

# Active Structural Control for Aircraft Efficiency with the X-56A Aircraft



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- The X-56A Multi-Utility Technology Testbed is an experimental aircraft designed to study active control of flexible structures. The vehicle is easily reconfigured to allow for testing of different configurations. The vehicle is being used to study new sensor, actuator, modeling and controls technologies. These new technologies will allow for lighter vehicles and new configurations that exceed the efficiency currently achievable. A description of the vehicle and the current research efforts that it enables are presented.

# Why?

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- Reduced weight is fundamental to aerospace design
- Many years of aerospace development has resulted in extremely efficient lightweight structures
- Advancement now requires a new paradigm
  - Retain strength but allow for reduced stiffness
  - Provide apparent stiffness with integrated active structural control
- Side Benefit: Advancement of full-authority adaptive flight control for realistic full-scale vehicles will not proceed until methods for sensing and accounting for structural limitations are developed

# Development Areas



- Modeling
  - Static Structures – large margins, very conservative
  - Dynamics – conservative notch filter designs result in large feedback phase loss
  - MDAO elastically tailored structures
- Sensors
  - Fiber Optic Shape Sensing (FOSS)
  - Hot films
  - Others ...
- Actuation
  - Potentially very high bandwidth requirements
  - Piezoelectric, MEMS, others ...
- Control Algorithms
  - Balance structural shape, structural load, dynamic interaction suppression, with rigid body performance requirements

