

TOR VERGATA



UNIVERSITÀ
DEGLI STUDI
DI ROMA

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

CANDIDATO: ANDREA LOPEZ

RELATORE: PROF. M. E. BIANCOLINI

CORRELATORE: ING. C. GROTH



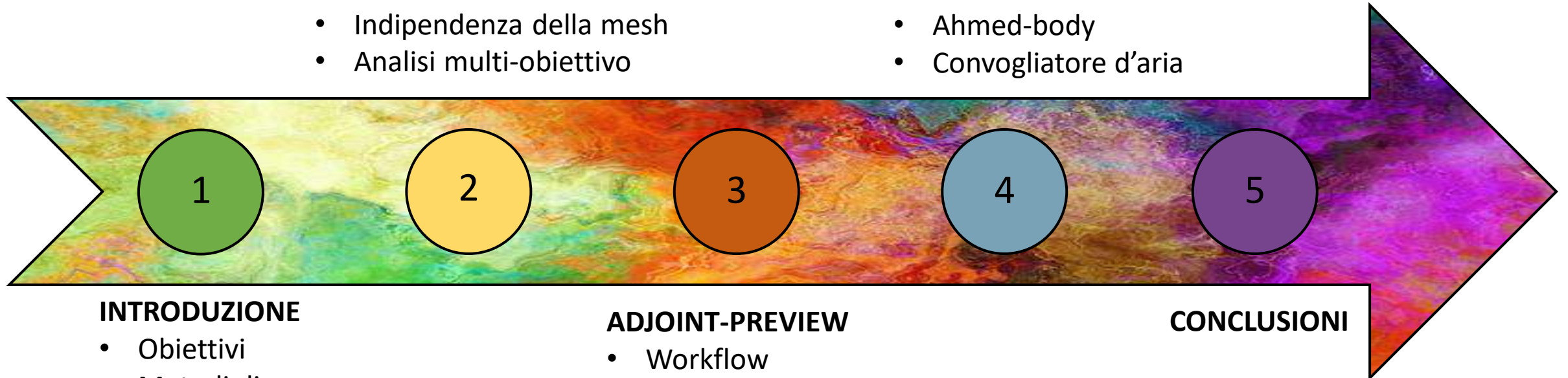
Ansys

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:

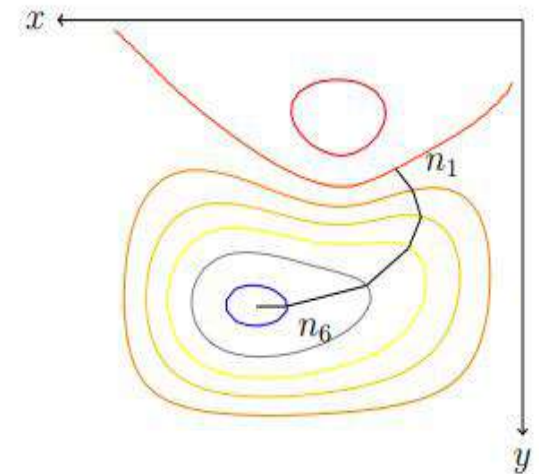
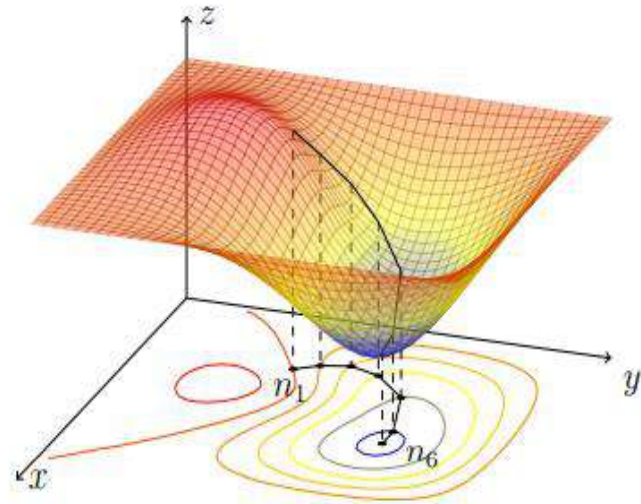
- Sviluppare metodi di ottimizzazione basati su CFD adjoint e mesh morphing
 - Flusso di lavoro di adjoint-sculpting
 - Flusso di lavoro di adjoint-preview
- Sviluppare script per automatizzare i workflow
- Applicazione su casi di interesse industriale

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

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

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

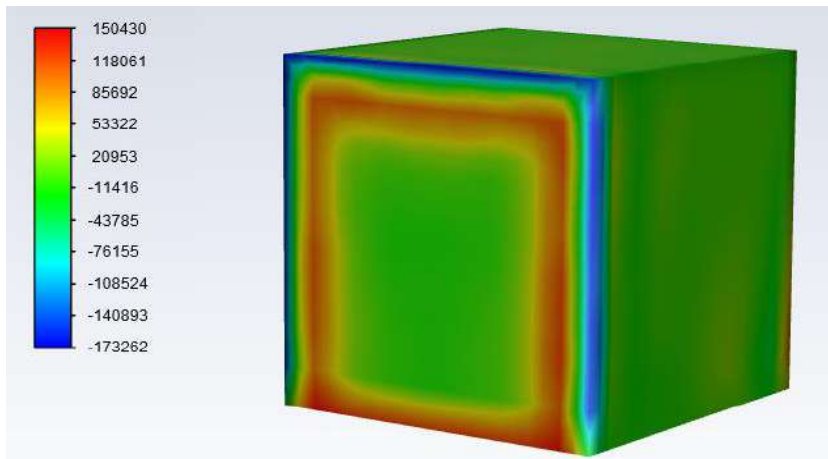
$$\delta f = \left[\frac{\partial f^T}{\partial x} - \lambda^T \frac{\partial R}{\partial x} \right] \delta x + \left[\frac{\partial f^T}{\partial \alpha} - \lambda^T \frac{\partial R}{\partial \alpha} \right] \delta \alpha$$

↓

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

↓

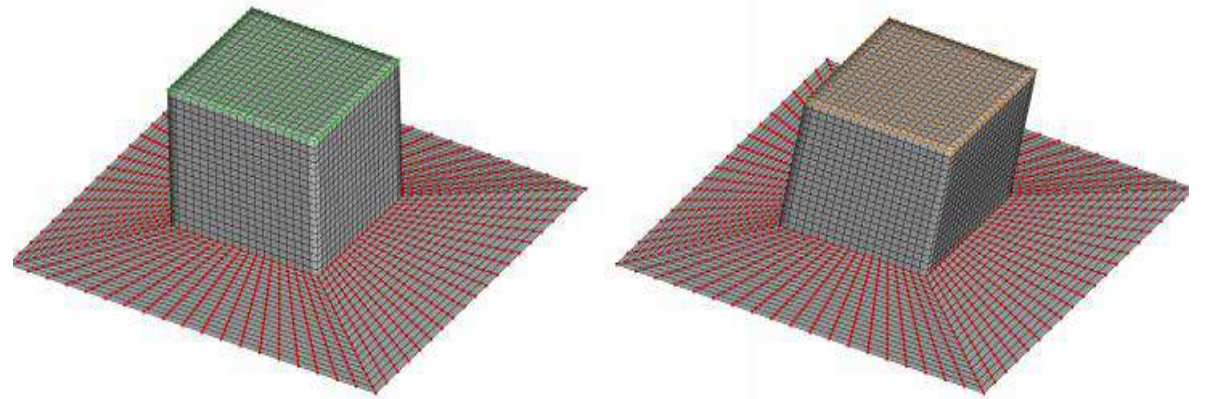
$$\delta f = G \delta \alpha, \quad \text{con } G = \frac{\partial f^T}{\partial \alpha} - \lambda^T \frac{\partial R}{\partial \alpha}$$



