Department of Hydrodynamic Systems

# Numerical simulation of self-sustained flow oscillations

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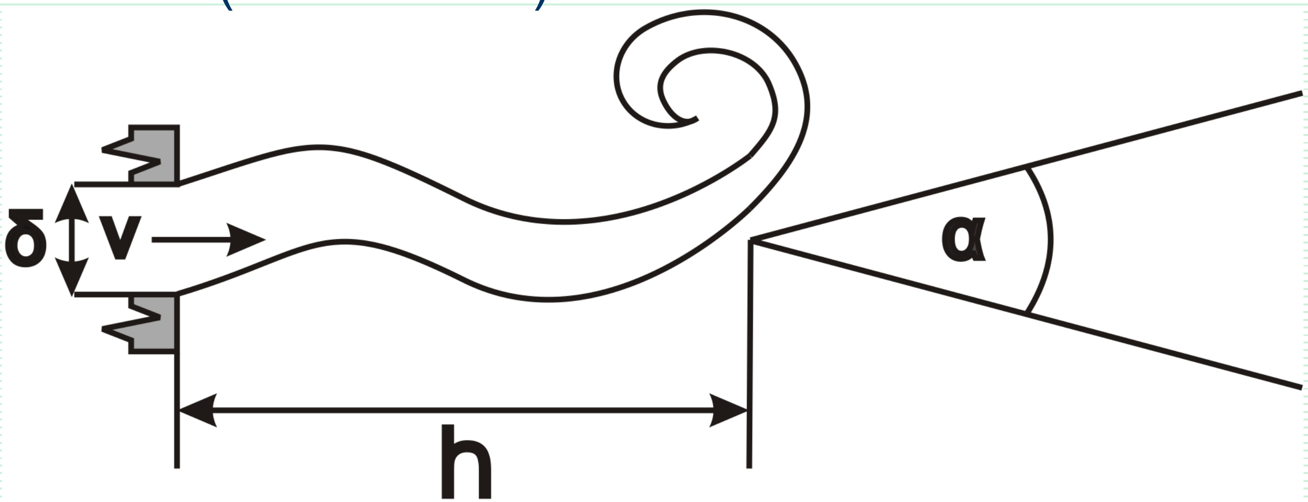
# Introduction I.

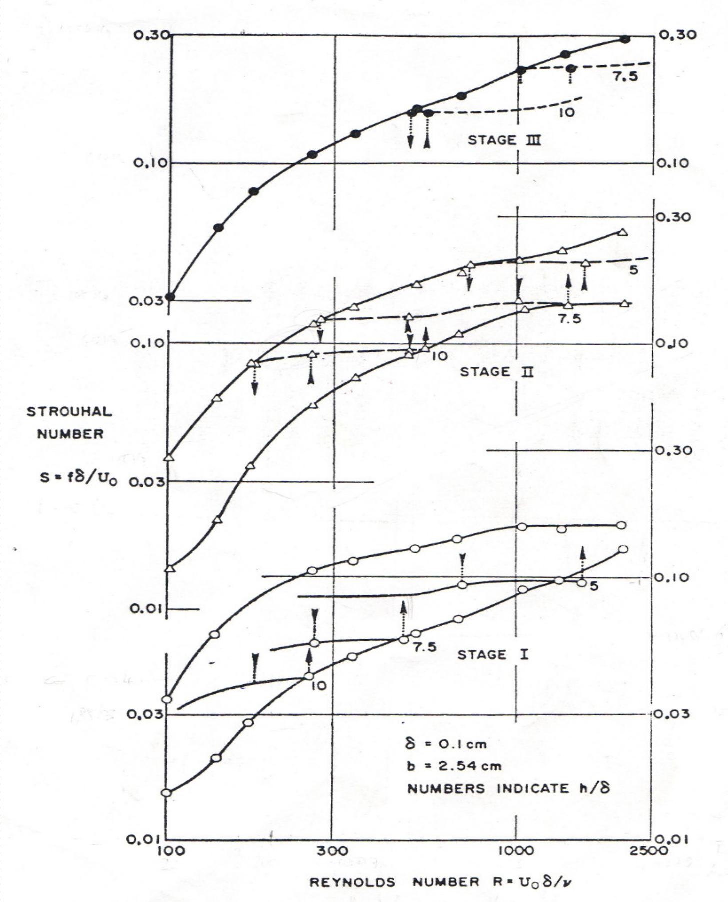
- Edge tone: basic flow configuration for organ pipes and recorders;
- Good example for self-sustained flows;
- Y-shaped pipe branches, tongue of spiral casing in turbomachines, etc.;
- Good model case for aeroacoustic research;

# Introduction II.

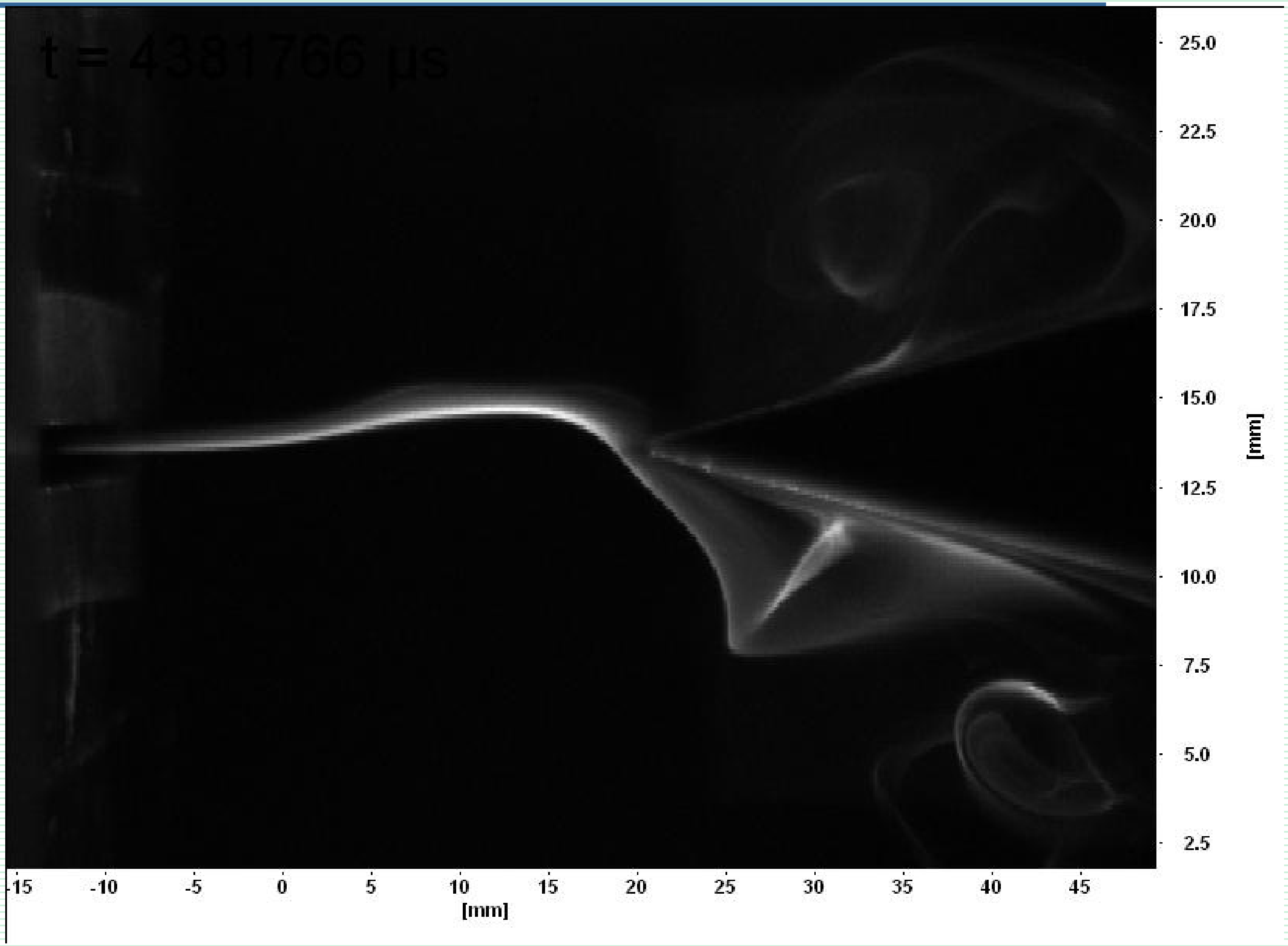
- Plane jet & wedge-shaped object produces periodic vortex shedding;
- Behaves as a dipole sound source;
- Nonlinear phenomena, hysteresis;
- $f \sim v / h^n$ $(n = 1 \ldots 1.5)$



