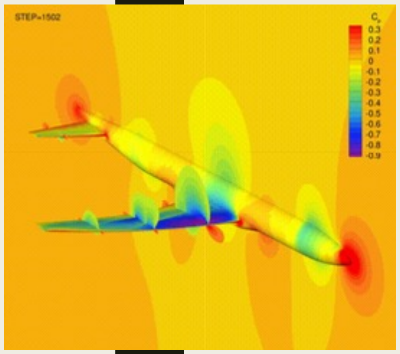
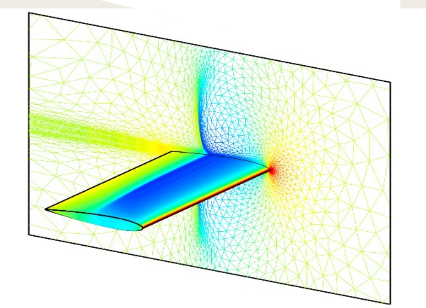


AEROELASTICITY



Walter Silva
NASA Langley Research Center
August 2nd, 2021

AIAA Aviation 2021

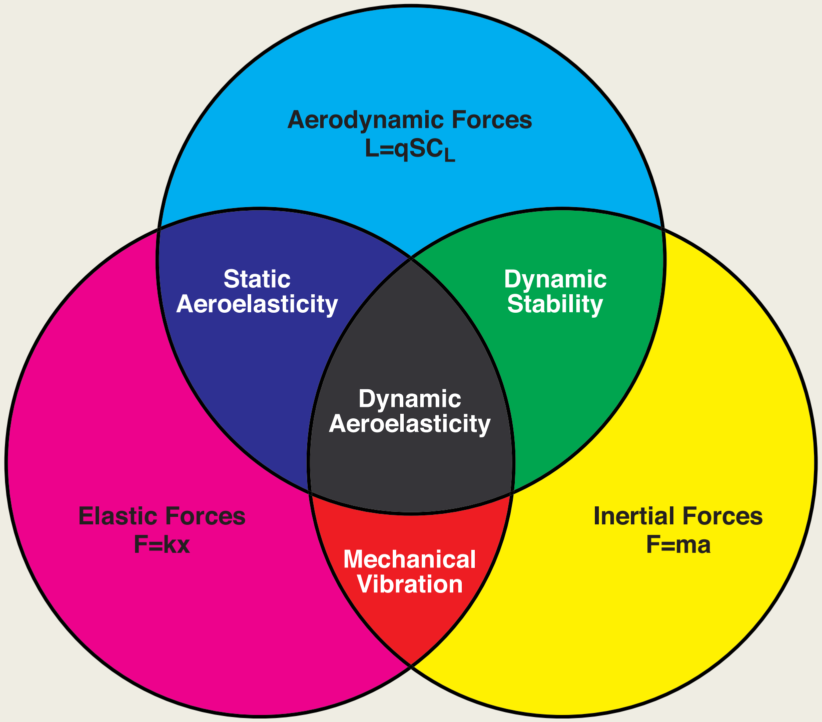

OUTLINE

- 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

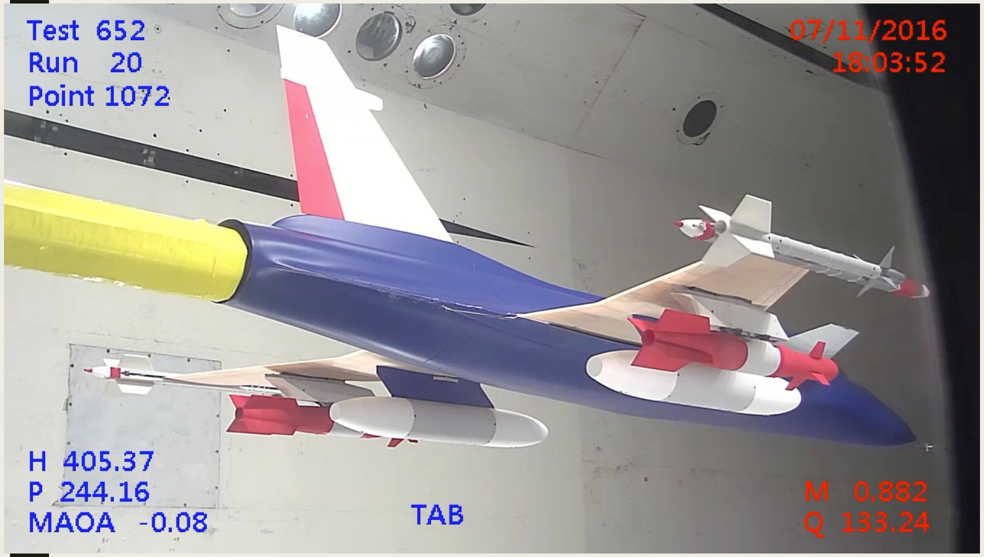
- Provide basic Tutorial on Aeroelasticity (concepts, terminology)
- Identify critical and important areas of research
- Share recent advances at NASA
- Significant levels of excellent work being performed at other national and international organizations but cannot properly address during this presentation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

What is Aeroelasticity?

