Tones encountered with a coannular nozzle and a method for their suppression

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Outline of talk:

Introduction

Experimental Facility

Experimental Results

Numerical Results

Summary

Scope of the work:

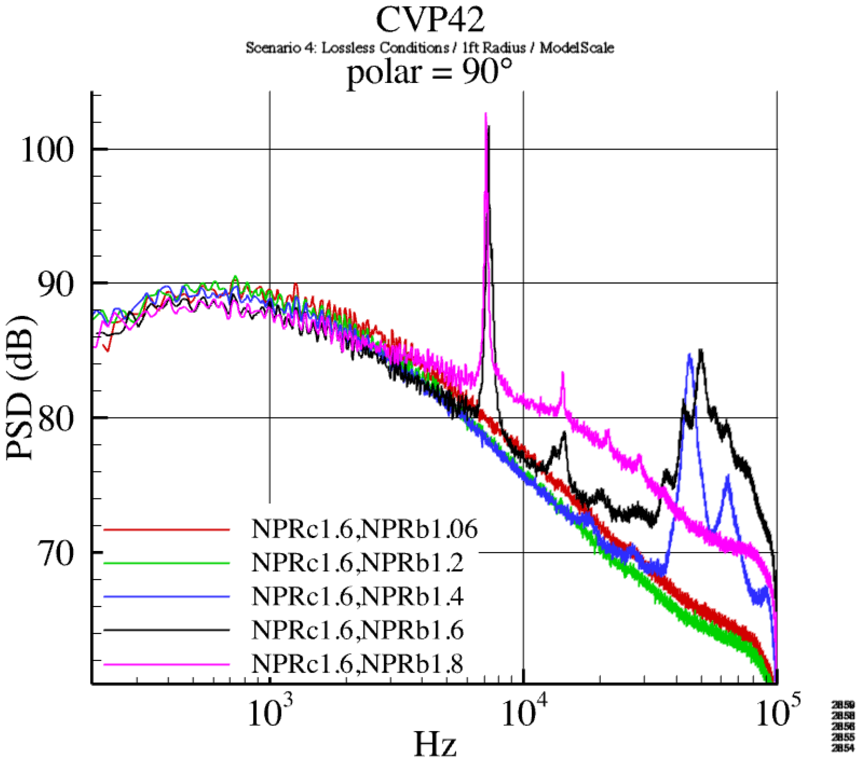
Tones were encountered in larger-scale, multi-stream nozzle tests in the Aeoacoustics Propulsion Laboratory (AAPL).

An approximately half-scale model of a 2-stream nozzle was built to study the tones and find possible remedy.

This paper presents results from the model-scale experiment.

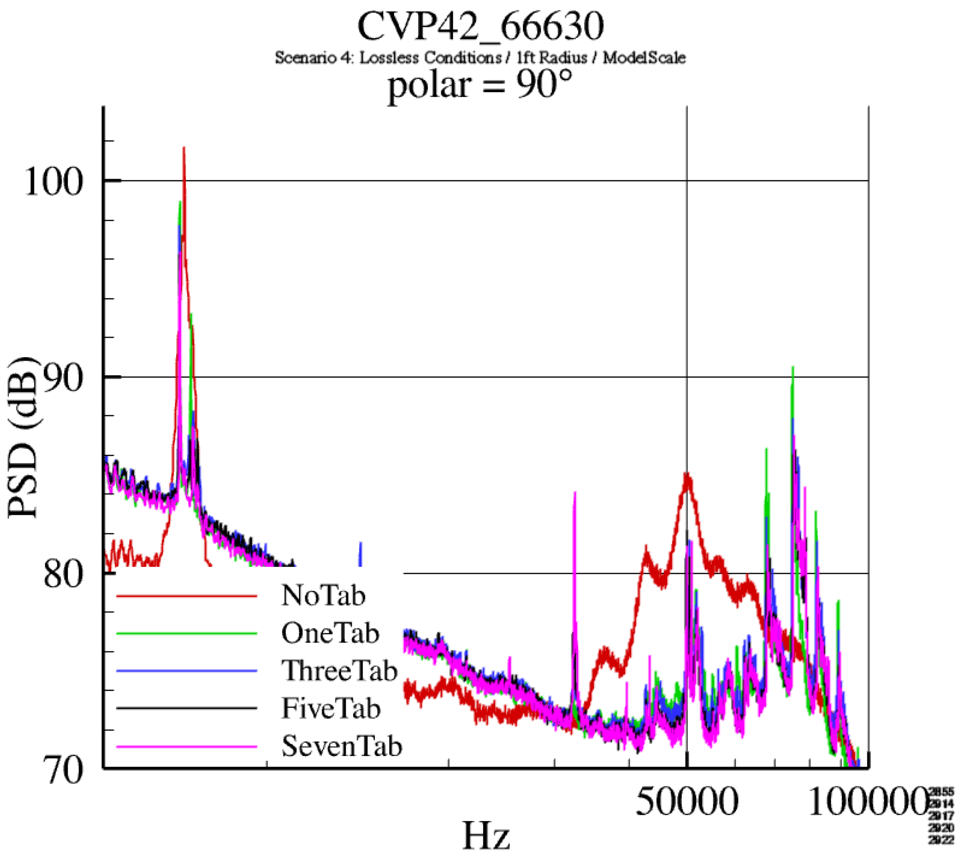
Results of a numerical study on duct acoustic modes corresponding to the tones are also presented.

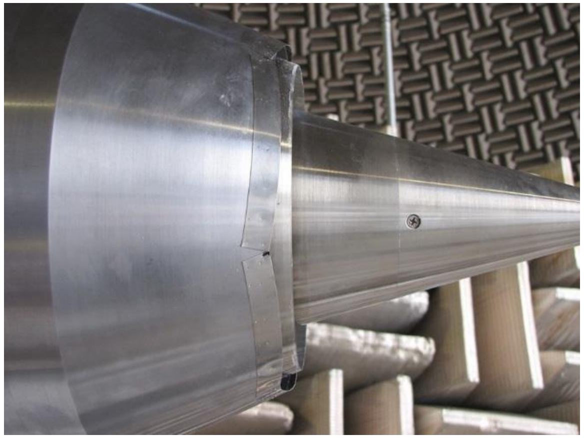
Tone problem faced in the AAPL with a 2-stream nozzle



