Università degli Studi di Padova – Dipartimento di Ingegneria Industriale

Corso di Laurea in Ingegneria Aerospaziale

Relazione per la prova finale «Analisi Fluidodinamica di un Profilo Alare»

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Laureando: *Galtarossa Luca*

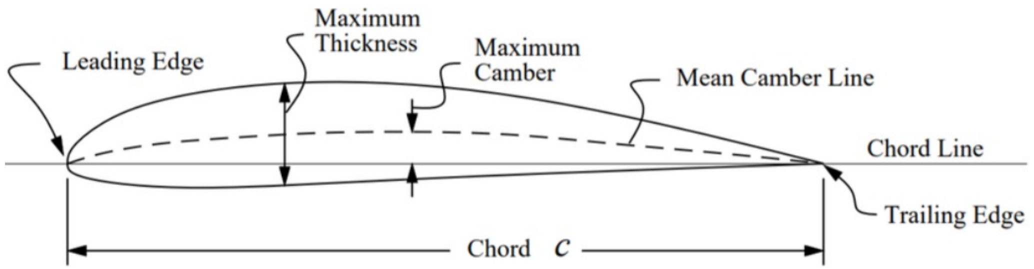
Padova, 24/03/2023

ANSYS FLUENT

XFOIL

CFD:

- Pre-Processor → Dominio e Condizioni al Contorno + Mesh + Fenomeni Fisici e Proprietà Fluidi
- Solver → Metodo dei volumi finiti
- Post-Processor → Geometria e Dominio + Grafici + Animazioni



NACA 0012

$$l = 1\ m \qquad V_\infty = 51.45\ \frac{m}{s} \qquad \rho = 1.1767\ \frac{kg}{m^3} \qquad \mu = 1.009 \cdot 10^{-5}\ \frac{kg}{ms} \quad \Longrightarrow \quad \mathrm{Re} = 6 \cdot 10^6 \qquad \alpha = 10°$$

Ipotesi Flusso: **continuo** **inviscido** **incomprimibile**

Bilancio di massa

$$\frac{dm_{\mathrm{sis}}}{dt} = 0 \quad \Longrightarrow \quad \frac{\mathrm{D}\rho}{\mathrm{D}t} = -\rho \vec{\nabla} \cdot \vec{\mathrm{V}}$$

Bilancio della quantità di moto

$$\frac{d\vec{\mathrm{P}}_{\mathrm{sis}}}{dt} = \vec{\mathrm{F}}_e \quad \Longrightarrow \quad \rho \frac{\mathrm{D}\vec{\mathrm{V}}}{\mathrm{D}t} = \rho \vec{g} - \vec{\nabla} p + \vec{\nabla} \cdot \vec{\vec{\Sigma}}$$

Equazioni Navier-Stokes

Incomprimibili

$$\vec{\nabla} \cdot \vec{\mathrm{V}} = 0 \qquad \rho \frac{\mathrm{D}\vec{\mathrm{V}}}{\mathrm{D}t} = \rho \vec{g} - \vec{\nabla} p + \mu \nabla^2 \vec{\mathrm{V}}$$

In forma adimensionale

$$\vec{\nabla} \cdot \vec{\mathrm{V}} = 0 \qquad \frac{\mathrm{D}\vec{\mathrm{V}}}{\mathrm{D}t} = -\vec{\nabla} p + \frac{1}{\mathrm{Re}} \nabla^2 \vec{\mathrm{V}}$$

Equazione di Eulero:

$$\mathrm{Re} \to \infty \quad \Longrightarrow \quad \vec{\nabla} \cdot \vec{\mathrm{V}} = 0 \qquad \rho \frac{\mathrm{D}\vec{\mathrm{V}}}{\mathrm{D}t} = -\vec{\nabla} p$$

ANALISI TEORICA

Lungo la direzione del moto:

Equazione di Bernoulli ⟶ $$\frac{1}{2}\rho V^2 + p = \text{cost}$$

Lungo la direzione normale:

$$\frac{\partial p}{\partial n} = \rho \frac{V^2}{R} > 0$$

Dorso

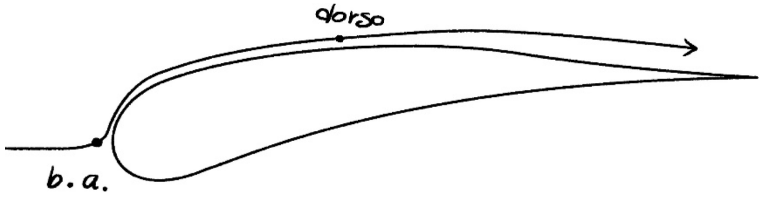
$$\frac{\partial p}{\partial n} = \rho \frac{V^2}{R} \implies \int_{\text{dorso}}^{\infty} \frac{\partial p}{\partial n}\, dn = \int_{\text{dorso}}^{\infty} \rho \frac{V^2}{R}\, dn > 0 \implies p_\infty - p_{\text{dorso}} > 0 \implies p_\infty > p_{\text{dorso}}$$

$$\frac{1}{2}\rho V_\infty^2 + p_\infty = \frac{1}{2}\rho V_{\text{dorso}}^2 + p_{\text{dorso}} \implies |V_{\text{dorso}}| > |V_\infty|$$