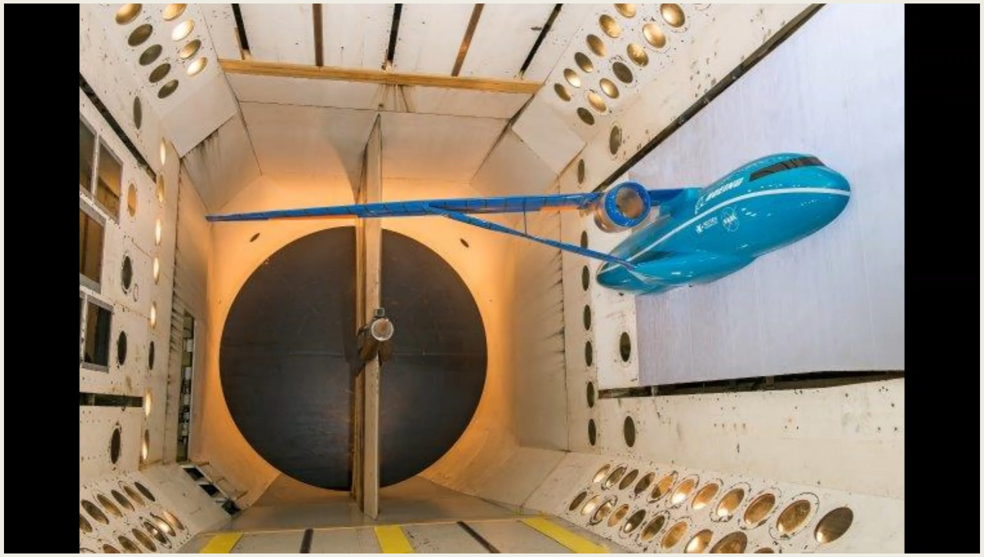


Aeroelasticity addresses the interaction between aerodynamic, elastic, and inertial forces

