AMTAS Autumn Meeting
March 16, 2010

The Effects of Damage and Uncertainty on the Aeroelastic /Aeroservoelastic Behavior and Safety of Composite Aircraft

Presented by

Francesca Paltera
UW Mechanical Engineering

Outline

- Motivation
- Objectives
- Background
- Review Past Accomplishments
- Recent Progress
- Future Work
- AMTAS Impact

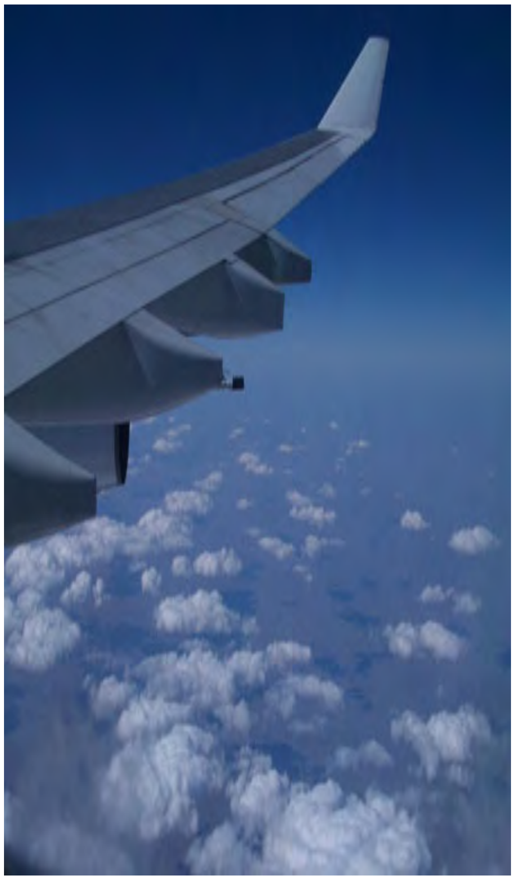
Motivation

- Understand effects of uncertainty on composite Aeroservoelastic structures in terms of Flutter and Limit Cycle Oscillations (LCO)
- Obtain experimental benchmark results for industry
- Develop automated computational tools for simulation of uncertain aeroelastic structures
- Establish collaborative expertise

Objectives

- Build an experimental model and carry out aeroelastic/ wind tunnel tests to Flutter and Limit Cycle Oscillations (LCO)
- Implement Uncertainty: local nonlinearities (damage, free play, broken actuator) and global nonlinearities (broken hinge)
- Develop automated computational tools for simulation of Flutter and LCO in presence of nonlinearities

Background



- Aerodynamic forces are generated by airflow over a surface
- Aeroelasticity is the study of a feedback process involving aerodynamic, elastic and inertial forces

Background

- Flutter is a structural vibration caused by a steady-state air flow over a surface

- Flutter induces a rapid periodic motion of the structure

- Flutter is affected by structure's design

- Flutter is self-starting

- In extreme cases it can cause serious structural damage

Background

- Change the aerodynamics of structure (stiffness, damping) to avoid flutter
- No speed regime is truly immune from flutter
- Flutter of real structures difficult to predict

Aeroelastic analysis and wind-tunnel tests **are needed** to predict flutter **for** our **safety !!**

Background

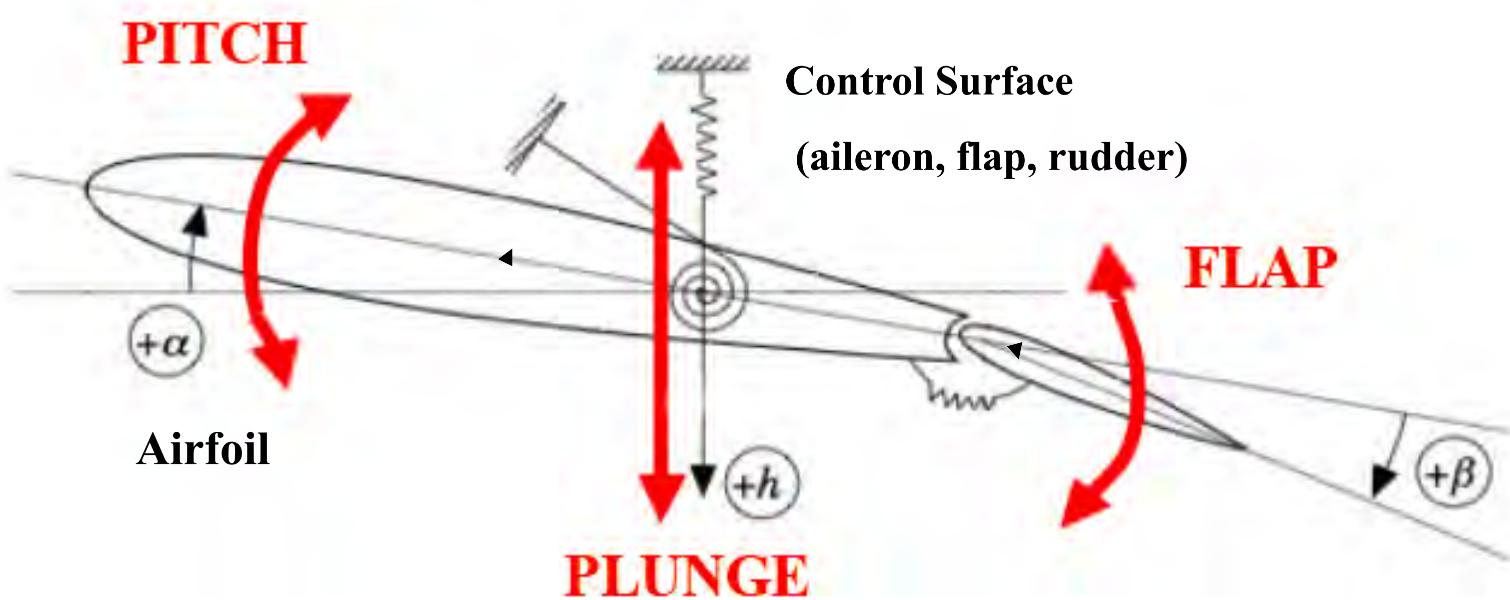
- Limit Cycle Oscillation (LCO) is a structural vibration in between decaying oscillations and flutter

- LCO induces oscillations that grow for a short period, then settle down to a constant magnitude, instead of continuing to amplify.

