Numeca

Thirty Month Review Meeting
23rd – 24th November 2017, INRIA - Bordeaux

Presented by B. Tartinville
Objectives:

To carry investigations using CFD so that the non-linearities in gust interactions are understood.

To create a gust loads process that does not require wind tunnel data and hence reduces the need for wind tunnel testing.

To develop updated reduced order models for gust prediction that account for non-linearity at an acceptable cost.

5 WPs and Numeca involved in all of them (except WP1: management) and Numflo as a third party.
WP1: Dissemination

Organization of Numeca worldwide user meeting in Brussels on 13\textsuperscript{th} and 14\textsuperscript{th} of November 2017. Presentation of Numeca activities in the framework of the AeroGust project.
WP1: Dissemination

Participation to the submission of two abstracts to the AIAA Aviation 2018 (25-29 June 2018, Atlanta)

Special session for AEROGUST project.

Cook et al. “Uncertainty quantification of aeroelastic systems with structural or aerodynamic nonlinearities”

Tartinville et al. “High fidelity gust simulations over a supercritical airfoil”
WP2: T2.2  Non-linear Aerodynamics of Gust Using LES/DES (9MM)

- Survey of high fidelity LES/DES methods for gust simulations.  
  Done
- Application to airfoil geometry.  
  Done
- Application of hybrid methods to investigate future full aircraft gust simulation.  
  Ongoing

Period: M1-M30

Deliverables @ M6, M18 and M30
Contribution from Numeca (WP2)

IDDES of FFAST crank airfoil (configuration I) with long gust (H=350 ft)
WP2: T2.2  Non-linear Aerodynamics of Gust Using LES/DES

- Application of hybrid methods to investigate future full aircraft gust simulation.
- A Navier-Stokes high order solver on unstructured grid is under development at Numeca.

Contours of Density for the isentropic vortex with $p=2$, $p=3$, and $p=4$ (from left to right) (mesh 32x32).
WP2: T2.2  Non-linear Aerodynamics of Gust Using LES/DES

We have been recently working on two important aspects for the application of high order methods to external aerodynamic applications:

• Generation of curved mesh

Original (orange) and curved (green) meshes generated around a blade leading edge.
WP2: T2.2  Non-linear Aerodynamics of Gust Using LES/DES

We have been recently working on two important aspects for the application of high order methods to external aerodynamic applications:

• Generation of curved mesh
• Develop a shock capturing scheme (artificial dissipation added)

Distributions of Mach number (upper panel) and artificial viscosity (lower panel) for an oblique shock along a flat plate (p=3).

Transonic flow around NACA0012 (p=3).
WP3: T3.3  Introduction of uncertainties into the gust load process (6MM)

- Development of methods to determine the effects of aerodynamic and structural uncertainties on the worst case loads.  

**Period:** M21-M30

**Deliverable @ M30**
WP3: T3.3  Introduction of uncertainties into the gust load process (6MM)

- Development of methods to determine the effects of aerodynamic and structural uncertainties on the worst case loads.

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Coupled system
Oofelie & FINE

Structural ROM : Modal
Aerodynamic ROM : NLH
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* The uncertainties are propagated into the coupled system through non-intrusive probabilistic collocation method.
WP3: T3.3 Introduction of uncertainties into the gust load process (6MM)

- Application of the non-intrusive probabilistic collocation method to Dassault Falcon

**Geometrical Uncertainties**
- Section Twist Angles at 8 Cross-Sections
  - Bounded Asymmetric Beta Distribution

**Operational Uncertainties**
- Mach Number
  - Bounded Asym. Beta Distribution
  - Maximum Likelihood at 0.8 Angle of Attack
- Maximum Likelihood at 2°

**Propagation technique**
- Sparse NIPColM
- Resulting in 31 collocation points

8 Wing Cross Sections Where Twist Angle Uncertainty Data is Available
WP3: T3.3  Introduction of uncertainties into the gust load process (6MM)

- Application of the non-intrusive probabilistic collocation method to Dassault Falcon

Global Results
- Lift Coefficient
  - Std = 0.0064
- Drag Coefficient
  - Std = 0.00027
- Moment Coefficient
  - Std = 0.0032

Lift Distribution
- Maximum Mean $C_L$ at Section 4
- Maximum Std $C_L$ at Section 3
  - Std $C_L = 0.0079$

Lift Coefficient Uncertainty Along Wing
(Error Bars Indicate +/- 1 Standard Deviation)
WP3: T3.3  Introduction of uncertainties into the gust load process (6MM)

• Computation of the UAV structure mode with Oofelie
  Wing geometry replace by a hollow rectangular box

  Box size: 1 m x 0.2 m x 12.5 m
  Thickness: 6 mm at root, 1.5 mm at tip

  Young Modulus: 69 Gpa
  Poisson ratio: 0.2778
  Density: 3,896 kg.m$^{-3}$

  Mesh: 576 quadratic pentahedrons
  2,648 nodes
  Clamp at root
WP3: T3.3 Introduction of uncertainties into the gust load process (6MM)
## WP3: T3.3 Introduction of uncertainties into the gust load process (6MM)

