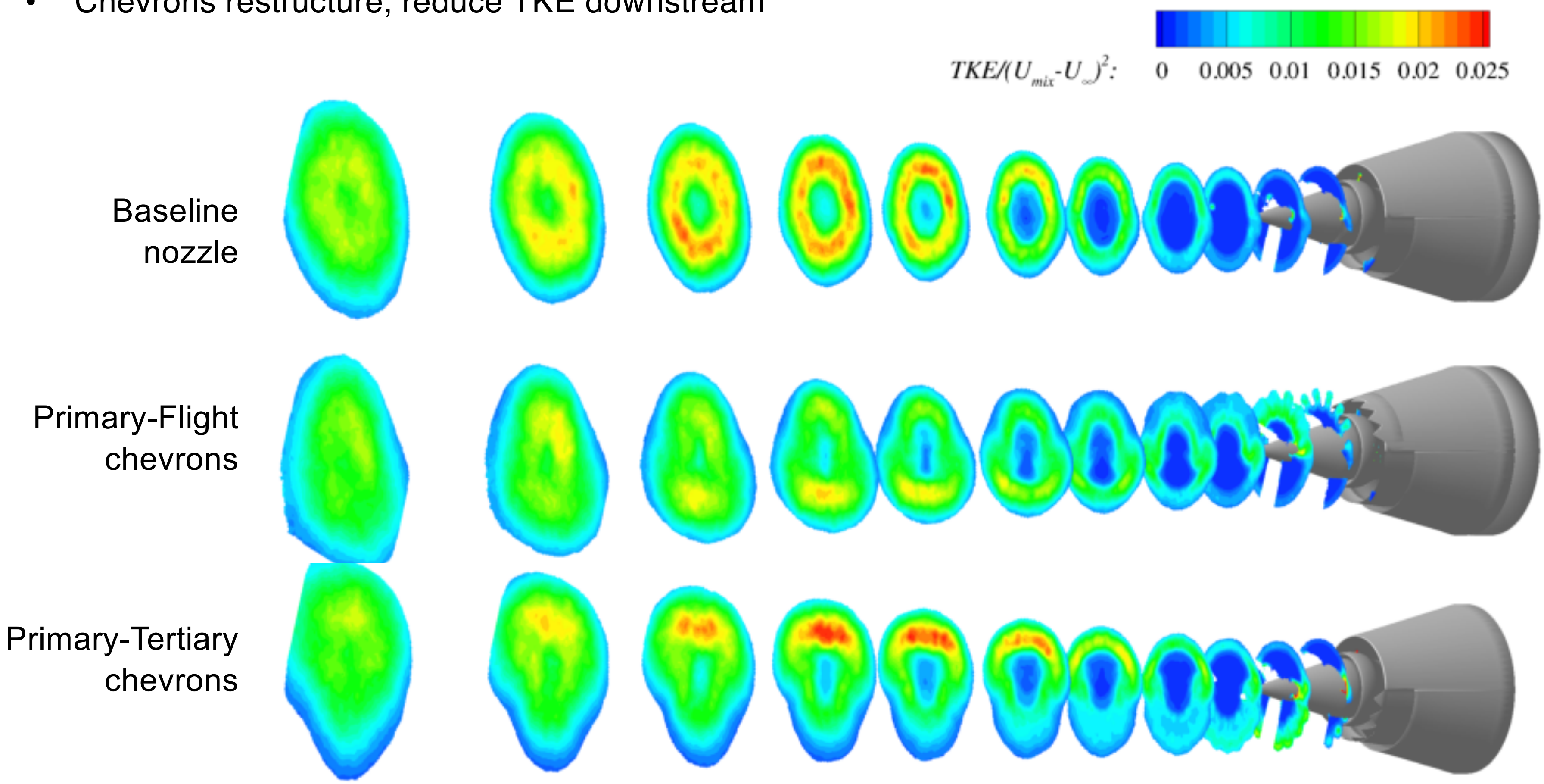
Effect of chevrons on mean velocity—isolated nozzle

- Chevrons reshaped high-speed plume, **did not substantially 'shorten' it**



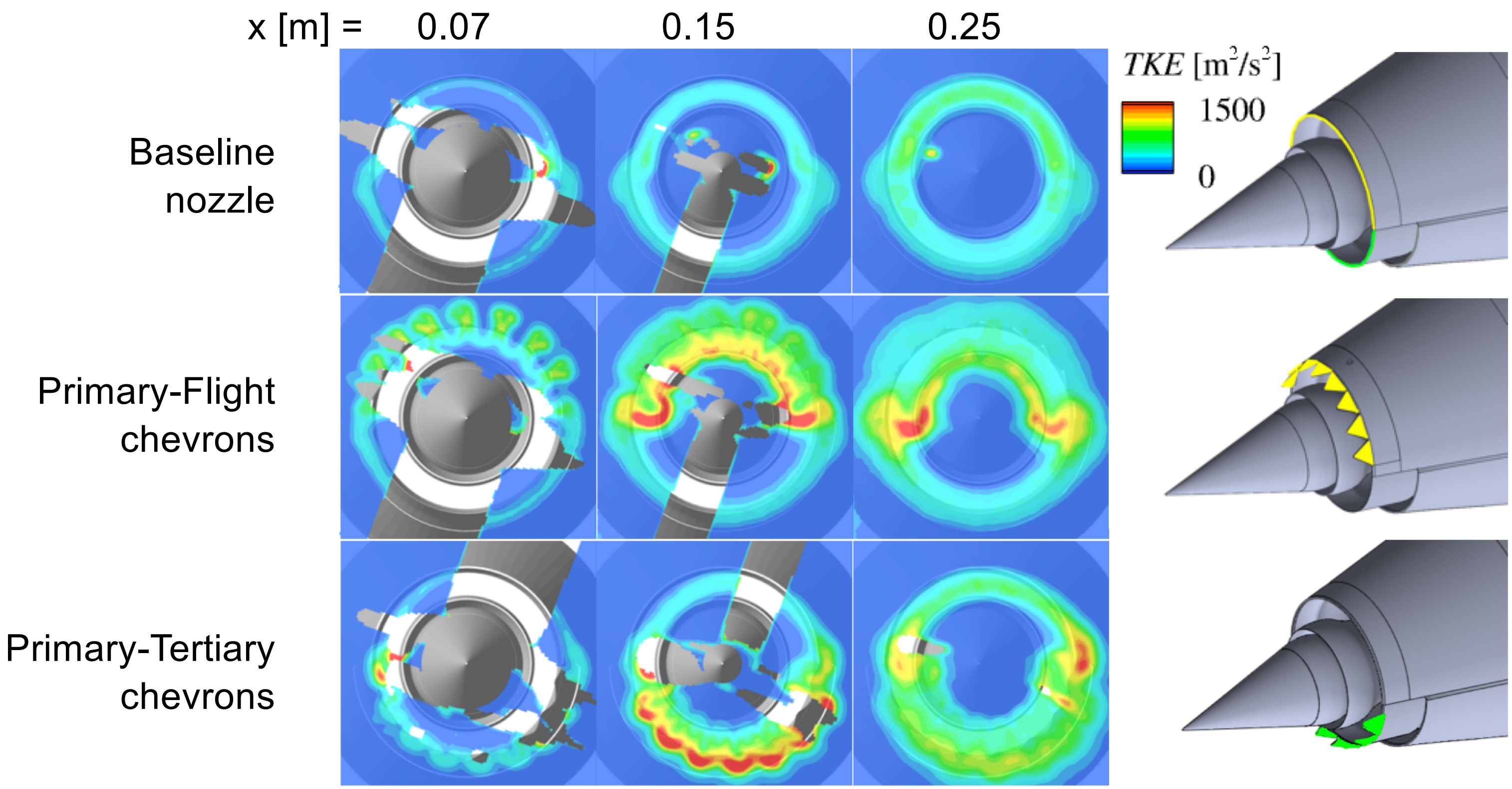
Effect of chevrons on TKE—isolated nozzle

- Chevrons restructure, reduce TKE downstream



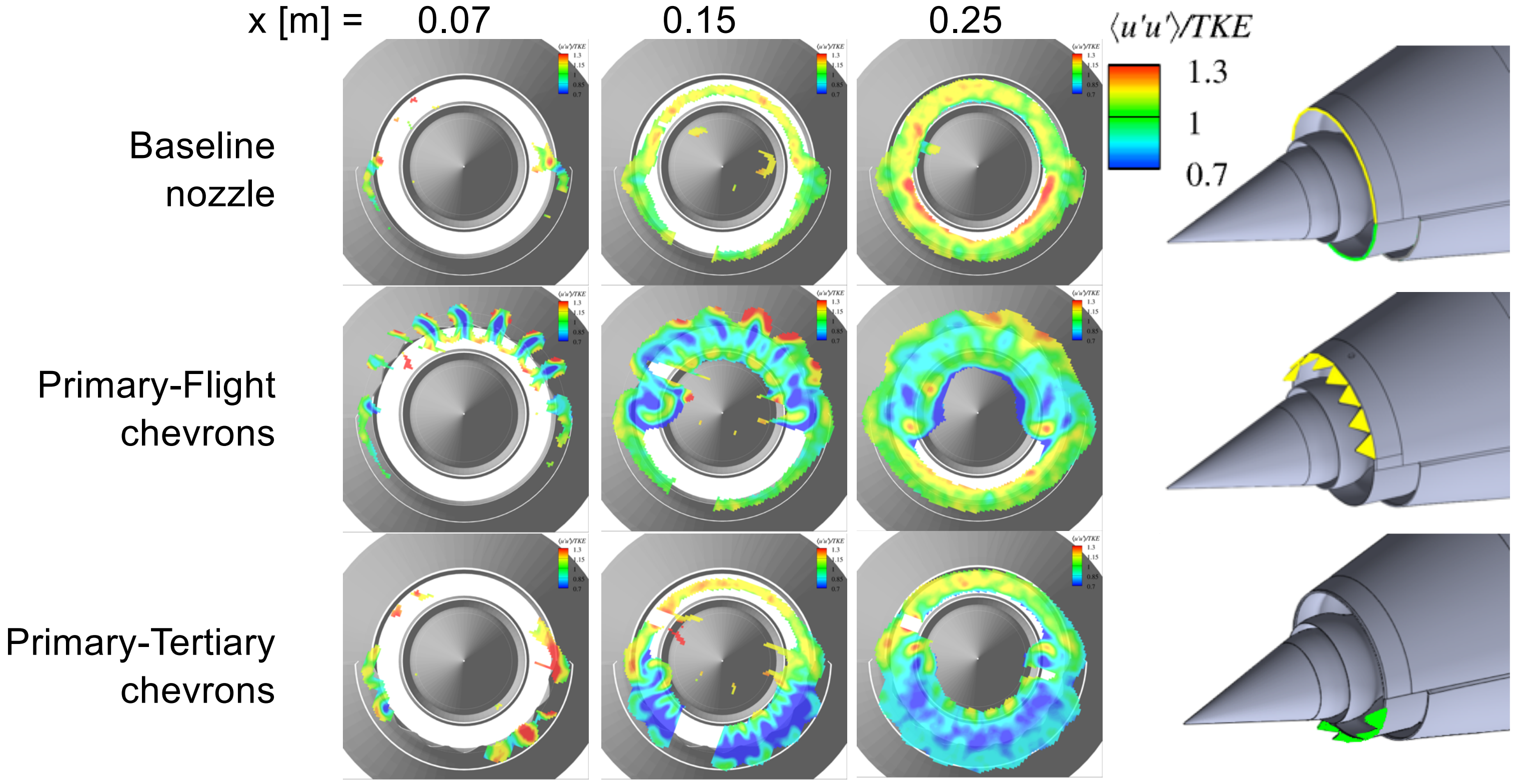
Impact of chevrons near nozzle

- Chevrons produce convoluted shear layers with enhanced TKE



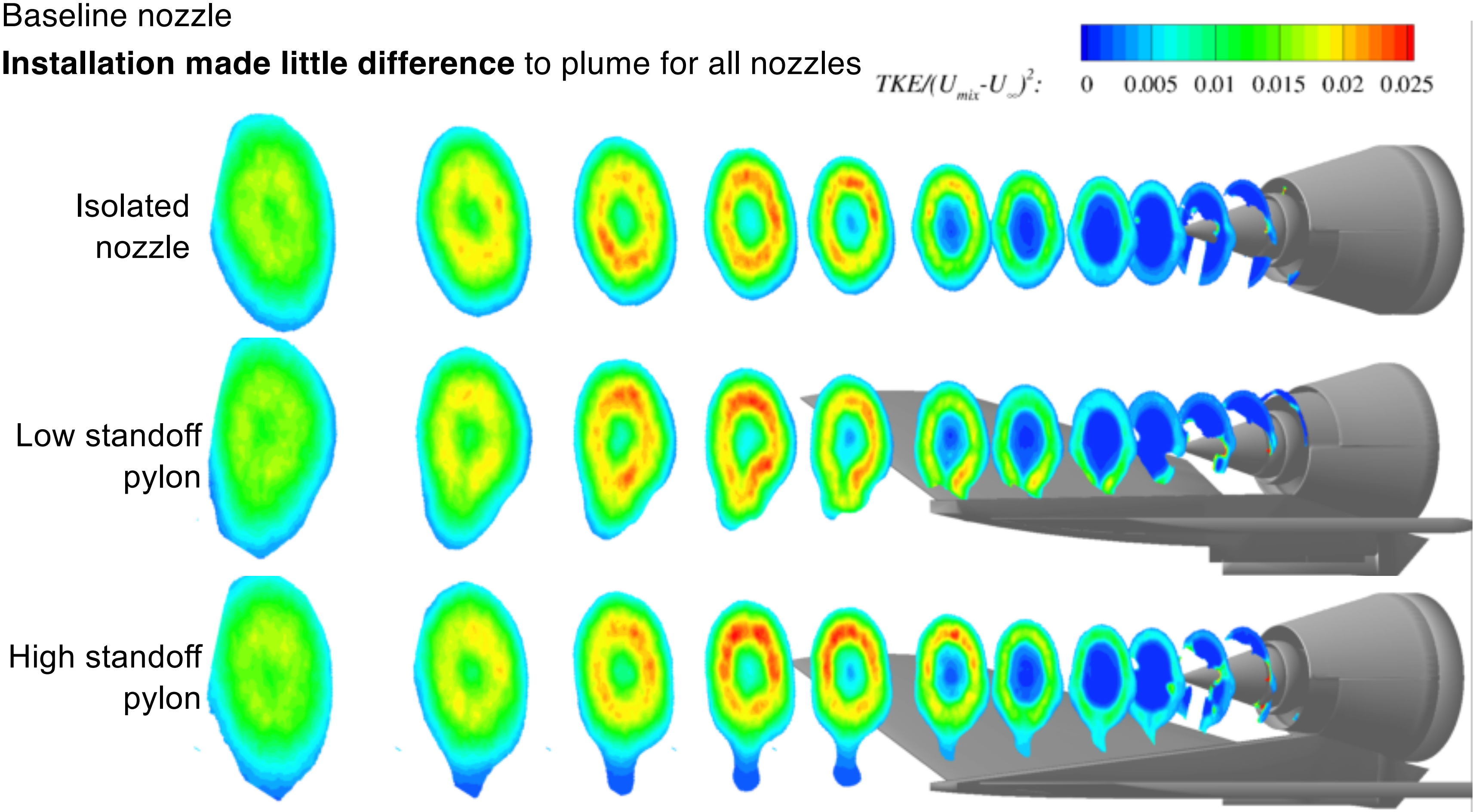
TKE anisotropy with chevrons

- In fully developed turbulence, $\frac{\langle u'u' \rangle}{\langle v'v' \rangle + \langle w'w' \rangle} \cong 1.$ $\therefore \frac{\langle u'u' \rangle}{TKE} = 1.$ Near chevrons $\frac{\langle u'u' \rangle}{TKE} \cong 0.8$
- **TKE produced by chevrons has strong transverse component; more efficient acoustically?**