Aeroelasticity: Videos = 10,000 words



KTH Wind-Tunnel Model – Flutter Test

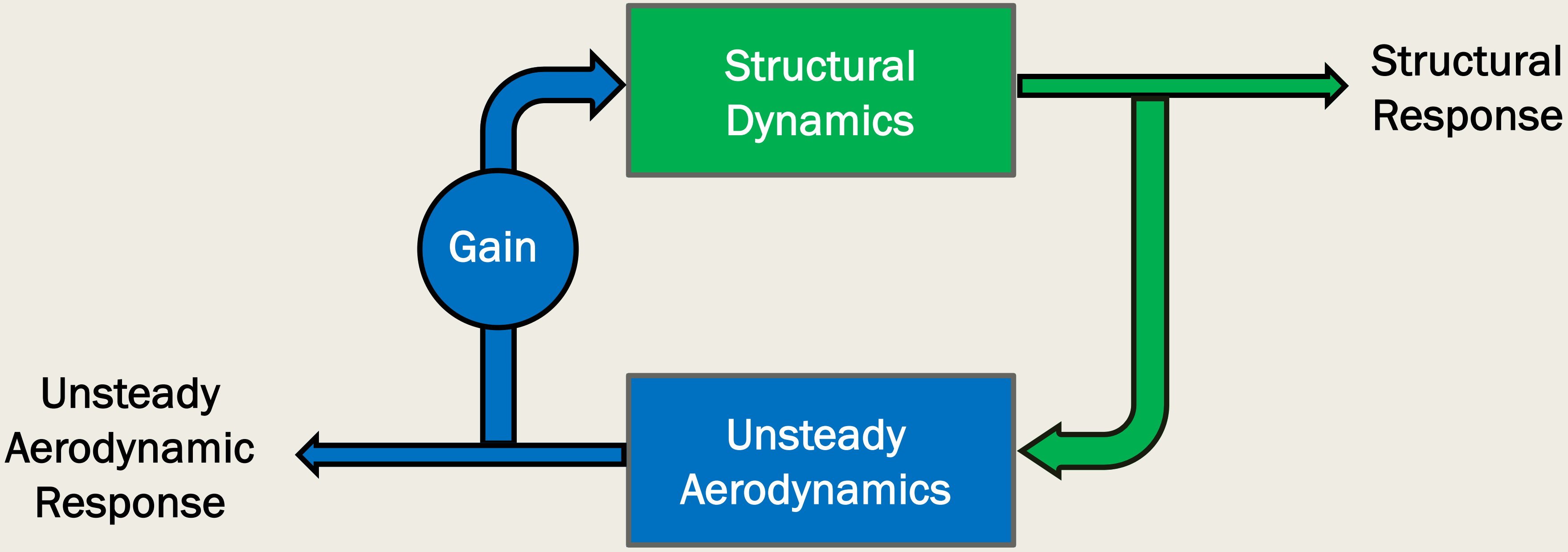


TTBW Wind-Tunnel Model – Flutter Test

Aeroelasticity is critical for efficient flight performance and flight safety

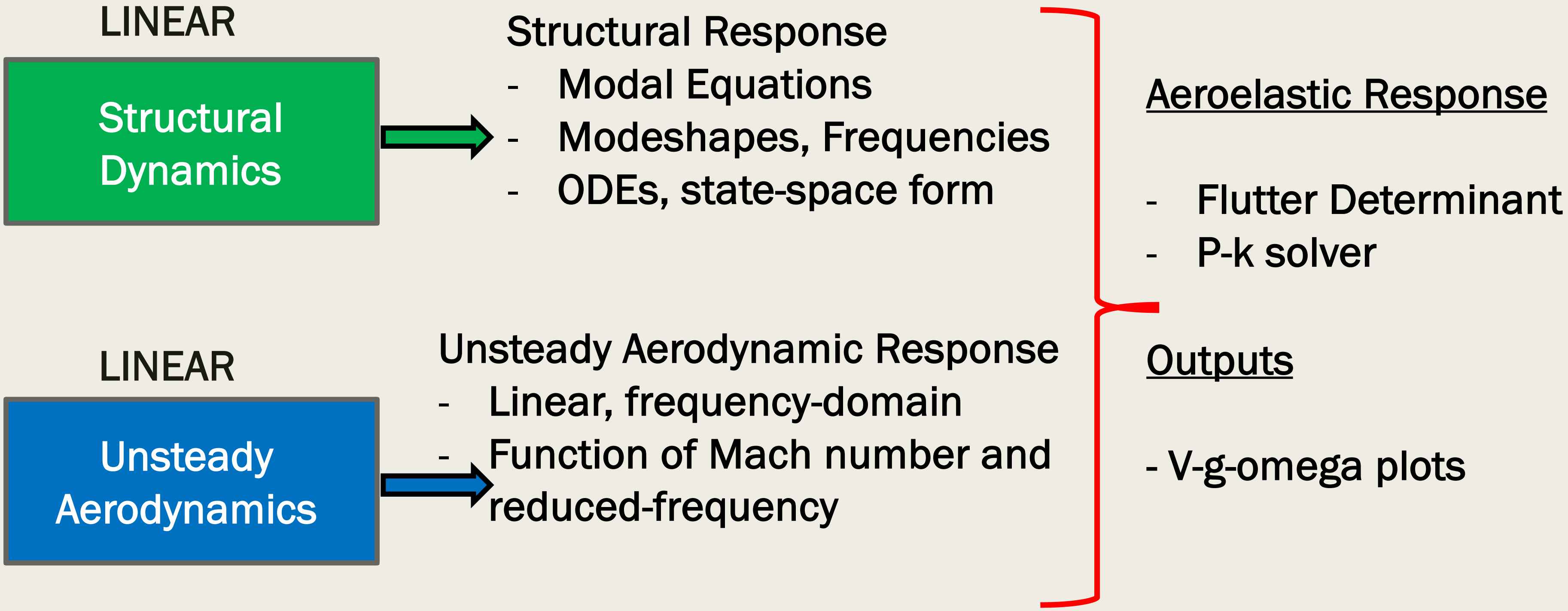
Aeroelasticity: Feedback Mechanism

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

LINEAR

Unsteady Aerodynamics

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

<u>Aeroelastic Response</u>

- Flutter Determinant
- P-k solver

<u>Outputs</u>

- 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

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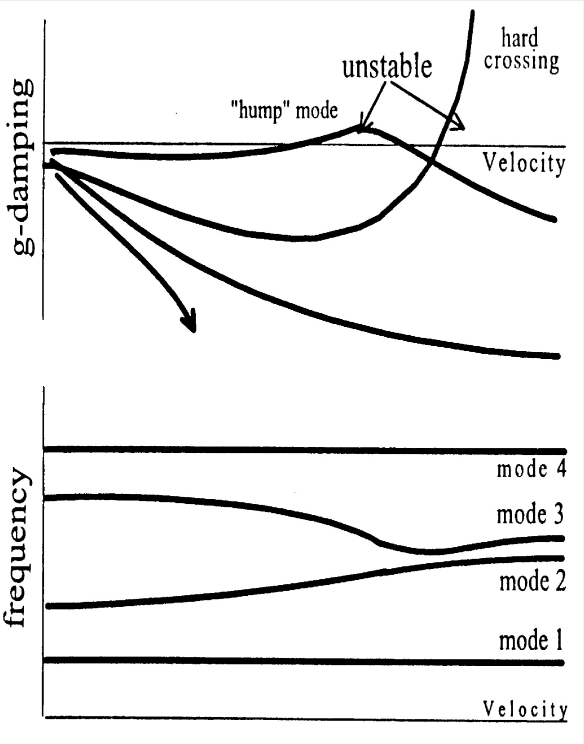
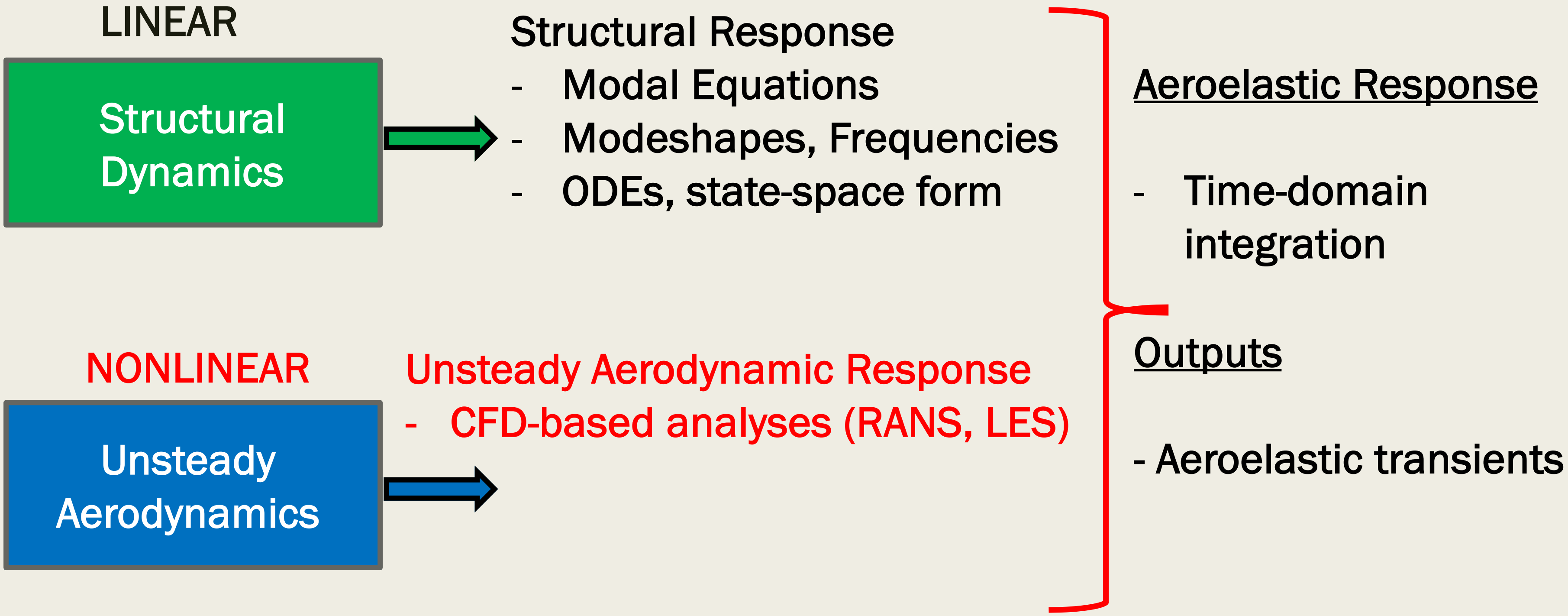


