# New developments and application of CF-MESH+ for the simulation of Internal Combustion Engines

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# What is CF-MESH

- A library consisting of various meshing algorithms that can be extended and combined into meshing workflows (meshers).
- Available meshing workflows:
  - Cartesian 2D and 3D
  - Tetrahedral
  - Arbitrary polyhedral
  - Hexahedra
- cfMesh is available under the GPL and CF-MESH+ is licensed commercially.

# Problem statement – ICE meshing

- Accuracy, robustness and ease-of-use of CFD simulations of ICE engines are critically dependent on the mesh and the underlying meshing algorithms.
- Meshing strategies based on inside-out approach have a strong potential for automation, and suffer from low quality in valve gaps and crevices.

- Solution:
  - Modify the initial mesh template by inserting layer of geometry-aligned mesh in the valve gaps and crevices.
  - Make the mesh easier-to-move.

# Problem statement – Boundary layers

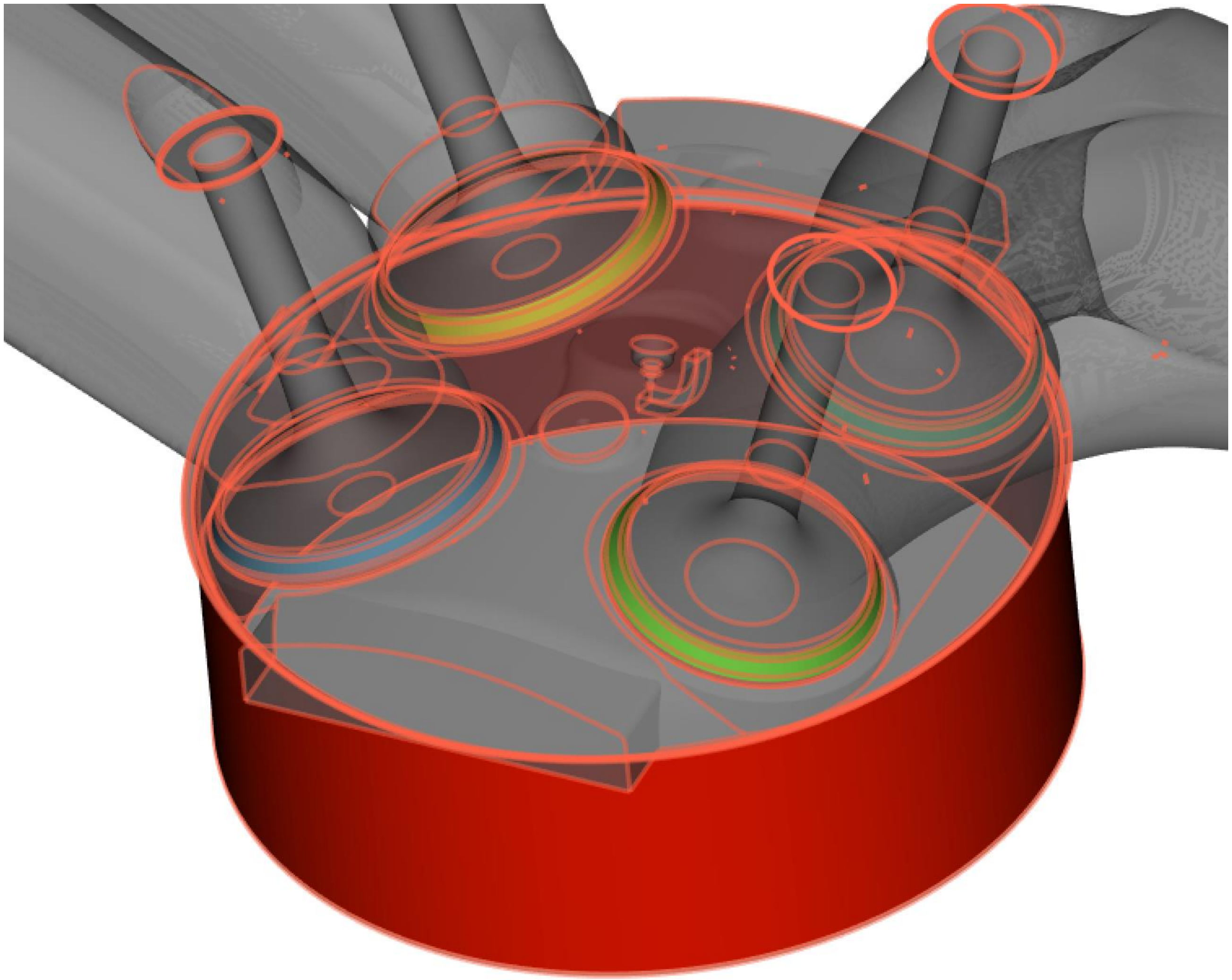
- Boundary layers are important for accurate prediction of wall-bounded flows where friction is important.
- Generation of prismatic layer is difficult due to:
  - Anisotropic nature of the layer cells.
  - Complex geometry at feature edges and corners.
  - Surface curvature and proximity of other layers.
- Our solution:
  - An iterative procedure for optimisation of boundary layer quality.
  - It is capable of generating high-quality layers in complex geometry.
  - Controlled cell size transition between the layer the rest of the mesh.

# Problem statement – Automatic cell sizing

- Complex geometries consist of part with significantly different sizes.
  - Inside-out methods require a cell sizing field in order to generate a template that is fine enough to generate a good quality mesh.
  - Requires many refinement zones to perform manually and may result in a prohibitively large number of cells.
  - It shall complement with other refinement regions defined in the meshing process.

- The solution shall not be limited to a particular type of cells.
  - The procedure is applied to the octree structure, which is the origin for Cartesian, polyhedral and tetrahedral templates.
  - It shall be flexible and allow the user to use only the criteria relevant for geometry under consideration.

