

Global stability and frequency response methods

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Motivation

The purpose of this project is to develop and use a general-purpose linear global stability solver to study the effect of surface imperfections on the boundary layer developing over an aircraft wing. Surface imperfections such as bumps, steps and gaps (cavities) modify the pressure gradient that the boundary layer experiences. In the presence of a sufficiently strong adverse pressure gradient, the boundary layer can separate. This boundary layer may then reattach further downstream - leading to a separation bubble. The separation bubble alters the stability properties of the boundary layer - in most cases, if not all, it makes the boundary layer more unstable. We wish to understand what modes of instability are excited and amplified and how this depends on the geometry of the surface imperfections.

There are many studies on the global stability of separation bubbles - over bumps, steps and cavities. In general, previous studies consider flows where the thickness of the boundary layer is smaller than the height/depth of the surface imperfection. In this study, however, we focus on flows where the thickness of the boundary layer is of the same order (and bigger) than the size of the surface imperfection as this is relevant to aircraft wings.

Research

We wish to calculate the linear global stability and linear global frequency response of the flow over surface and identify what modes of instability are excited and amplified and how this depends on the geometry of the surface discontinuities.

We have developed a general purpose solver that can be used to study the global stability and frequency response of flow over a variety of geometries. The solver uses an open source finite element discretization software and can be made parallel.

We focus, initially, on the two-dimensional incompressible flow over a gap (cavity) and studied its linear stability and response to spanwise-periodic three-dimensional disturbances. We find that this flow configuration exhibits strong amplification properties. The largest amplification is obtained for disturbances with a non-zero spanwise wavenumber and the resultant response consists of structures slanted in the streamwise direction. The frequency and wavelength of the disturbance that is most amplified varies with changes in the flow configuration. We use a combination of local and global analyses to try to identify the regions of the flow, the physical parameters, and the length scales that determine the frequency and wavenumber of the disturbances that are most amplified. The tools developed can easily be applied to flow over other geometries.

Application to industry

The tools and techniques developed in this project will provide useful information for designers of aircraft wings. In contrast to conventional CFD, the gradient-based tools developed in this project can tell the designer not just what happens, but why it happens as well. Particular applications include the effect of small gaps and steps due to the presence of flaps and slats and manufacturing techniques. These tools offer a useful advantage over the traditional e^N method that is used to predict transition because these tools take non-parallel, transient and non-modal effects into account and can provide useful sensitivity information for designers.