

Spectral Peaks Due to 'Guided Jet Waves' in Plug Nozzle Flows

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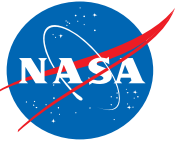
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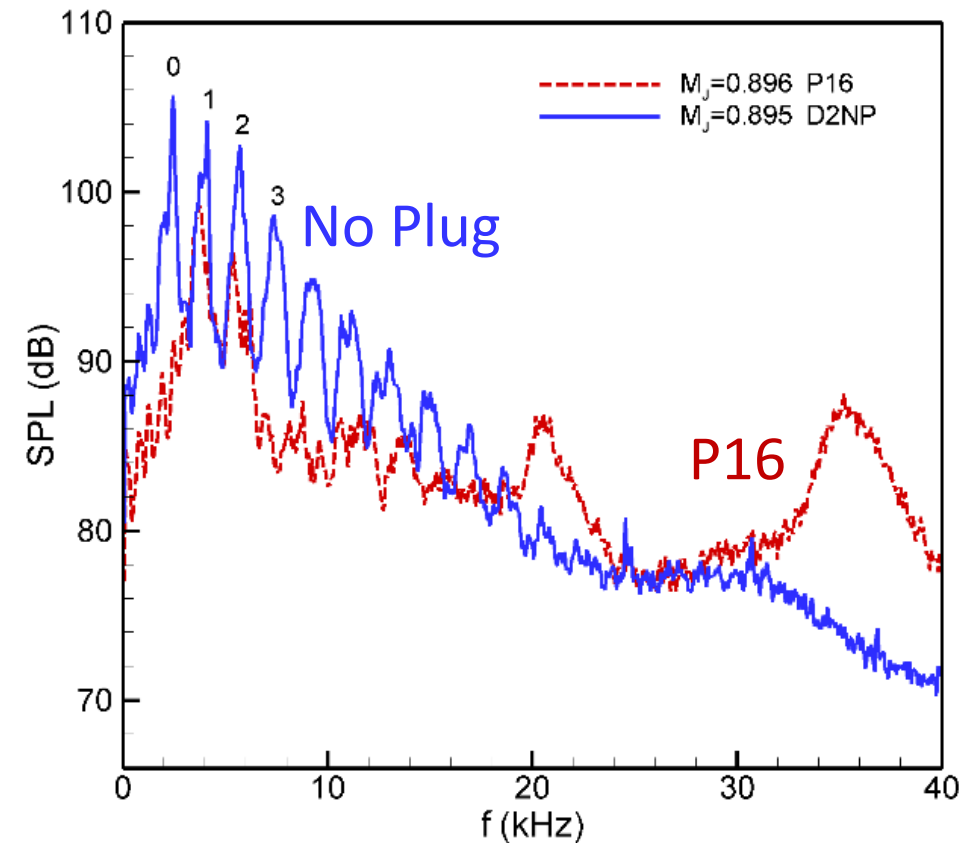


Outline

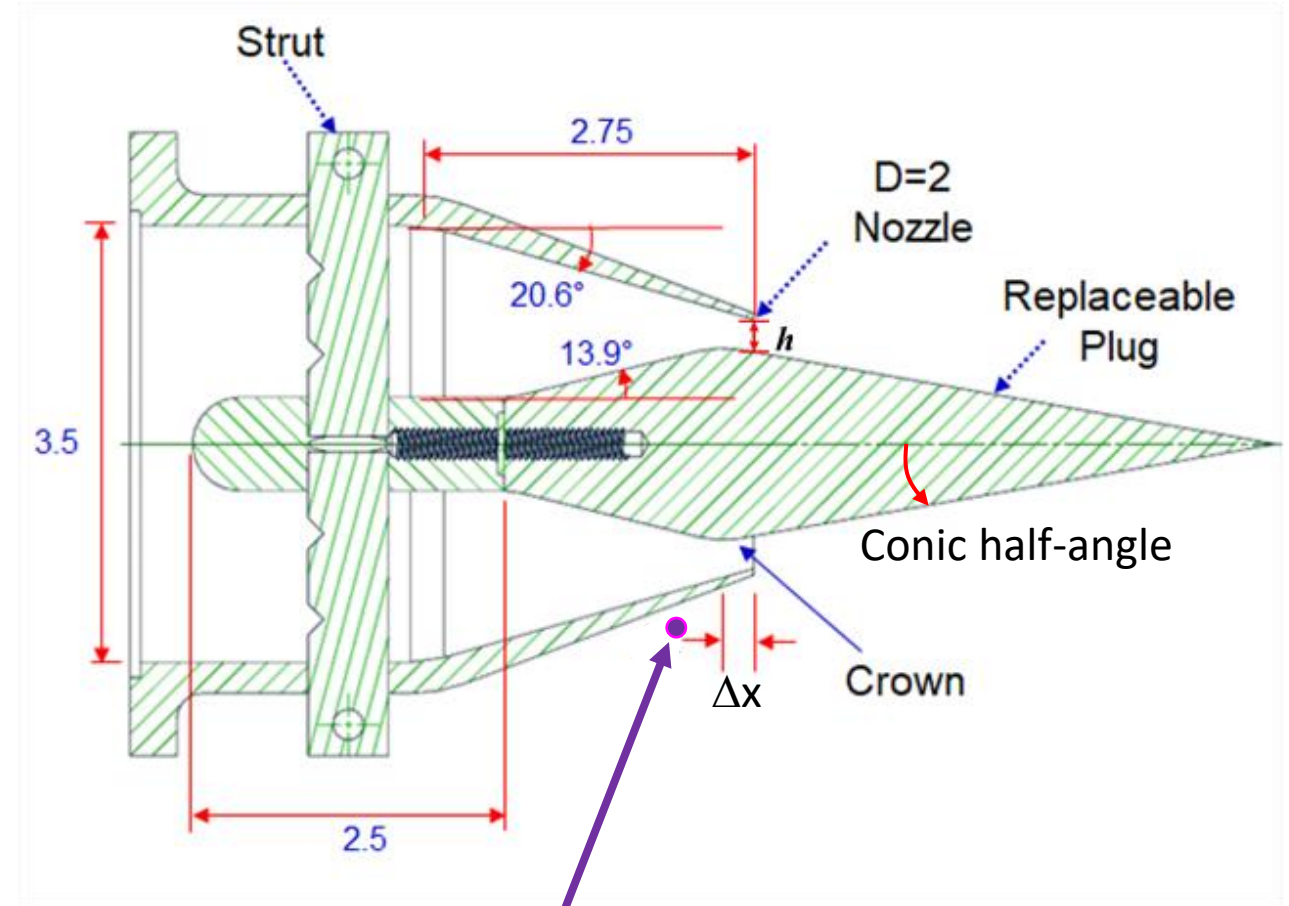
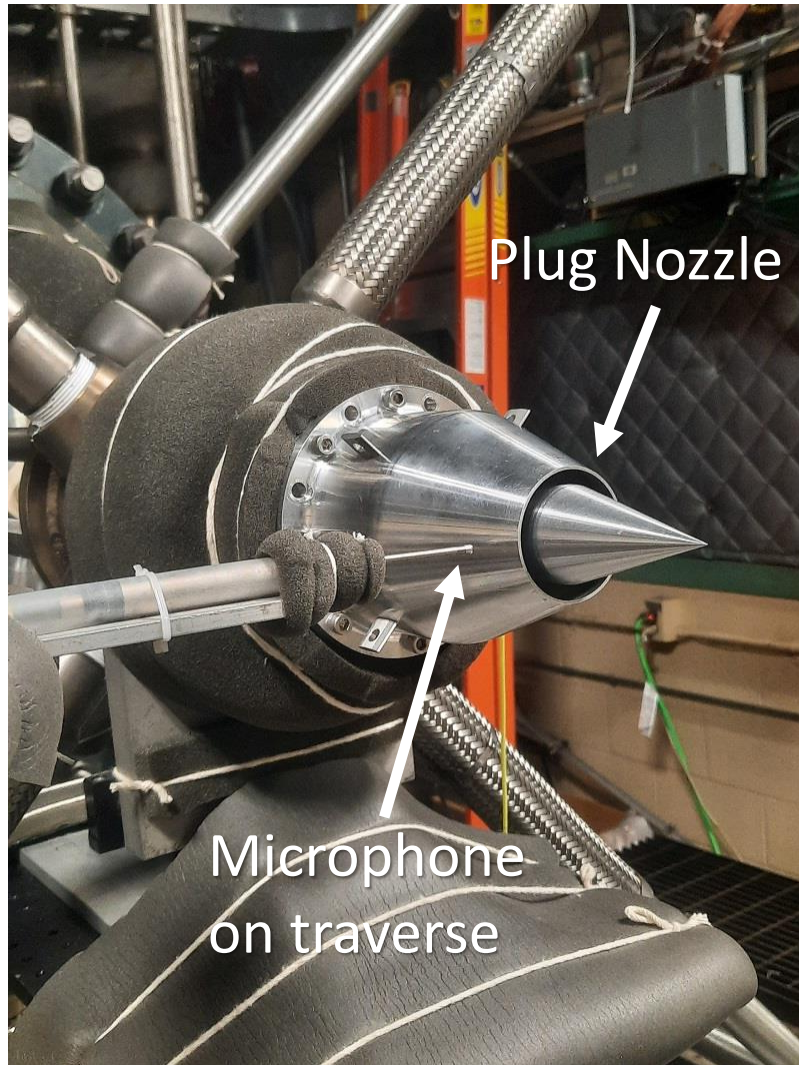
- Motivation
- Experimental Setup
- Configurations/Variables
- Results
- Correlation with Strouhal number, validation of critical length scale
- Conclusions

