Vibrations 2, Lecture 19
Introduction to Aeroelasticity

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Lecture 17-18 review

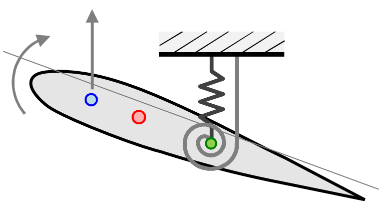
Energy-based methods for 1 DOF systems – energy conservation:

$$\sum_{(i)} E_{P,i}(q_{max}) = \sum_{(j)} E_{K,j}(\dot{q}_{max})$$

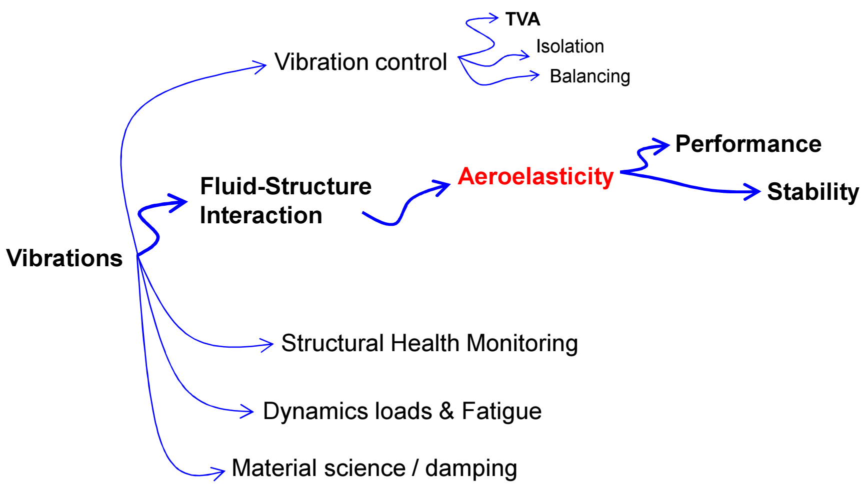
Energy-based methods for N DOF systems – Lagrange's equation:

$$\frac{d}{dt}\left(\frac{\partial \mathcal{L}}{\partial \dot{q}_j}\right) - \frac{\partial \mathcal{L}}{\partial q_j} = Q_j$$

2 DOF aerofoil in airflow:

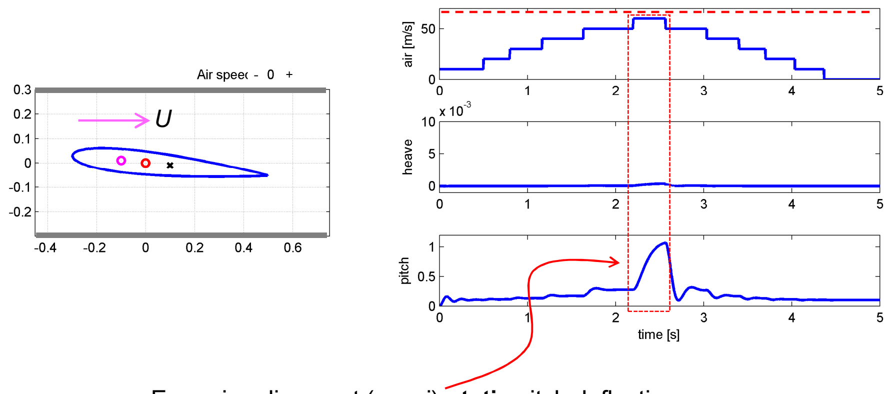


Applications of Vibrations in Aerospace



Suspended rigid wing in airstream

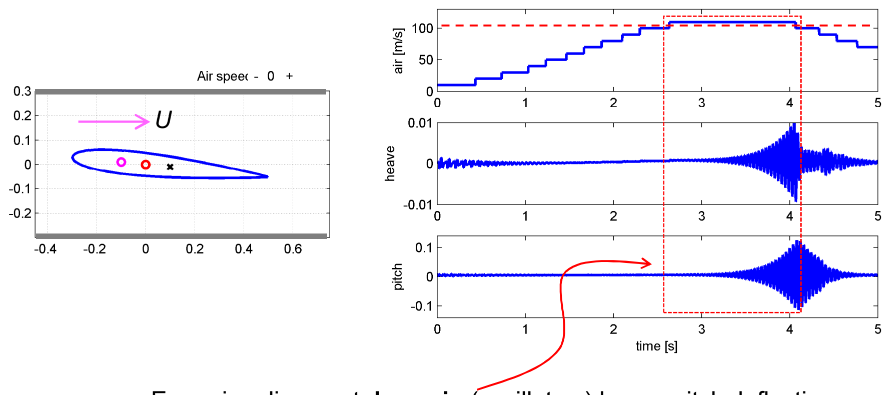
Consider a rigid wing *elastically suspended* with the heaving and torsional DOFs (lecture 18). The wing is placed in a wind tunnel-like configuration, i.e. exposed to free airstream with velocity *U*. The velocity is varied!



