

TOR VERGATA



UNIVERSITÀ  
DEGLI STUDI  
DI ROMA



# METODI DI OTTIMIZZAZIONE DI FLUSSI ESTERNI ED INTERNI MEDIANTE CFD ADJOINT E MESH MORPHING

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CORRELATORE: ING. C. GROTH



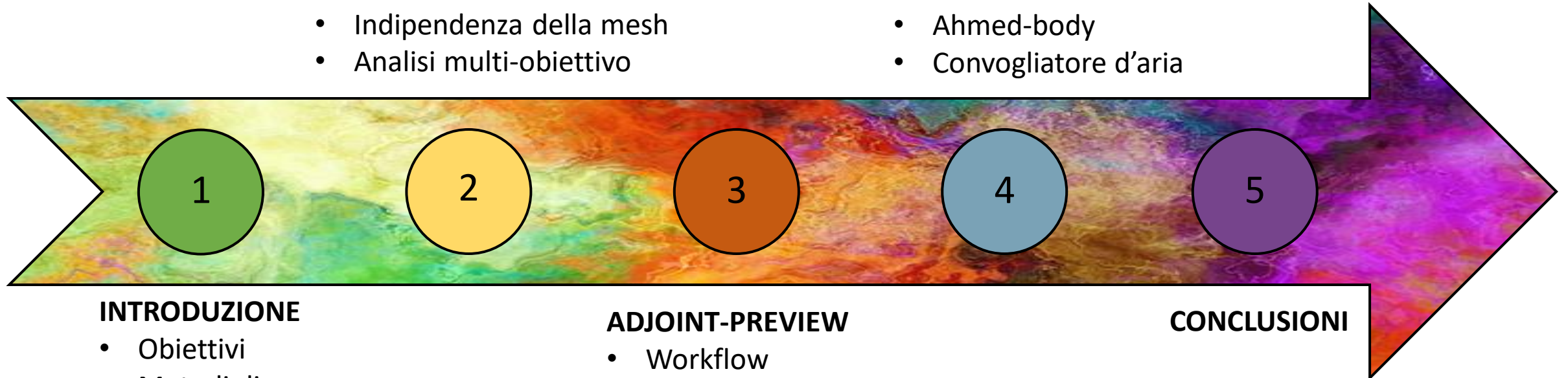
Ansys

## ADJOINT-SCULPTING

- Workflow
- Indipendenza della mesh
- Analisi multi-obiettivo

## APPLICAZIONI

- Ahmed-body
- Convogliatore d'aria



## INTRODUZIONE

- Obiettivi
- Metodi di ottimizzazione
- Adjoint
- Mesh morphing
- Programmi usati

## ADJOINT-PREVIEW

- Workflow
- Script automatico

## CONCLUSIONI

# OBIETTIVI:

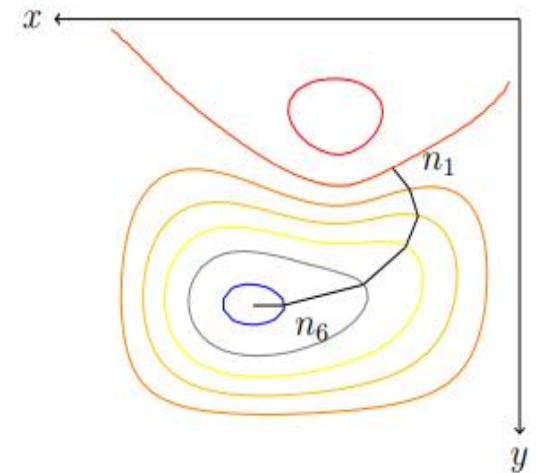
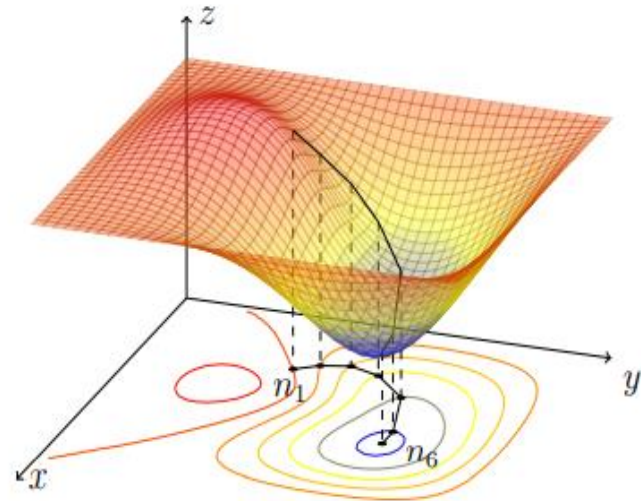
- Sviluppare metodi di ottimizzazione basati su CFD adjoint e mesh morphing
  - Flusso di lavoro di adjoint-sculpting
  - Flusso di lavoro di adjoint-preview
- Sviluppare script per automatizzare i workflow
- Applicazione su casi di interesse industriale

# METODO DI OTTIMIZZAZIONE DI DISCESA DEL GRADIENTE

$$x_i = x_{i-1} + k\delta_{i-1}$$

$$\delta = -\nabla f(x) = -\left[\frac{\partial f}{\partial x_1} \cdots \frac{\partial f}{\partial x_n}\right]^T$$

$$\delta = -\frac{\nabla f(x)}{\|\nabla f(x)\|}$$



## ADJOINT

$$f = f(x, \alpha) \rightarrow \delta f_i = \frac{\partial f_i}{\partial x_j} \delta x_j + \frac{\partial f_i}{\partial \alpha_k} \delta \alpha_k$$

$$\delta R = \left[ \frac{\partial R}{\partial x} \right] \delta x + \left[ \frac{\partial R}{\partial \alpha} \right] \delta \alpha = 0$$

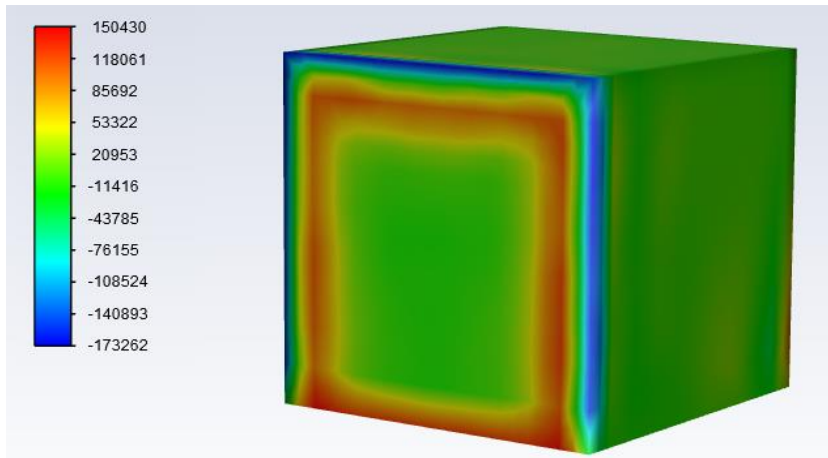
$$\delta f = \left[ \frac{\partial f^T}{\partial x} - \lambda^T \frac{\partial R}{\partial x} \right] \delta x + \left[ \frac{\partial f^T}{\partial \alpha} - \lambda^T \frac{\partial R}{\partial \alpha} \right] \delta \alpha$$

↓

**PROBLEMA AGGIUNTO:**  $\left[ \frac{\partial R}{\partial x} \right]^T \lambda = \frac{\partial f^T}{\partial x}$

↓

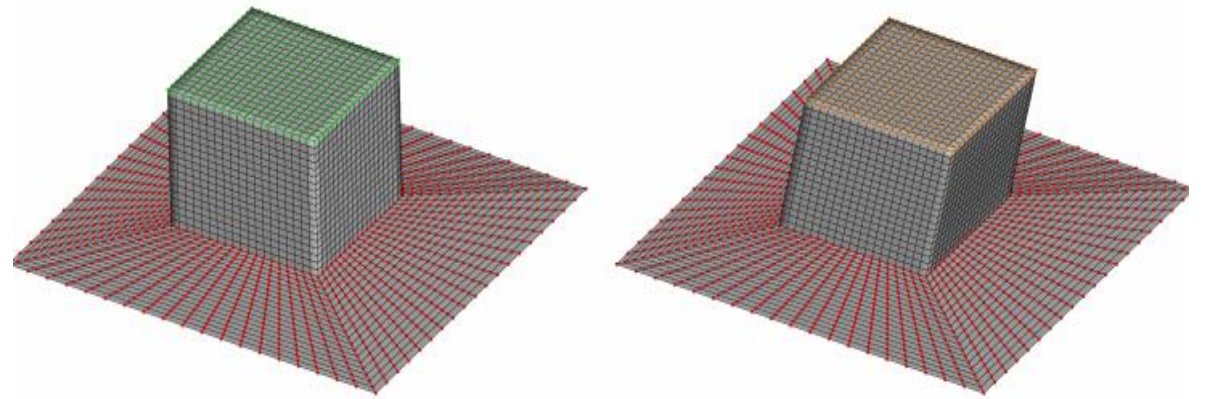
$$\delta f = G \delta \alpha, \quad \text{con } G = \frac{\partial f^T}{\partial \alpha} - \lambda^T \frac{\partial R}{\partial \alpha}$$



