# An Experimental investigation of jet noise from septa(e) nozzles

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# Outline of talk:

**Introduction**

**Experimental Facility**

**Results and Discussion**

**Summary**

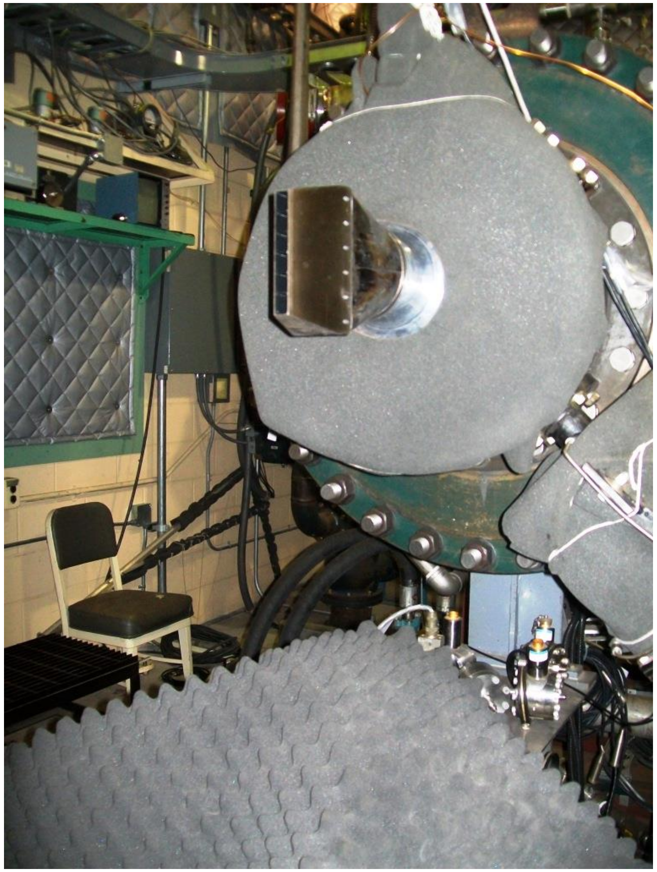
# Distributed Propulsion

(From Felder, Kim & Brown 2009)

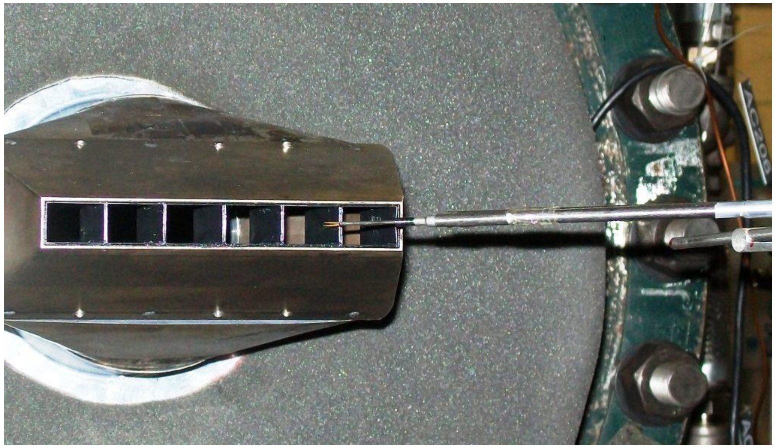
In one (hybrid) version of the concept each septum is driven by an electric fan

**Concern about impact on noise. Will noise be greater than that from a equivalent single jet ?**

# Experimental Facility



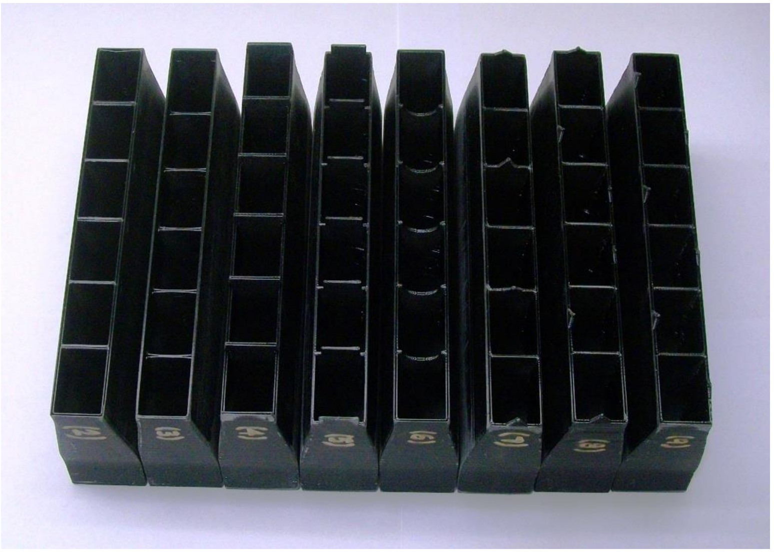
Open Jet rig (CW17)



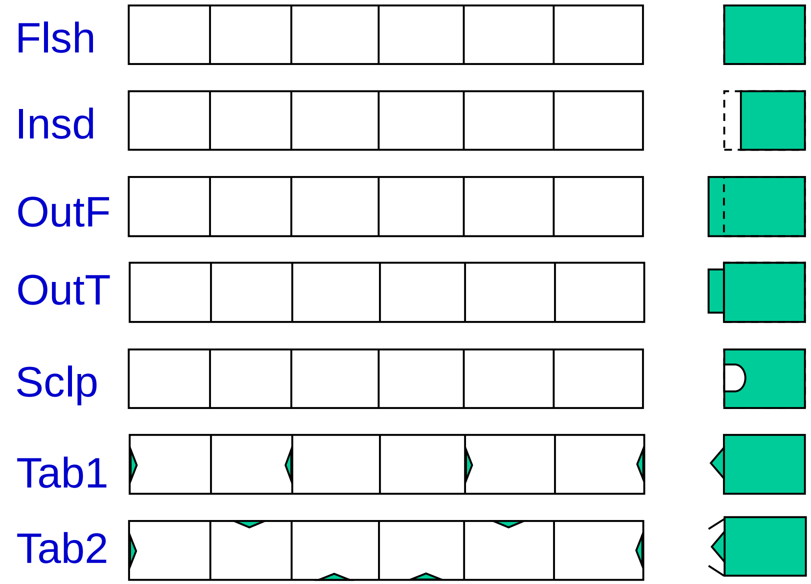
Close-up view of nozzle and HW

- Up to about 500 kPa allowed
- Microphones overhead
- 8:1 rectangular nozzle
  (14.1 cm x 1.68 cm)
- Inserts made by 3-D printing

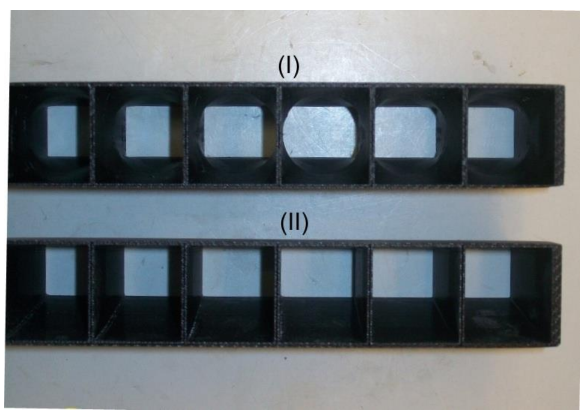
# Experimental Facility (inserts)



