



# Flow and noise from septa nozzles

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## **Outline of talk:**

**Introduction**

**Experimental Facility**

**Results and Discussion**

**Summary**

# Distributed Propulsion

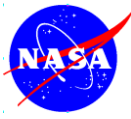
(From Felder, Kim & Brown 2009)



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



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

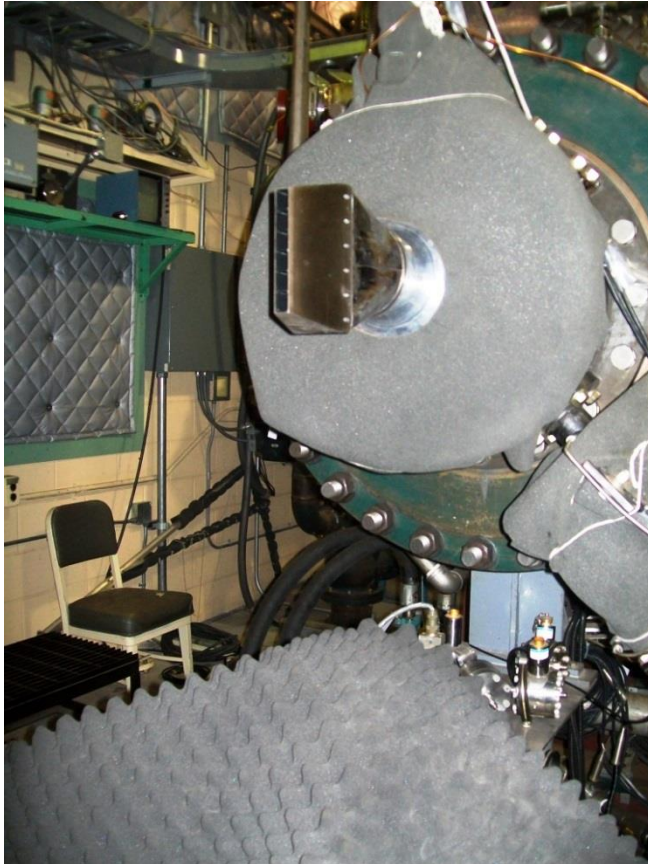


## **Scope of the paper:**

**To study some of these aero- and acoustic issues with distributed propulsion, experiments have been conducted at NASA GRC**

**This paper presents results of a smaller-scale fundamental experiment on the problem**

# Experimental Facility



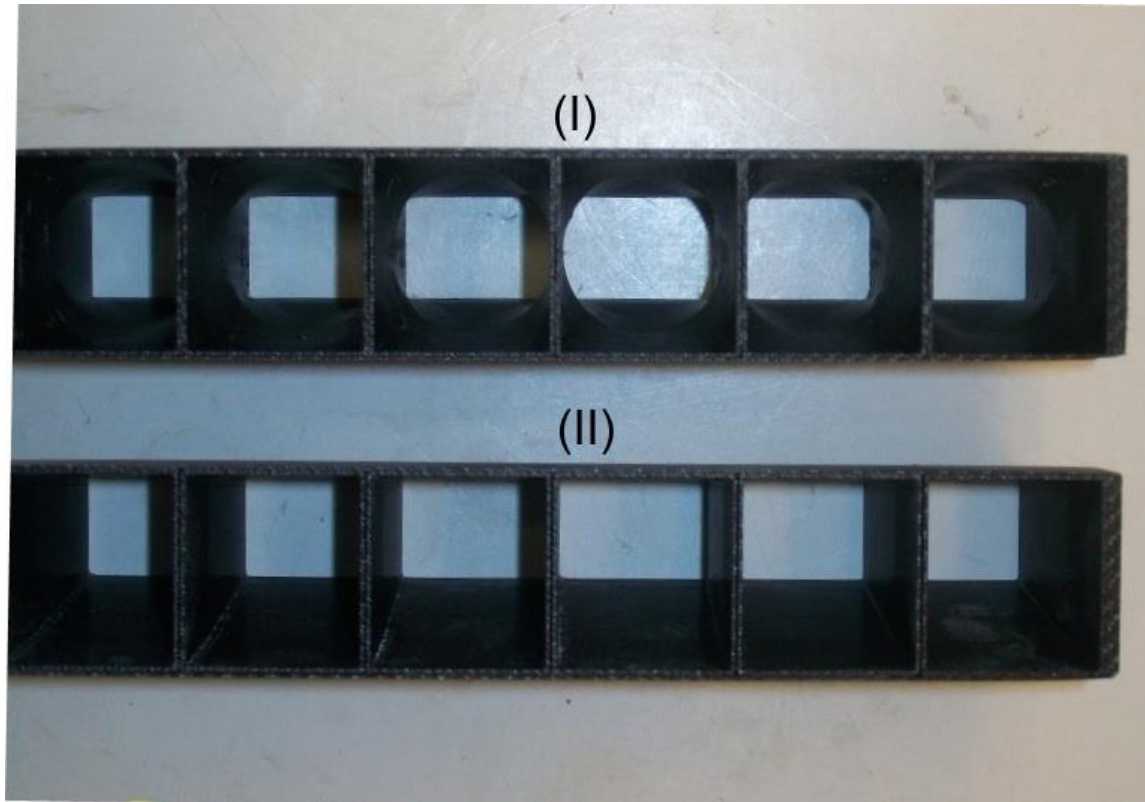
Open Jet rig (CW17)



Close-up view of nozzle and HW

- Up to about 70 psig allowed
- Microphones overhead
- 8:1 rectangular nozzle  
(5.34" x 0.66";  $D=2.12"$  )
- Inserts made by 3-D printing

## Experimental Facility (inserts)



### Internal geometry

Top: 'Fsh3' has rectangular-circular-rectangular passage

Bottom: '6Rec' has rectangular passage throughout

-Many other septa geometries are examined for maximum noise reduction

# Septa Insert Notations

Notation	Description
<b>Fsh3</b>	<b>Septa TE flush with nozzle exit (rect-circ-rect passage)</b>
<b>Fsh0</b>	<b>Duplicate of Fsh3</b>
<b>Insd</b>	<b>Septa TE stops 0.25" upstream of exit</b>
<b>OutF</b>	<b>Full-width TE protrudes out by 0.175"</b>
<b>ScIp</b>	<b>Semi-circular cut-out (scallop) at septa TE</b>
<b>6Rec</b>	<b>Same as Fsh0 or Fsh3 except rectangular passage</b>
<b>Dsn5–10</b>	<b>Same as Fsh0 or Fsh3 except passages are non-uniform</b>