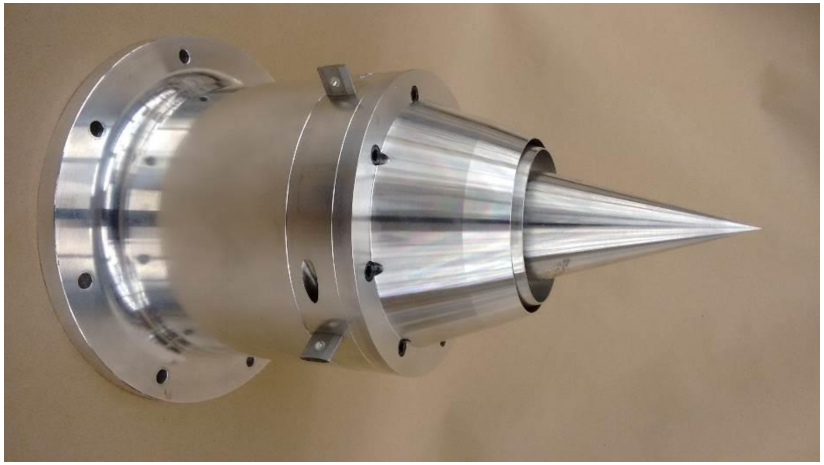
NPRc	**NPRb**	**NTRc**	**NTRb**	Notes
1.595	1.620	1.819	1.254	howling@7kH
1.551	1.597	1.797	1.249	howling@7kH
1.510	1.576	1.776	1.244	howling@7kH
1.434	1.534	1.735	1.234	howling@7kH
1.354	1.488	1.688	1.222	howling@7kH
2	2	1.776	1.25	howling@7kH
2	1.8	1.776	1.25	howling@7kH
2	1.5	1.776	1.25	rough stuff at
2	1.064	1.776	1.25	smooth
1.8	2.1	1.777	1.25	howling@7kH
1.8	1.8	1.777	1.25	howling@7kH
1.8	1.6	1.777	1.25	howling@7kH
1.8	1.4	1.777	1.25	rough stuff at
1.8	1.2	1.777	1.25	
1.8	1.06	1.777	1.25	
1.6	1.06	1.777	1.25	smooth
1.6	1.2	1.777	1.25	smooth
1.6	1.4	1.777	1.25	rough stuff at
1.6	1.6	1.777	1.25	howling@7kH
1.6	1.8	1.777	1.25	howling@7kH

