Università degli Studi di Genova

Corso di Laurea in Ingegneria Meccanica - Energia e Aeronautica
Dipartimento di Ingegneria Civile, Chimica
e Ambientale

Riduzione della resistenza fluidodinamica mediante riblets frattali

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Relatore:

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INTRODUZIONE – Riduzione della resistenza fluidodinamica

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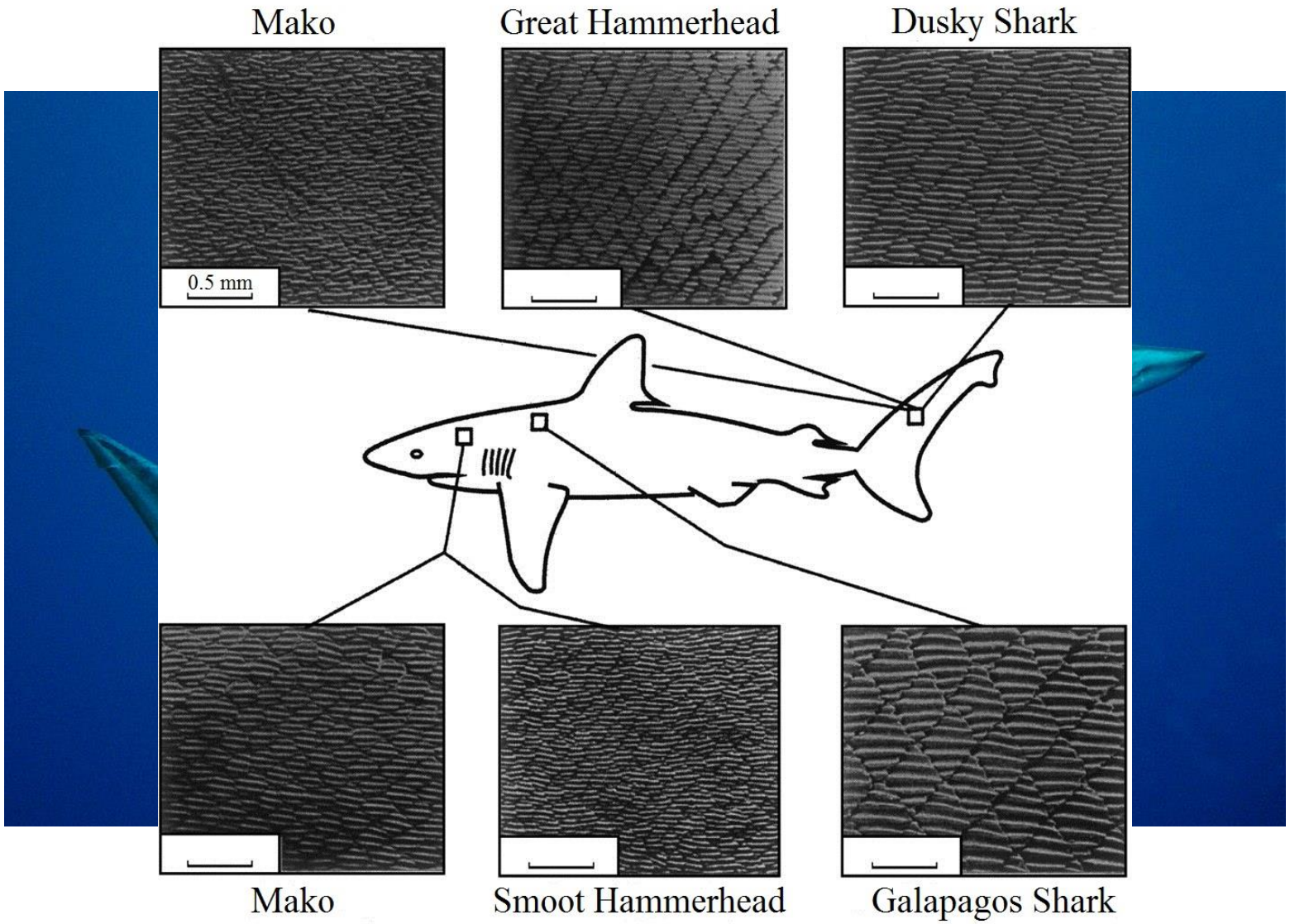
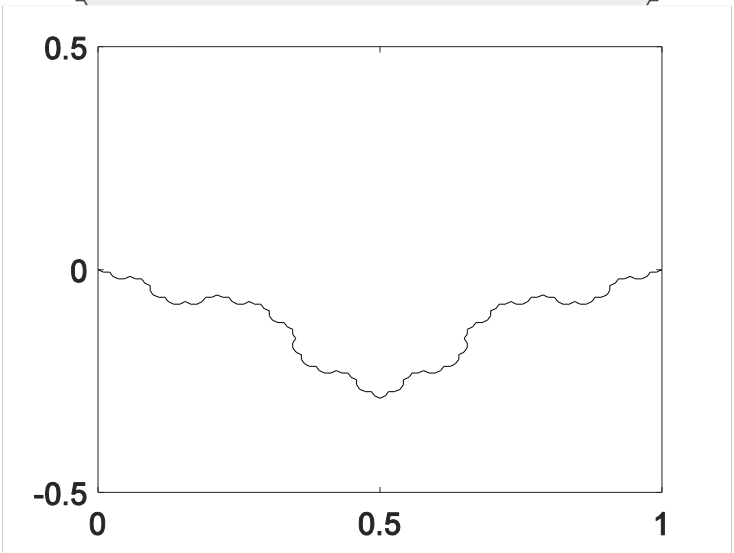


INTRODUZIONE – Le Riblets

Studiare numericamente
l'**influenza delle nano-strutture sull'efficacia dei riblets.**

Frattale
figura dotata di autosimilarità interna

1. Prendere un semplice riblet
2. Dividere ogni lato in tre parti
3. Sostituire il segmento centrale con un riblet scalato



INTRODUZIONE – Approccio al problema

Calcolo numerico del drag
su riblets semplici e riblets frattali

Difficoltà con approcci standard:

- Mesh estremamente fine
- Tempi di simulazione lunghi

Divisione del problema in due parti

Problema Microscopico
Flusso in prossimità della parte

Problema Macroscopico
Flusso lontano dalla parete

PROBLEMA MICROSCOPICO – Formulazione matematica

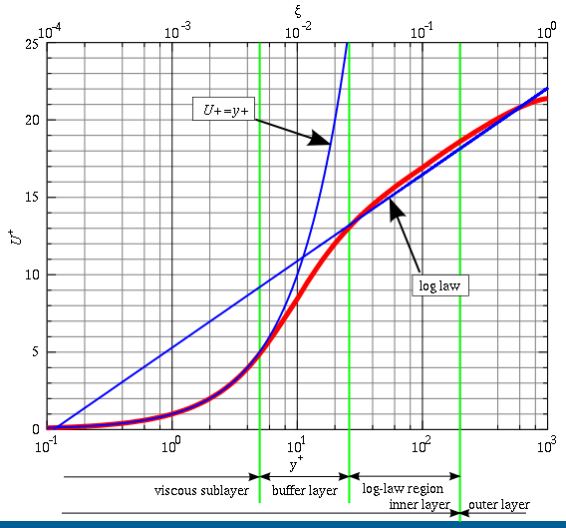
Ipotesi sul fluido :

Equazione di Stokes

Newtoniano, incomprimibile, isotermo

$$St\frac{\partial \hat{\mathbf{u}}}{\partial \hat{t}} + \hat{\nabla}\hat{P} = \hat{\nabla}^2\hat{\mathbf{u}}. \quad \frac{1}{Re}\hat{\nabla}^2\hat{\mathbf{u}},$$

Substrato viscoso



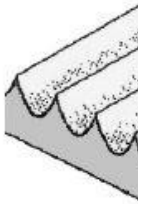
$$St \sim 0$$

$$Re \sim 0$$

PROBLEMA MICROSCOPICO – Formulazione matematica

Ipotesi sulla geometria :

