GENERATION OF FLUCTUATIONS BY TRANSONIC FLOW OVER SHALLOW CAVITY

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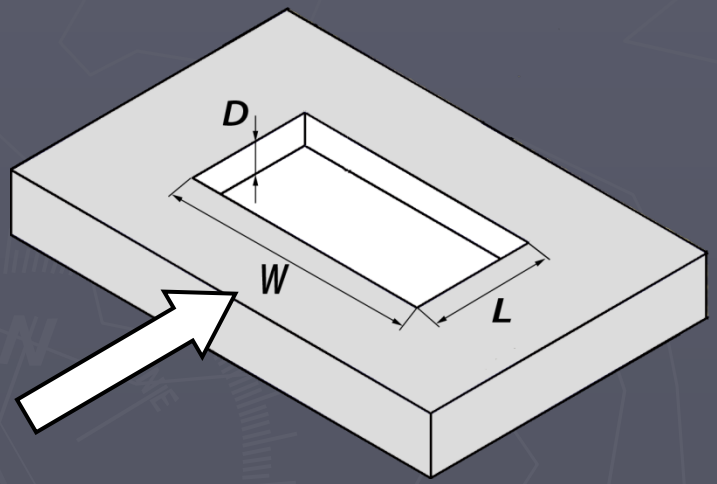
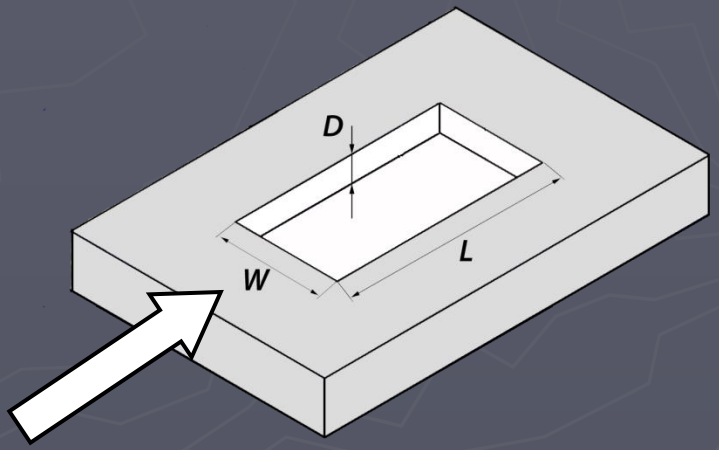
Shallow cavity

L/D > 1



U_∞

L/W < 1 (2D)

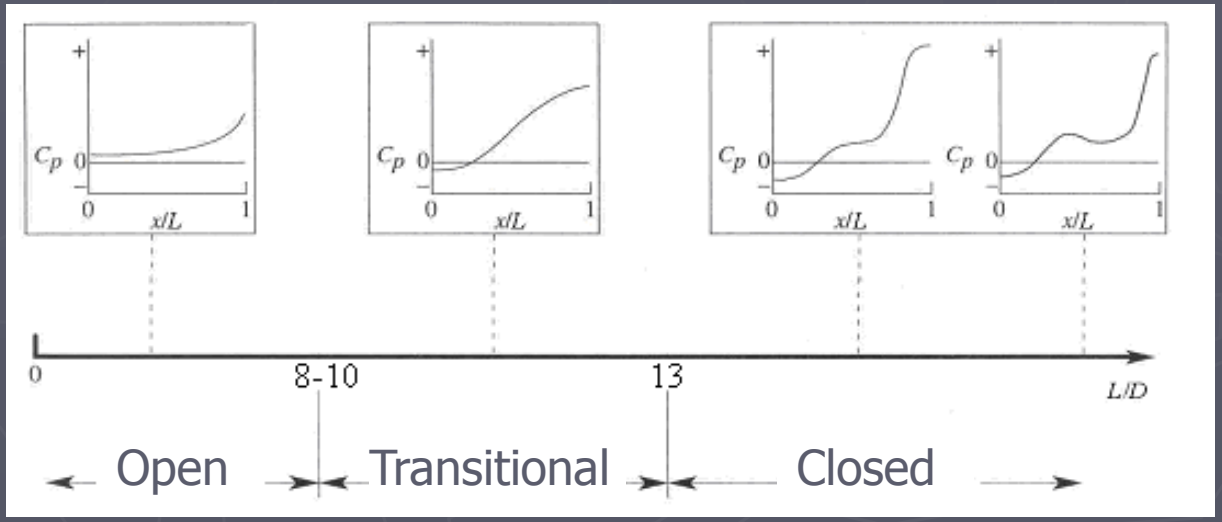


U_∞

L/W > 1 (3D)

Types of flow

- M
- Re
- δ
- L, D, W



Shallow cavity fluctuations

Rossiter formula

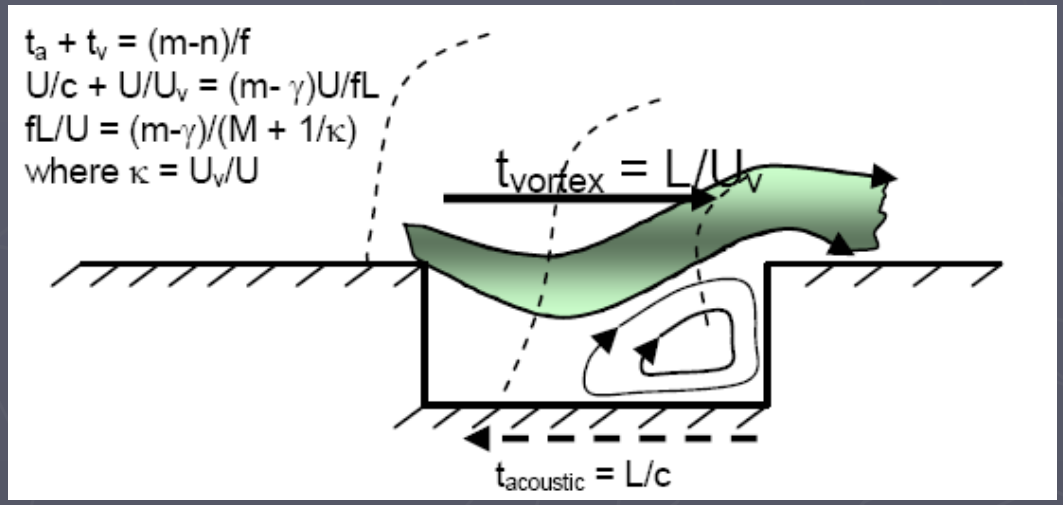
$$\frac{fL}{U} = N_{Fm} = \frac{(m-\alpha)}{\frac{1}{k}+M}$$

m = 1, 2, 3… – mode number

α, k – empirical constants

α = 0.25, k = 0.57

Rossiter, 1964



D.R. Williams, C.W. Rowley, 2006.

Resonance criterion

Laminar boundary layer

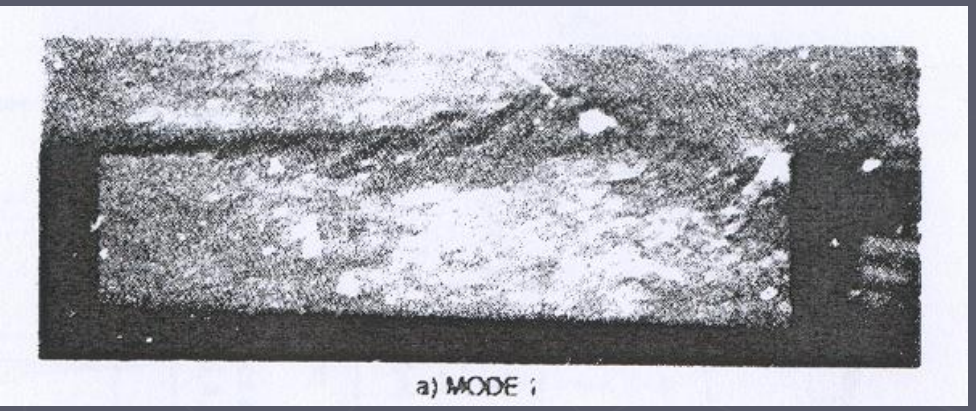
$80 < L/\theta < 155$ (Gharib, Roshko, 1987)

$L/\theta < 100$ and $(L/\delta)(Re_\delta)^{1/2} > 290$ (Sarohia, 1977)

