National Aeronautics and Space Administration

Fundamental Aeronautics Program

Supersonics Project

Plasma Actuators for Jet Excitation

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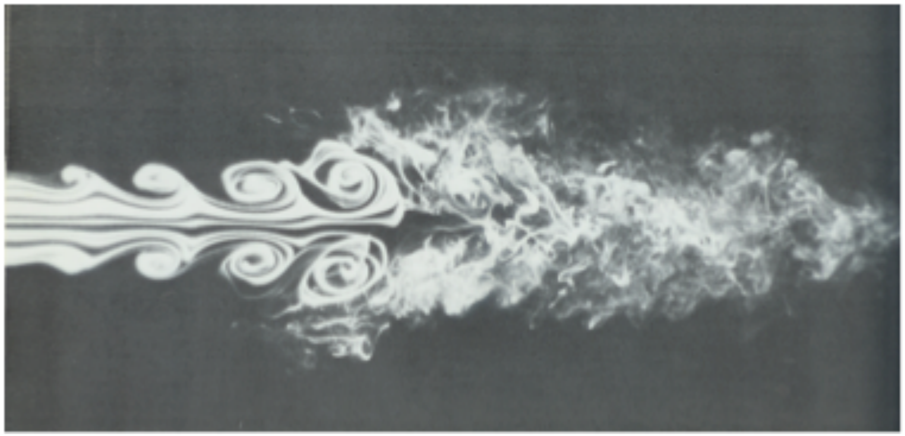
2012 Technical Conference
March 13-15, 2012
Cleveland, Ohio
www.nasa.gov

Outline

- Background
  - Jet Excitation
  - Localized Arc Filament Plasma Actuators (LAFPA)
  - Collaborative Agreement (NRA) to Develop Excitation for Jet Noise Reduction
    - NASA's Role: Scalability of Actuator System
- FY '12 Plasma Actuator Jet Excitation Test at GRC
  - Comparison OSU Results
  - Metric to Determine Scalability
  - Test Scale Factor of 3 – Constant Actuator Density
  - Test Scale Factor of 6.5 – Half Actuator Density
- Conclusions and Future Work

Background – Instability Waves

- Free shear layer in a jet is naturally unstable
- Instabilities grow and decay as the jet mixes with the ambient
  - Shear layer instabilities scale with the thickness of the initial free shear layer
  - Jet column instabilities scale with the jet diameter
  - Characterized by:
    - Amplification rate (linear stability theory)
    - Energy saturation limit (non-linear effects)
  - Described in terms of:
    - Mode (spatial)
    - Frequency (temporal)
- Instability waves govern the growth and decay of turbulent structures
  - Turbulent structures responsible for energy transport in the jet
  - Unsteady turbulent structures are responsible for much of the noise produced

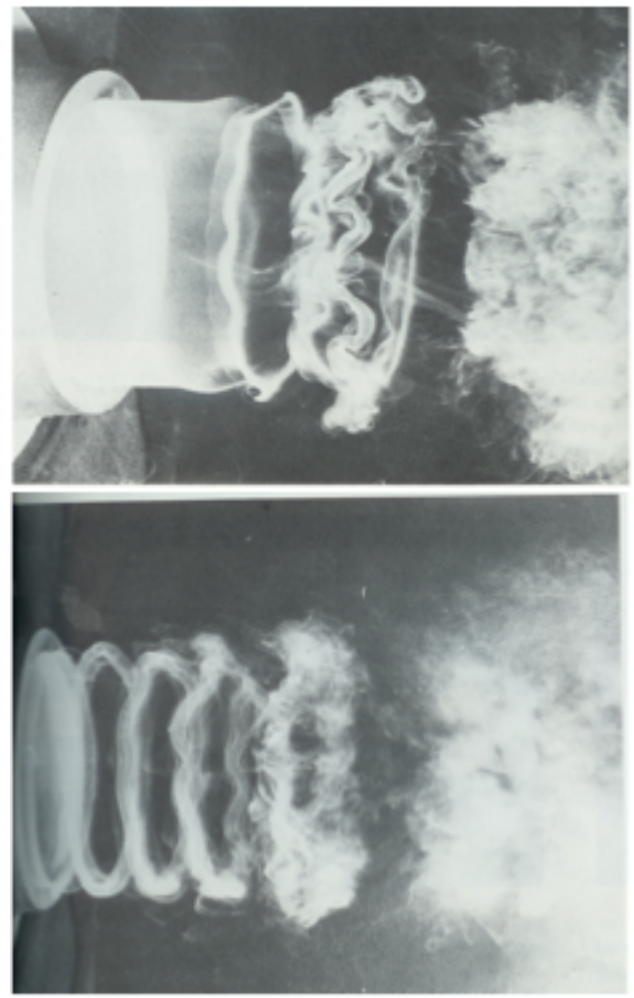


* Image from Van Dyke, "An Album of Fluid Motion", 1982

Background – Jet Excitation

Jet Excitation: Amplification of particular instability naturally present in a jet by some perturbing force that alters the characteristic of the downstream development of the jet