**Picture of 8 inserts**




**Schematic of exit shapes**

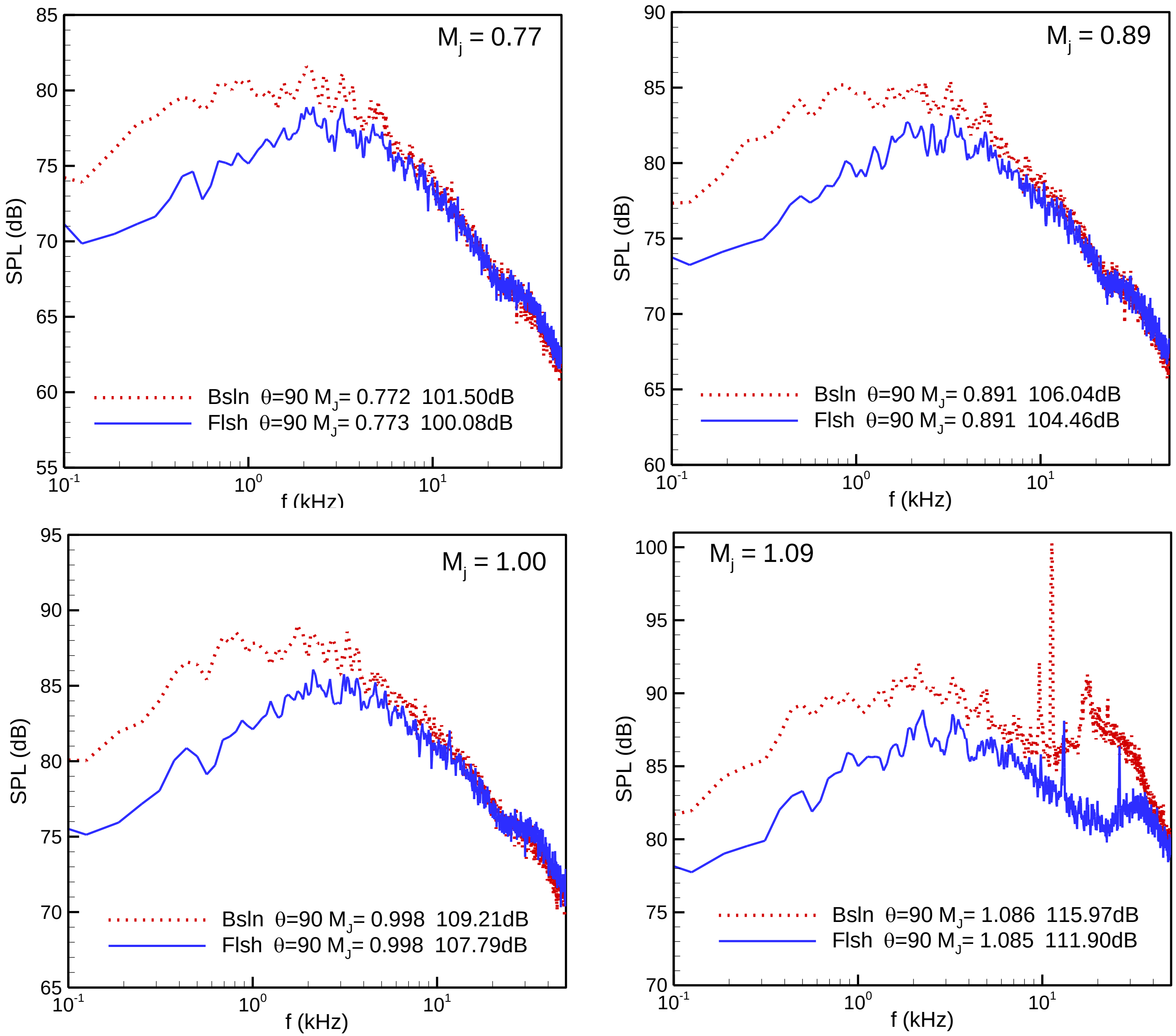



**Internal geometry design I and design II**

**-Different exit shapes examined for maximum noise reduction**

**-Number of septa varied with Design II**

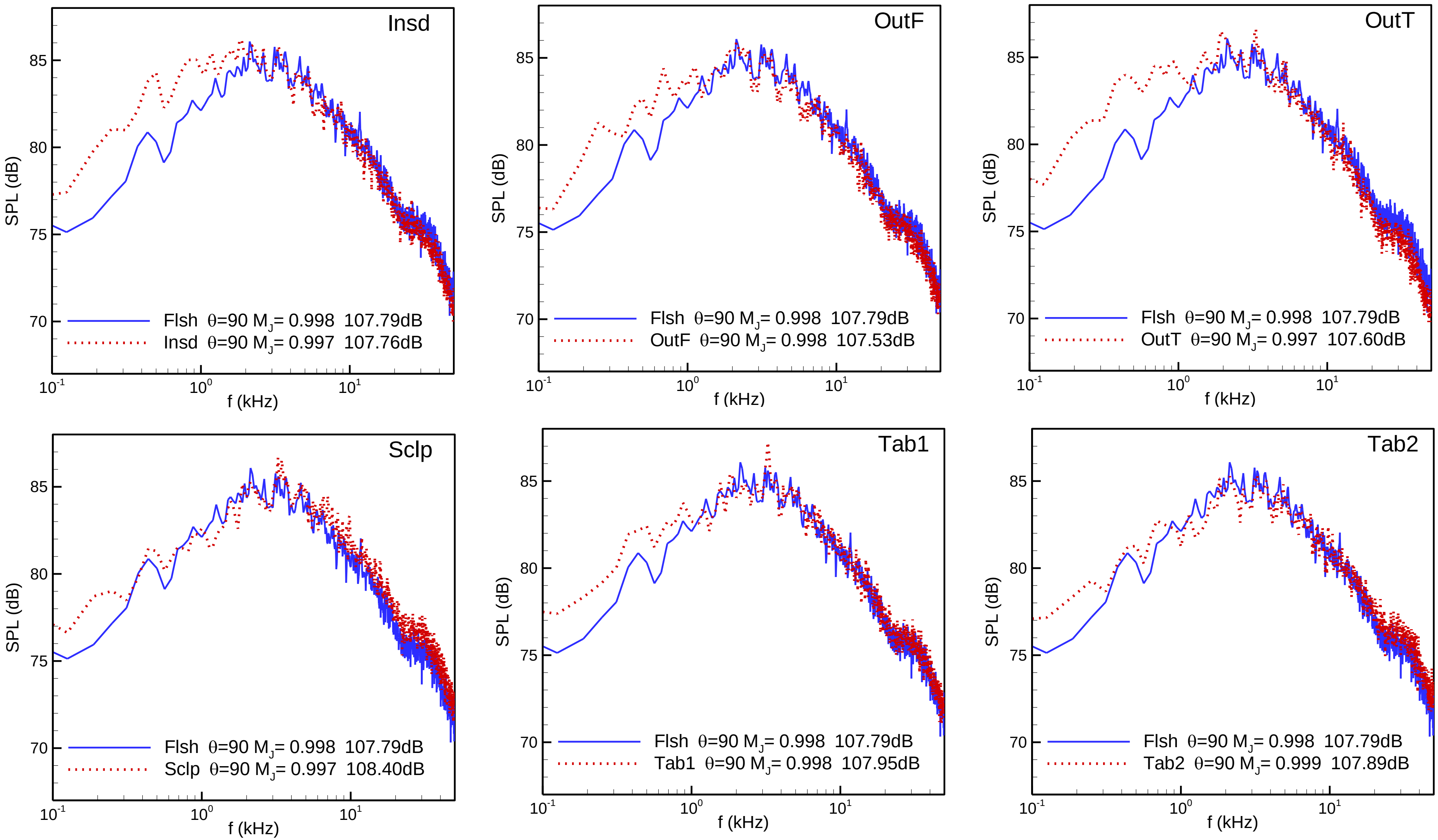
# SPL Spectra comparison: Baseline vs. Flsh cases




**Lower noise on low frequency end for the Flsh case, at all $M_j$.**

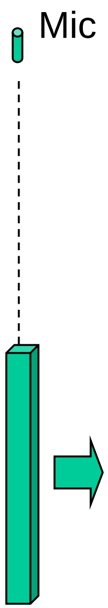
**Not accounted for by exit area reduction (11% smaller $D_{eq}$ => 1.3 dB)**

