Fast Aeroelastic Assessment Methods for Industrial Aircraft Design

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iPhD Project

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About

- University of Southampton, south coast UK
- Next Generation Computational Modelling (NGCM) iPhD
  - Taught 1^{st} year, scientific computation methods
  - 3 years of research
- Funded by Engineering and Physical Sciences Research Council

Outline

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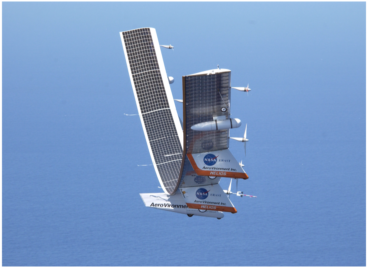
1. Overview
   - Aims
   - Methods
2. Results
   - Progress
   - Validation/Results
3. Summary

Aims

- Collaboration with Airbus UK
- Improved fidelity rapid method for aeroelastic loads assessment
- Bridge gap between CFD and linear methods
- Early in the design process
- Produce results overnight

Motivation

- Aeroelasticity (Gust response, Flutter..) is a threat for flexible aircraft.



NASA Helios Mishap [1]. Left: Pitching oscillations and dihedral angles beyond design limit (aeroelastic response).
Right: Structural disintegration resulting from critical loads

[1] Noll, T. et al, “Investigation of the Helios Prototype Aircraft Mishap: Volume I Mishap Report,” http://www.nasa.gov. Jan 2004

Applications

- Aircraft design, optimisation
- Flow control research
- Study of aeroelastic phenomena
- Agile vehicle research

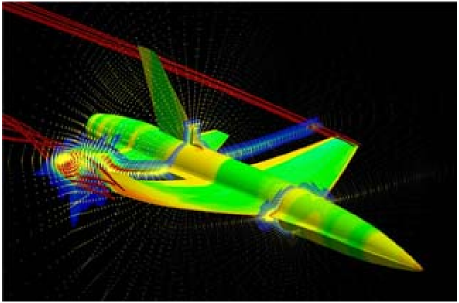


Figure 1: Aeroelastic modelling of a fighter aircraft [2]

[2] Patrick Hu, Source: `http://www.advanceddynamics-usa.com/`

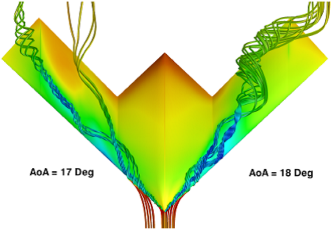
Outline

Aerodynamic Methods

- Unsteady Vortex Lattice Method (UVLM) - 3D inviscid
- Reynolds Averaged Navier Stokes (RANS), Infinite Swept Wing - '2.5D+' viscous
- Iterative 'α correction' method for viscous/inviscid coupling
- Implemented in solver code 'Tau' (C Programming language)

Alternative: Doublet Lattice Method

- Frequency Domain Approach
- Available in most aeroelasticity packages (e.g. NASTRAN)
- Fast **linear** Method
- Insufficient for non-linear flows



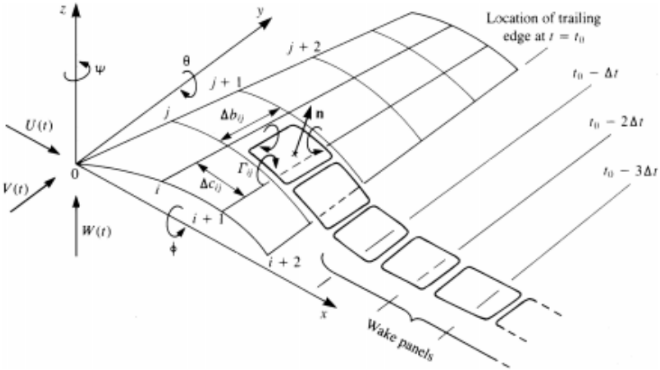
Late stages of vortex with breakdown occurring over the top surface of SACCON [3]

[3] Vallespin, D., Da Ronch, A., Boelens, O.and Badcock, K. J. (2011) Vortical flow prediction validation for an unmanned combat air vehicle model. Journal of Aircraft, 48, (6), 1948-1959.

Unsteady Vortex Lattice Method [4]

UVLM

- Time marching method, allows non-linearity
  - Induced velocity at collocation points (Biot Savart law)
  - No-penetration surface $\rightarrow$ Zero normal velocity
  - $A \cdot \vec{\Gamma} = \vec{RHS}(\vec{V_\infty}, \alpha, \vec{n}..)$ .. Solve $\vec{\Gamma}$.