Guided Jet Waves

- Previously observed for clean round nozzles (no plug):
 - Frequency of fundamental ('0') GW peak scales on nozzle diameter D
 - Harmonics ('1', '2', '3') have a fractional ($5/3$, $7/3$, $9/3$) relationship to the fundamental
- With P16 plug installed:
 - **Additional higher frequency peaks appear**
 - Some of the lower frequency peaks remain

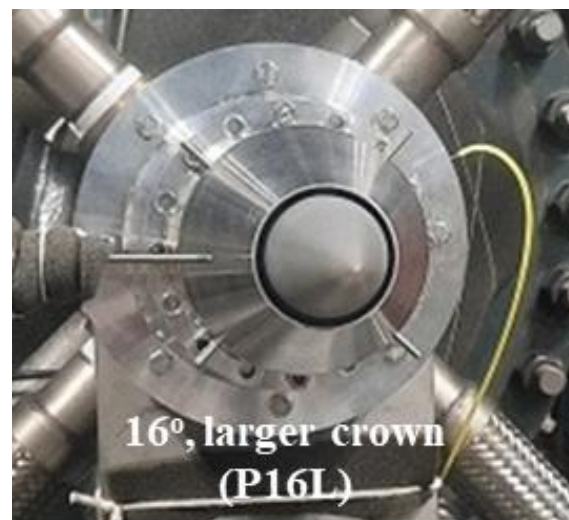
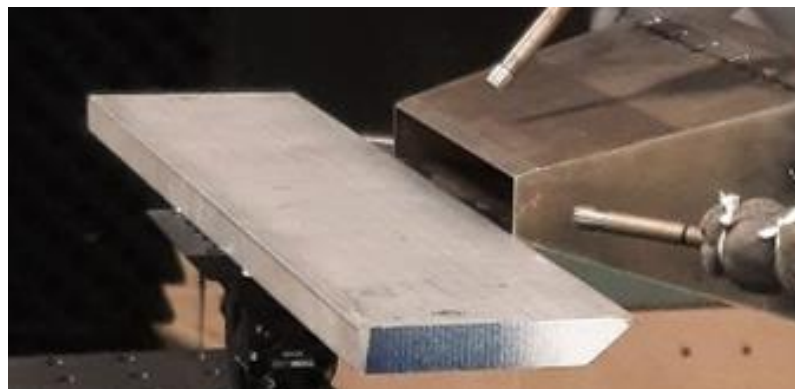
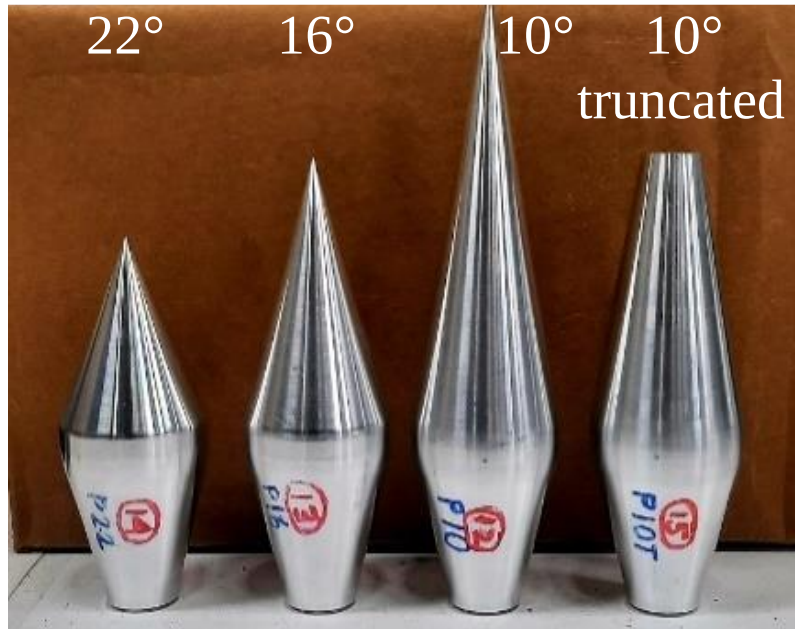


