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CFD mesh topology study of a truss geometry under forced oscillations

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CFD MESH TOPOLOGY STUDY OF A TRUSS GEOMETRY UNDER FORCED OSCILLATIONS

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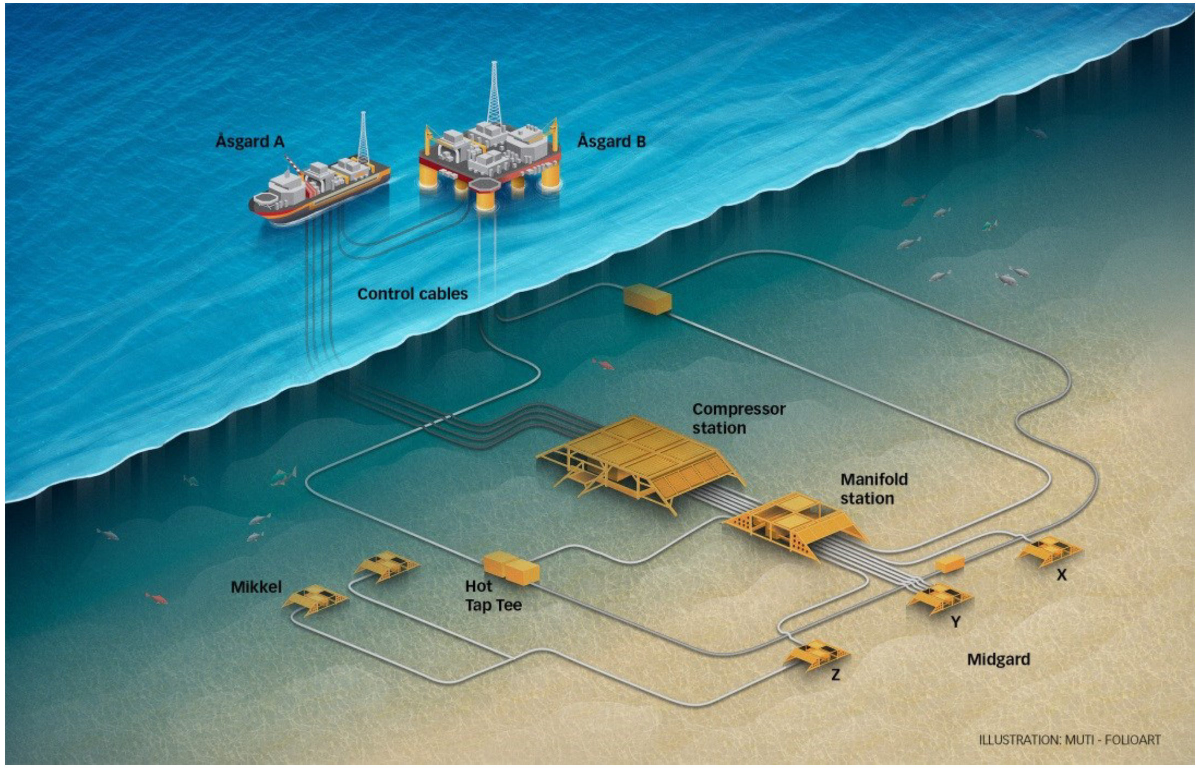
Introduction

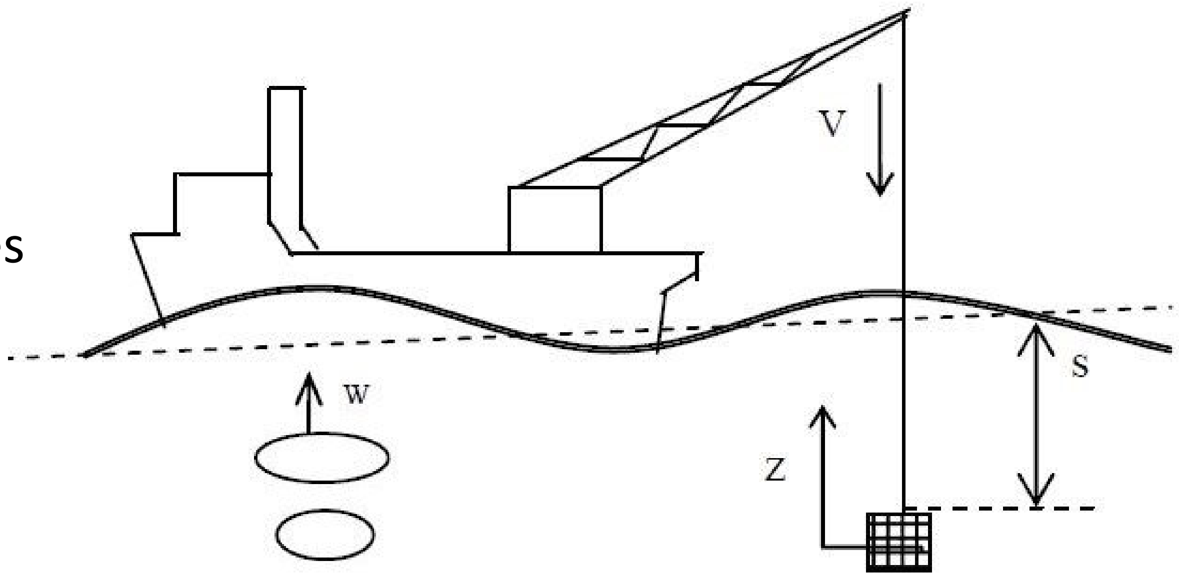
- Deep oil and gas fields
  - Usually, Floating production units are more cost-efficient
    - Large subsea equipment employed



Åsgard oil field (Simmons, 2017)

Introduction

- Environmental conditions
  - Operable window due to wind and waves
- Vessel's induced response
  - Crane motion
- Equipment hydrodynamics (C_a and C_d)



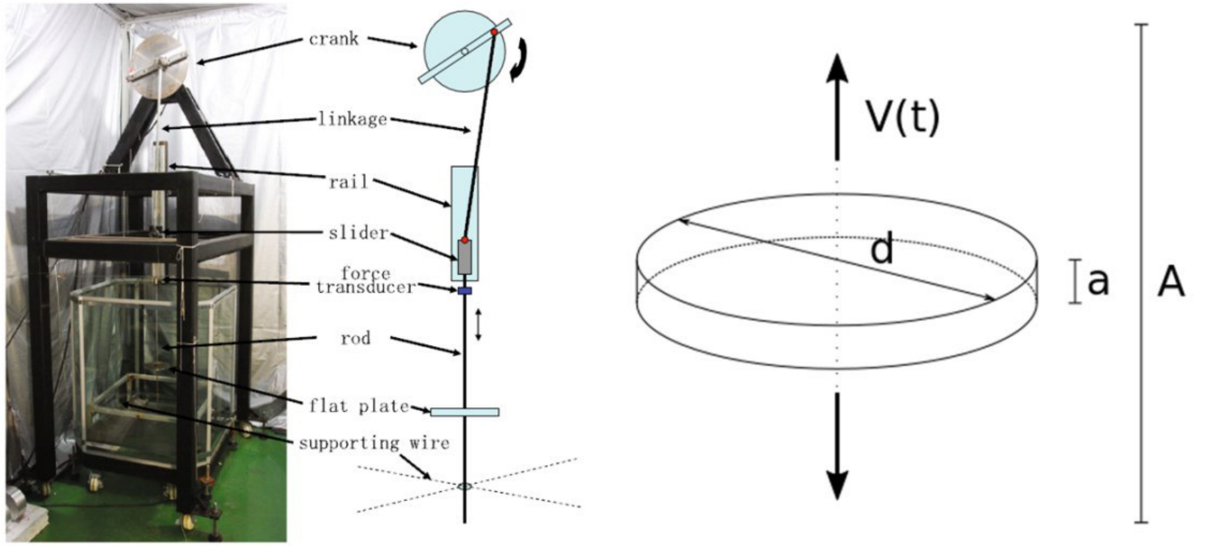
Subsea equipment deployment (Wadhwa and Thiagarajan, 2009)

Objective

This paper is a sequence of a previous works, it was done in order to progressively increase the complexity of the numerical model, this time with the focus of studying mesh topology and refinement

Previous works

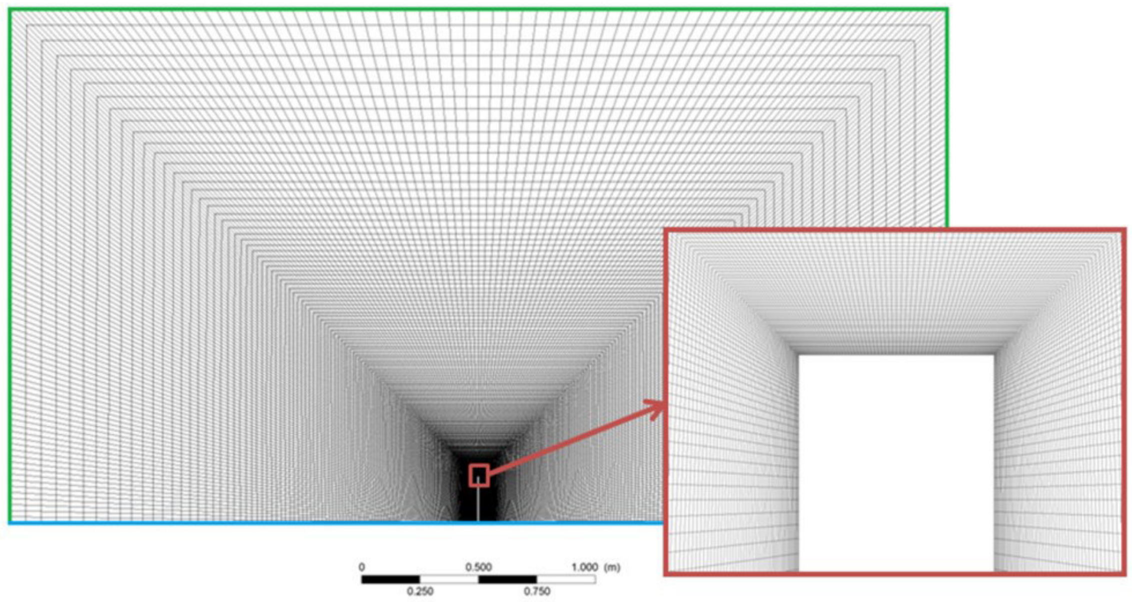
- Gomes *et al.*, 2019 and Gomes *et al.*, 2020
    - Simulations over disks and flat plates
- Morison equation
    - $F = \frac{1}{2} C_d S |V| V + \rho C_M \nabla \dot{V}$
        - $C_M = 1 + C_a$
- Hydrodynamic coefficients
    - Chreim *et al.*, 2020
- Main dimensionless parameter:
    - $KC = \frac{U_M T}{D} = \frac{2\pi A}{D}$



Experimental apparatus from (Tian et al., 2017) (left) and disk motion (right)

Previous works

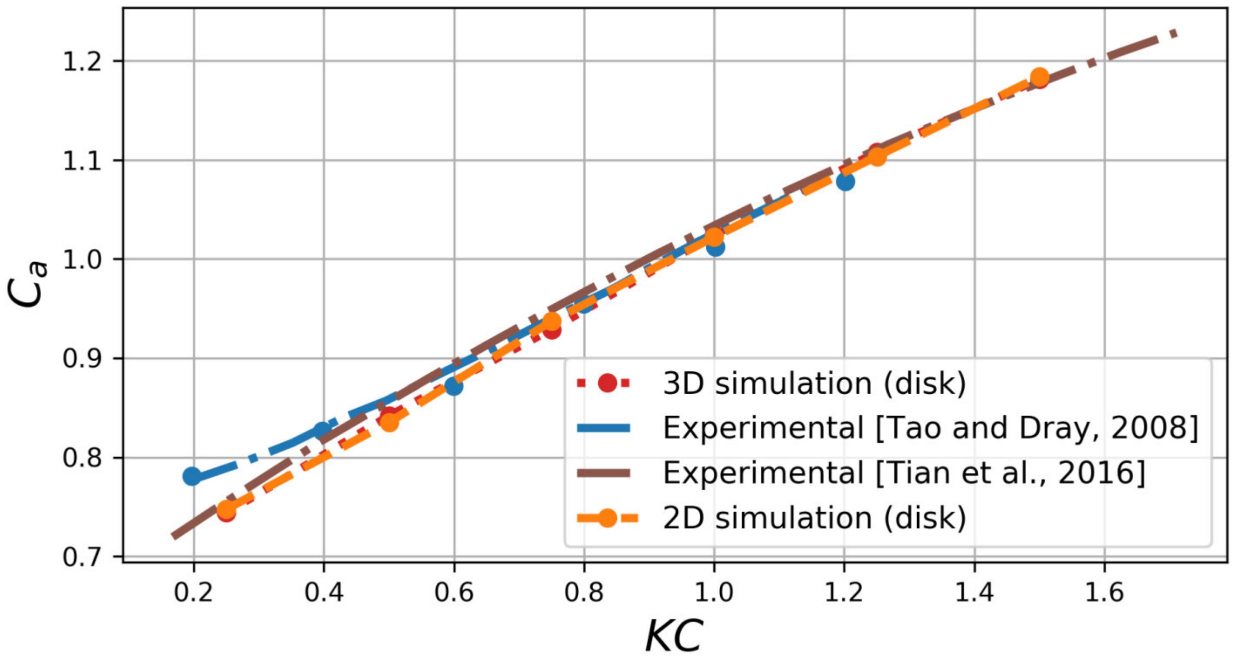
- Commercial CFD Software
    - ANSYS Fluent with double precision
- Incompressible fluid
- Reference frame motion in the entire domain
    - $\zeta(t) = A\cos(\omega t)$
- 2d axisymmetric mesh and 3d unstructured mesh
- Unsteady state
- Viscosity model:
    - k-k_l-ω