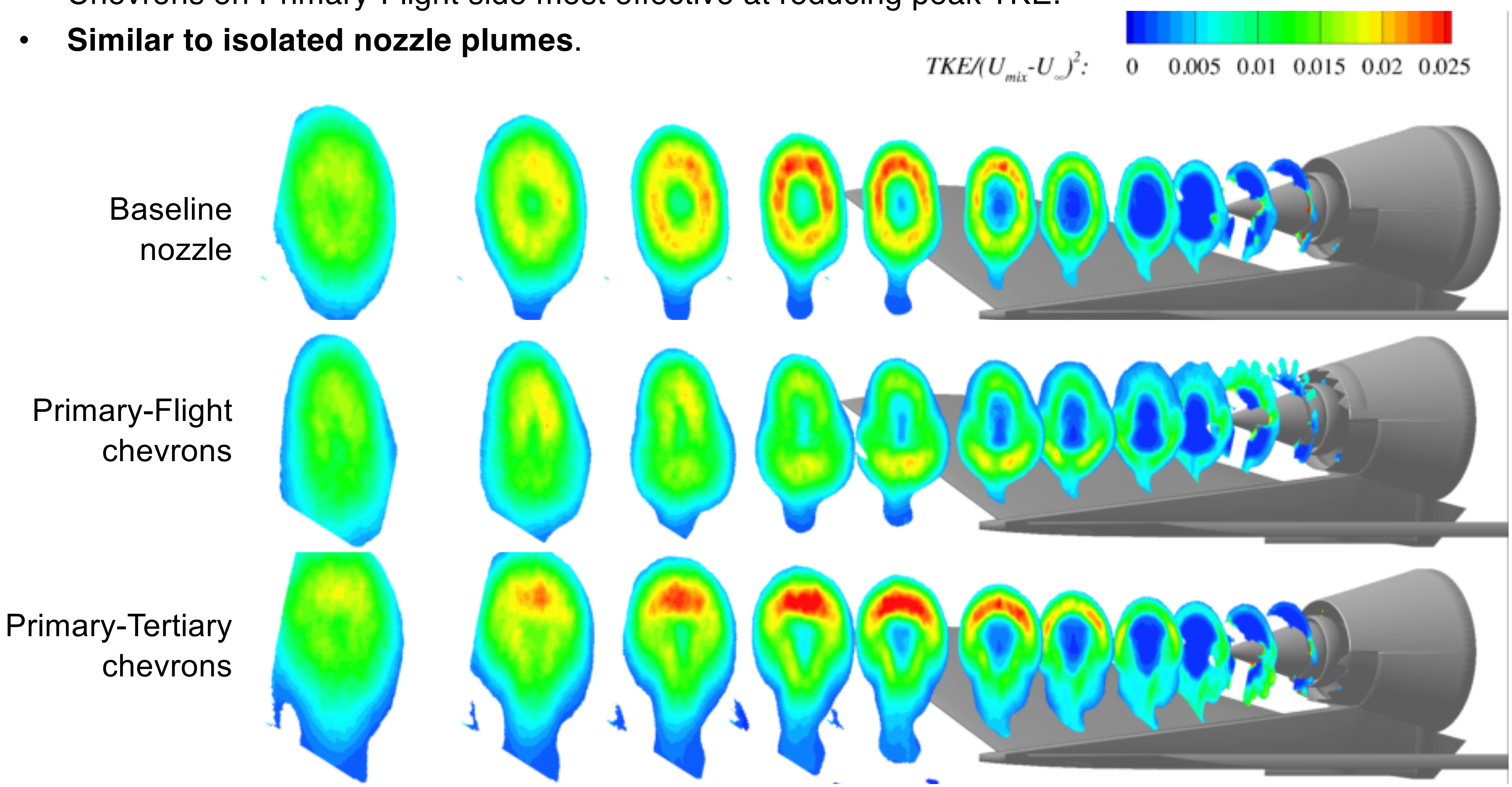
Effect of pylon standoff—TKE

- Baseline nozzle
- **Installation made little difference** to plume for all nozzles



Comparison of chevron placements — TKE

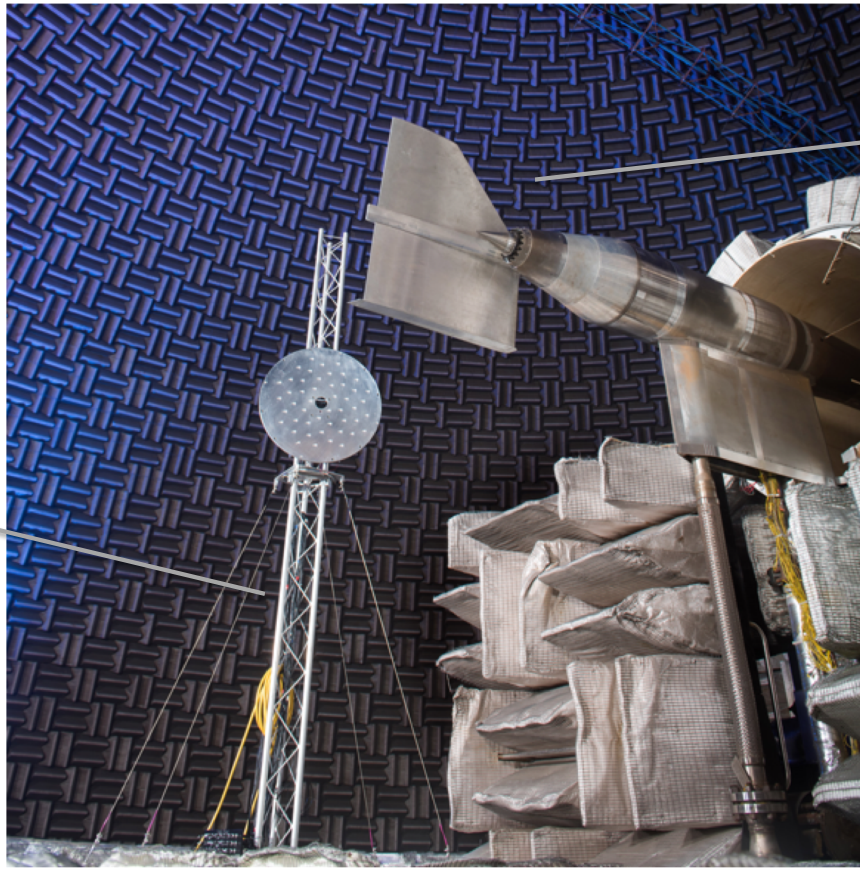
- Chevrons on Primary-Flight side most effective at reducing peak TKE.
- **Similar to isolated nozzle plumes**.



PIV Summary

- Peak TKE for IVP baseline nozzle scales similarly to static single-stream jets using U_{mix} for high-speed velocity and flight speed as low-speed velocity.
- **Chevrons** increase the **cross-stream components of TKE**, potentially changing sound source directivity.
- Chevrons did not substantially shorten jet plume.
- Chevrons did increase TKE near the chevrons, redistribute TKE further downstream.
- Chevrons on one side of nozzle lowered TKE on that side, increased it on other.
- **Installation had little impact on jet plume!**

Translating Phased Array

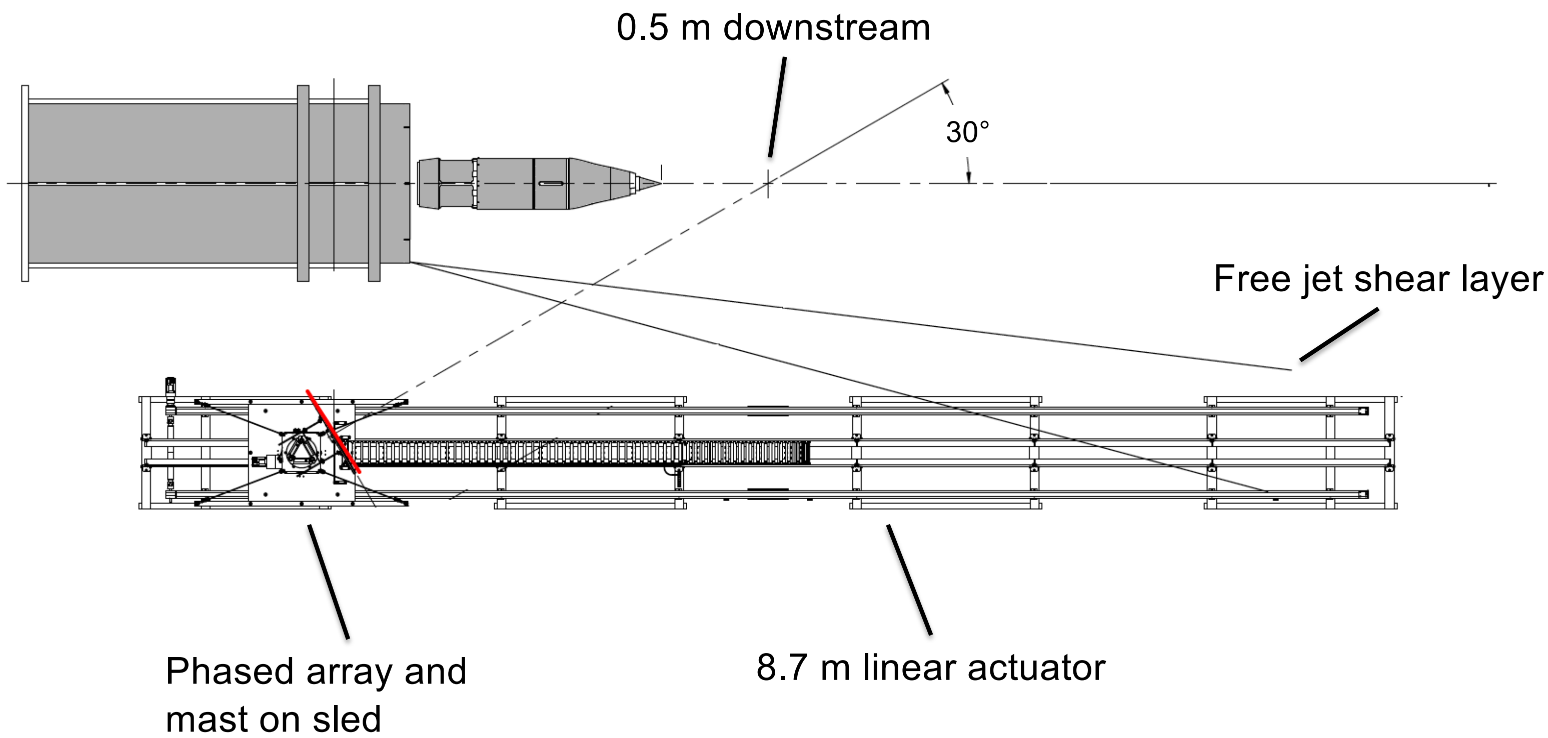


Planform rotated so array is “below” the model

Array mounted on rotating mast

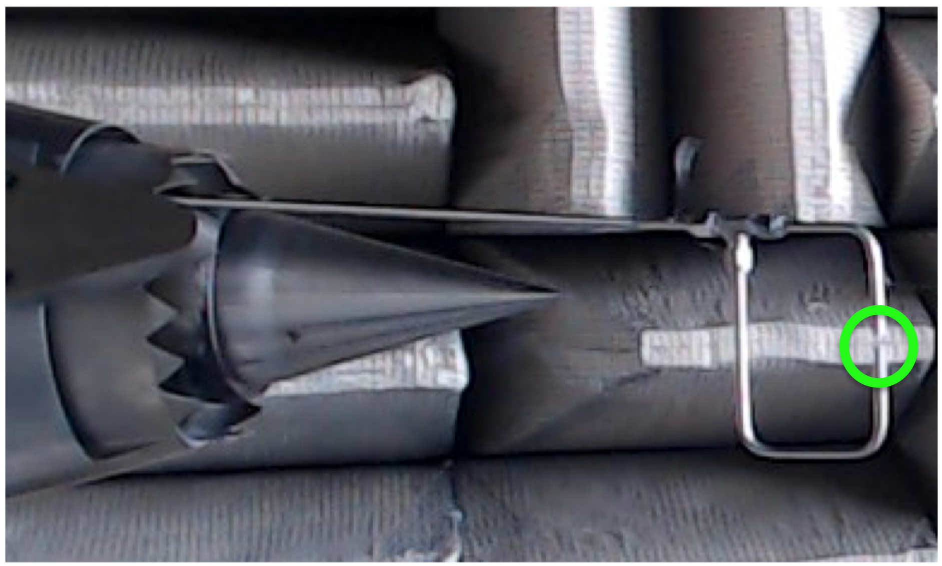
Translating Phased Array

Array shown at 30º polar location



Registration – Noise Source

- Impinging jet noise source supplied by shop air
- 250 mm downstream of the nozzle plug
- Impinging flows generate a loud broadband noise source with well known location