- It causes fatigue and leads to crack initiation and growth

Review Past Accomplishments
Wing Design

2D THREE DEGREES-OF-FREEDOM
airfoil section with control surface



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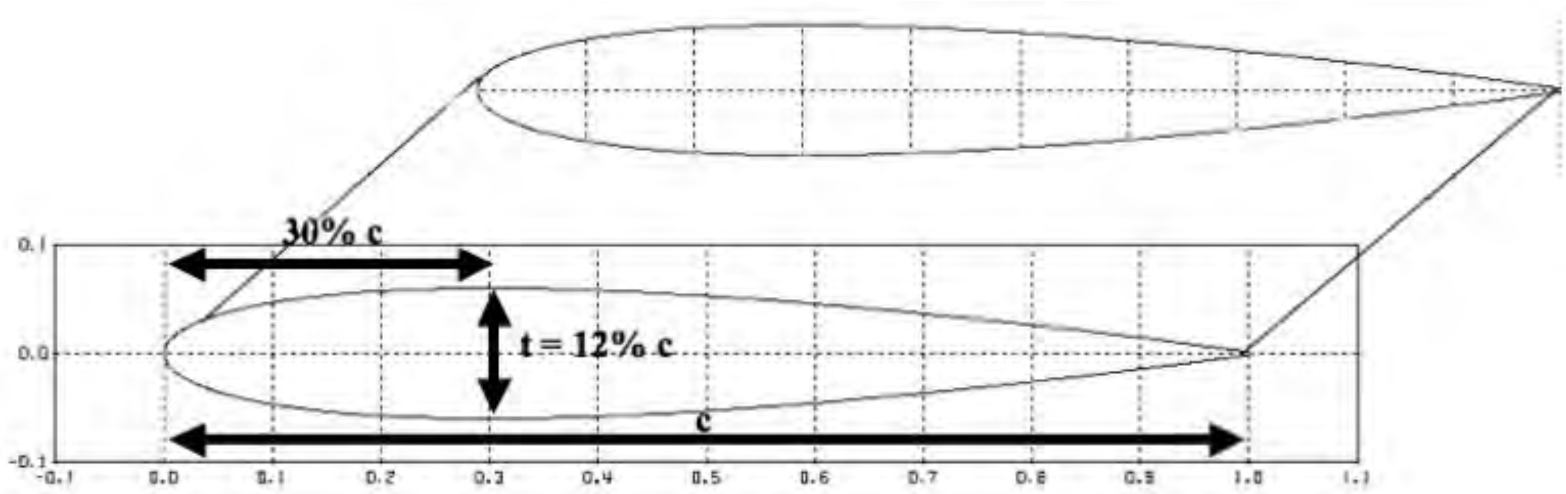

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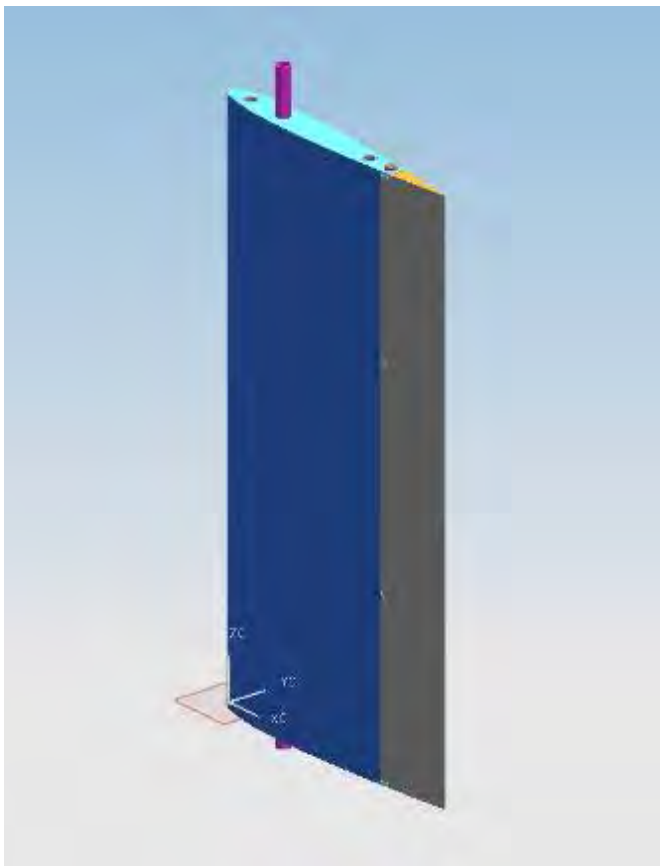
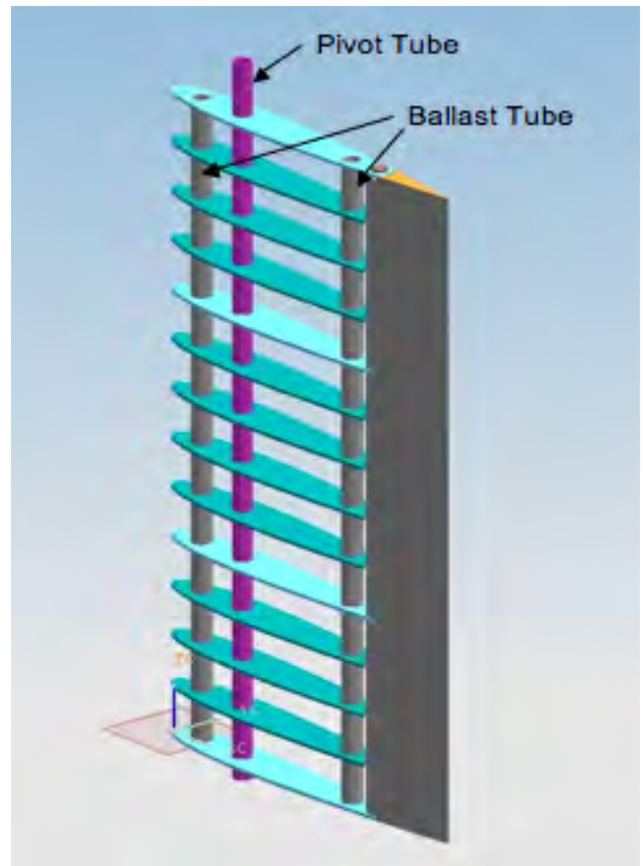
Review Past Accomplishments

