



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

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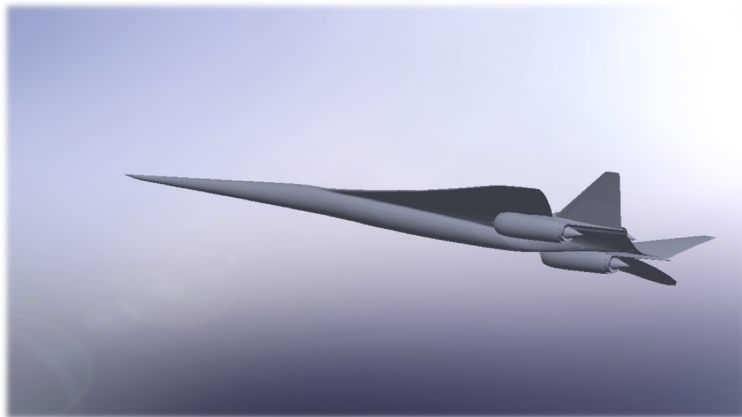
NASA Acoustics Technical Working Group
Langley Research Center
10 April 2019

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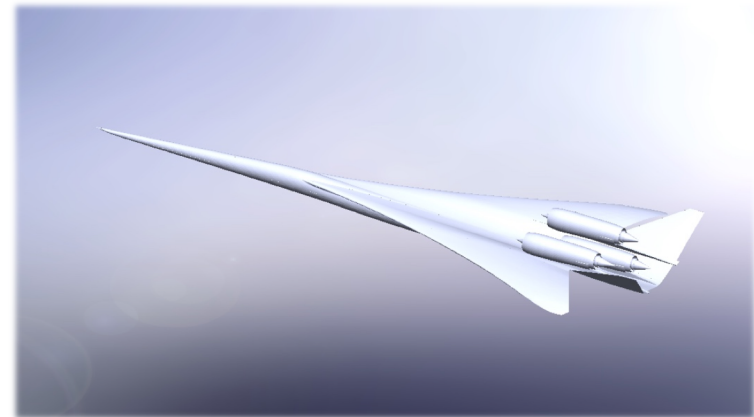
Motivation



- 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

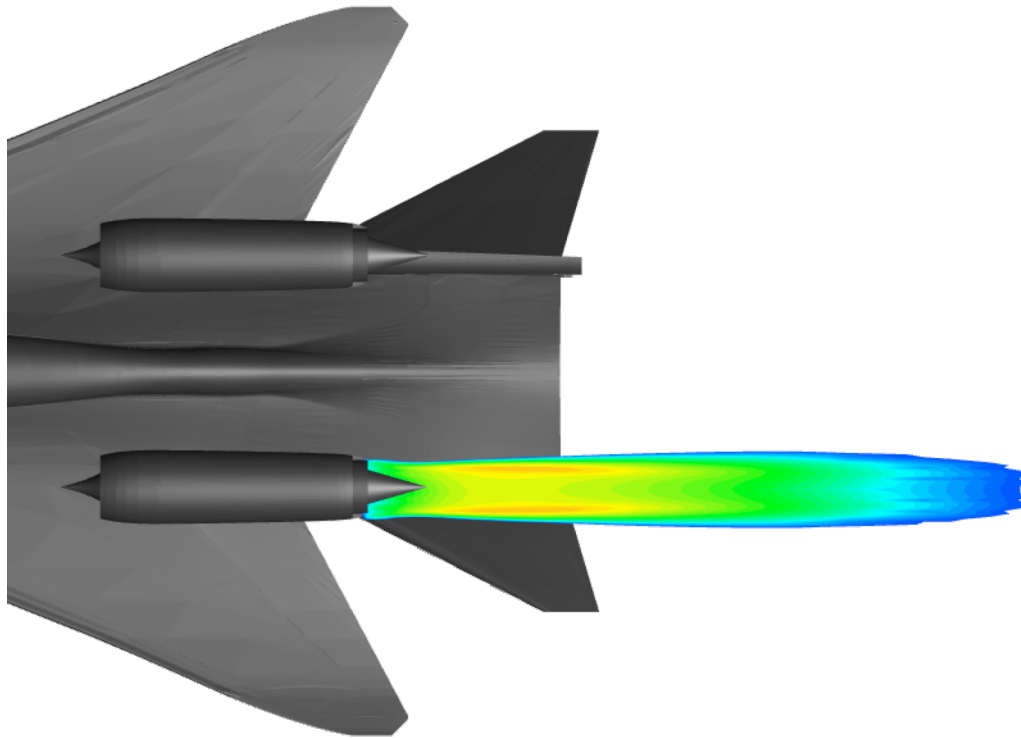


NASA LM1044/TMP
Quiet Top Mounted Propulsion Concept

Conventional nozzles, underbody installation



Observer view



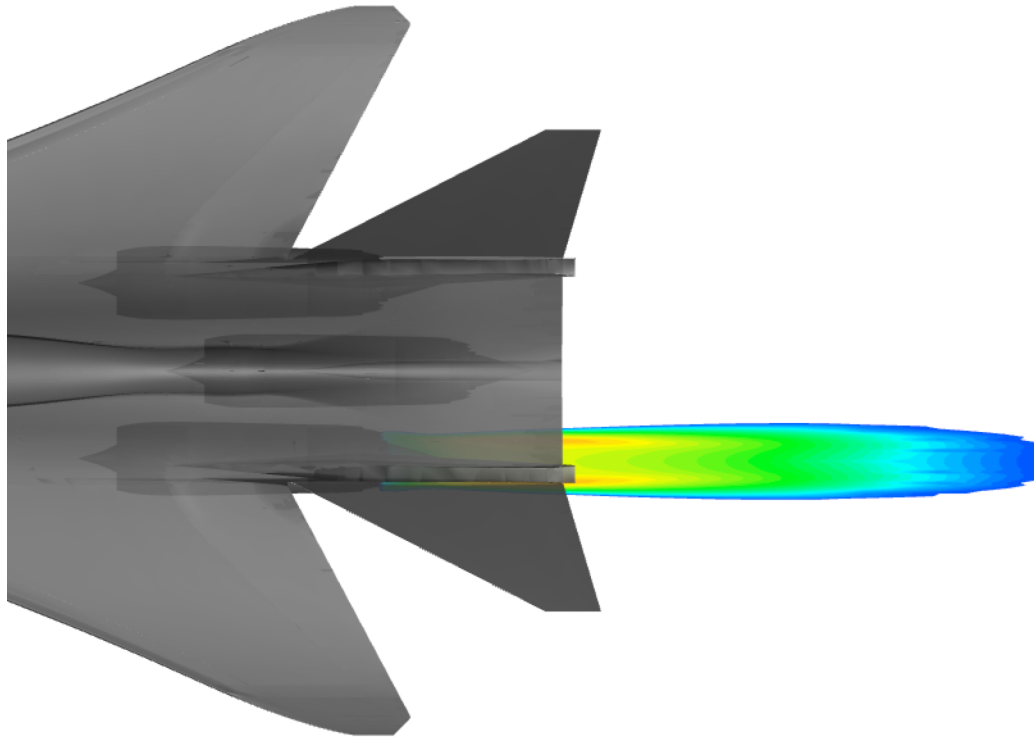
Noise sources

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

Conventional nozzles, top-mounted installation--shielding



Observer view



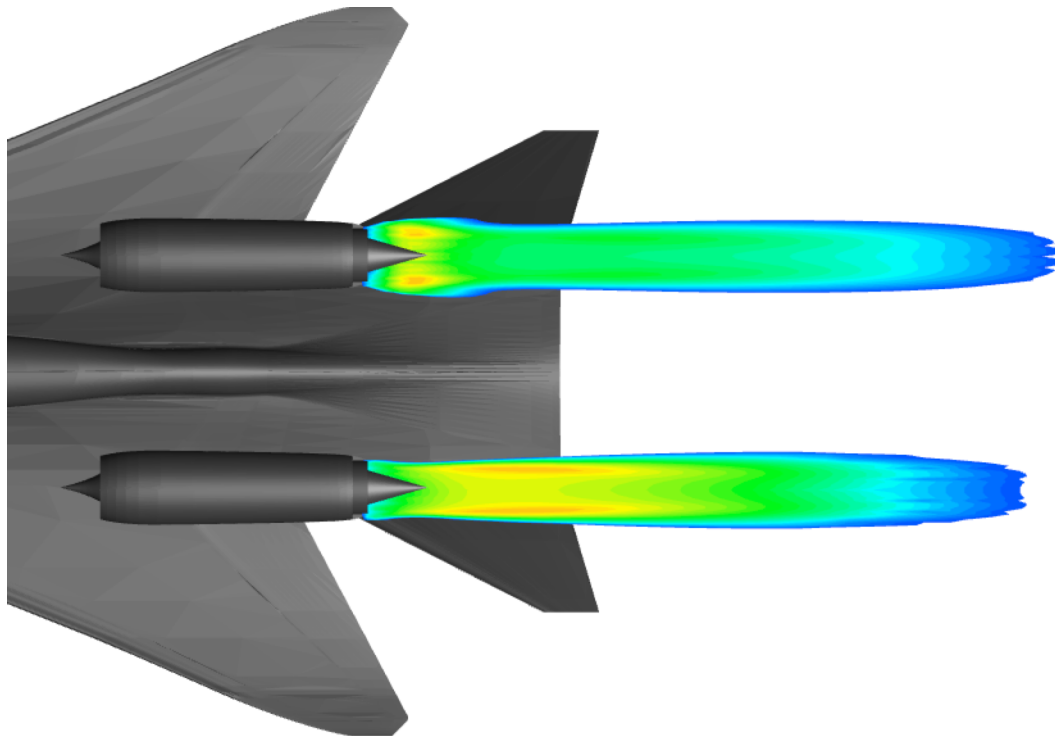
Noise sources

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

Modified nozzles, underbody installation



Observer view



Noise sources

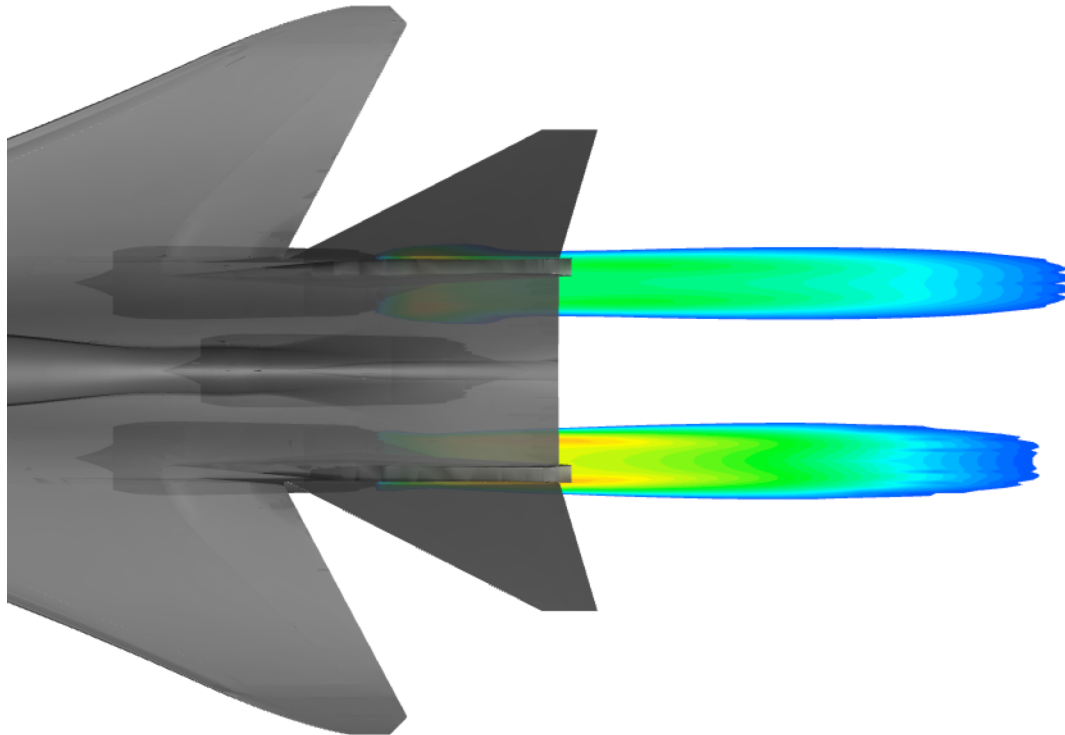
Chevron nozzles
Conventional installation
— *Shift source distribution.*

Conventional nozzles
Conventional installation

Nozzle Modifications + Shielding



Observer view

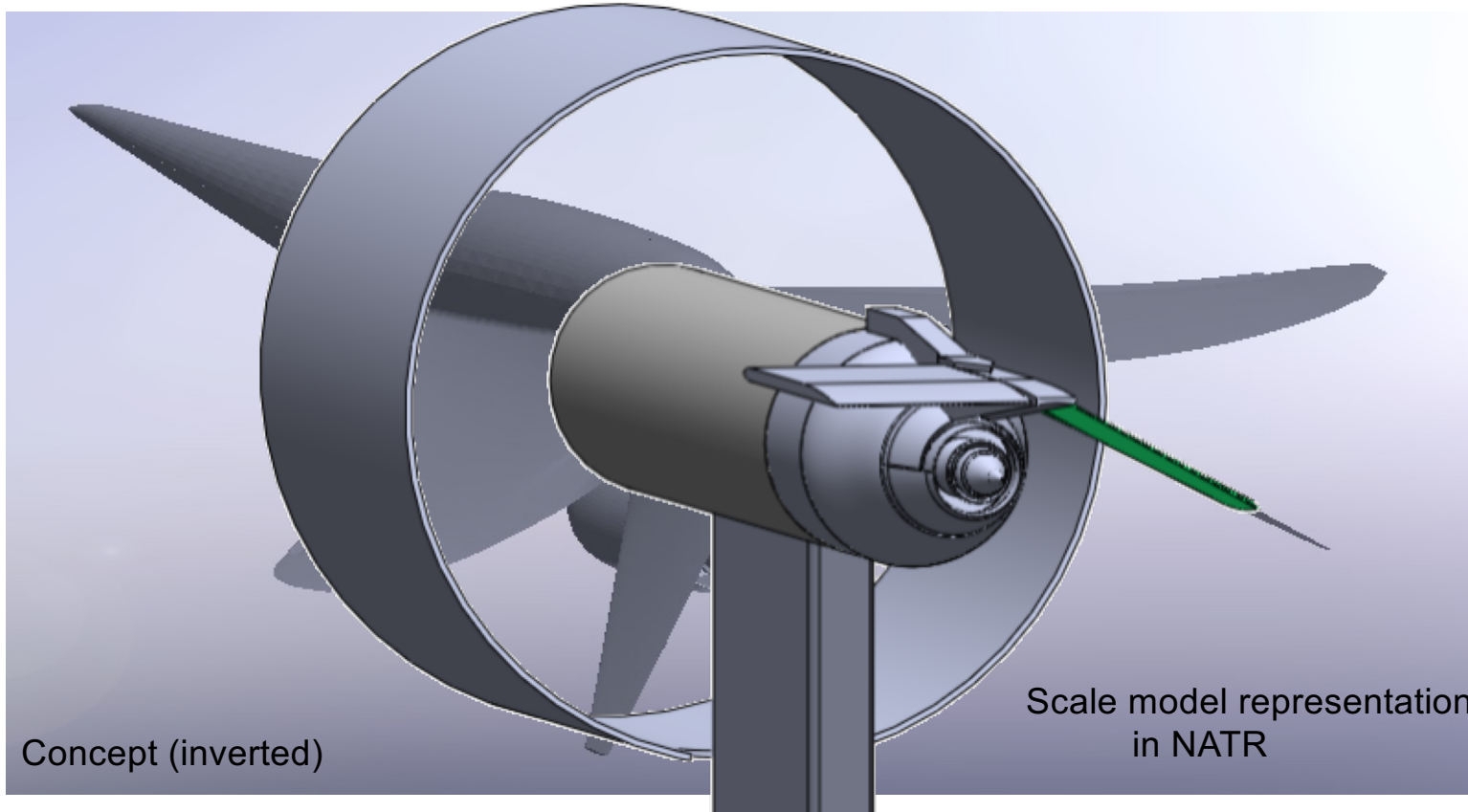
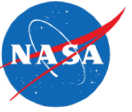


Noise sources

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:

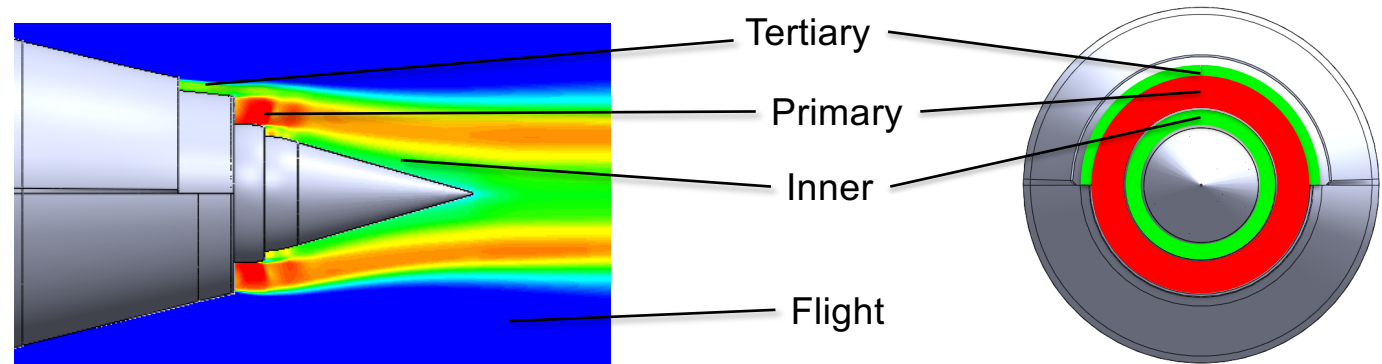
$1.4 < NPR_{primary} < 2.6$

$1.6 < NTR_{primary} < 2$

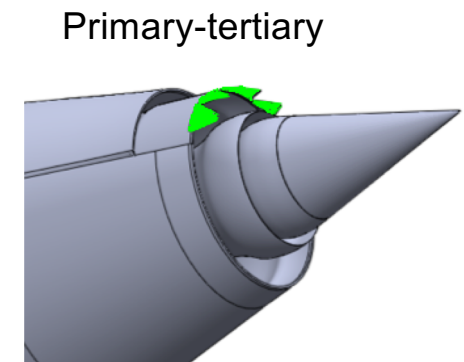
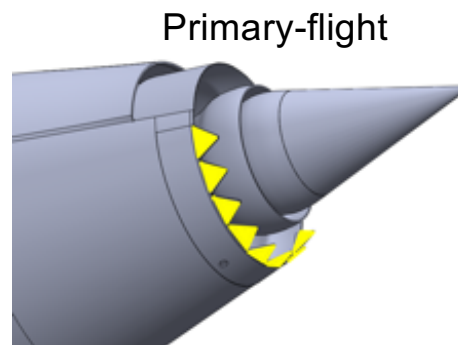
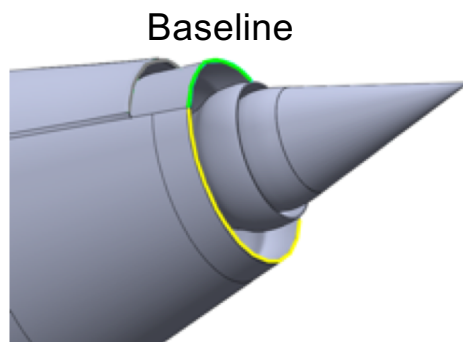
$1.7 < NPR_{inner} < 1.9$