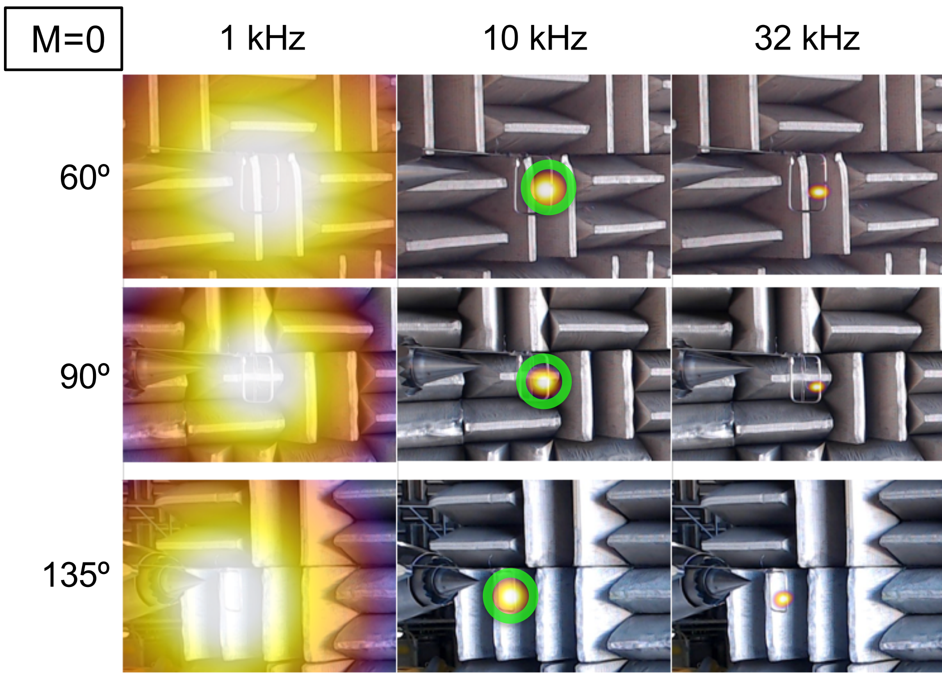
Registration – Free-stream M 0.2

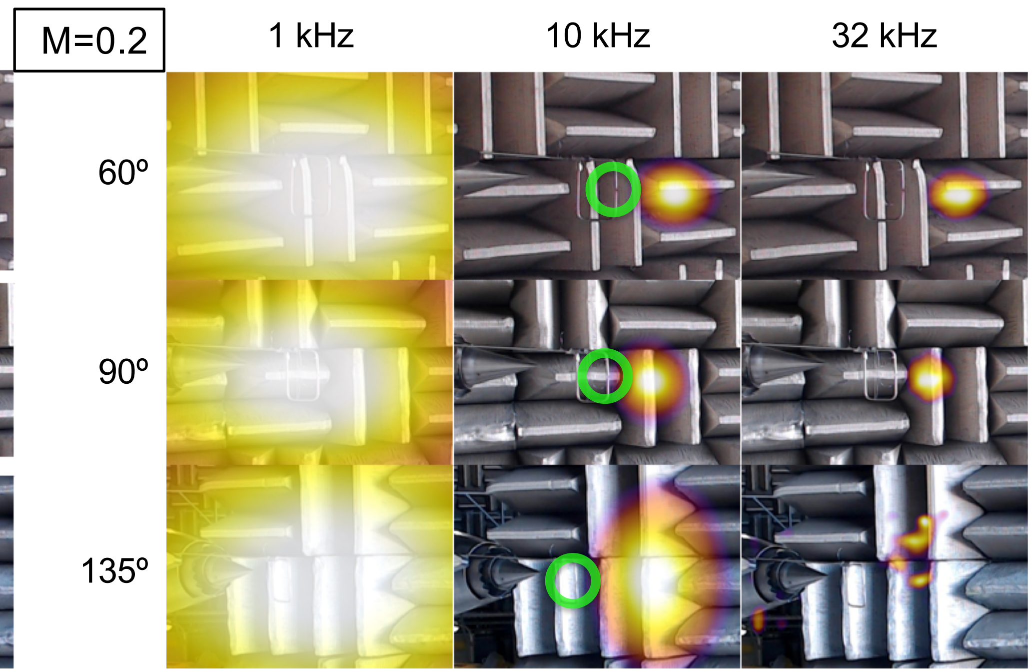
No Free-Stream Flow

- Mapped to parallel image plane
- Source accurately located

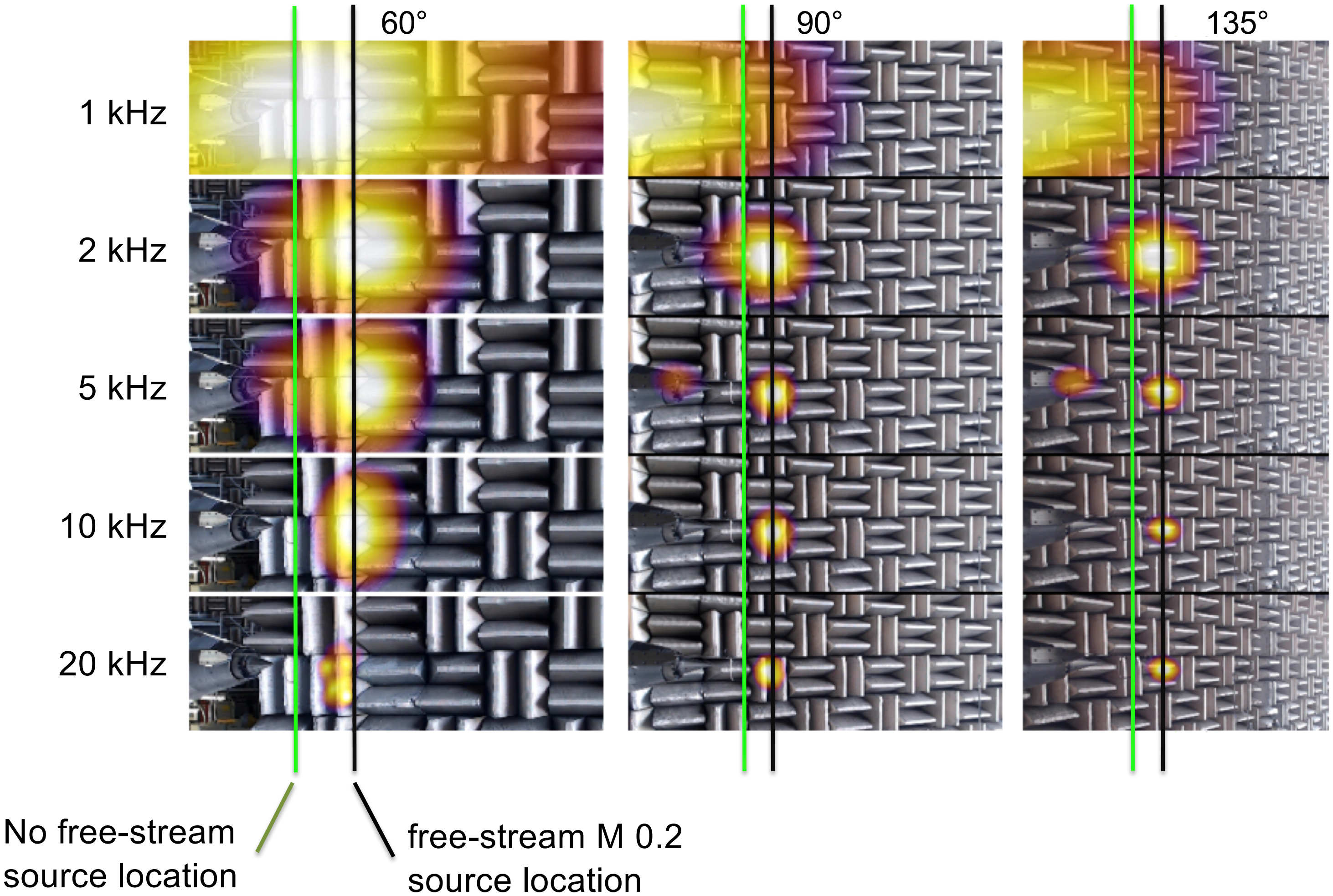
Mach 0.2 Free-Stream Flow

- Mapped to parallel image plane
- Source offset downstream

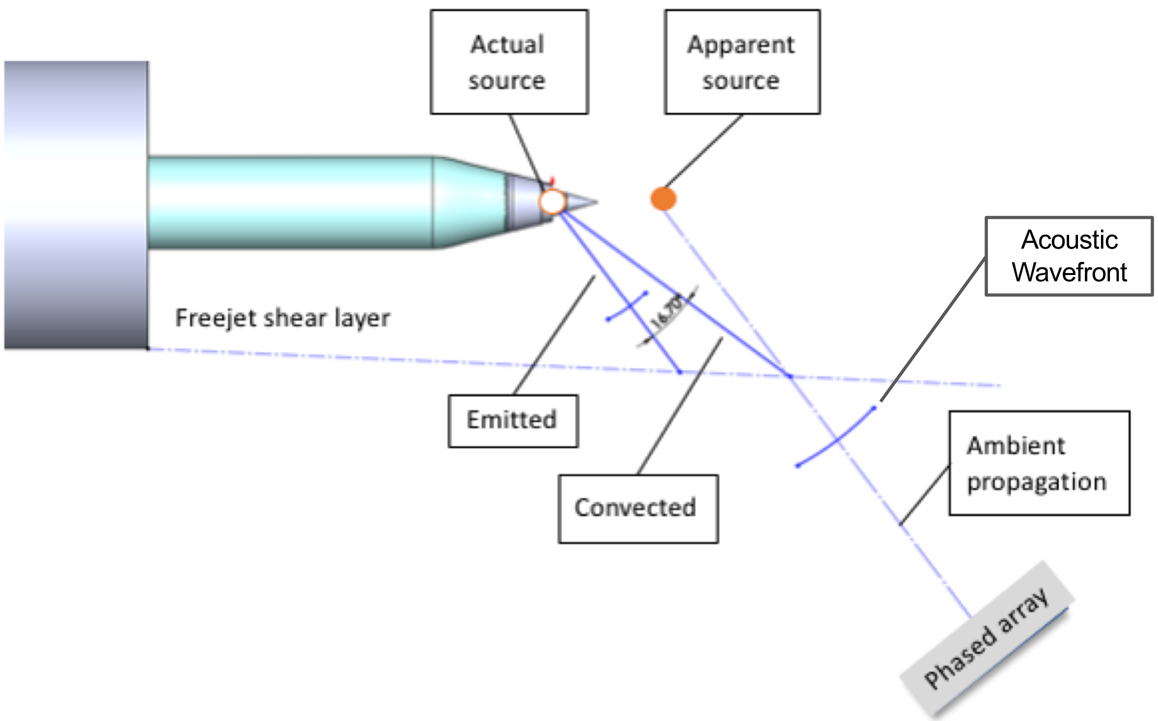




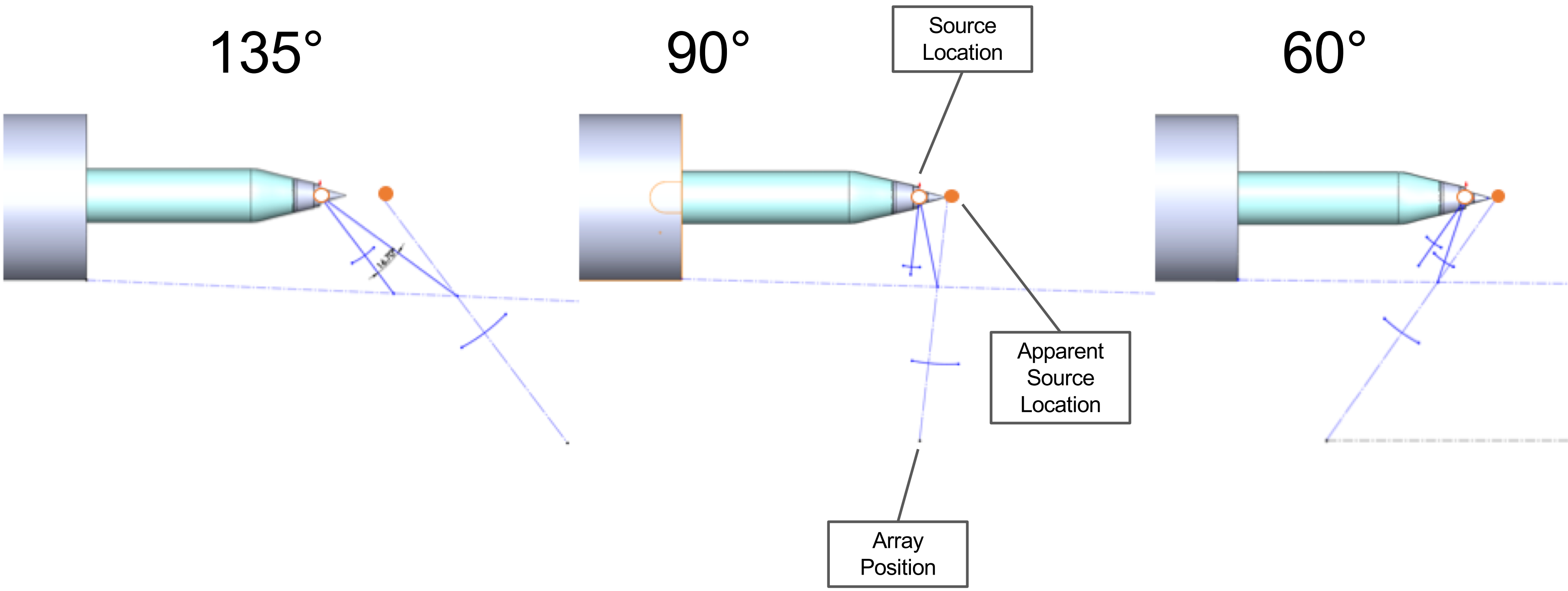
Registration Map Displacement – Free-stream M 0.2