B.A.

$$\int_{\infty}^{\text{b.a.}} \frac{\partial p}{\partial n}\, dn = \int_{\infty}^{\text{b.a.}} \rho \frac{V^2}{R}\, dn \implies p_{\text{b.a.}} - p_\infty > 0 \implies p_{\text{b.a.}} > p_\infty$$

$$\frac{1}{2}\rho V_\infty^2 + p_\infty = \frac{1}{2}\rho V_{\text{b.a.}}^2 + p_{\text{b.a.}} \implies |V_{\text{b.a.}}| < |V_\infty|$$



+ Irrotazionalità ⟶ **Teorema di Bernoulli:** $$\frac{1}{2}\rho V^2 + p = \text{cost}\ \textit{ovunque}$$

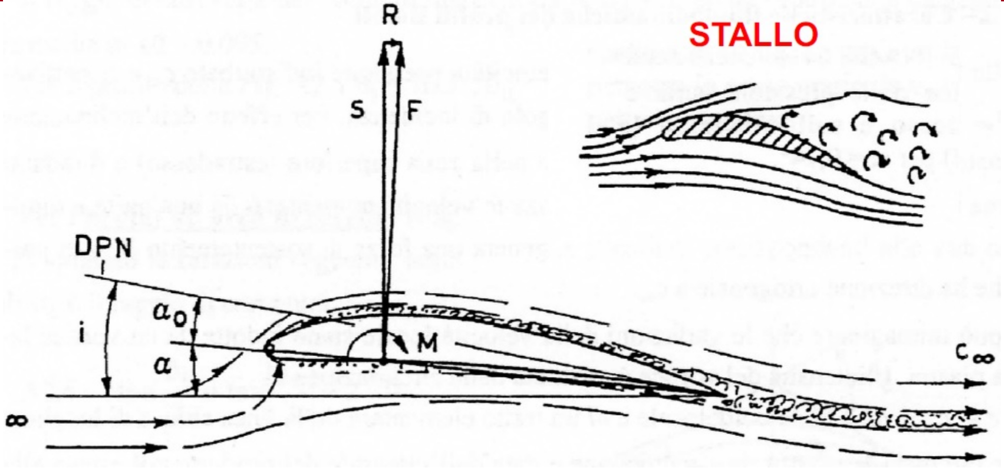
ANALISI TEORICA

Strato limite ⟶ Viscosità non trascurabile

Equazione di Eulero in forma adimensionale

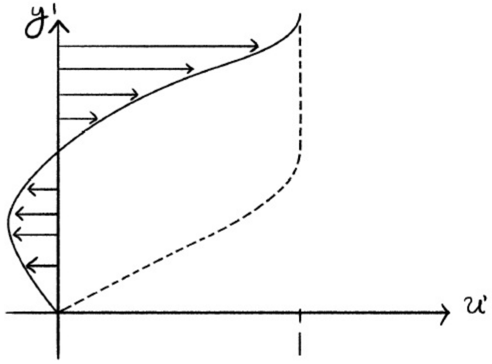
$$\frac{\partial \mathrm{P}^*_{e,0}}{\partial x^*} = -\mathrm{U}^*_{e,0}\frac{\partial \mathrm{U}^*_{e,0}}{\partial x^*} = \left.\frac{\partial^2 u'}{\partial y'^2}\right|_{y'=0}$$

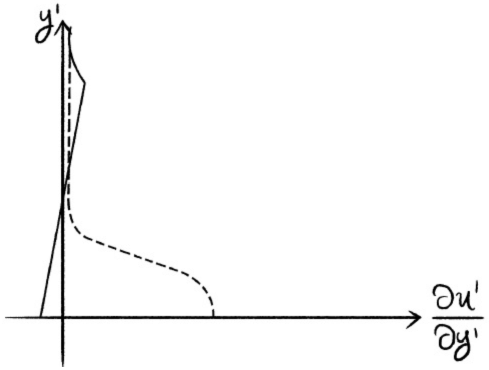
$$\frac{d\mathrm{P}^*_{e,0}}{dx^*} \ggg 0 \implies \left.\frac{\partial^2 u'}{\partial y'^2}\right|_{y'=0} \ggg 0 \implies \left.\frac{\partial u'}{\partial y'}\right|_{y'=0} = 0$$