$1.2 < NTR_{inner} = 1.25$

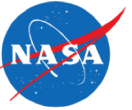
$0 < M_{flight} < 0.35$



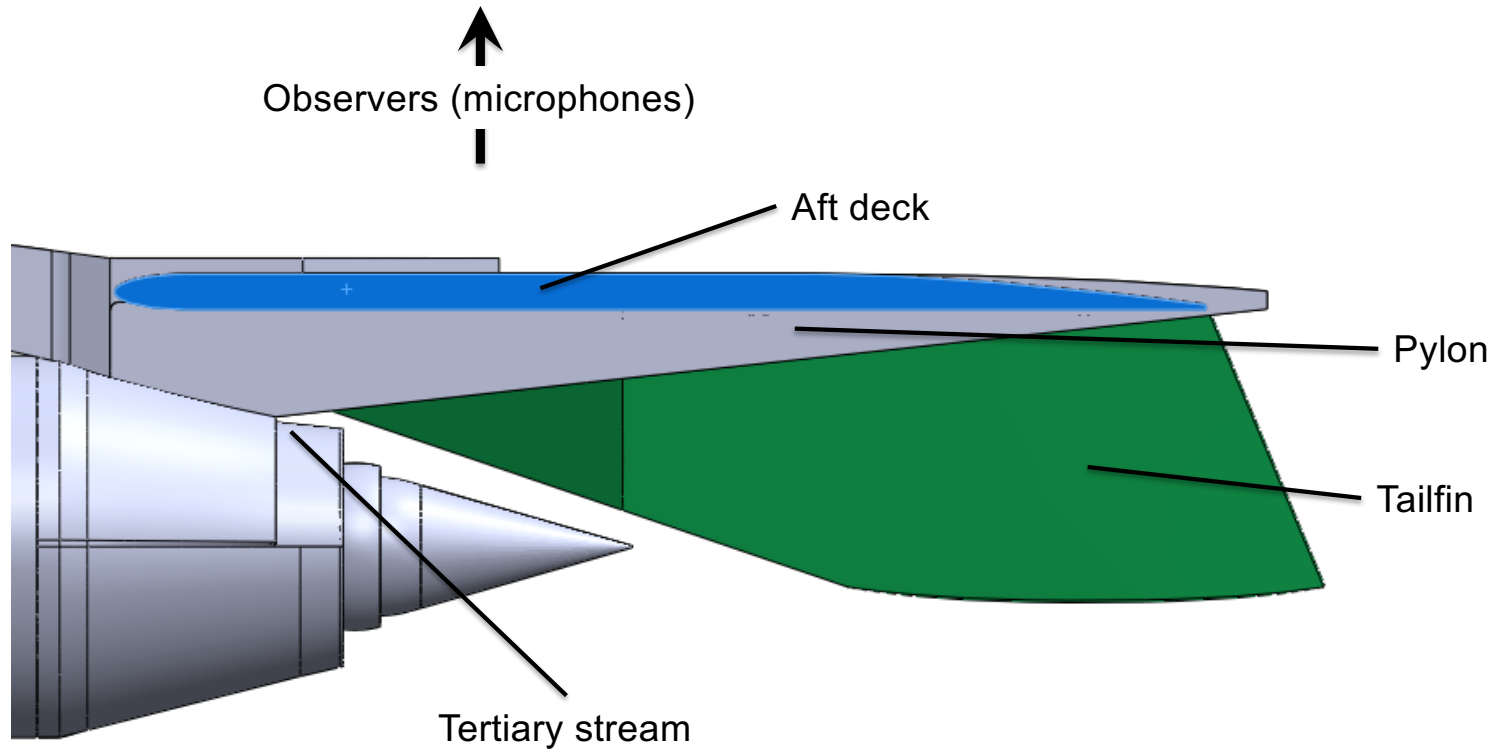
- Lip treatments



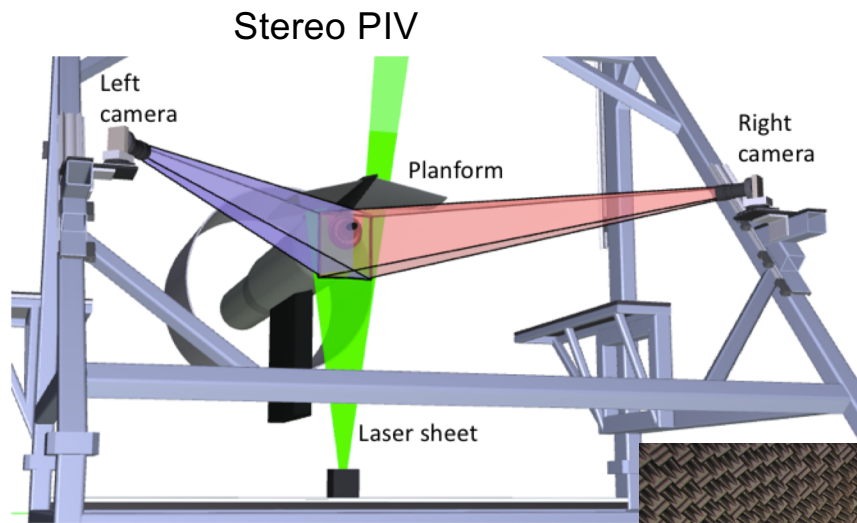
Test articles – Planform



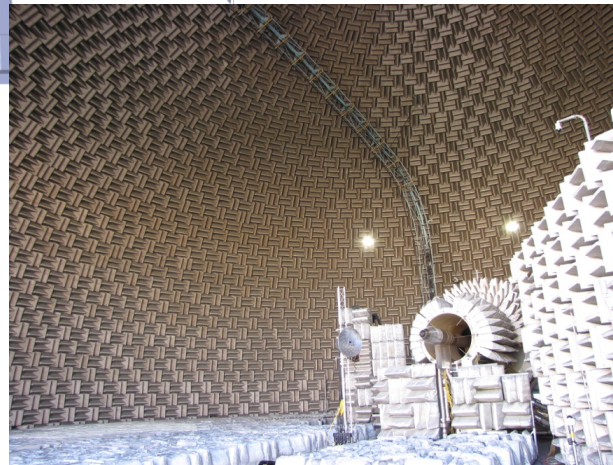
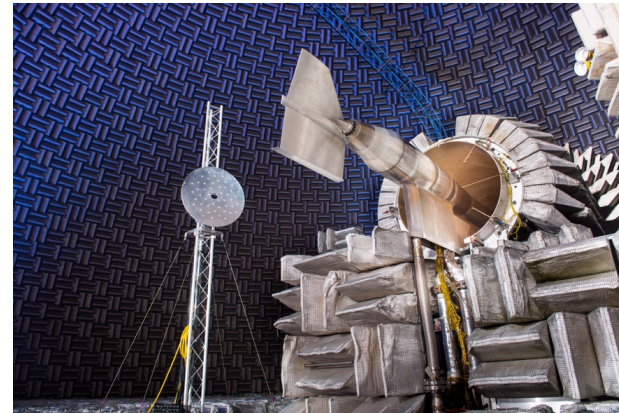
- Planform



Test instrumentation

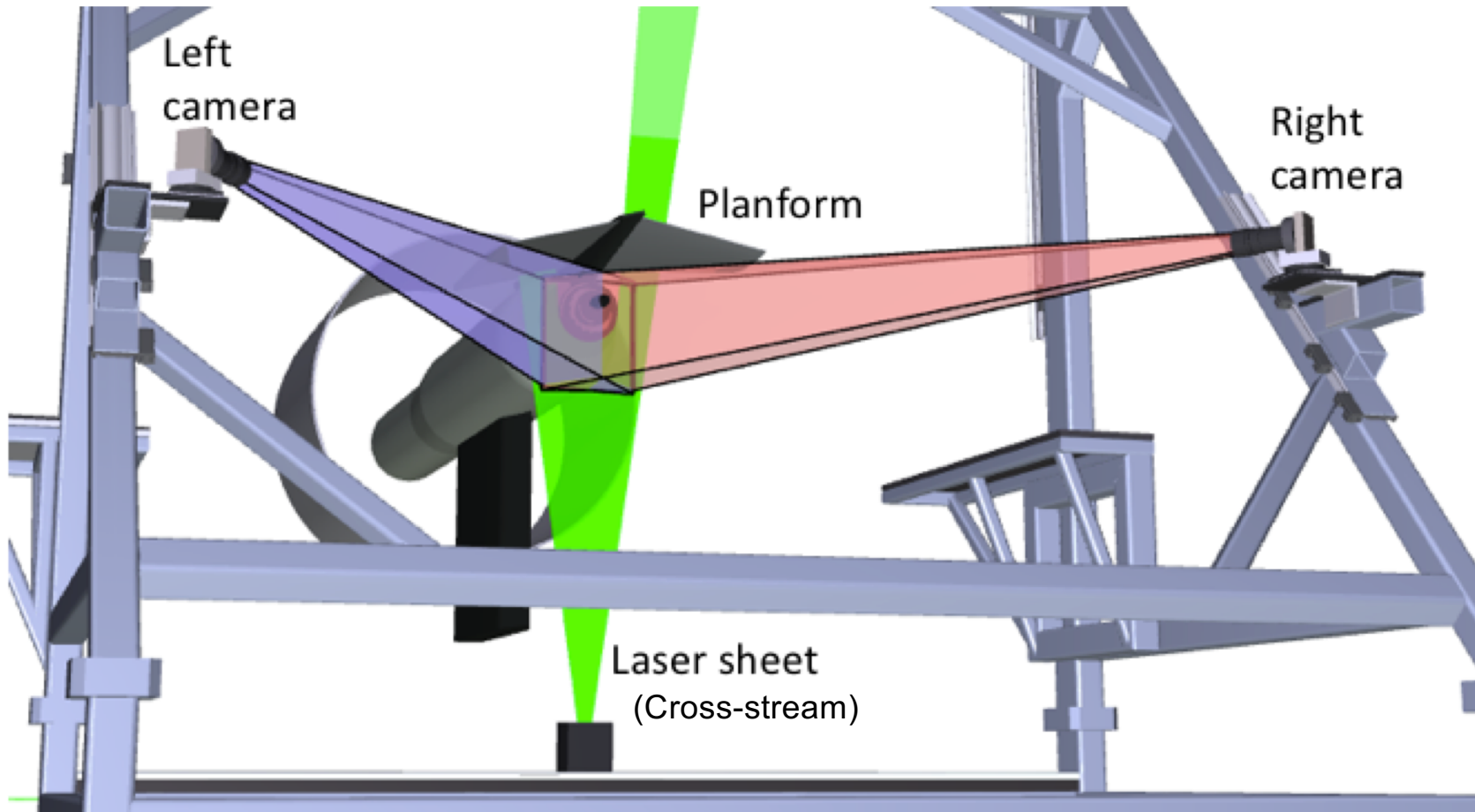
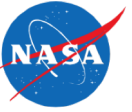


