

# Analisi delle performance del generatore di mesh nativo di OpenFOAM<sup>®</sup>: snappyHexMesh

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Tesi per il conseguimento della Laurea Triennale in  
Ingegneria Meccanica

Genova, 22 Dicembre 2014

# Prefazione

- **Generazione della mesh: argomento centrale nelle simulazioni CFD**
- **Caratteristiche di una mesh di qualità:**
  - **Discretizzazione dominio di calcolo ragionata;**
  - **Finezza;**
  - **Caratteristiche intrinseche tali da minimizzare gli errori commessi dalle approssimazioni degli schemi numerici.**
- **Trade off:**
  - **Numero di celle;**
  - **Tempo di creazione della mesh.**

# Outline

Introduzione ad OpenFOAM®

blockMesh

snappyHexMesh

Analisi parametrica

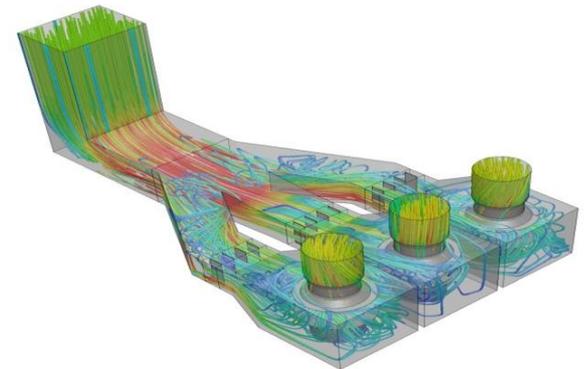
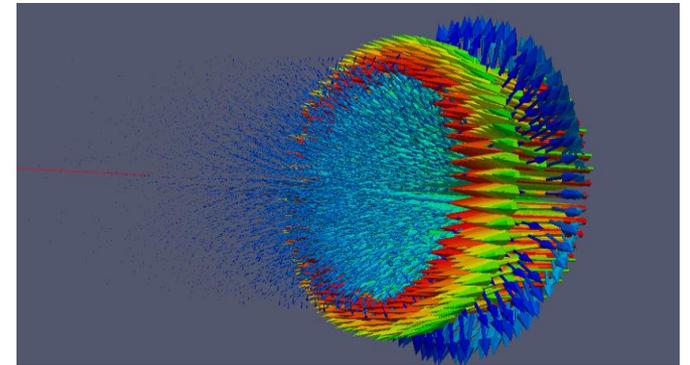
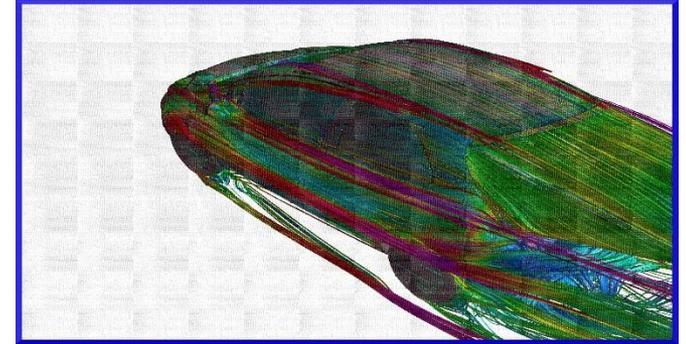
Conclusioni e sviluppi futuri

# OpenFOAM®

Pacchetto software OpenSource  
scritto in C++.

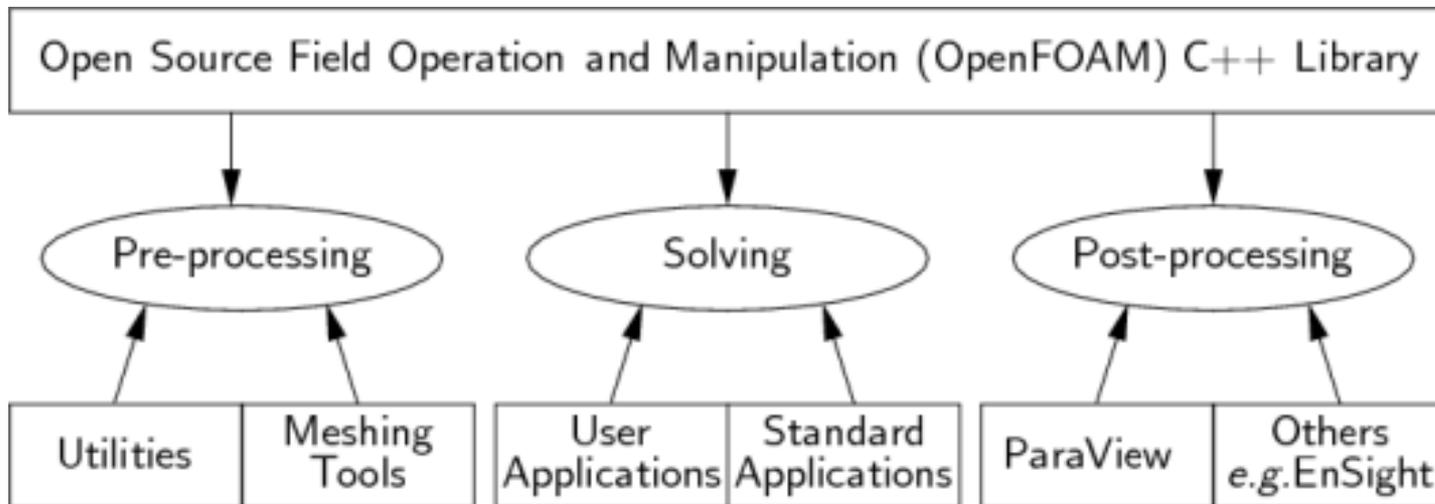
Largo utilizzo in ambito  
principalmente accademico :

- Fluidodinamica computazionale;
- Trasferimento di calore;
- Trasformazioni chimiche;
- Solutori per moti comprimibili ed  
incomprimibili;
- Modelli finanziari.



# Struttura di OpenFOAM®

- **Pre processing:** generazione della mesh;
- **Solving:** si adotta uno specifico solutore e si risolvono le equazioni ad esso associate;
- **Visualizzazione dati:** Paraview



# Paraview

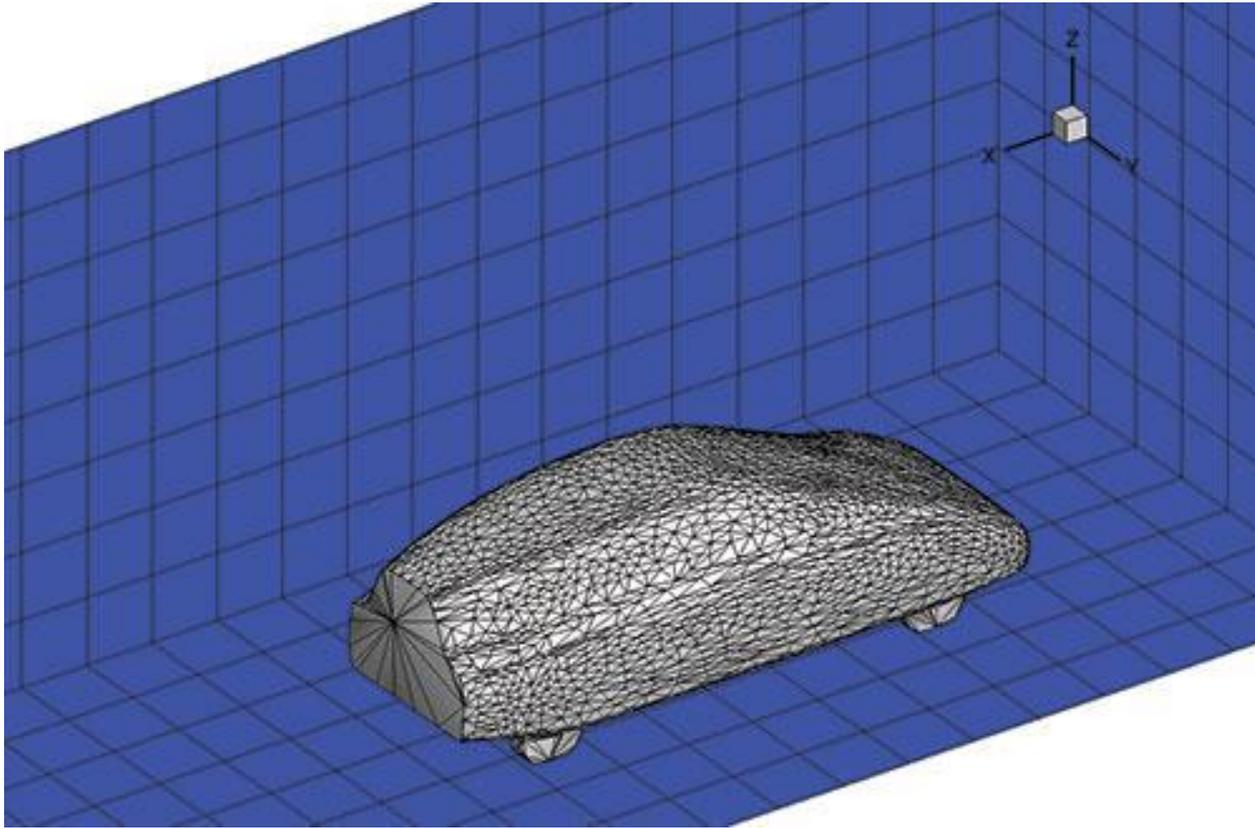
The screenshot displays the Paraview software interface with several key components highlighted by yellow callouts:

- Toolbars:** Located at the top, containing various icons for file operations, viewing, and data manipulation.
- Pipeline Browser:** Located on the left side, showing a tree view of the data pipeline with nodes like 'multicomb\_0.vts', 'GroupDatasets1', and 'Histogram2'.
- View Area:** The central 3D view showing a blue mesh structure with a probe. A color scale for 'Momentum Magnitude' is visible, ranging from 0 to 361.7159.
- Properties Panel:** Located at the bottom left, showing settings for the selected object, including 'Coloring' (Solid Color) and 'Styling' (Opacity).
- Histogram of Momentum:** A bar chart on the right showing the distribution of momentum values, with a legend for 'on\_values'.
- Table:** A data table below the histogram showing bin extents, bin values, and density statistics.
- Probe over line results:** A line graph at the bottom right showing 'Data Values' versus 'Probe Offset' for 'Density', 'Momentum (Magnitude)', and 'StagnationEnergy'.