**Fsh3**



**Insd**

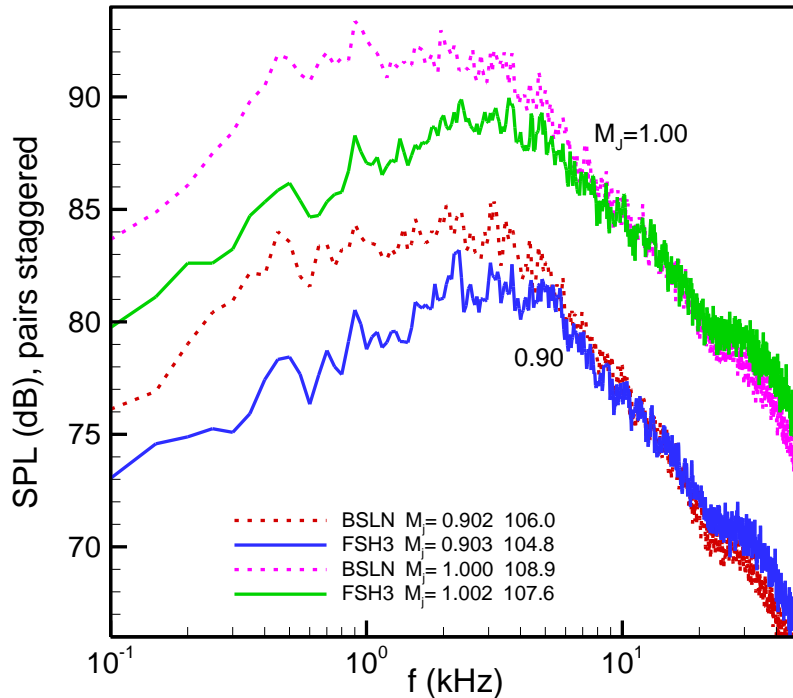


**OutF**

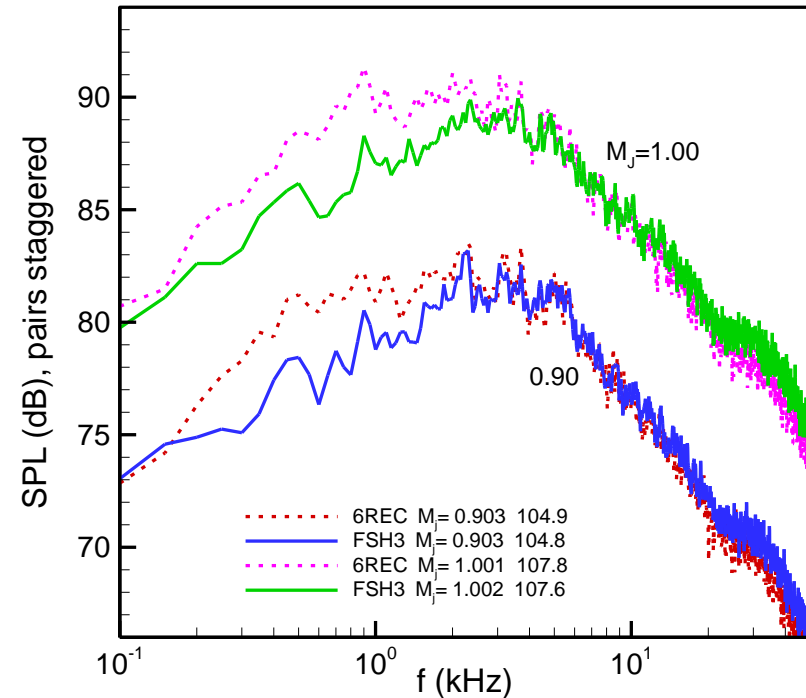
# SPL Spectra comparison at two jet Mach numbers

$\theta = 90^\circ$ ; mic on broadside of nozzle

Fsh3 vs Bsln



6Rec vs Fsh3



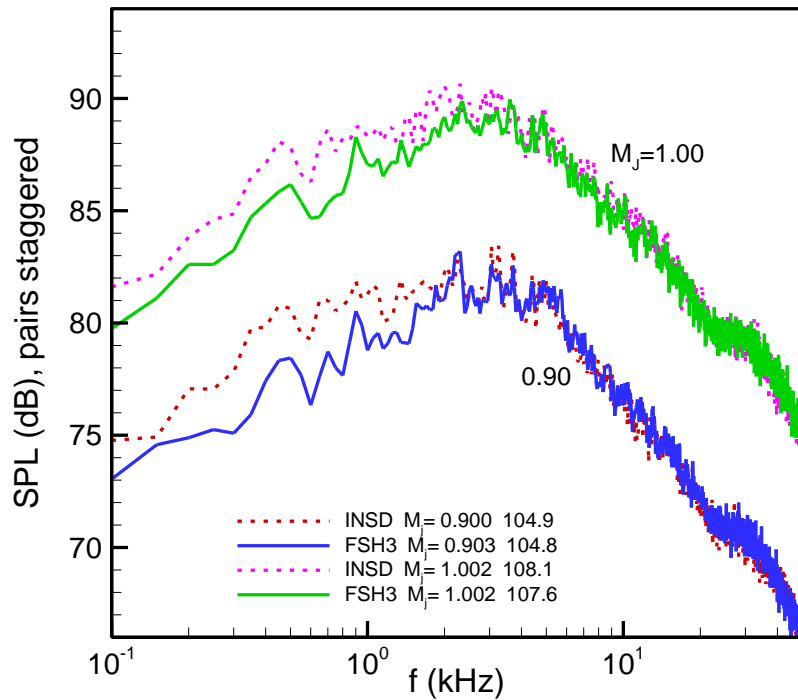
Lower noise on low frequency end for the Fsh case. Not accounted for by exit area reduction (11% smaller  $D \Rightarrow 1.3$  dB)