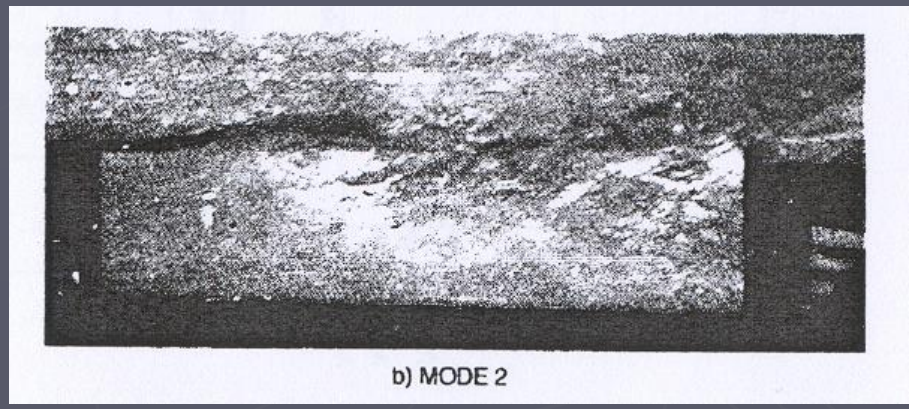
Turbulent boundary layer

$\delta / L < 0{,}066$ (Ahuja, Mendoza, 1995)

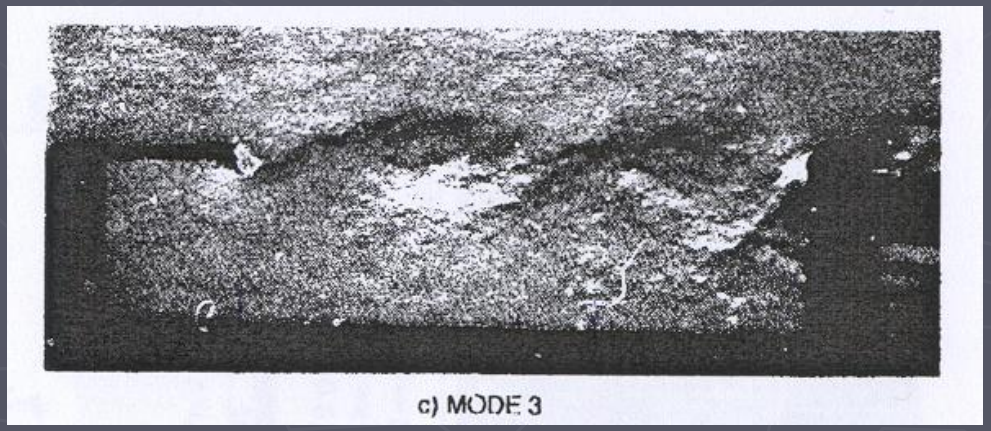
Mode switching



a) MODE 1



b) MODE 2



c) MODE 3

L.N. Cattafesta III, M.S. Kegerise, G.S. Jones, Experiments on Compressible Flow-Induced Cavity Oscillations, 29-th AIAA Fluid Dynamics Conferense, June 15-1 8, 1998

Experimental setup (1)

T-325M

- Test section: 40x40mm
- M: 0.4 – 4
- Re: $7.8 \cdot 10^5$ до $3 \cdot 10^8$ m^{-1}

Transonic Wind Tunnel ASTRC/NCKU

- Test section: 600x600mm
- M: 0.2 – 1.4
- max Re: $2 \cdot 10^7$ m^{-1}

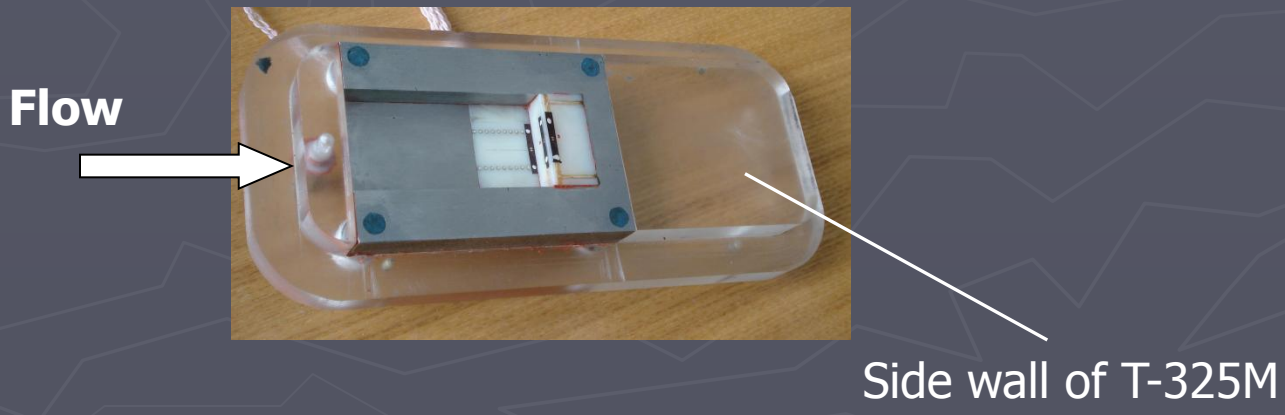
Experimental setup (2)

Cavity model

- L = 60 mm
- D = 9 mm
- W = 30 mm

L/D = 6.67; L/W = 2

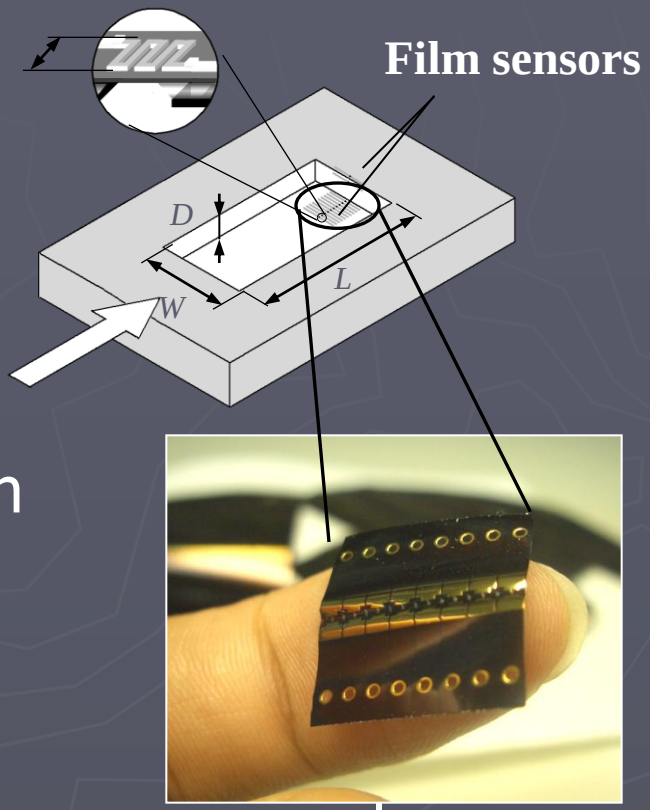
Open, 3D



Experimental setup (3)

Film sensors (NCKU)

- Thickness – 10 μm
- Sensitive area – 200x260 **μm**
- Resistance ~ 150 Ω



Constant temperature amplifier CTA-8ch

- Number of channels – 8
- Maximum overheat ratio – 0.3
- Frequency range – up to 20 kHz

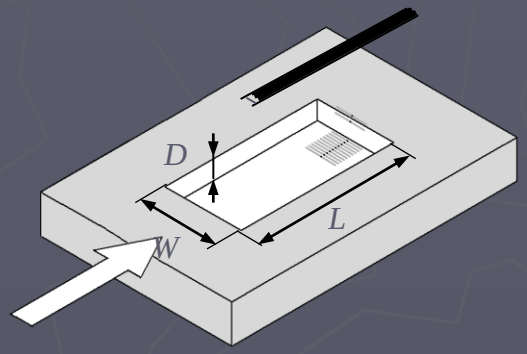
Experimental setup (4)