Beamform Map Displacement

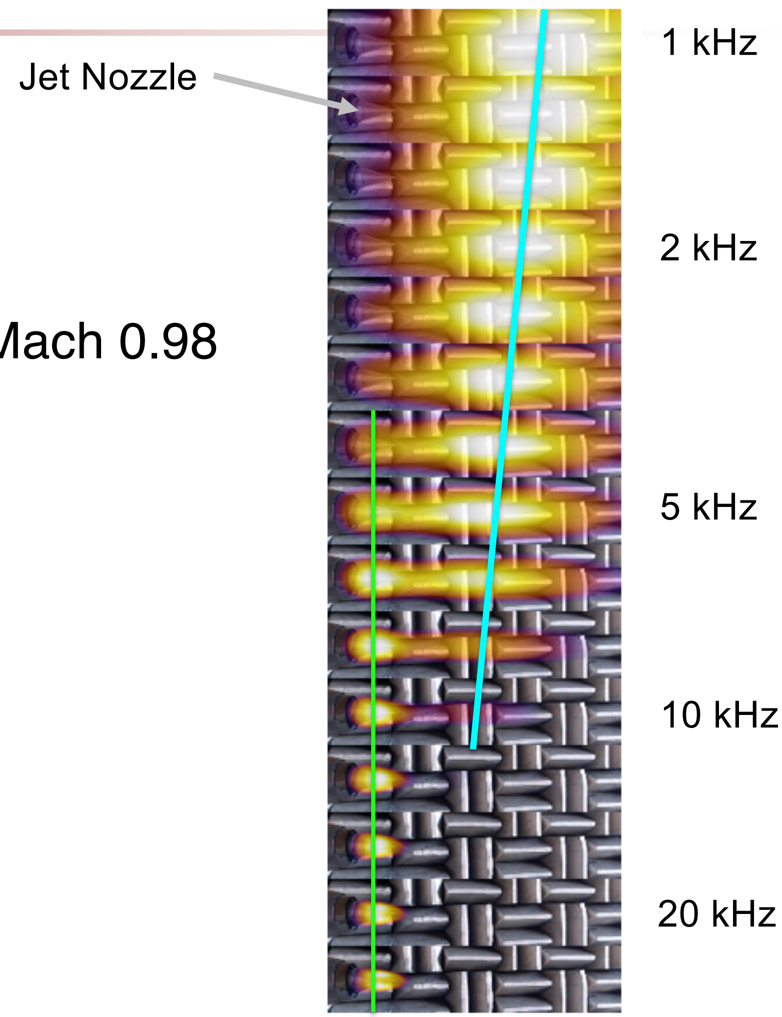


Beamform Map Displacement



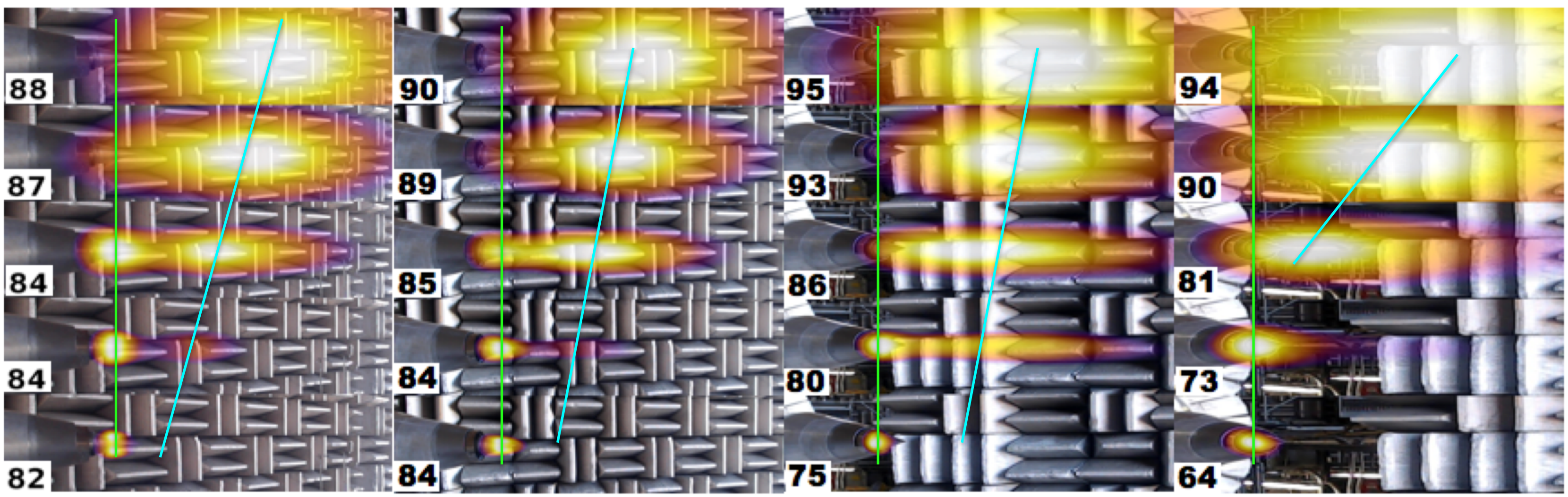
Simple Jet Flow Beamforming

- Primary flow nozzle operating at Mach 0.98
- No free-stream flow
- Array at 90°
- 2 main source regions are visible
  - "plume"
  - "nozzle-locked"

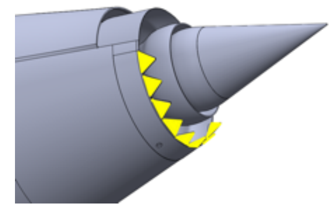


Single-Stream Jet Flow Beamforming

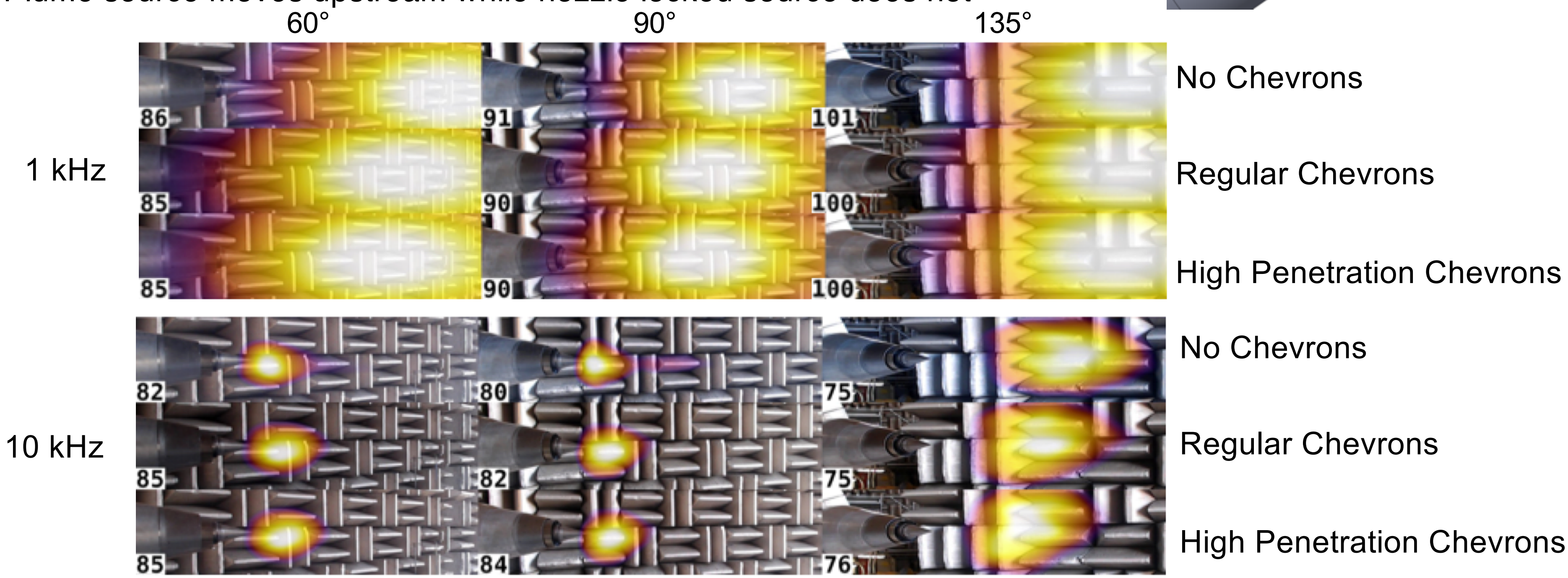
- Primary flow nozzle operating at Mach 0.98
- No free-stream flow
- 4 Polar angles
- 2 sources visible from upstream angle but become visually inseparable from downstream angles



Impact of Chevrons

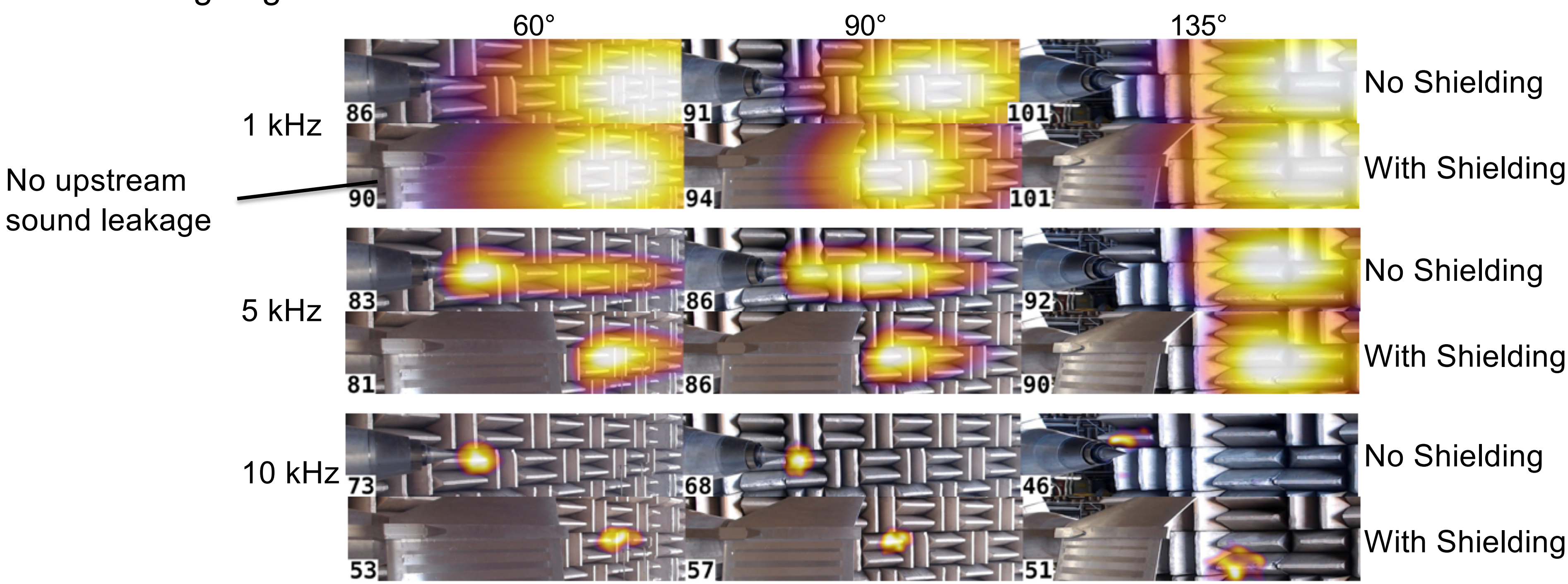


- Primary Mach 1.05, Tertiary Mach 0.95, freestream Mach 0.3
- Chevrons applied between primary and flight stream
- Plume source moves upstream while nozzle locked source does not



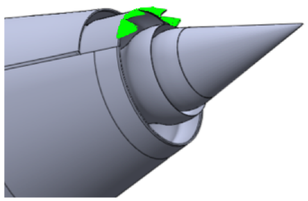
Planform Effects

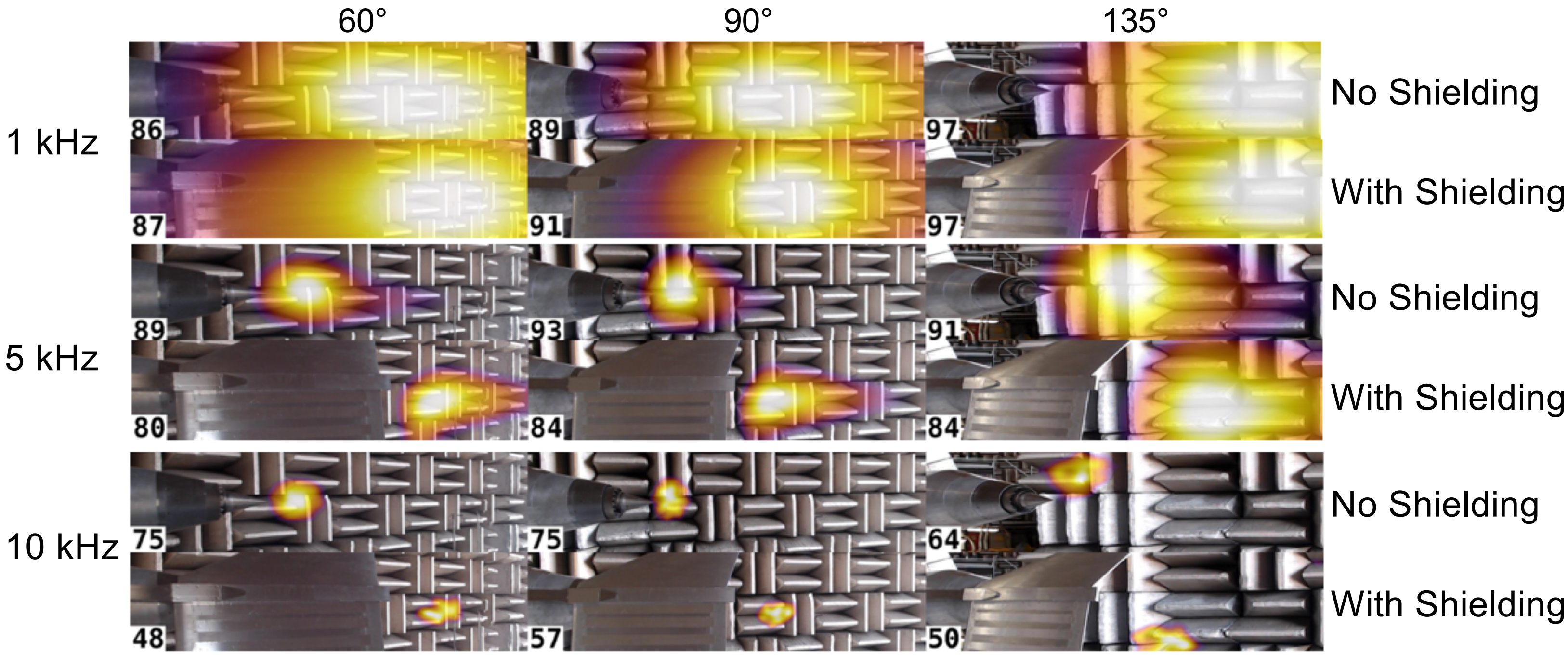
- Primary Mach 1.05, Tertiary Mach 0.95, freestream Mach 0.3
- Planform effectively blocks the nozzle-locked source but the plume source is mostly unmitigated
- Trailing edge noise visible at 5 kHz