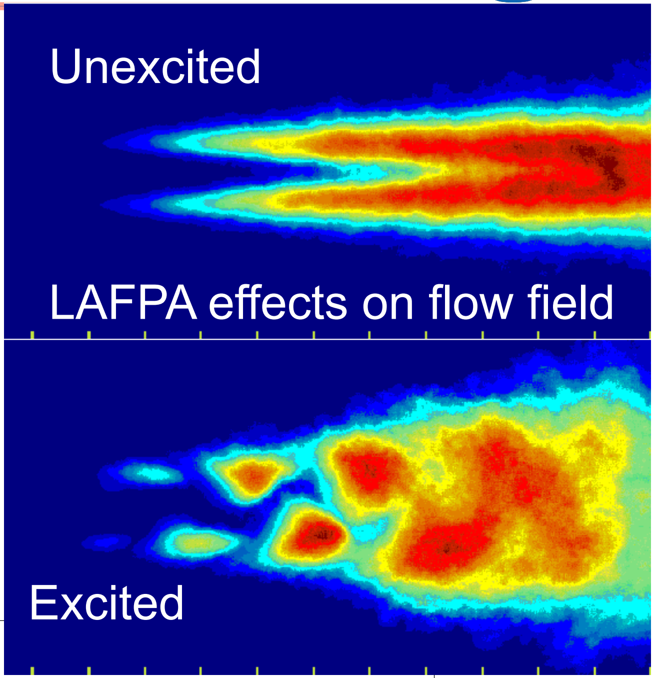
- Seed instability waves you want to grow rather than letting the jet choose
- Use natural instabilities – Small energy input gives big changes to the flow
- Why use jet excitation?
  - Enhanced mixing for chemical processes, heat transfer, plume reduction
  - Study of jet dynamics, particularly related to large-scale structures
  - Noise mitigation
- <u>Research has been limited by the jet actuator technology available</u>
  - Need high frequency bandwidth and high amplitude actuator

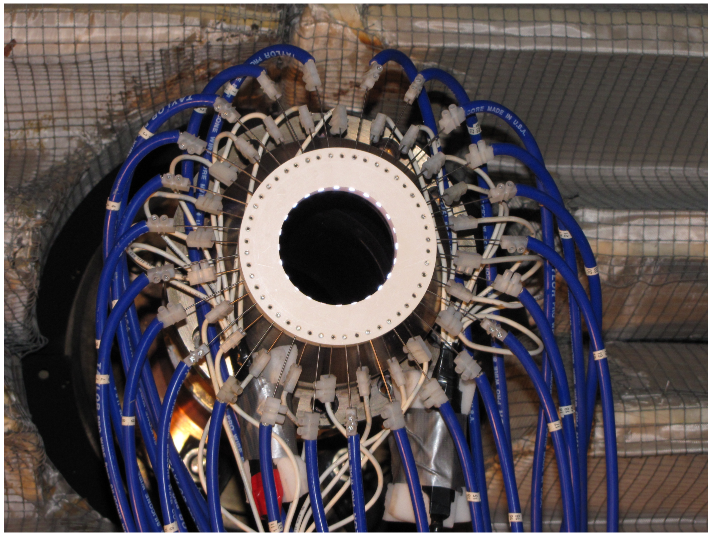


* Images from Van Dyke, “An Album of Fluid Motion”, 1982

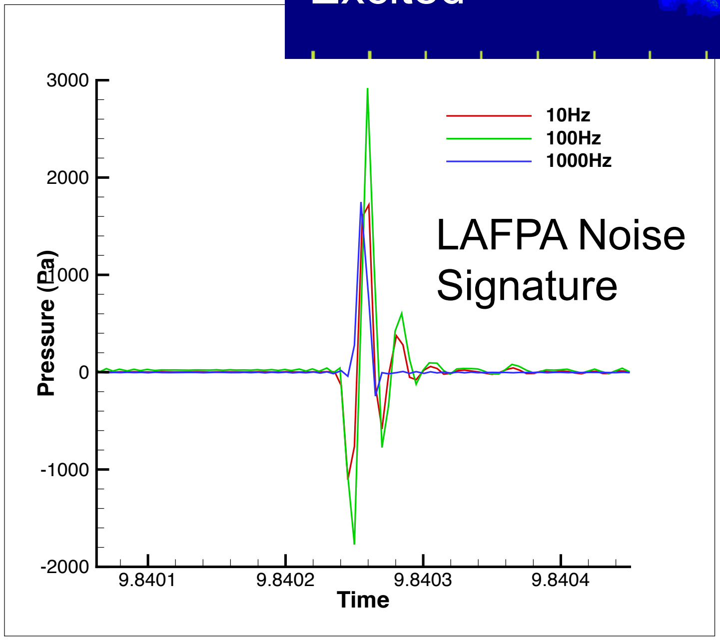
Background – Plasma Actuators

- Localized Arc Filament Plasma Actuators (LAFPA)
- Developed at Ohio State University, Mo Samimy
- Arc Regime Plasma – short rapid pulses
- High frequency bandwidth (10 Hz to 20 kHz)
- Demonstrated control on small-scale (D_j=1") high-speed (M_j=1.3) jet with $Re_{Dj} > 1x10^6$
- Currently testing 2nd generation system
  - Efficiency increases allow many more actuators



