7-2020

Noise Source Identification and Noise Directivity Analysis of Bladeless Fans by Combined CFD and CAA Method

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Influence of Geometric Parameters on Aerodynamic and Aeroacoustic Performance of Bladeless Fans

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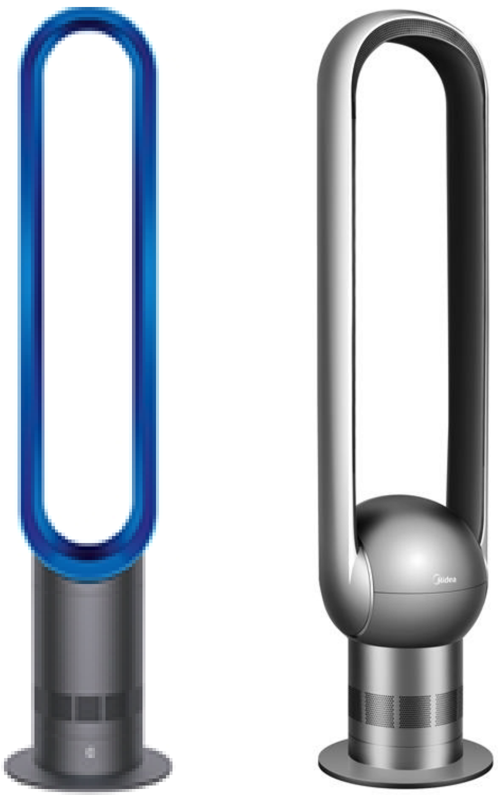
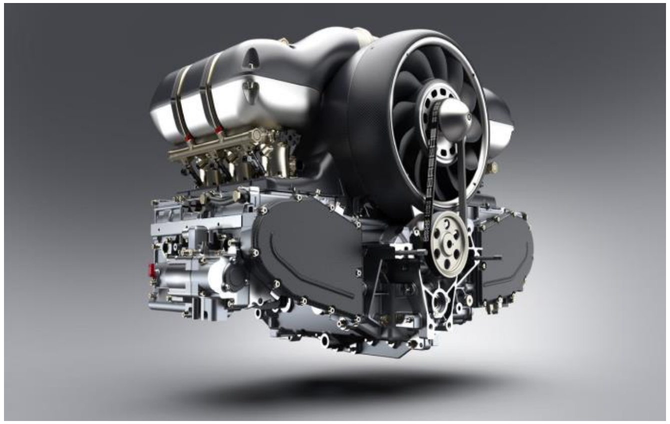
August 1st, 2019

OUTLINE

- Background & Motivation
- Methodology
  - Experiments
  - Numerical Simulations
- Results
- Conclusions

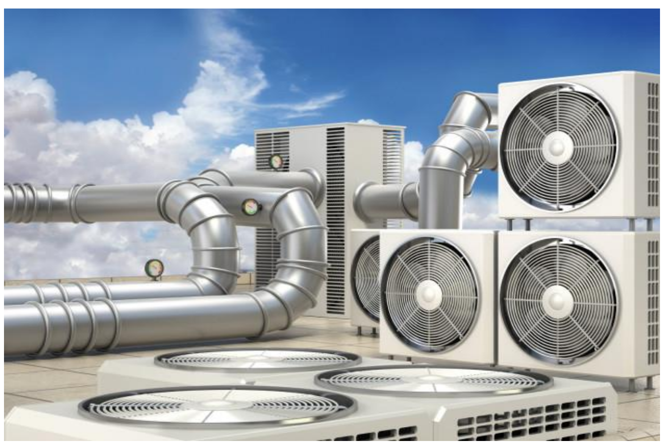


BACKGROUND: FANS IN INDUSTRY



Vehicle Engine

CPU Radiator Fan



HVAC

Cooling Fan

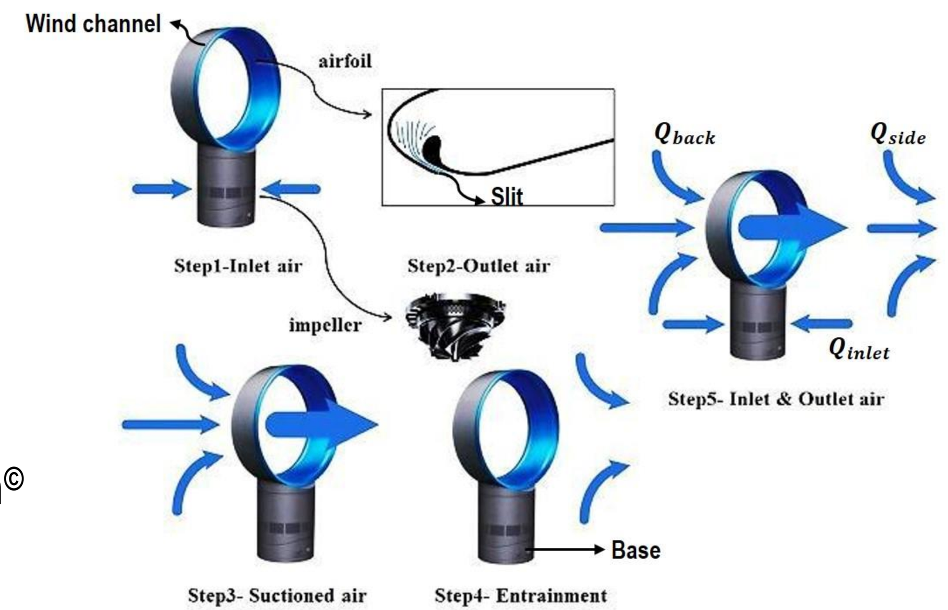
Applications
- Cooling system
- Ventilation
- Thermal comfort

Features
- High flow rate
- Low noise level

BLADELESS FAN

- Bladeless fans launched by Dyson©

Working mechanism of the bladeless fan



Jafari *et al.* (2015)

Advantages

– The produced wind is softer and more uniform.

– Flow rate at downstream is larger.

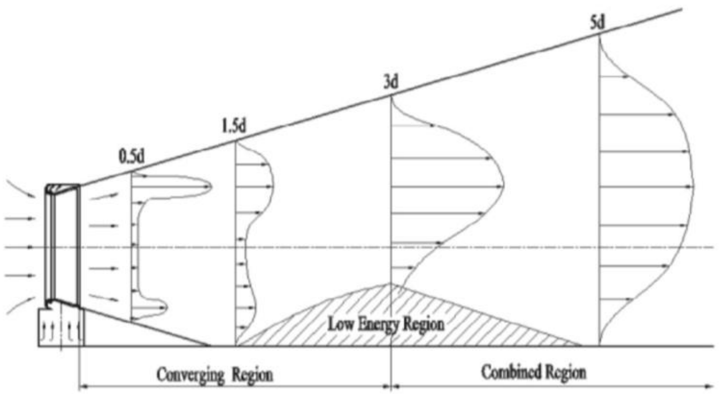
– No visible rotating blade is safer for children.

AN EXAMPLE OF THE BLADELESS FAN

– UK, Dyson. “Dyson Cool Fans - Air Multiplier Technology Explained - Official Video.” YouTube, YouTube, 5 Mar. 2014, www.youtube.com/watch?v=bUJ-X1rsKV4.

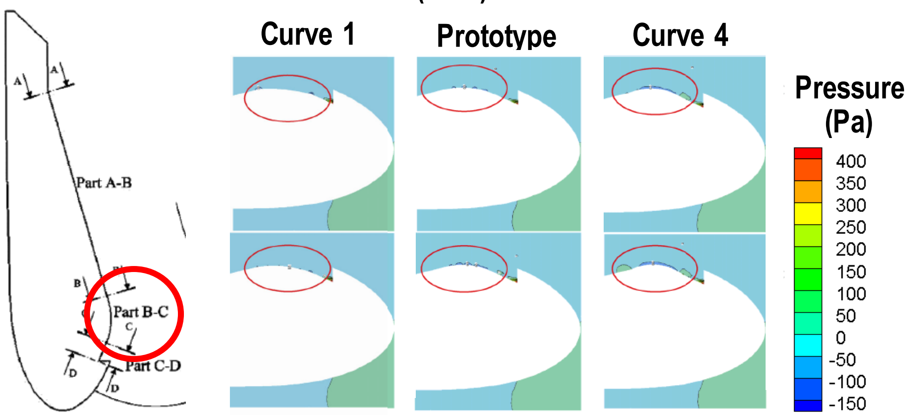
Previous work

Li *et al.* (2016)



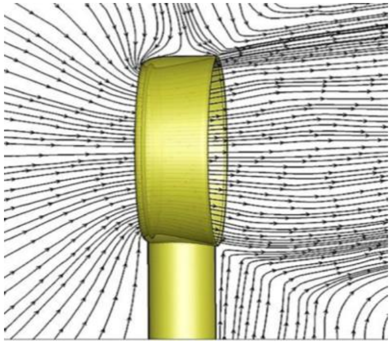
Flow field structure outside the bladeless fan over the center plane

Li *et al.* (2014)



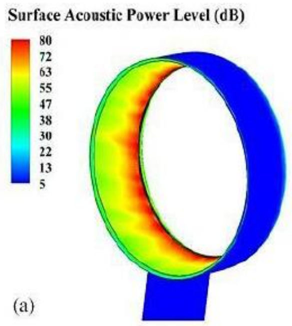
Pressure distribution near the slit with different Coanda surface curvatures

Jafari *et al.* (2015)



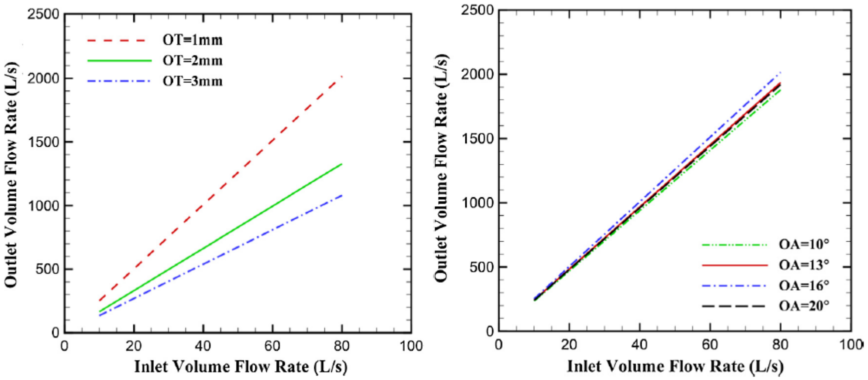
Streamlines outside the bladeless fan over the center plane