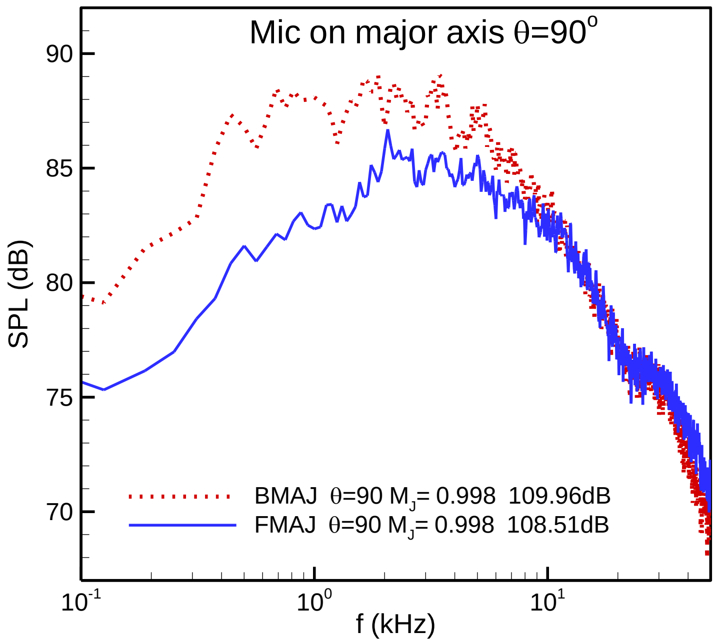
# SPL Spectra comparison: Flsh vs other cases at $M_j$=1



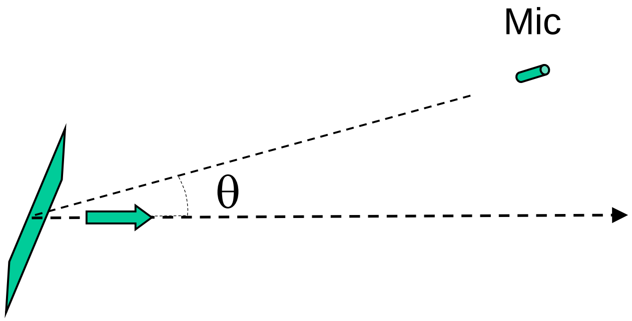

**Maximum noise reduction with Flsh case. Sclp and Tab cases have comparable result.**

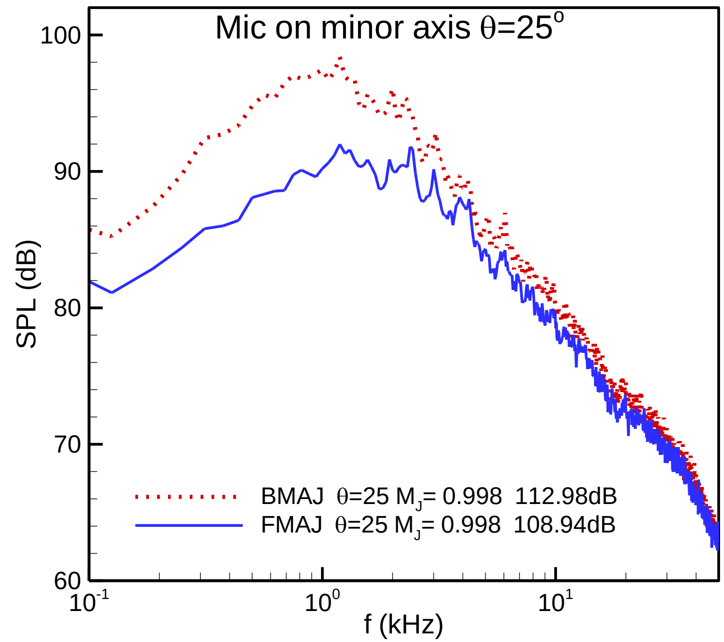
# SPL Spectra Flsh vs Baseline at other angular locations; $M_j$=1