Translating phased array



Far-field acoustics

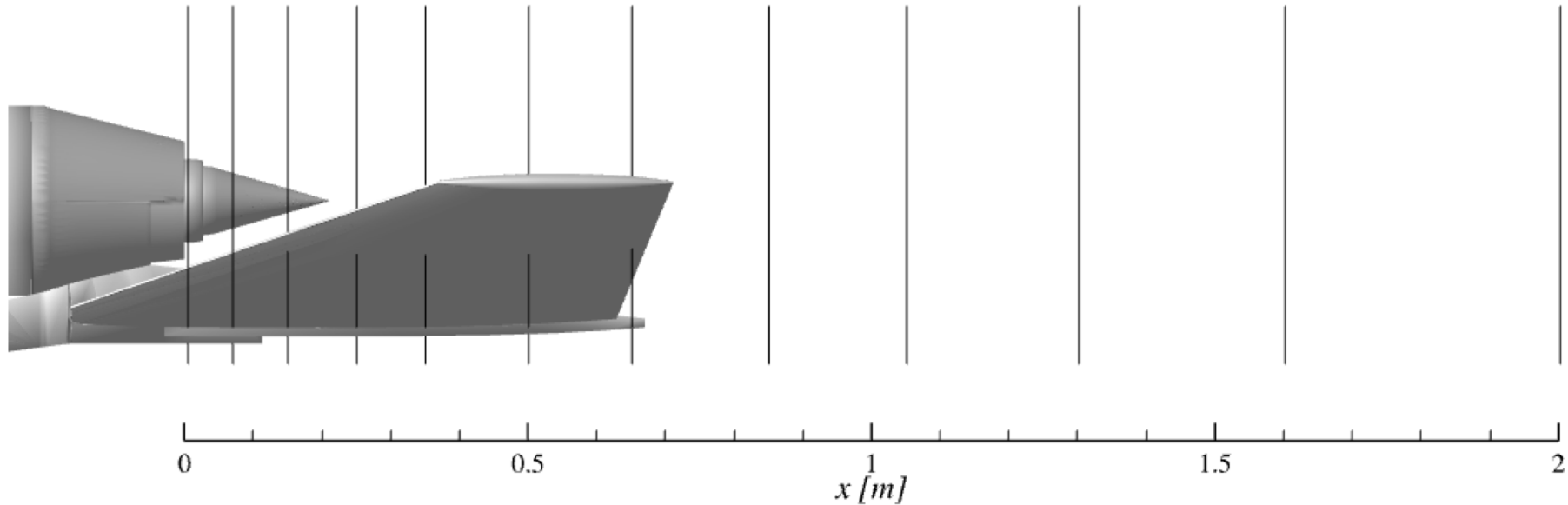
Stereo PIV





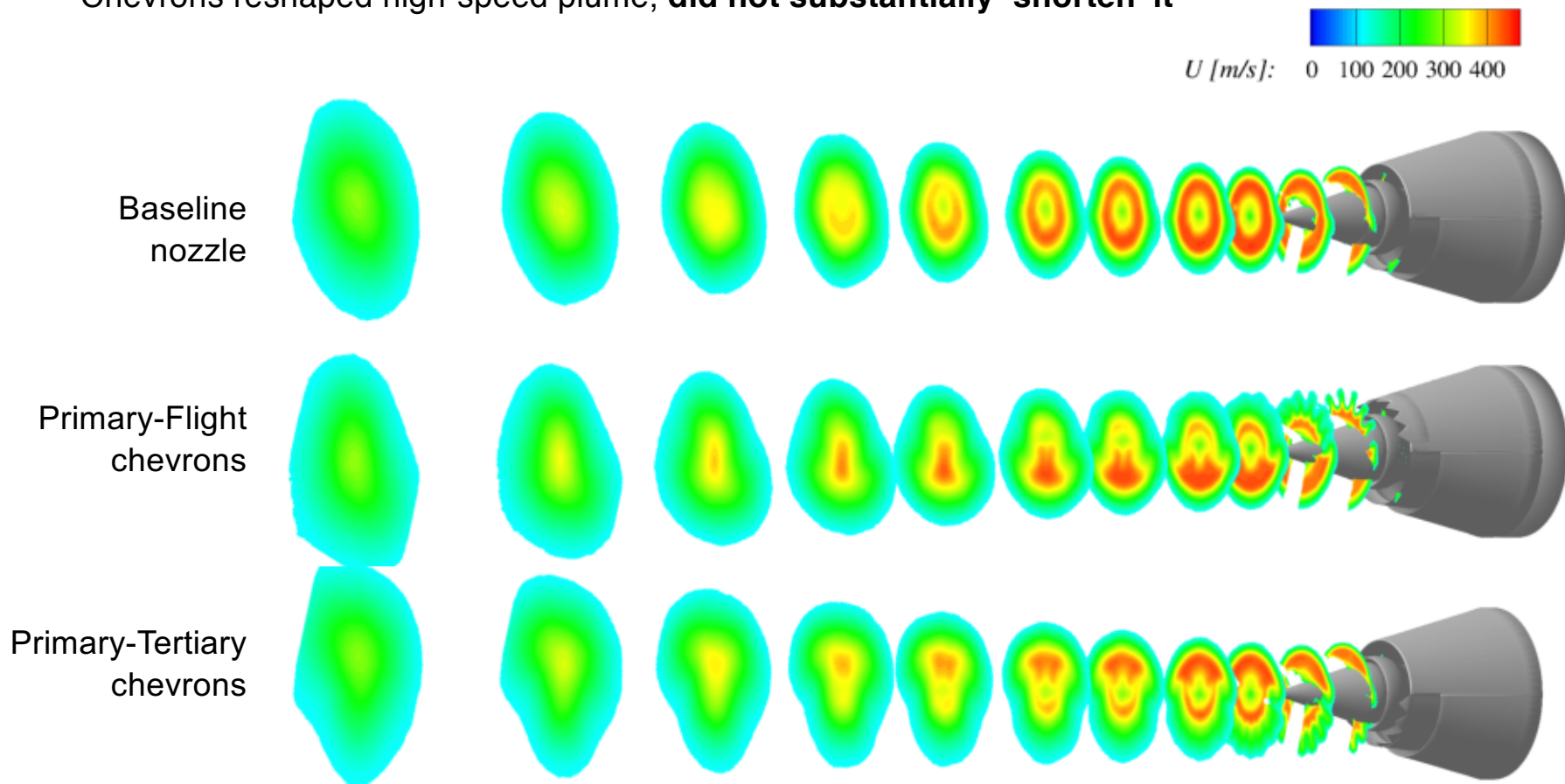
PIV measurement locations

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



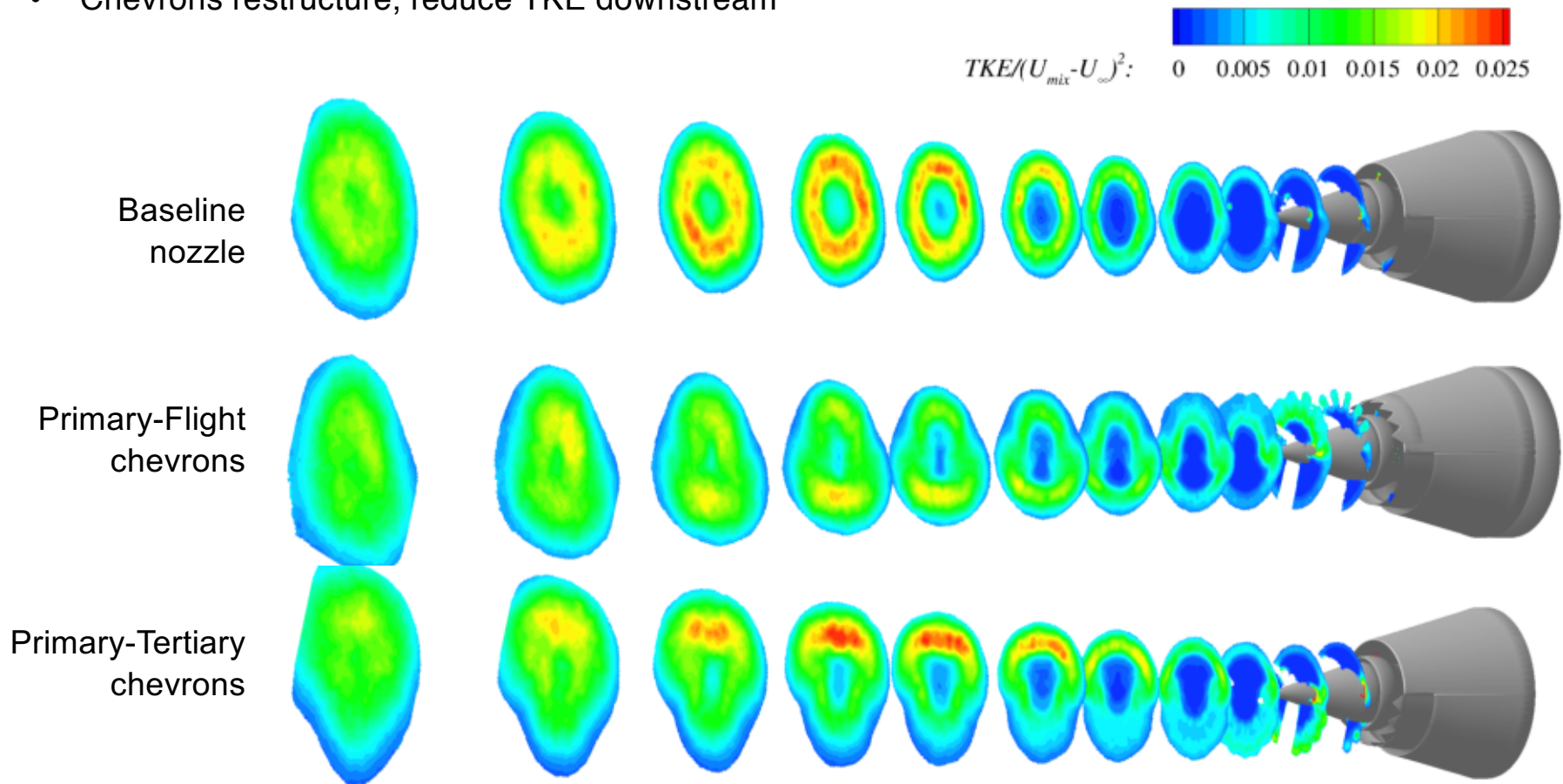
Effect of chevrons on mean velocity—isolated nozzle

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



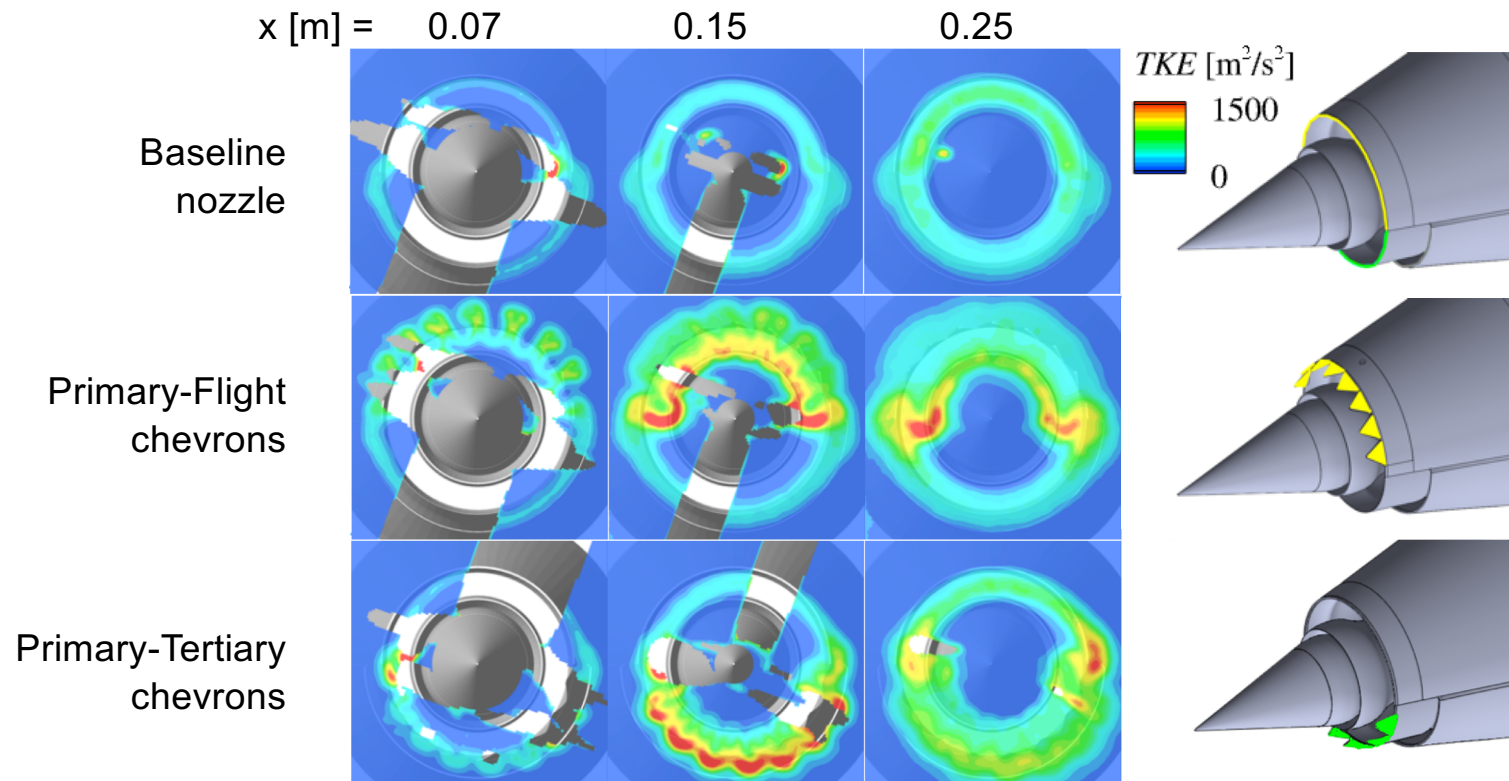
Effect of chevrons on TKE—isolated nozzle