# Powell, A. – Re-St relationship, stages



# Stage I. Re = 200 visualization

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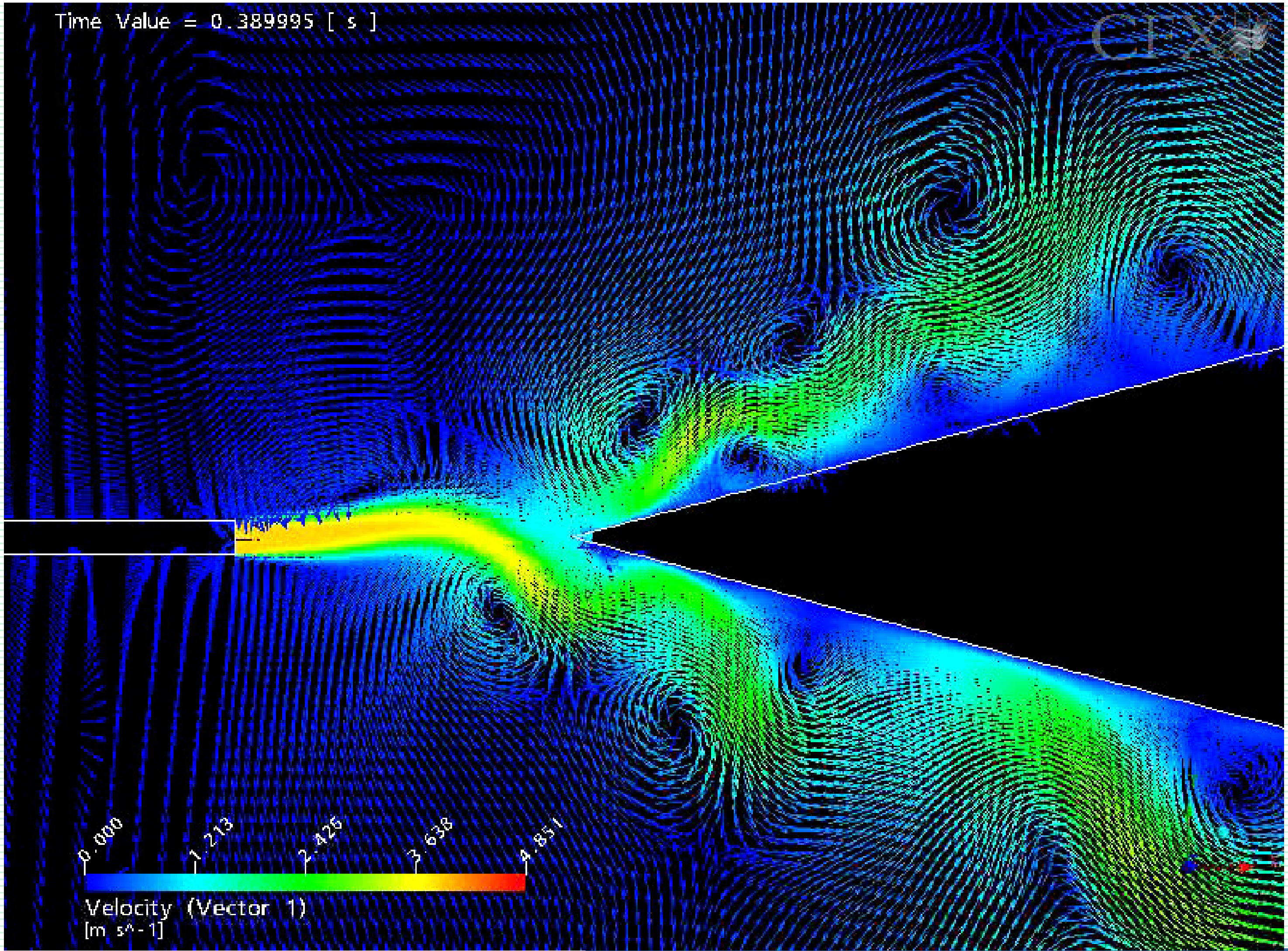
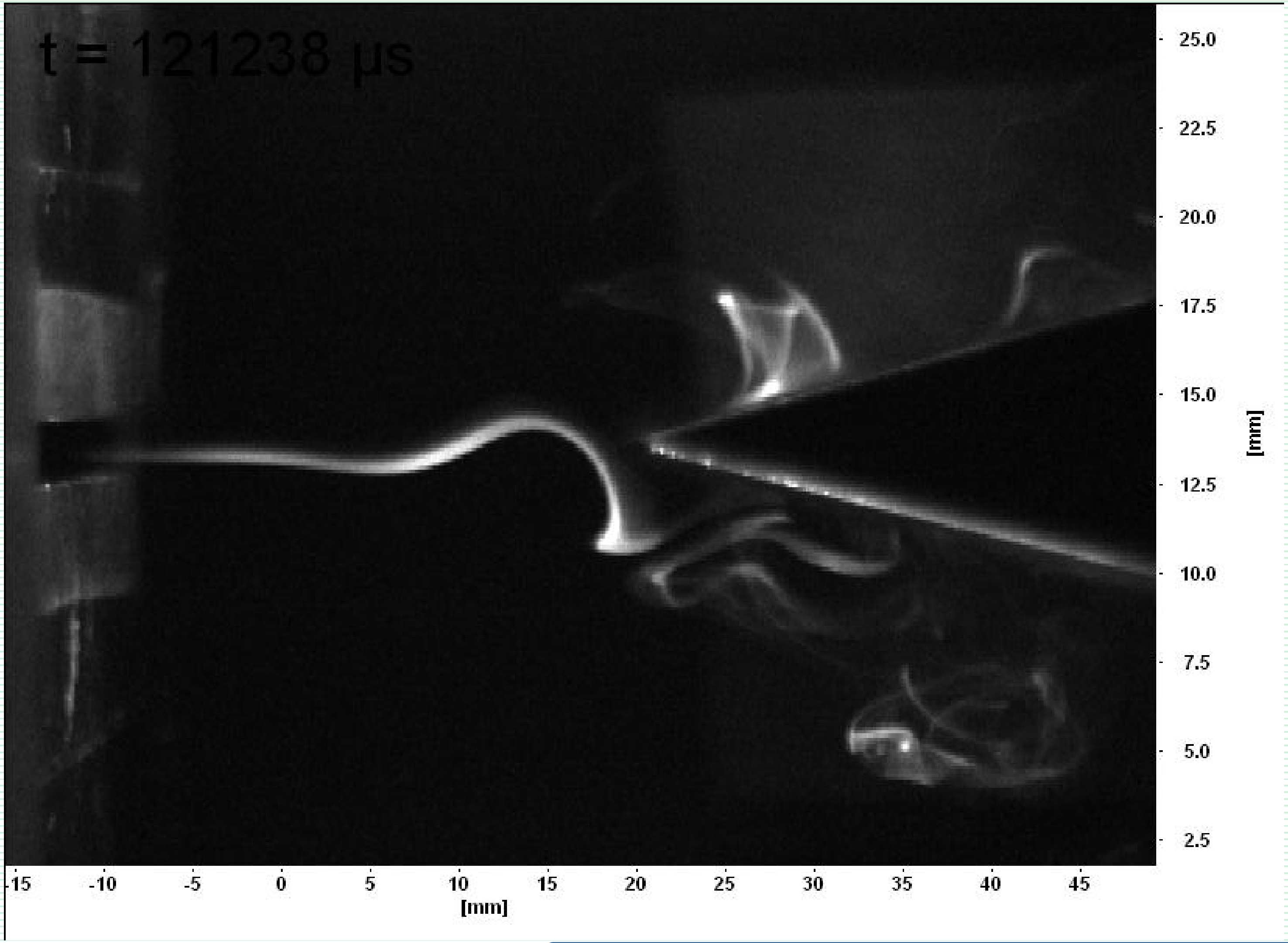
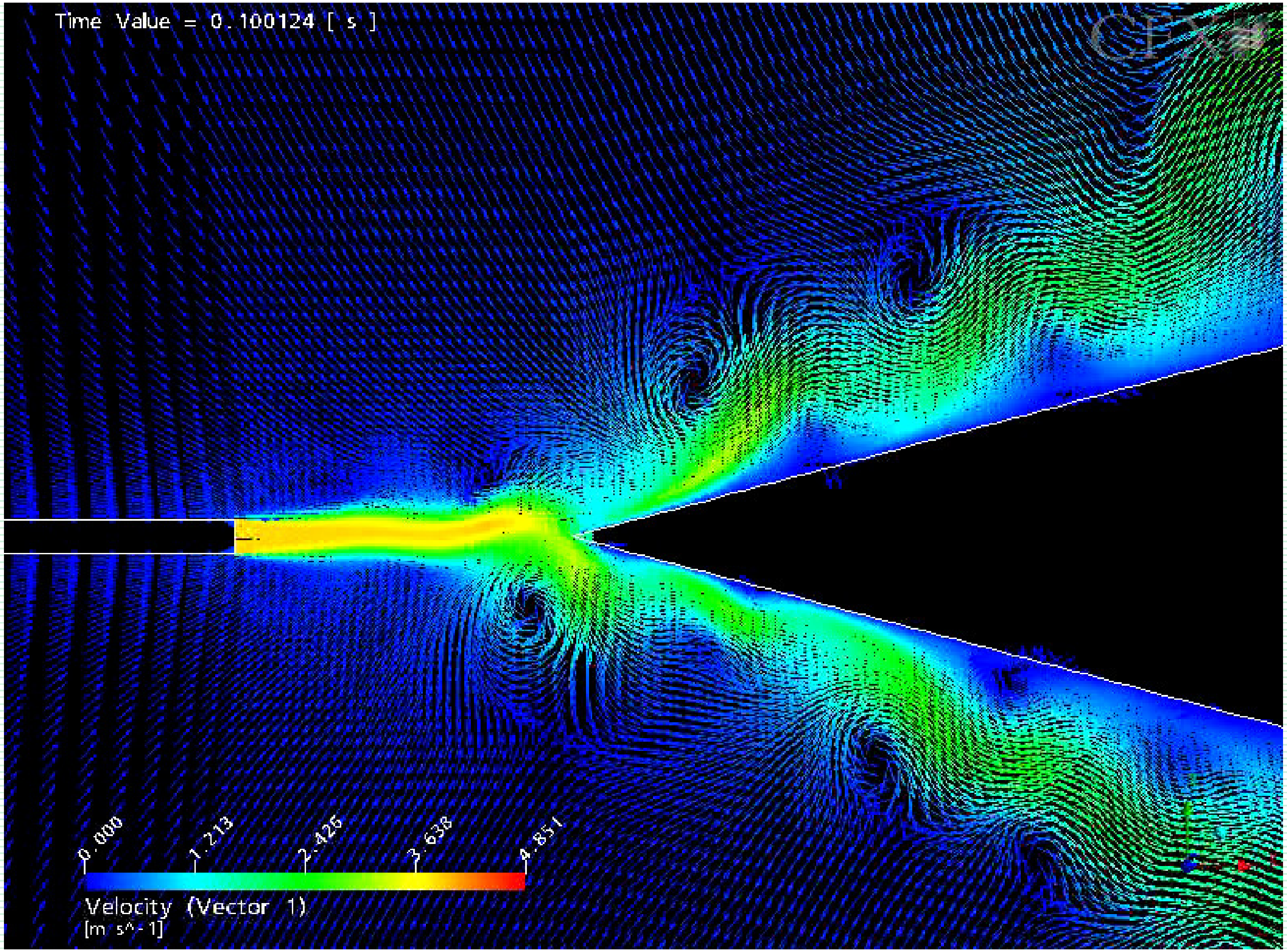
# Stage I. Re = 200 simulation