1. Invarianza nella direzione del flusso (z)



$$\begin{bmatrix} \dfrac{\partial P}{\partial x} \\ \\ \dfrac{\partial P}{\partial y} \\ \\ \cancel{\dfrac{\partial P}{\partial z}} \end{bmatrix} = \mu \begin{bmatrix} \dfrac{\partial^2 u}{\partial x^2} + \dfrac{\partial^2 u}{\partial y^2} + \cancel{\dfrac{\partial^2 u}{\partial z^2}} \\ \\ \dfrac{\partial^2 v}{\partial x^2} + \dfrac{\partial^2 v}{\partial y^2} + \cancel{\dfrac{\partial^2 v}{\partial z^2}} \\ \\ \dfrac{\partial^2 w}{\partial x^2} + \dfrac{\partial^2 w}{\partial y^2} + \cancel{\dfrac{\partial^2 w}{\partial z^2}} \end{bmatrix}$$

Longitudin

equazione di L

$$\nabla^2 w = 0$$

asversale

one di Stokes

$$\nabla p = \nabla^2 \mathbf{u}, \mathbf{u} = (u, v)$$

PROBLEMA MICROSCOPICO – Formulazione matematica

Ipotesi sulla geometria :

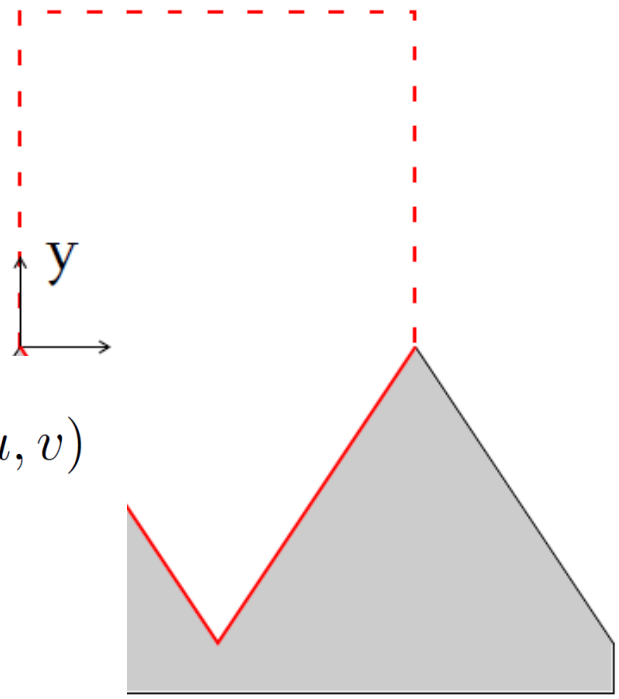
1. Invarianza nella direzione del flusso (z)
2. [illegible]à in direzione trasversale al flusso (x)

Problema Longitudinale :

$$\begin{cases} \nabla^2 w = 0 \\ w(x, y_0) = 0 \\ w_y(x, \infty) = 1 \end{cases}$$

Problema Trasversale :

$$\begin{cases} \nabla p = \nabla^2 \mathbf{u}, \mathbf{u} = (u, v) \\ \mathbf{u}(x, y_0) = (0, 0) \\ u_y(x, \infty) = 1 \end{cases}$$



Boundary Integral Method

Boundary Integral equation per il problema Longitudinale

$$w(\mathbf{x_0}) = \int_C w(\mathbf{x})\mathbf{n} \cdot \nabla G(\mathbf{x}, \mathbf{x_0}) dl - \int_C G(\mathbf{x}, \mathbf{x_0})\mathbf{n} \cdot \nabla w(\mathbf{x}) dl,$$

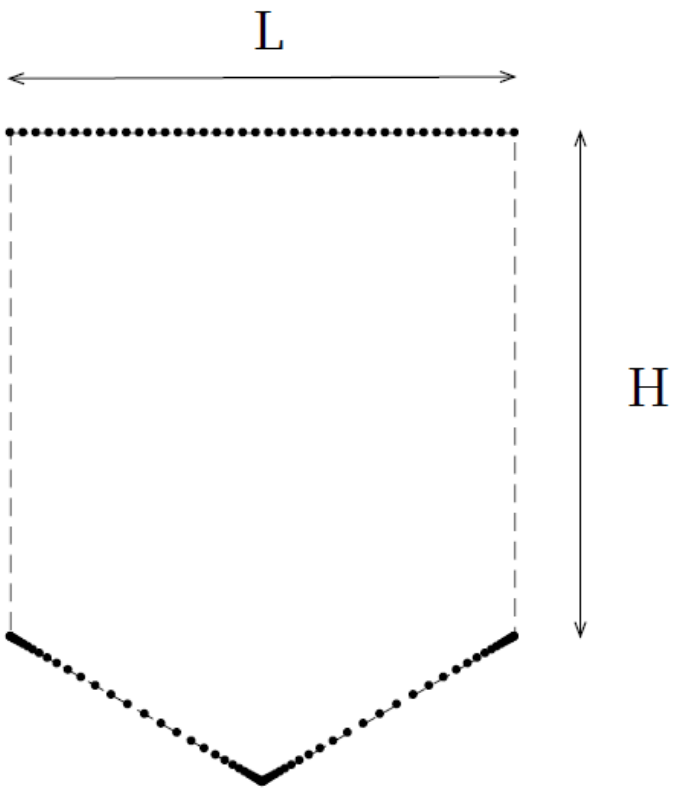
Boundary Integral Equation per il poblema Trasversale

$$u_i(\mathbf{x_0}) = \frac{1}{4\pi} \int_C u_i(\mathbf{x}) T_{ijk}(\mathbf{x}, \mathbf{x_0}) n_j dl - \frac{1}{4\pi\mu} \int_C G_{ik}(\mathbf{x}, \mathbf{x_0}) \sigma_{ij}(\mathbf{x}) n_j dl.$$

PROBLEMA MICROSCOPICO – Metodo numerico

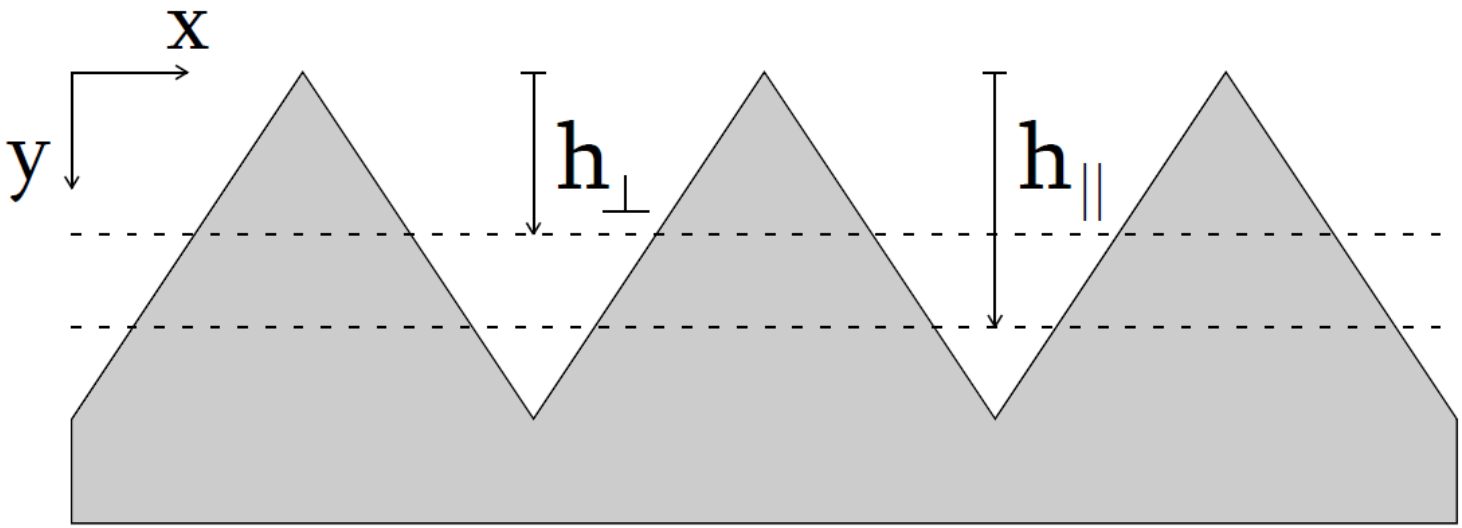
Boundary Element Method

1. Discretizzazione del dominio
2. Interpolazione della funzioni sui punti di discretizzazione



- Funzione di Green periodica
- Correzione dell'errore dovuto alla presenza di spigoli

