Investigating the feedback path in a jet-surface resonant interaction

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Outline of talk:

Background and Relevance

Experimental Facility

Results and Discussion

Summary

Background

In some aircraft designs the jet exhaust is close to a surface. This raises noise issues due to jet-surface interaction.

A research effort was initiated in 2012 to investigate this experimentally in the GRC AAPL (Dome) facility.

In a preliminary experiment in a smaller facility (CW17), an unexpected resonant interaction was encountered.

While larger-scale experiments with realistic flight hardware were conducted in the AAPL, the resonance problem was pursued in CW17.

A simple geometry of a flat plate near a 8:1 rectangular jet was studied.

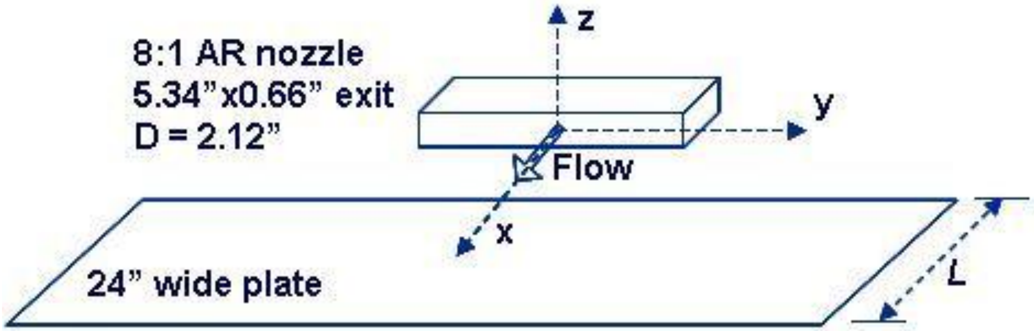
Motivation and Objective

An understanding of the resonance is important. It would be unacceptable not only for high noise but also structural concern.

Earlier results isolating structural vibration effects and on flow field details presented at SciTech 2014 (*AIAA Paper No. 2014-0877*).

This paper addresses specifically the feedback process in the resonance with data obtained since the last meeting.

Experimental setup in CW17



Nozzle is one from family of nozzles used in the AAPL expt

Noise spectra obtained by overhead mics all data shown for $\theta = 60°$

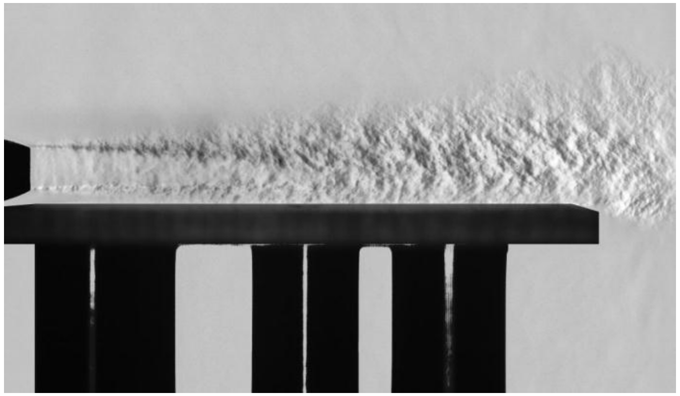
All lengths given in inches

L, x_{TE}, x_{LE}, z and M_j are varied

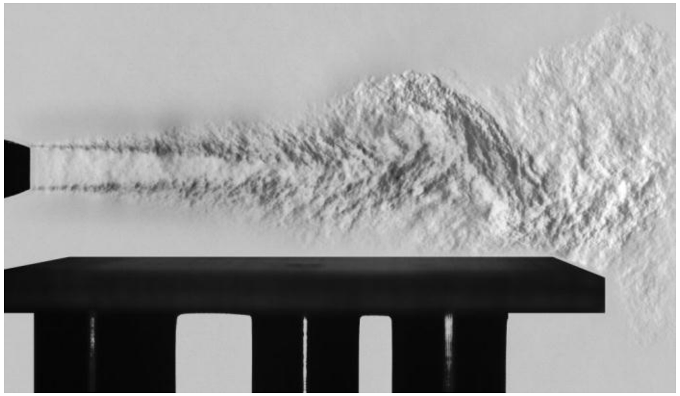
Schlieren pictures for varying *z*-location