Experimental Setup



Microphone location: $x = -0.6''$, $r = 1.5''$

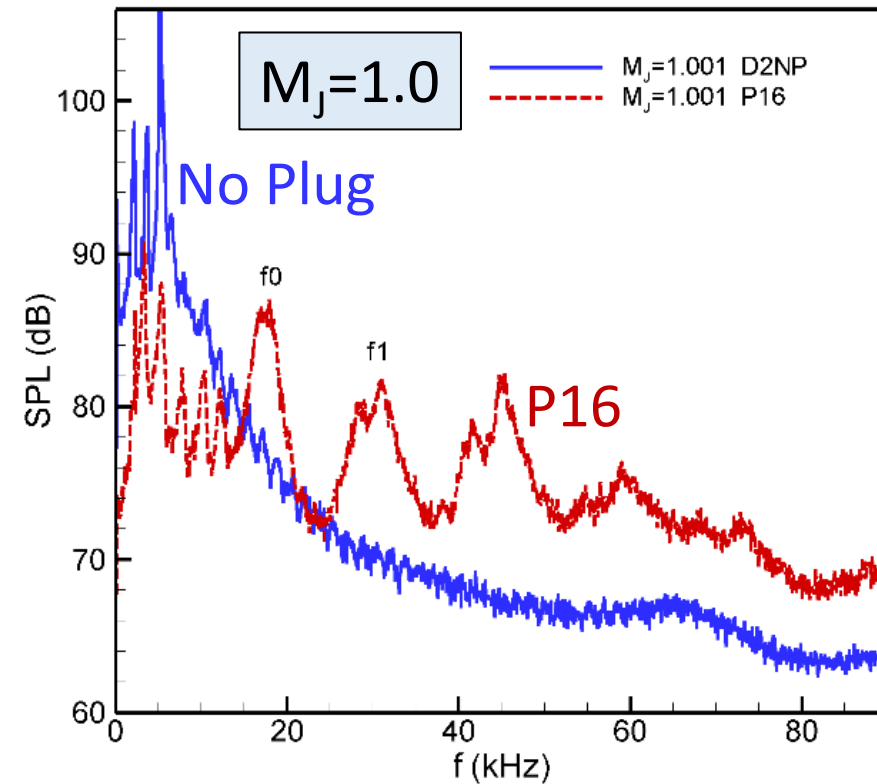
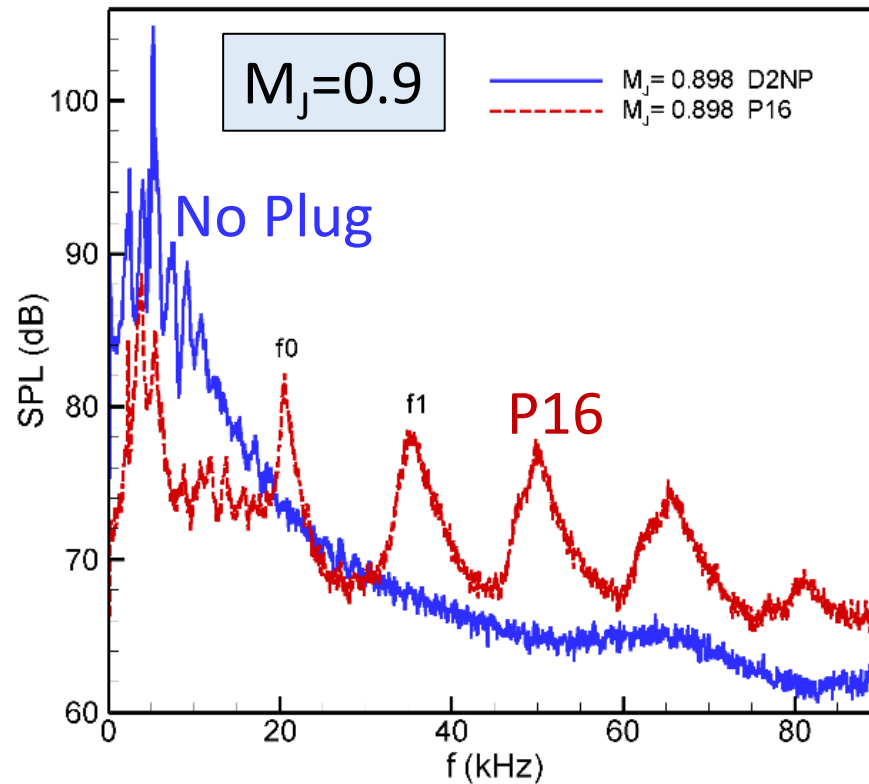
Plugs and other hardware



Experiment Variables:

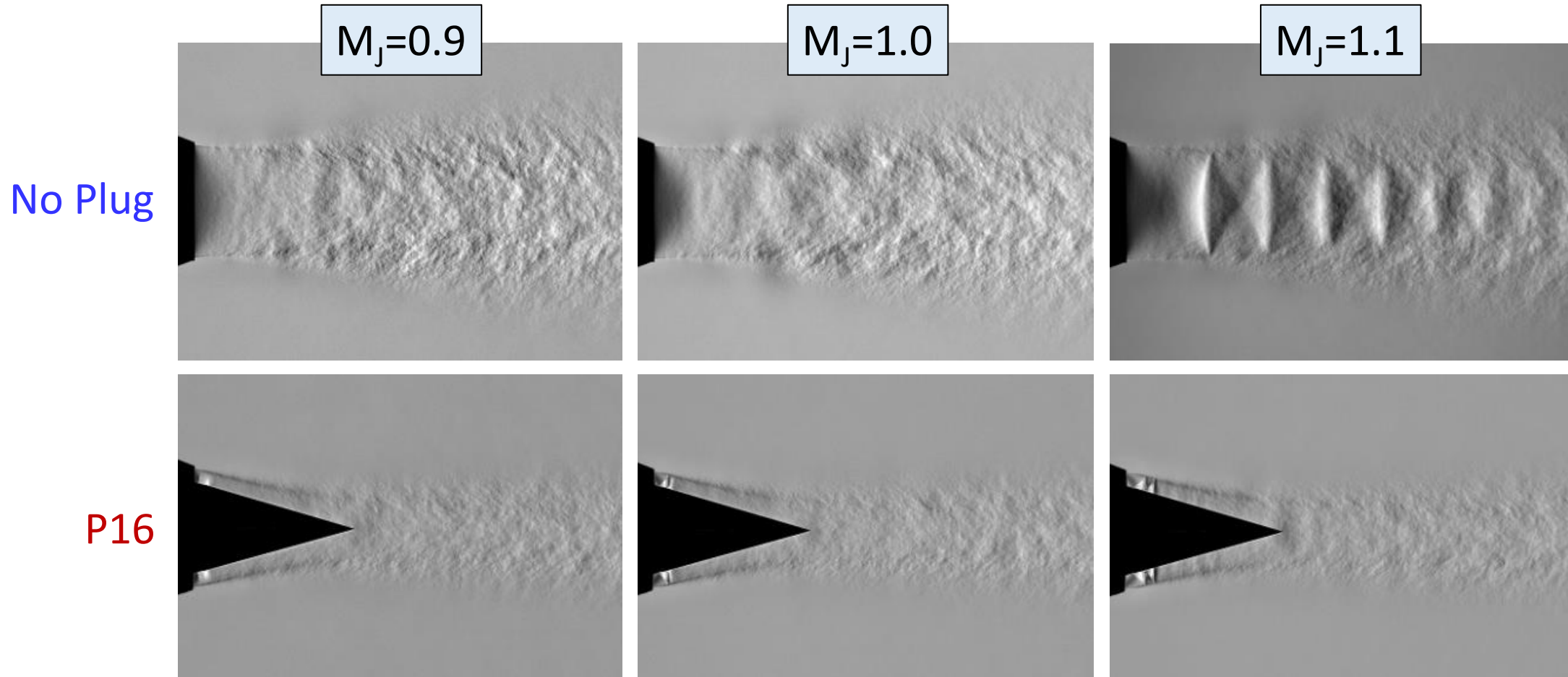
- Plug vs No Plug
- Jet Mach number (M_j)
- Conical plug apex half-angle
- Microphone location (x, r)
- Plug crown location (Δx , varies h)
- Exit gap width h
- Plug length