Jafari *et al.* (2016)



Sound power contour

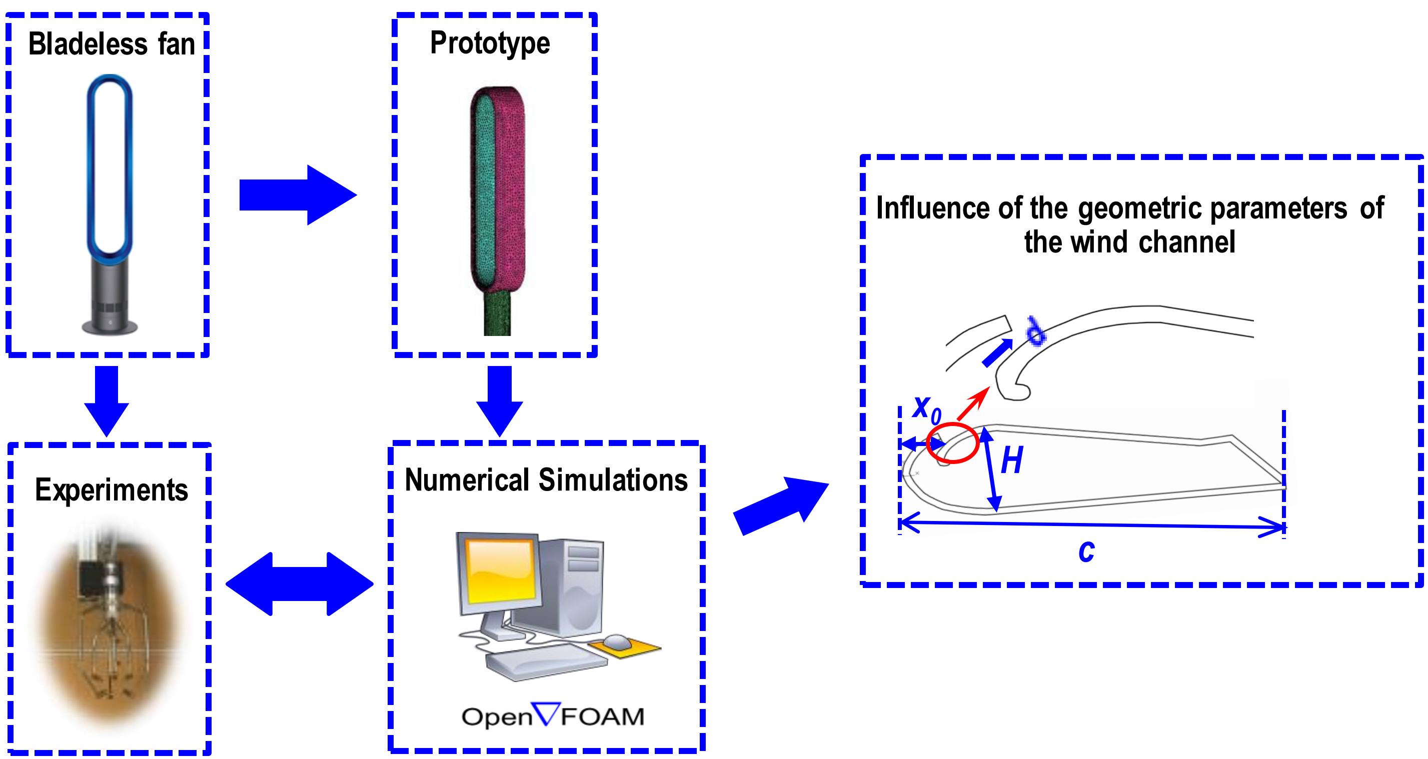
Jafari *et al.* (2016)



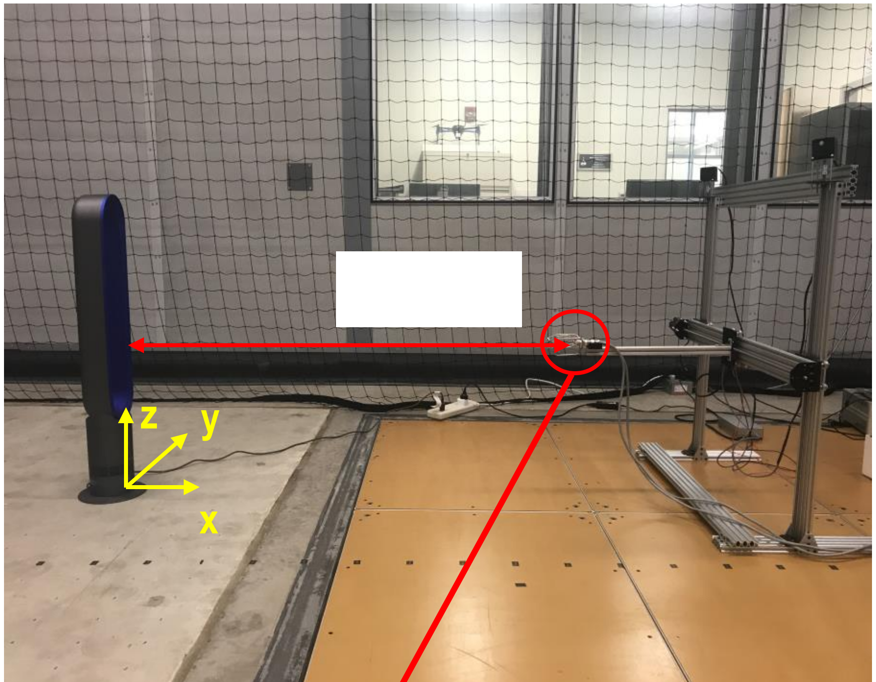
Effect of the outlet thickness and outlet angle on volume flow rate at downstream

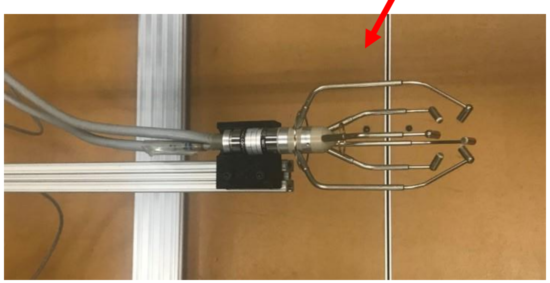
OBJECTIVE & RESEARCH STRATEGY

- Characterize the aerodynamic and aeroacoustic performances of the bladeless fan by a combined 3D numerical and experimental study
- Investigate the influence of geometric parameters of the wind channel on bladeless fan's performance



METHODOLOGY: VELOCITY MEASUREMENT AT FAR FIELD

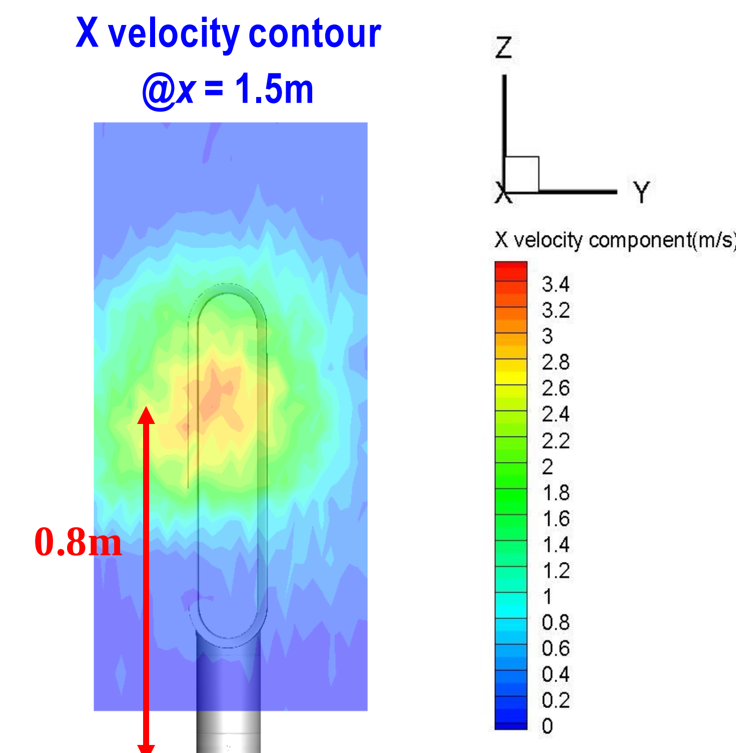




3D ultrasonic anemometer

Measurement in Herrick PBE Lab

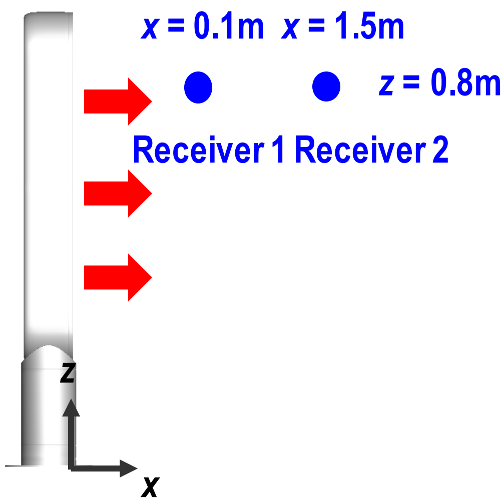
- Measurement position: 837
- Measurement duration at each position: 30s
- Sampling rate: 1s
- Accuracy: ±(2%+0.03m/s of indicated values)