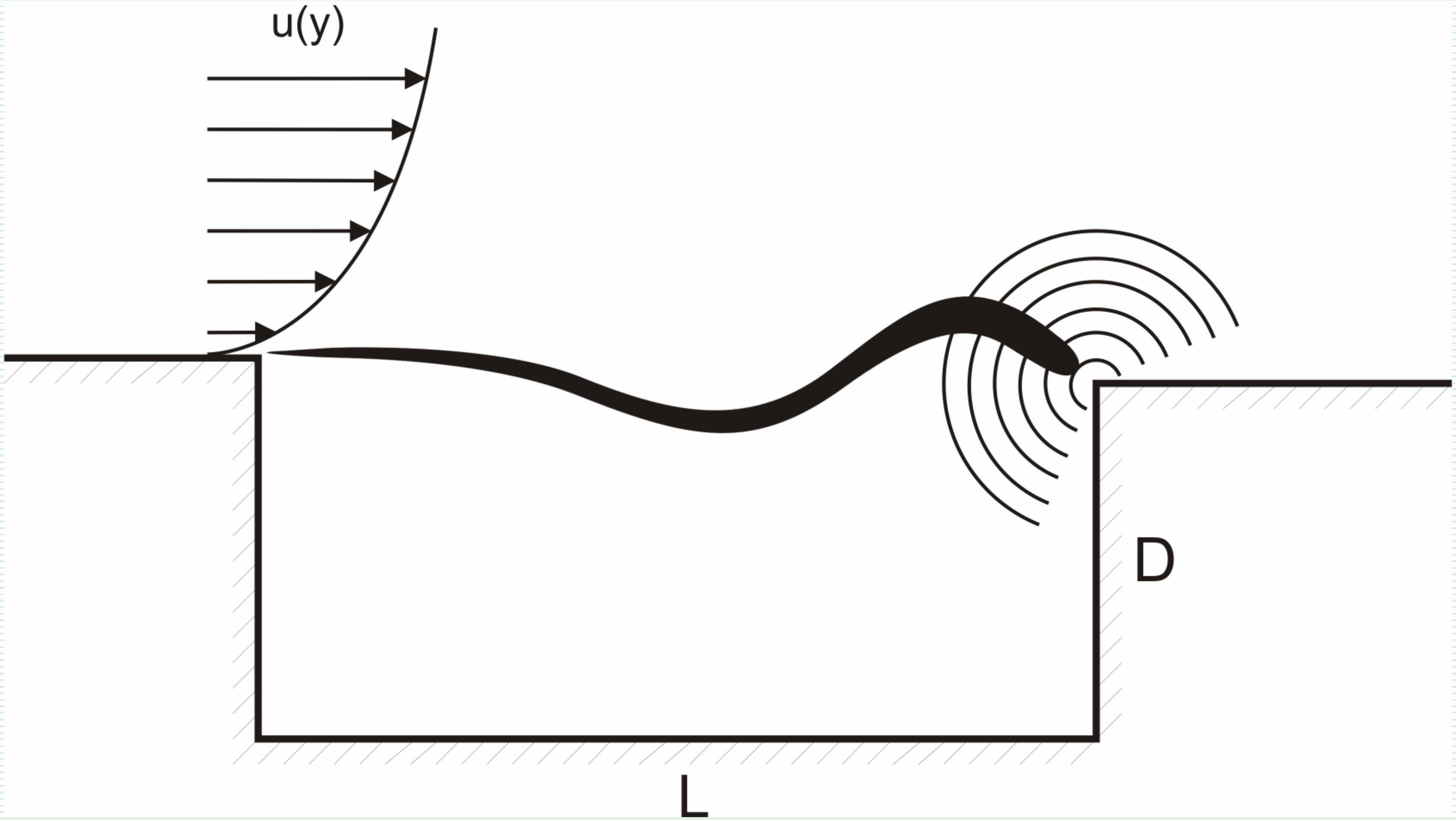
# Stage II. Re = 400 visualization



# Stage II. Re = 350 simulation



# Cavity tone



# Self-sustained oscillations – general scheme

Self sustained oscillations: closed feedback circuits

Shear flow (jet or shear layer)