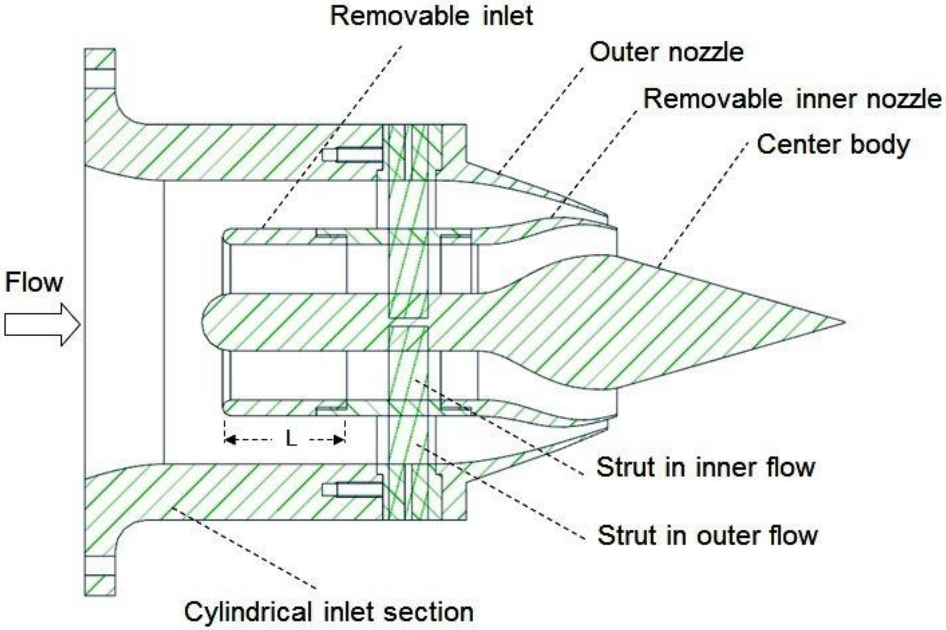
Remedies tried

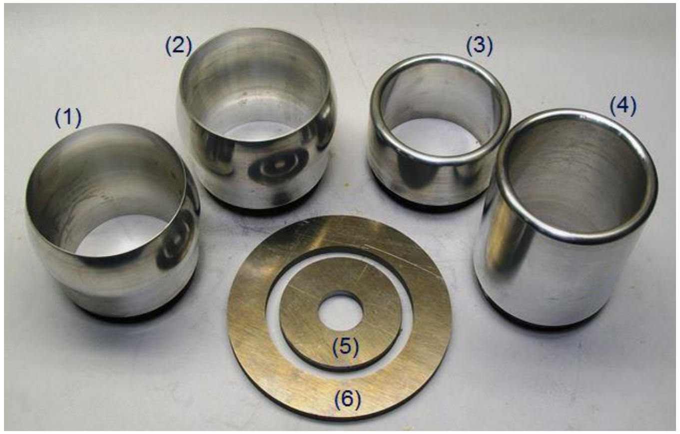




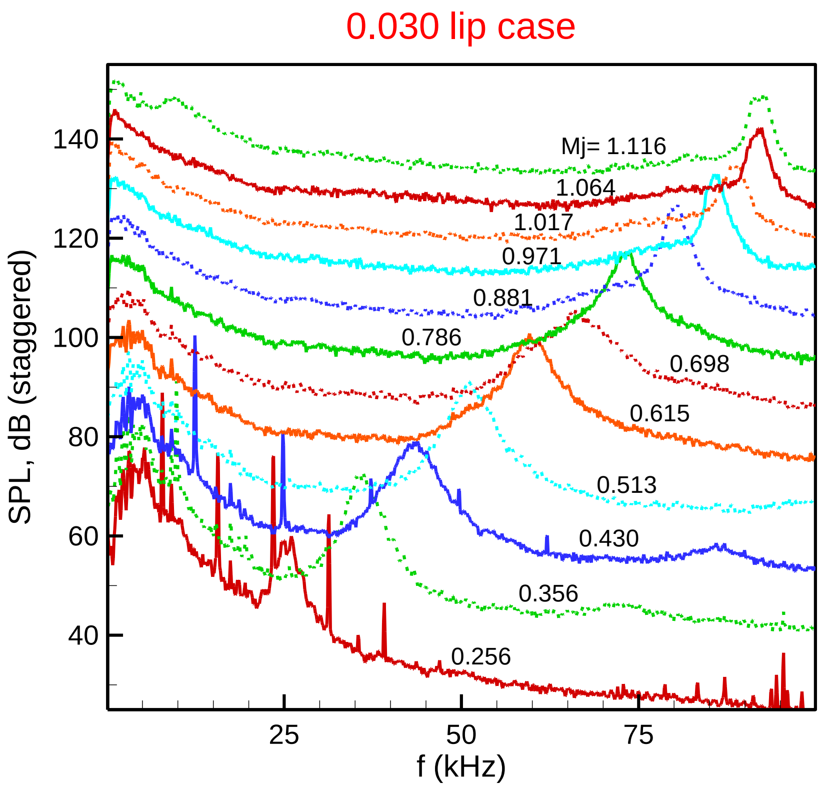
0.46-scale model of two-stream nozzle

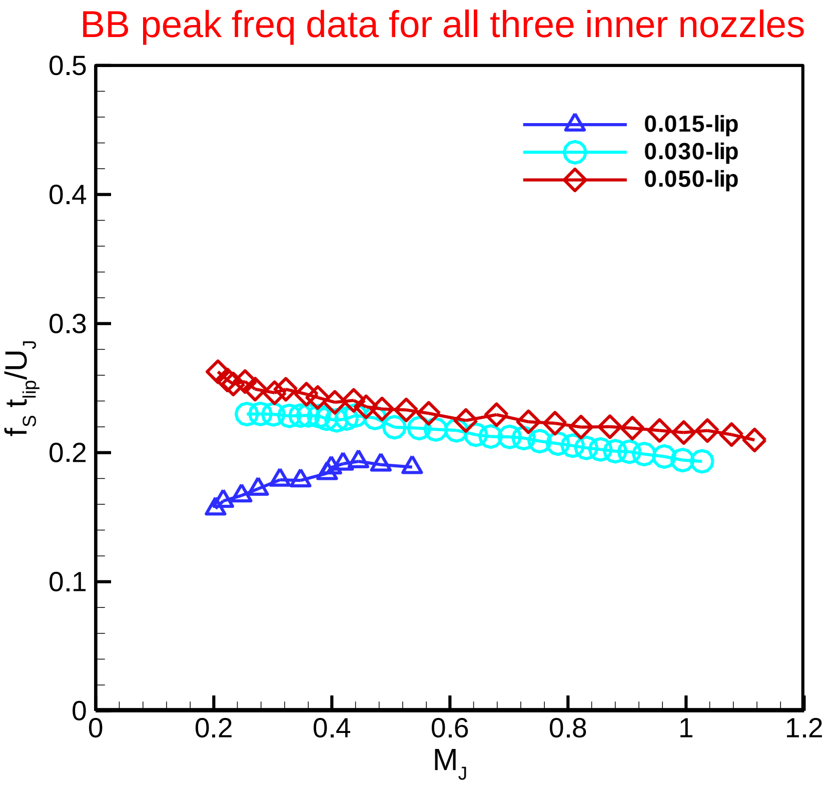






Sound pressure level spectra (θ=90°)


0.030 lip case

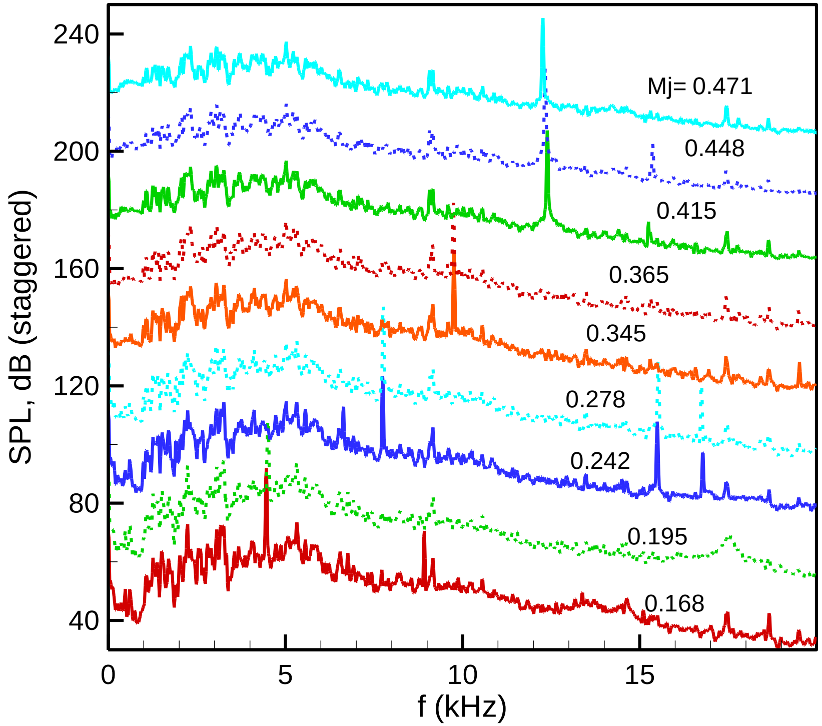

BB peak freq data for all three inner nozzles

--Broadband peak is due to TE shedding (frequency of peak increases with Mj);
Strouhal number based on lip thickness is about 0.2.

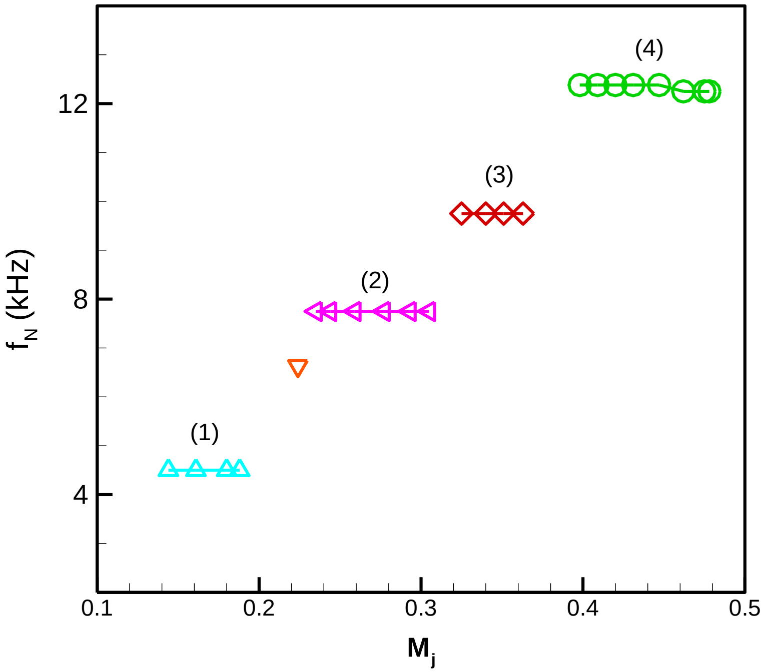
--There are sharp tones at lower Mj.