- Chevrons restructure, reduce TKE downstream



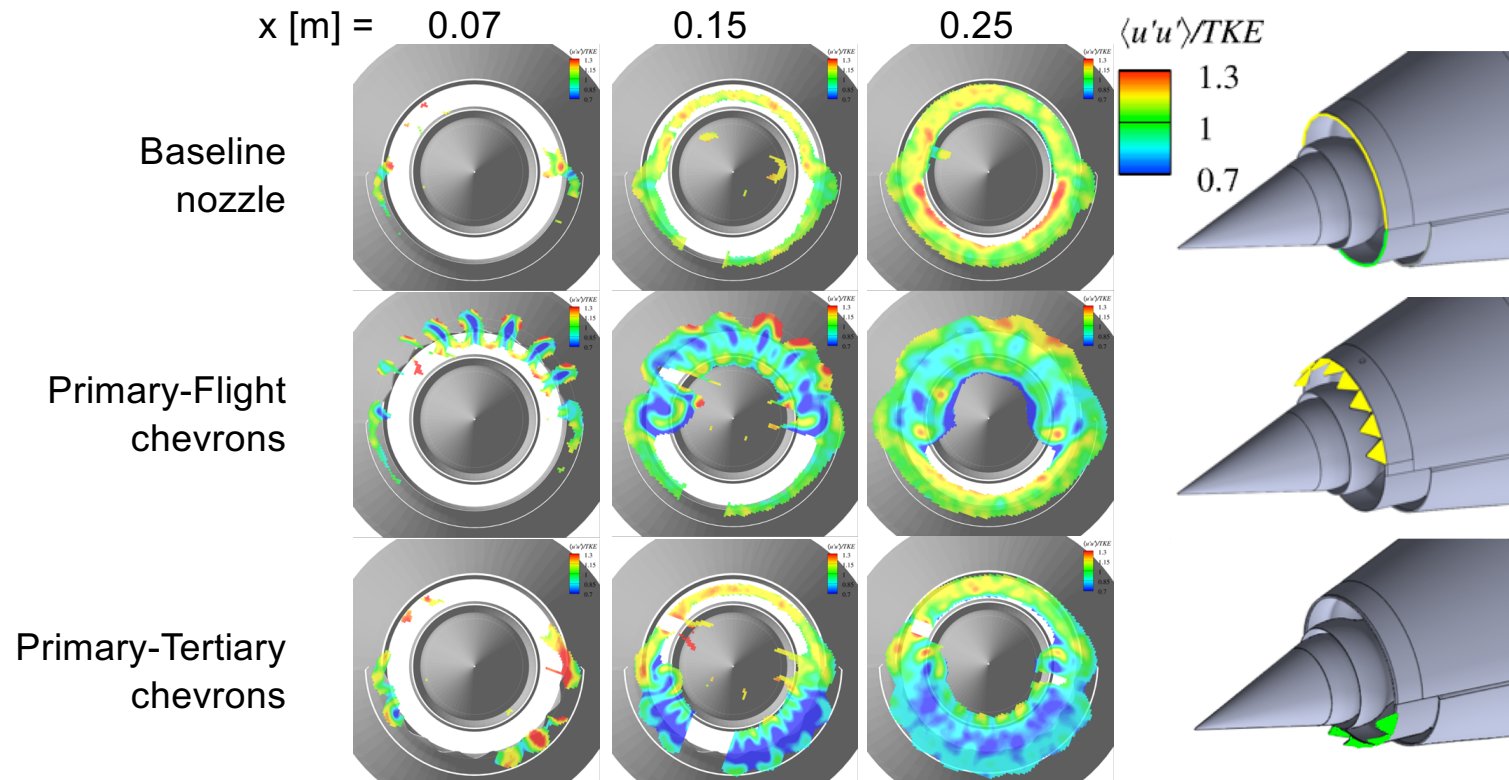
Impact of chevrons near nozzle

- Chevrons produce convoluted shear layers with enhanced TKE



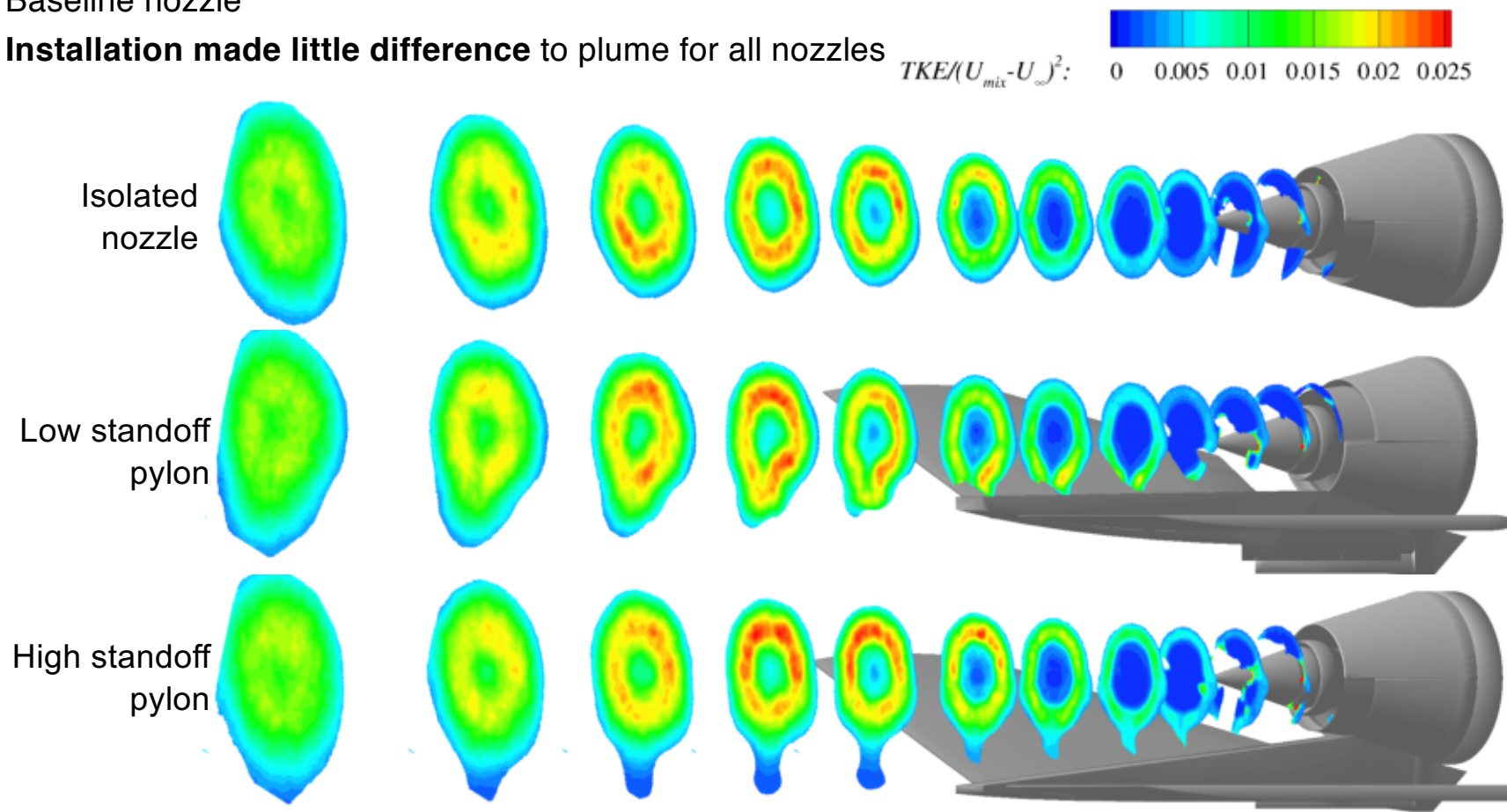
TKE anisotropy with chevrons

- 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?**



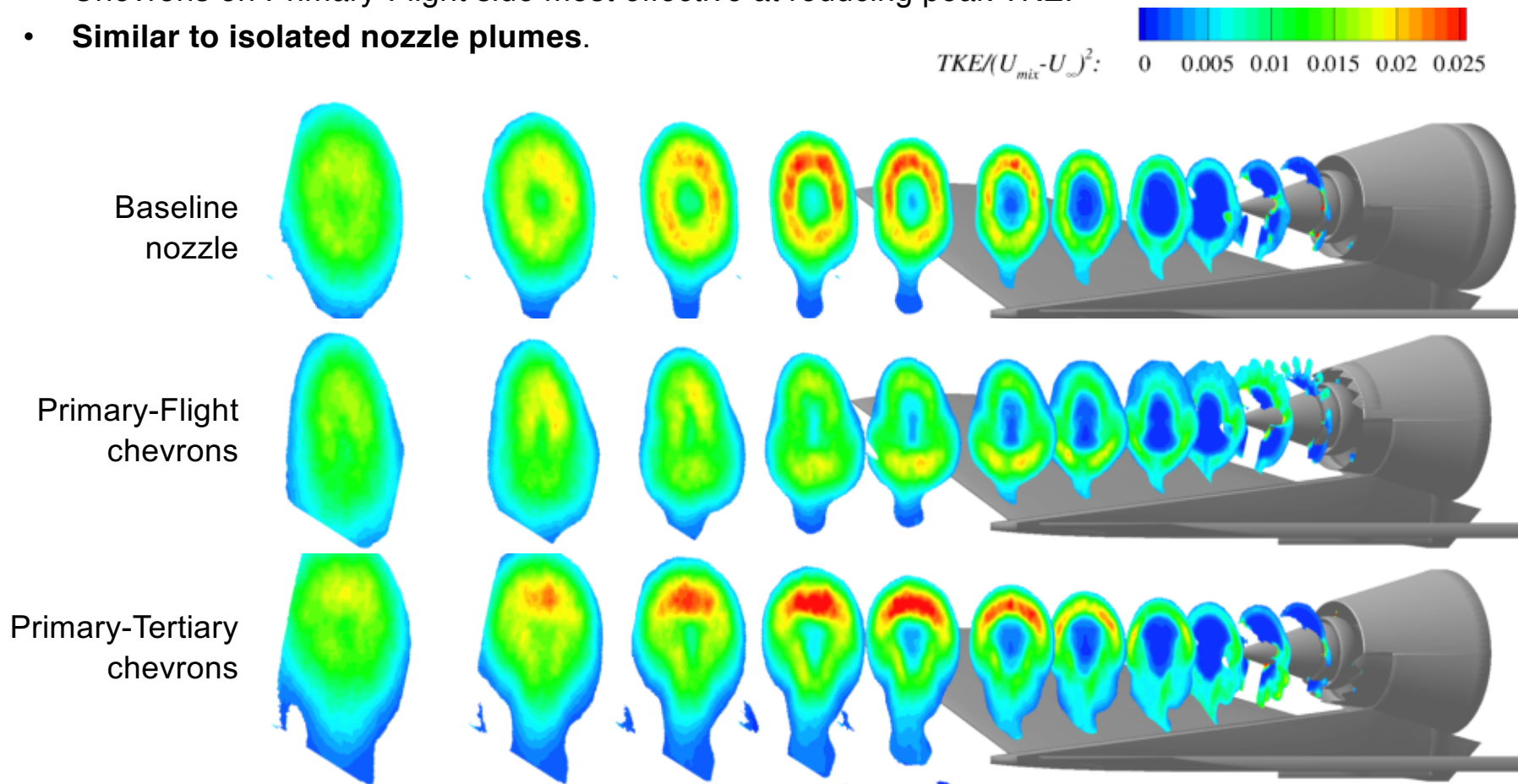
Effect of pylon standoff—TKE

- 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.**

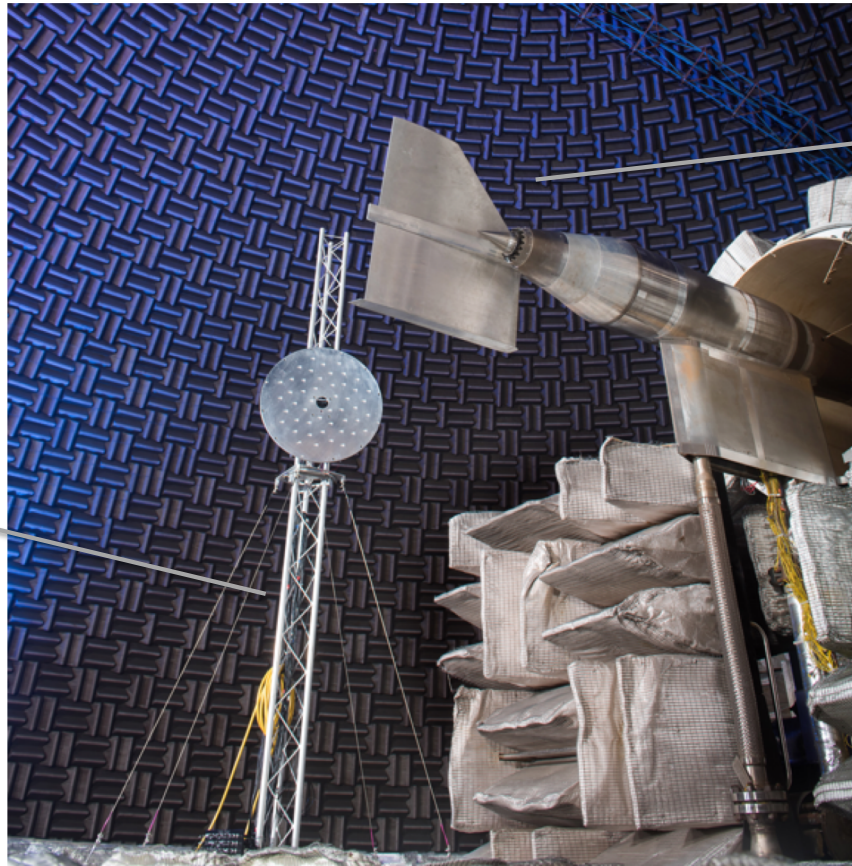
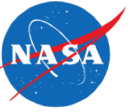




PIV Summary

- 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



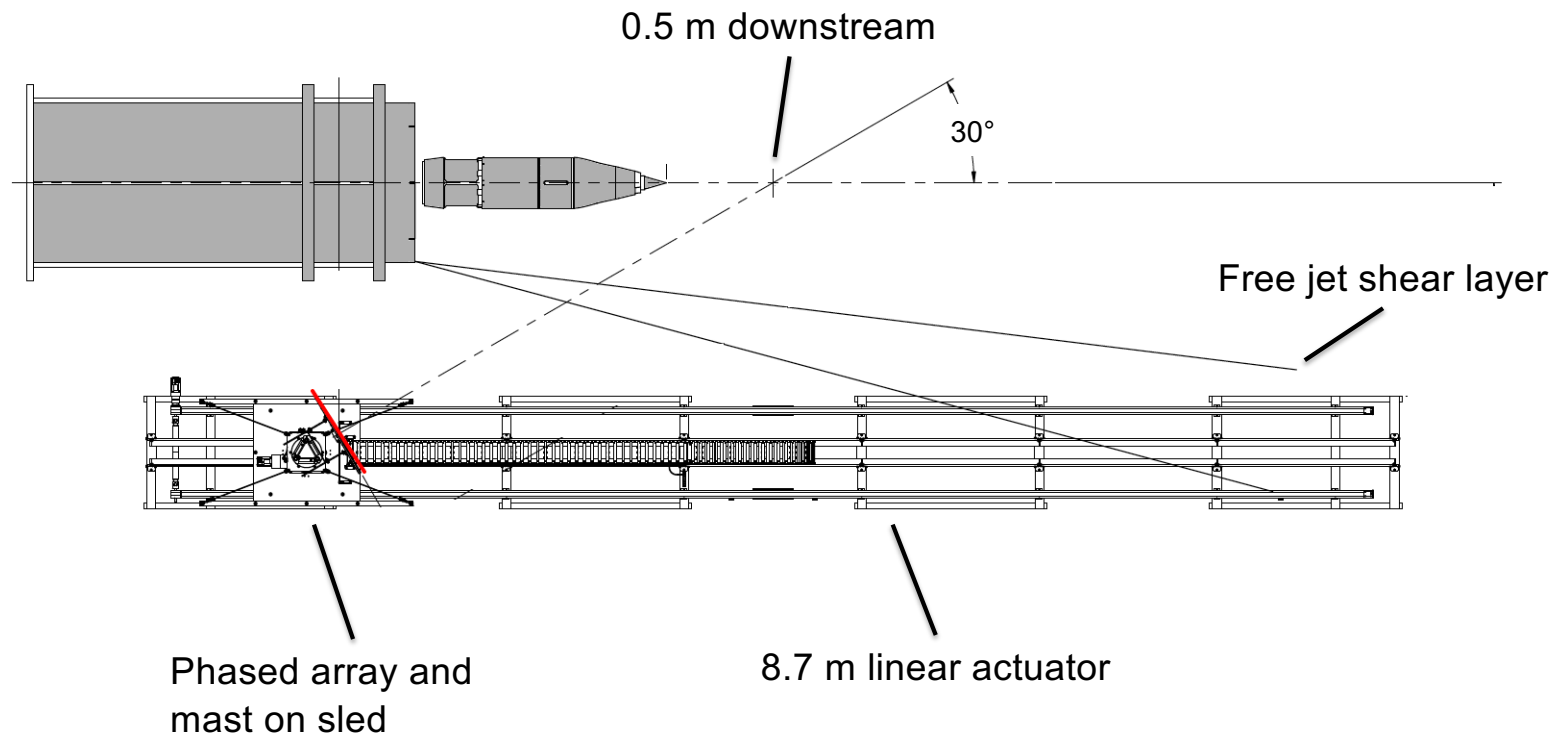
Array mounted on rotating mast

Platform rotated so array is "below" the model

Translating Phased Array



Array shown at 30° 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

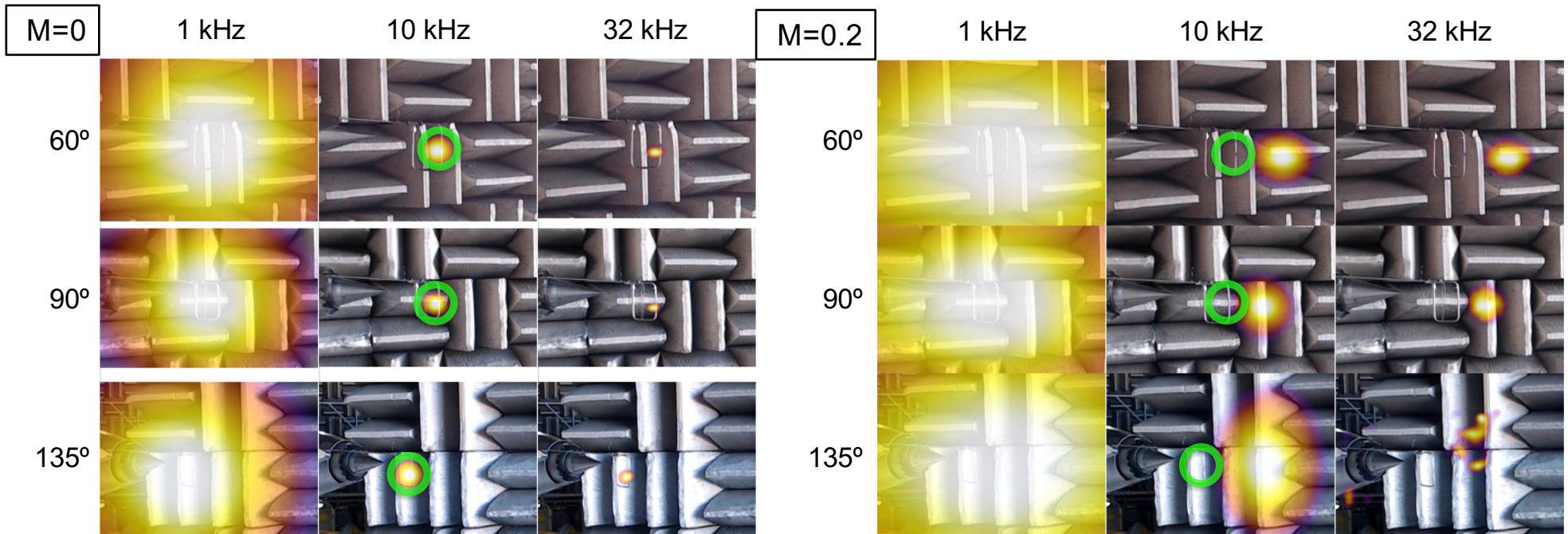


No Free-Stream Flow

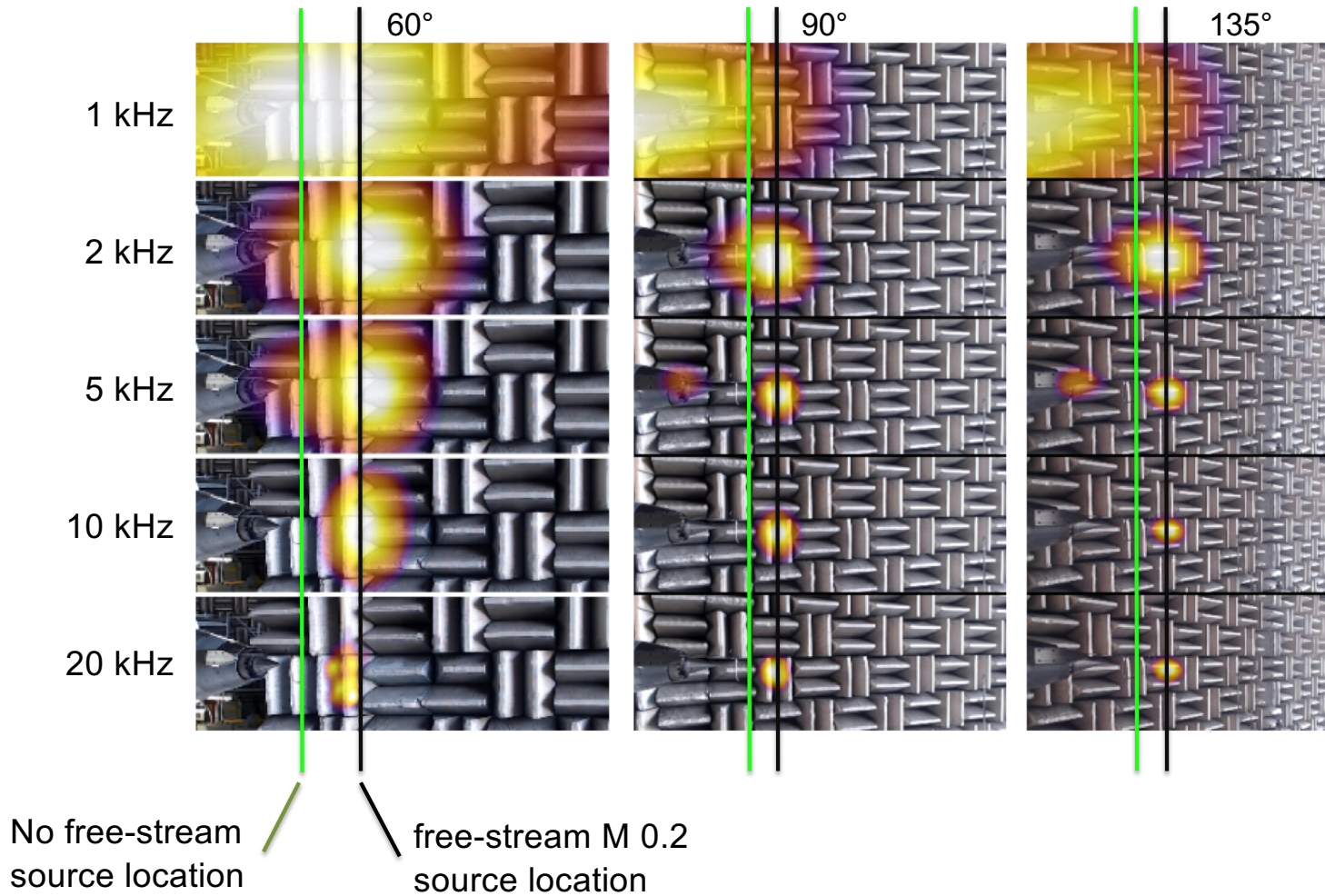
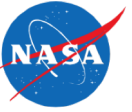
- Mapped to parallel image plane
- Source accurately located

Mach 0.2 Free-Stream Flow

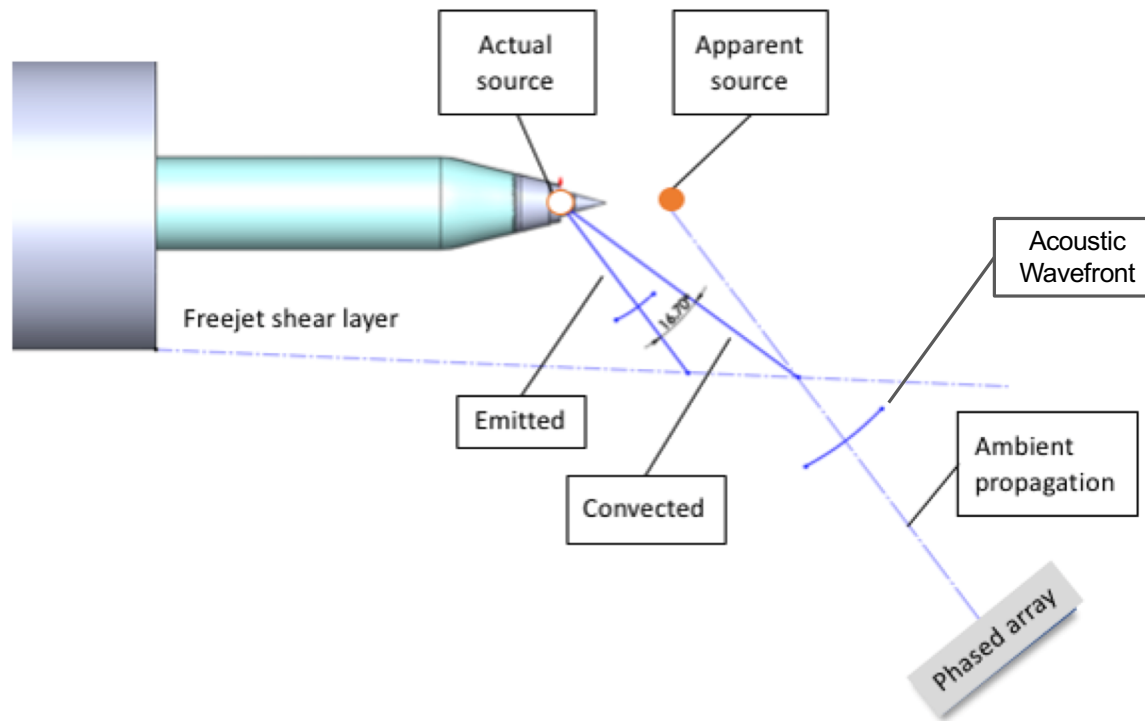
- Mapped to parallel image plane
- Source offset downstream