# Marking of valve seats and crevices





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# Settings in the dictionary

```
engineMeshProperties
{
    crevice
    {
        cylinderSideSubset  creviceOut;
        pistonSideSubset    creviceIn;
    }
    valves
    {
        exhaustValve1
        {
            valveSeatSubset exhaustSeat1;
        }
        exhaustValve2
        {
            valveSeatSubset exhaustSeat2;
        }
        intakeValve1
        {
            valveSeatSubset intakeSeat1;
        }
        intakeValve2
        {
            valveSeatSubset intakeSeat2;
        }
    }
}
```


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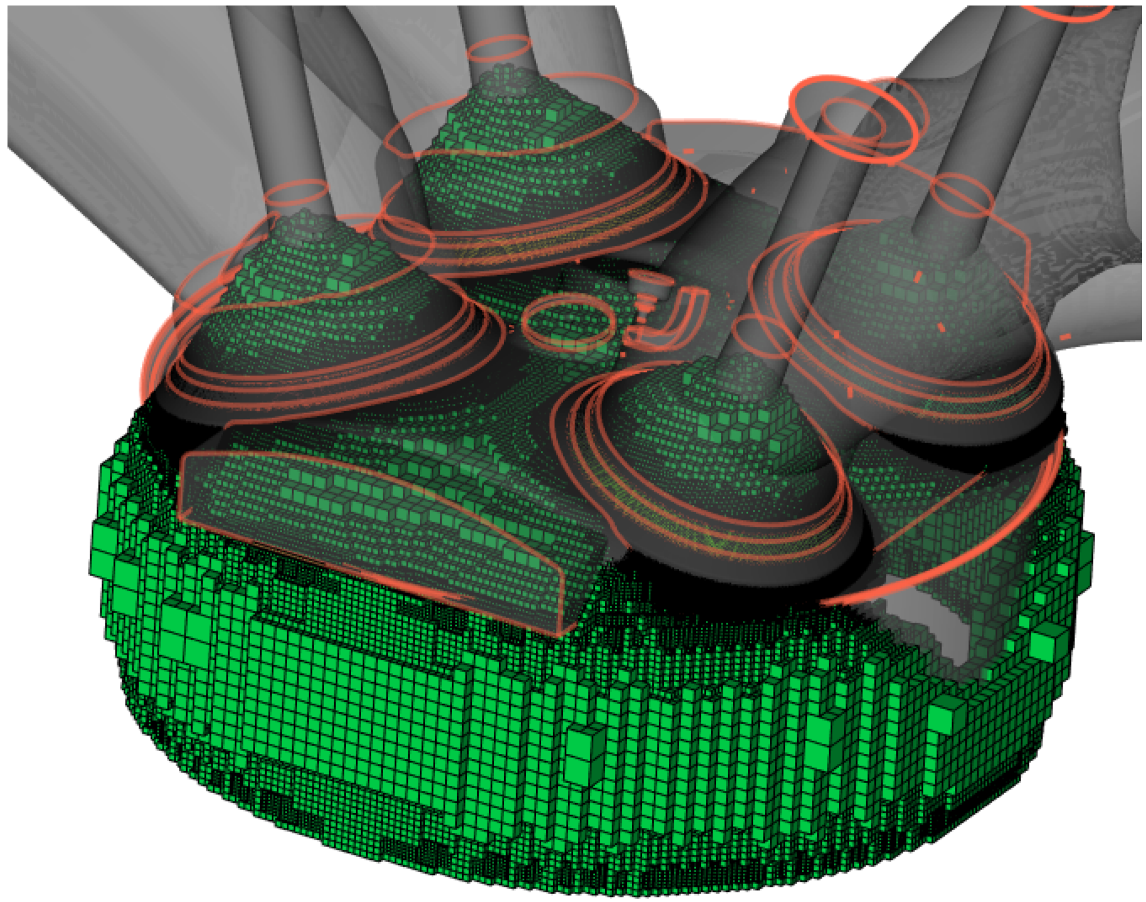
# Selection of faces for extrusion of geometry-aligned layers

- Calculate cylinder axis and valve axes based on the information provided in engine properties.
- Detect the interface between cells “inside” and “outside”.