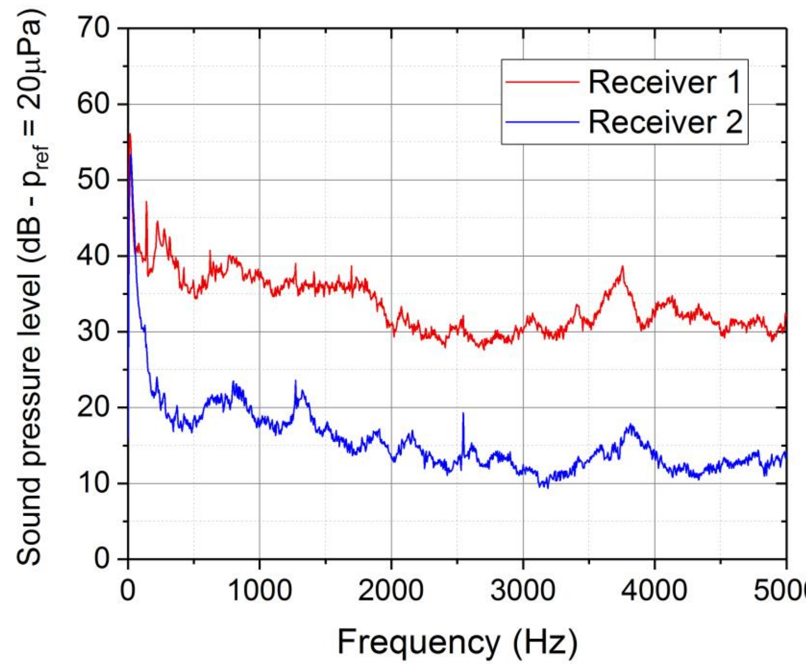
METHODOLOGY: SOUND PRESSURE MEASUREMENT AT RECEIVERS

Measurement in Herrick anechoic chamber

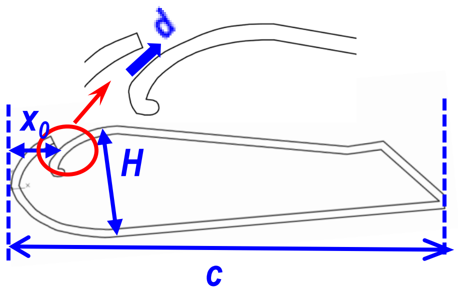
B&K intensity probe



Sound pressure level @ two receivers

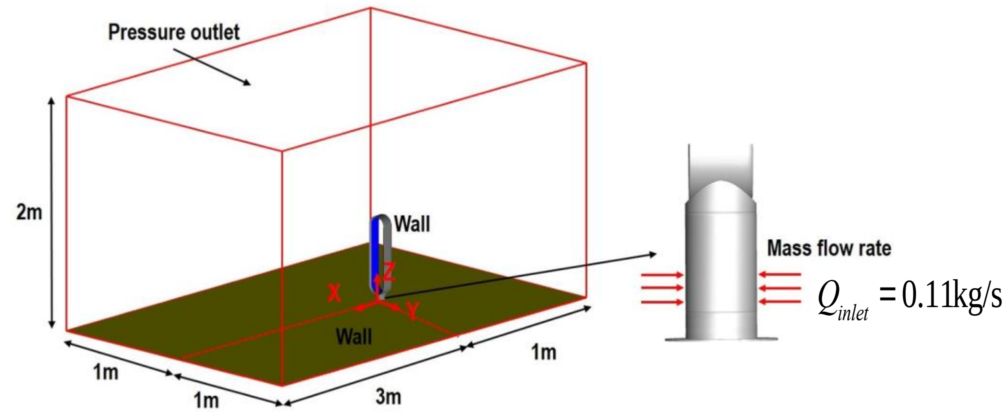


PROTOTYPE OF THE BLADELESS FAN

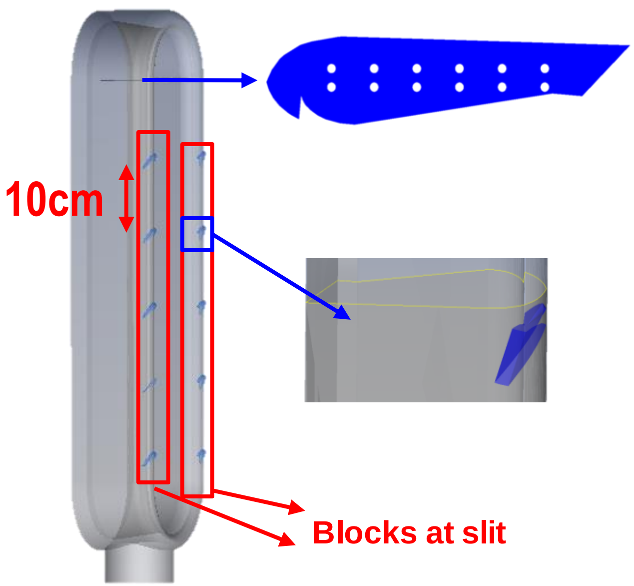


d=2mm, H=3cm, c=12cm, x_0/c=10%

Cross-section of the wind channel



Computational domain



Wind channel

Temperature: 25℃~ 30℃

Reynolds number at the intake and the slit:

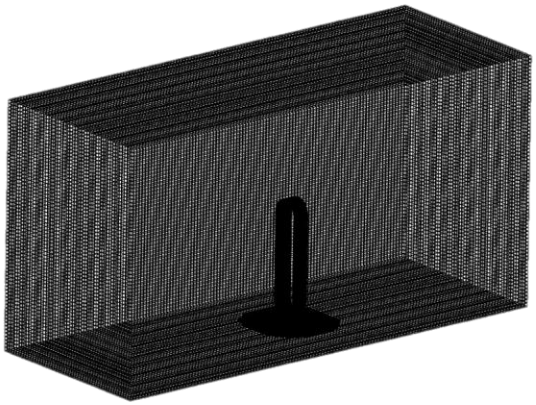
$\mathrm{Re}_{\mathrm{intake}} = 6723, \mathrm{Re}_{\mathrm{slit}} = 3000\sim4100$

Simulation Set-up

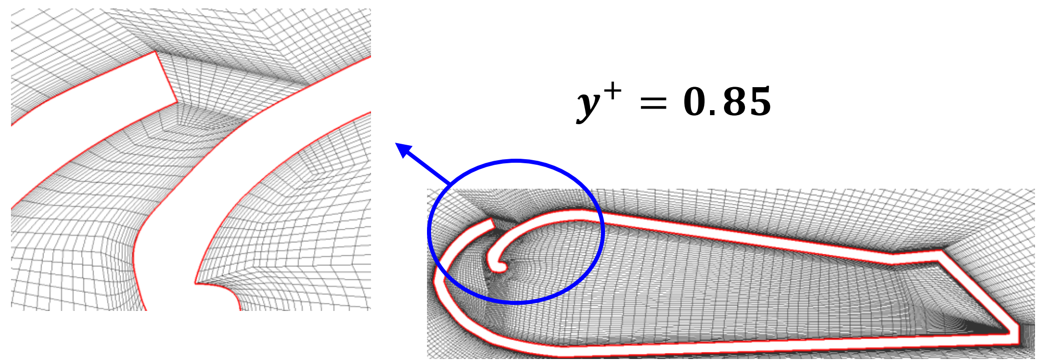
- The number of grids: 6,320,000
- Steady RANS: $k-\varepsilon$ model
- LES: Smagorinsky-Lilly model
- Time step: 1×10^{-4}s
- Flow solver: SIMPLE