Noise reduction with 6Rec case not as much

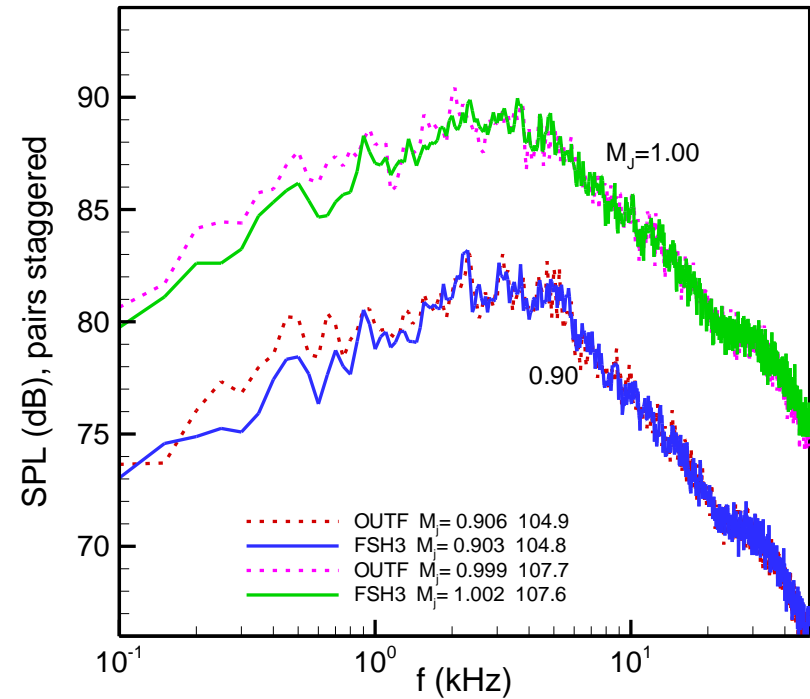


# SPL Spectra comparison at two $M_j$

Fsh3 vs Insd



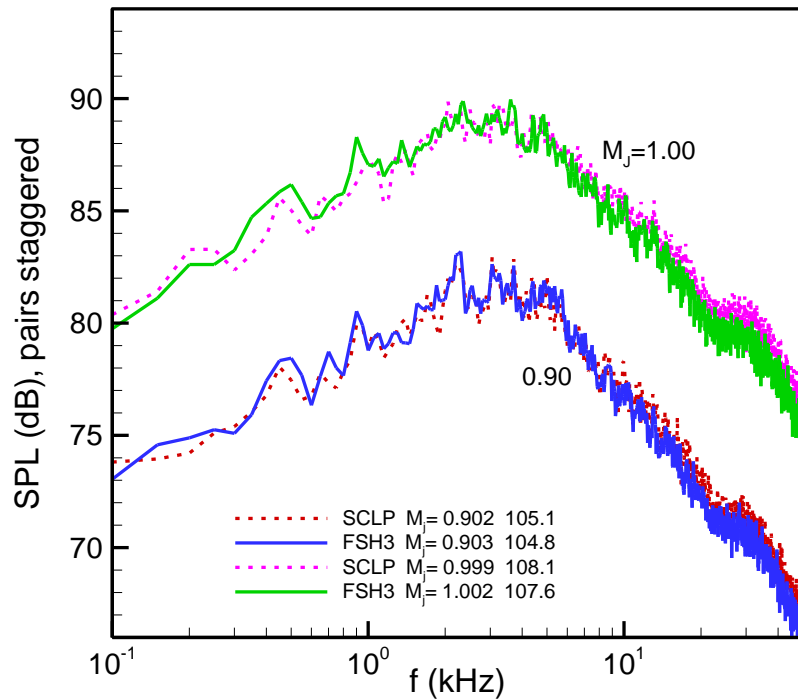
Fsh3 vs OutF



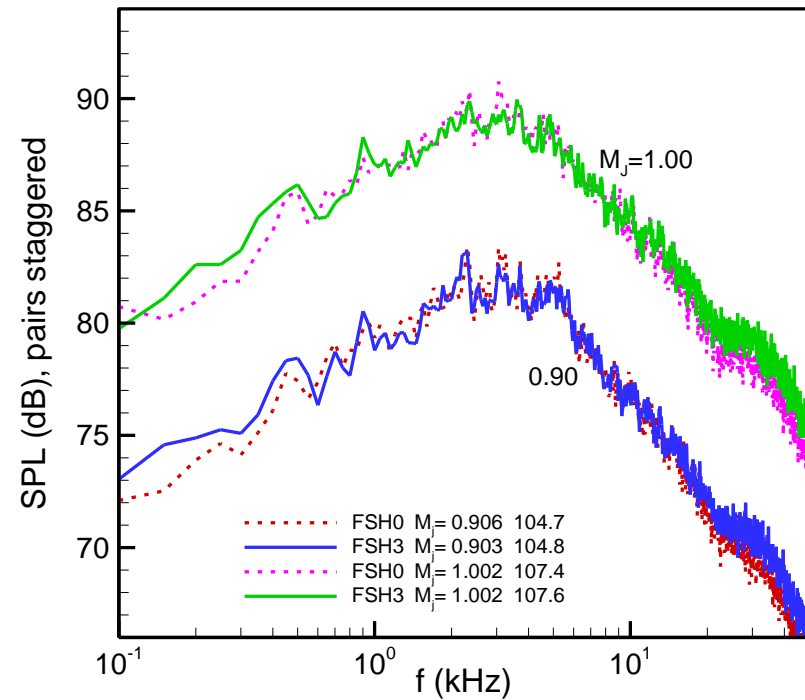
Noise reduction with Fsh3 is best so far

# SPL Spectra comparison at two $M_j$

## Fsh3 vs ScIp



## Fsh3 vs Fsh0



Noise reduction with ScIp and Fsh0 about same as that with Fsh3

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

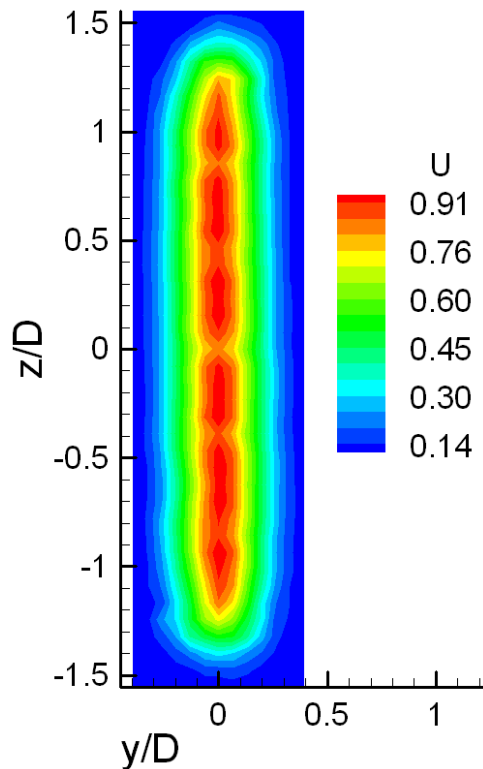
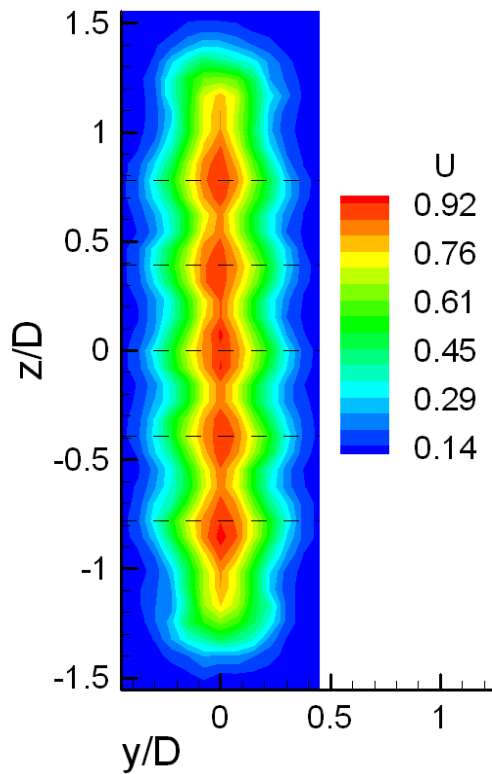
Hot-wire data

Fsh3: rectangular-circular-rectangular passage

6Rec: rectangular passage thru

Fsh3

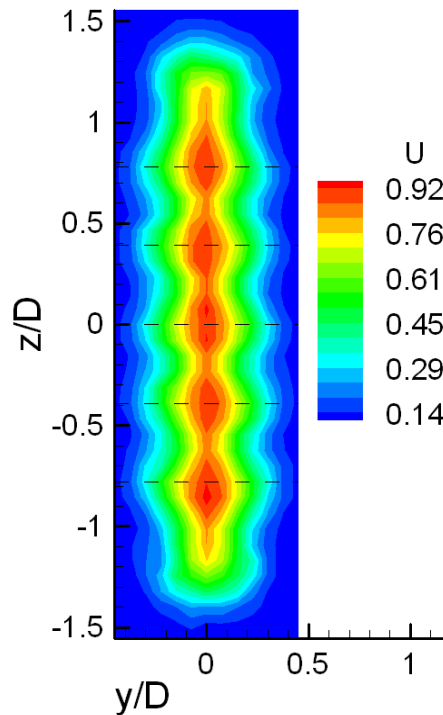
6Rec



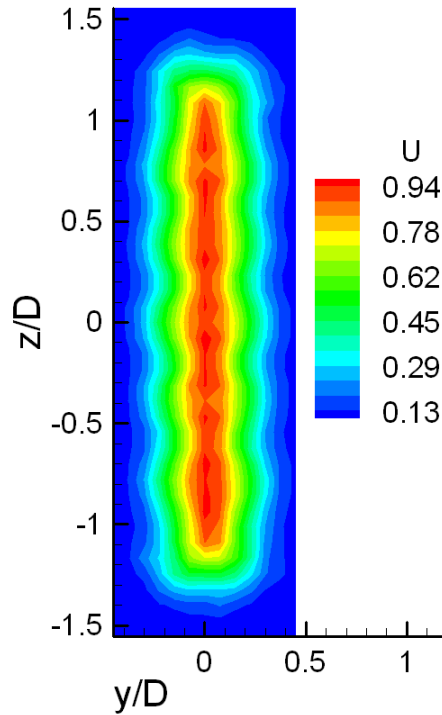
Note only 5 cells for Fsh3 case but 6 cells still discernible for 6Rec case