- Pros: computationally fast and efficient; excellent insight into mechanisms
- Cons: limited to flight conditions where linearity assumptions are valid

Aeroelasticity: Linear/NL Assumptions



LINEAR

Structural Dynamics

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

NONLINEAR

Unsteady Aerodynamics

Unsteady Aerodynamic Response
- 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

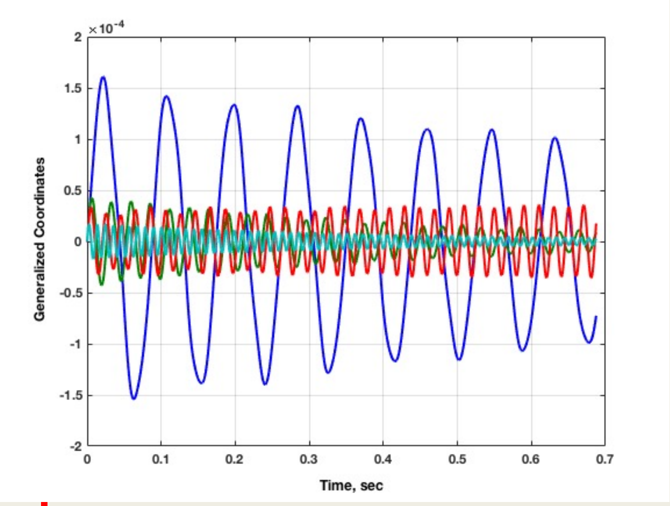
Structural Response
- Modal Equations
- Modeshapes, Frequencies
- ODEs, state-space form

NONLINEAR

Unsteady Aerodynamics

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

<u>Aeroelastic Response</u>



- 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

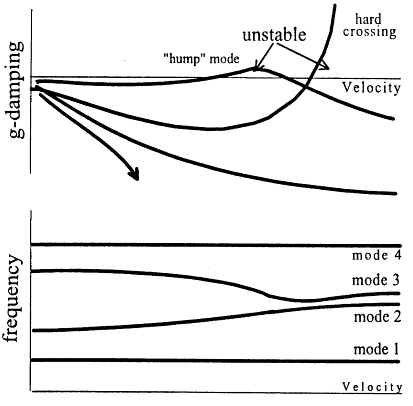
LINEARIZED

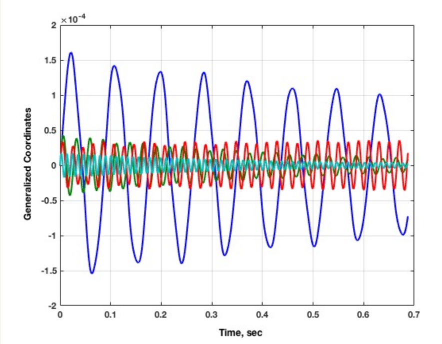
Unsteady Aerodynamics

Unsteady Aerodynamic Response

- CFD-based analyses (RANS, LES)
- In state-space form

Aeroelastic Responses



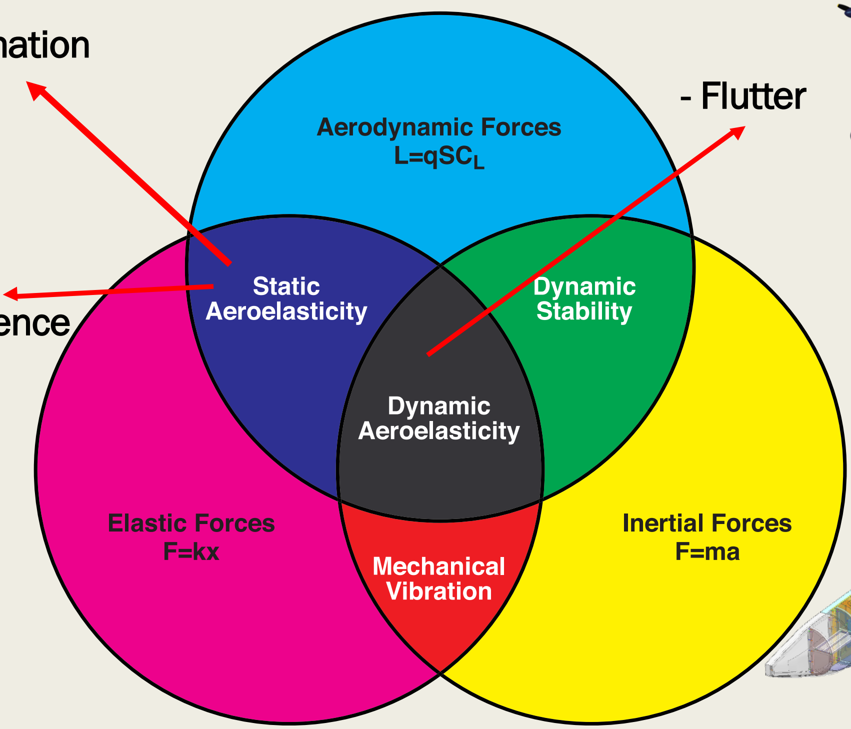


- Pros: computationally efficient, provides insight into mechanisms
- Cons: validity and accuracy might be limited to specific amplitude ranges