Sound pressure level spectra in low Mj range

SPL spectra

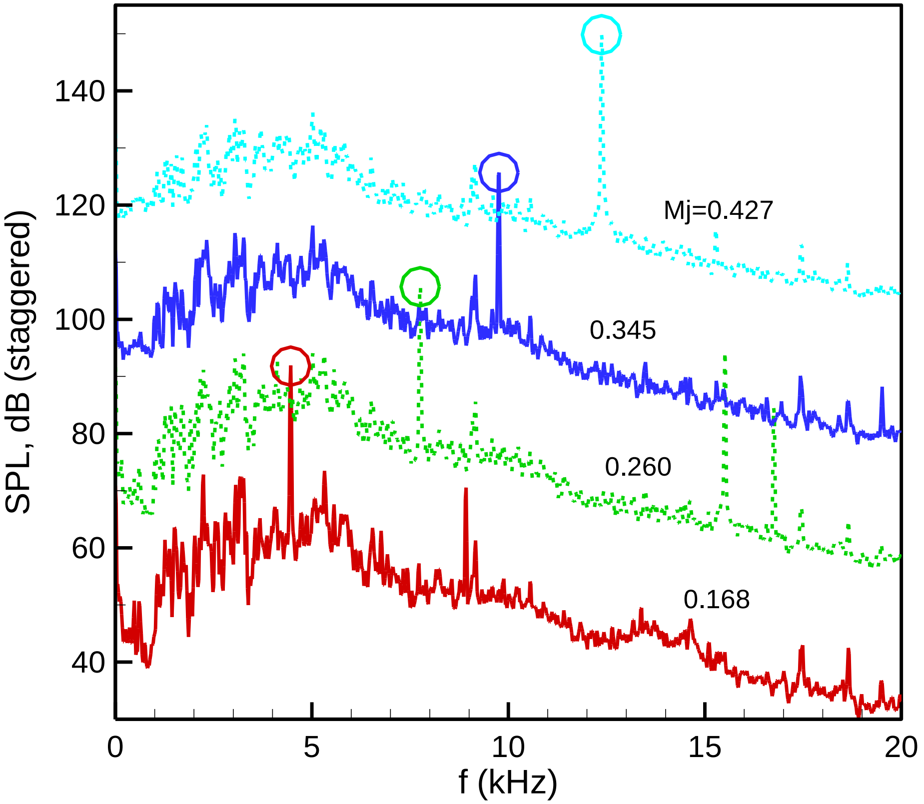


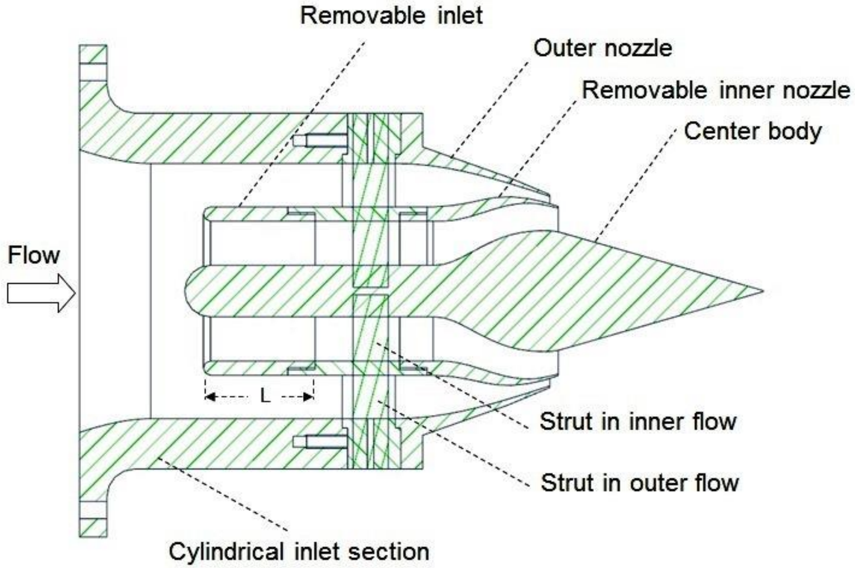
Frequency of dominant peak vs. Mj



--Frequency of tone varies with Mj in steps.

Four cases corresponding to the four stages are explored with parametric variation



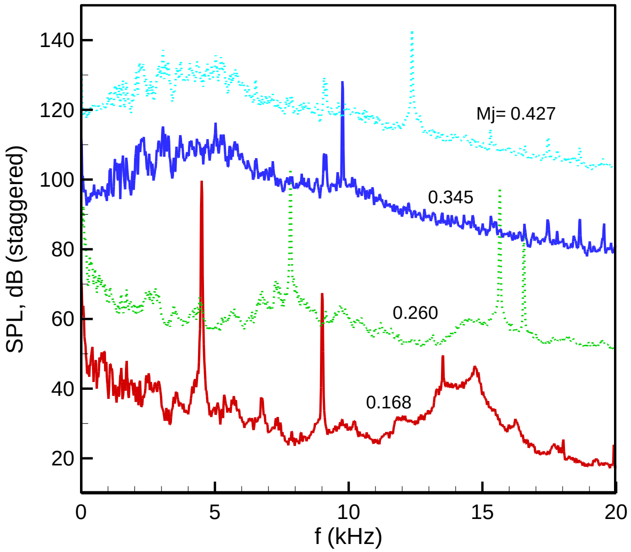


Parameters varied:
Lip thickness of inner nozzle
Inlet length (L = 0.75, 2, 4.75)
Flared and constricted inlets
Lip-to-lip distance