Planform Effects

- Primary Mach 1.05, Tertiary Mach 0.95, freestream Mach 0.3
- Chevrons installed between primary and tertiary stream
- Plume source is moved upstream and more effectively shielded by the planform

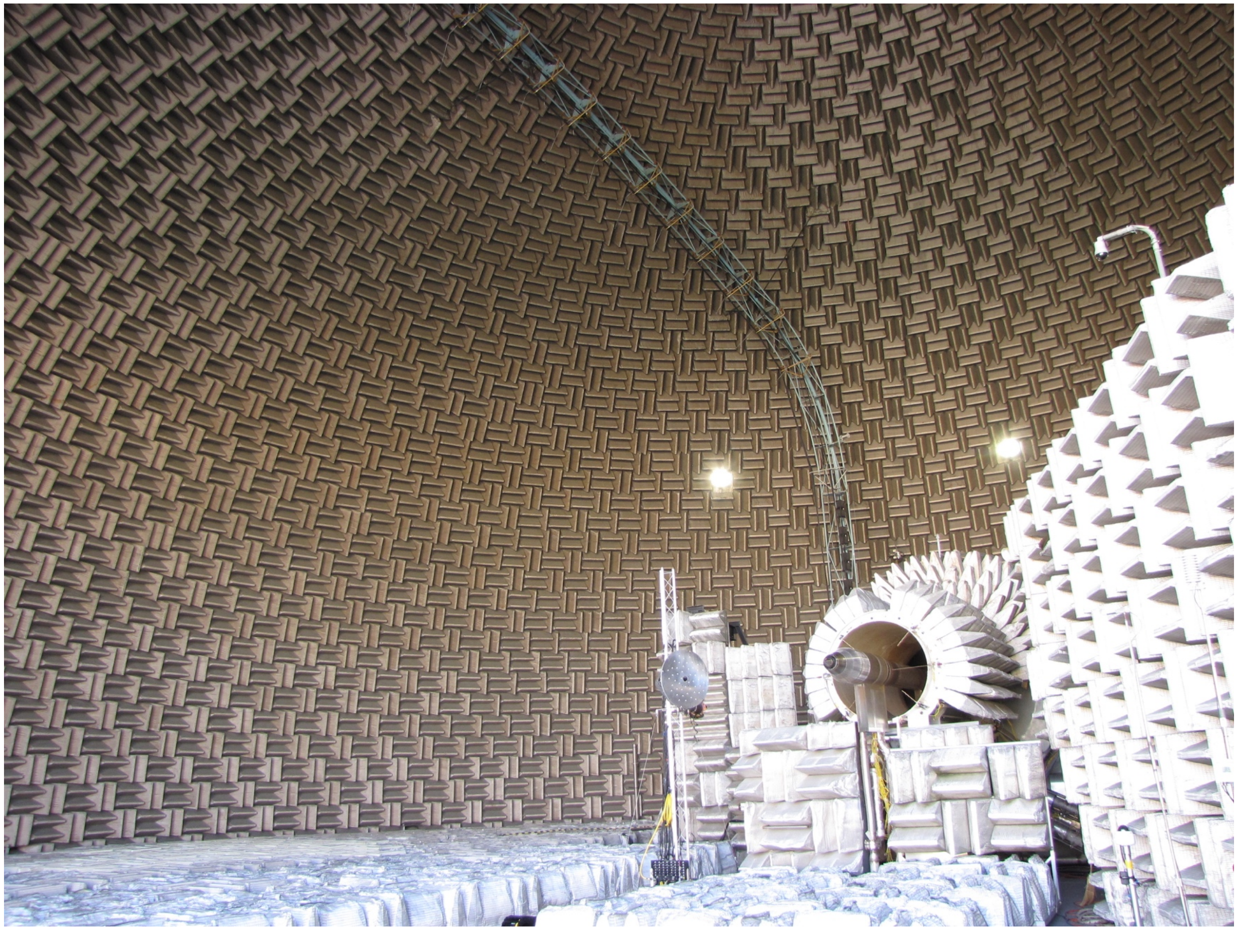




Phased Array Conclusions

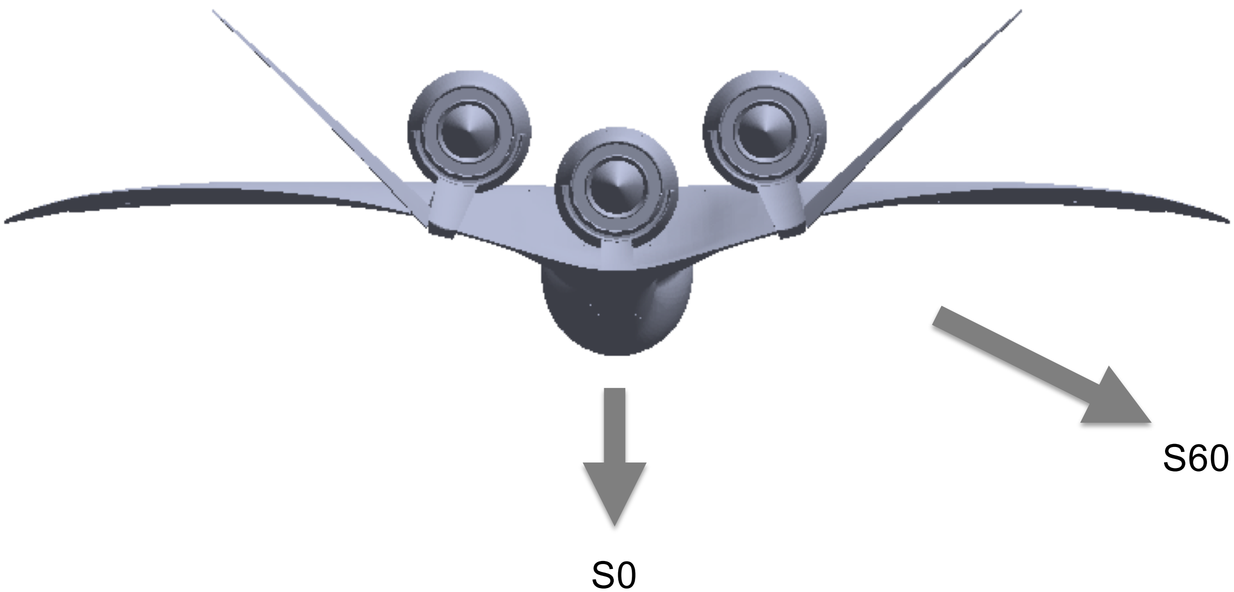
- The **Translating Phased Array** allows for **different perspectives** during an experimental run, increasing the breadth of information that can be extracted from beamforming on jet plume noise sources.
- The jet plume with center-body has **2 primary sour**ces, one locked to the **jet center-body** and one downstream in the **jet plume**.
- The model planform **does not have acoustic leakage** around the upstream end and so is simulating the full aircraft body acoustically.
- **Acoustic shielding** by an aircraft planform can **substantially alter the peak noise** source levels observed, particularly for sideline angles.
- The use of **chevrons** at various locations on the nozzle lip can be used to **shift the downstream source** further upstream, **increasing** the portion of the source that is **effectively shielded** by the aircraft planform, reducing noise directed toward observers on the ground below.

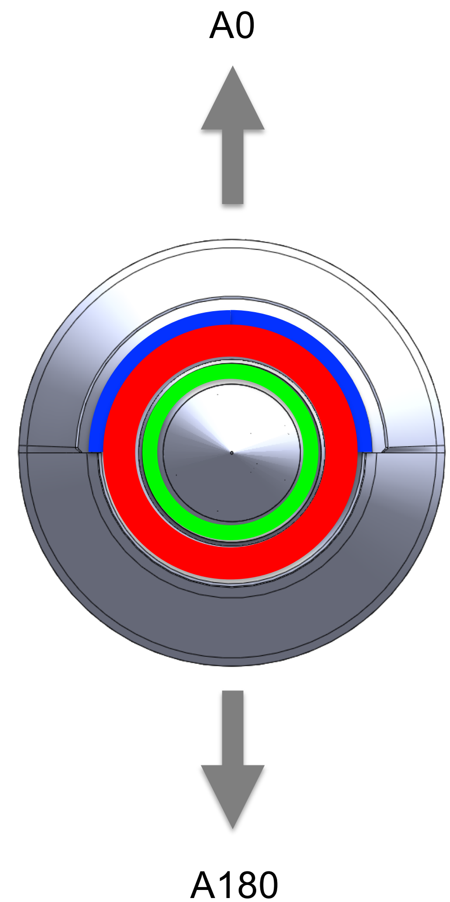
Far-Field Acoustics



Far-field observer angles

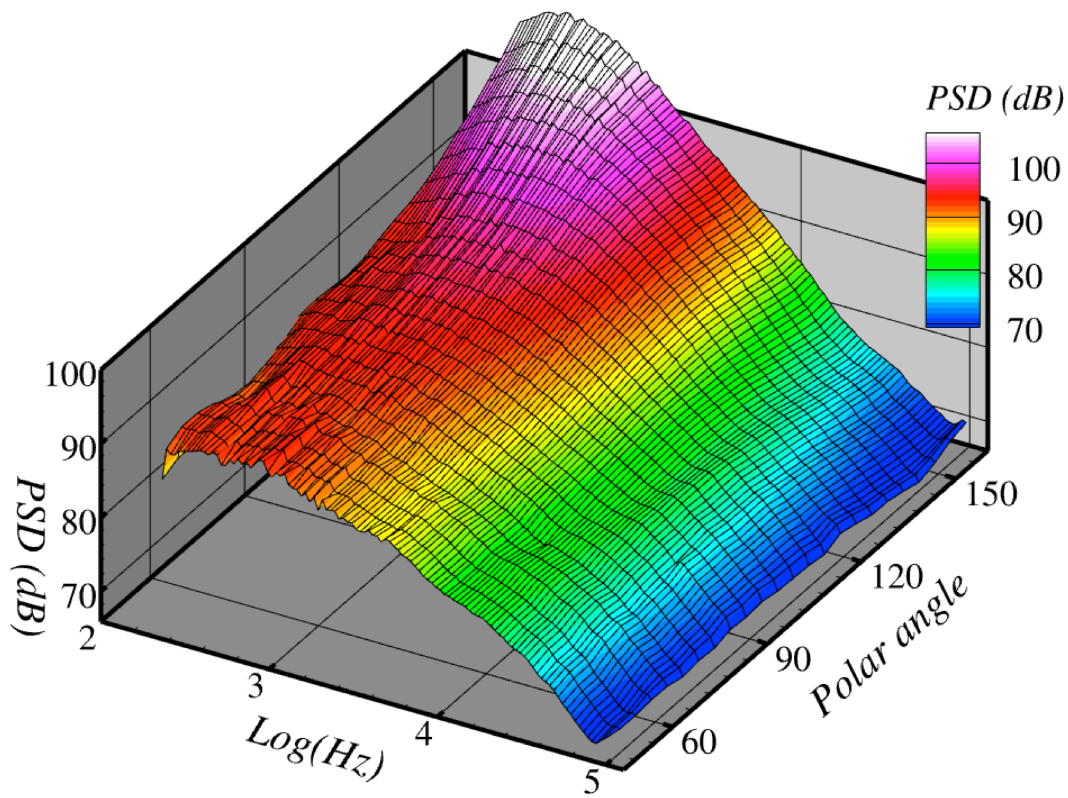
- Fixed overhead polar arc, 45° – 160° from flight axis; r/De = 93
- Rotating nozzle, planform
  - Flyover and sideline certification observers
  - Measure asymmetry of noise from isolated nozzle





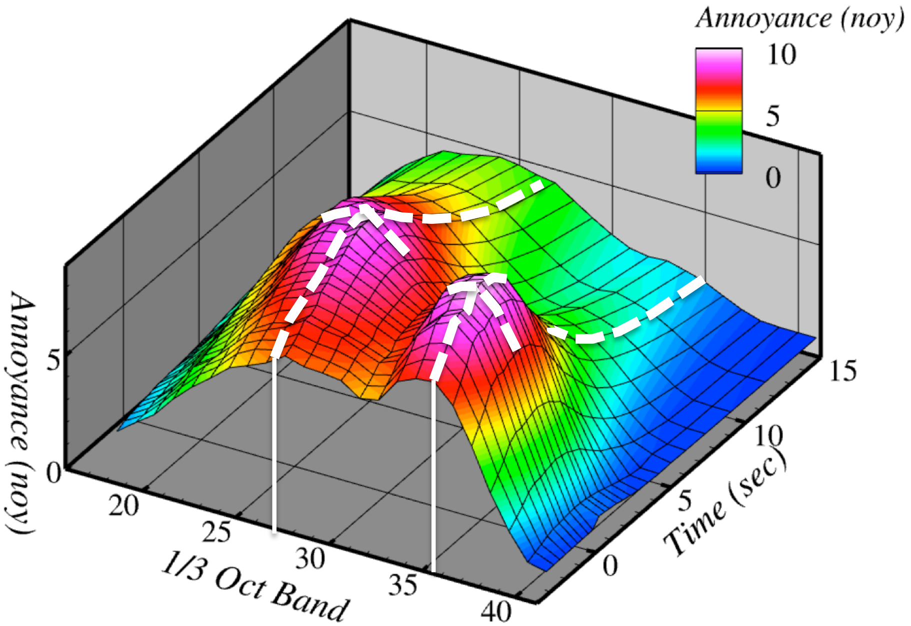
Interpreting noise spectral directivity

- Spectral directivity = Power Spectral Density of noise
  - PSD(freq, polar angle)