[4] Katz and Plotkin, *Low Speed Aerodynamics. (2002)*

Viscous Inviscid Coupling (steady state)

- Infinite Swept Wing [5]:
  - Spanwise decoupled RANS
  - Sectional viscous data lookup table C_L vs α
- Coupling: α correction[6] [7]:
  - VLM $\rightarrow$ inviscid lift coefficient $C_{L_{inv}}$, effective angle of attack α_{eff}
  - $\alpha_{eff} \rightarrow C_{L_{visc}}$
  - $\Delta\alpha = (C_{L_{visc}} - C_{L_{inv}})/C_{L_{\alpha,visc}}$
  - Correct α_{eff}, iterate to convergence in $|C_{L_{visc}} - C_{L_{inv}}|$

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[5] Ghasemi et al.*"A Two-Dimensional Infinite Swept Wing Navier-Stokes Solver,"* 52nd Aerospace Sciences Meeting, AIAA SciTech, Jan. 2014.

[6] Van Dam, C. P., *"The aerodynamic design of multi-element high-lift systems for transport airplanes"* Progress in Aerospace Sciences, Vol. 38, No. 2, 2002, pp. 101 144.

[7] Gallay, S. et al,*"Sweep effects on non-linear Lifting Line Theory near Stall"* 52nd Aerospace Sciences Meeting, AIAA SciTech, Jan. 2014.

Outline

Progress

- Steady VLM code implemented in C
- Some code validation
- Version control and testing
- Spanwise decoupled (ISW) RANS algorithm generated in Tau

Code structure

- Lifting surface object orientation, with attributed wake
- Multiple surface ‘objects’ support
- HDF5 file format read/write
  - CGNS based on HDF5
  - Supports large data sets with objects and attributes
  - File compression
- Fast LAPACK libraries for solving linear systems

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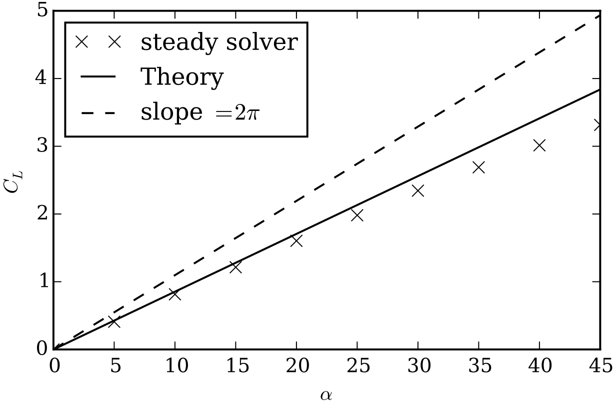
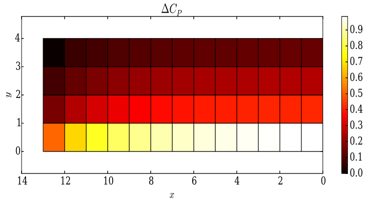
VLM Validation

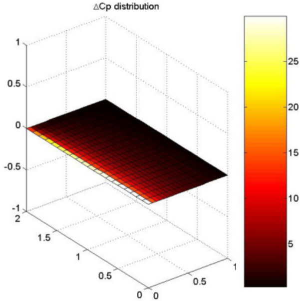
- Compare with finite wing theory -

$$C_{L_{\alpha}\_wing} = \frac{C_{l_\alpha}}{1 + \frac{C_{l_\alpha}}{\pi e AR}}$$



Results



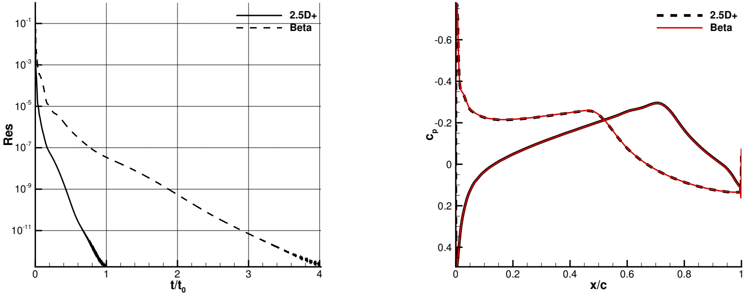


Pressure distribution
Left: VLM result
Right: DLM result, low reduced frequency ($k = 0.1$) [8]

[8] Da Ronch A., Cavagna, L.*"A Doublet-Lattice Method for Calculating Lift Distributions on Planar and Non-Planar Configurations in Subsonic Flows", May 2007.*

Progress

- Speedup factor of around 4 with 2.5D+ method compared with Tau standard method



Left: Convergence history speedup demonstration
Right: Pressure coefficient comparison

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To Be Implemented...

- Extension of α correction method and VLM to unsteady flight mechanics
- Fast multipole algorithm (wake)
- Eigenvalue modal decomposition for structural response (NASTRAN)
- Test case using non-confidential data, DLR-F6 wing-body

Summary

- Improved fidelity fast aeroelastic method
- Target vulnerable aircraft early in design
- Aerodynamic model: 3D UVLM coupled with 2D RANS
- Structural model: Modal approach

Thank you.