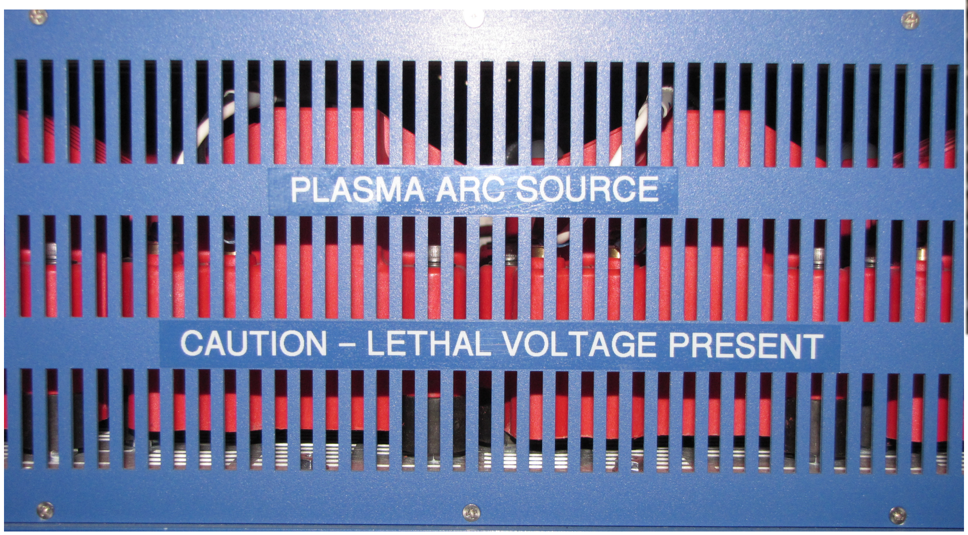


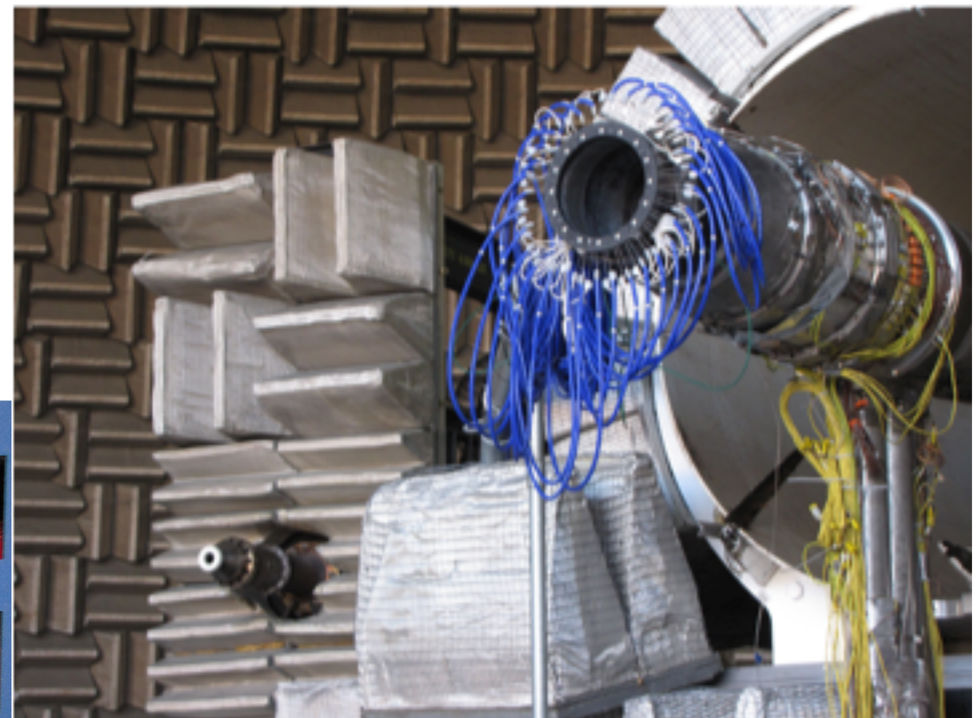
24 actuators system at NASA GRC



Background - NRA Collaborative Agreement

- NRA Collaborative Agreement awarded in 2006
- Three track approach:
  1. Optimization for Noise Reduction using LES and Adjoint Solvers
     - U. Illnois Urbana-Champagne, Bodony and Freund (Co-PI's)
  2. Actuator Development and Small-Scale Testing
     - Ohio State University, Samimy (PI)
  3. Actuator System Scalability
     - NASA GRC, Brown (COTR)