Hot-wire

- Length – 2 **μm**
- Diameter - 10 **μm**
- Resistance ~ 2 Ω

Position

- x/L = 0.68
- y/D = 2



Constant current anemometer CCA-6

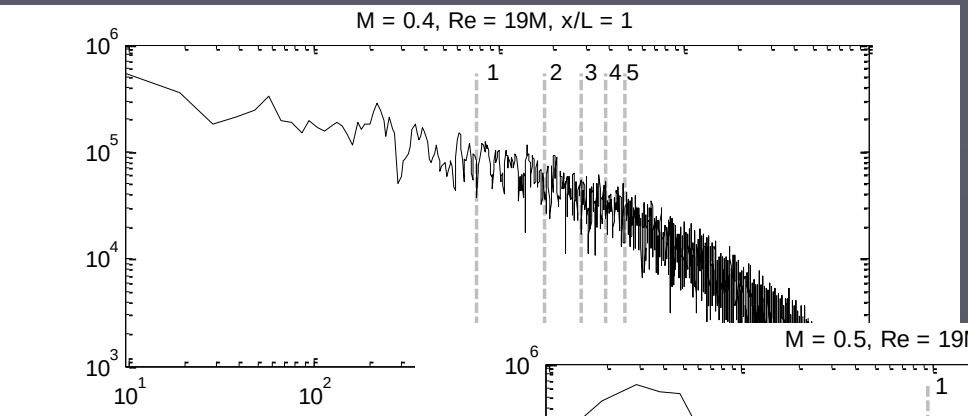
- Maximum resistance – 20 Ω
- Maximum current – 300 мА

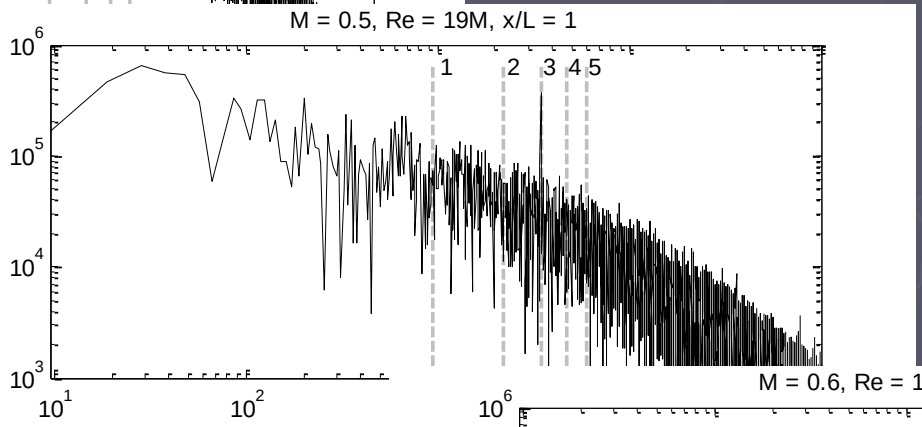
Flow conditions

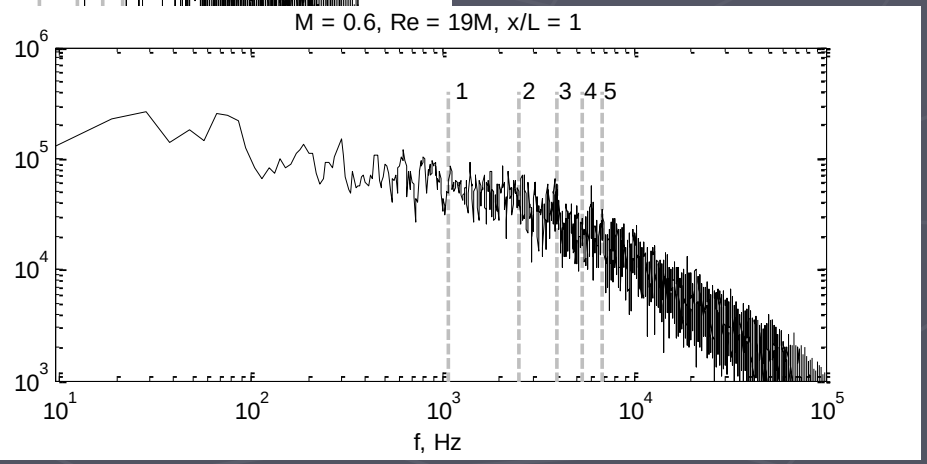
- M: 0.4 – 0.75
- Re: $13 \cdot 10^6 \div 26 \cdot 10^6$ m^{-1}

$\delta / L < 0{,}066$ for T-325M

Fourier spectra inside the cavity (film sensor) (1)



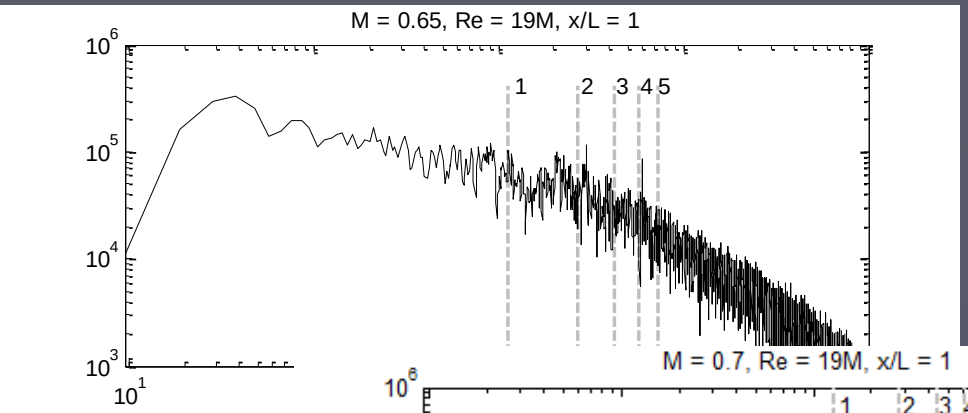


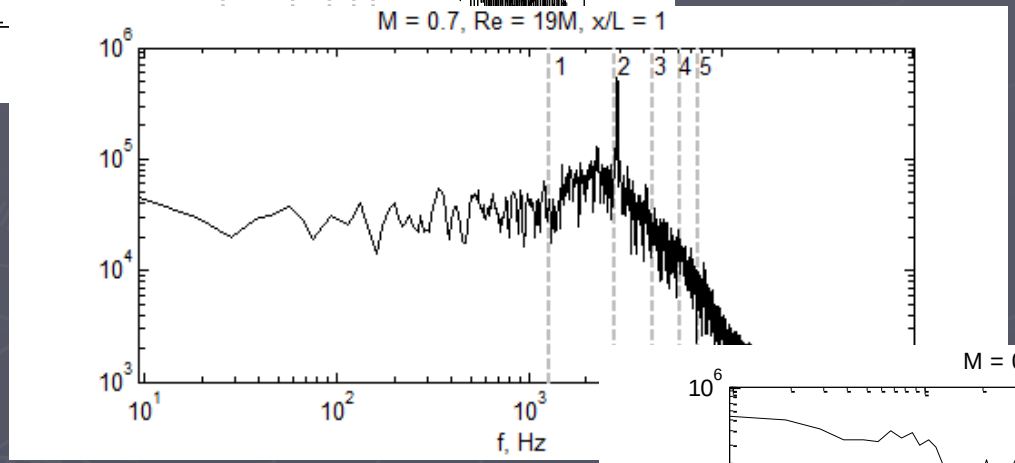


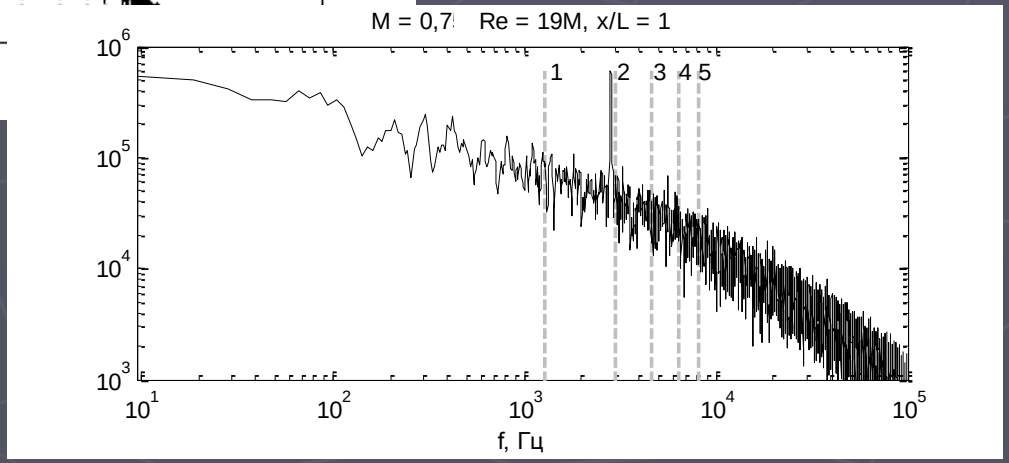
Film sensor on rear wall

x/L = 1

Fourier spectra inside the cavity (film sensor) (2)