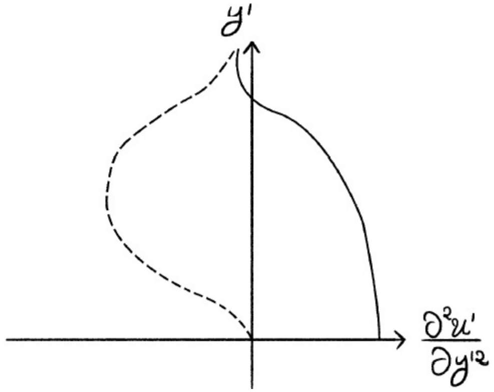


$$c_{\mathrm{L}} = 2\pi(\alpha - \alpha_0) \sim 1.1$$

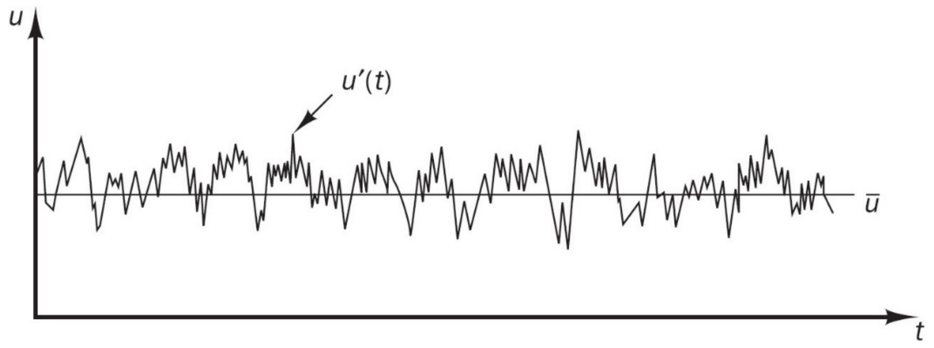
$\alpha[°]$	c_{L}	c_{D}
10.12	1.07	0.012
10.18	1.08	0.012







Ansys Fluent – Modello Matematico



$$u(t) = \overline{u} + u'(t)$$

Reynolds-Averaged continuity equation

$$\frac{\partial \overline{u}}{\partial x} + \frac{\partial \overline{v}}{\partial y} = 0$$

Reynolds-Averaged Navier-Stokes (RANS) equation

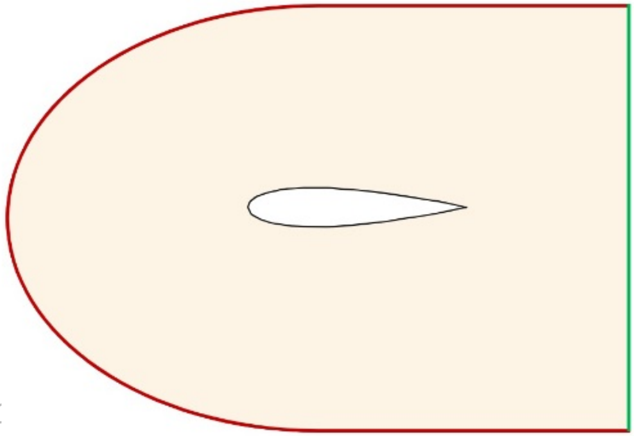
$$\rho \frac{\partial \overline{u}}{\partial t} + \rho \left(\overline{u} \frac{\partial \overline{u}}{\partial x} + \overline{v} \frac{\partial \overline{u}}{\partial y} \right) = -\frac{\partial \overline{p}}{\partial x} + \mu \nabla^2 \overline{u} + \left(\frac{\partial \tau^t_{xx}}{\partial x} + \frac{\partial \tau^t_{xy}}{\partial y} \right)$$

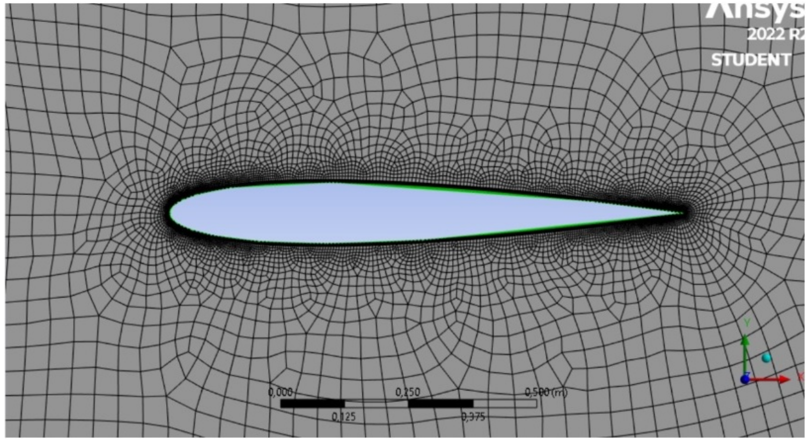
↓

$$\rho \left(\overline{u} \frac{\partial \overline{u}}{\partial x} + \overline{v} \frac{\partial \overline{u}}{\partial y} \right) = -\frac{\partial \overline{p}}{\partial x} + \mu \nabla^2 \overline{u} + \overline{f}_{turb,x}$$