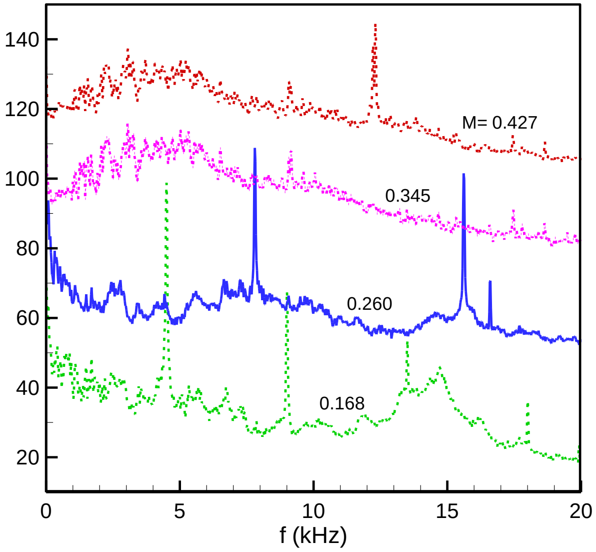
Effect of changed lip-to-lip distance

Changed by unscrewing inner nozzle

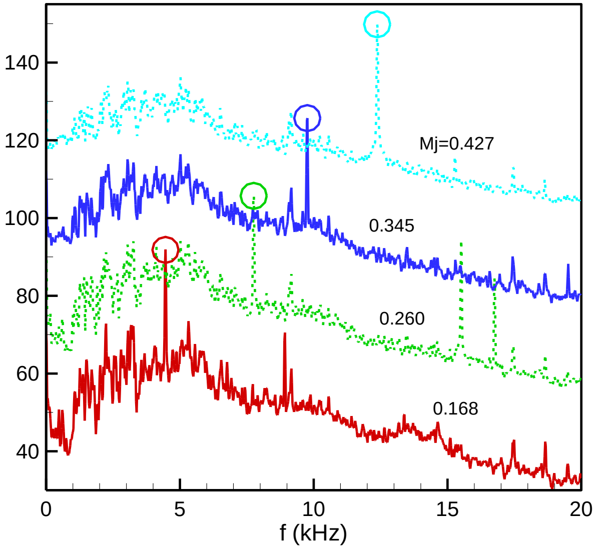
Gap = 0.16



Gap = 0.26

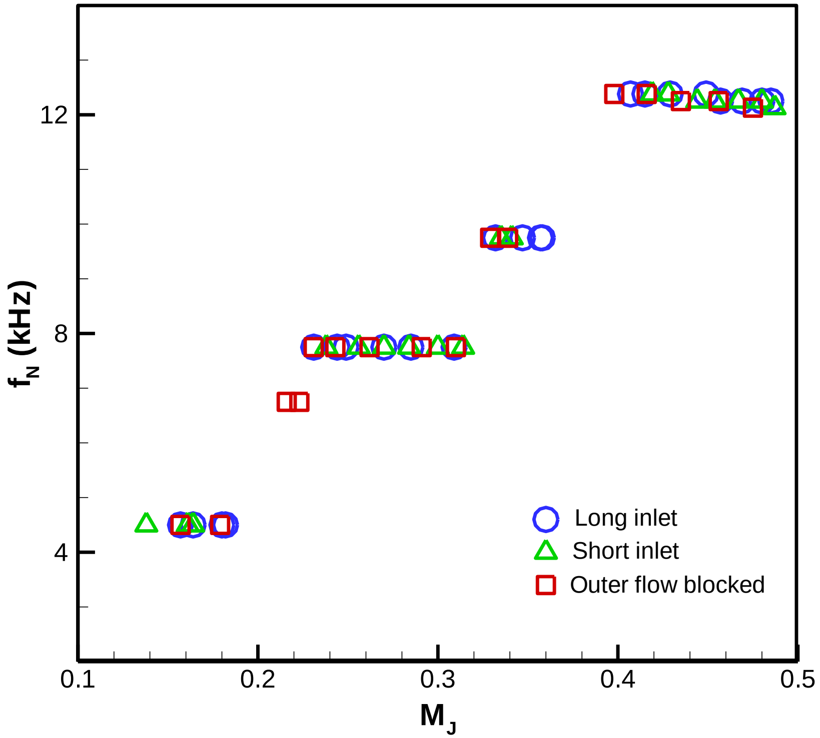


Gap = 0



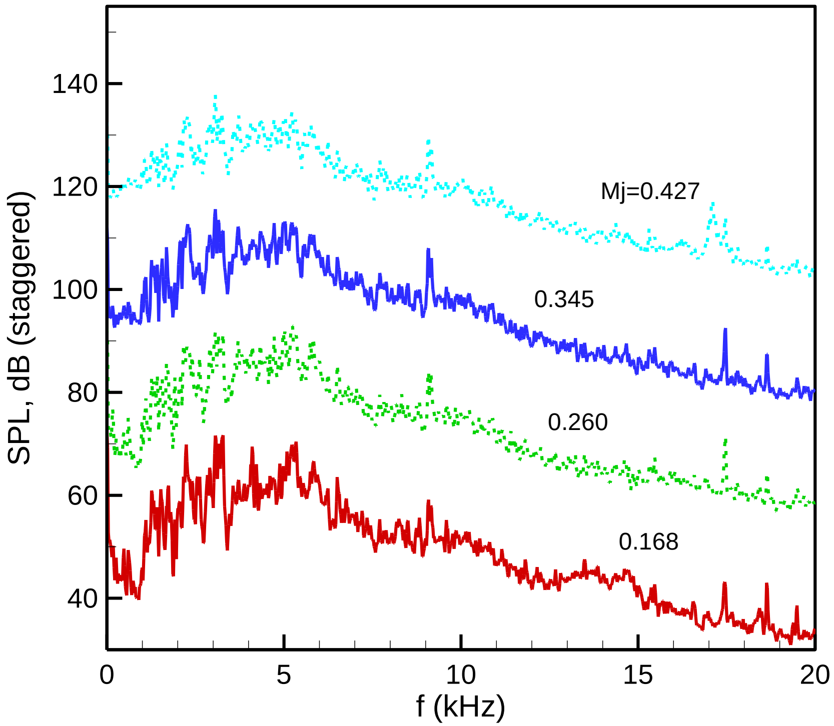
--Tone frequencies remained basically unchanged.

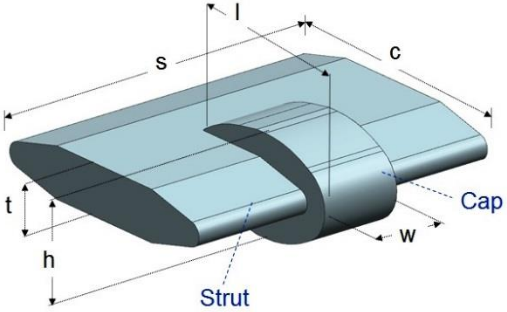
Tone frequency vs. Mj for different inlet lengths



--With parameter variations noted in last slide frequencies were basically unaffected.
-- Here data shown for inlet length variation and also with outer flow blocked.
-- Same four stages occurred in all cases.