bin_extents	bin_values	Density_total	ensity_averag	stagnationEnergy
0 -356.259	6	3.83561	0.639268	0
1 -331.695	0	0	0	0
2 -307.131	1	0.63738	0.63738	0
3 -282.567	2	1.27476	0.63738	0
4 -258.003	0	0	0	0
5 -233.439	4	2.55127	0.637817	0
6 -208.875	5	3.14076	0.628152	0
7 -184.311	18	10.2732	0.570734	0
8 -159.747	16	9.8004	0.612525	0
9 -135.183	16	9.83943	0.614964	0
10 -110.619	49	23.1051	0.471532	0

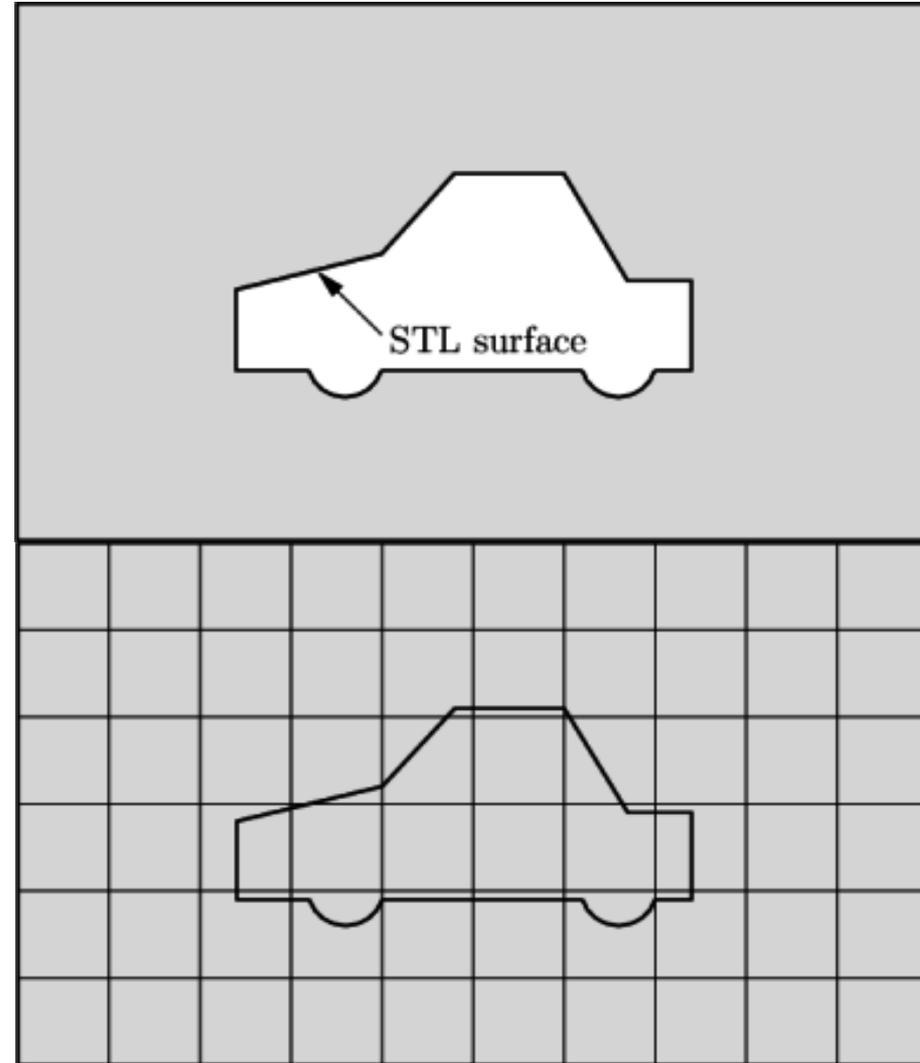
Extract different type of selections.

# asmoCar



# blockMesh

- **Definizione del dominio computazionale;**
- **Definizione del grado di refinement di base;**
- **Decomposizione del dominio in blocchi esaedrici**



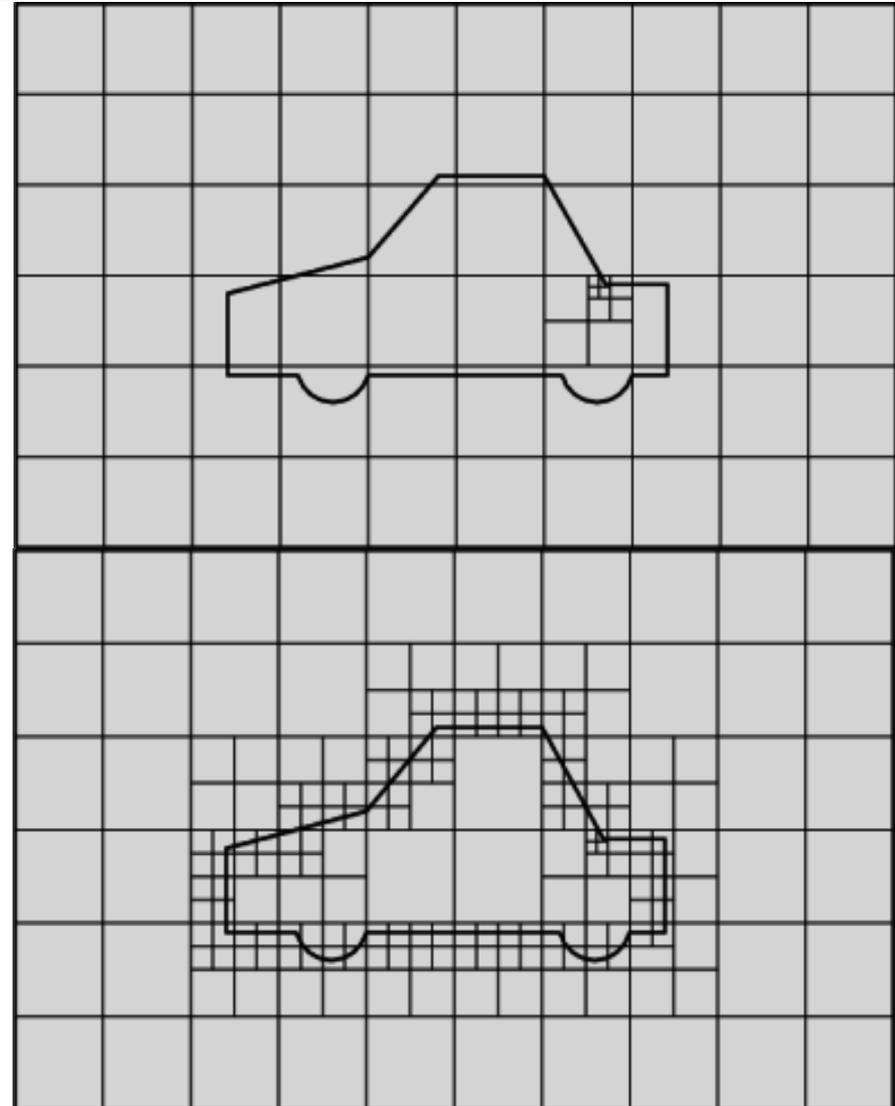
# snappyHexMesh



# CastellatedMesh

- Splitting in corrispondenza delle features;
- Splitting in corrispondenza della superficie;
- Splitting in accordo al livello di refinement:

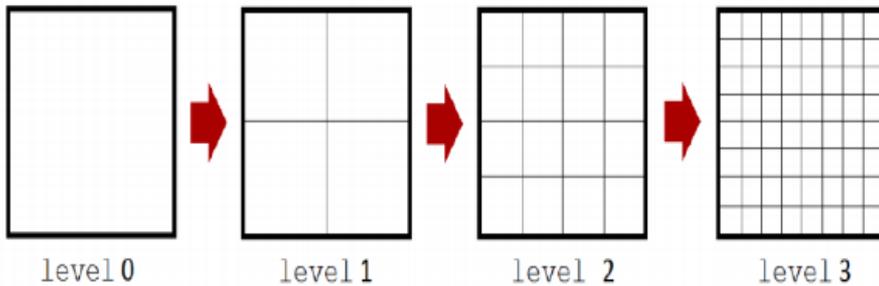
```
refinementSurfaces
{
    asmoCar
    {
        regions
        {
            body
            {
                level ( 4 6 );
            }
        }
    }
}
```



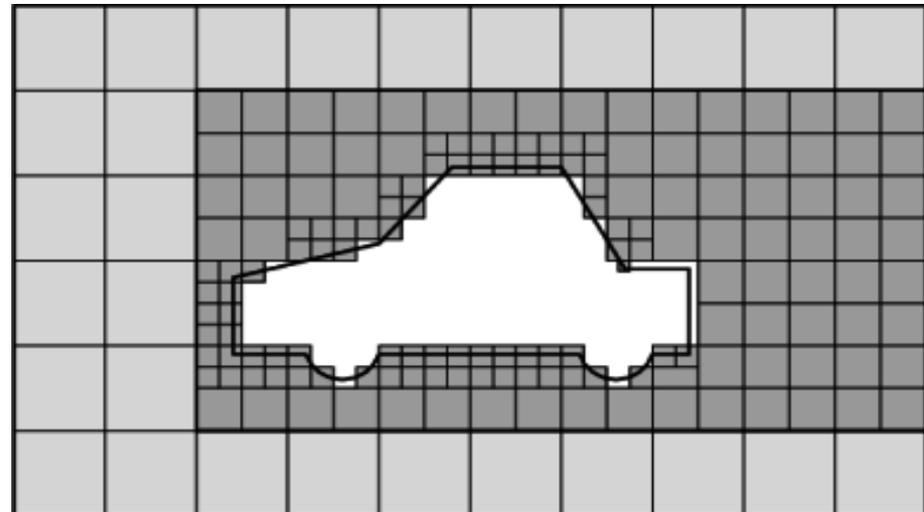
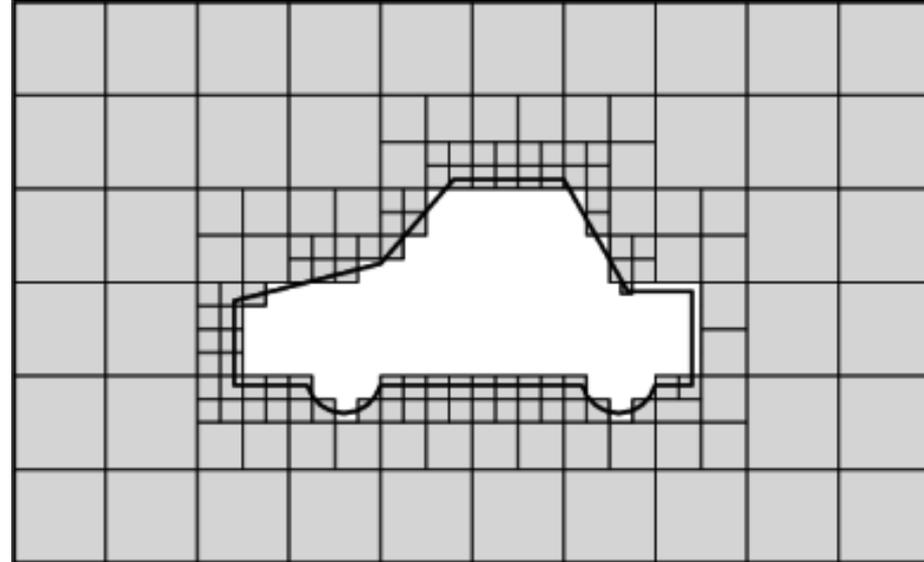
# CastellatedMesh

