Passive methods for drag reduction in boundary layers

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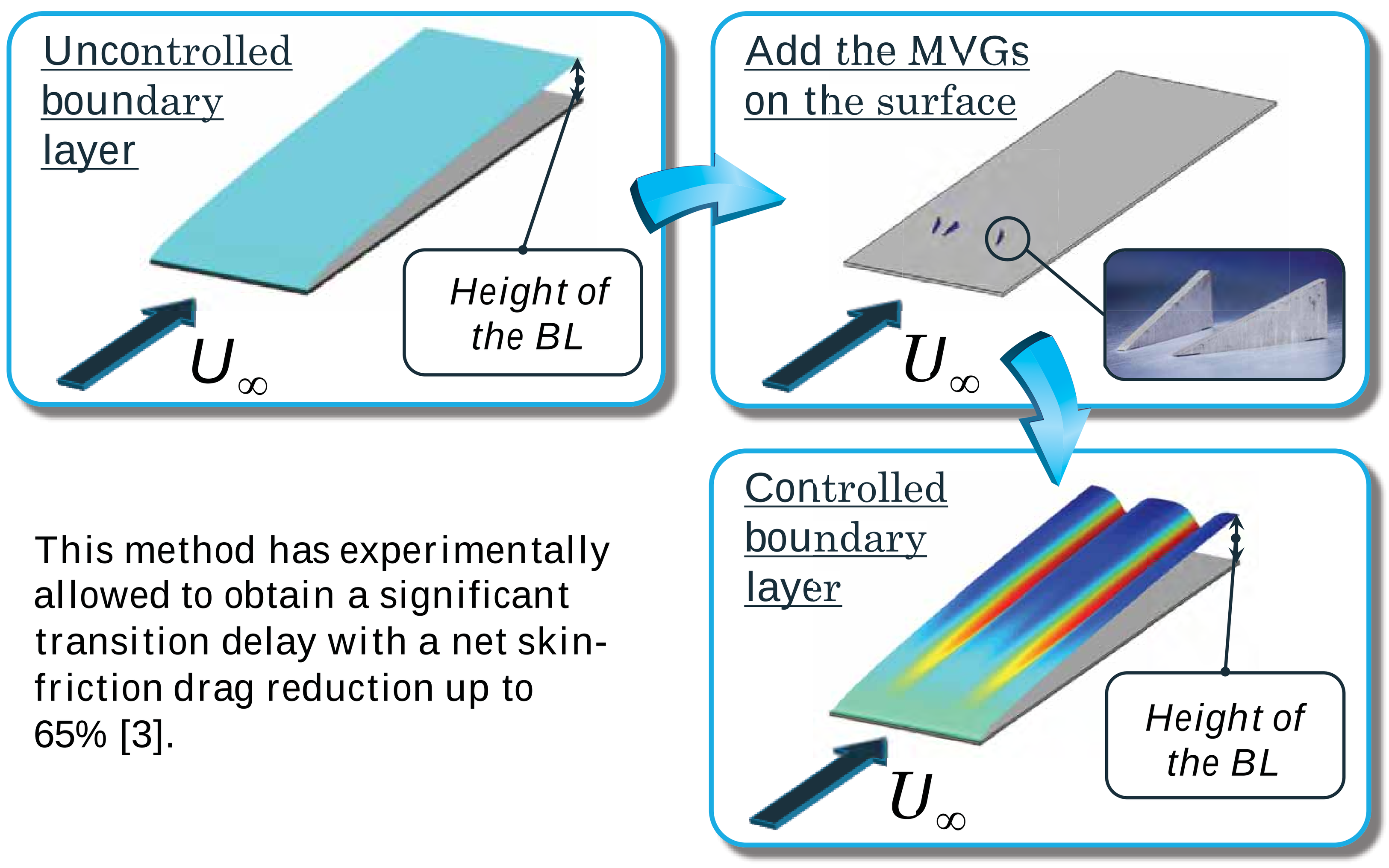
MOTIVATION

Improving the efficiency of the transport system is one of the main objectives of our time. Transport companies are looking for new ways of reducing aerodynamic drag to lower fuel consumption and to follow a *green* policy. For many of the common vehicles, as airplanes and trains, a significant reduction in drag can be obtained by stabilizing the laminar boundary layer and avoiding it to transition to turbulence. Turbulence enhances mixing and increases drag, hence, it is an unwanted flow state when reduced drag is sought after.