Mapa di sensibilità di forma

## MESH MORPHING

### RBF (Radial Basis Function)



$$\begin{aligned}
 f^x(x) &= \sum_{i=1}^m \gamma_i^x \phi(\|c_i - x\|) + \beta_1^x + \beta_2^x x_1 + \beta_3^x x_2 + \beta_4^x x_3 \\
 f^y(x) &= \sum_{i=1}^m \gamma_i^y \phi(\|c_i - x\|) + \beta_1^y + \beta_2^y x_1 + \beta_3^y x_2 + \beta_4^y x_3 \\
 f^z(x) &= \sum_{i=1}^m \gamma_i^z \phi(\|c_i - x\|) + \beta_1^z + \beta_2^z x_1 + \beta_3^z x_2 + \beta_4^z x_3
 \end{aligned}$$

Peso e funzione radiale

Termine polinomiale

$$\begin{aligned}
 \begin{bmatrix} M & P \\ P^T & 0 \end{bmatrix} \begin{Bmatrix} \gamma \\ \beta \end{Bmatrix} &= \begin{Bmatrix} g \\ 0 \end{Bmatrix} \\
 \text{Con } M &= \phi(\|c_i - c_j\|) \\
 P_j &= [1 \ x_1 \ x_2 \ \dots \ x_n]
 \end{aligned}$$

Condizioni al contorno

### VANTAGGI MESH MORPHING

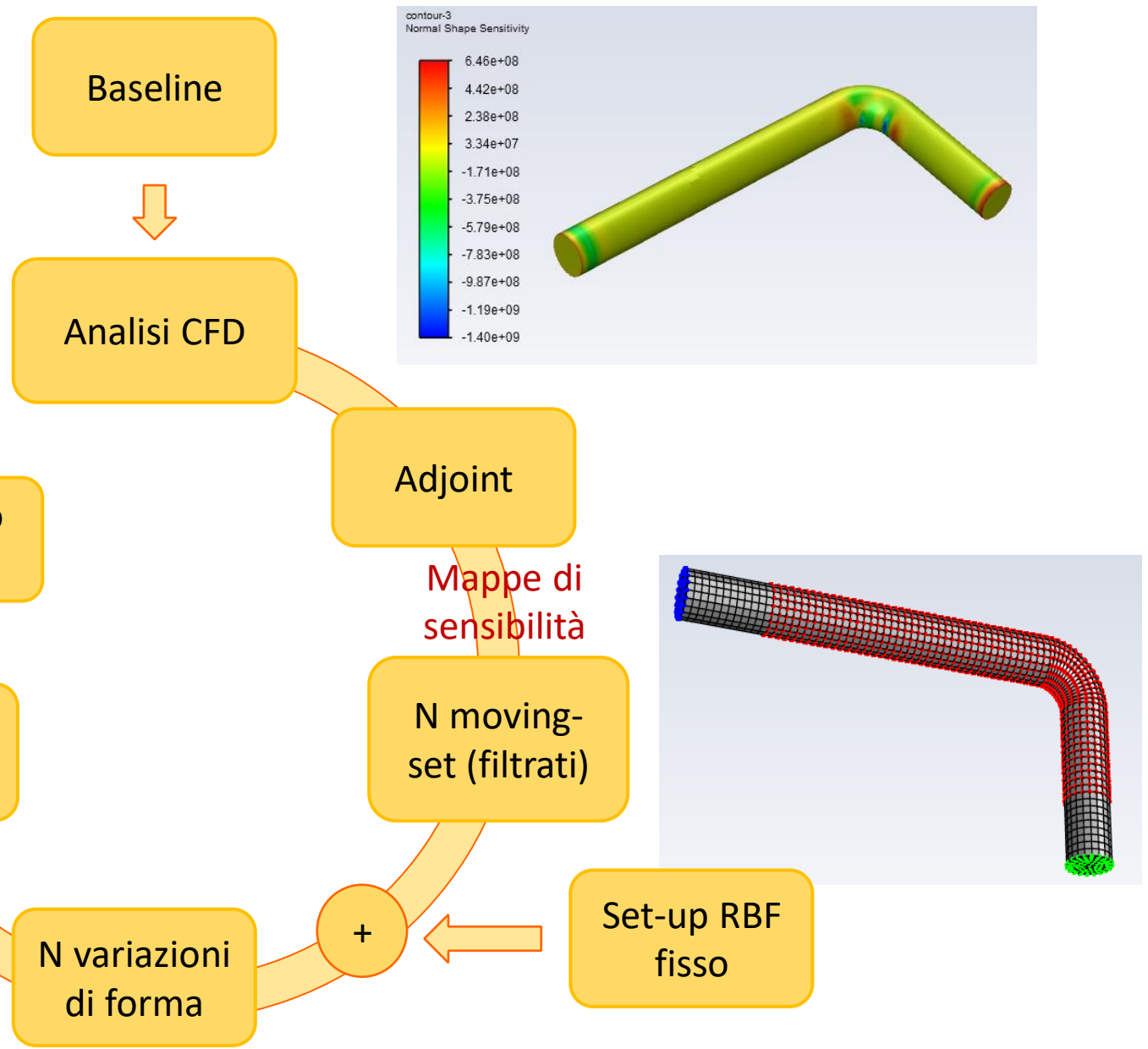
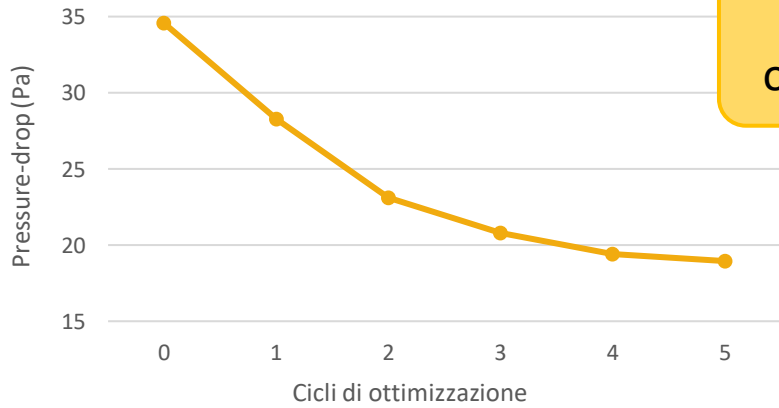
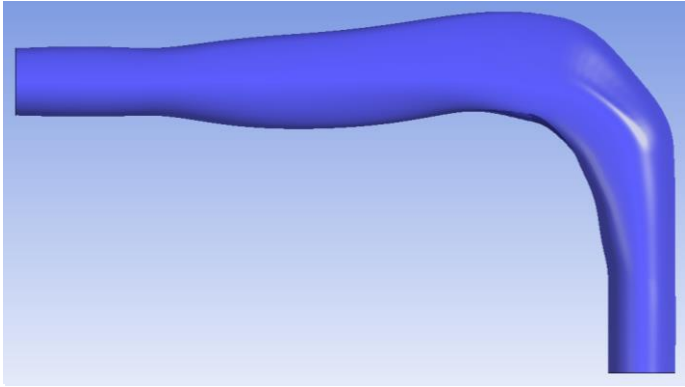
- Facile e veloce
- Metodo mesh-less
- Elevata espressività
- No rumore re-meshing
- Topologia inalterata