PROBLEMA MICROSCOPICO – Altezze di protrusione



$$\Delta h = h_{||} - h_{\perp}.$$

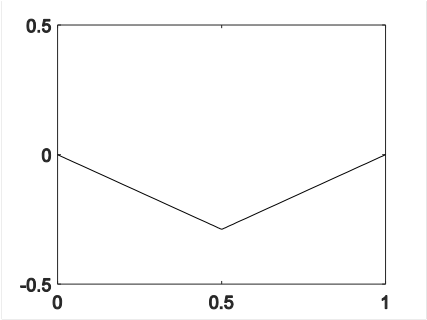
PROBLEMA MICROSCOPICO – Altezze di protrusione

$$h_{\parallel} = \frac{\dfrac{w_{\text{top}}}{\partial w/\partial y\big|_{\text{top}}} - H}{L}$$

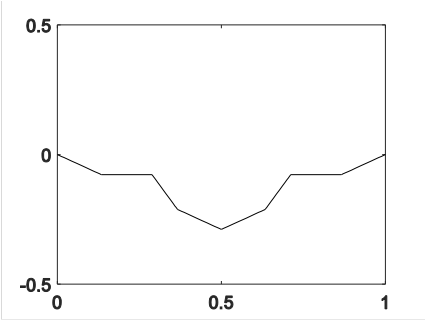
$$h_{\perp} = \frac{\dfrac{v_{\text{top}}}{\partial v/\partial y\big|_{\text{top}}} - H}{L}$$

PROBLEMA MICROSCOPICO – Risultati

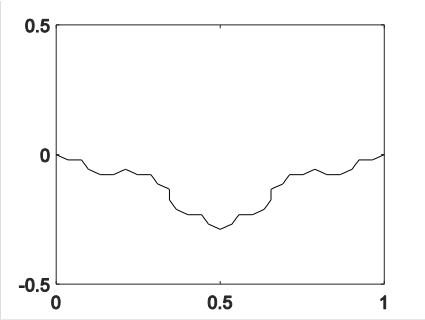
Iterazione 0



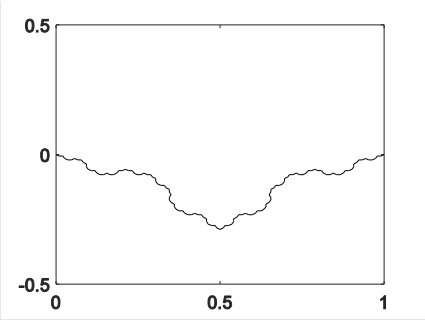
Iterazione 1

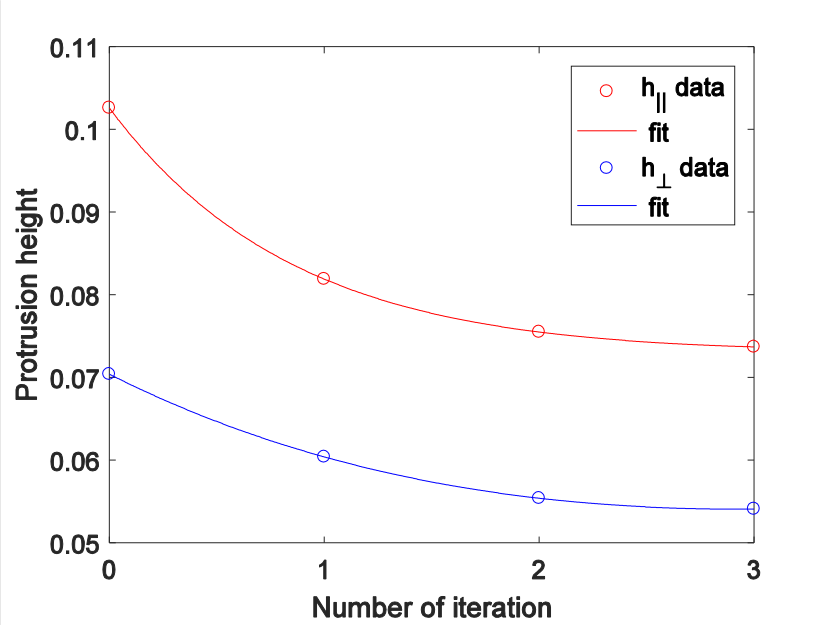


Iterazione 2

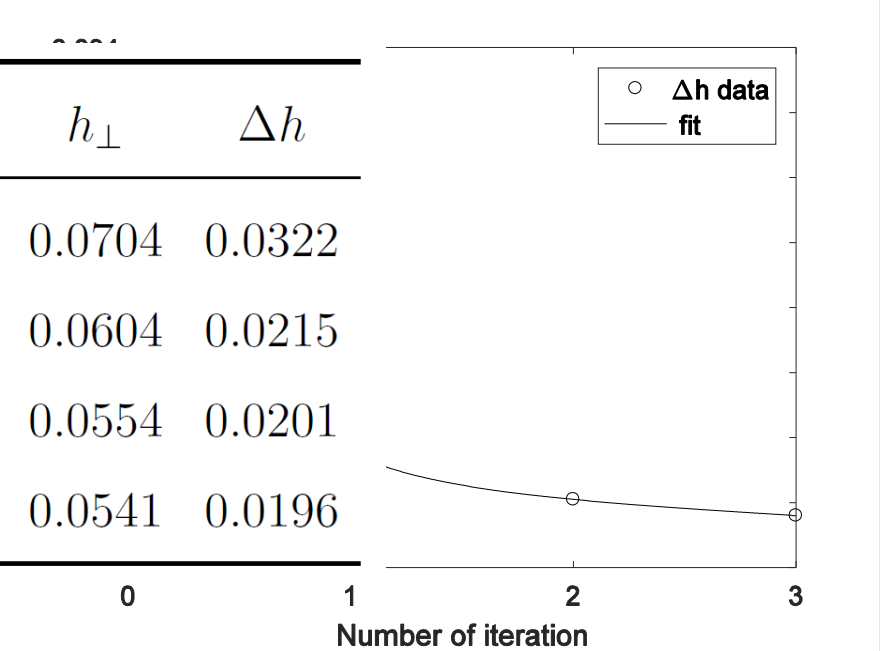


Iterazione 3



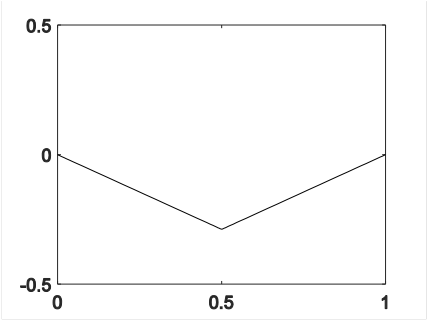


$h_{\parallel}$	$h_{\perp}$	Δh
026	0.0704	0.0322
819	0.0604	0.0215
755	0.0554	0.0201
737	0.0541	0.0196