L=8 plate, x_{TE} = 8.5; M_j = 0.96

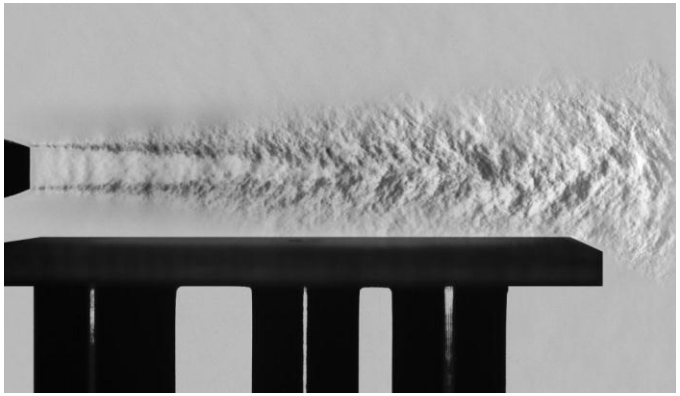
z = - 0.5



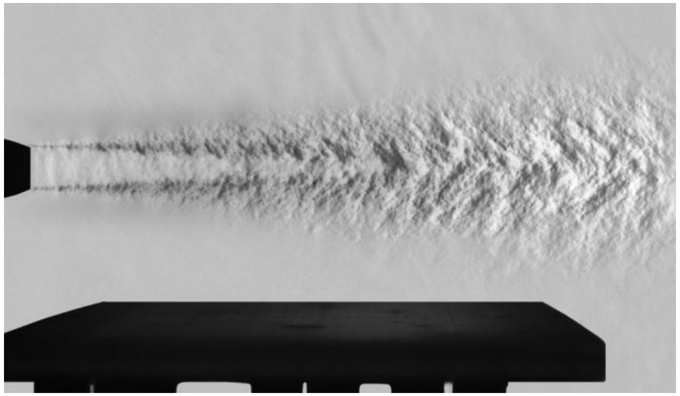
z = - 1.35



z = - 1.0

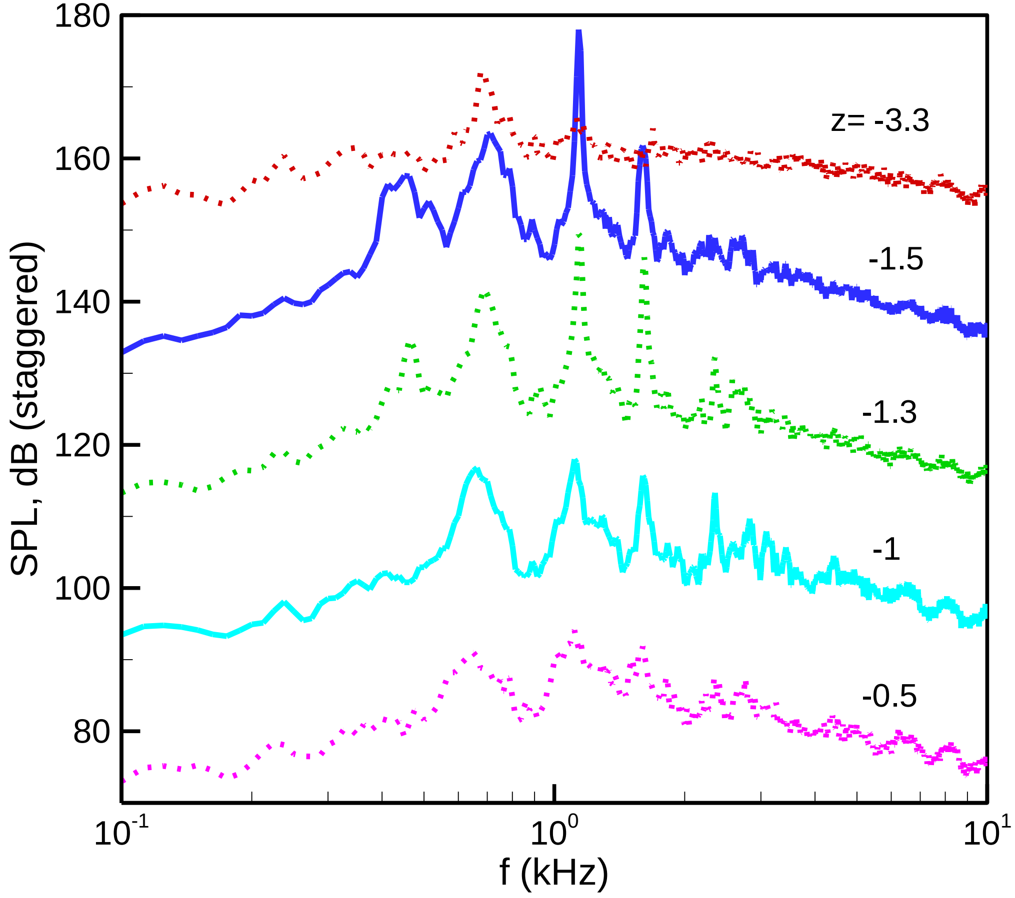


z = - 3.3



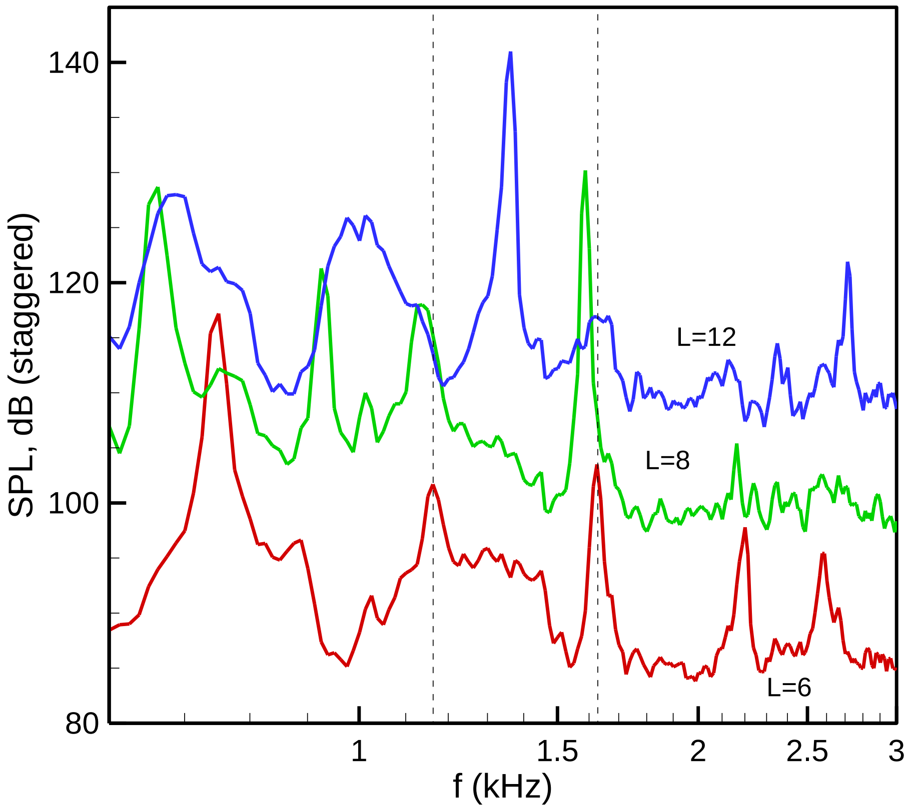
Resonance occurs for intermediate position of plate, not too close not too far

SPL spectra for varying *z*-location
L=8 plate, x_{TE} = 8.5; M_j = 0.96



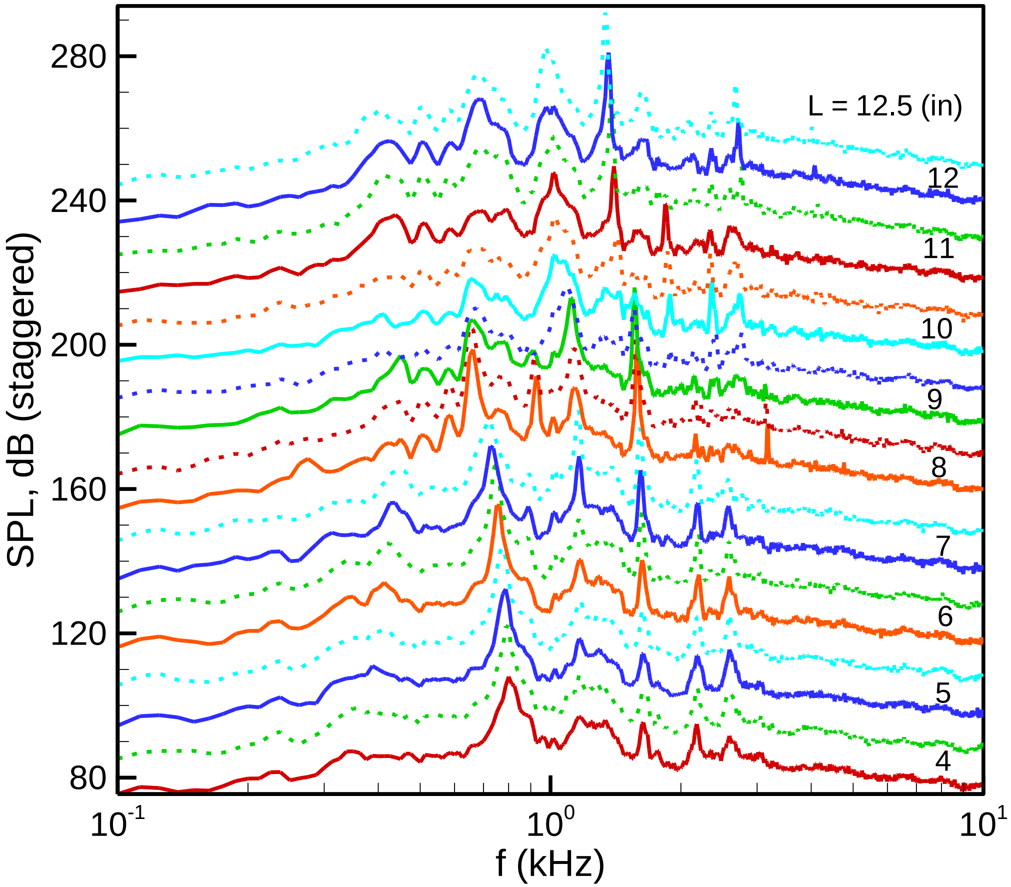
Sharp tone is heard for z range of about -1.2 to -1.8