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

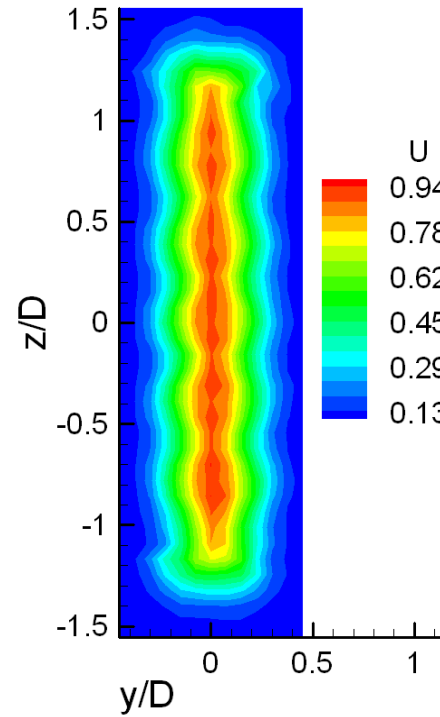
Flsh3



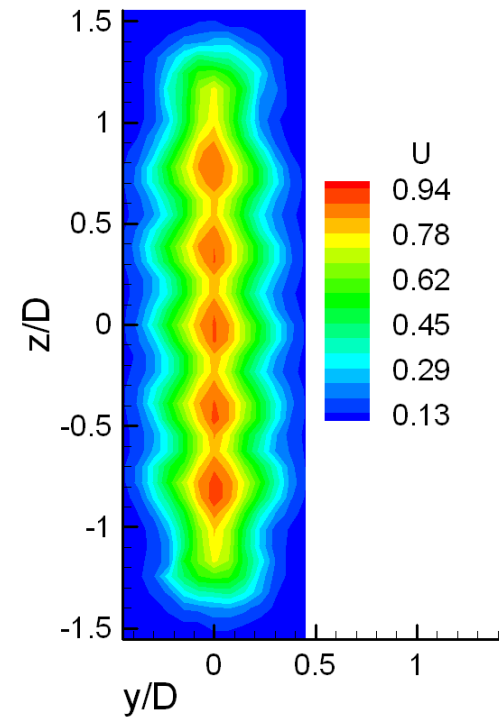
Insd



OutF



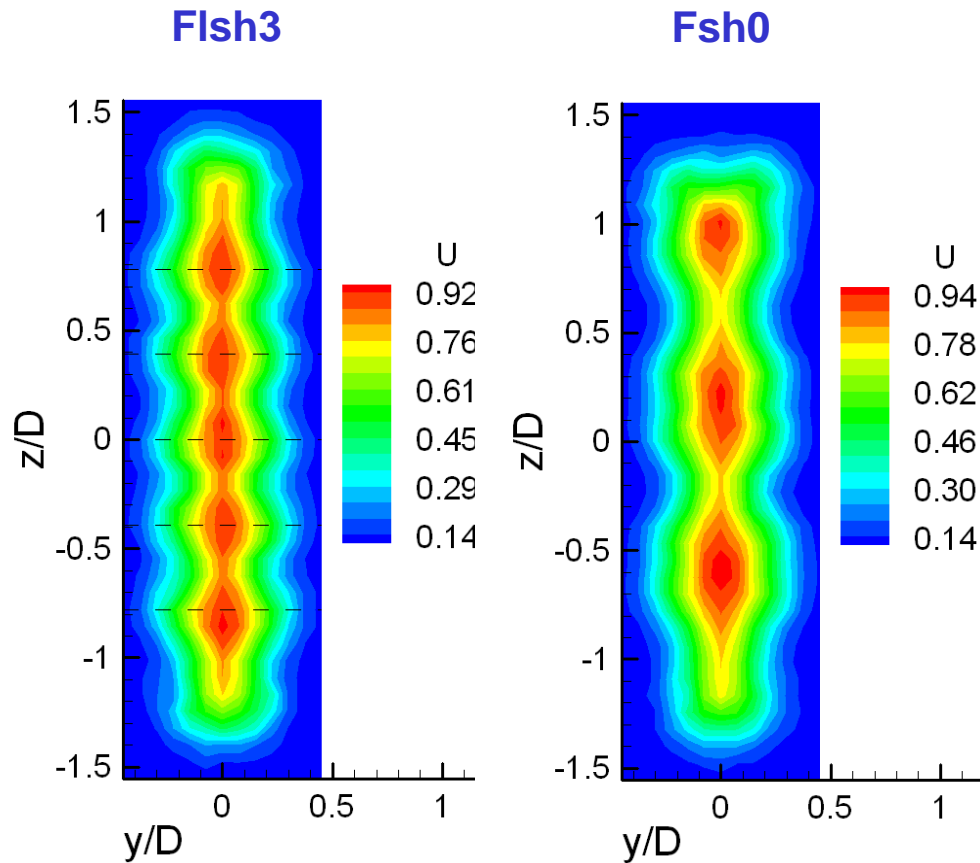
ScIp



Similar patterns

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

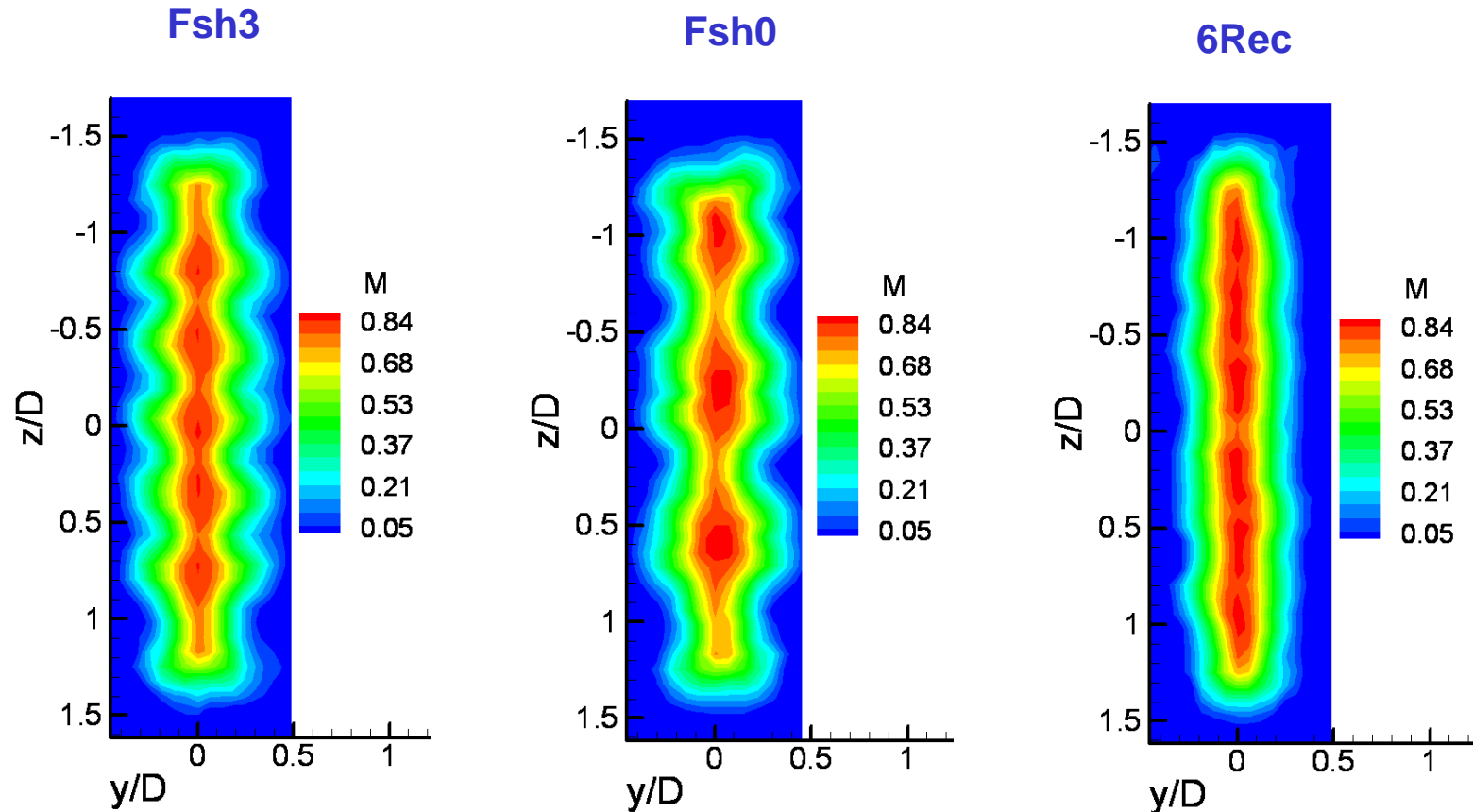
Fsh3 and Fsh0 are supposed to be identical