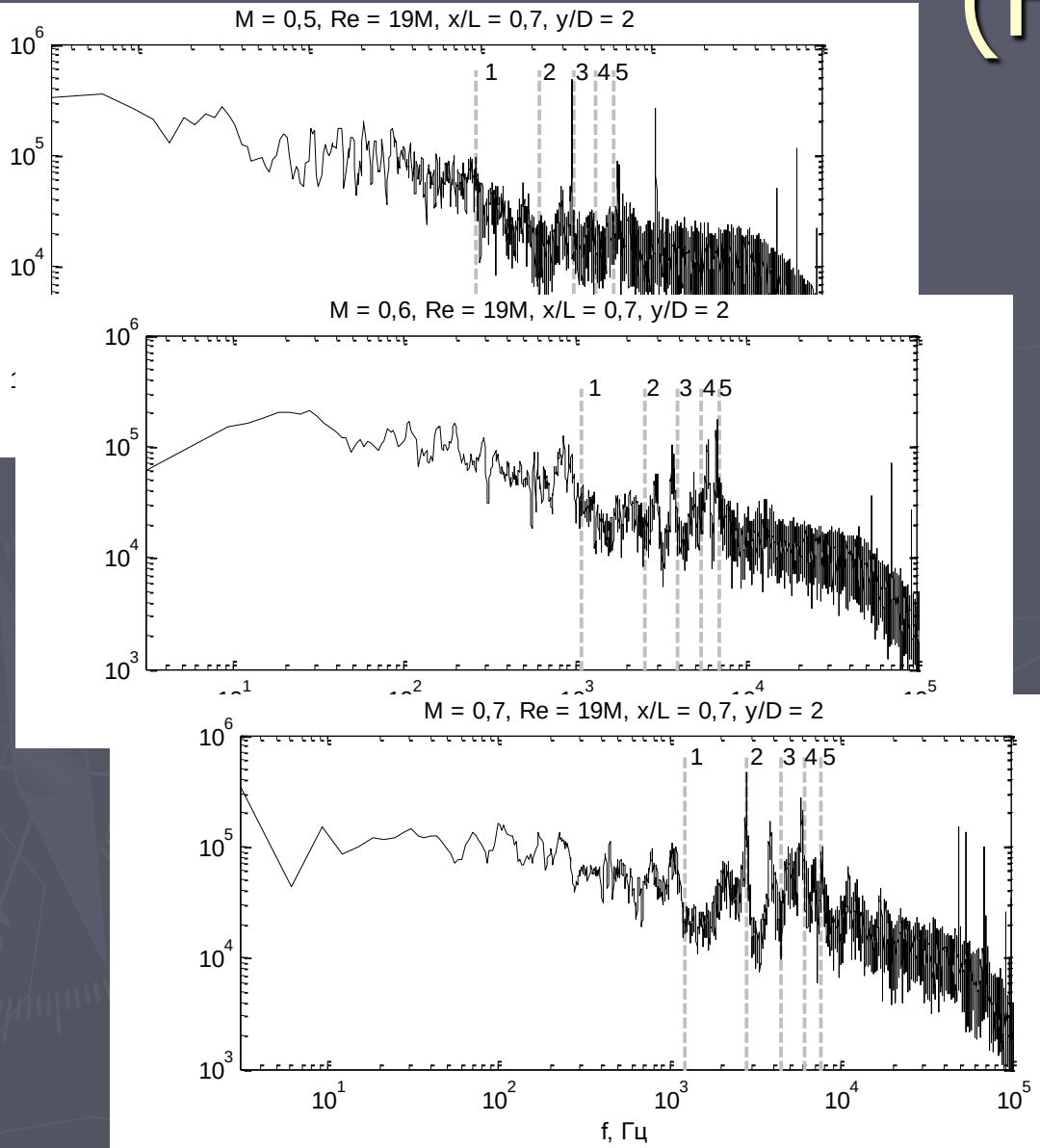




Film sensor on rear wall

x/L = 1

Fourier Spectra in shear layer (Hot-wire)



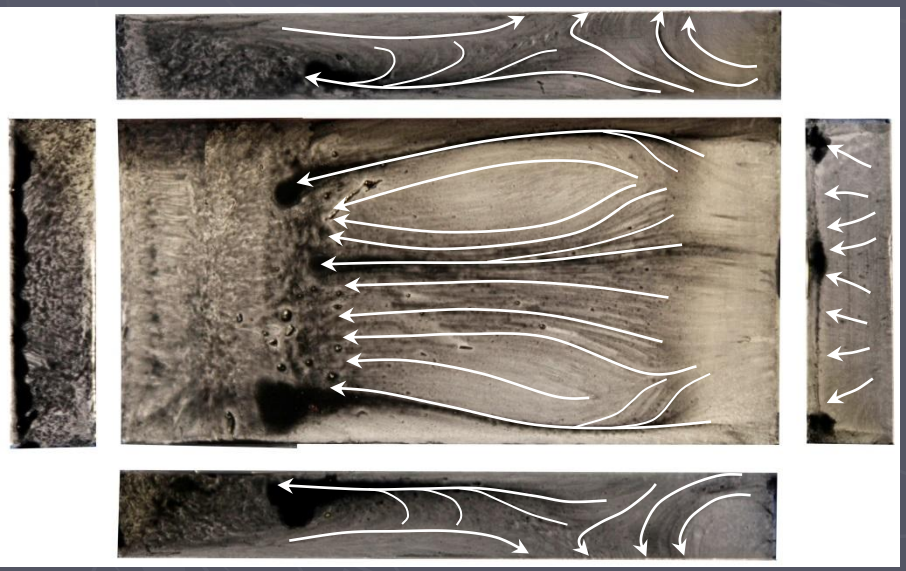
f_3 = 3384 Hz, f_5 = 6335 Hz

f_3 = 3644 Hz, f_5 = 6696 Hz

f_2 = 2802 Hz, f_4 = 5884 Hz

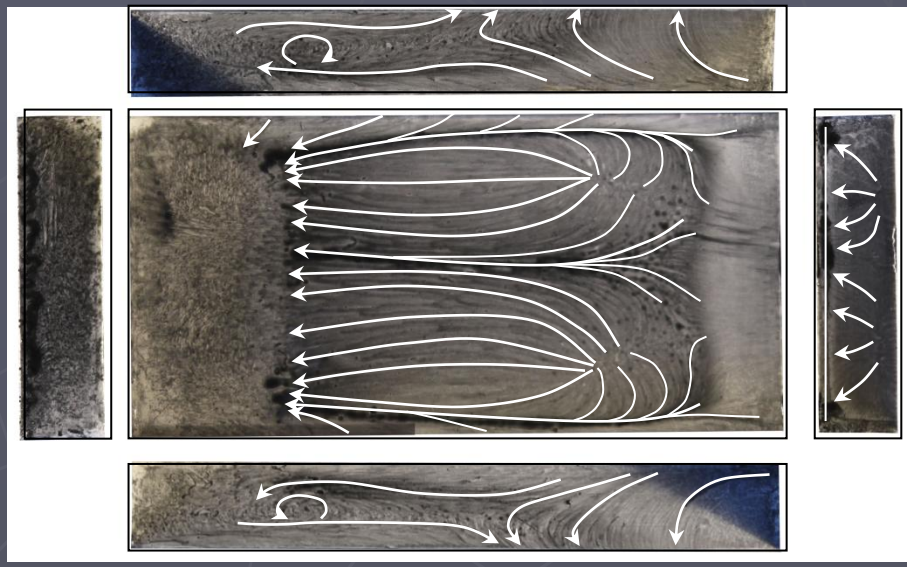
Oil-black visualization, T-325M (1)