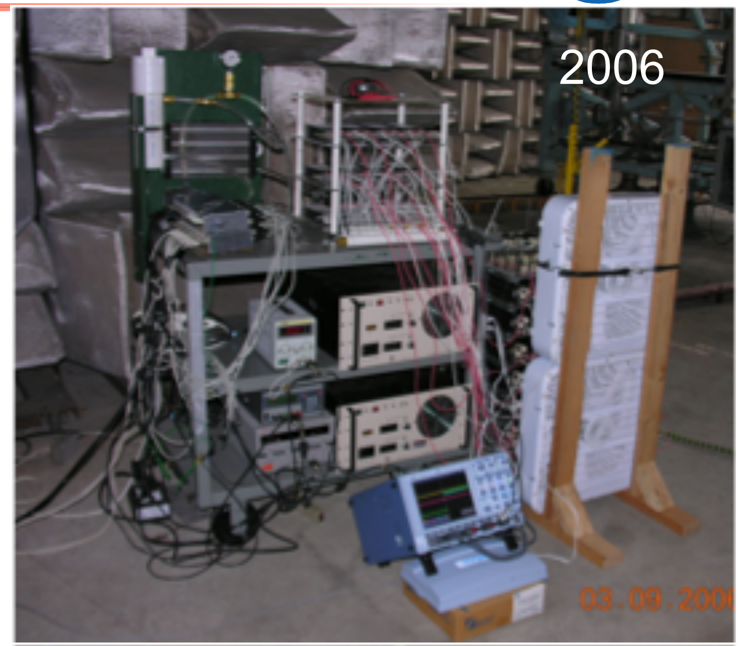




Scalability Testing at NASA GRC, 2012

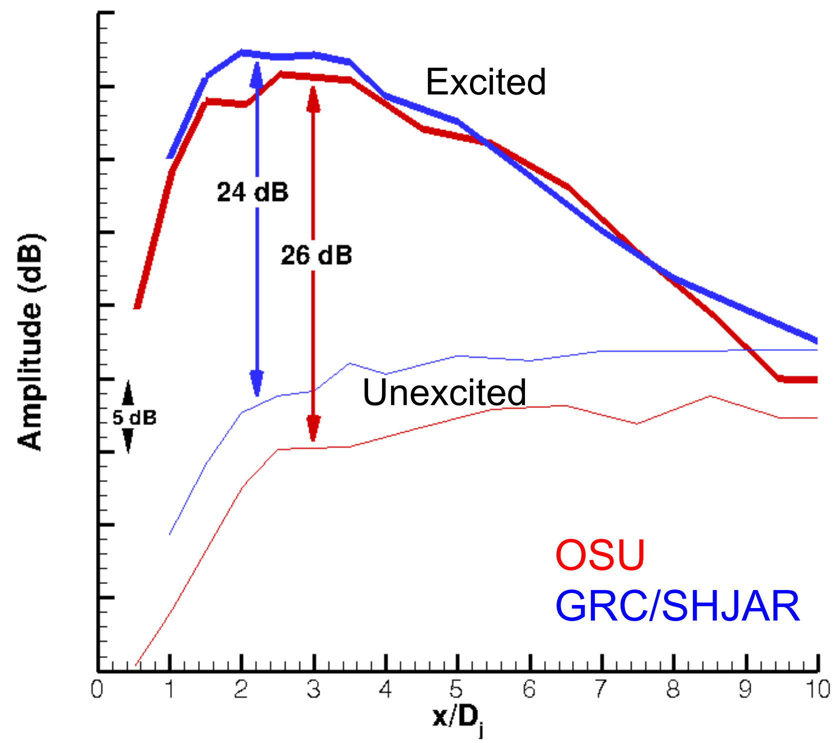
Background – History of System Scalability

- 2006 – First LAFPA test at GRC
  - Scale from D_j=1” (OSU) to D_j=7.5” (M_j=0.9)
  - 1st generation LAFPAs - limited to 8 actuators
  - Learning experience
    - EMI and instrumentation issues
    - Test procedures
- 2007-2010 – Scalability by CFD
  - Range of time scales limited simulations
  - How do actuators couple to flow?
- 2011 – GRC test using 2nd generation LAFPAs
  - Scale from Dj=1” (OSU) to D_j=6.5” (M_j=1.3)
  - 2nd generation LAFPAs allow 48 actuators
  - Many LAFPA development issues
- 2012 – Retested 2nd generation LAFPAs at GRC
  - Scale from D_j=1” (GRC) to 6.5” (M_j=0.9)
  - Use 8 to 24 actuators
  - Results to follow