Mappa 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

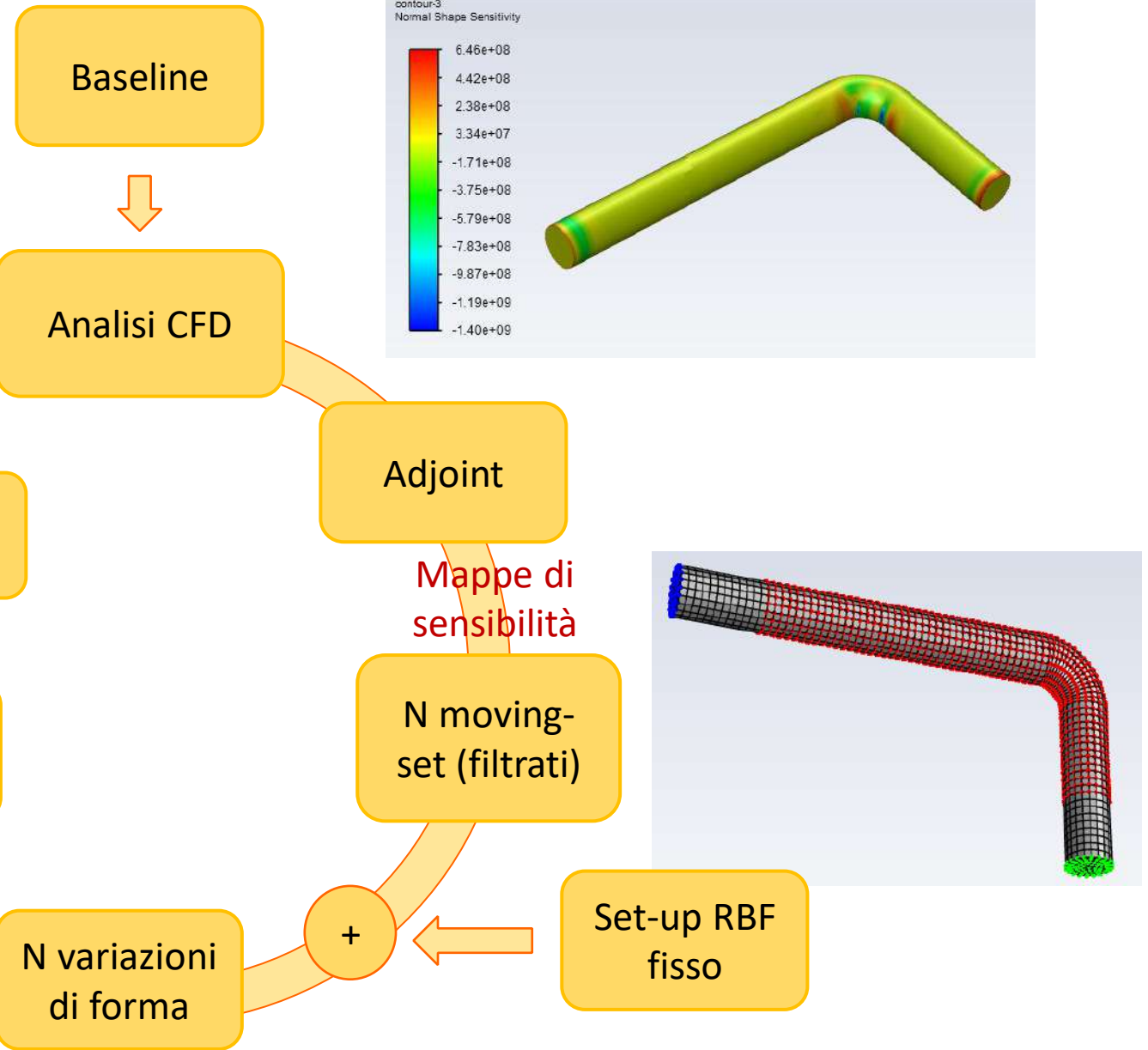
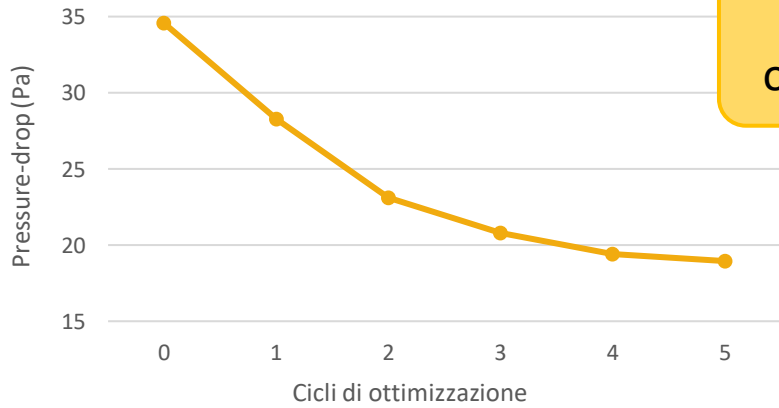
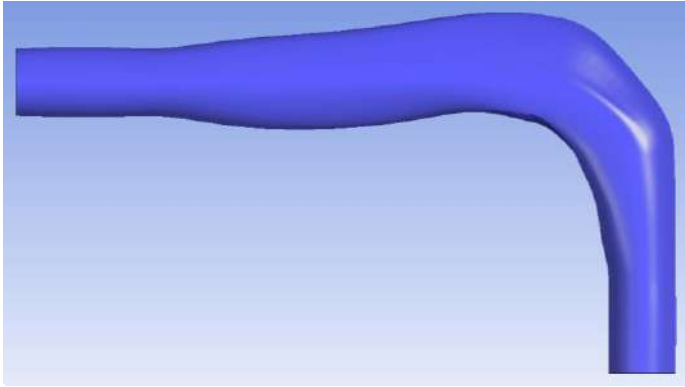
- Facile e veloce
- Metodo mesh-less
- Elevata espressività
- No rumore re-meshing
- Topologia inalterata



