FlowVision

AKANA MÜHENDİSLİK ve TİCARET A.Ş.

TMMOB MAKİNA MÜHENDİSLERİ ODASI 1954

Canlı Webinar

CFD; KÜÇÜK BOŞLUKLARDA VE DAR KANALLARDA AKIŞLAR & SIZINTI SİMÜLASYONLARI

Sunucu: Ali Göktaş
MMO Ankara Şube
Üye İlişkileri Birim Sorumlusu
ali.goktas@mmo.or.tr

Konuşmacı: Sinan Soğancı
Makine Mühendisi, MBA
Ürün Müdürü
Akana Mühendislik

Webinar saat 18:00'da başlayacaktır…

Akana Mühendislik

AKANA MÜHENDİSLİK ve TİCARET A.Ş.

- **Milli savunma, havacılık ve uzay sanayii**
  - **Stratejik çözüm ortağı**
  - **Alt sistem tasarımcısı/tedarikçisi**
- **~100 Personel**
  - **>40 Mühendis**
- **Alt sistem ve sistem seviyeleri**
  - **Müşteri gereksinimi odaklı tasarım**
    - **Mekanik, elektromekanik, hidrolik, pnömatik, kontrol, kimyasal süreçler…**
  - **CFD/FEA analizleri**
  - **Prototip üretim & test**
  - **Üretim & kalite kontrol**
  - **Devreye alma & teknik destek**

ATAK TEAM
TAI
aselsan
AgustaWestland

Akana Mühendislik

AKANA MÜHENDİSLİK ve TİCARET A.Ş.

HESAPLAMALI AKIŞKANLAR DİNAMİĞİ (CFD)

KÜÇÜK BOŞLUKLARDA VE DAR KANALLARDA AKIŞLAR
&
SIZINTI SİMÜLASYONLARI

İçerik:

1. *Simülasyon Zorlukları (Challanges)*
2. *Faydalanılan Teknolojiler (Technologies)*
3. *Vaka Çalışmaları (Case Studies)*

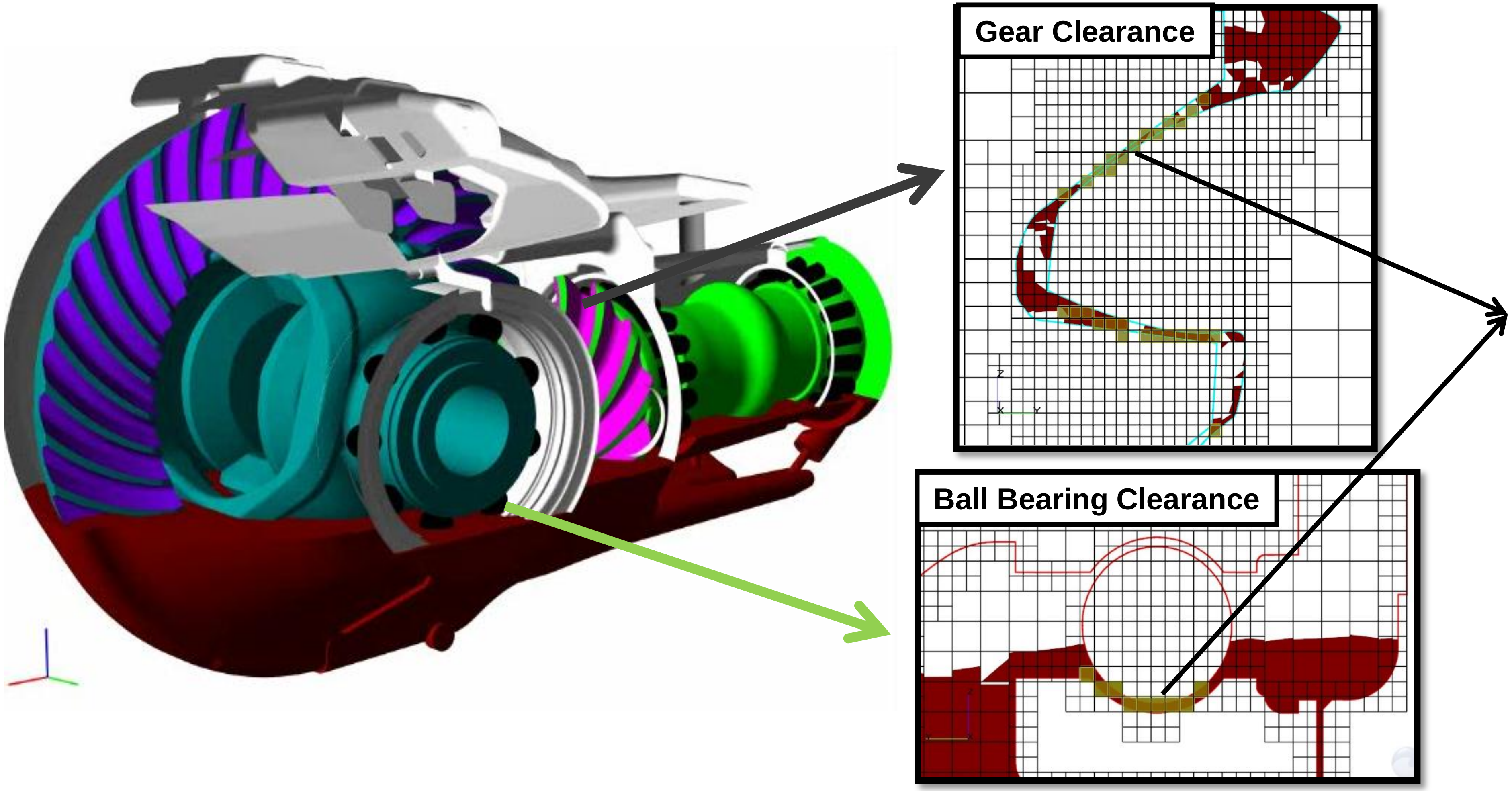
HESAPLAMALI AKIŞKANLAR DİNAMİĞİ (CFD)

KÜÇÜK BOŞLUKLARDA VE DAR KANALLARDA AKIŞLAR
&
SIZINTI SİMÜLASYONLARI

1. Simülasyon Zorlukları (Challanges)

1.1. Çok boyutluluk (Dimensionality)
1.2. Katı modelleme (CAD association)
1.3. Değişken boşluklar (Dynamic clearances)

1.1 Çok Boyutluluk (Dimensionality)



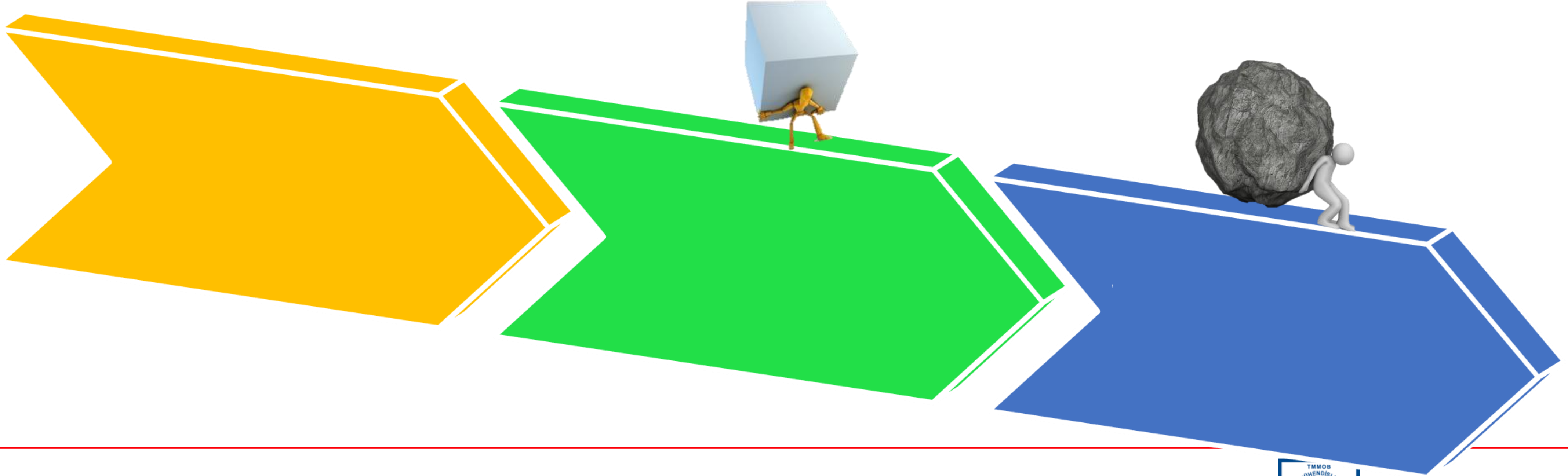
tiny channels in large domains!!!

Clearance: ≈ 10^{-6} meters

Domain Size: ≈ 10^{0} meters

1.2. Katı Modelleme (CAD Association)

- In some engineering applications, performance relies on small clearances
  - to be modelled with very small tolerances in CAD
- Representation of such geometrical features in simulation
  - is obtained by using excessive number of computational cells
    - which significantly increases computing power & solver expectations



1.3. Değişken Boşluklar (Dynamic Clearances)

- A small clearance between two surfaces is not necessarily constant.
- Time and space dependency of clearances can be observed due to:

Motion **Deformation** **Full closure!**

Courtesy of (from left to right): City, University of London, Dana Sealing Products, RWTH Aachen University

HESAPLAMALI AKIŞKANLAR DİNAMİĞİ (CFD)

KÜÇÜK BOŞLUKLARDA VE DAR KANALLARDA AKIŞLAR
&
SIZINTI SİMÜLASYONLARI

2. Faydalanılan Teknolojiler (Technologies)

2.1. *Çok boyutluluk* → ***Gap Model™***
2.2. *Katı modelleme* → ***SGGR™*** *(Sub-Grid Geometry Resolution)*
2.3. *Değişken boşluklar* → ***Moving Bodies & FSI***

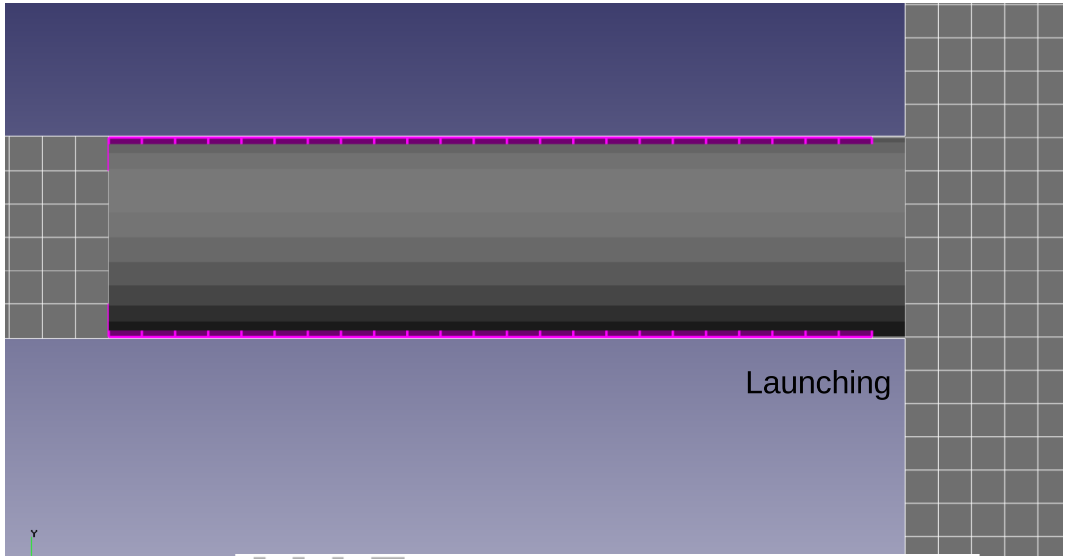
2.1. Gap Model™

Dimensionality issues → Extreme dimension ratios (microns/meters)

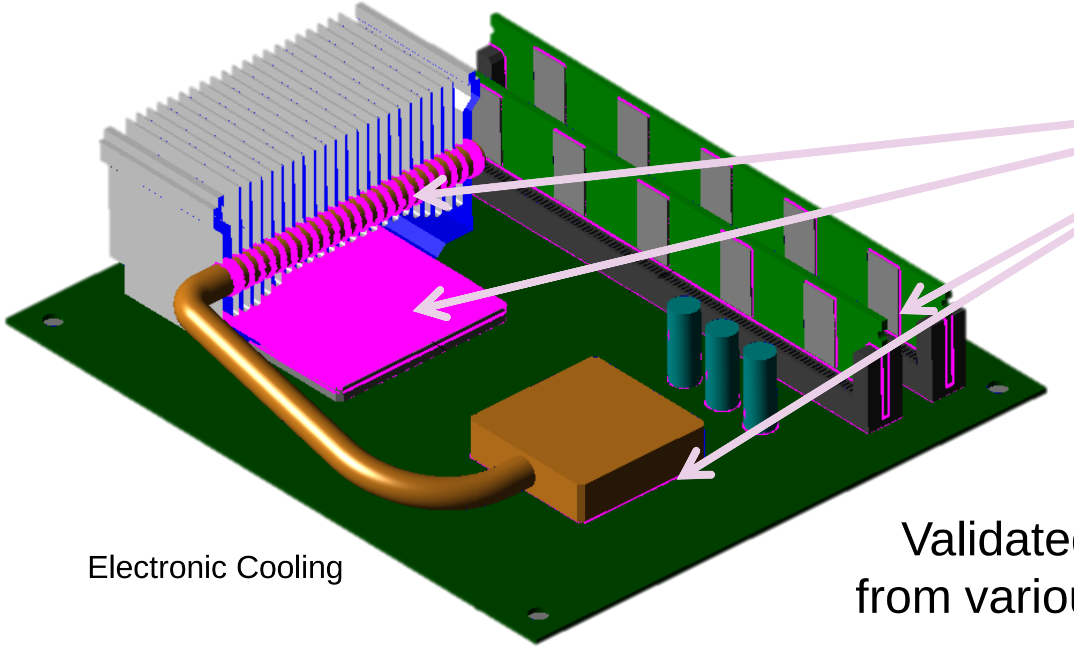
Clearance flows → Thin channels down to sub-microns

Initially developed for screw compressors (2000's)

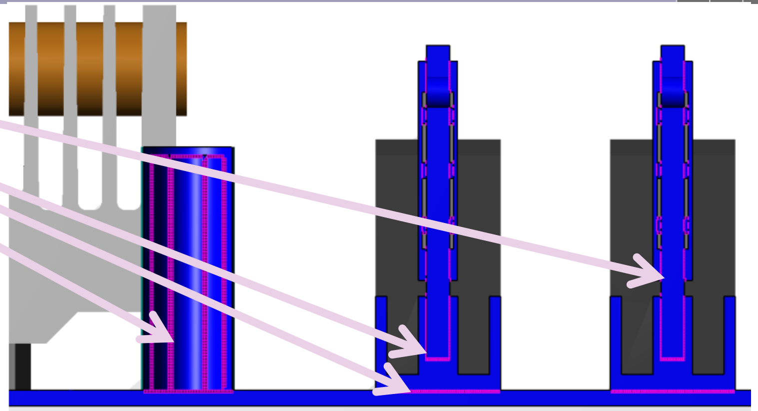
- By adding extra source term to momentum equation
- Based initially on Poiseuille flow assumption
- Further developed by analytical + empirical R&D



Gap Cells



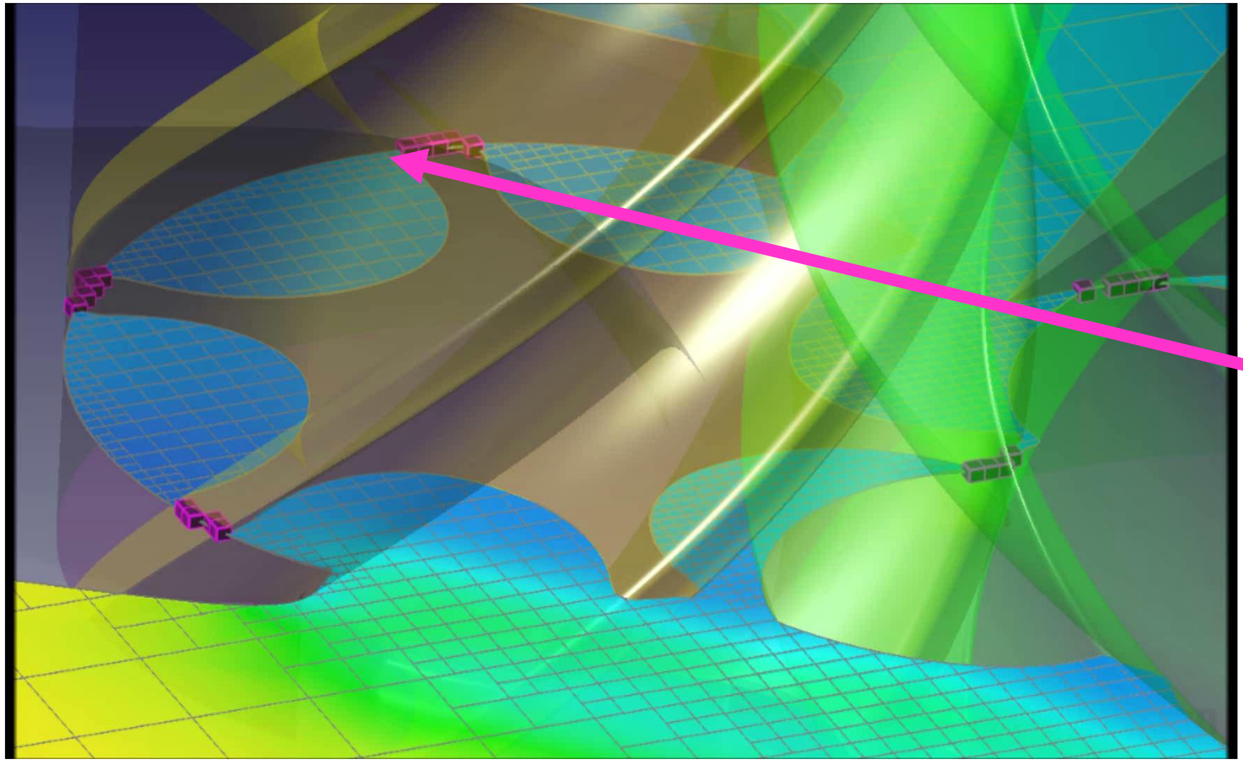
Electronic Cooling



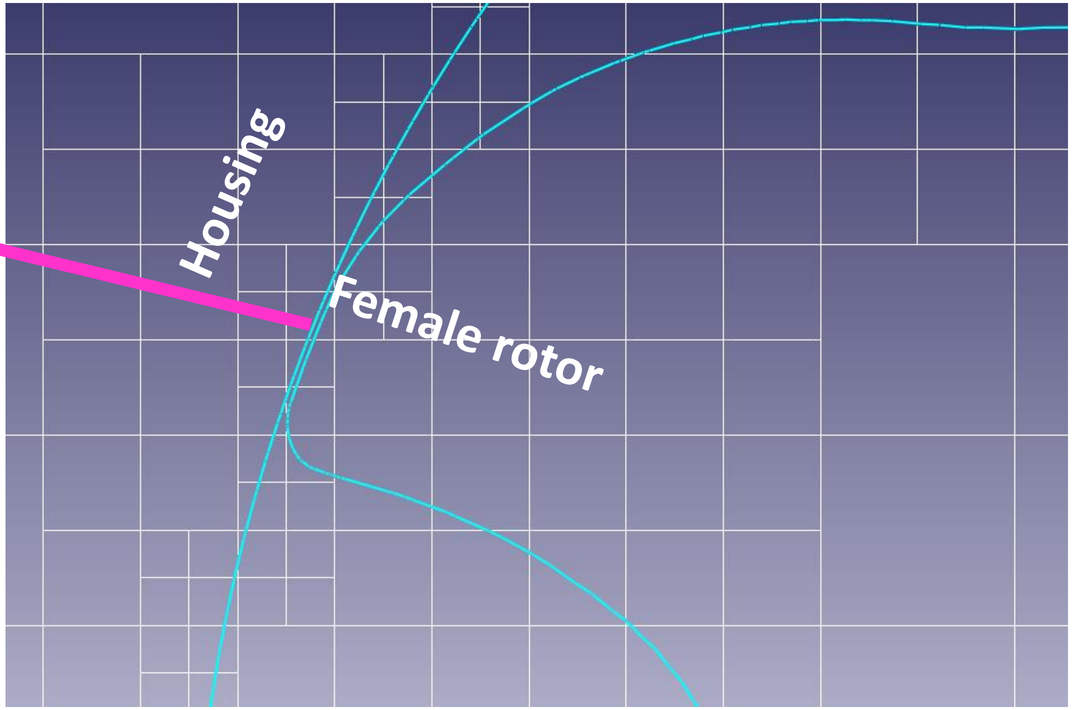
Validated by experimental data from various industries/applications: →

- Screw compressors
- Electronic assembly cooling
- Launching (defense)

2.1. Gap Model™



- Very simple usage
- No need for 3rd party tools

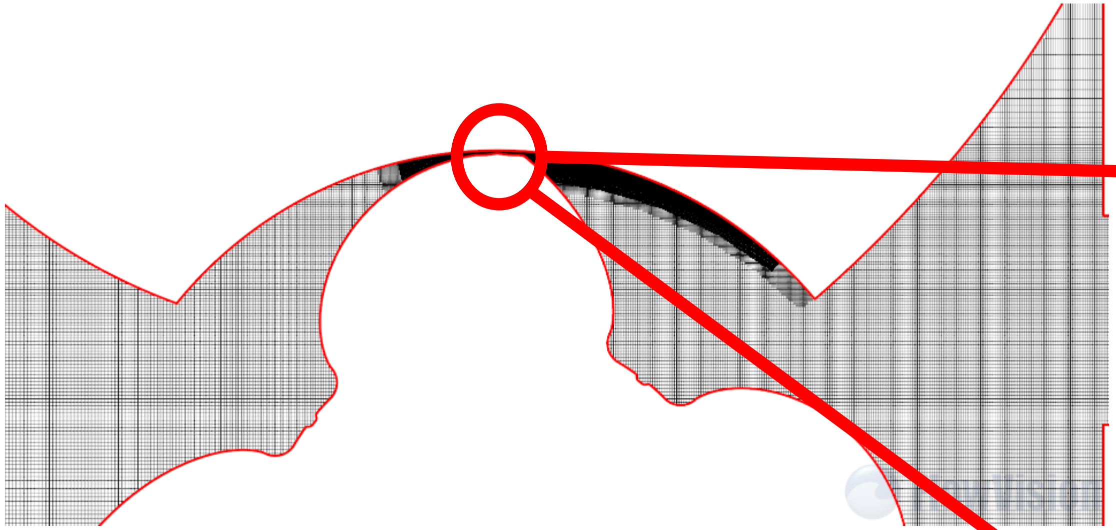


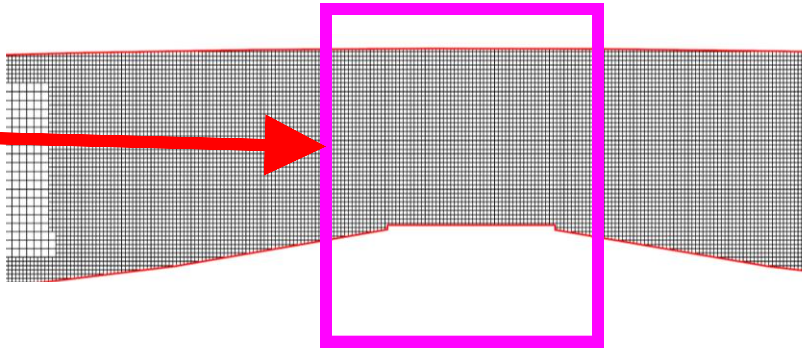
How the Gap Model works;

- User enters min-max clearance interval
- Gaps are automatically detected.
- Local calculations are manipulated.