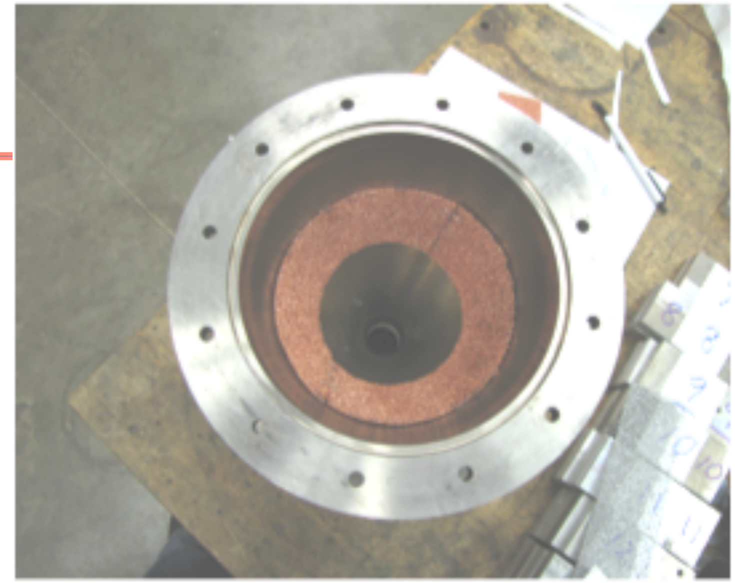
Comparison to OSU Data

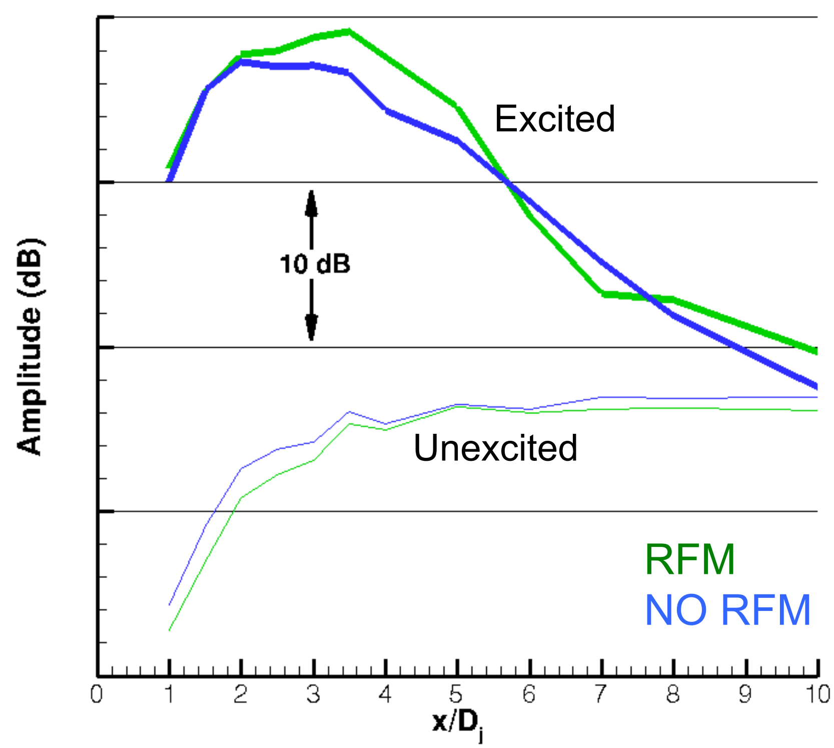
- Metric: Pressure fluctuations on nozzle lipline as a function of axial location
  - Extract the amplitude at the forcing frequency from spectra at each point
- Jet configuration:
  - Jet diameter (D_j) is 1"
  - 2.55 actuators / inch ($N/\pi D_j$)
- Excitation at:
  - Mode (m) 0
  - Strouhal frequency ($St_{Dj}=f^*D_j/U$) 0.3
- Results
  - Similar peak location and amplitude with excitation
  - Similar amplification from LAFPA inputs
  - Sensitivity to probe radial position?
  - SHJAR baseline higher – how does nozzle boundary change response?



Nozzle Boundary Layer Energy

- Use Reticulated Foam Metal (RFM) to energize the nozzle boundary layer
- Metric: Pressure fluctuations on nozzle lipline as a function of axial location
  - Extract the amplitude at the forcing frequency from spectra at each point
- Jet configuration:
  - $D_j = 1"$
  - $N/\pi D_j = 2.55$
- Excitation at:
  - $m = 0$
  - $St_{Dj} = 0.3$
- Results
  - Initial growth rate is similar
  - RFM baseline is slightly lower
  - RFM peak response is slightly higher
  - Boundary layer energy has small effect
    - Turbulent boundary layer w/o RFM?
    - Is this the right metric?