Emerging divergent (quasi)-**static** pitch deflections.
Air speed close to the divergence speed (see red dashed line).

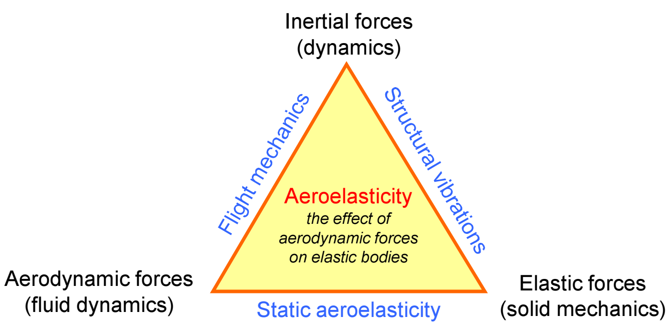
Suspended rigid wing in airstream

Consider a rigid wing *elastically suspended* with the heaving and torsional DOFs (lecture 18). The wing is placed in a wind tunnel-like configuration, i.e. exposed to free airstream with velocity *U*. The velocity is varied!



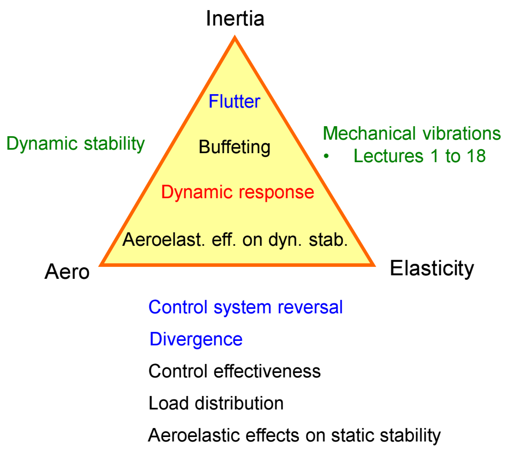
Emerging divergent **dynamic** (oscillatory) heave-pitch deflections. Air speed above the flutter speed (see red dashed line).

Collar's aeroelastic triangle – disciplines

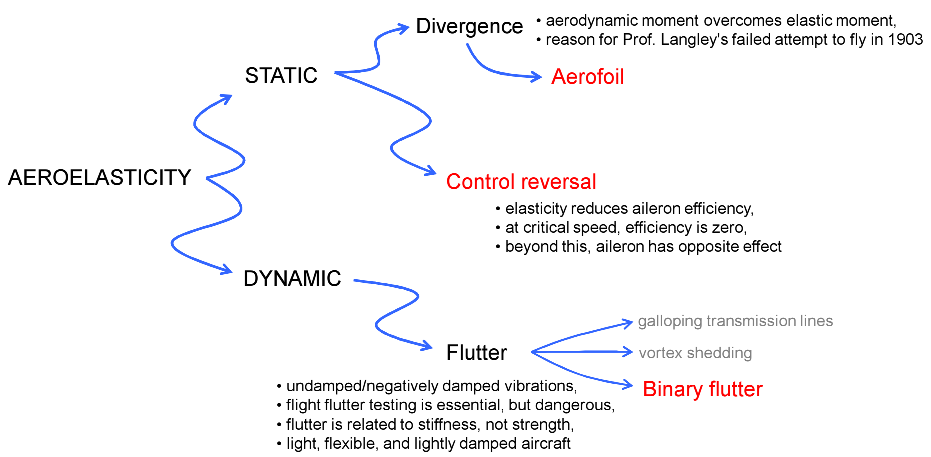


Collar's aeroelastic triangle – phenomena

Bisplinghoff, Ashley, Halfman, Aeroelasticity, Dover (p.2-3)



Introduction topics covered in V2



Origins of Aeroelasticity

EXPERIMENTAL AEROELASTICITY - HISTORY, STATUS AND FUTURE IN BRIEF, Rodney H. Ricketts, NASA Langley Research Center

I. Introduction

It is well known that Orville and Wilbur Wright were the first to design and fly a heavier-than-air vehicle at Kitty Hawk, NC, in 1903. In the process of designing their Wright flyer, they became the first experimental aeroelasticians. They tested a model with a five-foot wing span to investigate their innovative wing-warp (twist) method for roll control in 1899[1]. A photograph and drawing of the model are shown in figure 1. In addition they experimented with propeller blades to determine that the tips at high thrust loadings were causing the blades to twist and washout the load[2].