**Narrow side (ϕ=90°); θ=90°**



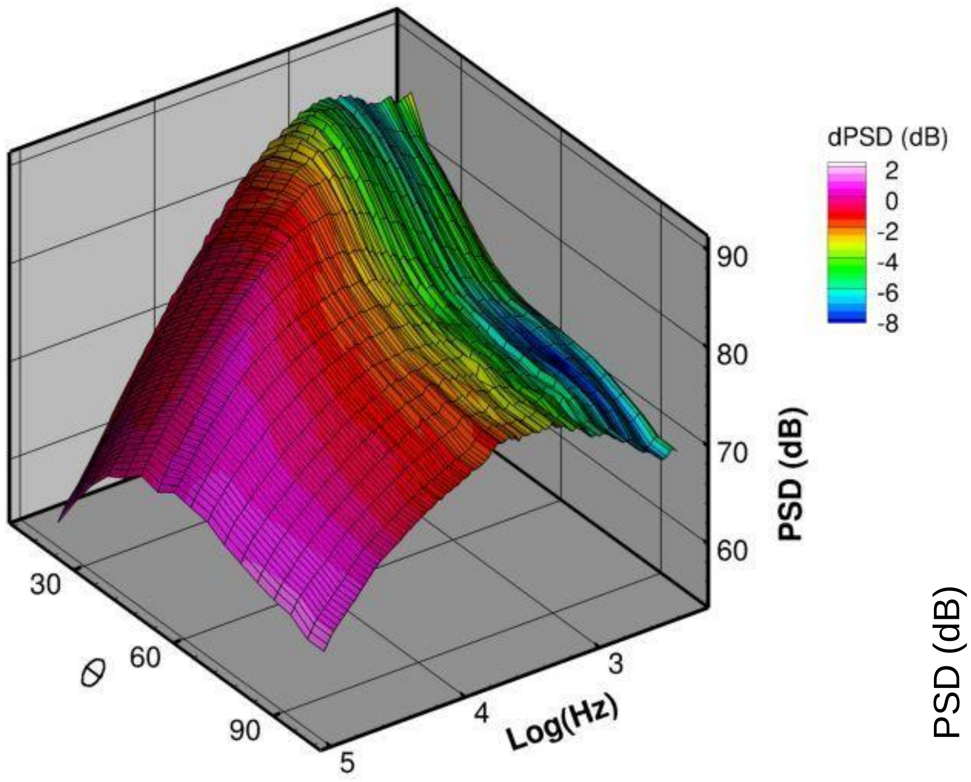




**Broad side (ϕ=0°); θ=25°**

**Flsh case exhibit similar noise reduction at other azimuthal (ϕ) and polar (θ) locations**

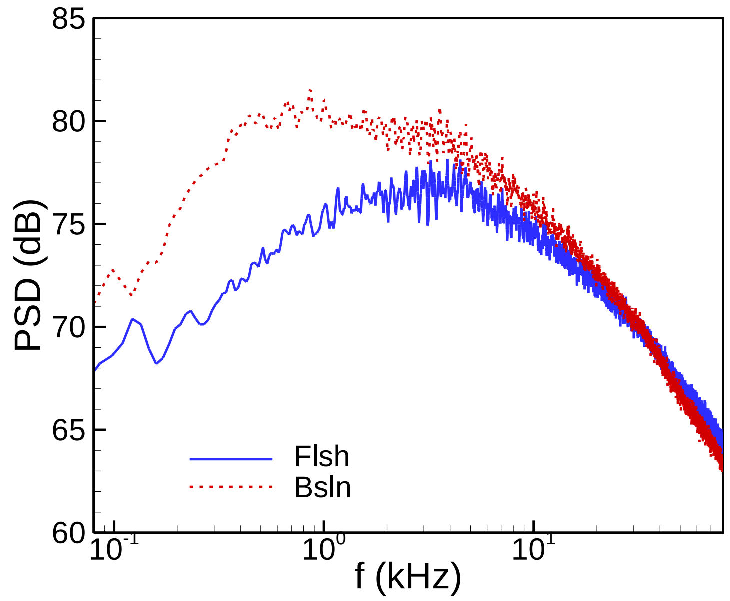
# SPL Spectra data measured in the AAPL

## Flsh vs. Baseline cases; $M_j$=0.99



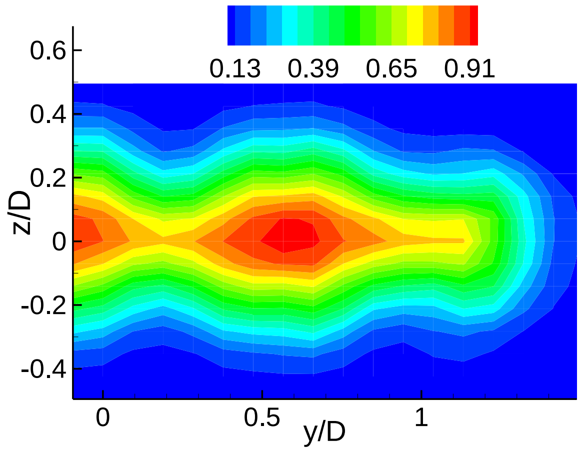

**Carpet plot of PSD**
**Broad side (ϕ=0°)**
**24 θ locations**

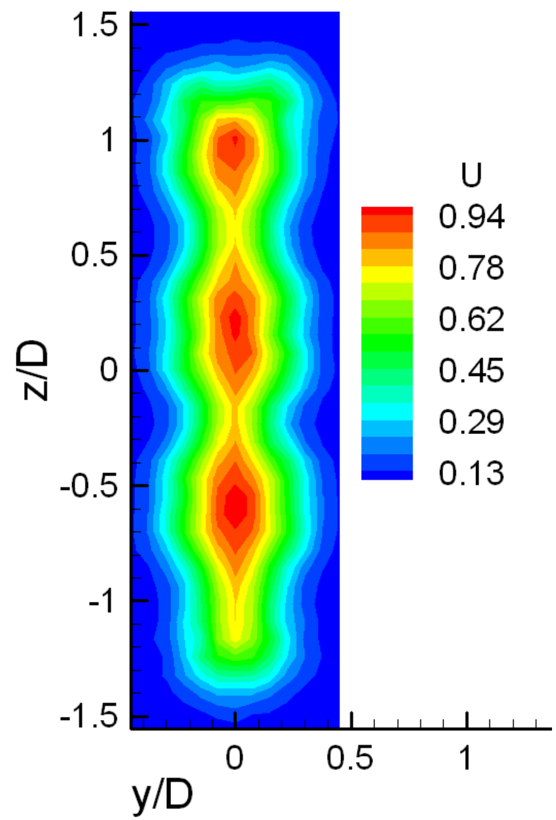
**Observation in CW17 is confirmed by accurate data taken in the AAPL**




**Direct comparison at ϕ=0°, θ=90°**

# $U/U_j$ contours at x/D=2, $M_j$=0.265

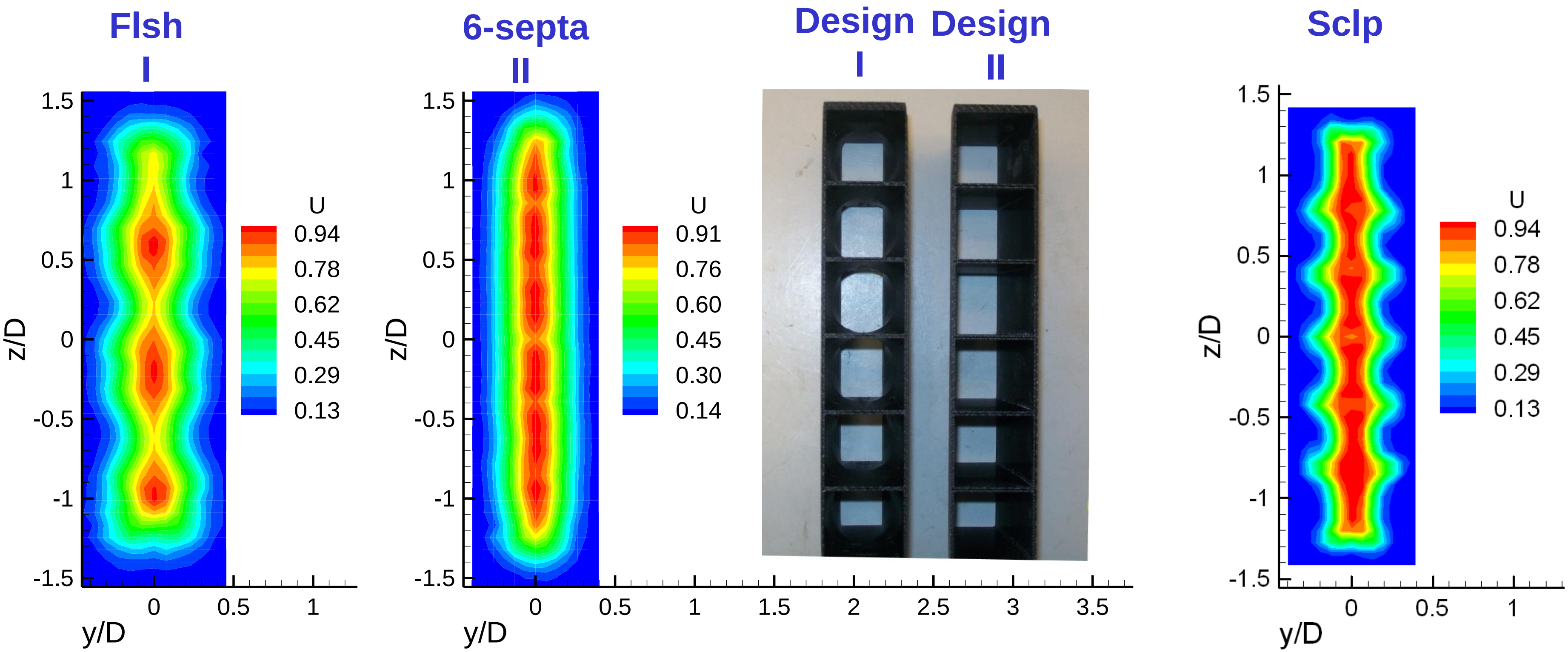



**For reasons not yet understood, an asymmetry develops. The pairing of cells is likely due to streamwise vortex dynamics.**