Name	Model #0
Use Gap model	Standard Gap model
Min. clearance	1e-008
Max. clearance	0.02

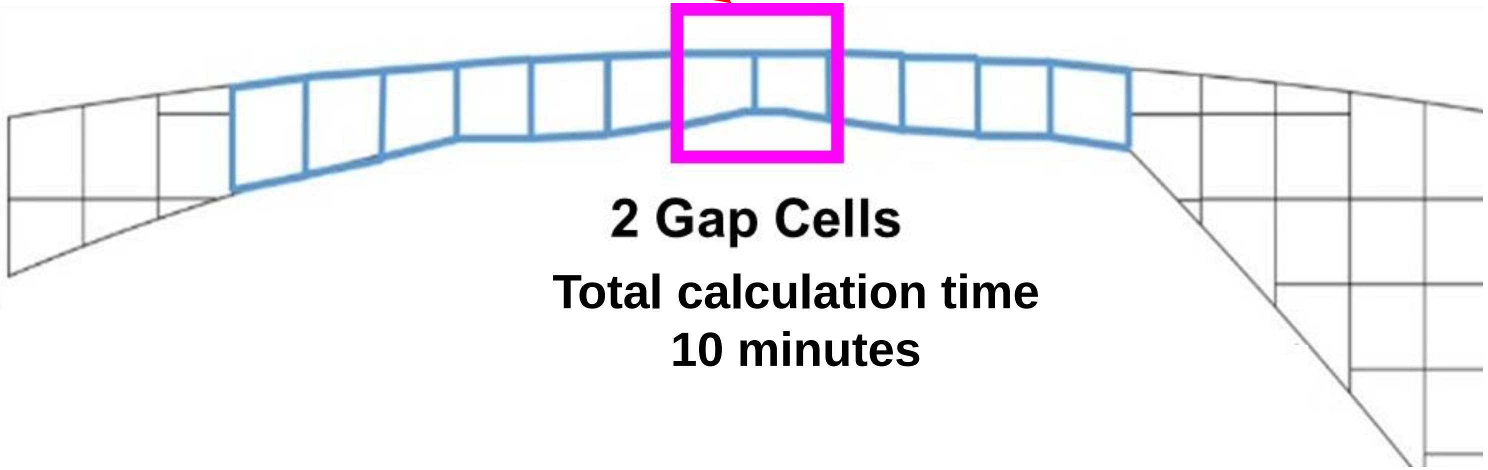
2.1. Gap Model™





44x40 Cells (2D)
Total calculation time
8 hours

Clearance = 0.04 mm

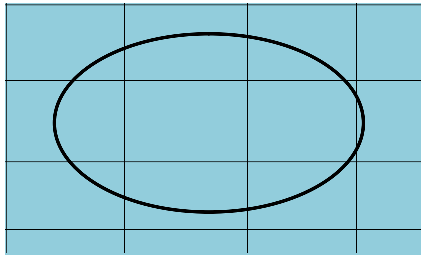


2 Gap Cells
Total calculation time
10 minutes

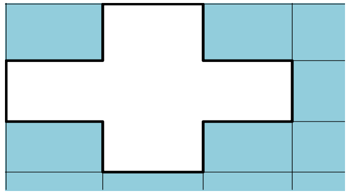
Experimental validation of Gap Model on transonic clearance flow setup of TU Dortmund

2.2. SGGR™: Sub Grid Geometry Resolution

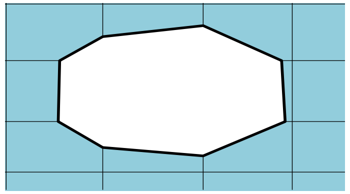
Resolve actual geometry → focus on PHYSICS…



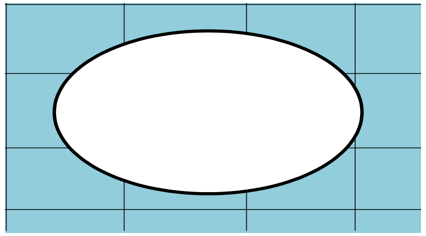
Real Geometry



Stepwise Method

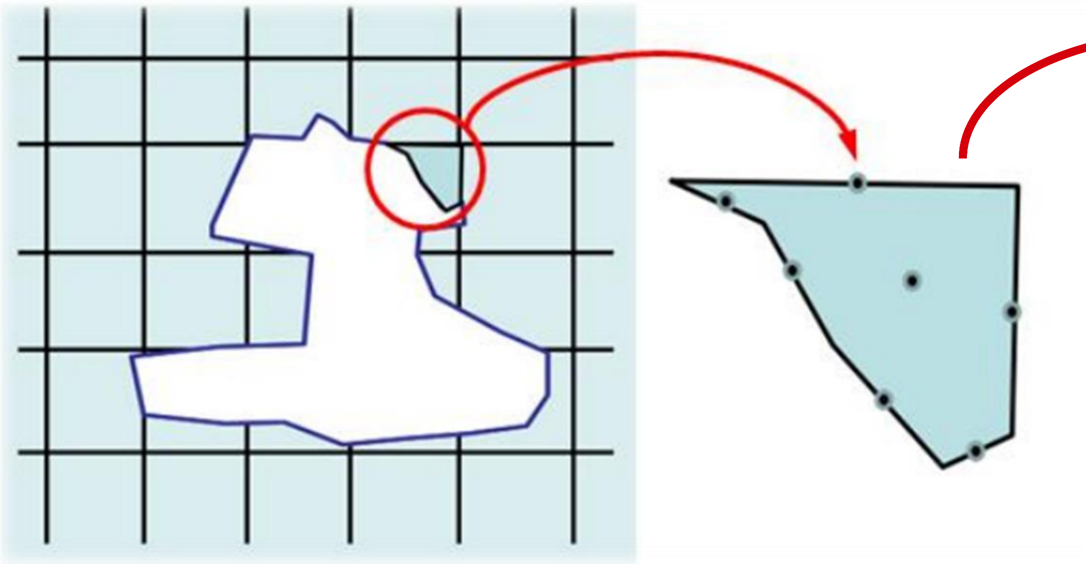


Cut-Cell

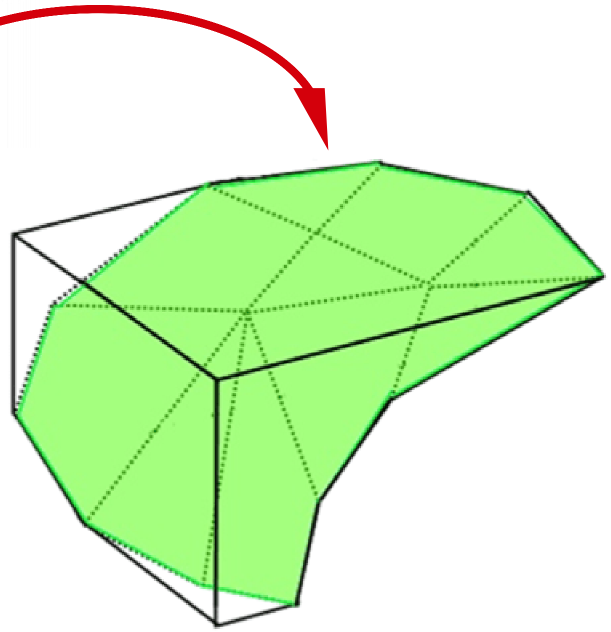


SGGR

- No simplification, no de-featuring, no approximation
- Perform simulation with original CAD/FE geometries



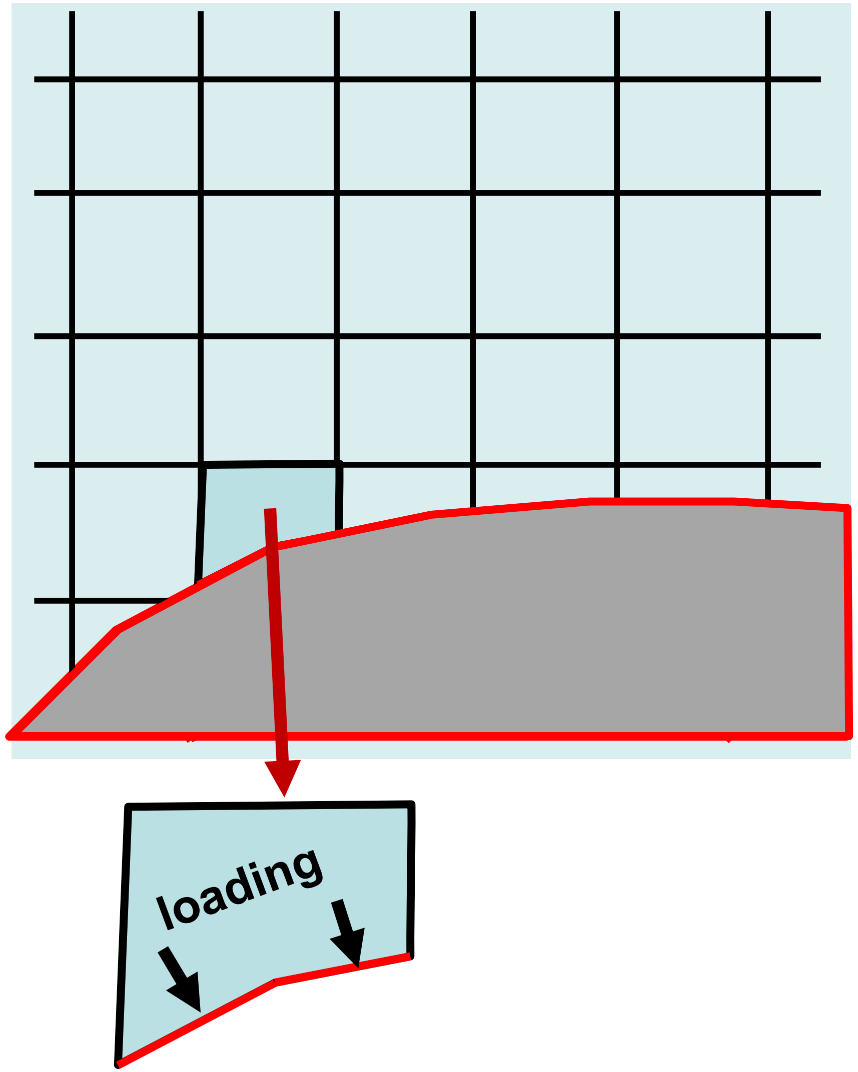
Parametric initial Cartesian grid is trimmed by exact CAD/FE Boundaries.



Hybrid SGGR cell

- CAD/FE facets (green triangles)
- CFD cell facets (transparent surfaces)

2.2. *SGGR™* Working Principle



- **Import CAD geometry or FE mesh**
- **Mesh generation:**
  Boolean subtraction of
  CAD/FE volume
  from CFD mesh
  CAD/FE border = CFD boundary
- **Each CFD cell contains CAD/FE outside border**

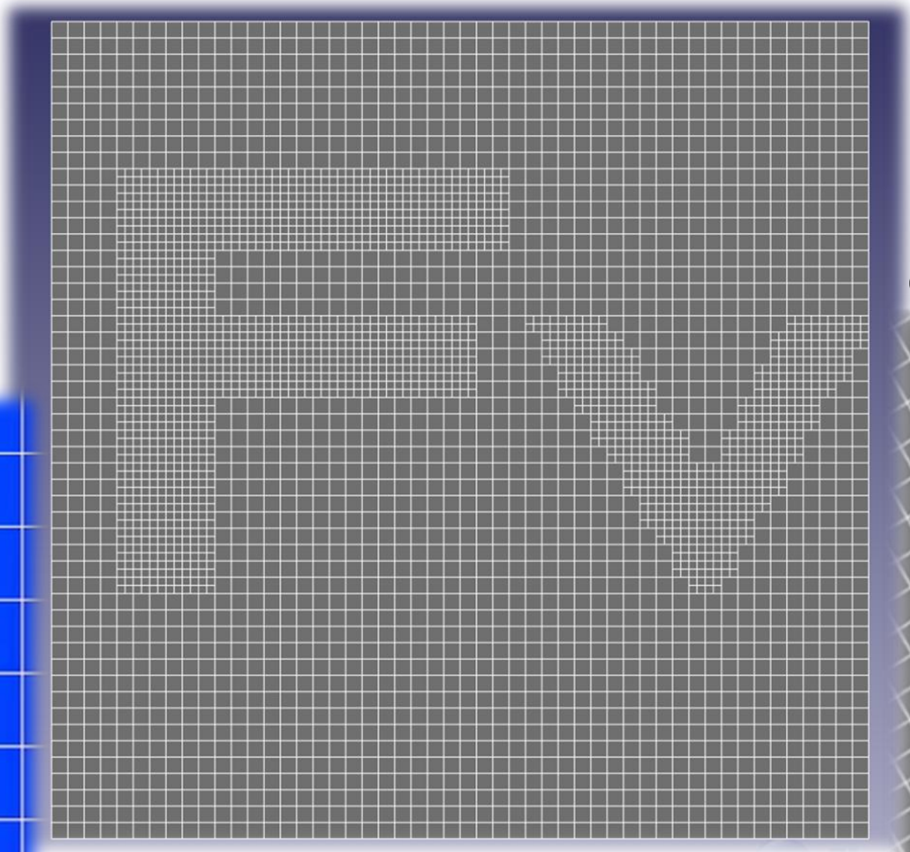
✓ **Perfect matching of fluid/solid domains**

✓ **Accuracy in hydrodynamic loads & body motions/deformations**

✓ **Avoid manual efforts for coupling**

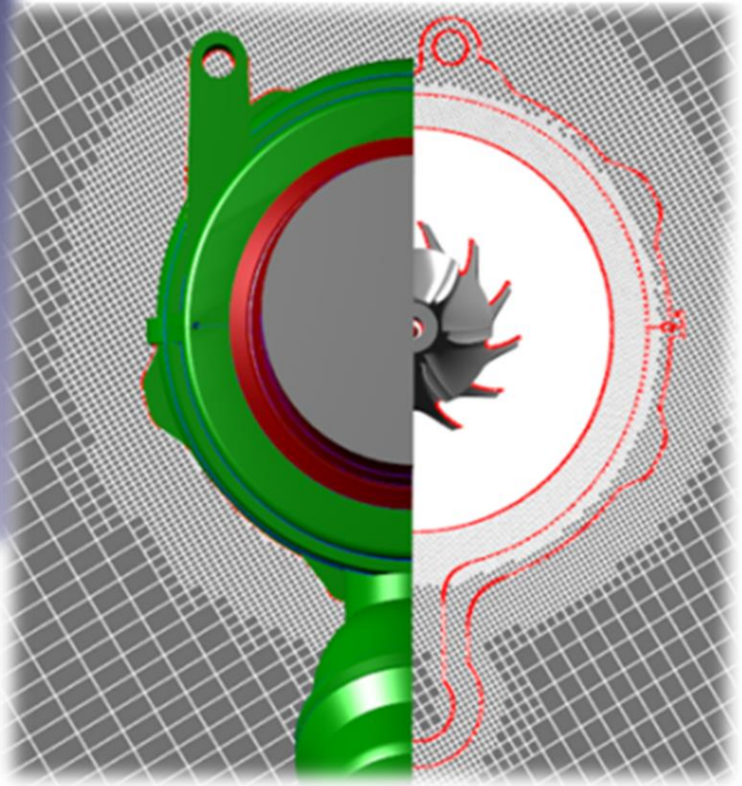
2.2. Grid Adaptation

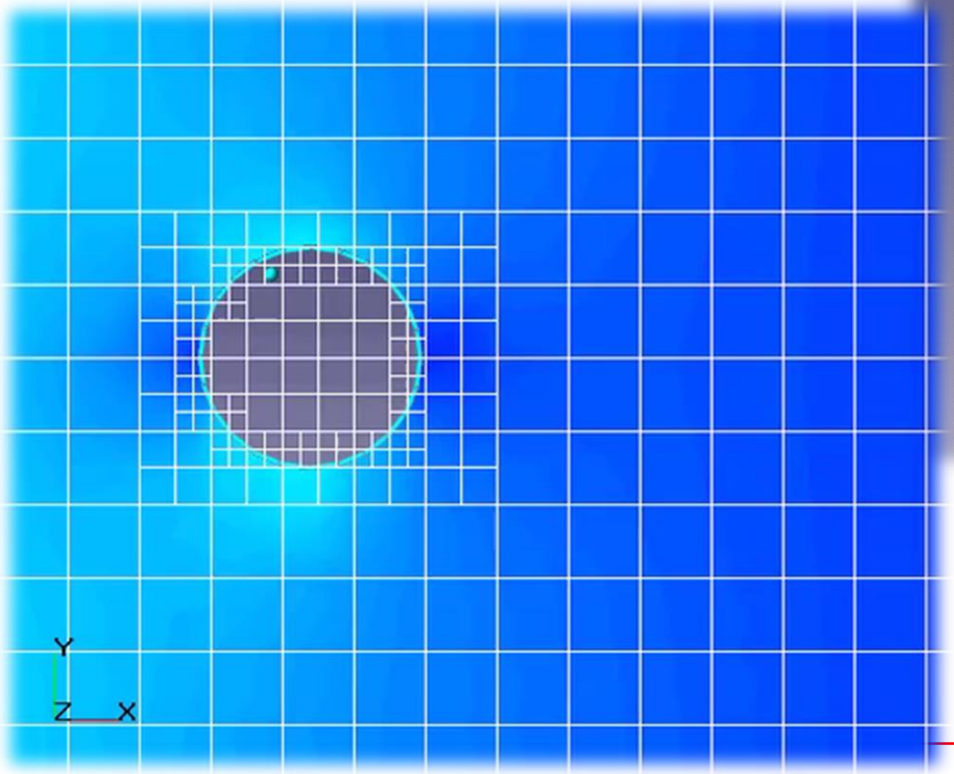
- Solution based
  - Gradients
  - Values (point/interval)
- Geometry based
  - Boundaries
  - Arbitrary shapes



Geometry (arbitrary shaped) based adaptation

Geometry (Boundary Condition) based adaptation
(courtesy of DSM, Mitsubishi Motors Corporation, USA)





Solution (velocity)
based adaptation

2.3. Moving Bodies

- Not limited by contacts, intersections or full closure
- No mesh deformation
  - Mesh is renewed automatically
  - No user manipulation required

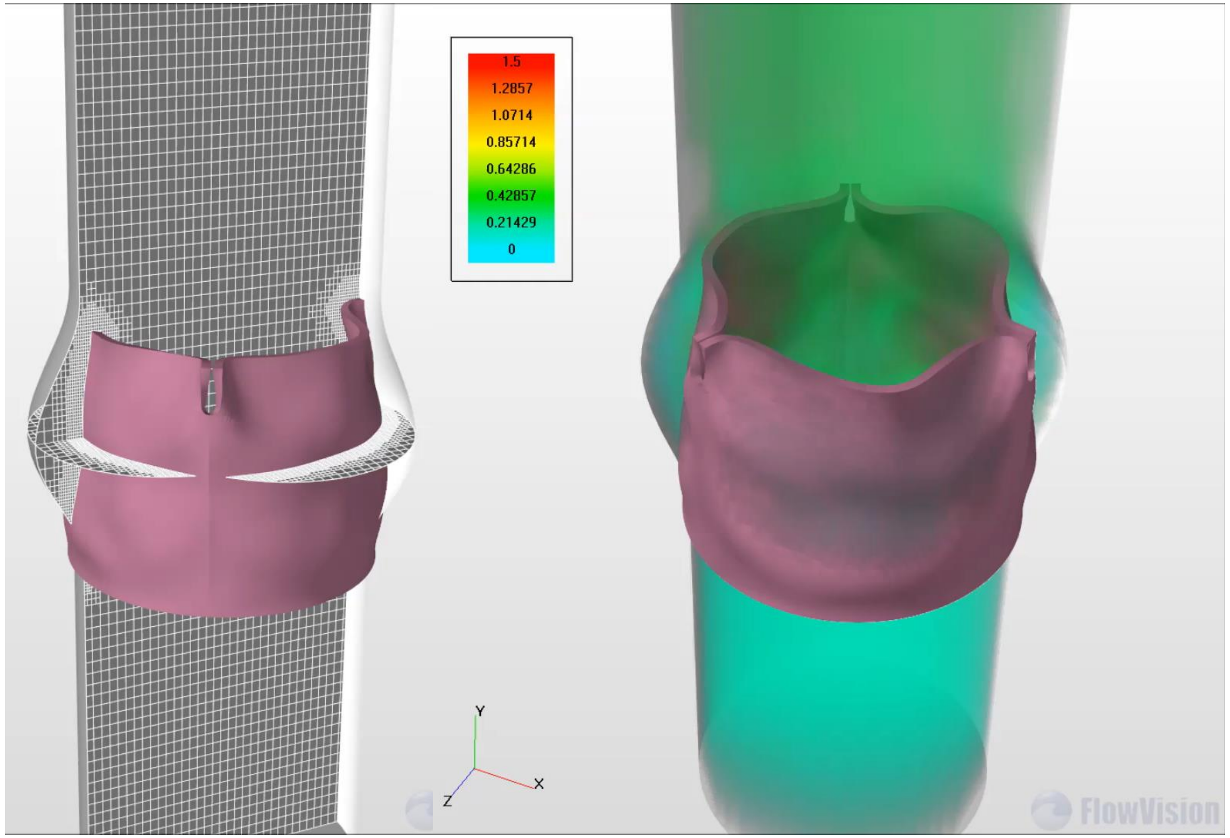
Motion Definition

- Translational & rotational velocities
- External forces & torques
- Rigid FSI → wrt. aero/hydrodynamics forces
- External Coupling

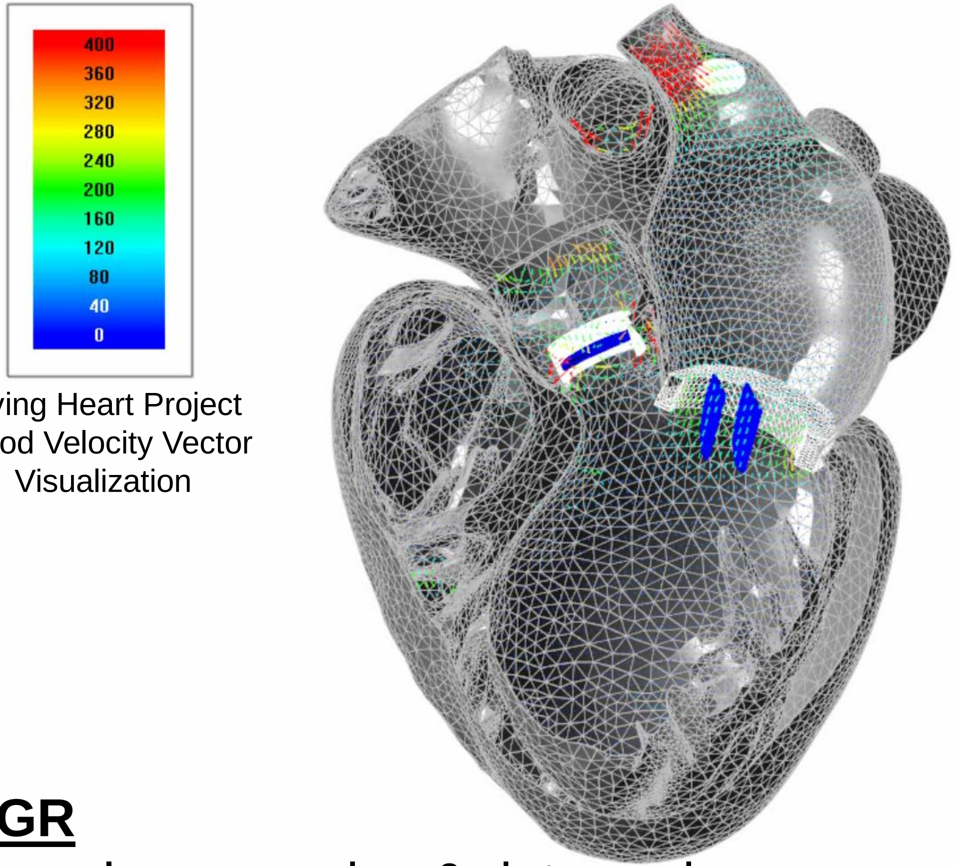
  (FEA / Optimization Software, Motion Capturing etc.)

2.3. Two-Way Strongly Coupled FSI

FSI: **F**luid **S**tructure **I**nteraction



Artificial Aortic Heart Valve
(Courtesy of RWTH Aachen University)



Living Heart Project
Blood Velocity Vector
Visualization

SGGR

→ Lossless mapping & data exchange

‘Co-Simulation with FEA’ tool

→ no need for 3rd party coupling codes

3. Vaka Çalışmaları

(case studies from different industries)

Vaka	Endüstri / Uygulama
3.1. Heat transfer at lamellate coils	HVAC
3.2. Differential gearbox	Automotive / Lubrication
3.3. Screw compressor performance	Energy / Positive displacement machines
3.4. Motherboard assembly cooling	Electronics
3.5. Underwater & airborne launching	Defense
3.6. Hydrodynamic bearing for wind turbines	Energy / Lubrication
3.7. Clutch groove pattern	Automotive / Lubrication

3.1. Case Study: HVAC

Heat transfer in lamellate coils

Problem Description

AKANA
MÜHENDİSLİK ve TİCARET A.Ş.

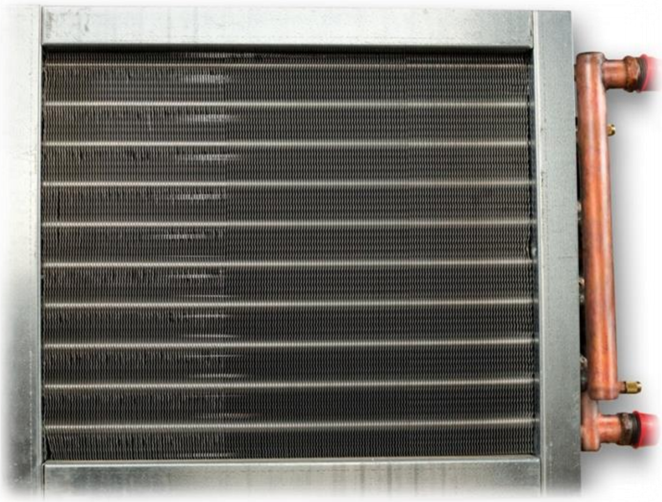
<u>Objective:</u>

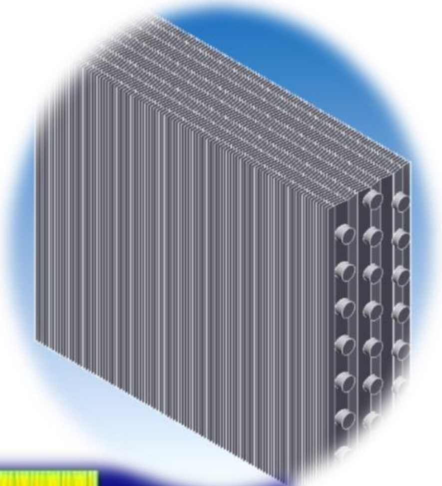
Predict / validate

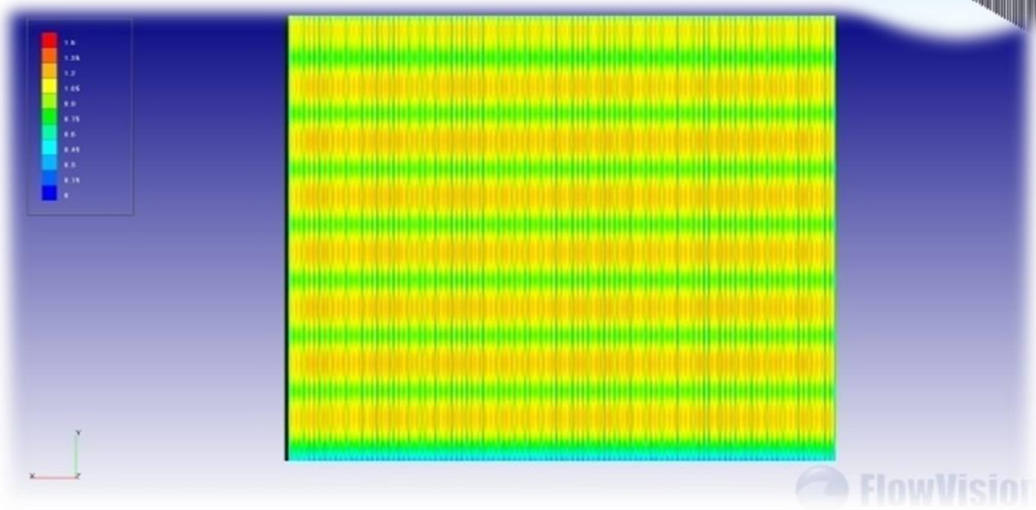
thermal performance of

lamellate coils

used in HVAC systems



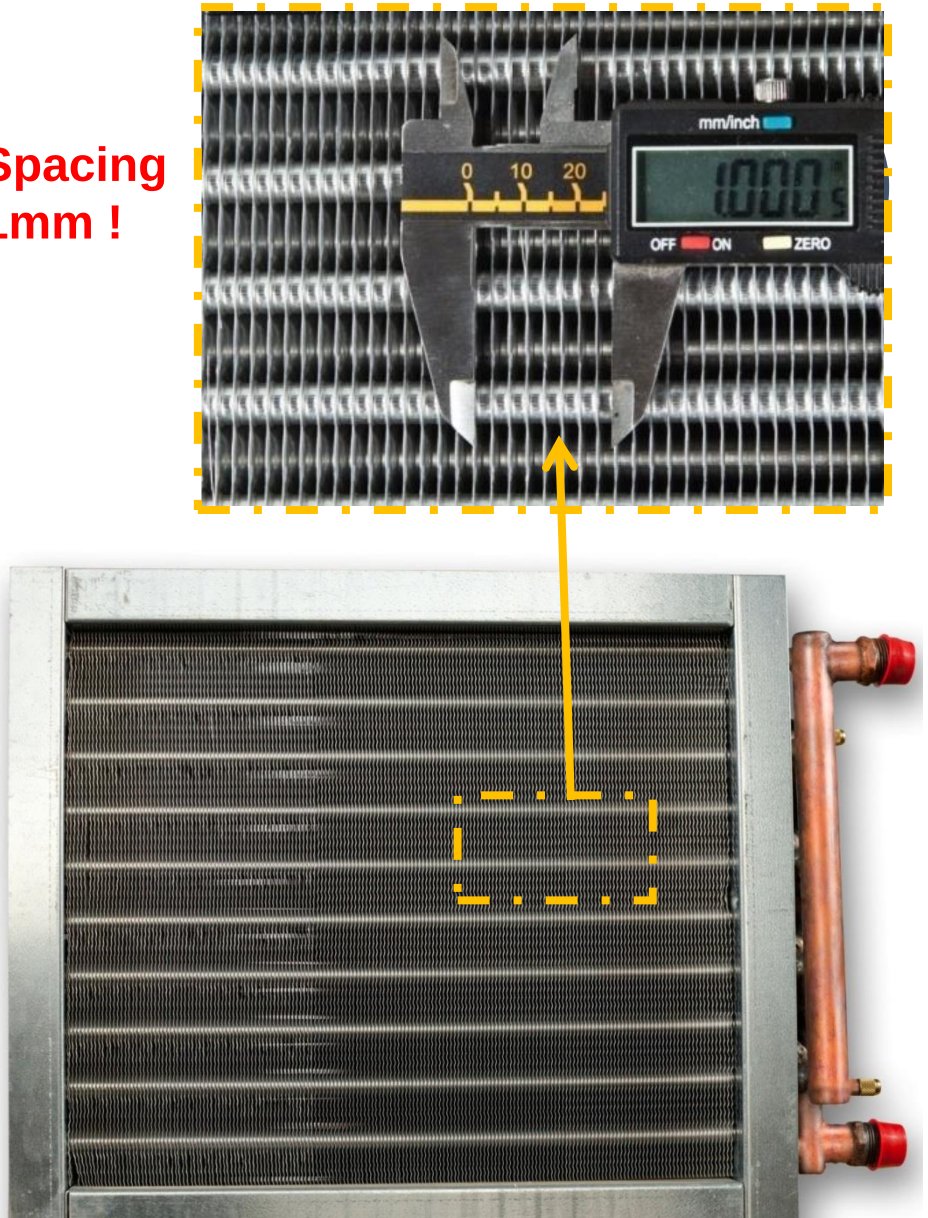




Relevance to the Topic…

- However,
  - Physical experiments are expensive
    - due to high cost of prototypes
  - Simulations are computationally costly
    - due to **dimensionality problems**
- Purpose:
  - HVAC system simulation
    - with less number of physical experiments
    - through **affordable numerical simulations**

Fin Spacing
2.1mm !



