Information Package: Workshop on Aeroelastic Prediction

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NASA
Hampton, Virginia
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Objectives of this information package

- Inform the aeroelastic technical community of
  - Progress on this activity
  - Upcoming events
  - Resources for participants

- Solicit participation
  - Performing computations
  - Serving on organizing committee
Outline

- Overview
- Schedule, Preliminary
- Configuration: HIRENASD
- Test Cases, Preliminary
- Participant Information Sources & Organizing Committee Solicitation
Aeroelastic Computational Benchmarking

- **Technical Challenge:** Assess state-of-the-art methods & tools for the prediction and assessment of aeroelastic phenomena
  - Modeling complex unsteady aerodynamic phenomena on complex geometries
  - Accurately predicting
    - Unsteady aerodynamic phenomena and their effect on the aeroelastic response of a vehicle
    - Flutter, LCO, buffeting loads
    - Aeroelastic deflections
    - Accurately resolving separated flows
    - ...

- **Fundamental hindrances to these challenges**
  - No comprehensive aeroelastic benchmarking validation standard exists
  - No sustained, successful effort to coordinate validation efforts
Approach

- Conduct Aeroelastic Prediction Workshops (AePWs)
  - Building block approach: Validate one aspect at a time
  - Utilize existing experimental databases for comparison
  - Pattern after the Drag Prediction Workshop Series
Objectives of AePW

- Perform comparative computational studies on selected test cases
- Identify errors & uncertainties in computational aeroelastic methods
- Identify gaps in existing aeroelastic databases
- Provide roadmap of path forward
  - Additional existing data sets?
  - New experimental data sets?
  - Analytical methods developments?
Validation Objective of 1st Workshop

- Unsteady aerodynamic pressures
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## Aeroelastic Prediction Workshop Schedule, Preliminary

- Identify organizing committee by Dec 1, 2010
- Data Release & Workshop Kickoff: IFASD 2011, Paris
- 1 year to perform computations
- Workshop: plan for June 2012; presentations within working group
- ~ 6 months to revise results & prepare papers for formal conference presentation
- Conference for presenting papers currently unidentified

<table>
<thead>
<tr>
<th>Activity</th>
<th>FY10</th>
<th>FY11</th>
<th>FY12</th>
<th>FY13</th>
<th>FY14</th>
<th>FY15</th>
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<td>Advocate</td>
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<td>Workshop kick-off</td>
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<tr>
<td>Config, grids, etc. available on-line</td>
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<tr>
<td>Perform analysis of selected config.</td>
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<tr>
<td>Conduct 1st Aeroelastic Prediction Workshop</td>
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<td>Update / improve CFD results / code(s)</td>
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<td>Perform comparisons, Statistical analyses</td>
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<td>Present conference papers</td>
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- Kickoff at IFASD

1. Identify organizing committee by Dec 1, 2010
2. Data Release & Workshop Kickoff: IFASD 2011, Paris
3. 1 year to perform computations
4. Workshop: plan for June 2012; presentations within working group
5. ~ 6 months to revise results & prepare papers for formal conference presentation
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Initial Configuration

High Reynolds Number Aero-Structural Dynamics (HIRENASD) Model

Tested in European Transonic Wind Tunnel (ETW), Cologne, Germany 2006

Funded by Deutsch Forschungsgemeinschaft (DFG)
The High Reynolds Number Aero-Structural Dynamics (HIRENASD) Project (http://heinrich.lufmech.rwth.aachen.de)

- Tested in the ETW in 2006
- Led by RWTH Aachen University w/ funding from the German Research Foundation

"Pros" for this data set:
- Available FEM, CFD grid, and published experimental data
- Good distribution of unsteady pressures (259 transducers)
- Balance loads data
- Quantitative deformation measurements
- Accelerometer and strain gage measurements
- Forced vibration data at 1st and 2nd bending and 1st torsion modes
- Transonic conditions with realistic flight Reynolds numbers
- Additional tests planned
- Limited scope: rigid unsteady pressure model

"Cons" for this data set:
- No flow visualization
- Only published data available
- Limited scope: rigid unsteady pressure model
Independent setting of $Ma$, $Re$ and model load $q/E$ enables separation of **aerodynamic** and **aeroelastic** effects.
No access to wind tunnel test section during tests

Due to thermal insulation, space for excitation mechanism is very limited

→ Excitation mechanism integrated in clamping unit
Finite Element Models

From HIRENASD main web site:
Follow web site links (choose “Geometry windtunnel model assembly” from menu; choose “Windtunnel assembly” from submenu)

**NASTRAN input deck** (.dat files)

Coming soon:
**Updated NASTRAN input** file incorporating changes
- File format issues
- Units converted to meters from millimeters
- Coordinate system
- Pressure transducer location
Geometry, Grids

From HIRENASD main web site:  

Follow web site links (choose “Geometry windtunnel model assembly” from menu and submenus open up)