There is pairing activity with Fsh0 leading to asymmetric flow

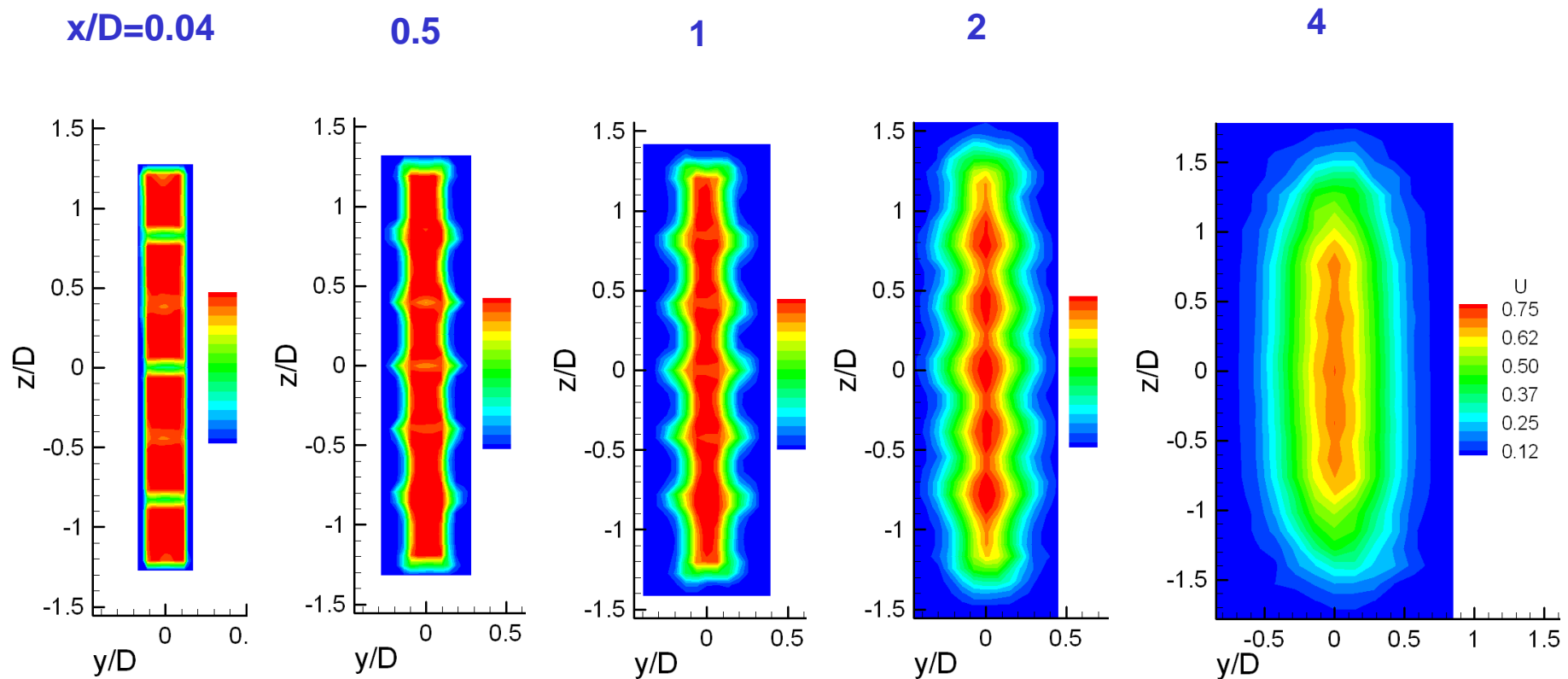
# $U$ contours at $x/D=2$ ; $M_j=0.90$

Pitot surveys



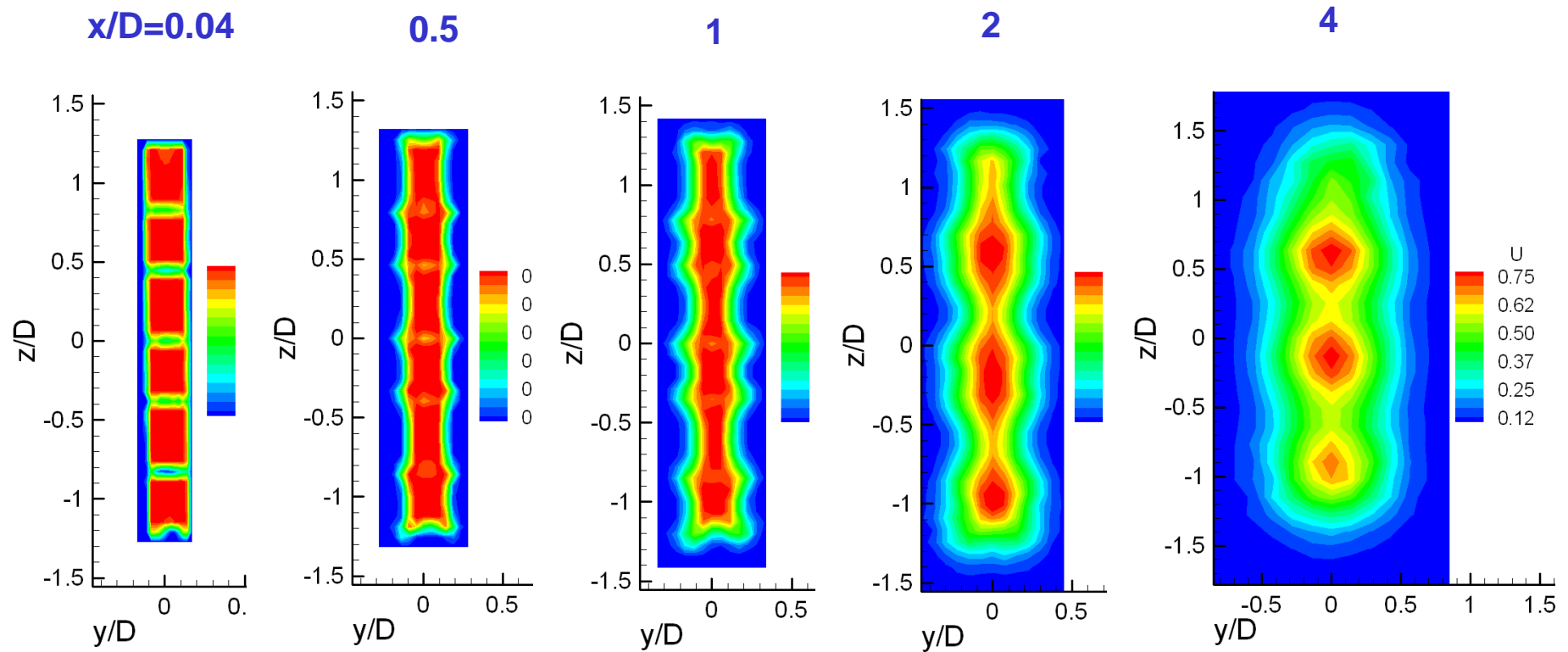
The flow patterns are the same (independent of compressibility effect)