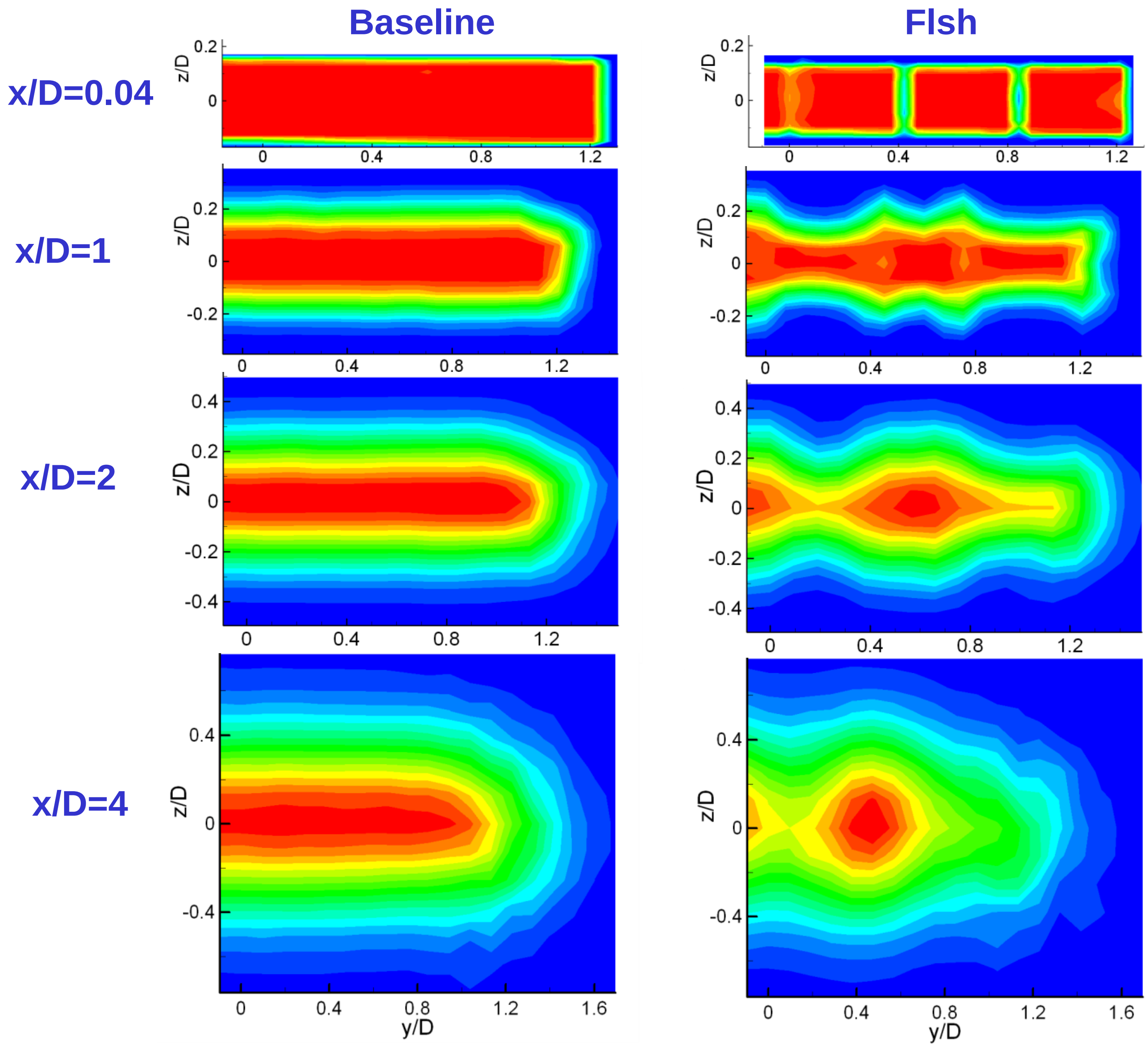
# *U* contours at x/D=2; $M_j$ =0.265
# 6-septa (flush) design I and II and Sclp case

Design I: rectangular-circular-rectangular passage
Design II: rectangular passage thru