# PROGRAMMI USATI

- ANALISI CFD ▶  Fluent
- ANALISI ADJOINT ▶  Fluent
- MESH MORPHING ▶  

# FLUSSO DI LAVORO





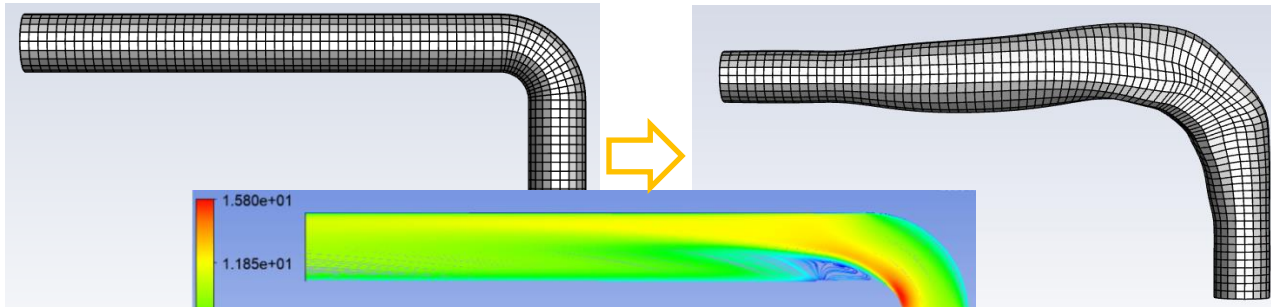
## 2. ADJOINT-SCULPTING

# MESH-LESS

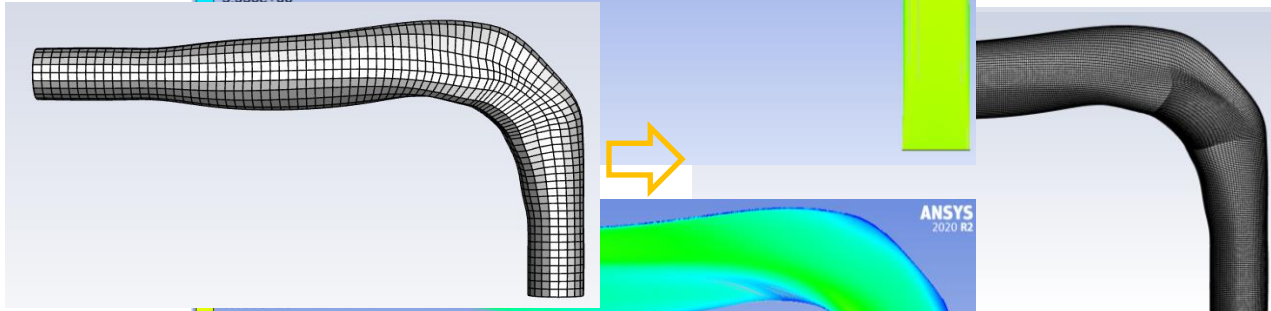
	Rada	Fitta
CFD	44s	1216s
Adjoint	72s	/

	Rada	Fitta
Numero nodi	13741	544353
Numero celle	12600	522480
Min. Ort. Qual.	0,9396	0,9023

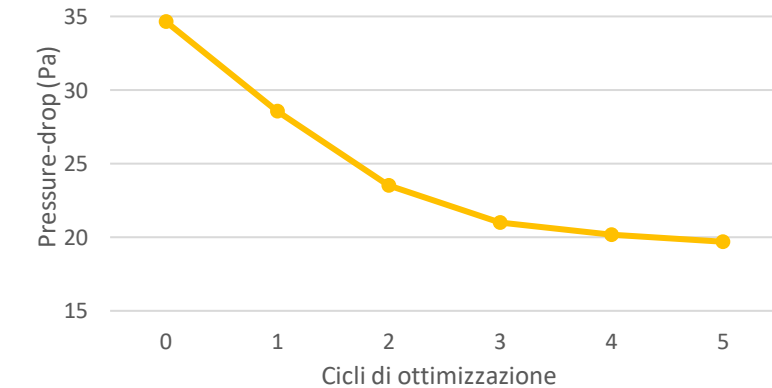
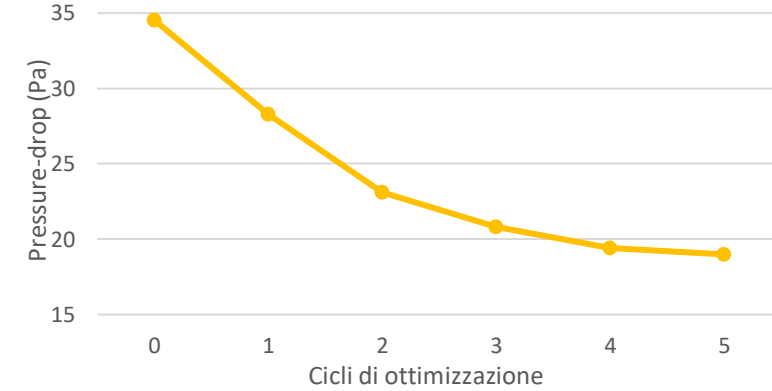
1. Flusso di lavoro implementato su mesh rada



2. RBF sono mesh-less → Spostamenti mappati su mesh fitta

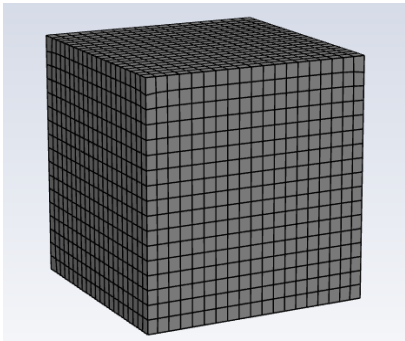


3. Risultati valutati su mesh fitta

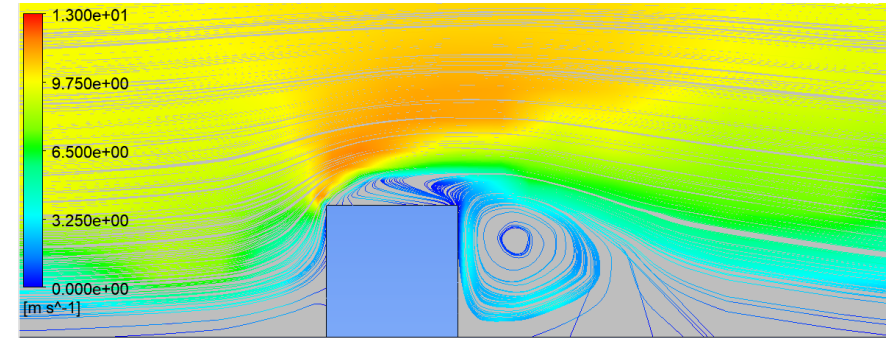
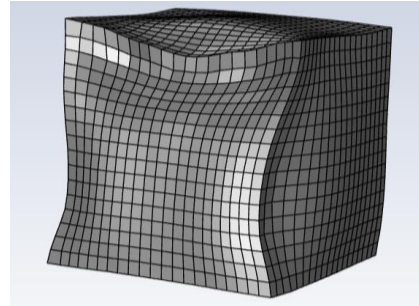


	Rada	Fitta
Pressure-drop	-47,5%	-46,5%

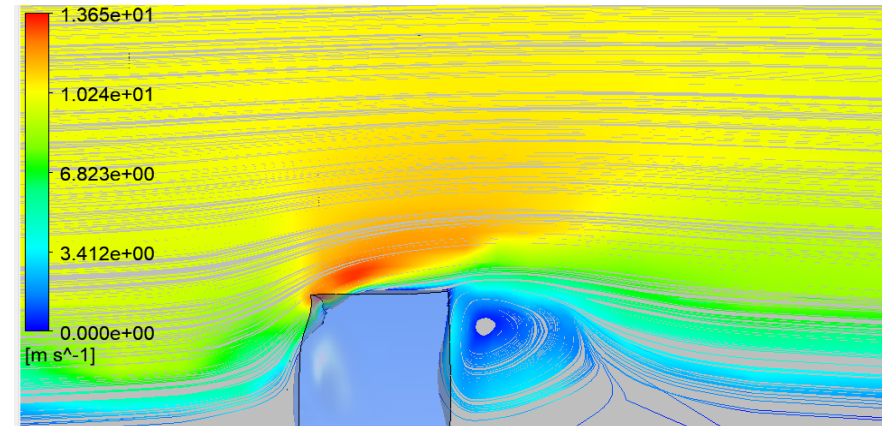
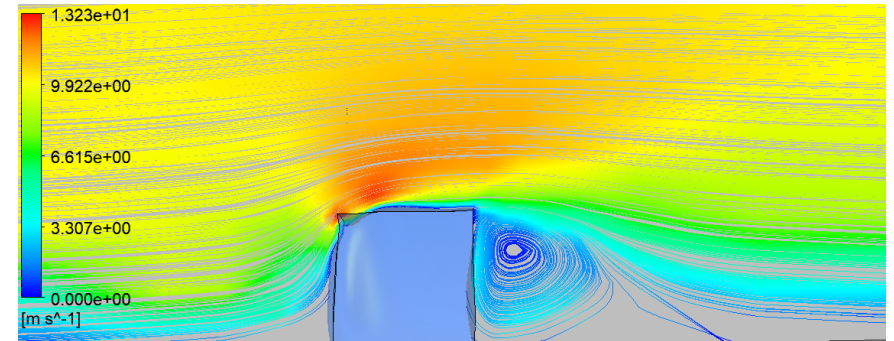
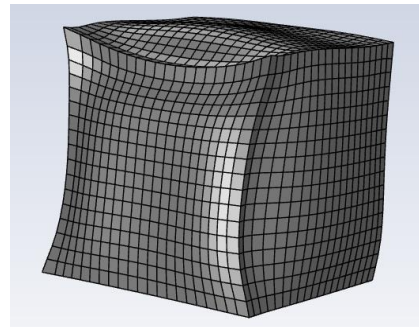
# ANALISI MULTI-OBIETTIVO



- 2 Osservabili
- 2 Calcoli adjoint
- 2 Soluzioni RBF
- > Controllo su ogni osservabile



- 1 Osservabile (sum)
- 1 Calcolo adjoint
- 1 Soluzione RBF
- < Controllo su ogni osservabile