# Flow evolution Fsh3 case; $M_j = 0.265$



Streamwise vortex pairs at ends of each of 5 septa (partitions) causes the observed pattern

# Flow evolution Fsh0 case; $M_j = 0.265$



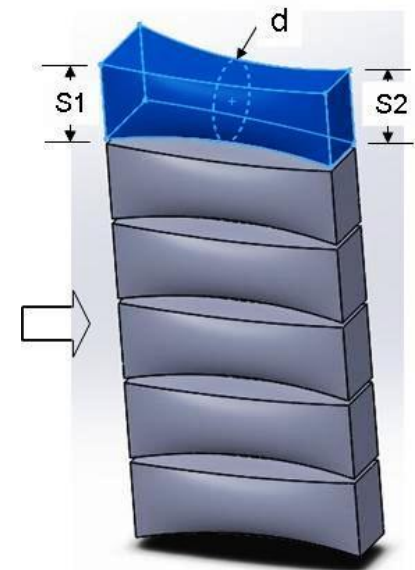
There is further interaction among Streamwise vortices



# Difference in dimensions of Fsh3 and Fsh0 cases

Optical method using 'Smartscope'

Passage	S1		S2		d	
	Fsh0	Fsh3	Fsh0	Fsh3	Fsh0	Fsh3
1	0.866	0.862	0.817	0.828	0.855	0.854
2	0.858	0.877	0.828	0.828	0.855	0.853
3	0.866	0.842	0.829	0.827	0.855	0.854
4	0.874	0.873	0.829	0.828	0.855	0.855
5	0.863	0.843	0.815	0.827	0.856	0.854
6	0.872	0.879	0.829	0.827	0.854	0.853



(#3) 2.8% max difference

Not much help in pinpointing cause of the difference in flow

# Flow evolution Dsn9 case; $M_j = 0.265$

Width at exit (S2) and diameter (d) varied

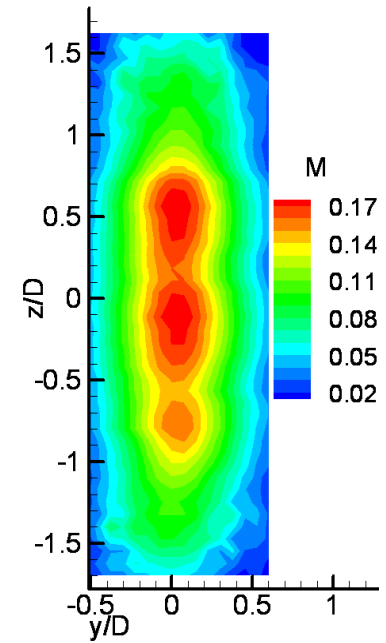
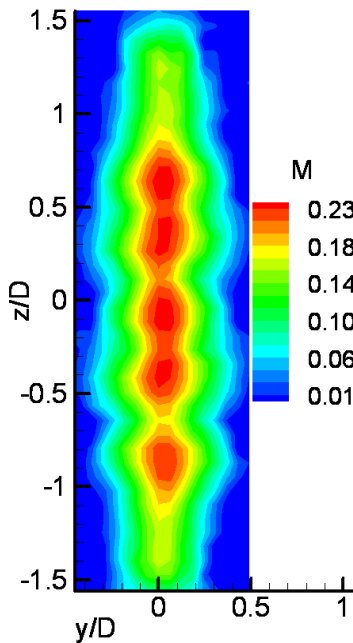
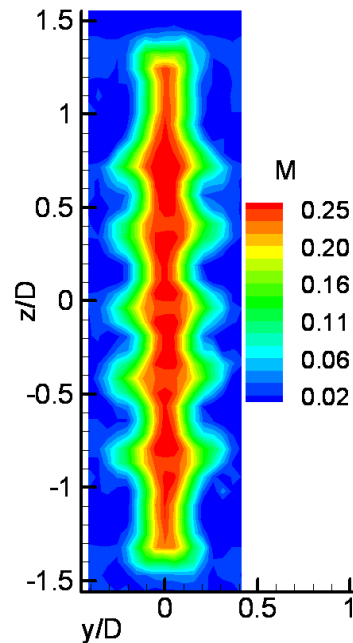
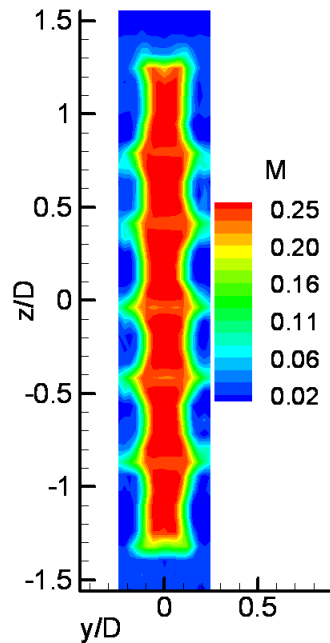
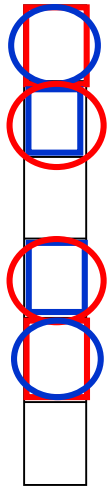
Dsn9

