KTH ROYAL INSTITUTE
OF TECHNOLOGY

Control of particle agglomeration with relevance to after-treatment gas processes

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Outline

- Motivation of the project
- Description of the model
- Results
- Summary
- Future plans

Motivation

NOMAD (https://commons.wikimedia.org/wiki/File:Trafficjamdelhi.jpg), „Trafficjamdelhi“, https://creativecommons.org/licenses/by/2.0/legalcode

- Nano sized particles in emissions from internal combustion engines(ICE) are a major health issue.
- Larger particles are easier to filtrate.
- Particle agglomeration is one way in which larger particles can be obtained from ICE particulate emissions.

Ruben de Rijcke (https://commons.wikimedia.org/wiki/File:Automobile_exhaust_gas.jpg), „Automobile exhaust gas“, https://creativecommons.org/licenses/by-sa/3.0/legalcode

Scope of the study

- (**Why?**)Reduce the number of particles in the internal combustion engine(ICE) exhaust gases.
- (**How?**)Using flow and acoustic forcing to enhance particle agglomeration.
- (**Insight**)Perform numerical studies to study particle behavior under pulsatile flow conditions. Make comparison against measurements on an actual engine exhaust system.
- (**Goal**)Utilize the insight to help the industry develop a suitable prototype that can be used as an after treatment device.

Model assumptions and agglomeration principle

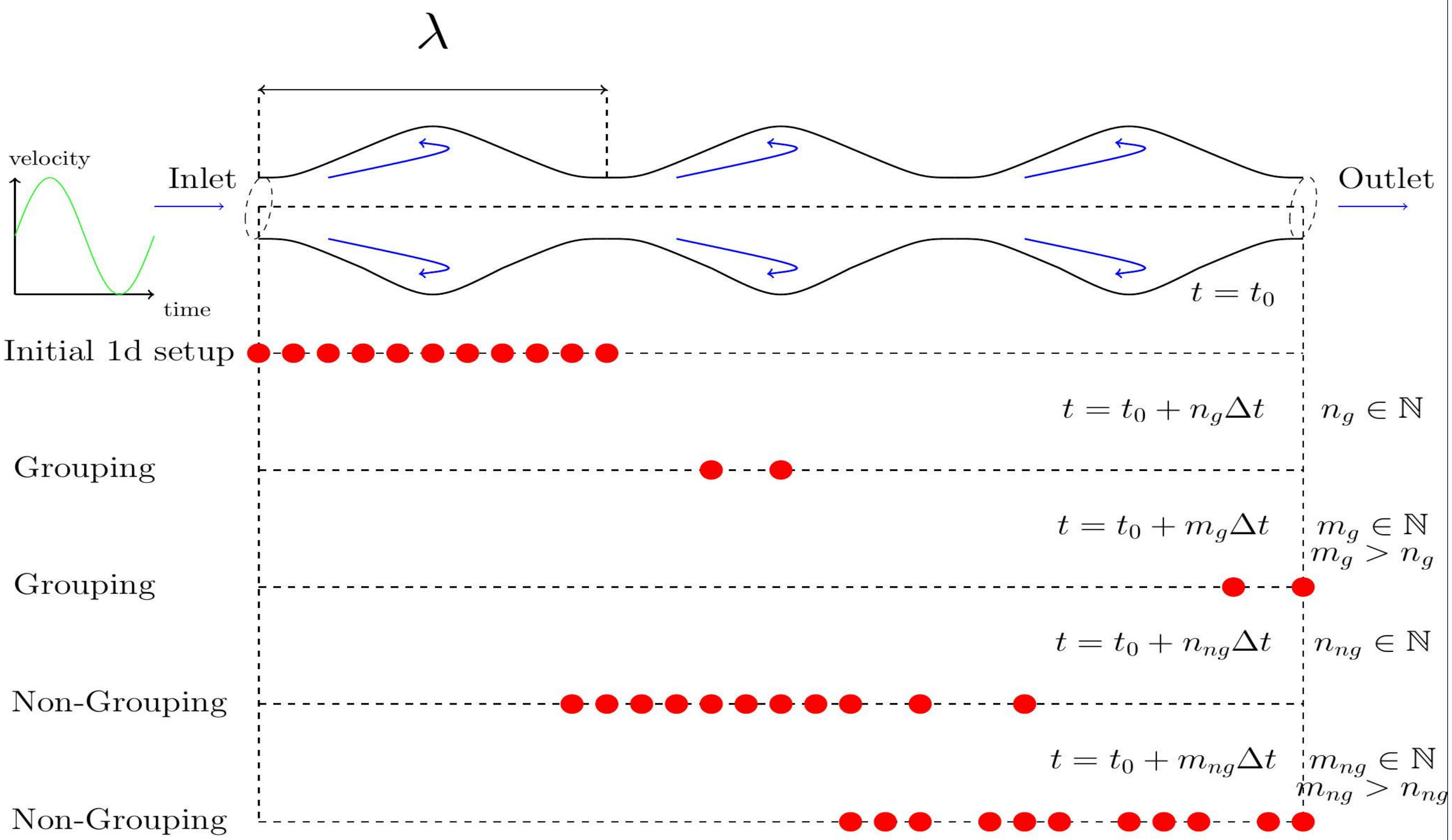
- 1D in nature.
- Laminar and incompressible flow field.
- Stokesian regime is assumed. The equation however can be extended to non-Stokesian regime by considering drag coefficients.