2" Round nozzle: No Plug vs 16° Conical Plug



- Note expanded frequency scale with 1/8" microphone
- Low frequency peaks remain; higher frequency peaks appear with the plug
- We will show that the 'harmonics'/modes of both sets of peaks bear a 5/3, 7/3, 9/3 fractional relationship

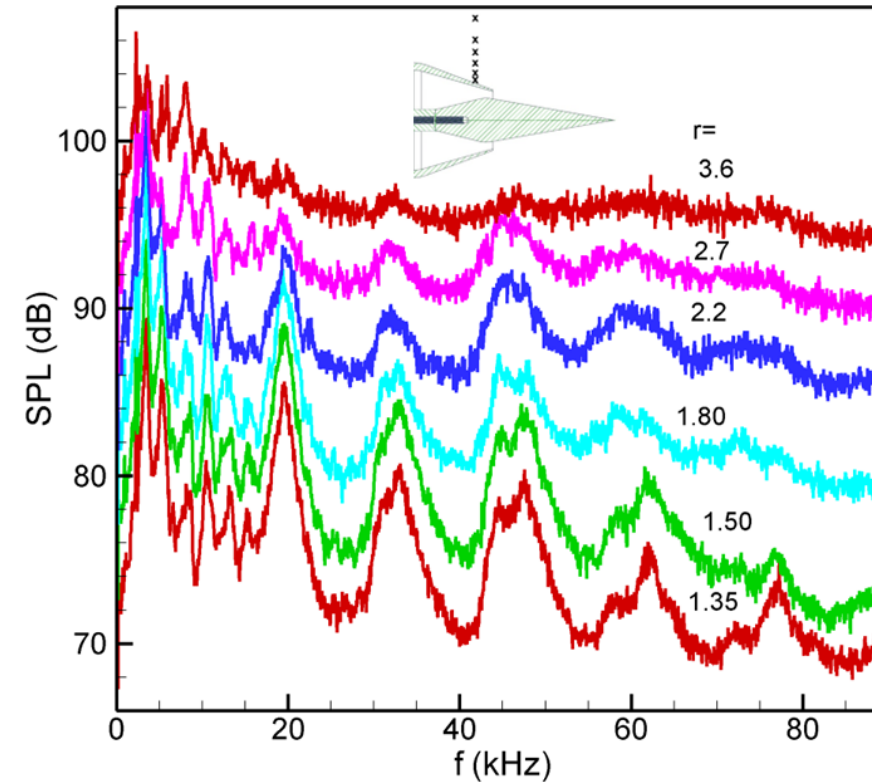
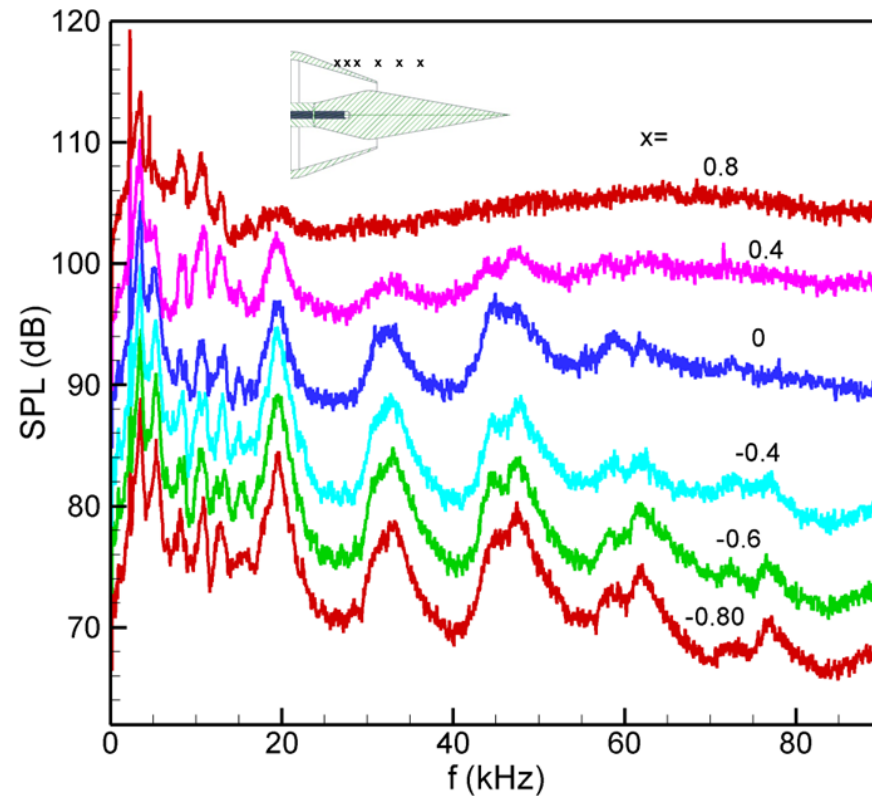
Schlieren: No Plug vs 16° Conical Plug



- With plug, shocks occur even at subsonic pressure ratios
- GW resonances not strong enough to be visually noticeable with schlieren