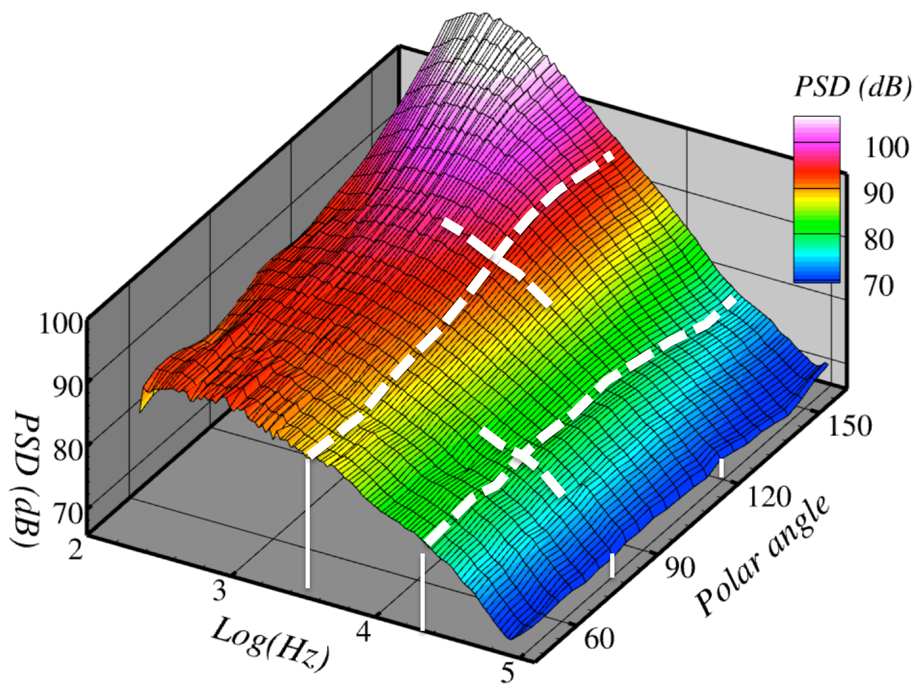


Interpreting noise spectral directivity

- EPNL is integral of Annoyance(Freq,Time)
- Annoyance is acoustic spectral directivity **weighted by human frequency response**.
- **Two peaks dominate Annoyance, are key to impacting EPNL.**

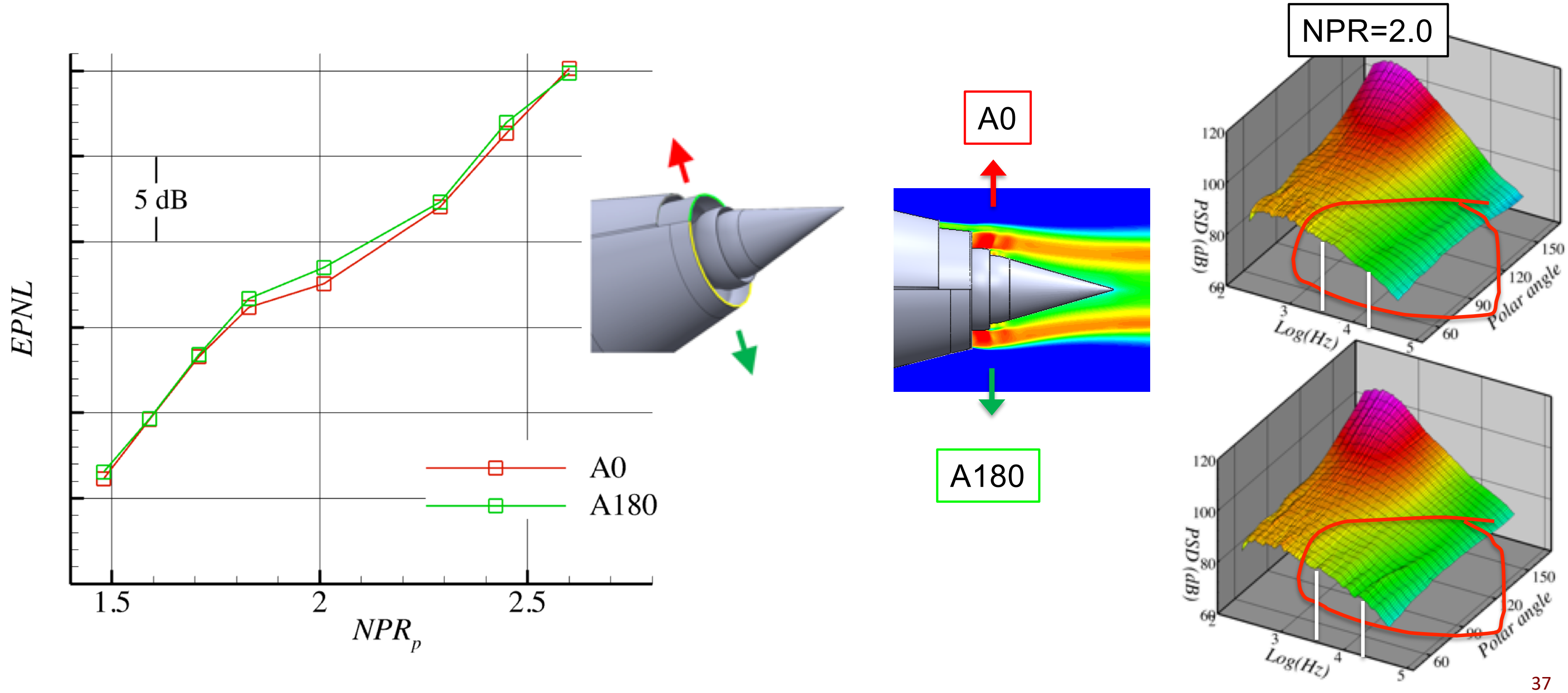


Full scale



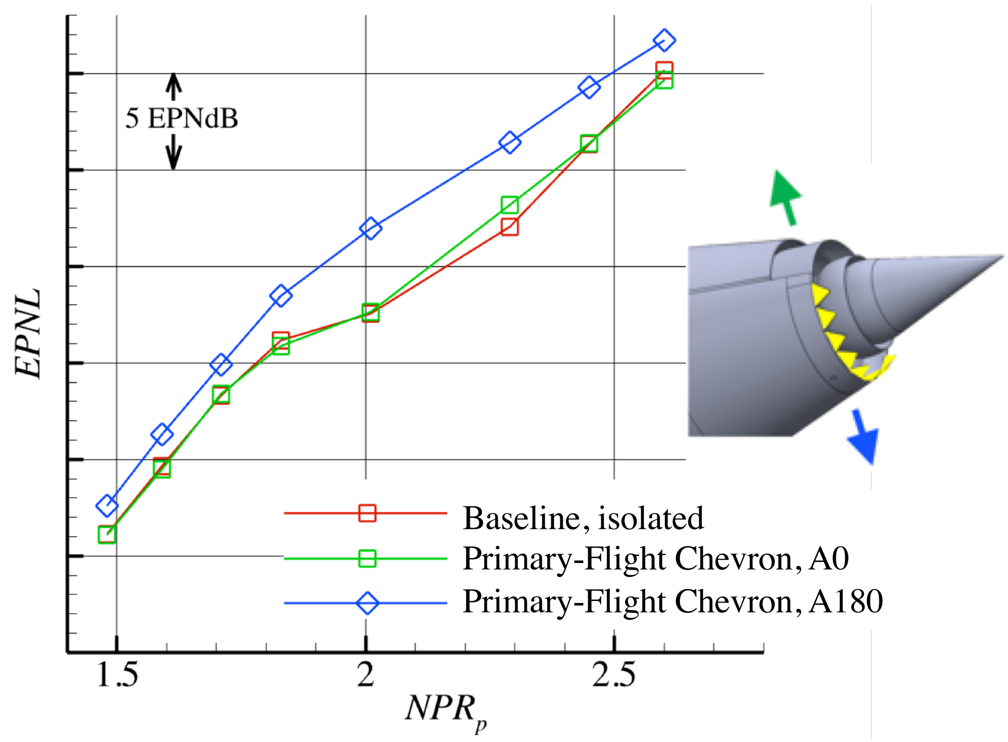
Results—Symmetry of isolated, baseline nozzle

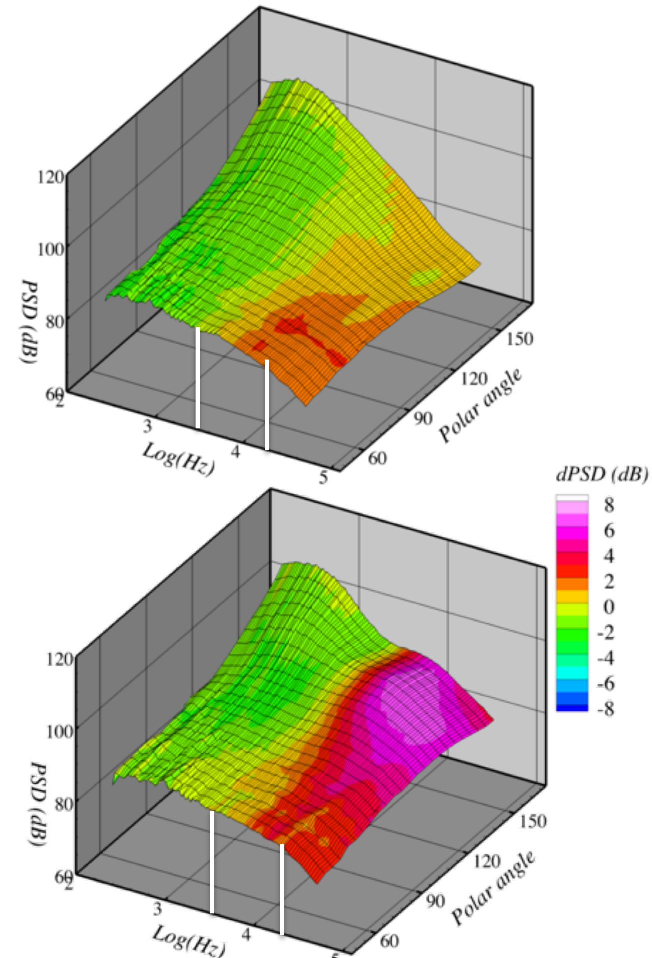
- Noise shown on two sides of nozzle.
- **Noise is nearly symmetric** except for slight asymmetry of broadband shock noise at NPR=2



Results — Symmetry of isolated, chevron nozzle

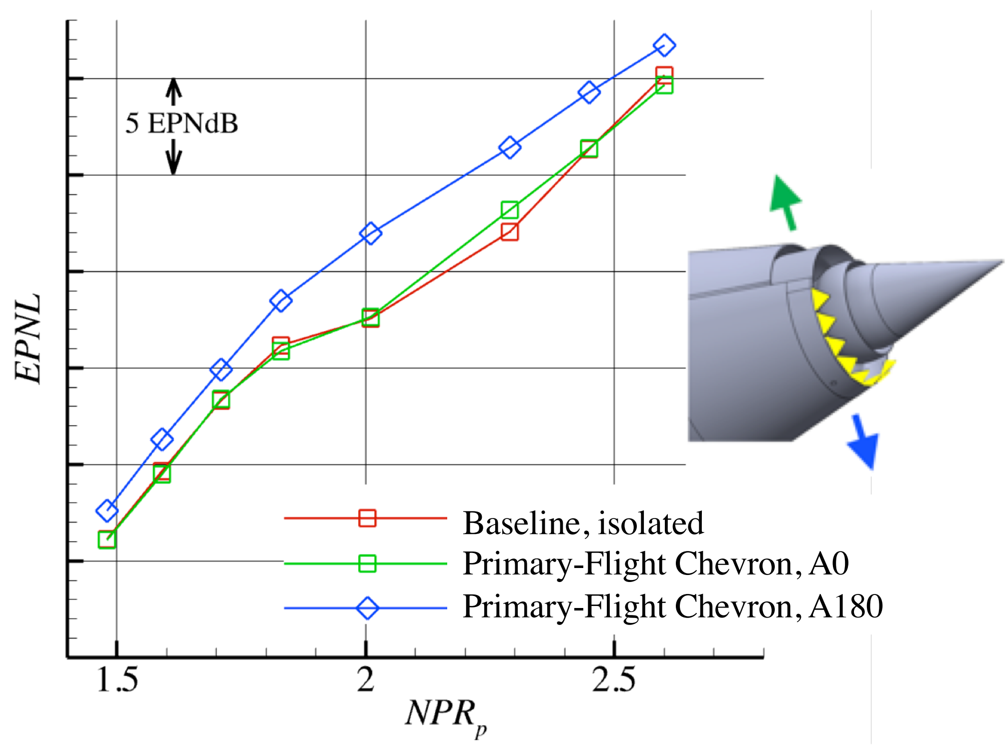
- Chevrons on **Primary-Flight** nozzle lip
- **EPNL much higher when chevrons toward observer**