MESH GENERATION OF THE BLADELESS FAN

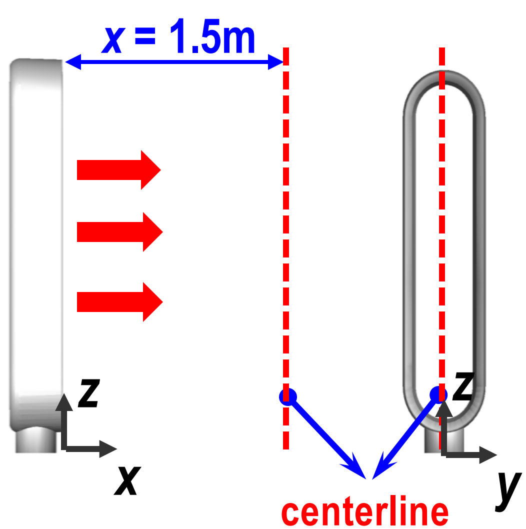
- Mesh for the computational domain

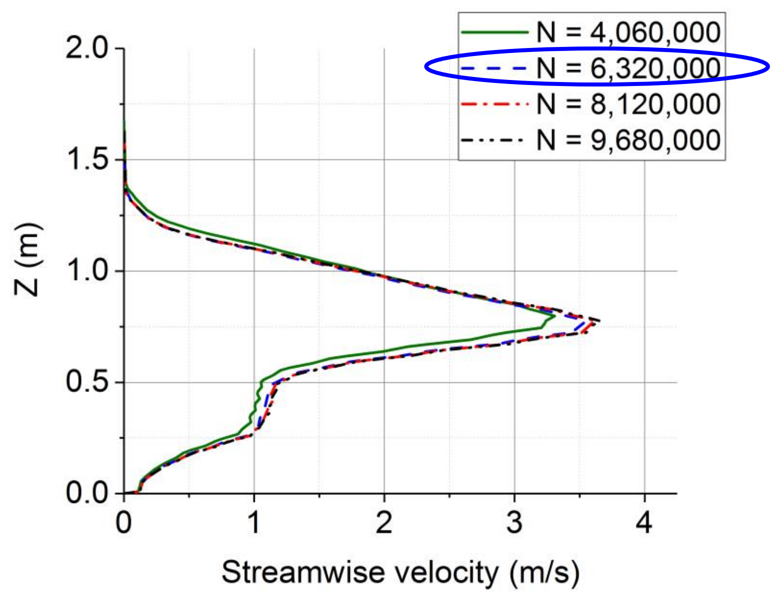


- Mesh for the cross-section of the wind channel

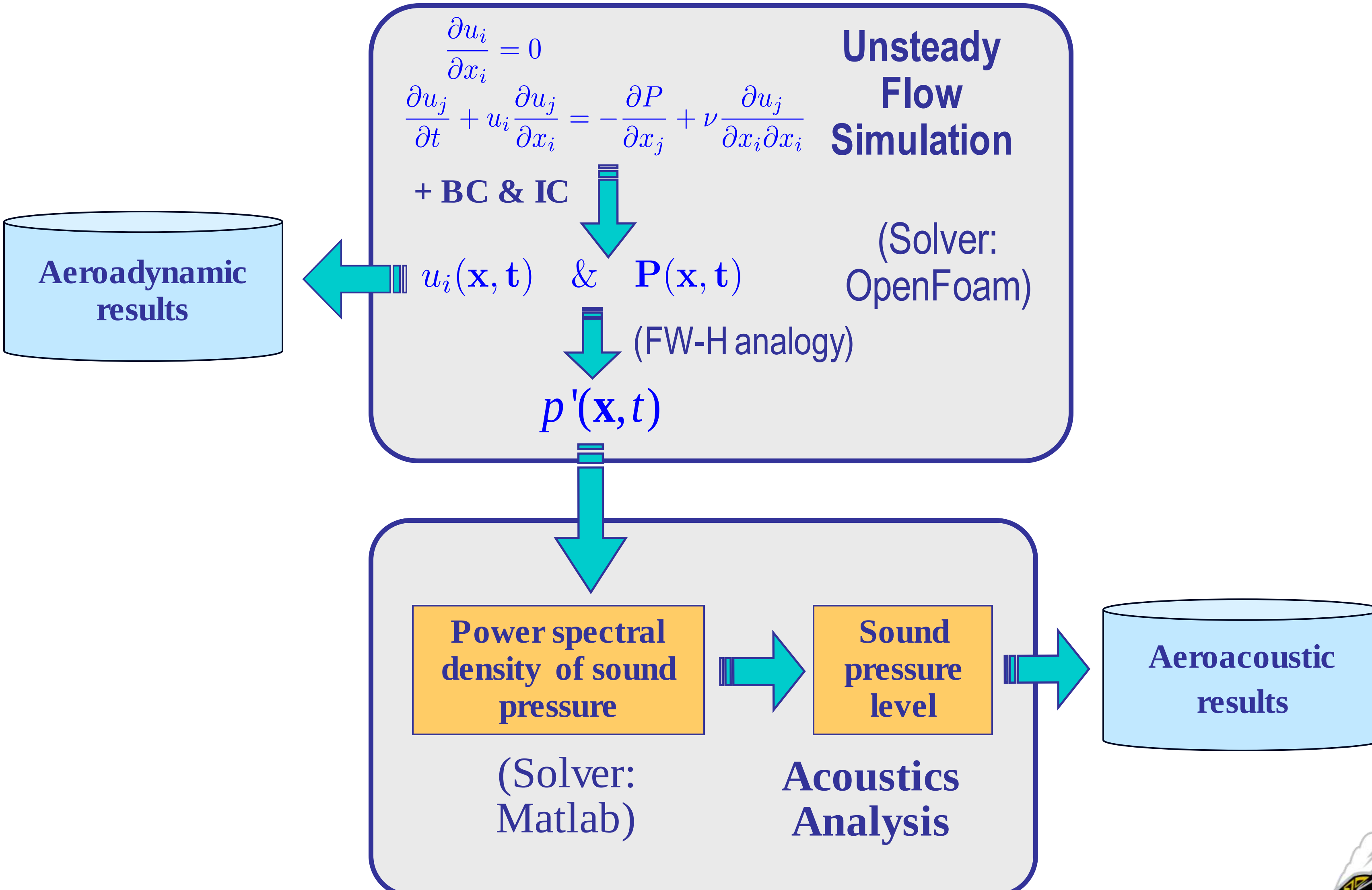


– Mesh independency test



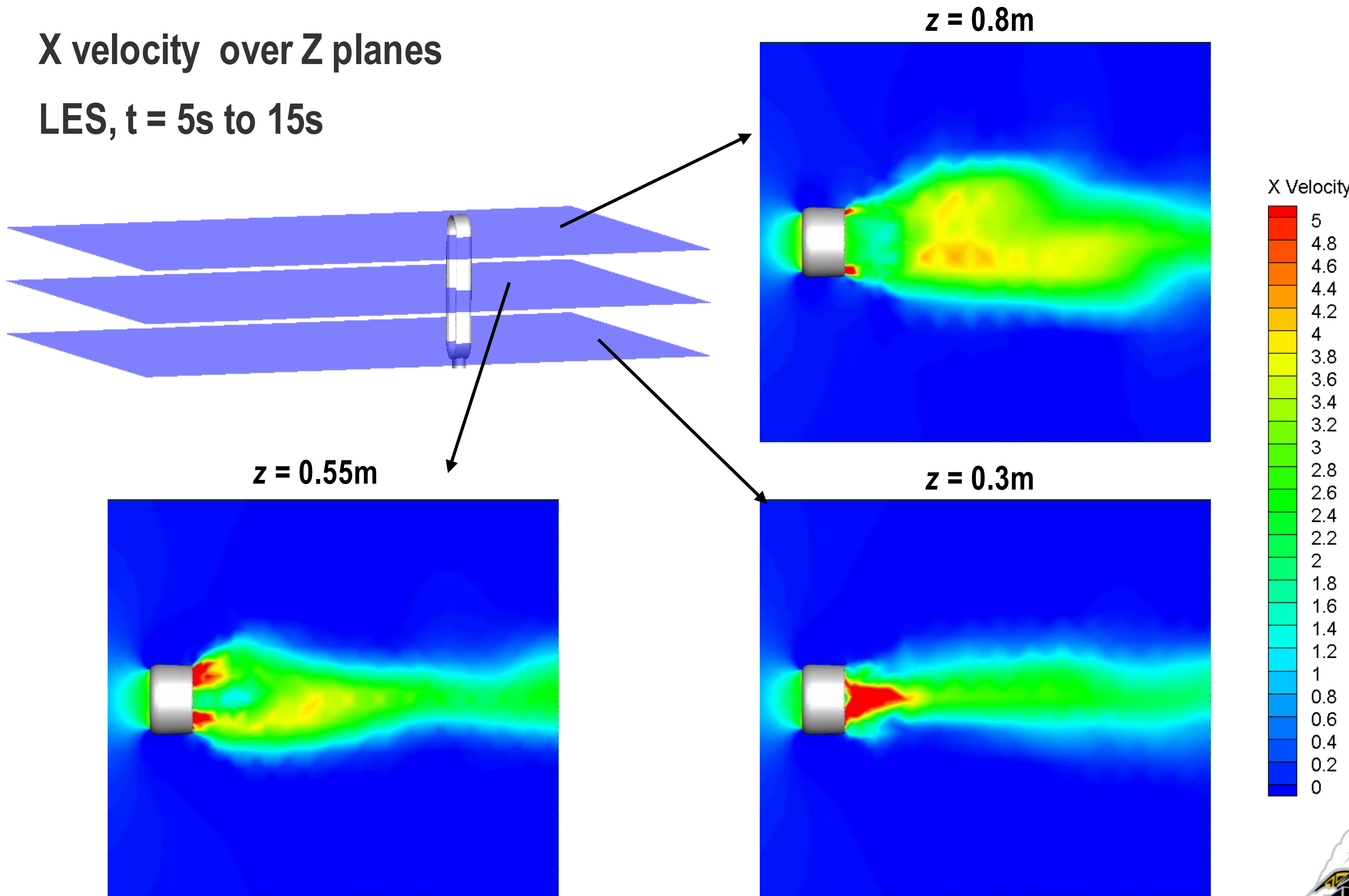


METHODOLOGY: DATA POSTPROCESSING



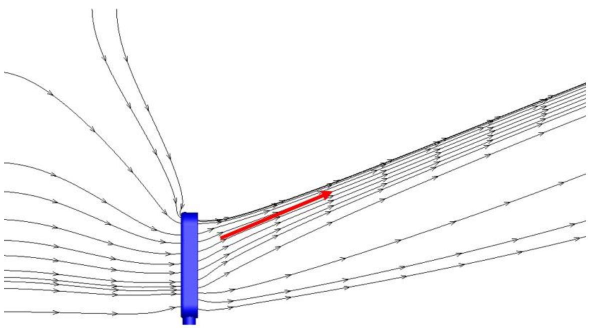
RESULTS: INSTANTANEOUS FLOW FIELD

- X velocity over Z planes
- LES, t = 5s to 15s

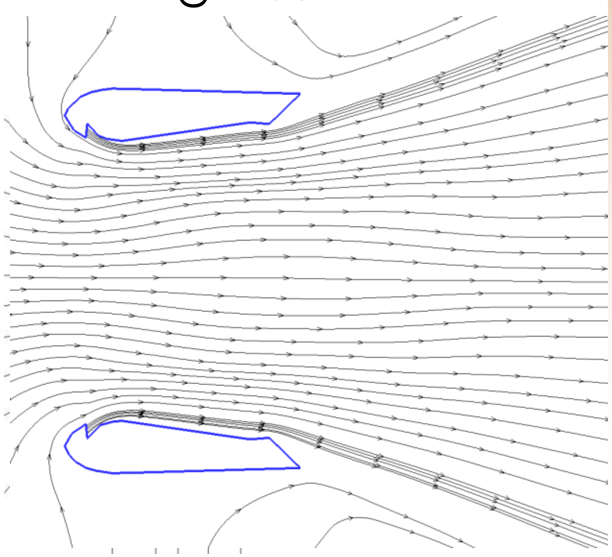


AERODYNAMIC CHARACTERISTICS: MEAN FLOW

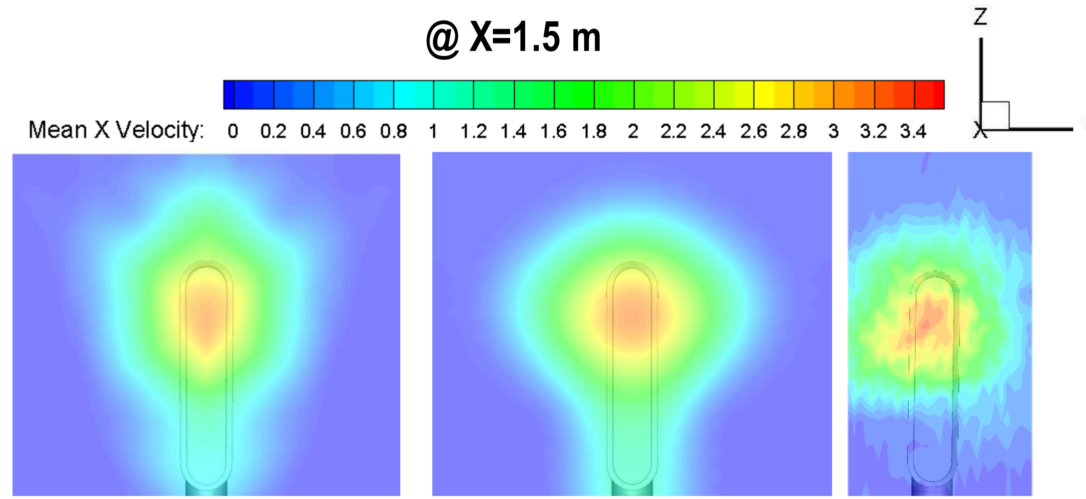
@ the center plane of the bladeless fan



@ *z* = 0.8m



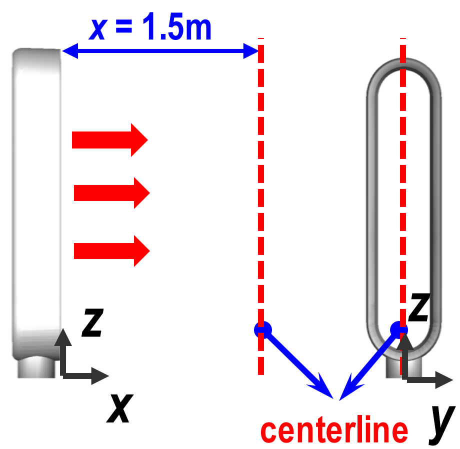
@ X=1.5 m

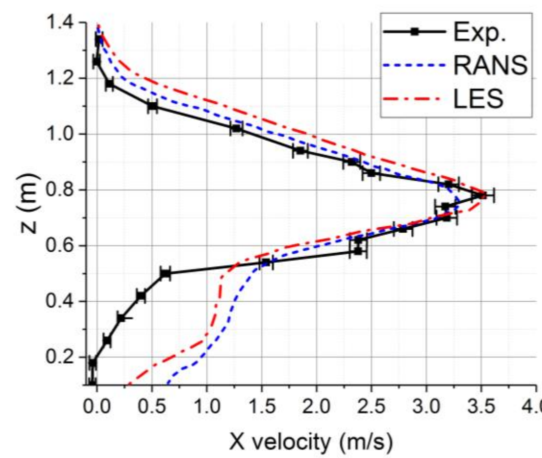


LES, time-averaged (t = 4s to 15s)