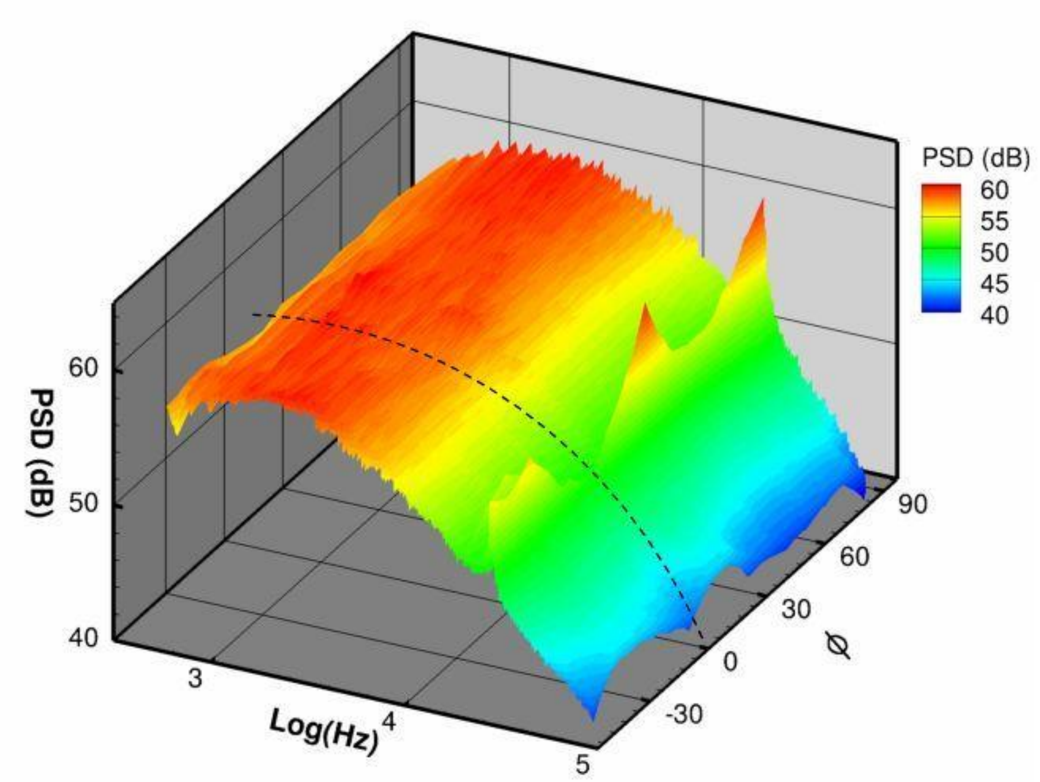

**No such pairing with design II case. Note only 5 cells for Sclp case.**

# Cross-sectional distributions of *U* at different *x*



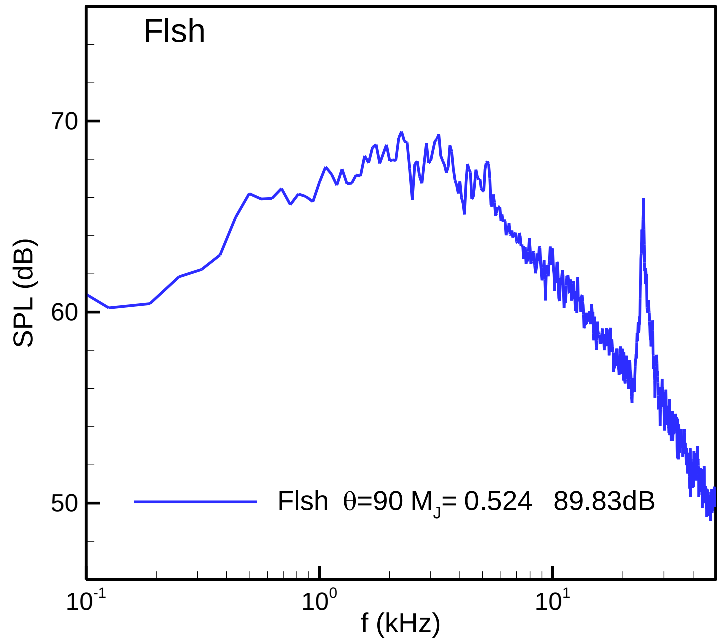

**Detailed profiles of *U* and *u'* in paper. By x/D=16 flowfield is seen to become axi-symmetric for both cases**

# SPL Spectra data for different ϕ ; $\theta$= 90º Flsh case; $M_j$=0.52



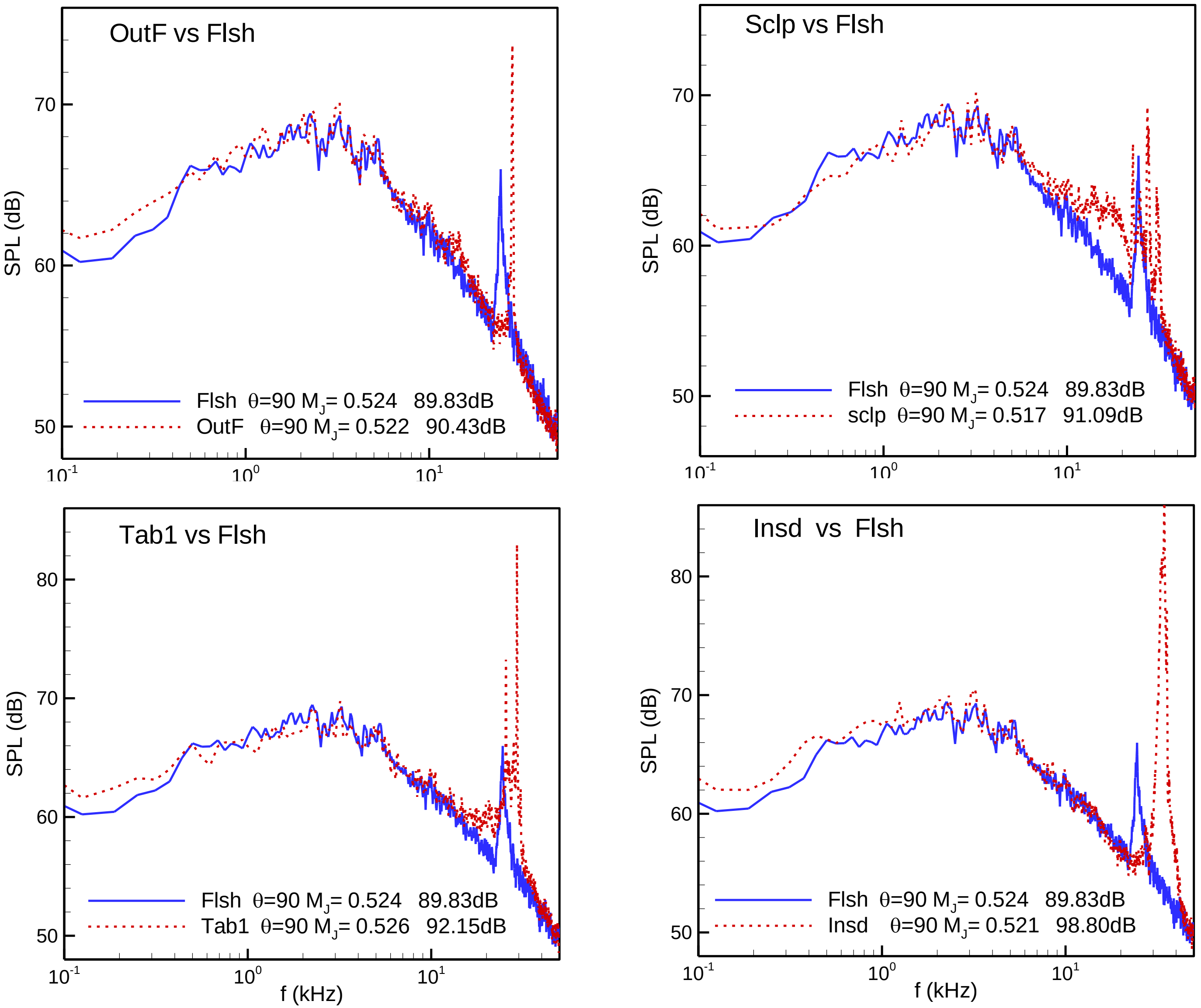

**Carpet plot of PSD**
**24 ϕ locations**
**AAPL data**

**Earlier measurement in CW17 (ϕ=0) missed the spectral peak. When nozzle turned 90° peak appeared**




**CW17 data on major axis (ϕ=90°)**

# SPL Spectra at $M_j$=0.52 on major axis for four different inserts compared to Flsh case



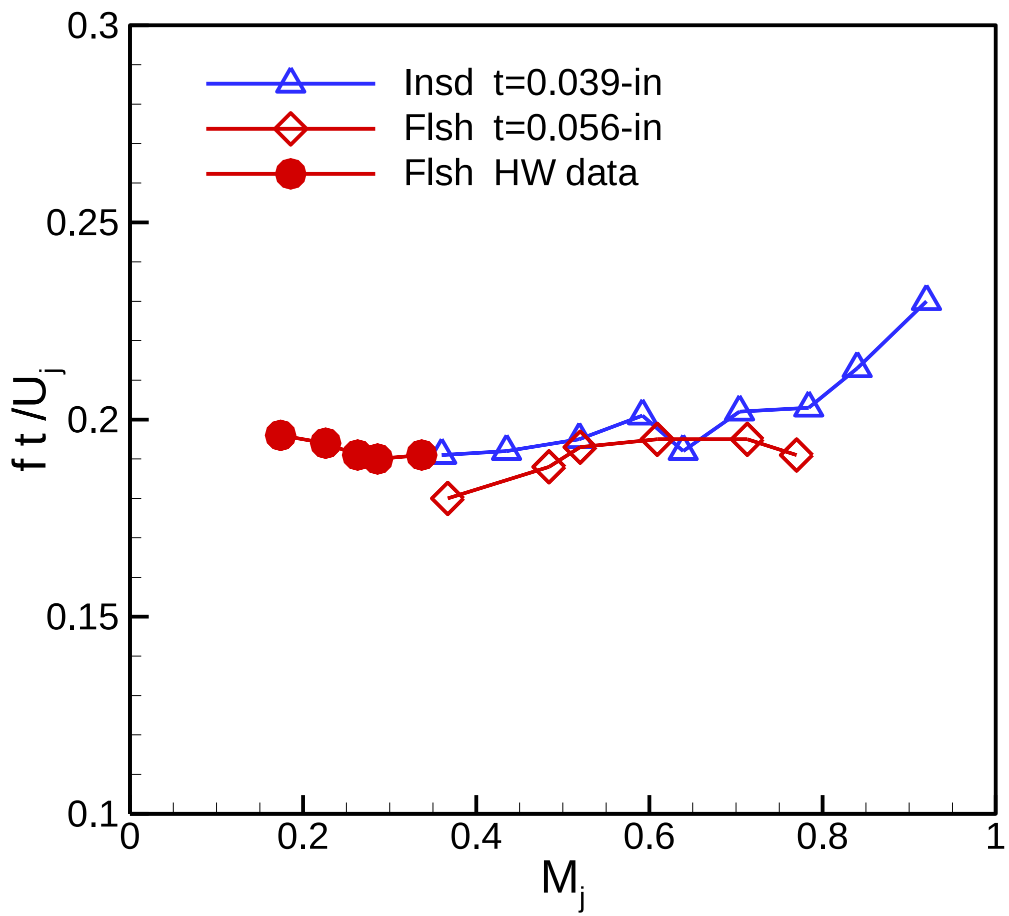

**All inserts yield the high-freq spectral peak at low $M_j$. It is most intense with the Insd case**

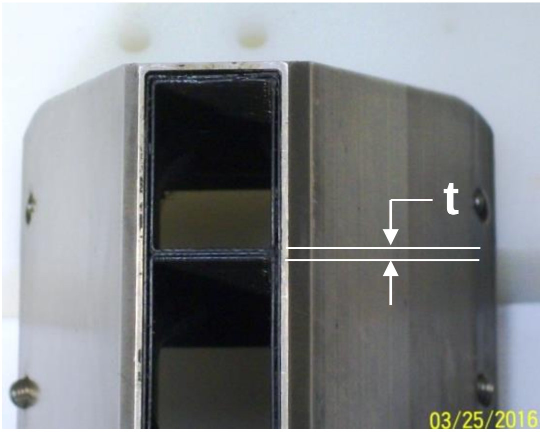
# Strouhal number corresponding to spectral peaks

Data for Flsh and Insd cases

*t* = trailing edge thickness of partition

(Microphone as well as HW data)




**These data clearly suggest the high-frequency spectral peak is due to Karman vortex shedding from the TE of the partitions.**