- Definizione livello di refinement

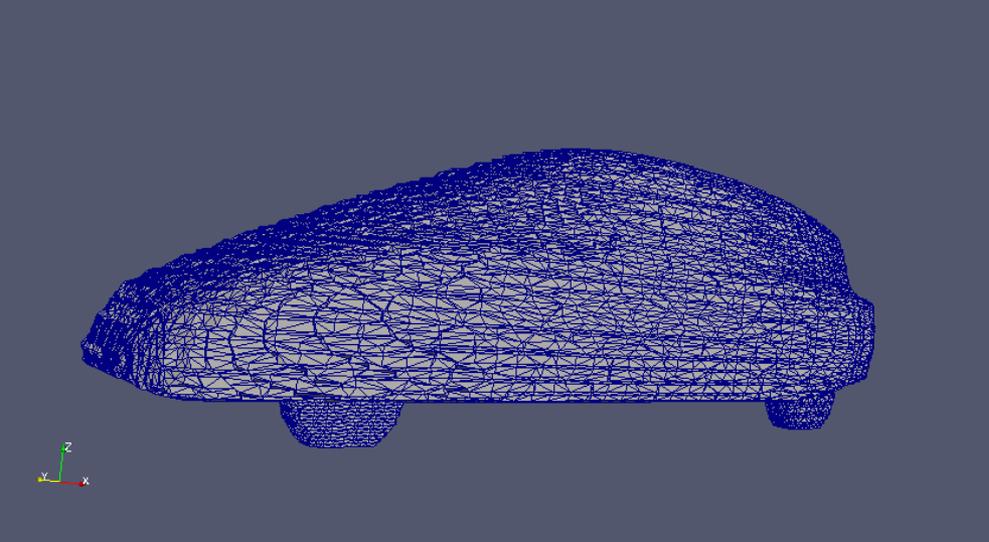
$$\Delta X_n = \frac{\Delta X_0}{2^n}$$



- Removing:** Rimozione delle celle interne;
- Ulteriore splitting** in regione interna.



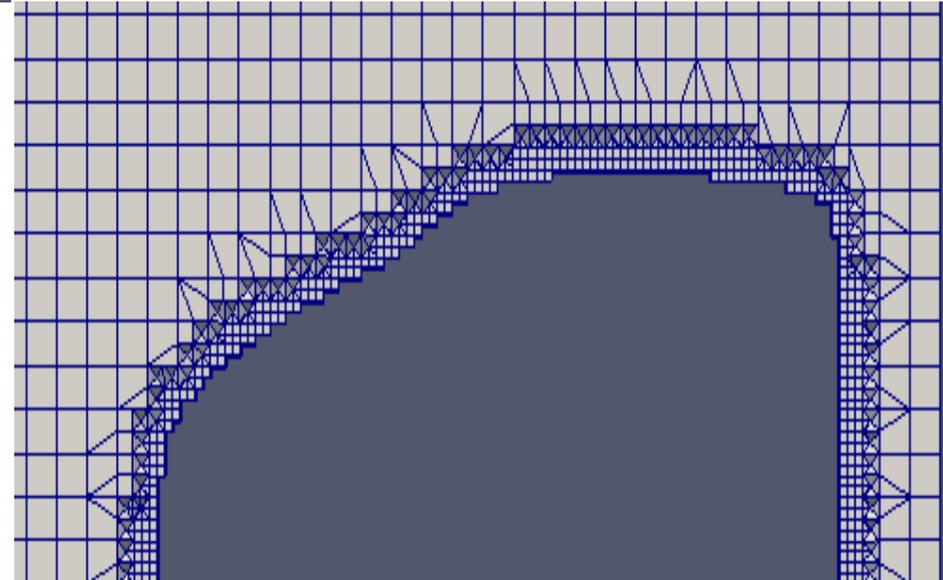
# CastellatedMesh



Vista dell'asmoCar

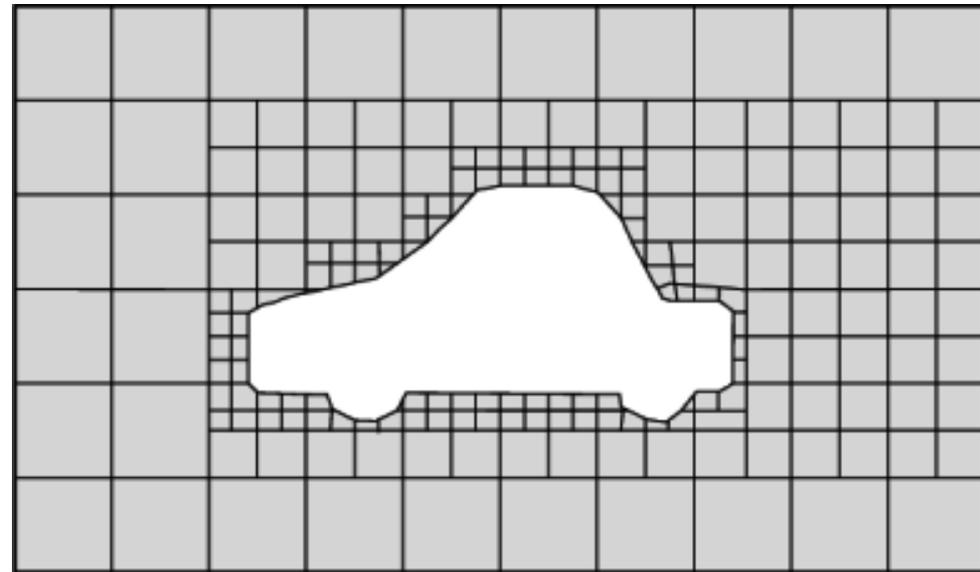


Vista del piano sagittale mediano

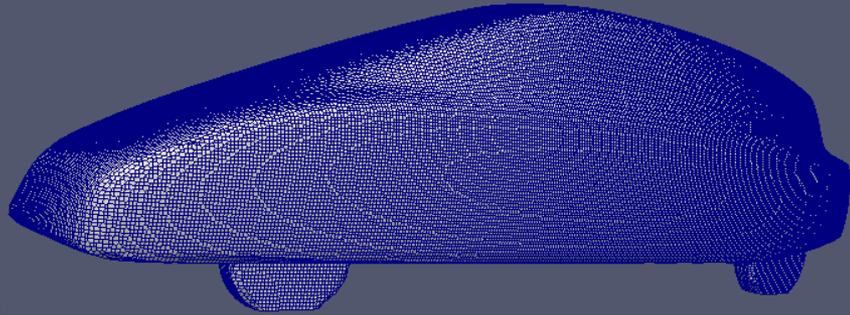


# Snapping

- Spostamento delle celle intersecate dalla superficie geometrica
- Body-fitted Mesh
- Soddisfacimento dei parametri alla voce *MeshQualityControls*:
  - Nel caso cui ciò non avvenga si adotta uno spostamento inferiore;
  - Si attiva un sub-processo iterativo al fine di ottenere una corretta mesh volumetrica.