BACKGROUND

In a flat plate boundary layer (BL), in a low-noise environment, the transition process from laminar to turbulent state is dominated by the growth of plane waves, commonly called Tollmien-Schlichting (TS) waves. However, TS waves can be damped and transition delayed through a spanwise modulation of the streamwise velocity inside the BL[1], typically obtained with wall mounted vortex generators or plasma actuators. The use of small winglets as vortex generators, commonly referred to as *miniature vortex generators* (MVGs), has been successfully investigated in the *Minimum Turbulence Level* wind tunnel at KTH in Stockholm [2]. The MVGs are immersed inside the BL.



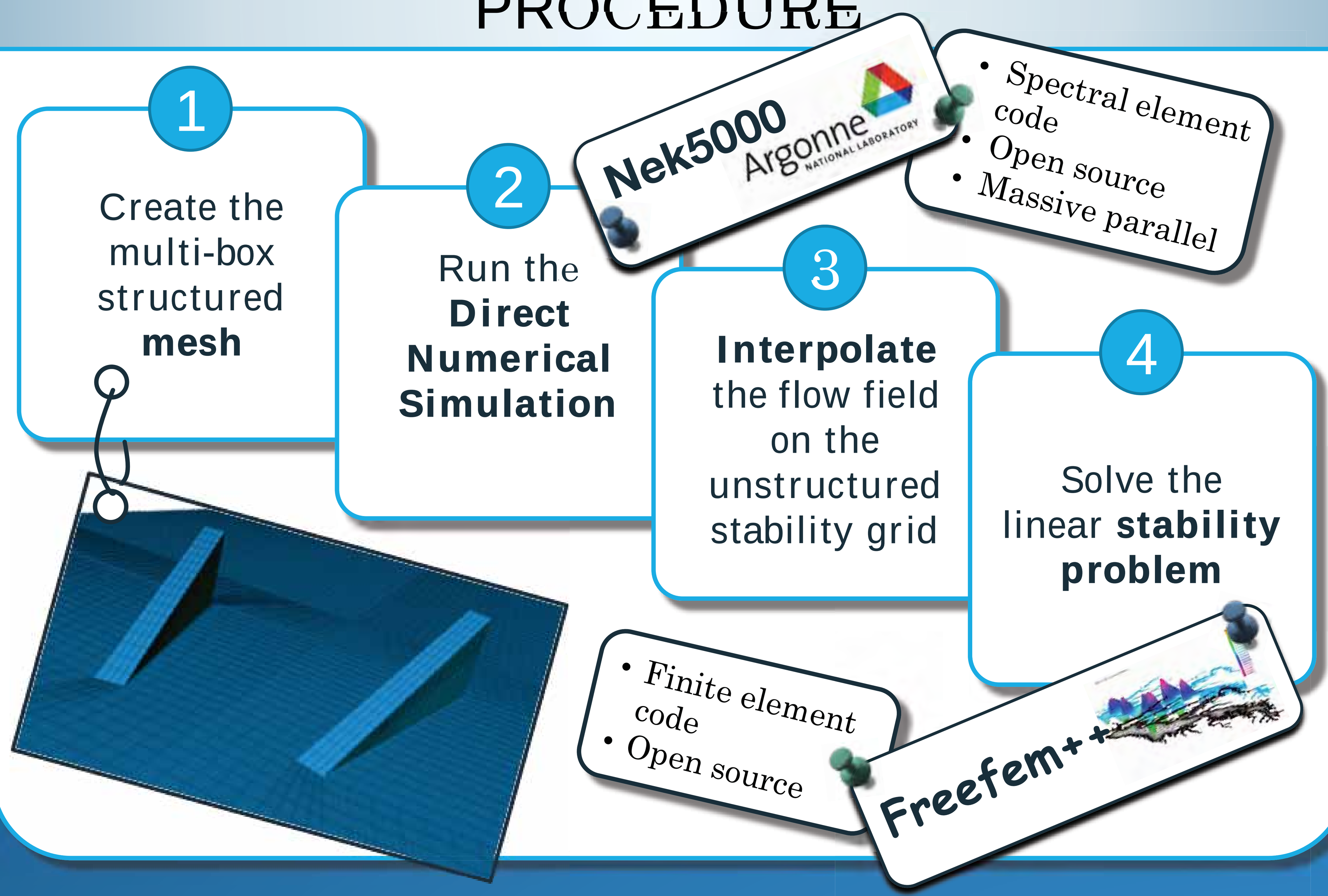
This method has experimentally allowed to obtain a significant transition delay with a net skin-friction drag reduction up to 65% [3].