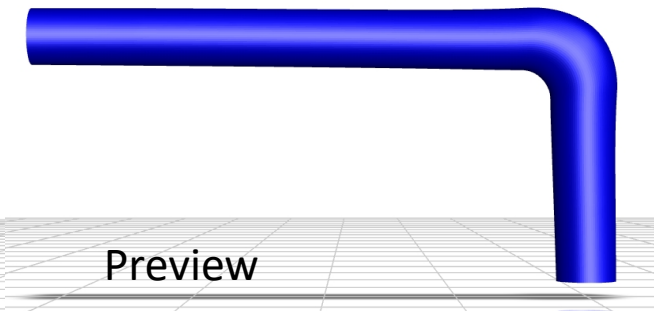
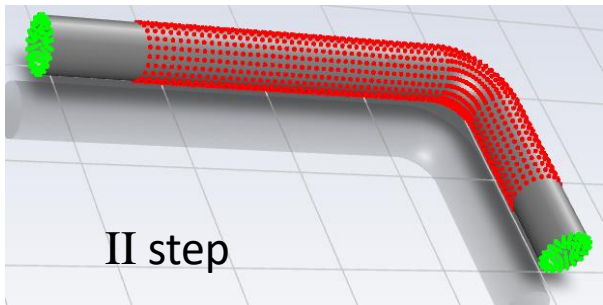
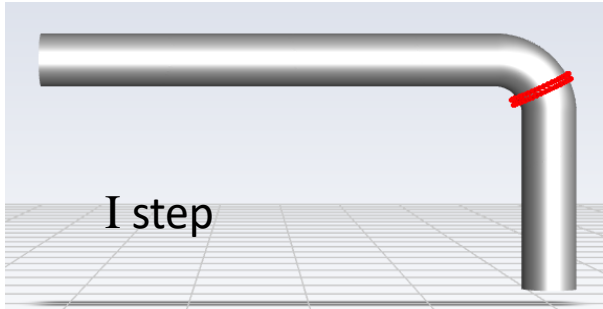


	A-S Sum	A-S 2 Oss.
Drag	-35,7%	-34,5%
Lift	-23%	-35,9%

### 3. ADJOINT-PREVIEW

- ✓ Mesh-less
- ✓ Analisi multi-obiettivo

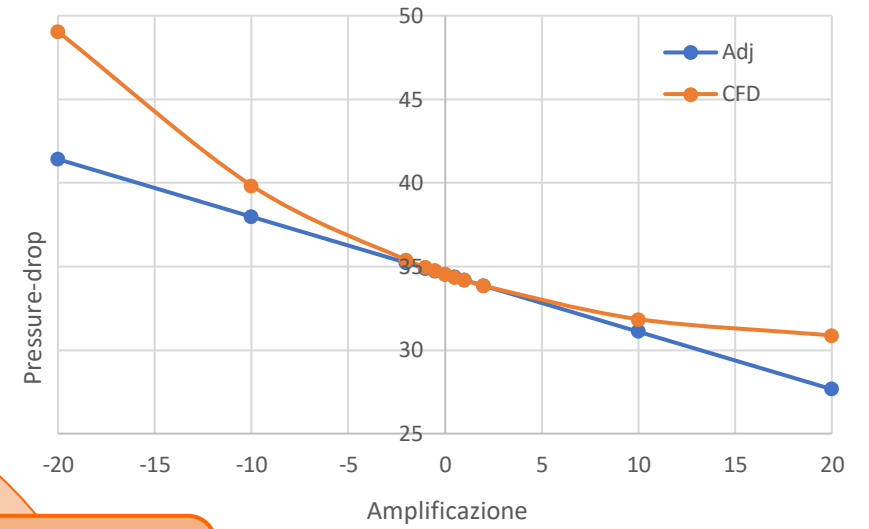
# FLUSSO DI LAVORO



Baseline



Analisi CFD



Aggiornamento mesh

Algoritmo di ottimizzazione

N·M  
variazioni di  
osservabile

$$\frac{\delta \Psi}{\delta a} = \frac{\delta \Psi}{\delta x} \cdot \frac{\delta x}{\delta a}$$

Adjoint

N mappe di  
sensibilità

M variazioni  
di forma

x

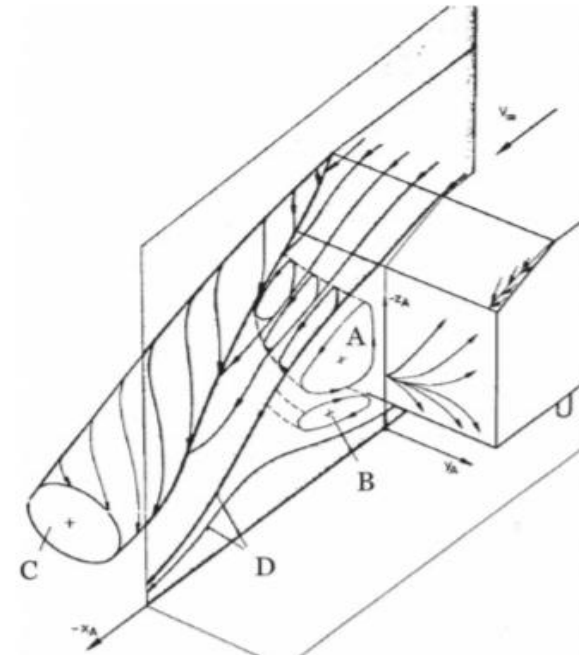
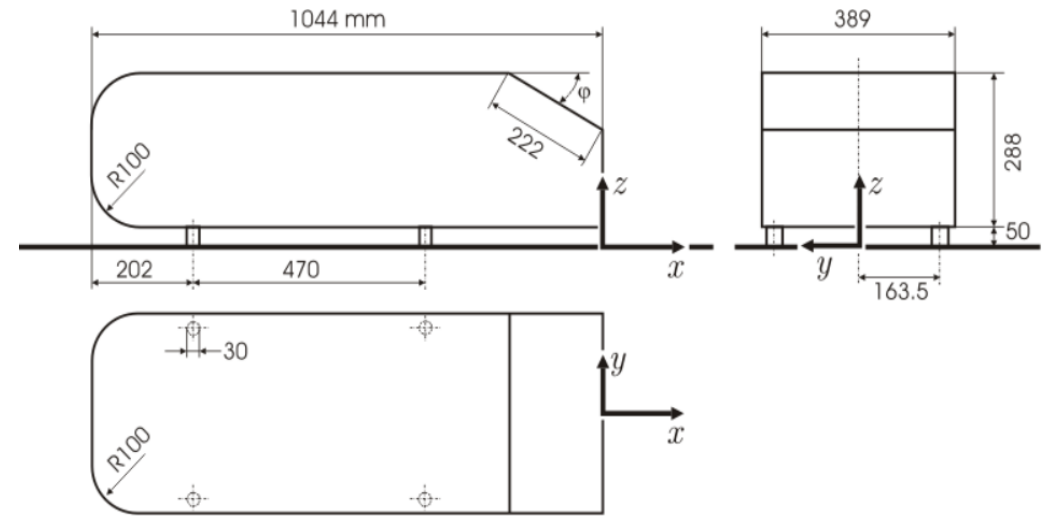
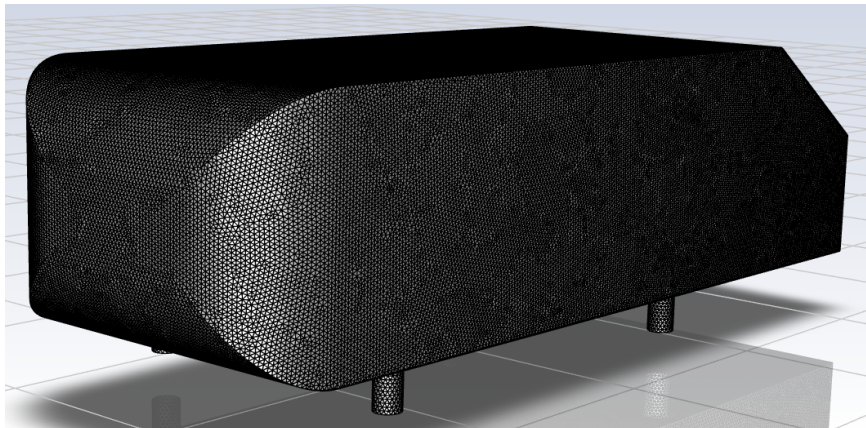
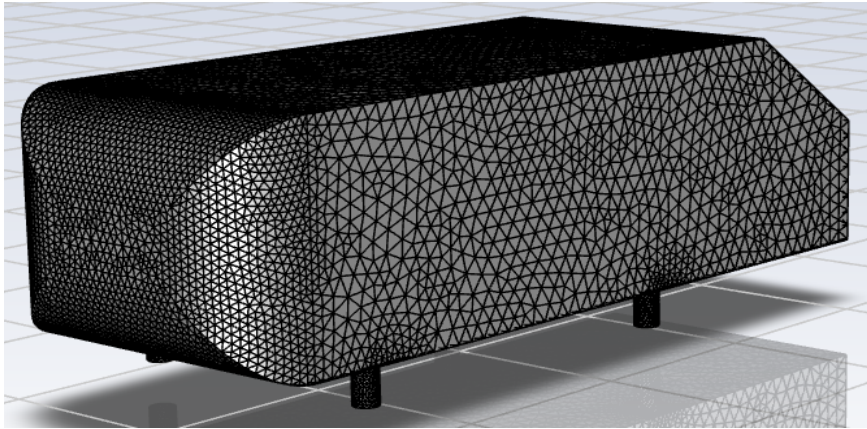
# SCRIPT AUTOMATICO