Wing Design

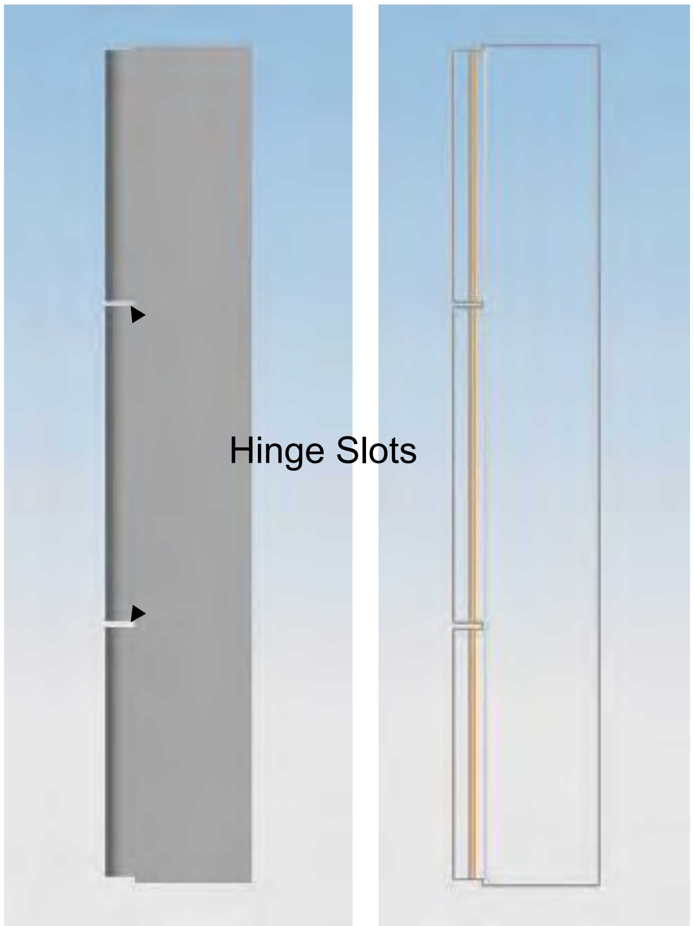
- UGS Unigraphics

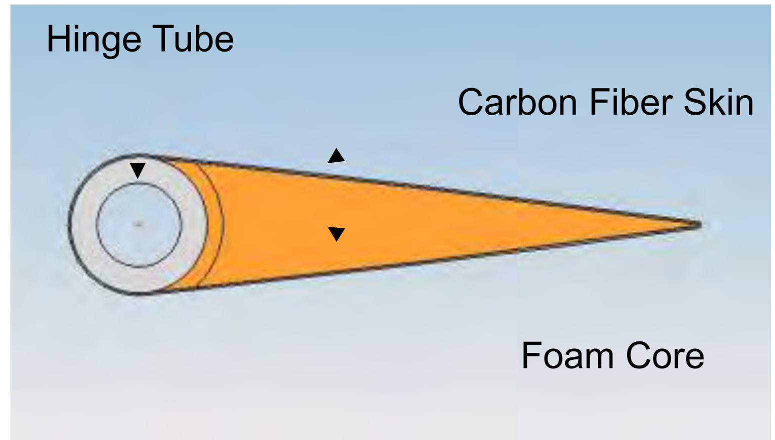


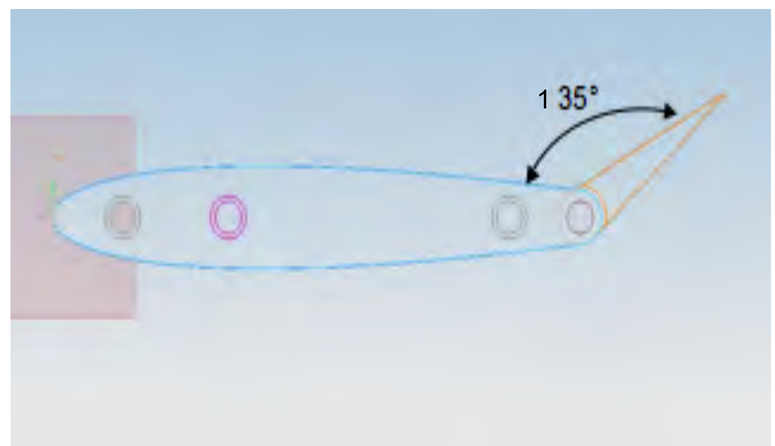


Review Past Accomplishments

Wing Design

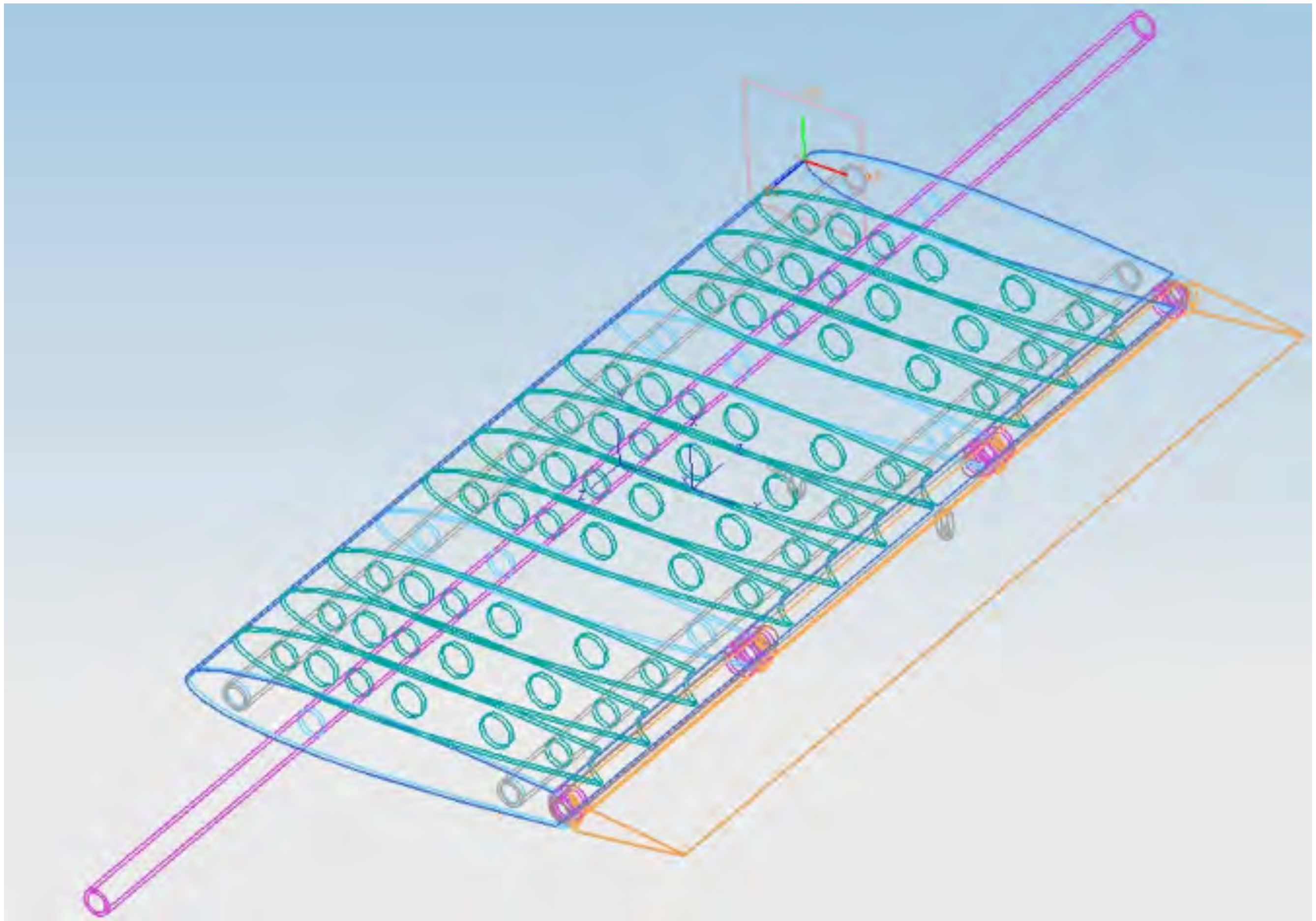






Review Past Accomplishments

Wing Design