SPL spectra for L= 6, 8 and 12 plates with x_{TE}= 8.5, z= -1.55, M_j = 0.96

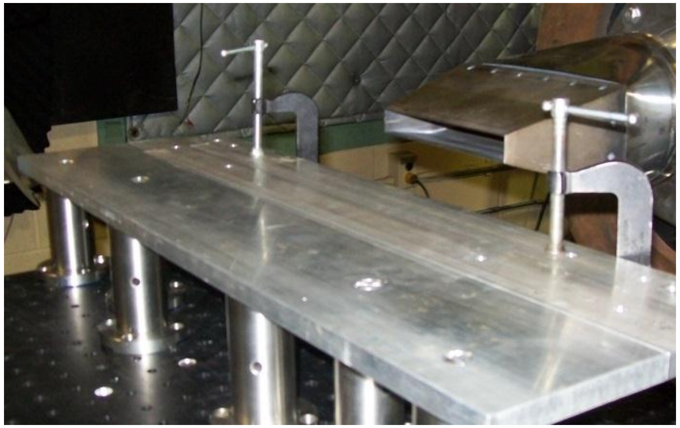


Spectral peaks shift even though TE is at same location for all three plates
Conflicts with simple feedback hypothesis between plate's TE and nozzle

SPL spectra for fixed TE location but varying *L*
x_{TE} = 8.5, z = -1.55; M_j = 0.96

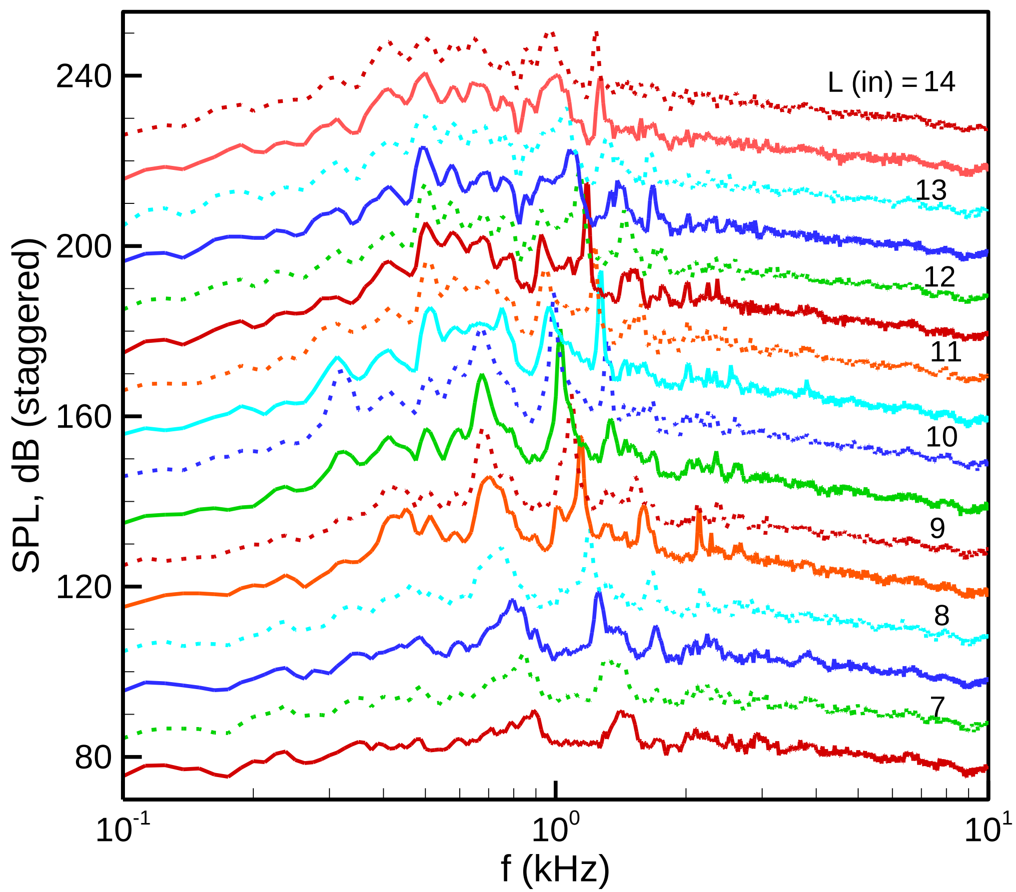


Streamwise length *L* is varied in increments of ½” by combination of ½”, 1”, 1-1/2” and 2” bars



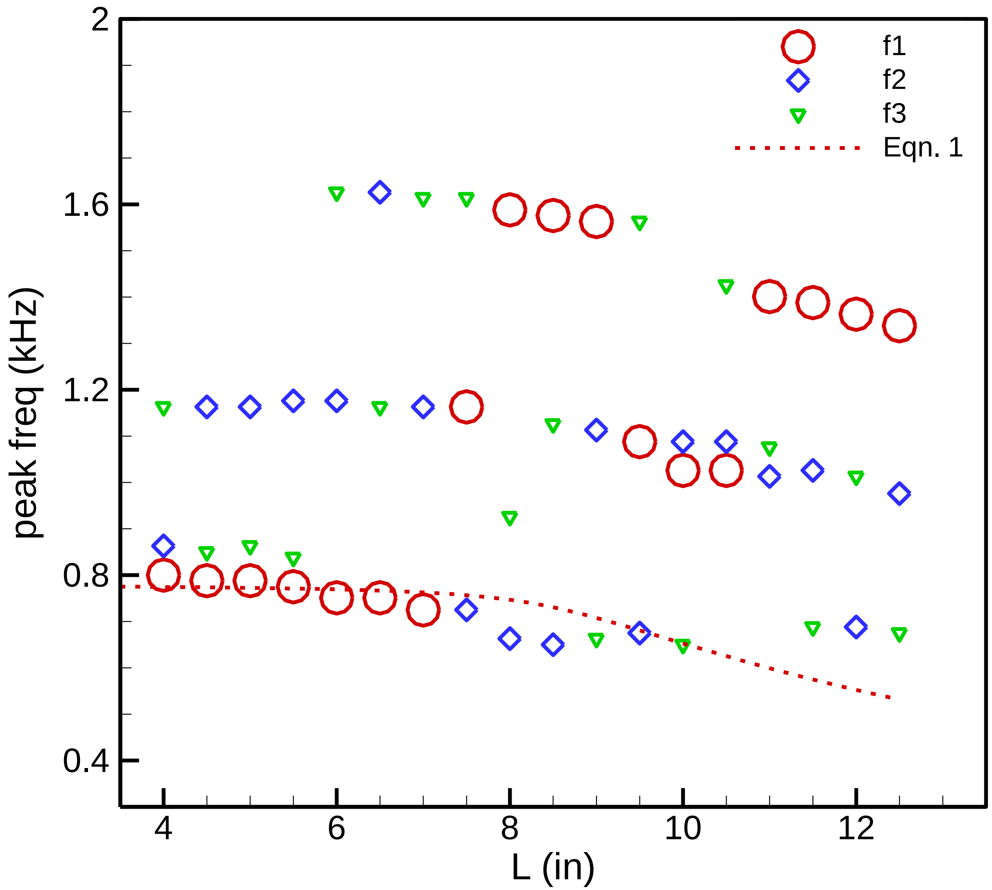
TE held fixed but spectral peak frequencies vary

SPL spectra for fixed LE location but varying *L*
x_{LE} = 0, z = -1.8; M_j = 0.96