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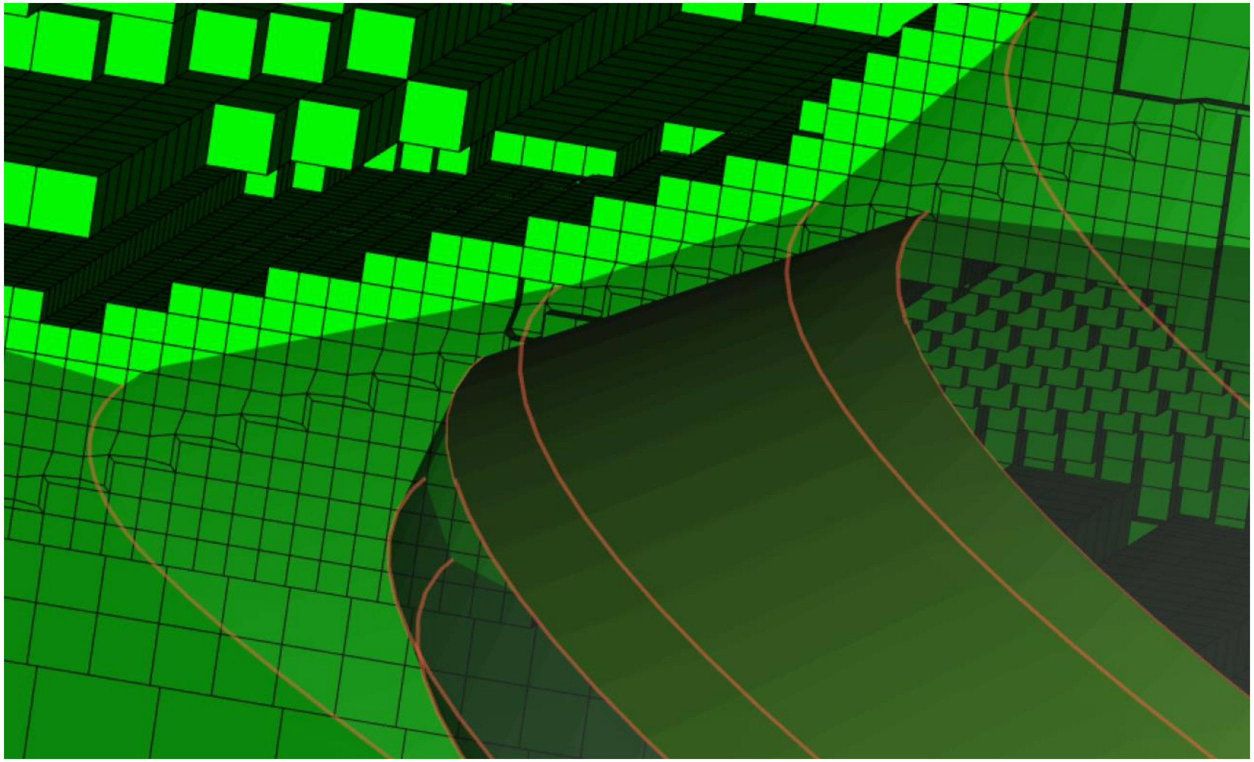
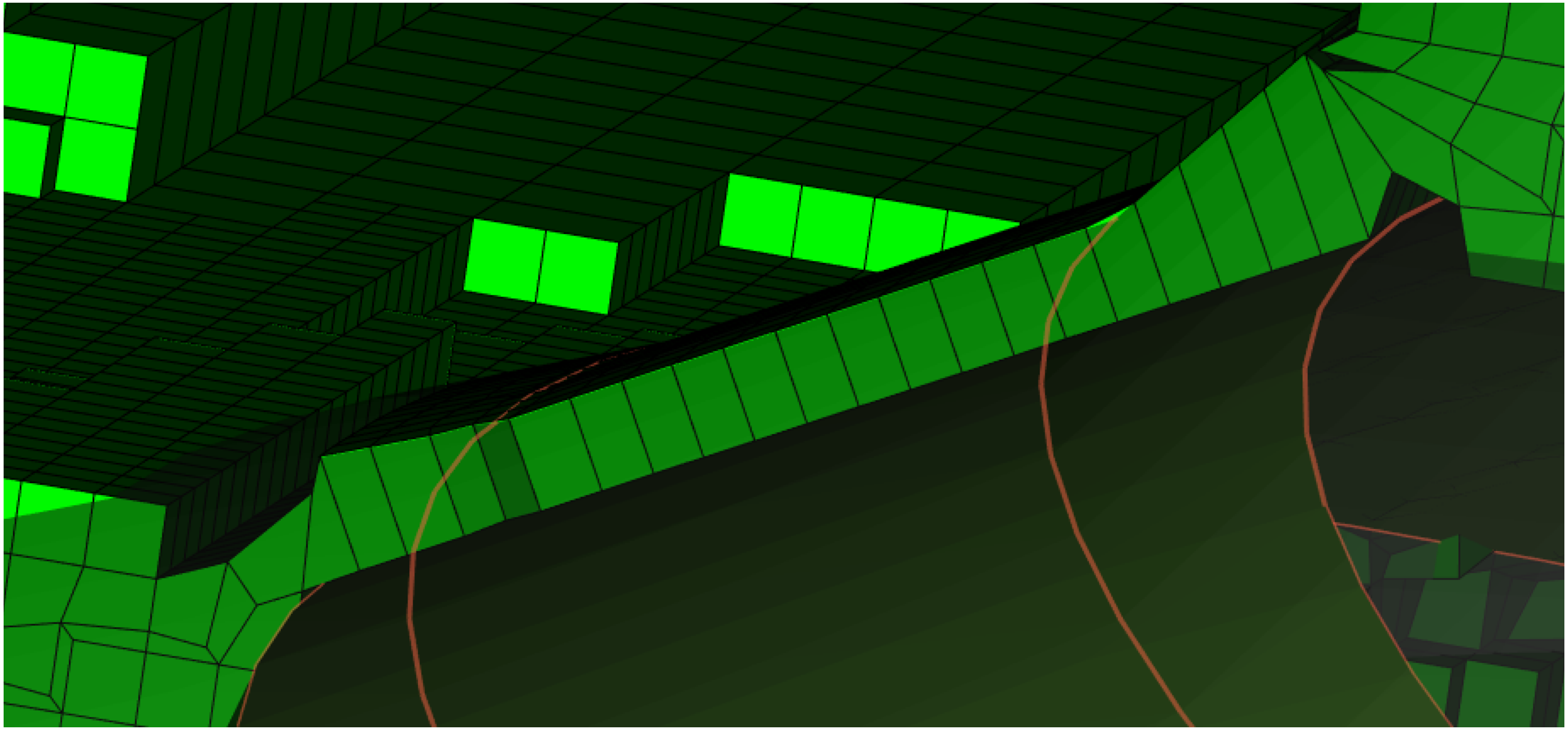
# Extrude geometry-aligned layers of cells

- Layers follow faces at the selected interface.