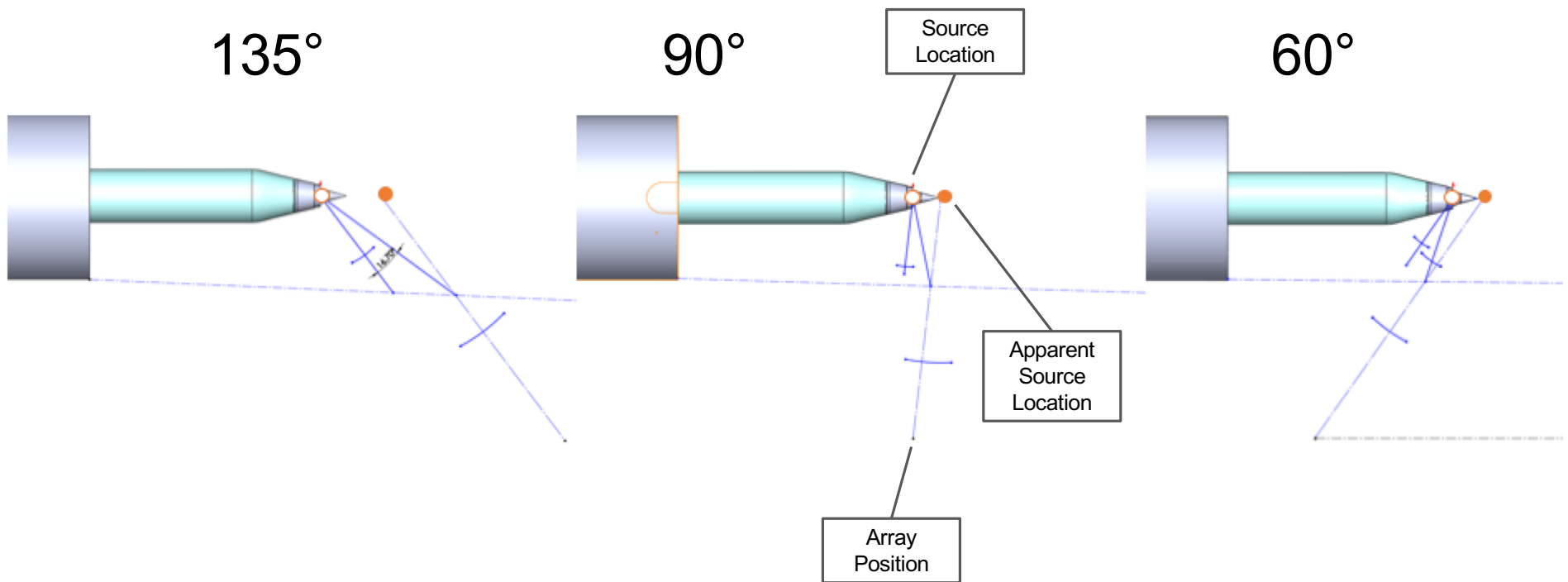
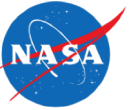
Registration Map Displacement – Free-stream M 0.2



Beamform Map Displacement



Beamform Map Displacement

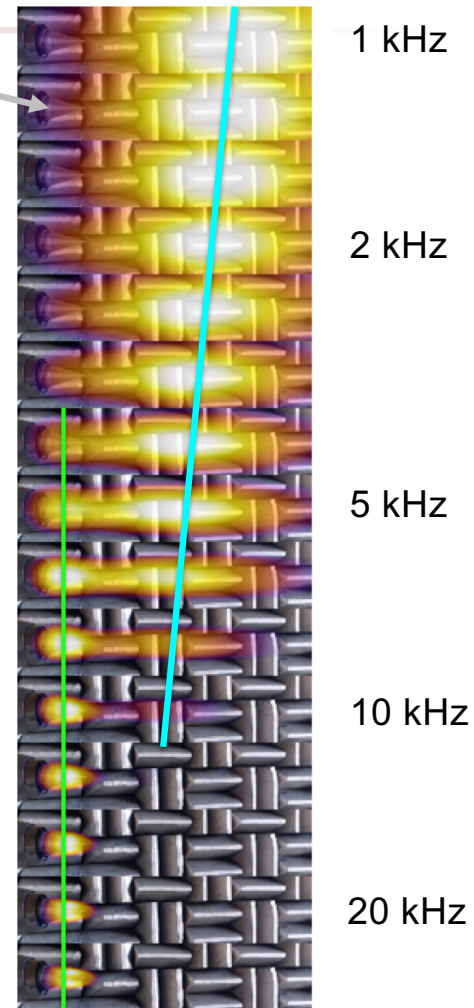


Simple Jet Flow Beamforming



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

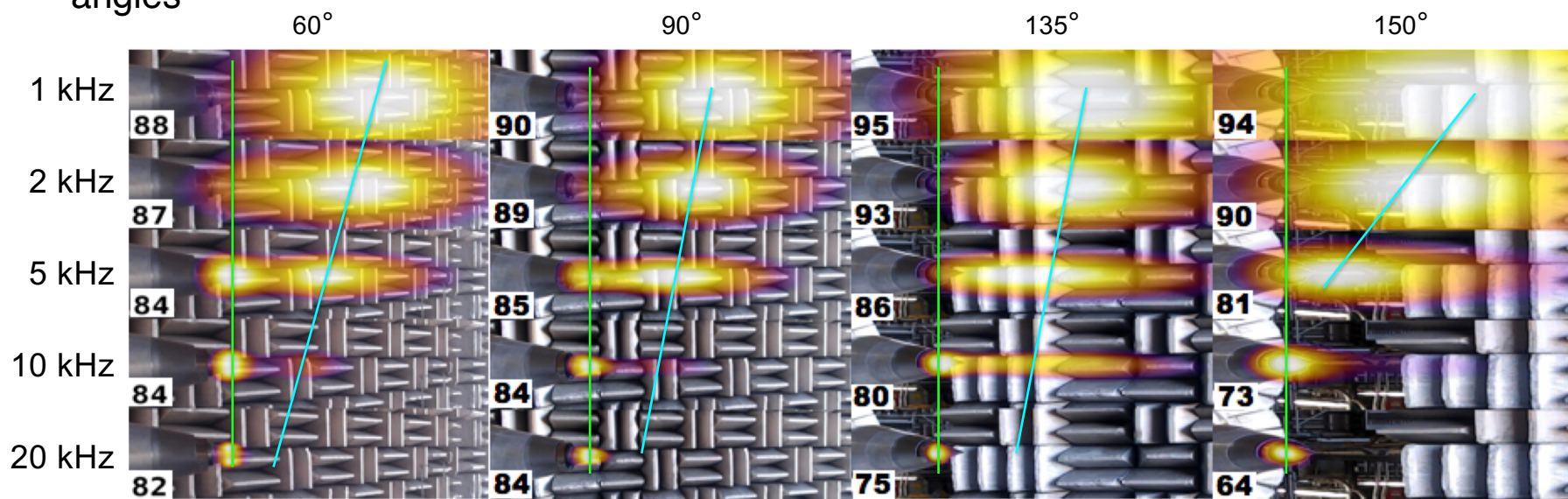
Jet Nozzle



Single-Stream Jet Flow Beamforming

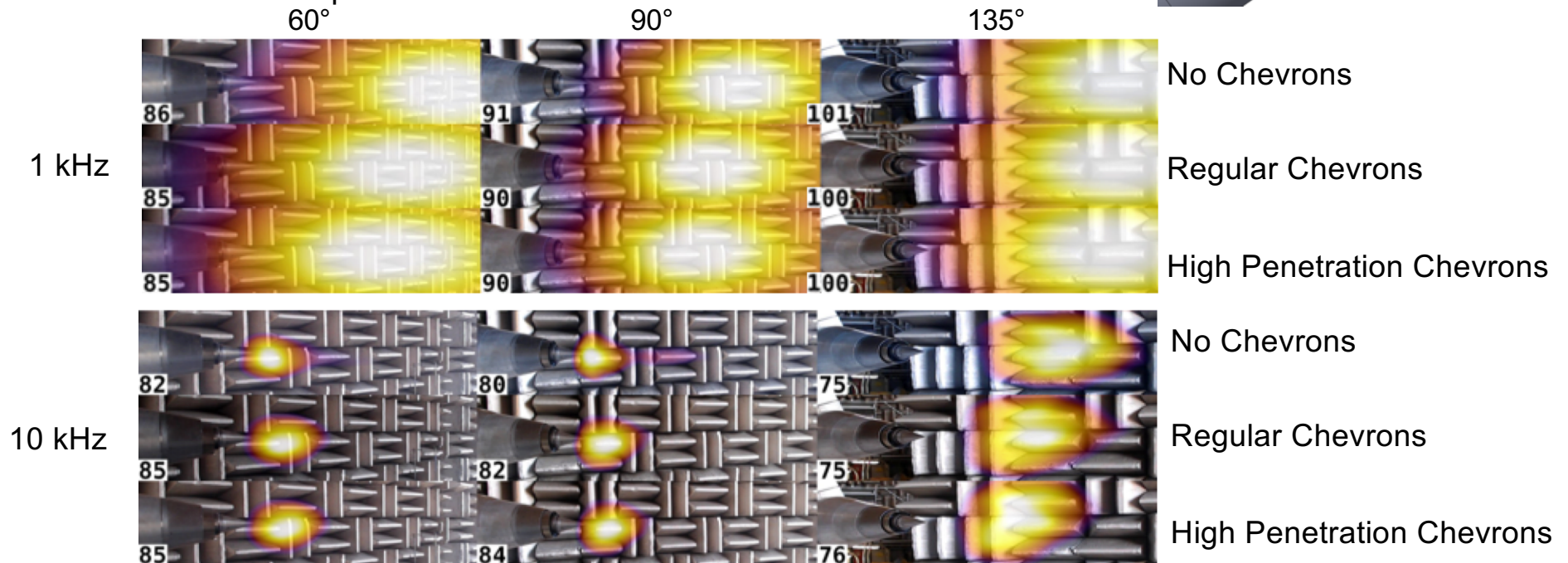
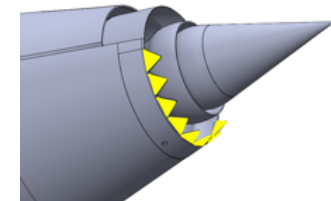


- Primary flow nozzle operating at Mach 0.98
- No free-stream flow
- 4 Polar angles
- 2 sources visible from upstream angle but become visually inseparable from downstream angles



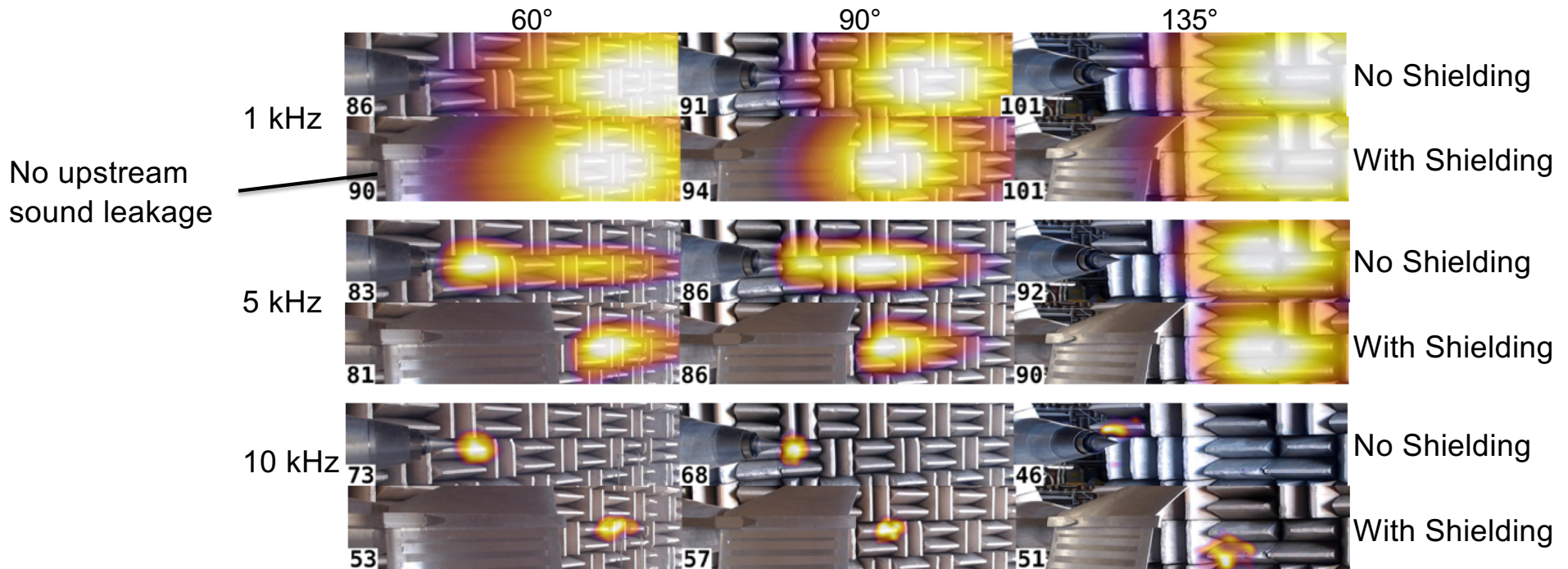
Impact of Chevrons

- 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

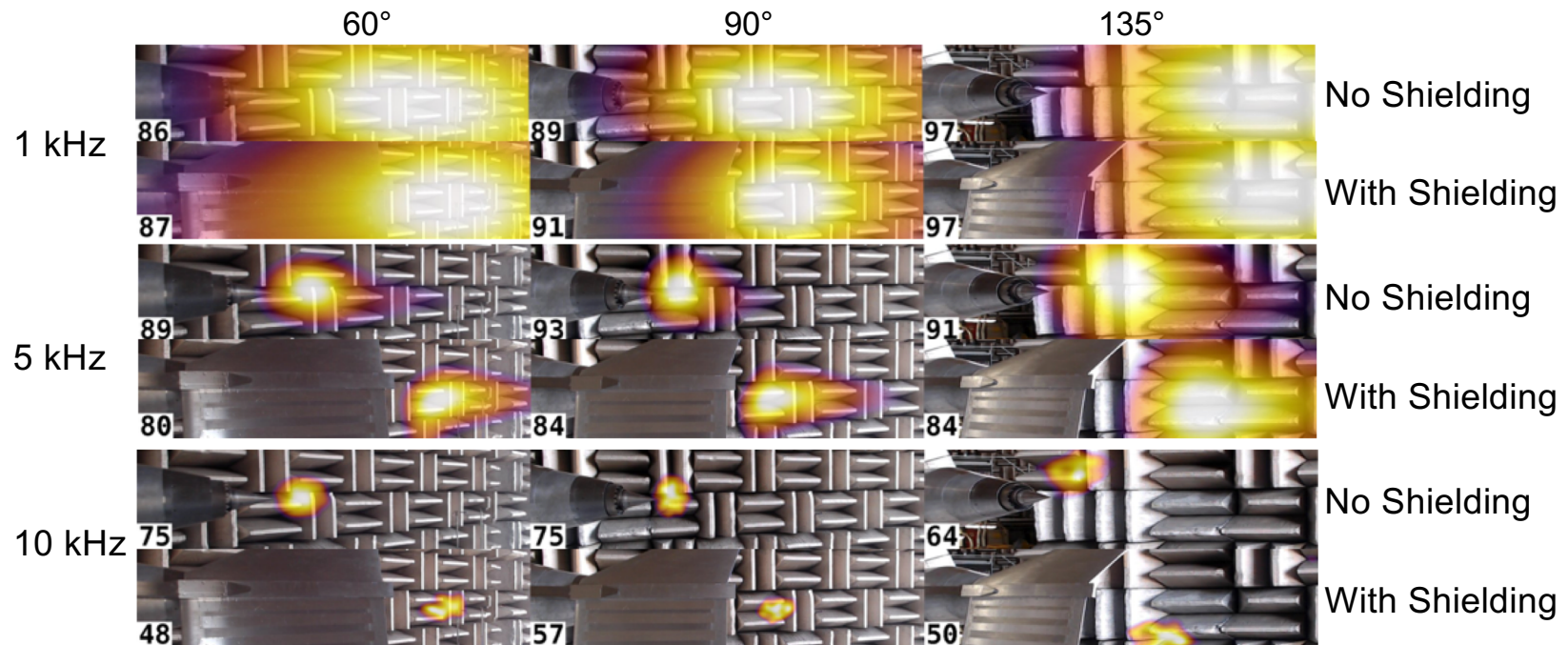
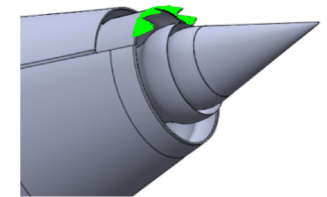
- Primary Mach 1.05, Tertiary Mach 0.95, freestream Mach 0.3
- Planform effectively blocks the nozzle-locked source but the plume source is mostly unmitigated
- Trailing edge noise visible at 5 kHz