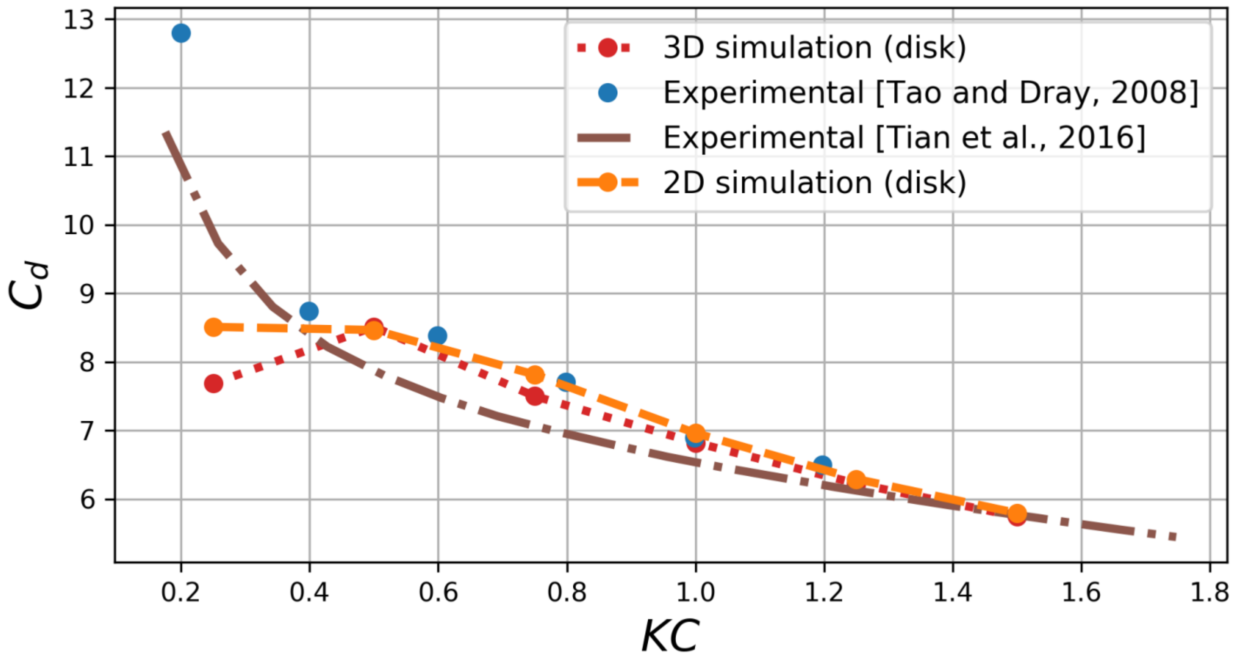


2d mesh used in the previous work

Previous works

- Hydrodynamic coefficient results





Current work

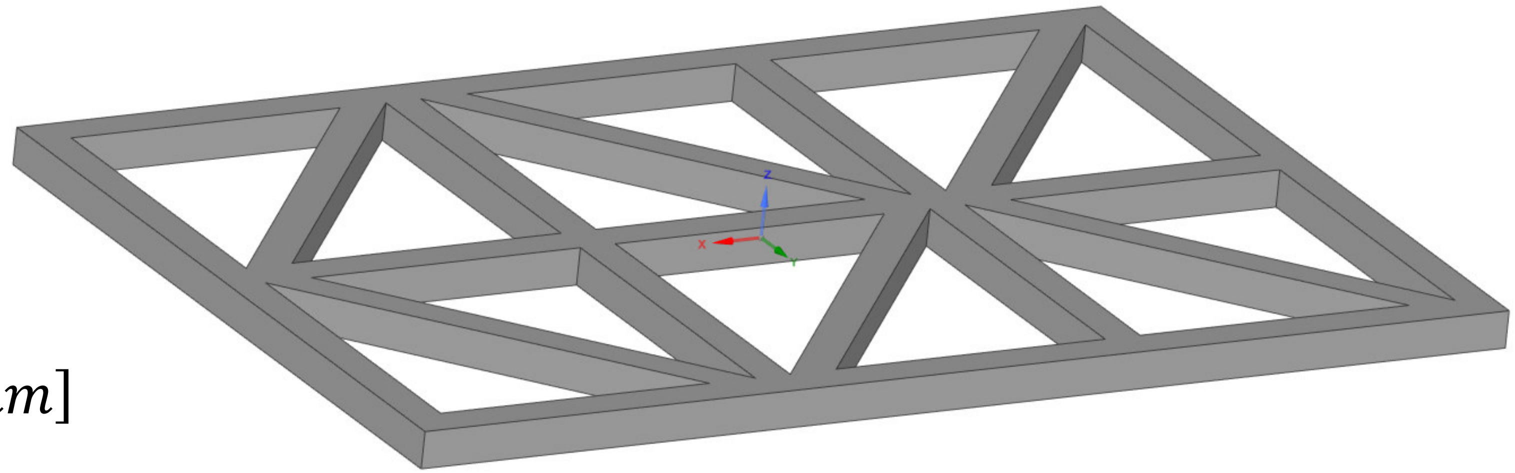
- Initially, the same approach used in the previous works was employed, but using a more complex geometry
    - Similar to a flat plate, but with increased porosity

- Later, due to the obtained results and the solution verification analysis, two new mesh topolgies are studied
    - In order to improve its outcome (hydrodynamic coefficients), reduce mesh uncertainty and computational cost
    - The study was based on the vorticity field results

Study case

Study case

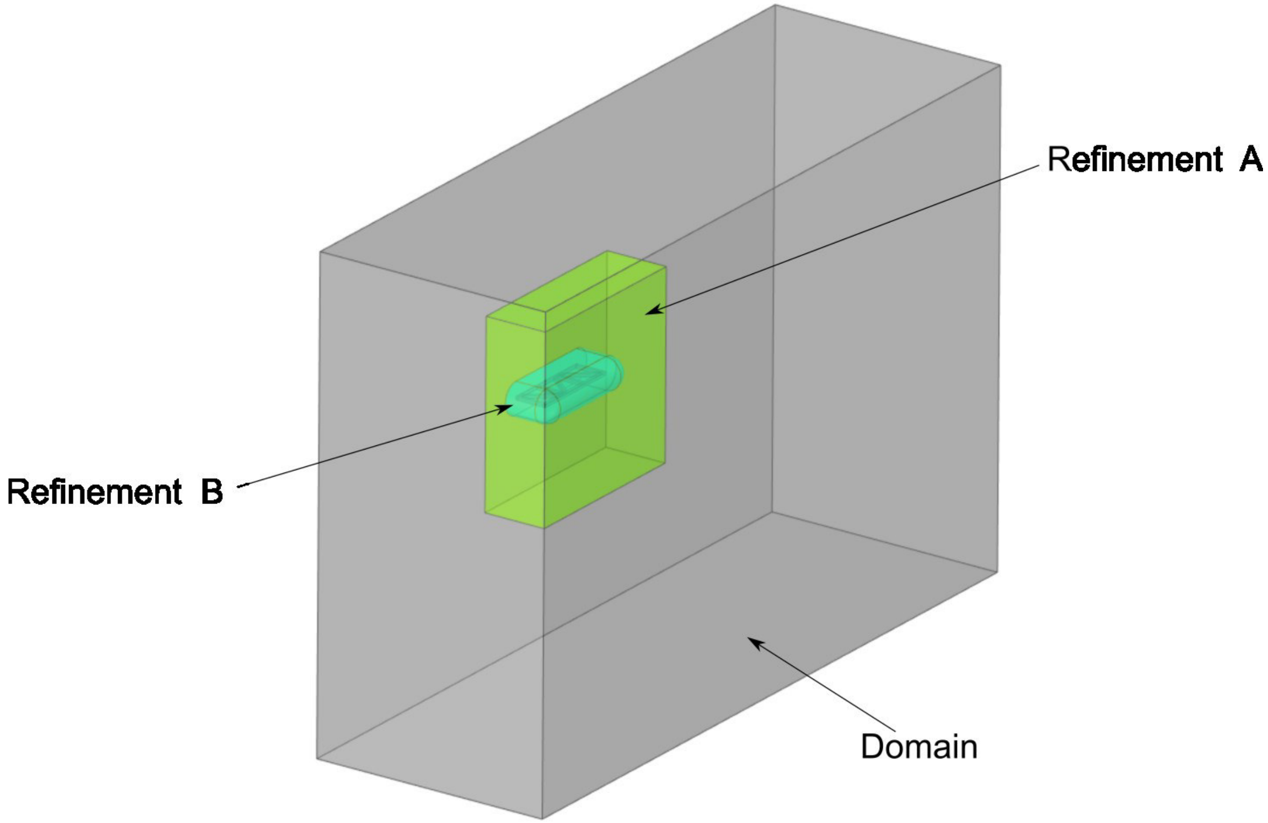
- Dimensions:
  - $(L_x = 465; L_y = 315\ ; L_z = 15)[mm, mm, mm]$
- Motion characteristics:
  - $0{,}15 \leq KC \leq 3{,}00$
  - 10 values
- Domain dimensions:
  - $[-7{,}5 \times L_x\ ; 7{,}5 \times L_x][mm]$
  - $[0\ ; 7{,}5 \times L_y][mm]$
  - $[-7{,}5 \times \max(L_x; L_y)\ ;\ 7{,}5 \times \max(L_x; L_y);][mm]$
- Symmetry plane
- Mesh topology -> Poly-hexcore

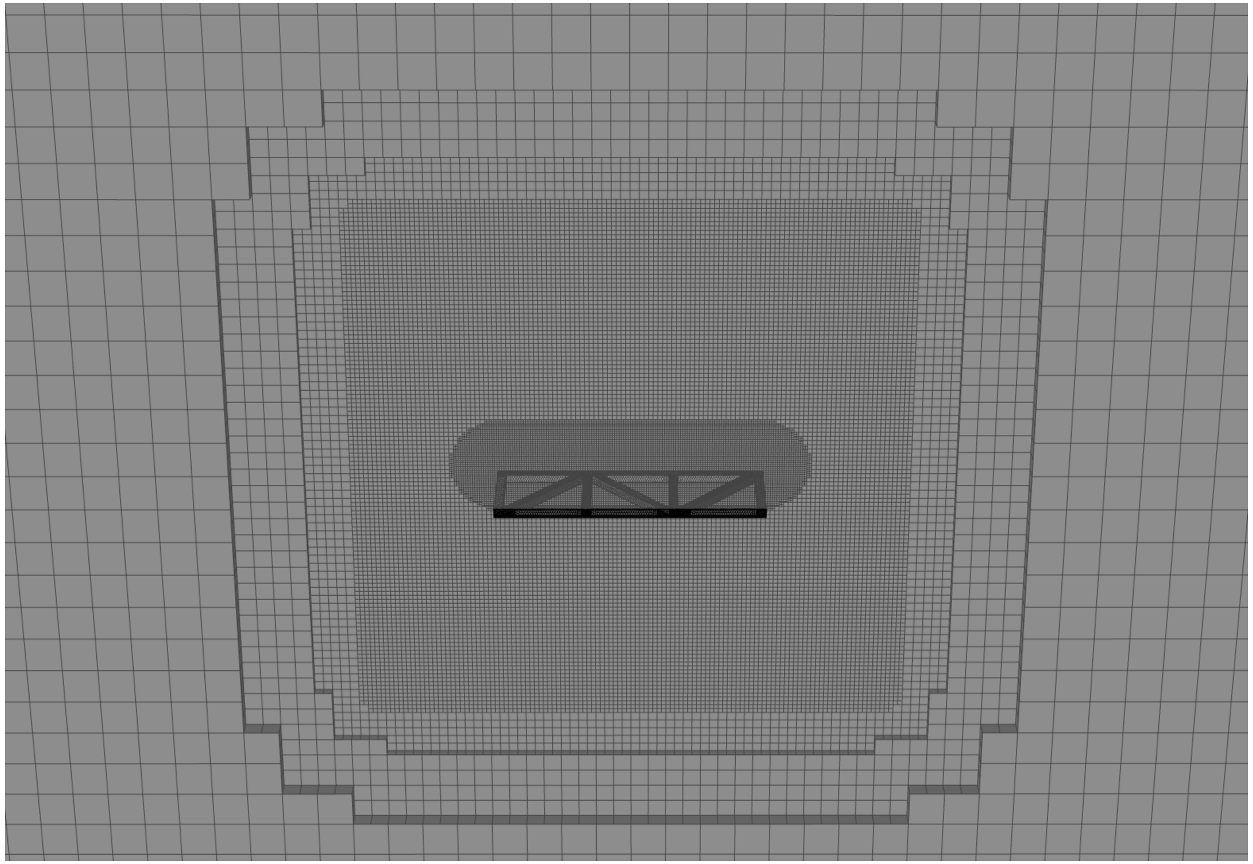


Study case - Domain and mesh

Max. Element dimension [mm]	Refinement A [mm]	Refinement B [mm]	Total number of elements (x10^3)
80	8	4	1204,25