# Adjustment of critical regions





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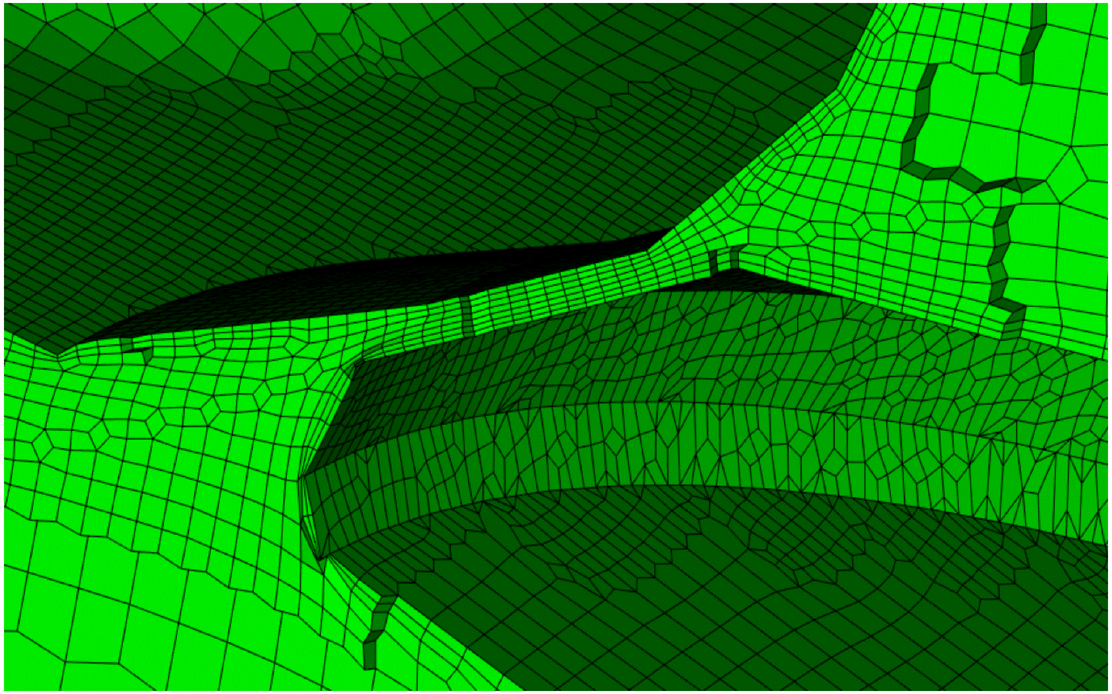
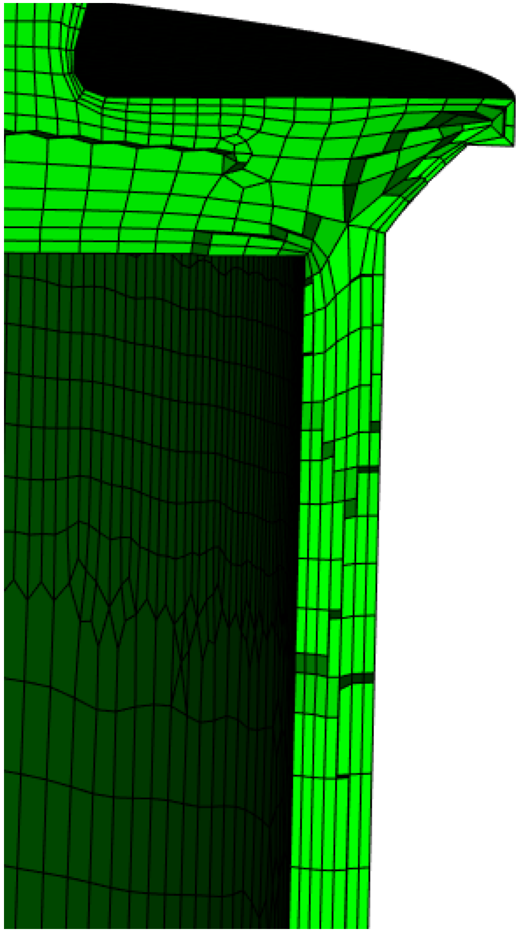
# Optimisation of the mesh







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# Boundary layers – optimisation parameters

- Iterative procedure for optimisation of geometric quality.
- The number of iterations can be controlled manually.
- By default, the layer procedure stops when the changes in the layer become smaller than required.
- Rule of thumb, max number of iterations shall be equal to the number of layers.
- More iterations are needed to generate thick layers.

```
boundaryLayers
{
    untangleLayers  0;

    optimisationParameters
    {
        maxDeviationFromFaceNormal  45.0;
        maxNumIterations    5;
        maxRelDisplacement  0.05;
        maxTwistAngle   60;
        relThicknessTol 0.99;
    }
}
```


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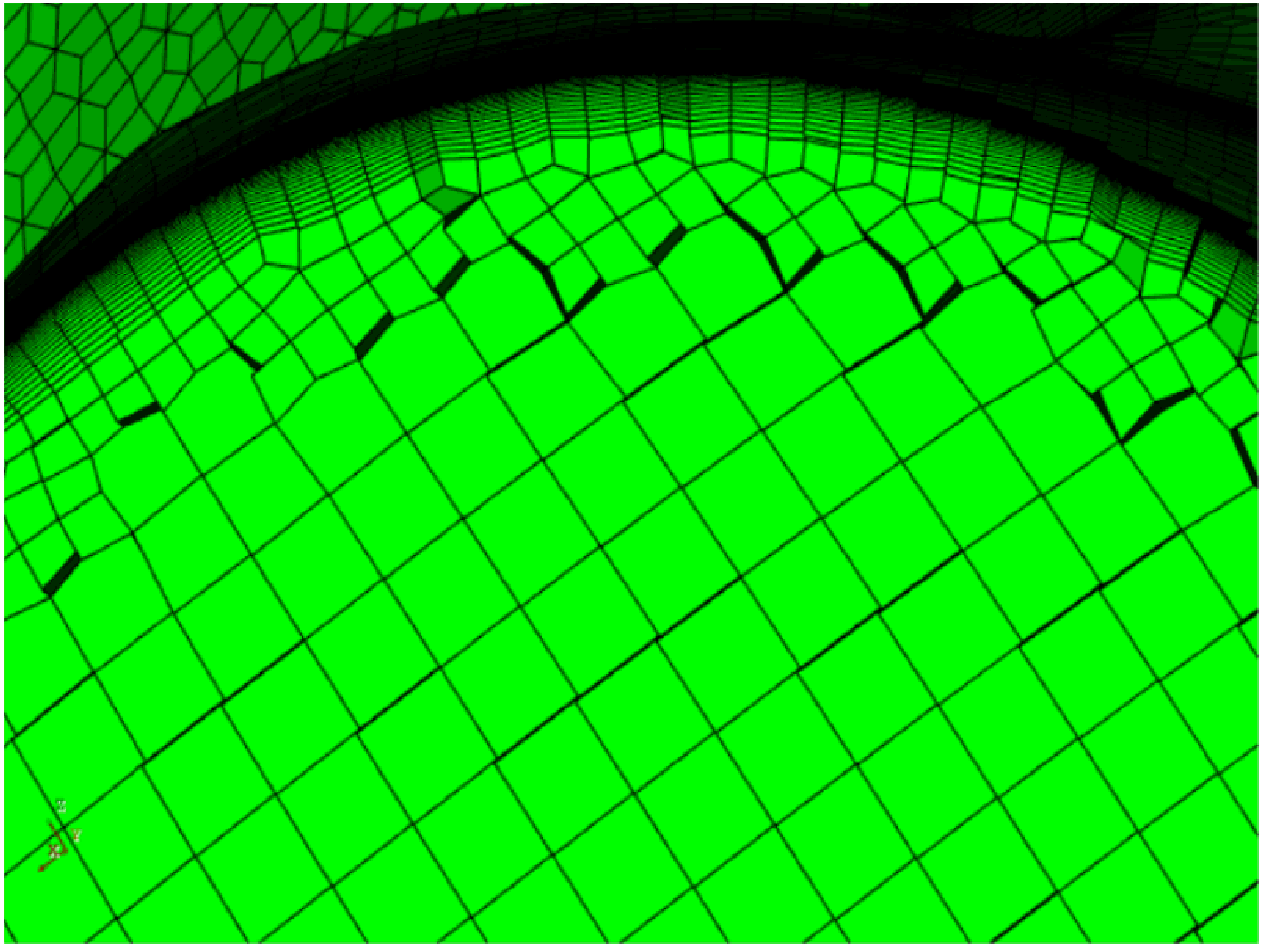
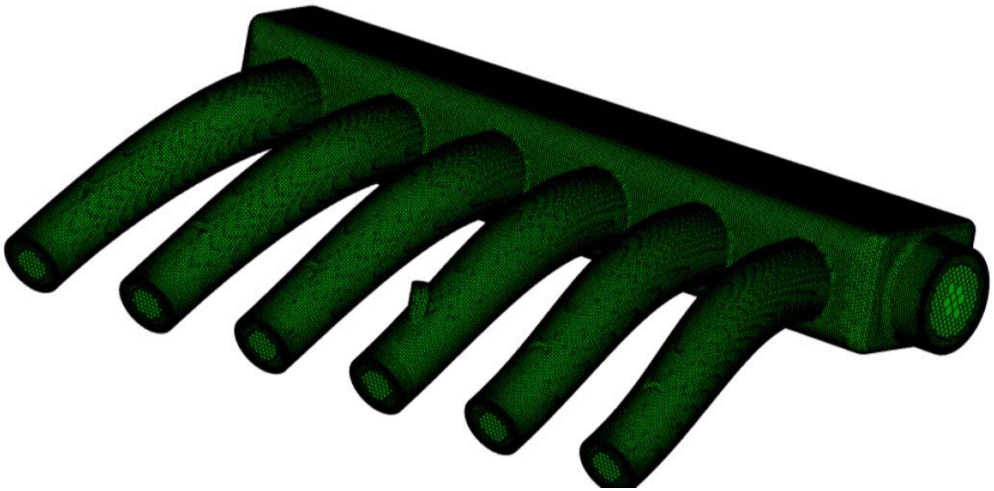
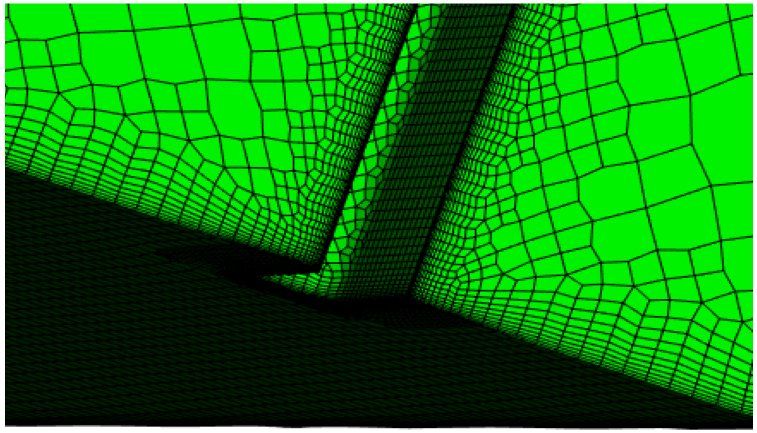
# Optimisation procedure