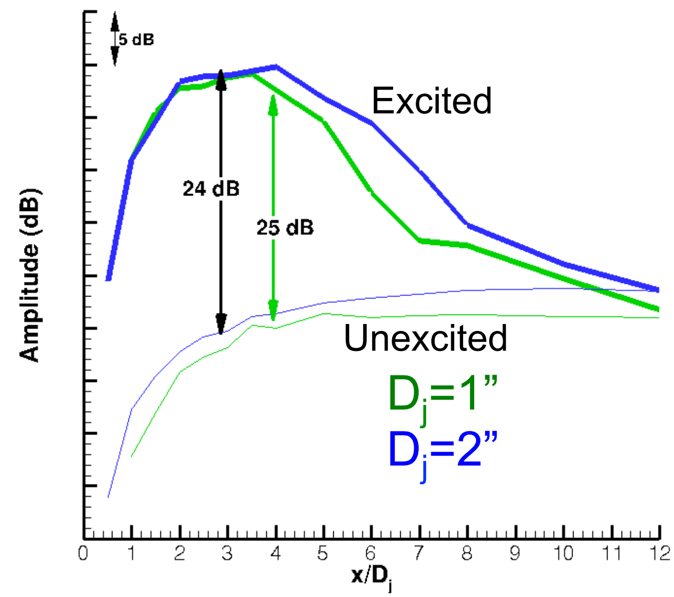




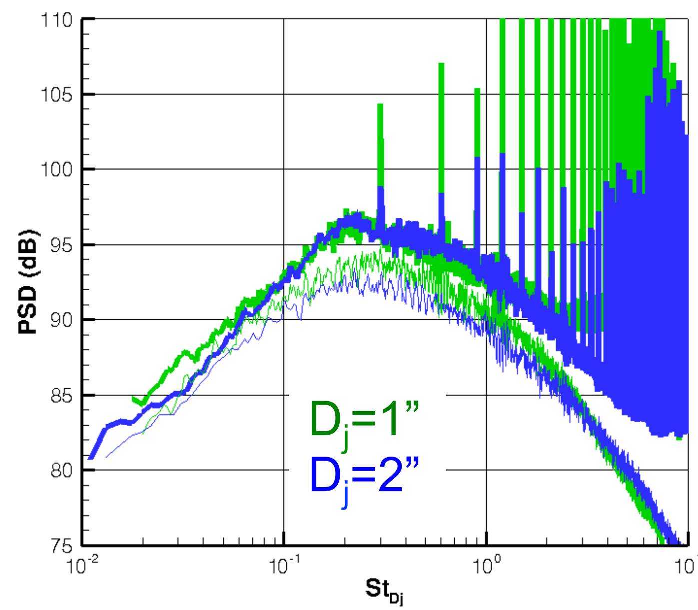
System Scalability – SHJAR

- Jet configuration:
  – Both nozzles run on the SHJAR
  – D_j = 1”, D_j = 2”
  – $N/\pi D_j$ = 2.55
- Excitation at:
  – m = 0
  – St_{Dj} = 0.3
- Results
  – Lipline pressure measurement
    - Similar peak location and amplification when excited
    - D_j=2” nozzle has slightly higher baseline and excited lipline pressures
  – Far-field noise data
    - Strong actuator tone in both noise spectra
    - Broadband amplification in both cases – expected for this excitation
    - Baseline spectra do not collapse as expected – nozzle lip effect?