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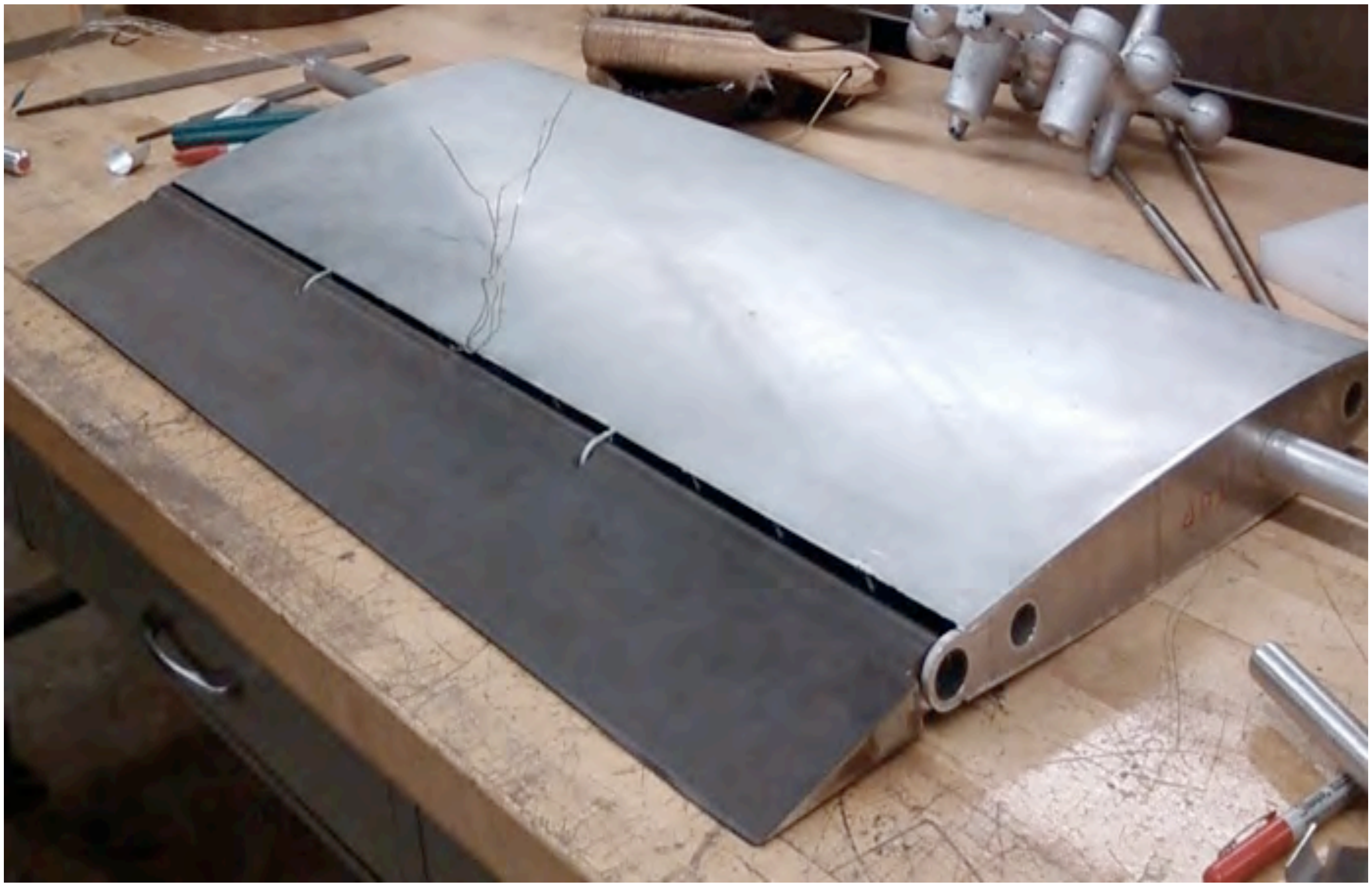
Review Past Accomplishments

Wing Manufacturing

Review Past Accomplishments

Wing Manufacturing



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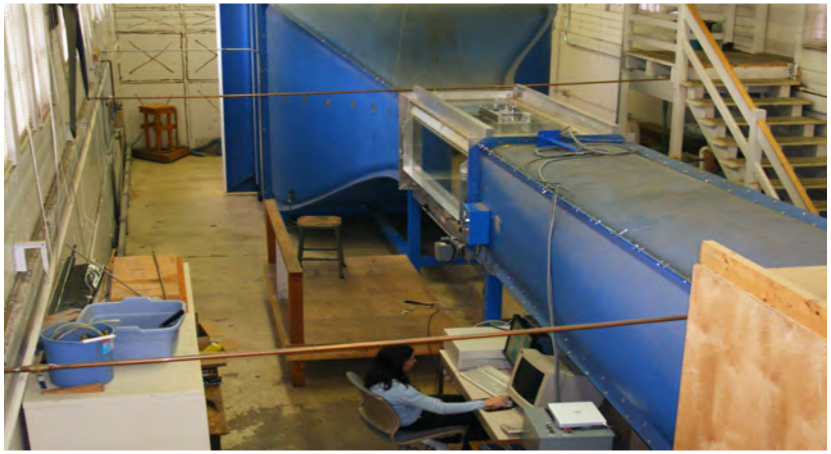
Review Past Accomplishments