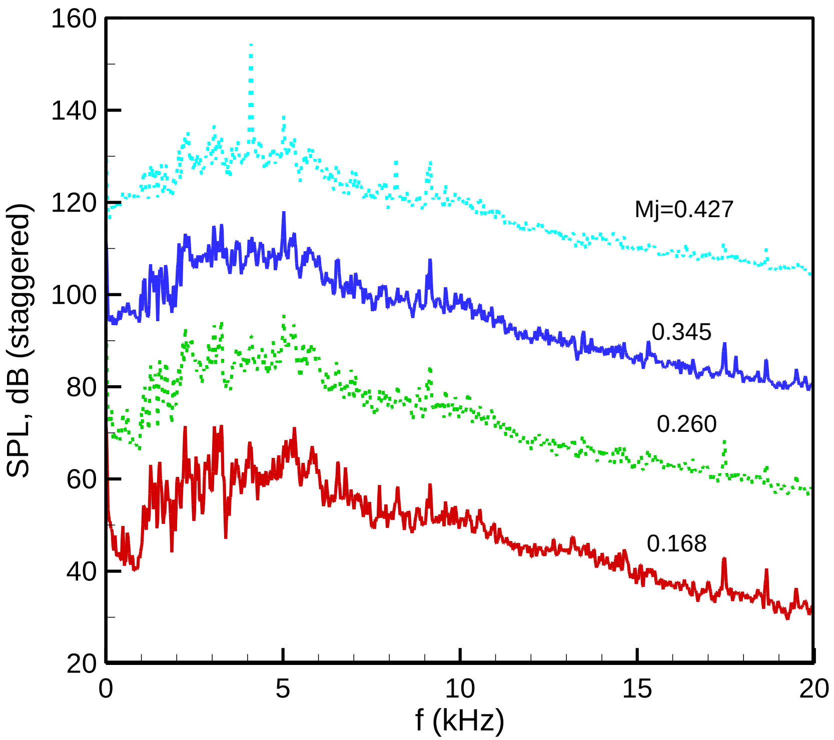
SPL spectra with caps on inner struts





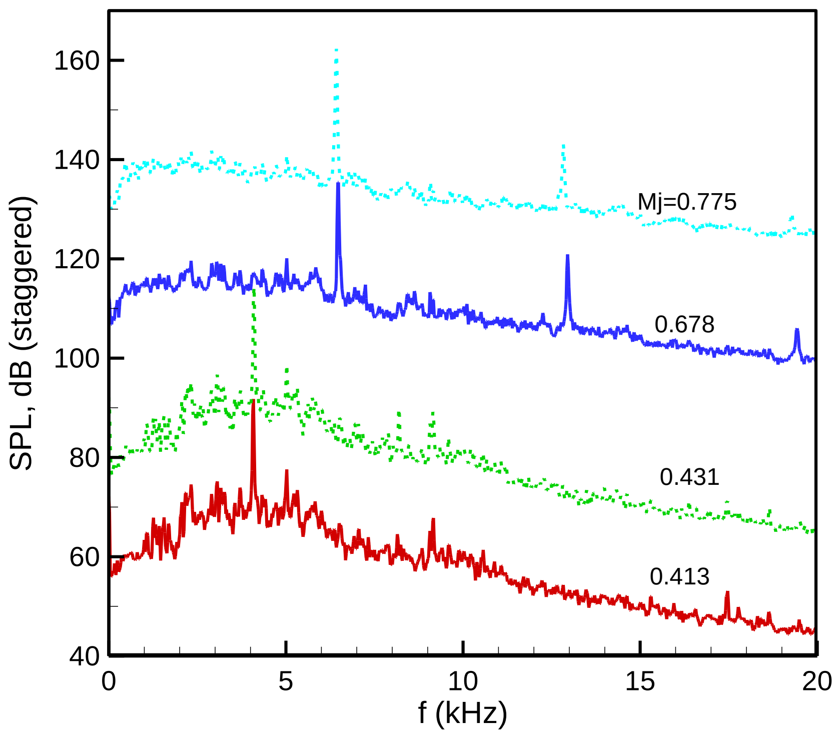
--caps with width w = 0.65 (full span 0.8) took the tones out !!
-- w = 0.3 or 0.1 were just as effective.

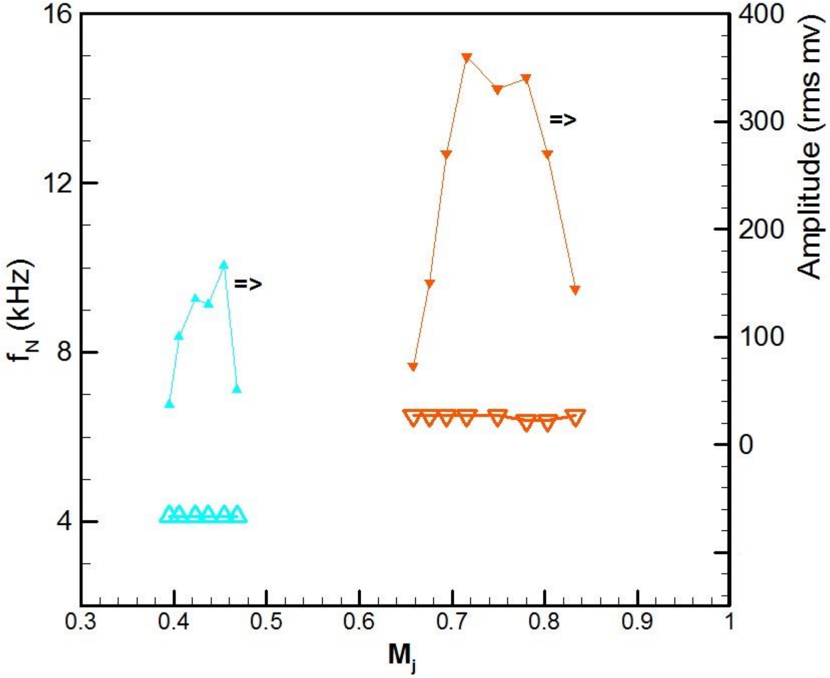
SPL spectra with full-span caps on inner struts



--Tones came back at higher Mj.

SPL spectra with full-span caps on inner struts

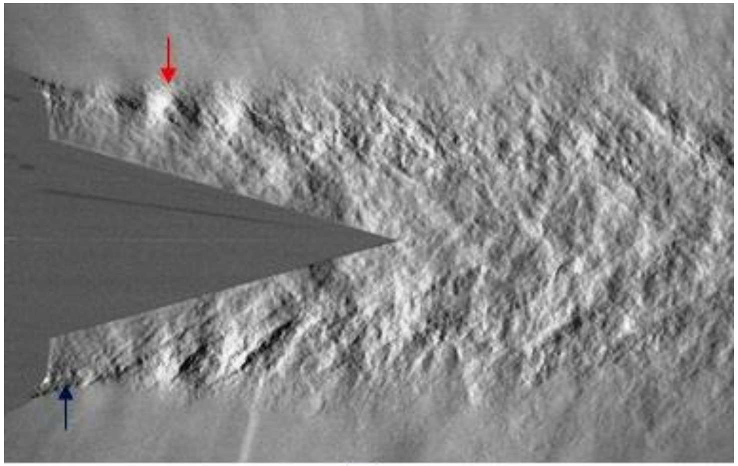




--Two stages of tones occurred in Mj range of 0.4–0.85.

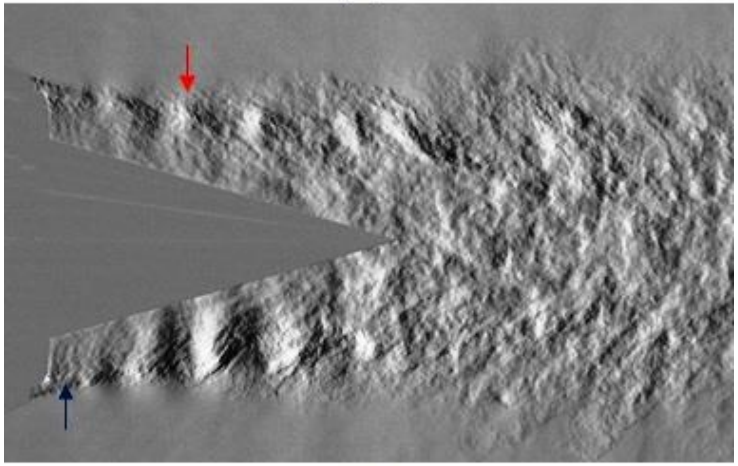
-- Amplitudes were the largest in the middle of each stage.