PROGRAMMI USATI

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

FLUSSO DI LAVORO



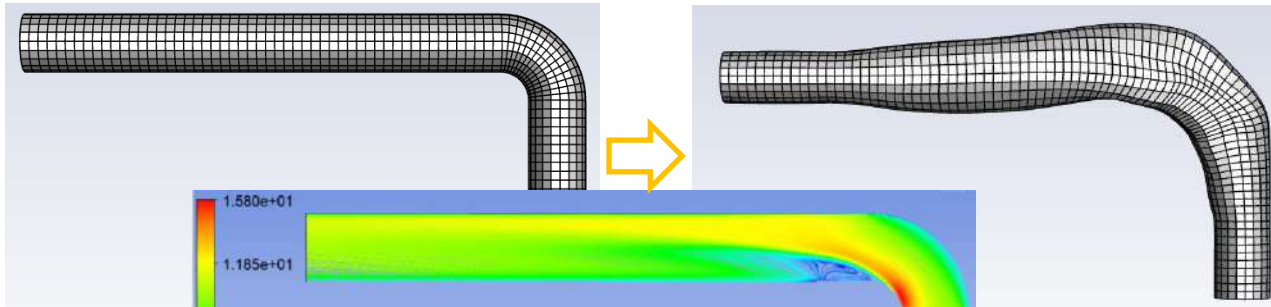
2. ADJOINT-SCULPTING

MESH-LESS

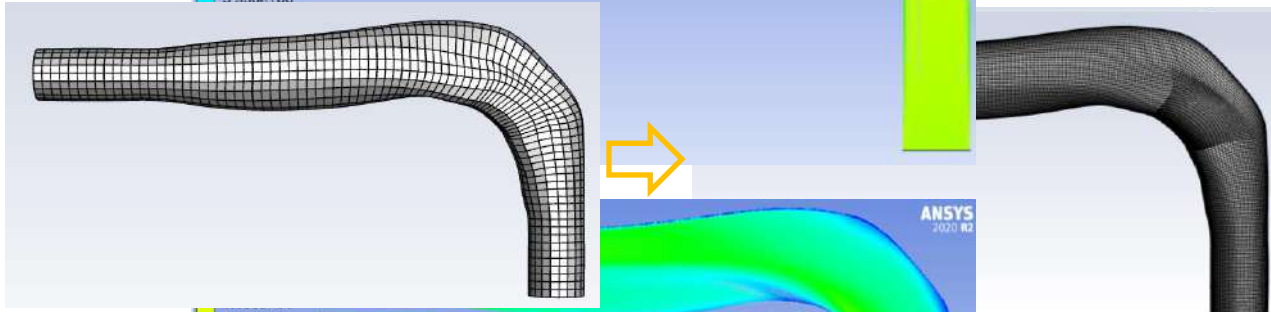
	Rada	Fitta
CFD	44s	1216s
Adjoint	72s	/

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

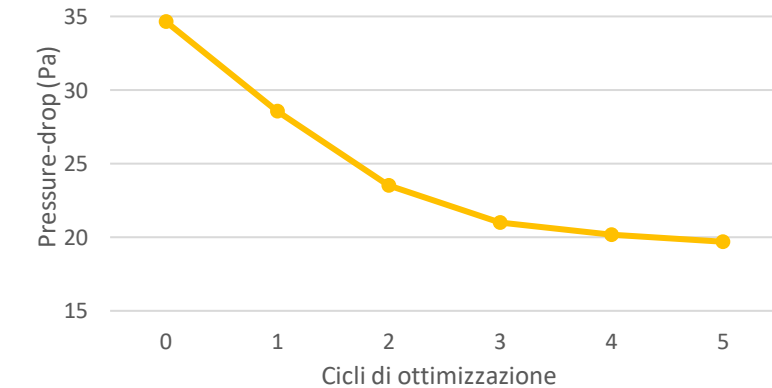
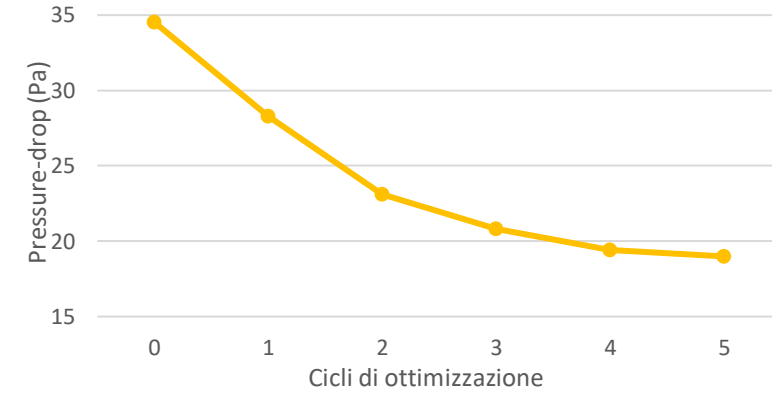
1. Flusso di lavoro implementato su mesh rada



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

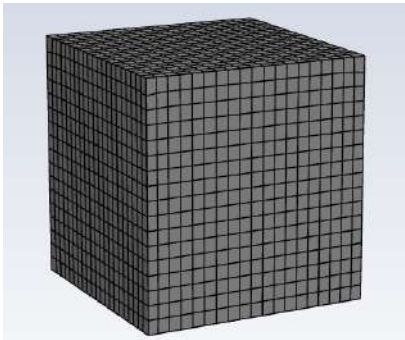


3. Risultati valutati su mesh fitta

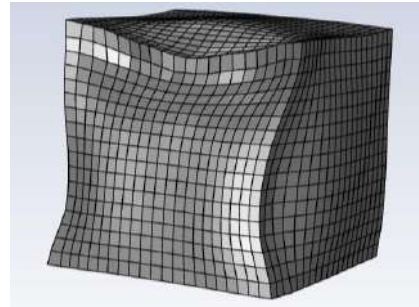


	Rada	Fitta
Pressure-drop	-47,5%	-46,5%

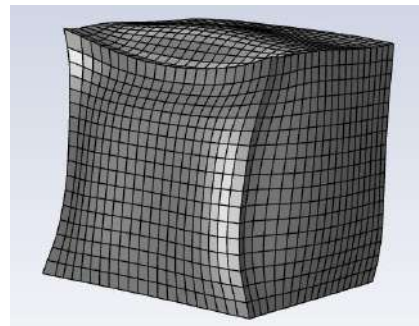
ANALISI MULTI-OBIETTIVO



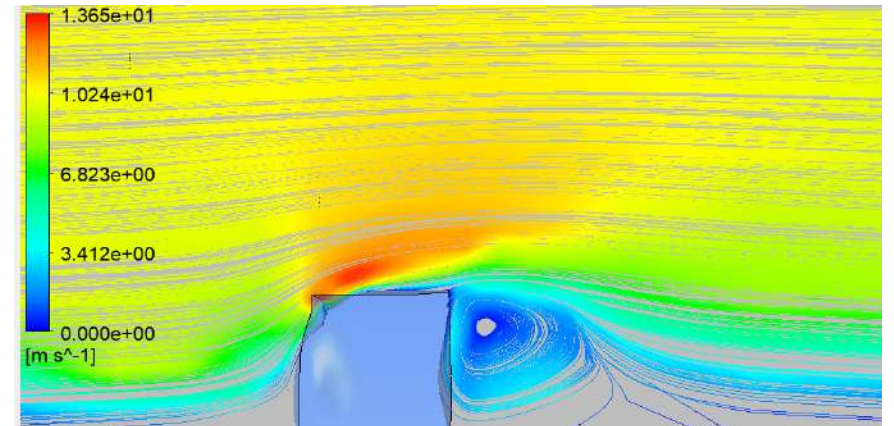
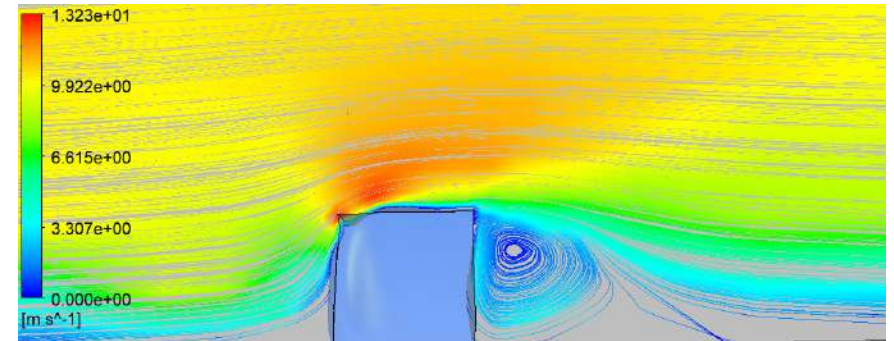
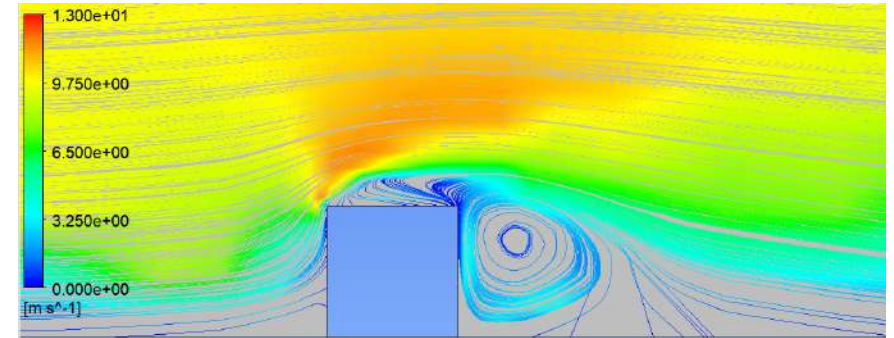
- 2 Osservabili
- 2 Calcoli adjoint
- 2 Soluzioni RBF
- > Controllo su ogni osservabile



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



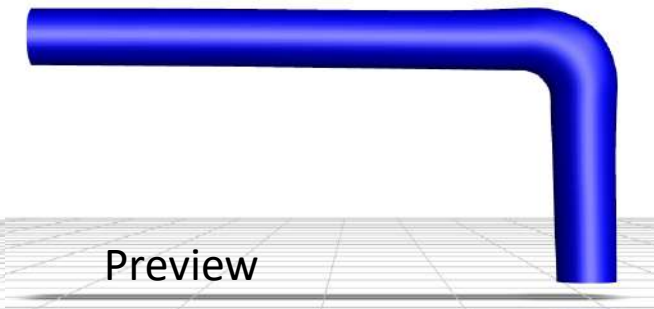
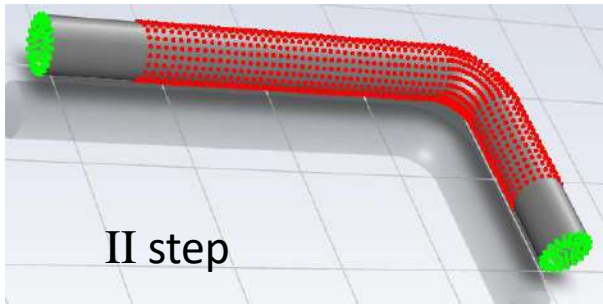
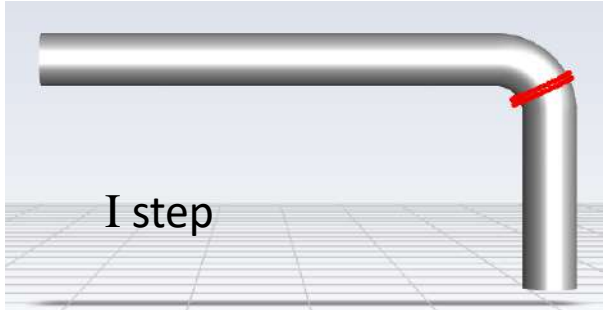
	A-S Sum	A-S 2 Oss.
Drag	-35,7%	-34,5%
Lift	-23%	-35,9%