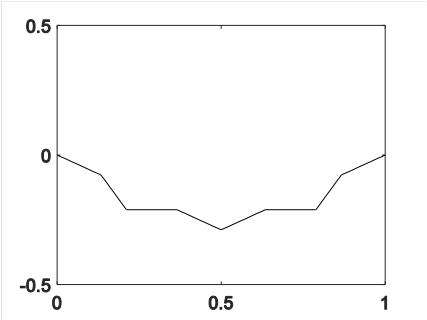


PROBLEMA MICROSCOPICO – Risultati

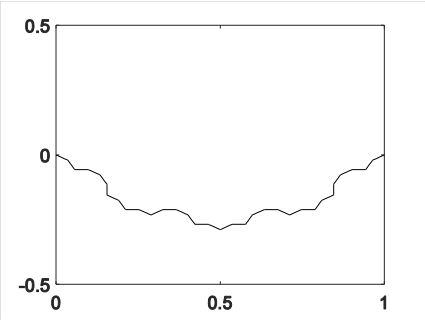
Iterazione 0



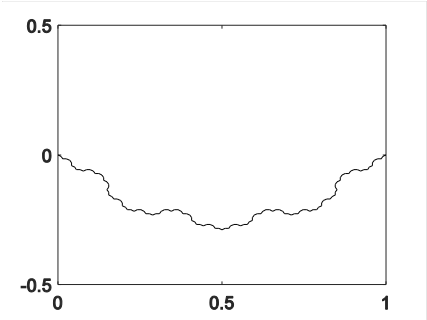
Iterazione 1

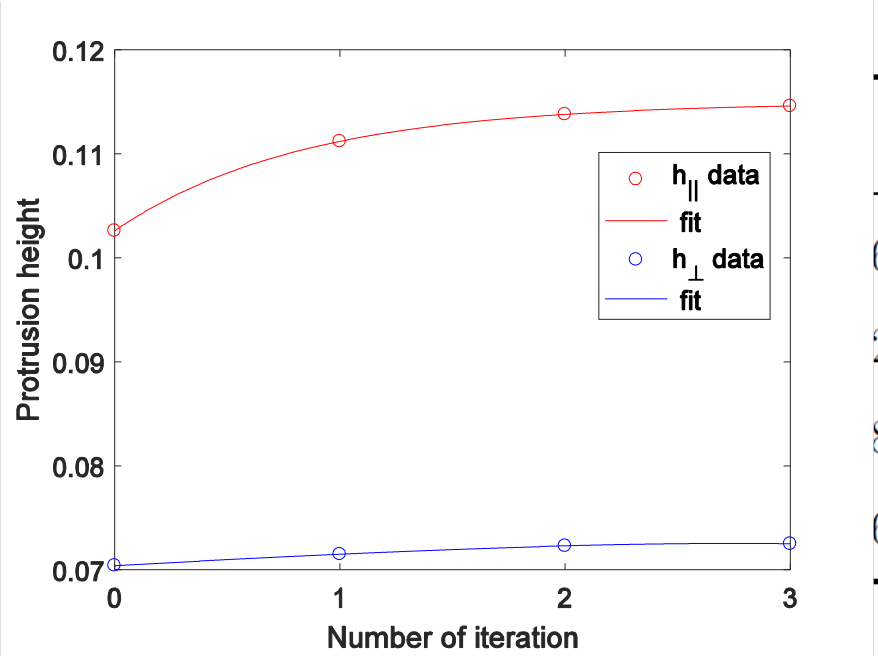


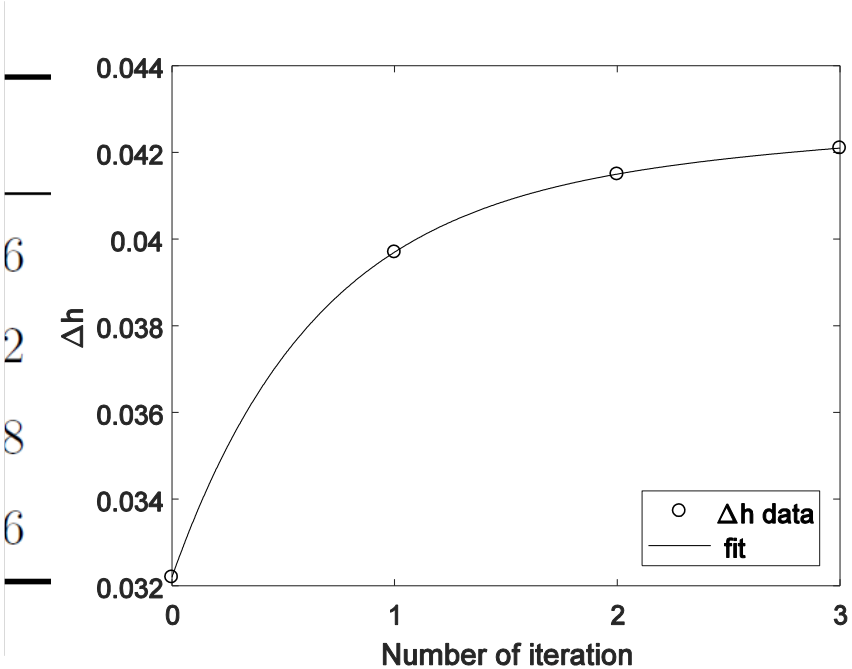
Iterazione 2



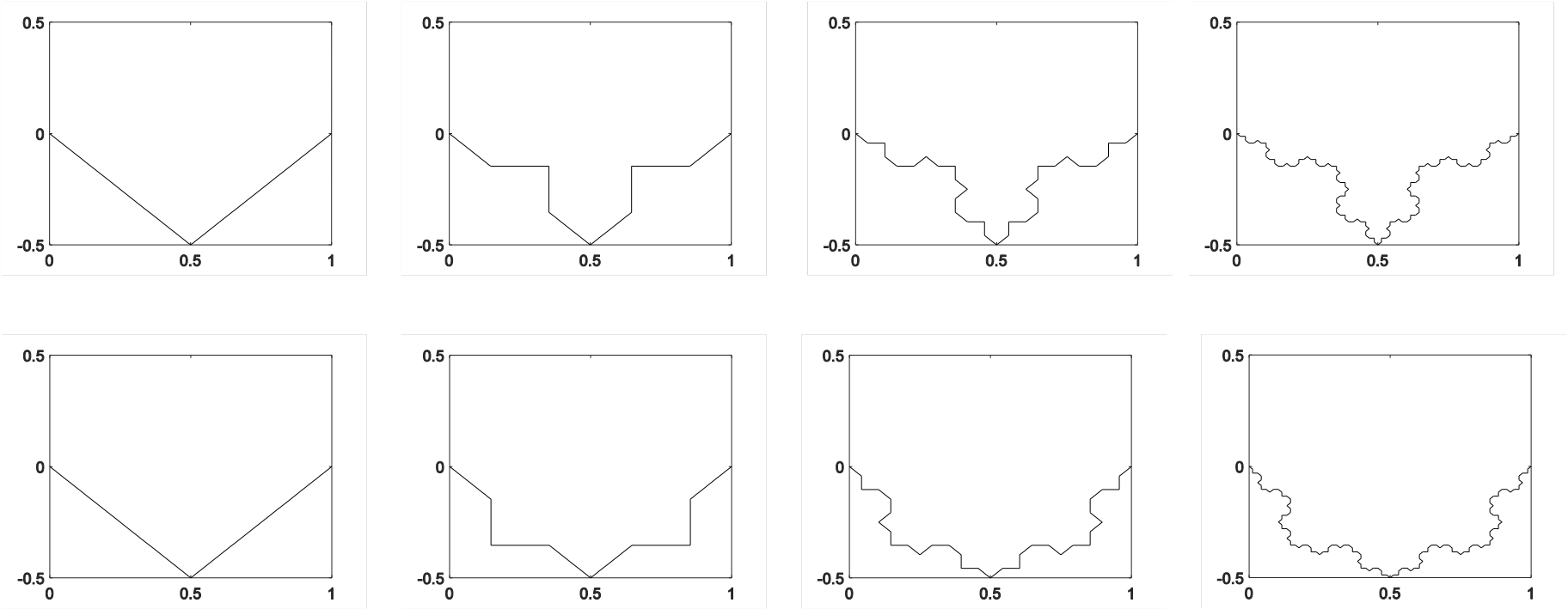
Iterazione 3





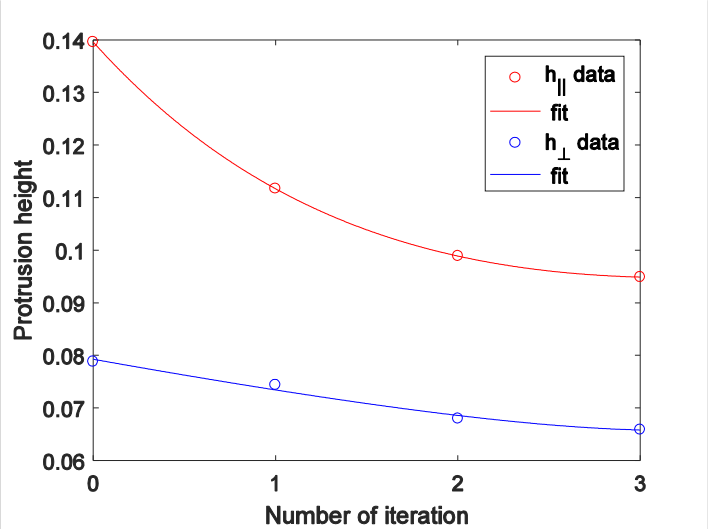


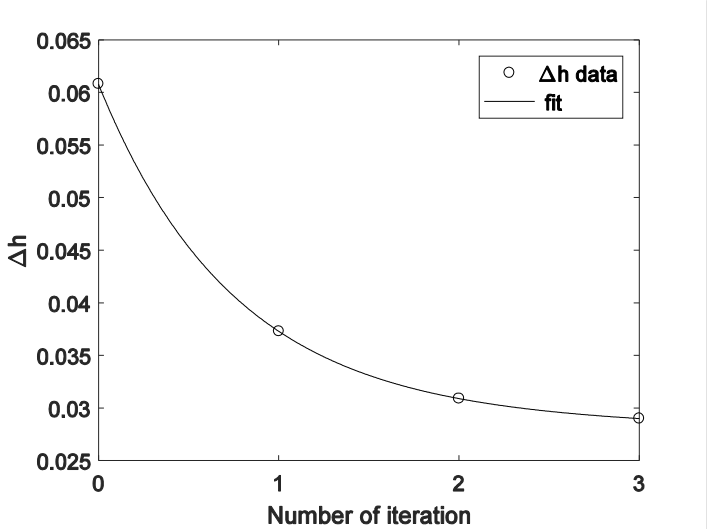
PROBLEMA MICROSCOPICO – Risultati