Aeroelasticity: Integral to NASA Missions

X-59

X-29



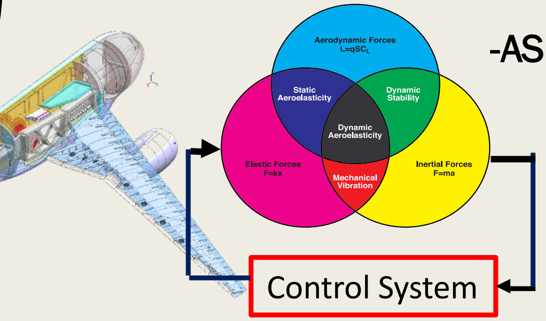
- Deformation

- Divergence

- Flutter

X-57

IAWTM WT Model



-ASE

Aeroelasticity is critical for efficient flight performance and flight safety

Aeroelasticity's Importance to NASA's Strategic Thrusts

Ultraefficient Subsonic Transports

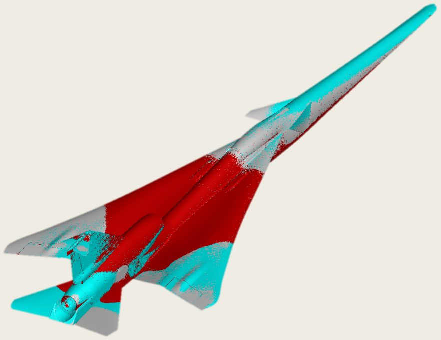
- Transonic flow regimes can produce stability boundaries (flutter) which are very complex and hard to predict
- Advanced material concepts allow for more-flexible wings and rotors
- Novel configurations can have aeroelastic problems not experienced with traditional designs


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

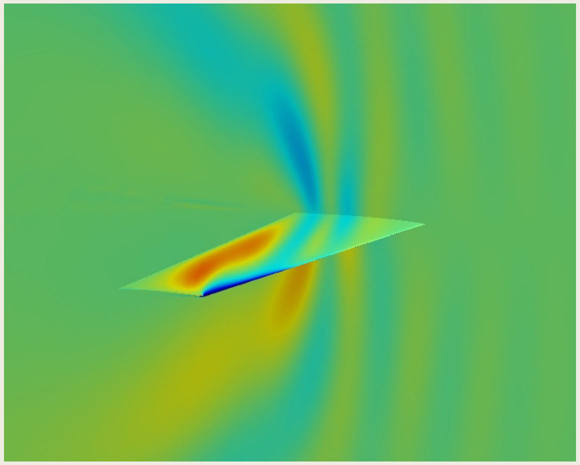
- Static aeroelastic deflections might affect supersonic boom shaping
- Aeroservoelasticity a potential concern

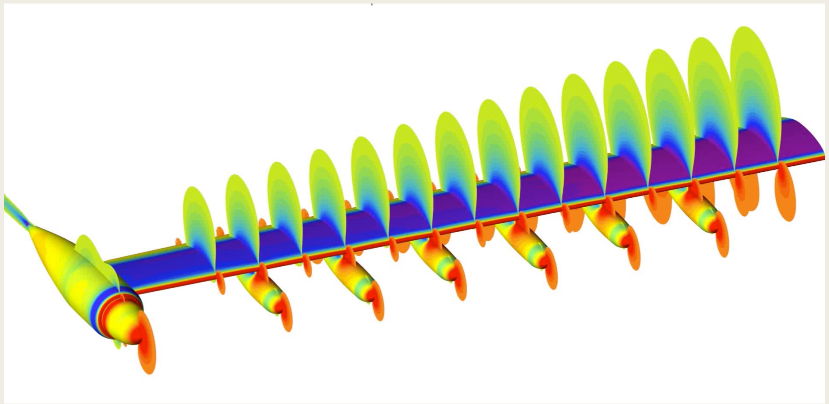


Aeroelasticity poses a critical challenge to novel and advanced configurations

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

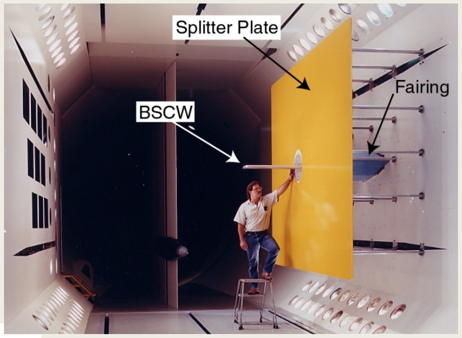


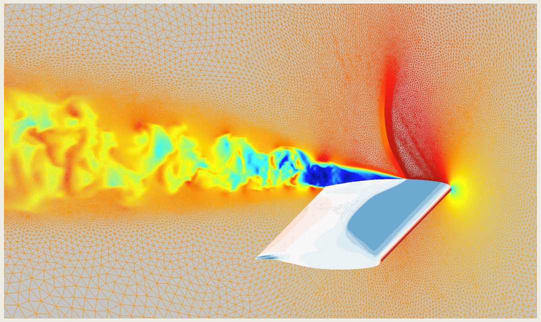


We are developing state-of-the-art tools for use by NASA and the larger aerospace community