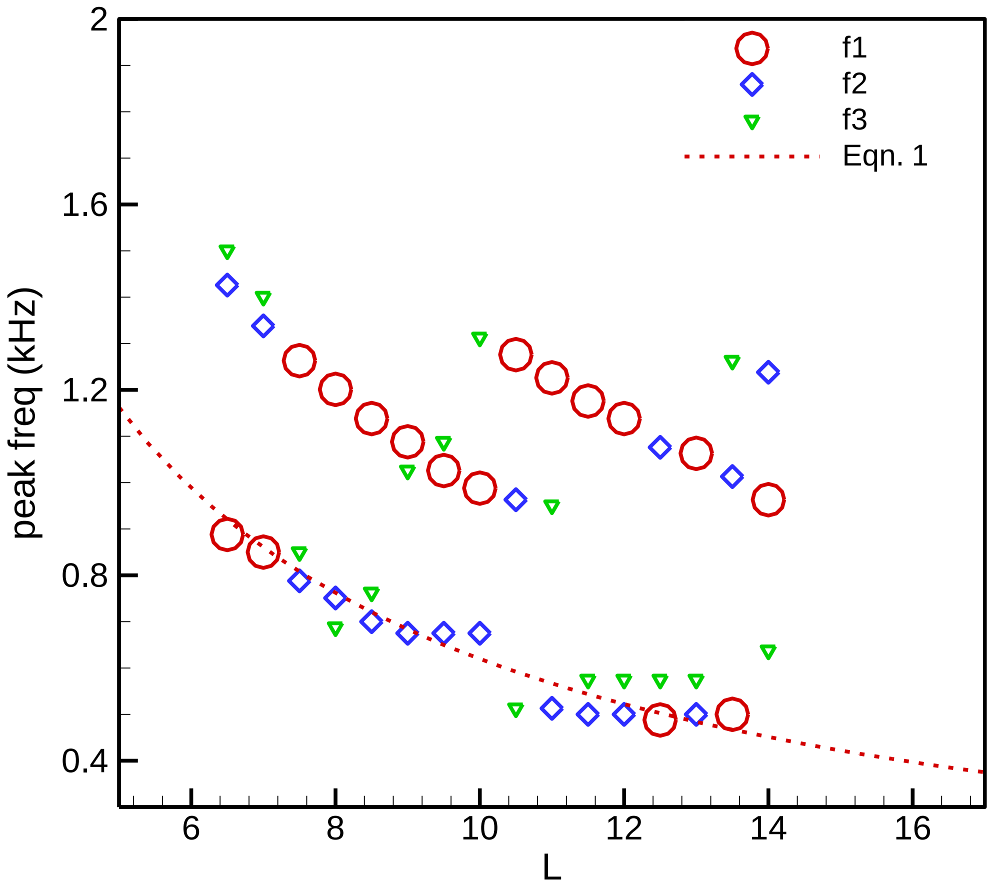
Spectral peak frequencies also vary while LE is held fixed
Thus, both TE and LE come into play in frequency selection

Frequencies of 3 tallest peaks in spectra fixed TE location but varying L; x_{TE} = 8.5; M_j = 0.96



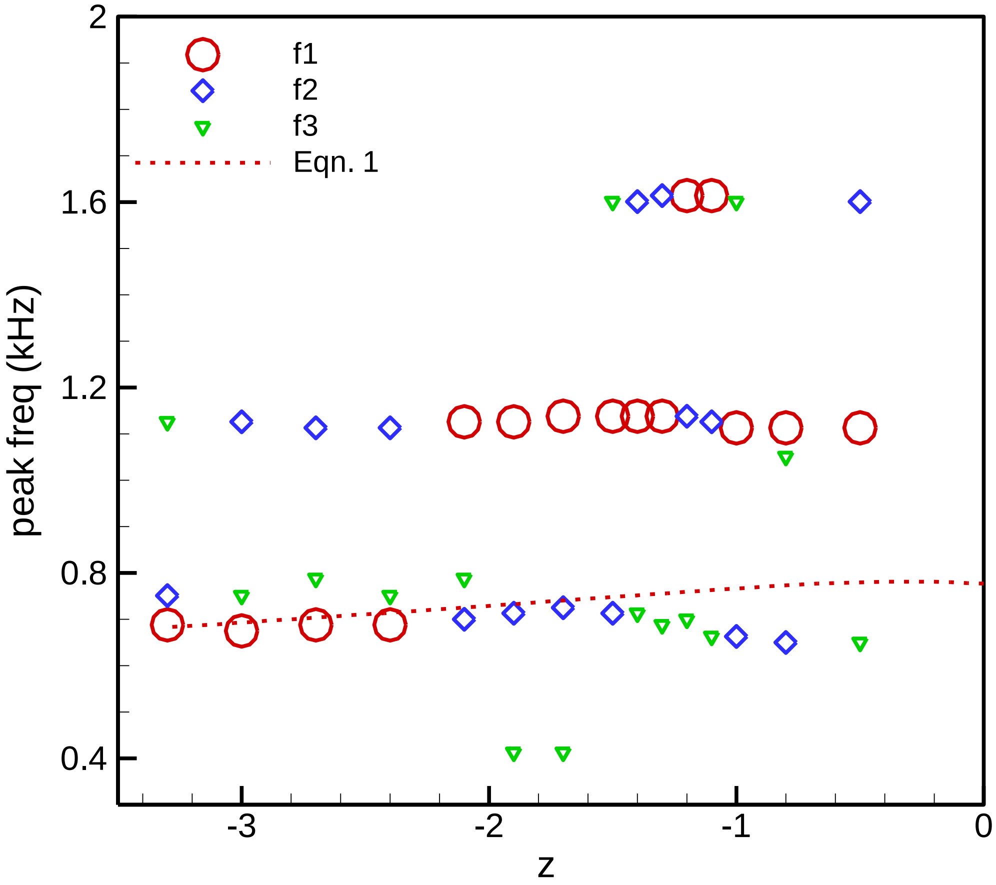
There is an order in the spectral peak frequencies!!
All fall in one or another distinct band
(Equation is explained shortly)

Frequencies of the 3 tallest peaks in spectra fixed LE location but varying L; $x_{LE} = 0$; $M_j = 0.96$



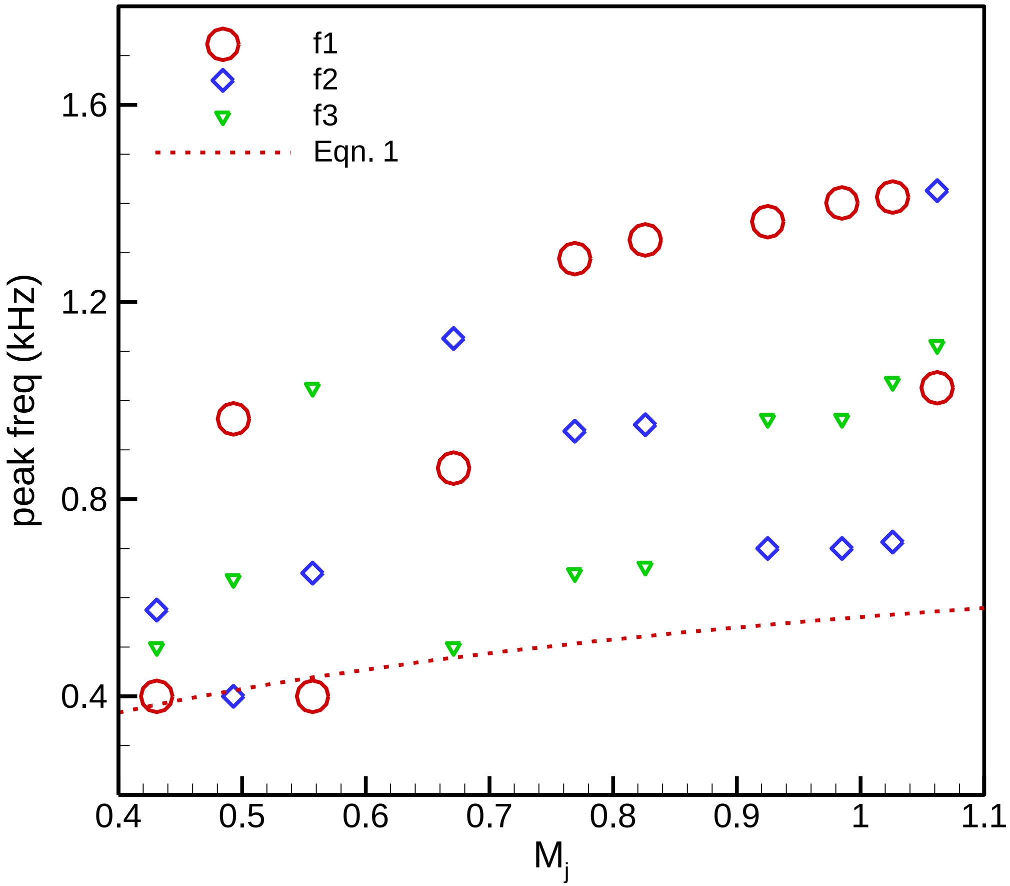
The same is true for variation of TE location, with LE remaining fixed