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

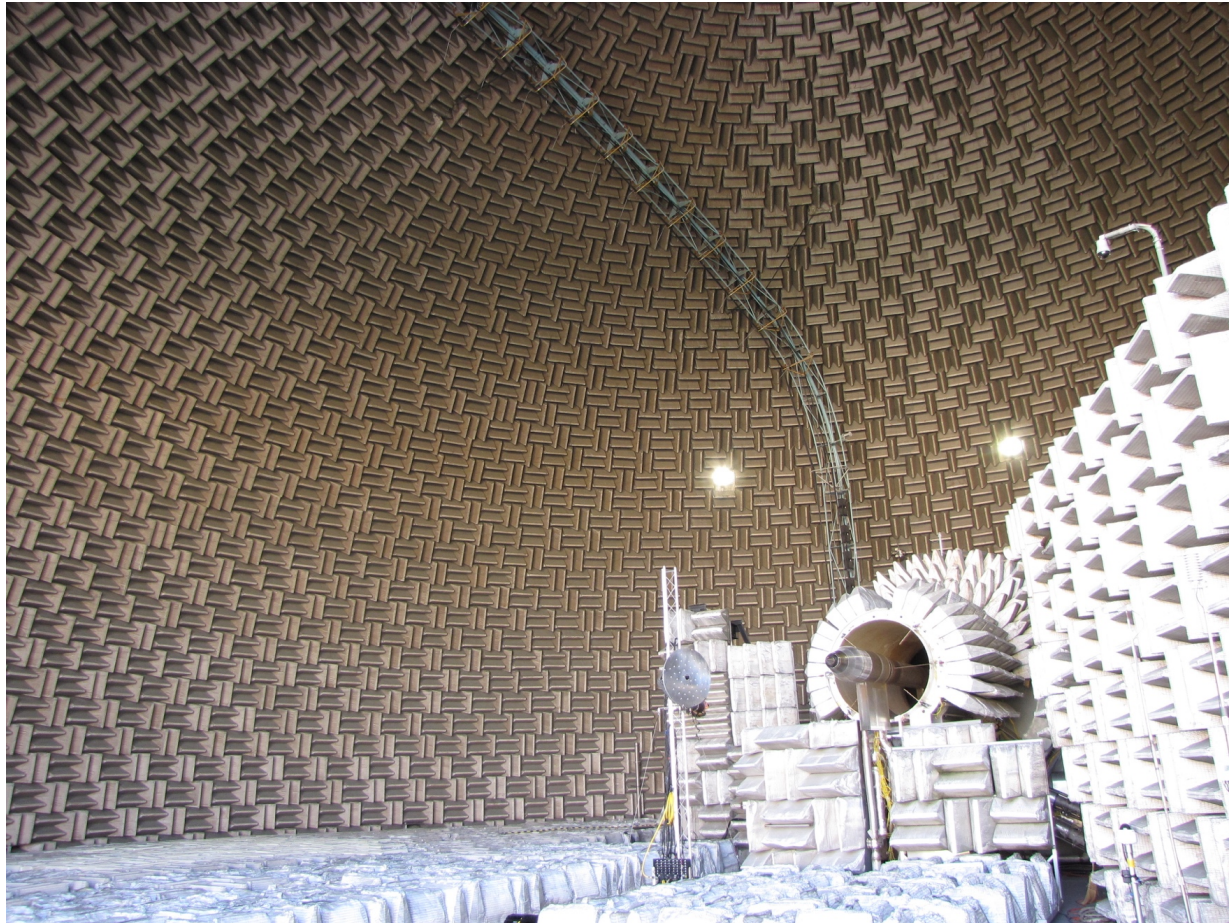
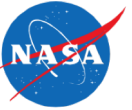




Phased Array Conclusions

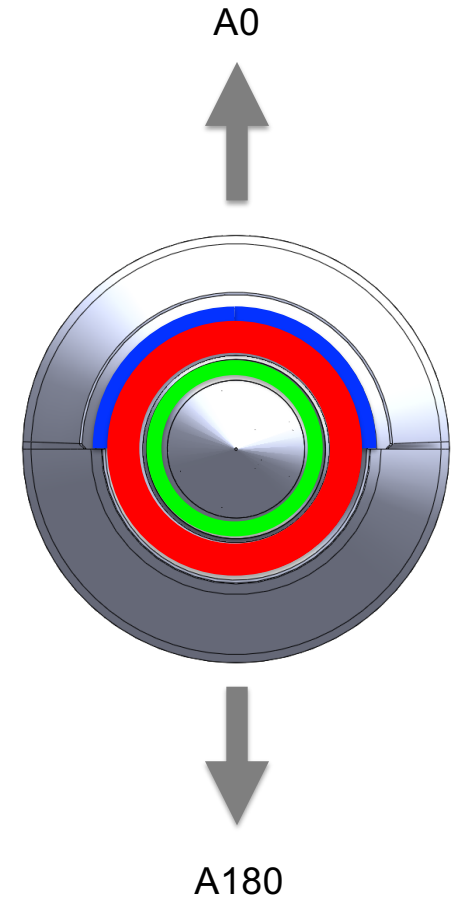
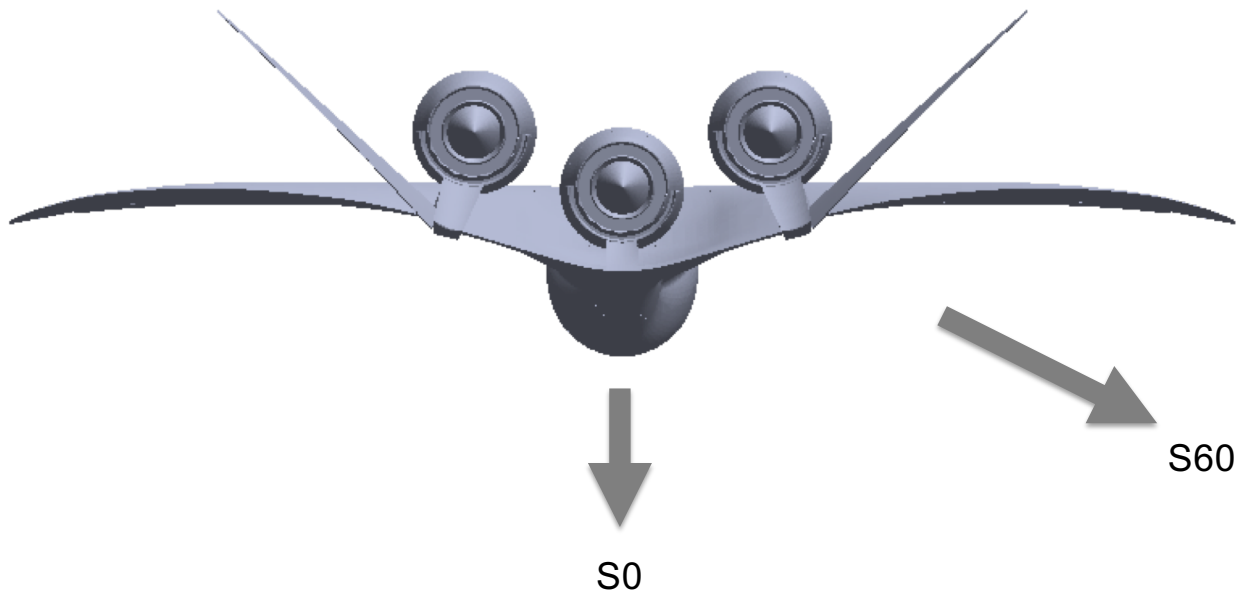
- The **Translating Phased Array** allows for **different perspectives** during an experimental run, increasing the breadth of information that can be extracted from beamforming on jet plume noise sources.
- The jet plume with center-body has **2 primary sources**, one locked to the **jet center-body** 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

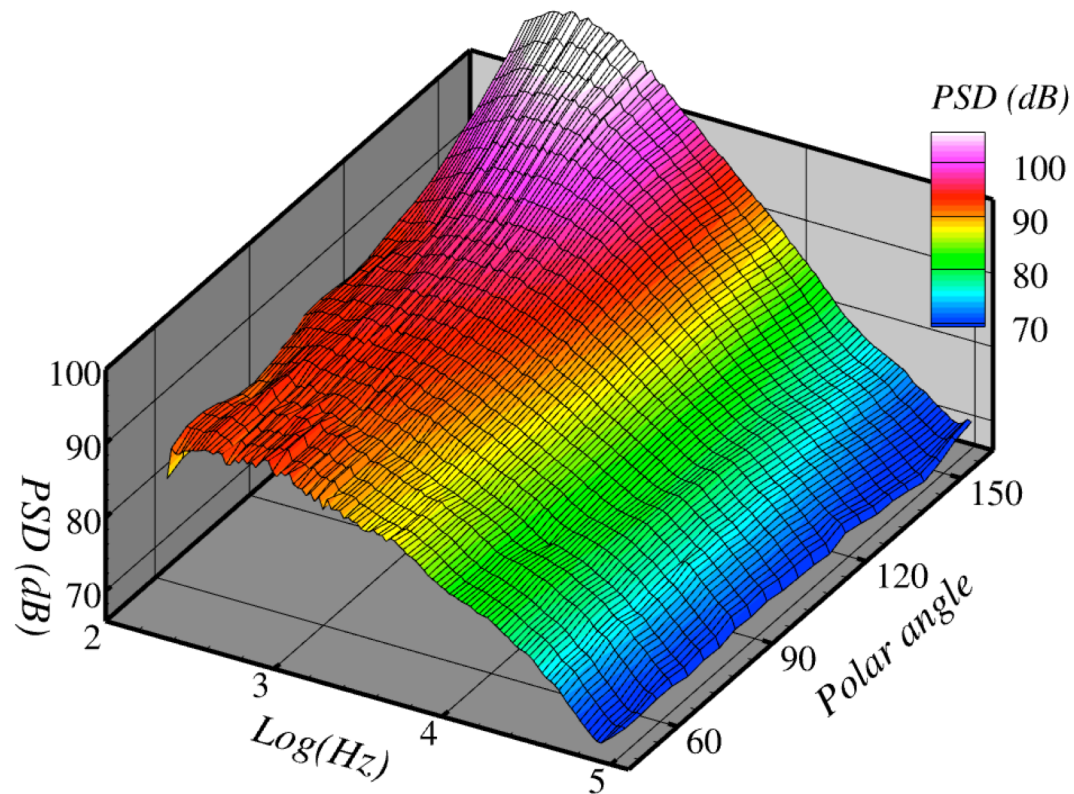
- Fixed overhead polar arc, $45^\circ - 160^\circ$ from flight axis; $r/De = 93$
- Rotating nozzle, planform
 - Flyover and sideline certification observers
 - Measure asymmetry of noise from isolated nozzle





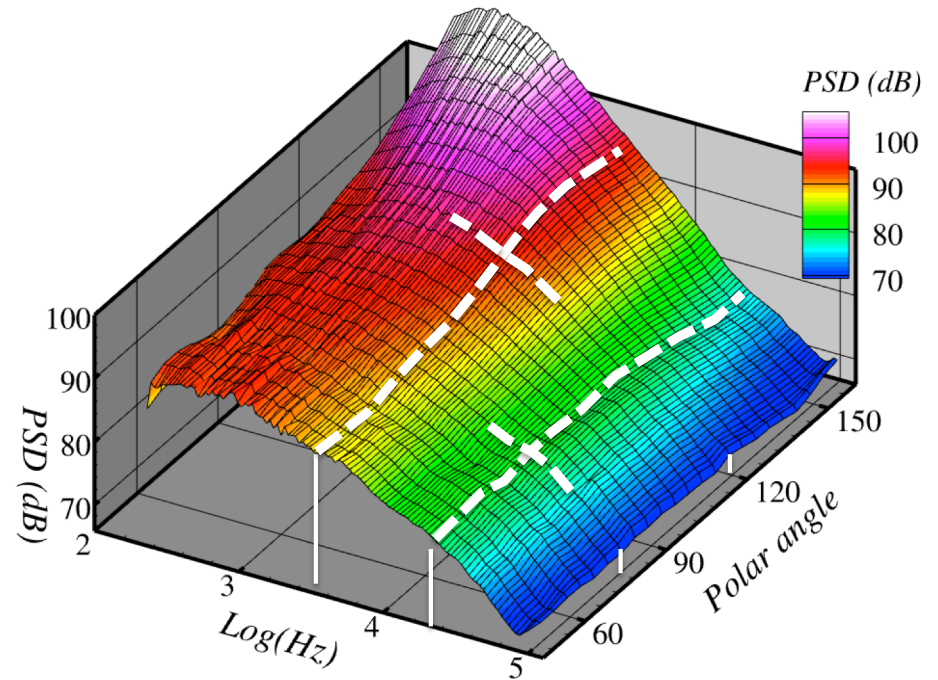
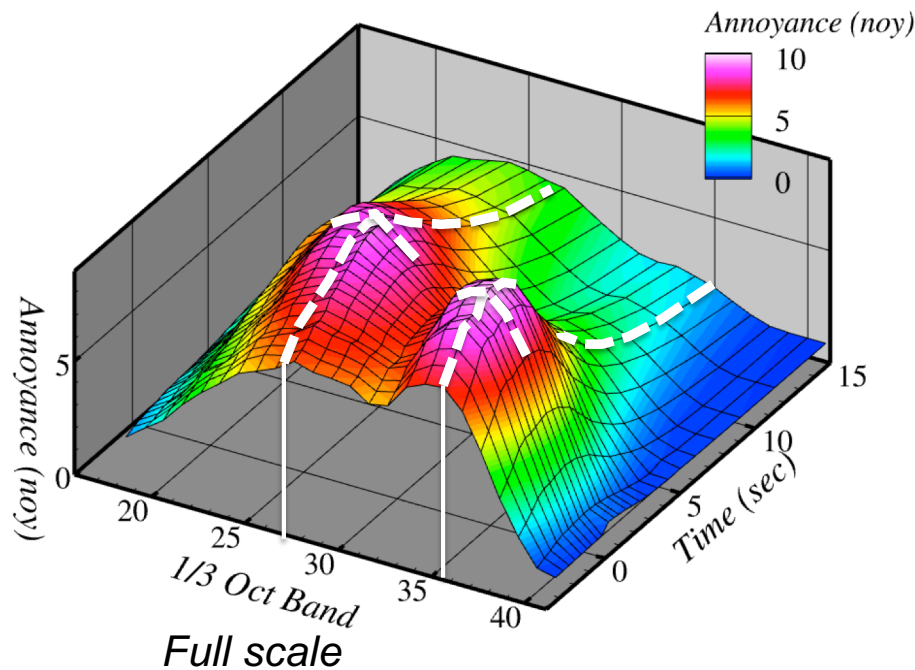
Interpreting noise spectral directivity