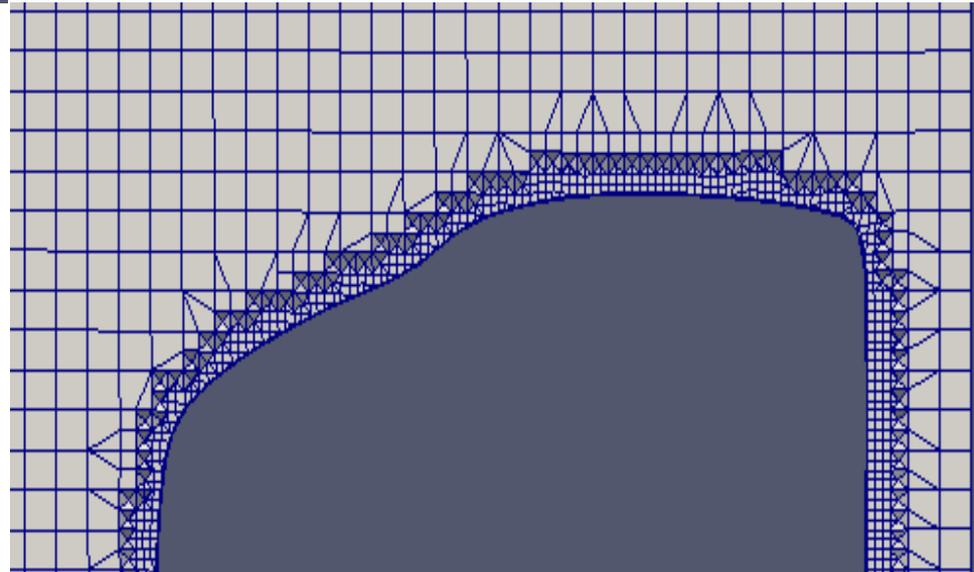
# Snapping



Vista dell' asmoCar



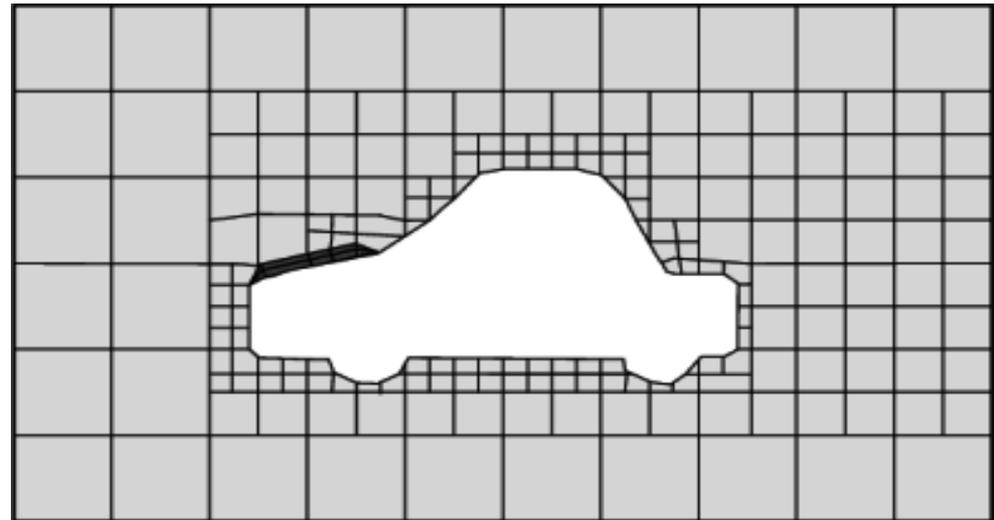
Vista del piano sagittale mediano



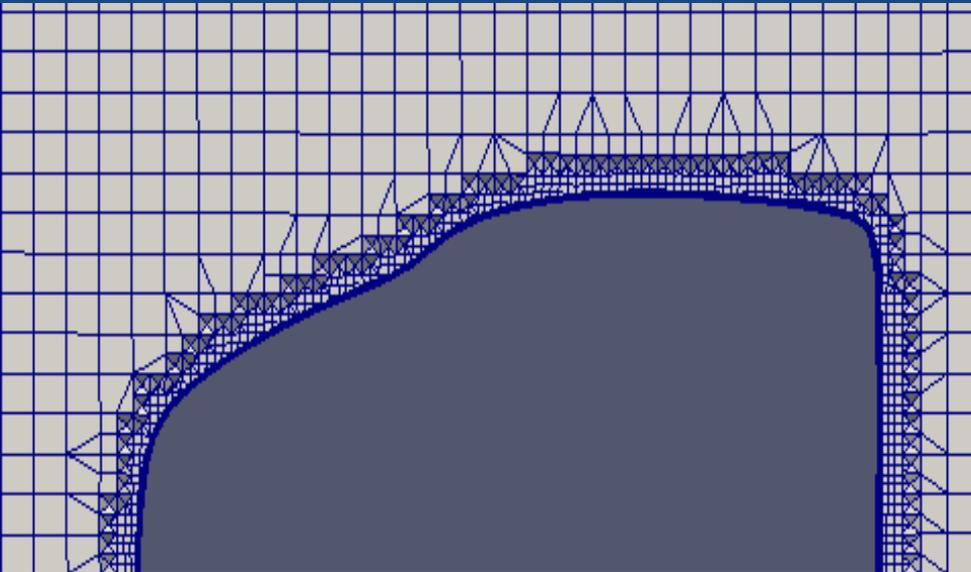
# Aggiunta dei layers

- Sostituzione celle irregolari;
- Migliore risoluzione dello strato limite;
- Processo articolato in più fasi:
  - Proiezione nella direzione normale alla superficie;
  - Processo iterativo: si controllano i dettami di qualità;
  - Eventuale aggiunta dei layers.

```
addLayersControls
{
  layers
  {
    asmoCar_body
    {
      nSurfaceLayers 5;
      relativeSizes true;
      expansionRatio 1.2;
      finalLayerThickness 0.2;
    }
  }
}
```



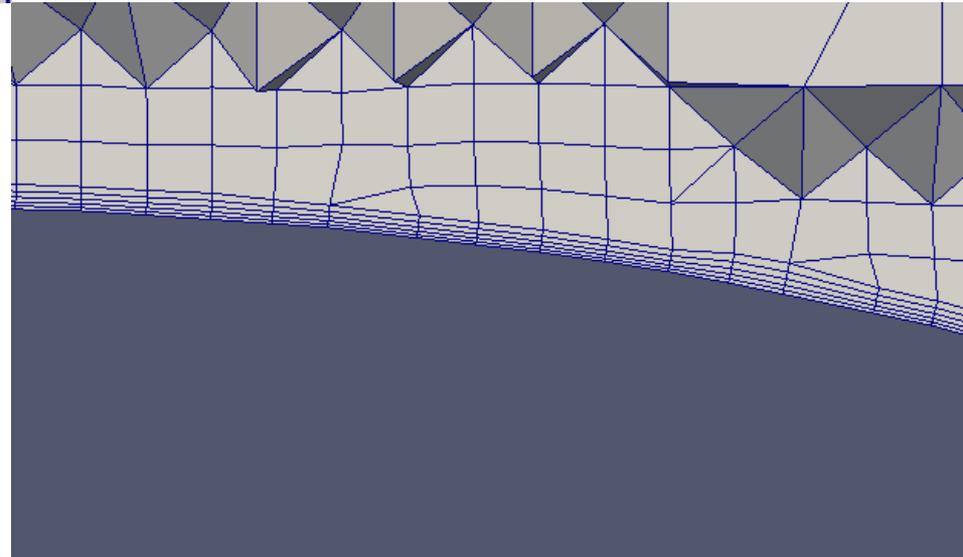
# Aggiunta dei layers



Vista del piano sagittale mediano



Zoom in corrispondenza della  
superficie



# Analisi parametrica

Studio dei principali parametri all'interno dello *snappyHexMeshDict*

Tempo di creazione della mesh,  
normalizzato rispetto al settaggio  
di default.

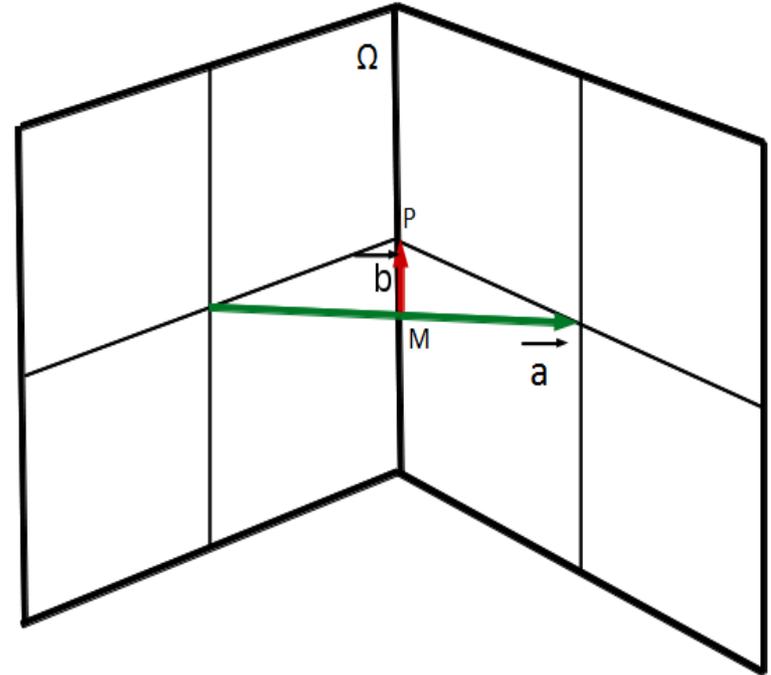
Numero di celle generate;

Grandezze caratteristiche della  
qualità;

# Qualità intrinseca della Mesh

## Skewness

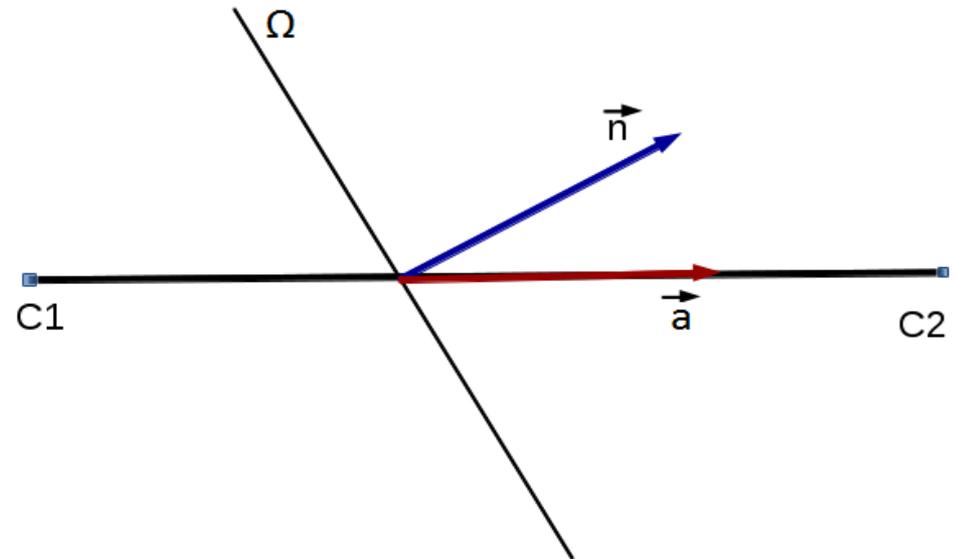
- Valutata come  $\frac{|\vec{b}|}{|\vec{a}|}$
- Massima Skewness settata a 4
- Valori elevati comportano approssimazioni dei flussi ( $\Phi_P \approx \Phi_M$ ) non accettabili.



