NLR contribution to AEROGUST

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Contributions of NLR to objectives of AEROGUST

1. Understanding non-linearities of gust interaction using CFD
   T2.1.1 *Use of highly accurate methods resolving gusts* and simplified approach *(Ongoing)*

2. Reduced reliance on wind tunnel data
   T3.1: Initial evaluation of current industrial loads process for gusts *(D3.2 has been delivered)*
   T3.2.2 Investigation of using multiple flight shape models for aeroelastic corrections *(Not started yet)*
   T3.3.1 *Effect of aerodynamic and structural uncertainties* on the worst case *(Ongoing)*

3. Adapting the loads process for non-linear and innovative structures
   T5.3.1 Develop comparison methodology *(Deliverable D5.4 has been delivered)*
   T5.3.? Fill the solution data base?
Non-linearities of gust interaction using CFD

T2.1.1 Use of highly accurate methods resolving gusts and simplified approach

• Gust Error-correction Method (GEM): solves the same continuous equations as gust-propagating methods on coarser meshes

• Simplified approach: Perturbation velocity field $u'(x, t)$: computed with non-linear Euler equations in perturbation form + GEM (+ high-order finite-volume method)

• First tests with simplified approach on Test case 1 (pitch-plunge airfoil) failed because of strong viscous effects – will be continued for other test case

• CRM test case has been set up, but no results yet

• Comparison of the results to study nonlinear effects
T3.3.1 Uncertainty for 1-cos gusts

• Approach: use Dakota (dakota.sandia.gov) as driver for polynomial chaos expansion of the outcome of a reduced order model

• Last half year: demonstrate functionality with simple aircraft model of NLR (NLR-TP-97379)

• Next half year this model should be replaced by ROM of one of the partners (discussion point)
Simple aircraft model

• simple flat planform
• strip theory aerodynamics with Sears-Theodorsen theory for induced incidence angles
• two rigid and three elastic modes
• (selected) input: elastic axes, cg position, lift factors, fuselage moment coefficient, scaling of flexible modes
• output: spectrum or time history of load factor, shear force, bending and torsion moment at wing root, and shear force in tail root
Dakota

• shell for optimization, design of experiments, uncertainty quantification
• easy file-based coupling with black-box simulation tools
• for uncertainty quantification, Dakota samples stochastic input values, and processes the resulting output to describe the output distributions and correlations
Demonstration

- Two parameter variation: location of elastic axes on wing and tail
  - variation in location is assumed to be normally distributed (variance 1% chord)
    - therefore output distributions are approximated with Hermite polynomials
- Output is maximum value of load response
- Validation with Monte-Carlo simulation and convergence study
Monte-Carlo simulation with 10000 samples serves as the reference.
Essential input for uncertainty quantification

• ROM model which allows variation of relevant structural and aerodynamic parameters
• (good estimate of) PDF of these parameters
• definition of the relevant output parameters
• which question to answer
  • maximum load (or other quantity?) will be less than xxx in 99% (or 99.9%?) of the cases
Backup slides
Gust Error-correction Method (GEM)

• Resembles split-velocity method, without actually splitting velocity
  • solves the same continuous equations as gust-propagating methods on coarser meshes

• Main idea:
  • compute all gradients of gust velocity analytically instead of numerically
  • discretize $\nabla u \rightarrow \nabla_{FV} u - (\nabla_{FV} u_g - \nabla u_g)$
    • where $u_g$ is the gust velocity, $\nabla$ is the analytical gradient, and
    • $\nabla_{FV}$ is the Finite-Volume discretization of the gradient $\nabla$

• Result:
  • LHS = discretized Euler or Navier–Stokes equations
  • RHS = error correction $\sim (\nabla_{FV} u_g - \nabla u_g)$
    • corrects discretization error when grid too coarse to capture gust (accuracy)
    • goes to zero in limit of zero mesh size (consistency)
Non-linearities of gust interaction using CFD

• Baseline approach: compute gust response using RANS + GEM

• Simplified approach:
  • Split velocity as $u(x, t) = \bar{u}(x) + u'(x, t)$
  • Mean velocity field $\bar{u}(x)$: computed with steady RANS
  • Perturbation velocity field $u'(x, t)$: computed with non-linear Euler equations in perturbation form + GEM (+ high-order finite-volume method)

• Advantages simplified approach:
  • boundary-layer resolution only required for steady RANS
  • accurate capturing of gust in far field without high grid resolution
  • accurate capturing of gust response with high-order method
  • allows relatively cheap time-accurate Euler computation with explicit time integration
Test case 1: pitch-plunge aerofoil

- FFAST crank aerofoil
  - chord = 8 m
  - Case I: Alt. = 35,000 ft, $M = 0.86$, $A_s = 0.74662$
    ($U = 255.1$ m/s, $Re_c = 5.41 \cdot 10^7$)
  - Gusts: $H = 30$ ft = 9.144 m, $U_g = 37.18$ ft/s = 11.33 m/s
    $H = 150$ ft = 45.72 m, $U_g = 48.62$ ft/s = 14.82 m/s
    $H = 350$ ft = 106.7 m, $U_g = 56.00$ ft/s = 17.07 m/s

- Structural model
  - see deliverable D5.2

- Baseline approach: RANS + GEM
Test case 1: pitch-plunge aerofoil

- Aerofoil response