Frequencies of the 3 tallest peaks in spectra
Varying z-location of L=8 plate; x_{TE} = 8.5; M_j = 0.96



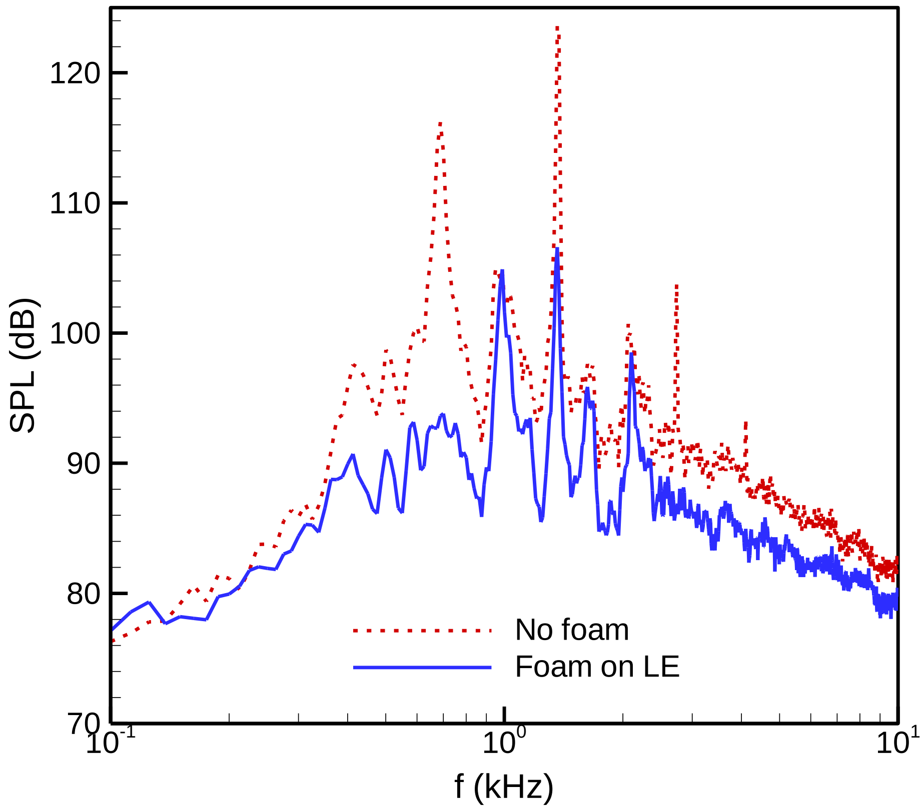
…and for variation of lateral location of plate

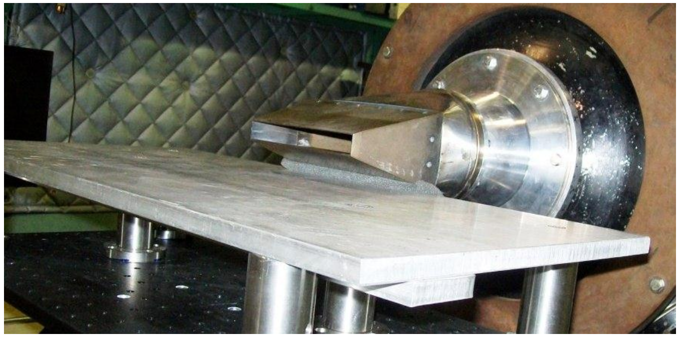
Frequencies of the 3 tallest peaks in spectra
Varying M_j, L=12 plate ; x_{TE} = 8.5; z= -1.5



…and for variation of jet Mach number

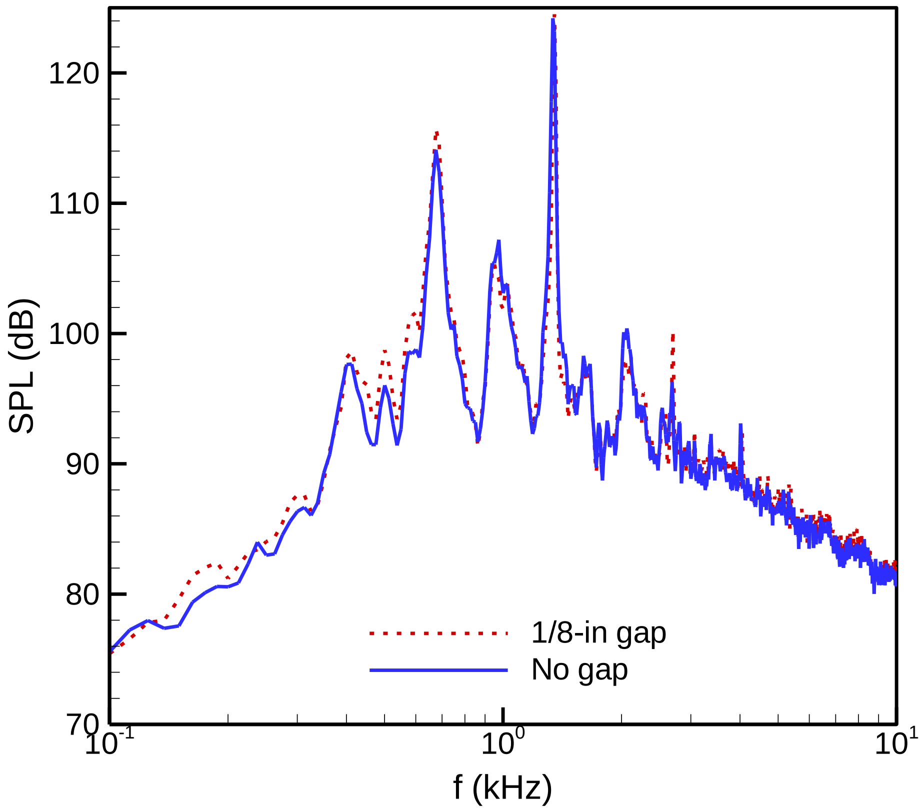
SPL spectra with and without sound absorbing material at LE
L= 12 plate, x_{TE} = 8.5; M_j = 0.96

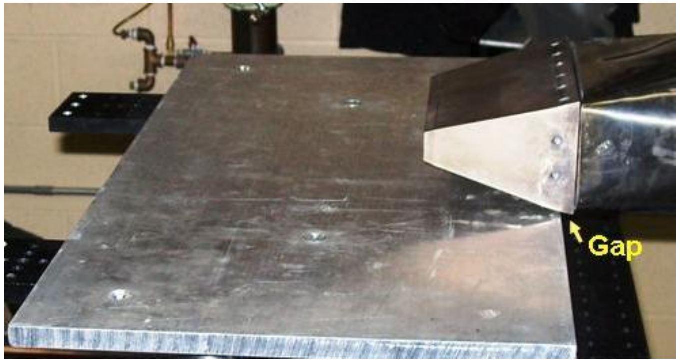




Sound absorbing material attached to LE diminishes the tone
Further evidence that LE comes into play in frequency selection

