UNIVERSITY OF WASHINGTON

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

Project:

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

Presented by Francesca Paltera
Department of Mechanical Engineering
University of Washington

AMTAS Meeting,
October 21 2010

Focus Topic:
Wind Tunnel Model Development for Aeroelastic Tests of Wing / Control-Surface Systems with Hinge Stiffness Loss and with a Velocity-Squared Damper

Presented by Francesca Paltera

Department of Mechanical Engineering

University of Washington

AMTAS Meeting,
October 21 2010

Contributors

- Department of Aeronautics and Astronautics
  - Dr. Eli Livne – PI, Professor
- Department of Mechanical Engineering
  - Francesca Paltera, PhD student
  - Dr. Mark Tuttle, co-PI, professor and chairman
- Boeing Commercial, Seattle
  - Dr. James Gordon, Associate Technical Fellow, Flutter Methods Development
  - Dr. Kumar Bhatia, Senior Technical Fellow, Aeroelasticity and Multidisciplinary Optimization
- FAA Technical Monitor
  - Lynn Pham, Advanced Materials & Structures, Aircraft and Airport Safety
  - Curtis Davies, Program Manager of JAMS, FAA/Materials & Structures
- Other FAA Personnel Involved
  - Dr. Larry Ilcewicz, Chief Scientific and Technical Advisor for Advanced Composite Materials
  - Carl Niedermeyer, FAA Airframe and Cabin Safety Branch (previously, Boeing flutter manager for the 787 and 747-8 programs)

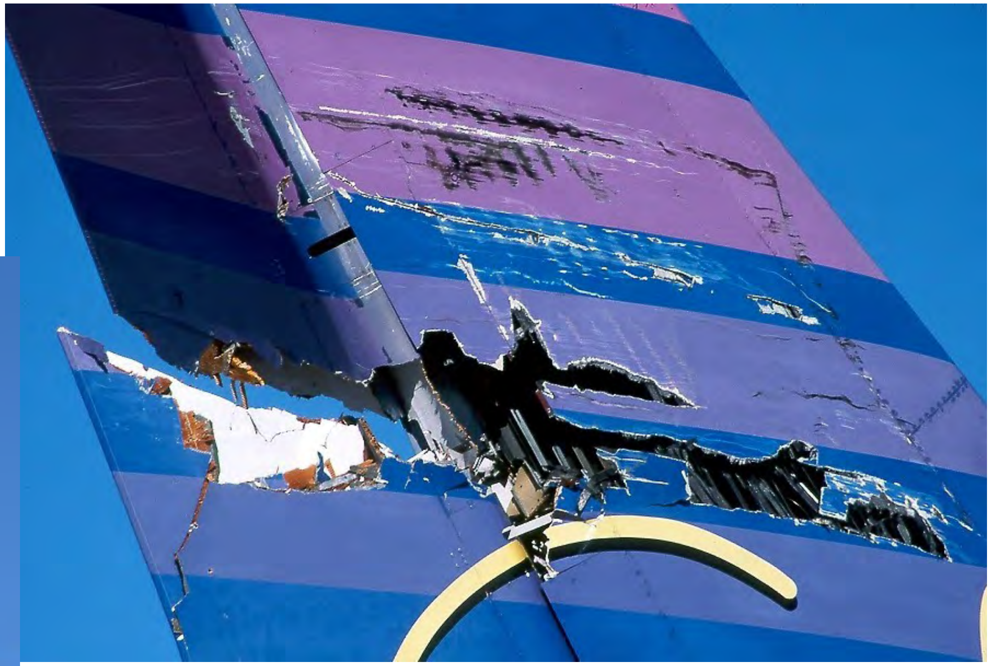
Scope of Presentation

2010 focus - Experimental aeroelastic capabilities for testing degraded and damaged composite airframes:

Wind tunnel tests of a Tail / Rudder configuration with no hinge stiffness and with a velocity-square damper