M=0.6, Re = $19 \cdot 10^6$ m^{-1}



No resonance

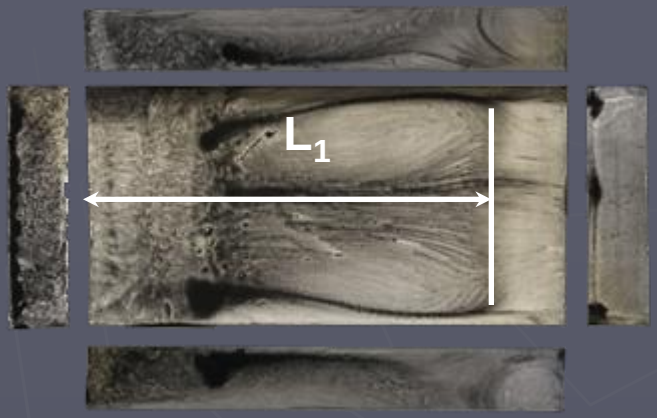
M=0.7, Re = $19 \cdot 10^6$ m^{-1}



Resonance

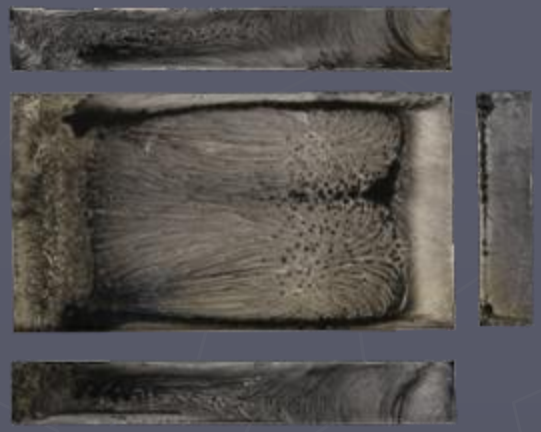
Oil-black visualization , T-325M(2)