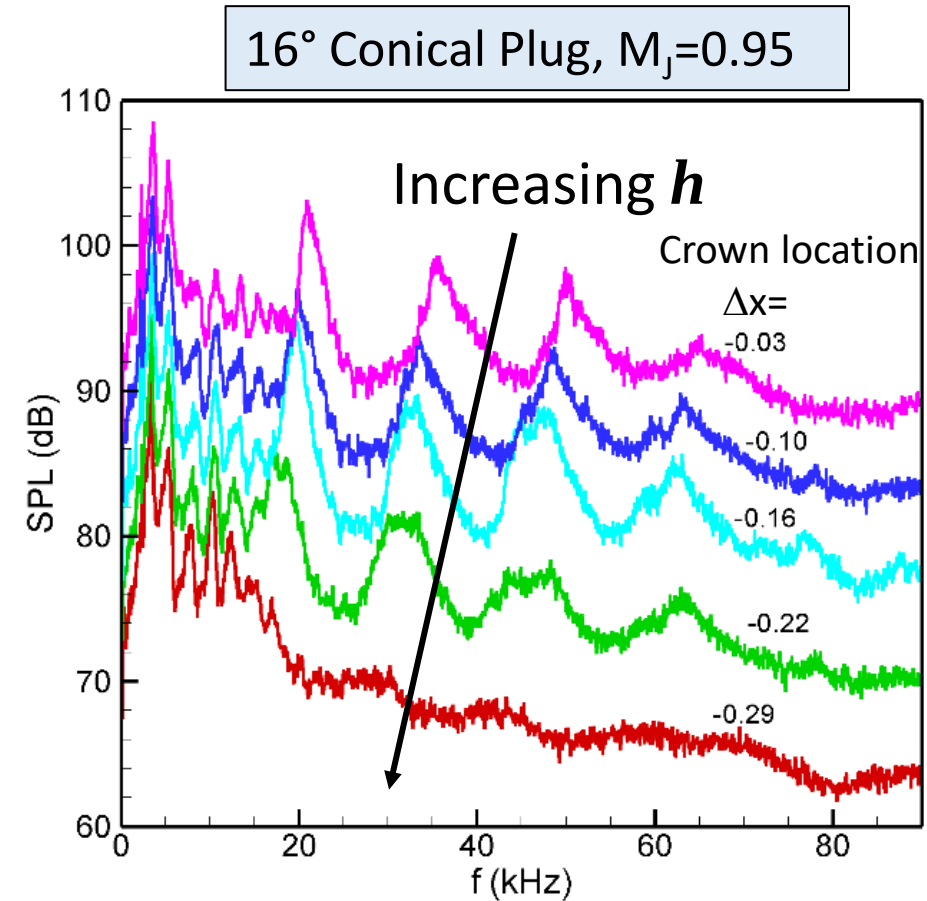
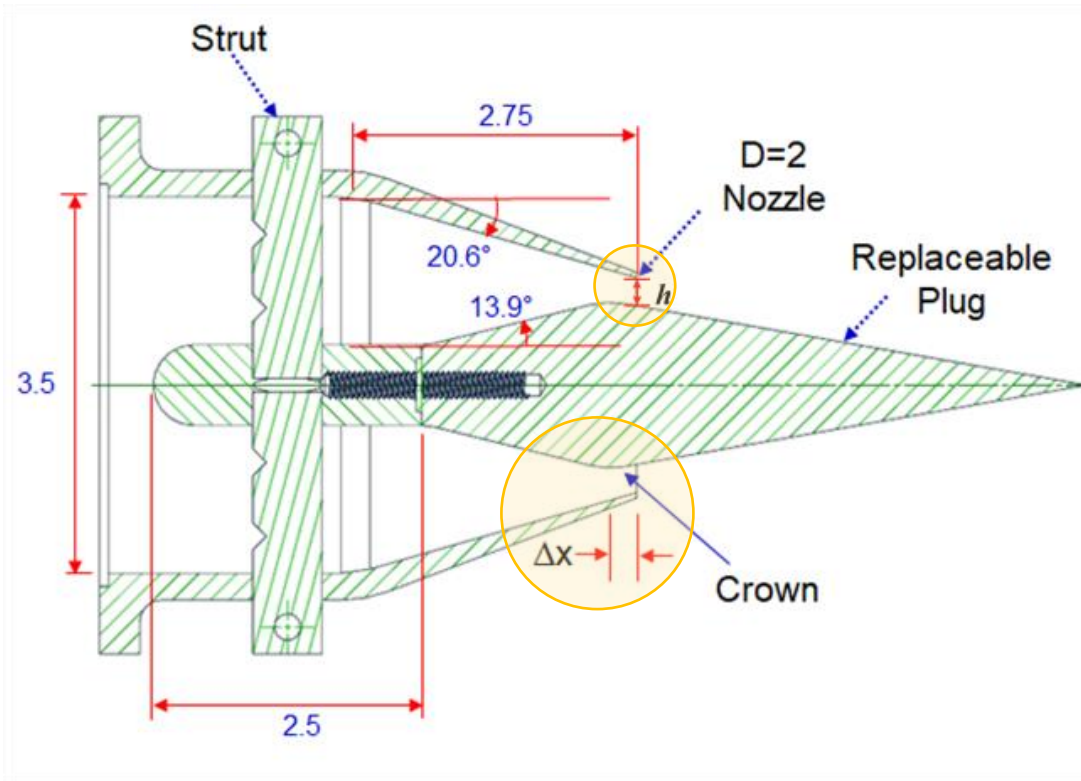
Varying Microphone Location

16° Conical Plug
 $M_j=0.95$



- Waves diminish with increasing x or r
- Suggests these are hydrodynamic waves
- Recently found these actually propagate upstream acoustically

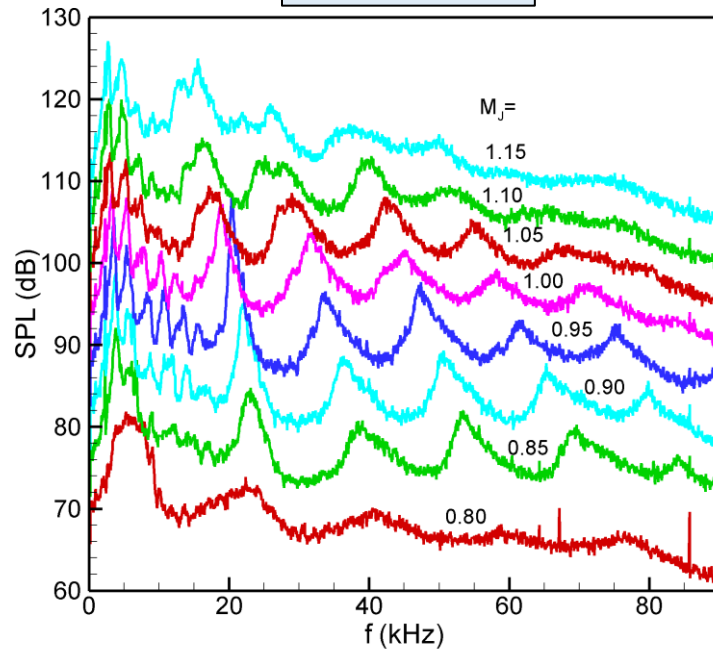
Varying Crown Location and Exit Gap Width