2010 Focus: Tail / Rudder Systems

Air Transat 2005



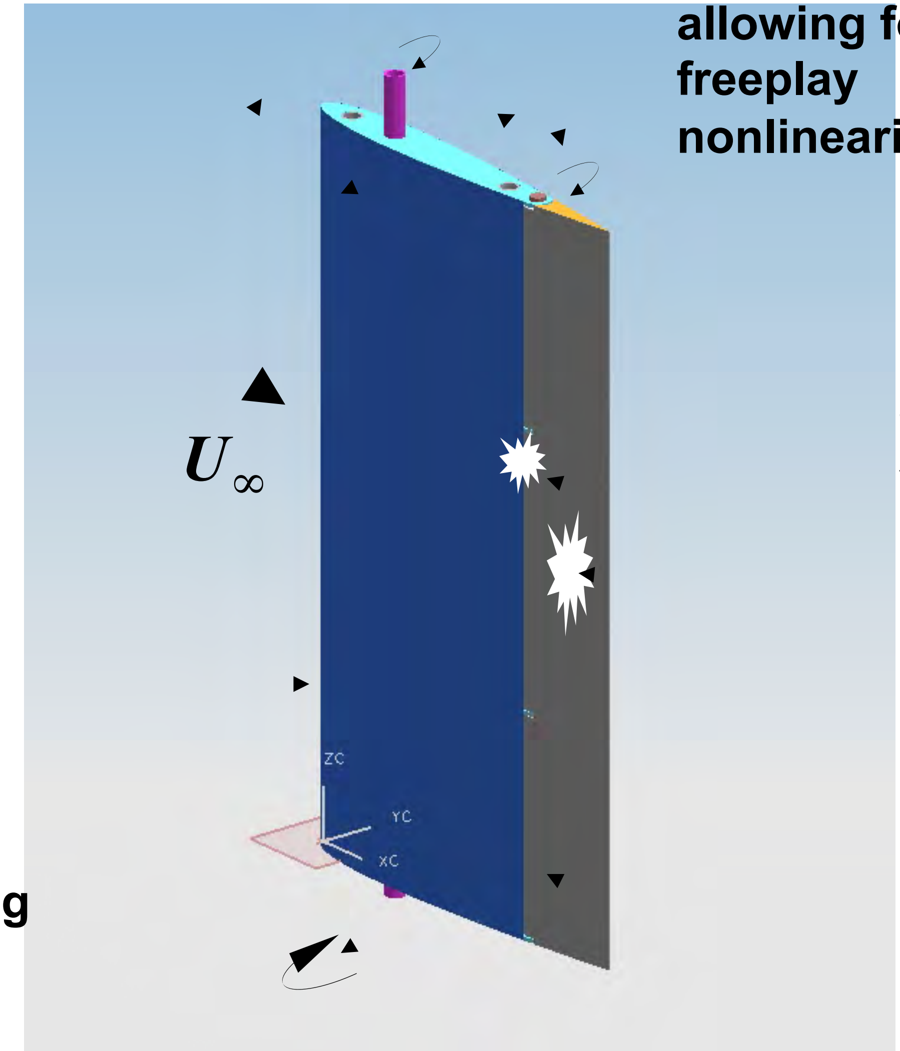
Damaged A310 in the hangar
(picture found on the web)

Experiments and experimental capabilities development

2010 Project Interests:

- Actuator / Actuator attachment hinge nonlinearities:
  - Freeplay / bilinear stiffness (hardening nonlinearity)
  - Actuator failure – nonlinear behavior with nonlinear hinge dampers

UW Flutter Test Wing / Control Surface Design mounted vertically in the UW A&A 3 x 3 wind tunnel