- Linguaggio Scheme
- Metodo di discesa del gradiente
- Vincoli sono sempre rispettati
- Controllo su amplificazione massima
- Convergenza:
  - Differenza di osservabile tra due step
  - Numero massimo di iterazioni

```
...
(do ((j 0 (+ j 1)))
    ((= j (length modes)))
        (set-car! (list-tail amplification j) (+ (list-ref amplification j) 0.1))
        (rbf-smorph-adjoint (map (lambda (x y) (list x y)) modes amplification))
        (set-car! (list-tail variation j) (%rpgetvar 'rbf/smorph-adjoint-eval))
    )
...
(do ((h 0 (+ h 1)))
    ((= h (length modes)))
        (set-car! (list-tail b h) (* K (list-ref variation h)))
        (set-car! (list-tail amplification h) (+ (list-ref amplification h) (list-ref b h)))
    )
...
(rbf-smorph (map (lambda (x y) (list x y)) modes amplification))
...
```

## 4. APPLICAZIONI

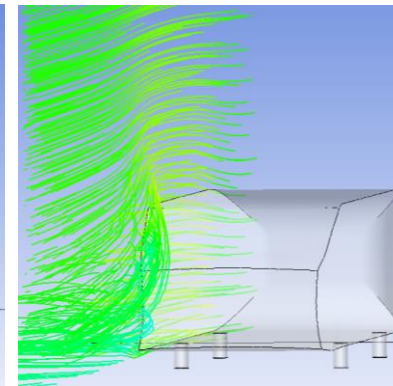
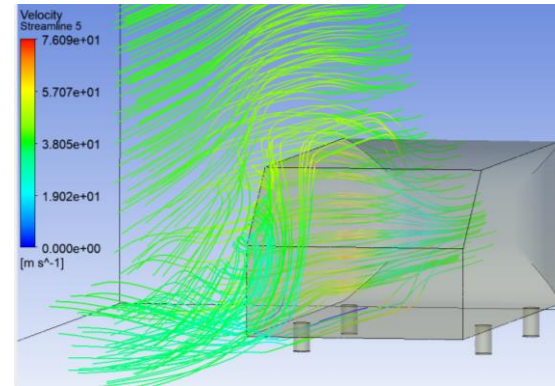
# AHMED-BODY



## 4. APPLICAZIONI

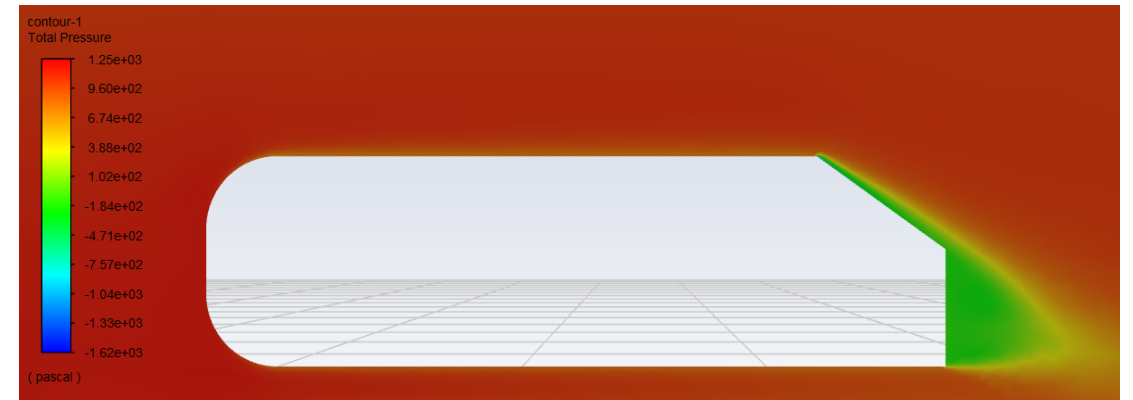
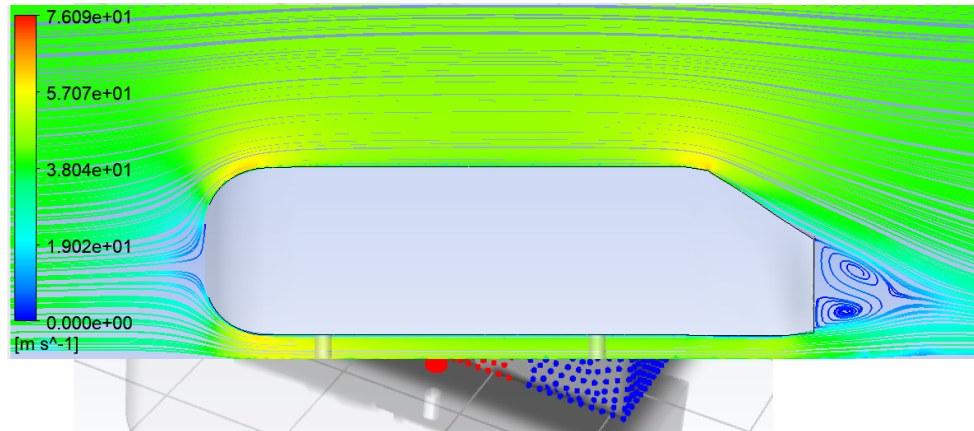
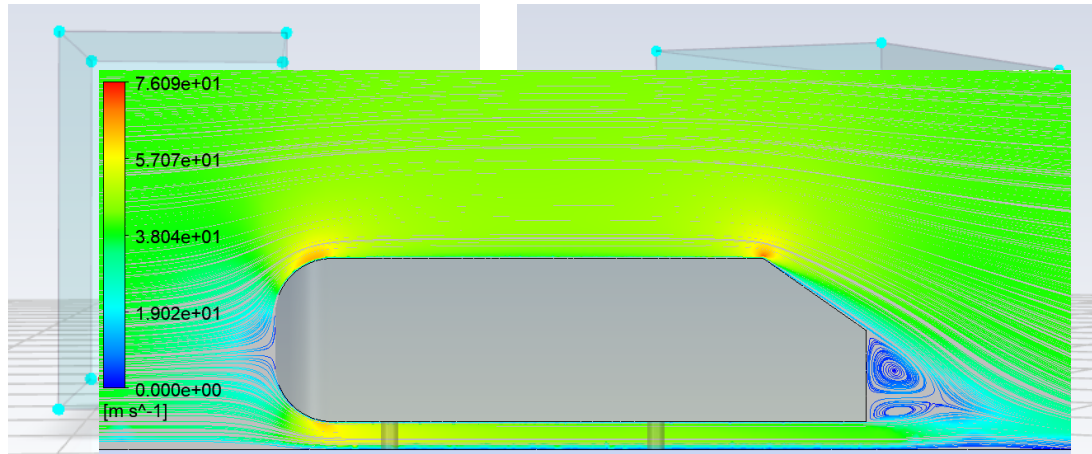
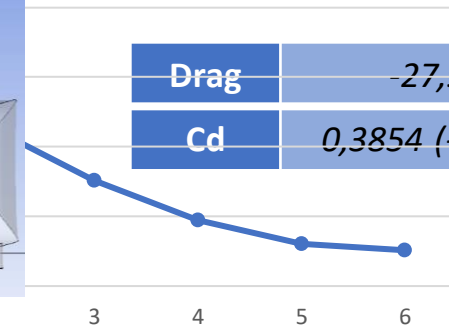
# AHMED-BODY

## Adjoint-sculpting



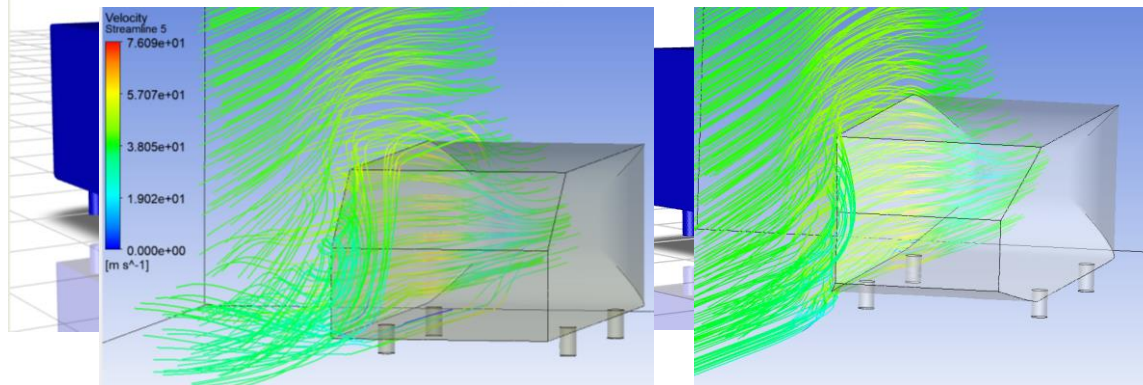
Cicli di ottimizzazione

Drag	-27,9%
Cd	0,3854 (-28,5%)

