Unlocking the Secrets of Turbulence: Instabilities in Flows Over Bluff Plates

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The Problem

- To design fuel-efficient and high-performance technologies, engineers need to accurately predict turbulent flow – e.g. aerodynamic drag forces on cars, aircraft and Space Shuttles.
- For such designs, computational fluid dynamics (CFD) software is widely used by industry to predict fluid flow.
- Due to a limited understanding of turbulence, present-day CFD produces typical errors of **~5%**, placing hard limits on achievable design efficiency.

Project Goals

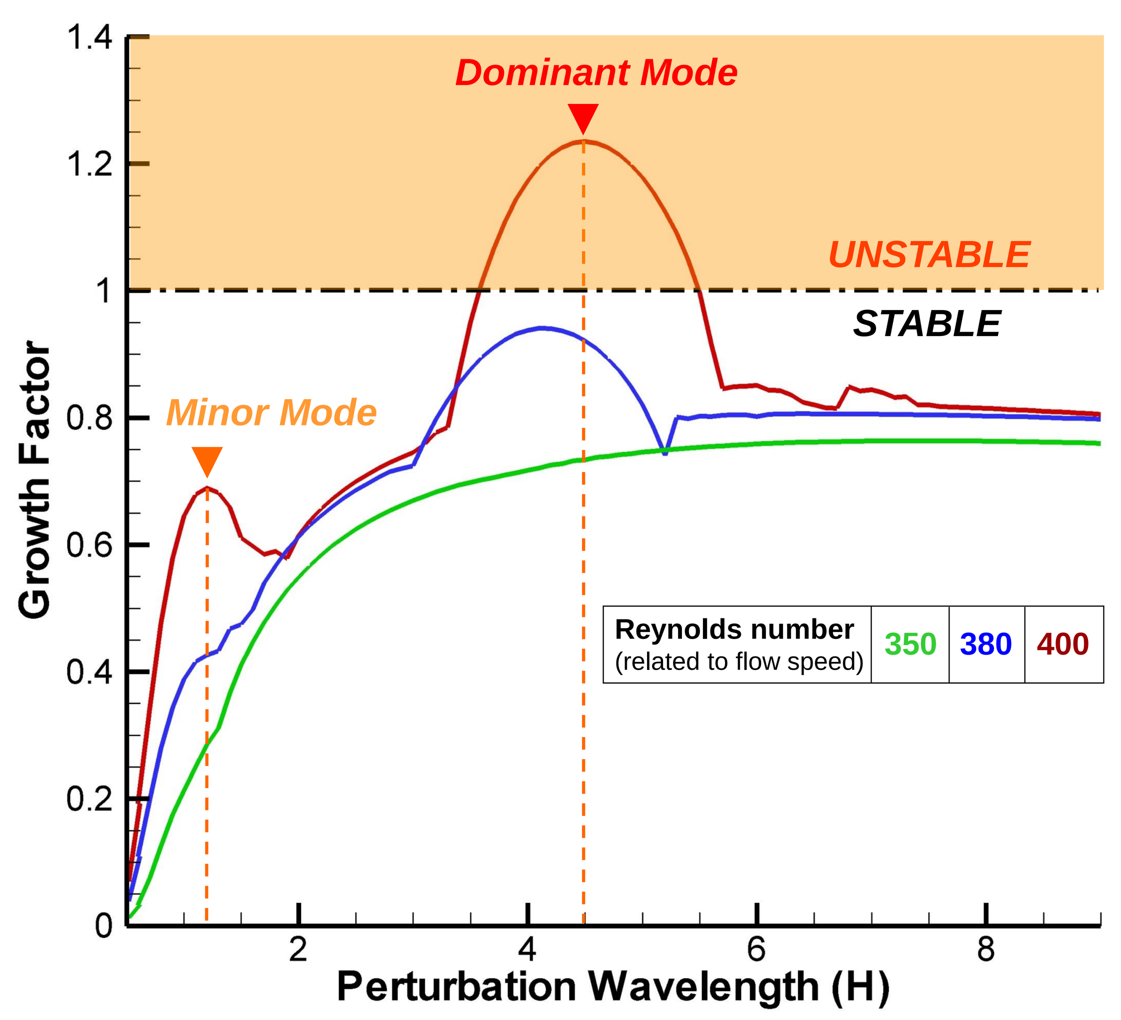
Simulate the transition to turbulence for flow over a flat-faced rectangular plate

Characterise the underlying "instability modes" governing the onset of this transition