Lipline Pressure



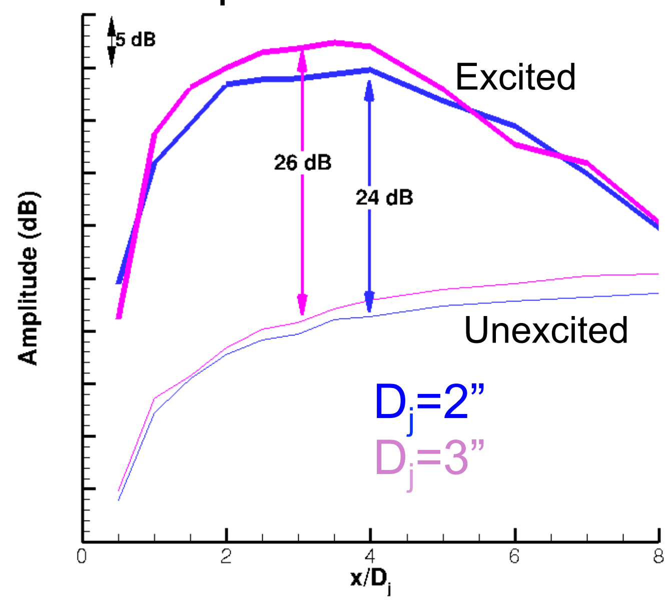
Far-Field Noise at 90°



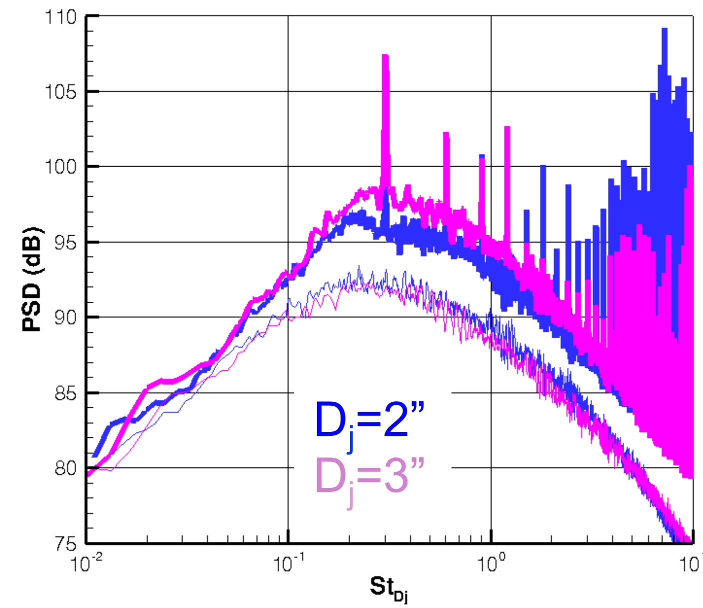
System Scalability – SHJAR

- Jet configuration:
  - Both nozzles run on the SHJAR
  - D_j = 2”, D_j = 3”
  - $N/\pi D_j = 2.55$
- Excitation at:
  - m = 0
  - $St_{Dj} = 0.3$
- Results
  - Lipline pressure measurement
    - Similar peak location and amplification when excited
    - D_j=3” nozzle has higher baseline and excited lipline pressures (remember D_j=2 was higher than D_j=1)
  - Far-field noise data
    - Actuator tone stronger in D_j=3”
    - Baseline spectra collapse
    - Broadband amplification in both cases – expected for this excitation