M = 0.4, Re = 19M



L_1/L = 0,85

M = 0.5, Re = 19M



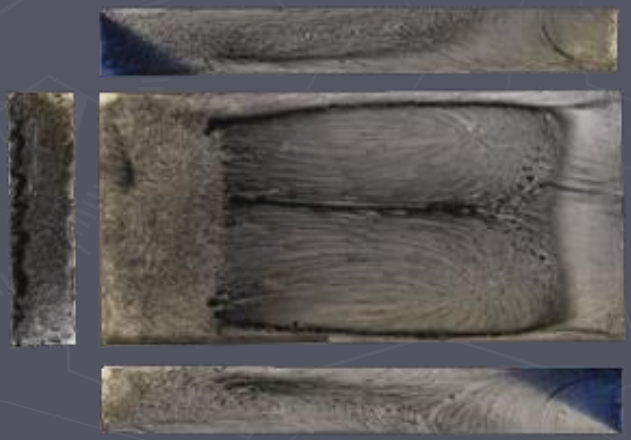
U_∞ $(L-L_2)/L$ = 0.9

M = 0.6, Re = 19M

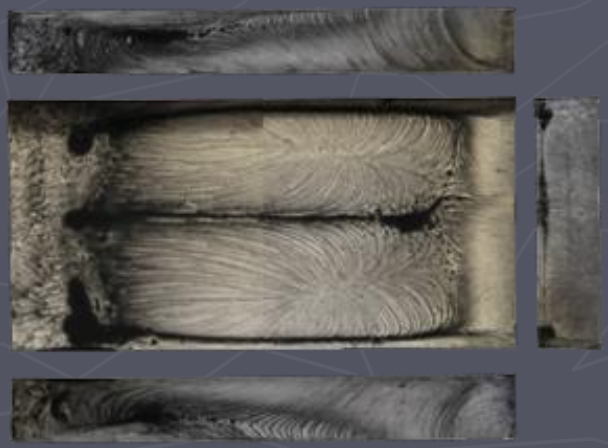
L_1/L = 0,86

L_1/L = 0,89

M = 0.7, Re = 19M



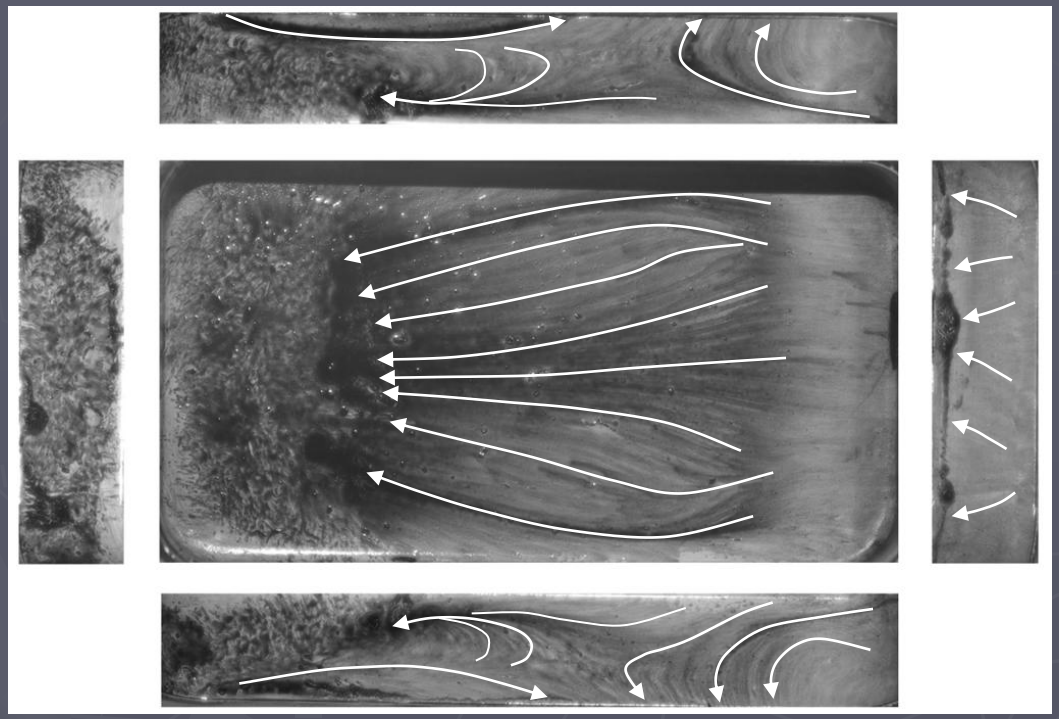
M = 0.75, Re = 19M



L_1/L = 0.9

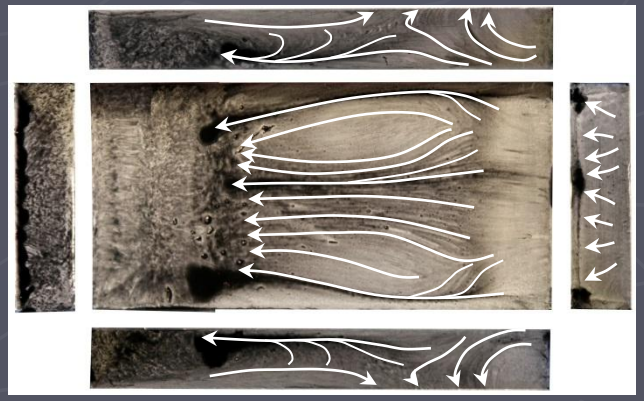
Oil black visualization, TWT

M=0.5, Re = $17 \cdot 10^6$ m^{-1}



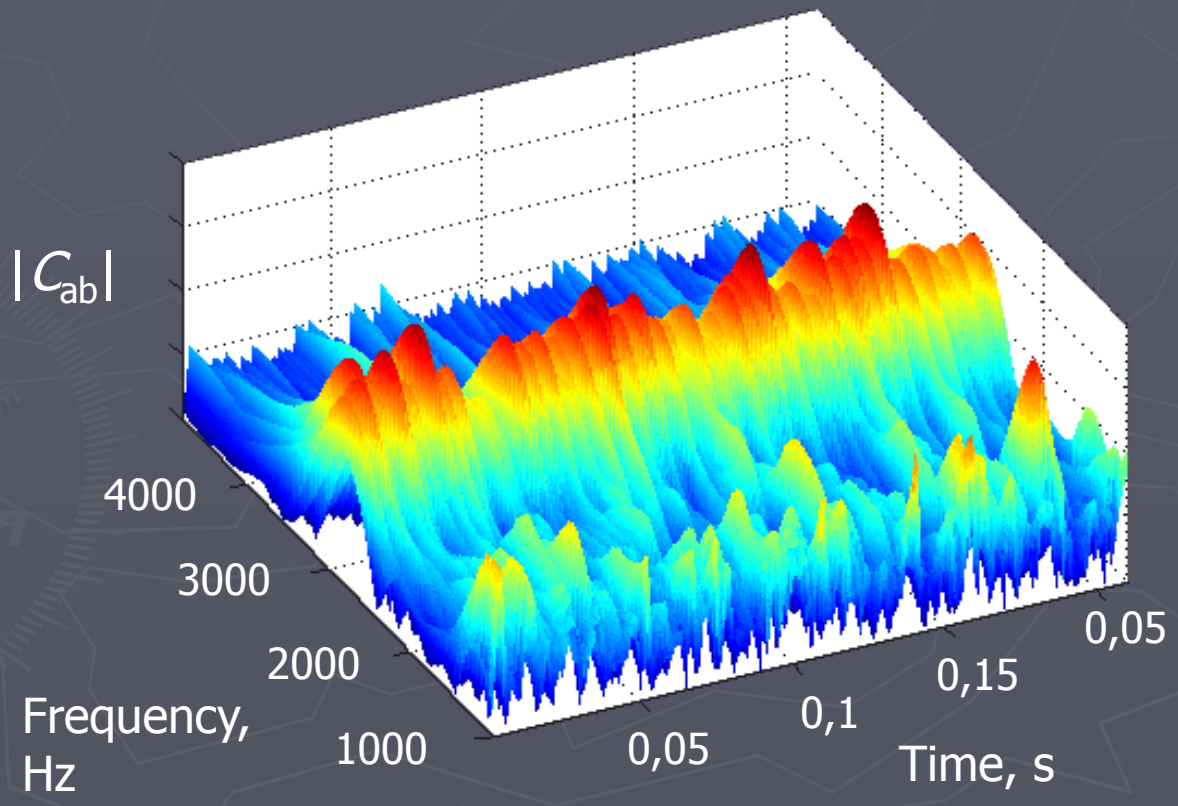
Identical to non-resonant case

M = 0.4, T-325M

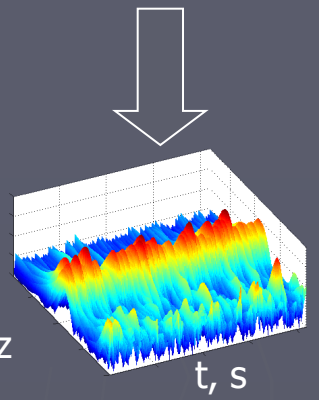


Wavelet transform

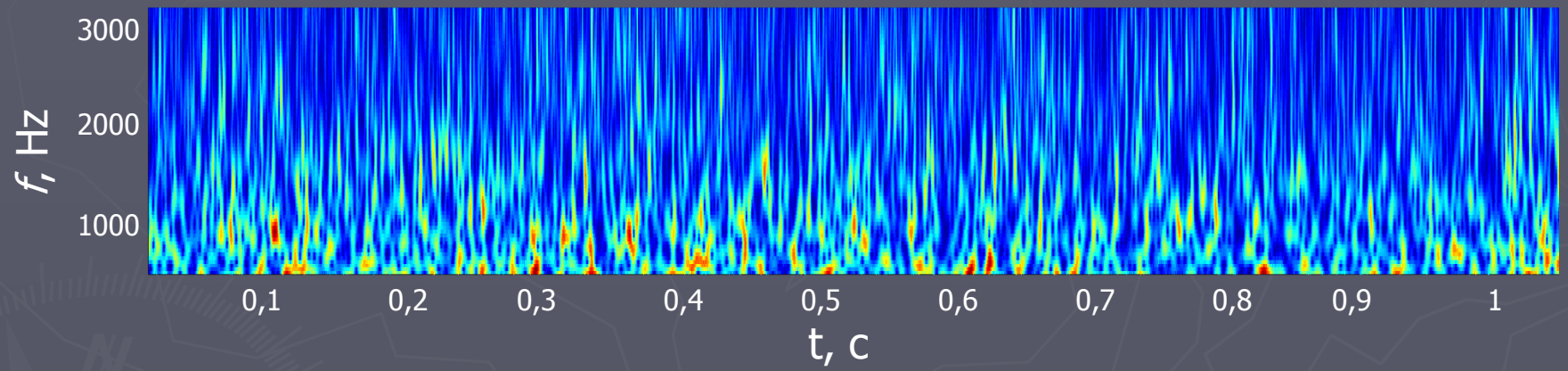
$$C_{a,b} = \frac{1}{\sqrt{a}} \int_R s(t)\psi\left(\frac{t-b}{a}\right)dt$$



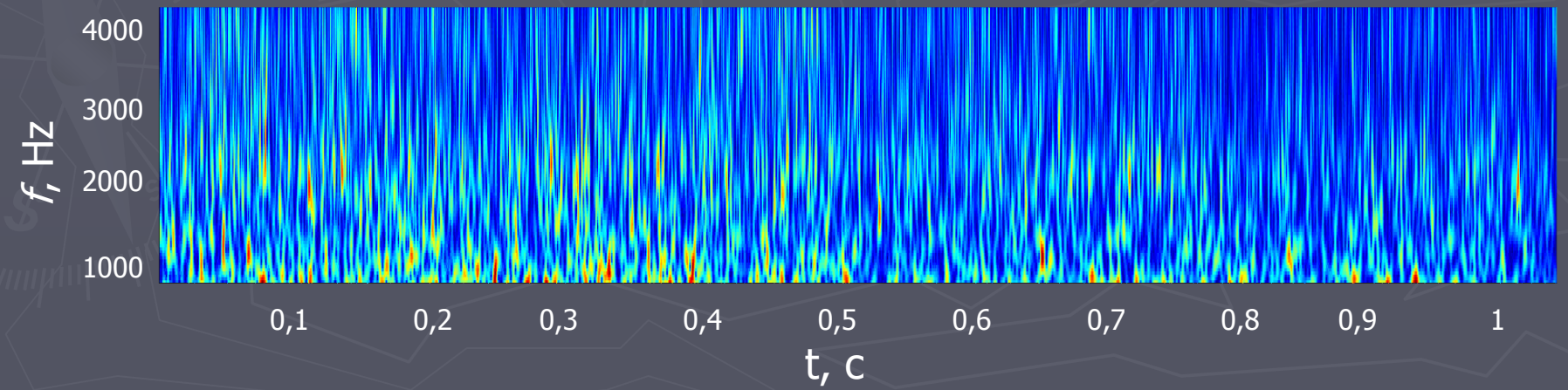
Wavelet spectra (1)