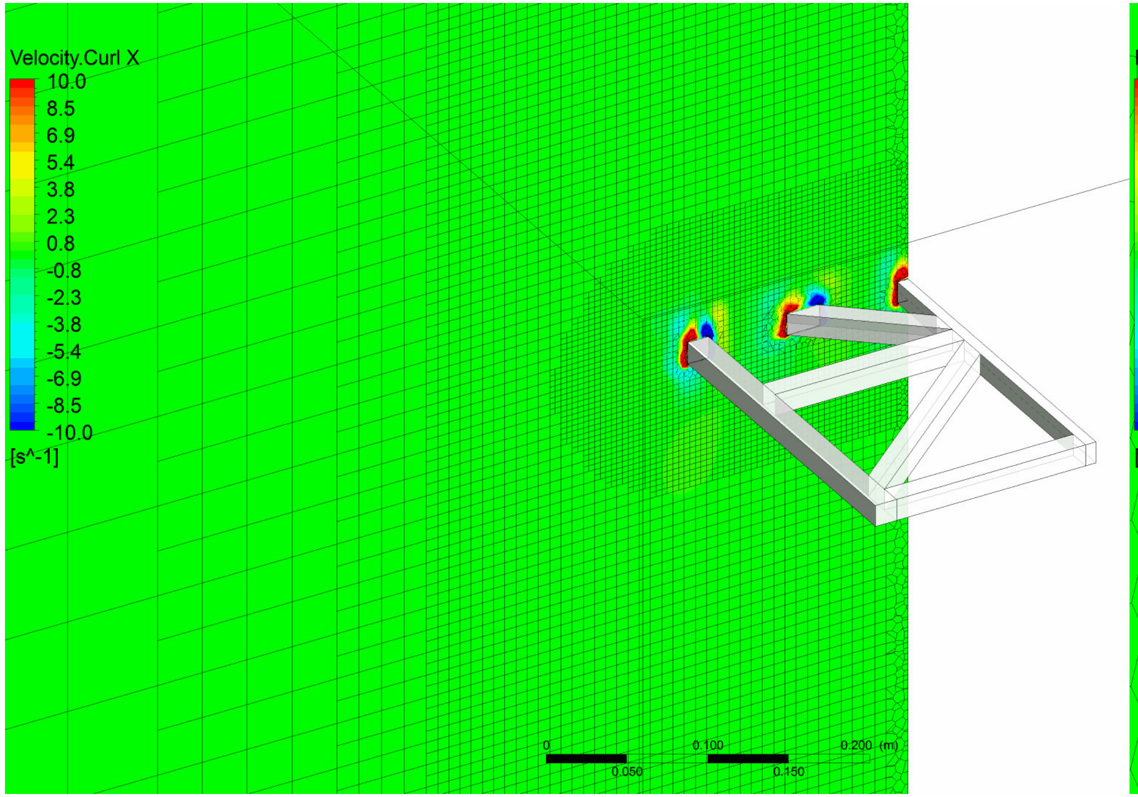
Domain 1

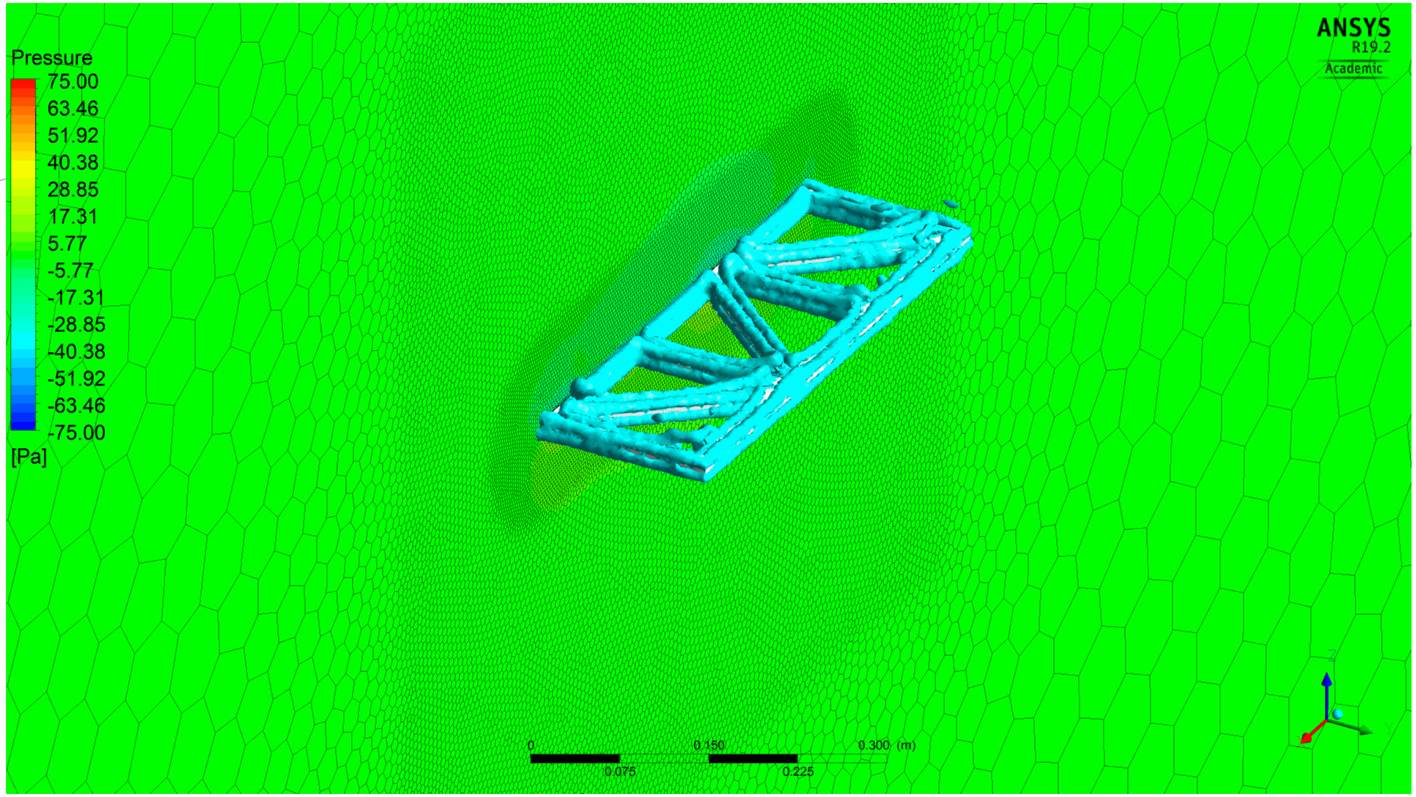




Study case - Results

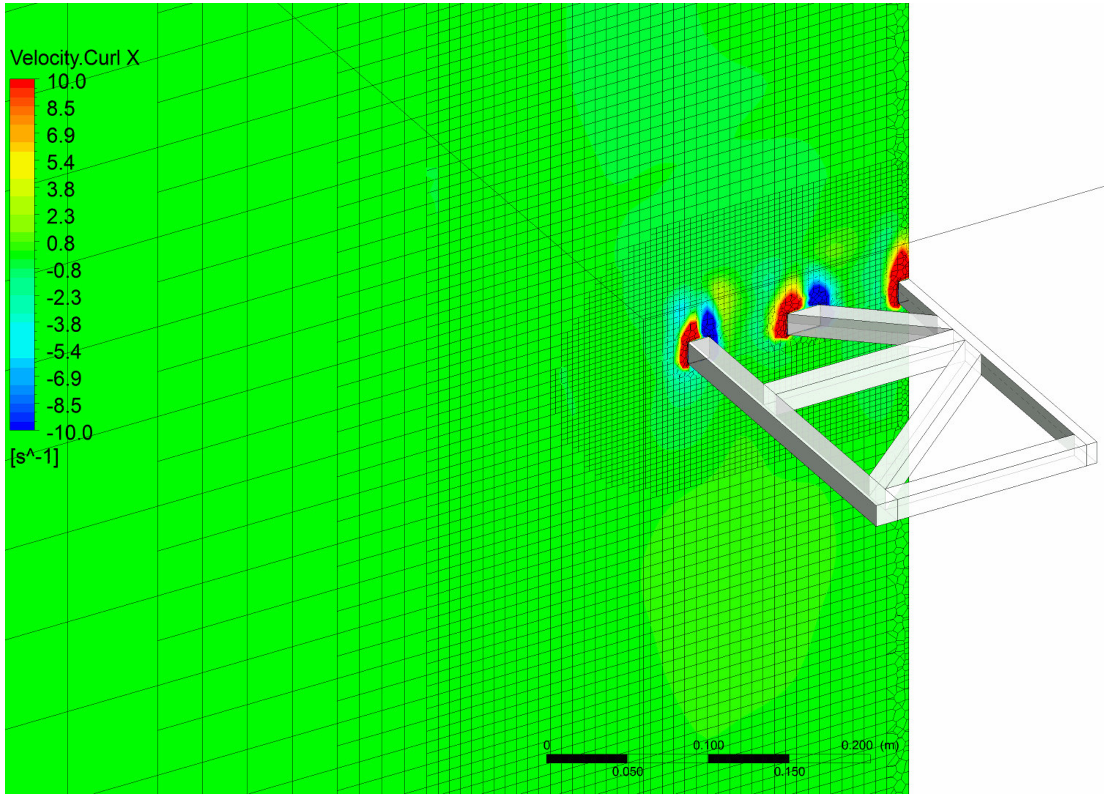
KC = 0,75

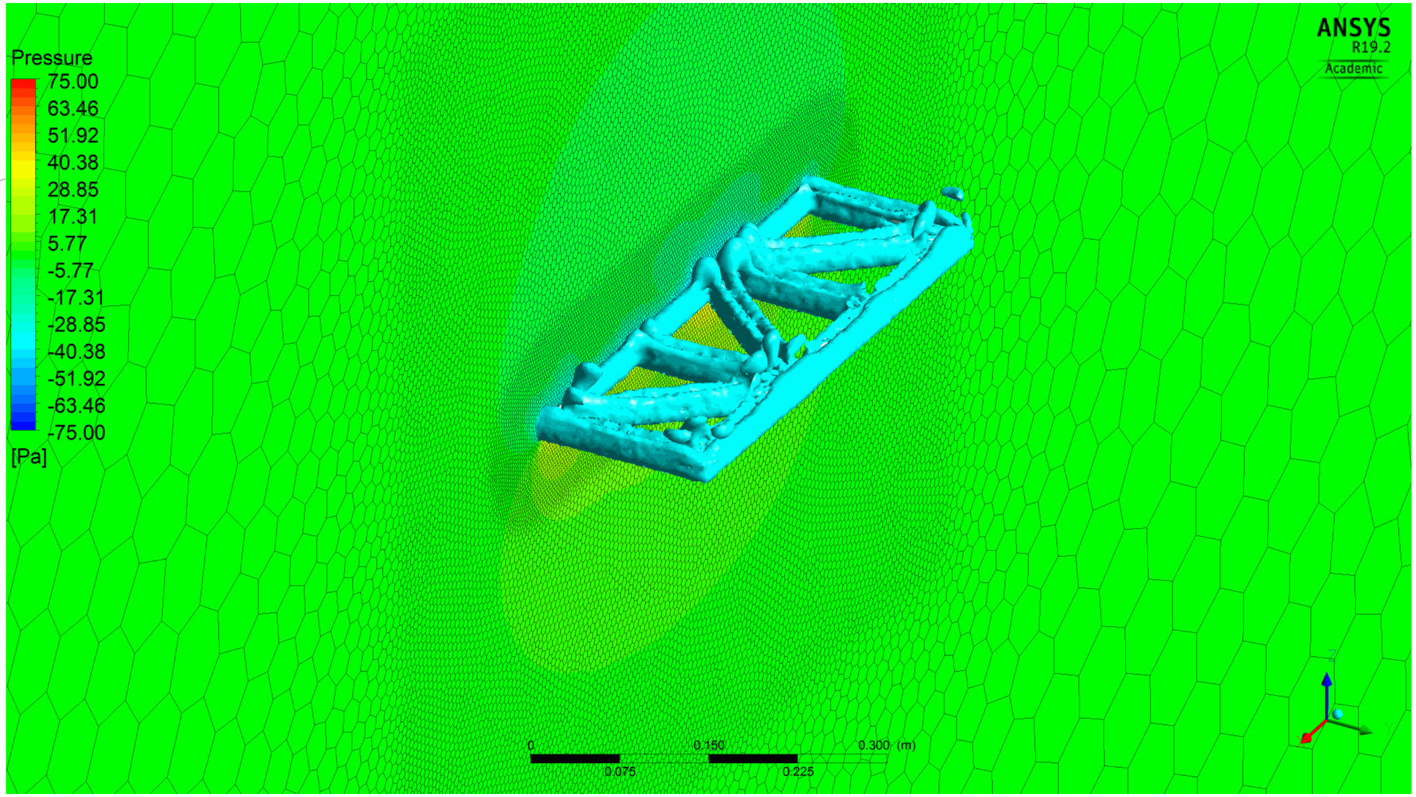




Study case - Results

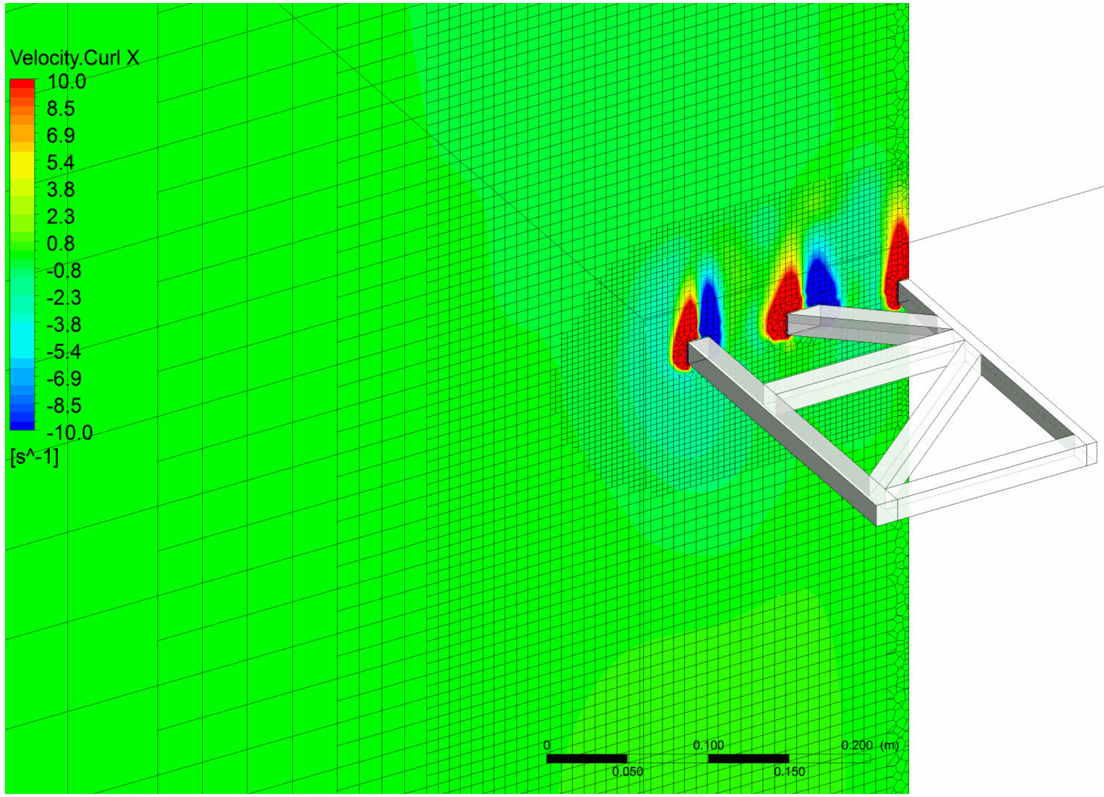
KC = 1,50

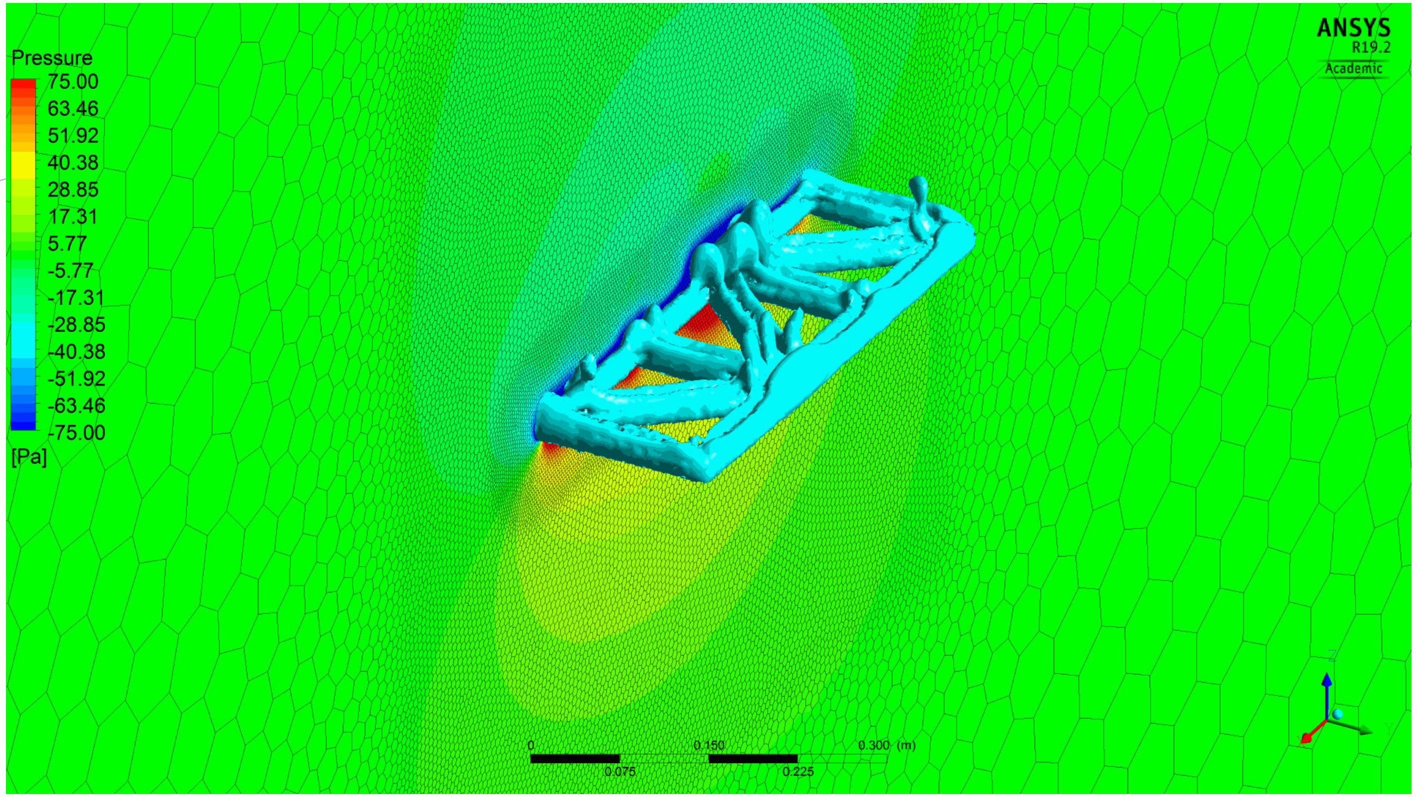




Study case - Results

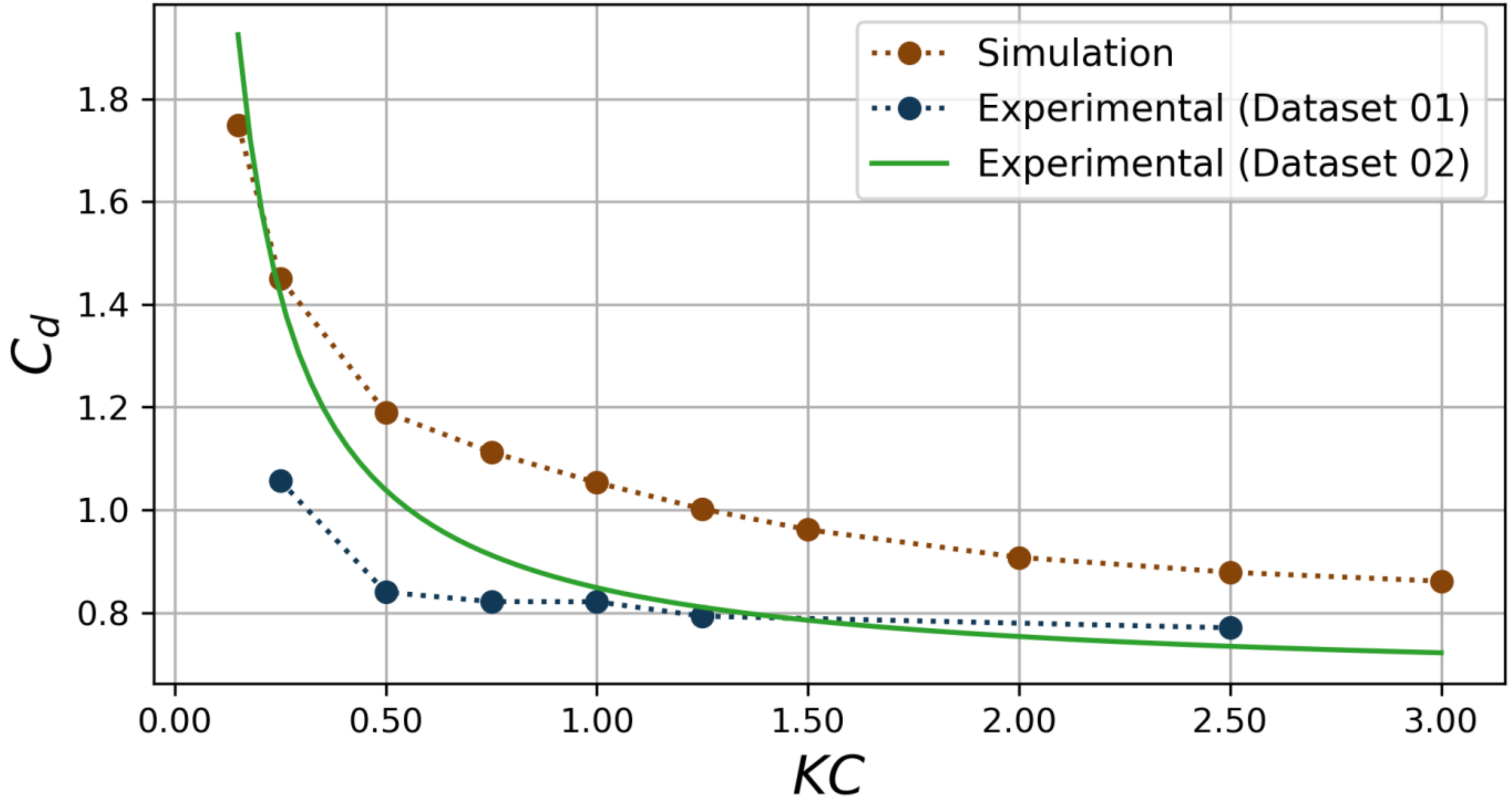
KC = 3,00





Study case - Results

- Drag coefficient results



Study case - Solution verification

