STABILITY OF ADAPTIVE AEROFOILS

Current resources offer the capability of enhancing the dynamic response of the typical aerofoil by making it deformable. Wing warping, for instance, represents a long-ago proposed technique for morphing aerofoils (Wright brothers, 1903), which is now making a comeback, as shown by USAF’s ‘Adaptive Aeroelastic Wing’ technology.

Camber deformations are expected to provide an efficient approach to modify aerodynamic loads, but might change the stability (flutter) boundaries. The objective of this work has been the investigation of these effects, illustrating the mechanisms that govern flutter.

CHORDWISE FLEXIBILITY

The general system consists of three degrees of freedom (DoF): pitch, plunge and camber. The distribution of vertical displacements along the aerofoil is given by:

\[ w(x) = h + x_0 \gamma + \left( \frac{x}{b} \right)^3 \]

The structural model is based on finite-section deformation modes and is coupled with a 2-D finite-state aerodynamic model, using Theodorsen’s function to represent the wake.

ONE DEGREE OF FREEDOM SYSTEM: CAMBER

A system with camber as the only DoF is first considered. In contrast to the classical DoFs pitch and plunge, single camber leads to flutter, which is originated by the energy exchange between camber oscillations and wake.

Flutter always occurs at a constant reduced frequency, given by:

\[ k = \frac{1}{\sqrt{1 + \kappa \beta}} \]

where \( G(k)/F(k) \) represents the phase lag due to the wake.

The flutter speed only depends on the mass parameter, \( \kappa \):

\[ V_f = \frac{1}{\sqrt{1 + \kappa \beta}} \]

Physical example: human snoring. The noise is produced by the flutter vibration of the soft palate, which can be seen as a flexible plate with camber as the only DoF.

THREE DEGREES OF FREEDOM: PITCH, PLUNGE AND CAMBER

In the case of a system with the three degrees of freedom, instability arises due to different mechanisms:

- Region A: Plunge-camber flutter
- Regions B, C and D: Triple flutter
- Region E: Static divergence

SO, CAN CARPETS FLY?

- Morphing aerofoils optimize performance continuously modifying contours.
- However, stability is substantially affected.
- Camber mode alone is unstable due to the lock-in with the wake.
- A triple mechanism is the root of flutter for a wide range of frequency ratios, reducing the stability envelope considerably.
- Although people-carrying flying carpets seem not plausible, small membrane-wing micro-aerial vehicles are a feasible alternative.

ACKNOWLEDGEMENTS

3. T Theodorsen (1934), General theory of aerodynamic instability and the mechanism of flutter, NACA Report No. 496.