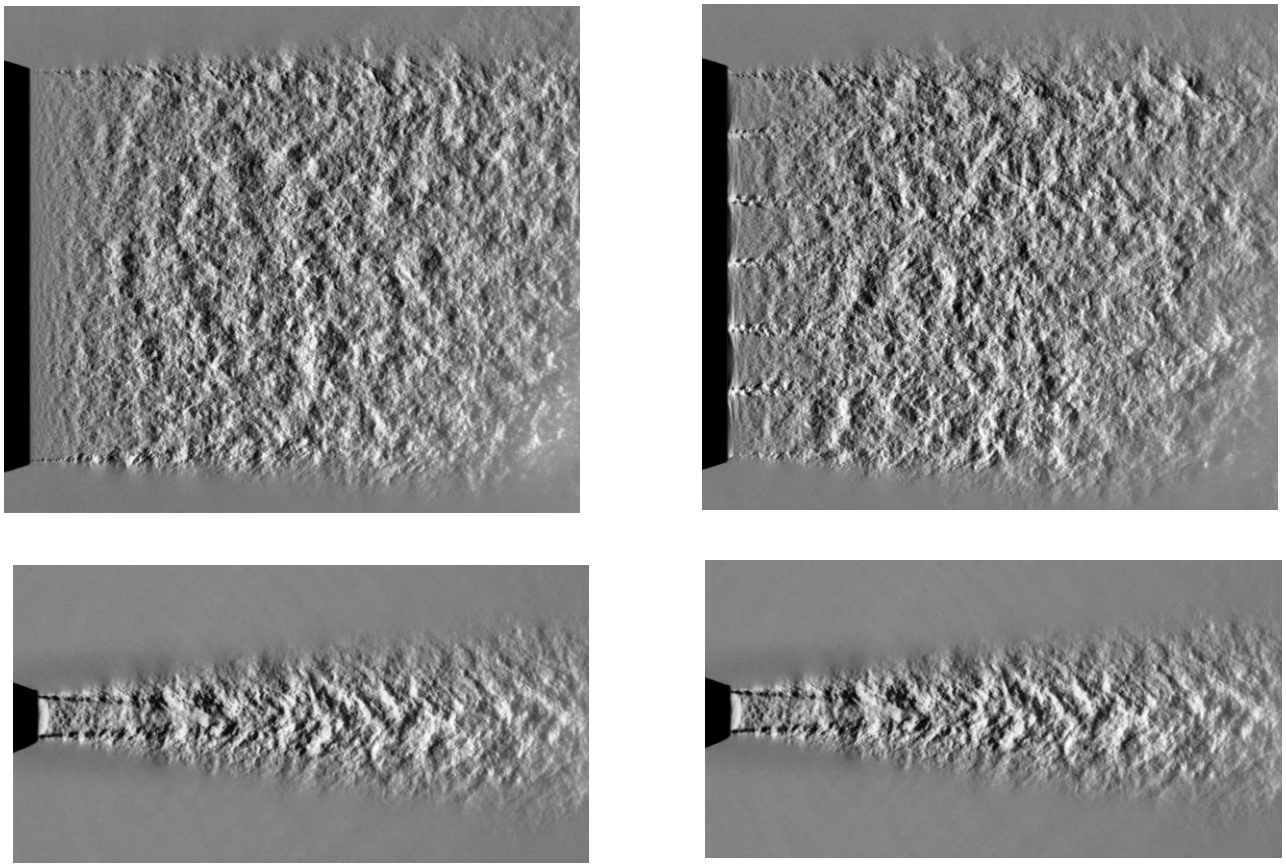
# Schlieren pictures of flowfield $M_j$=1.00

## Baseline and Flsh cases

**Baseline** | **Flsh**

**Major axis plane**

**Minor axis plane**

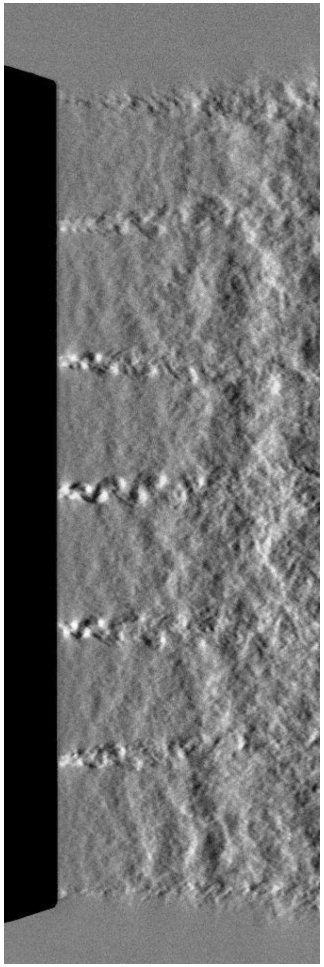


**The Flsh case exhibit vortex shedding from the TE of partitions**

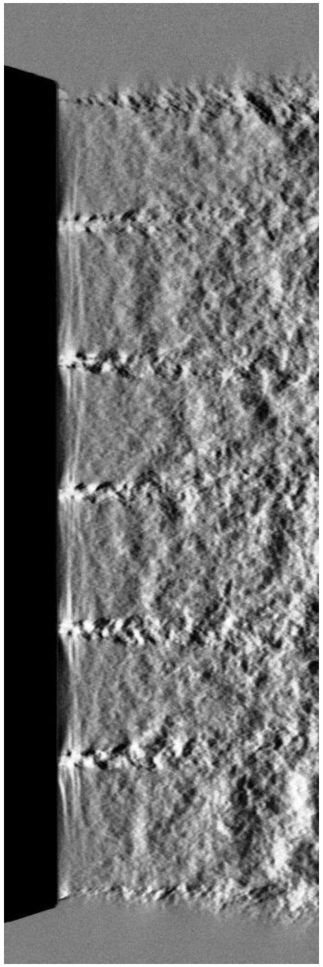
# Schlieren pictures of flowfield

## Flsh case, major axis plane

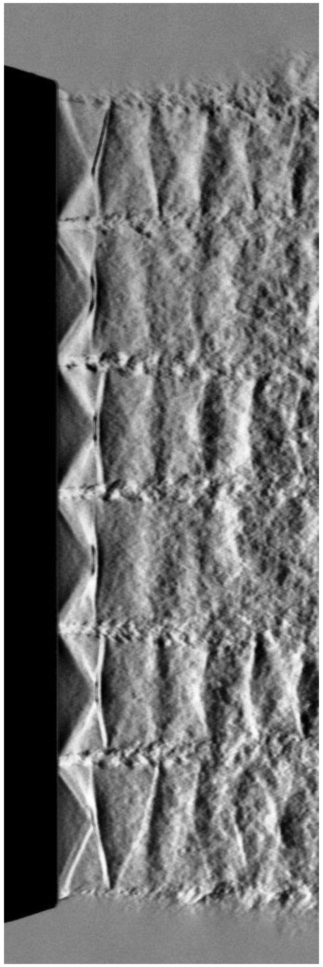
$M_j$ = 0.61



$M_j$ = 1.00



$M_j$ = 1.09



**Zoomed-in pictures show the asymmetric vortex shedding that is persistent even at supersonic condition with the presence of shocks**

# Conclusions

**Nozzle with septa is quieter than corresponding baseline nozzle.**

**Cellular flow structure for the septa case (design I) goes through a curious evolution downstream where adjacent cells pair.**

