LISA project *FORE*

POLITECNICO DI MILANO

Stability of boundary-layer flows over large roughness elements

Franco Auteri, V. Citro, F. Giannetti, M. Righi

franco.auteri@polimi.it

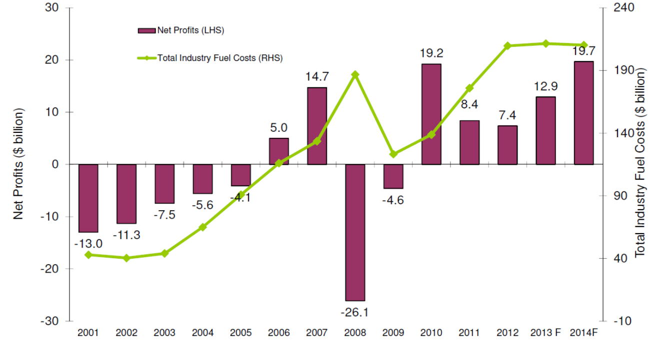
Politecnico di Milano

Milano February 18th, 2014

Boundary-layer stability: why?

Fact

The economic performance of global airline industry is strongly related to fuel costs



Fuel costs represent approx. one third of airline operating costs!

Airline economics is all about boundary layer!

Where does fuel consumption come from?

50% Skin friction → boundary layer!

30% Lift-induced drag

20% Other

Two kinds of boundary layers: laminar (low friction), turbulent (high friction).

The laminar boundary layer on airliners is unstable:

- Fore part of the aircraft: laminar
- Aft part of the aircraft: turbulent

The big question: Can we delay transition?

Large roughness elements: why?

Fact: Airliner skin has large roughness elements (or cavities).

Motivation

Large roughness elements usually promote instability and transition!

Long term research goals

Fact

The instability and transition process produced by large roughness elements is still not well understood.

The big goals

Shed light on boundary layer instability produced by large roughness elements by

- computing the critical value of the parameters beyond which the boundary layer will become unstable
- understanding the fluid dynamic mechanism which is responsible for instability
- assessing the role played by roughness shape
- find out passive or active means to prevent instability

FORE project goals

The project goals

- To ascertain if the boundary-layer instability produced by large roughness elements is related to the global instability of its wake.
- To investigate the shape of the unstable global mode
- To locate the flow region where the instability takes place

HPC: why?

Fact

Stability calculation require high accuracy
$\rightarrow$ high order discretization + very refined computational grids

Huge computational costs

One point in the parameter space requires

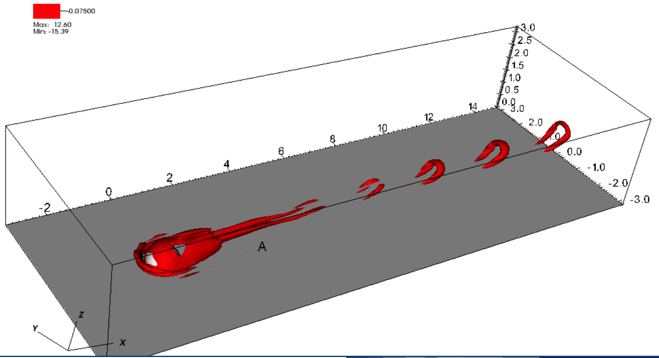
- Base flow calculation: 20k core hours on Fermi.
- Eigenvalue calculation: 160k core hours on Fermi.
- Nonlinear simulation: 60k core hours on Fermi.

Total: the cost of one point is approx. 250k core hours on Fermi!

Project results

A Kelvin–Helmholtz instability for $\mathrm{Re} \approx 450$

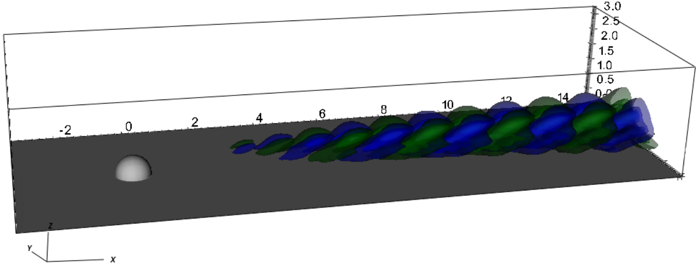
- Hairpin vortices are produced behind the roughness element.



The unstable mode

The linear eigenvalue analysis confirms:

- the nature of the instability
- the shape of the unstable mode



Concluding remarks

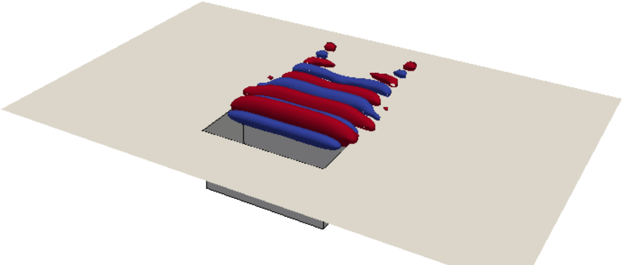
What we discovered in the FORE project

- A global instability of the wake of the roughness element
- The critical Reynolds number
- The instability is of Kelvin–Helmholtz type $\rightarrow$ time dependent
- The instability produced hairpin vortices, that are ubiquitous in turbulent boundary layer

Future developments

What next?

- Optimal control of the flow over roughness elements
- Drag reducing roughness elements
- Instability produced by cavity flows



Acknowledgements

This work was supported by Regione Lombardia award 'FORE' under the LISA initiative, for the availability of high performance computing resources and support.
The support by Cineca for program installation, calculation set-up and data postprocessing is gratefully acknowledged