3. ADJOINT-PREVIEW

- ✓ Mesh-less
- ✓ Analisi multi-obiettivo

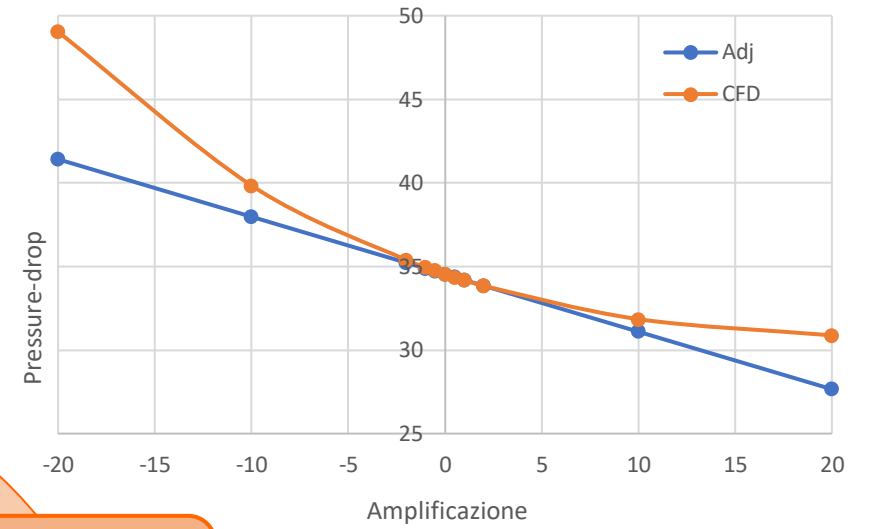
FLUSSO DI LAVORO



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

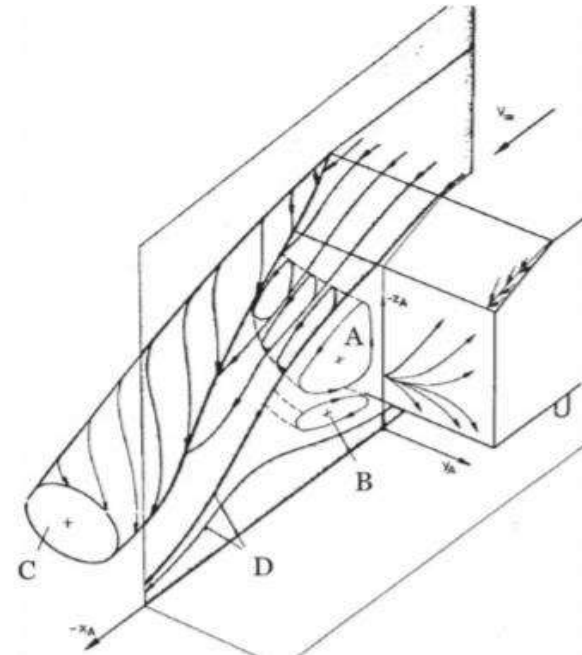
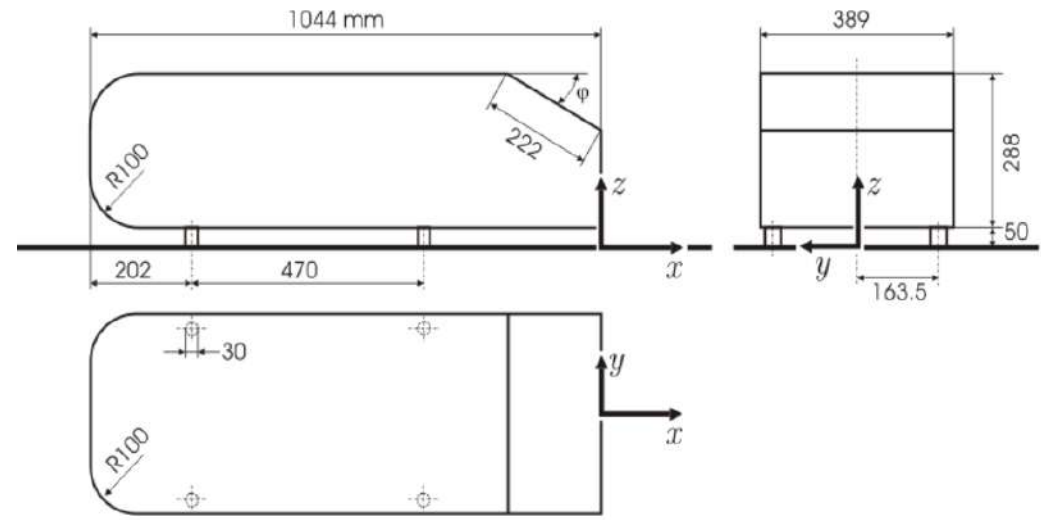
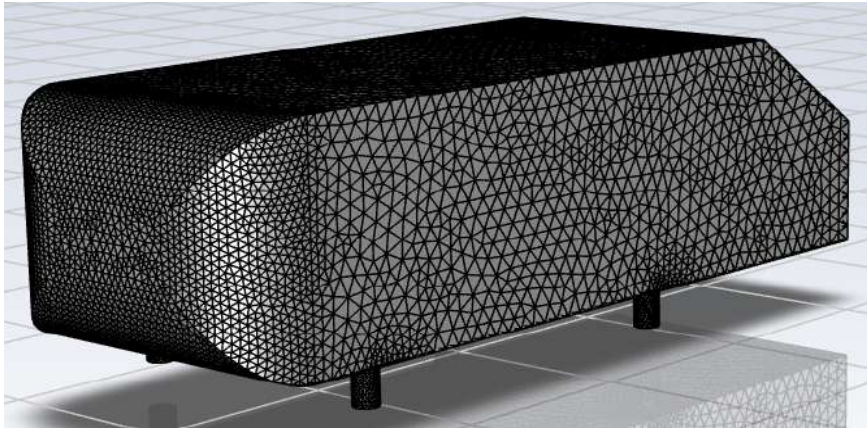
SCRIPT AUTOMATICO