Structured grid (.cgns file)
IGES files for wing only

Fun3D Unstructured Grids using GridTool & VGRID (coming soon):
Baseline grid ~ 20Million nodes
FUN3D Validation using the HIRENASD Data Set
Workshop Test Case Preparation

- Establish gridding guidelines for Aeroelastic Prediction Workshop (AePW)
- Build grids
- Establish computational comparison test cases
- Make experimental data available to compare with computations (Cp, SPT) in collaboration with RWTH Aachen
- Prepare guidelines for data reduction
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## Proposed Test Cases

<table>
<thead>
<tr>
<th>Test Case Number</th>
<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>Grid convergence study</td>
</tr>
<tr>
<td>2</td>
<td>Static aeroelastic study using the converged grid solution</td>
</tr>
</tbody>
</table>
| 3                | Forced excitation study  
Mach = 0.8  
Comparing with published data points |
| 4                | Forced excitation study  
Mach sweep  
Blind comparison |
| 5                | Forced excitation study  
Low Reynolds number case  
Previously analyzed by several participants |
Case 1: Grid convergence study

- Utilize experimental data point #250
  - Angles of attack: ? (experimental data available for an aoa sweep)
  - Re = 23.5M
  - Mach 0.8
  - q/E=0.48e-6

- Proposed data comparisons
  - Delta C_P, pressure distributions
  - Deflections
    - Spanwise distribution along
    - Aerodynamic twist along stations 3 and 7
  - Integrated quantities
    - Lift, Drag, Pitching Moment

- Notes: We are looking for parameters that are sensitive to grid. Can look at the in-plane component of the normal force at this angle of attack.

- Normal force distribution for the zero-lift condition? Tip twist for the zero-lift condition?
Grid Convergence: Groundwork & Sample Results

Preliminary FUN3D Analysis of HIRENASD

Drag Prediction Workshop - 4

Figure 4. Case 1a Continuum Estimates of Total Drag: $M = 0.85, C_l = 0.5, Re = 5 \text{ million}.$

Figure 5. Close 1a Grid Convergence on Total Drag: $M = 0.85, C_l = 0.5, Re = 5 \text{ million}.$
Case 2: Static aeroelastic study using the converged grid solution

- **Test conditions**
  - Mach 0.8
  - Re 23.5M, no transition strips
  - Experimental data set: #250, (q/E=0.48e-6)
  - Experimental data set: #316 (q/E=0.22e-6)

- **Proposed data comparisons**
  - Flexible stability derivatives
  - Static deformation
  - Static pressure distribution
Proposed Data Comparison: Static Aeroelastic Wing Deformation

Groundwork & Sample of Results

Twist angle: at $\alpha=0^\circ$, $\varphi=0.65^\circ$

at $\alpha=3^\circ$, $\varphi=1.35^\circ$

Proposed Data Comparison:
Static Aeroelastic Pressure Distributions
Groundwork & Sample of Results

Mach 0.8, AOA 2°
Proposed Data Comparison:
Static Aeroelastic Pressure Distributions
Groundwork & Sample of Results

Mach 0.8, AOA 0°
Proposed Data Comparison:
Static Aeroelastic Pressure Distributions
Groundwork & Sample of Results

Mach 0.8, AOA -2º
Case 3: Forced excitation study at Mach 0.8, comparing with published data points

- Mach 0.8
- Re = 23.5 M
- q/E = 0.48e-6

<table>
<thead>
<tr>
<th>Exp case study #</th>
<th>Angle of attack</th>
<th>Mode excited</th>
</tr>
</thead>
<tbody>
<tr>
<td>260</td>
<td>-1.34</td>
<td>1 (1st bending)</td>
</tr>
<tr>
<td>261</td>
<td>1.5</td>
<td>1 (1st bending)</td>
</tr>
<tr>
<td>270</td>
<td>-1.34</td>
<td>1 (1st bending: modified frequency)</td>
</tr>
<tr>
<td>271</td>
<td>-1.34</td>
<td>2 (2nd bending)</td>
</tr>
<tr>
<td>272</td>
<td>-1.34</td>
<td>5 (1st torsion)</td>
</tr>
</tbody>
</table>
Proposed Data Comparisons

- Transfer-function-like quantities: Pressure coefficient distribution relative to acceleration ($C_p/\text{accel}$)
  - Magnitude and phase at excitation frequency
  - For the entire airfoil
  - For several span locations: $1, 3, 7$
- Accelerations $(15,1), (13,1)$
- Balance loads?
Proposed Data Comparisons

Excitation of Modes: 1\textsuperscript{st} Bending, 2\textsuperscript{nd} Bending, 1\textsuperscript{st} Torsion
M=0.8, Re=23.5e6, q/E=0.48e-6, alpha=-1.34deg

Reimer, L., Boucke, A., Ballmann, J., and Behr, M.,
“Computational Analysis of High Reynolds Number Aero-Structural Dynamics (HIRENASD) Experiments,”
Proposed Data Comparison: Forced Excitation near Modal Frequencies
Groundwork & Sample of Results