# Qualità intrinseca della Mesh

## Non-ortogonalità:

- Valore massimo fissato a 65 nell'analisi parametrica;
- Non deve eccedere il valore 90 affinché la stabilità della simulazione sia garantita;
- In analogia alla skewness, valori diversi da 0 implicano approssimazioni dei flussi  $\Phi$  come se  $\Omega$  fosse perpendicolare ad  $\vec{a}$



# Qualità intrinseca della Mesh

## Relaxed Parameters:

- **MaxnonOrthogonality: 75;**
- **MaxinternalSkewness: 6;**
- **MaxboundarySkewness:20**

# Analisi dei risultati: Refinement Parameters

## Ncellsbetweenlevels

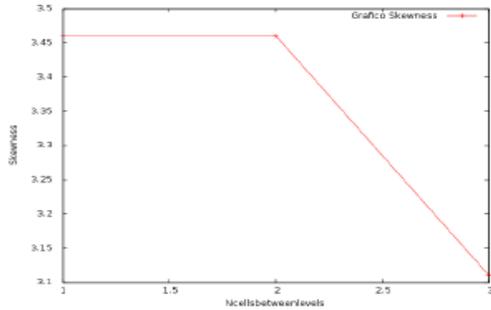


Figure 3.5: Skewness

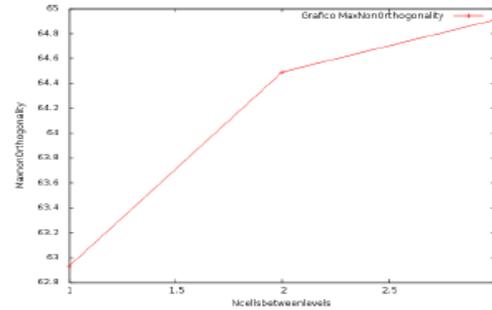


Figure 3.6: MaxnonOrthogonality

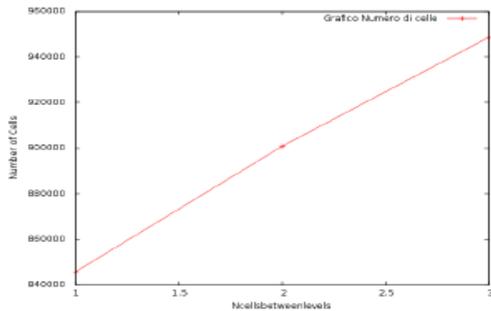


Figure 3.7: Numero di celle

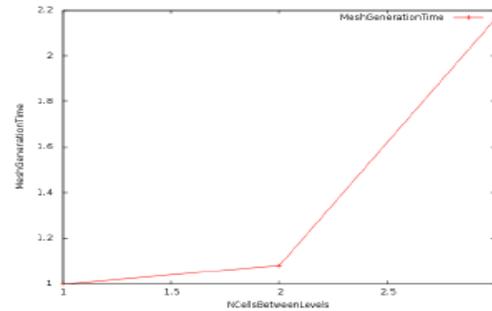
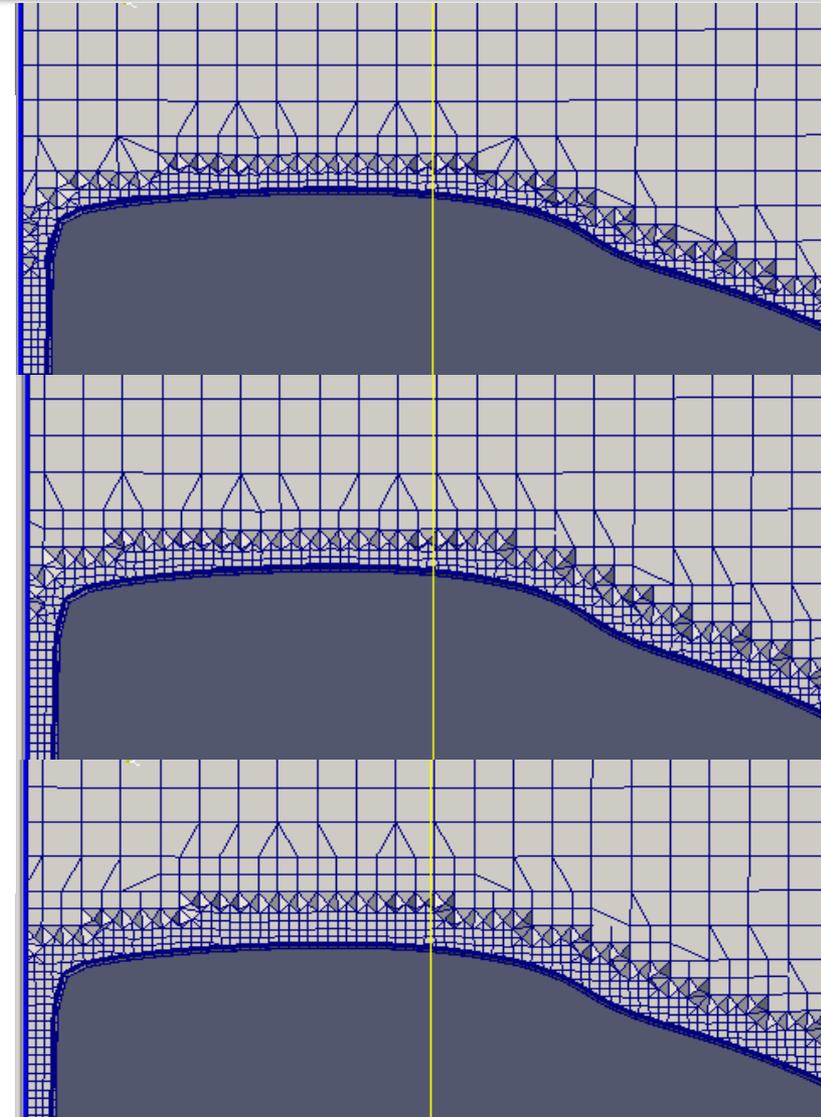


Figure 3.8: Tempo di creazione mesh normalizzato



	MaxnonOrthogonality	Max Skewness	Number of cells	Generation time
1	62.93	3.46	845690	1.00
2	64.49	3.46	900794	1.08
3	64.91	3.11	948569	2.16

Table 4.2: Ncellsbetweenlevels

# Analisi dei risultati: Snap Controls

## ResolveFeatureAngle

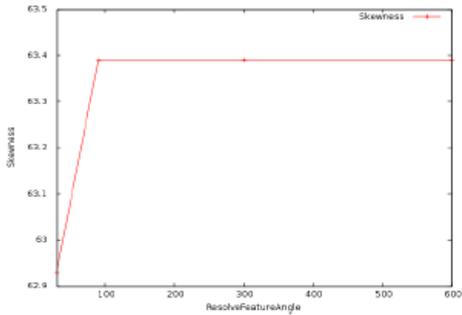


Figure 3.15: Skewness

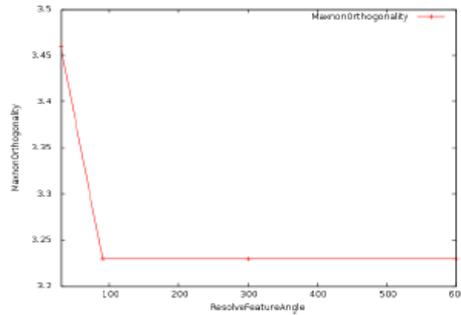


Figure 3.16: MaxnonOrthogonality

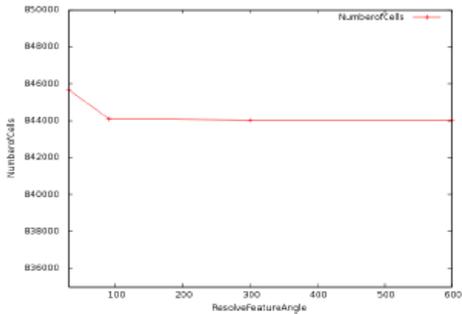


Figure 3.17: Numero di celle

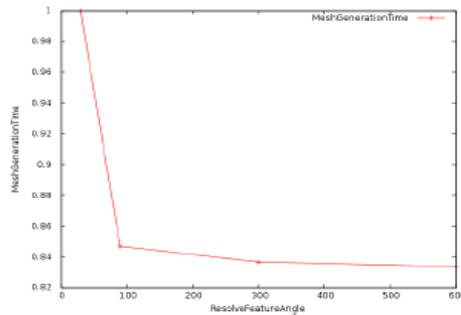
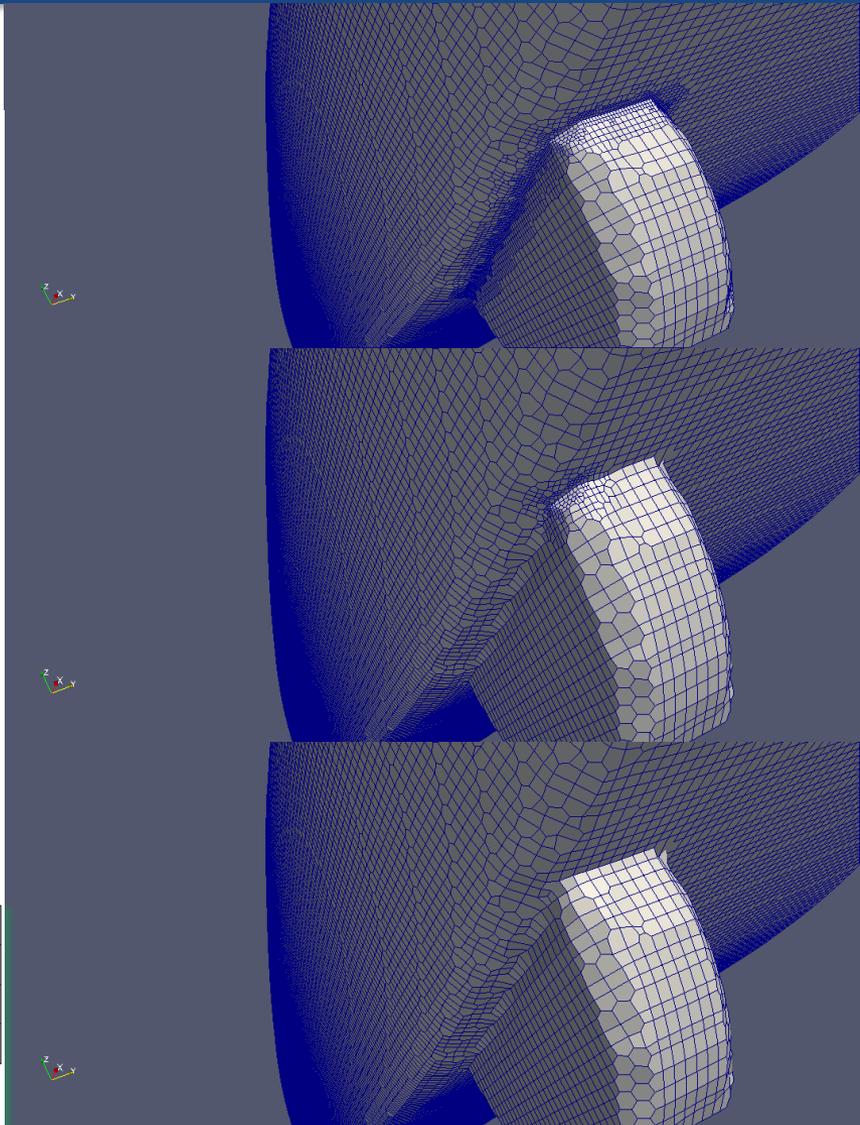