RANS

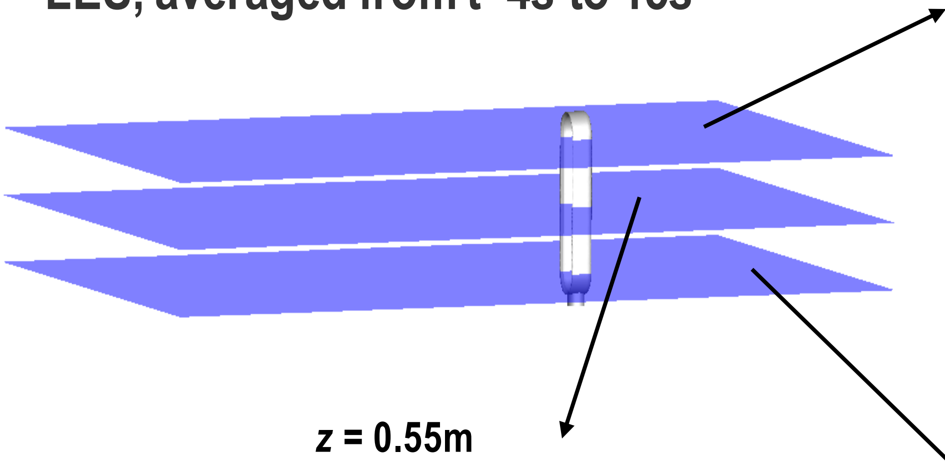
Exp.

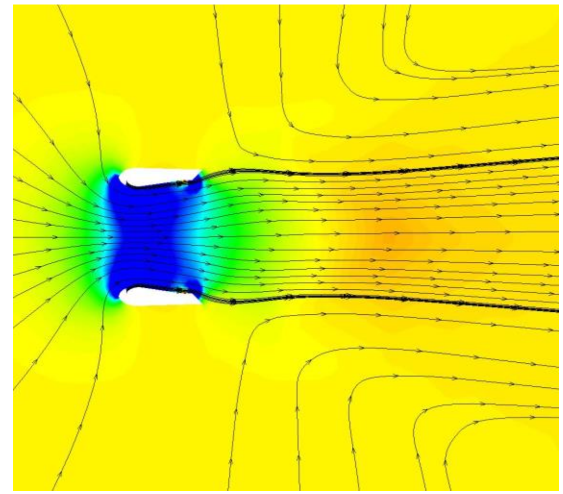


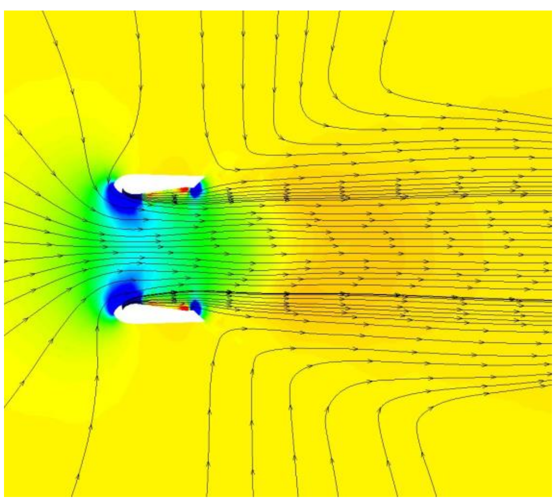


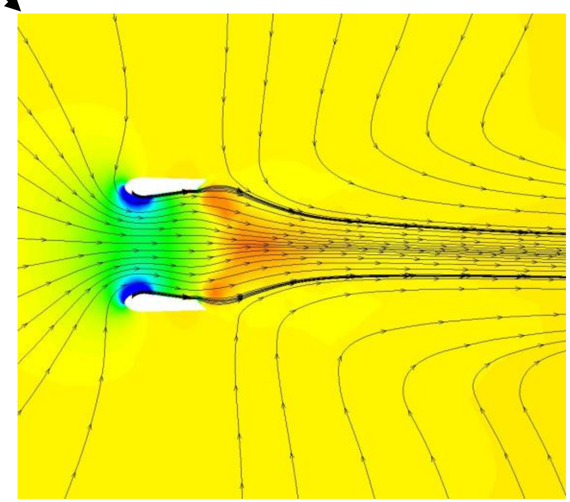
Aerodynamic characteristics: Mean pressure

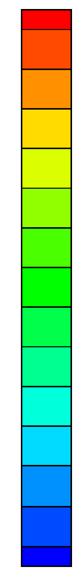
- Pressure over Z planes
- LES, averaged from t=4s to 15s



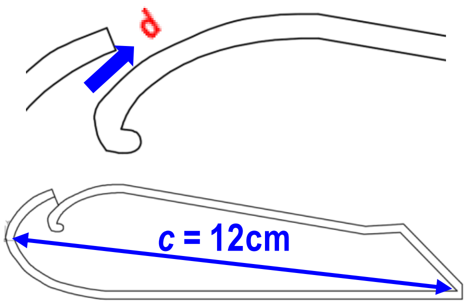




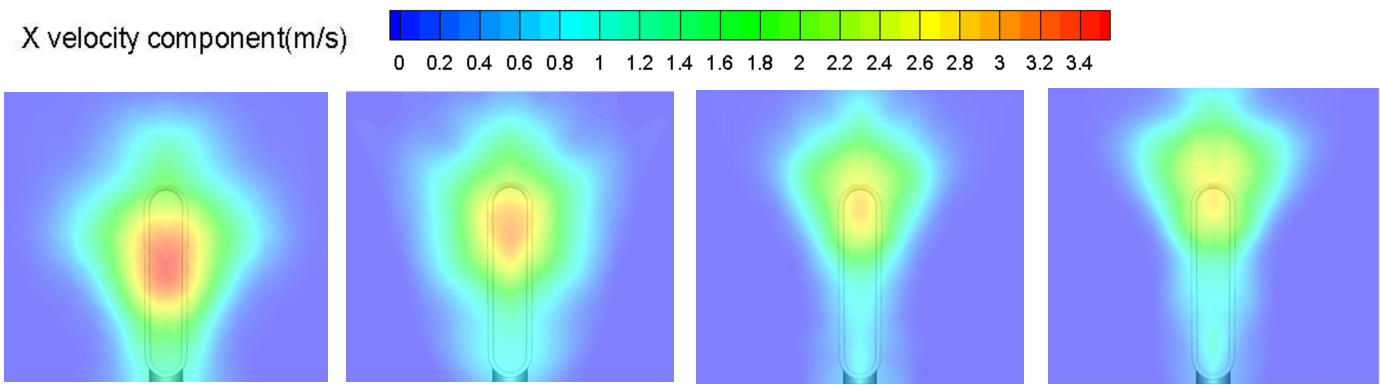




EFFECT OF THE SLIT WIDTH

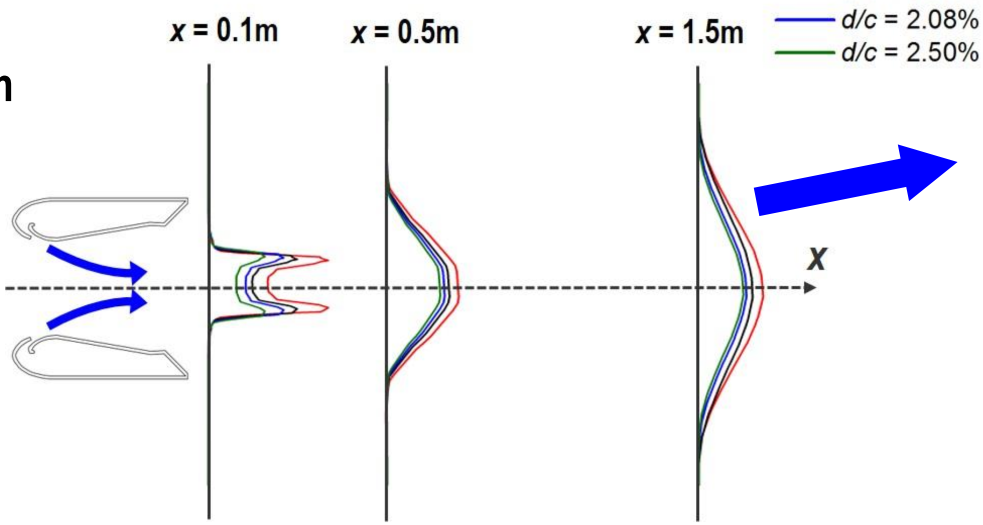


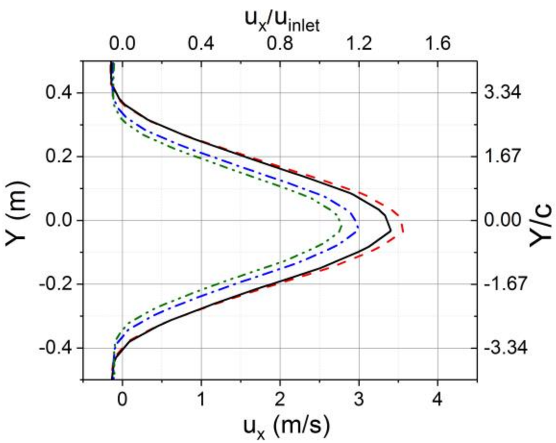
LES, time averaged for t = 4s to 15s, @ *x* =1.5 m