This knowledge may then be applied to devise CFD models which predict turbulent flow more accurately

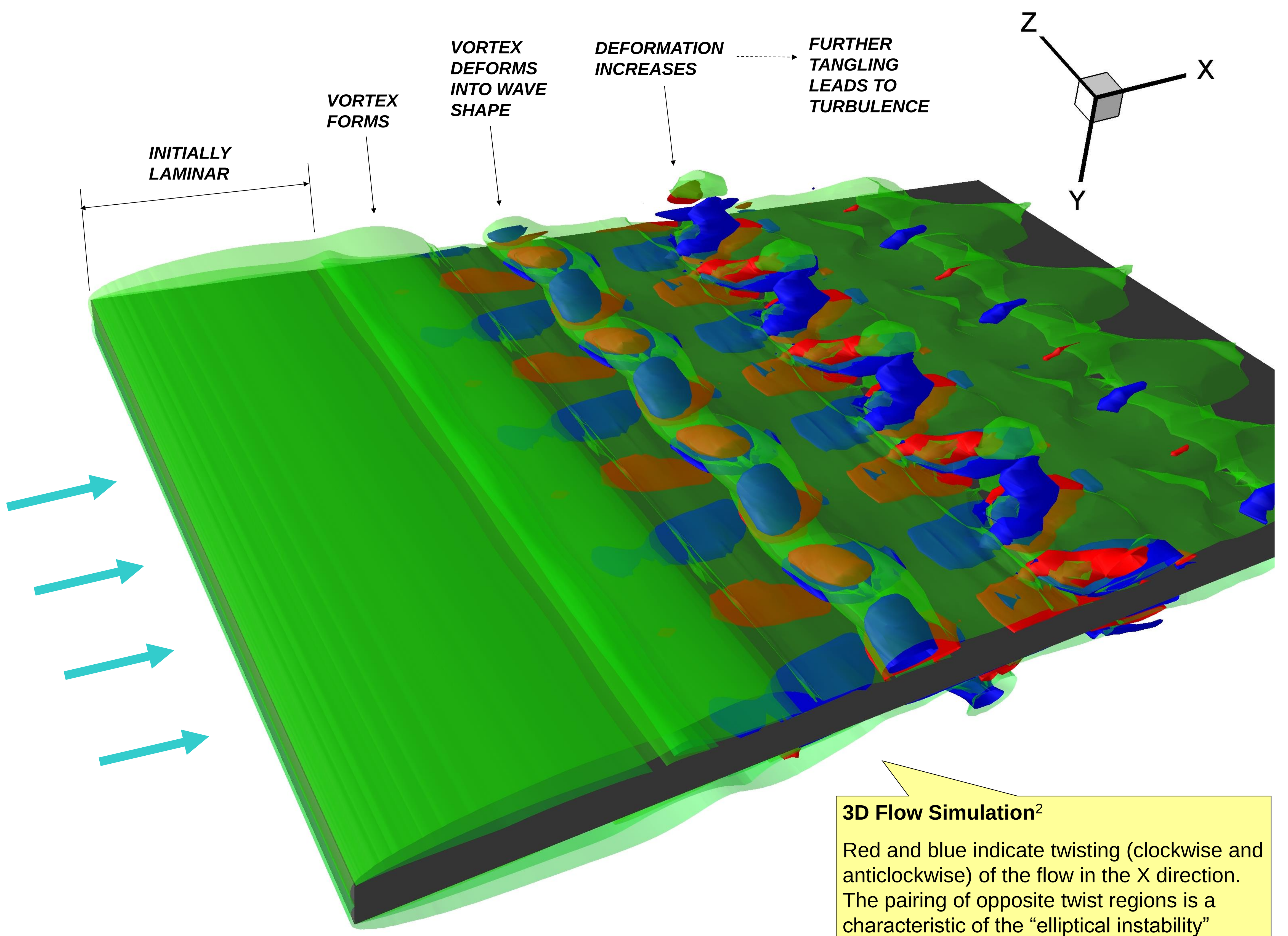
Method

- In-house direct numerical simulation CFD code ("SE2D")
- Spectral element method to simulate the flow; Floquet stability analysis technique[1] to examine flow transitions
- Results verified by independent 2D and 3D simulations
- Faculty of Engineering Beowulf Computer Cluster: converts 100 PCs in student computer labs into a powerful supercomputer after hours