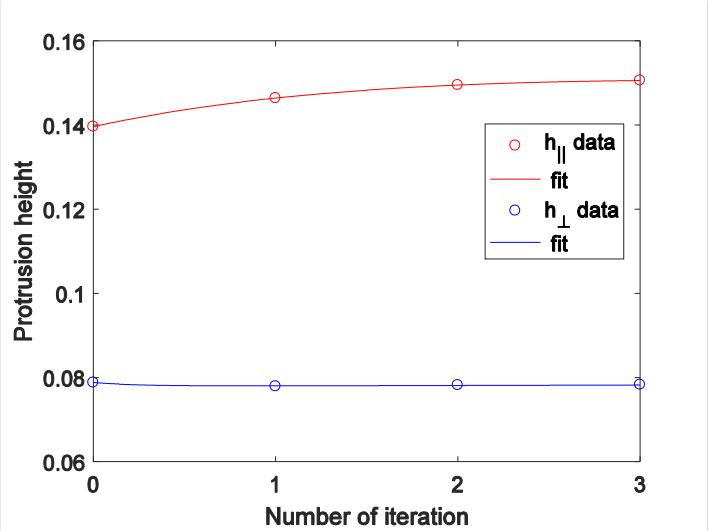
PROBLEMA MICROSCOPICO – Risultati

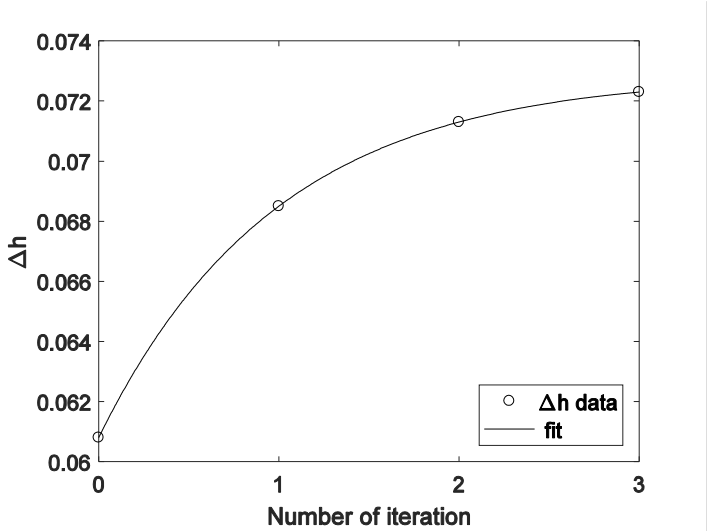
OUTWARD





INWARD



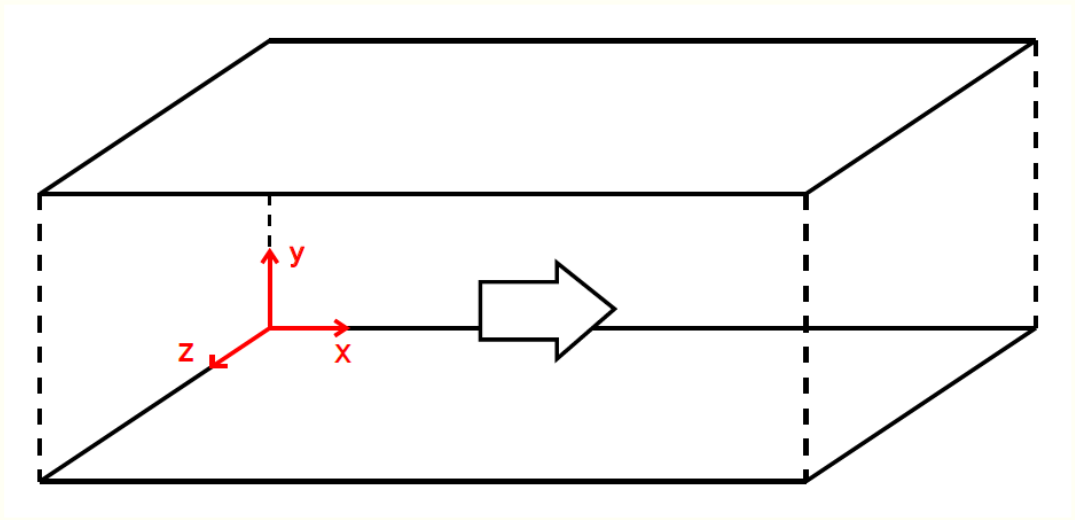


PROBLEMA MACROSCOPICO – Introduzione

Altezze di protrusione → Drag sulle superfici scanalate

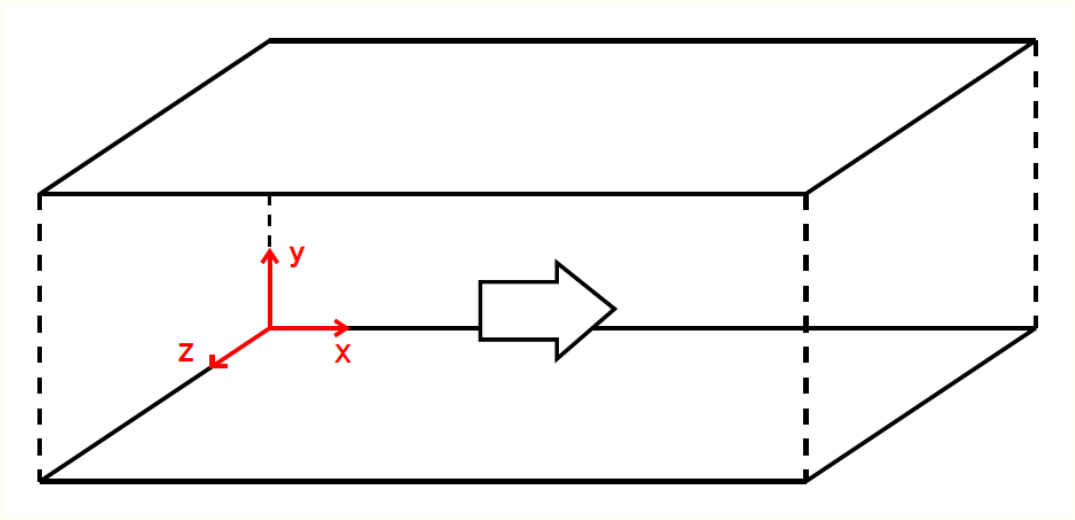
DNS di un canale rettangolare

- Fortran 77
- Volumi Finiti
- Fractional Step

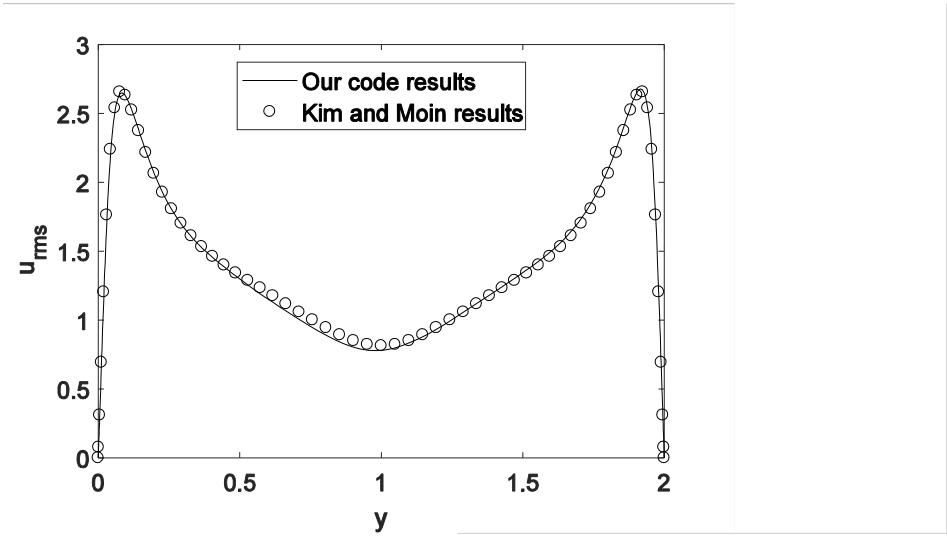