k-ε model: $\mu_t = f(k^2, \varepsilon)$

$$k \uparrow \;\Longrightarrow\; \mu_t \uparrow\uparrow \qquad \varepsilon \uparrow \;\Longrightarrow\; \mu_t \downarrow$$





Condizioni al contorno

+

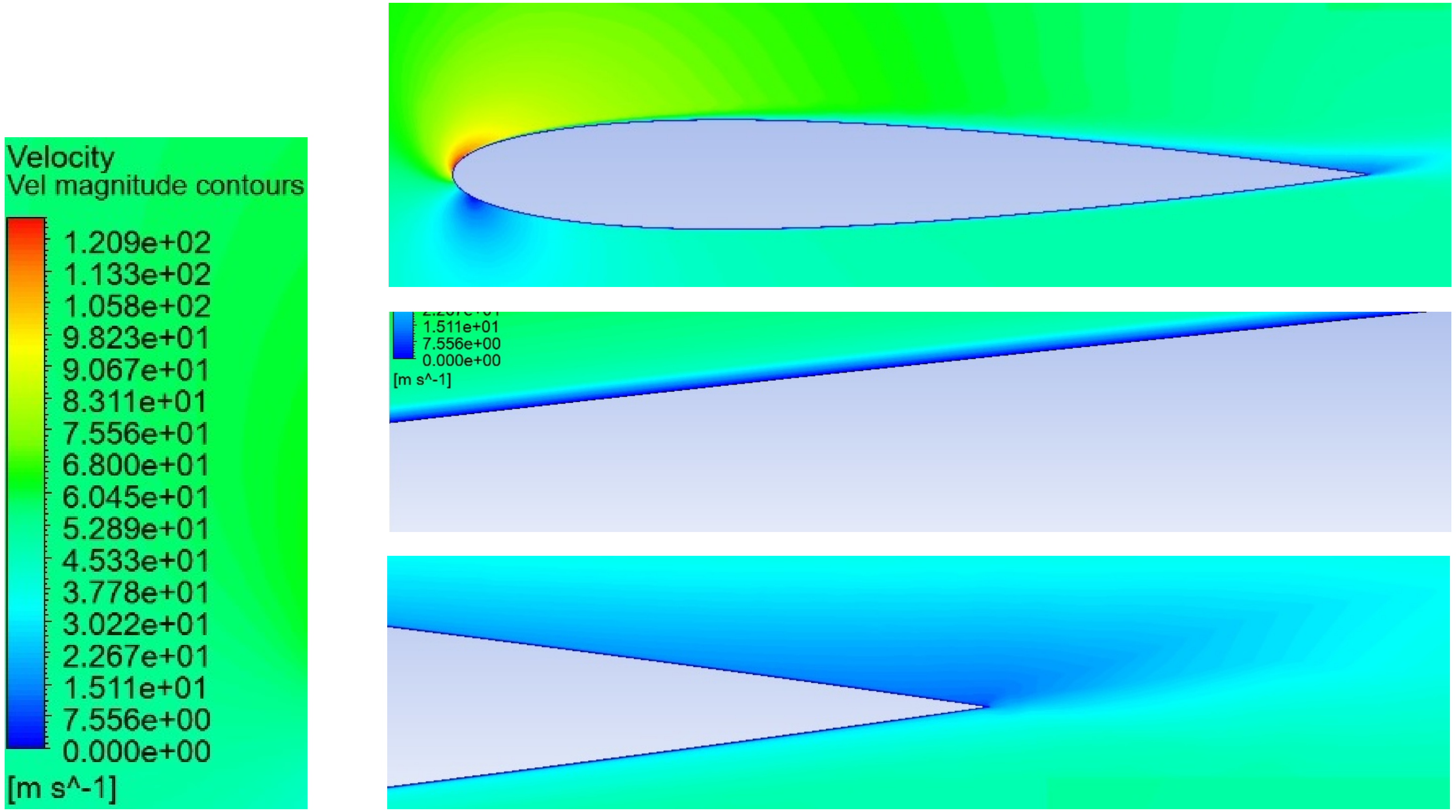
turbolenza

Precisione: 1° ordine 2° ordine