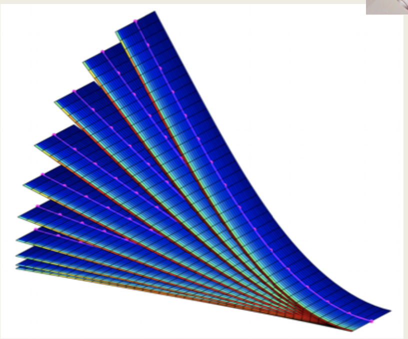
Aeroelastic Prediction Workshop

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

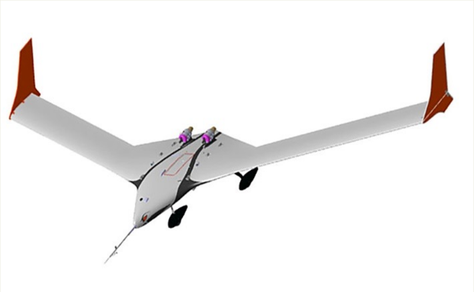


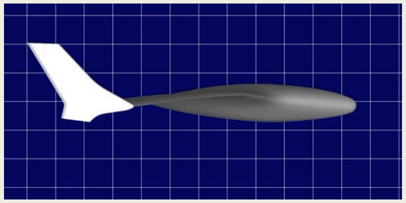


Transonic flutter



Highly flexible wings

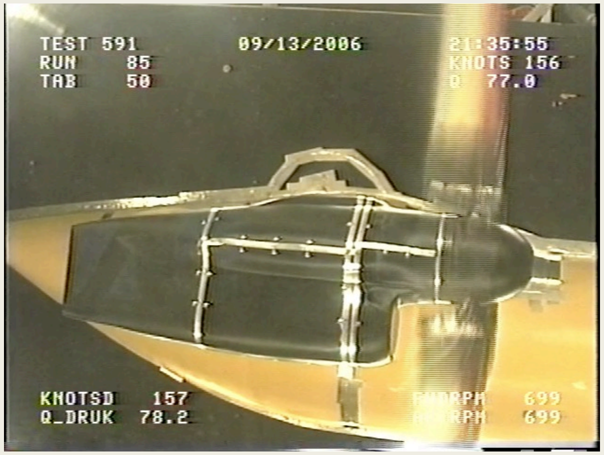




X-56A body freedom flutter (BFF)

Confidence in computational predictions is built by community participation and thorough verification and validation

X-57 Aeroelasticity

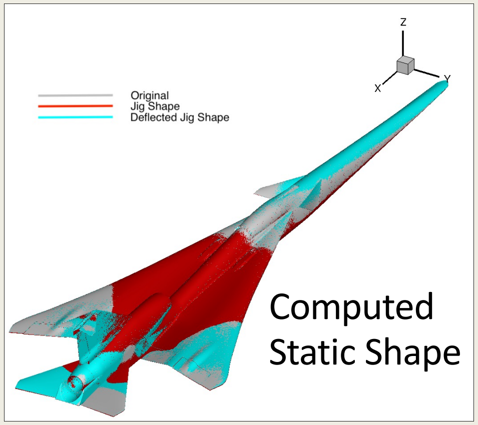


X-57's thin wing and added propellers present unique aeroelastic challenges, even for state-of-the-art analysis tools.

Ground Vibration Test (GVT)

NASA's aeroelastic expertise applied to ensure X-57 is safe to fly

X-59 Aeroelasticity

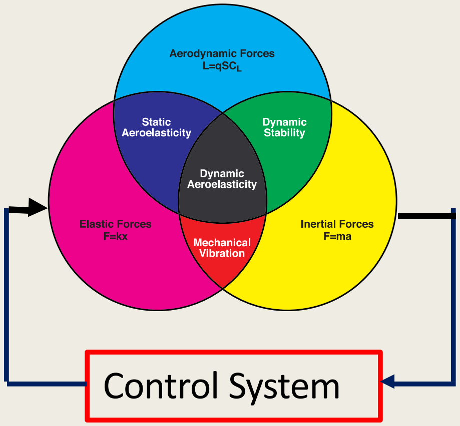


Computed Static Shape

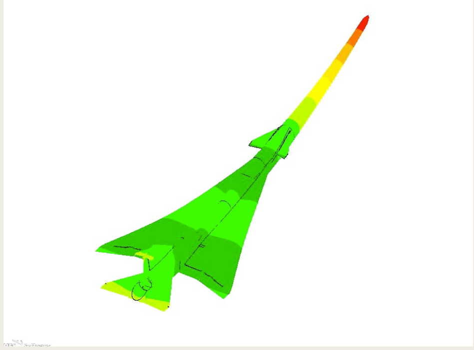
- Cruise static shape critical for success of low-boom experiment

- 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

AeroServoElasticity (ASE)