Forced Excitation of 1\textsuperscript{st} Bending Mode
Magnitude & Phase of Unsteady Pressure Distribution, Relative to Acceleration Response

Published Aachen University results:
Experiment & Analysis

Sample of Cp Surface from FUN3D Solution, Before Normalization

Case 4: Mach sweep study, blind comparison

- 1st Bending Mode Excitation
- Re=23.5M
- Angle of attack = 1.5
- q/E =0.48e-6
- Mach numbers:
  - 0.70, 0.75, 0.80, 0.83, 0.85, 0.88
- Proposed data comparisons:
  - Same as Case 3
**Case 5:** Low Reynolds number condition, previously analyzed by several participants

- Early bird comparison case
- Experimental data set #159
- Angle of attack = 1.5 degs
- Re = 7M
- Mach 0.8
- q/E = 0.22e-6
- Experimental configuration has transition strips
- Proposed data comparisons:
  - Same as Case 3
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Aeroelastic Prediction Workshop Organizing Committee

- **Desired diversity**
  - Of Organization: **Industry, Government, University**
  - Of Technical Knowledge: Computational, Experimental
  - International Representation

- **Desired traits**
  - Enthusiasm for the problem; Involvement
  - Access to computational aeroelasticians, even if they are not analysts themselves
  - Knowledgeable about the technical aspects
Aeroelastic Prediction Workshop Organizing Committee

- **Time line (near-term future activities)**
  - Identification of membership: Dec 1, 2010
  - First telecon: Dec 2, 2010
  - Final version of IFASD abstract: Dec 14, 2010

- **Anticipated responsibilities**
  - Provide direction, vision and active pursuit of resources
  - Promotion of activity within technical community & most particularly within their own organization
  - Oversight of technical and organizational aspects
  - Short term: assist in authoring overview abstract for IFASD, June 2011
  - Monthly telecons / meetings (discuss issues, make decisions)
  - Subcommittees / Assignments
    - Grid resolution study definition; grid development
    - Website development & maintenance
    - Analysis results coordination and comparison
    - ...

Participant Information Sources

- Workshop website (temporary home):
- Links to:
  - HIRENASD website (German and English languages)
    - http://www.lufmech.rwth-aachen.de/HIRENASD/
  - NASA White Paper reviewing experimental data sets
  - 2011 International Forum on Aeroelasticity & Structural Dynamics
  - Fun3D
    - http://fun3d.larc.nasa.gov/
  - Drag Prediction Workshop
    - http://aaac.larc.nasa.gov/tsab/cfdlarc/aiaa-dpw/
- POCs (for now, email us directly):
  - Jennifer Heeg (jennifer.heeg@nasa.gov)
  - Jennifer Florance (jennifer.p.florance@nasa.gov)
  - Pawel Chwalowski (pawel.chwalowski@nasa.gov)
  - Boyd Perry (boyd.perry.iii@nasa.gov)
  - Carol Wieseman (carol.d.wieseman@nasa.gov)
Credits

- The experimental HIRENASD research program is led by Professor Josef Ballmann of Aachen University and funded by DFG. This data and these results are his. I wish to gratefully acknowledge their willingness to allow it to be reproduced and presented here.
- The NASA work is funded by the NASA Fundamental Aeronautics Program, Subsonic Fixed Wing Project.
- The NATO RTO Aerospace Vehicle Technology Panel is supporting the international collaboration under a Research Task Group, “Joint Exercise on Aeroelastic Prediction”
High Reynolds Number
Aero-Structural Dynamics (HIRENASD)
- Numerical Prediction, Experiments and Code Validation -

J. Ballmann
Department of Mechanics (LFM) and Chair of Computational Analysis of Technical Systems (CATS)
RWTH Aachen University
Germany
The Aerodynamic and Aeroelastic Community has been invited to visit our homepage [http://www.lufmech.rwth-aachen.de/HIRENASD/](http://www.lufmech.rwth-aachen.de/HIRENASD/) for model and experimental conditions data, to produce their own (blind test) computational results and to participate in the first HIRENASD workshop for presenting these and discussion in Aachen, Germany, on May 15-16, 2008.

Downloadable data, e.g. ...

... block-structured flow grids

... CAD data sets of the outer aerodynamic geometry

... CAD data sets of the inner structural geometry

... FE meshes of the inner model structure

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[KOPINDA-Format (Portable Parallelization of Industrial Aerodynamic Applications)]
Project Partners at Aachen University:

- Department of Mechanics
- Institute for Lightweight Structures
- Institute for Geometry and Applied Mathematics
- Shock Wave Laboratory

Thanks to ...

- German Research Foundation (DFG) for funding HIRENASD
- Airbus Industry for supporting the balance for dynamic force measurement
- DLR for advice concerning data acquisition and providing AMIS II
- ETW for providing windtunnel adaptations, for e.g. dynamic force measurement, and continuous advice during preparation of model and measuring equipment
• References