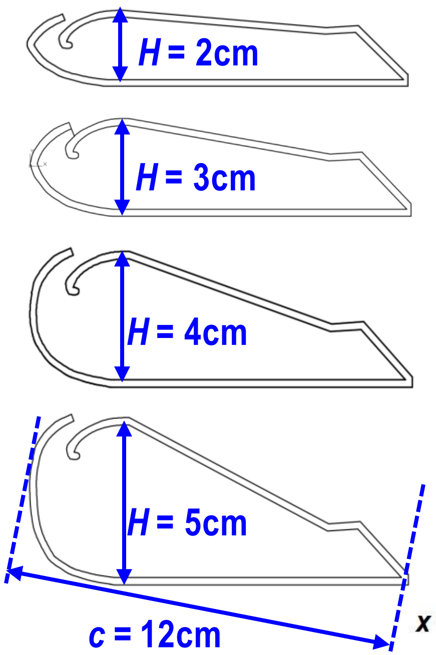
d/c = 1.25% *d/c* = 1.67% (baseline) *d/c* = 2.08% *d/c* = 2.50%

@ *z* = 0.8m

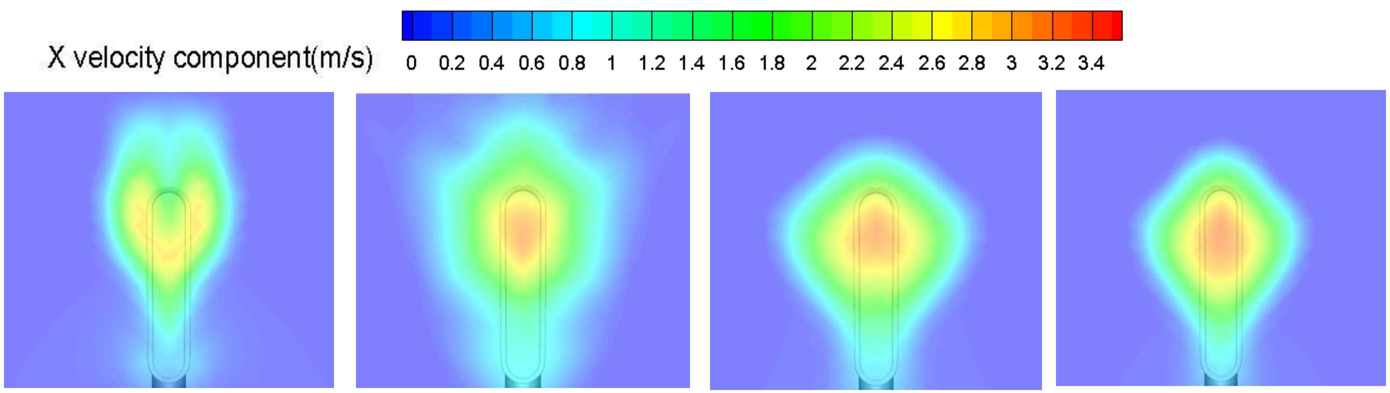




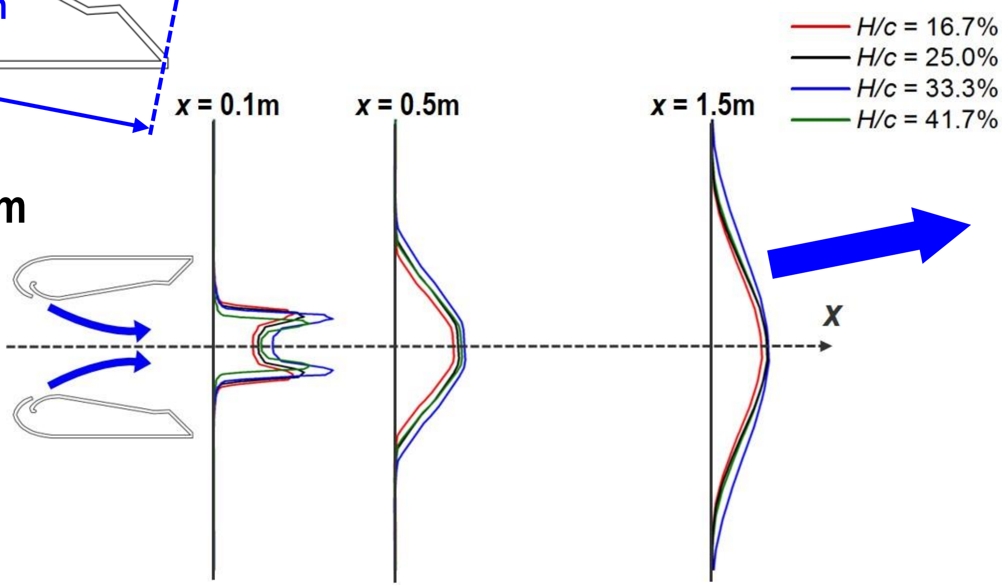
EFFECT OF THE CROSS-SECTION HEIGHT

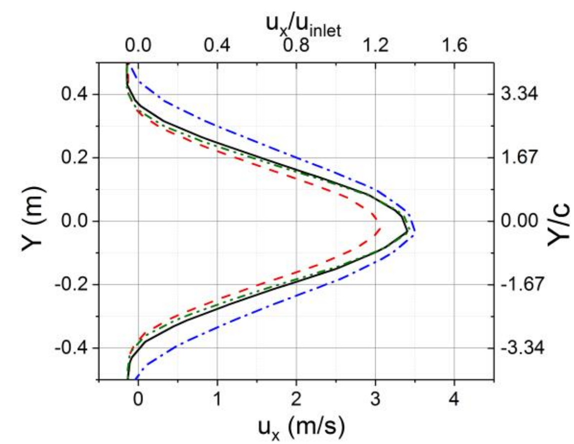


LES, time averaged for t = 4s to 15s, @ *x* =1.5 m

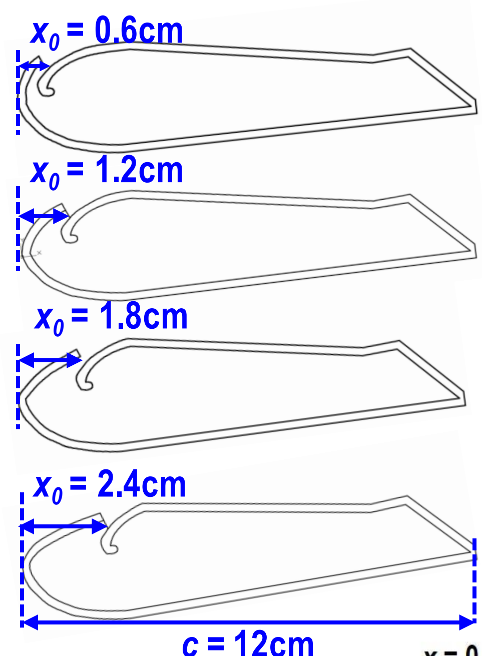


@ *z* = 0.8m

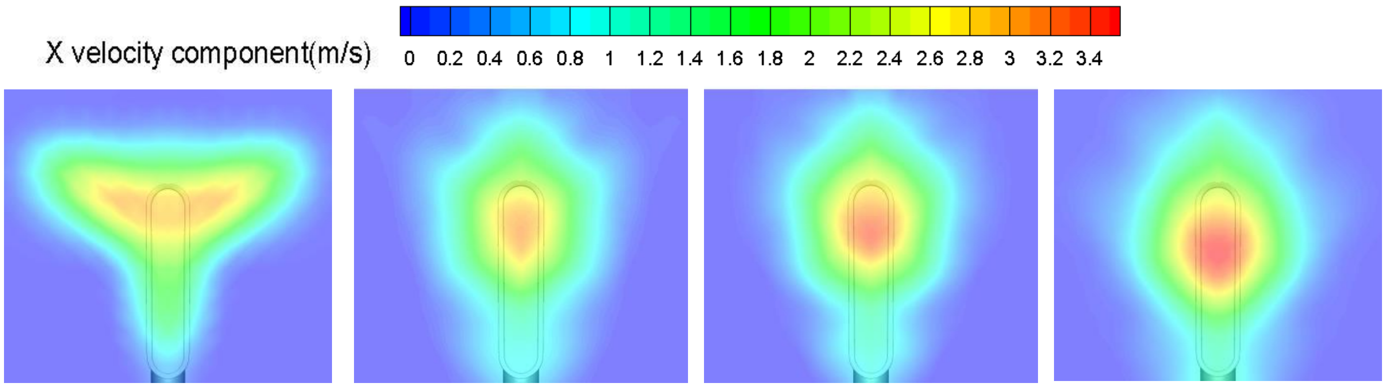




EFFECT OF THE SLIT LOCATION

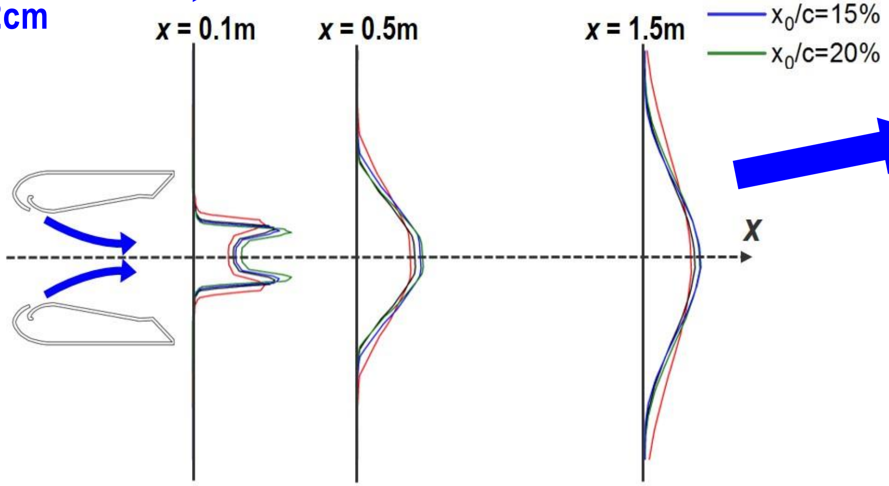


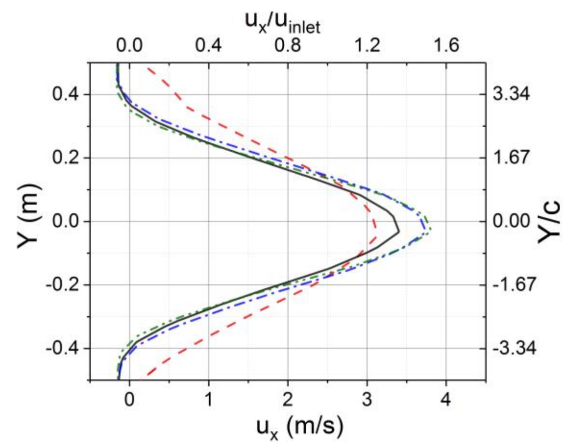
LES, time averaged for t = 4s to 15s, @ x =1.5 m