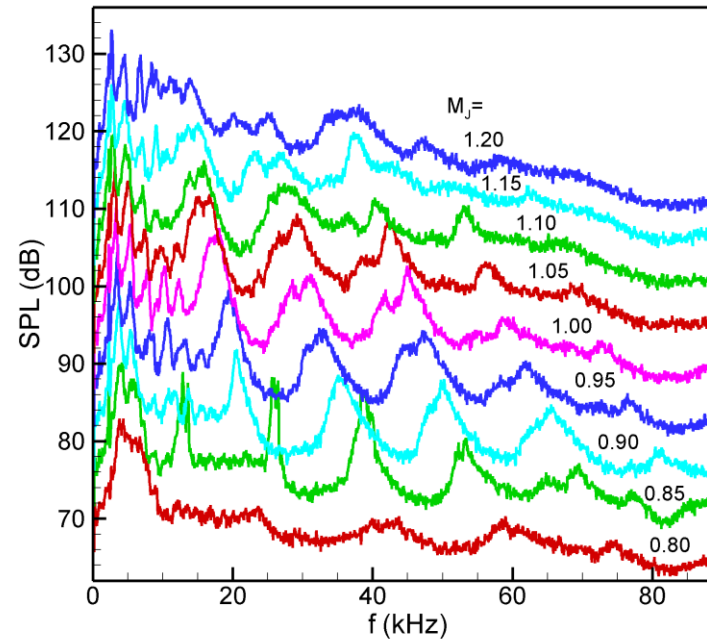
- First clue that gap width h might be the length-scale governing the behavior of the high-frequency GW peaks
- Amplitude of peaks decreases as the crown is positioned further inside the nozzle

Varying Mach number and apex half-angle

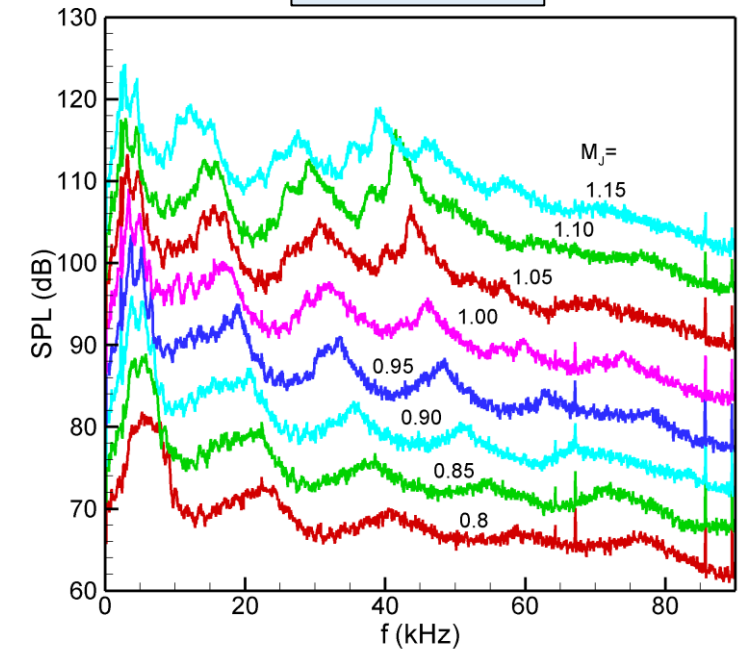
22° Plug



16° Plug



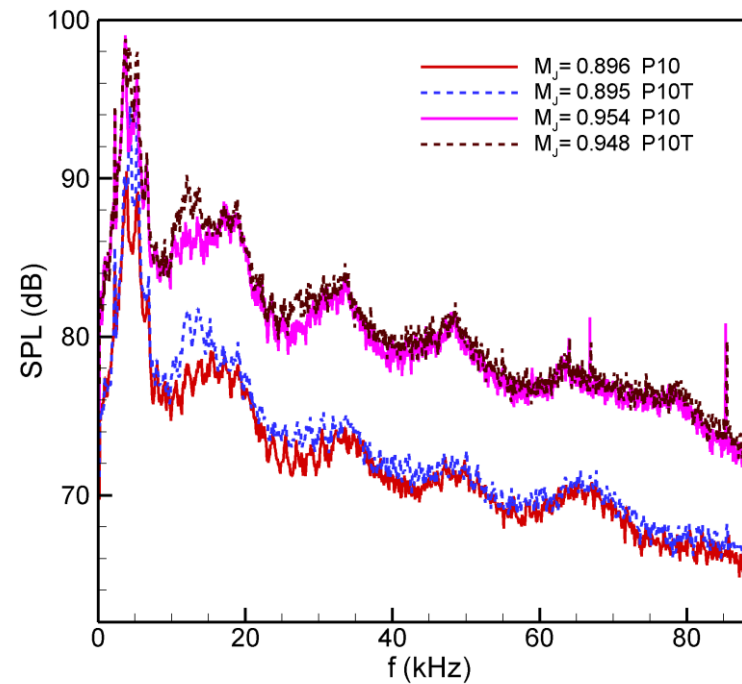
10° Plug



- Spectra are vertically offset by 5dB for clarity
- Peaks are visible for $M_j > 0.8$
- Strouhal numbers corresponding to the spectral peaks will be looked at next