- The solution verification analysis was based on the work of Eça and Hoekstra (2014) and was performed using the Numerical Uncertainty Analysis (NUA);

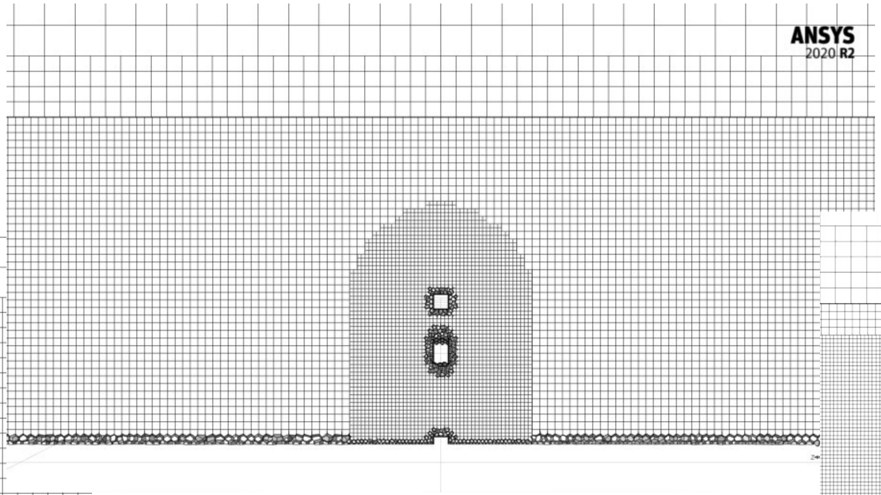
- The adopted method to estimate the uncertainty, U_{ϕ}, uses an integral or local result from the simulation, and requires a series of geometrically similar meshes with a systematic refinement between each one of them;

- Due to the computational effort required only the value of KC = 1,00 was simulated over 6 different meshes;

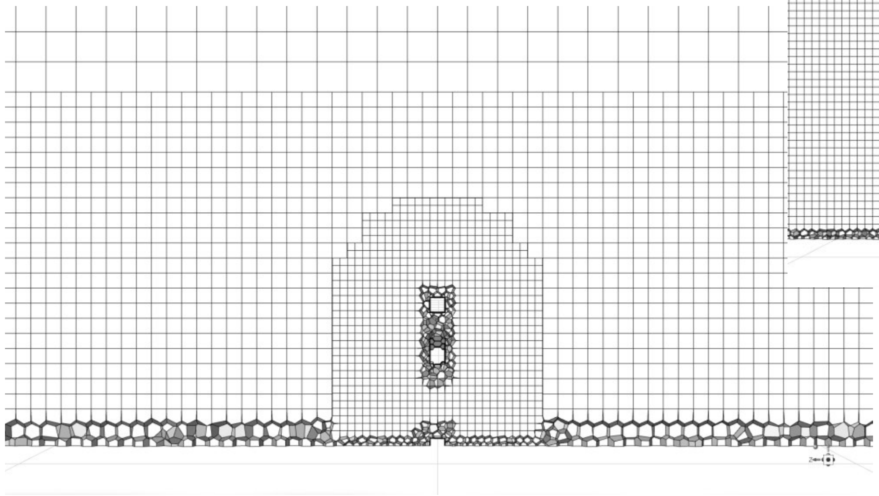
- In this study only the spatial discretization was analyzed.