Length x Height x Width
460mm x 200mm x 60mm

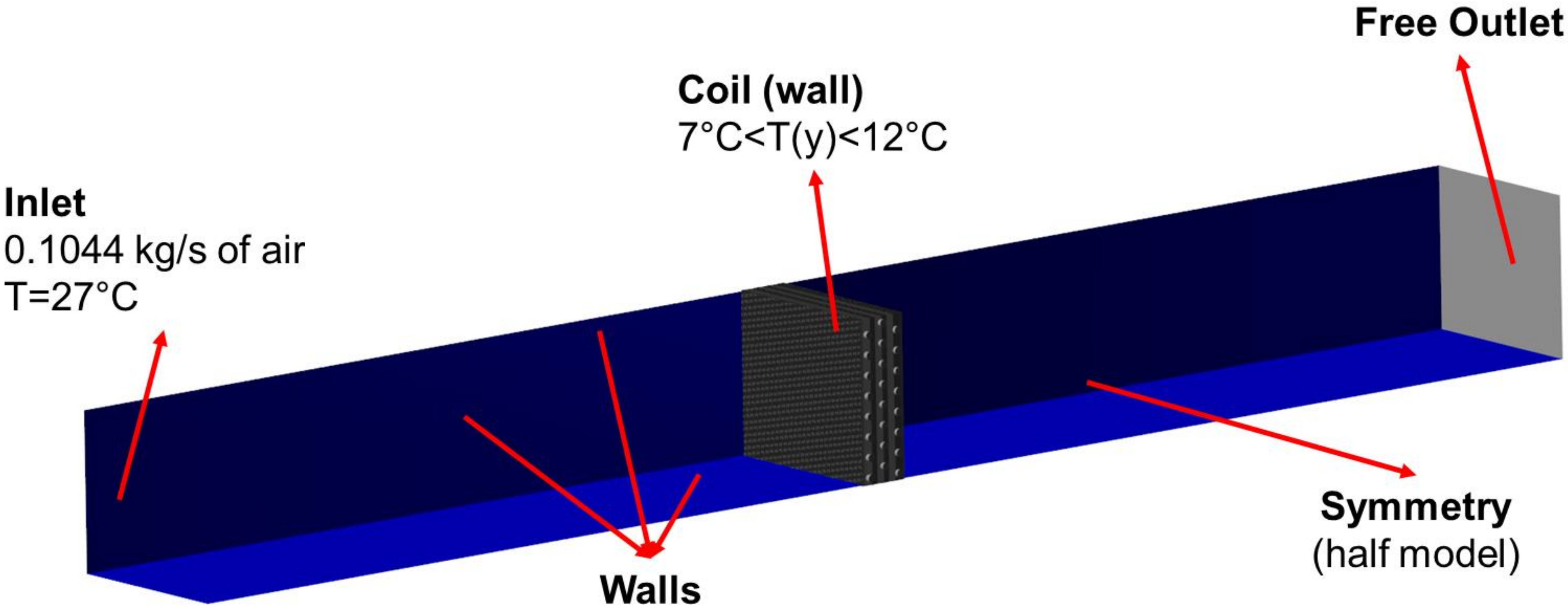
Modeling Alternatives

Resolution of spacings by grid elements (traditional approach)

→ Requires **at least five cells** between neighboring fins

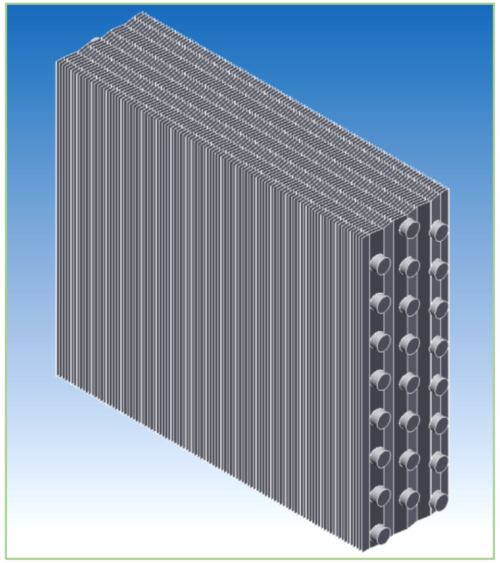
Resolution of spacings by Gap Model:

→ Requires **only one row of cells** between neighboring fins

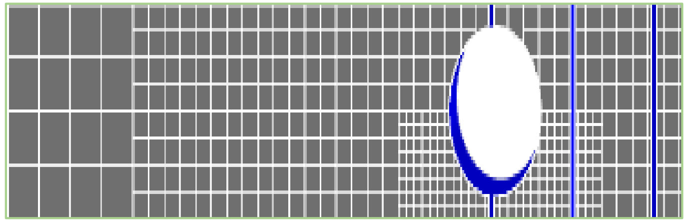


Coil Resolution by Grid (Actual Geometry)

- Need for high tolerance geometry



- Excessive amount of computational cells



- Enormous computational power requirement

A common remedy

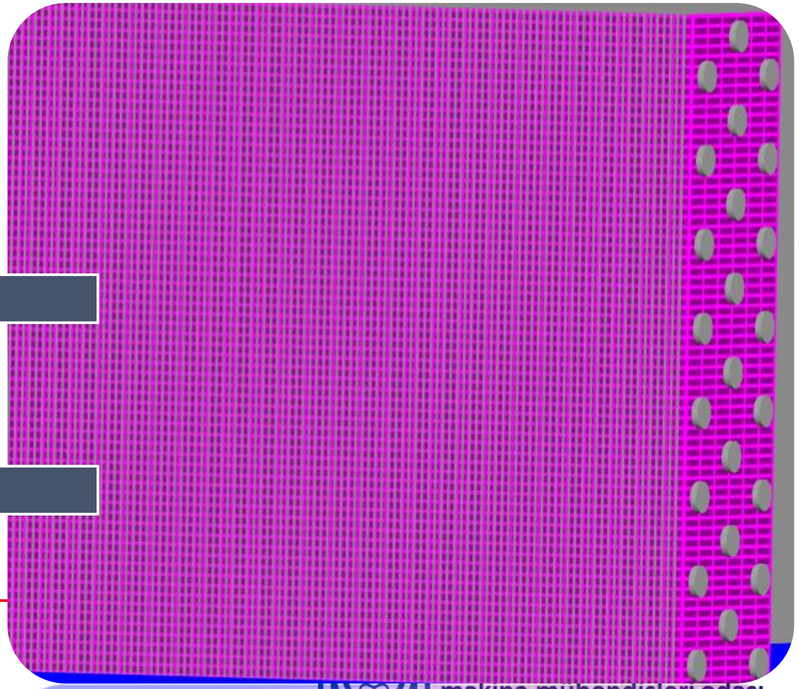
- Separate solutions
- (eg. section 1 outlet results = section 2 inlet BC)

Coil Resolution by Gap Model

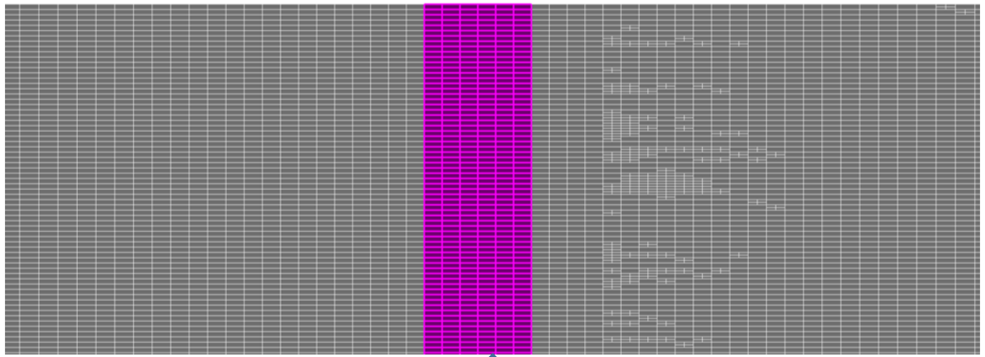
- ✓ No manual effort for meshing
  - ✓ automatic detection of Gap Cells

- ✓ Only one row of cells in spacing
  - ✓ instead of five or more cells

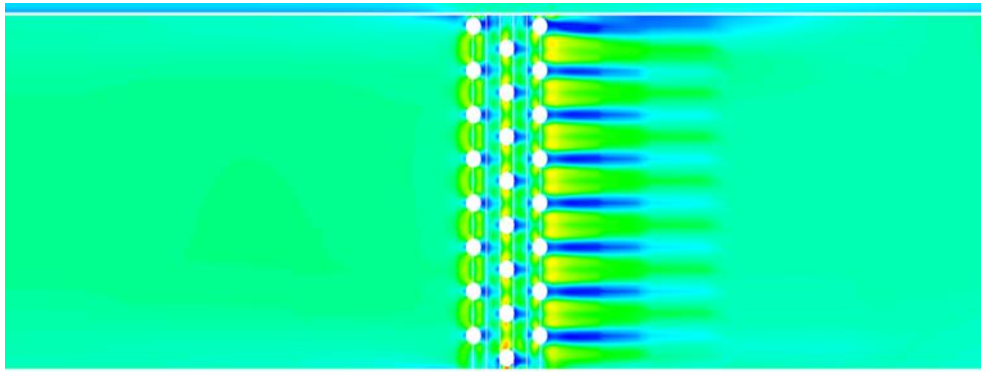
- Significantly less number of cells in total
  - in this case study ≈ **85%**
- Significantly less computation time
  - in this case study ≈ **50 %**



Results

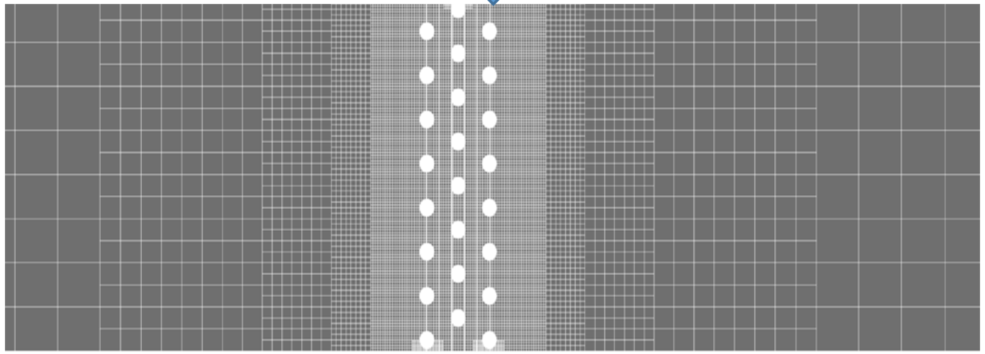


Gap Model

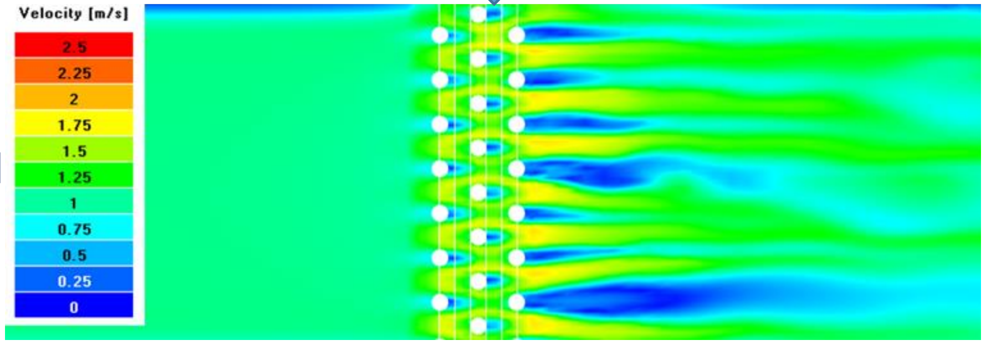


Computational grid

Velocity distribution



Grid resolved



Results & Conclusion

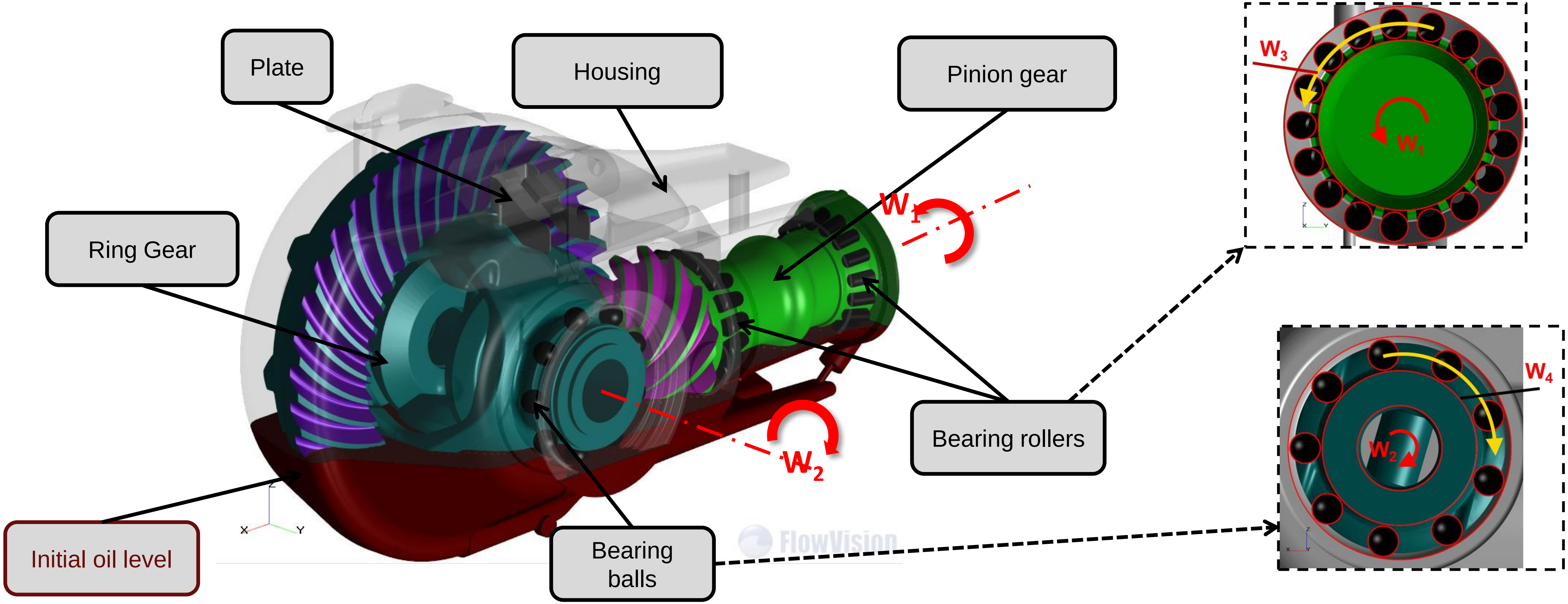
	Grid Resolved	Gap Model	Comparison
Results			
Grid Size [# of cells]	5.78 M	870k + 40k Gap Cells	85% less
Pressure Drop [Pa]	8.0	8.1	1.2% deviation
Outlet Temperature [°C]	15.5	15.2	1.9% deviation
Heat Flux [W]	1380	1356	1.7% deviation
User Experience			
Geometry	Enclosed gap volume resolved by grid elements	Distance between gap forming surfaces = clearance height	Simpler CAD can be used.
Workflow	Import CAD Define BC Detailed grid generation	Import CAD Define BC Automatic Gap Cell detection	Less manual efforts Shorter project preparation

3.2. Case Study: Automotive

Differential Gearbox
(with rotating ball bearings)

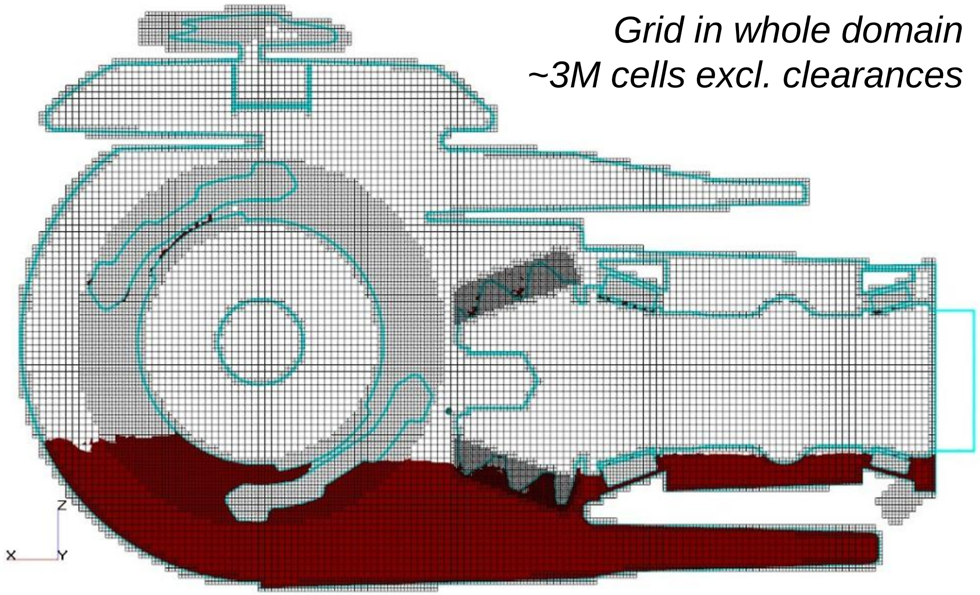
Problem Description

In a gearbox **determine minimum oil level that ensures full wetting** **by considering all rotating components**

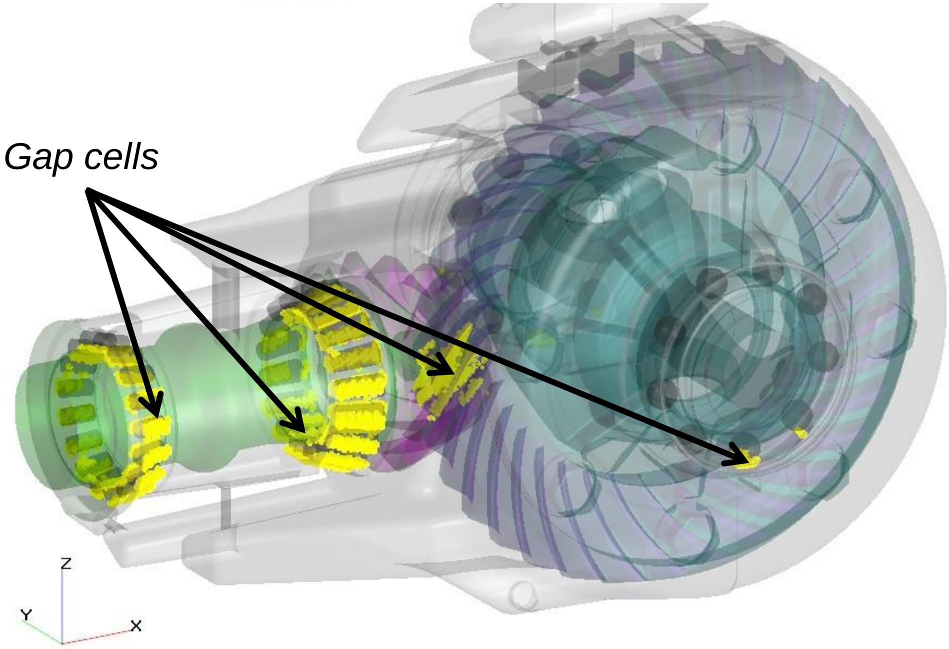


Computational Grid

Grid in whole domain
~3M cells excl. clearances



Gap cells



What if we don't have the Gap Model?

At least 3 cells would be required in all thin channels.