$x/D = 0.5$

1

2

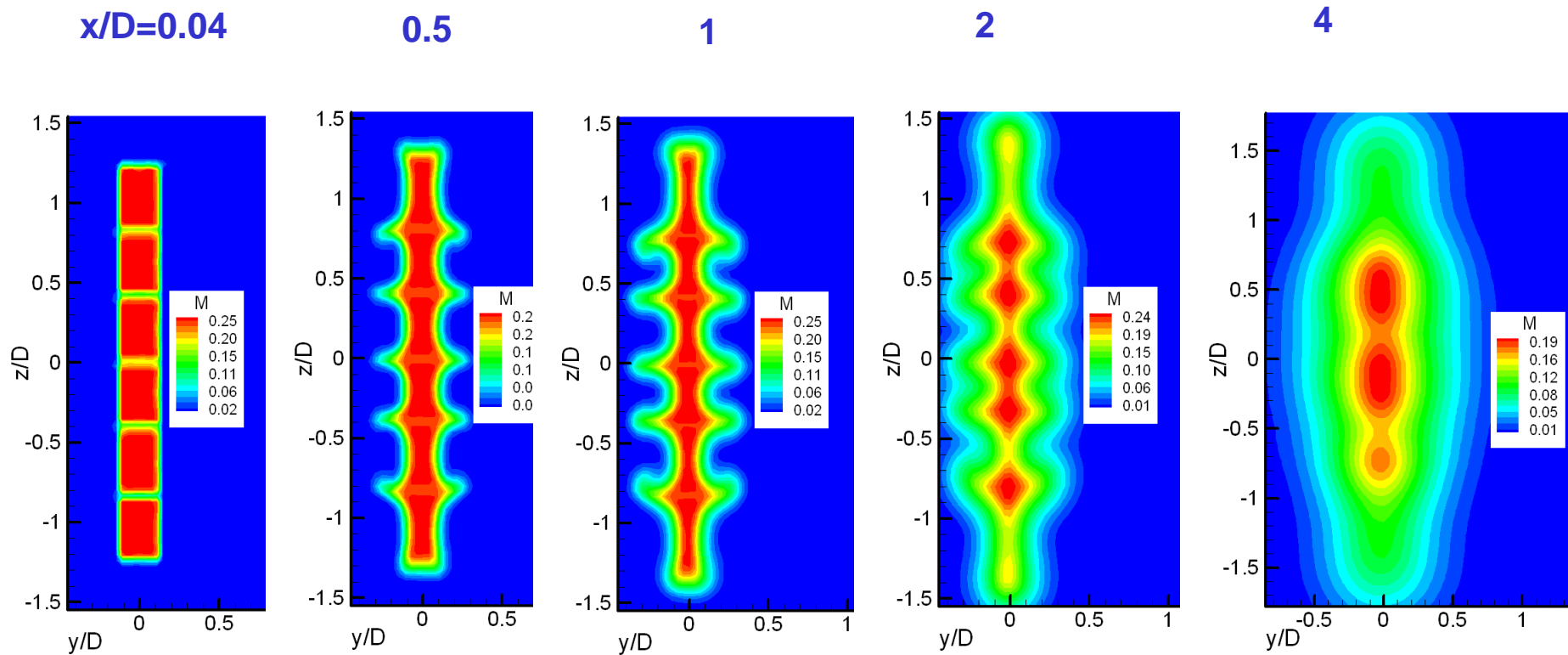
4



Flow field similar to Fsh0 case was finally realized

# CFD mean flow evolution Dsn9 case; $M_j = 0.27$

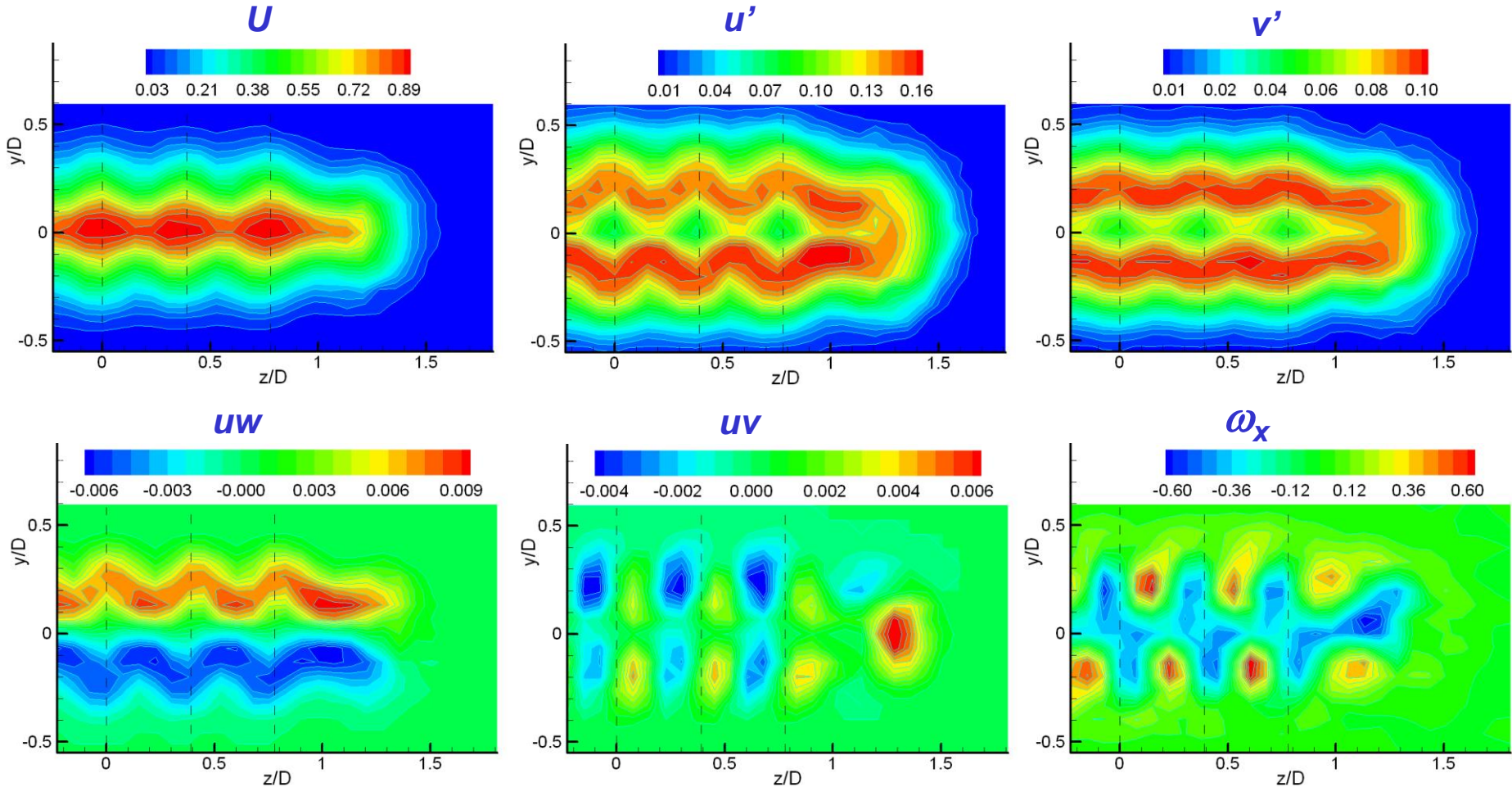
(CFD package with Solidworks)



Similar flow fields as in the experiment  
(also good agreement for Fsh3 case)

# Detailed flow field for Fsh3 at $x/D=2$ ; $M_j=0.265$

Two X-wire measurements



$u'$  larger than  $v'$  (or  $w'$ ). Streamwise vortex pairs at ends of septa.



## Conclusions

Nozzle with septa is quieter than corresponding baseline nozzle.

Apparently, noise reduction occurs due to introduction of streamwise vortices in the flow. These vortices are produced by secondary flow within the septa passages.

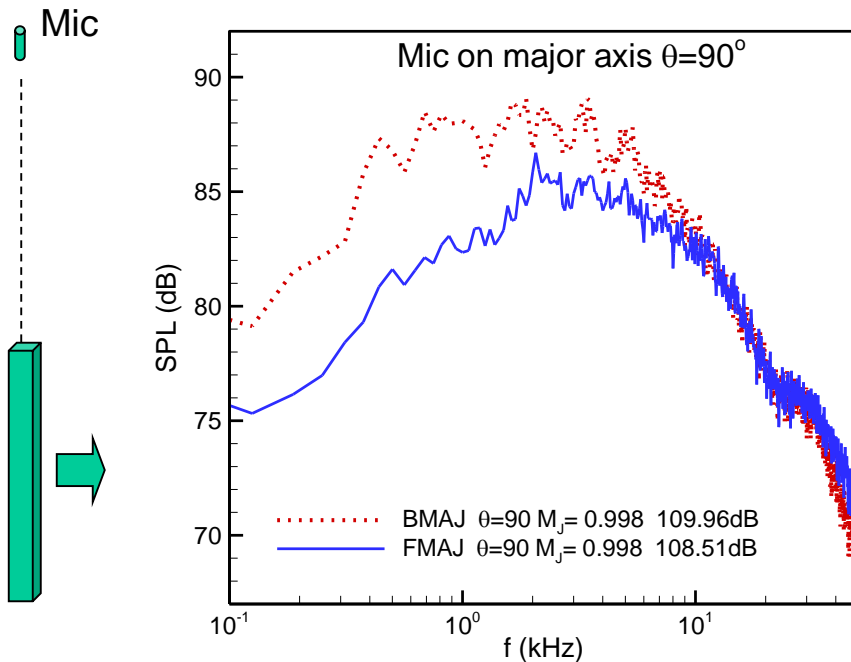
For the flush case, six cellular flow structures readjusts to produce five regions of high-speed flow by the action of  $\omega_x$ -pairs.