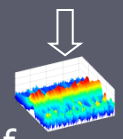
Sensor 11, x/L = 1, M = 0.4



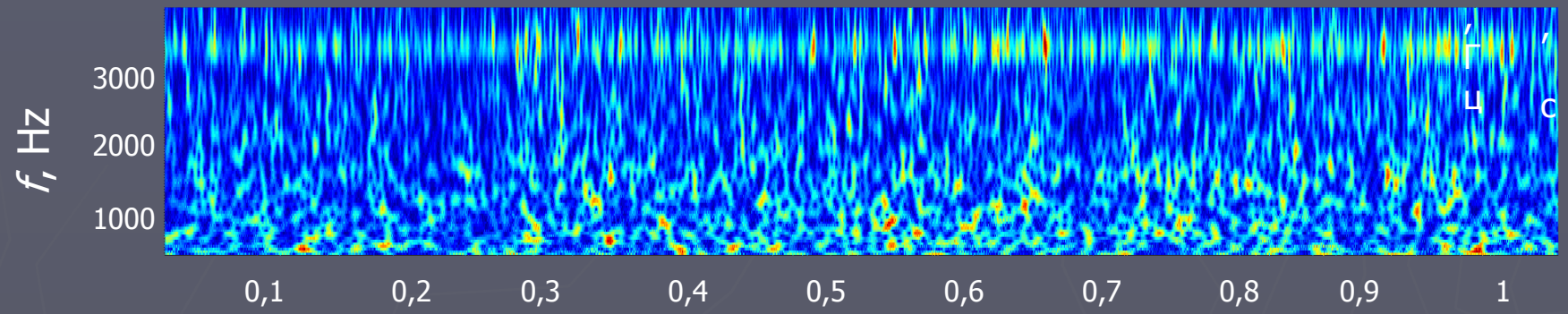
Sensor 11, x/L = 1, M = 0.6



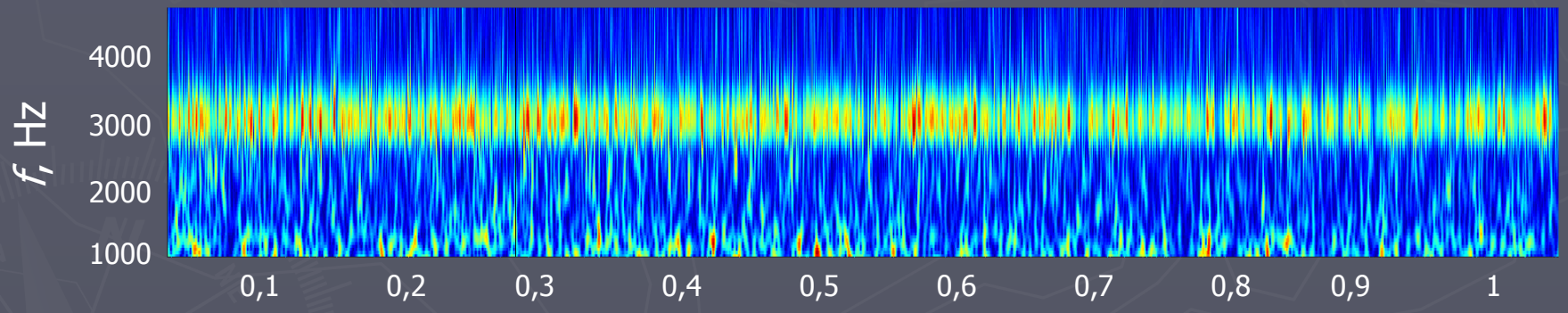
Wavelet spectra (2)



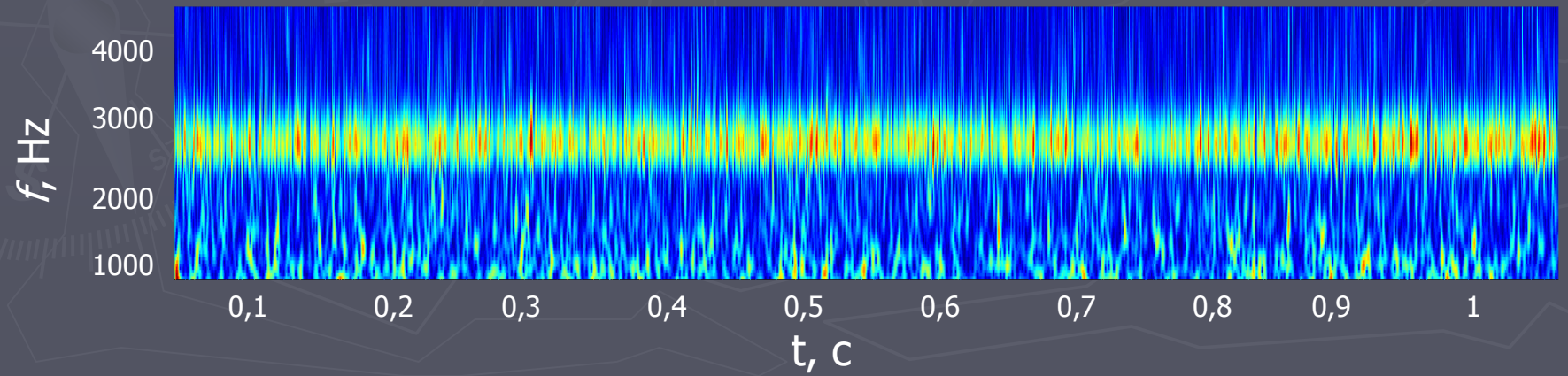
Sensor 11, x/L = 1, M = 0.5, m = 3



Sensor 11, x/L = 1, M = 0.7, m = 2

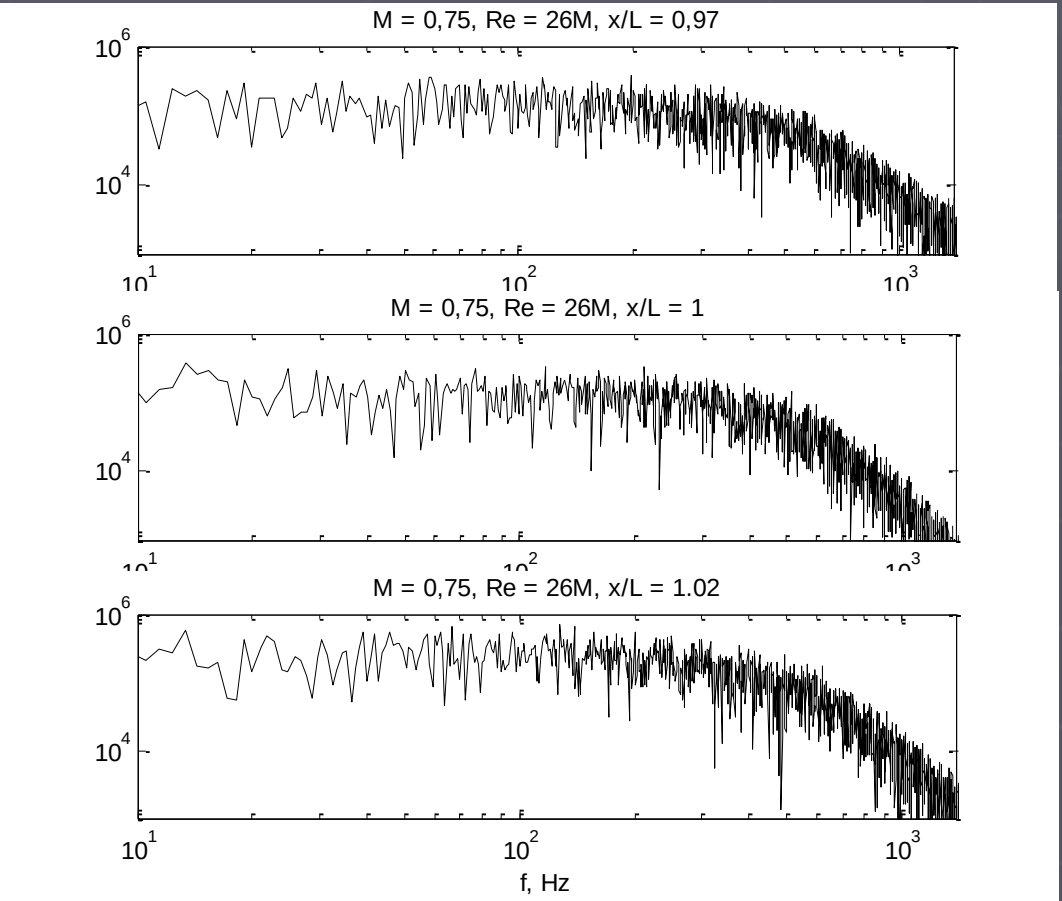


Sensor 11, x/L = 1, M = 0.75, m = 2



Amplitude variation

FFT of wavelet amplitude of resonant mode
f_2 = 2,8 kHz, M = 0.75



Hilbert-Huang transform

EMD HT

Original signal → Intrinsic mode function → Instantaneous amplitude and frequency → Time frequency spectrum