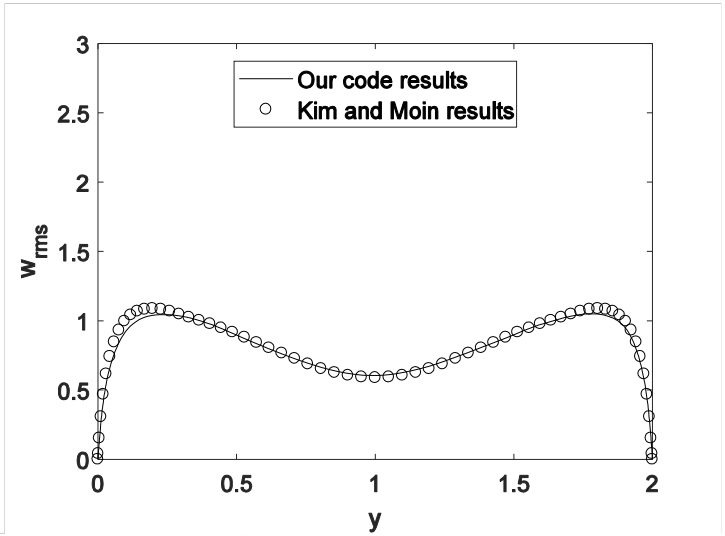
PROBLEMA MACROSCOPICO – Dominio di calcolo

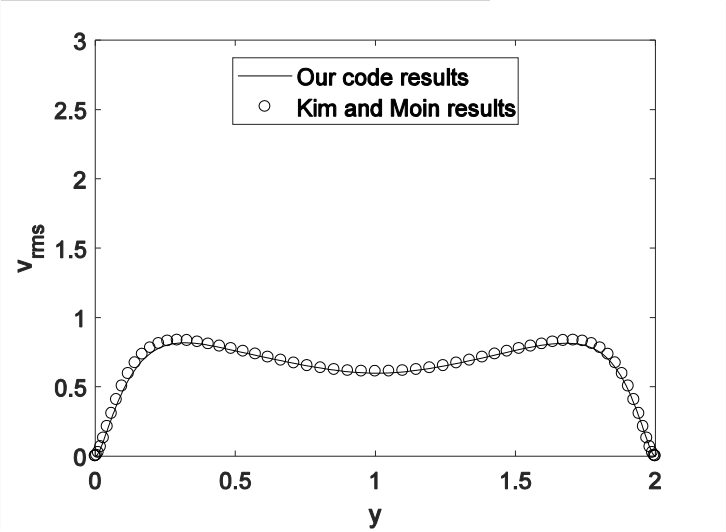
	Canale	Riferimento
Dominio [w.u.]	1106 x 352 x 552	2212 x 352 x 1104
Re_τ	180	180
Griglia	161 x 201 x 129	192 x 129 x 160
Y^+ min	0.0025	0.0050



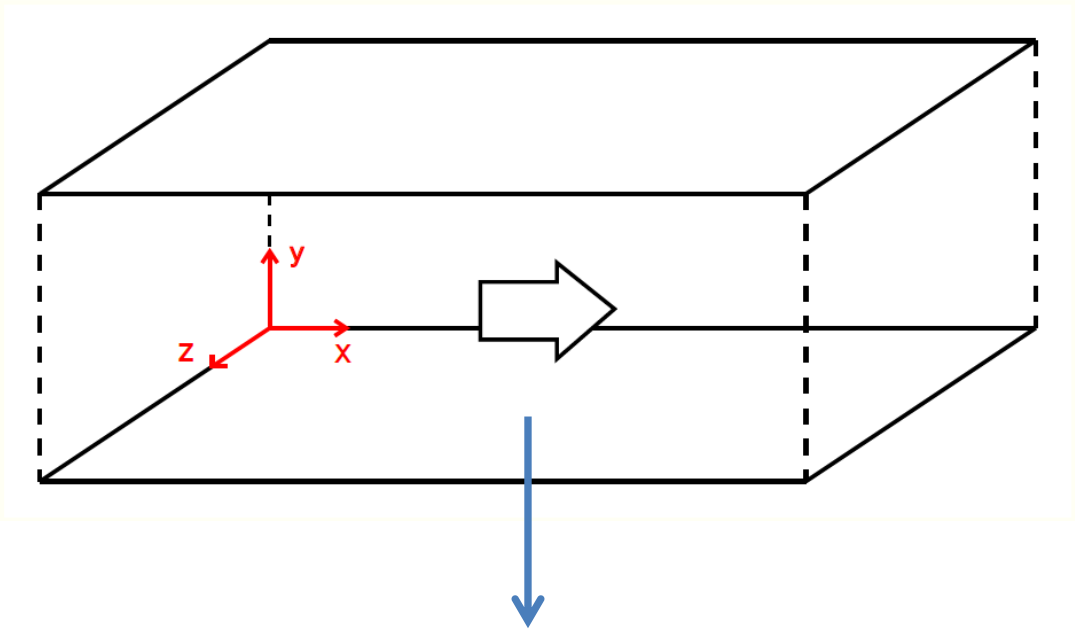
PROBLEMA MACROSCOPICO – Validazione







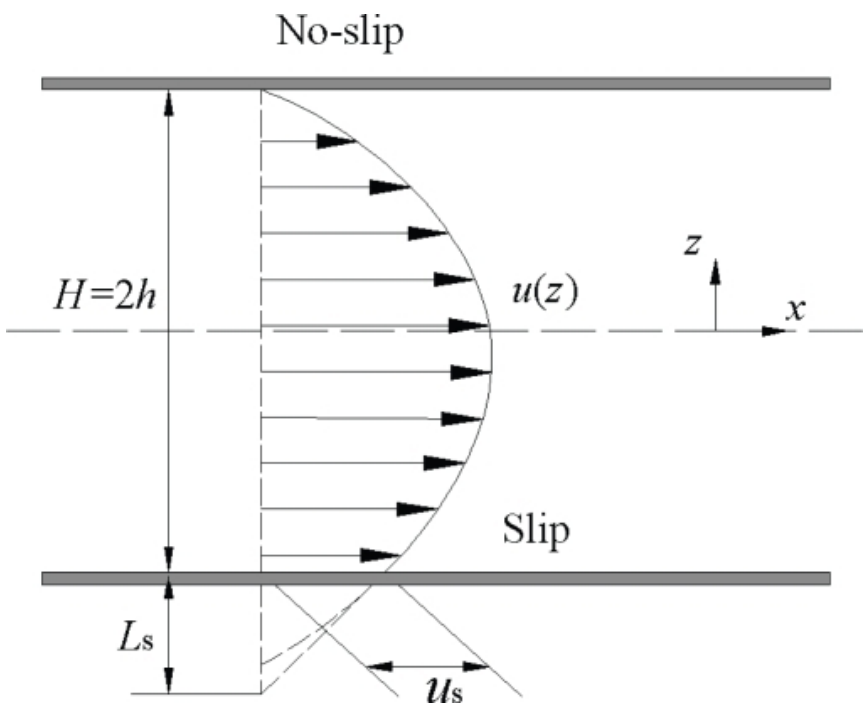
PROBLEMA MACROSCOPICO – Condizioni al contorno