Induced Damage

Review Past Accomplishments

Wind Tunnel Fixture



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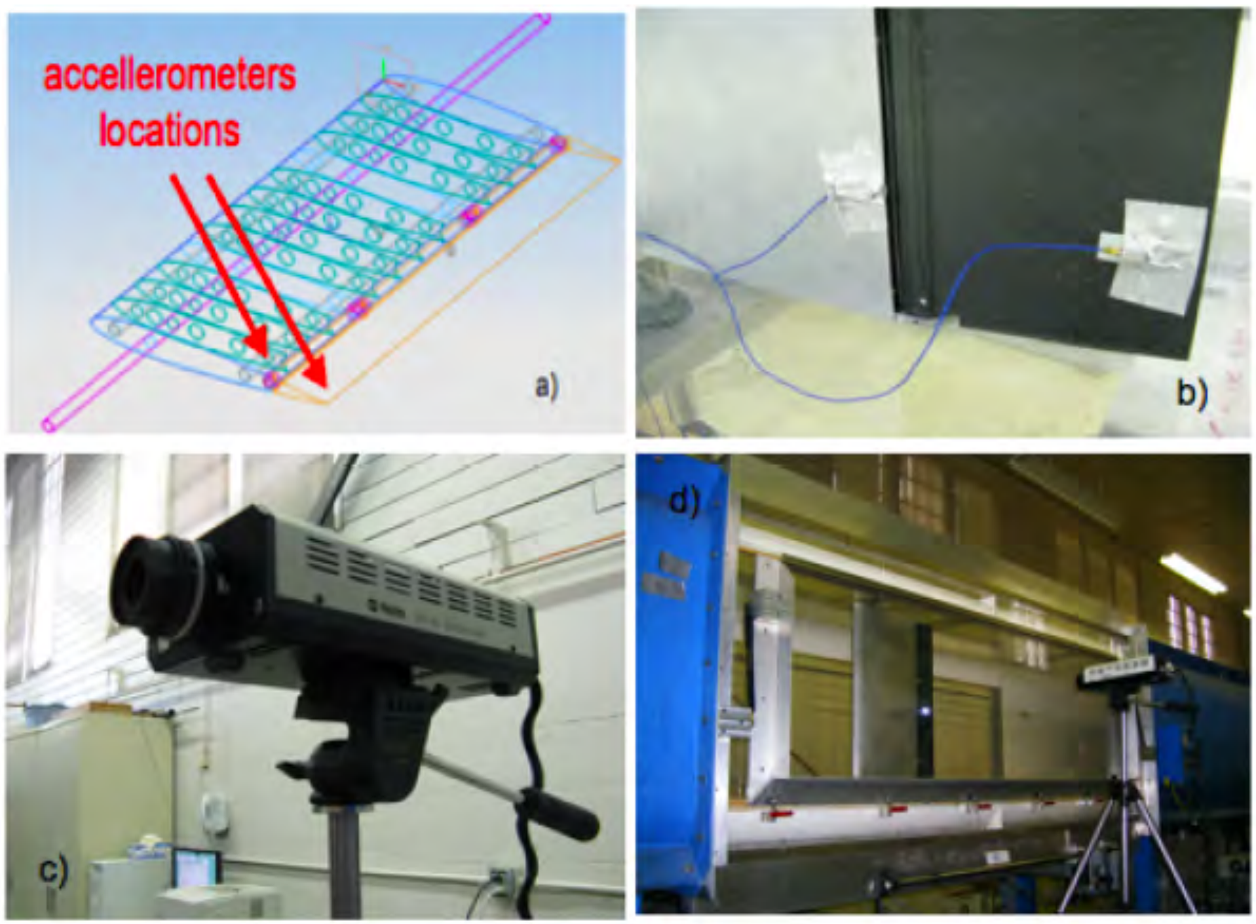
Review Past Accomplishments

Wind Tunnel Fixture



Review Past Accomplishments

Analytical Development for pristine structure

- Equation of motion of the system:

$$[M]\begin{Bmatrix}\ddot{h}\\ \ddot{\alpha}\\ \ddot{\beta}\end{Bmatrix}+[C]\begin{Bmatrix}\dot{h}\\ \dot{\alpha}\\ \dot{\beta}\end{Bmatrix}+[K]\begin{Bmatrix}h\\ \alpha\\ \beta\end{Bmatrix}=\begin{Bmatrix}P\\ M_{\alpha}\\ M_{\beta}\end{Bmatrix}=\frac{1}{2}\rho\, u_{\infty}{}^{2}b^{2}\left[A\left(j\left(\frac{\omega b}{u_{\infty}}\right),a,c\right)\right]\begin{Bmatrix}h\\ \alpha\\ \beta\end{Bmatrix}$$

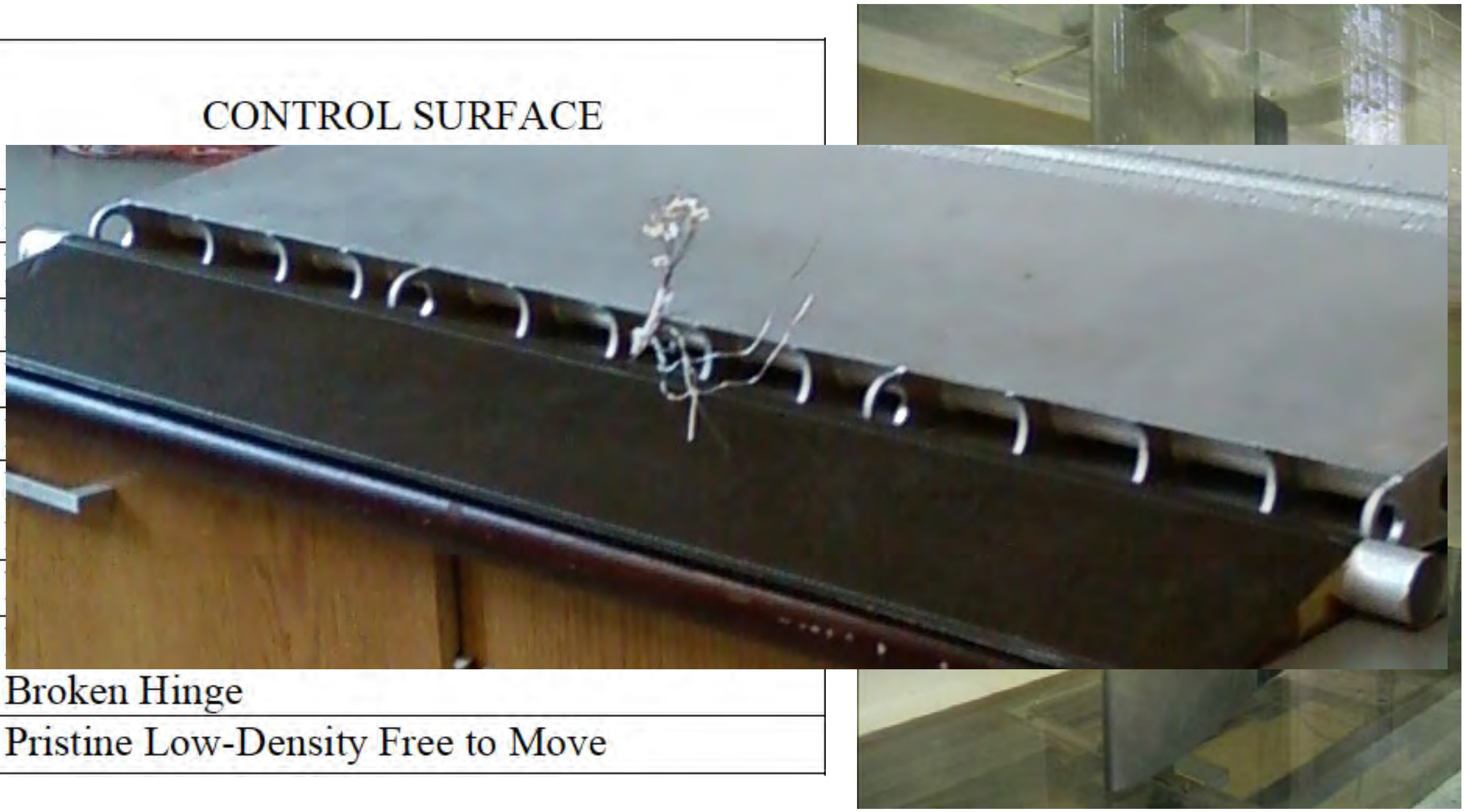
- Two different methods to predict flutter: UG METHOD and ROOT LOCUS TECHNIQUE.

- Two different approaches to solve the equation of motion.