# 3D example – intake manifold

```
boundaryLayers
{
    nLayers 2;
    thicknessRatio  1.2;
    optimisationParameters
    {
        maxNumIterations    10;
    }
    patchBoundaryLayers
    {
        walls
        {
            nLayers 10;
            thicknessRatio  1.2;
        }
        wallsRibs
        {
            nLayers 10;
            thicknessRatio  1.2;
        }
    }
}
```







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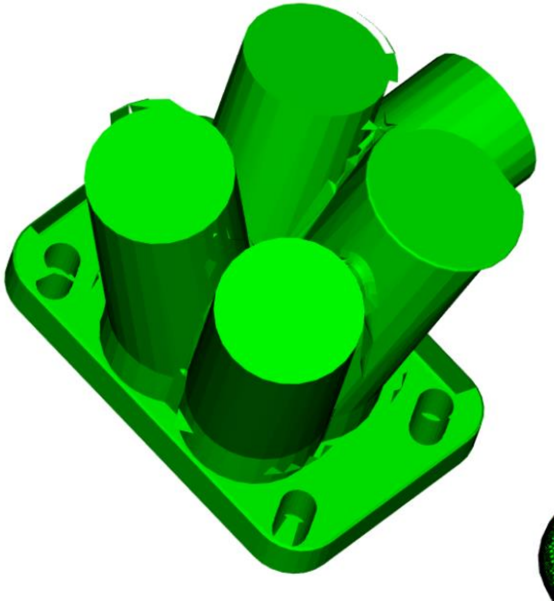
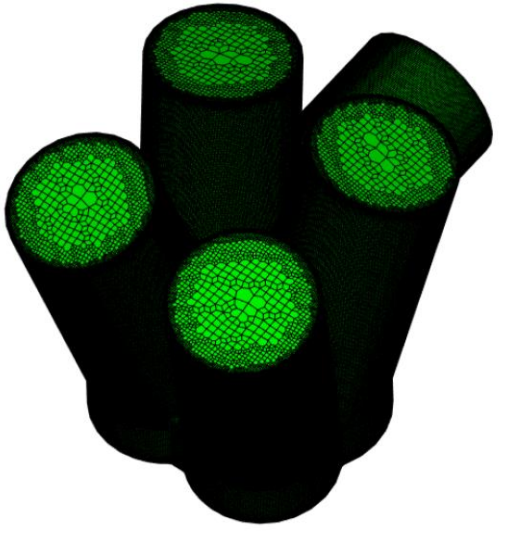
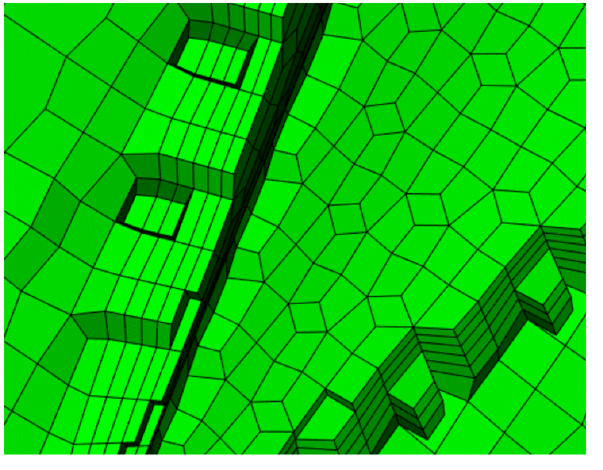
# 3D example – turbine manifold

```
boundaryLayers
{
    nLayers 2;
    thicknessRatio  1.2;
    optimisationParameters
    {
        maxNumIterations    5;
    }
    patchBoundaryLayers
    {
        walls
        {
            nLayers 5;
            thicknessRatio  1.1;
        }
    }
}
```