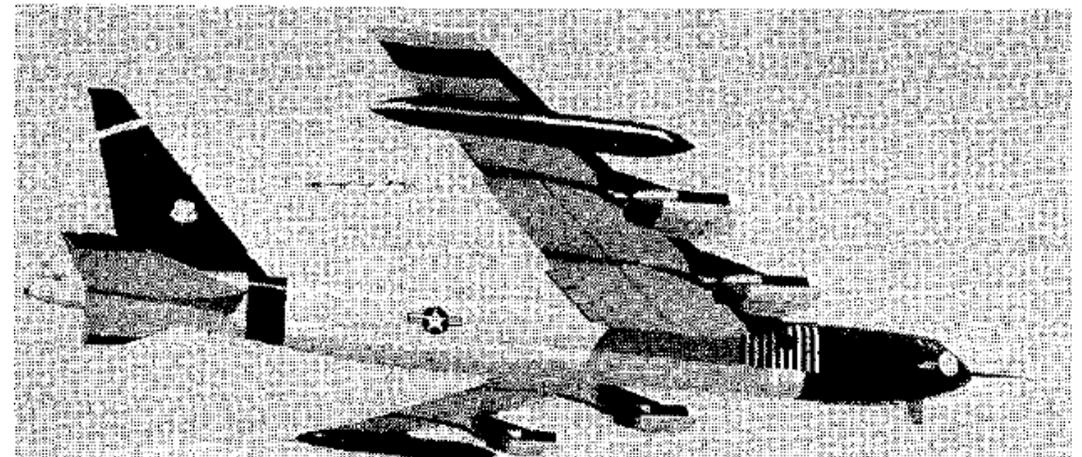


# Past Experiments



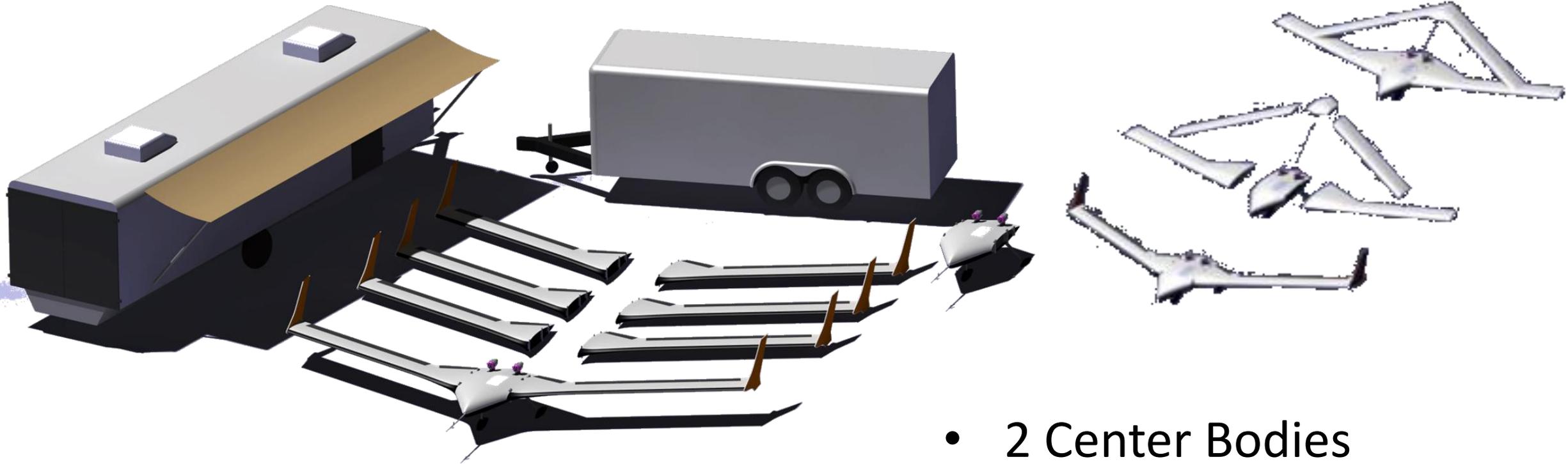
- Previous Active Structural Control
  - Boeing did flutter suppression on B-52 in 1973
  - Boeing Subsonic Ultra Green Aircraft Research. (SUGAR)
  - Rockwell B-1 Structural mode suppression system
  - Boeing 747-8 Outboard Aileron Mode Suppression (OAMS)
  - Active Aeroelastic Wing (AAW)

- All cases had limited or no coupling between rigid body and structural dynamics
  - Rigid body and flight dynamics are integrally coupled
  - Cannot neglect any of the coupling



Roger, Hodges, and Felt, 1975

# Multi-Utility Technology Testbed (MUTT)



- Designed by Lockheed Martin
- Funded by Air Force Research Lab

- 2 Center Bodies
- 1 Stiff Wing Set
- 3 Flexible Wing Sets
- 1 Ground Control Station

# Current Research



- Stiff Wings

- Completed Stiff Wing Flight Phase
- Do not have structural instabilities
- Built for system development
- Development of testing techniques
- Validation of modeling techniques

- Flex Wings

- Expecting flutter to occur within the flight envelope
- Additional marginally stable modes



# X-56 Modeling



- Developing models for control development
  - Existing methodologies from structural dynamics
- Different requirements
  - Need models with arbitrary inputs
  - Need to capture the vehicle drag
  - Need to model gravity
- Desire state consistency
  - Save variables describe the vehicle at all flight conditions
    - Consistent sign conventions etc.
  - Required by many control methodologies
  - Not enforced by many existing tools

# X-56 Modeling Uncertainty



- Cannot know the system exactly
  - Analysis needs to consider these uncertainties
- Methods exist for modeling and analyzing uncertainty
  - Mu-analysis
  - Does not work well with many parameters or very high order systems
- What are the critical parameters?
  - Which parameters have the largest effect?
  - Which parameters have the largest uncertainty?
- What are reasonable bounds on the parameters?

# X-56 Modeling Validation and Tuning



- Testing Techniques
  - Input design
- Validation
  - Determination of a sufficient and achievable set of test points
  - Sufficient isolation of the different dynamics
- Tuning
  - Must identify the critical parameters
  - How do you isolate the effect of the critical parameters?



# X-56 Simulation



- Piloted simulation needed for handling qualities
- Structural dynamics are significantly changing handling
- Simulation must run in real-time



# Controls Research



- Stiff Wing Controller
  - Design from flexible models
  - Validated in traditional simulation
- Flex Wing Controller
  - Control of a high order system (many states/degrees of freedom)
  - Requirements for controller robustness
    - Classical single output methods limited
  - Control of a system with significant changes in the dynamics
    - Type of instability changes over the flight envelope
- Exploring other control methodologies
  - Linear parameter varying



- Sensors
  - How can modern sensors improve the structural control?
  - How can these sensors be integrated with a flight controller?
    - E.g. FOSS has very large number of measurements
- Control Effectors
  - Novel effectors
    - E.g. piezoelectric/shape memory alloys
  - Optimal effector placement
  - Conformal/Continuous control surfaces



# Conclusions

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- X-56 is designed for studying active control of aircraft structures
  - Will enable future aircraft to be lighter and more efficient
- NASA stiff wing testing has been completed
  - Preparing for flexible wing with unstable flutter modes
- Studying advance control techniques
- Studying modeling of flexible aircraft
- Exploring new sensor and effector technologies

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