Hilbert transform

$$y(t) = \frac{1}{\pi}\int_{-\infty}^{+\infty} \frac{x(\tau)}{t-\tau}\,d\tau$$

Instantaneous amplitude

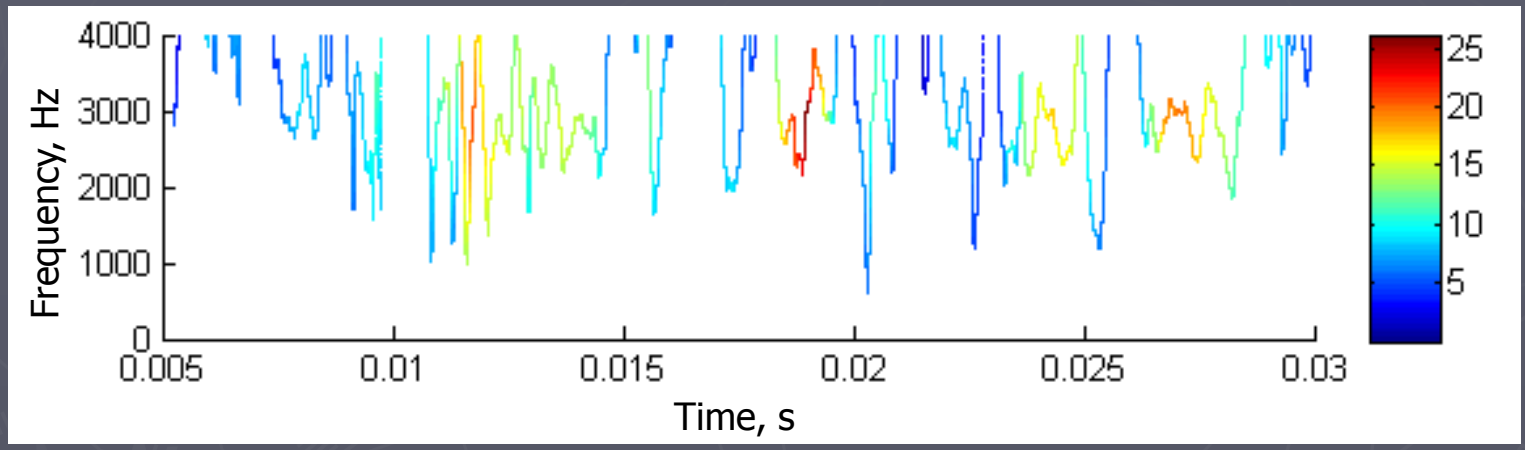
$$A(t) = \sqrt{x^2(t) + y^2(t)}$$

Instantaneous frequency

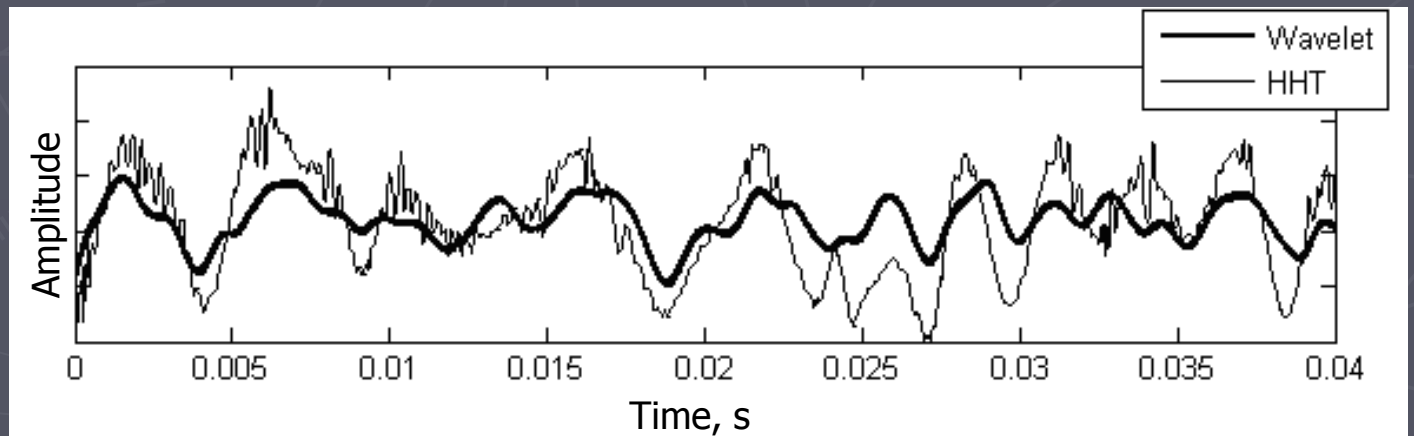
$$\theta(t) = \arctan\left(\frac{y(t)}{x(t)}\right) \quad \Rightarrow \quad \omega(t) = \frac{d\theta}{dt}$$

Hilbert-Huang spectra

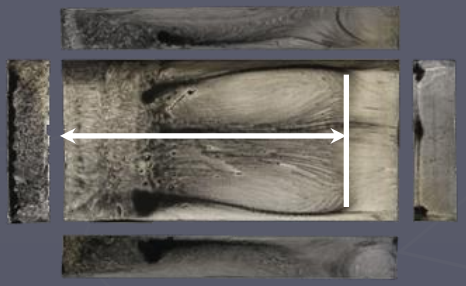
M = 0,75, Re = 26M, x/L = 1

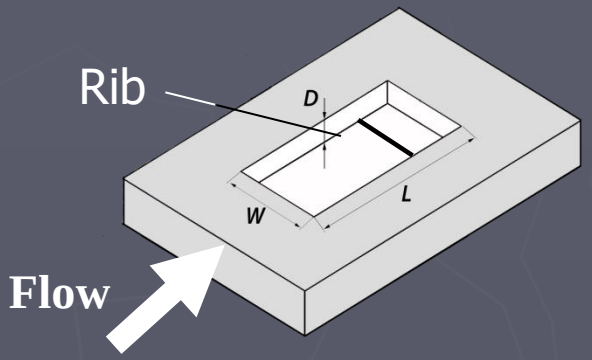


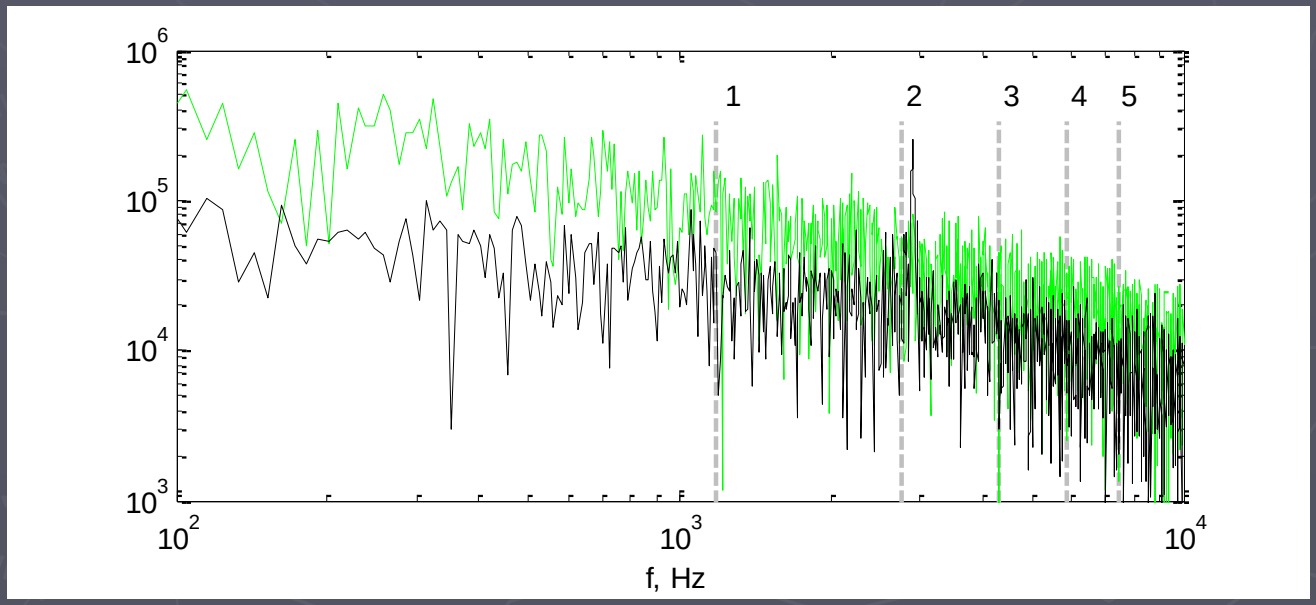
Amplitude variation of second Rossiter mode at M = 0,75



Flow control







Without rib

With rib

Conlusion

- Rossiter fluctuations are not always observed in the flow even resonance criterion is satisfied
- Higher order modes are observed in outer flow
- Number of dominant Rossiter mode decreases if Mach number increases
- Rear separation line on cavity floor moves downstream when resonance appears
- HHT traces faster amplitude variation compared to wavelet transform
- Presence of a rib on cavity floor decreases amplitude of resonant mode but increases overall background noise