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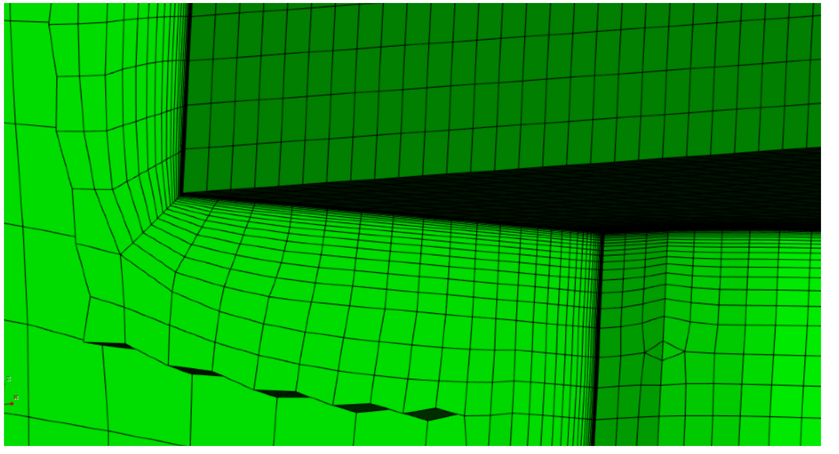
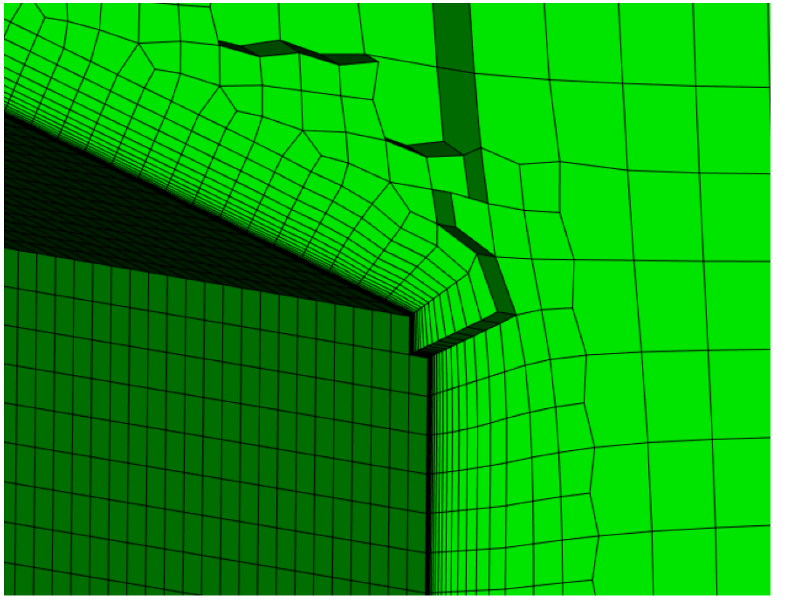
# 3D example – Ahmed body

```
boundaryLayers
{
    patchBoundaryLayers
    {
        AhmedBody
        {
            maxFirstLayerThickness  0.0005;
            nLayers 10;
            totalLayerThickness 0.015;
        }
    }
}
```







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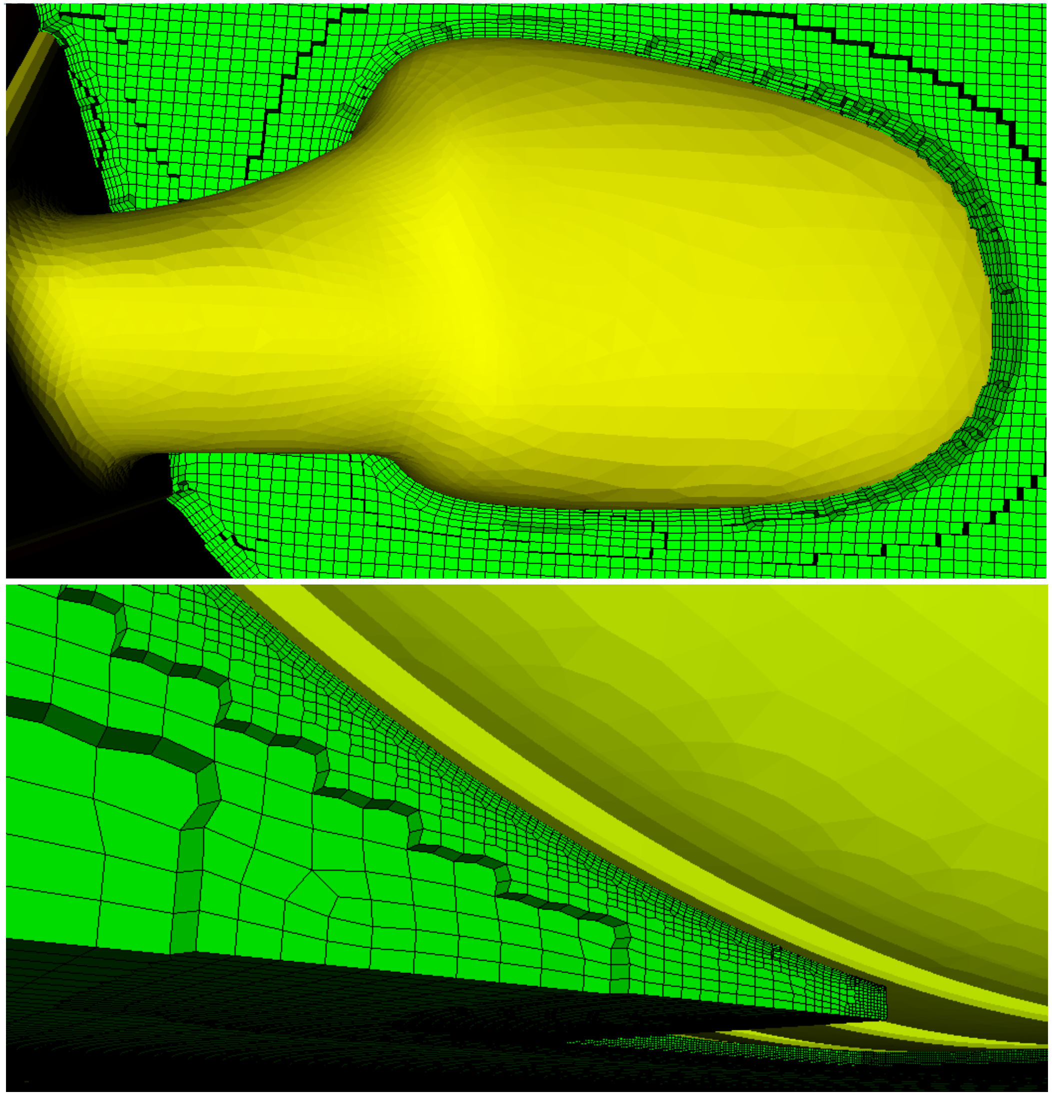
# 3D example - DrivAer

```
boundaryLayers
{
    optimiseLayer   1;
    untangleLayer   0;
    optimisationParameters
    {
        featureSizeFactor   0.4;
        maxDeviationFromFaceNormal   90;
        maxNumIterations     5;
        maxTwistAngle   90;
        relThicknessTol 0.9;
    }
    patchBoundaryLayers
    {
        floor
        {
            nLayers 2;
            thicknessRatio   1;
        }
        "wall_.*"
        {
            nLayers 5;
            thicknessRatio   1.2;
        }
    }
}
```