- **Between differential tooth (Average gap size is = 0,1 mm)**

With Gap Model → Average cell size in this area = 0,5 mm

→ Converted to 1200 Gap cells

Without Gap Model → Necessary cell size in this area ≈ 0,03 mm

→ Necessary to refine the grid ≈ 15 times

→ 1200 x 15^3 ≈ 4 million cells

- **Between bearing rollers (Average gap size is = 0,01 mm)**

With Gap Model → Average cell size in this area = 0,1 mm

→ Converted to 2500 Gap cells

Without Gap Model → Necessary cell size in this area ≈ 0,003 mm

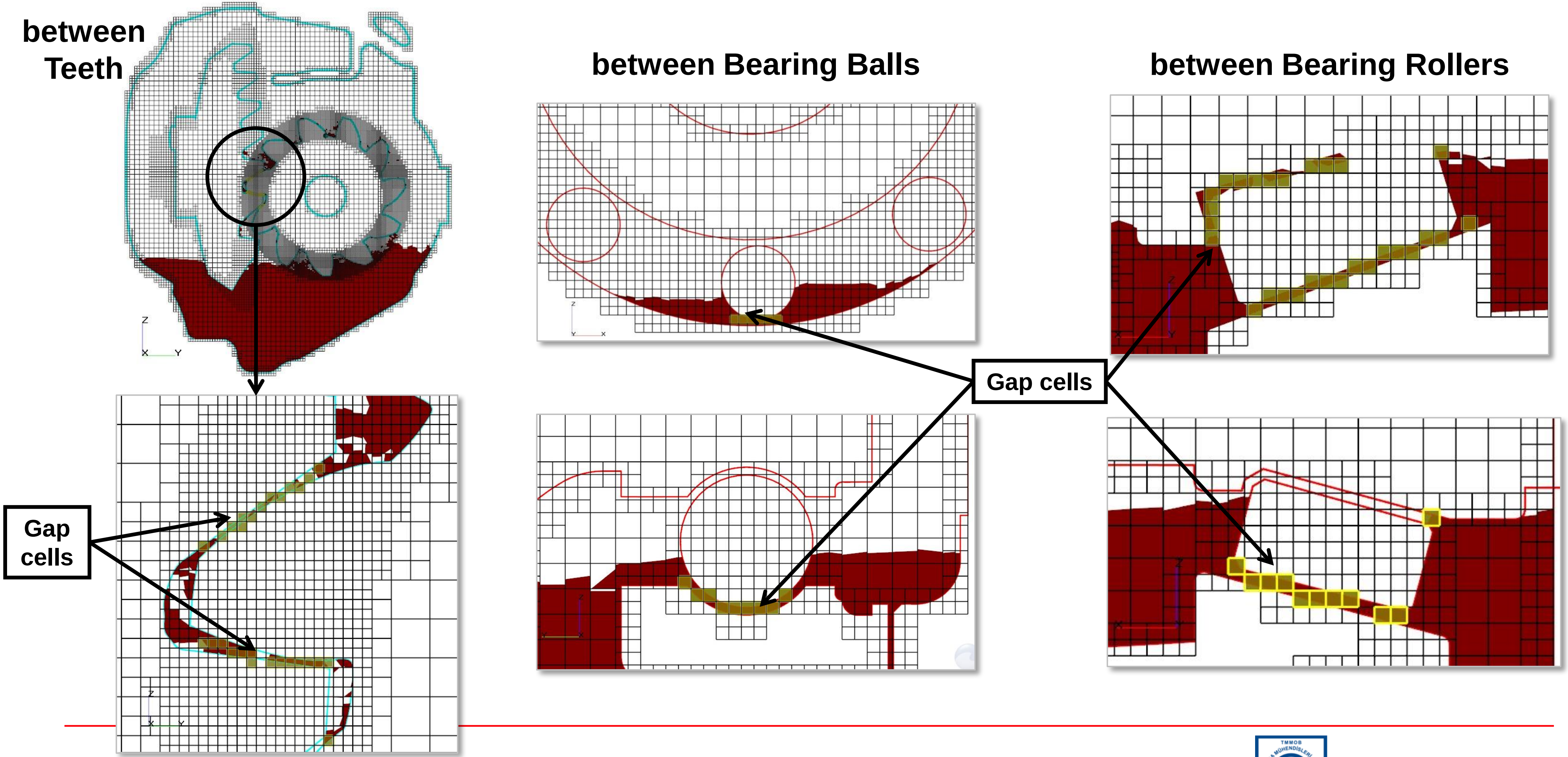
→ Necessary to refine the grid ≈ 30 times

→ 2500 x 30^3 ≈ 67,5 million cells

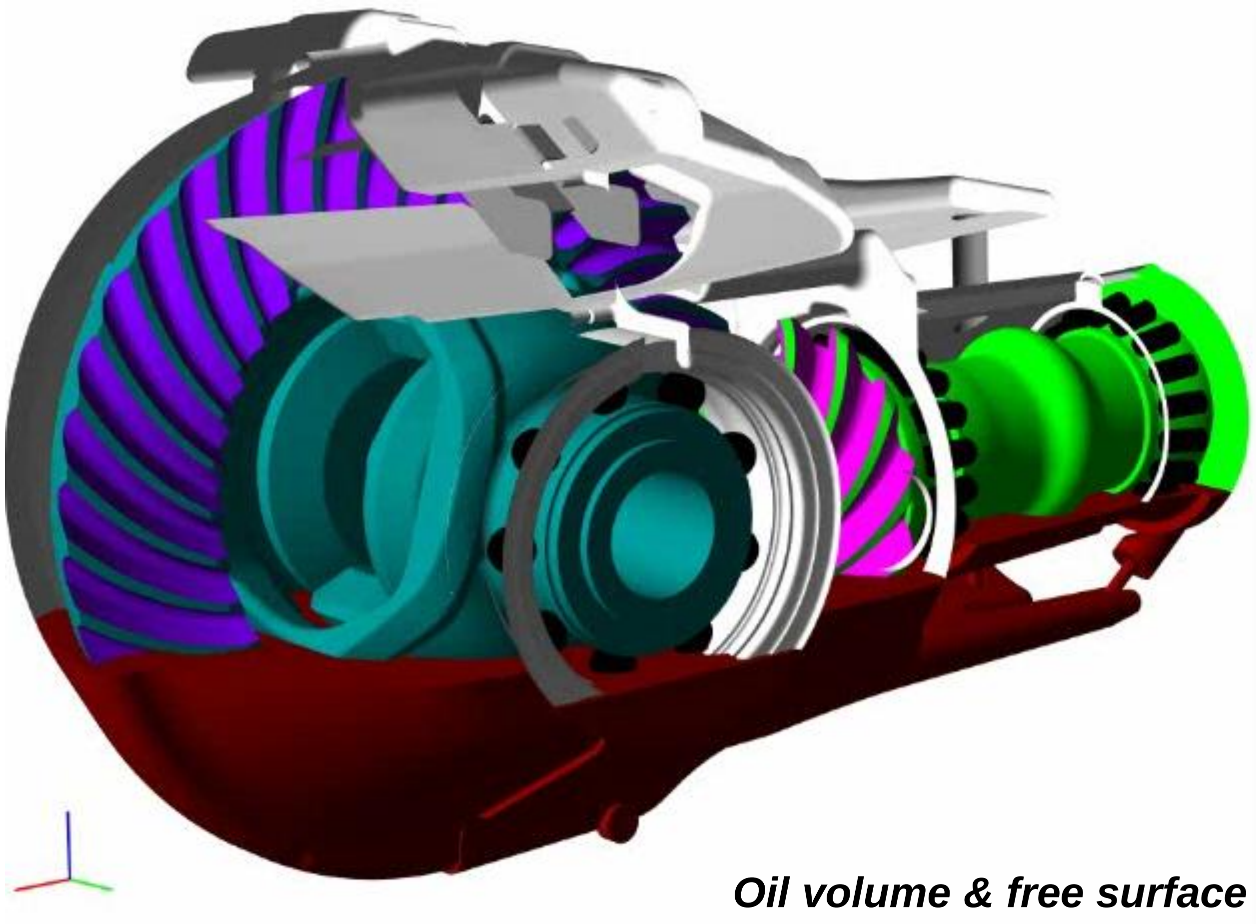
- **In this case;**

3700 Gap Cells instead of 71,5 million cells!

Computational Grid – Gap Cells



Computational Performance



Oil volume & free surface

- Hardware: **64 cores**

  (16 x Intel I7920)

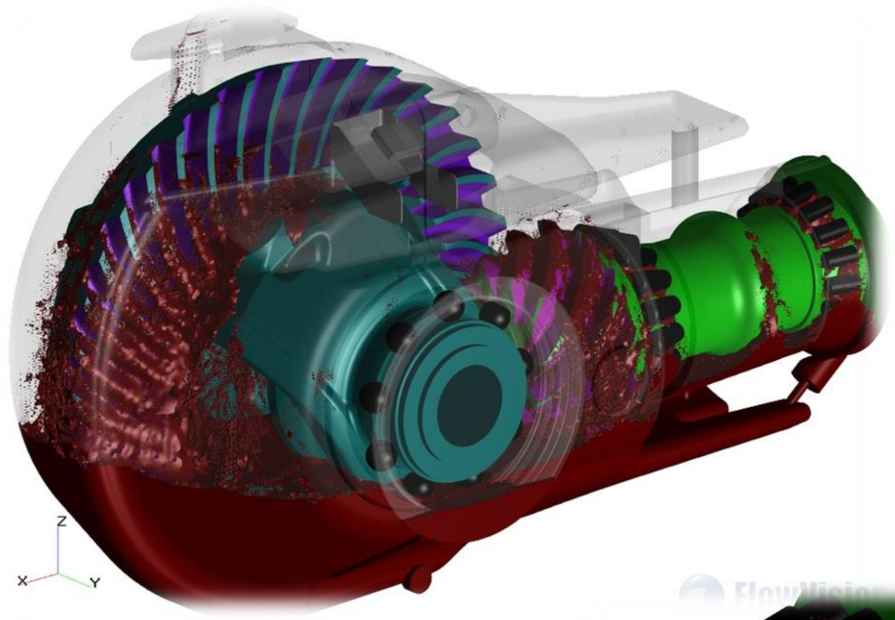
- Computation time: 40 seconds/time step

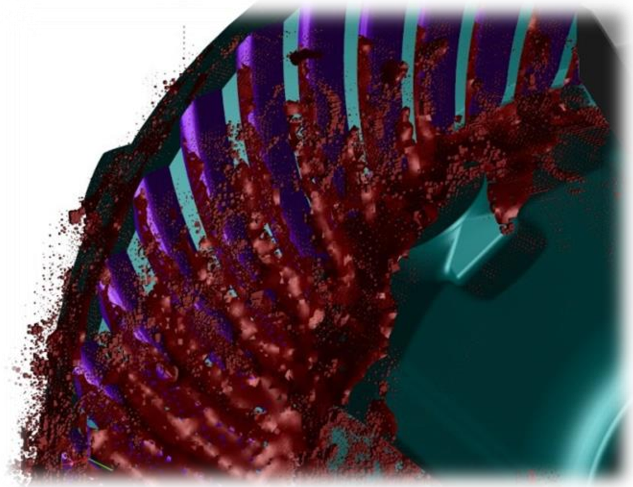
Convergence requirements;

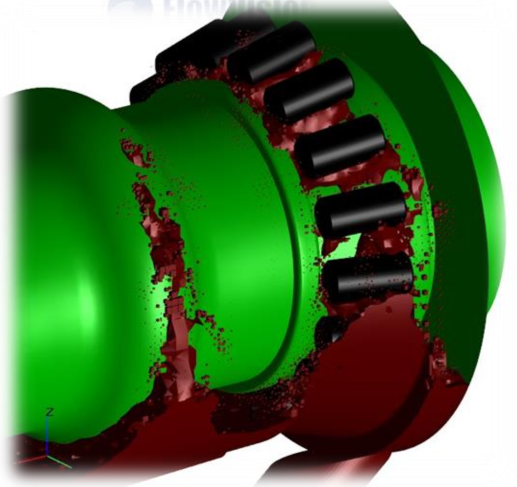
- Time step ≈ 1e-5 seconds
- 2-4 revolutions

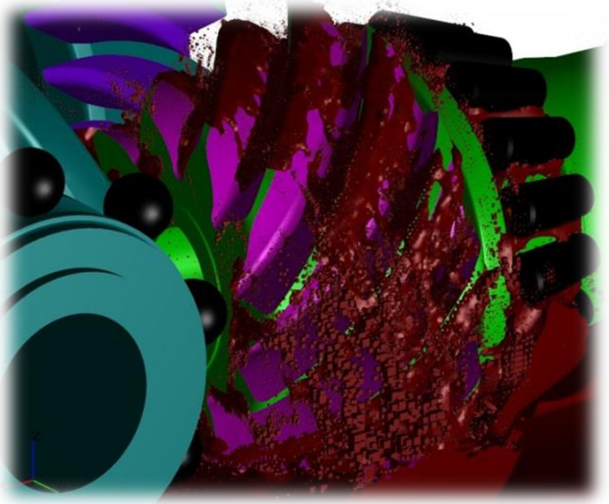
- 2000 rpm → ~0.1 seconds for **3 revolutions**
- 0.1 seconds of physical time;
  - 10000 time steps required
  - **4-5 days**

Results





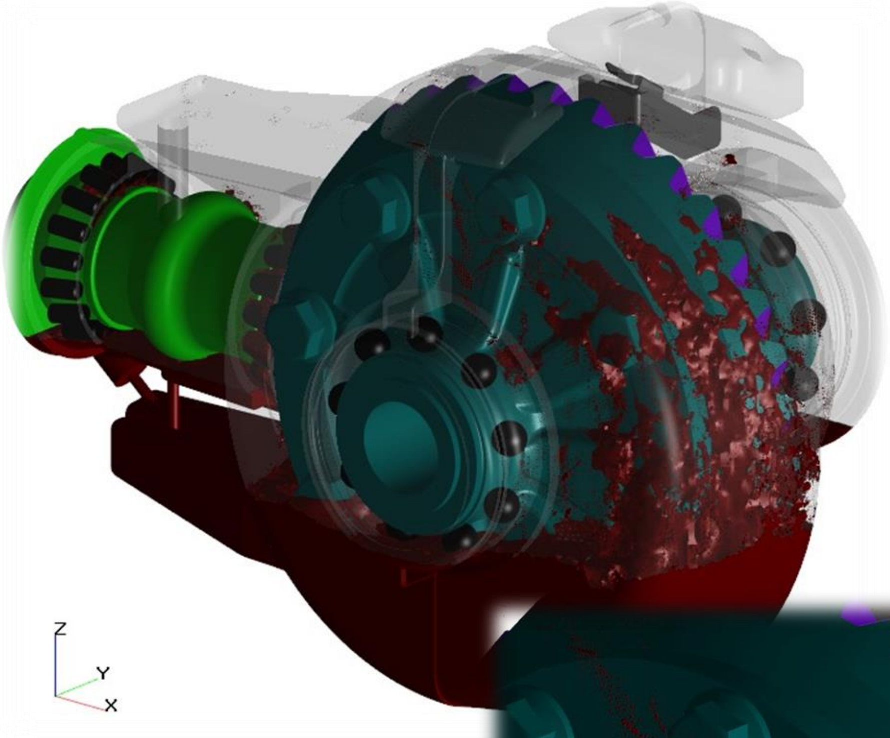


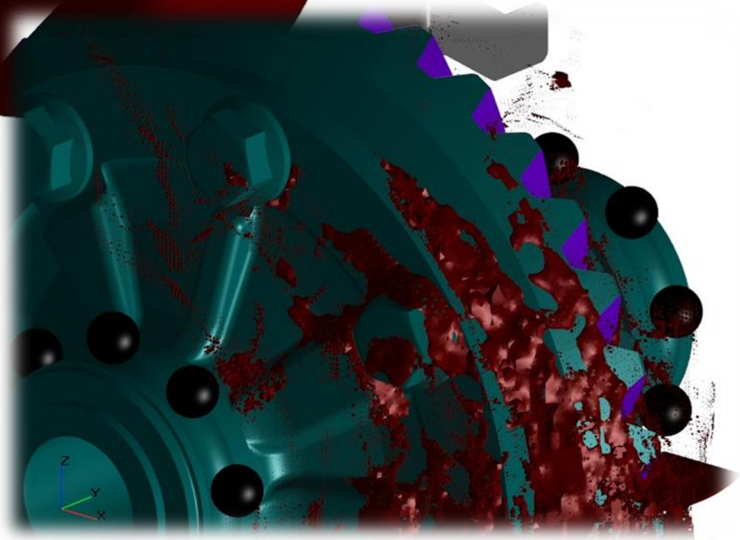


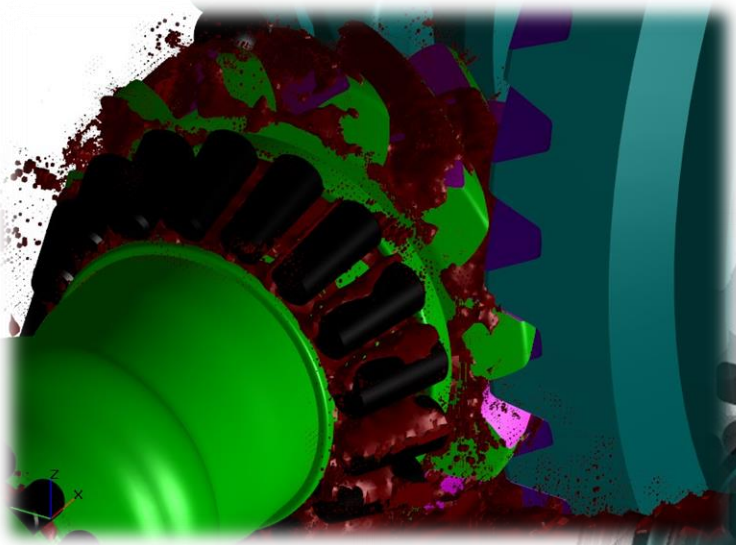
Instantaneous

oil distributions

Results

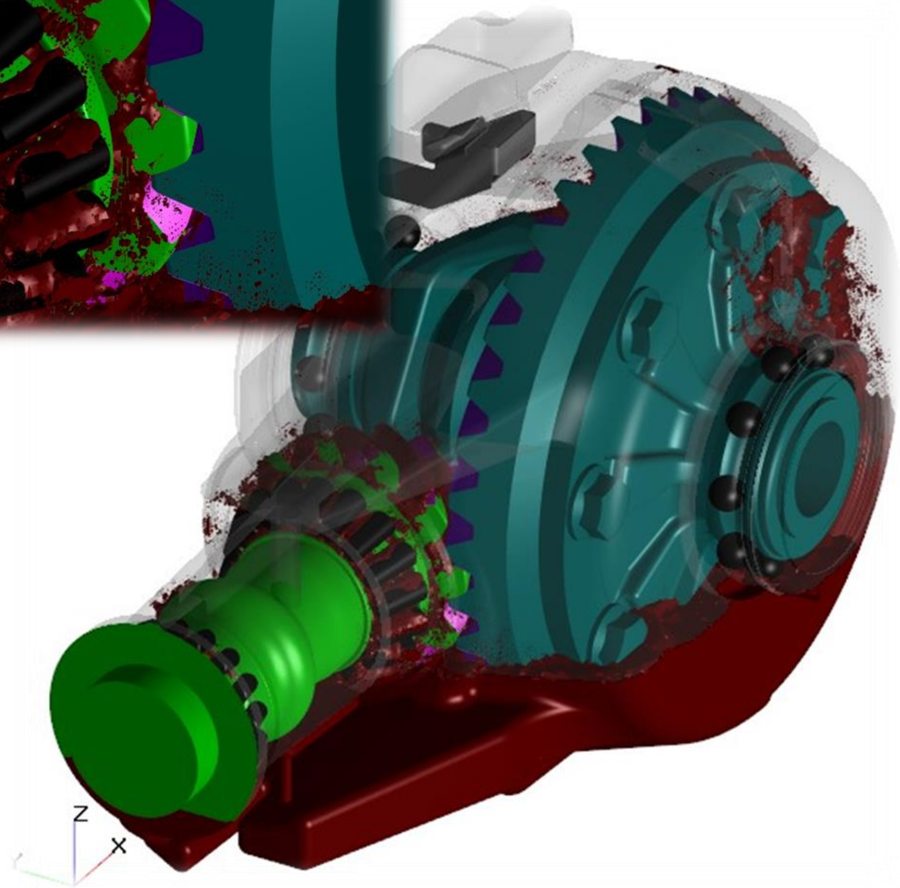






Instantaneous

oil distributions



3.3. Case Study: Energy

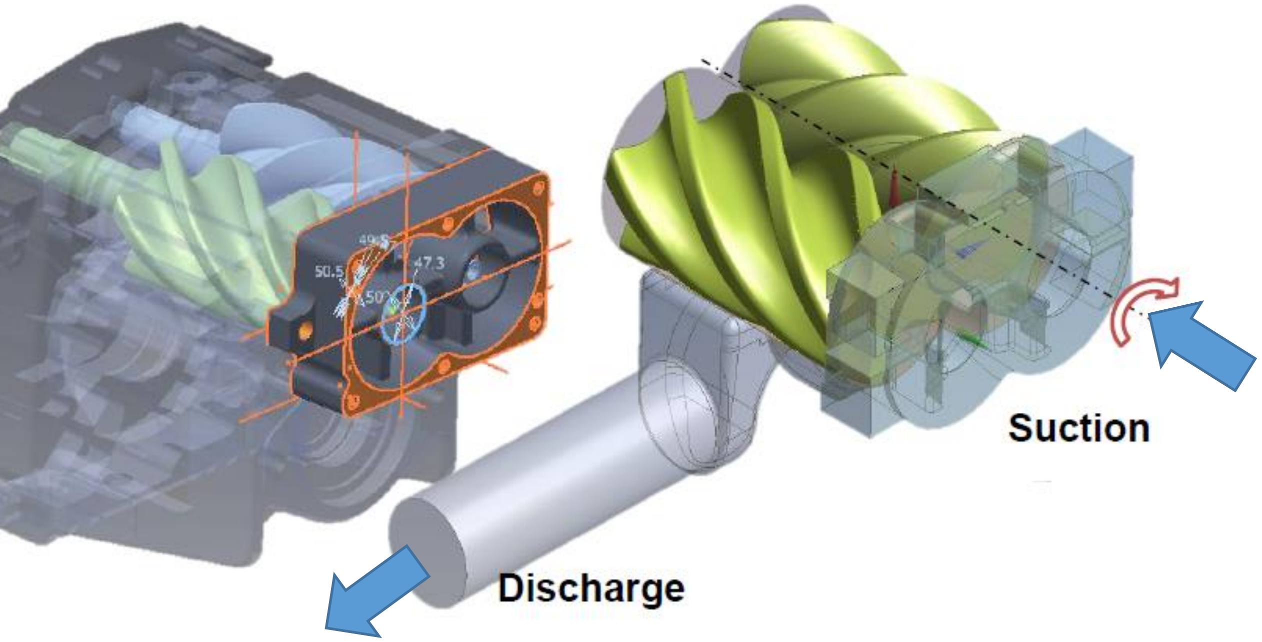
Screw Compressor Performance

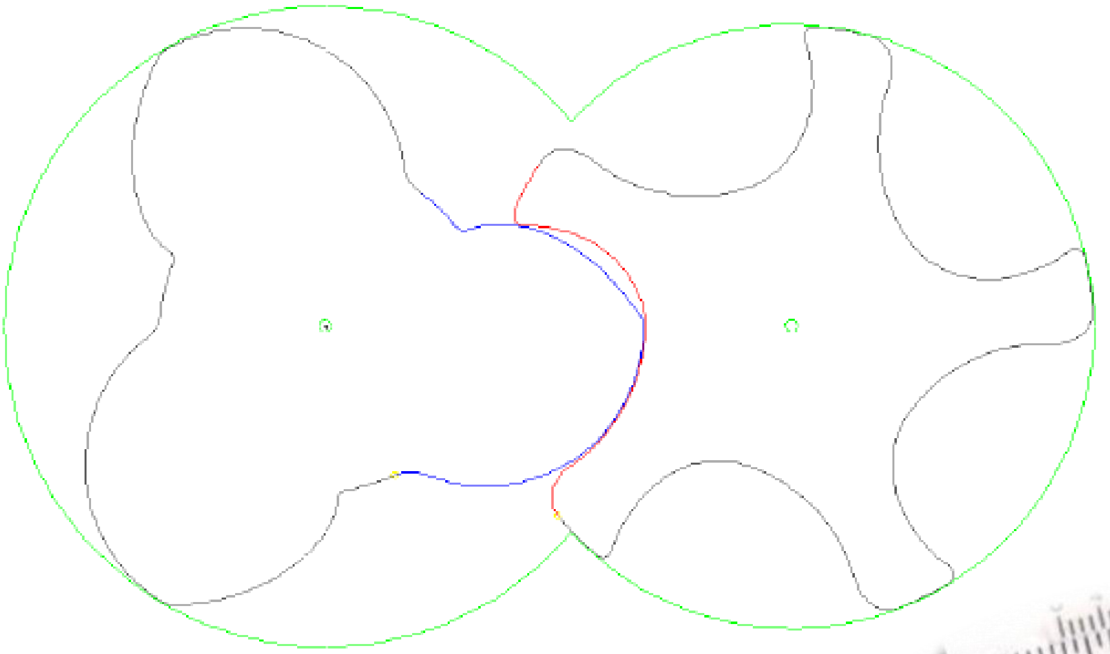
Problem Description

AKANA
MÜHENDİSLİK ve TİCARET A.Ş.

Objective: Performance prediction

- of an oil-free 3/5 lobed twin screw compressor
- & experimental validation of numerical simulations



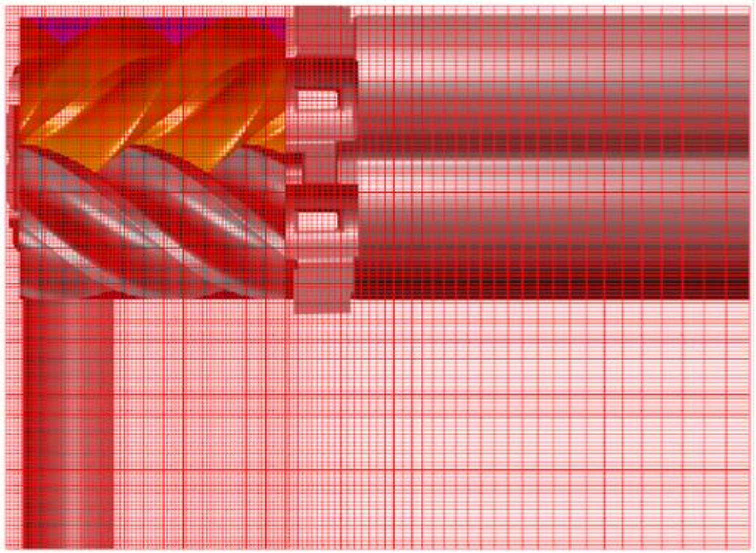


- Center to center → 93.00 mm
- Male rotor → 127.45 mm Ø
- Female rotor → 120.02 mm Ø
- **Clearances**
  - → **Interlobe: 160 μ**
  - → **Radial: 180 μ**
  - → **High Pressure End:120 μ**

CITY
UNIVERSITY OF LONDON
EST 1894

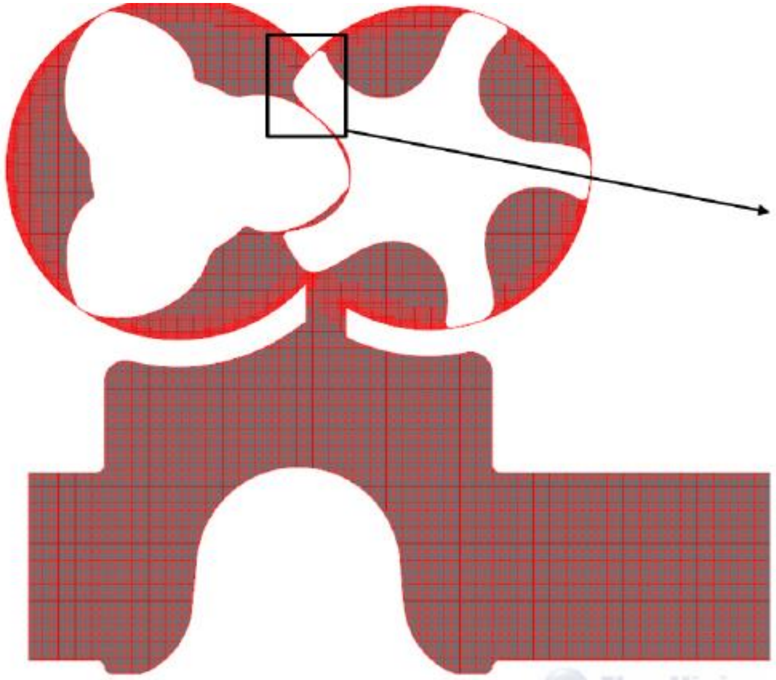
tmmob
makina mühendisleri odası
ankara şubesi

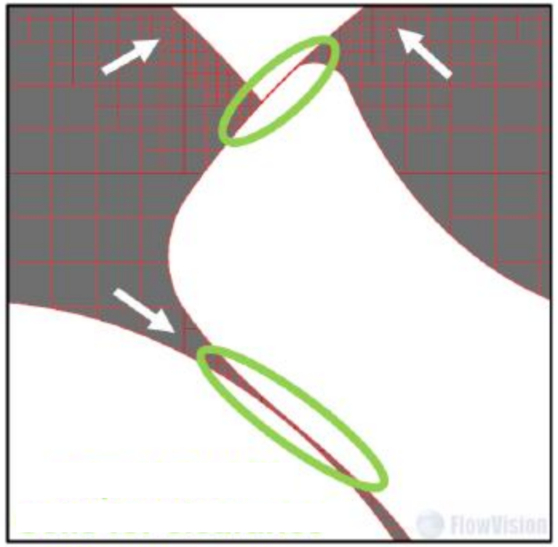
Computational Grid



Initial Grid
(denser around rotors)

Adaptations around housing & wall
(minimum cell size: 3 mm)

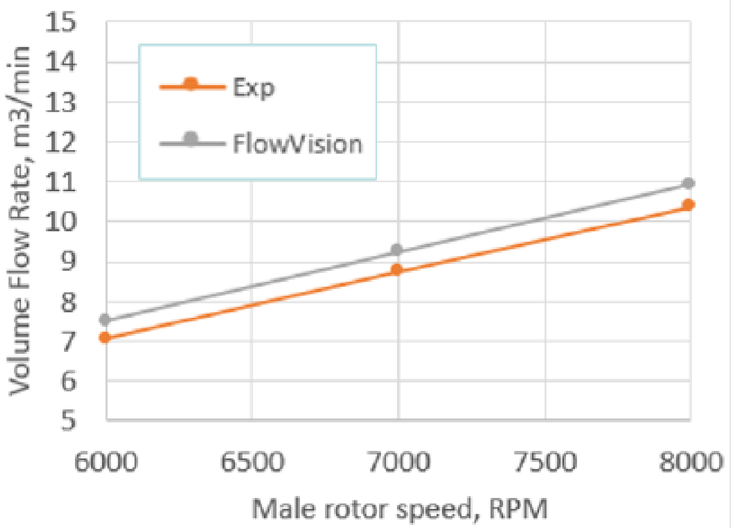


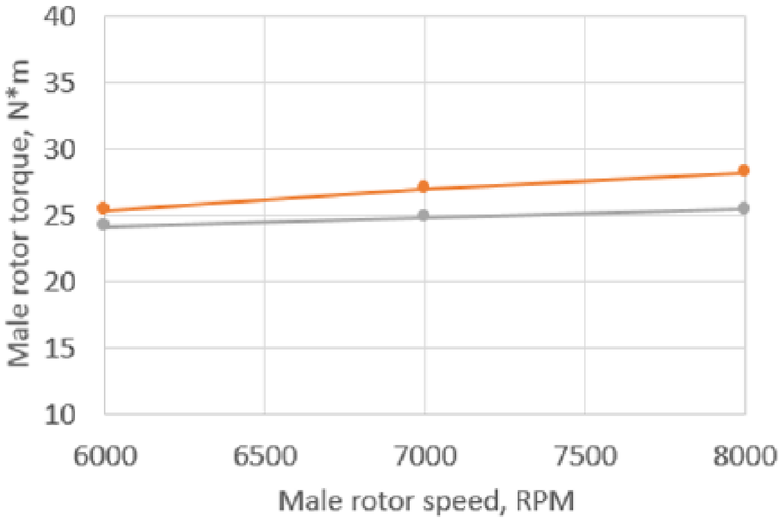


Automatic Gap detection
(Gap Cells are activated.)