- 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

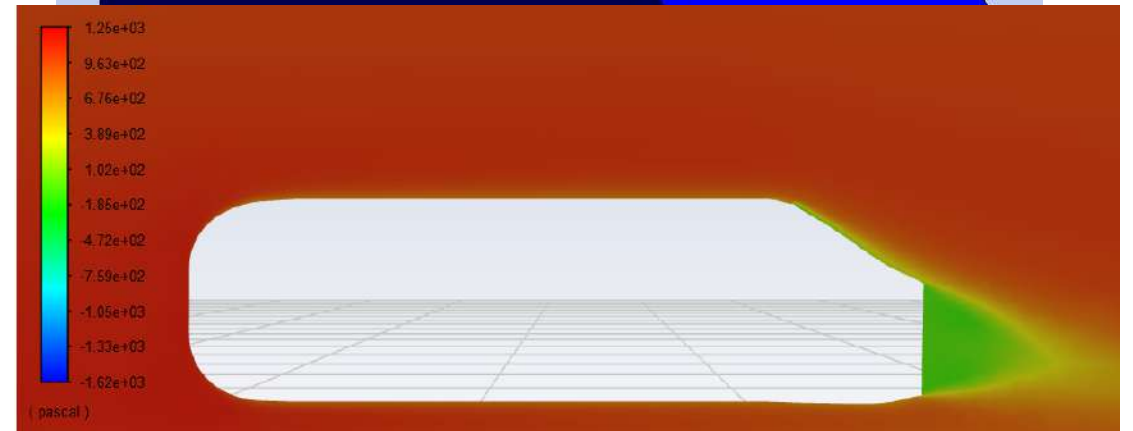
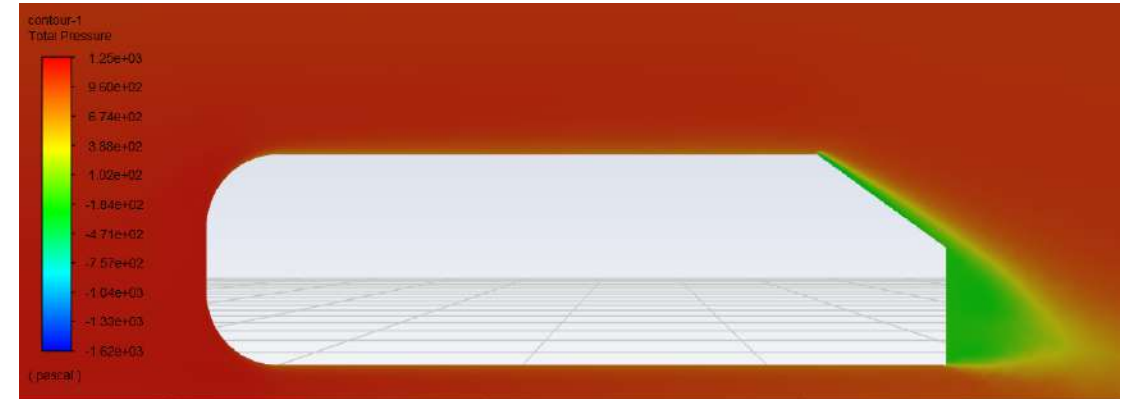
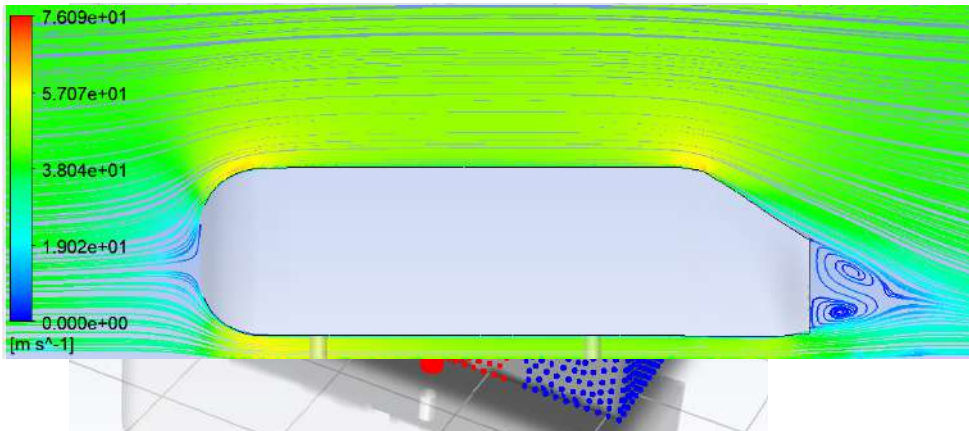
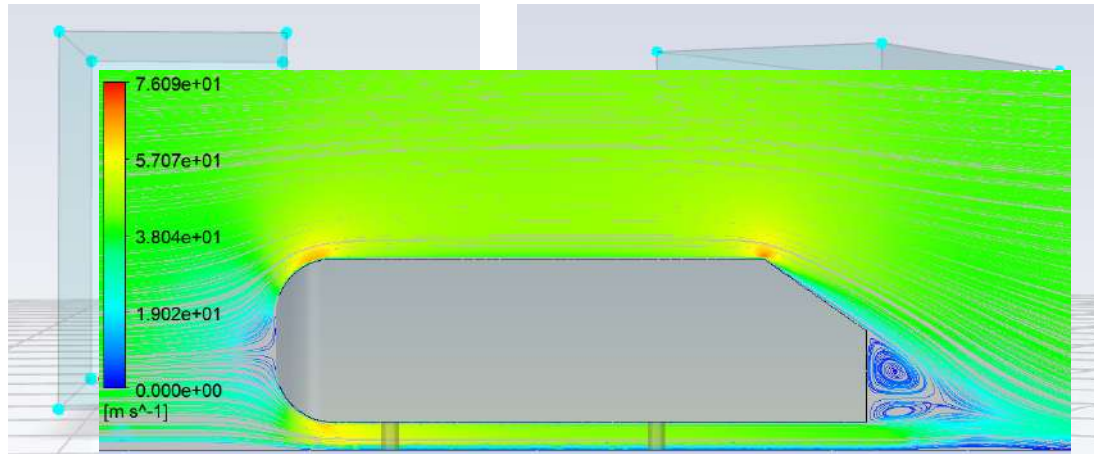
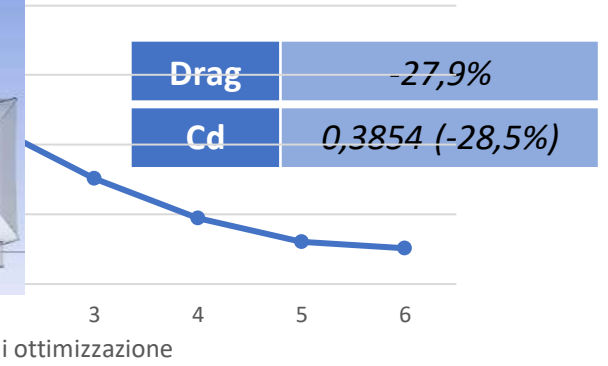
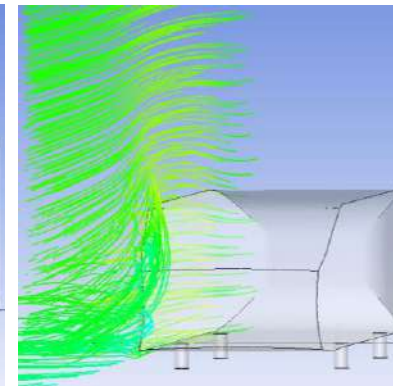
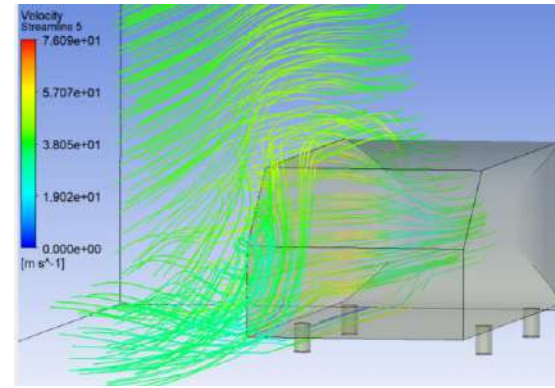
AHMED-BODY



4. APPLICAZIONI

AHMED-BODY

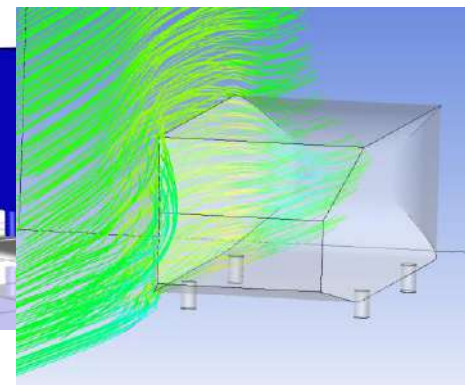
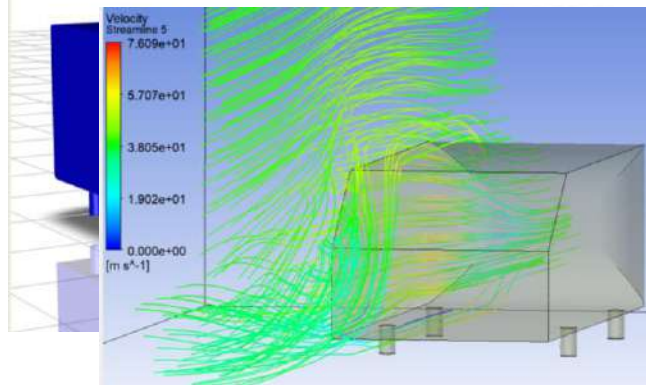
Adjoint-sculpting



