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Introduction to turbulence

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THE NEED OF TURBULENCE MODELS

P. Bradshaw, 1994

Turbulence was probably invented by the Devil on the seventh day of creation when Good Lord wasn't looking.

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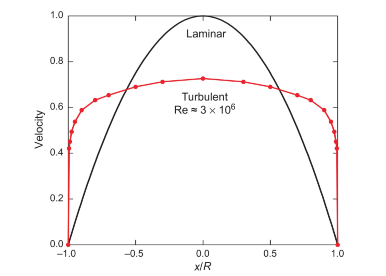
Key property: diffusion (of momentum, species, etc)



- *Big whirls have little whirls, which feed on their velocity. Little whirls have lesser whirls, and so on to viscosity*

- The often-repeated statement that: *Given the initial conditions we know what a deterministic system will do far into the future* **is false.** (P. Cvitanovič, 1983)

Outline

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- Reynolds experiment,
- Energy cascade,
- RANS/LES,
- Turbulence models
- Example

Reynolds experiment

The Reynold's experiment

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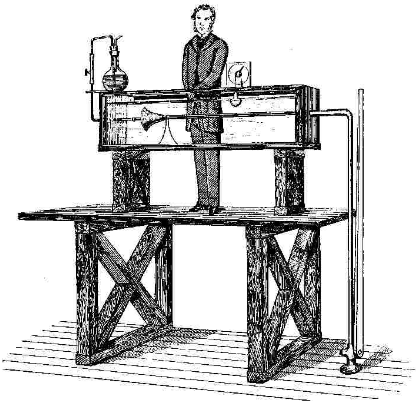

$$Re \triangleq \frac{\rho L u}{\mu}$$

The ... experiments were made on three tubes ... The diameters of these were nearly 1, 1/2 inch and 1/4 inch. They were all fitted with trumpet mouthpieces, so that the water might enter without disturbance. The water was drawn through the tubes out of a large glass tank, in which the tubes were immersed, arrangements being made so that a streak or streaks of highly coloured water entered the tubes with the clear water.

The Reynold's experiment

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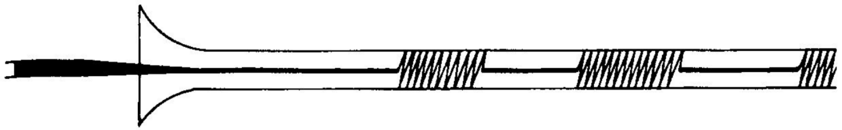
”The critical velocity was very sensitive to disturbance in the water before entering the tubes .... This at once suggested the idea that the condition might be one of instability for disturbance of a certain magnitude and stability for smaller disturbances.

Just above the critical velocity “another phenomenon ... was the intermittent character of the disturbance. The disturbance would suddenly come on through a certain length of the tube and pass away and then come on again, giving the appearance of flashes, and these flashes would often commence successively at one point in the pipe. The appearance when the flashes succeeded each other rapidly was as shown in Figure”



The Reynold's experiment

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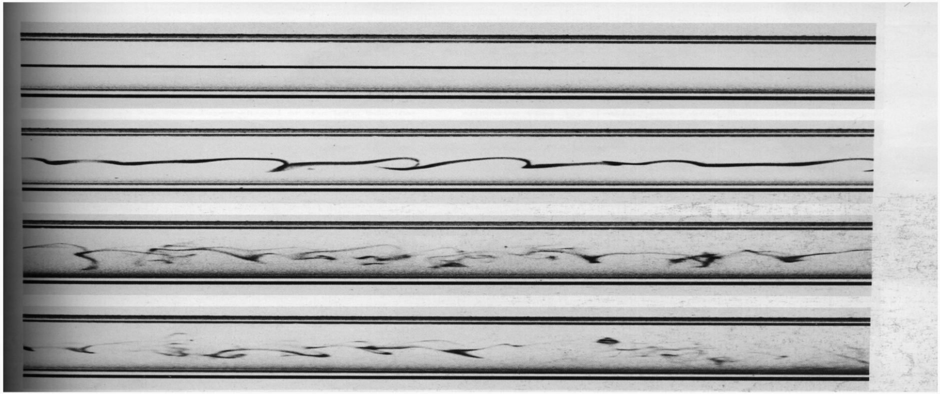