Figure 3.18: Tempo di creazione mesh normalizzato

	MaxnonOrthogonality	Max Skewness	Number of cells	Generation time
30	62.93	3.46	845690	1.00
90	63.39	3.23	844106	0.85
300	63.39	3.23	844029	0.84

Table 4.5: ResolveFeatureAngle



# Analisi dei risultati: Snap Controls

- **NRelaxIter**

	MaxnonOrthogonality	Max Skewness	Number of cells	Generation time
2	62.93	3.47	845670	0.91
5	62.93	3.46	845620	1.00
10	62.93	3.45	845850	1.05

Table 3.8: NRelaxIter

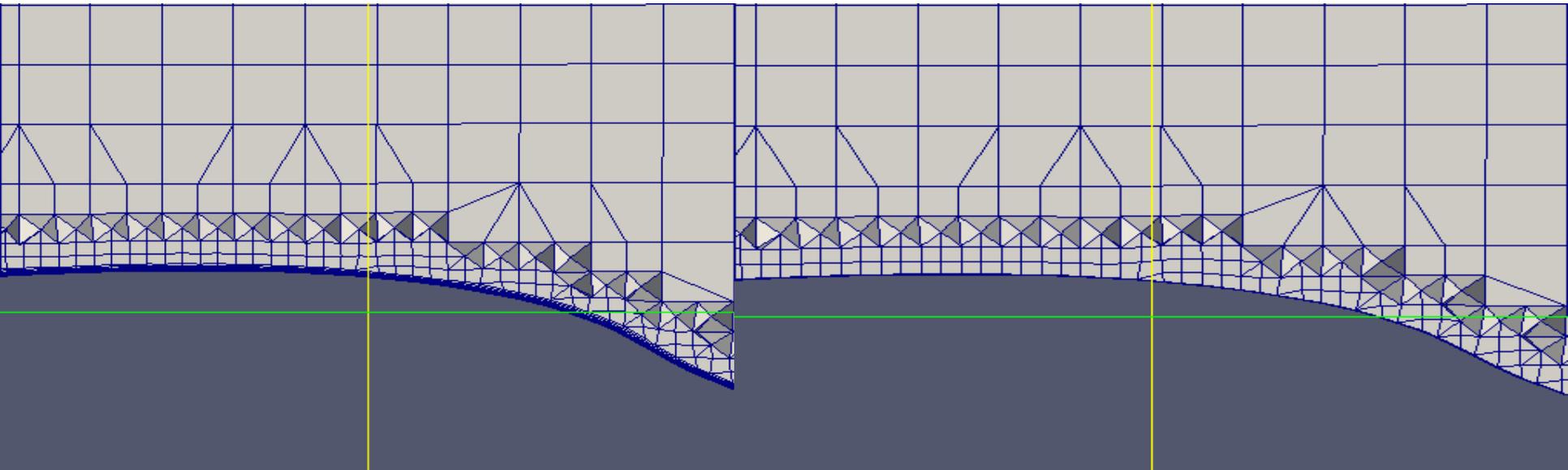
- **NSmoothPatch**

	MaxnonOrthogonality	Max Skewness	Number of cells	Generation time
1	64.08	3.46	845363	0.93
3	62.93	3.46	845620	1.00
5	64.54	3.46	845618	1.02

Table 4.6: NSmoothPatch

# Analisi dei risultati: Feature Snapping

## NGrow



	MaxnonOrthogonality	Max Skewness	Number of cells	Generation time
0	62.93	3.46	845690	1
1	56.82	2.85	564911	1.7805

Table 4.12: NGrow

# Analisi dei risultati: static analysis of starting mesh

## Feature Angle

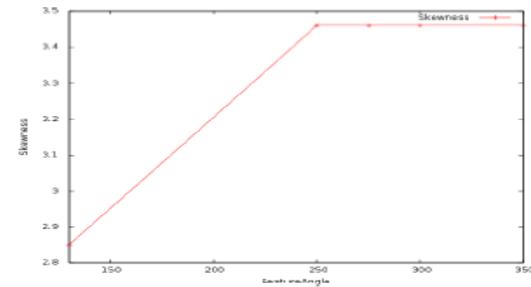


Figure 3.37: Skewness

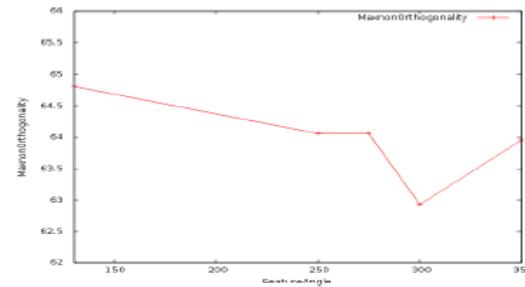


Figure 3.38: MaxnonOrthogonality

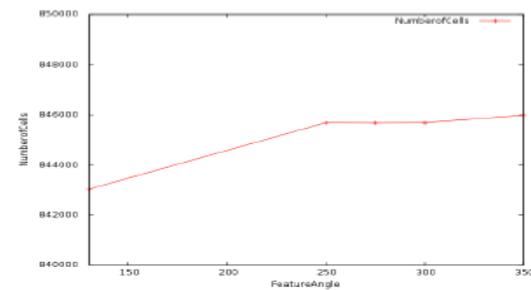


Figure 3.39: Numero di Celle

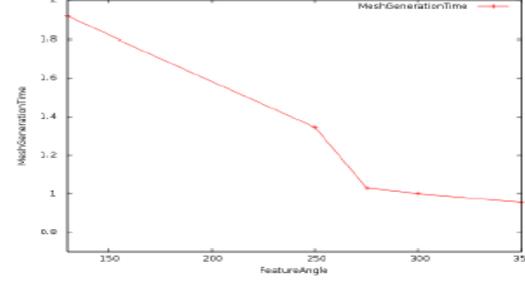
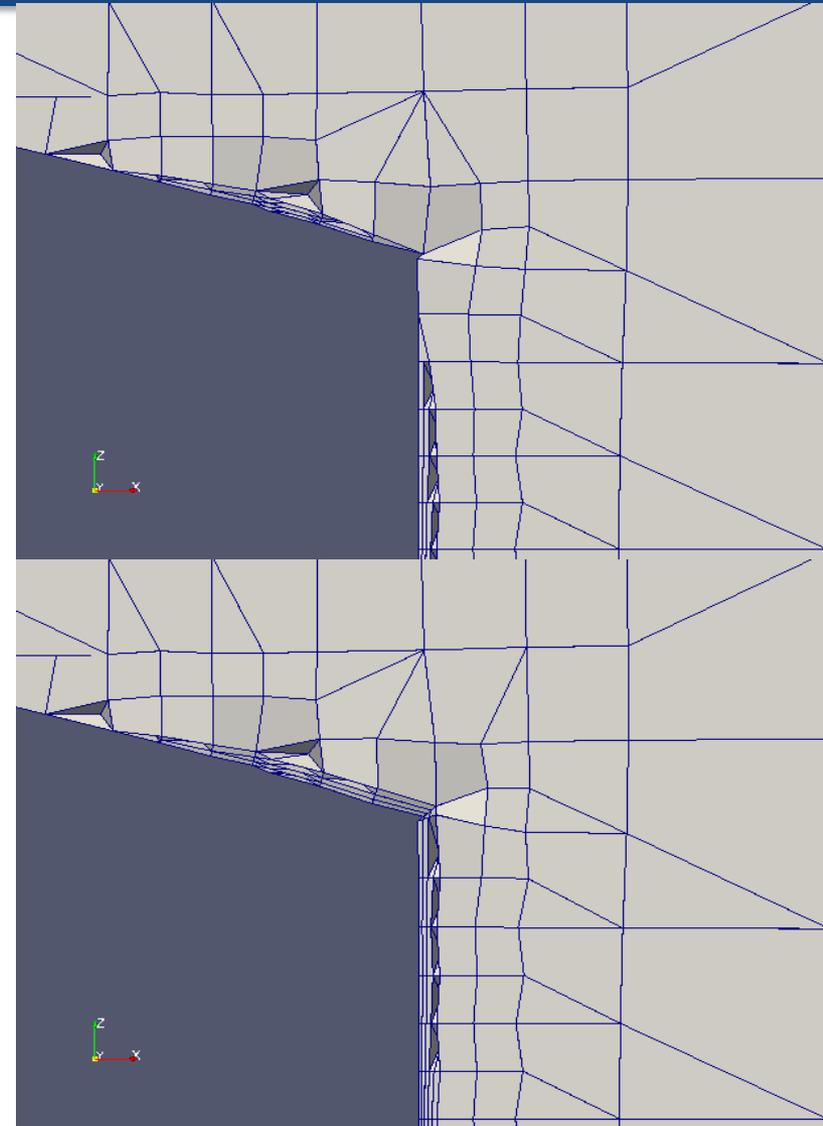


Figure 3.40: Tempo di creazione mesh normalizzato

	MaxnonOrthogonality	Max Skewness	Number of cells	Generation time
130	64.81	2.85	843031	1.92
250	64.06	3.46	845690	1.34
275	64.06	3.46	845684	1.03
300	62.93	3.46	845690	1.00
350	63.96	3.46	845983	0.96