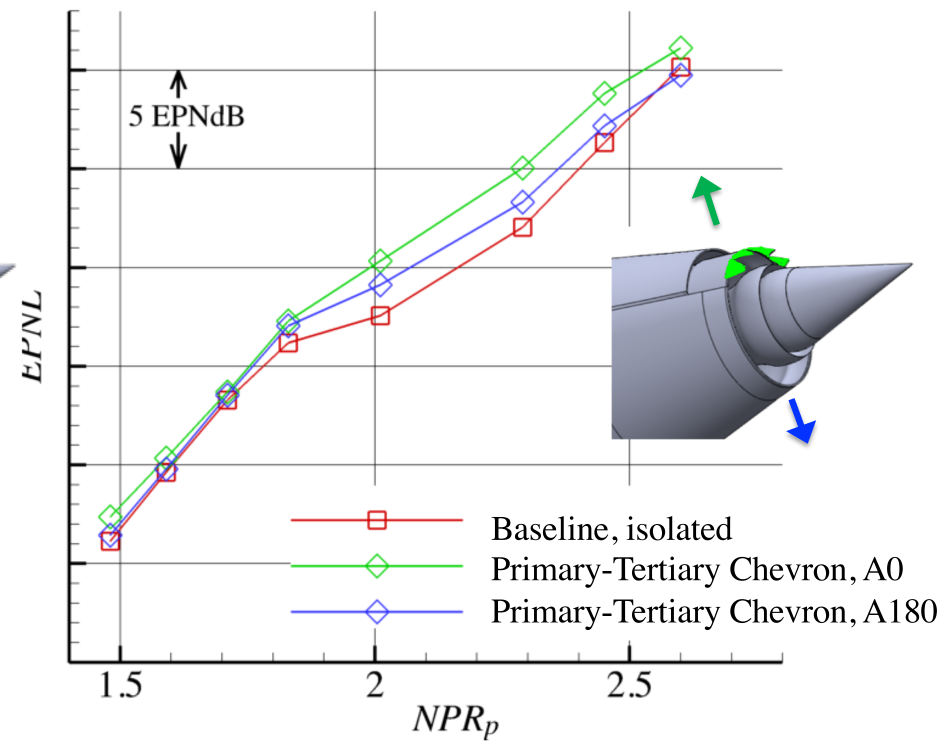




Results—Symmetry of isolated, chevron nozzle

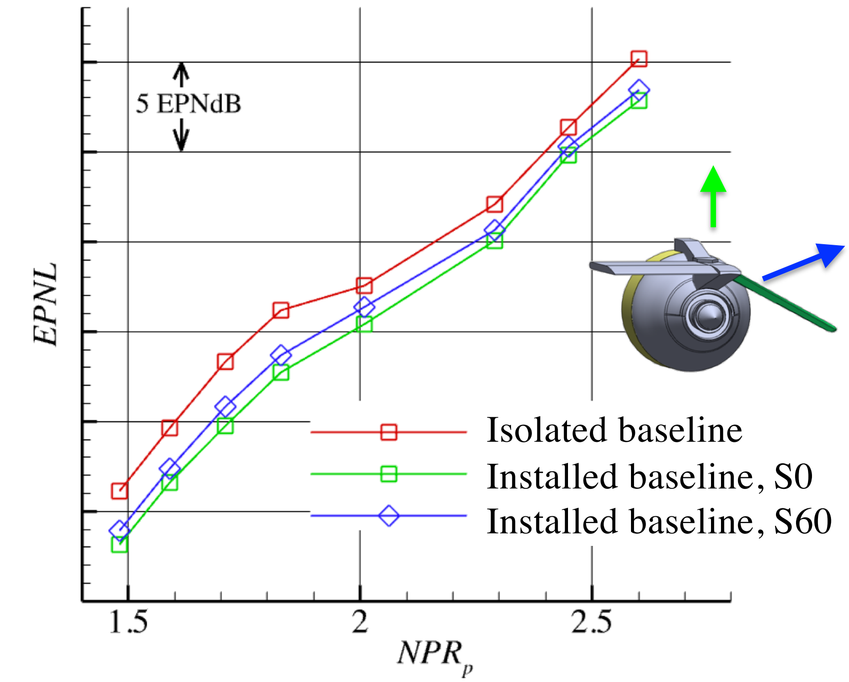
- Similar asymmetry—due to plug shielding/reflecting, not tertiary stream
- **Chevron noise can be 'shielded' by plug!**

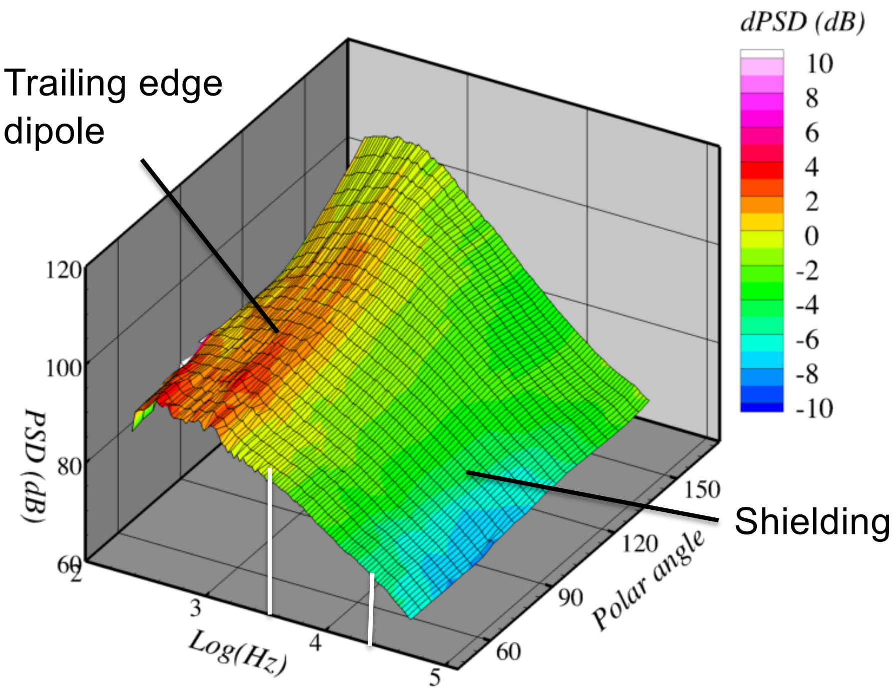




Results—Installed baseline nozzle

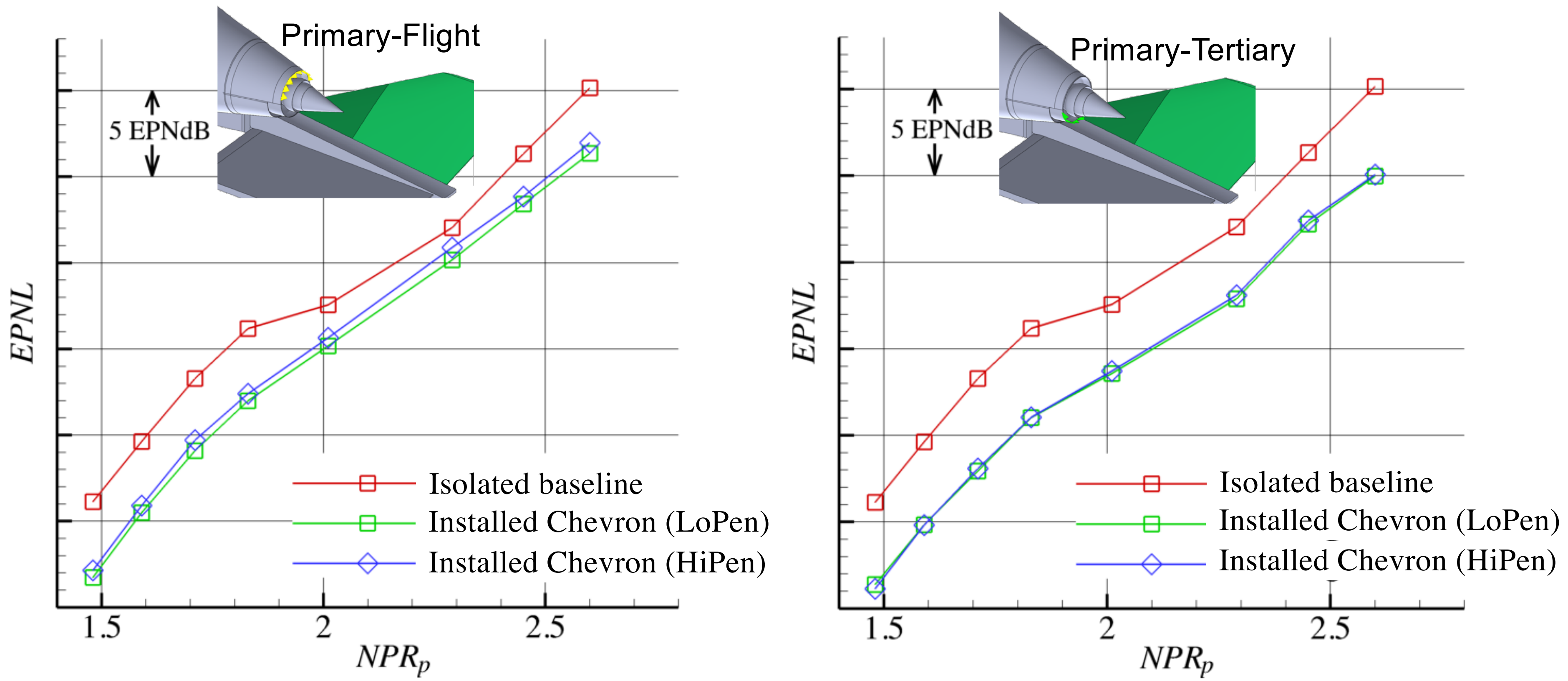
- Noise reduction from top-mounted installation, baseline nozzle
- **Planform yields 2-3.5dB reduction** under aircraft, 1-2.5dB at sideline observer





Results—Installed chevron nozzles

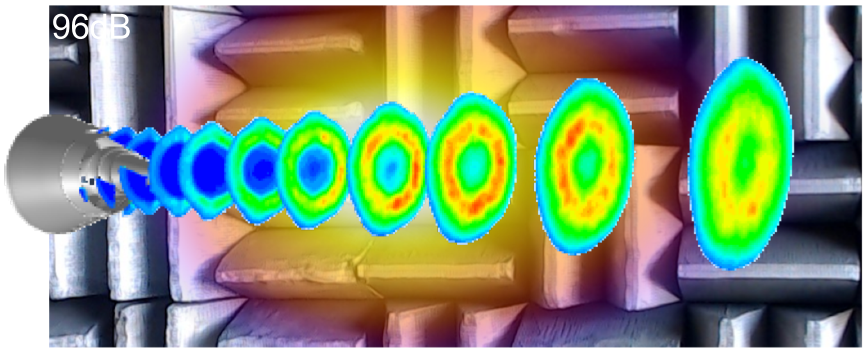
- More shielding benefit (**up to 5EPNdB**) achieved with chevrons applied.

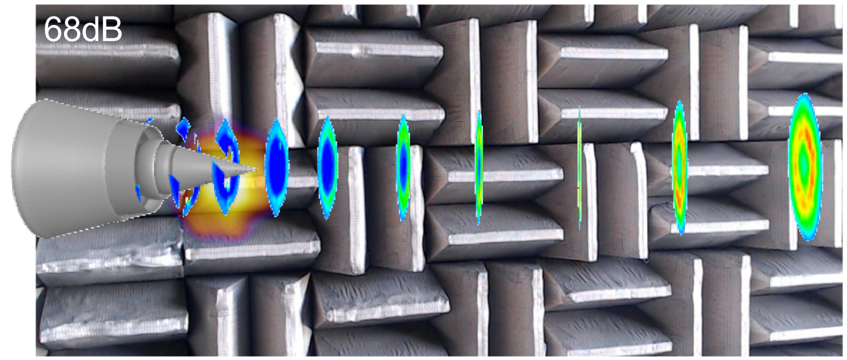


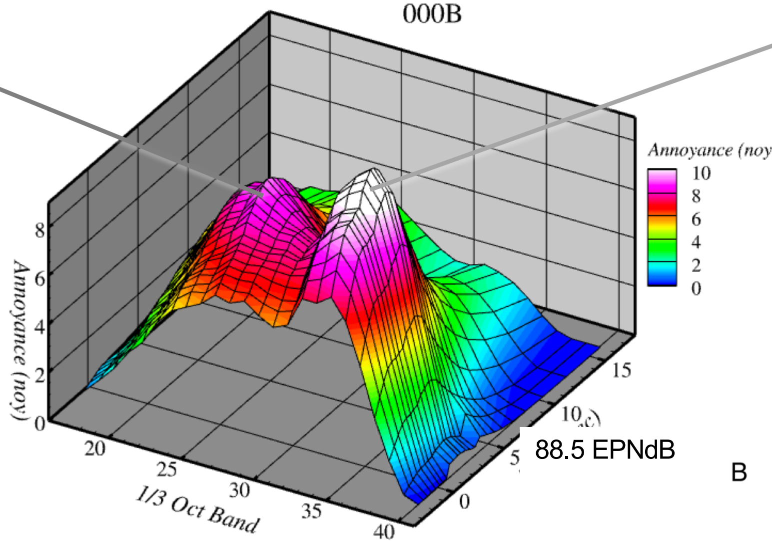
Far-Field Acoustics Summary

- Up to **5 EPNdB suppression** documented combining enhanced mixing and shielding.
- Suppression targeted at key angle/frequencies to maximize impact on EPNL
  - Low-frequency, aft-angle reduction can be achieved by enhanced mixing.
  - High-frequency, broadside noise of enhanced mixing can be shielded by airframe.
- High-frequency noise of chevrons can also be shielded/reflected by plug.