In this **1D** model we have:

- Oscillations with respect to **time**.
- Oscillations with respect to **geometry**.

These oscillations will cause particles to accelerate or decelerate based on their location.

Pipe and corresponding 1D schematic

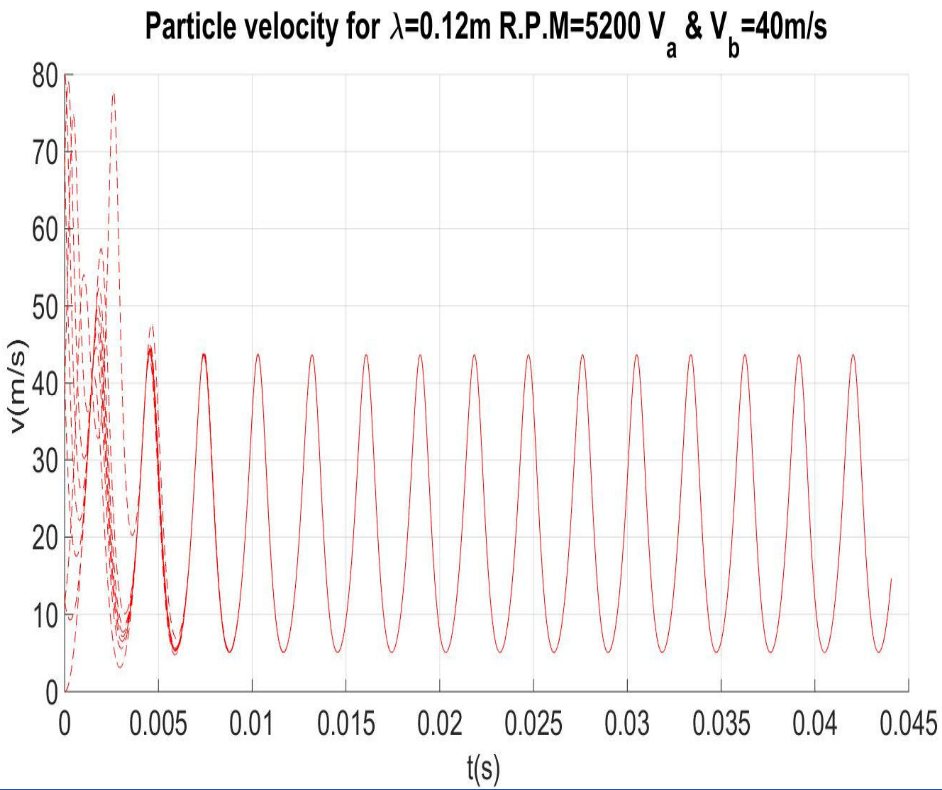


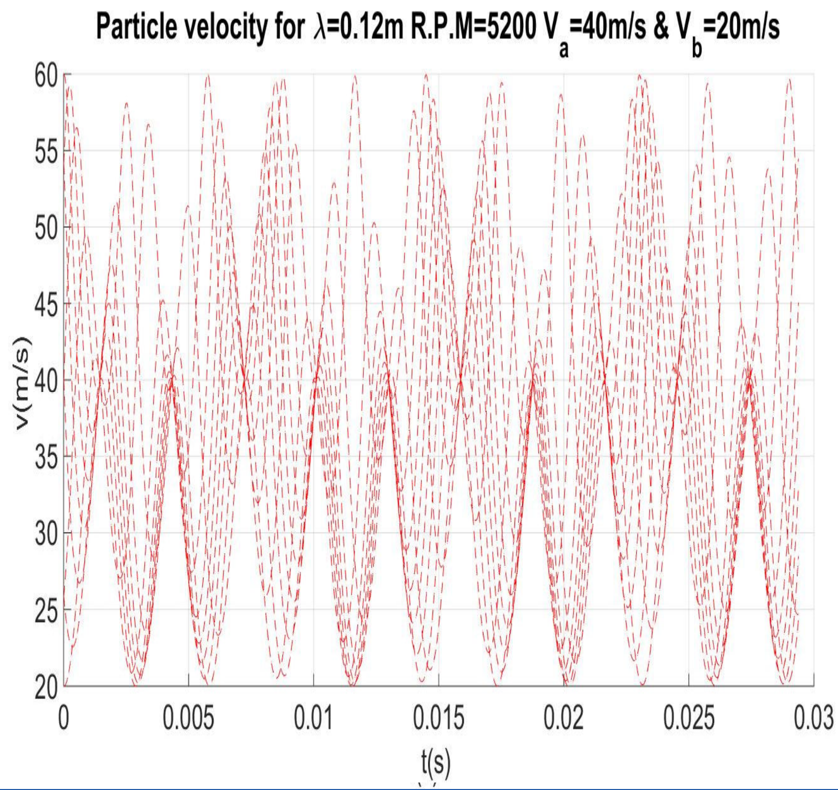
Pipe length is considered to be 1m.

Picture of grouping vs. non grouping

Grouping: all particle trajectories collapse into one of the two bands and particle velocities stay the same.

Non grouping: particle trajectories move individually and particle velocities differ.





Description of model equation

- The model gas velocity equation is given as:

$$v_g(x,t) = \underbrace{V_a}_{\text{Mean Part.}} - V_b \underbrace{(\sin(\omega t + \phi))}_{\text{Oscillations from engine.}} \underbrace{\cos(kx)}_{\text{Oscillations from geometry.}}$$

- The (non-dim)equation for the motion of particles in such a flow field:

$$\ddot{x}^* = \underbrace{\frac{1}{St}}_{\text{Stokes number controls inertia.}} \left(v_g^* - \dot{x}^*\right)$$

❑ **Enforce the restrictions $V_a \geq V_b$ and $V_a + V_b \leq 80m/s$.**

Important Parameters

- Two parameters were identified by Katoshevski et.al(2005) as being important.
- The beta parameter given as:

$$\beta = \frac{V_a - \lambda f}{V_b} = \frac{V_a^* - 1}{V_b^*}.$$

{ Mean flow vs. Oscillations. }

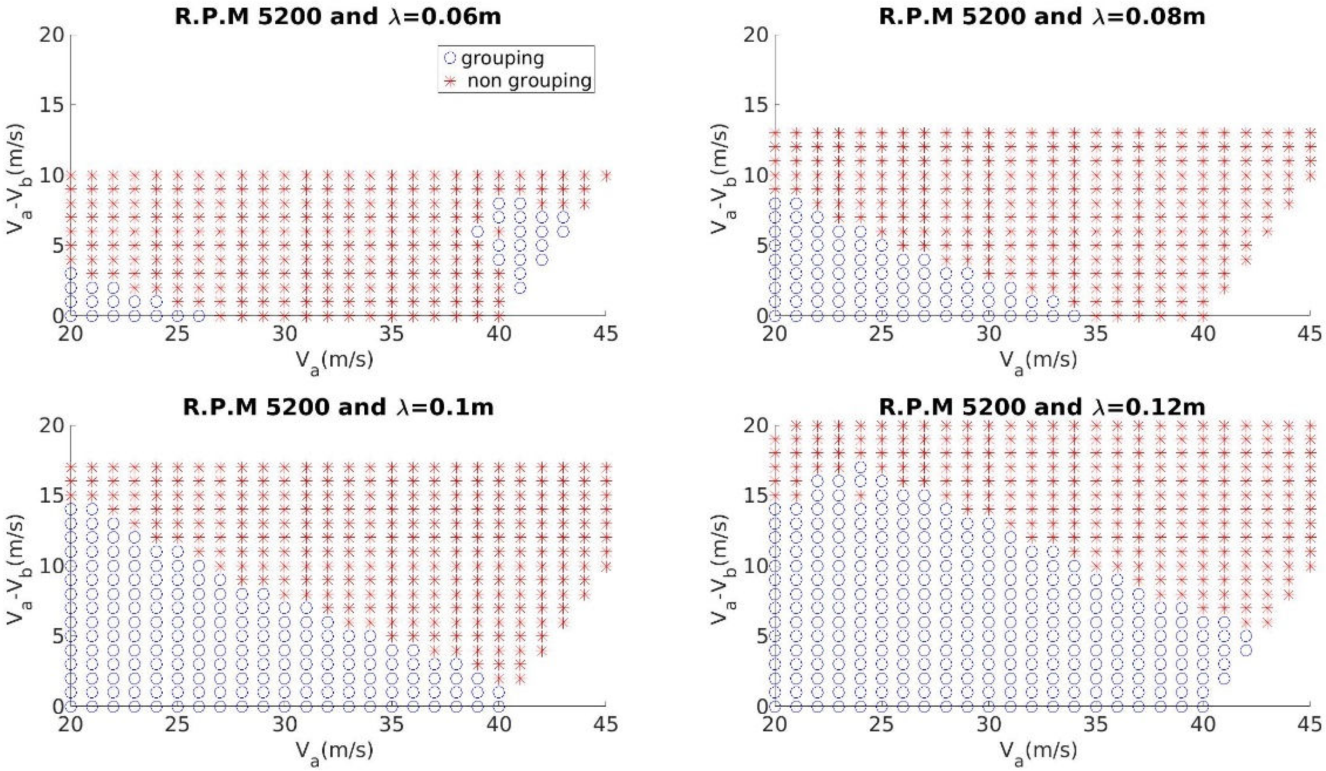
- The alpha parameter given as:

$$\alpha = \frac{1}{\sqrt{(V_b^* St)}}.$$

{ Size of the particles. }

❑ **Likely indicators of grouping $|\beta| \leq 1$ and α should be large.**

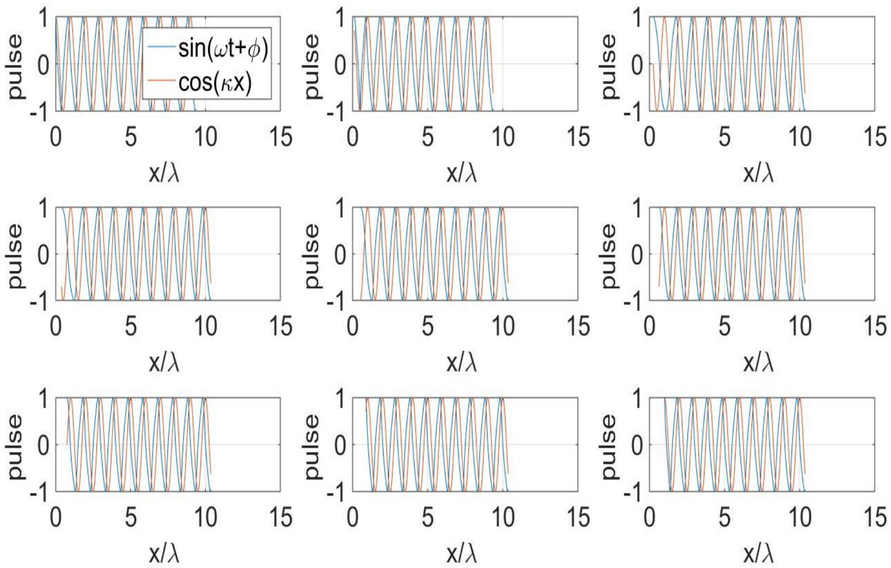
Parameter Studies

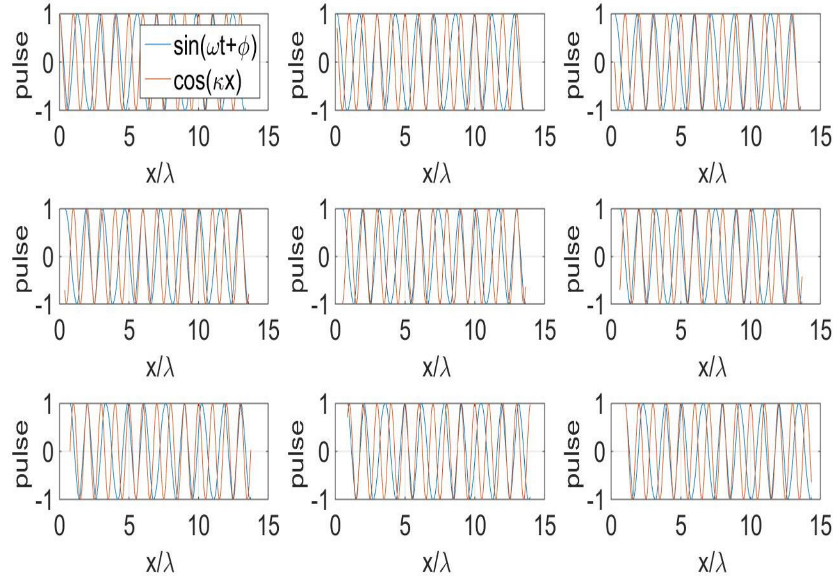


Trend shows that the highest grouping points for high wavelengths(0.1 and 0.12m).

❑It is important to think about the design in order to be in the right operating points.

Pulse synchronization





Grouping case with $V_a = 21$m/s, $V_b = 19$m/s, $\lambda = 0.1$m and R.P.M value of 5200.

Non grouping case with $V_a = 26$m/s, $V_b = 10$m/s, $\lambda = 0.1$m and R.P.M value of 5200.

- **In the case of grouping pulses are synchronized.**

Summary

- Conclusion of the 1D study and submission of manuscript for SAE World Congress.
- Verification/Validation study using a BFS case by Fessler et. al 99.