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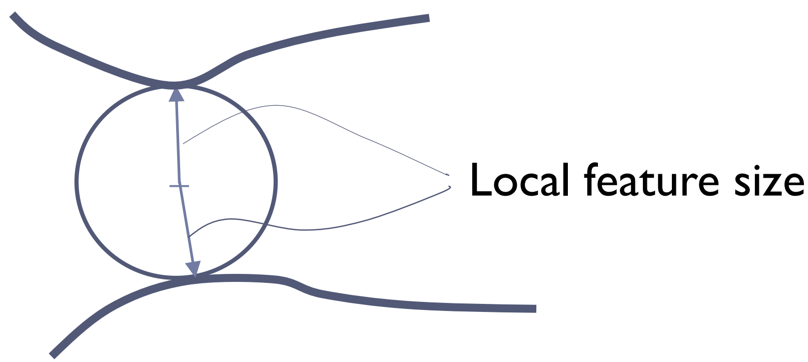
# Feature size and mesh quality

- Feature size is defined by a ball touching the geometry at two points.
- Most meshing algorithms require cell size smaller than the feature size to achieve required mesh quality.



# Activation of criteria from a menu

- Each criterion can be applied globally or locally (patch, face subset).
- Min allowed cell size can be applied locally.

```
automaticRefinement
{
    // allows up to 6 refinement level on top of maxCellSize
    maxAdditionalRefinementLevels   6;

    // it is possible to set the limit
    // on the smallest cell size, too.
    //minCellSize           1e-3;

    // Activates curvature estimation and refinement
    curvatureRefinement 1;

    // Activate checking if patches that do not share
    // a common edge are present in a cell
    distinctPartsRefinement 1;

    // Refines mesh if the cell size is larger
    // than the shortest edge in the triangulation
    edgeLengthRefinement    1;

    // min number of cell over feature size
    numCellsOverFeatureSize 1;

    // surface triangle with normal deviation
    // larger than the prescribed angle are skipped
    proximityAngle  80;

    // activates check for the number of regions within a ball
    proximityRefinement 1;

    // activates ray-casting check
    rayCastingRefinement    1;

    // used for poor quality surface mesh with cracks and overlap
    // analize if there exists a continuous surface or not
    stickyDistance  0;
}
```



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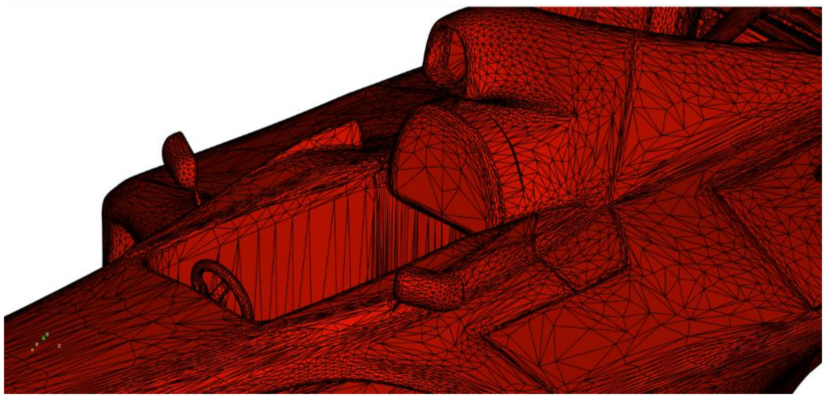
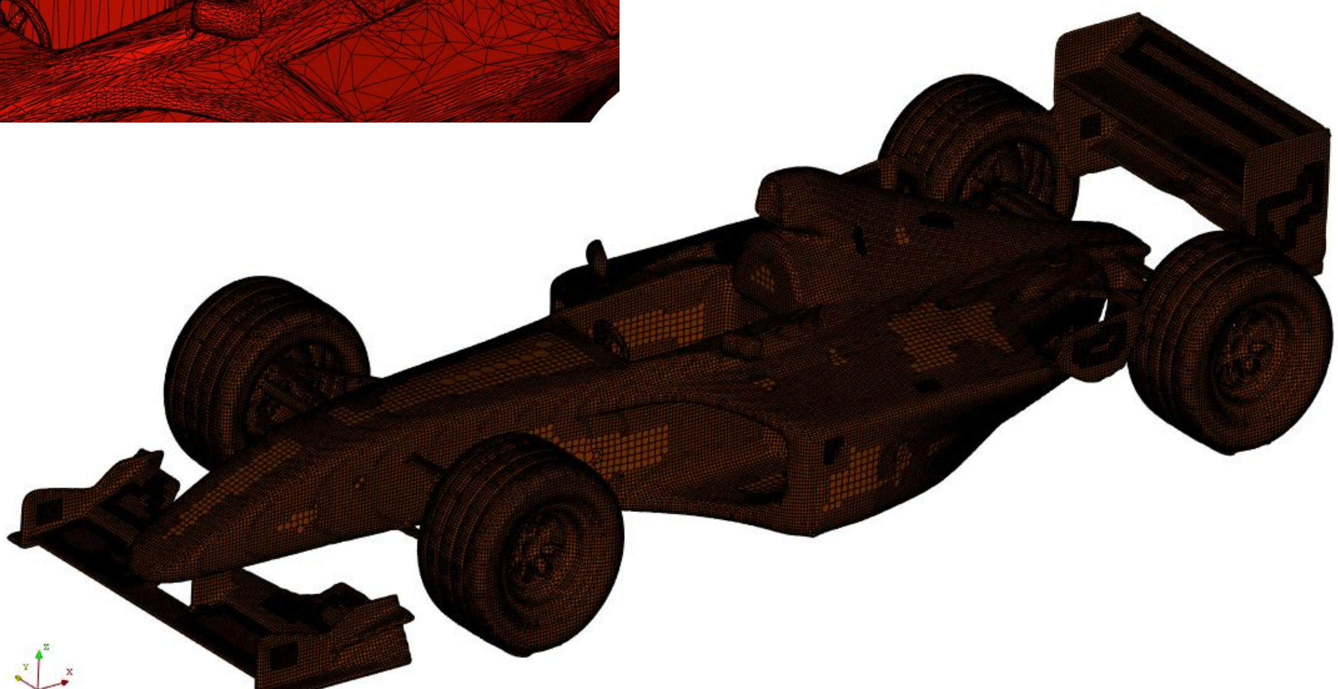
# Examples – F1 car