Schlieren pictures of flow-field for full-caps on inner struts



(a)

M_j =0.45, *f*=4.13 kHz
(shedding at 45 kHz)



(b)

M_j =0.67, *f*=6 kHz
(shedding at 65 kHz)

--Tones excite the shear layer.

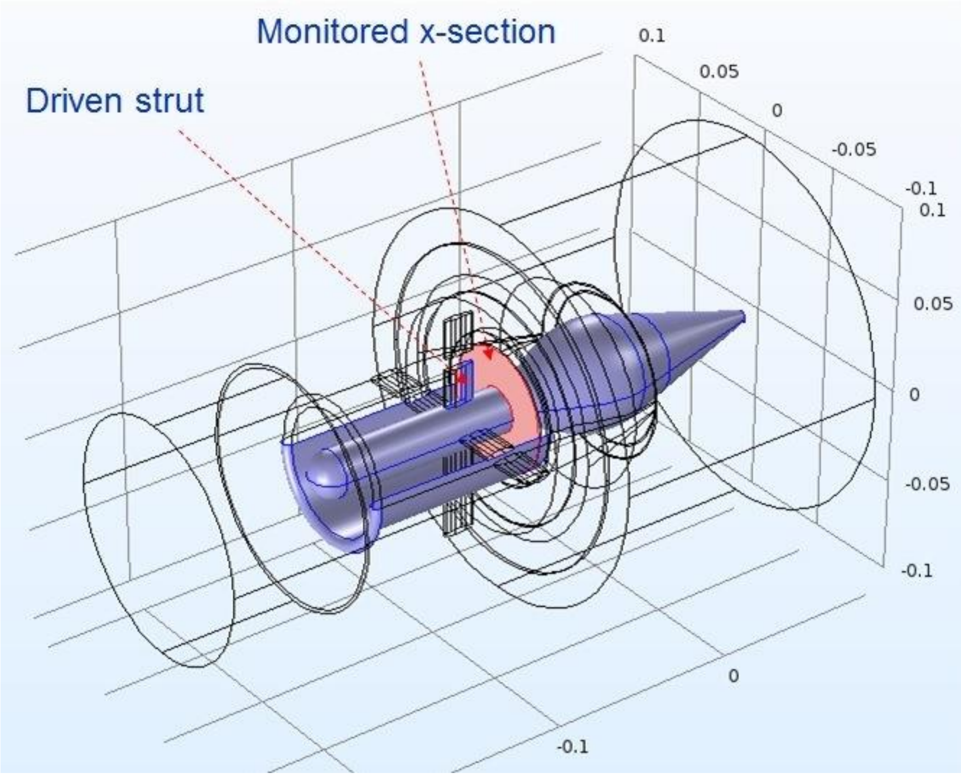
--Shedding from the inner nozzle lip can also be discerned upon inspection.

-- Obviously, shedding from the struts couples with duct resonances to generate the tones.

-- Experimental data did not shed any light on the nature of the duct modes.

-- In order to study this, numerical simulation was done using a code, ‘COMSOL Multiphysics’, for the given geometry of the nozzle and struts.

Numerical simulation



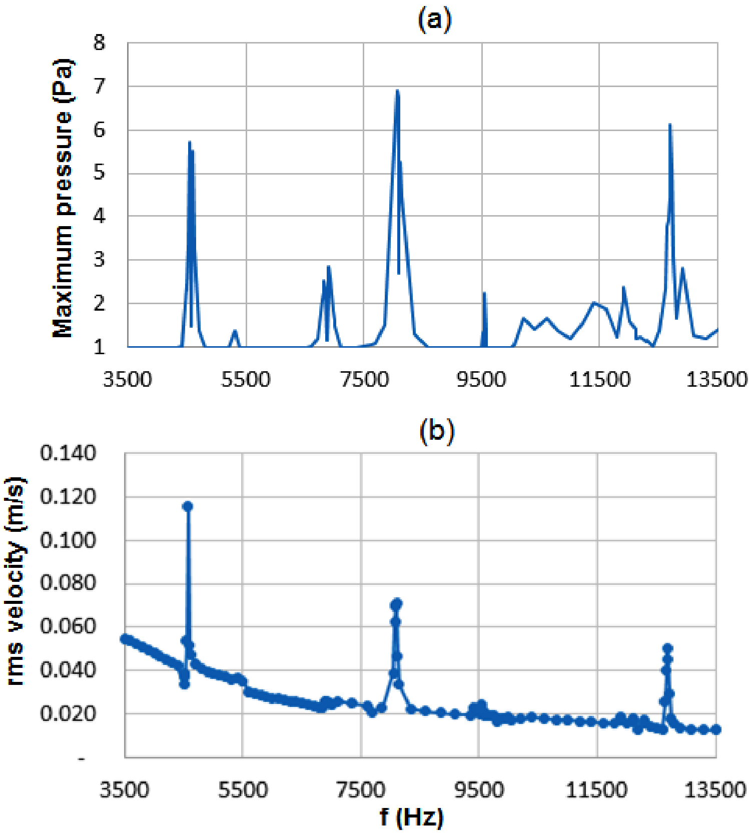
-- No flow.

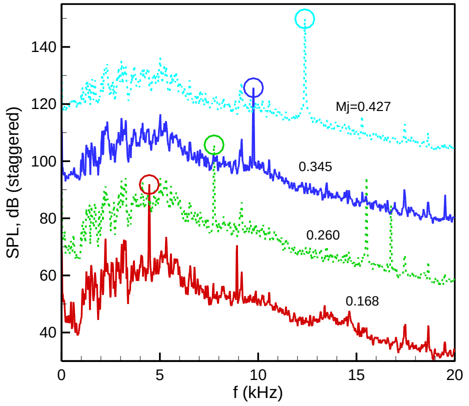
-- Asymmetric perturbation imparted near TE of one of the four struts.

-- Solves for acoustic pressure field within the domain.

-- With perturbation at a given frequency maximum pressure and maximum velocity in the domain are monitored.
This way a spectrum of the Response function is constructed.

Numerical simulation



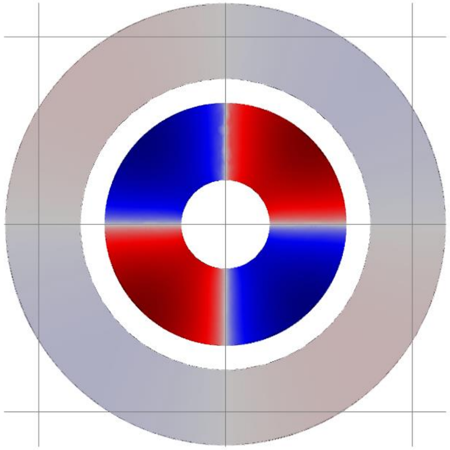


M_j	f (Hz) experiment	f (Hz) simulation
0.168	4460	4565
0.260	7760	8054
0.427	12375	12522

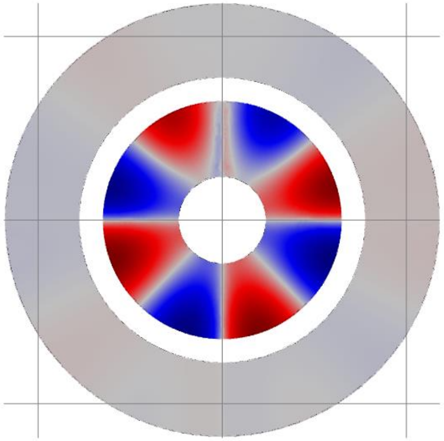
-- Peaks at 4.46, 7.76 and 12.37 kHz are captured reasonably well !