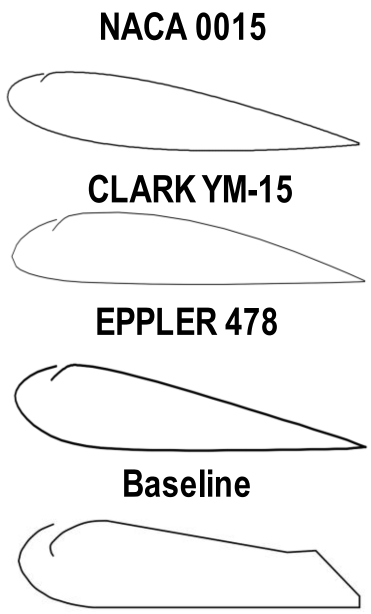
x_0/c = 5% | x_0/c = 10% (baseline) | x_0/c = 15% | x_0/c = 20%

@ z = 0.8m

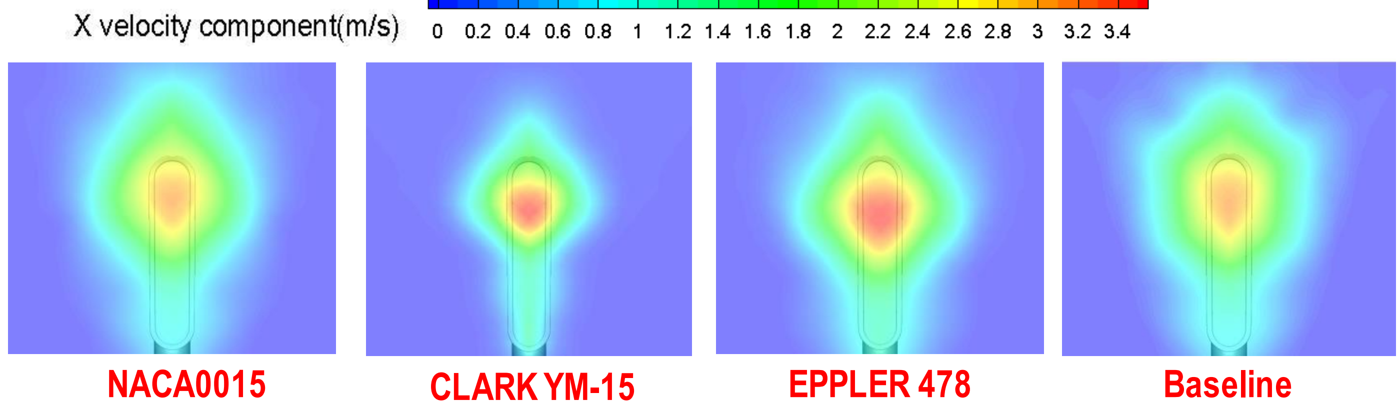




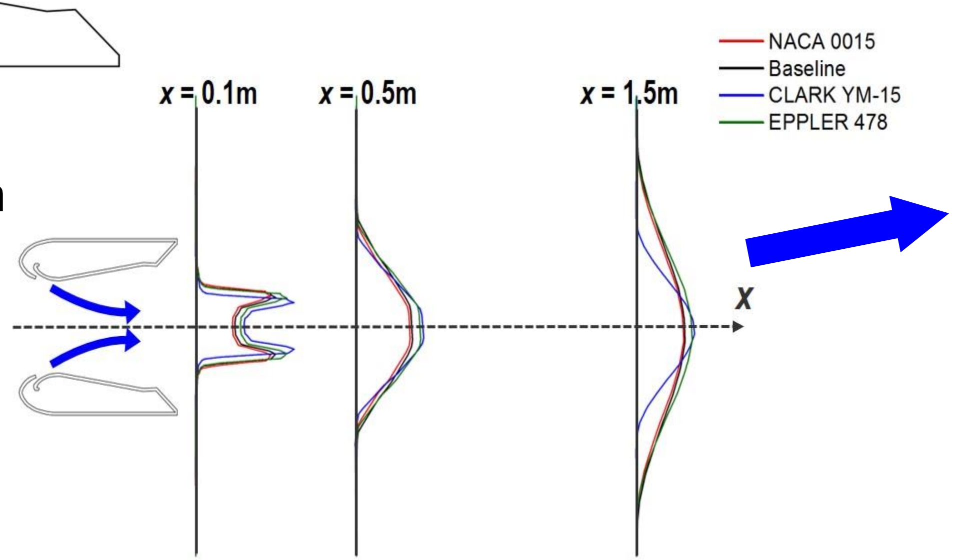
EFFECT OF THE PROFILE OF CROSS-SECTION

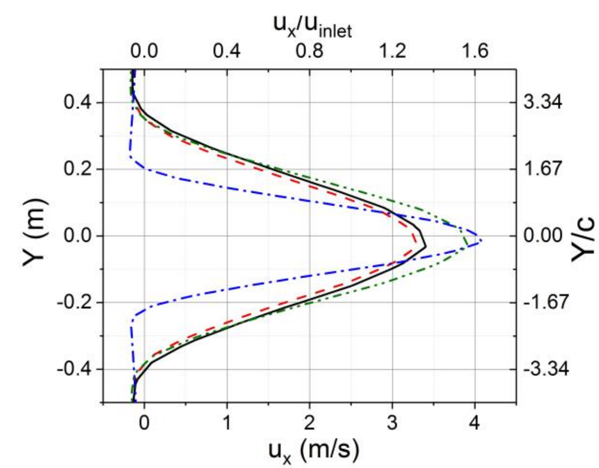


LES, time averaged for t = 4s to 15s, @ *x* =1.5 m

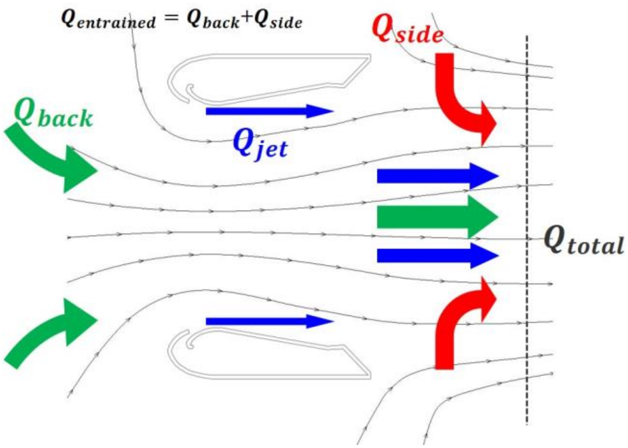


@ *z* = 0.8m





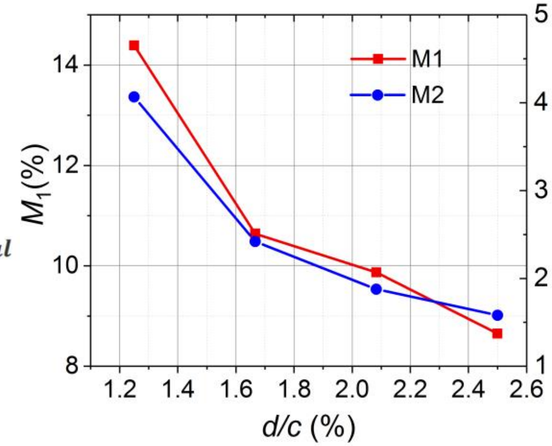
RATIO OF MASS FLOW RATE



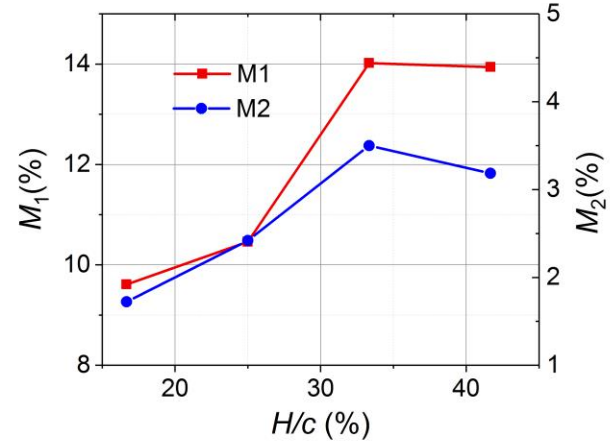
$$M_1 = \frac{Q_{total}}{Q_{inlet}}$$

$$M_2 = \frac{Q_{back}}{Q_{inlet}}$$

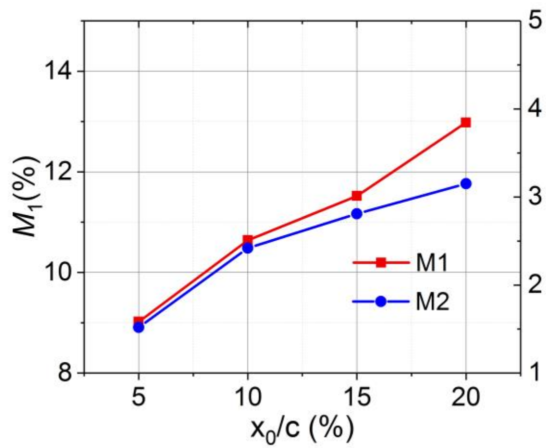
Effect of slit width



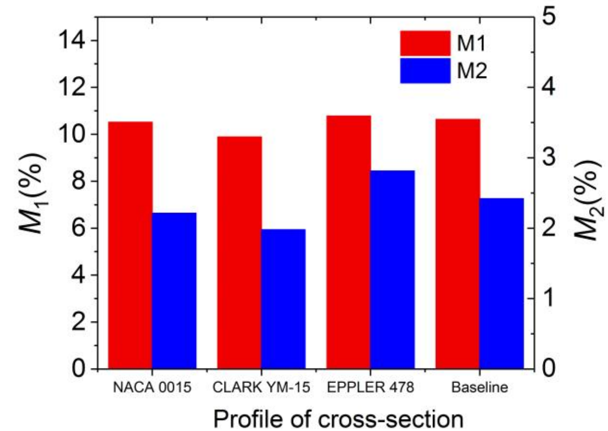
Effect of cross-section height



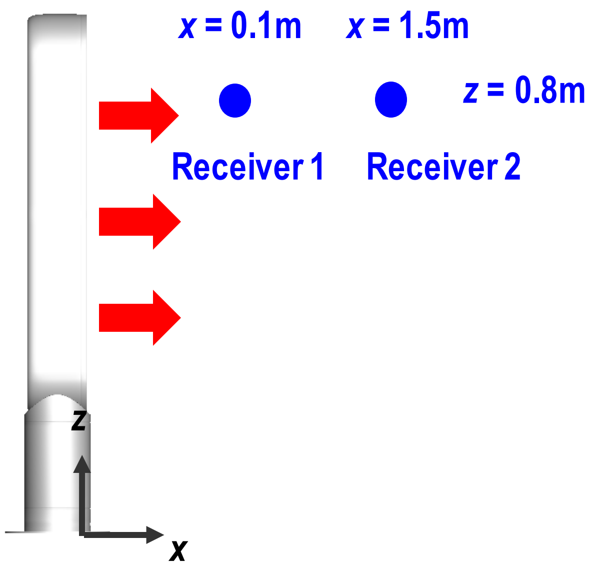
Effect of slit location



Effect of profile of the cross-section

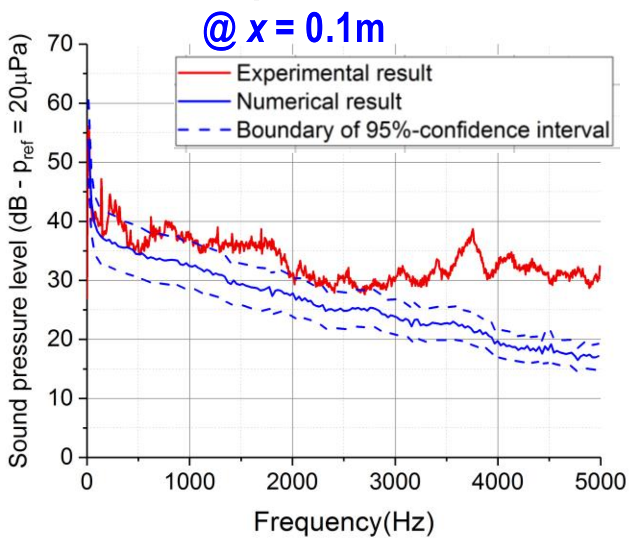


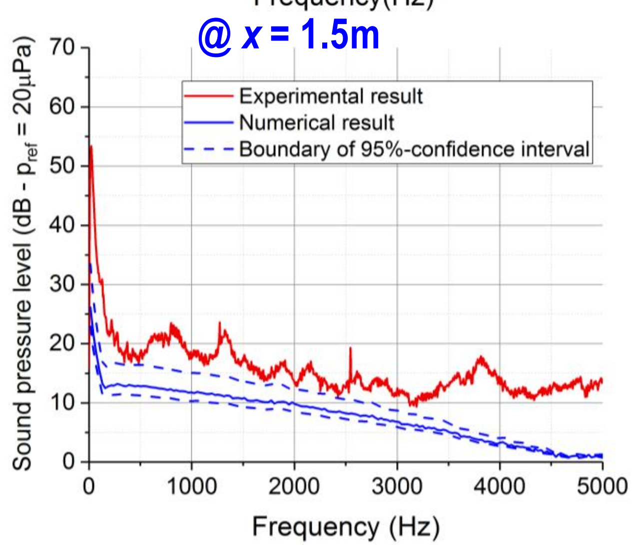
AEROACOUSTIC CHARACTERISTICS



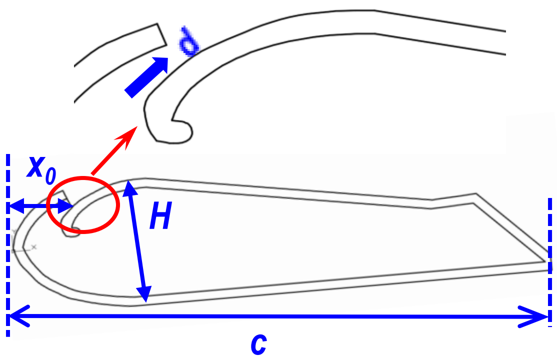
- Acoustic model: FW – H model
- Density: $1.225 \mathrm{kg/m^3}$
- Sound speed: $340 \mathrm{m}/s$
- Reference acoustic pressure: $20 \mu\mathrm{Pa}$
- Noise source: Bladeless fan

Sound pressure level

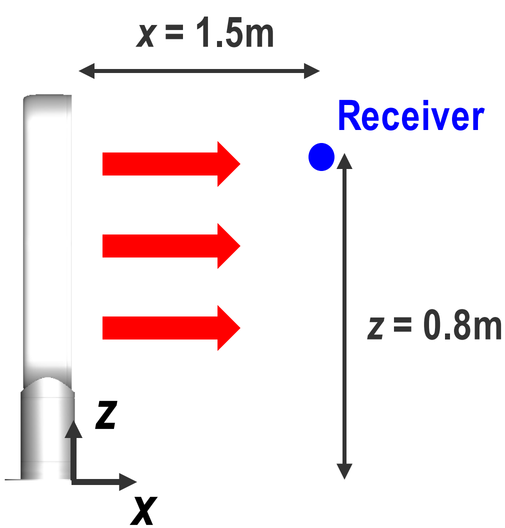




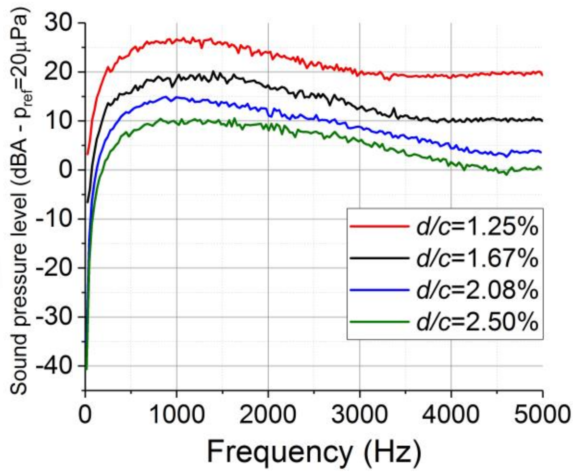
EFFECT OF THE GEOMETRIC PARAMETERS ON AEROACOUSTIC PERFORMANCE



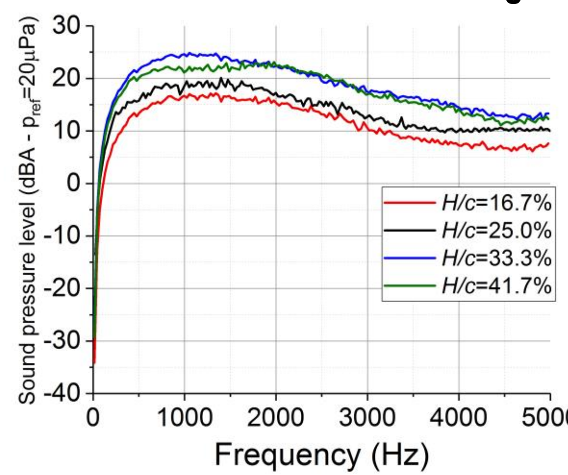
d=2mm, *H*=3cm, *c*=12cm, x_0/c=10%