Where Reynold's number comes from

$$
\begin{aligned}
x &\triangleq \tilde{x}L \\
u &\triangleq \tilde{u}U \\
&\vdots
\end{aligned}
$$

Where Reynold's number comes from

$$\begin{cases} \tilde{\nabla}\tilde{\mathbf{u}} & = & 0 \\ \dfrac{\partial\tilde{\mathbf{u}}}{\partial\tilde{t}} + \left(\tilde{\mathbf{u}}\tilde{\nabla}\right)\tilde{\mathbf{u}} & = & \dfrac{1}{\mathrm{Re}}\tilde{\nabla}^2\tilde{\mathbf{u}} - \dfrac{1}{\rho}\tilde{\nabla}\tilde{p} \end{cases}$$

Energy budget

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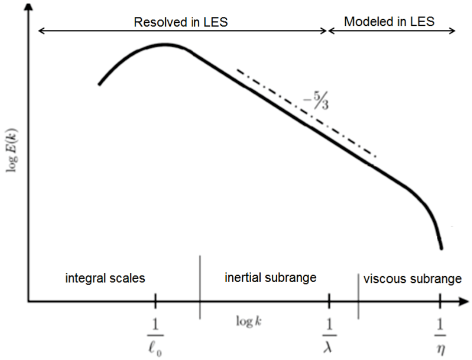

THE ENERGY CASCADE:

- the interaction between pressure gradients, inertial terms and viscous forces

How small are the small scales?

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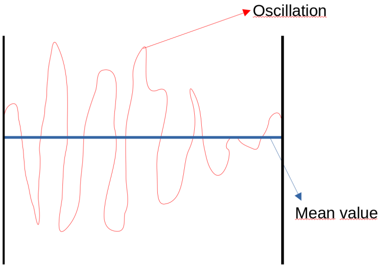
No matter how powerful future computers will be, it will always exist a turbulence problem that can not be solved in human time![Maurizio Quadrio]

Many ways to compute the mean that lead to diffierent models (RANS,ILES,ELES)



$$x \triangleq \bar{x} + x', \quad \text{WITH} \quad \overline{(\bullet)} \rightarrow \text{MEAN OPERATOR}$$

The more intuitive is ILES, but concepts are the same also for other approaches

The Closure problem

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- Reynolds Stress Tensor,
- Closure of the averaged equations,
- Turbulence models

- Businnesque hypothesis (algebraic) ν_t,
- 1 equation (differential) Spallart-Almaras,
- 2 equations (differential) $\kappa - \epsilon$,$\kappa - \omega$,
- Machine learning approaches?

The Nicetrip Testcase

Nicetrip

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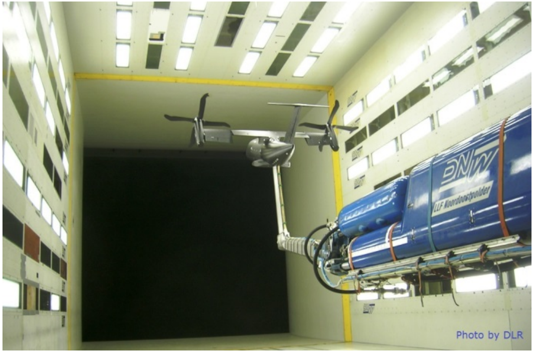