Table 4.13: FeatureAngle



# Analisi dei risultati: Patch displacement

## NSmoothSurfaceNormals

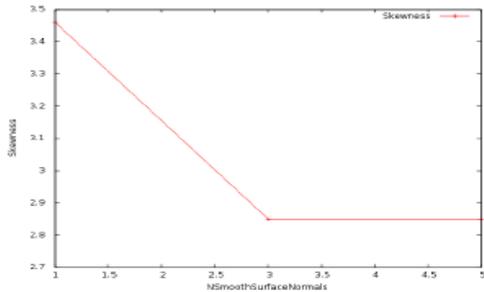


Figure 3.46: Skewness

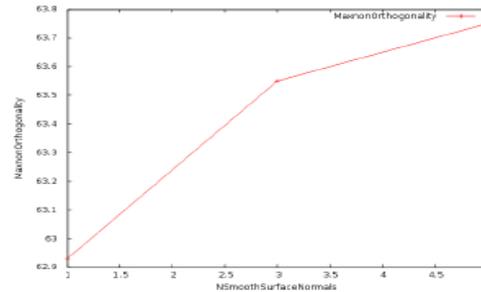


Figure 3.47: MaxnonOrthogonality

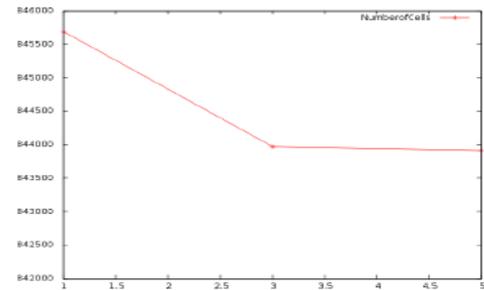


Figure 3.48: Numero di Celle

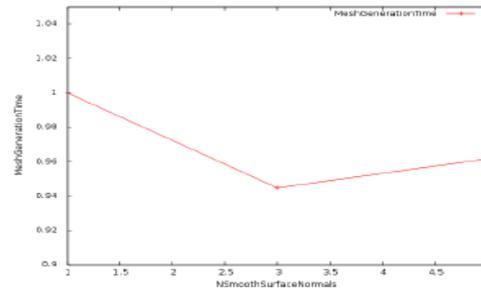
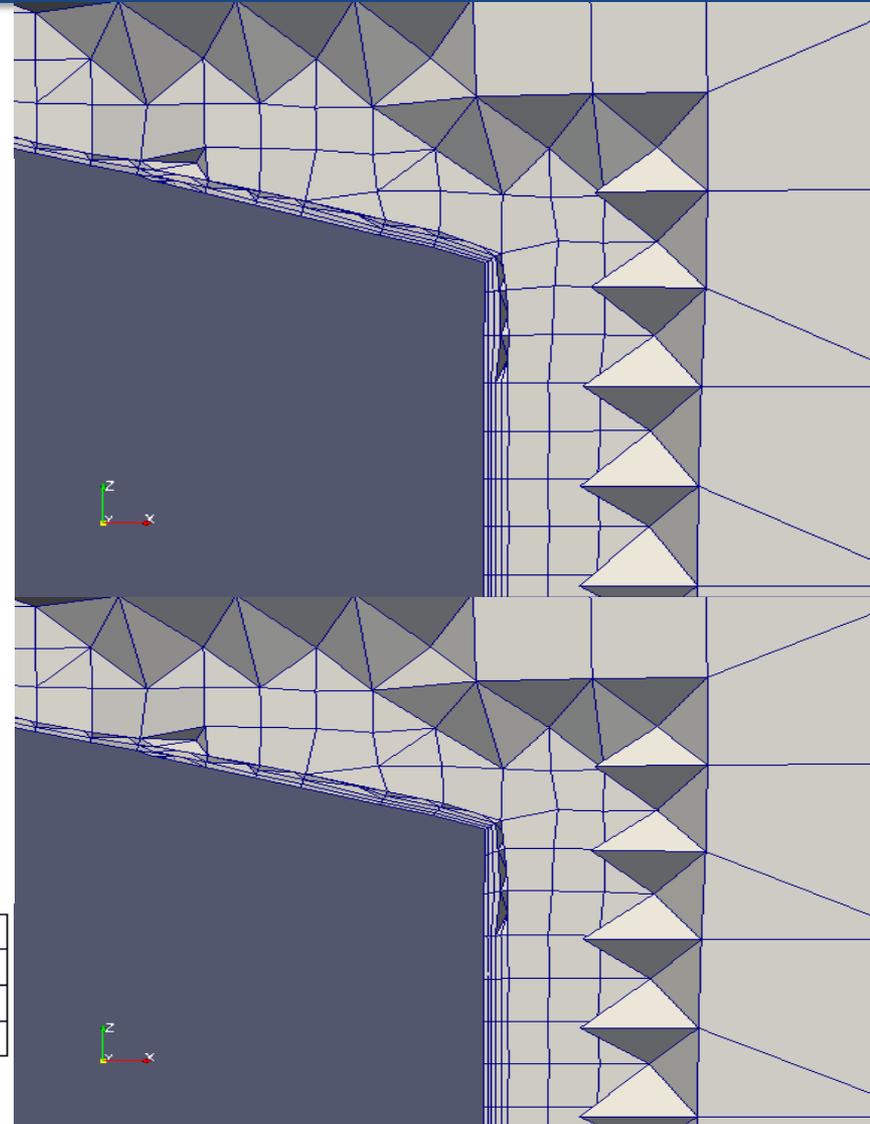


Figure 3.49: Tempo di creazione Mesh normalizzato

	MaxnonOrthogonality	Max Skewness	Number of cells	Generation time
1	62.93	3.46	845690	1.00
5	63.55	2.85	843971	0.95
10	63.75	2.85	843913	0.96

Table 4.15: NSmoothSurfaceNormals



# Analisi dei risultati: Patch displacement

## NSmoothThickness

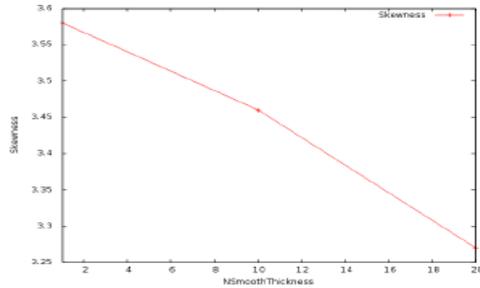


Figure 3.51: Skewness

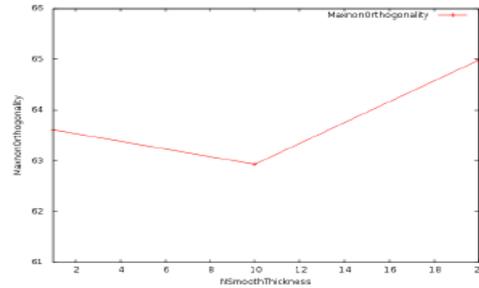


Figure 3.52: MaxnonOrthogonality

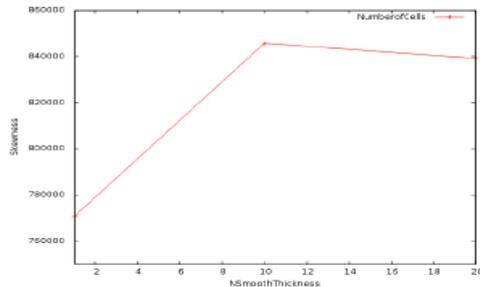


Figure 3.53: Numero di Celle

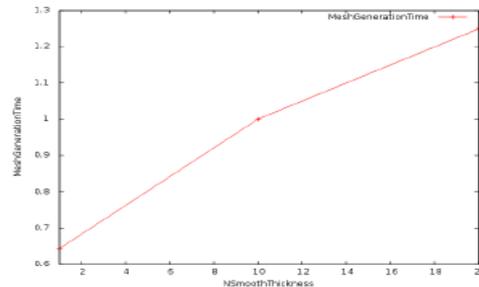
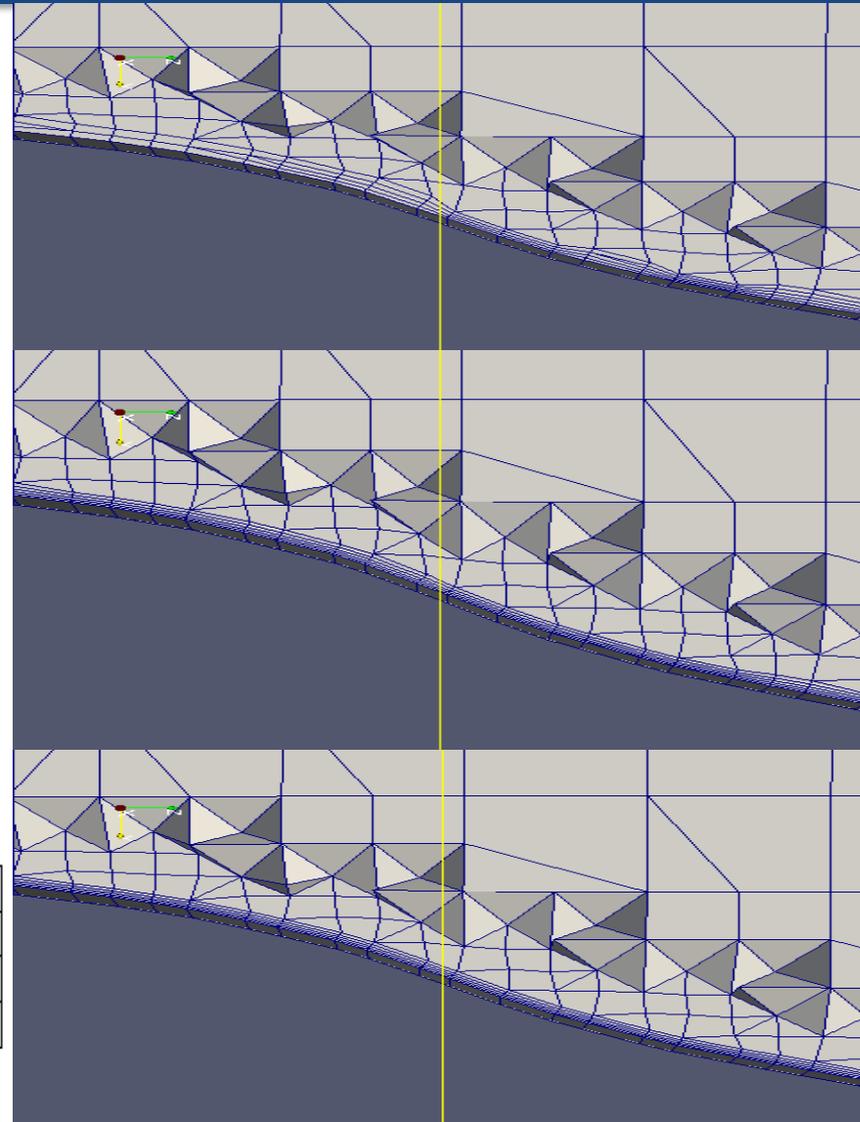