- *Total of ~1.25M computational cells*

Results





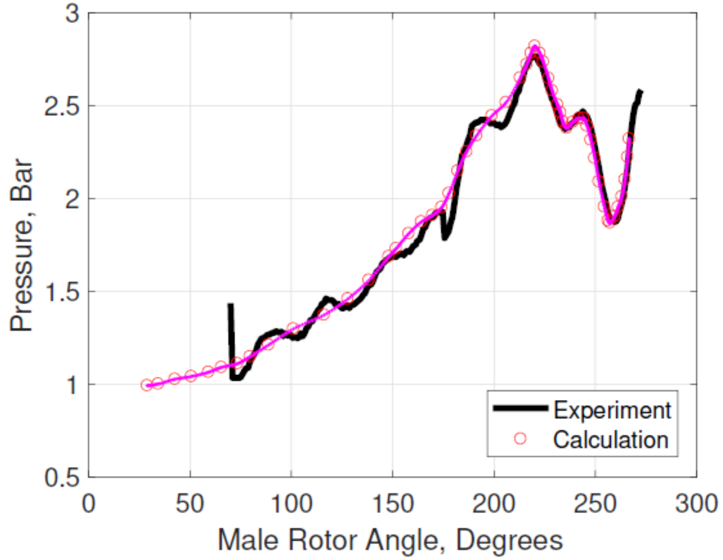
CFD with Gap Model

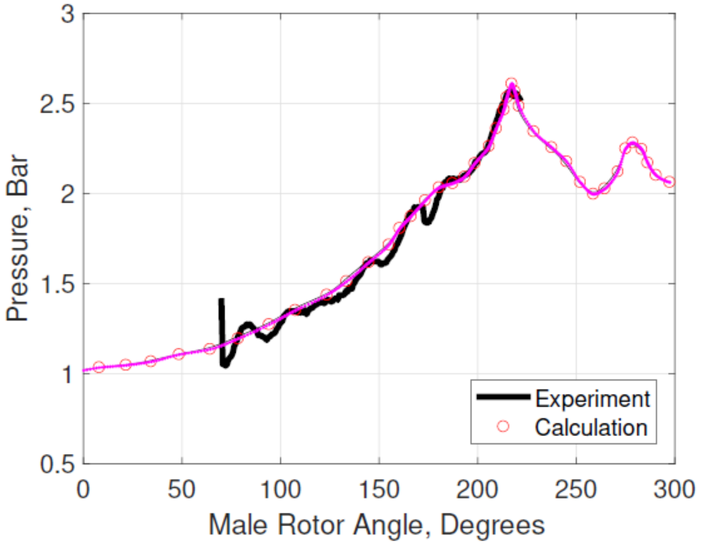
vs.

Physical Experiments

- Simulation time: 21.8 hours
  (using 4 processors)

- Agreement of results
  Largest deviation observed among all parameters and rotation speeds ≈ 6.3%

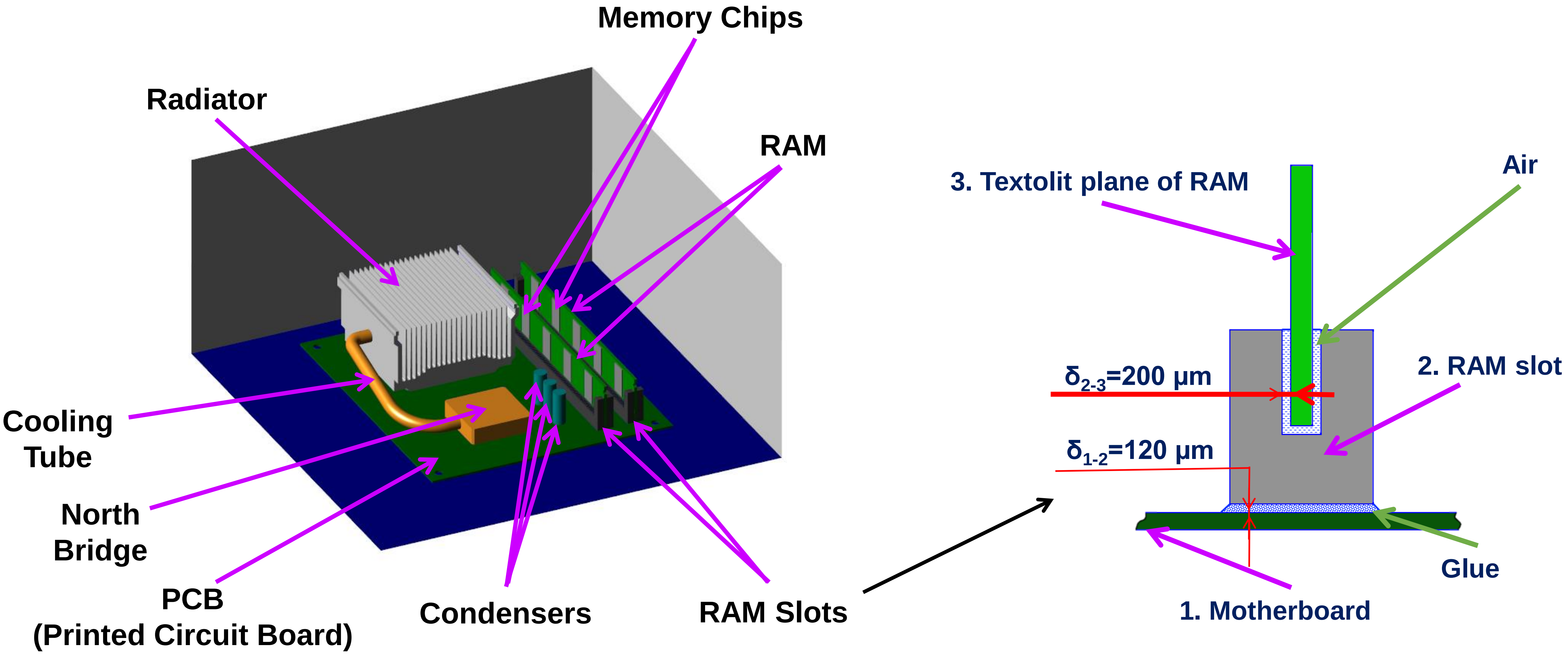




3.4. Case Study: Electronics

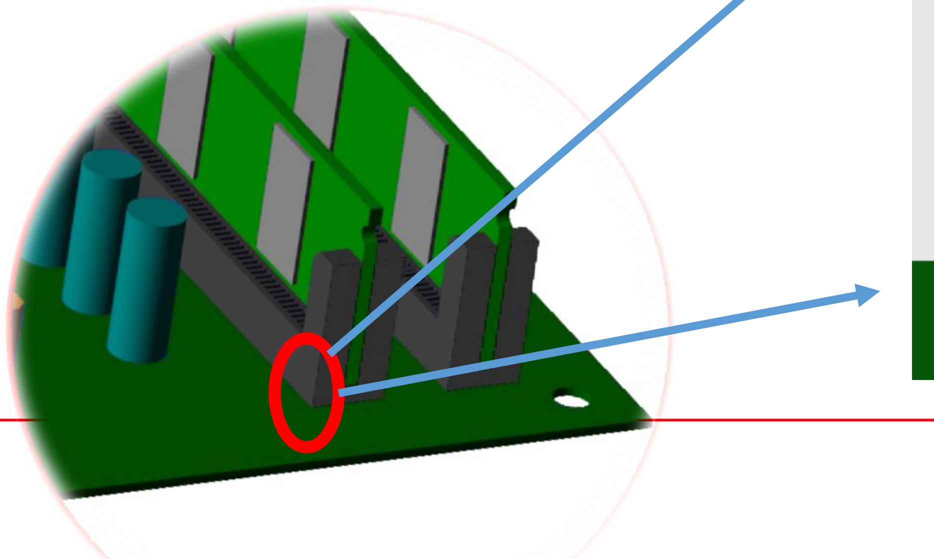
Motherboard Assembly Cooling

Problem Description

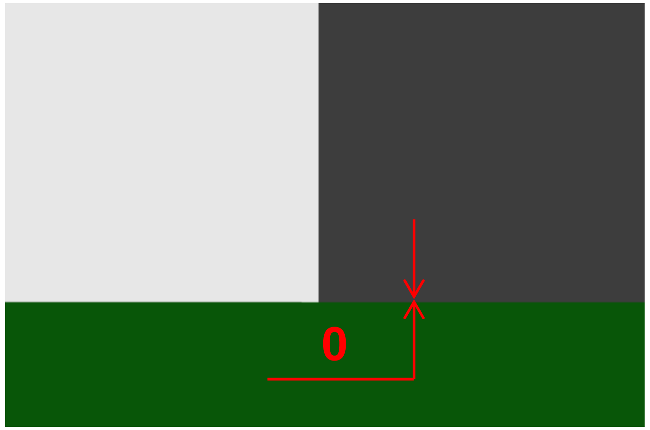


Assembly with Contacting Components

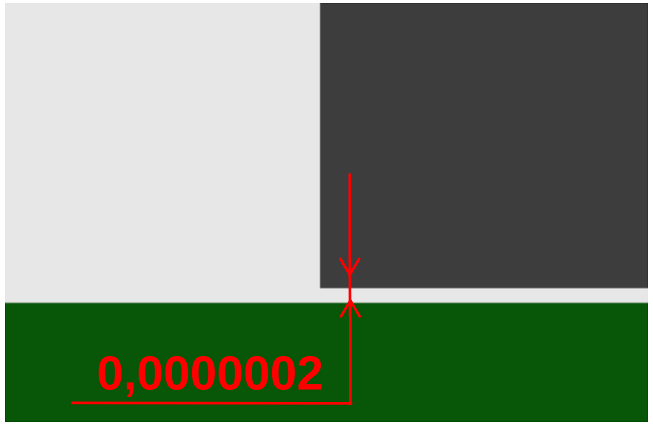
- Import assembly
- Surfaces with small clearances → Gap Cells
- Surfaces in contact → surface offsetting → Gap Cells
- All steps can be done automatically.
- Gap Cells physics:
  - Momentum in gap is solved by Gap Model.
  - Gap heat transfer coefficient to account for thermal bridges



Before Offset



After Offset

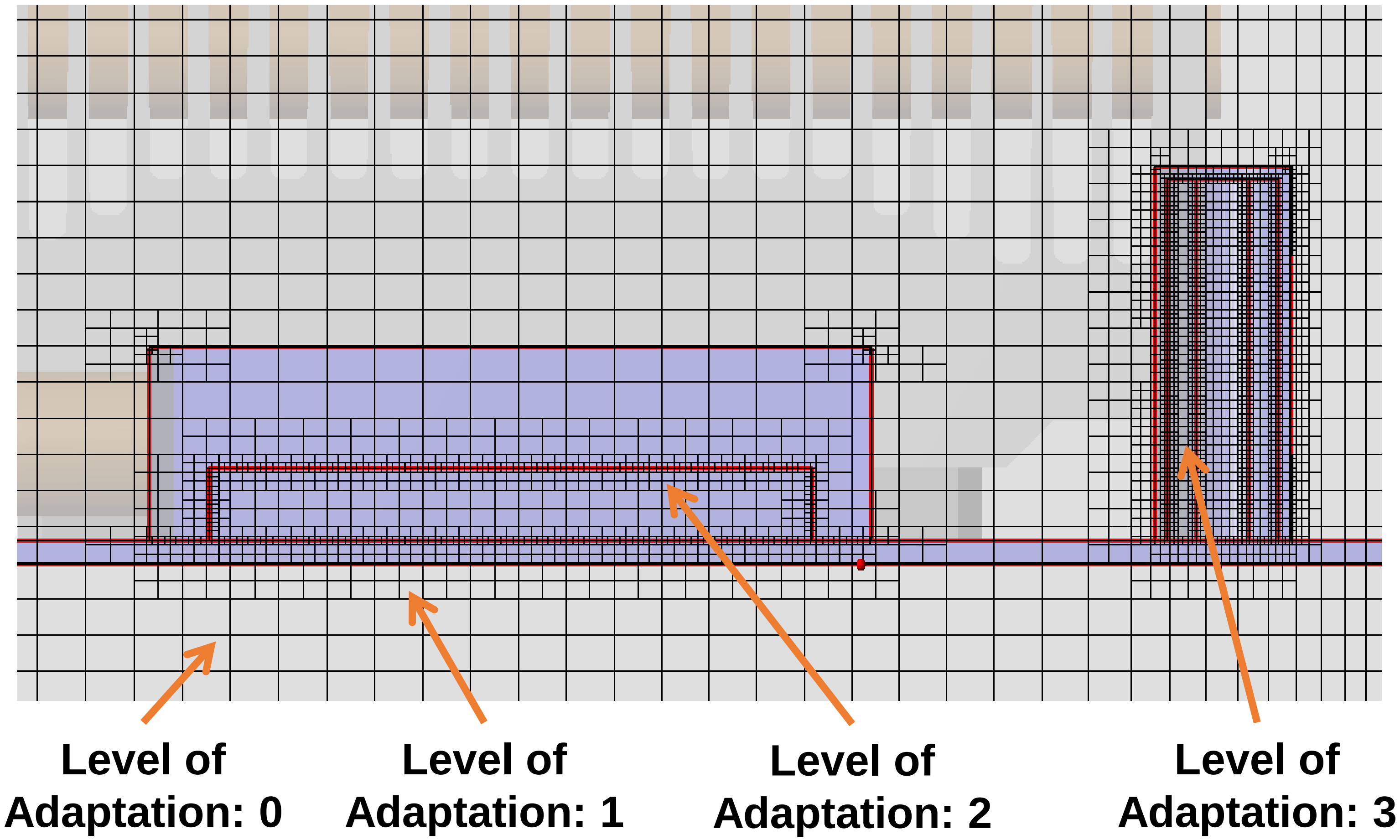


Computational Grid

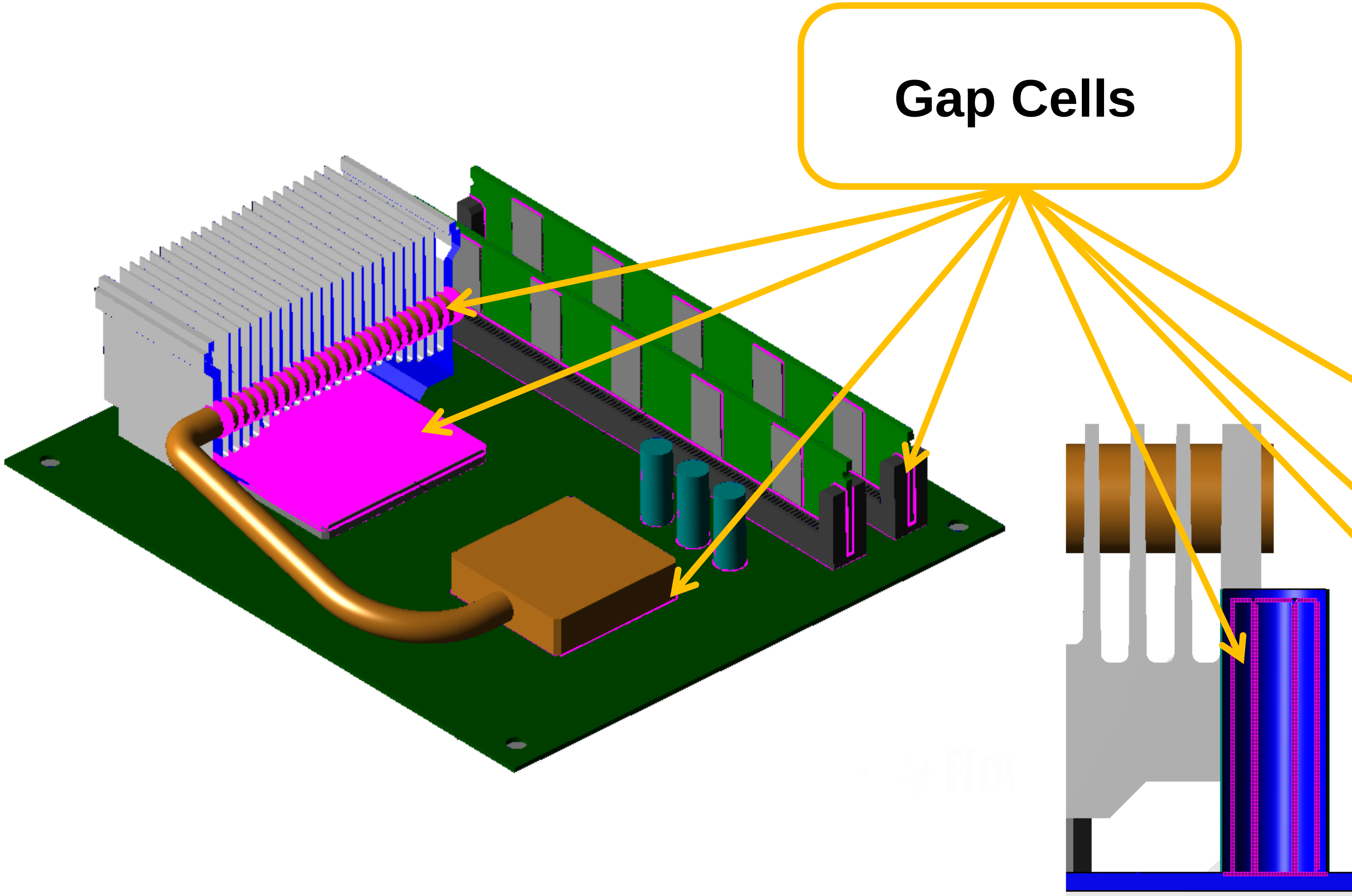
AKANA MÜHENDİSLİK ve TİCARET A.Ş.

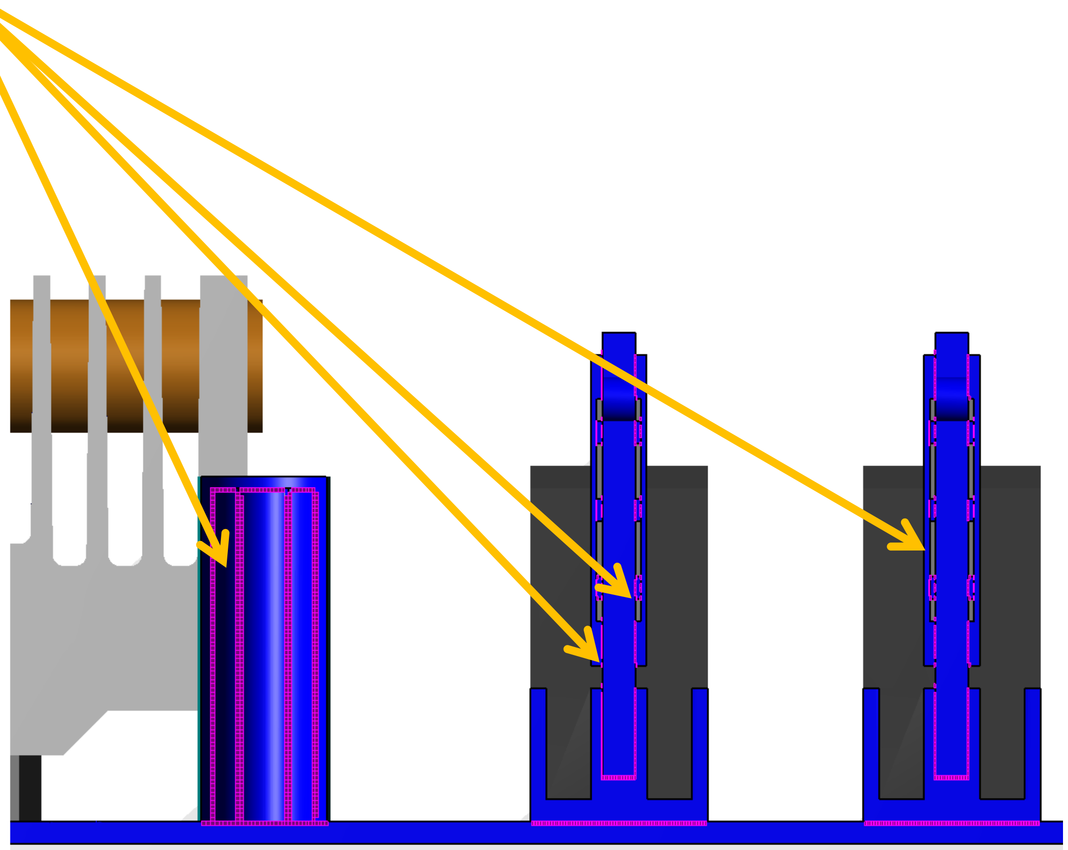
Minimum Element Size: 0.0625 millimeters