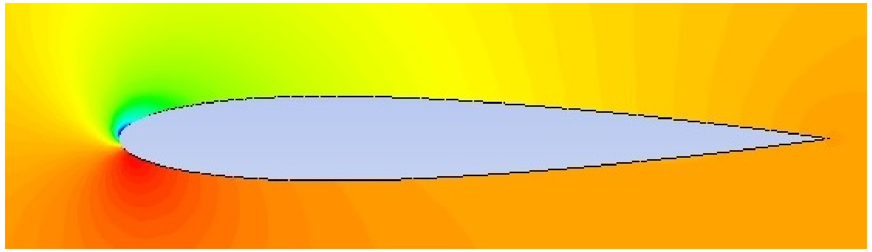
$c_L = 1.0 \qquad c_D = 0.0518$ $\qquad$ $c_L = 1.06 \qquad c_D = 0.017$

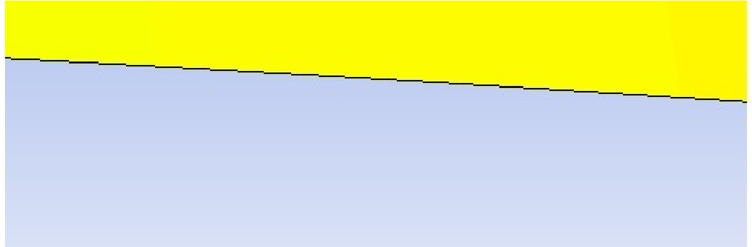
Studio della velocità

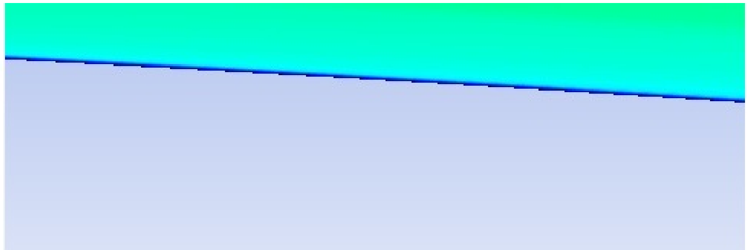
- *Area di ristagno*
- *Suction peak*
- *Trailing Edge*