Small difference in fabrication of the flush case causes vortex pairing activity leading to an asymmetric flow structure.

By intentionally varying the dimensions of the flush case the latter flowfield could be reproduced.

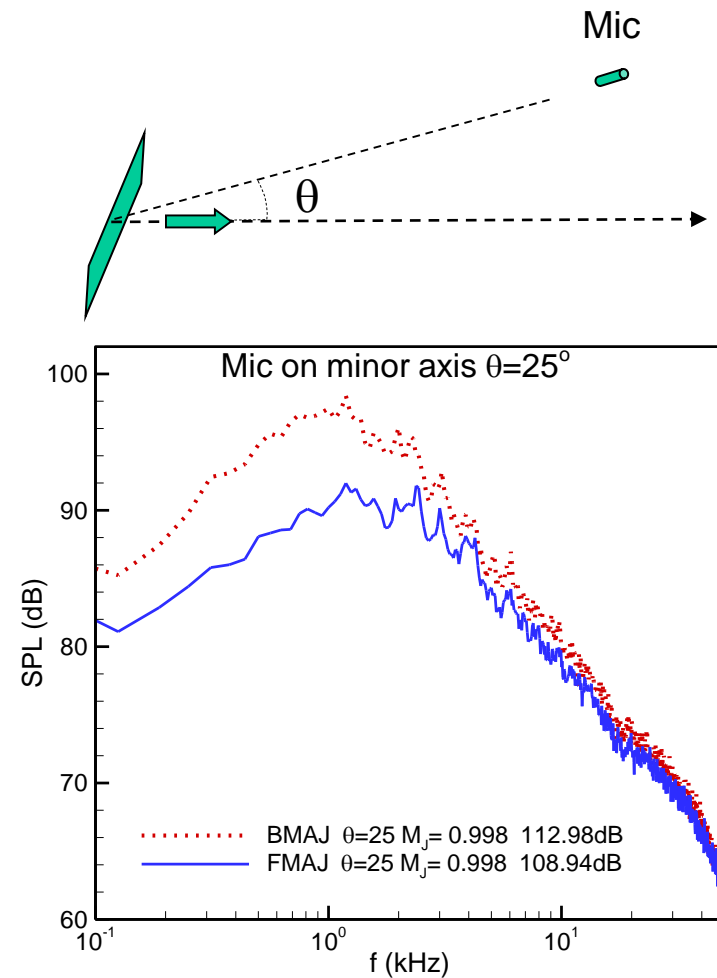
Lesson: the streamwise vortices and hence the flow and noise from the jet are quite sensitive to the septa geometry.

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



Narrow side ( $\phi=90^\circ$ );  $\theta=90^\circ$

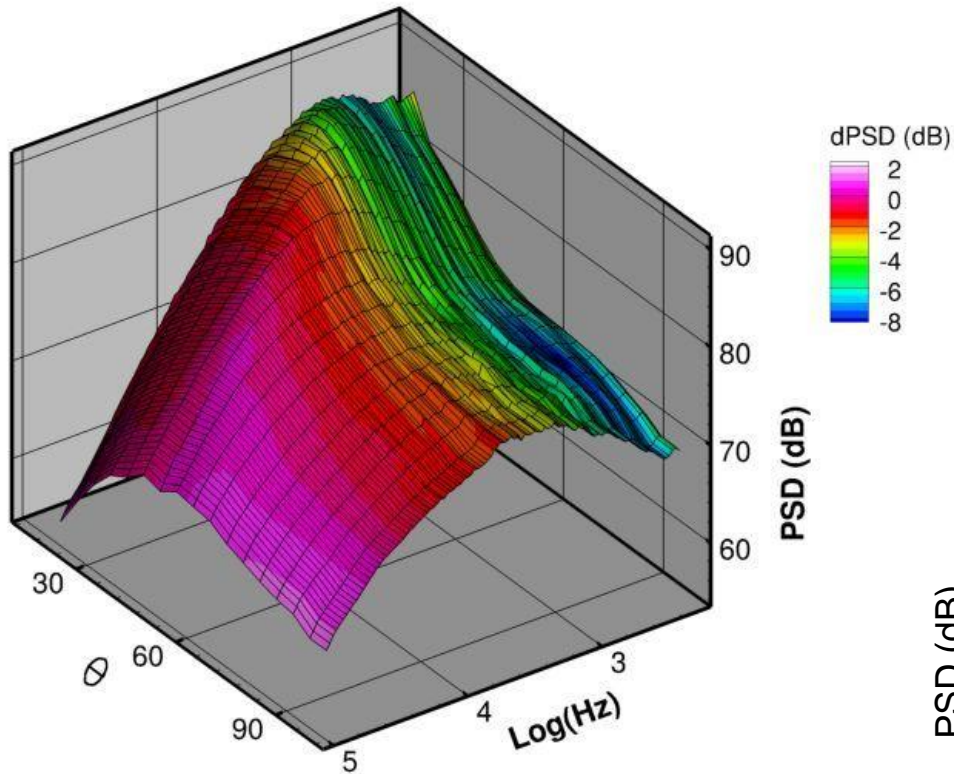
Fish case exhibit similar noise reduction at other azimuthal ( $\phi$ ) and polar ( $\theta$ ) locations



Broad side ( $\phi=0^\circ$ );  $\theta=25^\circ$

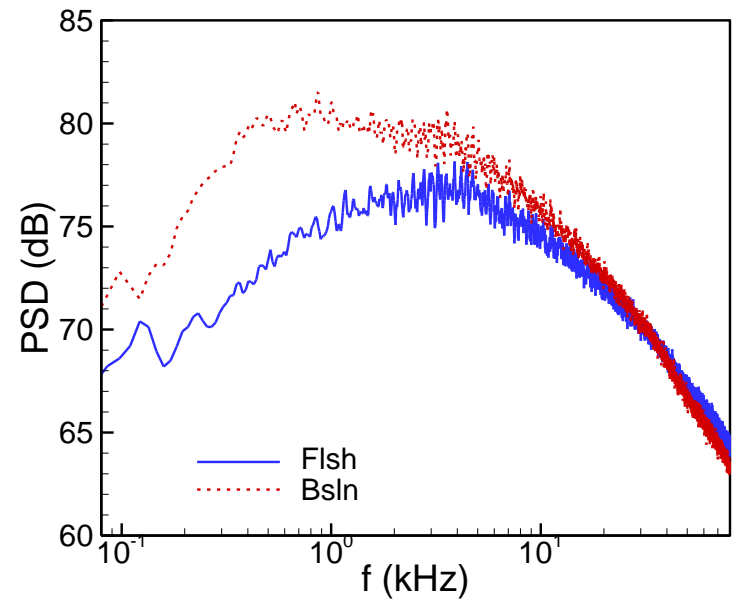
# SPL Spectra data measured in the AAPL

Flsh vs. Baseline cases;  $M_f=0.99$



Carpet plot of PSD  
Broad side ( $\phi=0^\circ$ )  
24  $\theta$  locations

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



Direct comparison at  $\phi=0^\circ$ ,  $\theta=90^\circ$