Simulated actuator allowing for freeplay nonlinearities

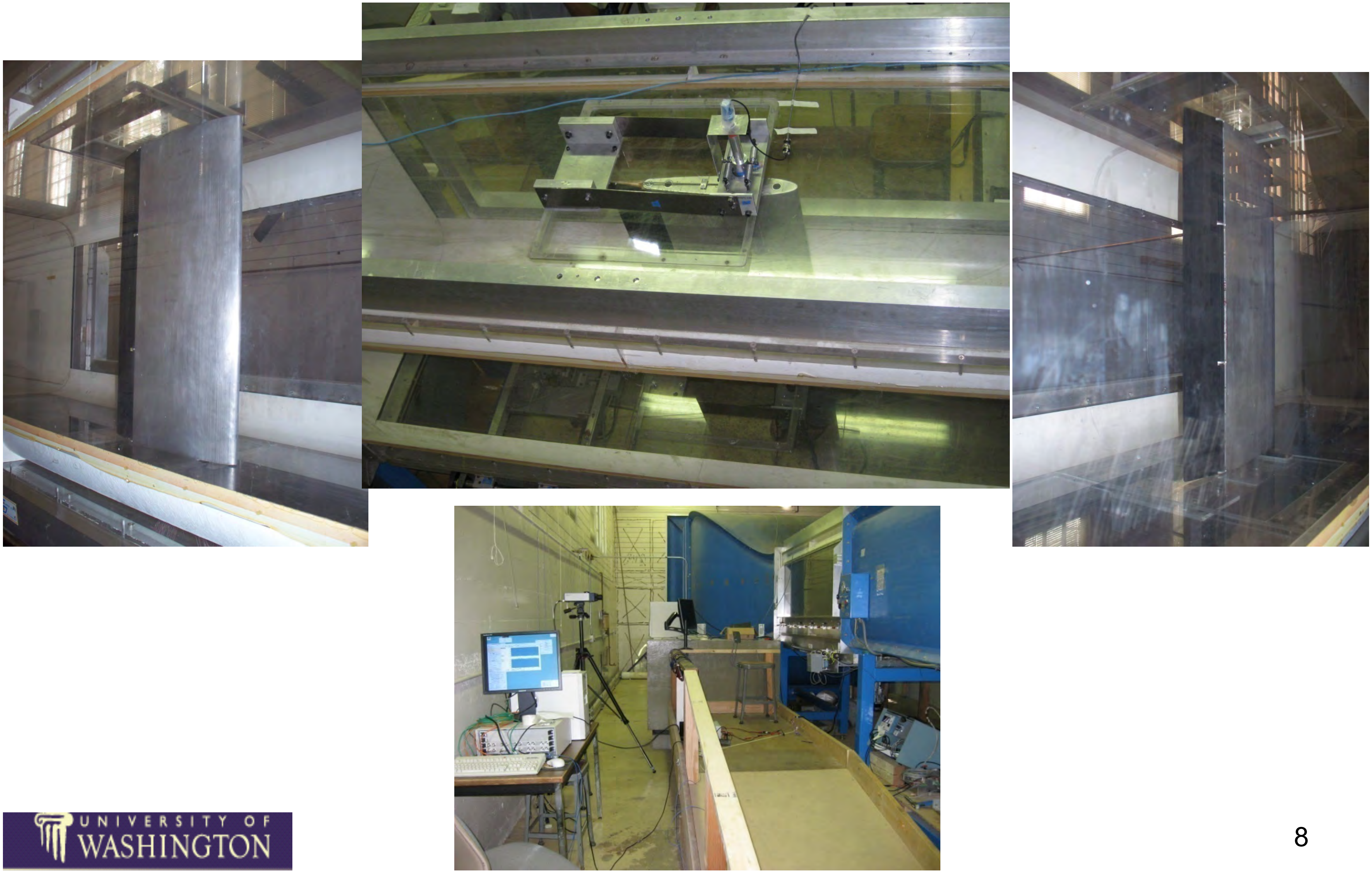
Wing - wind tunnel mount
Providing linear
Plunge
And torsional pitch stiffnesses

Rudder – composite construction allowing for simulations of hinge failure and Rudder damage