OBJECTIVE

Our activity is focused on the simulation of the flow past MVGs and on the characterization of the stability properties of the controlled flow. The numerical data, validated against experiments, allow us to:

- evaluate quantities related with the flow fields which are difficult to obtain from experiments (skin friction coefficient, flow field near the MVG, etc.);
- perform stability analysis to explain the stabilizing behaviour observed in the experiments;
- investigate alternative control methods, as for instance the usage of winglets just outside the BL [4].

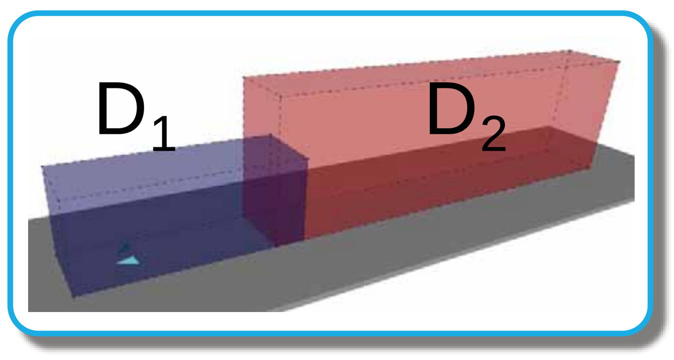
PROCEDURE



COMPUTATIONAL COMPLEXITY

Flow obtained by **Direct Numerical Simulations.** Two overlapping domains are used:

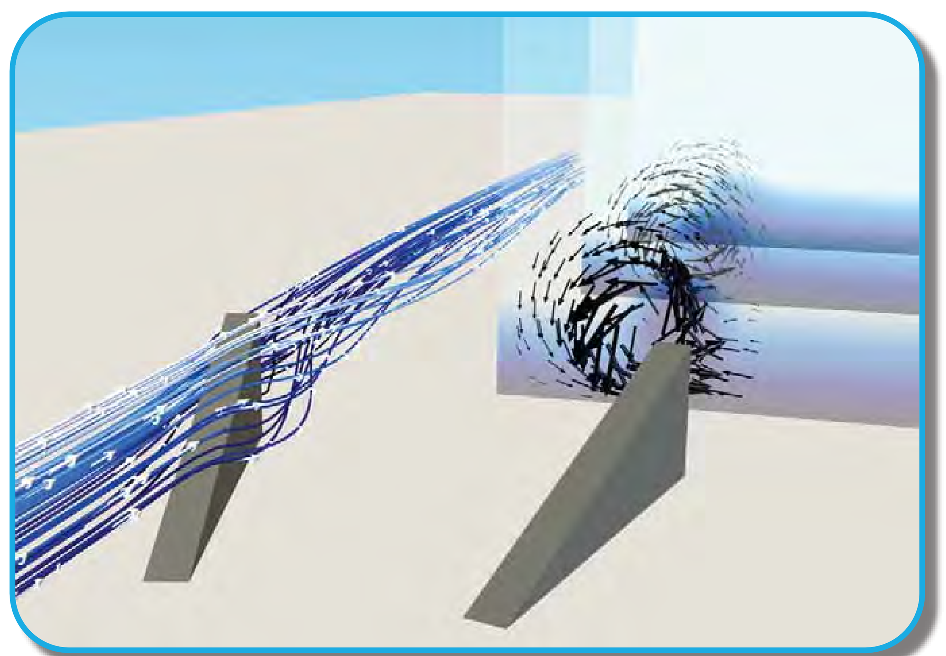
a) D_1 =164000 HP elements and 8.1*10^7 dofs
b) D_2 = 31000 HP elements and 1.6*10^7 dofs