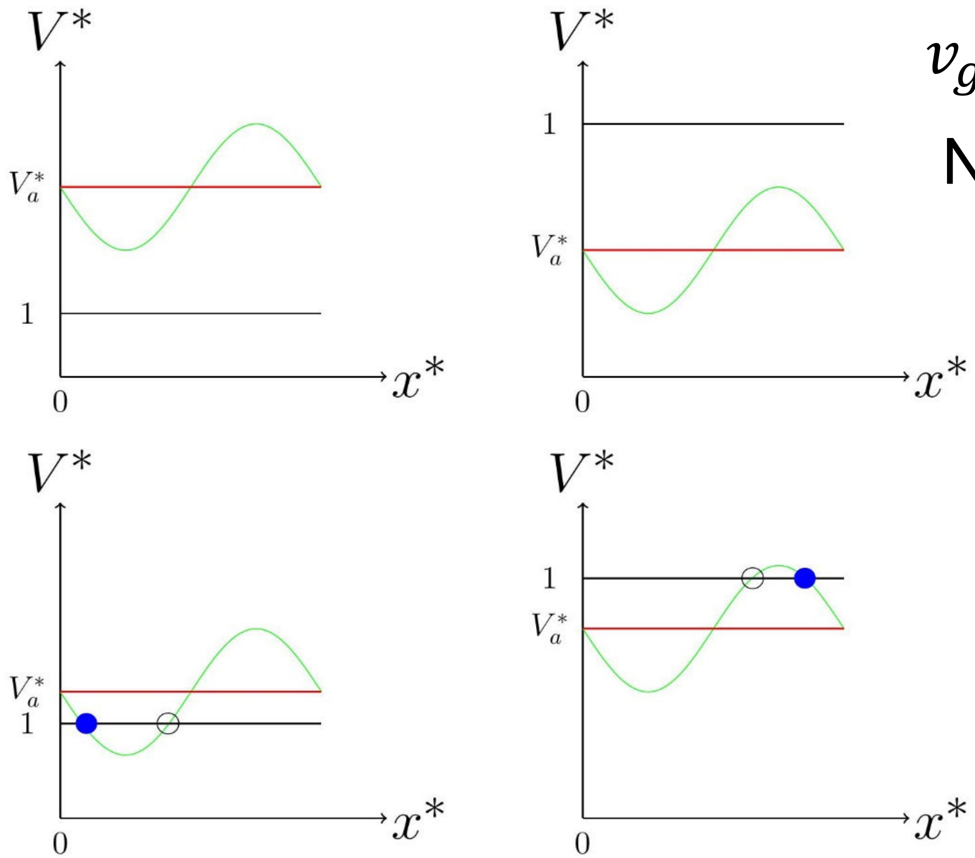
Future plans

- Introduce particles inside **3D** geometries.
- Perform high fidelity studies in **3D** using OpenFOAM.

Competence Center for Gas Exchange

”Charging for the future”

Illustration of equilibrium points' scenario



Model gas velocity:

$$v_g(x,t) = V_a - V_b\,(\sin(kx - \omega t))$$

Non-dim gas velocity:

$$v_g^*(x,t) = V_a^* - V_b^*\,(\sin(x^* - t^*))$$

Model gas velocity equal to V_w in non dim form:

$$1 = V_a^* - V_b^*\,(\sin(x^* - t^*))$$

- Normalization of time, displacement and velocity is done using ω,k and $\omega/_k = V_w$.

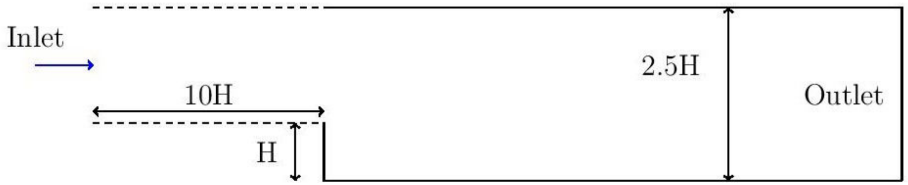
Grouping criterion used

- Particle velocities are observed at different points.
- If the following criteria is satisfied at all the aforementioned observed points then that case is considered as grouping:

$$\sqrt{\left(v_{p1}-v_{p2}\right)^2+\left(v_{p2}-v_{p3}\right)^2+\cdots+\left(v_{p8}-v_{p9}\right)^2}<1$$

where v_{pi} denotes the particle velocity of the *i*'th particle.