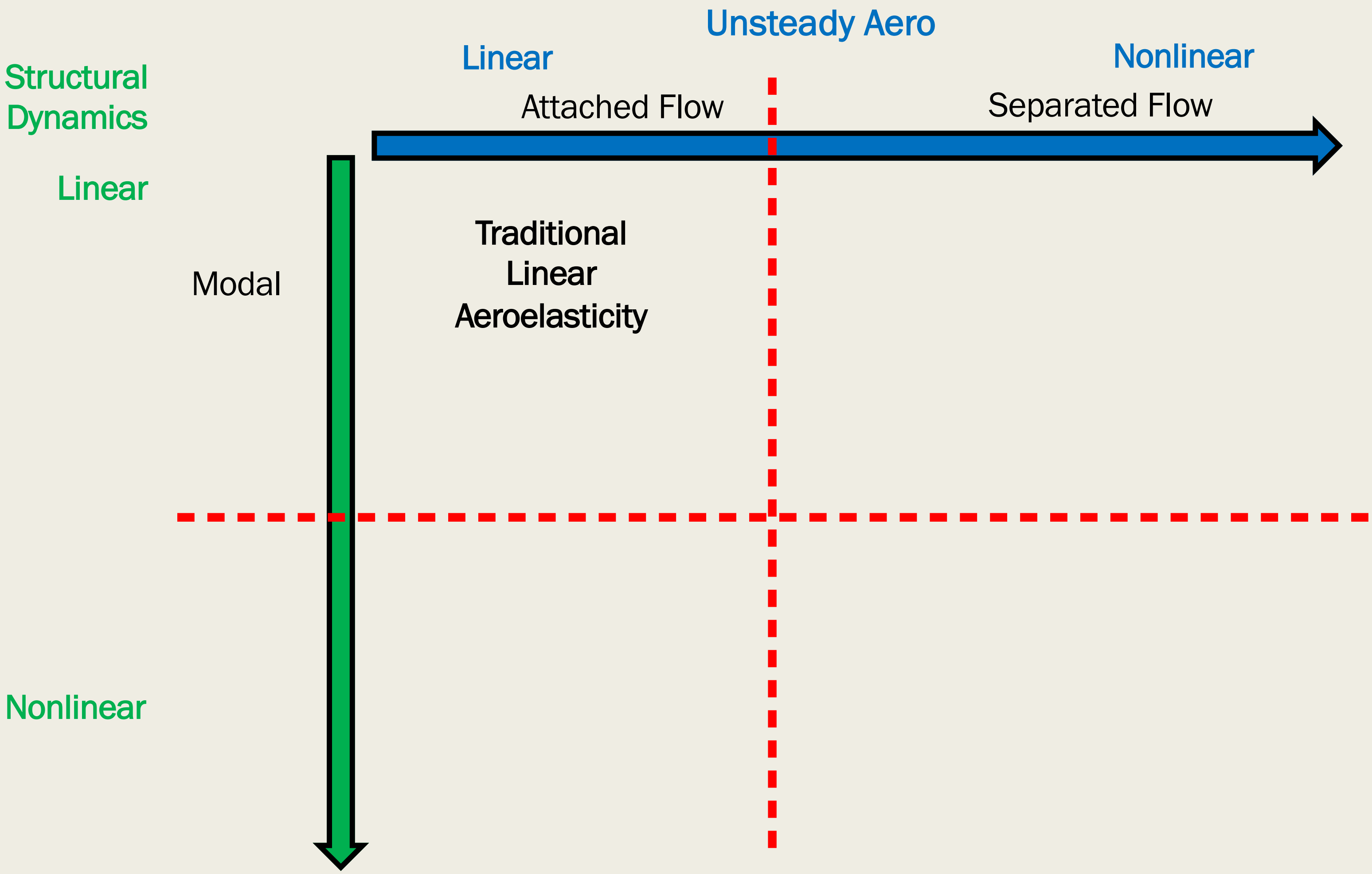


- ASE sensitivity identified



NASA's aeroelastic/ASE expertise essential for success of X-59 project

Challenges and Future Directions



Unsteady Aero

Linear

Nonlinear

Attached Flow

Separated Flow

Structural Dynamics

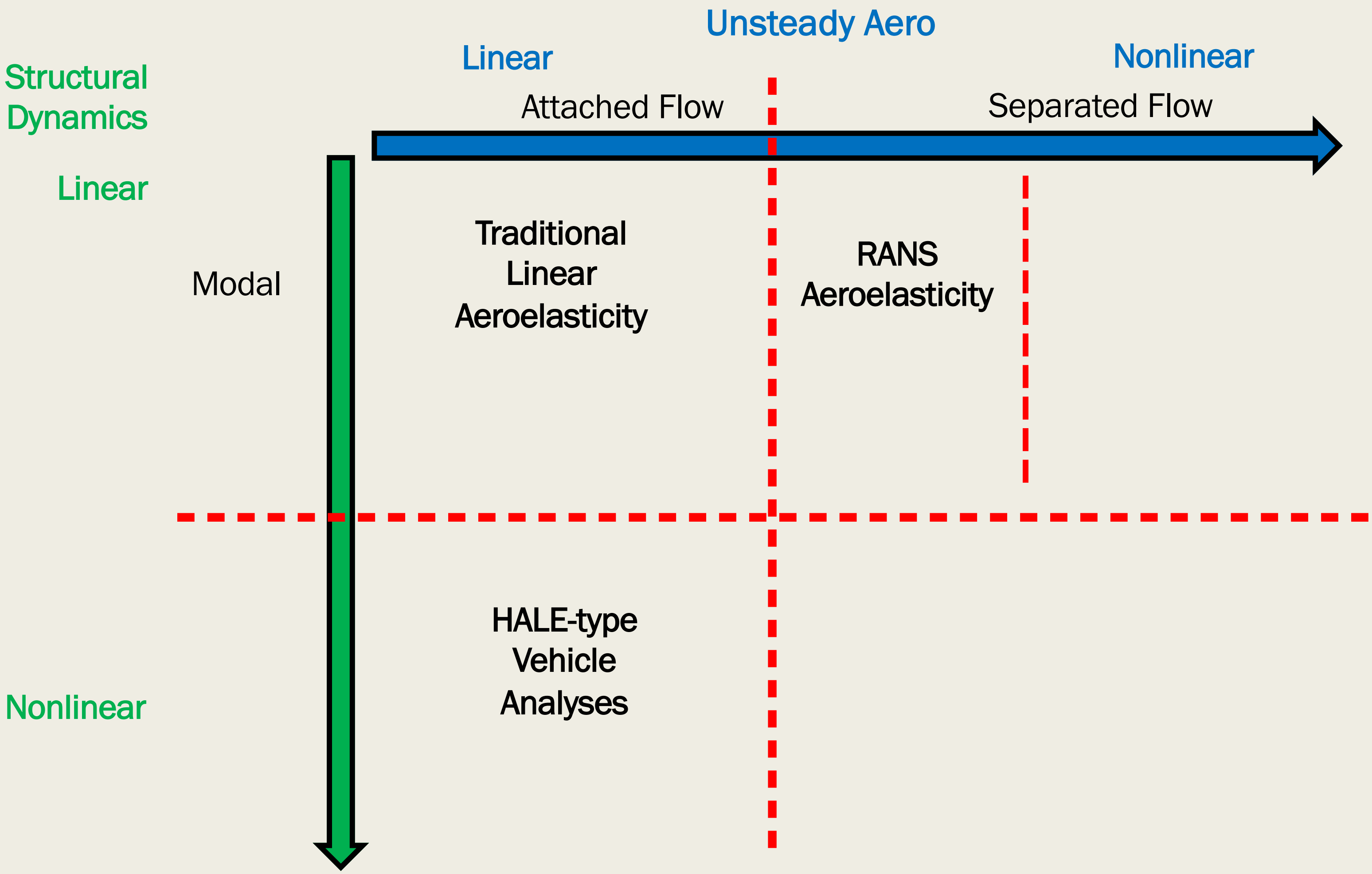
Linear

Modal

Traditional Linear Aeroelasticity

Nonlinear

Challenges and Future Directions



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RANS Aeroelasticity