Review Past Accomplishments

Flutter Tests

CONTROL SURFACE



Broken Hinge

Pristine Low-Density Free to Move

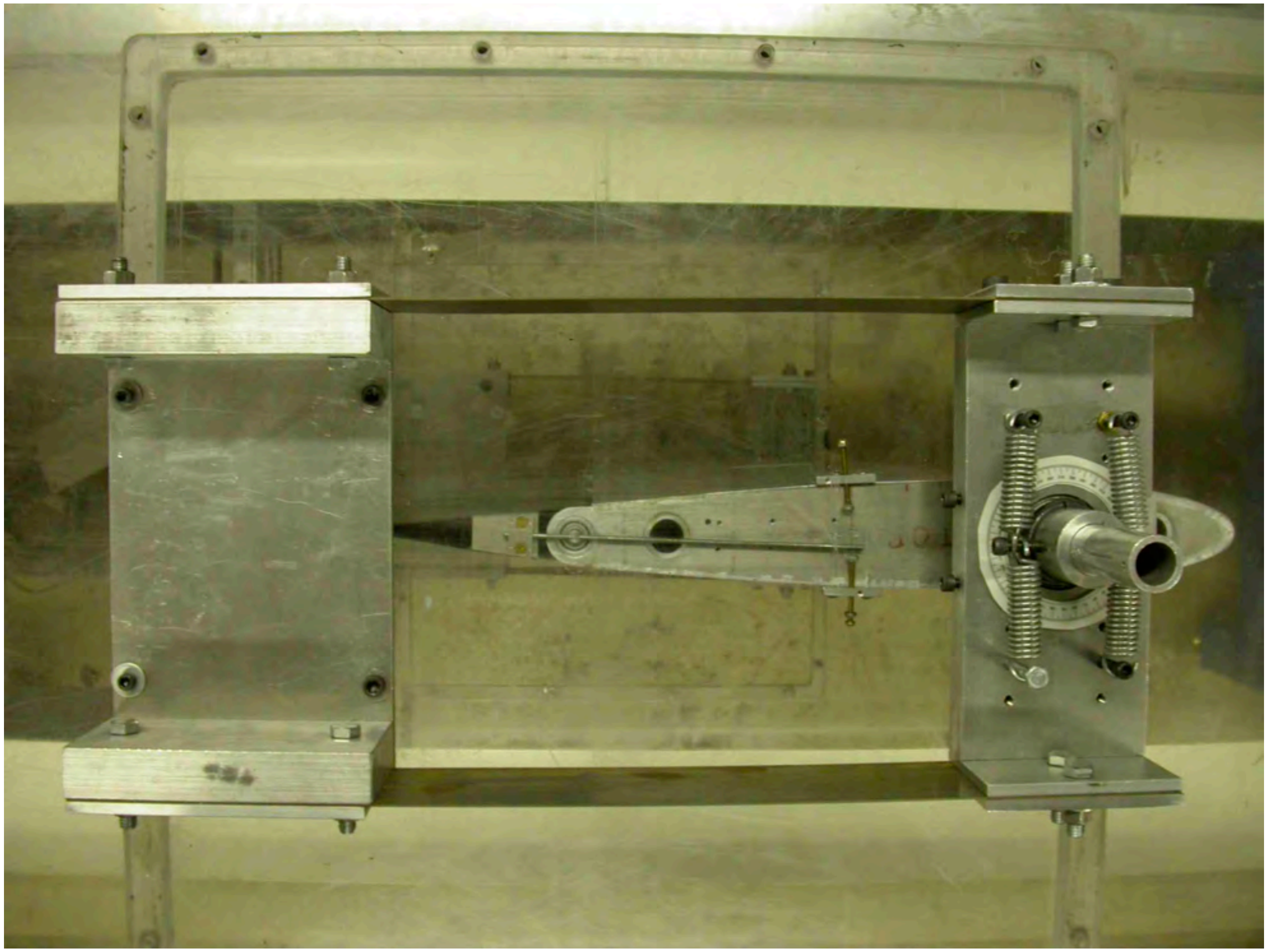
Review Past Accomplishments

Flutter Tests

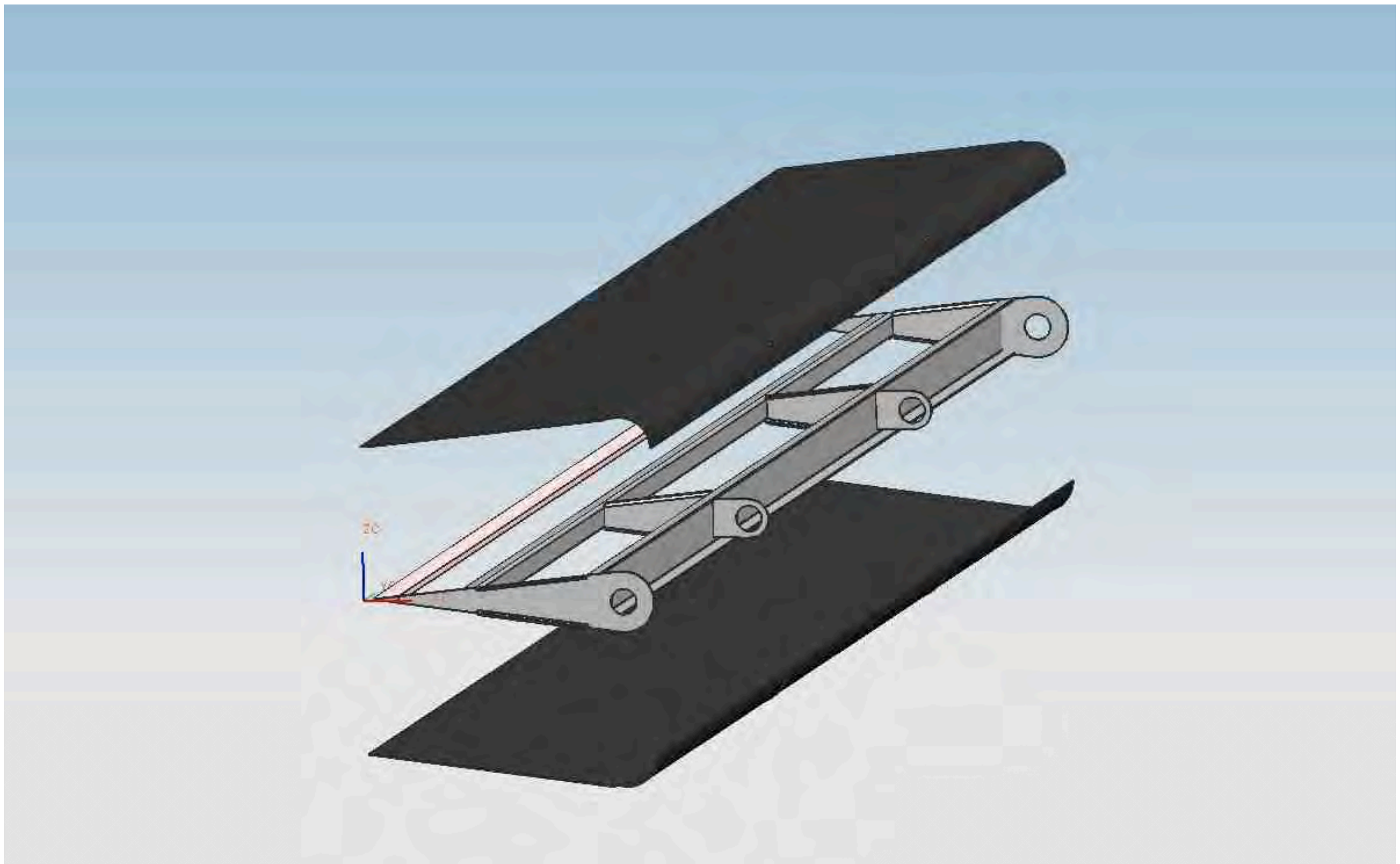
Flutter speed was decreased:

- As the distance between the cg of the control surface and the hinge line was increased
- Due to delamination between skin and core
- Due to induced free-play (localized hinge bearing damage)
- Due to free-rotation (broken actuator)

Recent Progress
Freeplay



Recent Progress
Improved Control Surface Design



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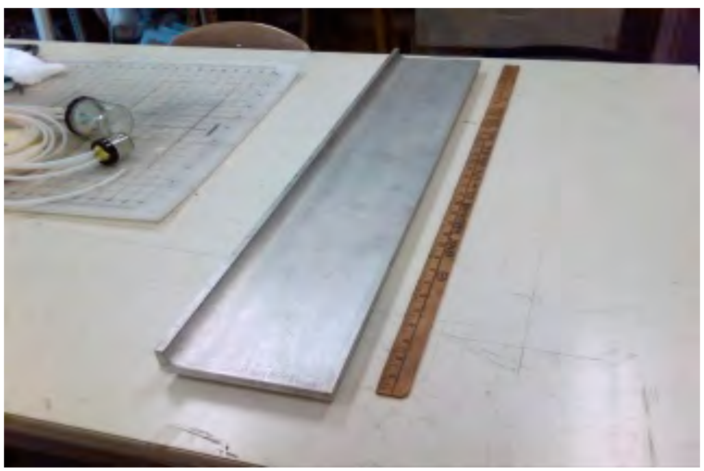
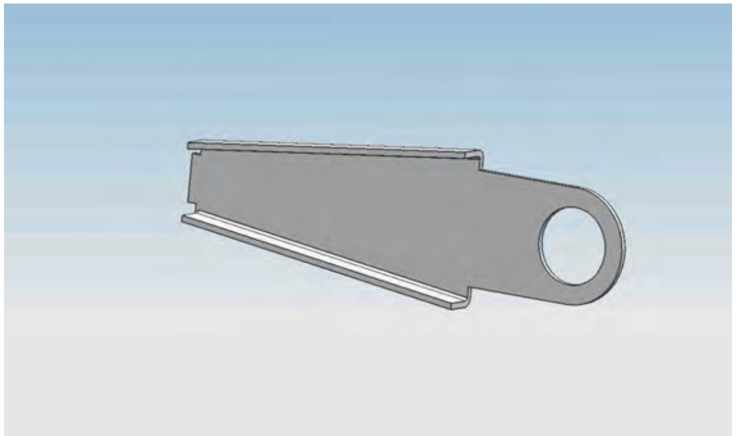
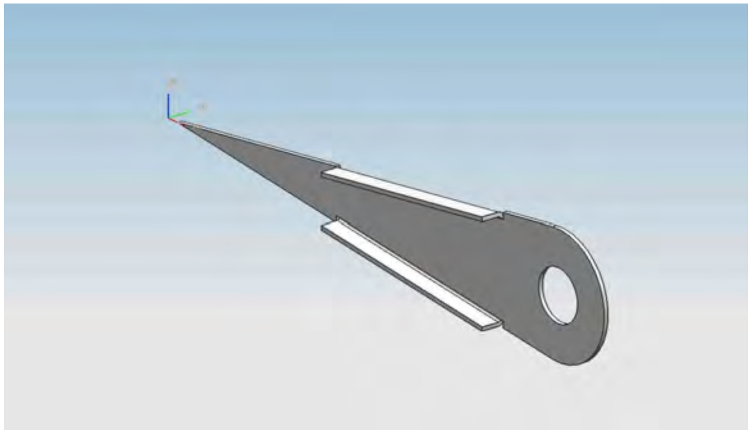
Recent Progress
Improved Control Surface Design