Superficie con le Riblets

Condizioni al contorno di Navier
In direzione x e z

PROBLEMA MACROSCOPICO – Condizioni al contorno



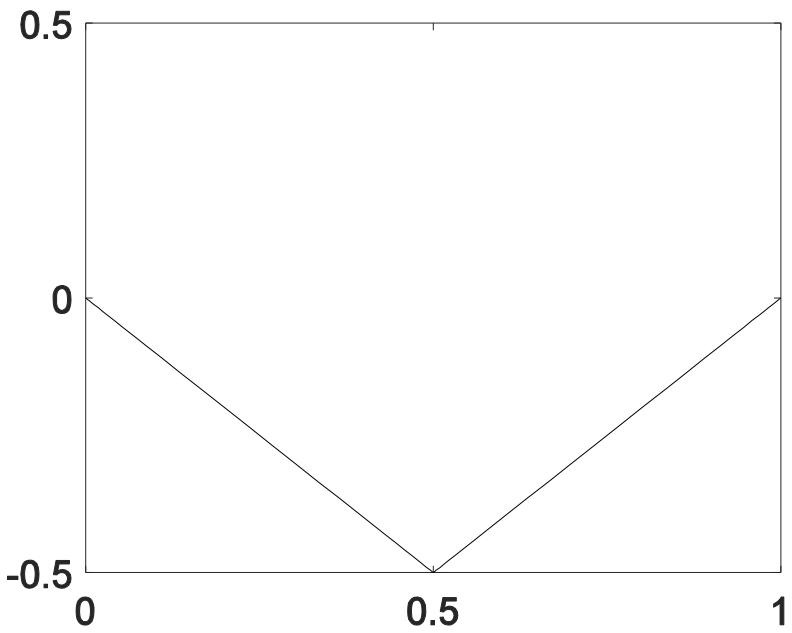
$$u_{\text{wall}} = kh_{||} \left.\frac{\partial u}{\partial y}\right|_{\text{wall}}$$

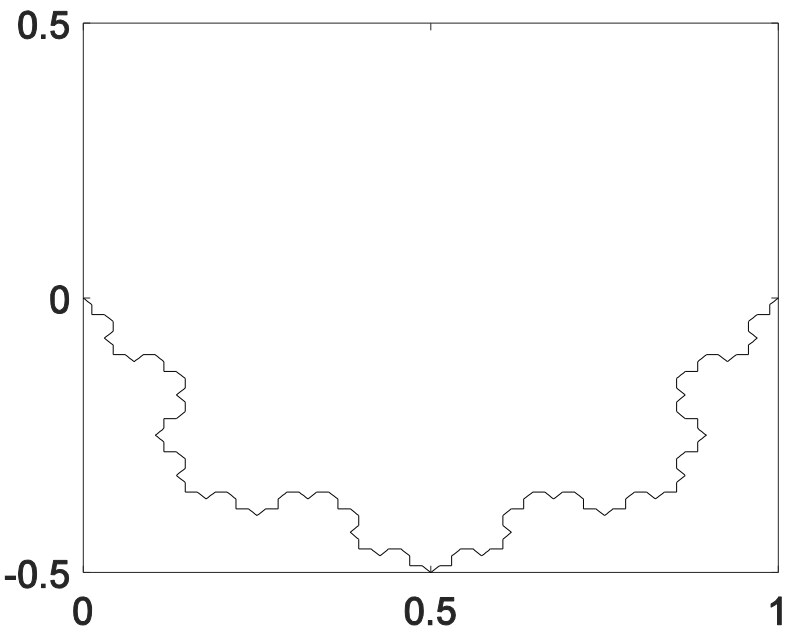
$$v_{wall} = 0$$

$$w_{\text{wall}} = kh_{\perp} \left.\frac{\partial w}{\partial y}\right|_{\text{wall}}$$

