Nonlinear Structural Modal Model for Aeroelastic Applications

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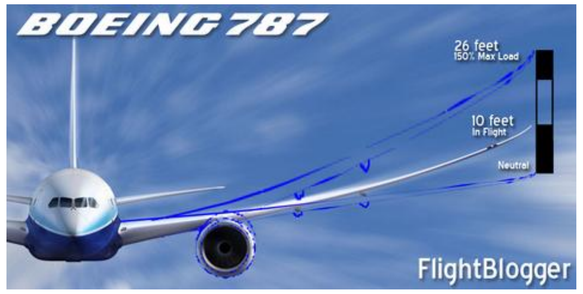
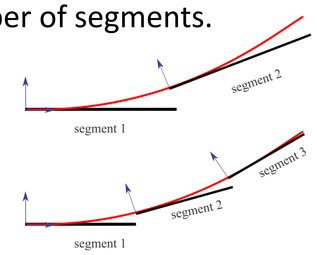
Motivation and Goals



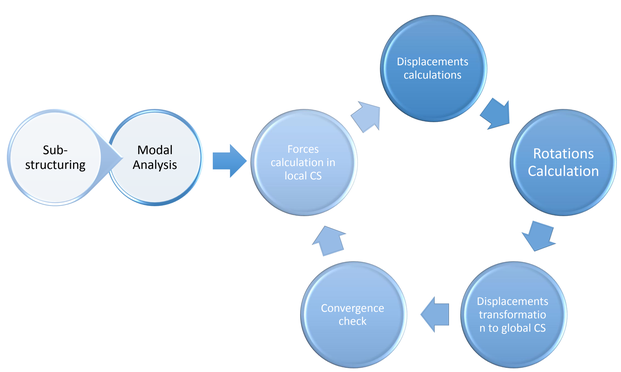
- Traditionally, aeroelastic phenomena are analyzed based on linear models.
- In recent years, the push towards lighter and more efficient structures has led to aircraft configurations featuring very large deformations in their operative conditions.
- Analysis of such configurations requires nonlinear structural models.
- Nonlinear structural models are available within some commercial FE tools. They are computationally expensive, and are not readily available for aeroelastic analyses.
- The current study presents a method for aeroelastic analysis of highly flexible structures that is based on linear modes of sub-structures.[1]
- The method is computationally efficient, and does not rely on nonlinear FE tools.

Nonlinear Modal Approach

- Displacements are described as a combination of large, rigid-body displacements and small elastic deformations.
- The structures is divided into a few number of segments.

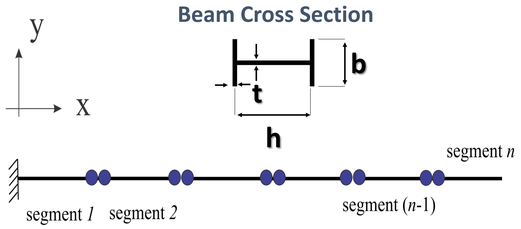


- Each segment is fitted with a body attached coordinate system that undergoes large RB displacements.
- (Small) elastic deformations are computed about the local CS.
- Elastic deformations computed using the modal approach. Advantages:
  - Linear
  - Computationally efficient
  - Can be used with traditional aeroelastic tools



Numerical Test Case

Structural Model:



- Length (L): 30 m
- Web and flange thickness (t): 2 cm
- Web height (h): 40 cm
- Flange width (b): 20 cm
- Elastic Modulus (E): 70 GPa
- Poisson ratio (ν): 0.3

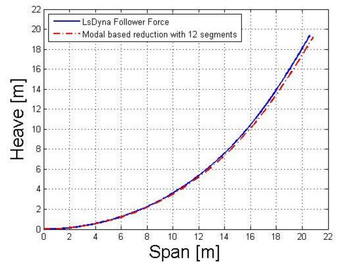
Aerodynamic Model (strip theory):

- Wing Chord (c): 2.438 m
- $C_{l\alpha}$: 2π
- Airfoil Aerodynamic Center (a.c.): 0.25·c
- Elastic Axis (e.a.): 0.4·c
- Wing Surface Area: c·L

Results

5kN follower tip force:

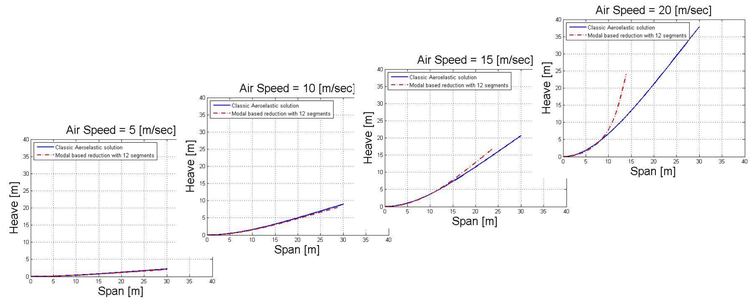
- Comparison to LsDyna® solution



- 28 sec on a quad-core desktop with 4 GB RAM, compared to 15 mins for the LsDyna solution solved on a 12 node machine with 48 GB RAM

Static aeroelastic load:

- Compared to a linear FE solution for different airspeeds.
- Nonlinearity plays a significant role in airspeeds higher than 10 m/sec



Conclusions

- A nonlinear test case of a beam acted by a follower tip force resulted in excellent agreement with nonlinear analysis performed with the commercial nonlinear finite-element software, with significant reduction of the CPU time.
- A nonlinear test case of an aeroelastic load resulted in excellent agreement with classic linear aeroelastic solution in low airspeeds.
- With increase of airspeed the nonlinear aeroelastic solution defers significantly from the linear one

Future Study

- Use the nonlinear modal model to solve a dynamic aeroelastic test case.

References

[1] Bernhammer, L. O. et. Al, "Wind Turbine Structural Model Using Non-Linear Modal Formulations", 2014.