Varying Plug Length

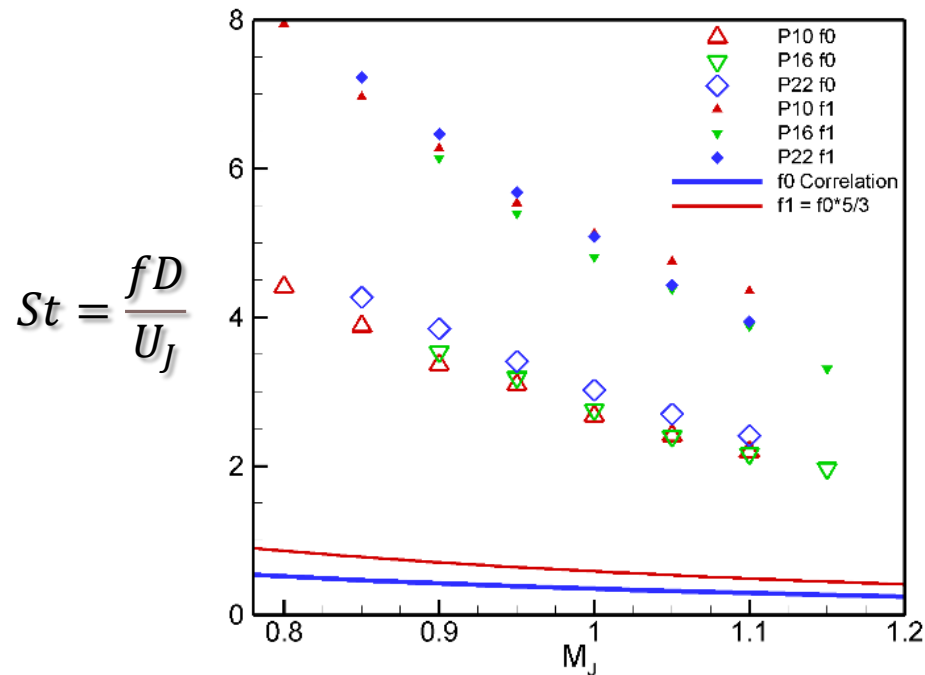
10° Plug (P10) vs. Truncated 10° Plug (P10T)



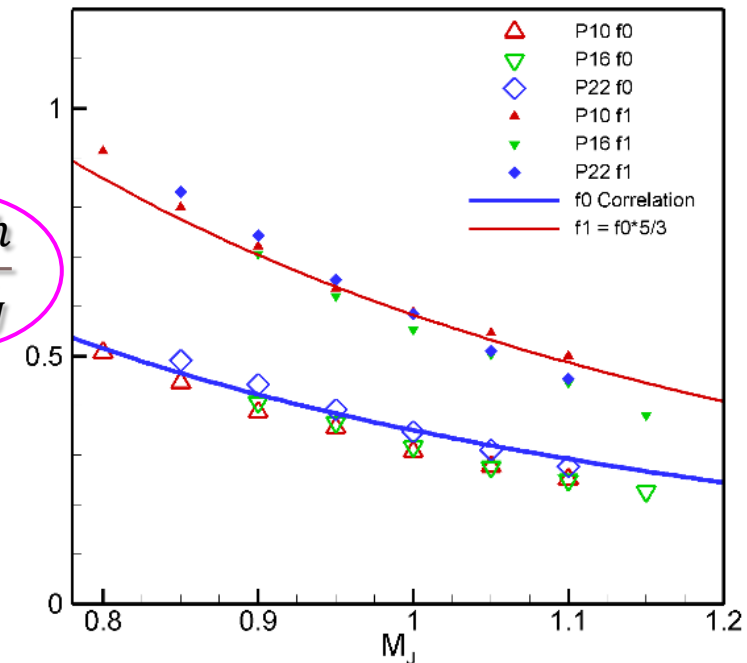
- Length of the plug does not change the frequencies of the GW peaks

Correlation with Strouhal Number

$$St = \frac{\left(\frac{1}{M_J^2} - 1\right)}{13} + \frac{\left(\frac{1}{M_J} - 1\right)}{2} + \frac{(M_J - 1)}{20} + 0.35 \quad \rightarrow J. Fluid Mech., Vol. 931, A30, 2021$$

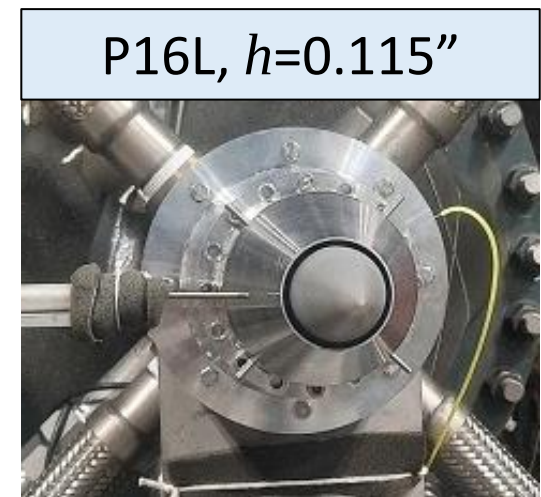
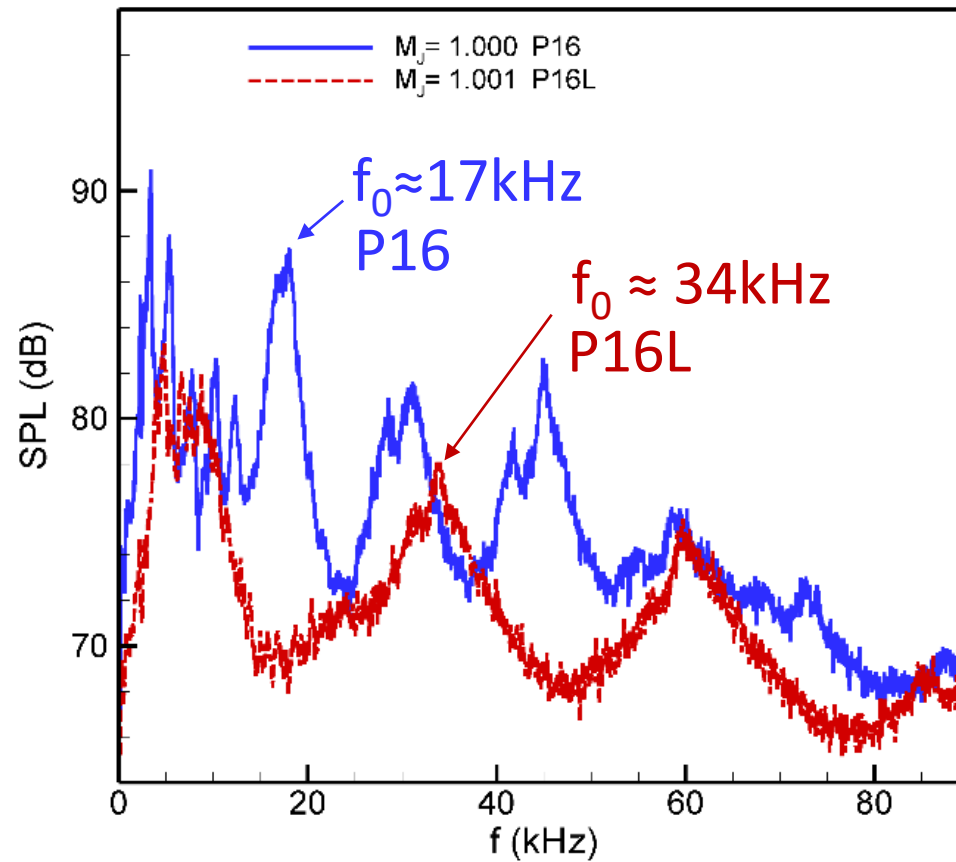


$$St = \frac{fh}{U_J}$$

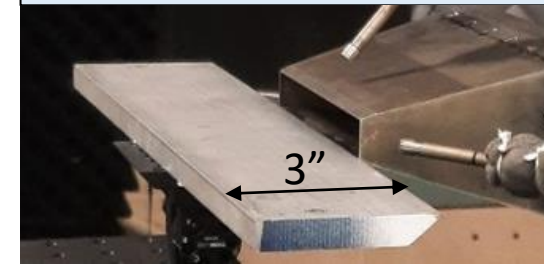


- Annular gap width ***h*** is the length-scale driving the high-frequency GW Peaks seen with plug nozzles
- ‘Harmonics’ bear a similar fractional (5/3, 7/3...) relationship as with simple round nozzles