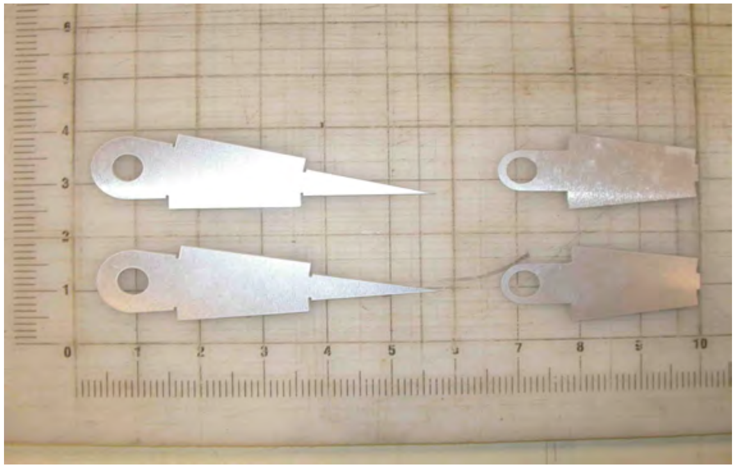


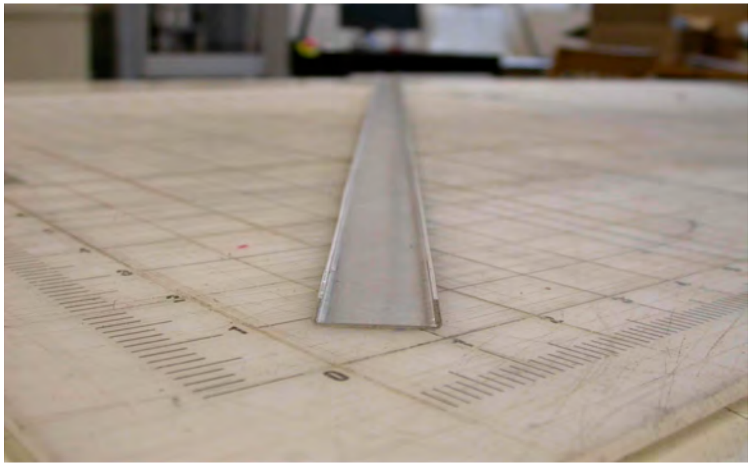
Recent Progress

Improved Control Surface Design





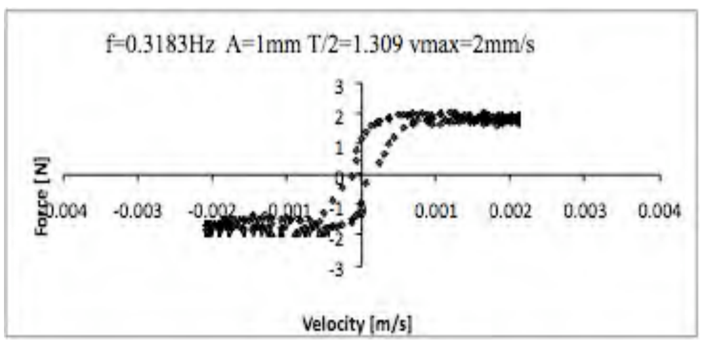




Recent Progress
Improved Control Surface Design

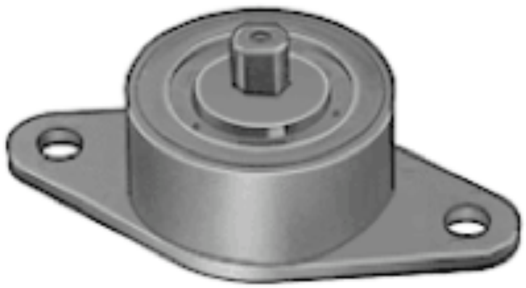
Recent Progress

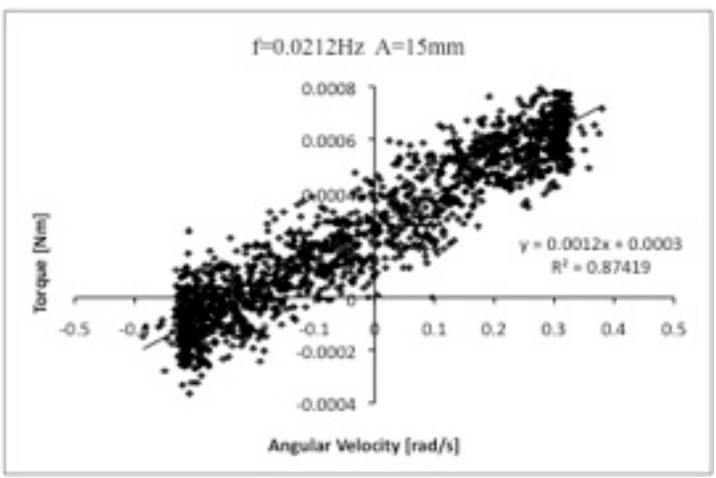
Non Linear Damper



Recent Progress

Non Linear Damper





Recent Progress
Non Linear Damper

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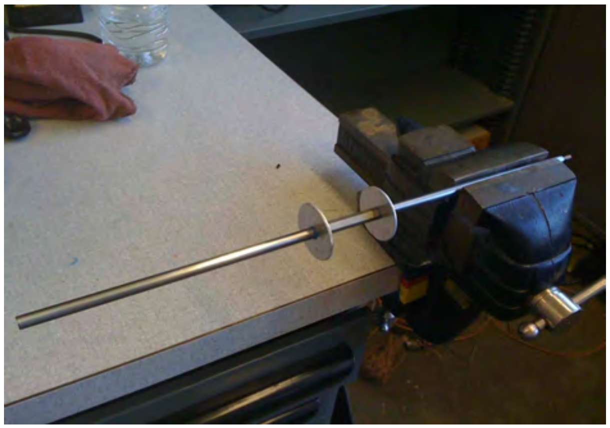

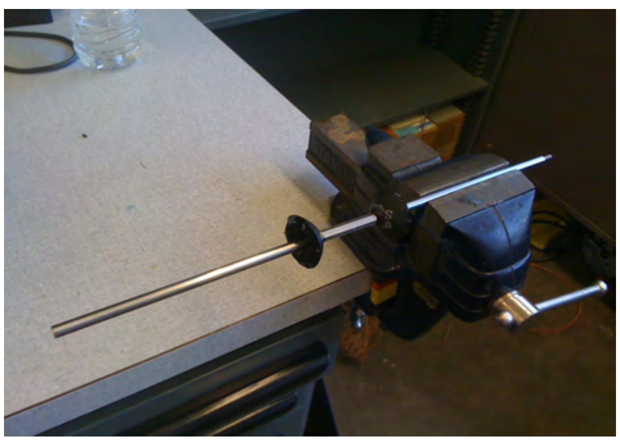

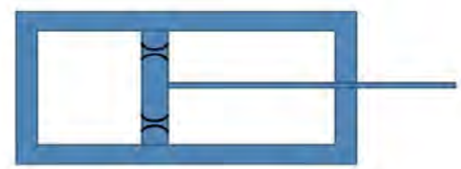

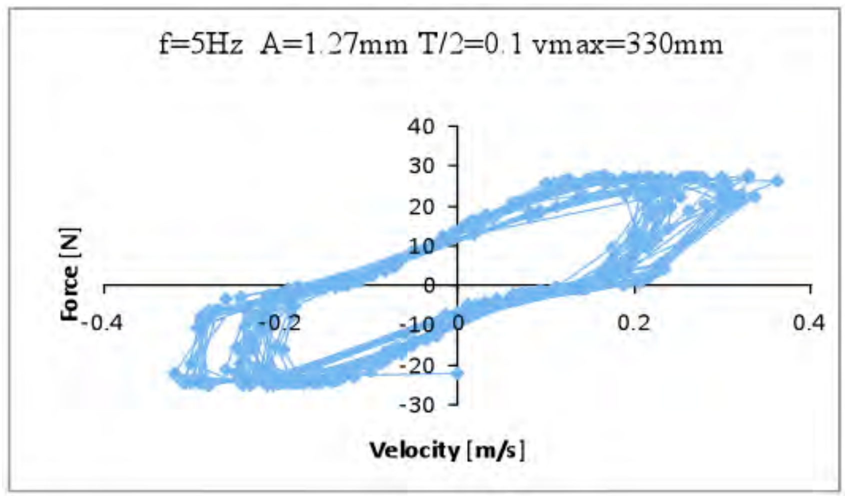

Future Work

- Customize damper response through design (HELP!)
- Non-linear damper characterization
- Continue wind tunnel experiments on the wing model WITH non-linearities
- Develop automated computational tools for dynamic behavior simulation of non-linear aeroelastic models

AMTAS Impact

- Networking with Industry and Government Experts
- Developing Mentors
- Technical Talks
- Converging onto a Carrier Path

Contributors

Thank you!

- Department of Mechanical Engineering
  - Francesca Paltera, PhD student
  - Dr. Mark Tuttle, co-PI, professor and chairman
- Department of Aeronautics and Astronautics
  - Dr. Eli Livne – PI, Professor
- Boeing Commercial, Seattle
  - Dr. James Gordon, Associate Technical Fellow, Flutter Methods Development
  - Dr. Kumar Bhatia, Senior Technical Fellow, Aeroelasticity and Multidisciplinary Optimization Curing
- FAA Technical Monitor
  - Curtis Davies, Program Manager of JAMS, FAA/Materials & Structures Future Work
- Other FAA Personnel Involved
  - Dr. Larry Ilcewicz, Chief Scientific and Technical Advisor for Advanced Composite Materials
  - Carl Niedermeyer, Airframe and Cabin Safety Branch (ANM-115), Standards Staff - Transport Airplane Directorate (previously: Boeing flutter manager for the 787 and 747 programs)