↓

Growing instabilities

↓

Fluctuating force on an object

↓

Acoustic signal (or vorticity) generates new instability wave at the exit

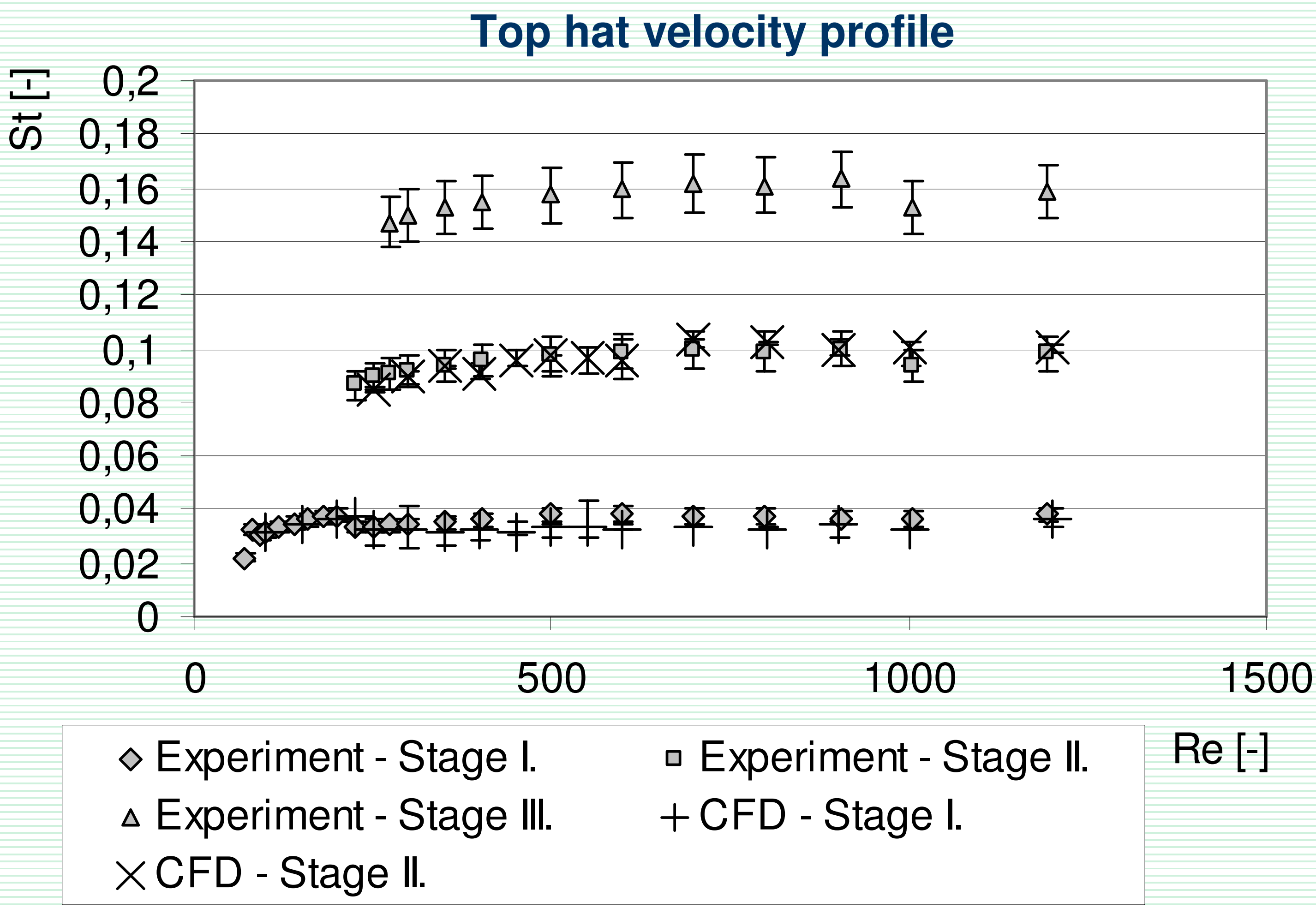
# Self-sustained oscillations – other examples

- Jet-slot;
- Jet-surface;
- Jet-ring;
- Jet-cylinder;
- Jet-hole;
- Shear layer-edge;

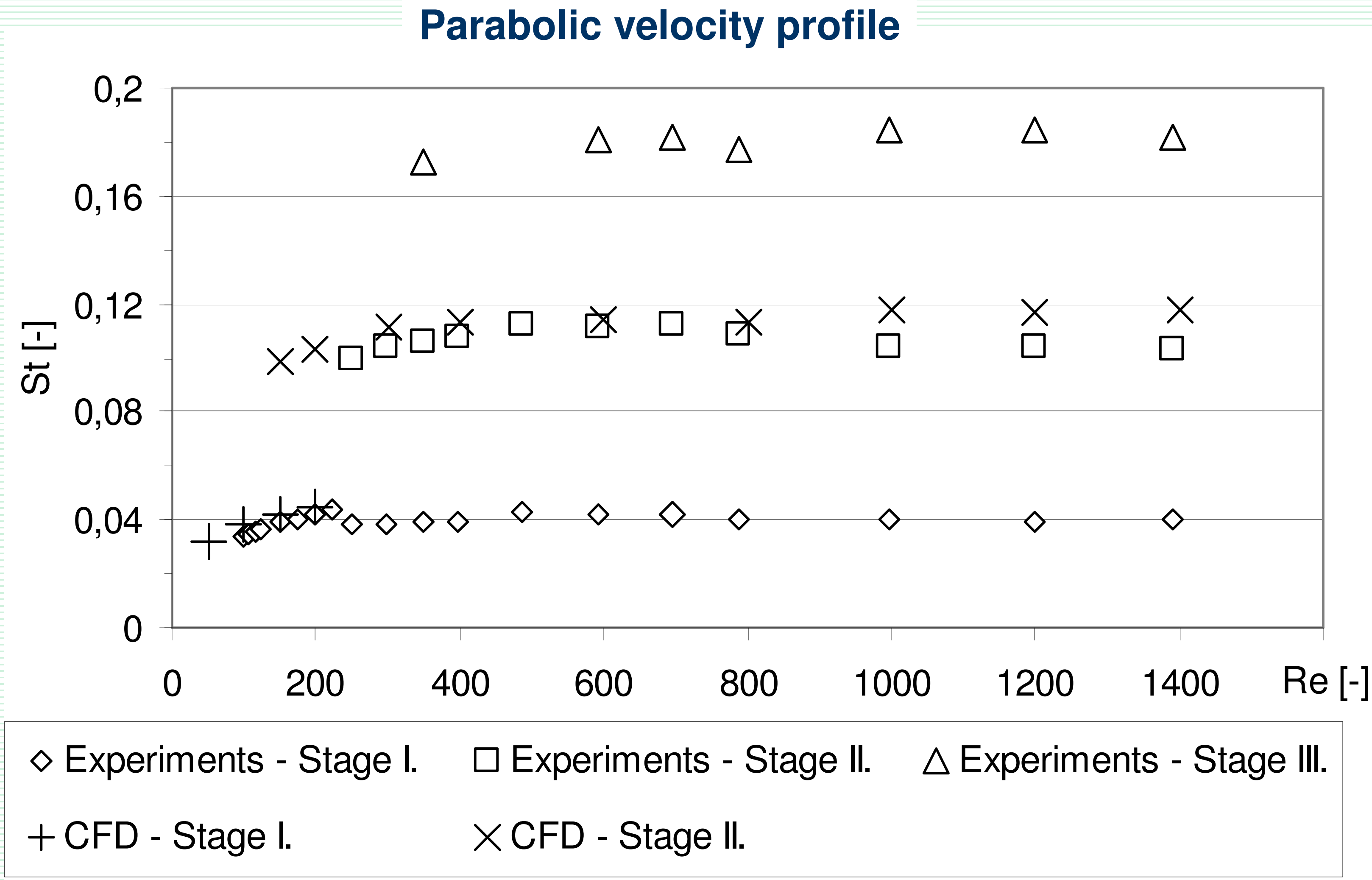
# CFD parameters

- laminar, incompressible, 2D flow;
- fluid: air@ 25C°
- second order spatial and temporal discretization;
- Optimum timestep: determined after extensive studies using time signals, spectra and analytical methods;
- block-structured mesh, careful mesh study;
- Total time of run: determined by the frequency resolution. Requirement: about 1% of maximum frequency. In addition ~0.1 s for the transient part which is cut off for the FFT;
- Initial condition: no influence;

