AEROELASTICITY

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OUTLINE

- Objectives
- Brief Tutorial (What is Aeroelasticity?)
- Criticality (Why does Aeroelasticity matter?)
- Recent Developments at NASA (What’s new in Aeroelasticity?)
- Challenges (What are the needed advancements in Aeroelasticity?)
- Concluding Remarks
OBJECTIVES

- Provide basic Tutorial on Aeroelasticity (concepts, terminology)
- Identify critical and important areas of research
- Share recent advances at NASA
- Significant levels of excellent work being performed at other national and international organizations but cannot properly address during this presentation
- Provide a forward vision for advances in Aeroelasticity
What is Aeroelasticity?

Aeroelasticity addresses the interaction between aerodynamic, elastic, and inertial forces.
Aeroelasticity is critical for efficient flight performance and flight safety
Aeroelasticity: Feedback Mechanism

At a given flight condition:

- Gain typically dynamic pressure or velocity
- Nature of feedback depends on nature of Structural Dynamic and Unsteady Aerodynamic systems: LINEAR or NONLINEAR??
Aeroelasticity: Linear Assumptions

**LINEAR**

**Structural Dynamics**
- Structural Response
  - Modal Equations
  - Modeshapes, Frequencies
  - ODEs, state-space form

**Unsteady Aerodynamics**
- Unsteady Aerodynamic Response
  - Linear, frequency-domain
  - Function of Mach number and reduced-frequency

**Aeroelastic Response**
- Flutter Determinant
- P-k solver

**Outputs**
- V-g-omega plots

**Pros:** computationally fast and efficient; excellent insight into mechanisms

**Cons:** limited to flight conditions where linearity assumptions are valid
Aeroelasticity: Linear Assumptions

**Structural Dynamics**
- Modal Equations
- Modeshapes, Frequencies
- ODEs, state-space form

**Unsteady Aerodynamics**
- Linear, frequency-domain
- Function of Mach number and reduced-frequency

**Pros:** computationally fast and efficient; excellent insight into mechanisms
**Cons:** limited to flight conditions where linearity assumptions are valid
Aeroelasticity: Linear/NL Assumptions

**LINEAR**
- Structural Dynamics
  - Modal Equations
  - Modeshapes, Frequencies
  - ODEs, state-space form

**NONLINEAR**
- Unsteady Aerodynamics
  - CFD-based analyses (RANS, LES)

**Aeroelastic Response**
- Time-domain integration
- Outputs
  - Aeroelastic transients

**Pros:** used to simulate effect of complex flow physics on structure
**Cons:** computationally expensive, difficult to gain insight into mechanisms
**Aeroelasticity: Linear/NL Assumptions**

**LINEAR**
- Structural Dynamics
  - Structural Response
    - Modal Equations
    - Modeshapes, Frequencies
    - ODEs, state-space form

**NONLINEAR**
- Unsteady Aerodynamics
  - Unsteady Aerodynamic Response
    - CFD-based analyses (RANS, LES)

**Aeroelastic Response**

- Pros: used to simulate effect of complex flow physics on structure
- Cons: computationally expensive, difficult to gain insight into mechanisms
Aeroelasticity: Reduced-Order Model (ROM)

**LINEAR**
- Structural Dynamics
  - Structural Response
    - Modal Equations
    - Modeshapes, Frequencies
    - ODEs, *state-space* form

**LINEARIZED**
- Unsteady Aerodynamics
  - Unsteady Aerodynamic Response
    - CFD-based analyses (RANS, LES)
    - In *state-space* form

**Aeroelastic Responses**

- Pros: computationally efficient, provides insight into mechanisms
- Cons: validity and accuracy might be limited to specific amplitude ranges
Aeroelasticity is critical for efficient flight performance and flight safety.
Aeroelasticity’s Importance to NASA’s Strategic Thrusts

Ultraefficient Subsonic Transports

- Transonic flow regimes can produce stability boundaries (flutter) which are very complex and hard to predict
- Advanced material concepts allow for more-flexible wings and rotors
- Novel configurations can have aeroelastic problems not experienced with traditional designs

Safe, Quiet, and Affordable Air Vehicles

- Potential whirl flutter: coupling of wing flexibility with the propeller motion
- Rotor vibration → ride comfort and acoustics

Commercial Supersonic Aircraft

- Static aeroelastic deflections might affect supersonic boom shaping
- Aeroservoelasticity a potential concern

Aeroelasticity poses a critical challenge to novel and advanced configurations
Recent Developments

- FUN3D GPU port for ~18x faster analysis
- FUN3D Linearized Frequency Domain (LFD) Solver
- AEROM Development and Applications
- Applications Using KESTREL CFD code
- Structural and Design Optimization Tools

We are developing state-of-the-art tools for use by NASA and the larger aerospace community
Aeroelastic Prediction Workshop

• An open forum for code-to-code and code-to-experiment comparisons
• Studying aeroelastic problems most critical to design of future aircraft

Confidence in computational predictions is built by community participation and thorough verification and validation.
X-57 Aeroelasticity

X-57’s thin wing and added propellers present unique aeroelastic challenges, even for state-of-the-art analysis tools.

Ground Vibration Test (GVT)

NASA’s aeroelastic expertise applied to ensure X-57 is safe to fly
X-59 Aeroelasticity

- **Unique geometry** presents aeroelastic/ASE challenges
- **Close collaboration** with Lockheed-Martin (LM)
- **Close collaboration** with Flight Dynamics
- **NASA providing independent verifications** and unique analyses methods
- **OM sensitivity identified**

**Computational Static Shape**

**NASA’s aeroelastic/ASE expertise essential for success of X-59 project**
Challenges and Future Directions

- Unsteady Aero
  - Linear Attached Flow
  - Nonlinear Separated Flow

- Structural Dynamics
  - Linear
  - Modal

- Nonlinear

- Linear Aeroelasticity
Challenges and Future Directions

- Unsteady Aero
  - Linear
    - Attached Flow
  - Nonlinear
    - Separated Flow
- Structural Dynamics
  - Linear
    - Modal
  - Nonlinear
- Aeroelasticity
  - Traditional Linear Aeroelasticity
  - RANS Aeroelasticity
- HALE-type Vehicle Analyses
Challenges and Future Directions

- Unsteady Aero
  - Linear Attached Flow
  - Nonlinear Separated Flow

Future Directions
- Separated flows beyond RANS
- Buffetting interactions

Challenges
- Large deformations
- Modal not applicable (unless local linearizations)
- Traditional AE analyses based on LINEAR concepts: eigenvalues, root locus, etc.; will required NEW tools
Concluding Remarks

- Aeroelasticity is an evolving, multidisciplinary field involving the interaction of (and feedback between) structural dynamic and unsteady aerodynamic models.
- Inclusion of active controls (Aeroservoelasticity) and thermal effects (Aerothermoelasticity) are also prominent disciplines that can be included in an aeroelastic analysis.
- Significant and important contributions in Aeroelasticity being performed by many national and international organizations; too many to cover adequately in this presentation.
- Recent developments and contributions within NASA research and flight projects presented.
- Future Directions in Aeroelasticity include applications beyond RANS-based CFD codes, where larger levels of separated flow can be properly computed.
- Future Challenges include application of nonlinear structural dynamics with nonlinear unsteady aerodynamics, beyond local linearizations.
- The origins of Aeroelasticity are deeply set in linear concepts: eigenvalues, root locus, modal structural models; a fully nonlinear structural dynamic model coupled with a fully nonlinear unsteady aerodynamic model will required analysis tools beyond these linear concepts.