-- Peak at 9.76 kHz is not but there is a hint of energy around that frequency.

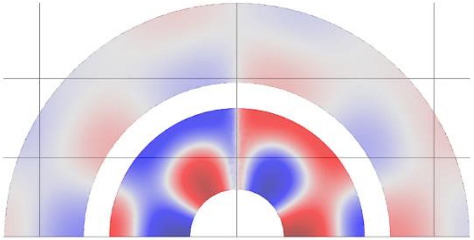
‘Mode shapes’ at monitored plane just downstream of struts



4.53 kHz



8.05 kHz



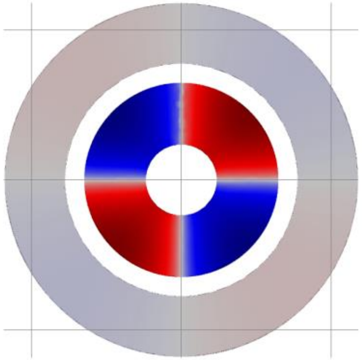
12.52 kHz

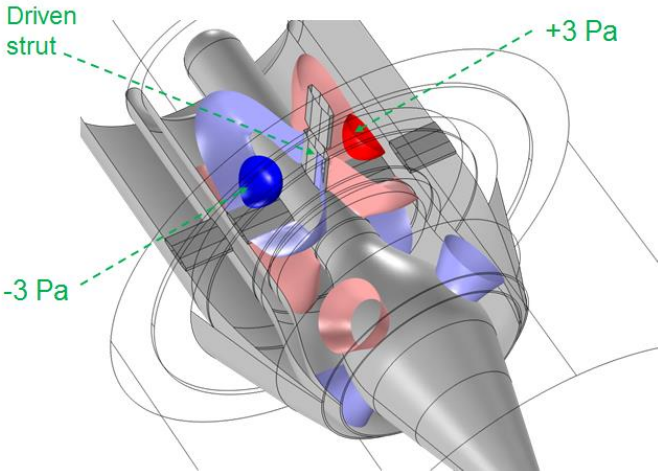
-- ‘Fundamental’ involves positive and negative pressure regions in alternate intra-strut spaces, at a given instant.

-- First harmonic involves pairs of positive and negative pressure regions within a intra-strut space.

-- 12.52 kHz involves a complex azimuthal/radial distribution.

Pressure and velocity distribution for fundamental (4.525 kHz) in entire domain



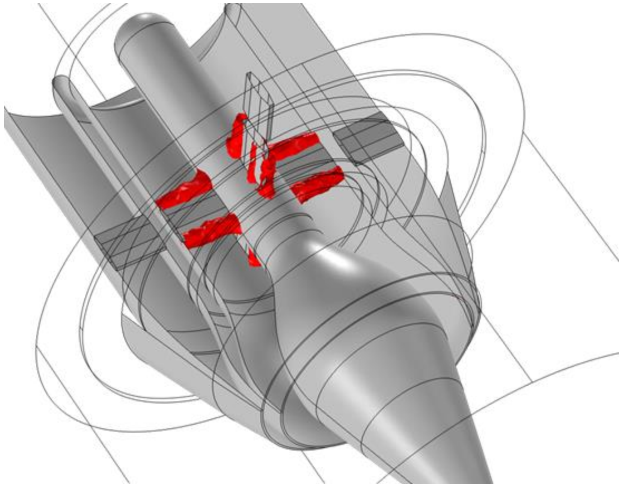


-- Complex standing waves are set up around the struts.

-- High pressure regions (anti-nodes) occur against the duct inner wall in between pairs of struts.

-- Even though only one strut is driven, synchronized motion occurs from all four struts.

-- Struts themselves are regions of velocity anti-nodes.



Conclusions:

-- The source of the tones is traced to vortex shedding from the struts.

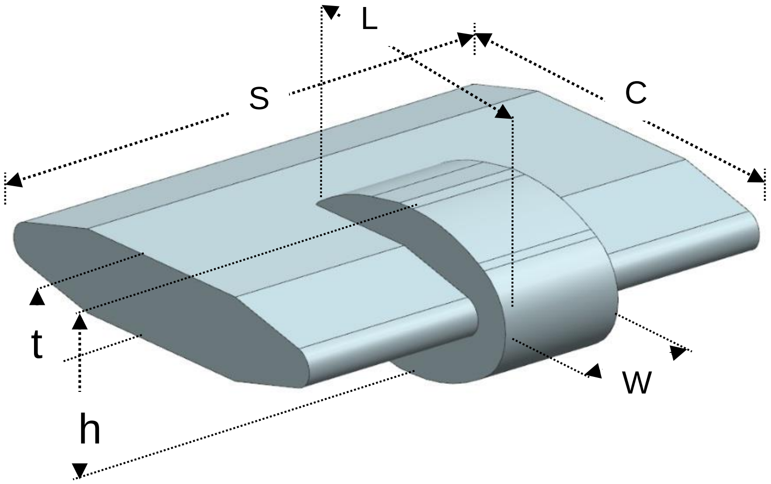
-- Perturbation from shedding couples with acoustic modes of the nozzle/strut, leading to step-like variation of tone frequency with Mach number.

-- Standing waves form around struts. The fundamental involves alternating positive and negative pressure regions in intra-strut spaces. The pattern is anti-symmetric about a diametral plane. With increasing frequency the shape of the standing wave become more complex.

-- A leading edge treatment of the struts in the inner nozzle eliminates the tones. This is due to a disruption of two-dimensionality of the flow that in turn disrupts organized vortex shedding.

-- It is possible a similar remedy may work in other situations, e.g., in wind-tunnel tests where tones are generated by coupling of vortex shedding from some component with tunnel acoustic modes.

Strouhal number based on local velocity and strut thickness



t= 0.125
c= 0.65
h= 0.265

Straight inlet
No cap

M_j	f (kHz)	ft/U_{in}
0.168	4.5	0.30
0.260	7.75	0.33
0.345	9.5	0.31
0.427	12.38	0.32

Straight inlet
Full caps on 4 inner struts

M_j	f (kHz)	fh/U_{in}
0.45	4.13	0.22
0.75	6.45	0.21

-- Shedding Strouhal number depends soemwhat on geometry of strut
-- It is apparent Karman shedding is the instigator for the observed tones