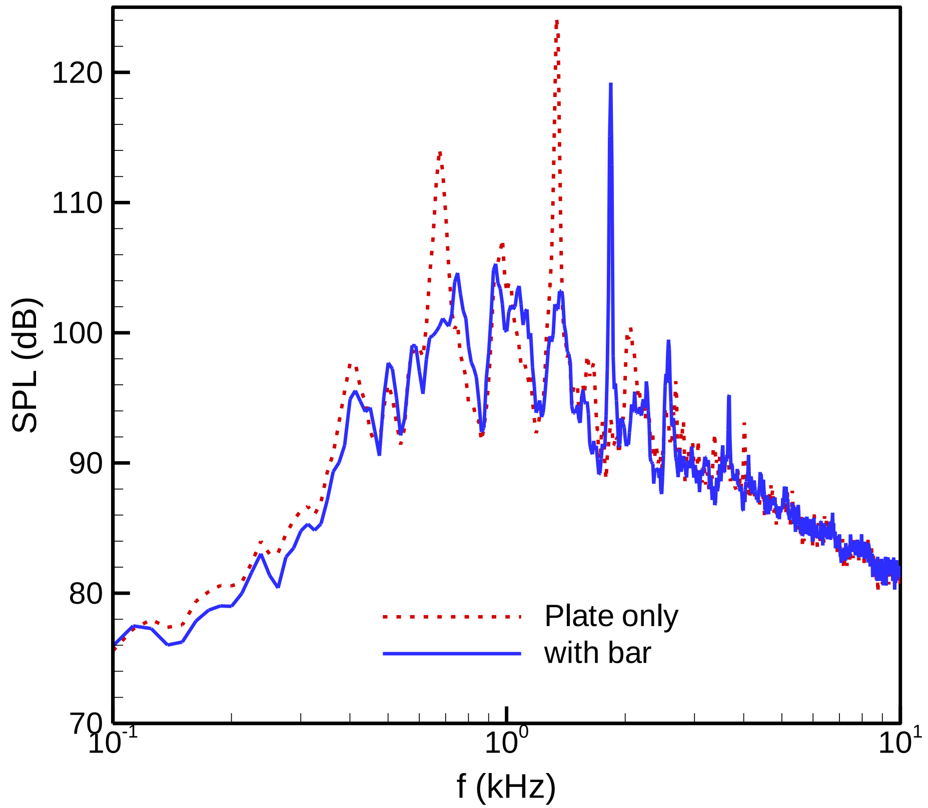
SPL spectra with and without a gap between nozzle underside and LE
L= 12 plate, x_{TE} = 8.5; M_j = 0.96





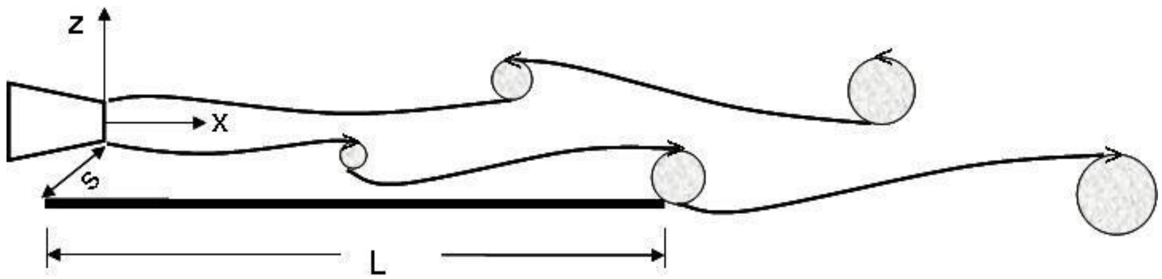
Closing a gap between LE and the underside of nozzle did not change spectra!
(Rules out an 'unsteady breathing' due to entrainment around LE as source)

SPL spectra with and without a bar wedged between nozzle and plate
L= 12 plate, x_{TE} = 8.5; M_j = 0.96

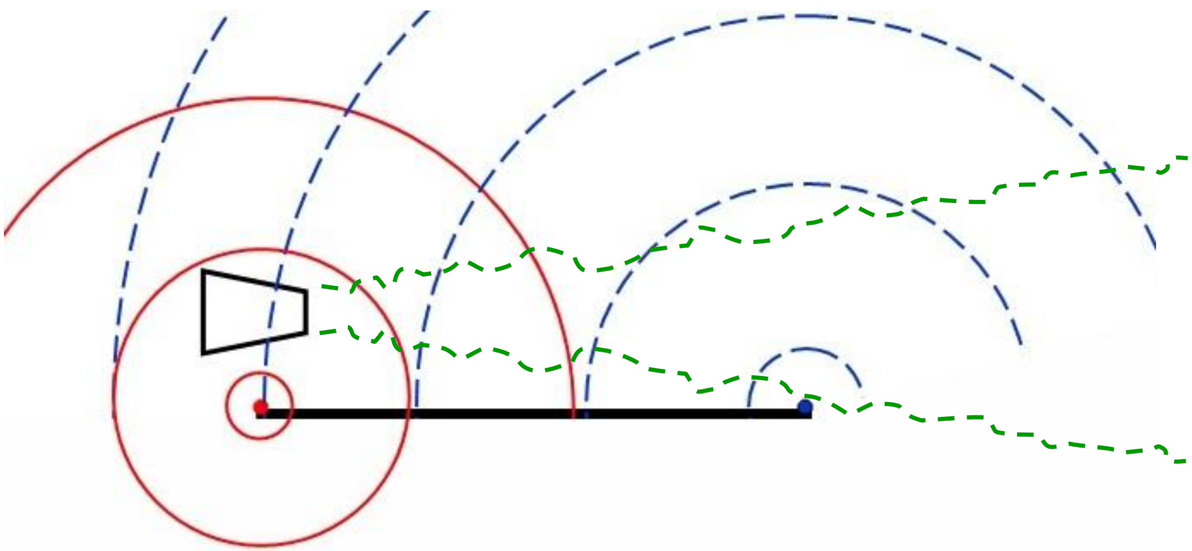


Placing a hard fence or bar near LE changes the spectra.
Tone frequency has increased in this instance

Hypothesis for feedback mechanism



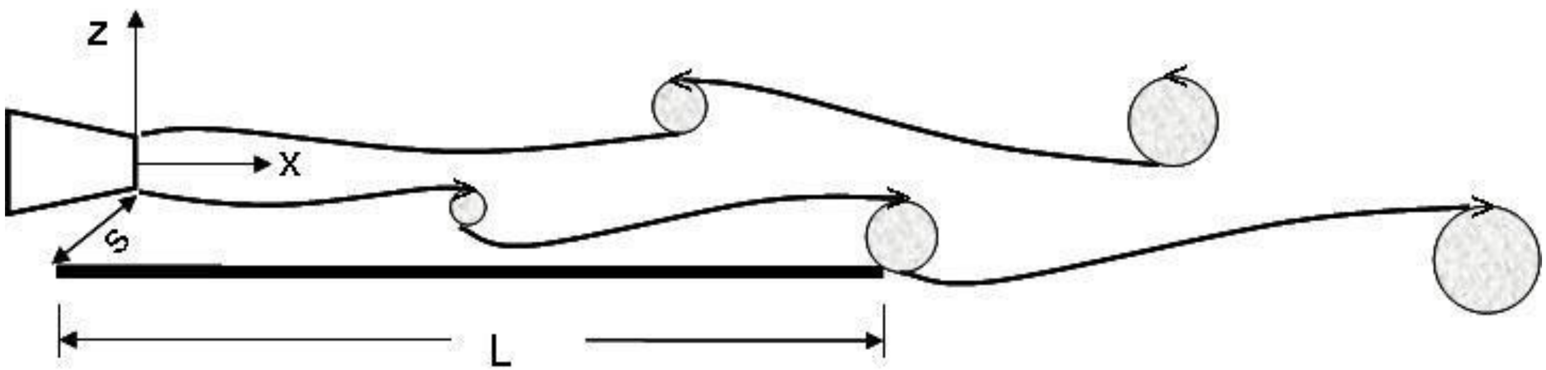
Vorticity Distribution



Diffraction From LE

'Primary' acoustic waves from TE get distorted by the flow
Waves from 'secondary' source due to diffraction from LE reach nozzle lip
Undistorted (spatially coherent) and thus more effective in the feedback