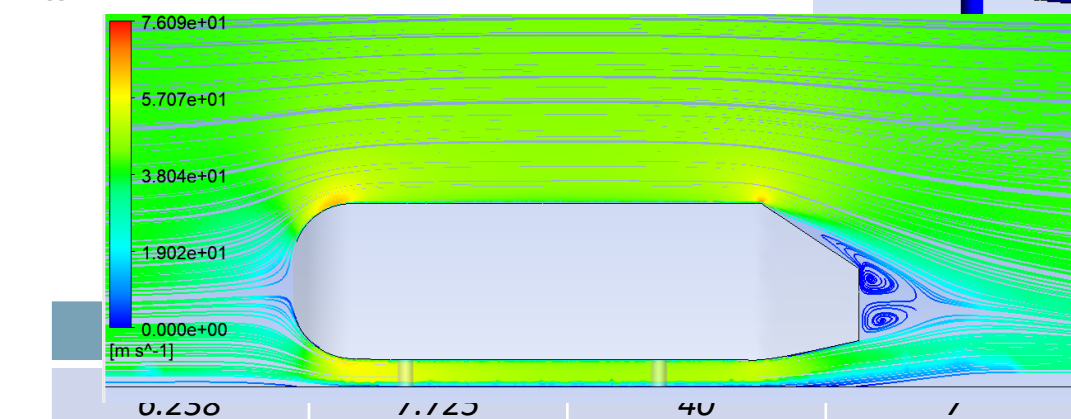
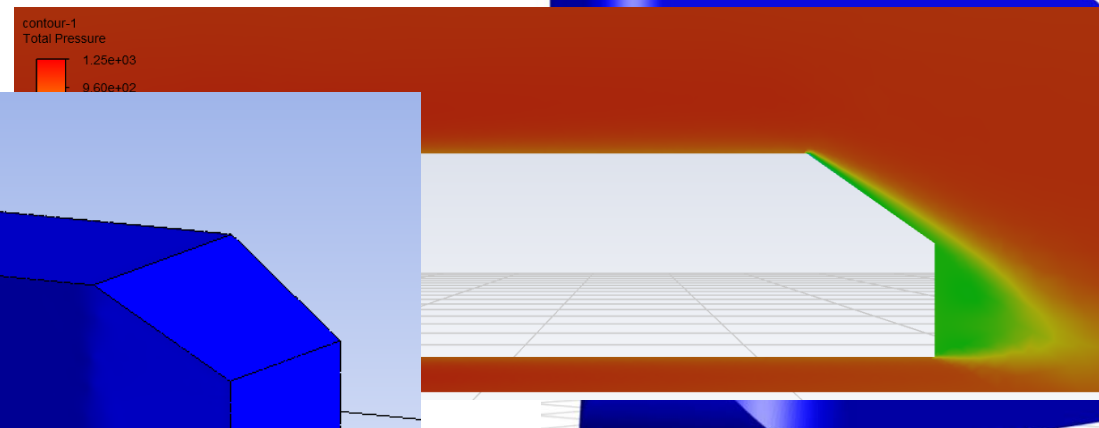
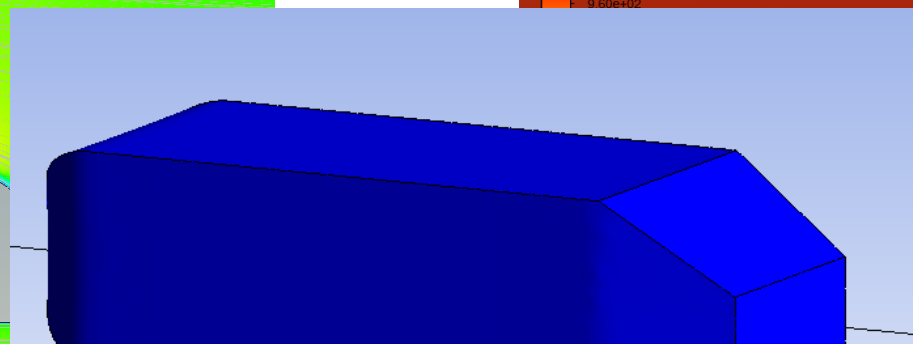
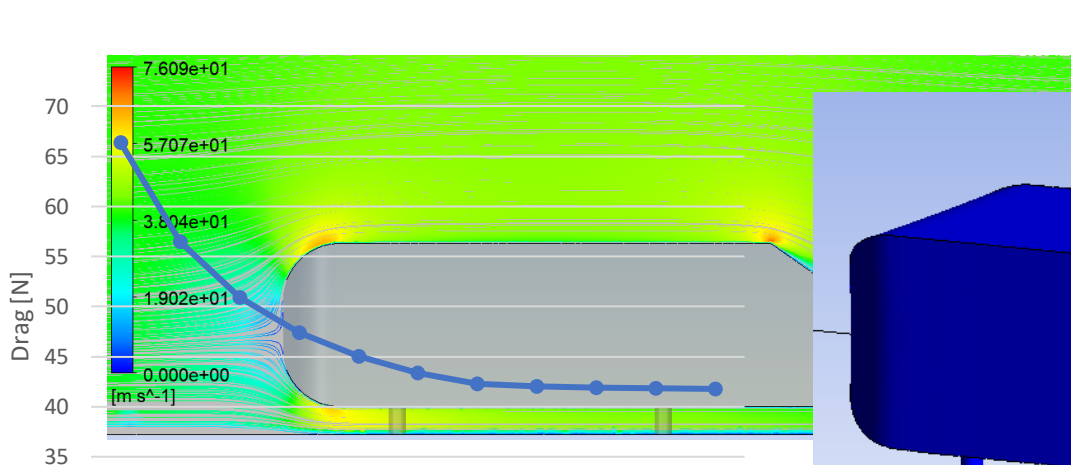


# 4. APPLICAZIONI

## AHMED-BODY Adjoint-preview

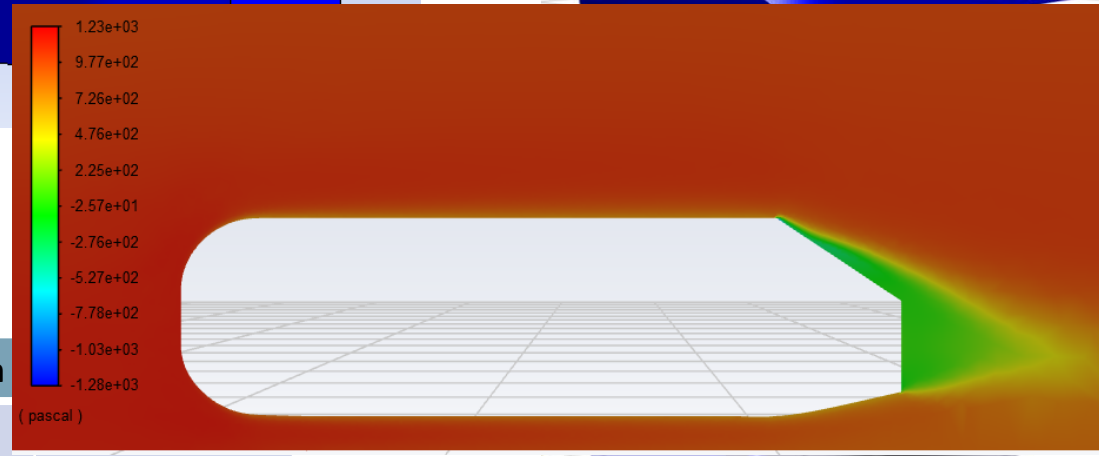


Drag	-39,5%
Cd	0.3282 (-39%)