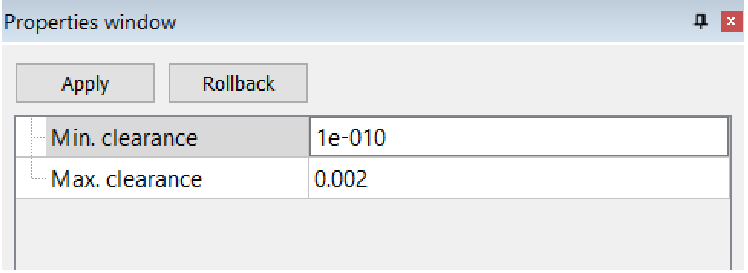
Maximum Element Size: 9 millimeters



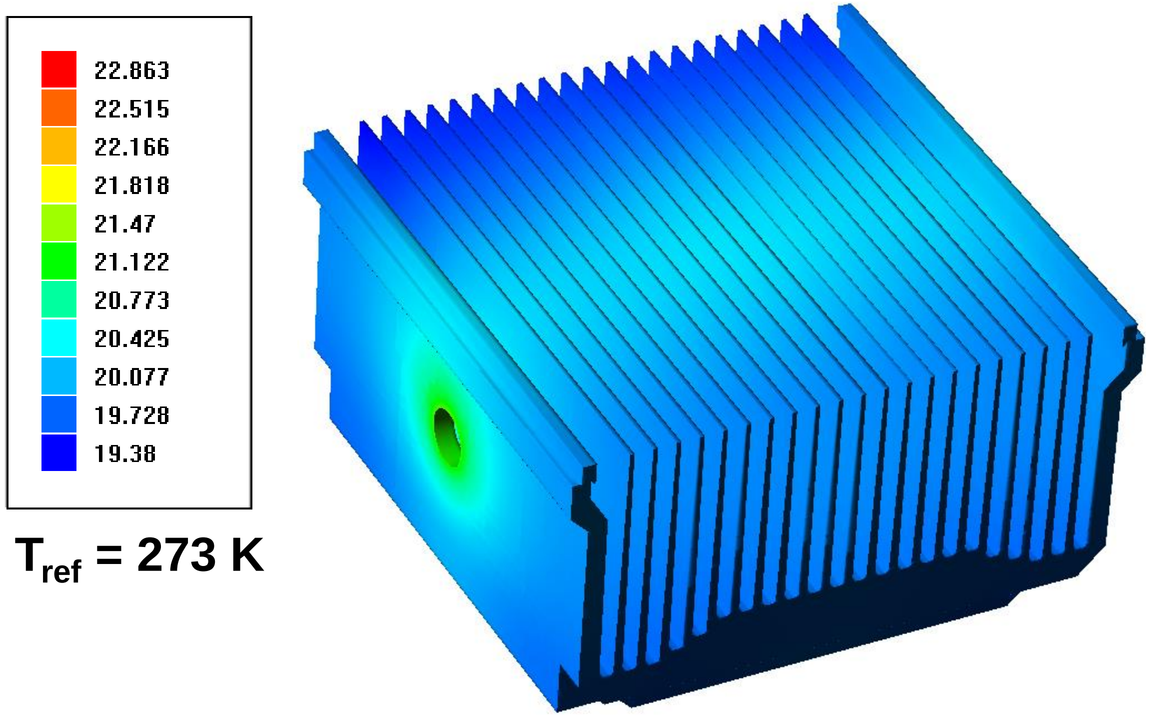
Gap Cells


Gap Cells



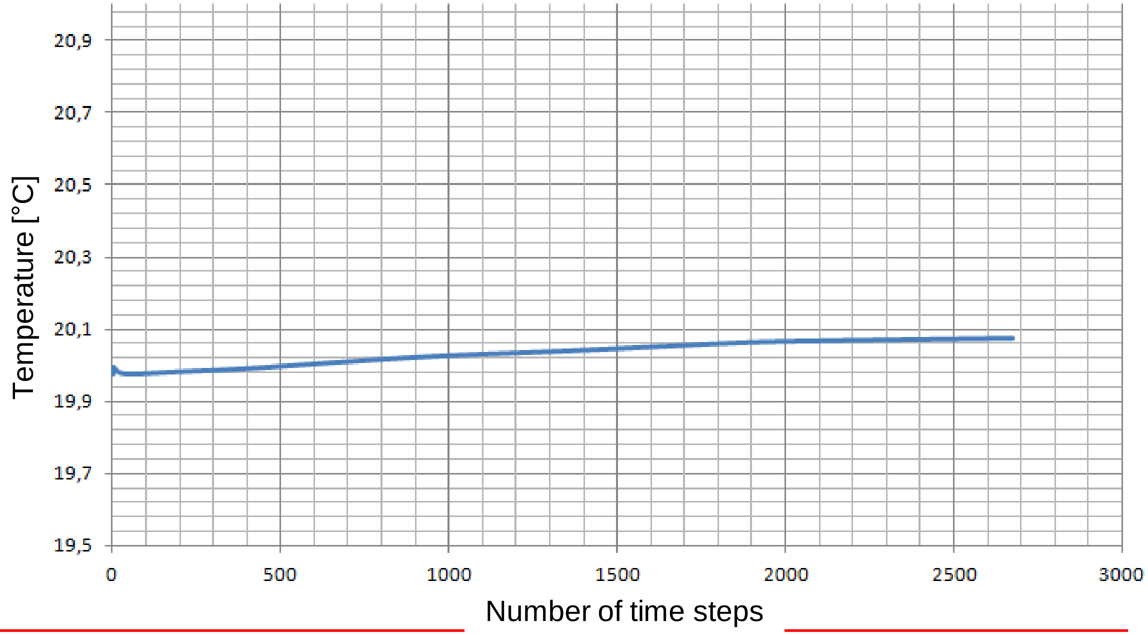

Properties window
Apply
Rollback
Min. clearance
1e-010
Max. clearance
0.002

Temperature Distribution in Volume

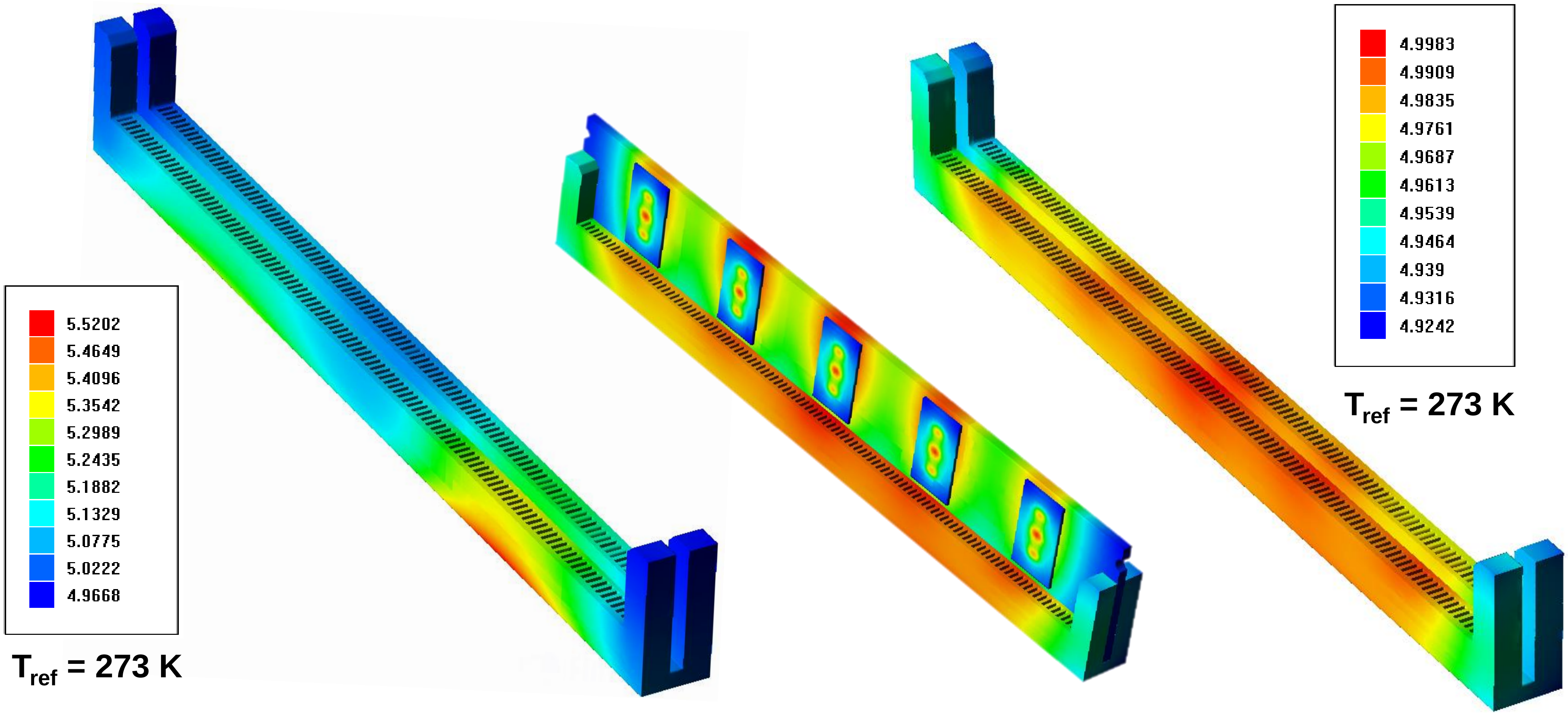


T_{ref} = 273 K

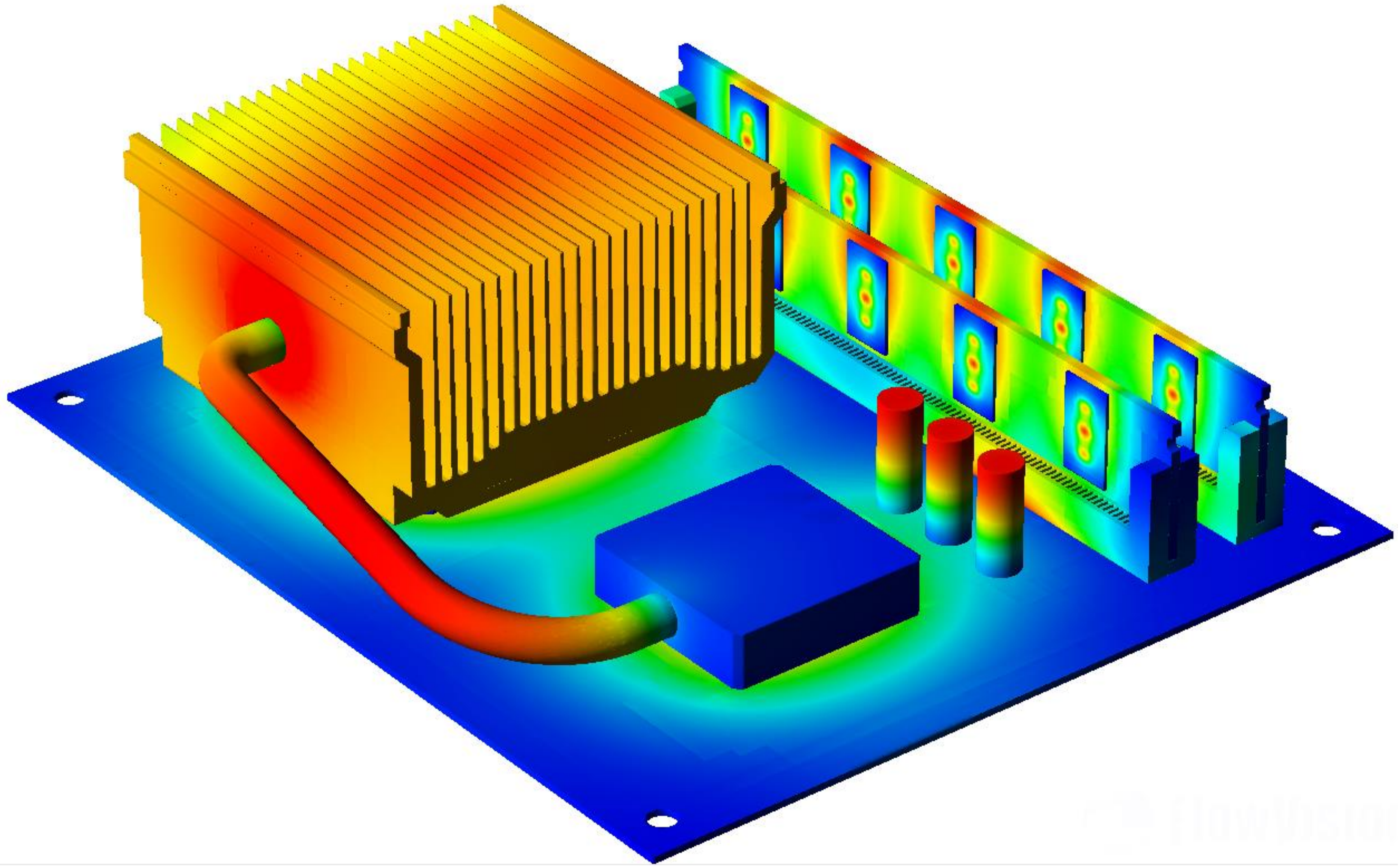
Average Temperature in Volume



Temperature Distribution on Surfaces



Temperature Distribution in Assembly



3.5. Case Study: Defence

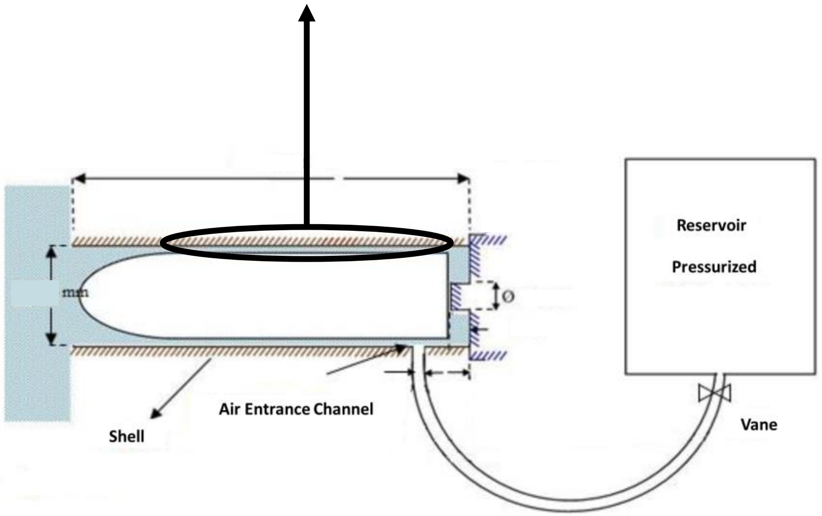
Underwater & Airborne Launching

Problem Description

- Launching payloads (missiles, decoys etc.)
- Objective is to predict;
  - Acceleration vs. time
  - Directional stability
  - Thrust & resistance forces

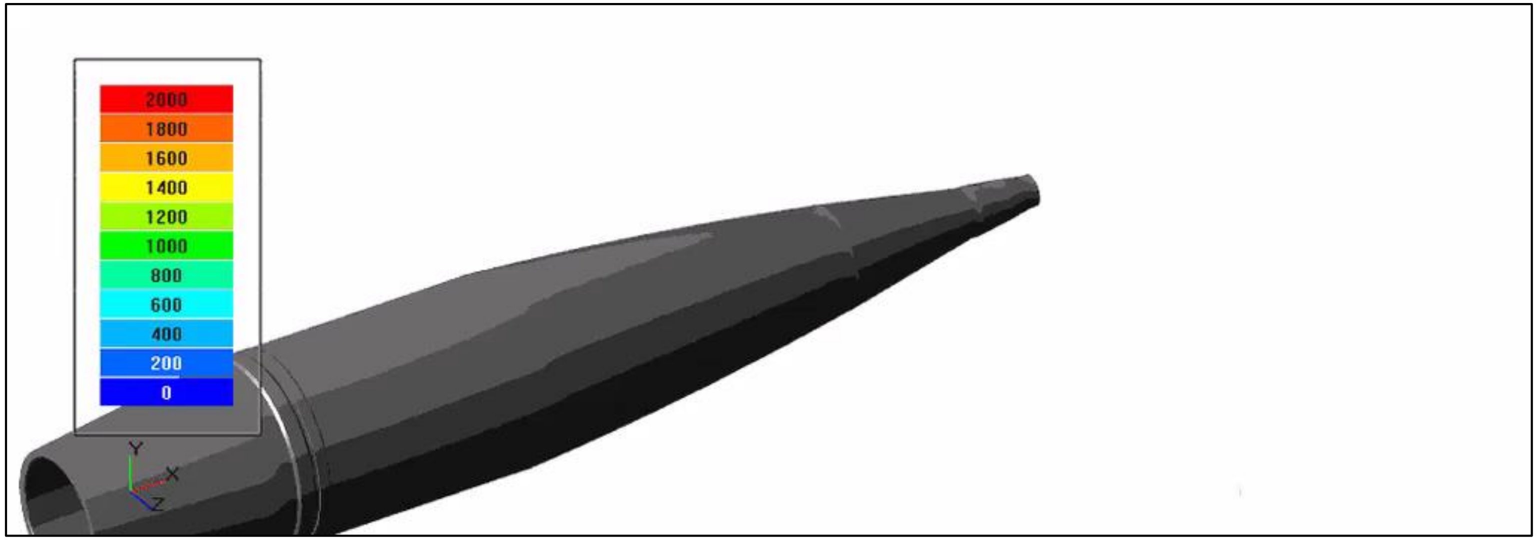
Simulation Challenge

Comparably very thin clearances



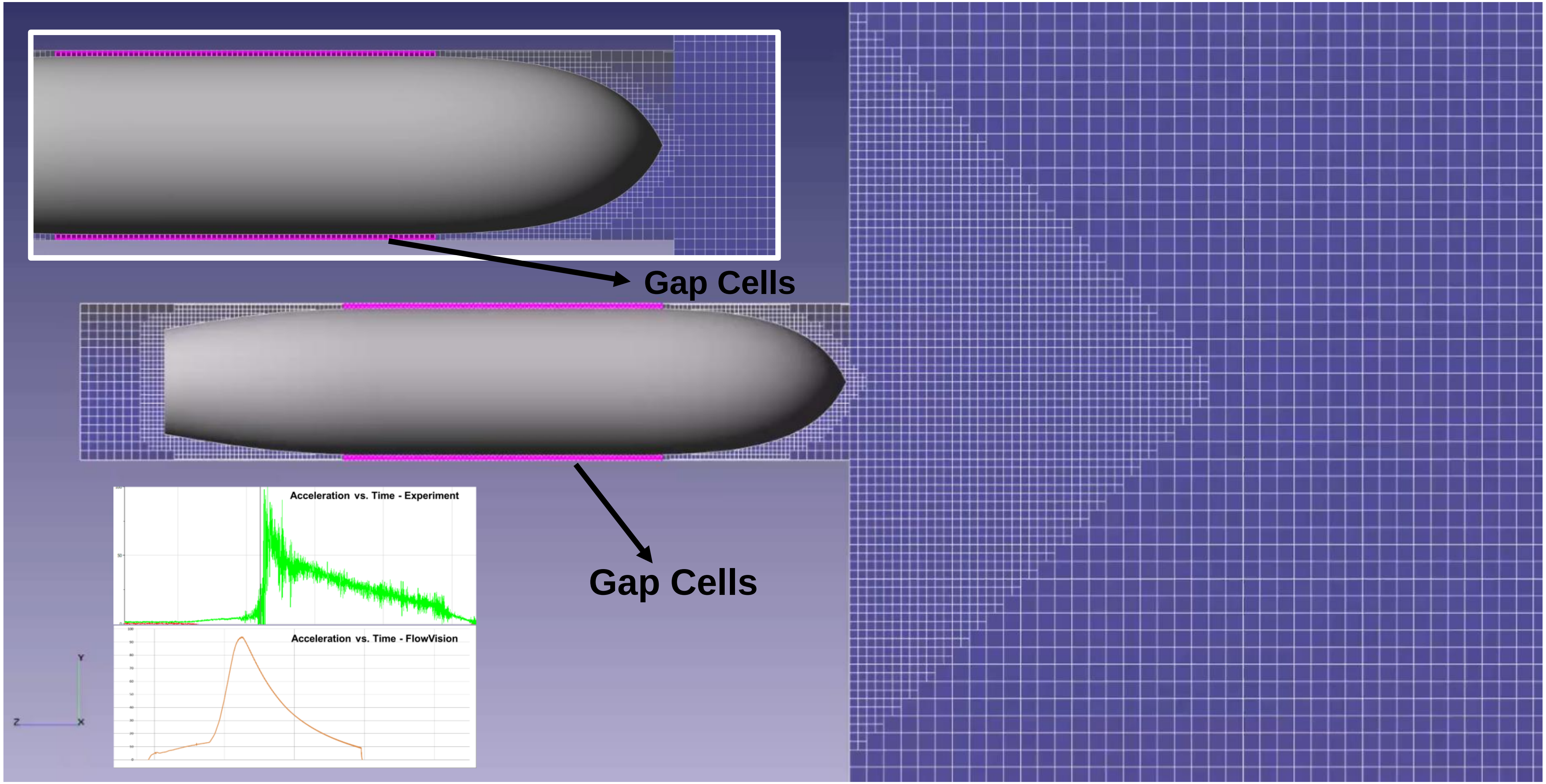
Pressurized launching

(representative sketch)

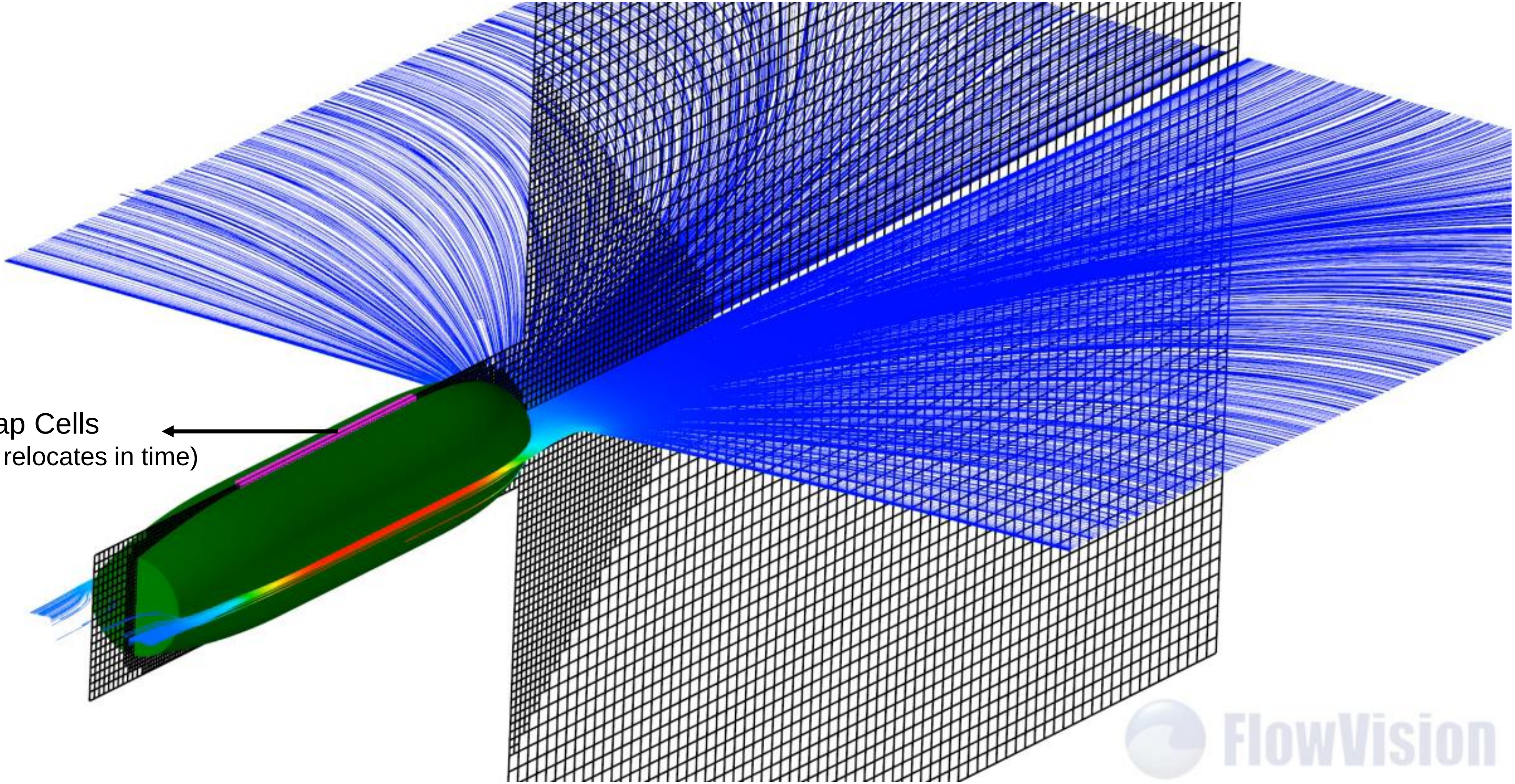


Muzzle brake optimization

Underwater Launch



Underwater Launch

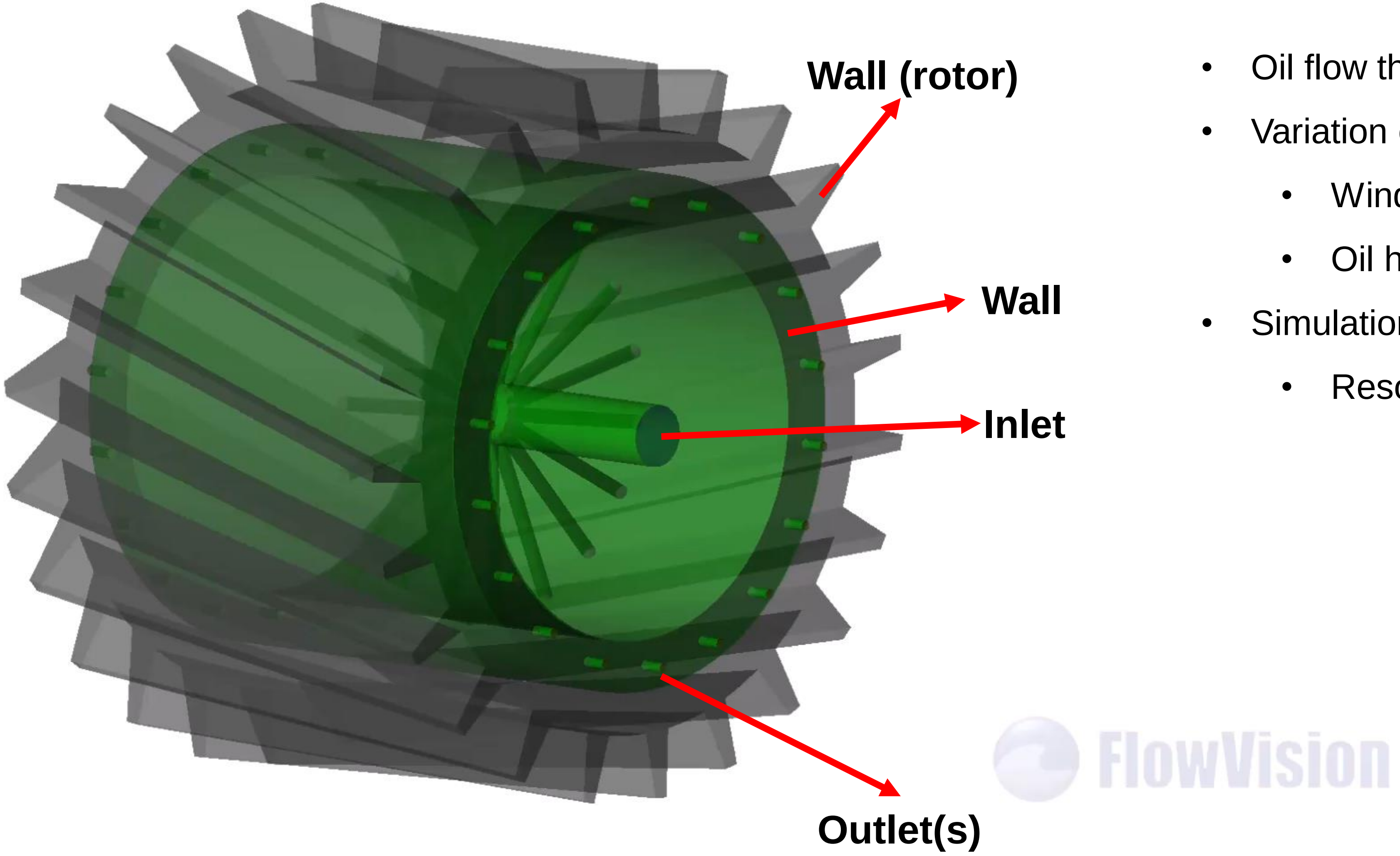


Gap Cells
(Clearance relocates in time)

3.6. Case Study: Energy

Hydrodynamic Bearing
(for wind turbines)