Equation for resonance frequency



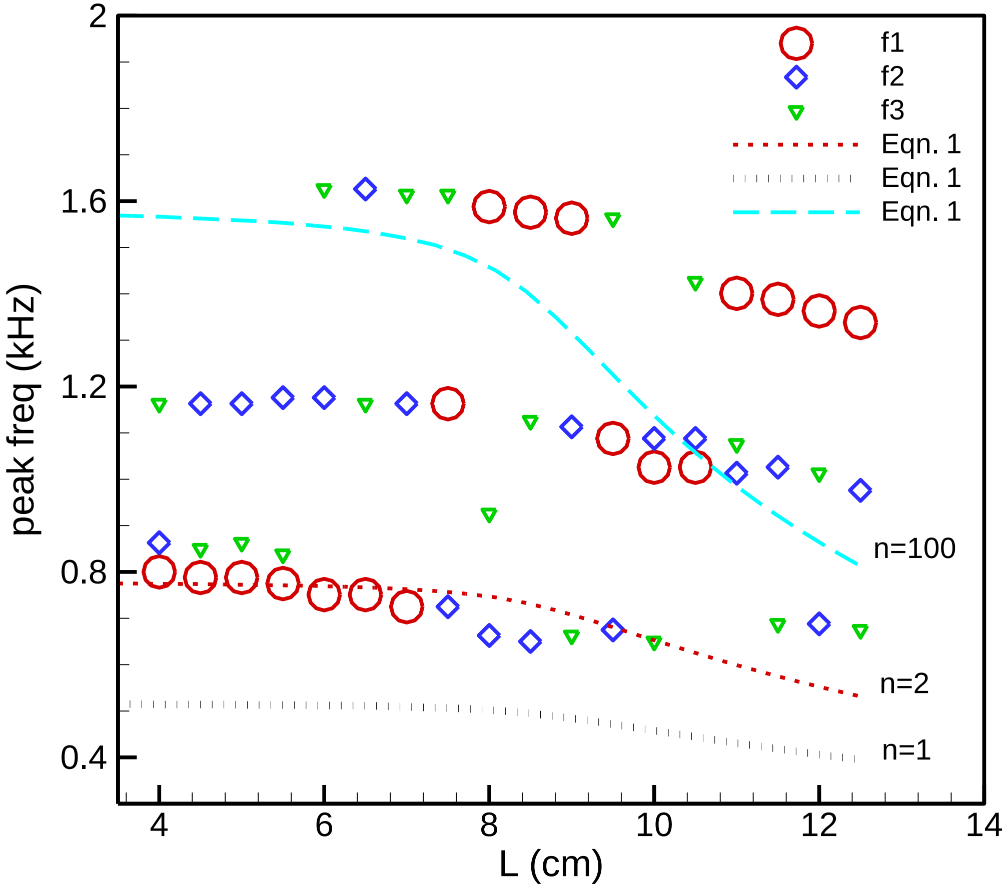
Period = vortex passage time over distance x_{TE}/n
+ travel time for acoustic wave over distance of $L+s$

$$f = c/(2x_{TE}/nM_j + L + s) \qquad (1)$$

Prediction from this equation with *n*=2 shown in all previous charts
Appears to capture the 'fundamental stage' for all parametric variation

Not everything is explained

***n* =2 predicts the fundamental. Why?**
Does not seem to explain the upper stages



Fixed TE, varying *L*
x_{TE} = 8.5, z= -1.5
M_j = 0.96

Summary

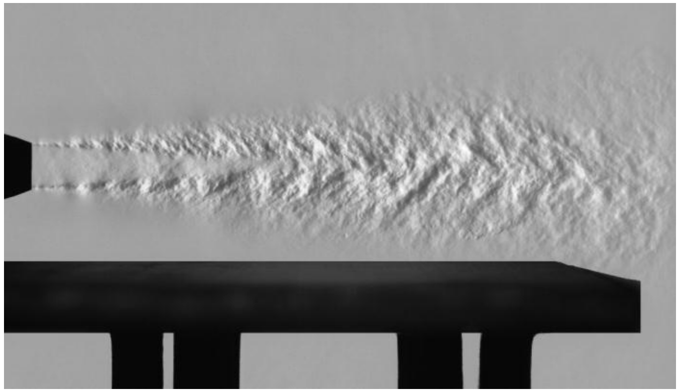
-- Simple feedback between plate's TE and nozzle lip is ruled out as the mechanism for sustaining the resonance

-- A hypothesis based on interaction of vortices with plate's TE and diffraction from plate's LE appears to explain the main feature of frequency selection

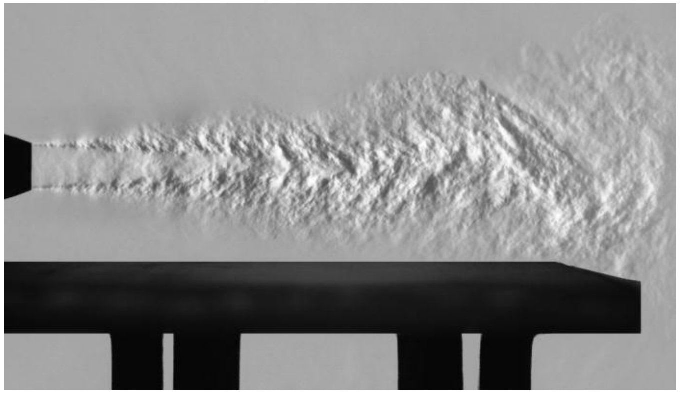
-- An equation based on the hypothesis captures the 'fundamental stage' of frequency variation for all parameters considered in the experiment (x_{TE}, x_{LE}, z and M_j)