Baseline nozzle, isolated

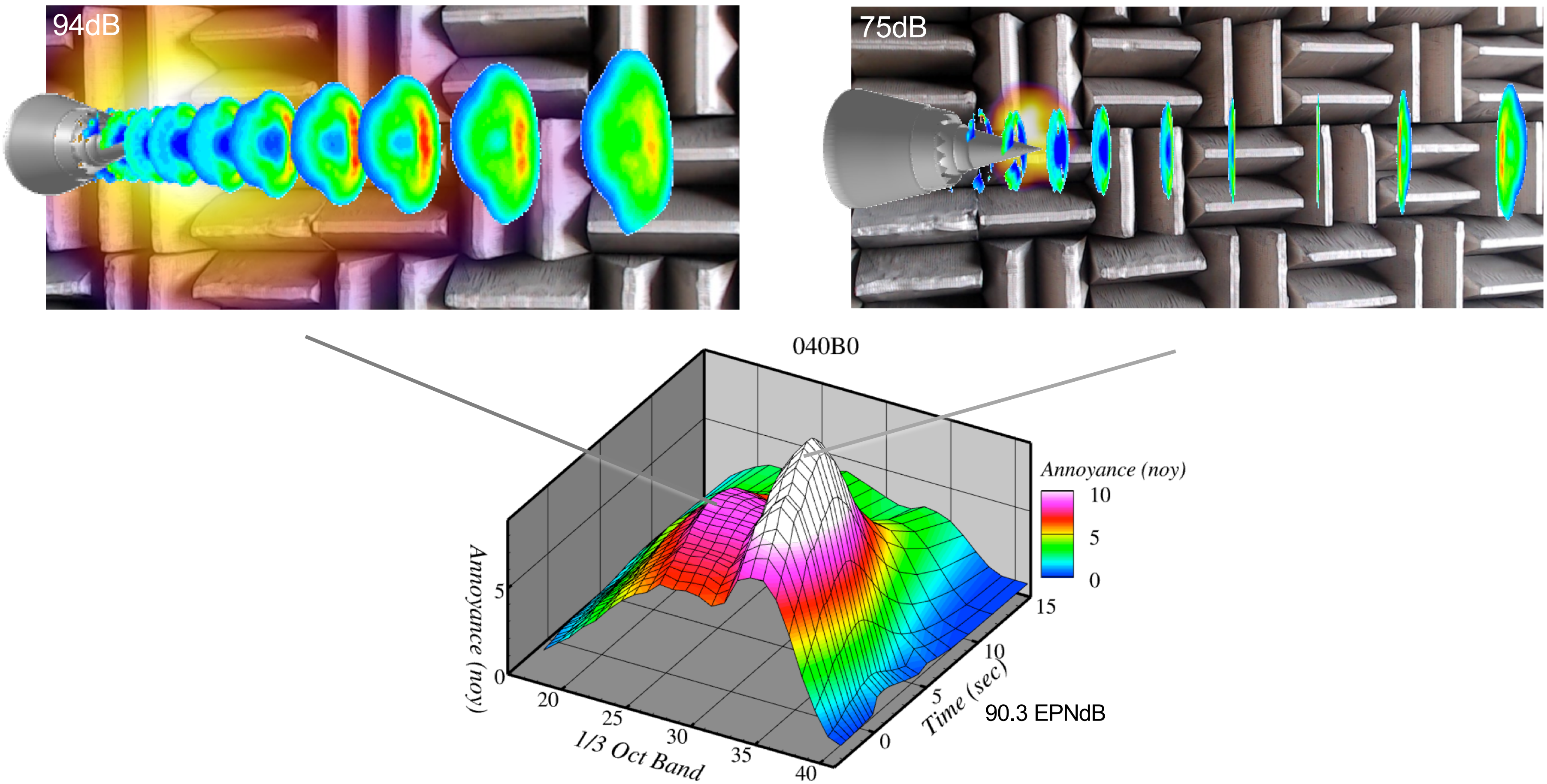




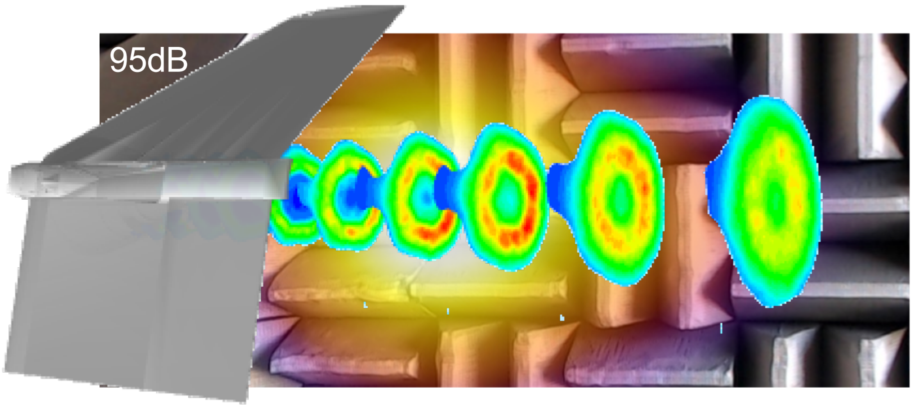


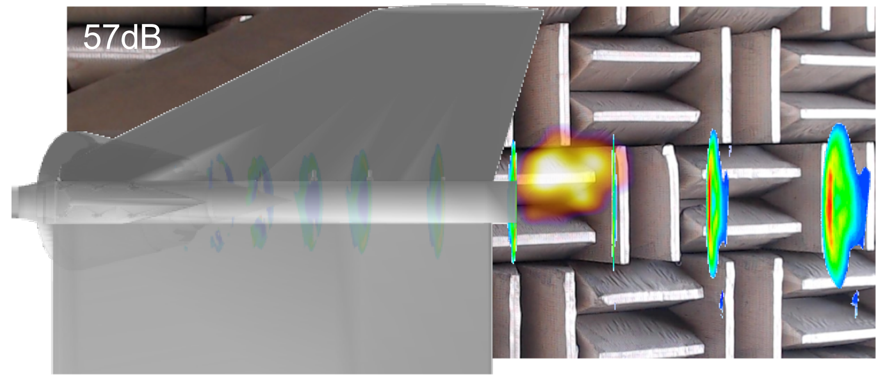
B

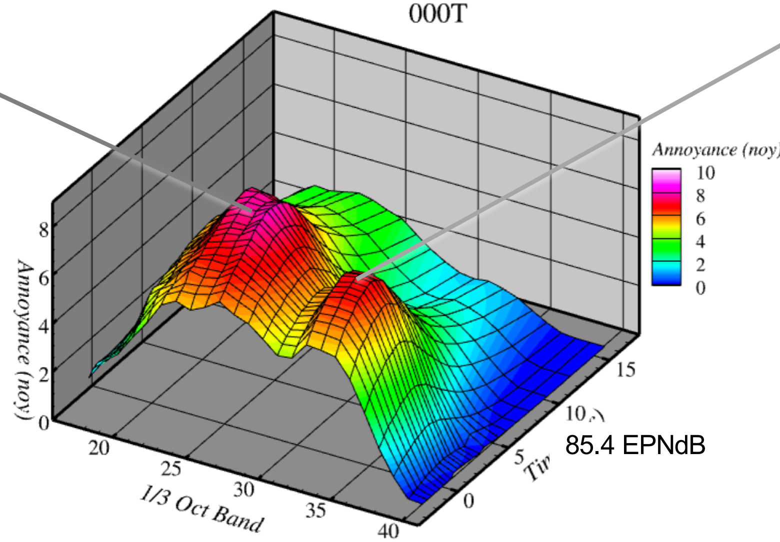
Chevron nozzle, isolated



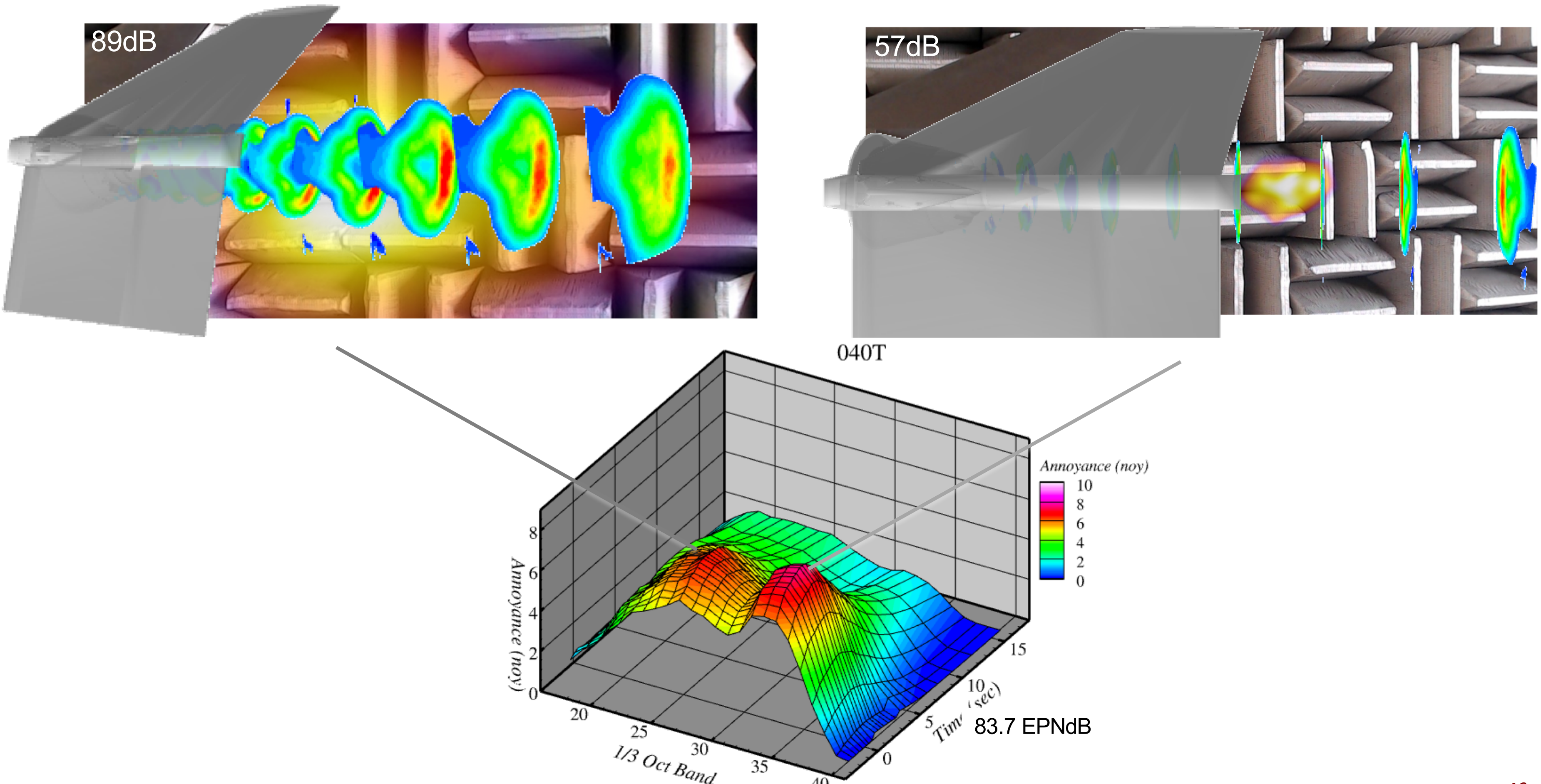
Baseline nozzle, installed





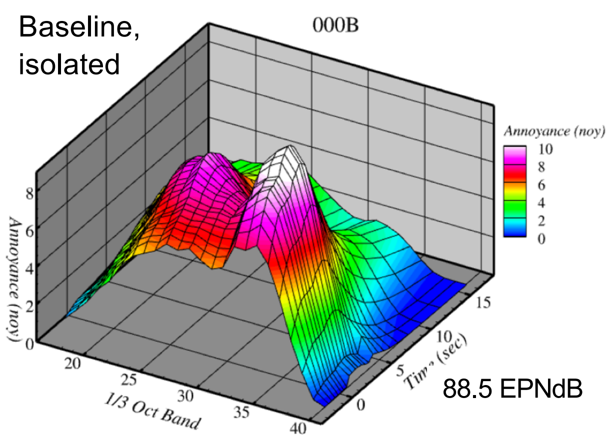


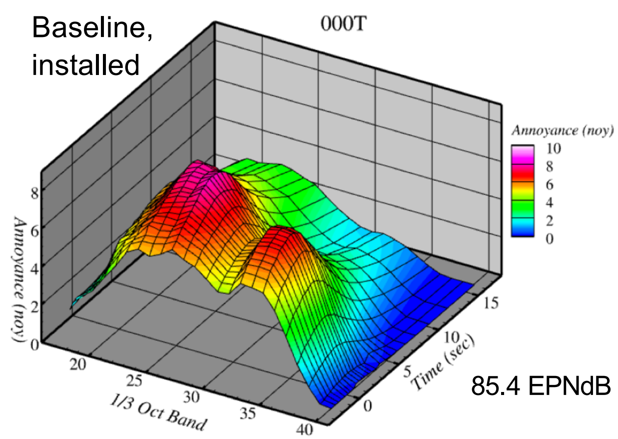
Chevron nozzle, installed

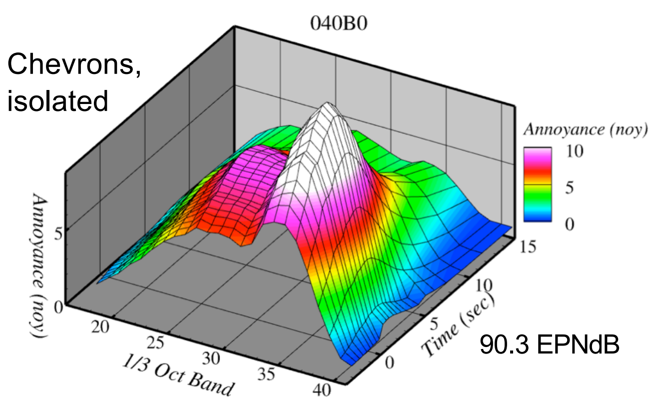


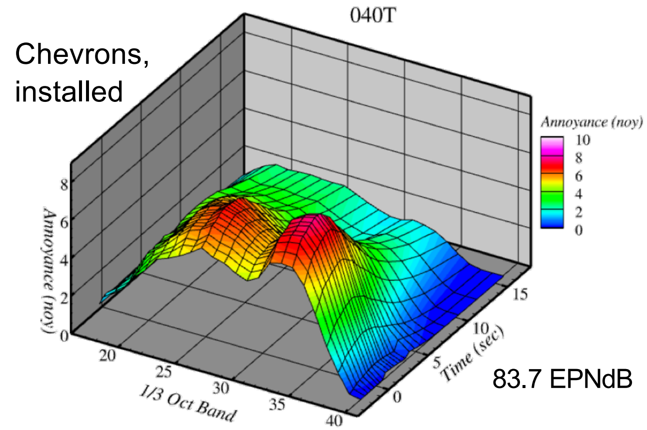
Far-Field Acoustics Visual Summary

- To lower EPNL—reducing peaks in annoyance with chevrons and installation









Summary

- Concept of **source relocation and shielding** of exhaust noise demonstrated experimentally.
- Balancing enhanced mixing and shielding requires prediction of source distributions and complicated Green's functions.
- Top-mount installation can offer **fan** noise reduction as well.
- Aerodynamically, mixing devices must be optimized for thrust, and top-mounting is inherently poor.
- Top-mounted propulsion is advantageous for low sonic boom.
- **Fast, accurate prediction of noise** is the key to successful design.

Questions