Backward facing step validation study

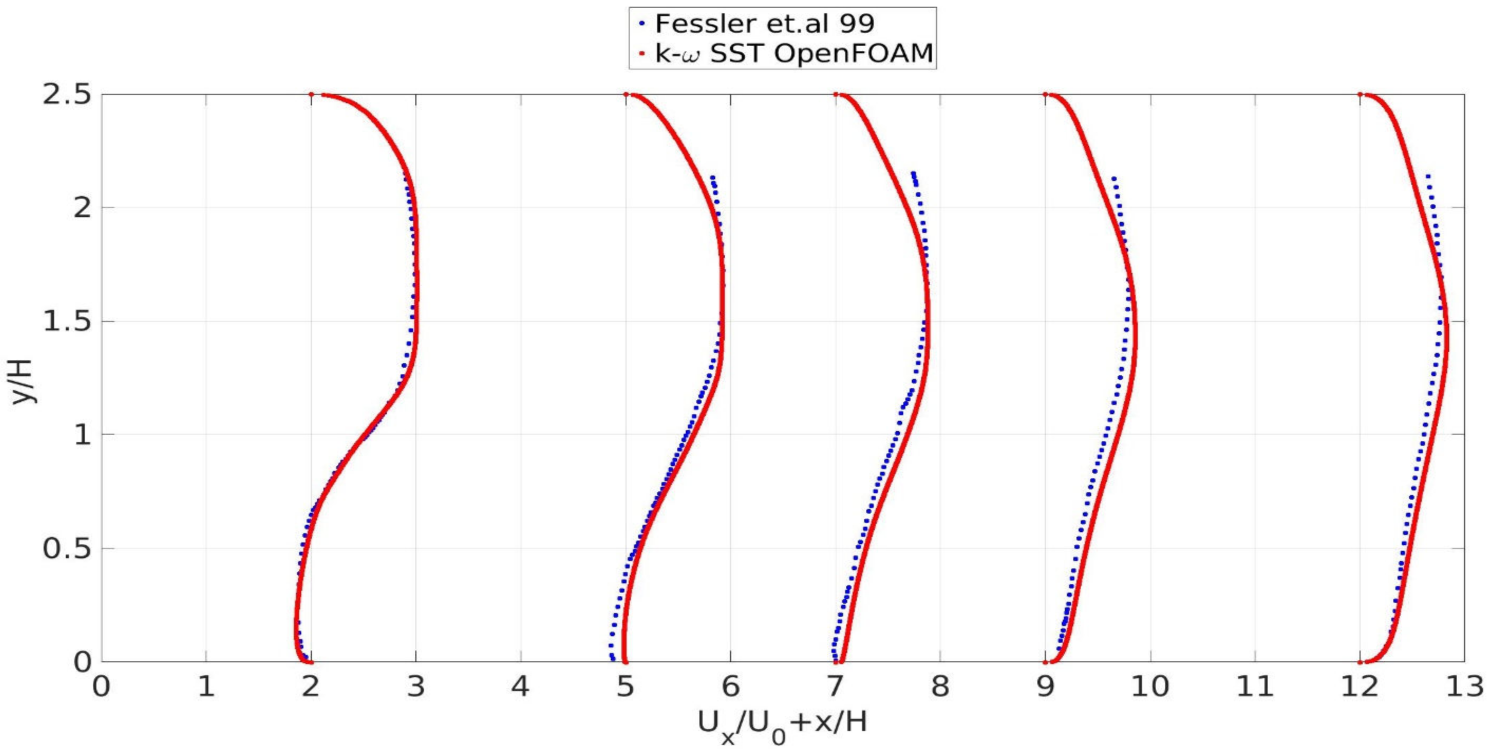


RANS k-omega SST model.

BC: 1) Inlet: Velocity Dirichlet(9.37,0,0)m/s,
Pressure zero Gradient.
2) Outlet: Velocity zeroGradient,
Pressure Dirichlet(zero).
3) Walls: No Slip Dirichlet(zero).
Periodic in the spanwise direction