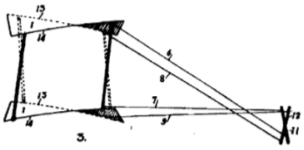
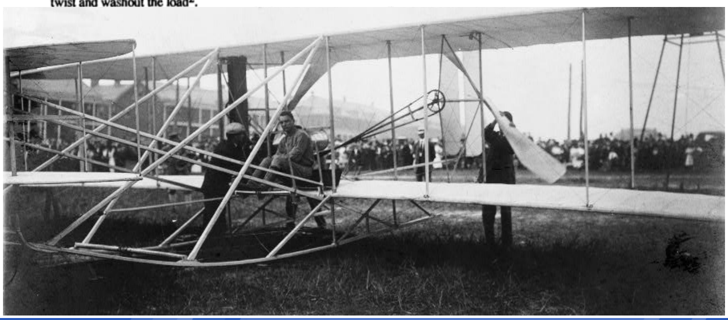


Figure 1. Wright Brothers' aeroelastic model.



Aeroelasticity in Bristol

Arthur Roderick Collar. 22 February 1908-12 February 1986
R.E.D. Bishop, Biographical Memoirs of Fellows of the Royal Society, Vol. 33 (Dec., 1987), pp. 165-185, The Royal Society

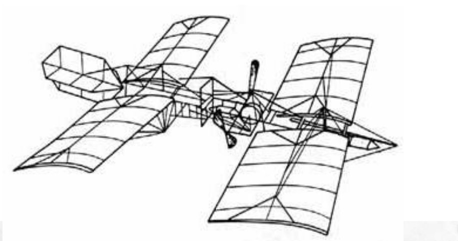
Bristol University

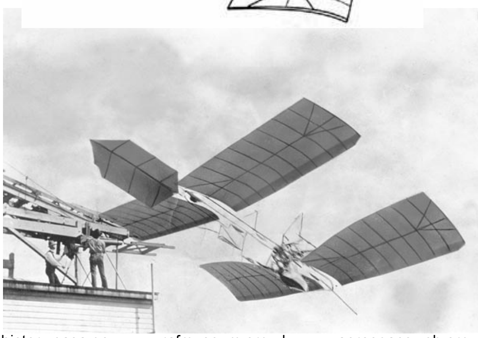
By the end of World War II Bristol had become an important centre in the aircraft industry. Both engines and airframes were manufactured in the city and it was hardly likely that civil needs would fail to take up the slack as military procurement ran down. The University decided to set up a Department of Aeronautical Engineering and the Bristol Aeroplane Company endowed the chair, naming it after Sir George White, the eminent aeronautical engineer who was the company's chairman. Roderick Collar's appointment as the first Sir George White Professor of Aeronautics dated from 1946.

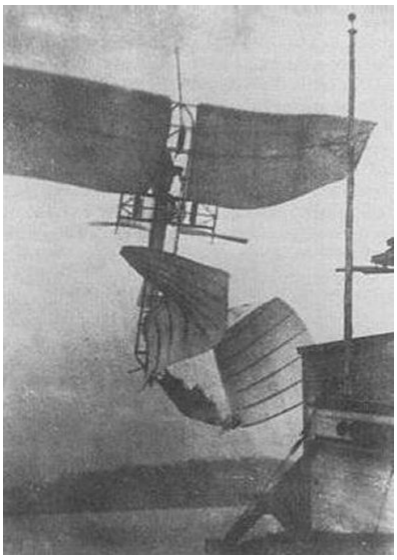
… credited for Collar's aeroelastic triangle and …

RA Frazer, WJ Duncan, AR Collar: "*Elementary matrices and some applications to dynamics and differential equations*". Cambridge U. Press, 1946 (1938 1st ed.) "… the use of matrices in problems of applied mathematics has become more widespread and part of the credit for this is due the book …"