Figure 3.54: Tempo di Creazione Mesh normalizzato

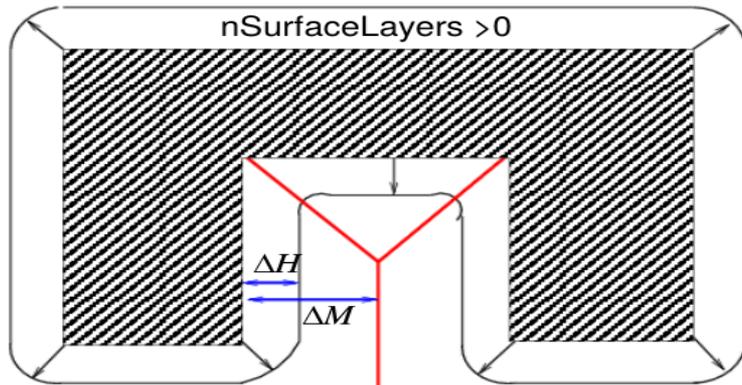


	MaxnonOrthogonality	Max Skewness	Number of cells	Generation time
1	63.61	3.58	770742	0.64
10	62.93	3.46	845690	1.00
20	64.98	3.27	839149	1.25

Table 4.16: NSmoothThickness

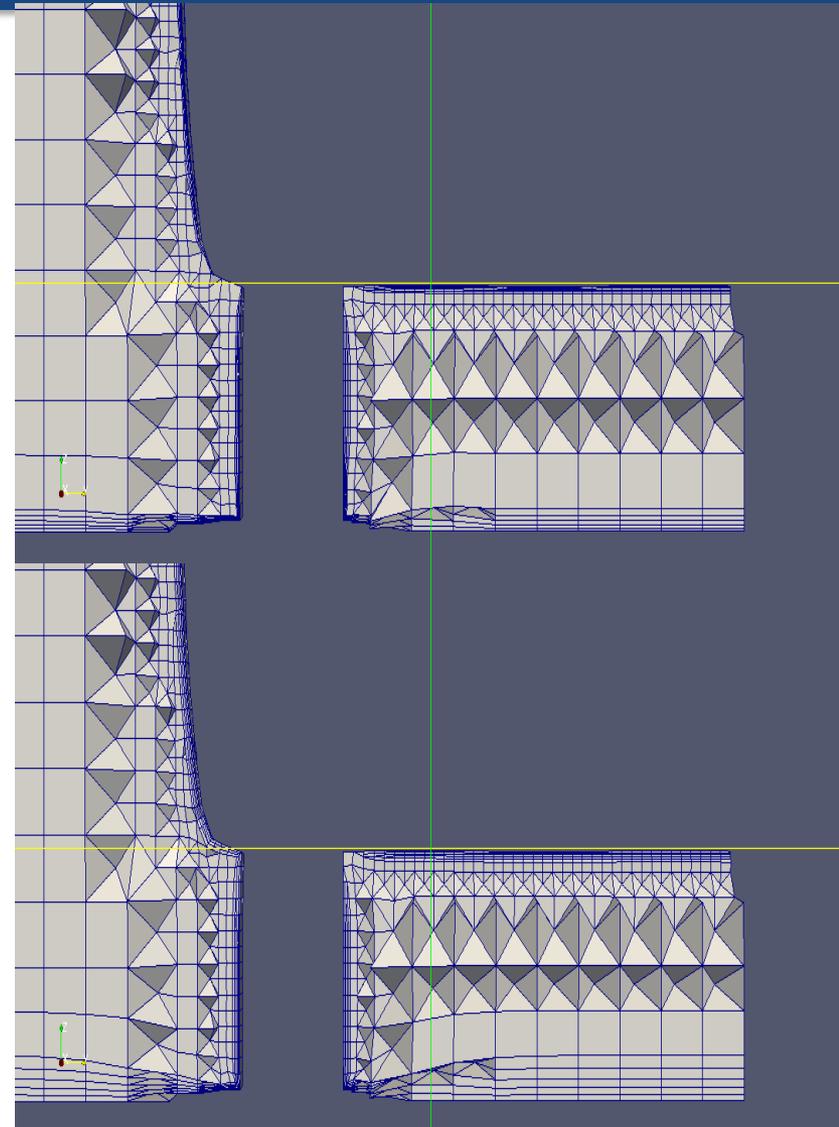
# Analisi dei risultati: Medial Axis Analysis

## MaxThicknessToMedialRatio



— Medial Axis

nSurfaceLayers = 0



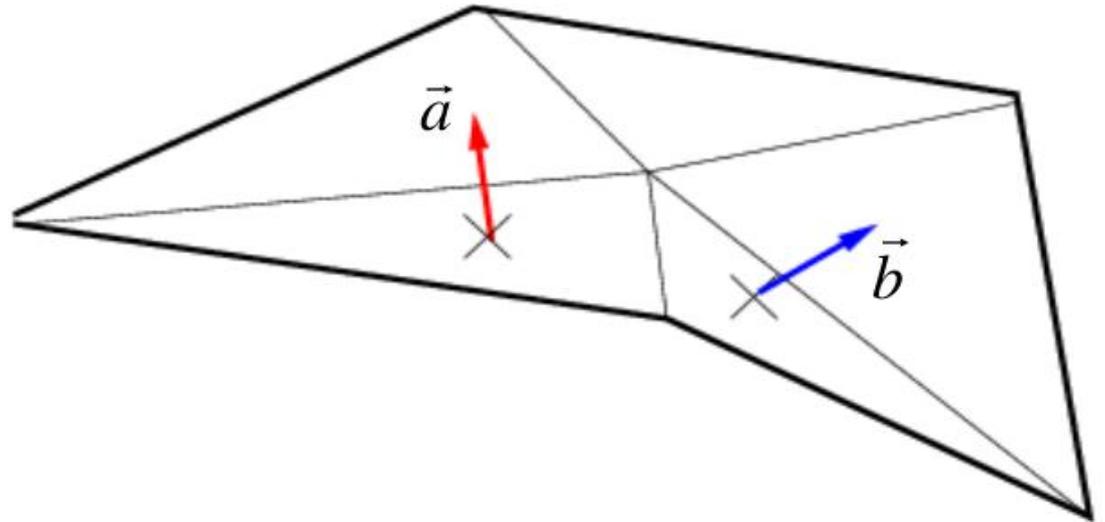
	MaxnonOrthogonality	Max Skewness	Number of cells	Generation time
0.3	62.93	3.46	845620	1.00
0.5	64.6	3.67	864039	1.01
1	62.93	3.46	845690	1.04

Table 3.18: MaxThicknessToMedialRatio

# Analisi dei risultati: Mesh quality controls

## MinTriangleTwist

$$\text{triangletwist} = \frac{\vec{a} \cdot \vec{b}}{|\vec{a}| * |\vec{b}|}$$



	MaxnonOrthogonality	Max Skewness	Number of cells	Generation time
-1	62.93	3.46	845620	1.00
0	64.06	3.46	845684	0.67

Table 3.31: MinTriangleTwist

# Conclusioni

Parametro	Valore selezionato
MinRefinementCells	100
NcellsBetweenLevels	1
MaxLoadUnbalance	0.5
AllowFreeStandingZoneFaces	false
ResolveFeatureAngle	90
NSmoothPatch	3
NSolveIter	30
NRelaxIter	2
NFeatureSnapIter	20
ImplicitFeatureSnap	false
ExplicitFeatureSnap	true
NGrow	0
FeatureAngle	300
MaxFaceThicknessRatio	1

Parametro	Valore selezionato
Nsmoothsurfacenormals	5
NSmoothThickness	20
MinMedianAxisIter	130
MaxThicknessToMedialRatio	0.3
NSmoothNormals	5
NMedialAxisIter	10
NSmoothDisplacement	0
SlipFeatureAngle	20
NRelaxIter	5
NBufferCellsNoExtrude	0
NLayerIter	50
NRelaxedIter	10
MinDeterminant	0.001
MinTriangleTwist	-1.0

# Conclusioni

- **Migliorie in termini di skewness:**

- **FeatureAngle:** per un valore pari a 130;
- **NSmoothSurfaceNormals:** per un valore pari a 5;

Si ottiene una skewness pari a 2.85.

- **NonOrtogonalità:**

Il valore inferiore risulta 62.93 in corrispondenza dei settaggi di default;

- **Tempo di creazione:**

- **NRelaxIter:** Per il valore 2 riduzione del 9%;
- **Resolve Feature Angle:** Per il valore 90 riduzione del 15%;
- **NFeatureSnapIter:** Per il valore 5 riduzione del 13%;
- **NMedialAxisIter:** Per il valore 10 riduzione del 17%.

- **Numero di celle:**

- **Ncellsbetweenlevels:** da 850000 a 900000 a 950000 rispettivamente per i valori 1,2 e 3.
- **Ngrow:** 565000 celle per il valore 1
- **Nsmooththickness:** 770000 per il valore 1.

# Sviluppi futuri

- **Analisi parametrica al variare di più valori in contemporanea;**
- **Parallel computing;**
- **Confronto con altri generatori di mesh Open-Source:**
  - **cfMesh**
  - **enGrid**
  - **Netgen**
  - **Salome**
  - **GMSH**
  - **MeshKIT**

Grazie per l'attenzione