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



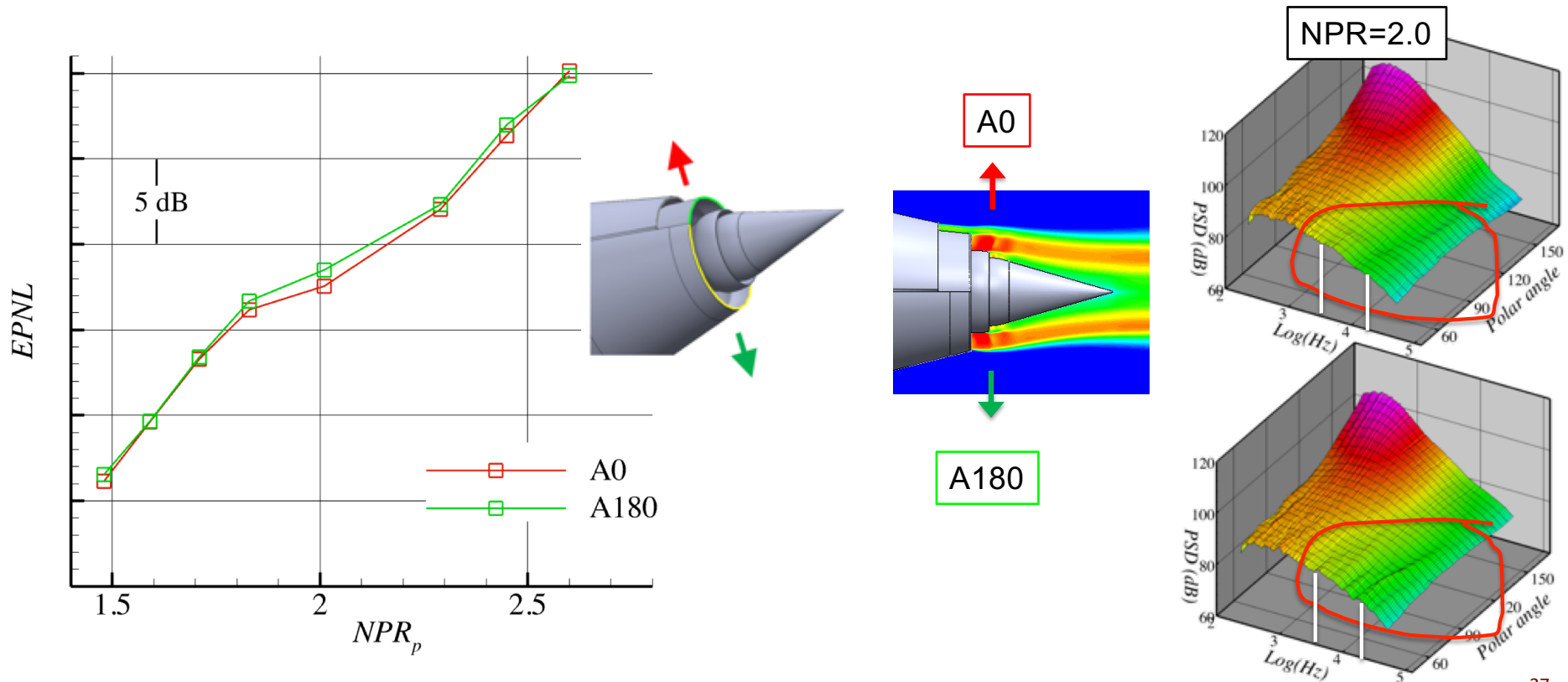
Interpreting noise spectral directivity

- 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.**



Results—Symmetry of isolated, baseline nozzle

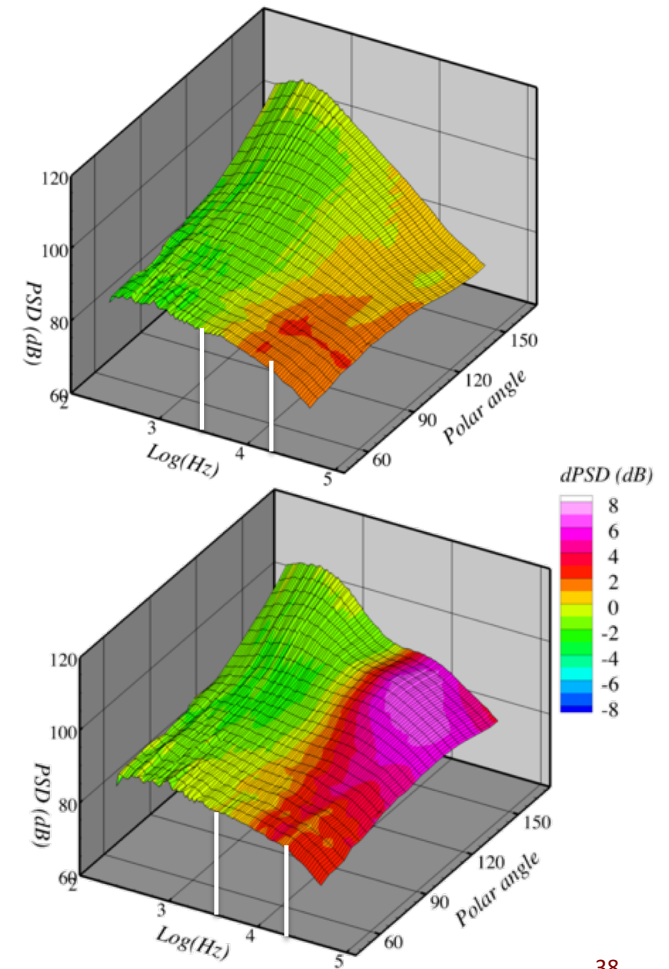
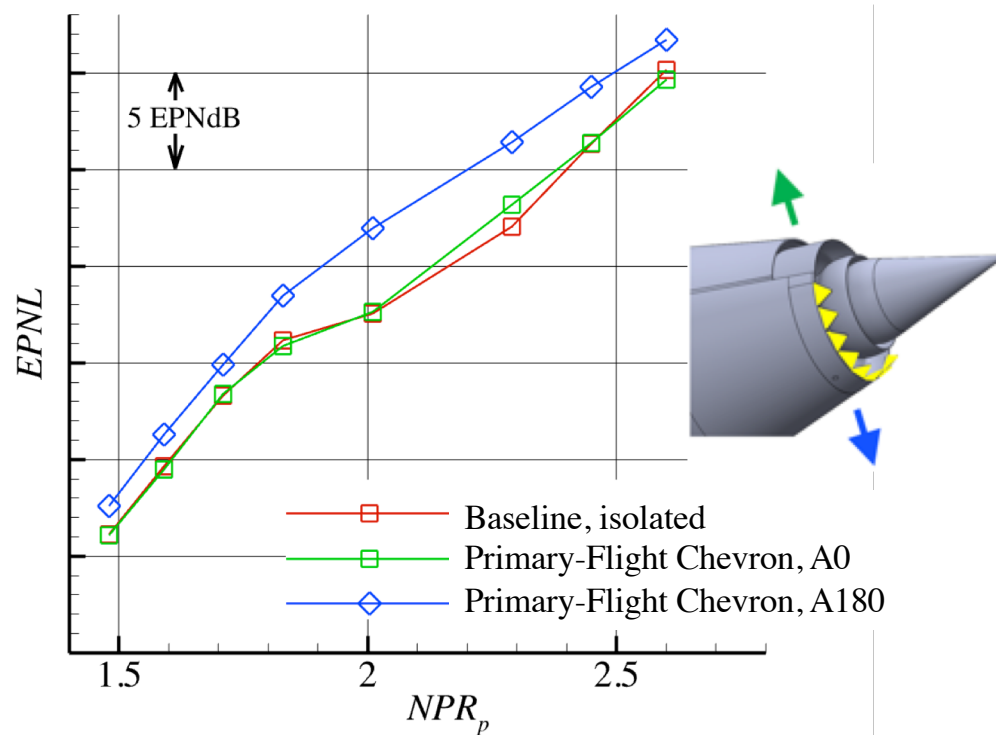
- Noise shown on two sides of nozzle.
- **Noise is nearly symmetric** except for slight asymmetry of broadband shock noise at $NPR=2$



Results—Symmetry of isolated, chevron nozzle

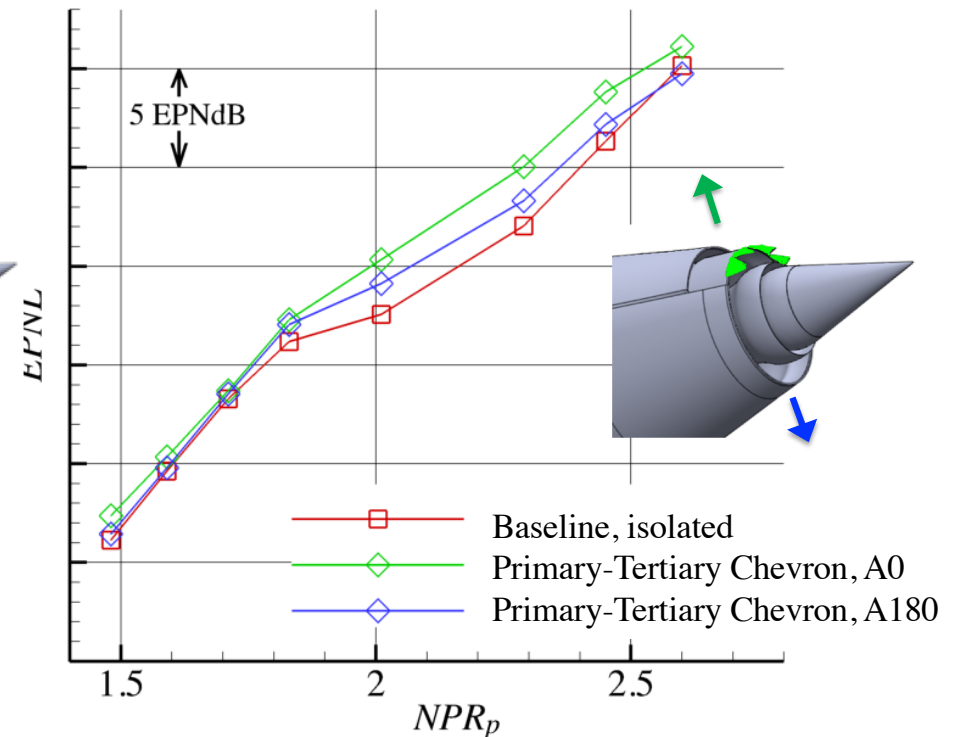
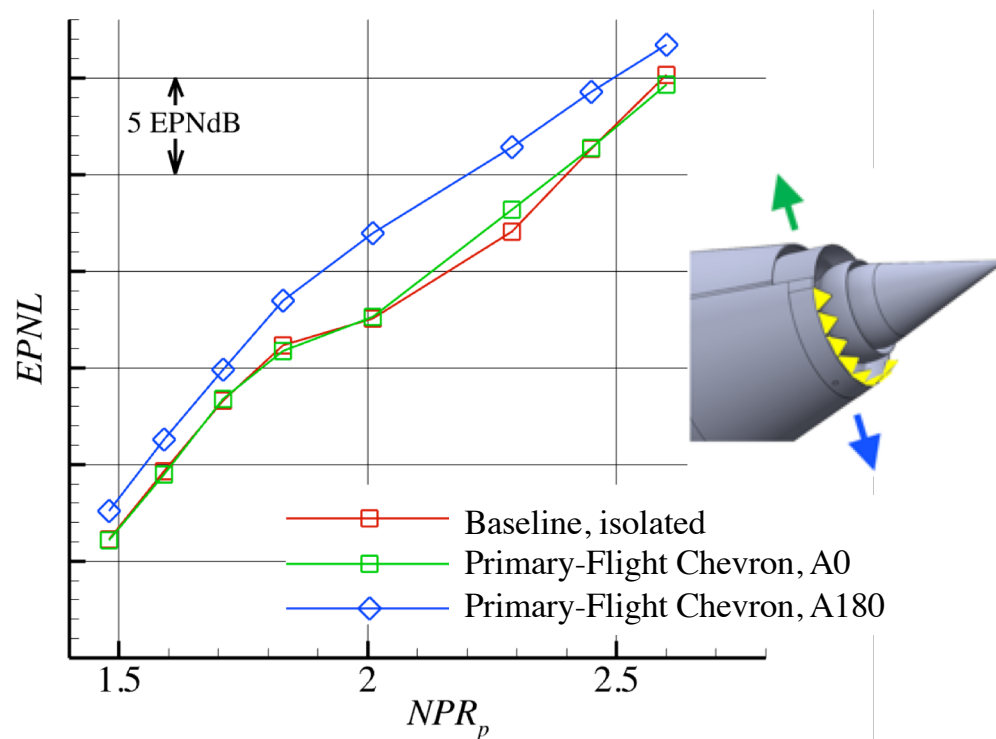


- Chevrons on **Primary-Flight** nozzle lip
- **EPNL** much higher when **chevrons toward observer**



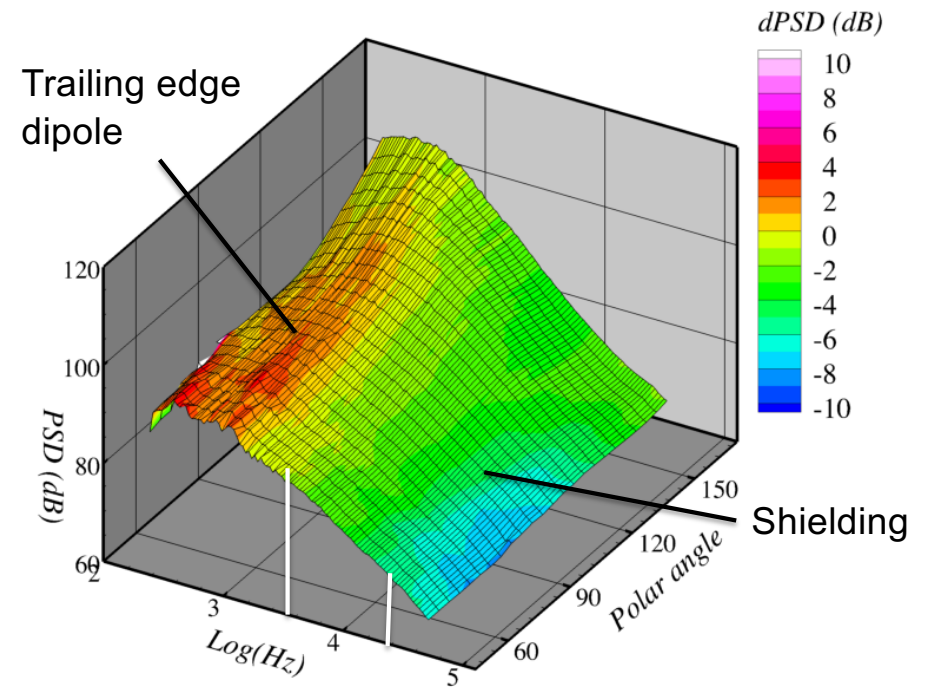
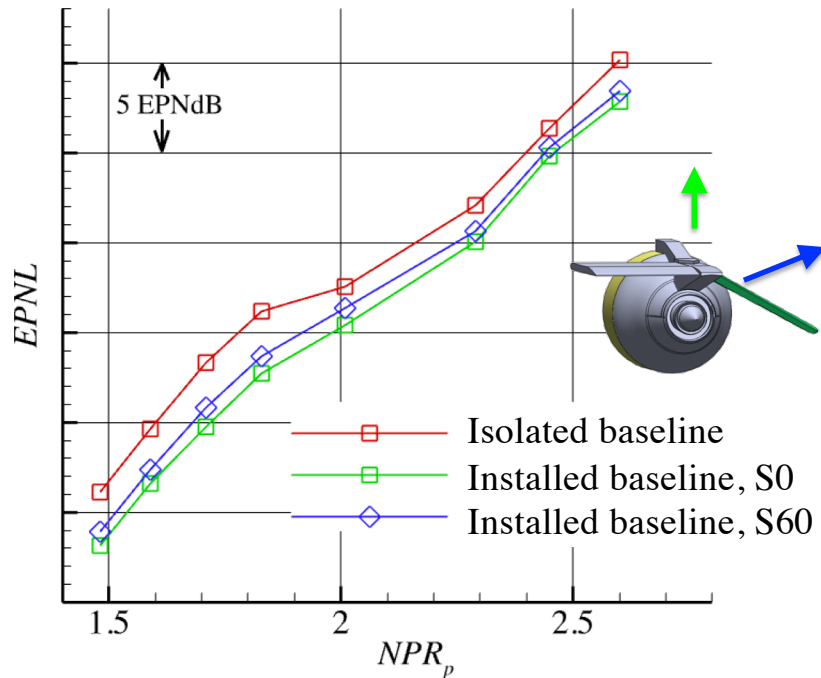
Results—Symmetry of isolated, chevron nozzle

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



Results—Installed baseline nozzle

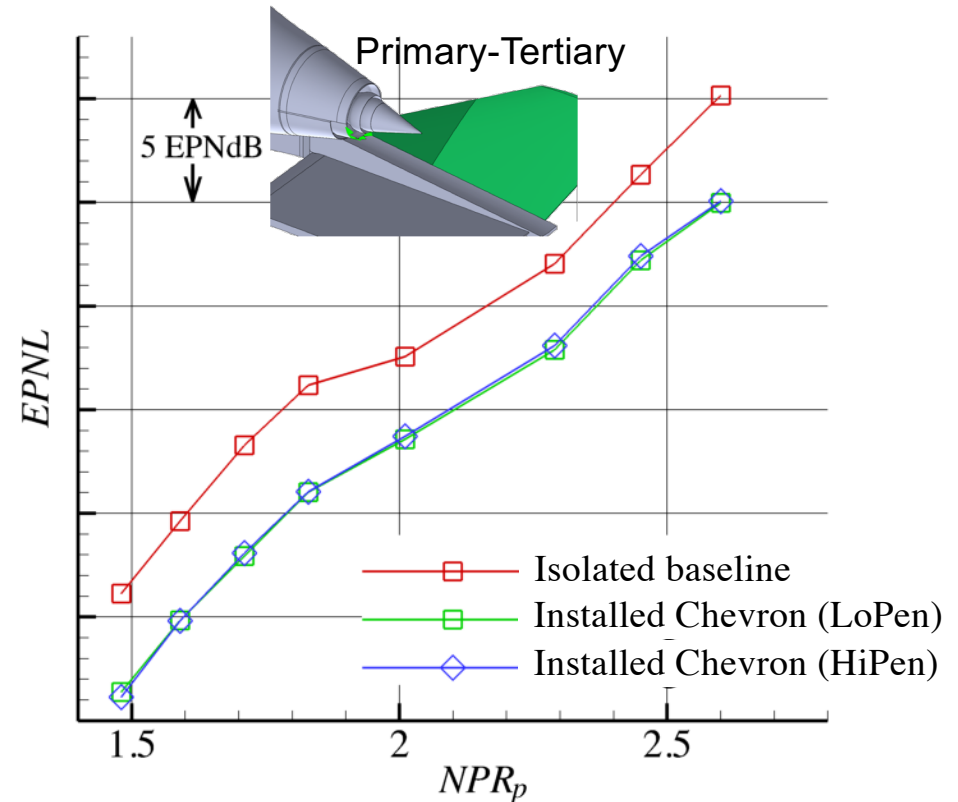
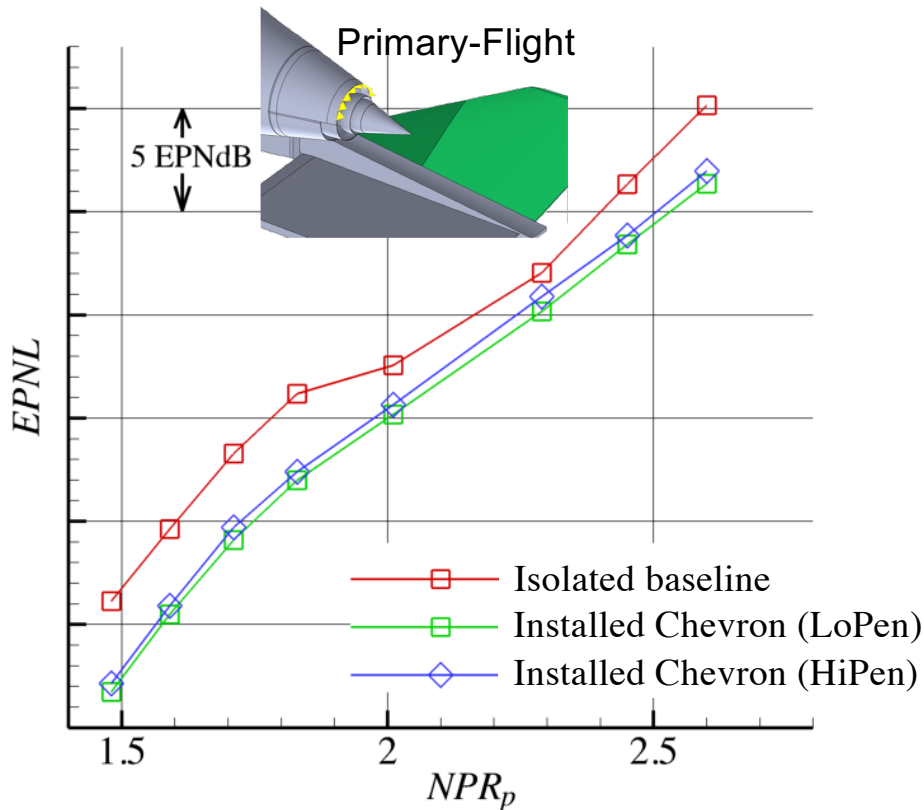
- Noise reduction from top-mounted installation, baseline nozzle
- **Planform yields 2-3.5dB reduction** under aircraft, 1-2.5dB at sideline observer