Lipline Pressure

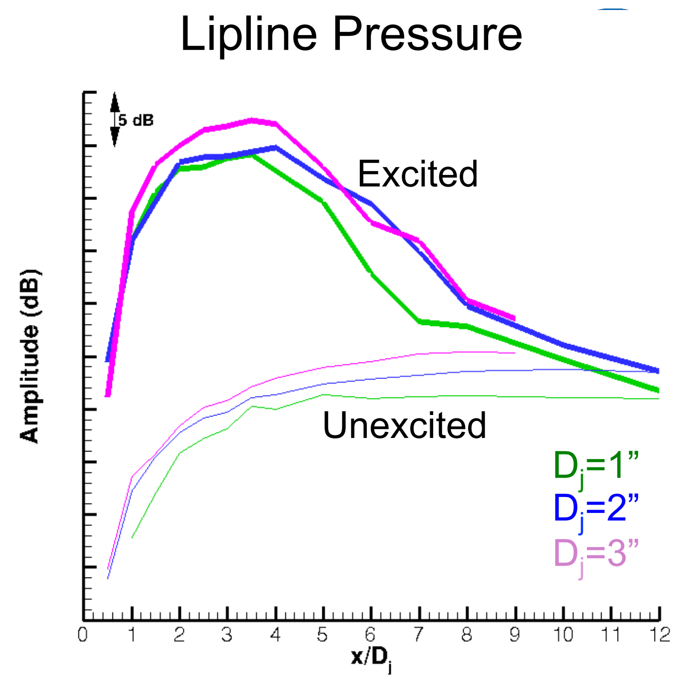


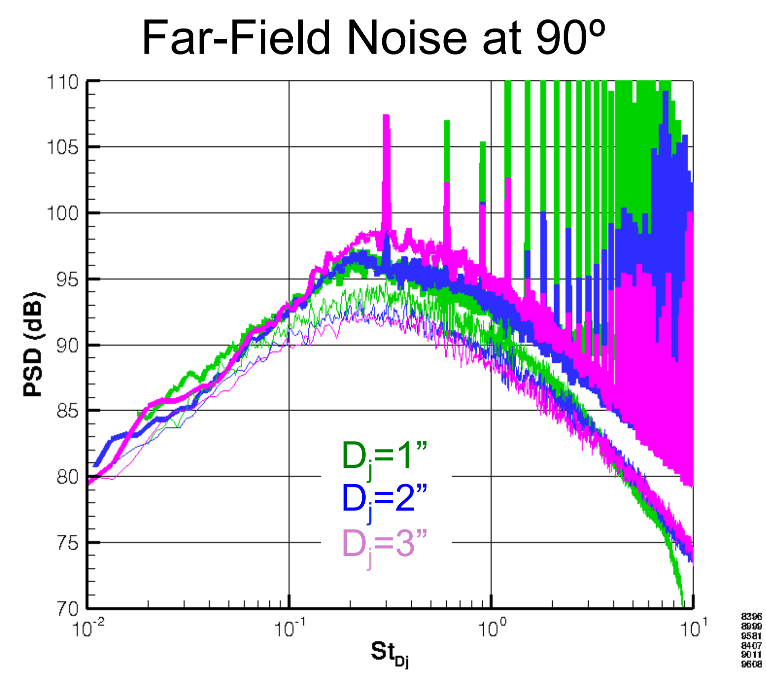
Far-Field Noise at 90º



System Scalability – SHJAR Summary

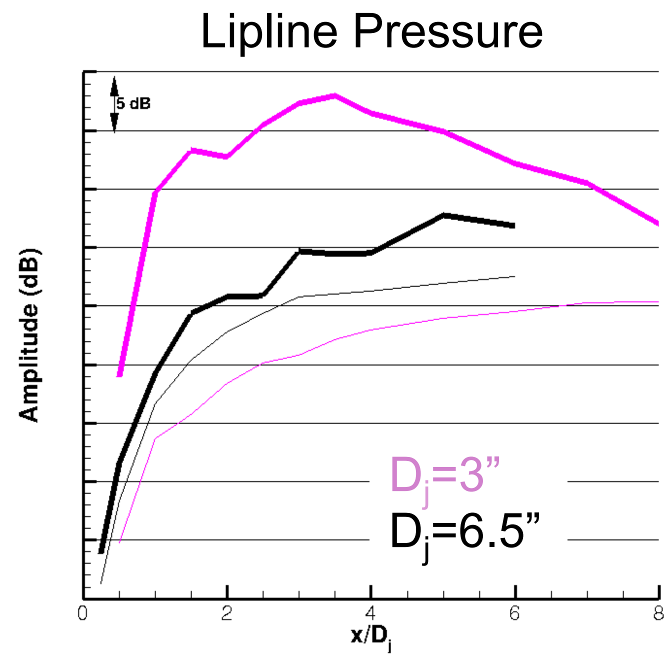
- Jet configuration:
  - Dj=1”, D_j = 2”, D_j = 3”
  - $N/\pi D_j = 2.55$
- Lipline pressure measurements
  - Unexcited level increases with nozzle diameter
  - Amplification is similar at each nozzle diameter
- Far-field noise data
  - Actuator tone strongest in D_j=3” data
  - Unexcited spectra from Dj=1” nozzle does not collapse with others
  - Broadband amplification in each case, as expected for this excitation
    - The amplification increases slightly with nozzle diameter
- <u>Linear system scalability with jet diameter is reasonable to a scale factor of 3</u>

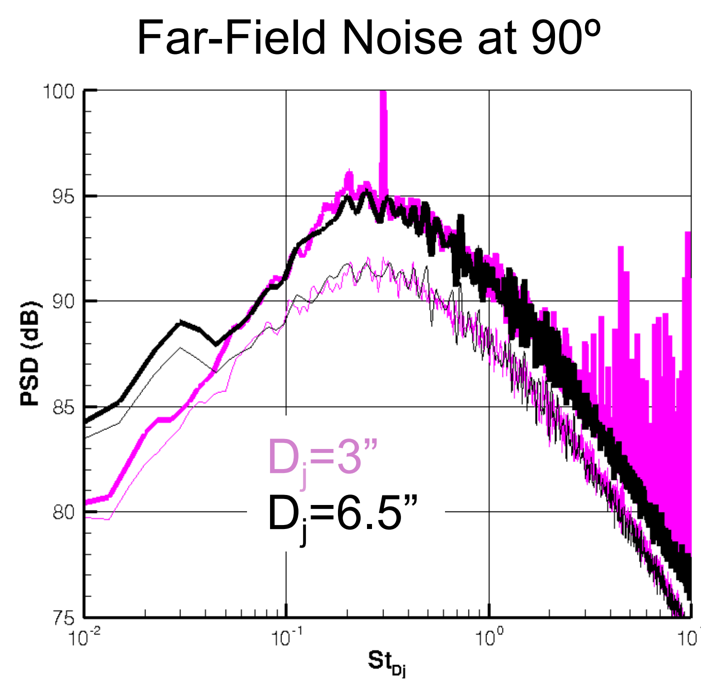




System Scalability – NATR

- Jet configuration:
  - D_j = 3.0", SHJAR, $N/\pi D_j$ = 1.27
  - D_j = 6.5", NATR, $N/\pi D_j$ = 1.18
- Excitation at:
  - m = 0
  - St = 0.3
- Results
  - Lipline pressure fluctuations do not scale
    - How does lipline pressure change as nozzle diameter increases?
    - Is this the right metric for larger nozzles?
  - Far-field noise scales nicely
    - Unexcited spectra collapse
    - Actuator tone not in D_j=6.5" data
    - 4 dB broadband amplification in both cases – expected for this excitation
    - <u>Linear scale-up to a factor of 6.5</u>





Conclusions and Future Work

- The 2nd generation LAFPA system has been tested at NASA GRC with linear scaling to a factor of 6.5
- Lipline pressure data from GRC at D_j=1” agrees with measurements at OSU
- Experiments show linear scalability for broadband noise to a scale factor of 6.5
  - Lipline pressure measurements show linear scalability up to a factor of 3 but break down above that – Is this a good metric for scalability at larger scale factors?
- Future Work
  - How does the actuator couple to the flow?
    - Temperature, pressure, etc.
  - Optimization for noise reduction using simulations
    - How do you treat the actuator?
  - How can we use excitation with these actuators to better understand jet noise?

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