- 1.7 million cells
- 7 minutes on 4 core machine
- Curvature and proximity







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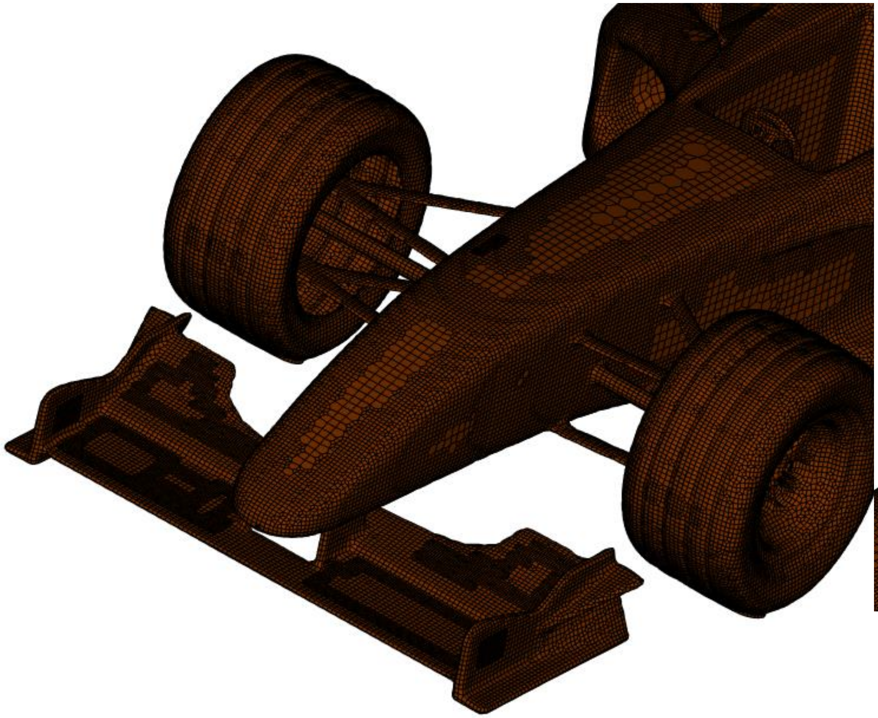

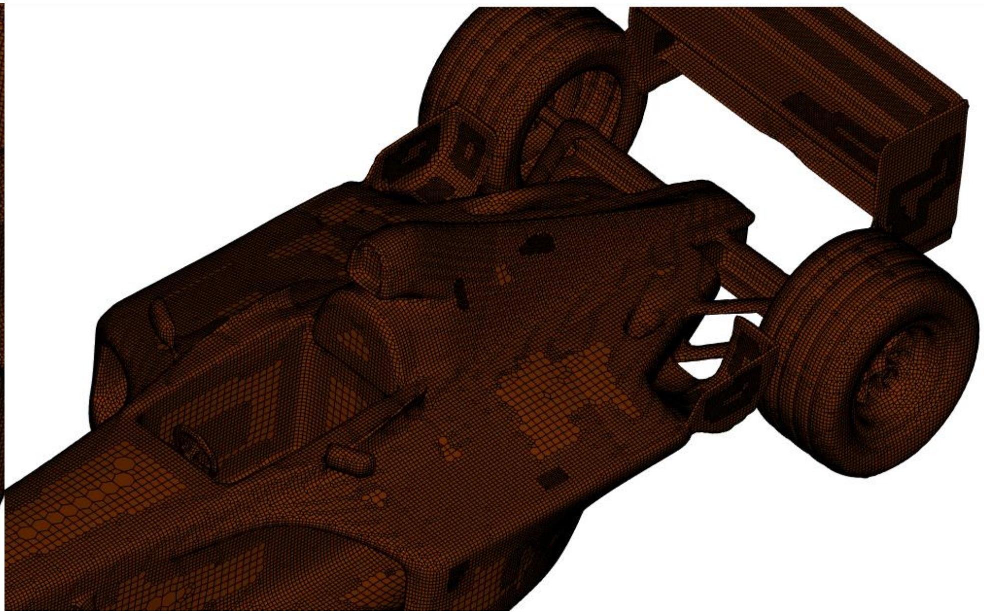



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# Summary

- Presented a current status of work targeted towards efficient meshing of valve gaps and crevice volumes.
- Developed a novel robust method for generation of boundary layers in complex geometries.
- Implemented various criteria for automatic mesh refinement to reduce manual effort required for complex geometries.


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# Thank you for your attention!

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