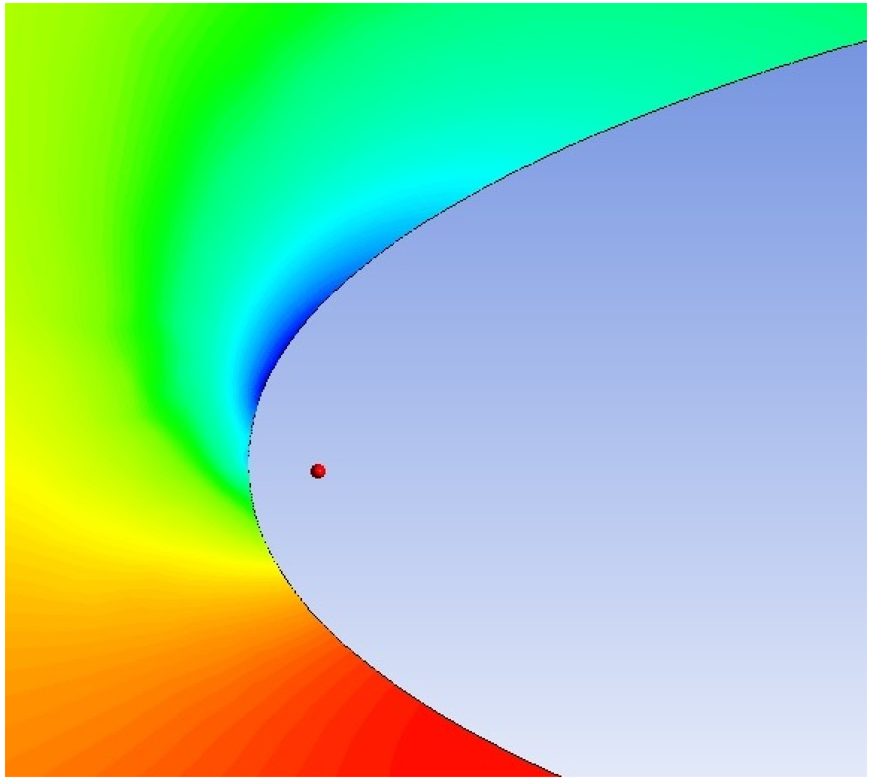


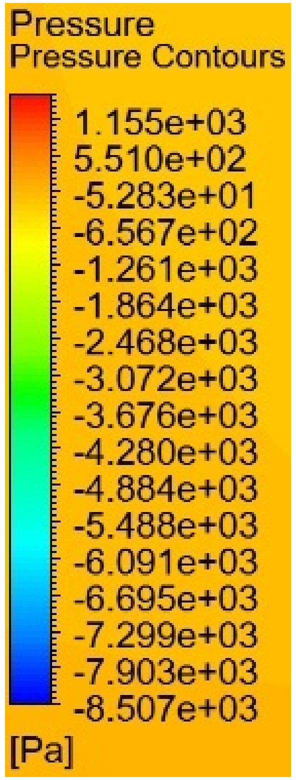
Studio della pressione

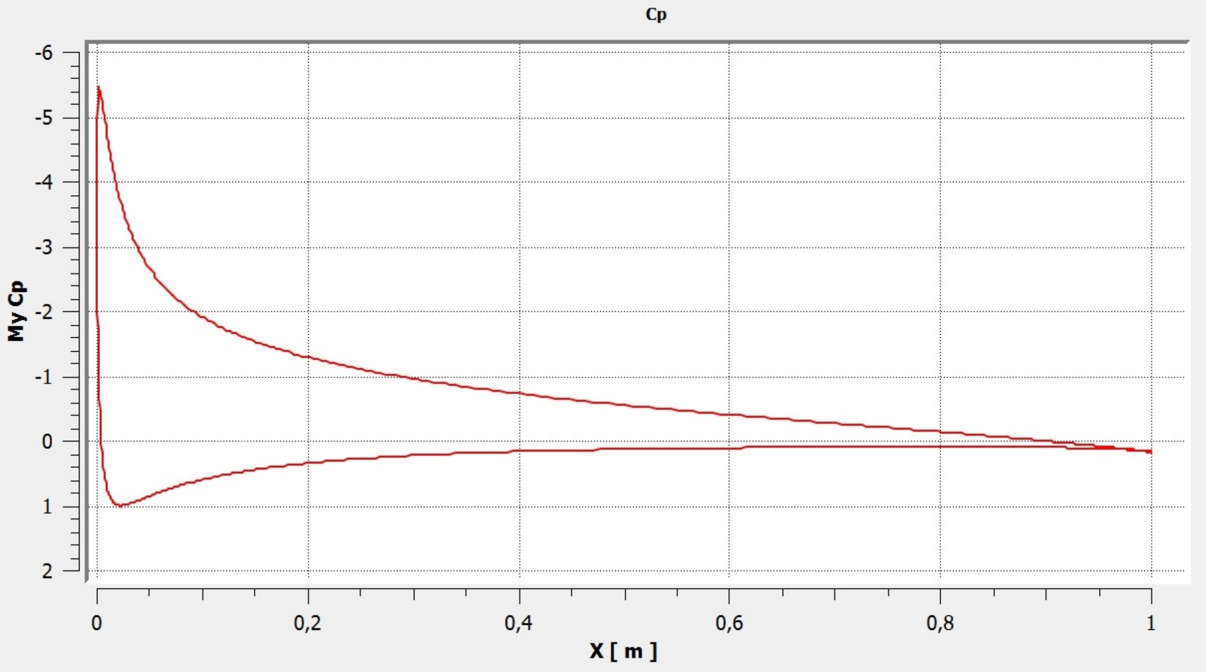










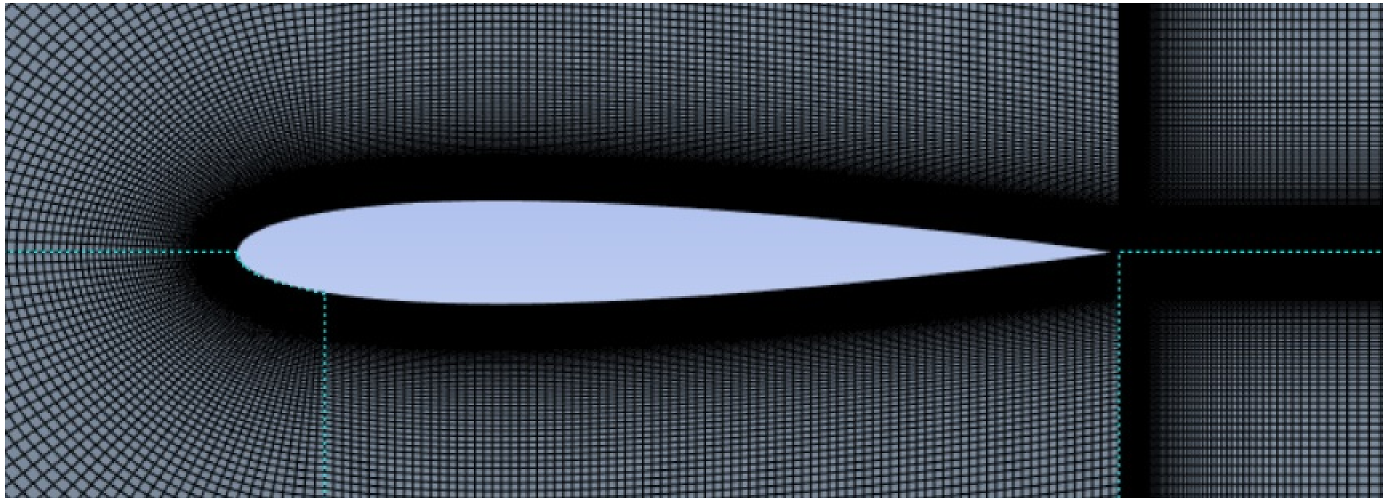