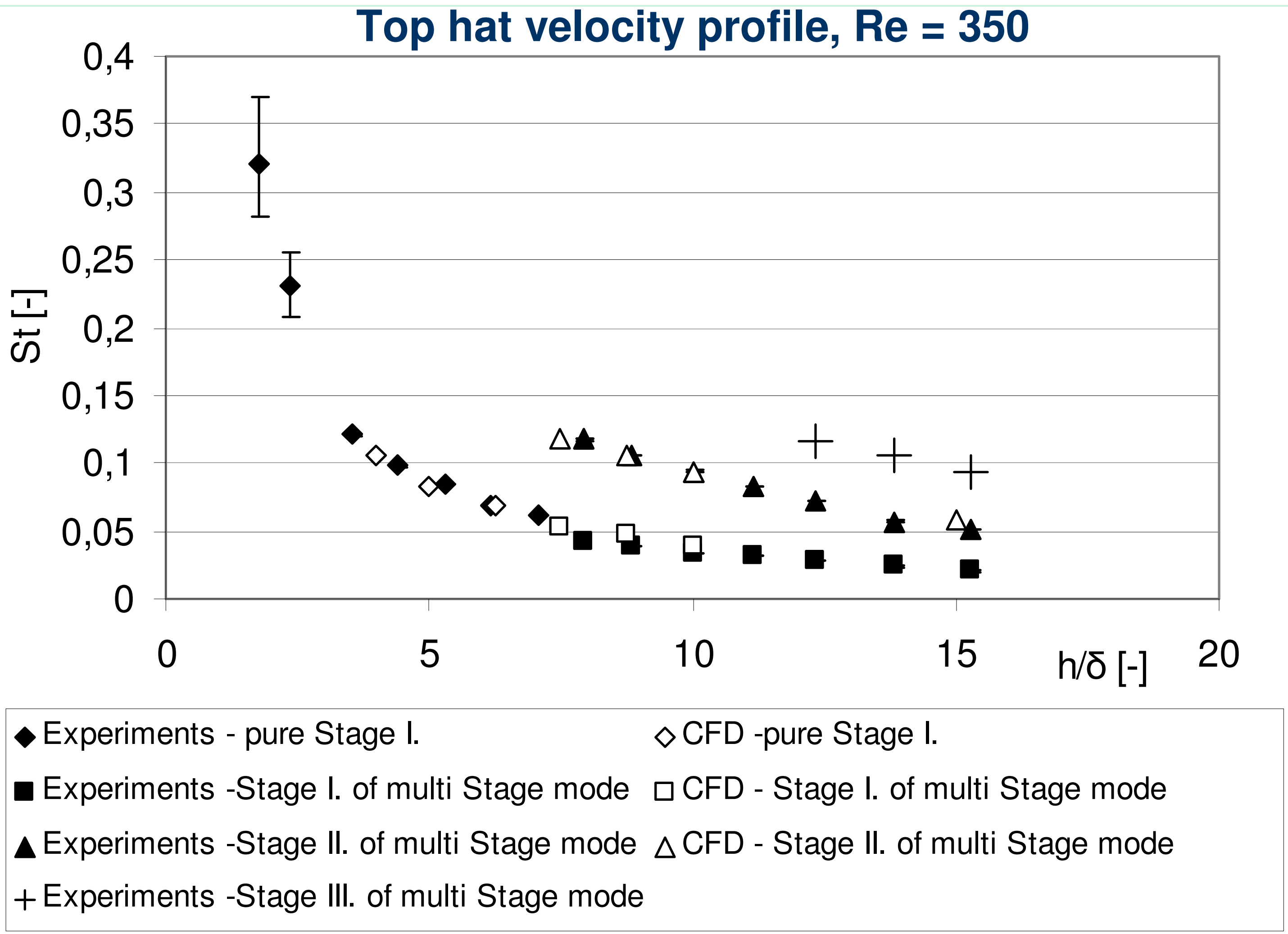
# Selected results for the edge tone I.



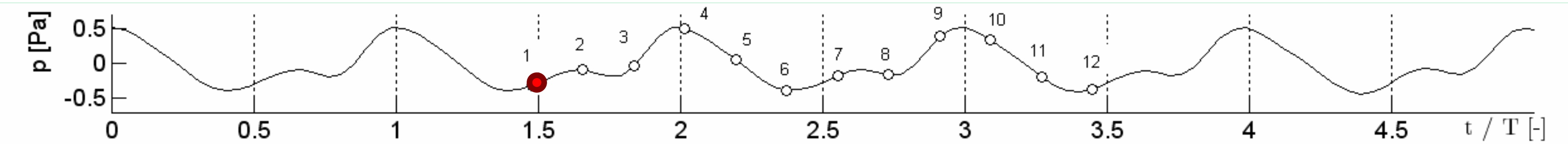
# Selected results for the edge tone II.

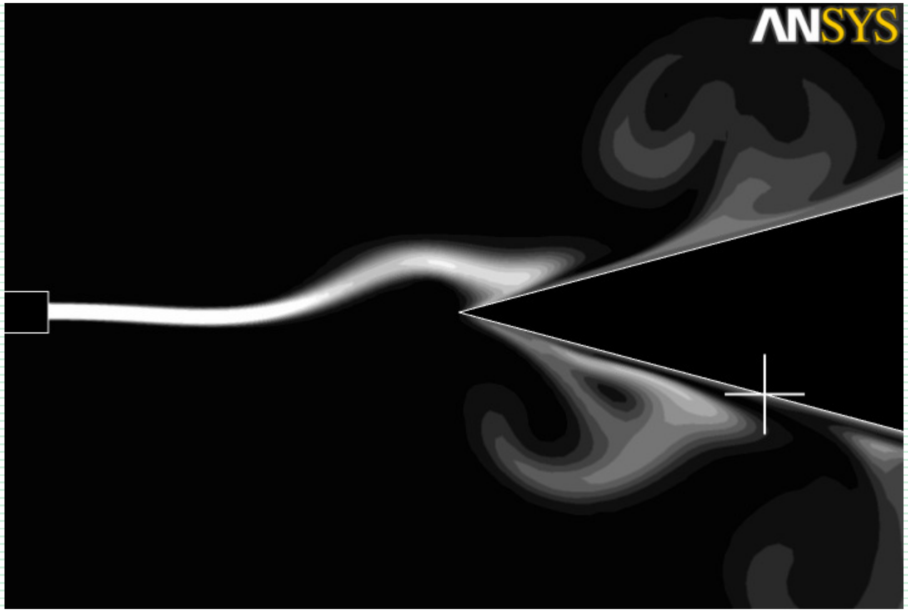


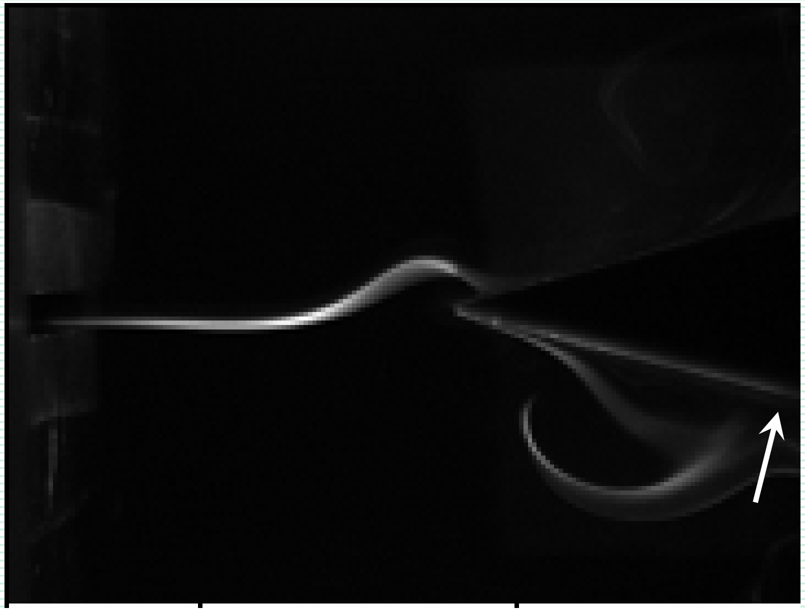
# Selected results for the edge tone III.