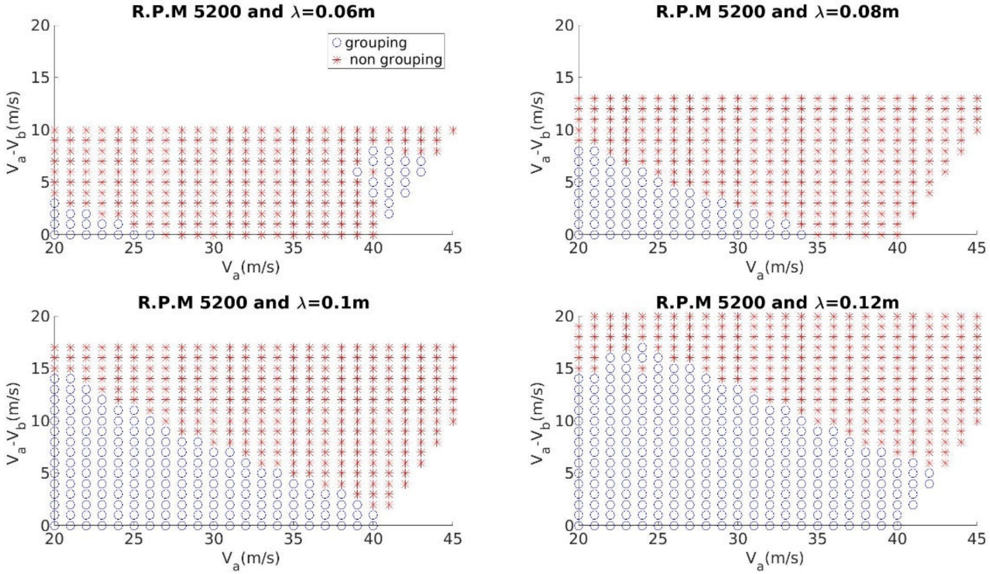
No. of Cells: ~3mil

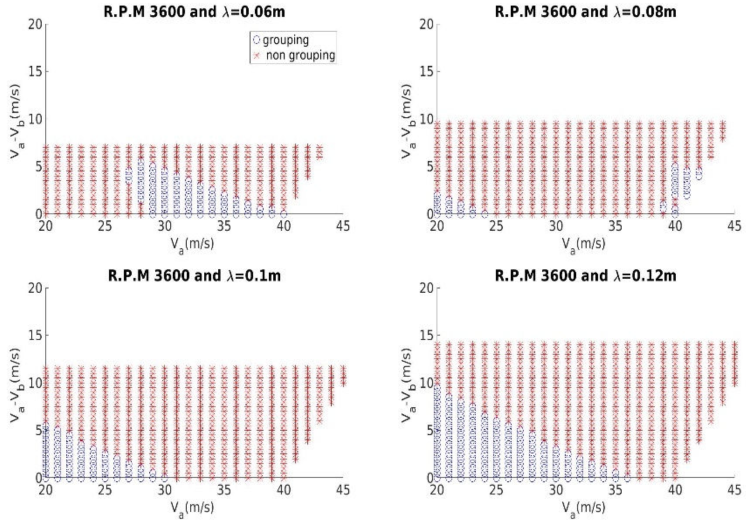
Comparison of CFD with experiments

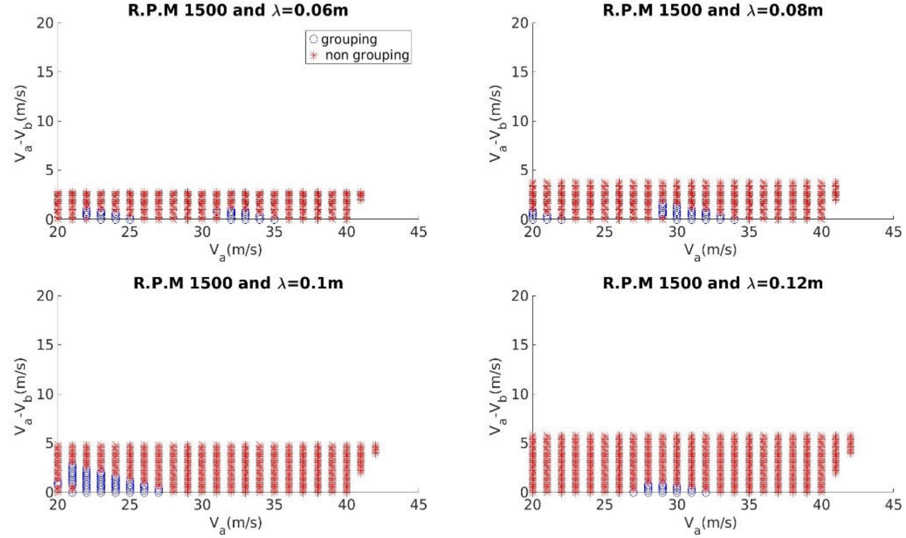


Mean streamwise velocity profiles downstream of the step are shown. U_0 is the centerline velocity.

Parameter Studies







Trend shows that the highest grouping points for high wavelengths(0.1 and 0.12m).