ANSYS FLUENT – VALIDAZIONE DELLA MESH

112000 elementi

Migliore orthogonal quality

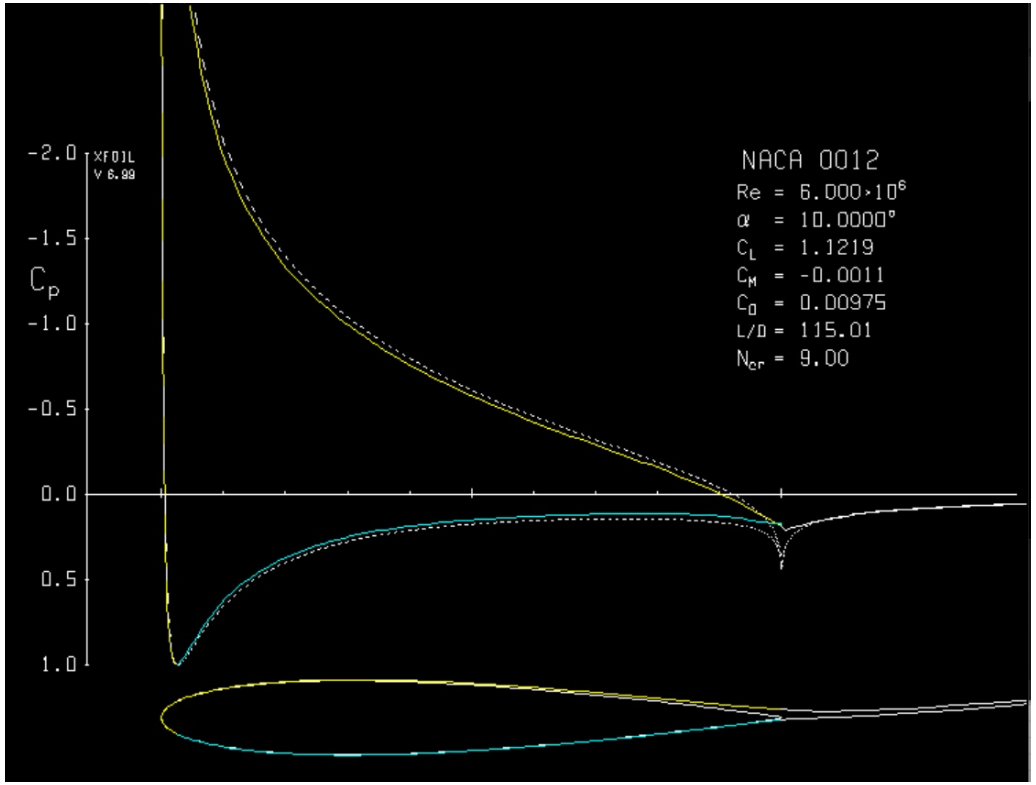
$c_{\mathrm{L}} = 1.072 \qquad c_{\mathrm{D}} = 0.015$