Study case - Solution verification

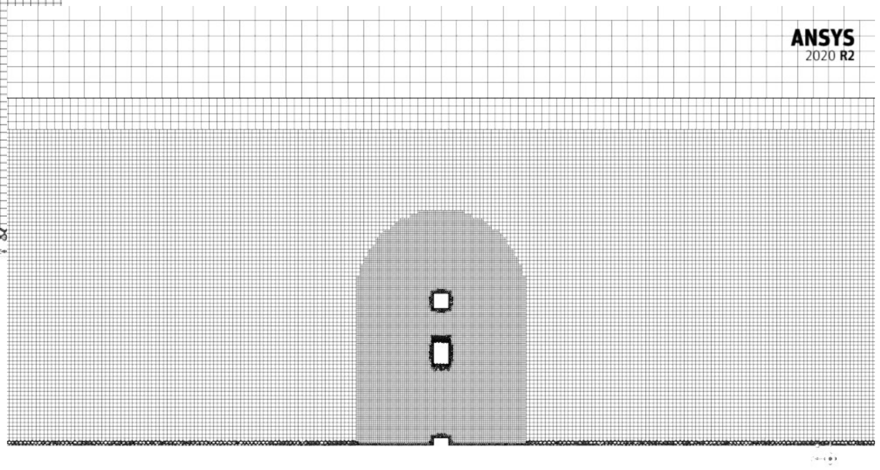
VVM0



VVM2-

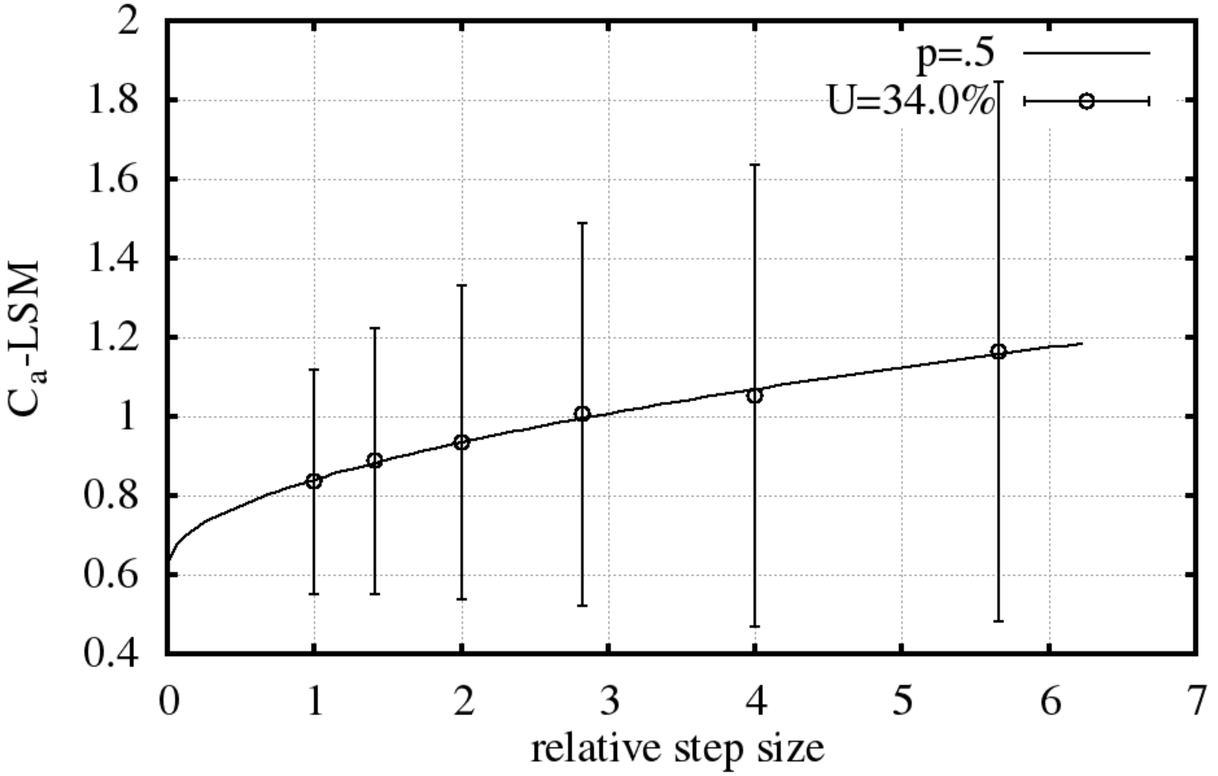


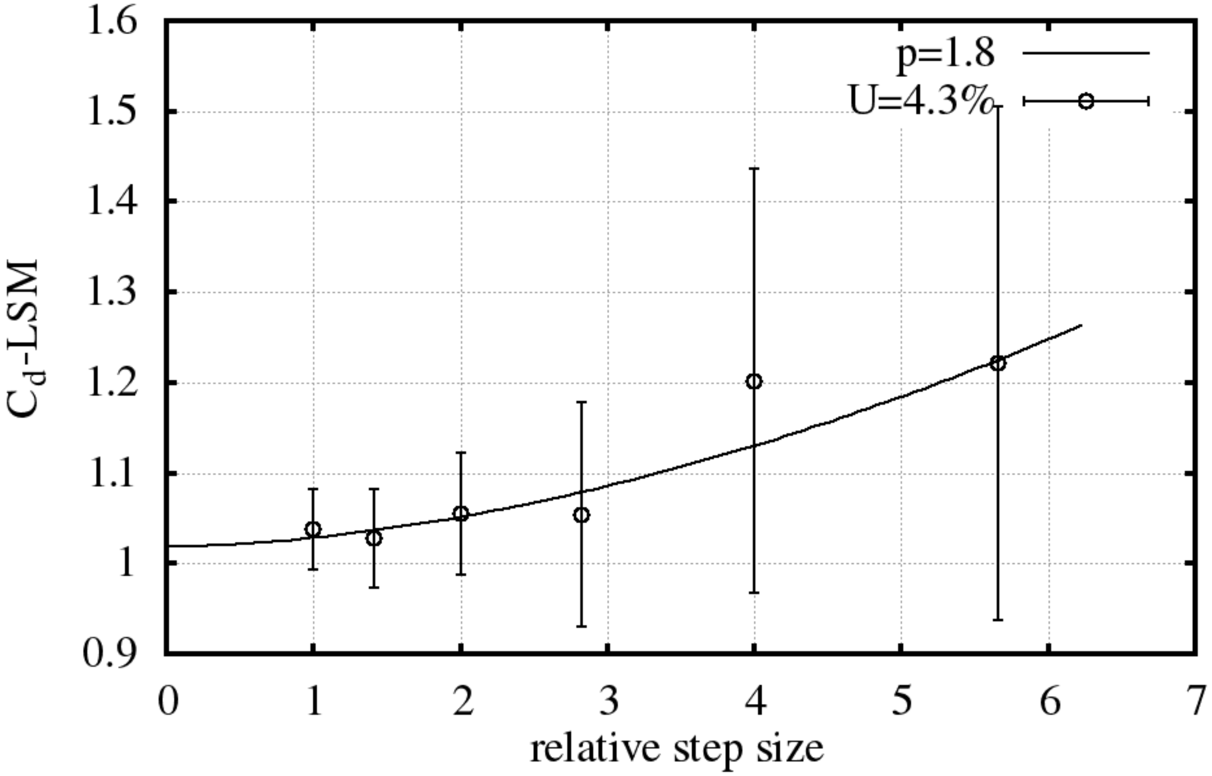
VVM2+



	VVM2-	VVM-	VVM0	VVM+	VVM2+	VVM3+
Relative step size	$4\sqrt{2}$	4	$2\sqrt{2}$	2	$\sqrt{2}$	1
Number of elements (10^3)	205,8	472,2	1204,2	3001,9	7819,4	20786,4

Study case - Solution verification results

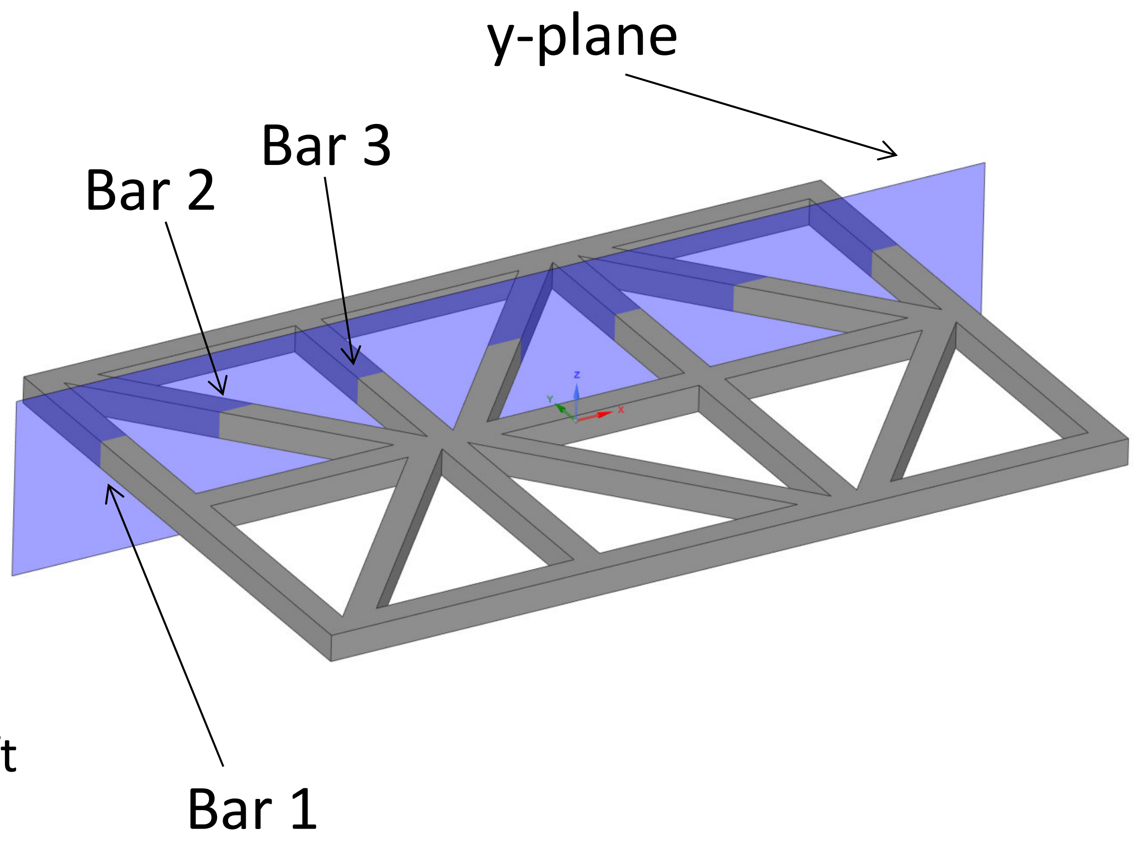




Mesh topology study

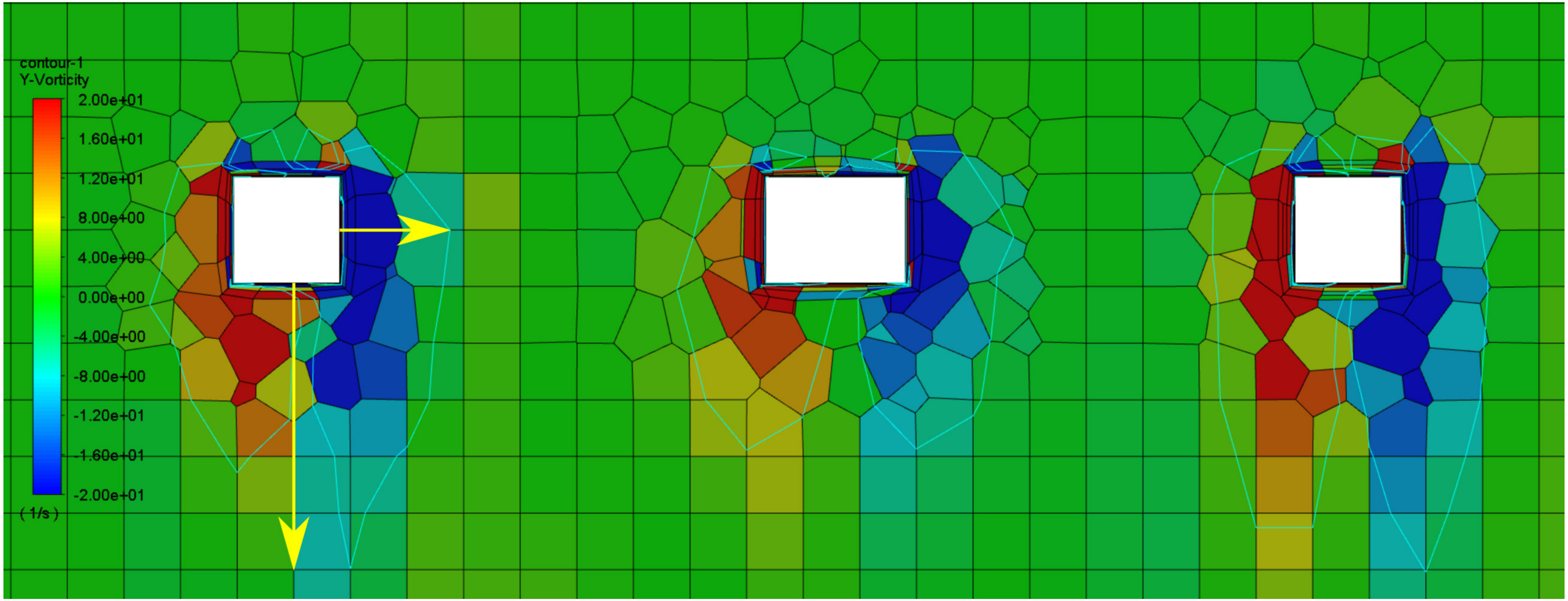
Mesh topology study

- Investigation of the regions of major interest to be further refined
    - Creation of new mesh topologies that can better capture both the forces generated by the movement and the resulting vortices
- Flow results from the previous simulations were analyzed (KC = 1,00), based on the vorticity field in a Y-plane that passes through the structure
- It was established an absolute vorticity value of 5 s^{-1} as basis for comparison between the simulations
- Only the first 3 squared bars of the structure, from left to right, were selected and numbered in the same order