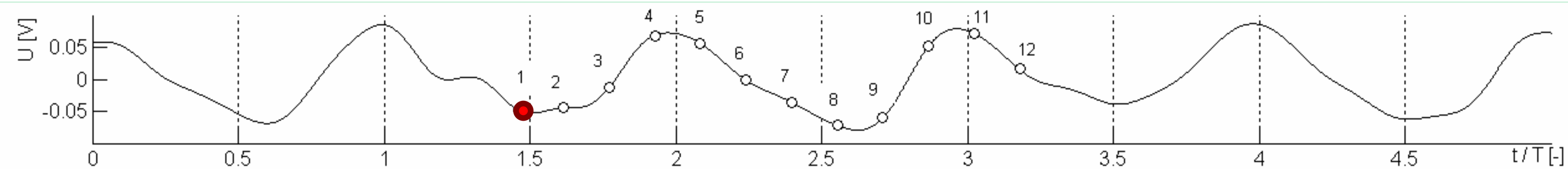


# Comparison of visualisation and computation I.



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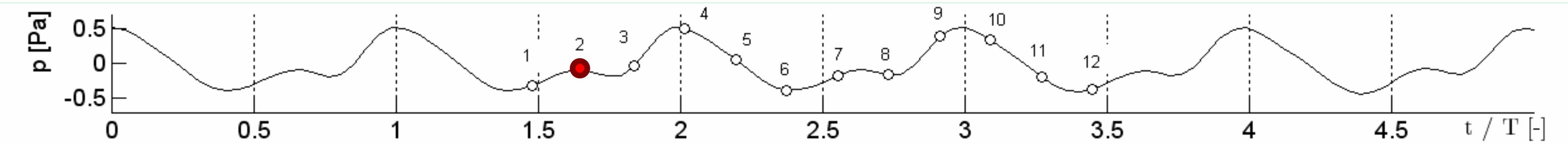
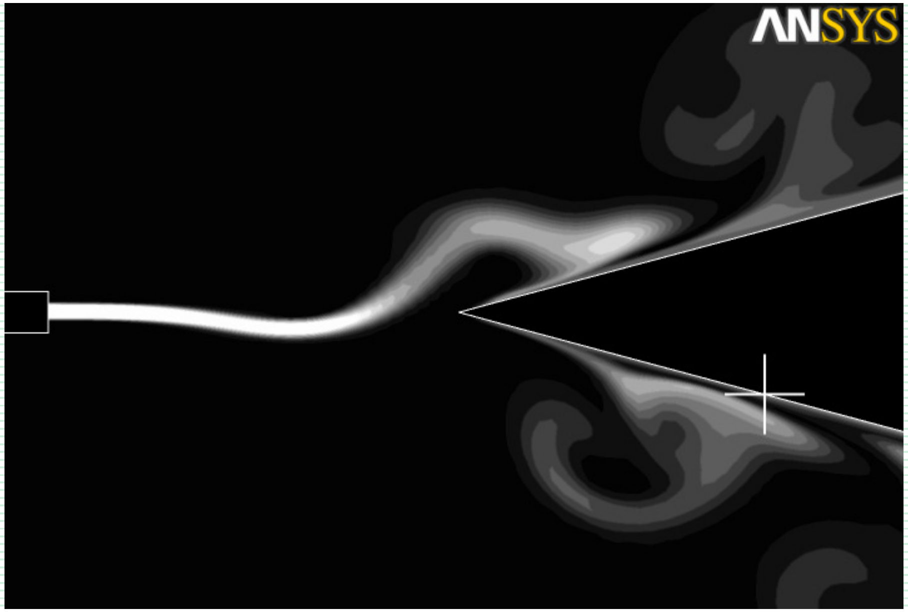
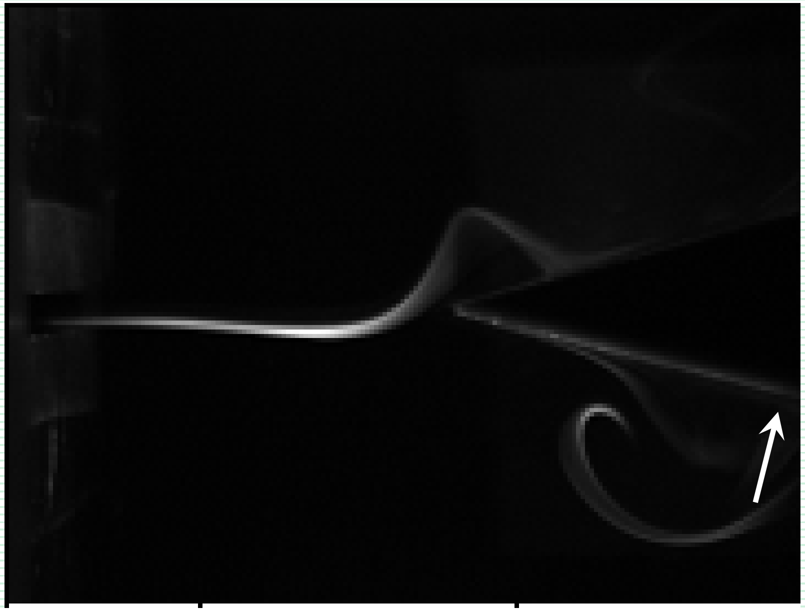
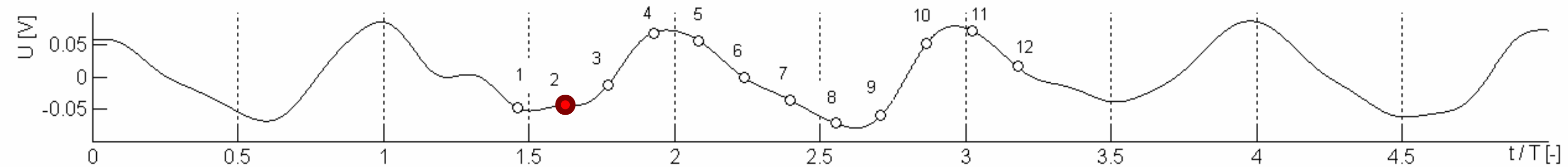
# Comparison of visualisation and computation II.



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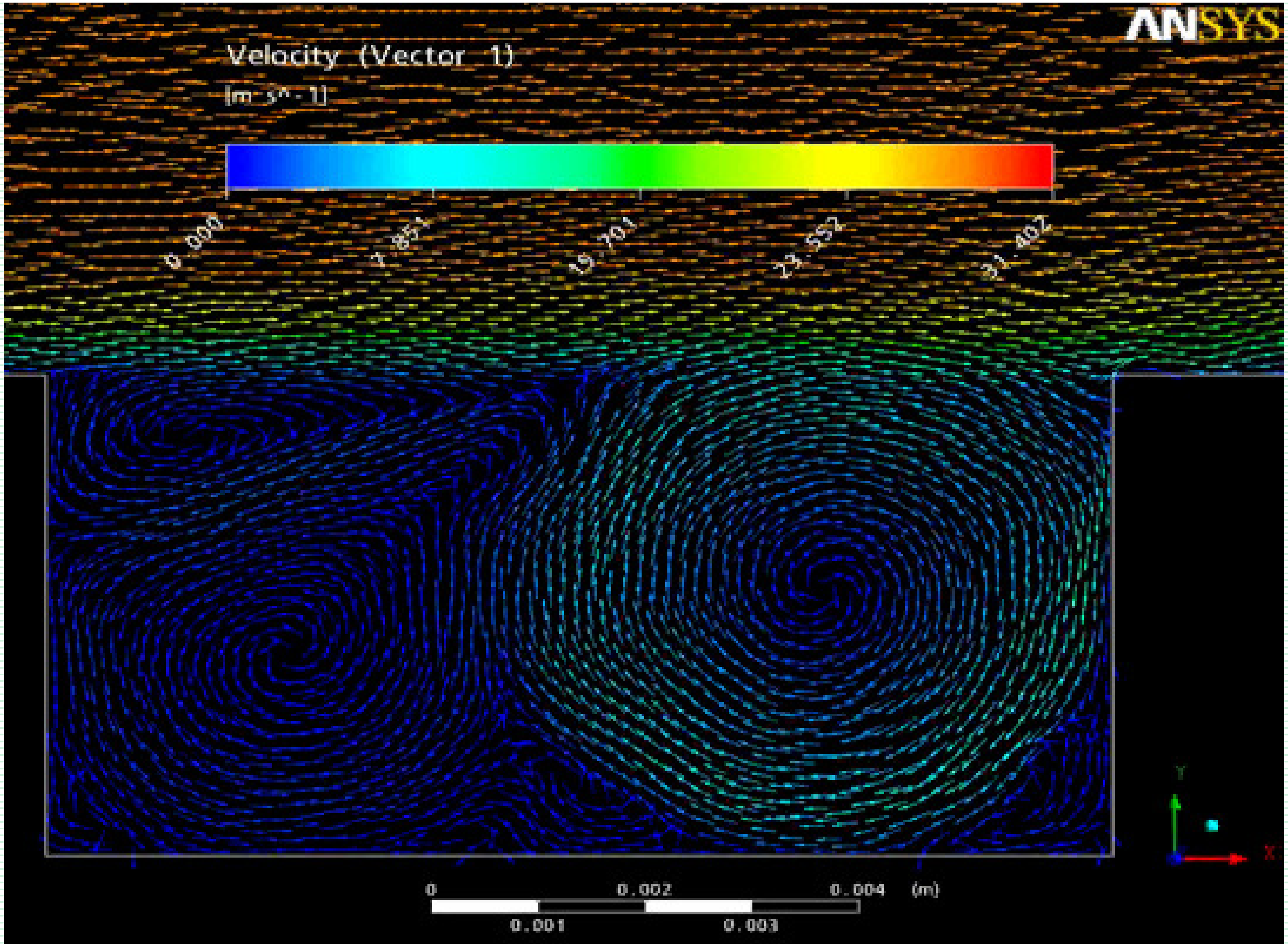
# Selected results for the cavity tone I.