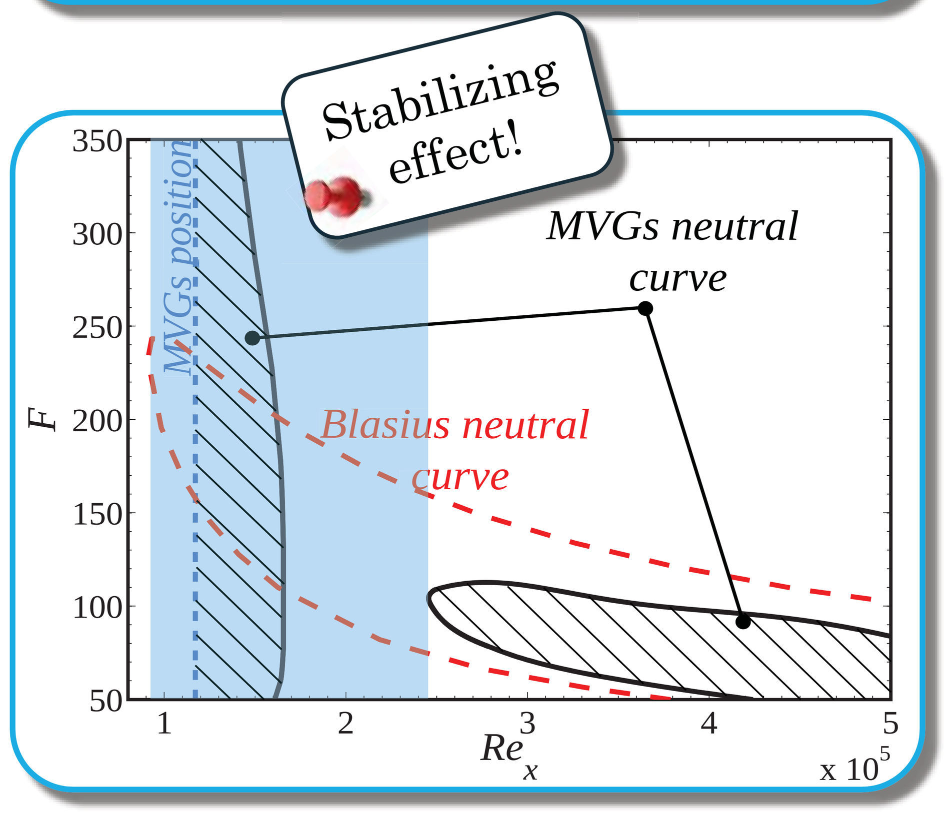
Multiple scales: D2 extends about 600 times the height of the MVG blade.
Each configuration requires two runs of 4 hours with 8192 cpus to reach the steady state solution.
Spatial stability analysis is applied at different streamwise sections. The associated non linear eigenvalue problem (Taylor-Hood finite elements) has typically 8000 dofs for each streamwise section. Ad-hoc non-linear eigenvalue solver employing a shift-invert strategy and parallel sparse LU factorization.