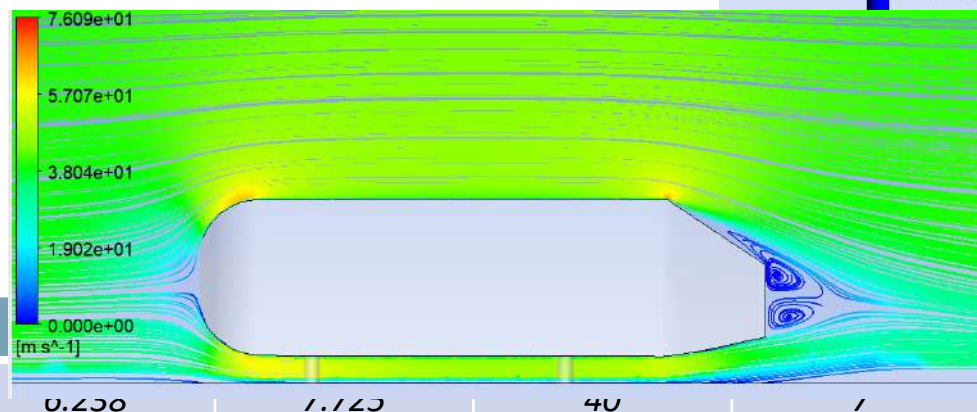
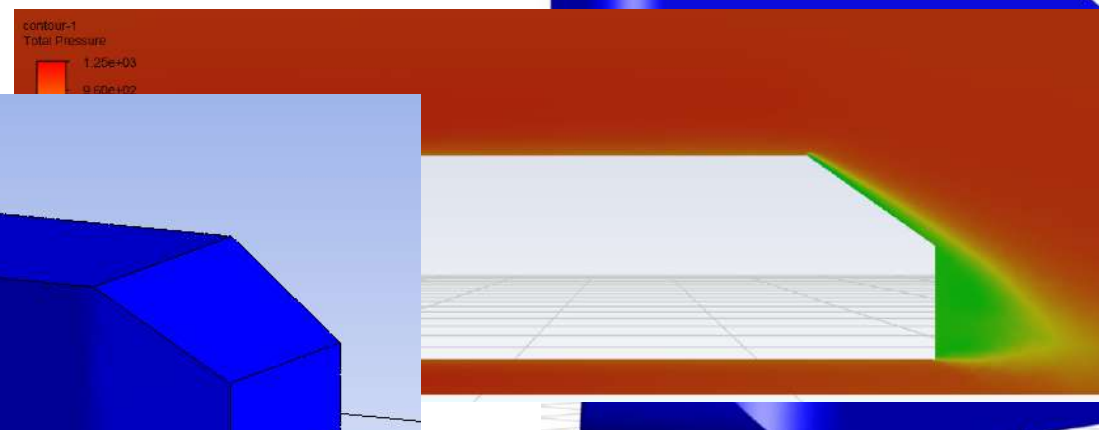
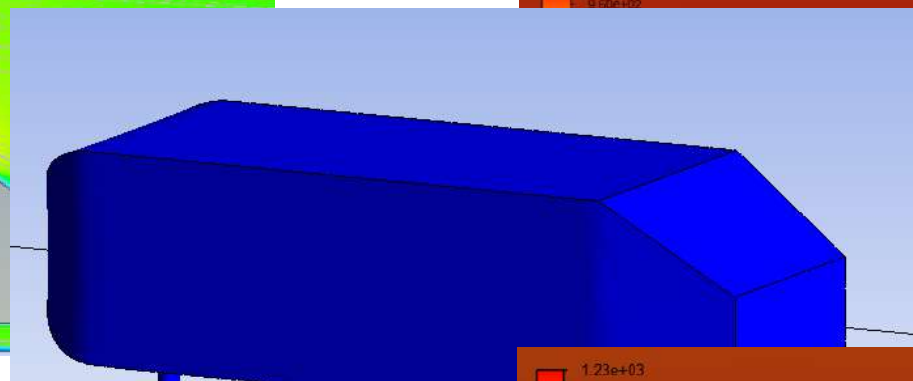
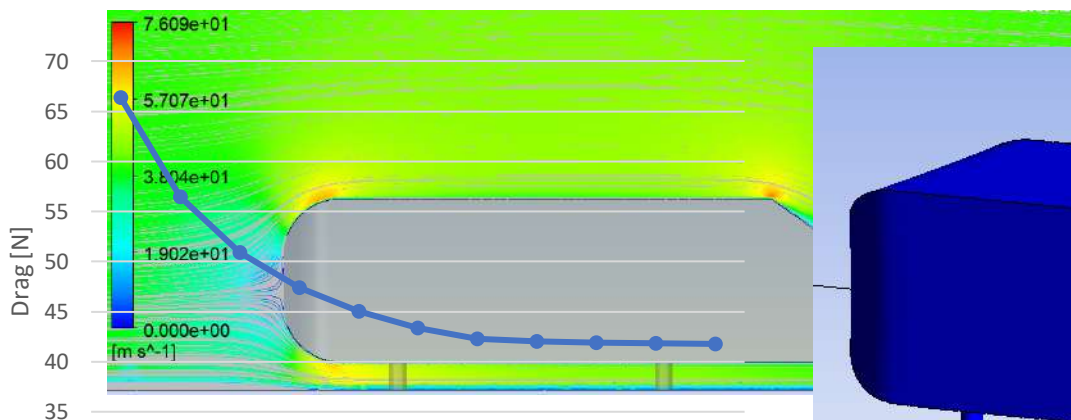
4. APPLICAZIONI

AHMED-BODY

Adjoint-preview



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

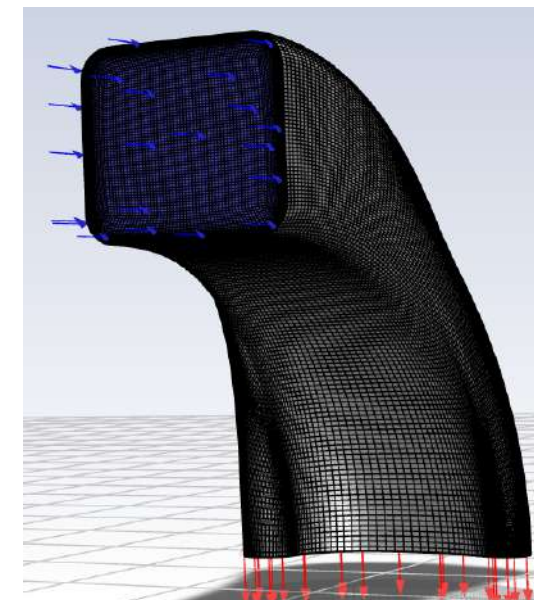
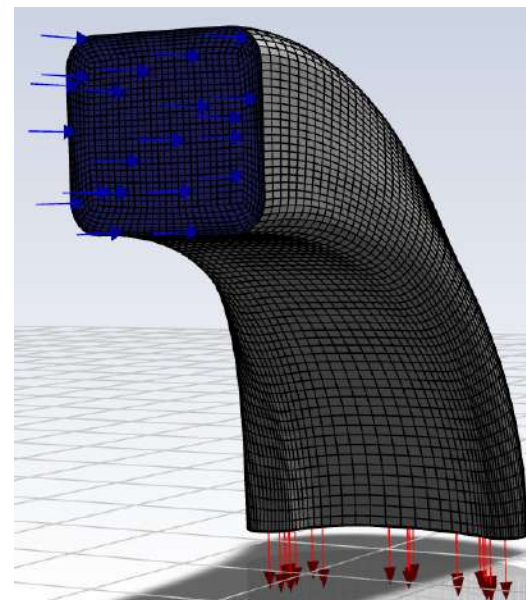
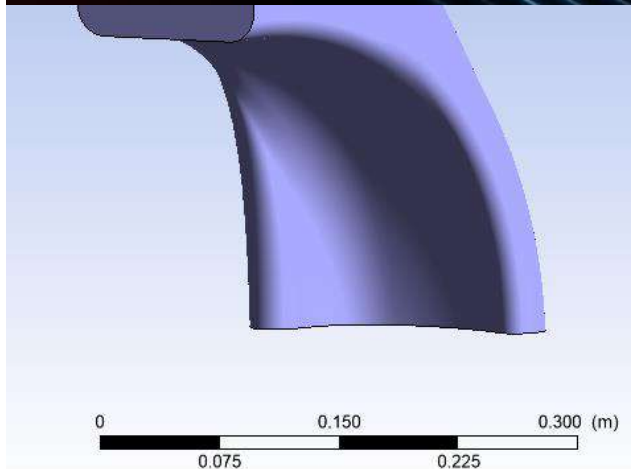
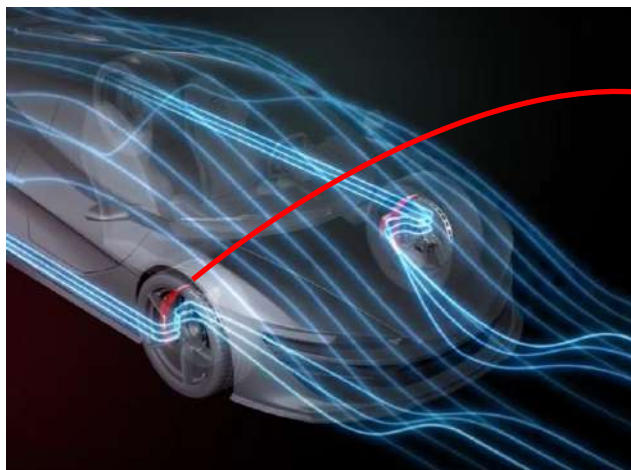