HALE-type Vehicle Analyses

Nonlinear

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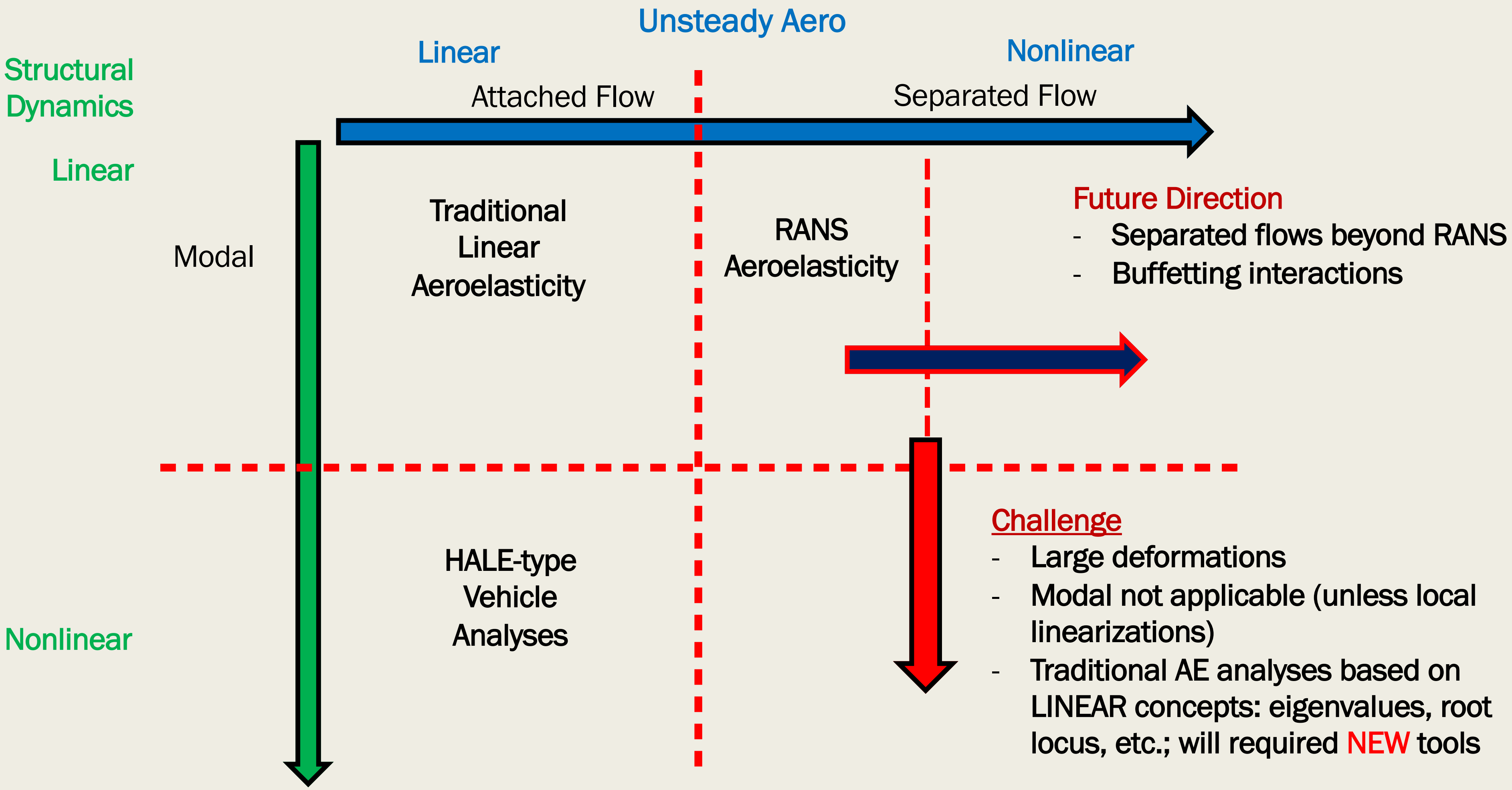

Unsteady Aero

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Separated Flow

Structural Dynamics

Linear

Nonlinear

Modal

Traditional Linear Aeroelasticity

RANS Aeroelasticity

Future Direction

- Separated flows beyond RANS
- Buffetting interactions

HALE-type Vehicle Analyses

Challenge

- 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