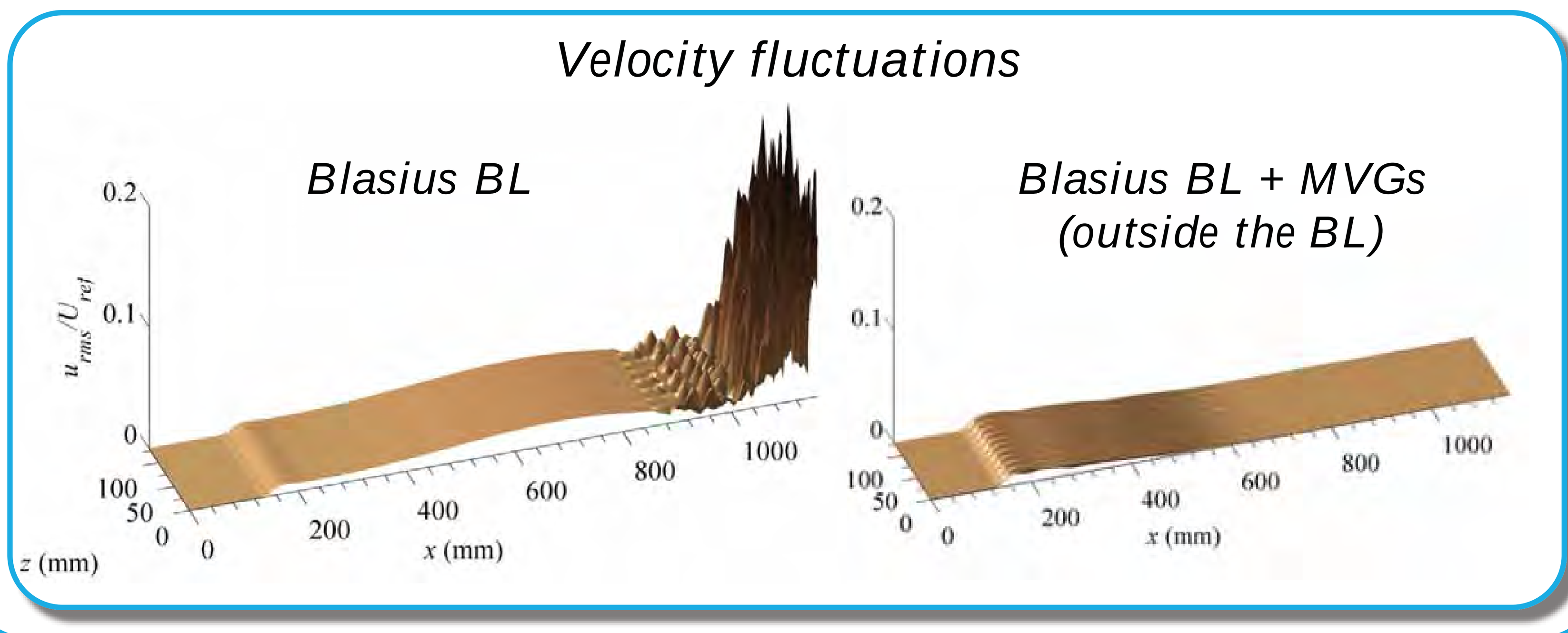
RESULTS

The results from the DNSs allow us to characterize the flow near the MVGs. From each couple of winglets, a pair of counter-rotating vortices are generated, which induce a stabilizing modification of the velocity field in the BL.



The neutral curve from the spatial analysis confirms the stabilizing effect produced by the MVGs on the BL (right figure).
The transition delay is also confirmed by ad-hoc non linear simulation with an imposed high-amplitude TS wave (lower figure).





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