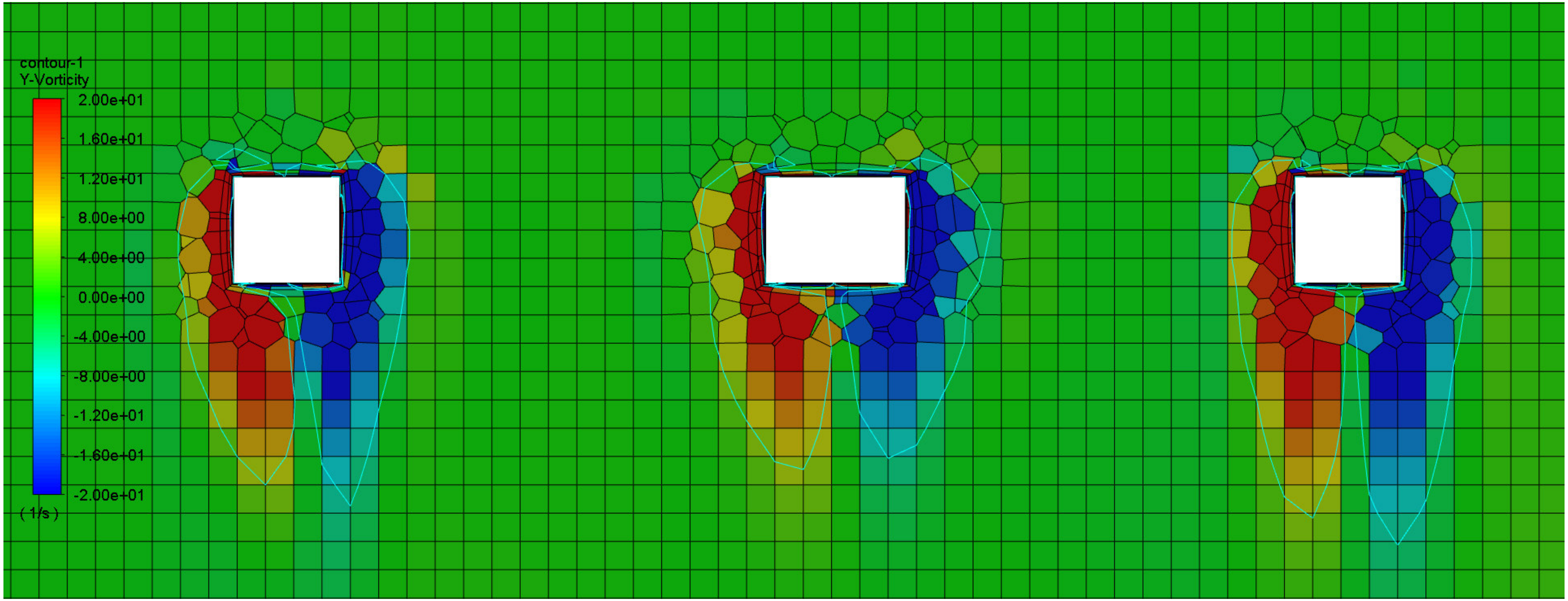
Mesh topology study

VVM2-



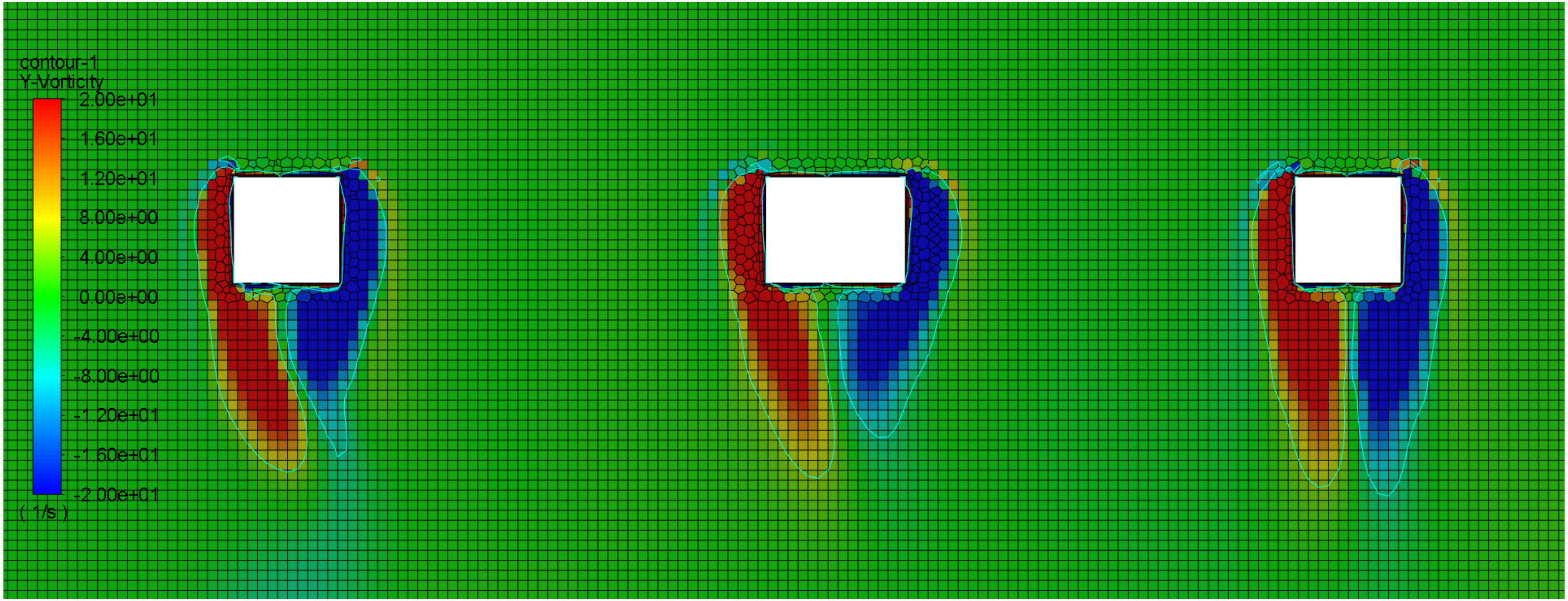
Mesh topology study

VVM0



Mesh topology study

VVM3+



Mesh topology study

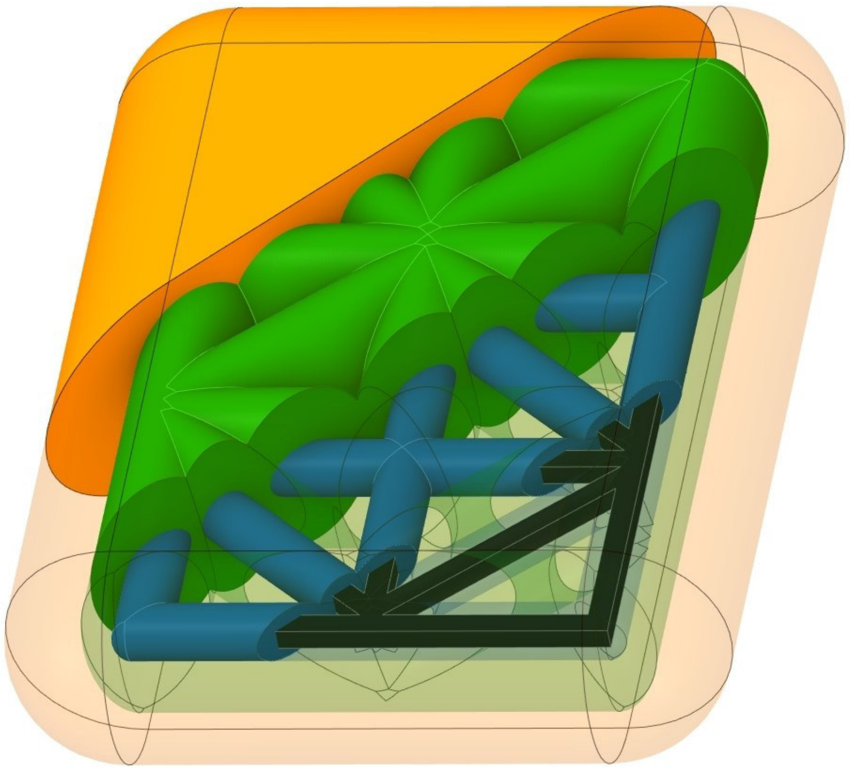
Units in [mm]

	Vertical direction						Horizontal direction					
	Maximum Velocity			Minimum Velocity			Maximum Velocity			Minimum Velocity		
	Bar 1	**Bar 2**	**Bar 3**	**Bar 1**	**Bar 2**	**Bar 3**	**Bar 1**	**Bar 2**	**Bar 3**	**Bar 1**	**Bar 2**	**Bar 3**
VVM 2-	40,00	32,00	40,00	32,00	8,00	4,00	16,00	16,00	16,00	16,00	16,00	16,00
VVM-	50,91	28,28	39,60	33,94	16,97	19,80	16,97	16,97	11,31	16,97	16,97	11,31
VVM0	36,00	28,00	**40,00**	20,00	10,00	14,00	12,00	16,00	12,00	16,00	16,00	12,00
VVM+	28,28	25,46	33,94	16,97	8,49	14,14	8,49	11,31	8,49	14,14	14,14	11,31
VVM2+	30,00	26,00	32,00	18,00	10,00	16,00	8,00	10,00	8,00	16,00	16,00	14,00
VVM3+	26,87	28,28	29,70	22,63	9,90	16,97	7,07	8,49	7,07	**18,36**	14,14	14,14

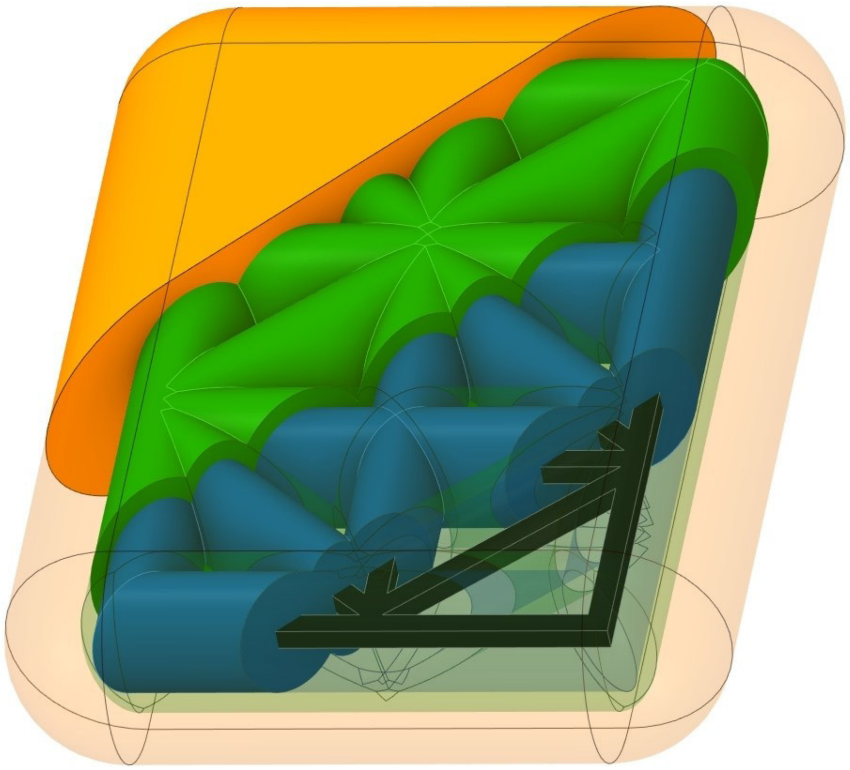
New mesh topologies

- Two new refinement bodies
- Refinement B (Orange)
  - The same used in domain 1
- Refinement C (Green)
  - Common to both: minor radius of 37,5 mm; major radius of 62,5 mm
- Refinement D (Blue)
  - Domain 2: radius of 18,75 mm
  - Domain 3: minor radius of 27,5 mm; major radius of 47,5 mm