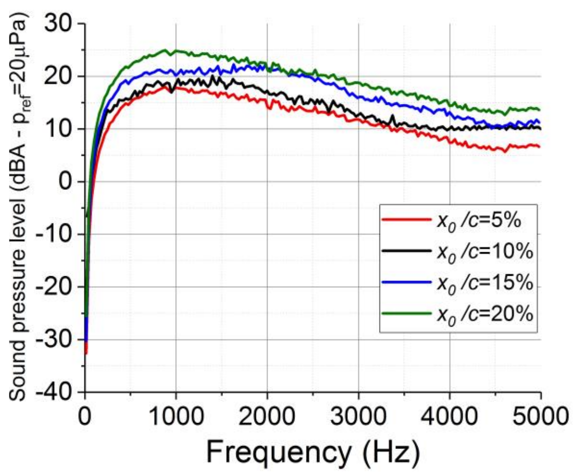
Effect of slit width



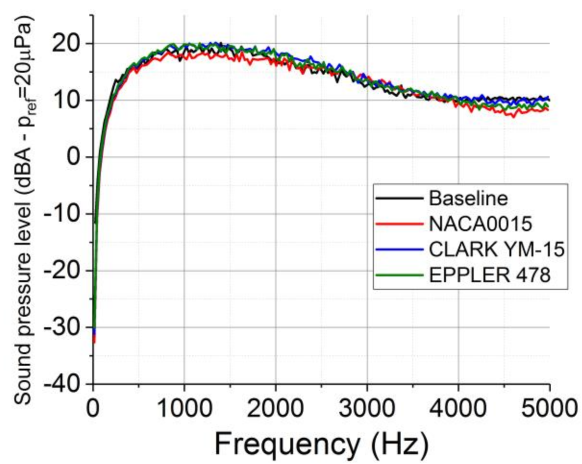
Effect of cross-section height



Effect of slit location



Effect of profile of the cross-section



CONCLUSIONS

- When the wind produced by the bladeless fan becomes more powerful, the aerodynamic noise is louder.
- With the decrease of the slit width, the wind strength becomes more powerful. The generated noise increases at the same time.
- The bladeless fan with the cross-section of 4cm has the best aerodynamic performance, but the generated noise is the loudest.
- With the slit moves away from the leading edge, both wind strength and noise level increase.
- The profile of the cross-section affect the shape of the influence zone, but has insignificant effect on outflow mass flow rate and the generated noise.

ONGOING EFFORT

– Investigate the performance of the bladeless fan prototype with the impeller in the base
– Identify the main noise source
– Analyze the noise directivity of the bladeless fan
– Come up with a general criteria to evaluate the aerodynamic performance of the bladeless fan (i.e. strength, uniformity and steadiness of the wind)
– Propose a criteria to evaluate the compromise between the aerodynamic and aeroacoustic performance
– Apply the results to optimize the design of the new-generation bladeless fan.

ACKNOWLEDGEMENT

- Thanks to the financial support and professional feedback provided by M ,