Back-bottom

35



CONVOGLIATORE D'ARIA

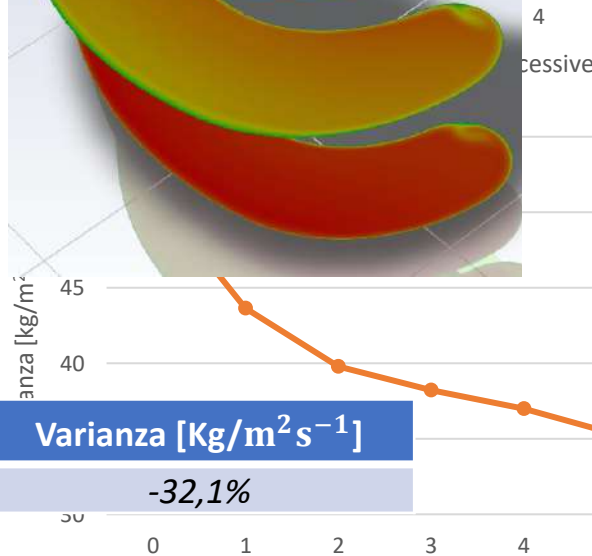
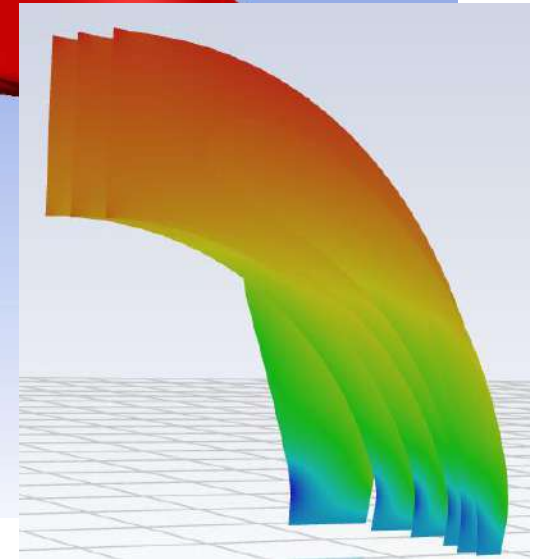
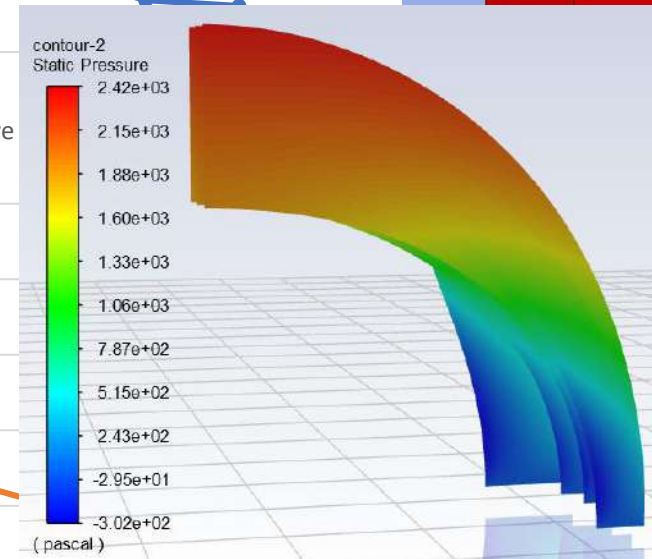
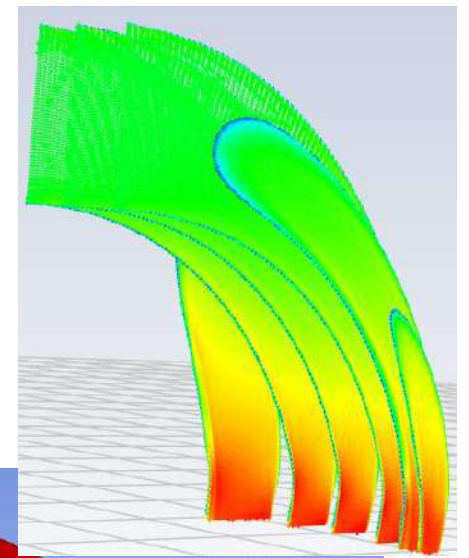
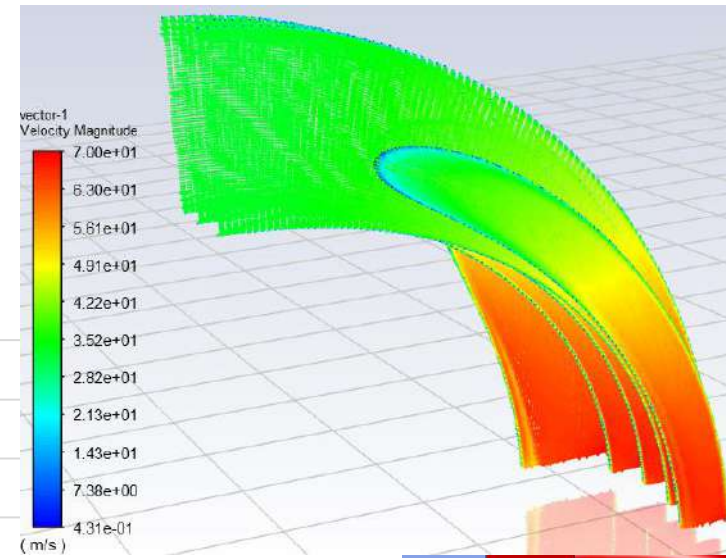
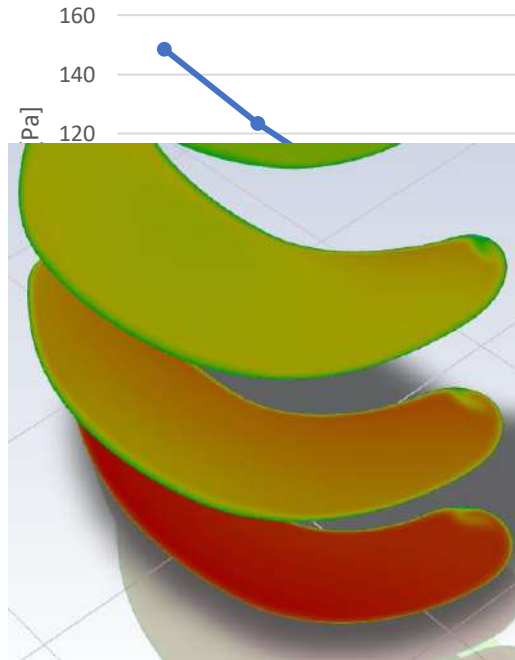
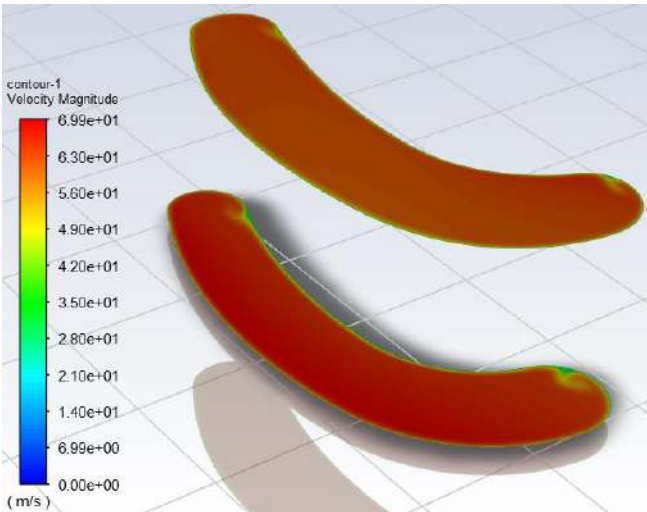