Results—Installed chevron nozzles



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

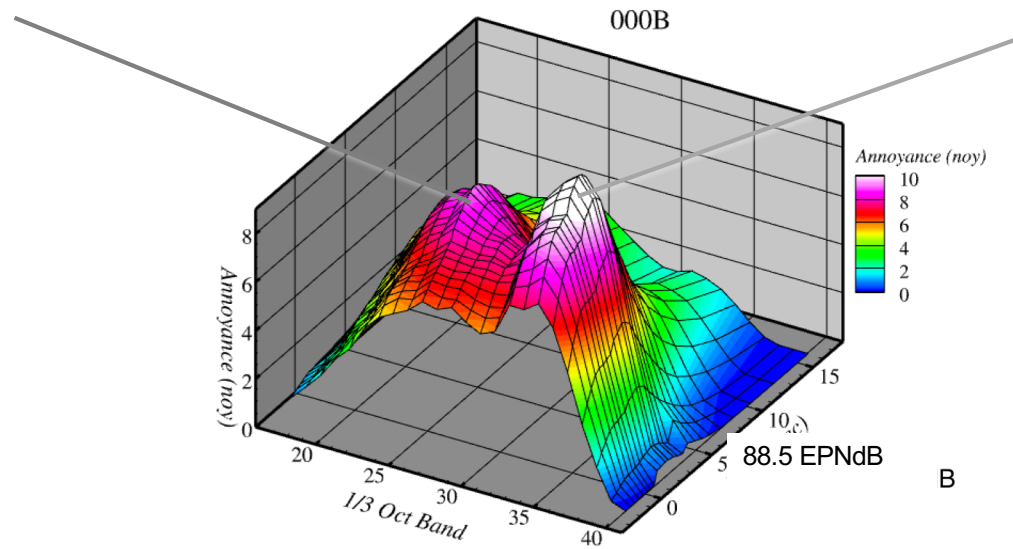
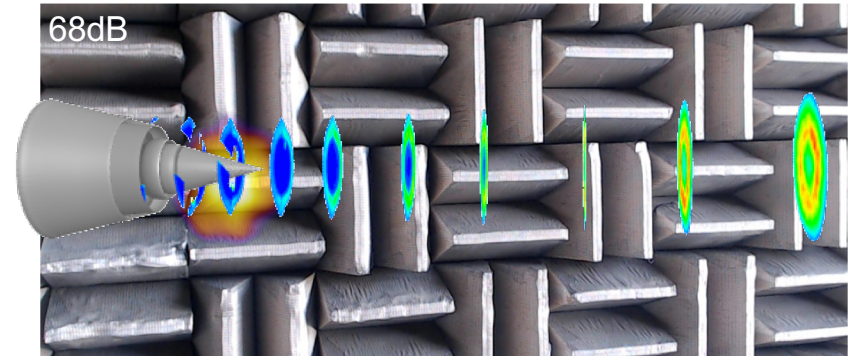
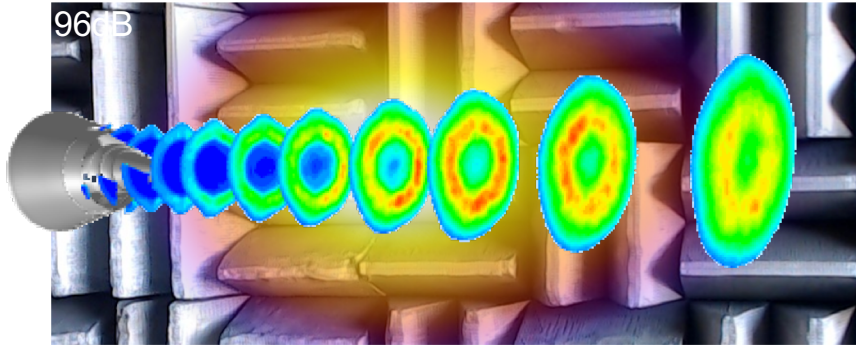
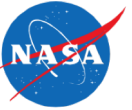




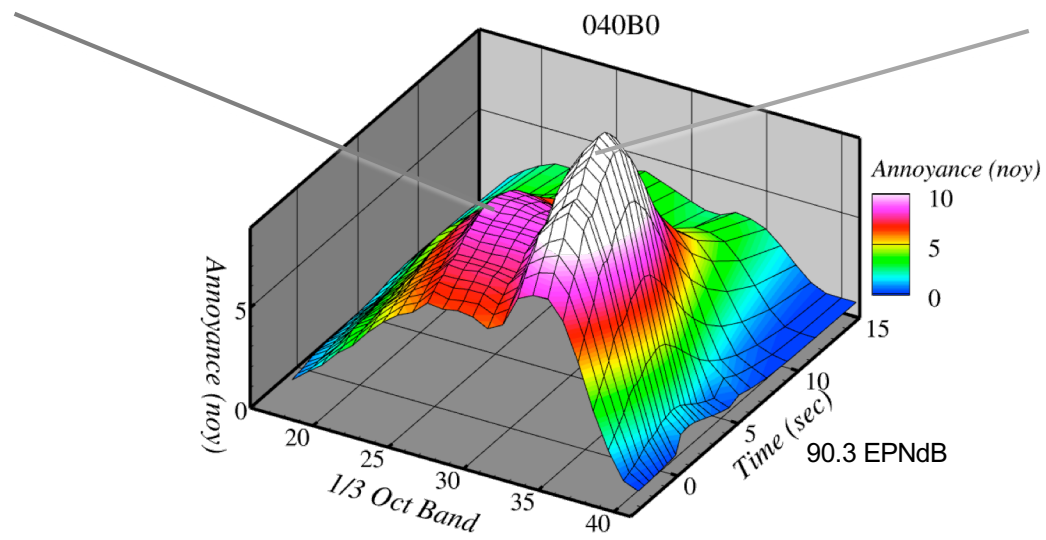
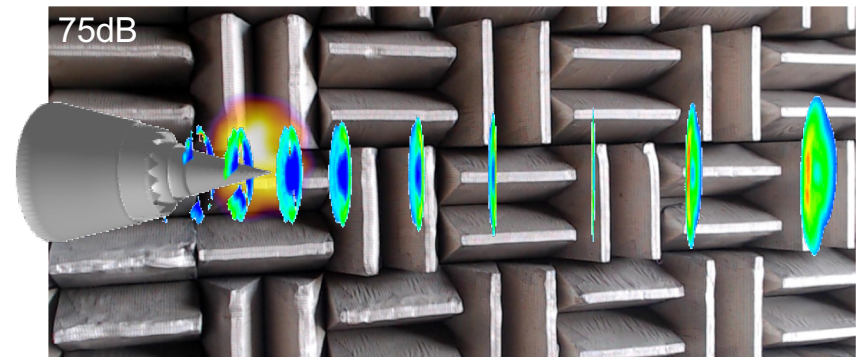
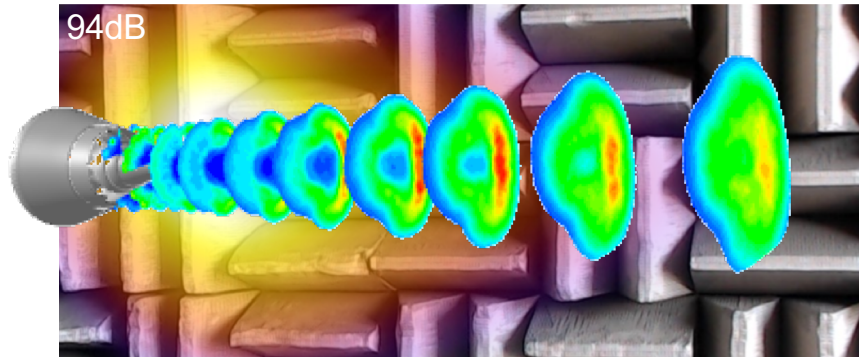
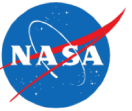
Far-Field Acoustics Summary

- 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.

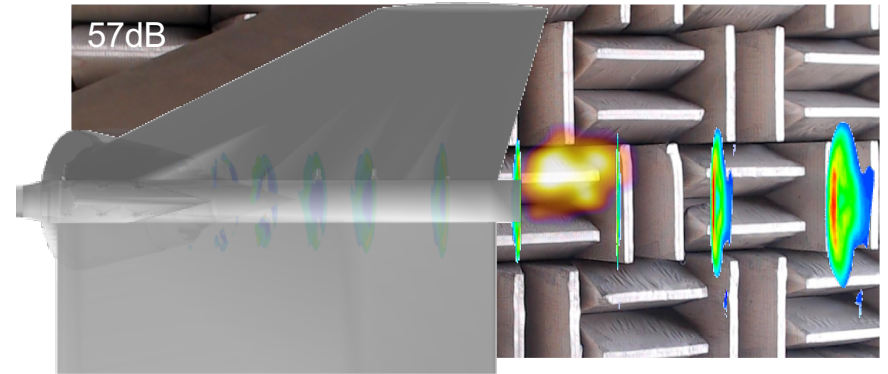
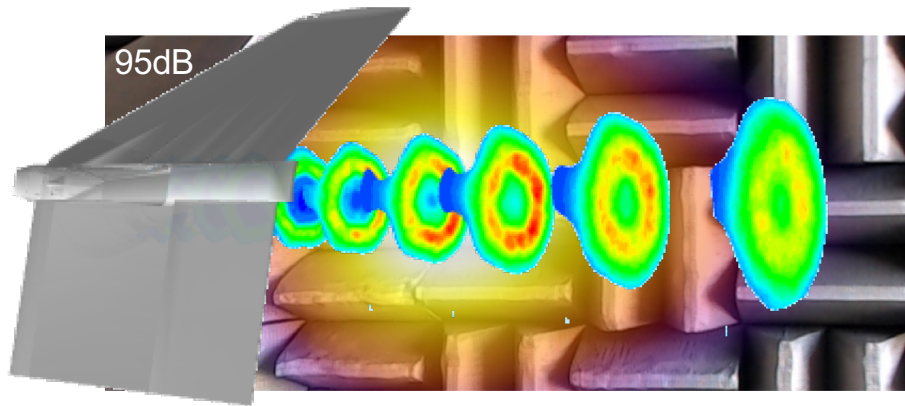
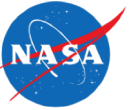
Baseline nozzle, isolated



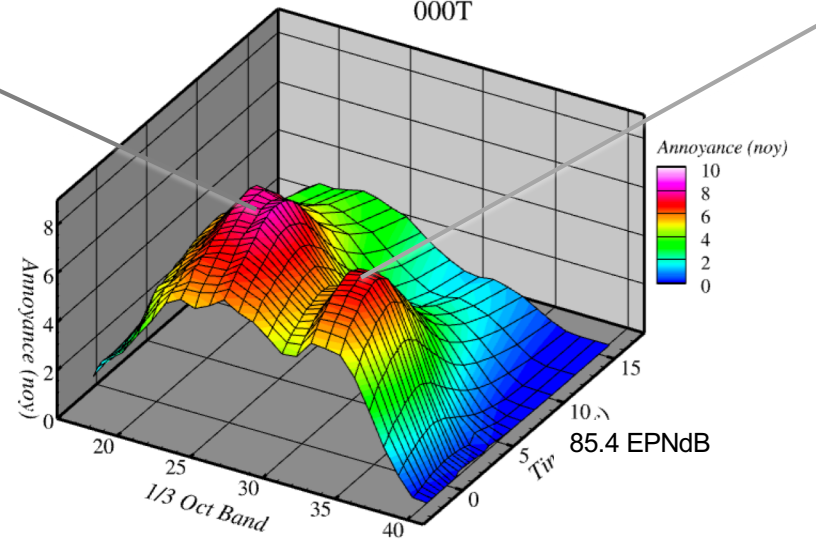
Chevron nozzle, isolated



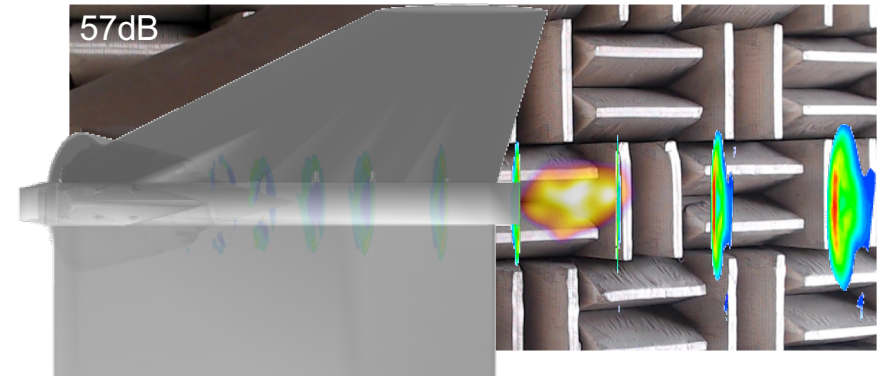
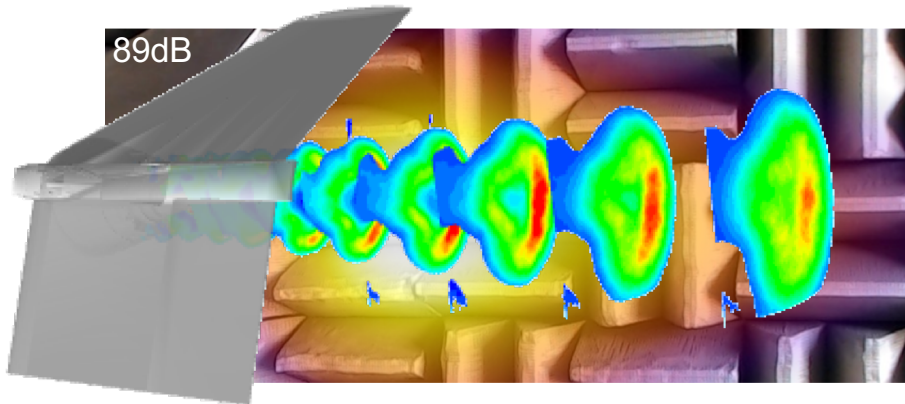
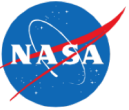
Baseline nozzle, installed



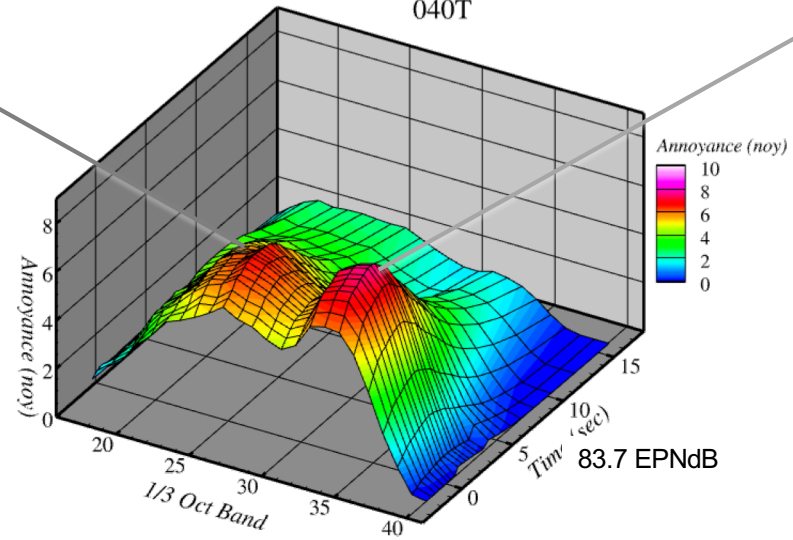
000T



Chevron nozzle, installed



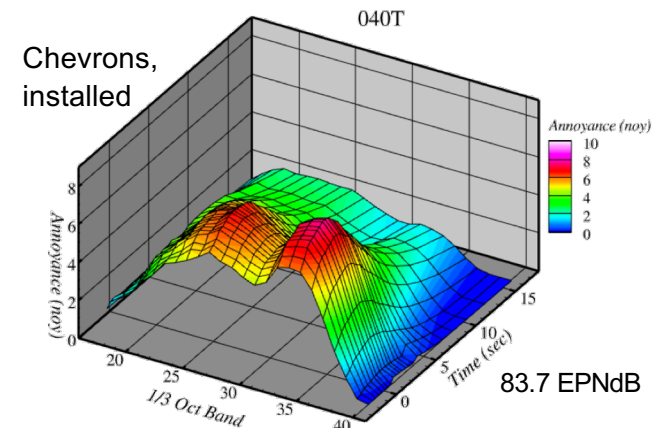
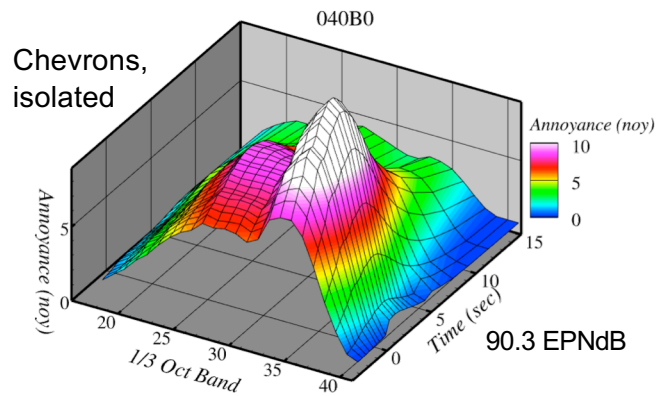
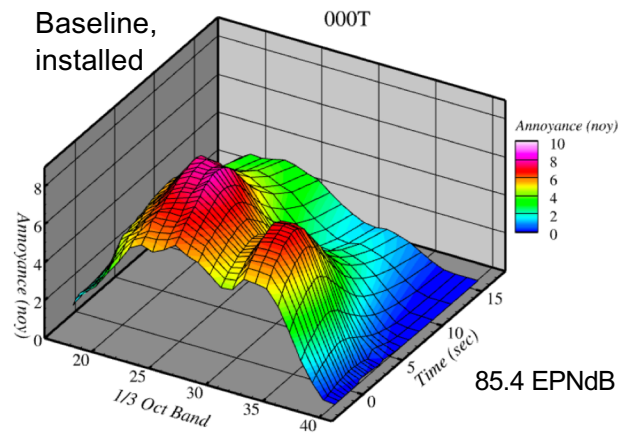
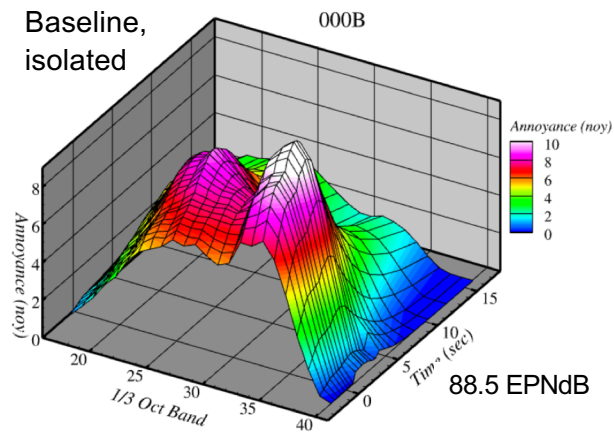
040T



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