Nicetrip

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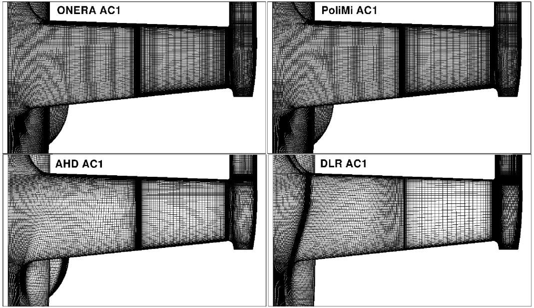
Label	Speed $[m/s]$	Mach number	angle of attack $[°]$	Re (mean chord)	$\alpha_{\text{tiltable wing}}$ $[°]$	α_{nacelle} $[°]$	θ_0 $[°]$	θ_{1C} $[°]$	θ_{1S} $[°]$
AC1	59.1	0.168	9.9	1.7 E6	0	0	26.0	−0.3	1.8
CC4	59.1	0.168	5.3	1.7 E6	4	30.1	16.6	0.0	0.0

Table 1: Description of the two test cases choosen for CFD comparison

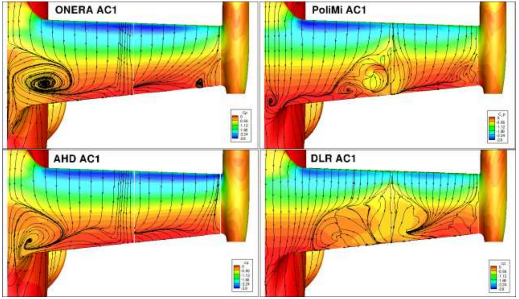
	Tubulence model	Gap size $[mm]$
Onera	$\kappa-\omega$ Menter with SST correction	2.0
PoliMi	Spalart-Allmaras	2.0
AHD	$\kappa-\omega$ Wilcox and Menter SST	4.0
DLR	$\kappa-\omega$ Wilcox	1.0

Table 3: Turbulence model and gap size

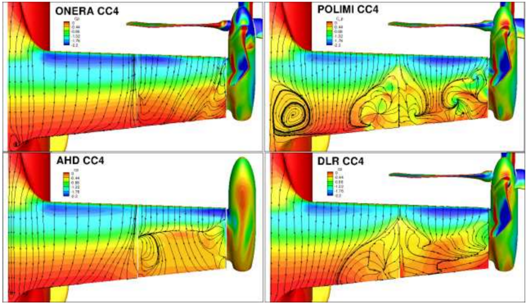


	Onera	PoliMi AC1	PoliMi CC4	DLR	AHD
Fuselage and Fixed wing	5.8	5.6	5.6	36.7	18.6
Tiltable wing	2.0	2.0	2.0	0.7	1.7
Nacelle	3.8	3.8	5.8	10.4	5.7
Rotor Blades *4	4.0	4.0	4.0	5.4	0.0
Actuator disc	0.0	0.0	0.0	0.0	0.4
Model support	0.8	0.8	0.8	0.3	2.3
Auxiliary grids	0.0	0.0	7.5	0.0	0.0
Wind tunnel	9.8	9.8	9.8	0.5	10.8
Total	**26.2**	**26.0**	**33.5**	**53.9**	**39.5**

Table 2: Volume grids dimension, given in millions of nodes



ONERA AC1
PoliMi AC1
AHD AC1
DLR AC1



ONERA CC4
POLIMI CC4
AHD CC4
DLR CC4

Nicetrip

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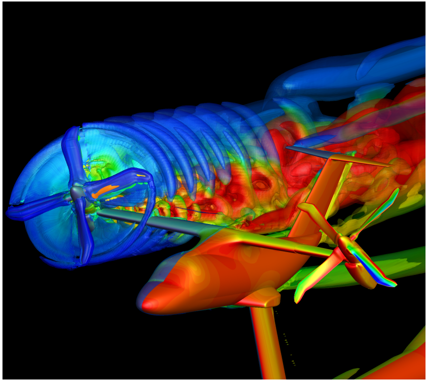

Thank you for your attention!