	Rada	Fitta
Numero nodi	64850	916400
Numero celle	61152	897435
Min. Orth. Qual.	0.2023	0.1932

4. APPLICAZIONI

CONVOGLIATORE D'ARIA

Adjoint-sculpting



Pressure-drop [Pa]
-37,9%

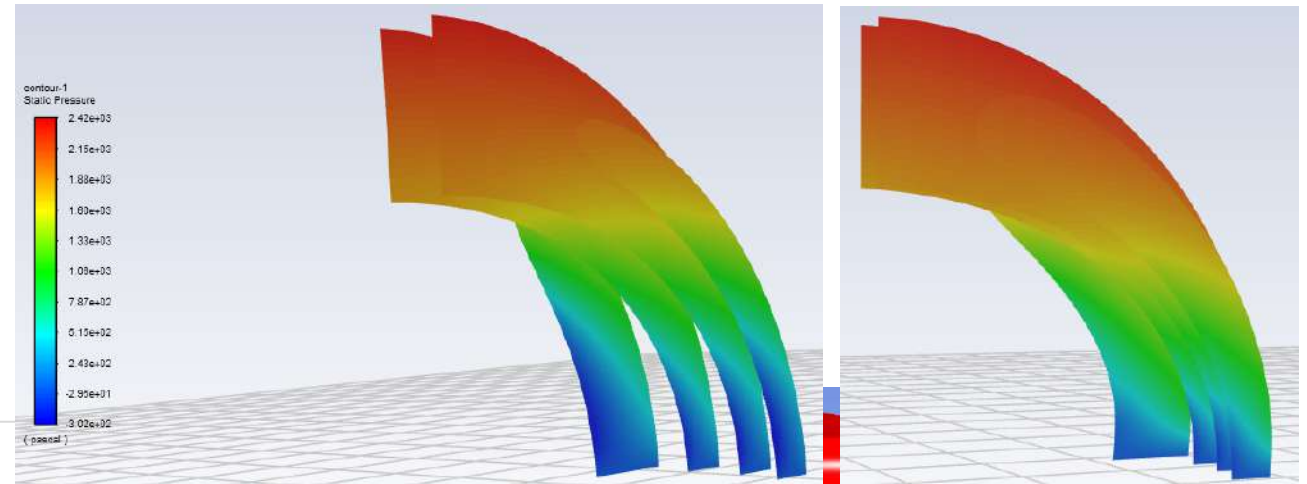
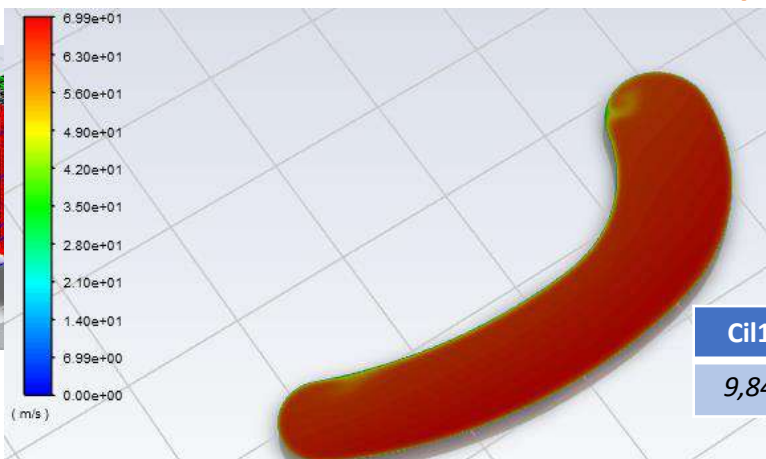
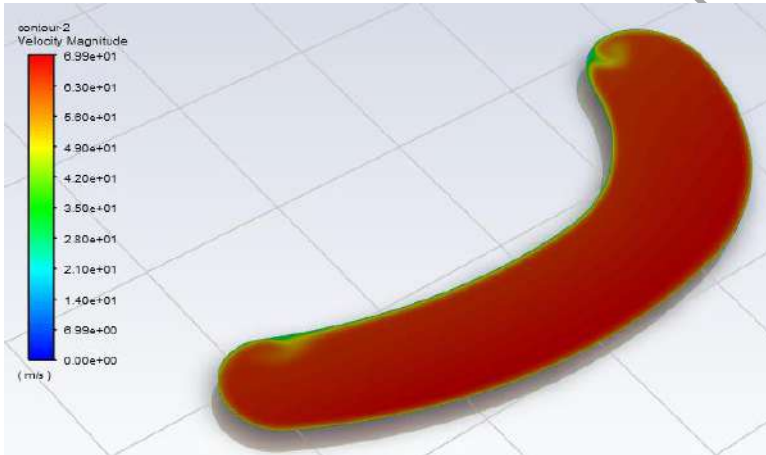
Varianza [Kg/m²s⁻¹]
-32,1%

Iterazioni successive

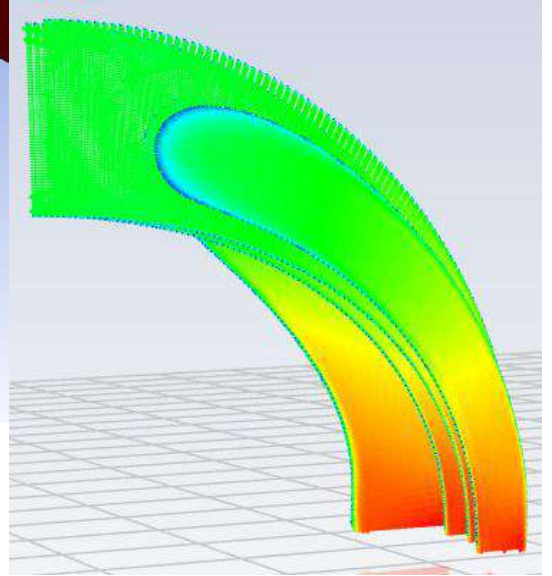
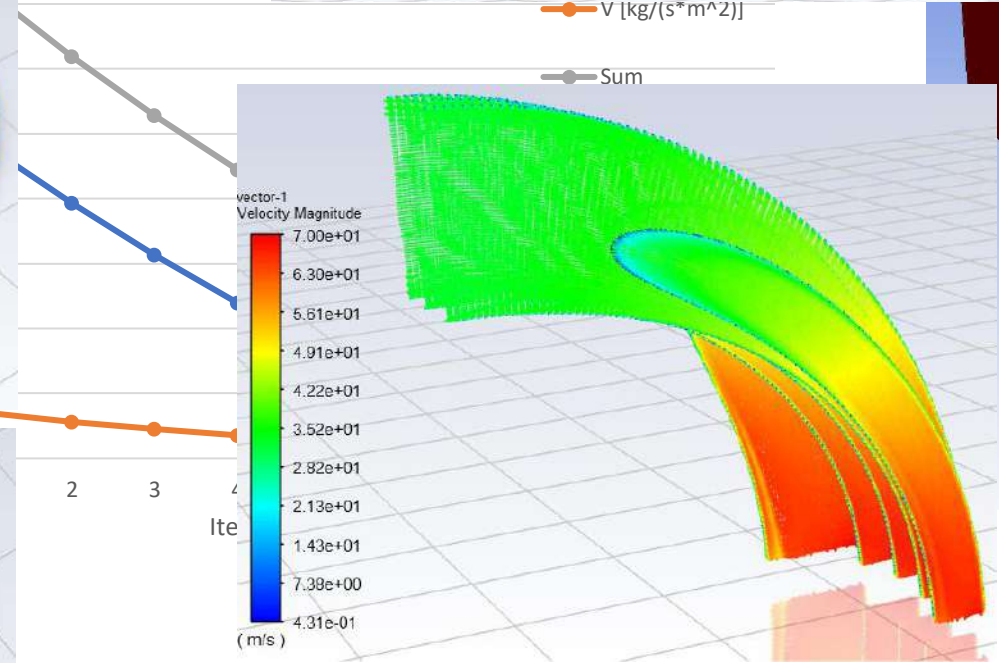
CONVOGLIATORE D'ARIA

Adjoint-preview

194



— V [kg/(s*m^2)]
— Sum



2 3 4
lte

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

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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