k = 0.05 → $b^+ = 10$

PROBLEMA MACROSCOPICO – Risultati



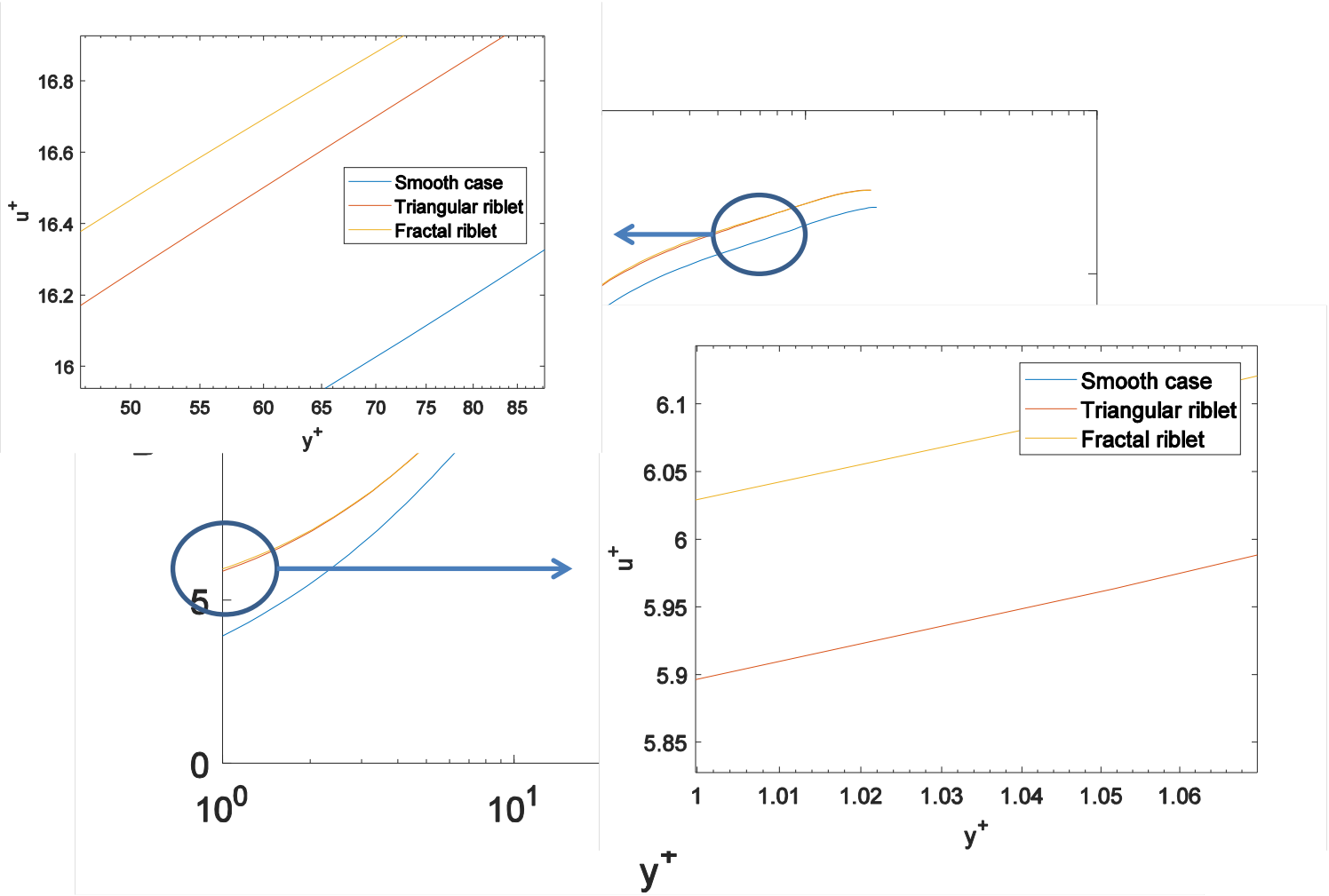


PROBLEMA MACROSCOPICO – Risultati

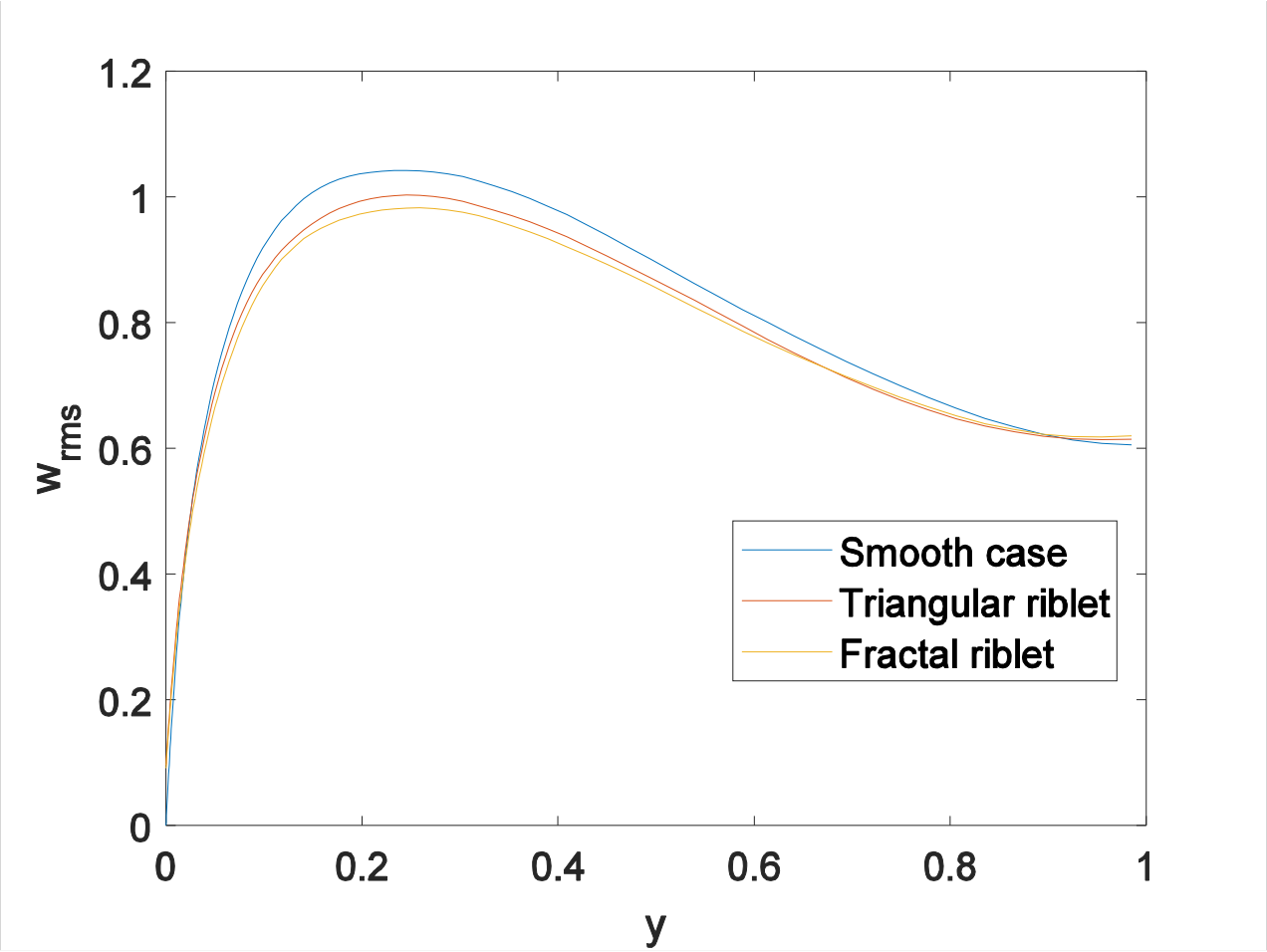
$$DR = \frac{\overline{\frac{\partial p}{\partial x}}\Big|_0 - \overline{\frac{\partial p}{\partial x}}\Big|_i}{\overline{\frac{\partial p}{\partial x}}\Big|_0} \text{x}100,$$

	Gradiente di pressione	DR
Senza riblet	0.00397	-
Con riblet semplici	0.00376	5.3 %
Con riblet frattali	0.0608	6.8 %

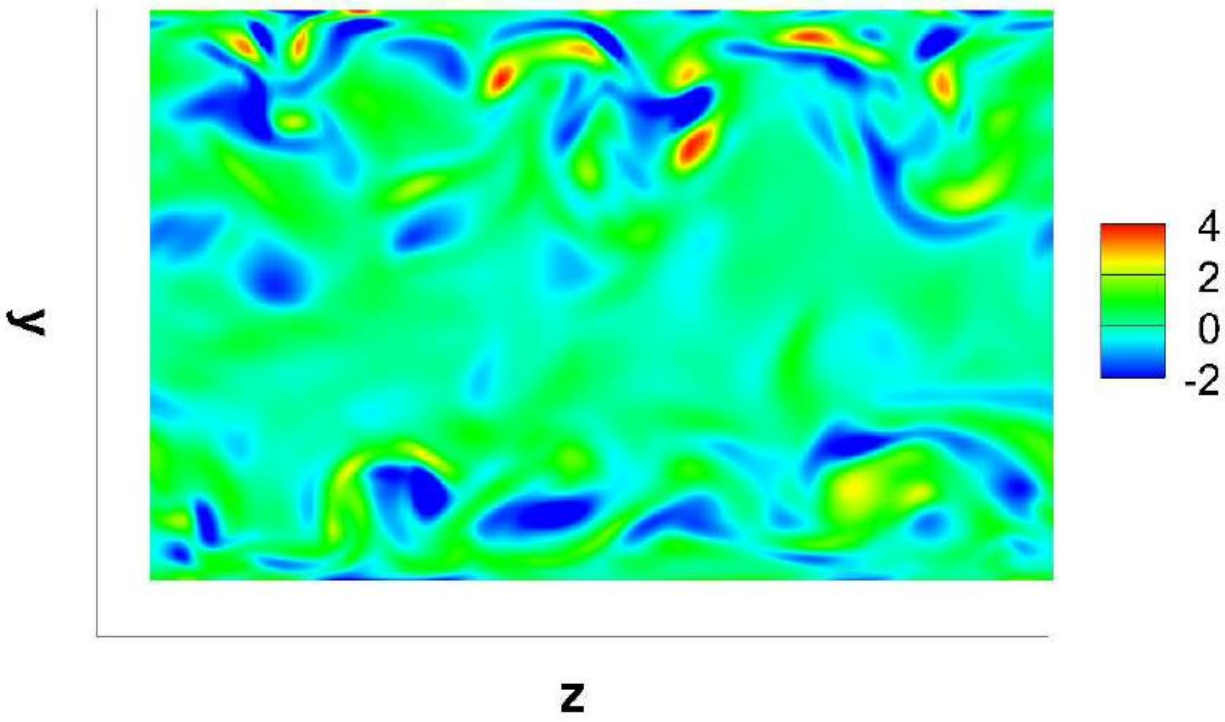
PROBLEMA MACROSCOPICO – Risultati



PROBLEMA MACROSCOPICO – Risultati



Vorticità lungo x



PROBLEMA MACROSCOPICO – Conclusioni

- Le altezze di protrusione sono in grado di valutare qualitativamente l'efficacia dei riblets.
- Le nano-strutture interne alle riblets influenzano la resistenza fluidodinamica.
- La frattalizzazione dei riblet fa aumentare di circa il 28 % la riduzione di resistenza fluidodinamica.

AIAA journal

Fractal riblets

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I. Introduction

In 1972 the NASA Langley Research Center begun a new skin-friction program in order to reduce the aircraft fuel consumption. After a lot of studies, in 1976, Dr. L. R. Ash had the idea that small flow-aligned fences might modify the near-wall structure of the turbulent boundary layer, thus reducing the skin-friction. The small fences were called "riblets", and a small research study was initiated at NASA Langley Resech Center (Bushnell [1]).

The idea that a longitudinally grooved surface could reduce the turbulent skin friction drag

Grazie per l’attenzione