Problem Description – Boundary Conditions



- Oil flow through channels & clearances
- Variation of clearance due to
  - Wind turbine load characteristics
  - Oil hydrodynamics
- Simulation challenge
  - Resolve small & varying clearances

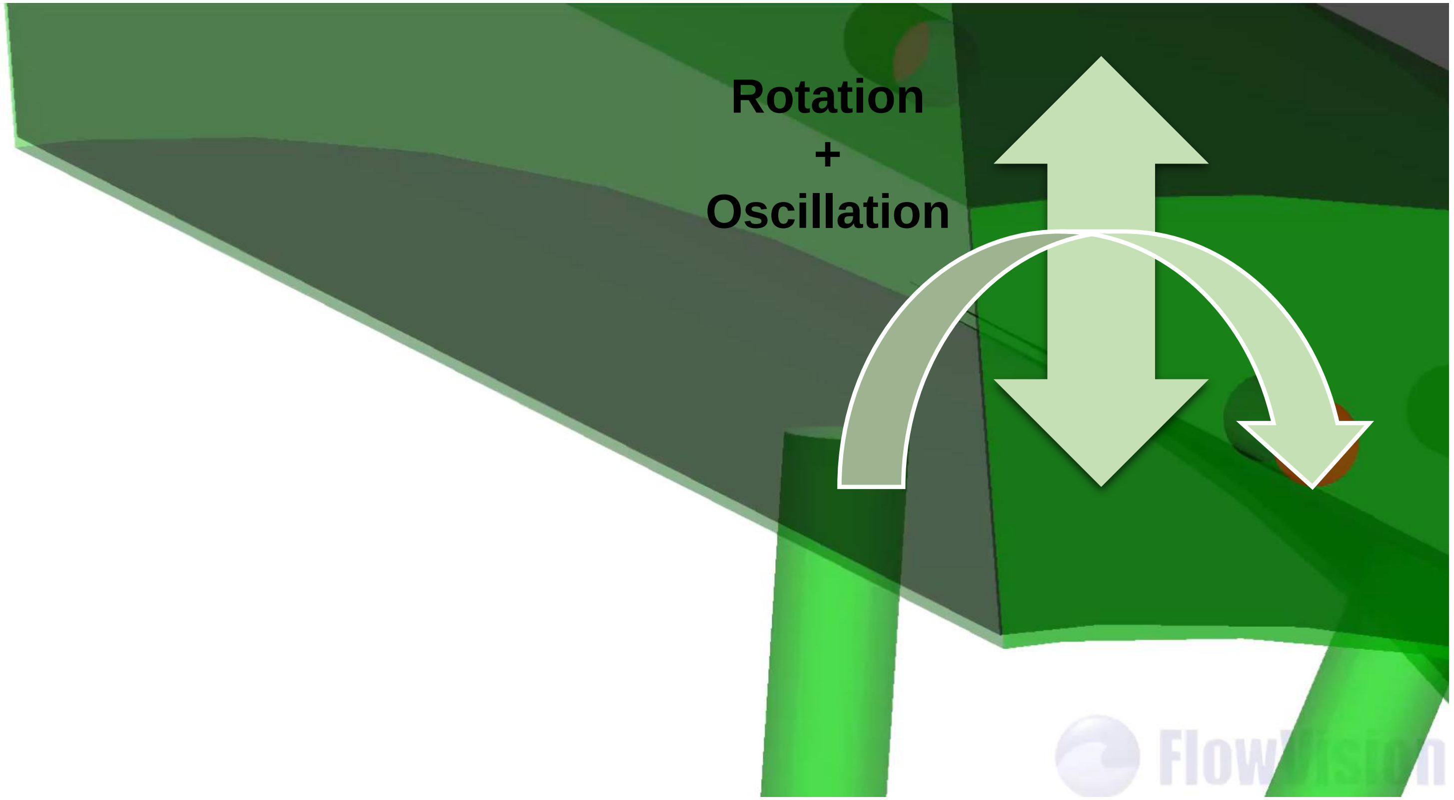
Motions & Clearance Variation

Radial clearance varying:
300±100μ

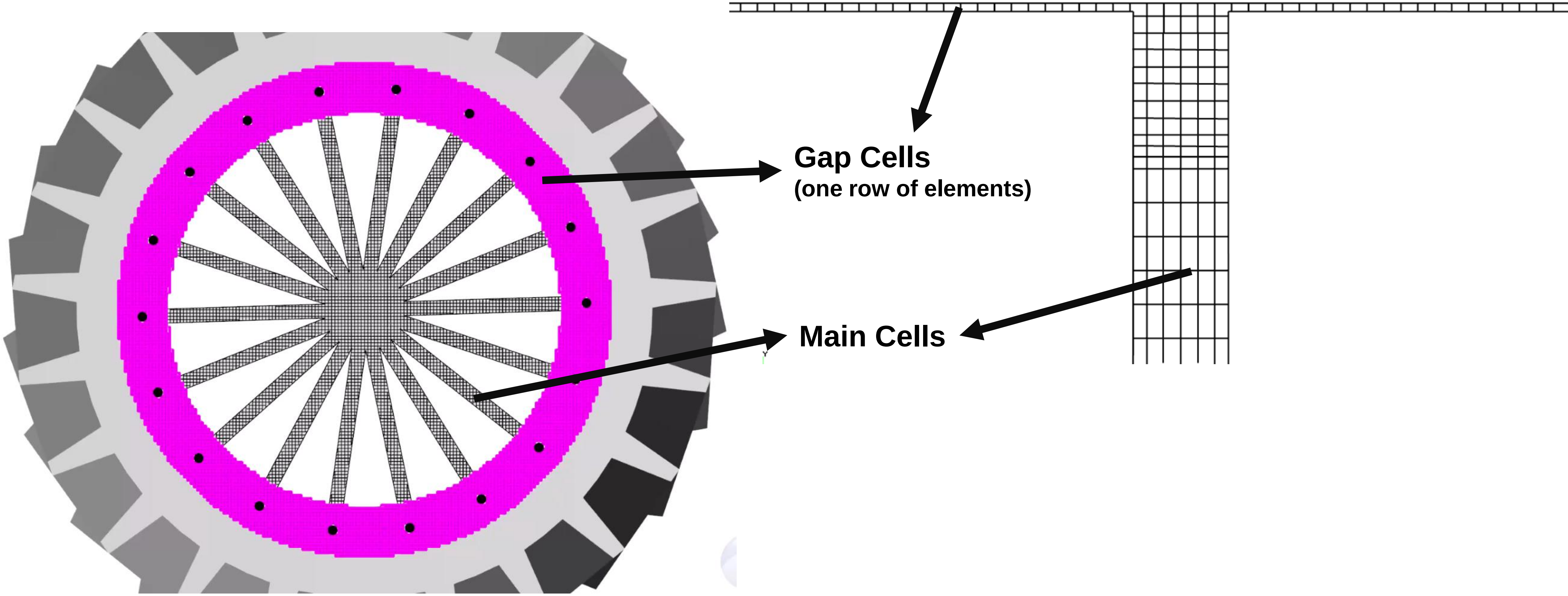
Clearance y+
0
0

Clearance y+
0
0

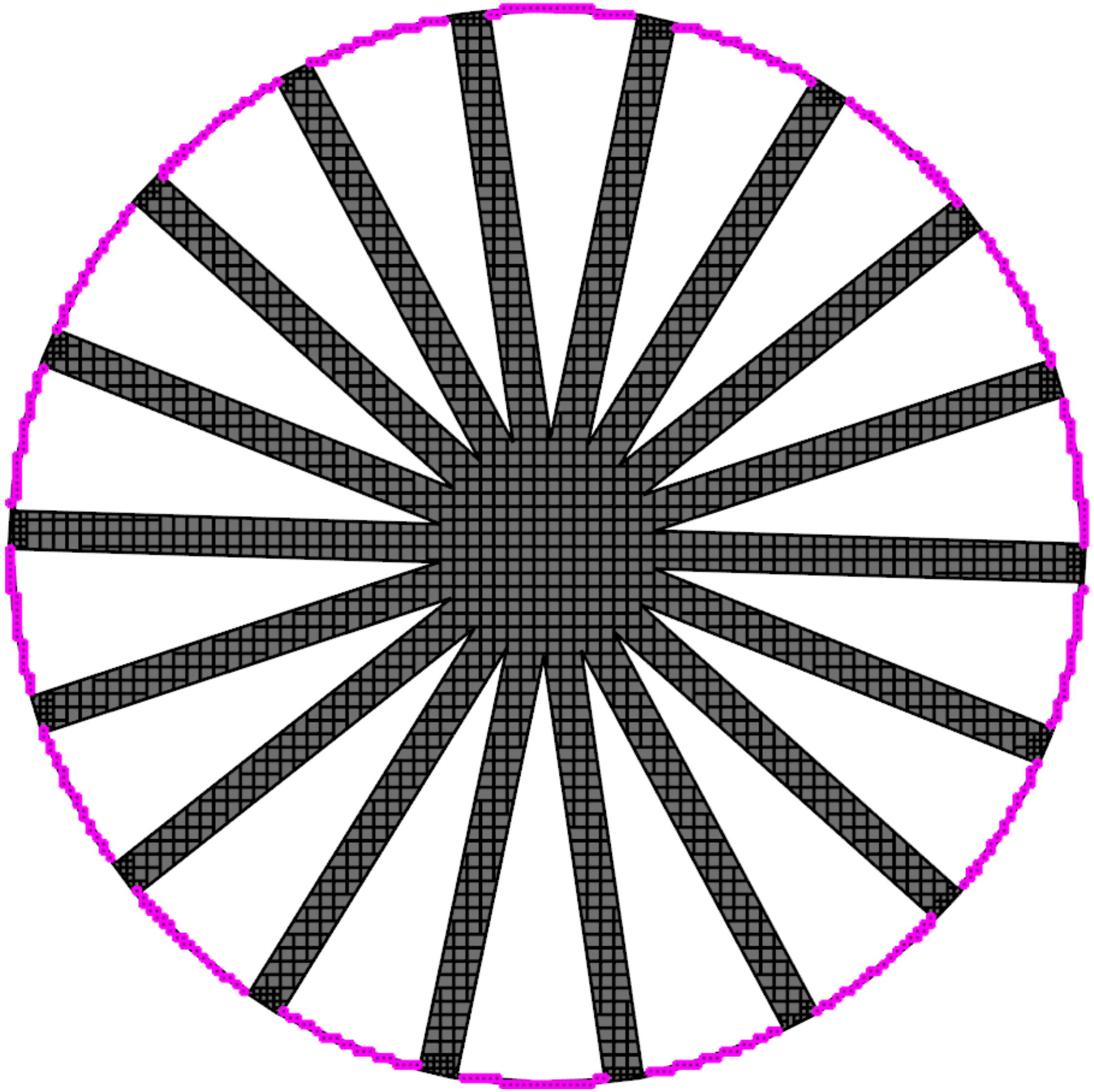
Clearance y-
0
0



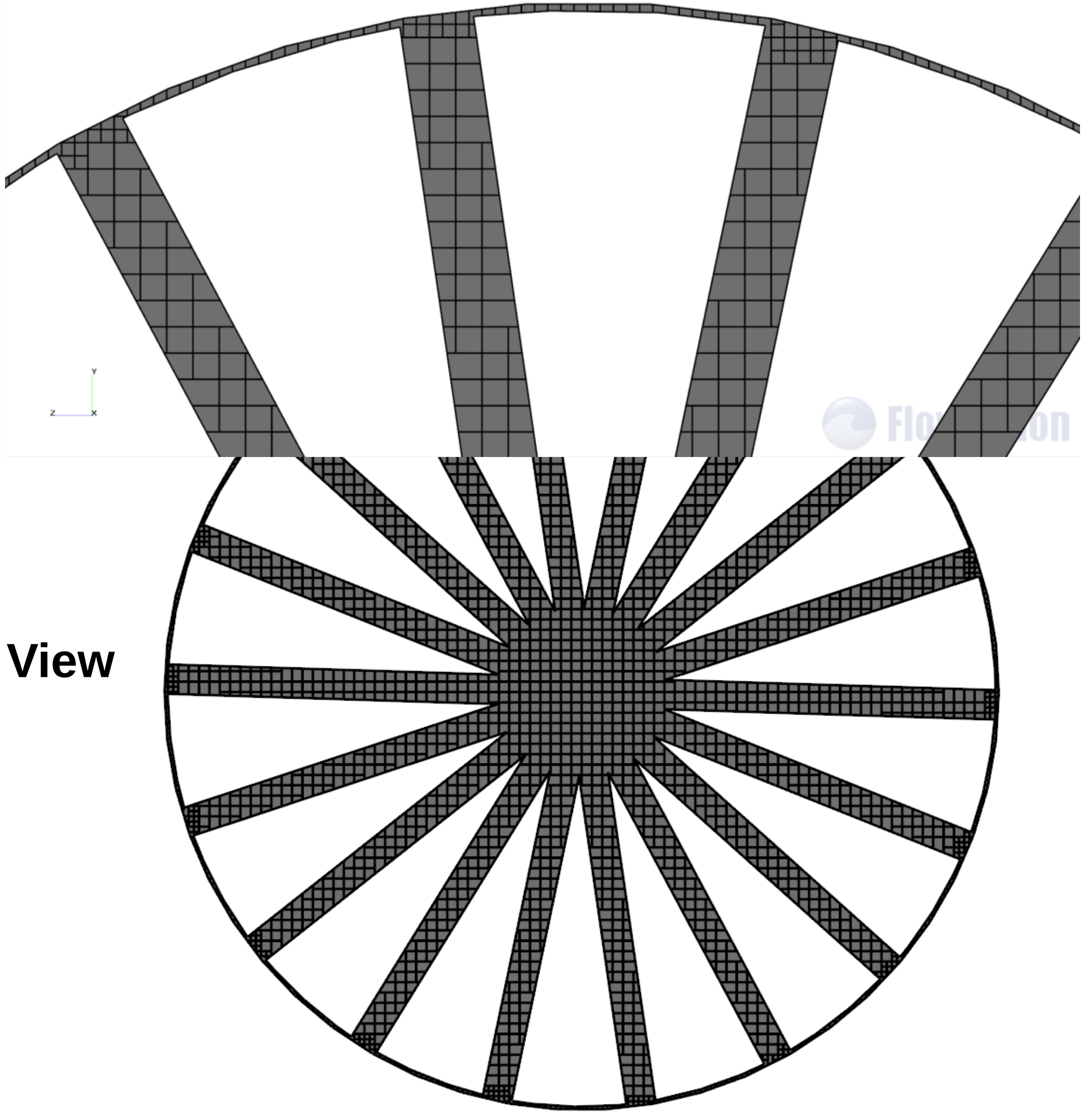
Computational Grid



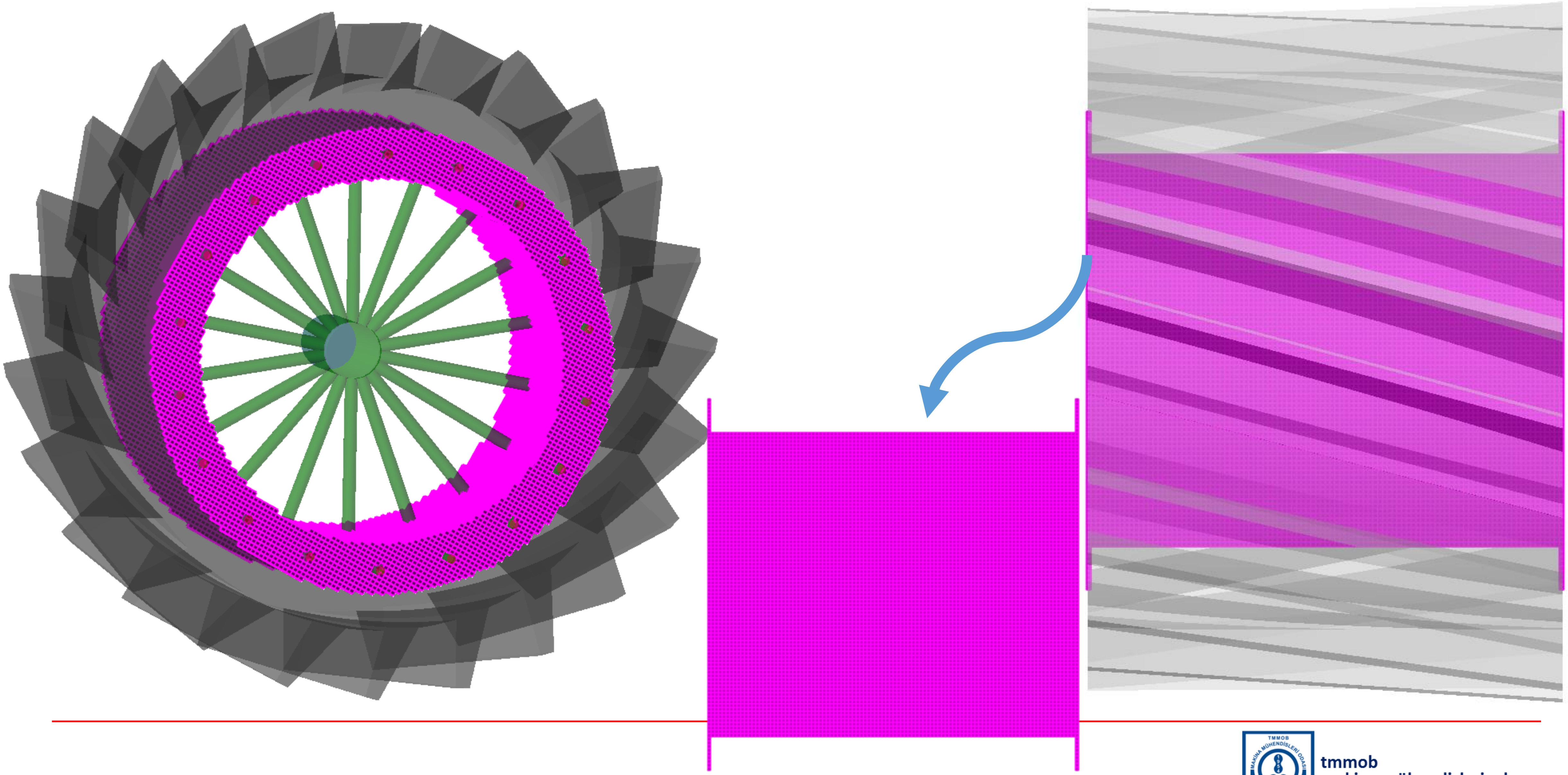
Main Cells & Gap Cells



Front View



Gap Cells



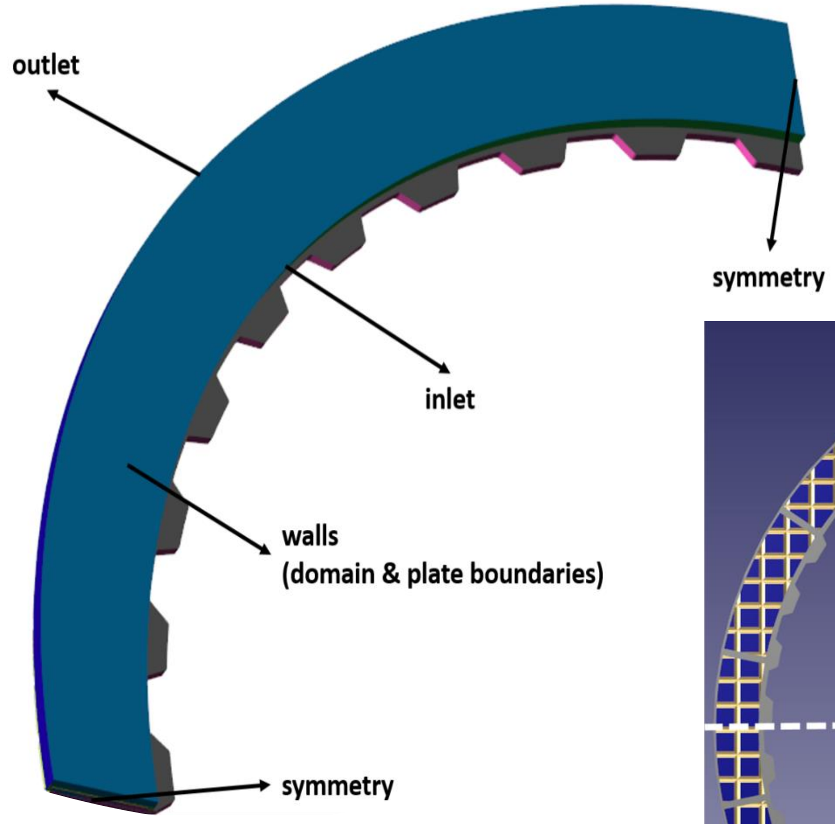
3.7. Case Study: Automotive

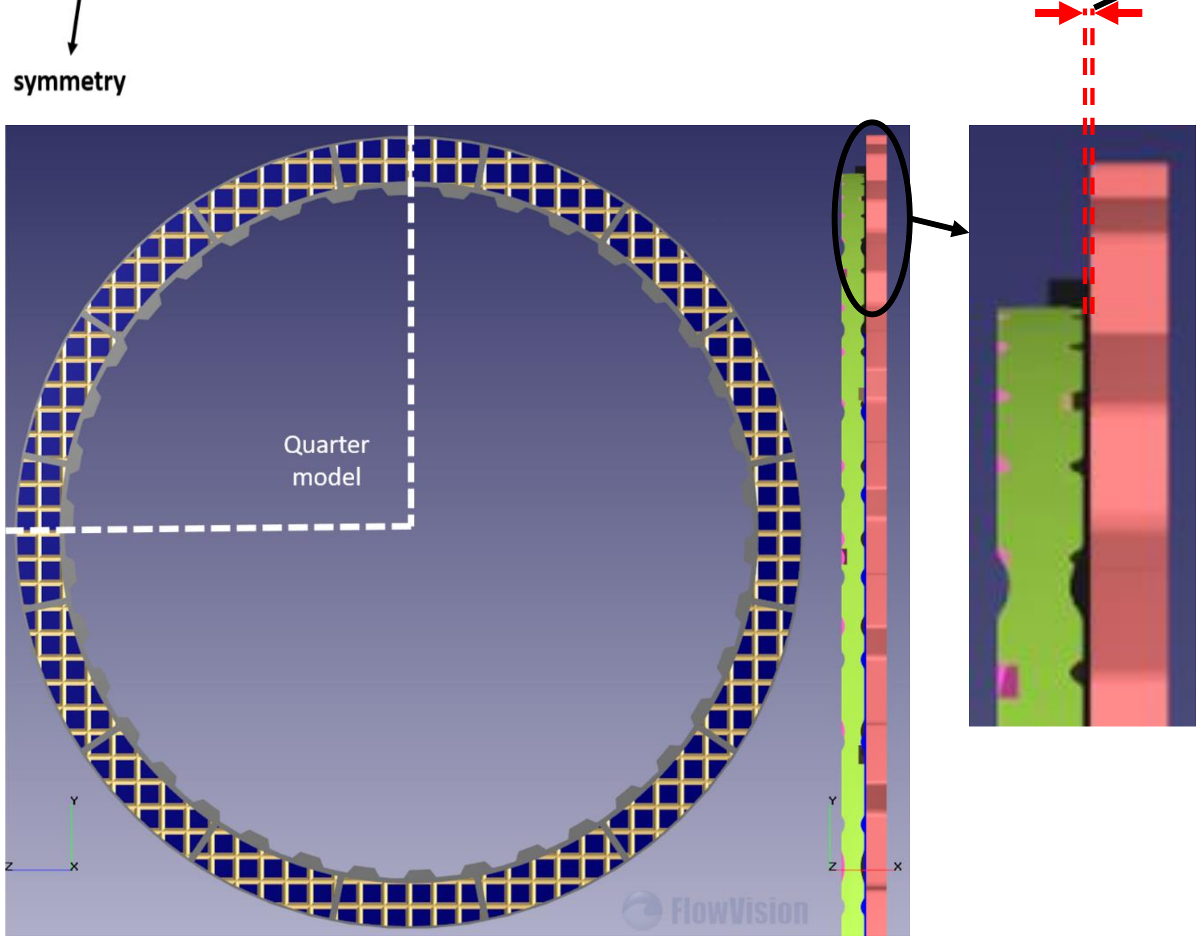
Clutch Groove Pattern
(lubrication & torque conversion)

Project Description

- Objective:
  - Simulating oil flow in radial direction between steel and friction plates
  - to investigate friction losses, torque conversion and lubrication
  - based on parameters
    - → forces & torques on plates
    - → inlet/outlet pressure drop

Simulation Setup





Distance between plates during operation

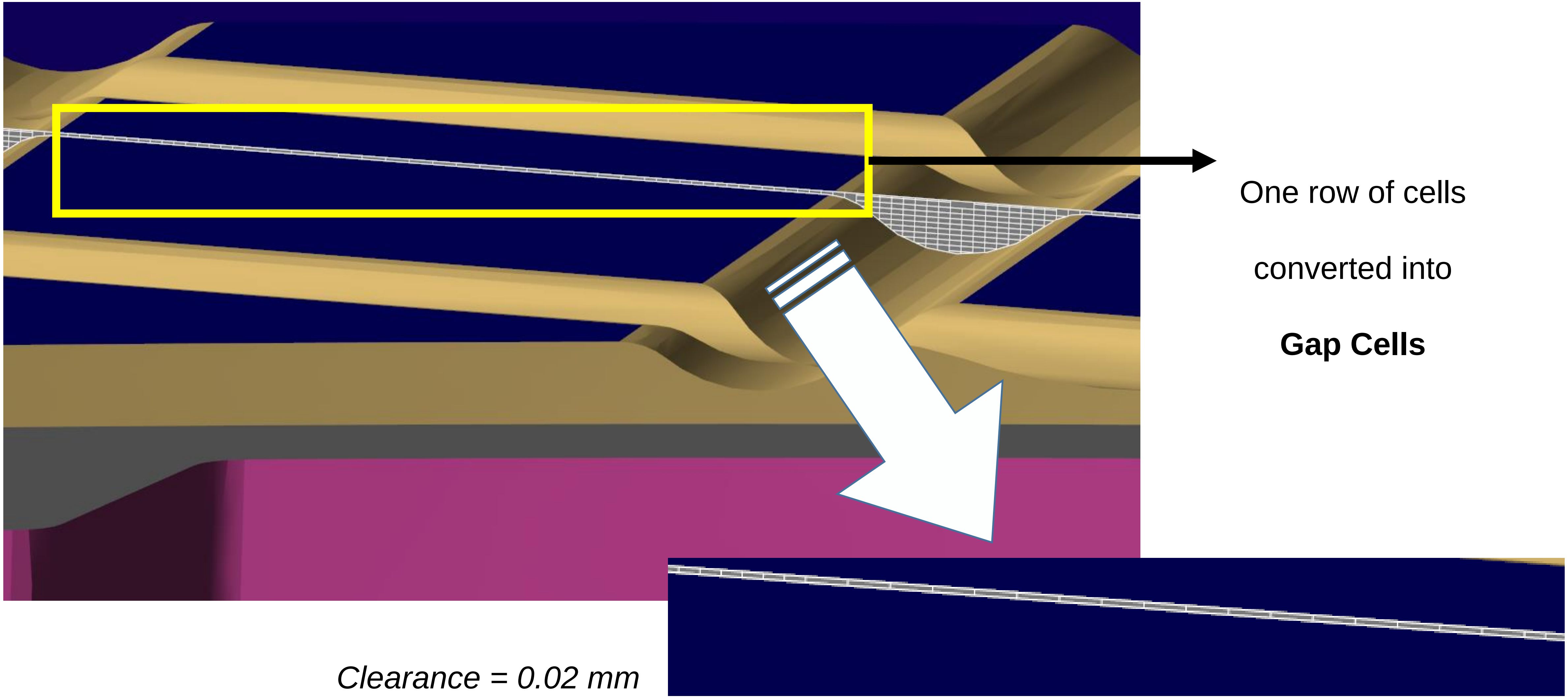
Closed clutch Clearance = 0 Full Closure
Just before clutch Clearance = 0.02 mm Small gap
Open clutch Clearance = 0.2 mm