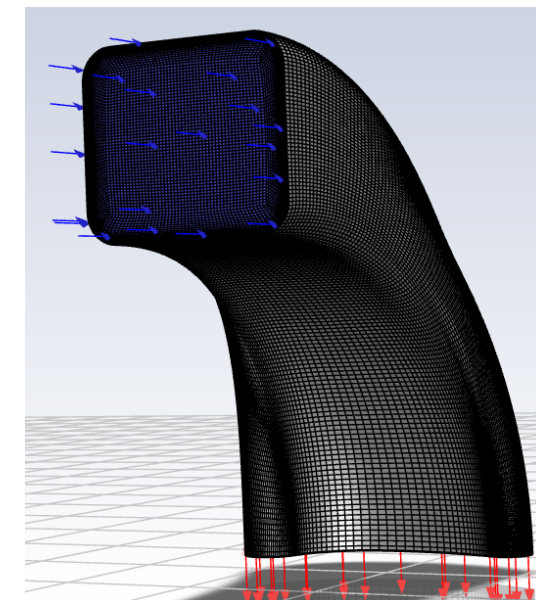
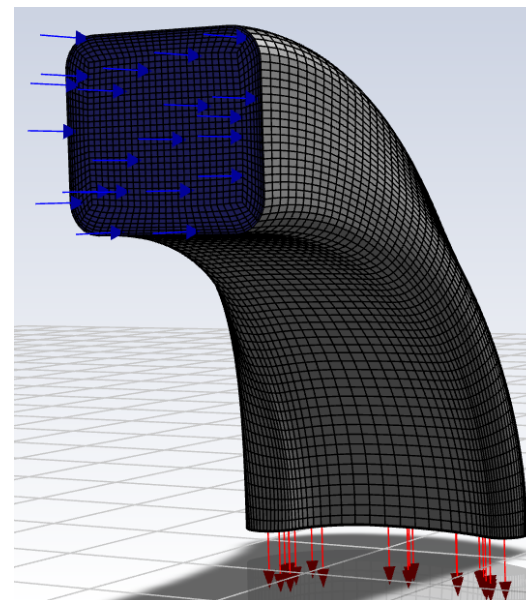
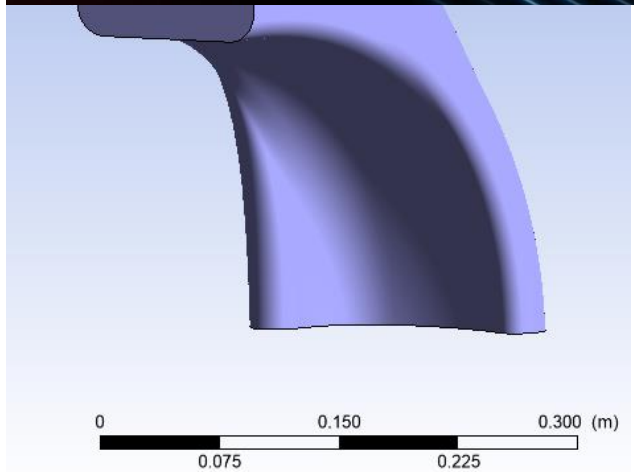
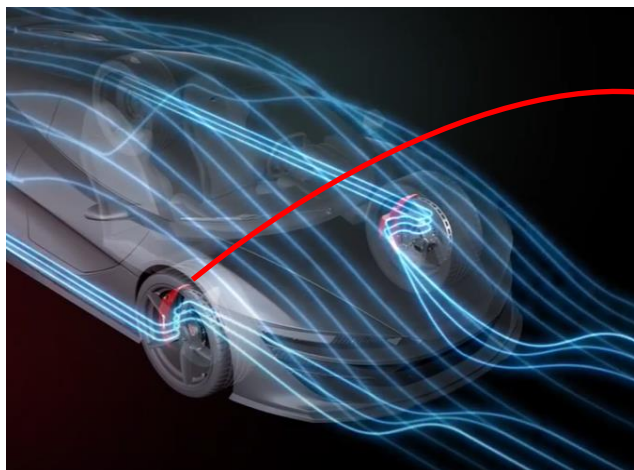


Back-bottom

35



# CONVOGLIATORE D'ARIA

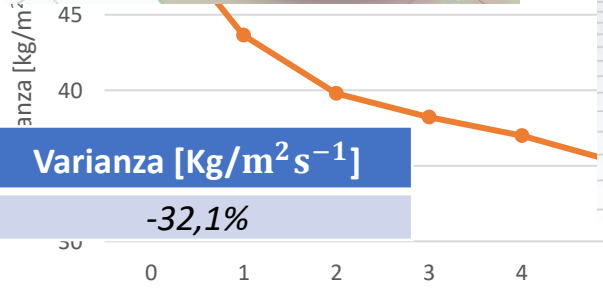
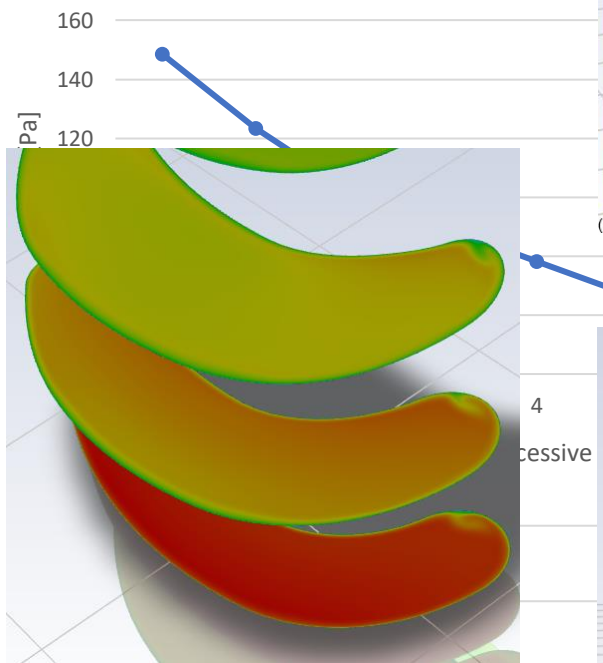
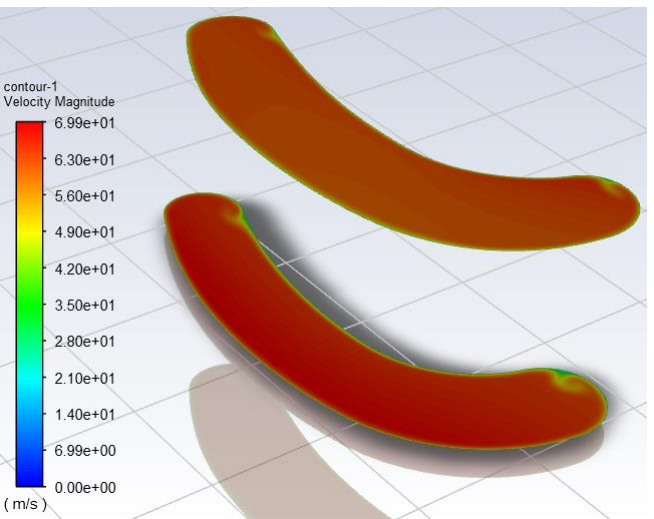
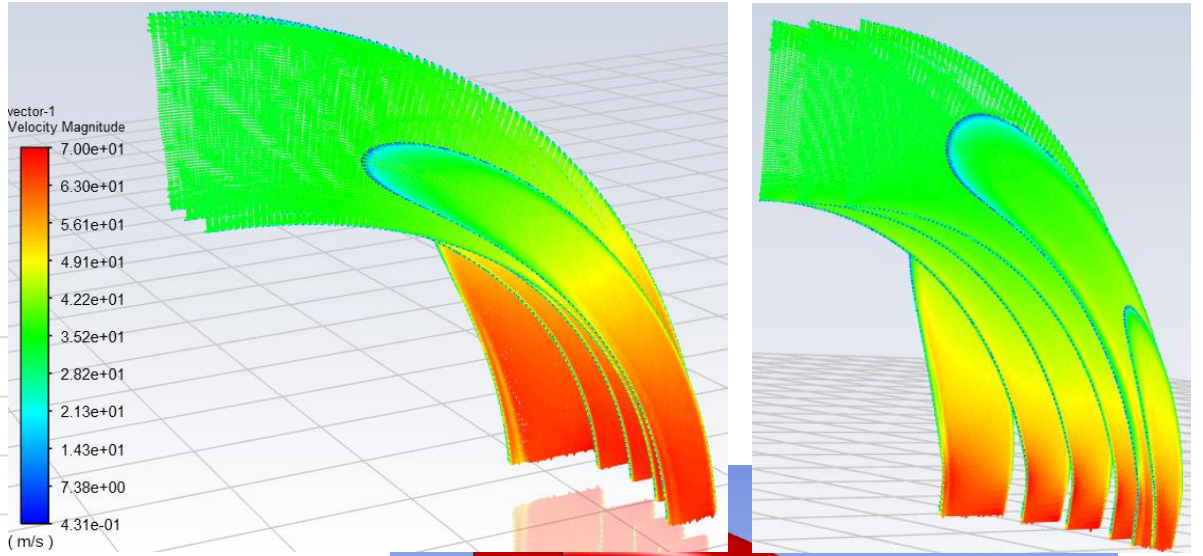


	Rada	Fitta
Numero nodi	64850	916400
Numero celle	61152	897435
Min. Orth. Qual.	0.2023	0.1932