- Rossiter modes: $f_n = \frac{U}{L}(n-\gamma)\cdot\kappa$ where $\gamma$ is a phase delay and $\kappa$ is a dimensionless disturbance wave propagation speed;
- Relevant length scale: incoming momentum thickness;
- With increasing speed or cavity length:

steady flow ⟶ shear layer mode ⟶ wake mode

# Shear layer mode

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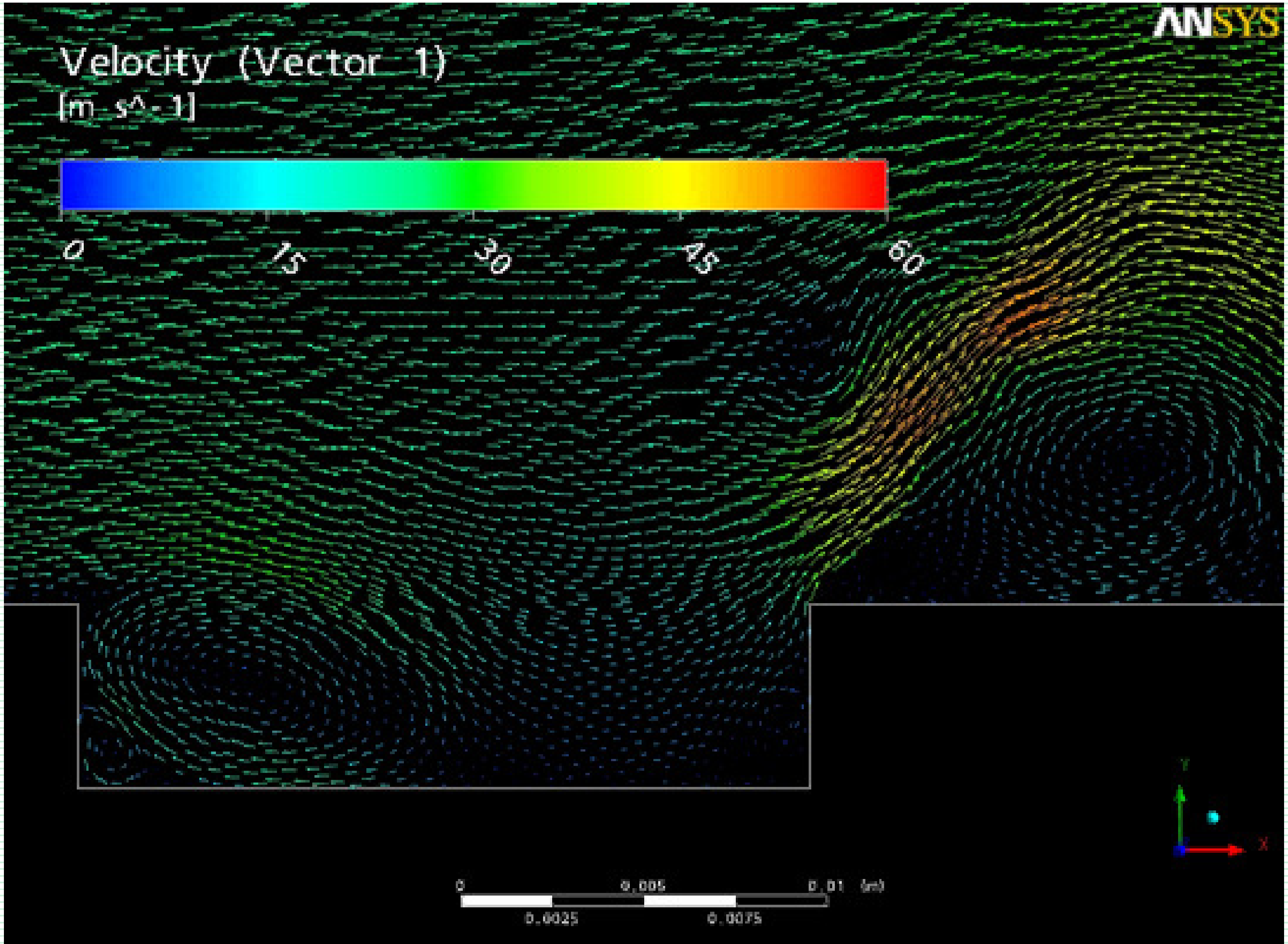
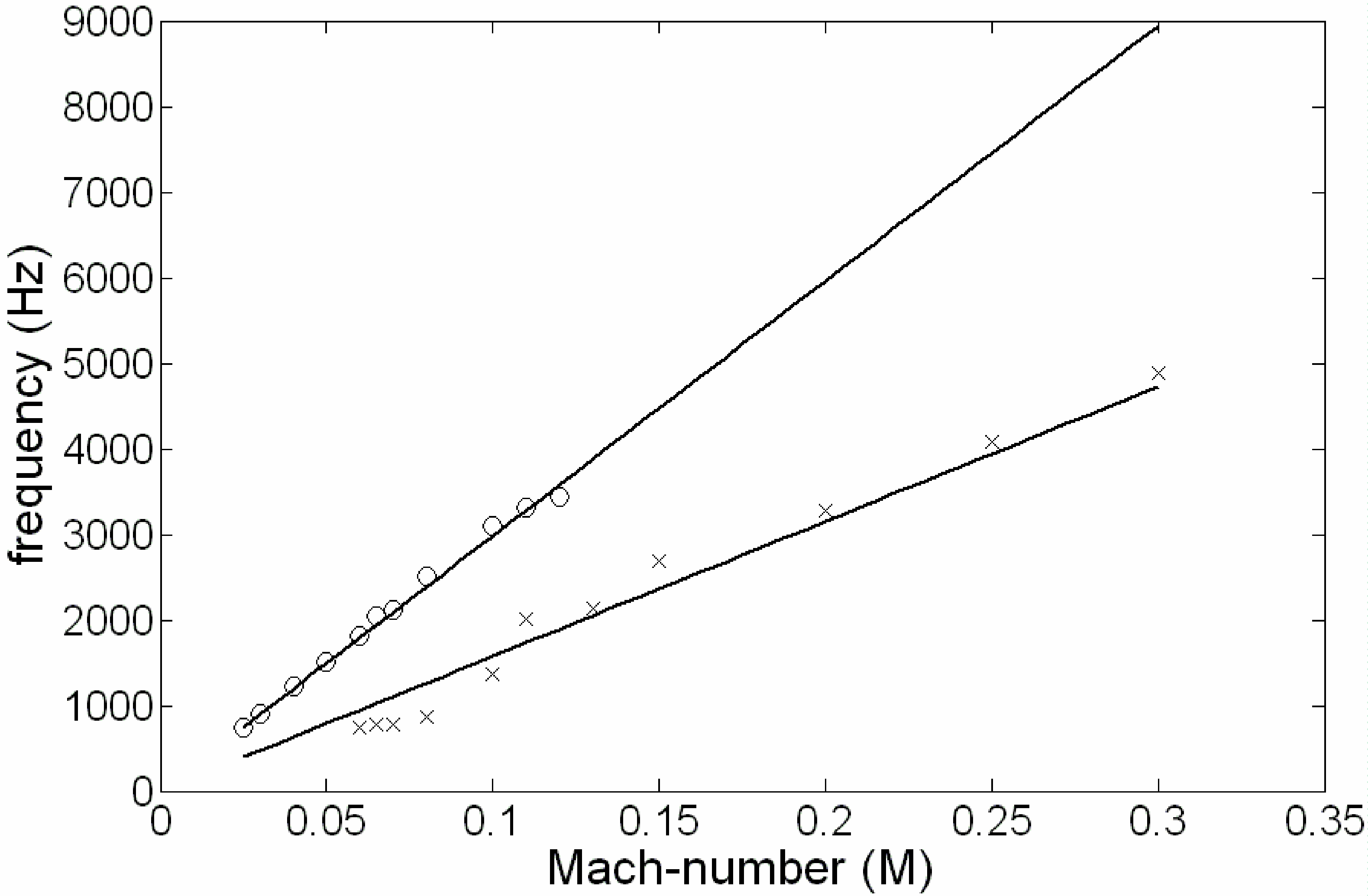
# Wake mode

