Aeroelastic Analysis for Full Aircraft

IN THIS WEBINAR:

- Running a static aeroelastic trim analysis on a full aircraft
- Running a flutter analysis on a full aircraft

PRESENTED BY:

Ben Names
Sr. Aerospace Stress Engineer
Structural Design and Analysis
ben@structures.aero
Agenda

1. SDA Overview
2. Setting up an aeroelastic model for a full aircraft
3. Static aeroelastic trim analysis example
4. Full vehicle flutter example
5. Conclusions
Structural Design and Analysis (Structures.Aero)

Structural Analysis

• Team of 14 engineers that help our clients design lightweight and load efficient structures.
• We service aerospace companies and other industries that require high level analysis.
• Specialty in composites and lightweight structures
• Tools used include hand analysis, HyperSizer, Femap, NX Nastran, Fibersim, NX, Solid Edge, Simcenter 3D, LS Dyna, and LMS.

Software Sales and Support

• Value added reseller providing software, training, and support for products we use on a daily basis.
• Support Femap, NX Nastran, Simcenter 3D, Fibersim, Solid Edge, and HyperSizer.
Meet Vanilla Aircraft’s VA001
Static Aeroelastic Analysis

• Static aeroelastic analysis takes into account two sources of forces
  – Elastic forces within the structure
  – Aerodynamics forces from the aero potential flow model
• Analysis is linear
• Process:
  – Calculates rigid aero influence coefficients
  – Calculates an aerodynamic “modified stiffness matrix” (dependent on q)
  – Solves displacements for a given q

\[(K - q_\infty Q)x = F_{aero}(q_\infty) + F_{external}\]
Aero Modeling: Adding incidence and twist

$ Initial Downwash

$1111111222222233333444445555556666666777777888888899999990000000

<table>
<thead>
<tr>
<th>DMI</th>
<th>NAME</th>
<th>&quot;0&quot;</th>
<th>FORM</th>
<th>TYPEIN</th>
<th>TYPEOUT</th>
<th>M</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMI</td>
<td>W2GJ</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>6353</td>
<td>1</td>
</tr>
</tbody>
</table>

$ NAME J I11 A(I11,J)THRU I1N I21 A(I21,J)

| DMI | W2GJ  | 1   | 1    | 0174532THRU | 5250 | 5826 | -0.034906+DM1 |

$ THRU I2N
+DM1 THRU 6325

- M: number of aero panels in your model
- N: number of trim cases in analysis
- J: trim case where downwash is added
- I11: ID of the first Aero box with added downwash
- A(I11,J): Initial downwash (radians)
- I1N: Last box to apply the downwash
- Continue for as many added downwashes as desired…

Fuselage center line
When creating an aero panel, the orientation of the “element” normal depends on how the points are selected.

When choosing the following orientation, element normal point in the +z direction.

If it is necessary to add aerodynamic/geometric twist to the lifting surface, adding a positive downwash using this convention effectively increases AoA.
Aero Modeling: Pay attention to panel normal’s

• When creating an aero panel, the orientation of the “element” normal depends on how the points are selected.

• When choosing the following orientation, element normal point in the -z direction.

• If it is necessary to add aerodynamic/geometric twist to the lifting surface, adding a negative downwash using this convention effectively increases AoA.
Aero Modeling: Pay attention to panel normal’s

- Right and left wing use different element normal, no initial downwash applied

- Right and left wing use different element normal, initial downwash applied
Control Surfaces
Constraints VS Supports

Constrain DOF with no relevant trim variables

Support DOF associated with trim variables

Model is allowed to accelerate along the z-axis, and rotate about the y-axis (i.e., it can pitch and plunge)
Static Aeroelastic Results

- All info provided by a static analysis (displacements, stresses, strains, etc.)

- Accurate, 3D aero panel distributions (dp, not true pressure)

- Trim variables of control surfaces

- Non-dimensional stability derivatives
Flutter Analysis

- Flutter analysis takes into account three sources of forces
  - Elastic forces within the structure
  - Aerodynamics forces from the aero potential flow model
  - Inertial forces from the structure
- Is linear
- Process
  - Conduct a normal modes analysis
  - Calculate AIC matrices at each combination of Mach number and reduced frequency
  - Solve eigenvalue problem at each q for frequency and damping
Wing (Substructure) VS Aircraft

- **Wing**
  - Fewer modes needed to consider
  - Rigid body motions can be ignored
  - Interaction of aeroelastic behavior with other structures ignored
  - Smaller run times

- **Aircraft**
  - Many more modes needed to be considered! (20-30)
  - Coupling of rigid body motions with elastic modes can occur (i.e., body freedom flutter)
Damping vs Airspeed

Mode 5
Mode 6
Mode 7
Mode 8
Mode 11
Mode 12
Mode 13
Mode 14
Mode 16
Mode 21
Mode 25
Flutter Speed for aircraft at 310 mph

Mode 13 and 25 go unstable slightly more gradual
Unstable Flutter Mode at $V_f=310$ MPH (mode 21)
Flutter Mode from NASA Video
BFF Frequency vs Airspeed

- Mode 6
- Mode 7
- Mode 11
- Mode 12
- Mode 13
- Mode 14
- Mode 18
- Mode 20
BFF Damping vs Airspeed

Damping vs. Airspeed for different modes:
- Mode 6
- Mode 7
- Mode 11
- Mode 12
- Mode 13
- Mode 14
- Mode 18
- Mode 20
Development of BFF VS Airspeed

\[ V = 73 \text{ mph}, \text{ damping} = -0.23137 \]
\[ V = 150 \text{ mph}, \text{ damping} = -0.16197 \]
\[ V = 220 \text{ mph}, \text{ damping} = 0.003128 \]
Femap and NX Nastran Training

### Topics
- Geometry Preparation and Meshing
  - Midsurfaces, meshing toolbox, hex and tet meshing
- Materials, properties, and boundary conditions
- Analysis Model Checks and Solver Submission
- Post-processing tools
  - Data Table, Postprocessing Toolbox, Freebody diagrams, XY Plots

### Logistics
- Hosted at SDA’s office in Sterling, Virginia
  - Located near Dulles Airport and Udvar-Hazy Space Museum
- Cost: $1575 per attendee
  - FREE Copy of Learning FEMAP by Eric Gustafson

More information at [https://structures.aero/femap-training/](https://structures.aero/femap-training/)
Do you require aeroelastic analysis?

Hire SDA
Trust your analysis to experienced engineers

Experience modeling aeroelastic trim and flutter for full aircraft as well as sub-structures

Deep understanding and knowledge of the underlying physics

Purchase NX Nastran Aeroelasticity
Included in the NX Nastran Advanced Bundle

Contact Marty Sivic at msivic@structures.aero to get a quote.
Questions?

For questions on the material covered today, please contact Ben Names.

Ben Names
Aerospace Stress Engineer
ben@structures.aero
703-935-2827

For questions about pricing, or to see a demo, please contact Marty Sivic.

Marty Sivic
Director of Sales
msivic@structures.aero
724-382-5290