## CONVOGLIATORE D'ARIA

### Adjoint-sculpting

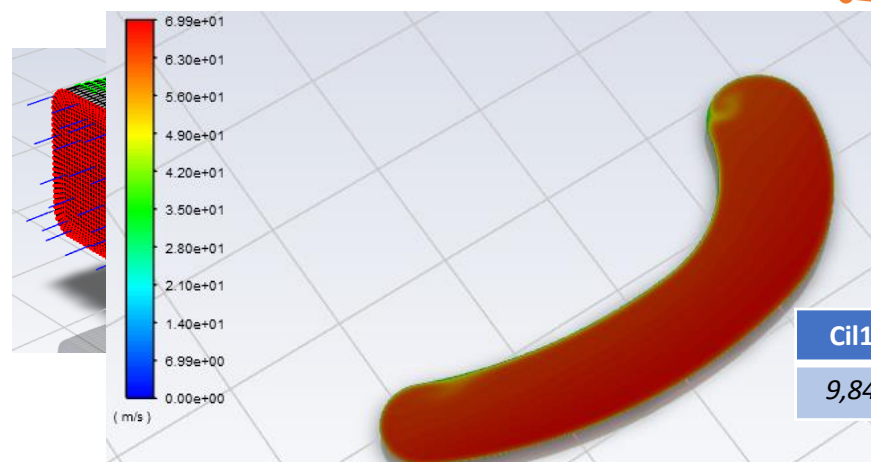
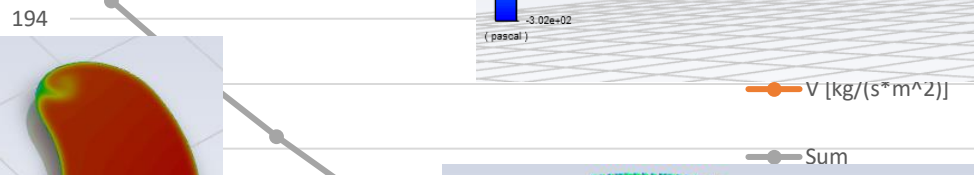
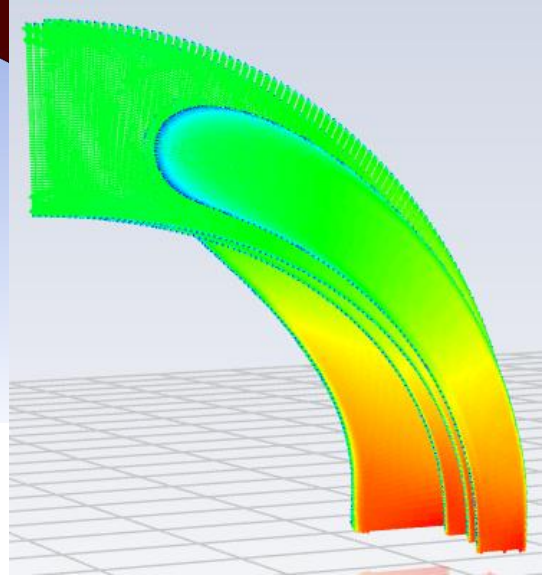
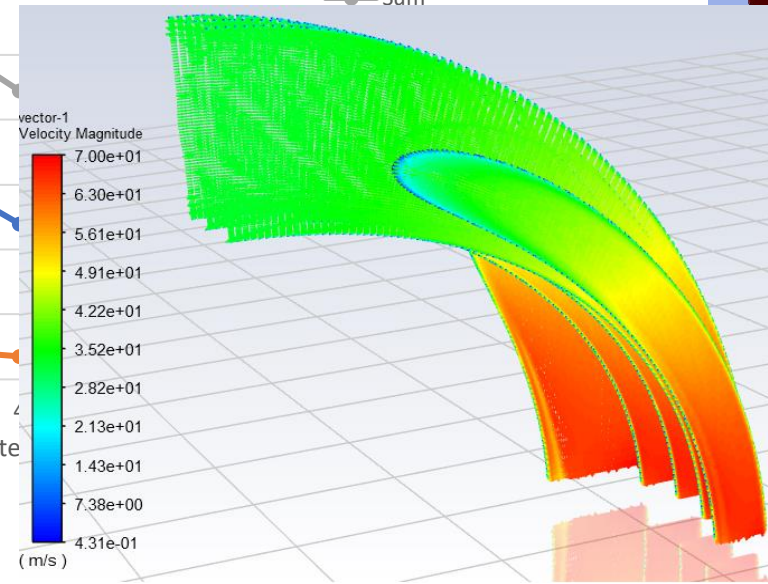
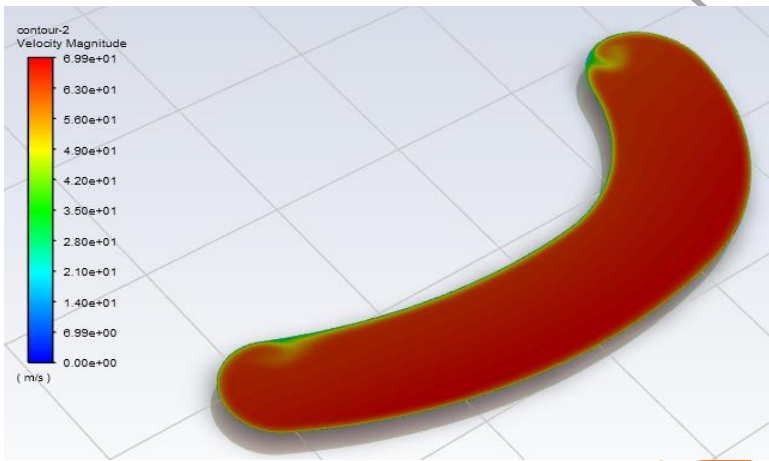
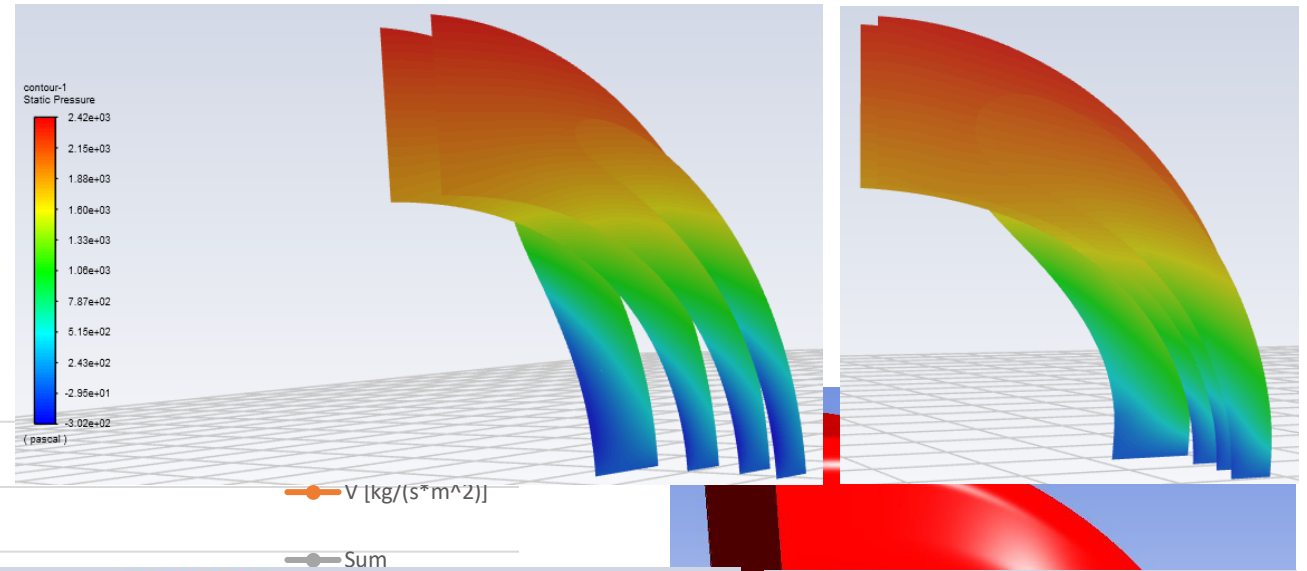


**Pressure-drop [Pa]**  
-37,9%

**Varianza [Kg/m<sup>2</sup>s<sup>-1</sup>]**  
-32,1%

## CONVOGLIATORE D'ARIA

Adjoint-preview



Cil1x	Cil1z	Cil2x	Cil2z	Cil3x	Cil3z	Cil4x	Cil4z	Cil5x	Cil5z	Cil6x	Cil6z
9,843	12,98	11,00	11,88	15,17	13,53	23,46	19,54	30	28,8	30	30

# CONFRONTO METODI

	Parametrizzazione	Vantaggi	Svantaggi
<b>Adjoint-sculpting</b>	Automatica	<ul style="list-style-type: none"> <li>• Permette di esplorare <u>soluzioni nuove</u></li> <li>• Parametrizzazione automatica</li> </ul>	<ul style="list-style-type: none"> <li>• <u>Minimo locale</u></li> <li>• Minor controllo sulla variazione di forma (vincoli sempre rispettati)</li> </ul>
<b>Adjoint-preview</b>	Definita dall'utente	<ul style="list-style-type: none"> <li>• <u>Costo indipendente dal numero di parametri</u></li> <li>• Maggior controllo sulla variazione di forma</li> </ul>	<ul style="list-style-type: none"> <li>• <u>Minimo locale</u></li> <li>• Parametrizzazione più complessa</li> </ul>
<b>Metodi DOE</b>	Definita dall'utente	<ul style="list-style-type: none"> <li>• <u>Minimo globale</u></li> <li>• Maggior controllo sulla variazione di forma</li> </ul>	<ul style="list-style-type: none"> <li>• <u>Costo insostenibile per elevato numero di parametri</u></li> <li>• Parametrizzazione più complessa</li> </ul>

## 5. CONCLUSIONI

- Sono stati predisposti i flussi di lavoro per l'ottimizzazione di forma considerando due metodi
  - Flusso di lavoro di adjoint-sculpting
  - Flusso di lavoro di adjoint-preview
- Sono stati esaminati problemi di fluidodinamica interna ed esterna di complessità crescente (cubo, curva a gomito, Ahmed body, convogliatore freno)
- Entrambi i metodi hanno consentito miglioramenti consistenti (dal 28% al 48%)
- Gli algoritmi sviluppati e collaudati possono essere utilizzati per applicazioni di interesse industriale

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## GRAZIE PER L'ATTENZIONE

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