Domain 2



Domain 3



New mesh topologies

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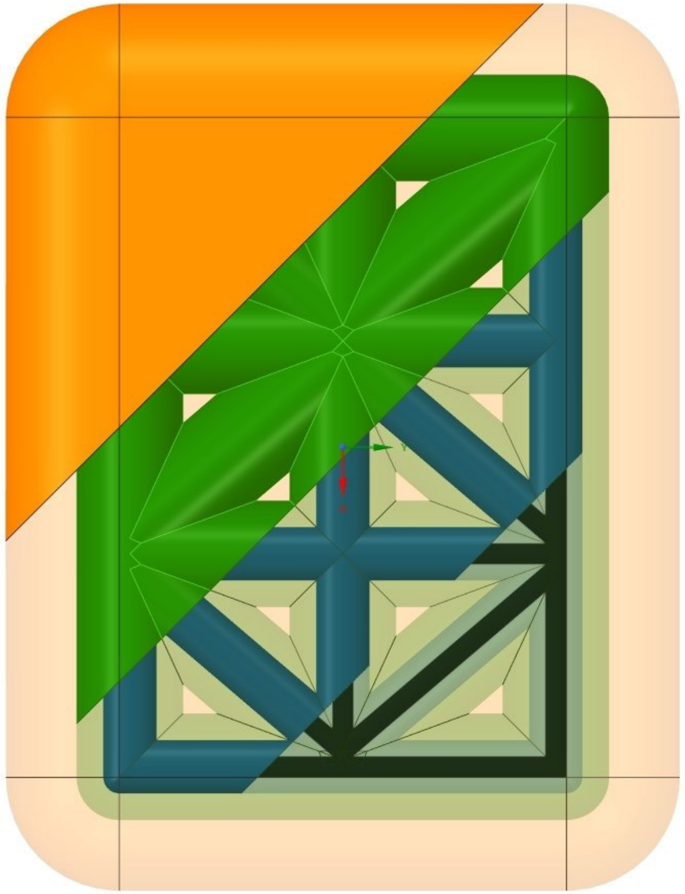
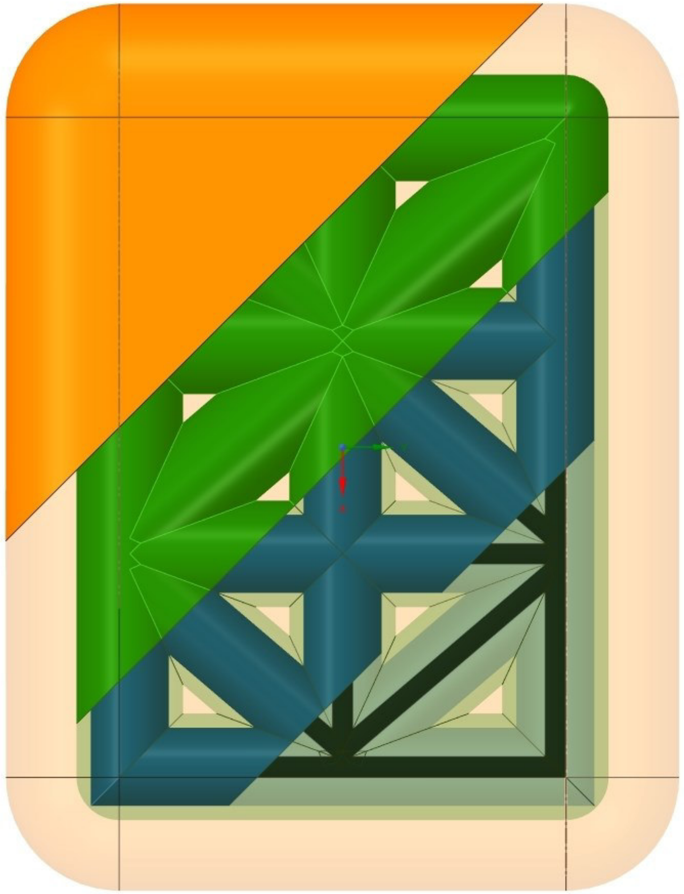
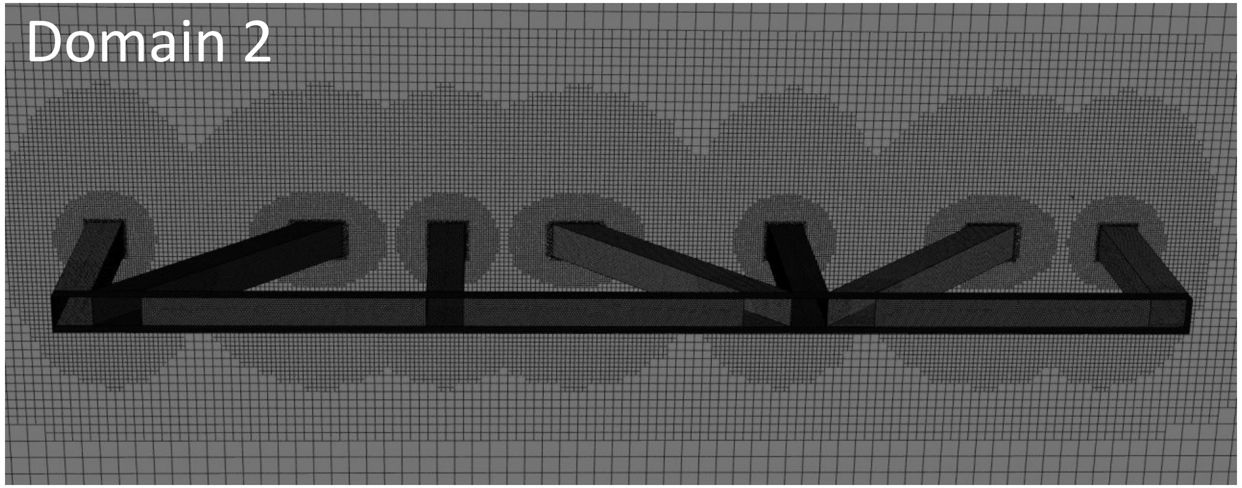
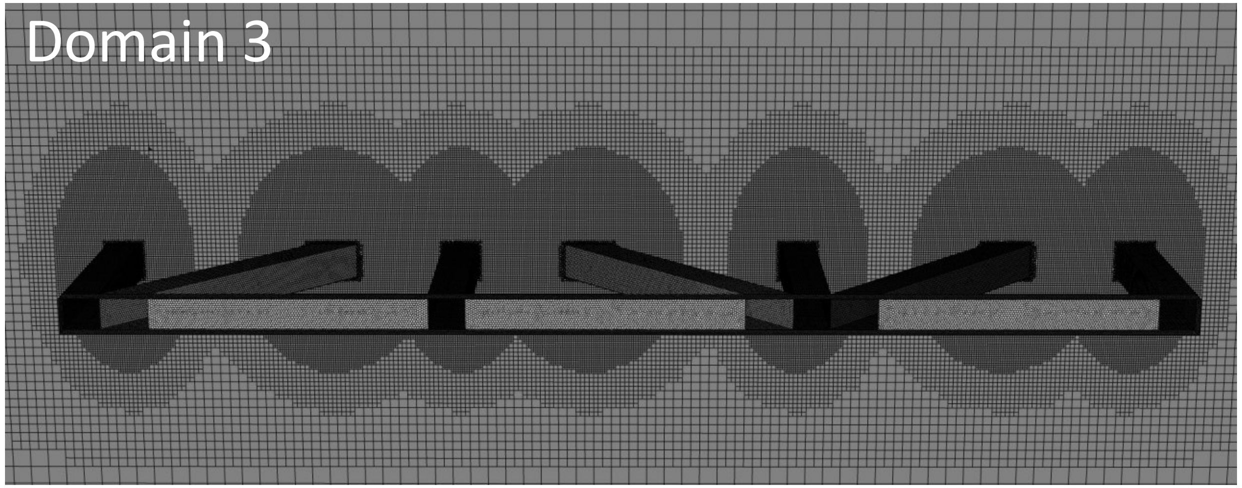


Domain 3



New mesh topologies

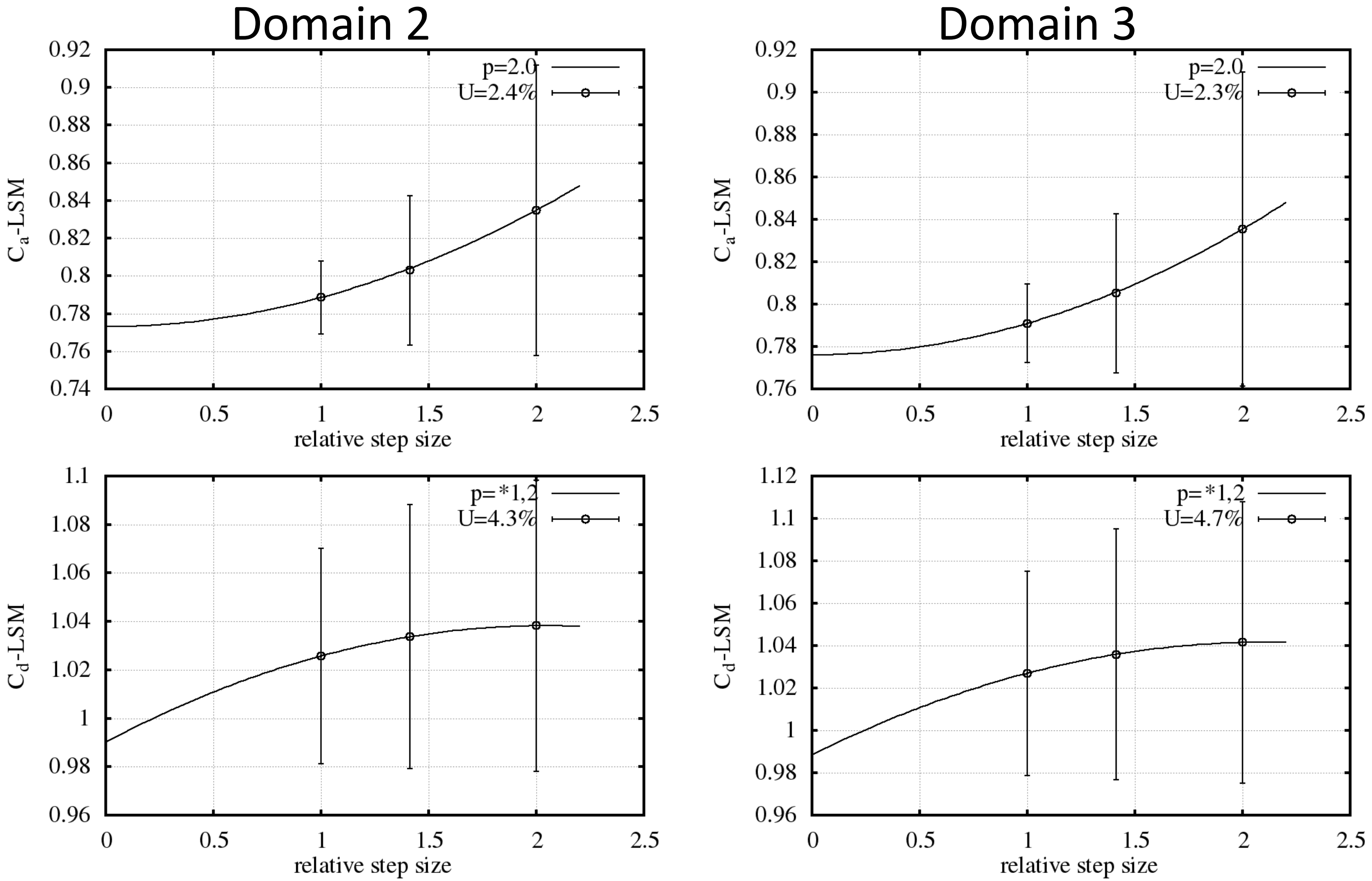




Domain	Max. Dim. [mm]	Ref. A [mm]	Ref. B [mm]	Ref. C [mm]	Ref. D [mm]	Number of elements (10^6)
VVM0 (1)	80	8	4	-	-	1,20
VVM3+ (1)	$20\sqrt{2}$	$2\sqrt{2}$	$\sqrt{2}$	-	-	20,79
2	80	8	4	2	1	5,21
3	80	8	4	2	1	9,58