<table>
<thead>
<tr>
<th>reference</th>
<th>Variable</th>
<th>Value</th>
<th>Distribution</th>
<th>Coefficient of variation</th>
<th>$\sigma$</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>Liaw and Yang [1991]</td>
<td>Young Modulus</td>
<td>138 Gpa</td>
<td>Gaussian</td>
<td>5 %</td>
<td>6.9 Gpa</td>
<td>Graphite/Epoxy laminated square plate</td>
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<td>Bullough [2000]</td>
<td>Young Modulus</td>
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<td>Gaussian</td>
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<td>Petit and Beran [2003]</td>
<td>Stiffness Coefficients</td>
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<td>Two DOF airfoil</td>
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<td>Initial Incidence</td>
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<td>0.2 rad</td>
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<td>Witteveen [2009]</td>
<td>Damping ratio</td>
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<td>0.2 rad</td>
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<td>Young Modulus</td>
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<td>0.07 Gpa</td>
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<td>Incidence</td>
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<td>Symmetric Beta</td>
<td>22.4 %</td>
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<td>NACA0012</td>
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<td>Shinde and Panchal [2016]</td>
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<td>NACA0012 composite structure</td>
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<td>Shear Modulus</td>
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<td>Poisson ratio</td>
<td>0.42</td>
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WP3: T3.3 Introduction of uncertainties into the gust load process (6MM)

- Definition of structural and operational uncertainties

Potential uncertainties in independent variables
- Young Modulus: Gaussian distribution, COV(E) = 5%
- Shear Modulus: Gaussian distribution, COV(G) = 5%
- Damping ratio: Beta distribution in the range [0;0.1] with maximum likelihood at 0
- Flow incidence: Gaussian distribution, $\sigma = 2^\circ$
- Flight altitude: …

This need to be discussed and finalized.
**WP4: T4.1** New ROM development for gusts

**T4.5** Investigation of aeroelastic ROM for gusts (20MM total)

- Fourier decomposition ROM for gusts

**Period:** M9-M33

**Deliverables @** M24, and M33

**Contribution from Numeca (WP4)**

- Ongoing
- Ongoing
WP4: T4.1 New ROM development for gusts
T4.5 Investigation of aeroelastic ROM for gusts

The Fourier decomposition ROM for gust has been implemented into our unstructured flow solver Fine™/Open with OpenLabs and it has been also extended to aeroelastic configurations.

Three configurations are treated:
• 2D FFAST Crank airfoil
• NASA LRN 1015
• NASA CRM

Three key numerical parameters are investigated:
• Gust windowing
• Spectrum truncation
• Space discretization
WP4: T4.1 New ROM development for gusts
T4.5 Investigation of aeroelastic ROM for gusts

Example for the FFAST crank airfoil
(flow configuration D – H=30 ft)
WP4: T4.1 New ROM development for gusts
T4.5 Investigation of aeroelastic ROM for gusts

Example for the UAV (flow configuration P – H=30 ft)
10 harmonics (periodicity 10 gust length) and 10 structure modes.
WP4: T4.1 New ROM development for gusts
T4.5 Investigation of aeroelastic ROM for gusts

Example for the NASA CRM (flow configuration F – H=350 ft)
10 harmonics (periodicity 10 gust length) and 3 structure modes (standard steel).
WP4: T4.1 New ROM development for gusts
T4.5 Investigation of aeroelastic ROM for gusts

Example for the NASA CRM (flow configuration F – H=350 ft)
10 harmonics (periodicity 10 gust length) and 3 structure modes (standard steel).

Displacement has been amplified by a factor 10
WP4: T4.1  New ROM development for gusts  
T4.5  Investigation of aeroelastic ROM for gusts

Nastran bdf models available on Nasa CRM website

Fuselage and tail material:  
Young Modulus: 199.9 Gpa  
Poisson ratio: 0.278  
Density: 7,999 kg.m⁻³

Main wing material:  
Young Modulus: 182.7 Gpa  
Poisson ratio: 0.31  
Density: 7,916 kg.m⁻³

However the models correspond to the wind tunnel geometry and model structural properties.

Open question: How to modify/scale the structural properties to fit a real aircraft size?
<table>
<thead>
<tr>
<th>WP</th>
<th>Task</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
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</table>

Start date 1st May 2015.

Done
Done
Ongoing
Ongoing
Ongoing
Done
Planning for next period

WP4: All the activities have been planned with Numflo
- End December 2017: dead line for FFAST crank aeroelastic simulations
- End January 2018: dead line for UAV aeroelastic simulations
- End February 2018: dead line for CRM aeroelastic simulations
We need to have a coherent structural model of the CRM and of the UAV
We propose to merge deliverables D-4.5 and D-4.16.

WP3:
- Finalize set up of the UQ chain until the end of the year
- UQ simulations should start in January 2018
We need to cross check the modal representation of the UAV with other partners.