Aeroelastic Gust Modelling
DiPaRT 18.11.15

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University of Bristol
AeroGust Partners

- University of Bristol
- Institut National De Recherche En Informatique Et En Automatique (INRIA)
- Stichting Nationaal Lucht - En Ruimtevaartlaboratorium (NLR)
- Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)
- University of Cape Town
- Numerical Mechanics Applications International SA (NUMECA)
- Optimad engineering s.r.l.
- University of Liverpool
- Airbus Defence and Space
- Dassault Aviation SA
- Piaggio Aero Industries SPA
- Valeol SAS
The AeroGust Project

- EU funded Horizon 2020 project
- Collaboration between industry and academia
- Inspiration from Flight Path 2050
- Maintaining and extending industrial leadership

Background

- Market trend for adoption of more flexible structures, novel design configurations and higher flight speeds
- Pushing limits of linear analyses
- Process relies on wind tunnel data from predicted cruise geometry
- Gust loads considered relatively late in design procedure – design space limited
- Extension of aerospace technologies to wind turbine design
AeroGust Work Packages

- WP1: Management, Dissemination and Exploitation
- WP2: Understanding the Nonlinearities of Gust Interaction
- WP3: Reduced reliance on wind tunnel data
- WP4: Adapting the loads process for non-linear and innovative structures
- WP5: Data Collection and Comparison
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WP2: Understanding the Nonlinearities of Gust Interaction

- Investigate aerodynamic nonlinearities due to aircraft-gust responses
  - compare the computational capability of different approaches
- Investigate classical gust definitions
  - develop new models incorporating compressibility effects
- Investigate the impact of structural nonlinearities on aircraft-gust responses
- Investigate the interaction of aerodynamic and structural nonlinearities in aircraft-gust responses
Potential Test Cases

Military – high speed

Civil transport

Wind turbine

UAV-high AR
WP3: Reduced Reliance on Wind Tunnel Data

- Recreate the industrial loads process
  - Using CFD to generate the experimental corrections
- Assess Impact of Underlying Assumptions of the Current Loads Process
- Extend the Current Process
  - Highly flexible structures
  - Innovative structures
- Include Uncertainty in Aerodynamic and Structural Models
  - Impact on gust loads
WP4: Adapting the Loads Process for Non-linear and Innovative Structures

- ROMs for Gusts
  - Implementation and development of aerodynamic ROMs
  - Use of small amounts of high quality numerical or experimental data to improve accuracy and range of aerodynamic ROMs
  - Aeroelastic ROMs

- Hybrid ROM/High Fidelity Methods.
  - Accuracy, cost, robustness and range of applicability will be investigated

- Uncertainty Methods for ROM Development
Preliminary Investigations

- Aeroelastic analyses on highly flexible wing
- Considered Hodges’ HALE UAV wing for analysis
- Intrinsic beam methodology with VLM/UVLM

<table>
<thead>
<tr>
<th>Wing Geometric Properties</th>
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<tbody>
<tr>
<td>semi-span (m)</td>
<td>16</td>
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<tr>
<td>chord (m)</td>
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<tr>
<td>Taper ratio</td>
<td>1</td>
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<tr>
<td>1/4 chord sweep (°)</td>
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<tr>
<td>dihedral (°)</td>
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<tr>
<th>Wing Structural Properties</th>
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<tbody>
<tr>
<td>mass per unit length (kg/m²)</td>
<td>0.75</td>
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<tr>
<td>In-Plane Bending Stiffness, $E_{xx}$</td>
<td>$2 \times 10^4$</td>
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<tr>
<td>Out-of-Plane Bending Stiffness, $E_{zz}$</td>
<td>$4 \times 10^6$</td>
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<tr>
<td>Torsional Stiffness, $GJ$ (Nm/rad)</td>
<td>$1 \times 10^4$</td>
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Flight Condition
- Airspeed (m/s) | 30
- Air density (kg/m³) | 0.0881
- Mach No. | 0.1017
- Altitude (ft) | 20000

- Considerable differences observed for follower, non-f, and linear analyses
- Code validated against NASTRAN/other UoB codes
Preliminary Investigations

- Comparisons of aeroelastic analyses to traditional linear approaches

- Linear aeroelastic analyses become poor, even at relatively low AoA
- Nonlinear aeroelastic models show considerable sensitivity to drag modelling
Preliminary Investigations – Dynamic Model

- Eigenmodes can be calculated
- Good agreement with exact solution
- Dynamic solver agrees with modal results

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<th>Current Work</th>
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<tr>
<td></td>
<td>Exact rad/s</td>
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<tr>
<td>1st Bending</td>
<td>2.24</td>
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<tr>
<td>2nd Bending</td>
<td>14.06</td>
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<tr>
<td>1st Torsion</td>
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<tr>
<td>Fore-Aft Bending</td>
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<tr>
<td>3rd Bending</td>
<td>39.36</td>
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Rapid Loads evaluation

stitched VLM components

CFD or experiment

Loads Database

universal correction process / matrices

High T-tail

Strut braced

Prop wash

rapid & robust unsteady VLM

Target

Funded by the European Union
UVLM correction process

\[ C_0 + C_w w_b + w_w = A\Gamma \]

Map CFD loads on to UVLM mesh

Iterate correction matrices calculation due to interaction with wake
UVLM gust

- Vertical 1-cosine gust
- \( U_\infty = 162 \text{m/s} \)
- Gust gradient = 30ft
- Gust velocity = 5.21 m/s
UVLM rigid pitch

- Rigid pitching UAV wing
- $\mathbf{U}_\infty = 162\text{m/s}, K=0.2$
Acknowledgement

This work has been funded by the European Commission through the AeroGust project (grant agreement number 636053).