Meshing & Computational Performance

Simulation wall time*	← Computational grid	← Approaches & benefits	← Distance between plates during operation
1.7 hours	1.28M	**Deal with full closure** without simplification without manual efforts	**Closed clutch** Clearance = 0 Full Closure
2 hours	1.57M + 166k Gap Cells	**Gap Model** No need to resolve gap by large number of cells	**Just before clutch** Clearance = 0.02 mm Small gap
5 hours	3.7M	**Local adaptations** Automatic adaptive grid adaptations	**Open clutch** Clearance = 0.2 mm

* The hardware configuration utilized is a desktop workstation with 24 cores (2 x 12 cores/processor, 3 GHz, Intel(R) Xeon(R)), 64 GB RAM

Gap Cells



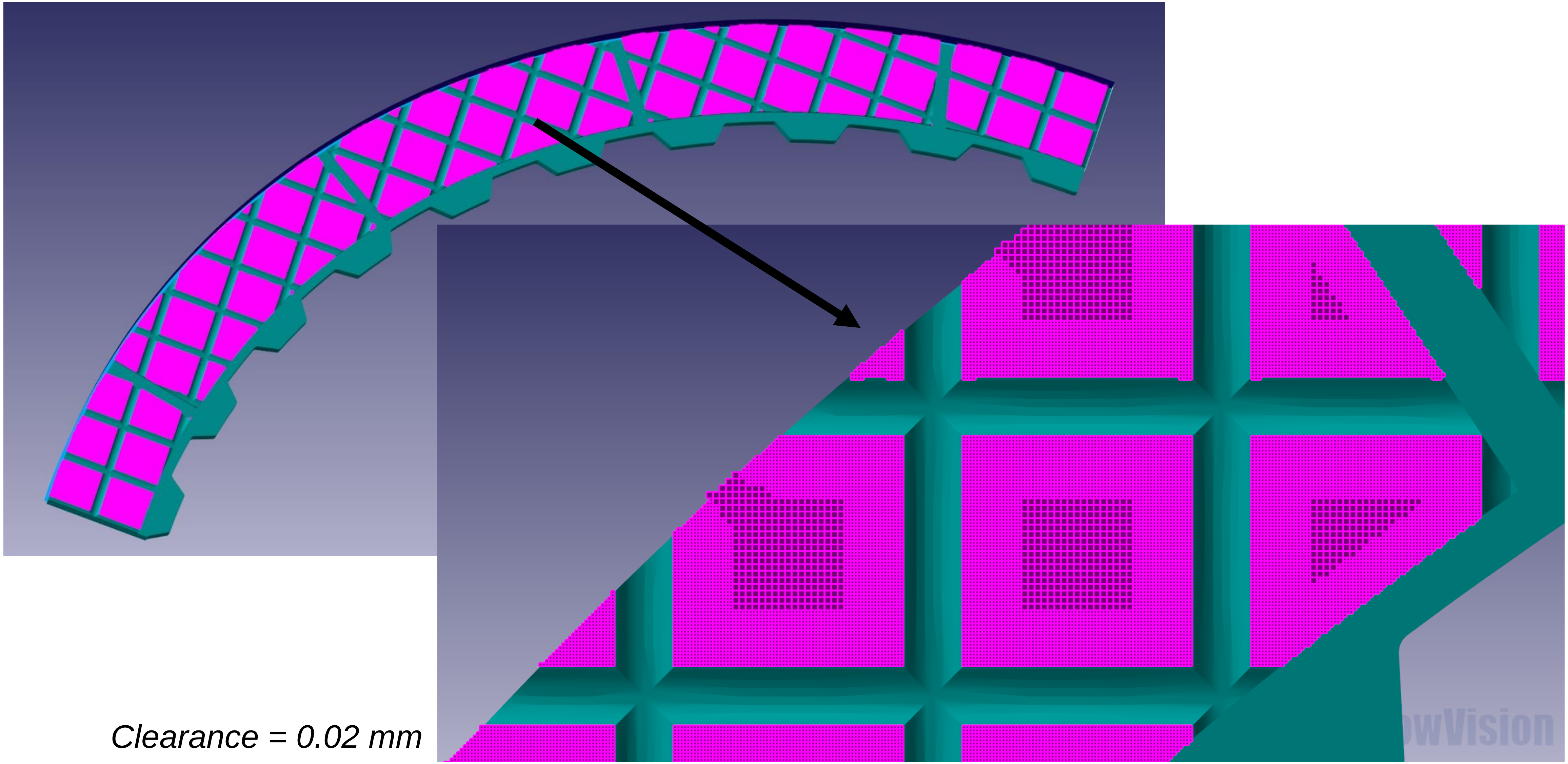
One row of cells

converted into

Gap Cells

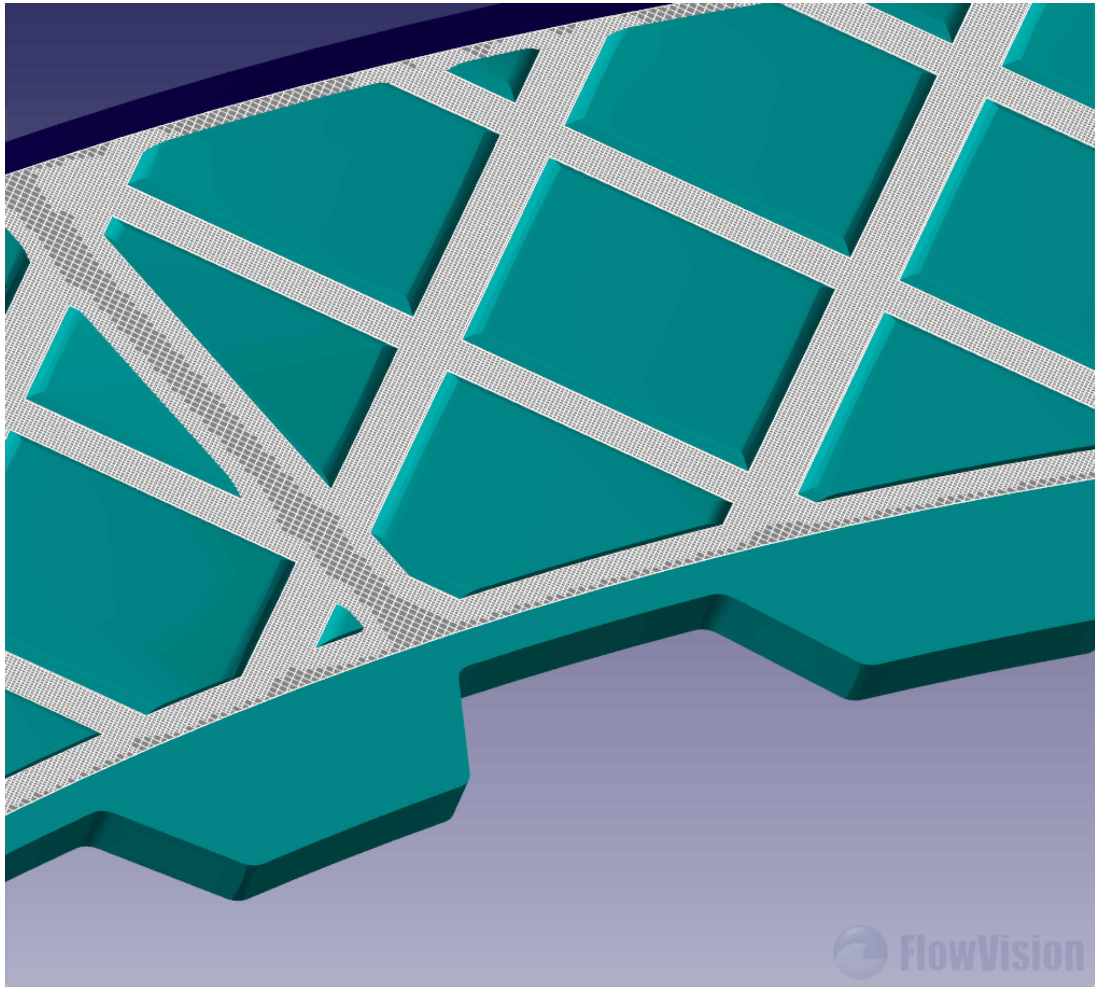
Clearance = 0.02 mm

Gap Cells

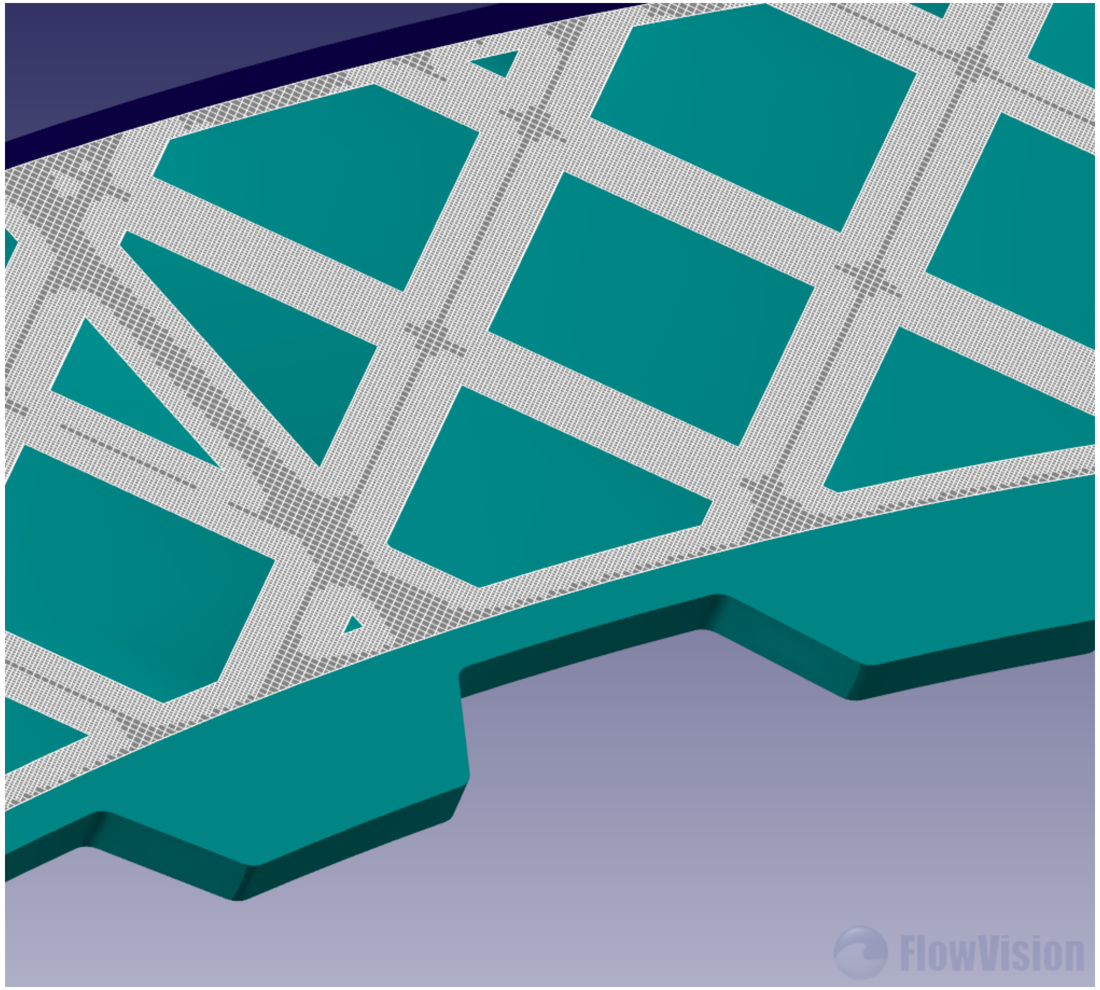


Clearance = 0.02 mm

Regular Cells



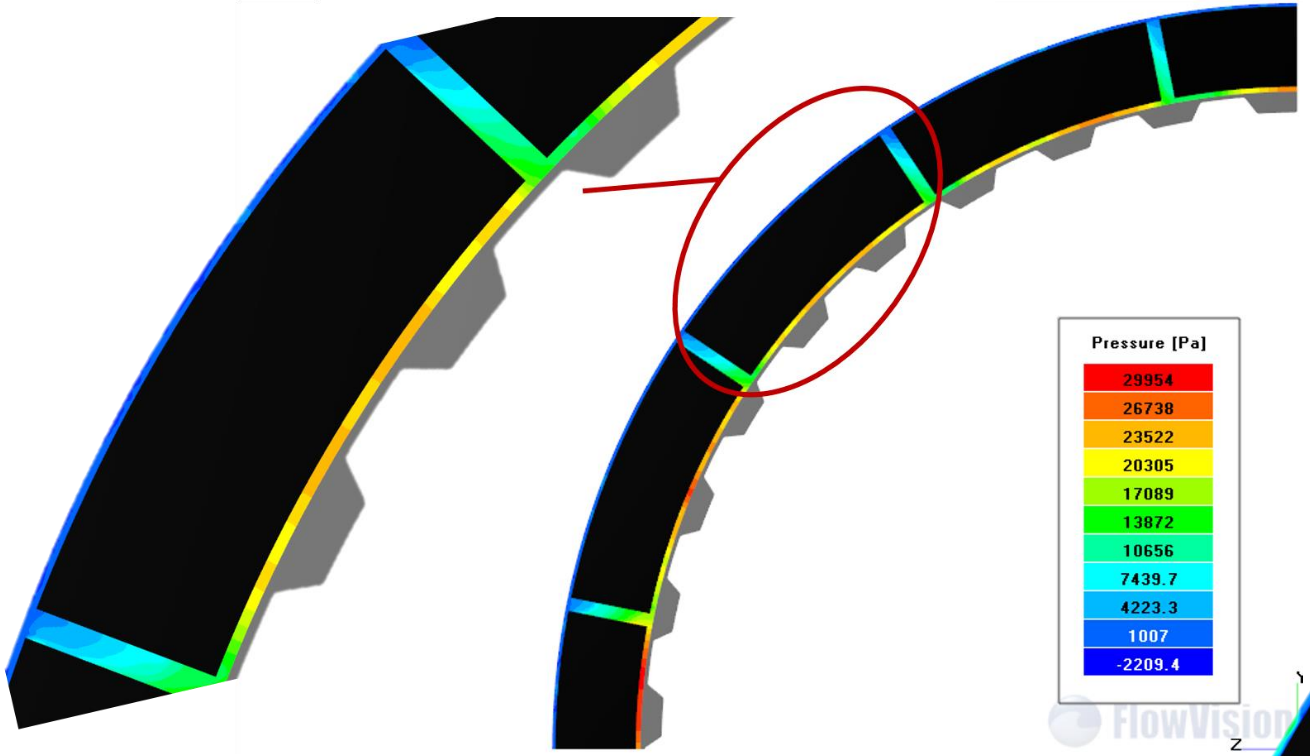
Cross section at middle height of groove

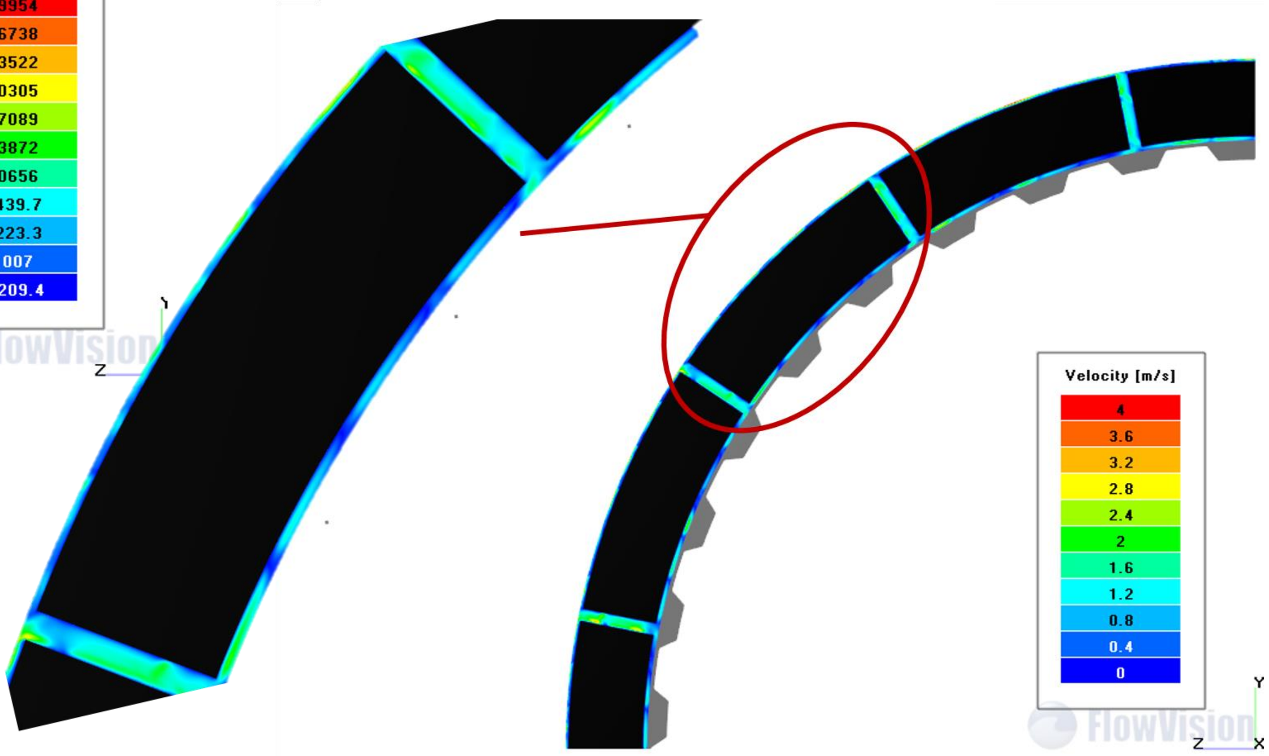


Cross section at waffle top

Sample Results

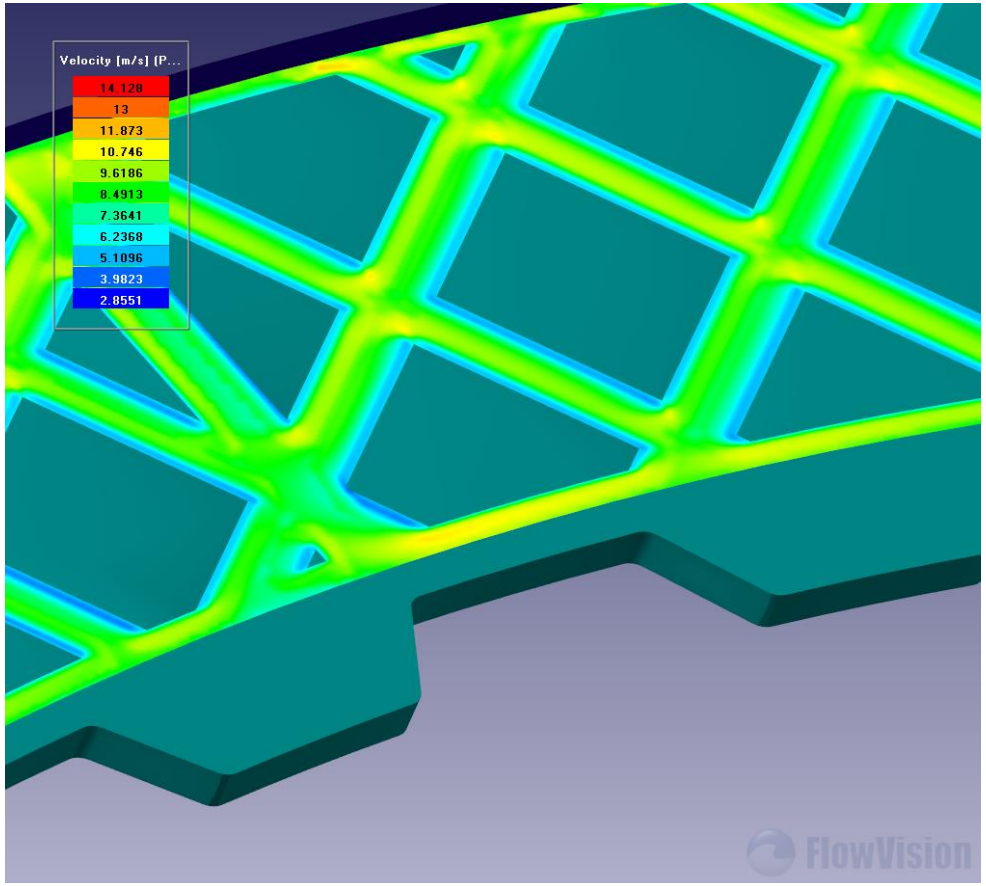
AKANA MÜHENDİSLİK ve TİCARET A.Ş.

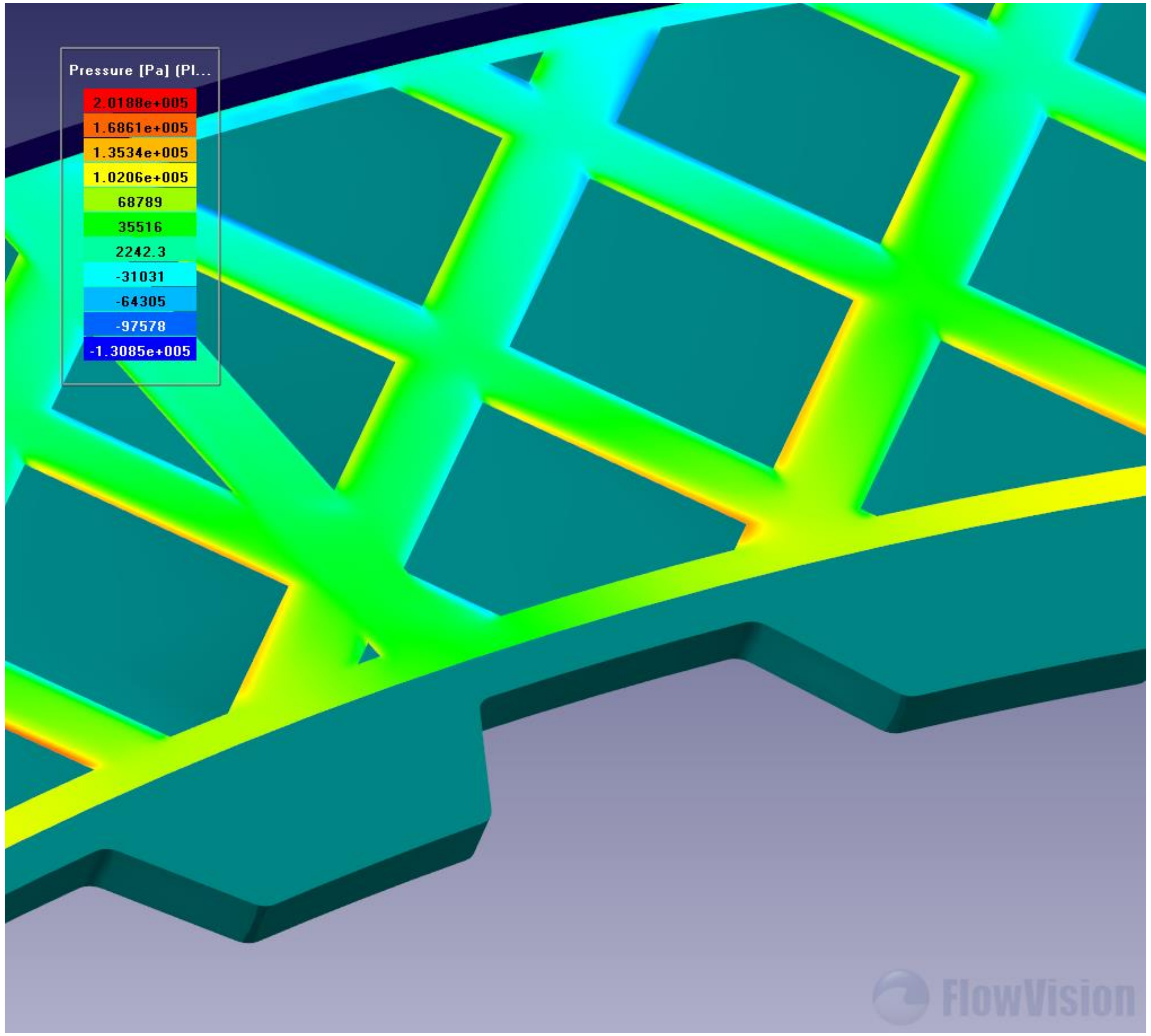




<u>Pressure & velocity distributions</u>
Extracted from 'open clutch' case
Cross section at middle height of groove

Sample Results





<u>Pressure & velocity distributions</u>
Extracted from 'just before clutch' case
Cross section at waffle top

Dinlediğiniz için teşekkürler…