Prof. Langley's Aerodrome 1903

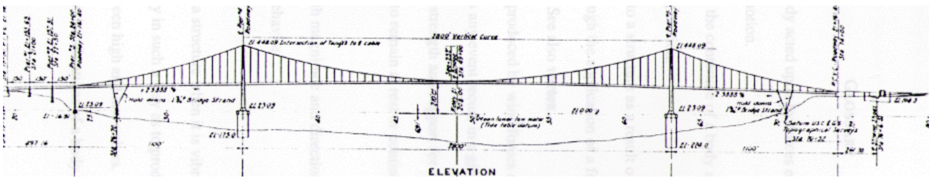


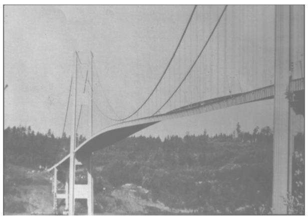


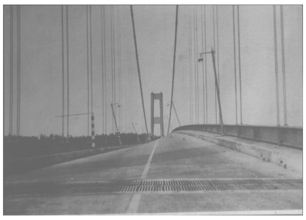


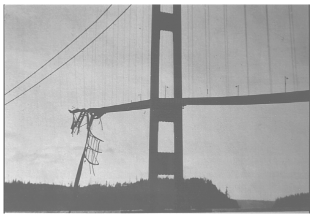
history.nasa.gov, www.rafmuseum.org.uk, www.aerospaceweb.org

The Tacoma bridge 1940

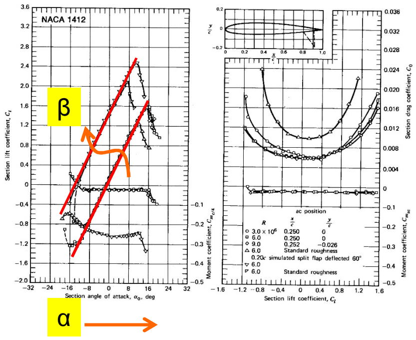








Aerofoil characterization



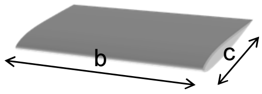
Aerodynamic coefficients and loads:

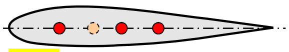
$$C_L = C_{L0} + C_{L,\alpha}\alpha + C_{L,\beta}\beta, \quad C_{M,a.c.} = C_{M0} + C_{M,\beta}\beta$$

$$L = qSC_L, \quad M_{a.c.} = qScC_{M,a.c.}, \quad M_{D,e.c.} \approx 0$$

$$q = (1/2)\rho v_\infty^2, \quad S = cb$$

Moment action due to D with respect to e.c.



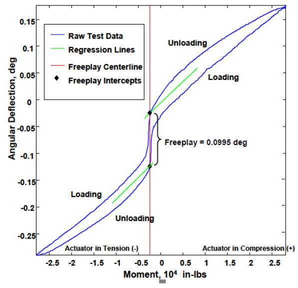


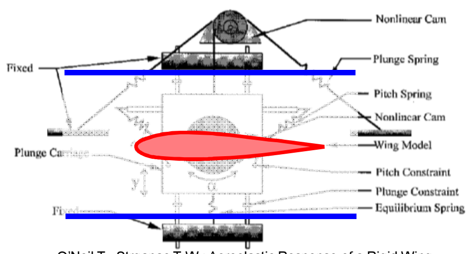
Important sectional points: a.c. c.p. c.m. s.c.

- c.p. (centre of pressure): the total moment due to aerodynamic forces is zero (for a given α and v_∞),
- a.c. (aerodynamic centre): the point on the aerofoil where the moment is independent of angle of attack (subsonic ≈c/4; negative for positively cambered aerofoils; zero for symmetric aerofoils),
- c.m. (sectional centre of mass): average location of the sectional mass distribution,
- s.c. (shear centre): beam/blade will not twist if loaded at this point.

Case study: F-22 flutter testing

Anderson, Mortara, F-22 Aeroelastic Design and Test Validation, AIAA 2007-1764





O'Neil T., Strganac T.W.; Aeroelastic Response of a Rigid Wing Supported by Nonlinear Springs, JA, 35/4, 1998

Summary

- Aeroelastic triangle
  - Disciplines and phenomena
- Static and dynamic aeroelasticity
  - Stability and performance
- Aerofoil characterization
  - Important sectional points