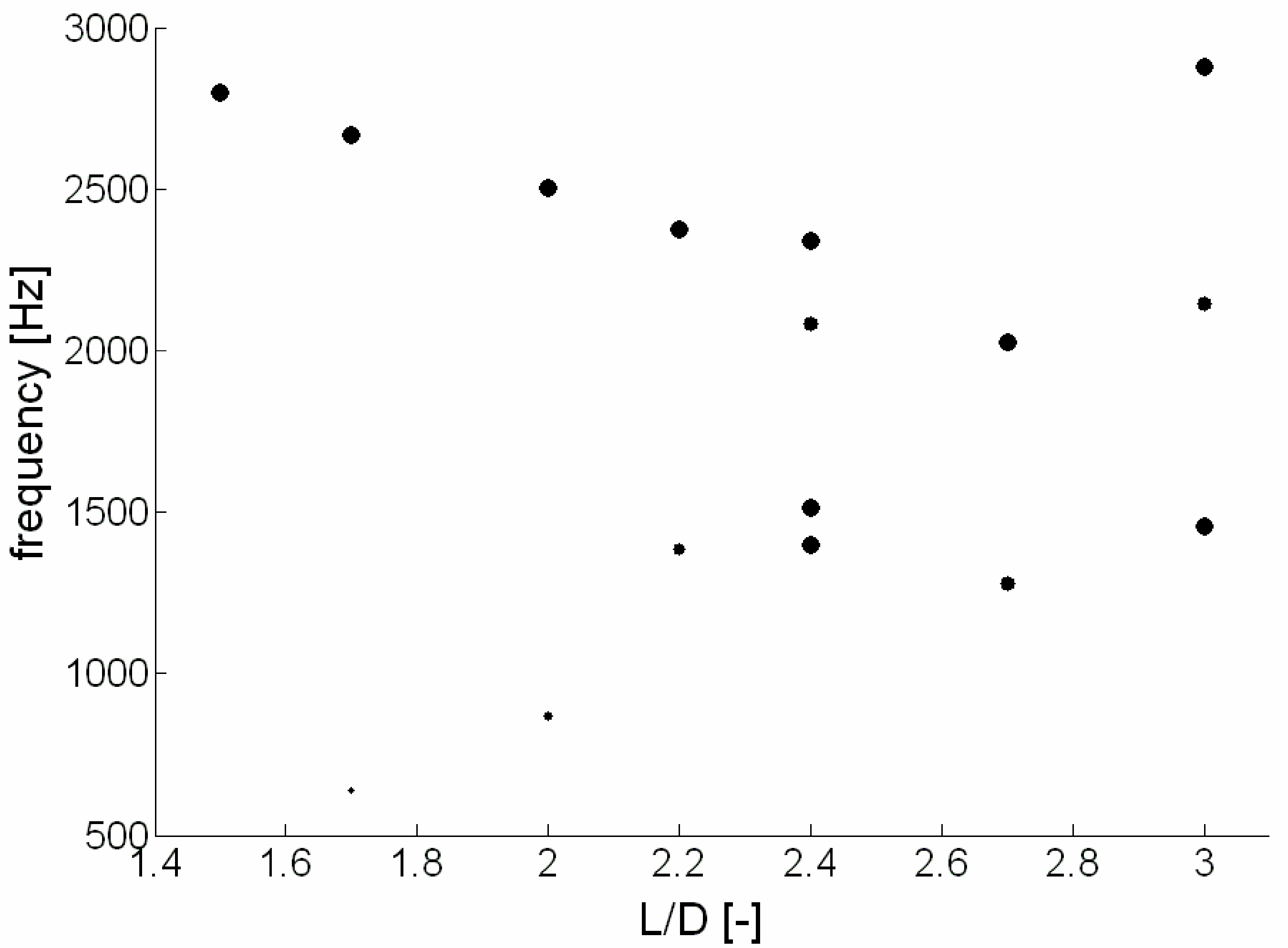


ANSYS
Velocity (Vector 1)
[m s^-1]
0
15
30
45
60
0
0.005
0.01 (m)
0.0025
0.0075
Y
X

# Selected results for the cavity tone II.



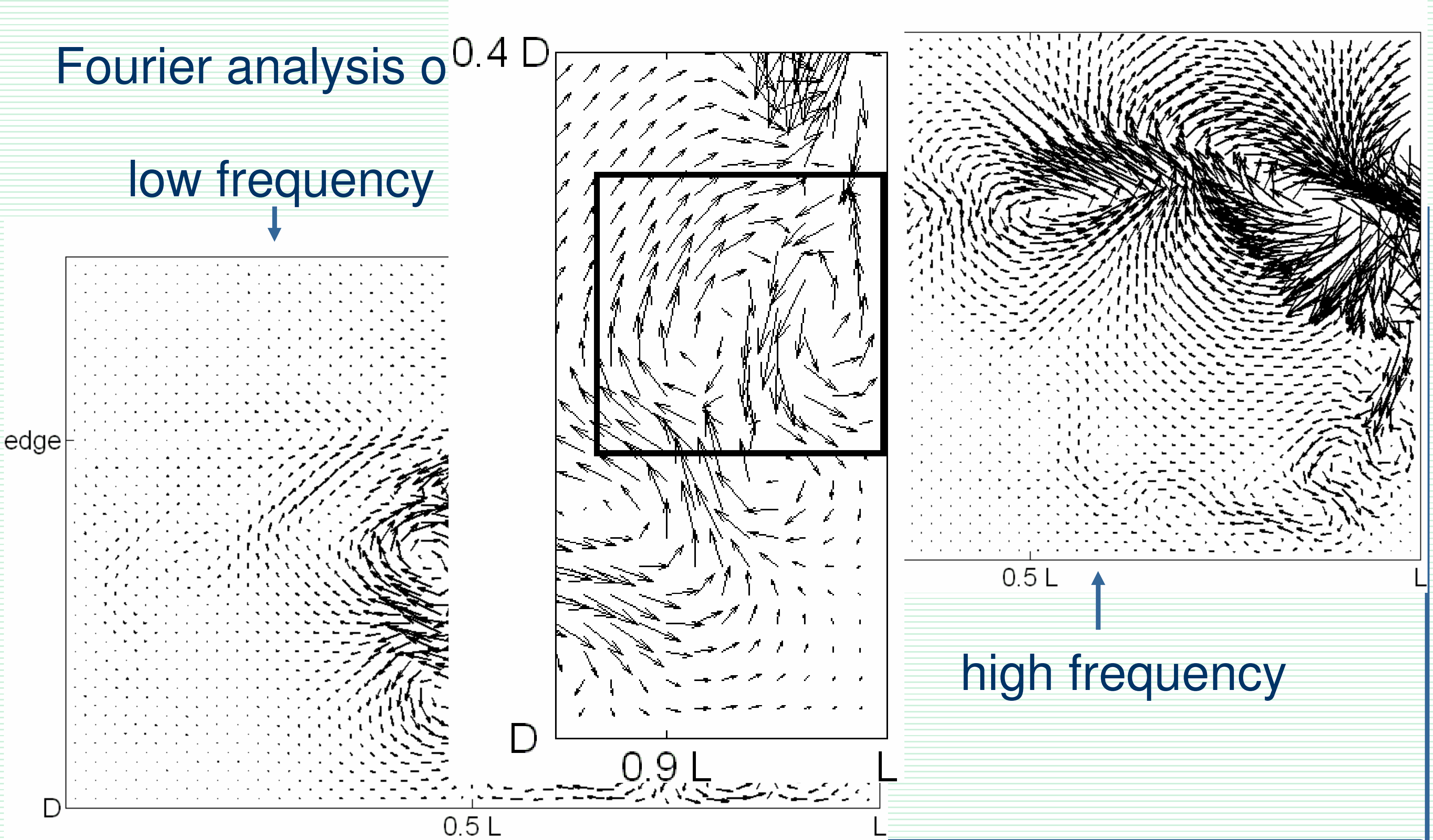
# Selected results for the cavity tone II.



# Selected results for the cavity tone IV.

Fourier analysis o

low frequency




high frequency

# Summary

- Having performed a large amount of accurate simulations, we succeded to reproduce the stages both for the edge tone and the cavity tone;
- Very good agreement was found between experiments, computations and literature in both cases (with the exception of the third stage of the edge tone);
- It was demonstrated  that the exponent of the h-dependence of the edge tone is -1 and not -3/2;
- Several new phenomena were detected, such as the appearance of a „modulating frequency” in the cavity tone case