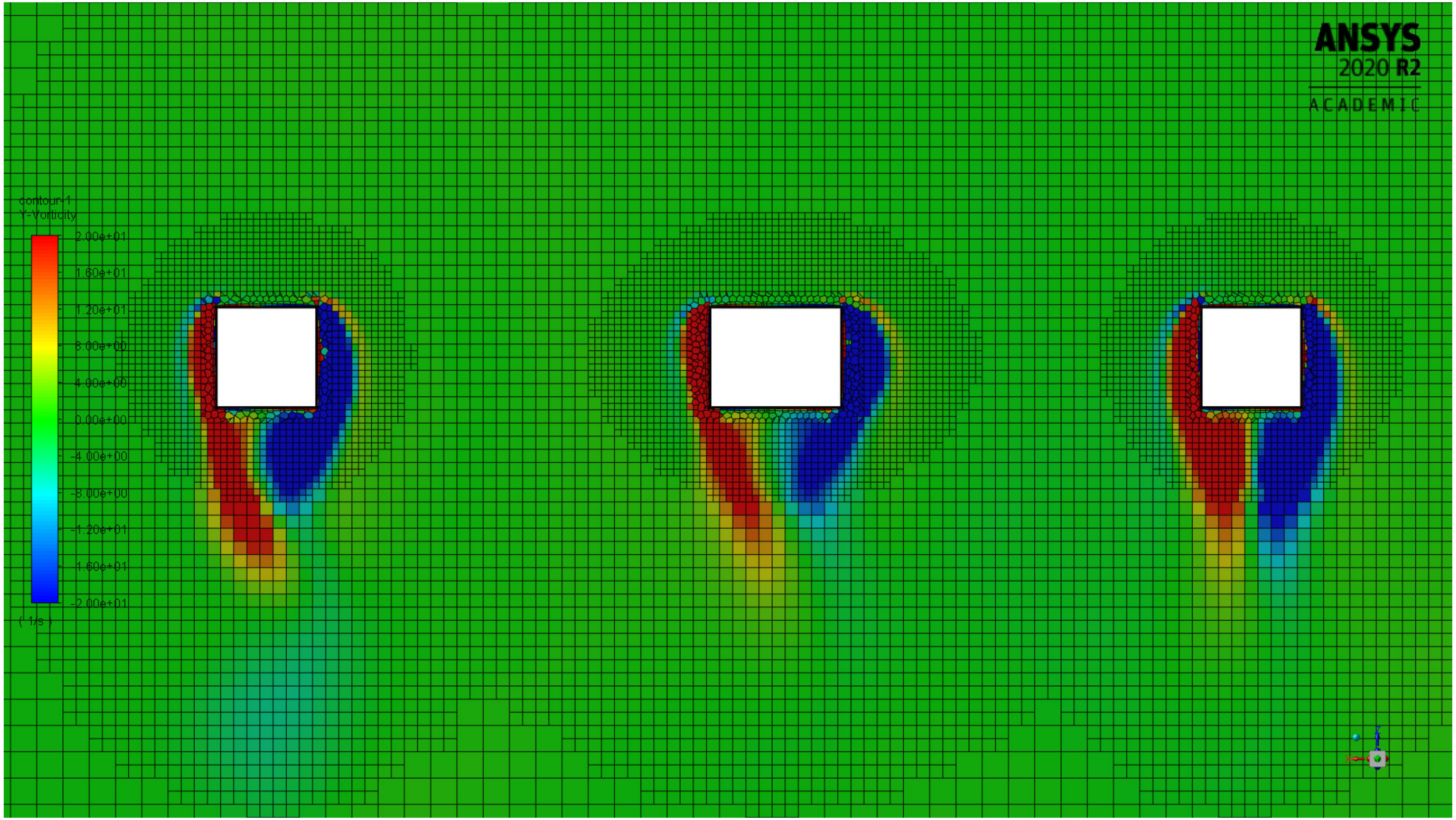
Mesh topology study – Solution verification

- Due to the computational effort required only the value of KC = 1,00 was simulated only over 3 different meshes



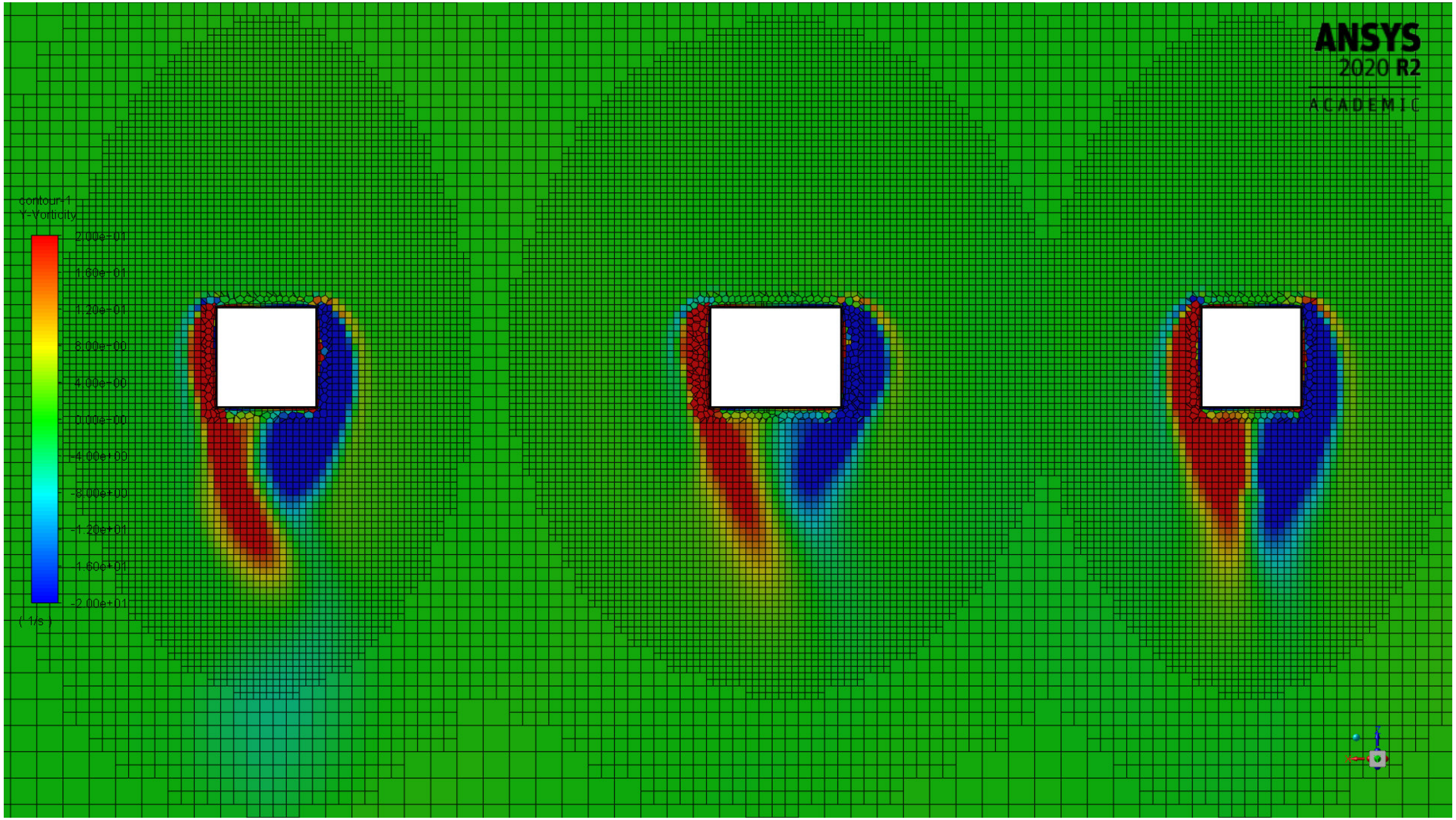
Mesh topology study

Domain 2



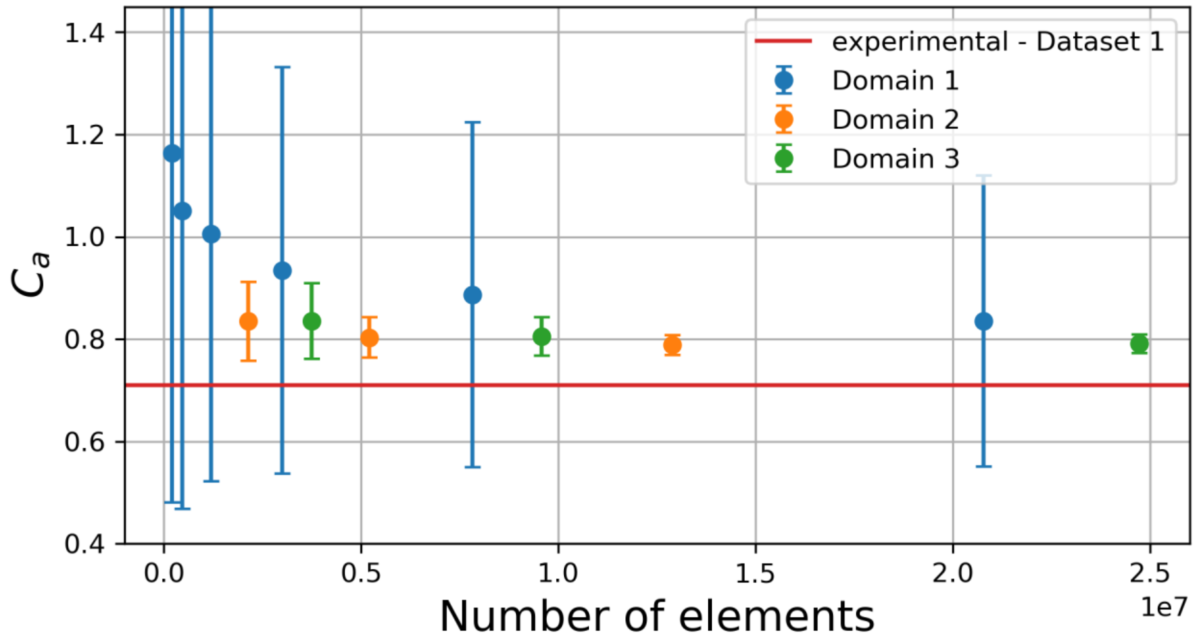
Mesh topology study

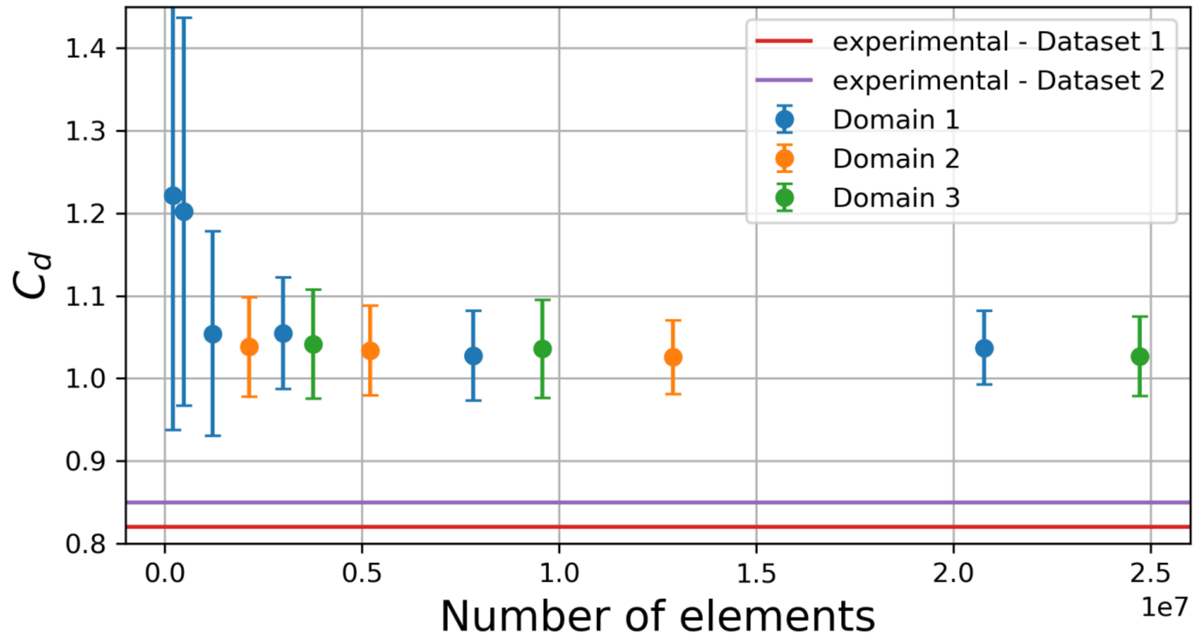
Domain 3



Mesh topology study – Mesh efficiency

- Comparison between all simulated meshes for KC = 1,00





Conclusion

- This paper presented a study related to mesh topology and refinement of CFD simulations;
- It is a continuation of a research related to the calculation of hydrodynamic coefficients of subsea structures under sinusoidal motion using CFD simulations;
- In the new mesh topologies there was a reduction of both computational cost and numerical uncertainty, with a similar final coefficient result;
- If more focus is given to the value of the obtained coefficients, domain 2 may be a better choice, because of its analogous results and lower computational cost; Whereas, if more focus is given to the resultant flow topology, domain 3 may be recommendable, since it has a higher number of elements with small size near the geometry.

Conclusion

- In future stages, it is intended to estimate the uncertainty related to both spatial and temporal discretization of the simulations with the three different domains, in order to have a better picture of its most relevant uncertainties;

- It will be interesting to simulate using the presented method, more realistic geometries, which are representative of equipment used in the offshore industry.

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Thank you

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