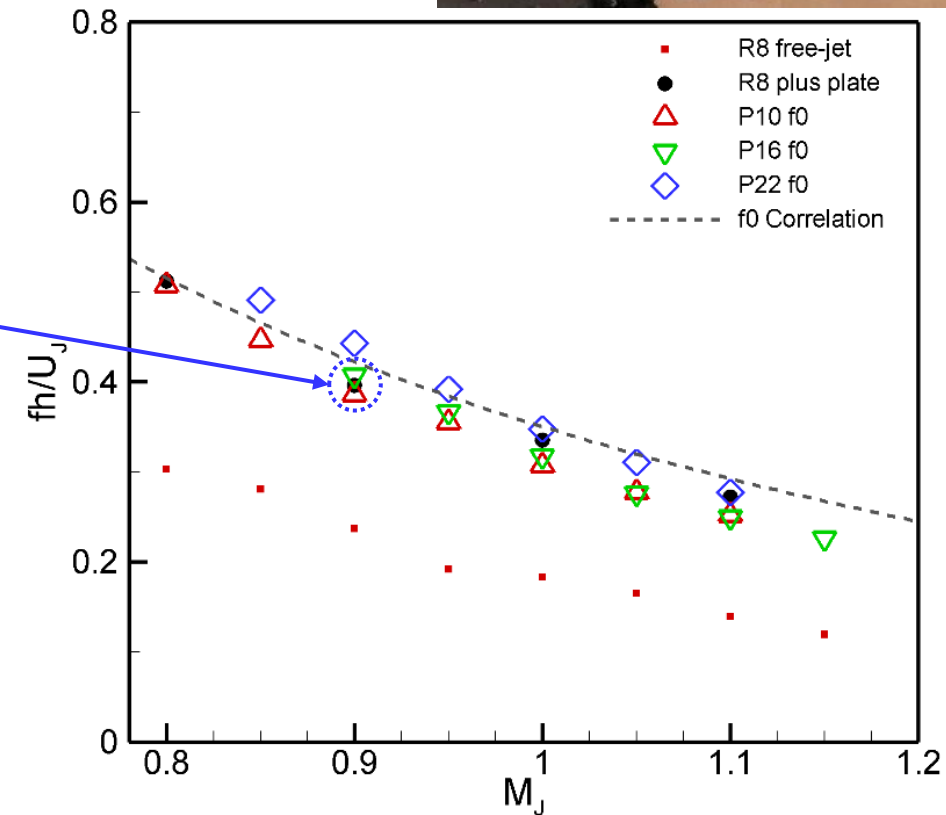
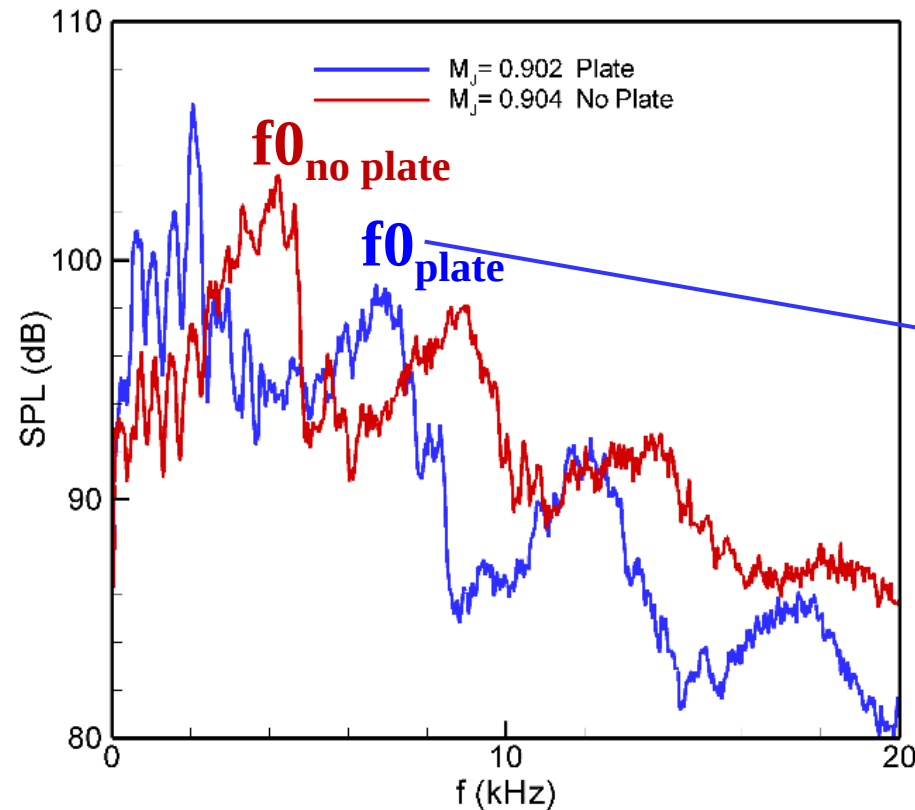
Varying h by Changing Plug Crown Diameter



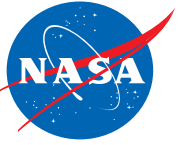
- With M_j being constant, halving h roughly doubles f_0 .



8:1 Rectangular Nozzle Experiment

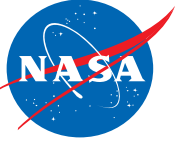


- With presence of the plate, the narrow dimension of the nozzle scales $f0$
- R8 nozzle plus a plate behaves like an *'unwrapped'* plug nozzle flow



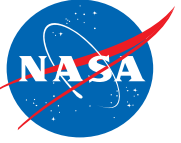
Conclusions

- When a central plug is added to a round nozzle, the near-nozzle pressure fluctuation spectra is altered
- Two sets of Guided Jet Wave (GW) resonant peaks occur:
 - Low frequency peaks scale on nozzle diameter (as if plug is not there).
 - Annular gap width h is the characteristic length scale that dictates the high-frequency GW peaks
- Data from various plug cases and a rectangular nozzle with flat plate agreed with correlation equation developed for round nozzles when nozzle diameter D was replaced with gap width h



Acknowledgments

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