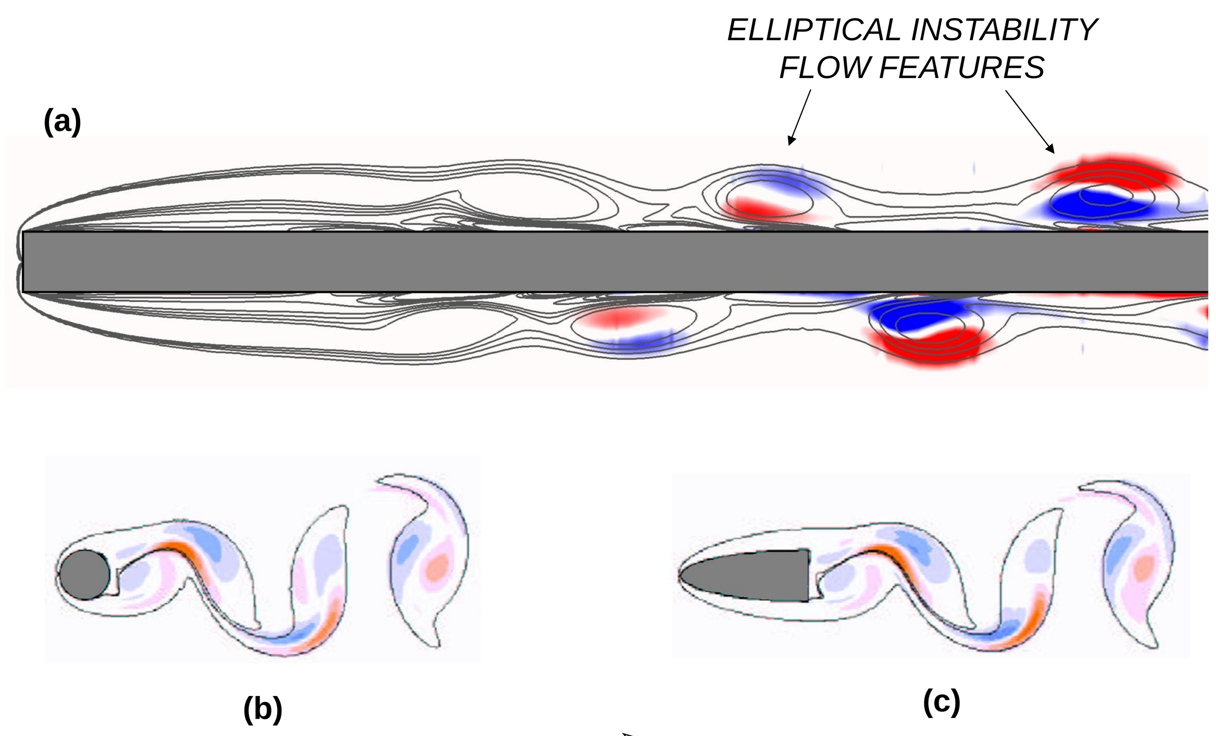
Stability Analysis Results[2]

The flow was subjected to a range of perturbations which were modulated in a wave-like manner across the width of the plate. The wavelength of these perturbations was varied and their growth or decay over time measured. We thereby identified two preferred wavelengths or "instability modes" – the pathways to turbulence.



3D Flow Simulation[2]

Red and blue indicate twisting (clockwise and anticlockwise) of the flow in the X direction. The pairing of opposite twist regions is a characteristic of the "elliptical instability" mechanism: a well-known theoretical flow instability that may be central to the onset of turbulence[3].



2D Simulations of Dominant Instability Mode Structure

Here, line contours indicate vortex locations. Red and blue again indicate clockwise and anticlockwise "twisting" in the flow direction. In the bluff plate flow[2] we see twisting occurring only in opposing pairs, confined within vortex cores (**a**). This distinctive feature of the "elliptical instability"[3] is virtually identical in simulations of completely different wake flow geometries[4] (**b**,**c**).

Key Findings

- **Identified two instability modes with wavelengths ~1*H* and 4-5*H* (dominant).**
- **Dominant mode shows characteristics of the "elliptical instability": a well-known theoretical mechanism for fluid instability.**
- **These same characteristics are seen in cylinder and bluff body wake flows[4].**
- **This suggests that the elliptical instability mechanism may play an important role in the process of turbulent transition itself, independent of flow geometry.**
- **Such knowledge may enable CFD models that better predict turbulent flow.**

References:
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4. Ryan, K. *et al*, 2005, "Three-dimensional transition in the wake of bluff elongated cylinders", *J. Fluid Mech* **538**, 1-29

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