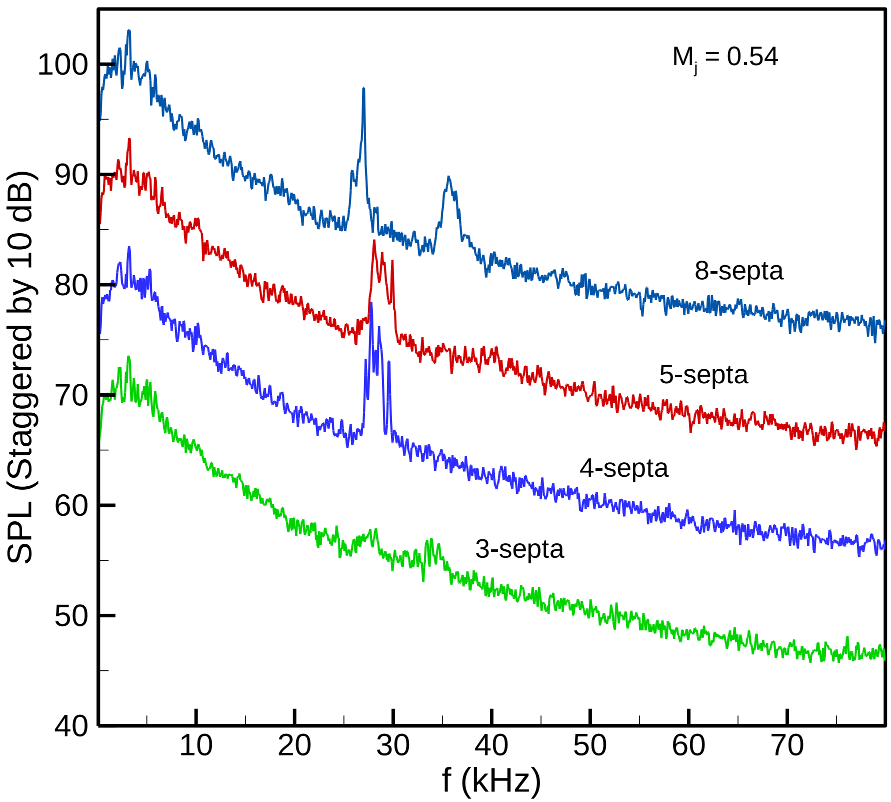
**Centerline mean velocity exhibit an upstream shift of the jet for the septa case. Turbulence intensity is reduced downstream.**

**At lower $M_j$ a high-frequency tone occurs that is heard prominently on the major axis. It is due to Karmann vortex shedding from the TE of partitions separating the septa.**

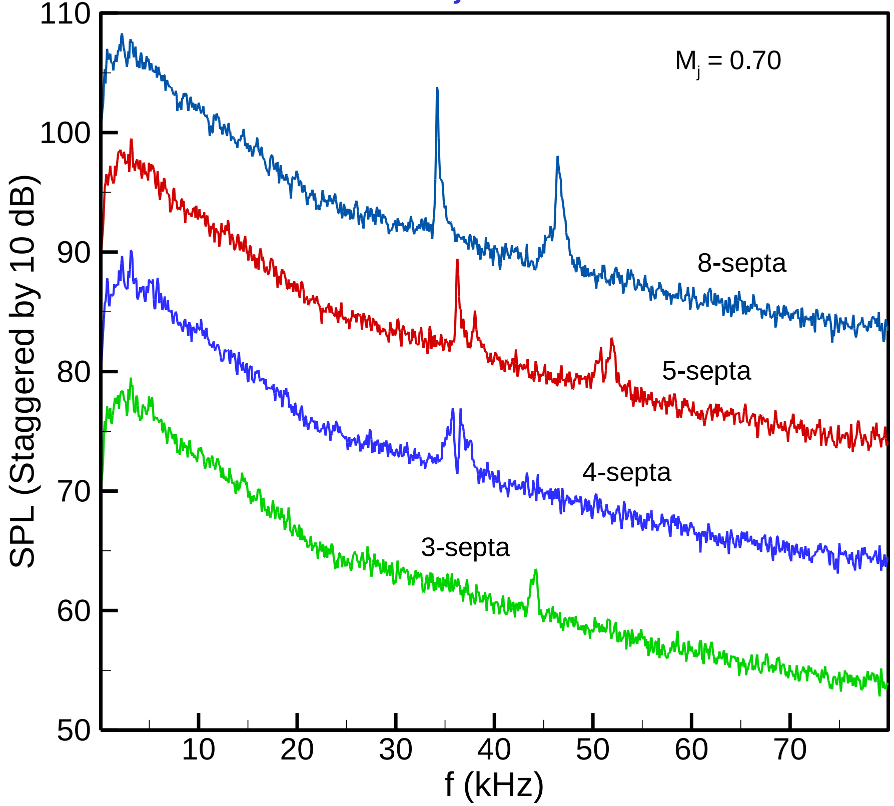
# SPL spectra for Design II inserts with varying number of septa

## Microphone on major axis

### $M_j$ = 0.54

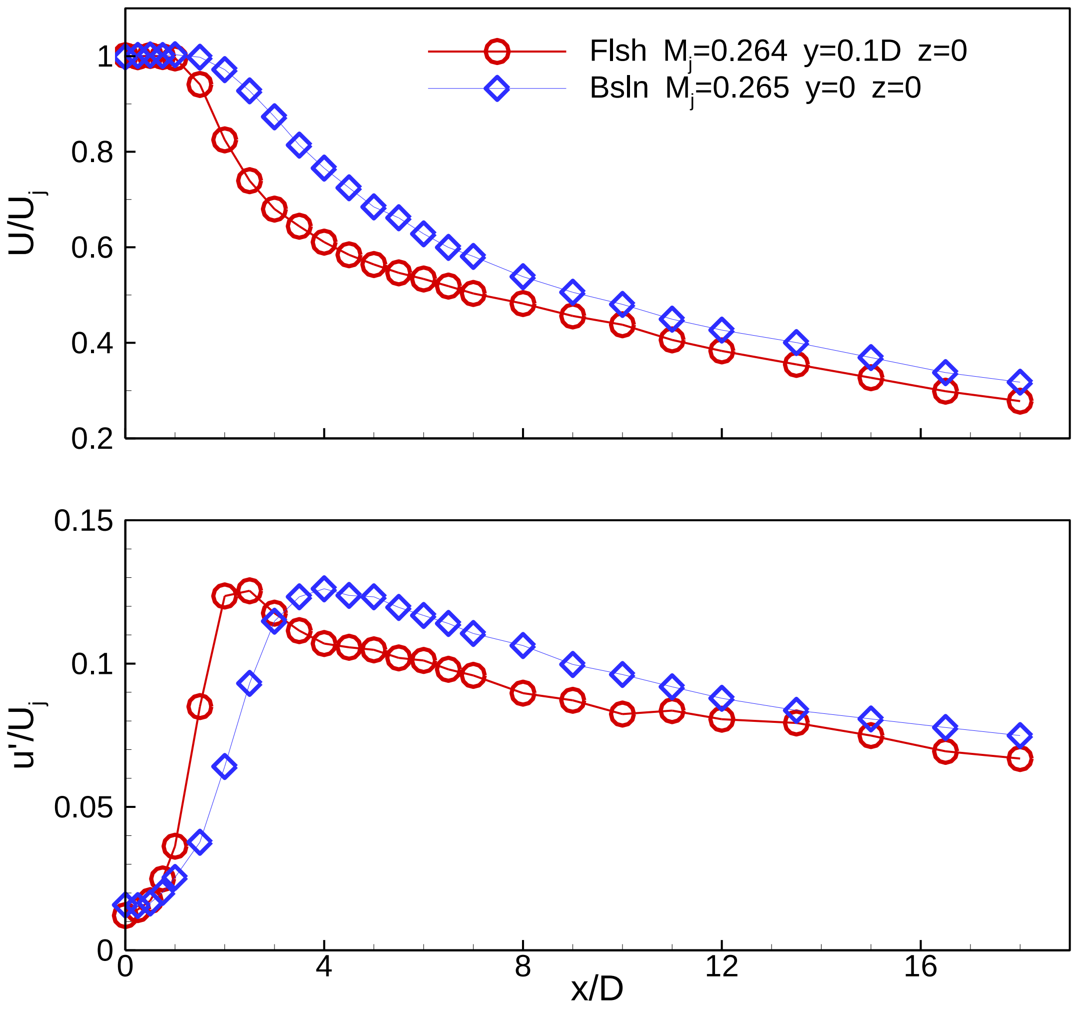



### $M_j$ = 0.70




**These results demonstrate that the shedding tone intensifies with more number of septa (closer proximity of the partitions).**

# Centerline profiles of *U* and *u'*
# Flsh vs Baseline cases; $M_j$ = 0.265




**Flsh septa case involves a faster plume decay and lower turbulence downstream**