Schlieren pictures for varying M_j
L=12 plate, x_{TE} = 8.5; z = -1.5

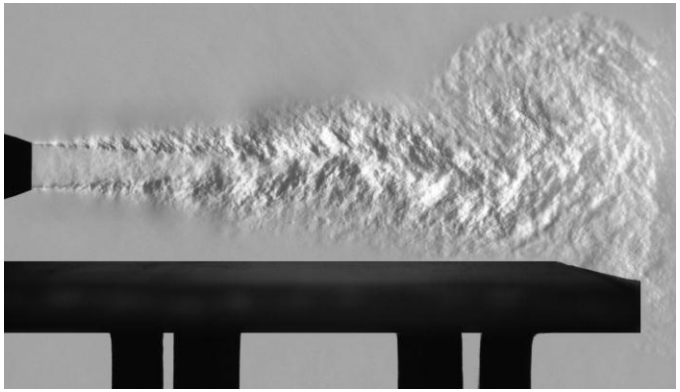
M_j = 0.76



M_j = 0.86



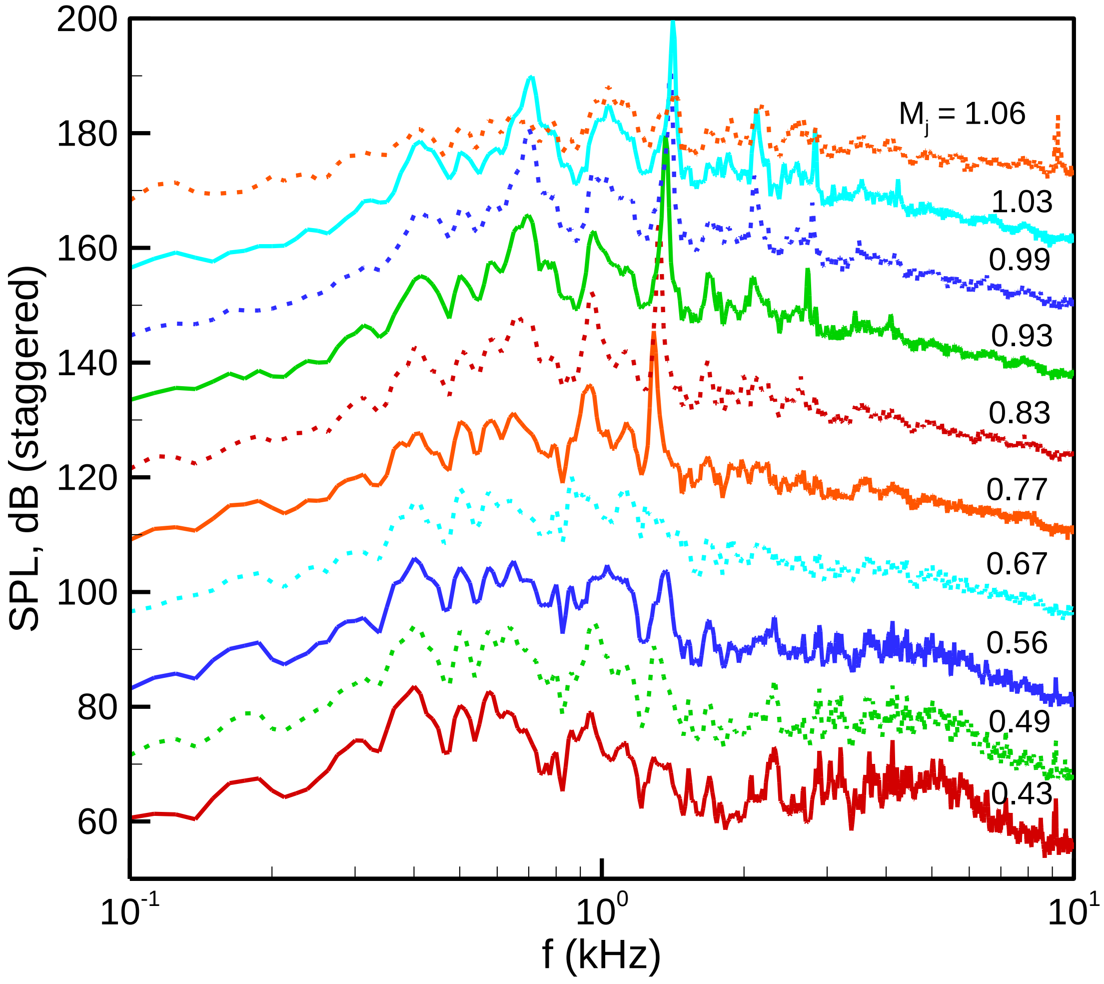
M_j = 0.99



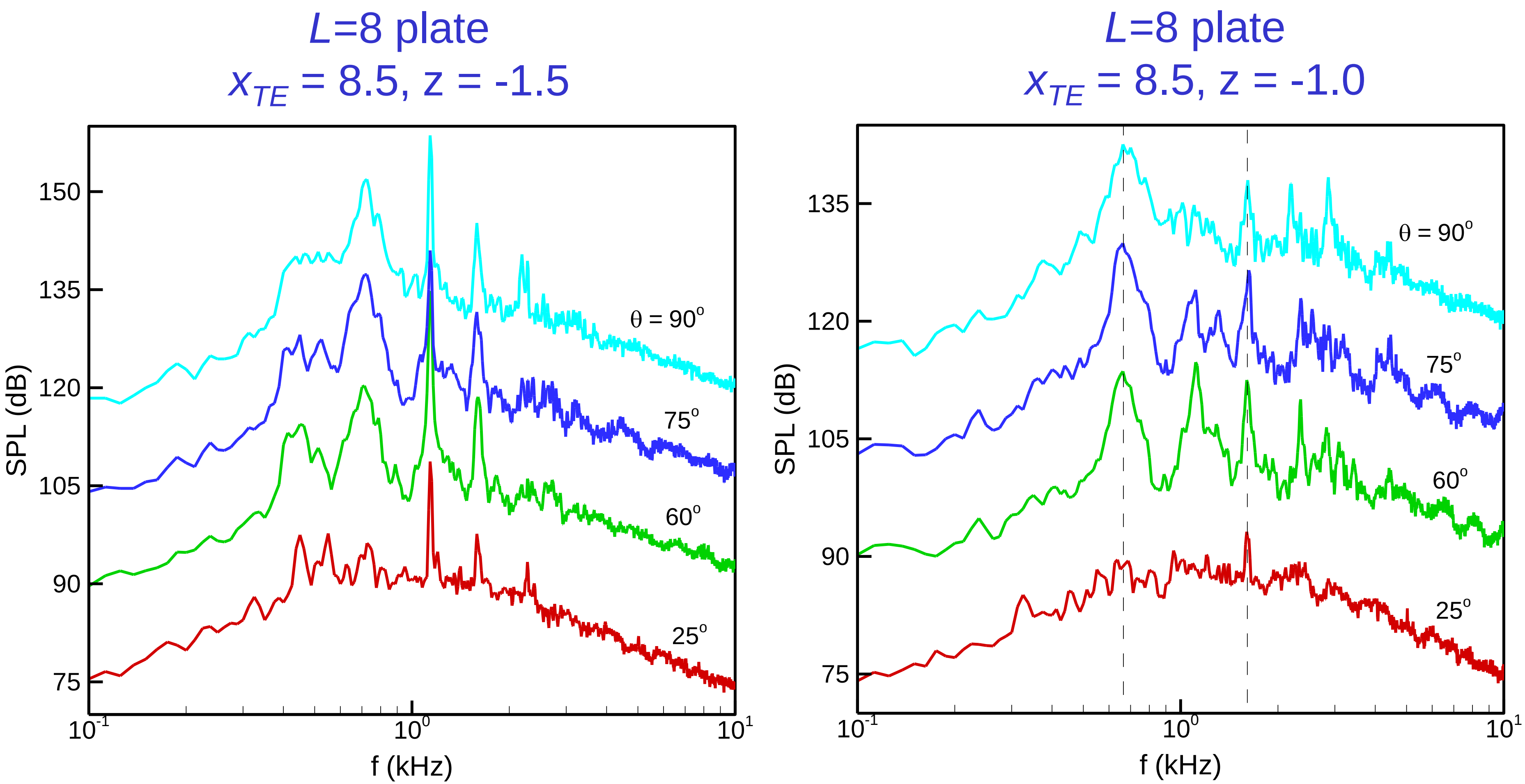
M_j = 1.06

Resonance for this configuration is prominent at high subsonic conditions

SPL spectra for varying M_j
L= 12 plate, x_{TE} = 8.5, z = -1.5



SPL spectra for 4 different polar location; $M_j = 0.96$



Tone heard at all polar locations. No change in spectral peak frequencies with varying θ.