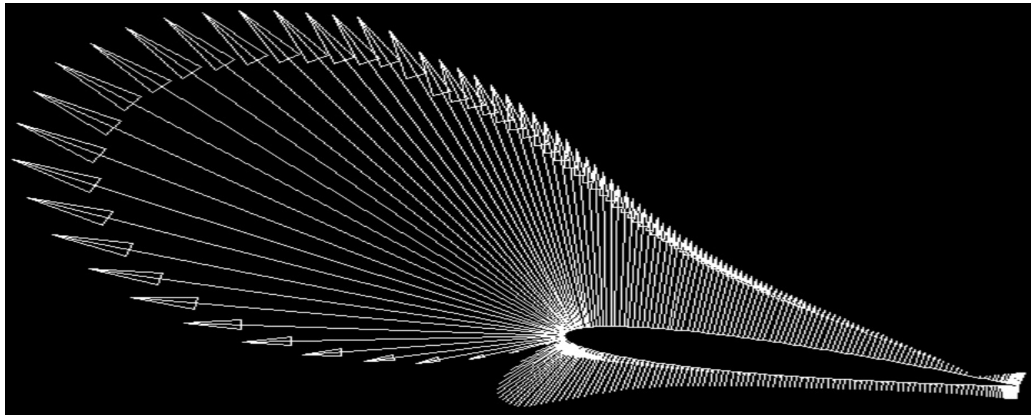


iter	continuity	x-velocity	y-velocity	k	epsilon	cd-1	cl-1	time/iter	
2228	4.9150e-11	1.0566e-13	2.2764e-14	3.4623e-07	2.2253e-06	1.5097e-02	1.0727e+00	0:00:06	10
2229	4.9132e-11	1.0562e-13	2.2755e-14	3.4607e-07	2.2243e-06	1.5097e-02	1.0727e+00	0:00:06	9
2230	4.9110e-11	1.0558e-13	2.2746e-14	3.4591e-07	2.2232e-06	1.5097e-02	1.0727e+00	0:00:04	8
2231	4.9091e-11	1.0553e-13	2.2737e-14	3.4574e-07	2.2221e-06	1.5097e-02	1.0727e+00	0:00:04	7
2232	4.9072e-11	1.0549e-13	2.2727e-14	3.4558e-07	2.2210e-06	1.5097e-02	1.0727e+00	0:00:03	6
2233	4.9054e-11	1.0545e-13	2.2718e-14	3.4542e-07	2.2199e-06	1.5097e-02	1.0727e+00	0:00:03	5
2234	4.9032e-11	1.0541e-13	2.2709e-14	3.4526e-07	2.2189e-06	1.5097e-02	1.0727e+00	0:00:02	4
2235	4.9013e-11	1.0536e-13	2.2700e-14	3.4509e-07	2.2178e-06	1.5097e-02	1.0727e+00	0:00:02	3
2236	4.8994e-11	1.0532e-13	2.2691e-14	3.4493e-07	2.2167e-06	1.5097e-02	1.0727e+00	0:00:01	2
2237	4.8974e-11	1.0528e-13	2.2681e-14	3.4477e-07	2.2157e-06	1.5097e-02	1.0727e+00	0:00:01	1
2238	4.8955e-11	1.0524e-13	2.2672e-14	3.4461e-07	2.2146e-06	1.5097e-02	1.0727e+00	0:00:00	0

XFOIL

```
Side 1  free  transition at x/c =  0.0158   38
Side 2  free  transition at x/c =  0.9920  102

 15   rms: 0.5258E-01   max: -.6714E+00   T at  102  2   RLX: 0.745
      a = 10.000       CL =  1.1165
     Cm =  0.0001      CD =  0.00979   =>   CDf =  0.00455    CDp =  0.00523

Side 1  free  transition at x/c =  0.0160   38
Side 2  free  transition at x/c =  0.9992  106

 16   rms: 0.7584E-02   max: -.6904E-01   D at  101  2
      a = 10.000       CL =  1.1220
     Cm = -0.0011      CD =  0.00975   =>   CDf =  0.00455    CDp =  0.00521

Side 1  free  transition at x/c =  0.0159   38
Side 2  free  transition at x/c =  0.9991  106

 17   rms: 0.1318E-03   max: 0.2171E-02   C at  106  2
      a = 10.000       CL =  1.1219
     Cm = -0.0011      CD =  0.00975   =>   CDf =  0.00455    CDp =  0.00520

Side 1  free  transition at x/c =  0.0159   38
Side 2  free  transition at x/c =  0.9991  106

 18   rms: 0.8490E-06   max: -.7596E-05   D at  106  2
      a = 10.000       CL =  1.1219
     Cm = -0.0011      CD =  0.00975   =>   CDf =  0.00455    CDp =  0.00520
```





Risultato: $c_L = 1.1219$ $c_D = 0.00975$

CONCLUSIONI

Xfoil : $\frac{c_{L_{\text{Xfoil}}}}{c_{L_{\text{atteso}}}} = \frac{1.1219}{1.1} = 1.0199 = 101.99\%$ $\frac{c_{D_{\text{Xfoil}}}}{c_{D_{\text{atteso}}}} = \frac{0.00975}{0.012} = 0.8125\% = 81.25\%$

Ansys : $\frac{c_{L_{\text{ANSYS}}}}{c_{L_{\text{atteso}}}} = \frac{1.0727}{1.1} = 0.9751 = 97.51\%$ $\frac{c_{D_{\text{ANSYS}}}}{c_{D_{\text{atteso}}}} = \frac{0.015097}{0.012} = 1.2581\% = 125.81\%$

Software	c_L	c_D
Ansys Fluent	sottostimato	sovrastimato
Xfoil	sovrastimato	sottostimato

→ Fattore di sicurezza

Software	iterazioni	tempo di calcolo	Post-Processing
Ansys Fluent	oltre 2000	massimo 1 ora	Sì
Xfoil	18	qualche secondo	No