Aluminum wing allowing for variable inertia / cg properties

Simulated actuator / damper attachment allowing for different nonlinearities

The tail / rudder model at the UW's 3 x 3 wind tunnel 2010



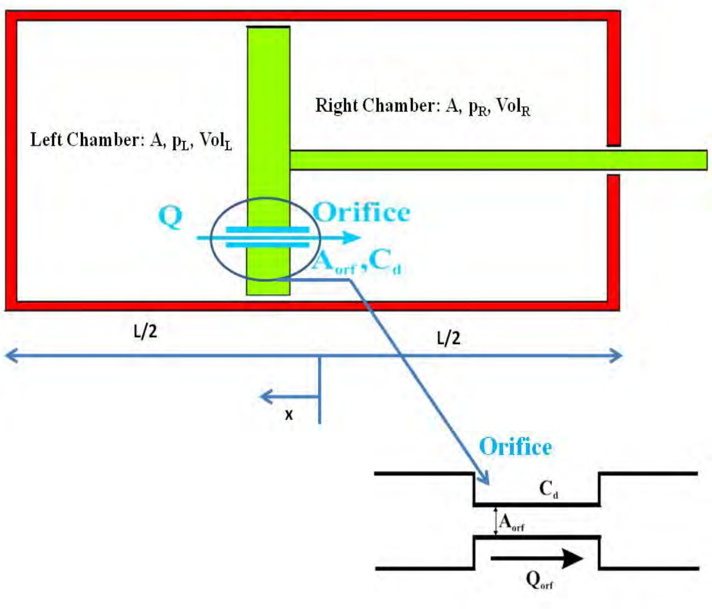
- An important condition in the aeroelastic design and certification of lifting-surface / control-surface systems is the case of loss of actuator stiffness, with control surface rotation resisted only by a velocity-square damper.

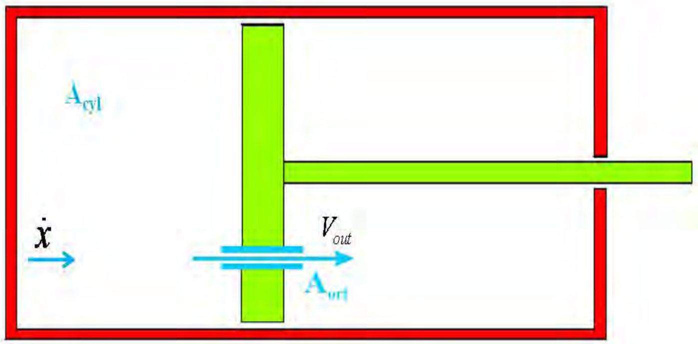
- No experimental wind tunnel aeroelastic results are available for this case.

The Challenge

- **Design and build a small velocity-squared damper keeping linear damping small relative to the velocity-squared effect**

The Design of a Small Velocity Squared Damper





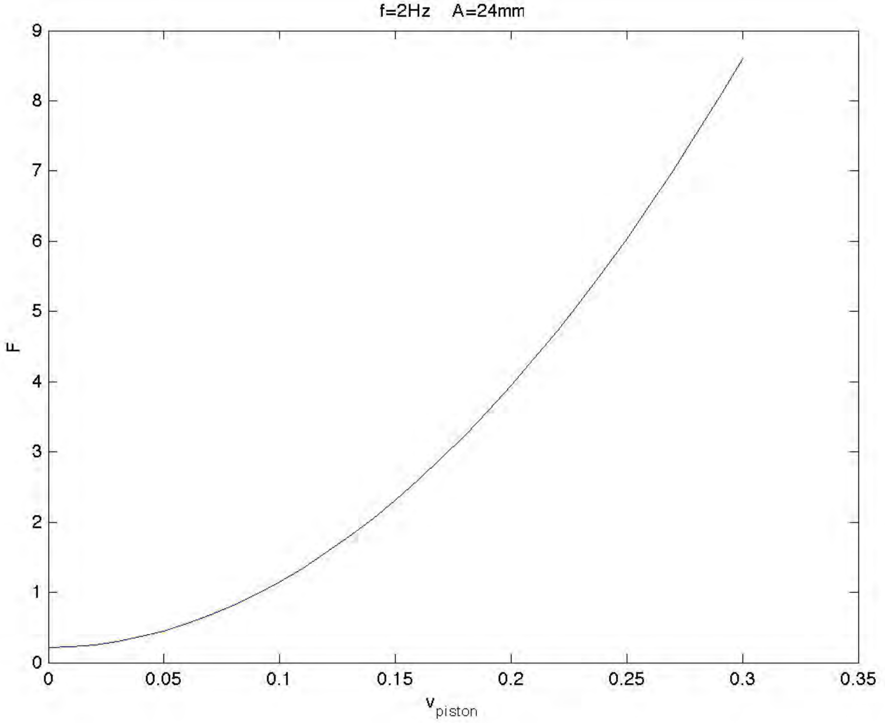
Axes chosen so that
Piston at rest
with respect to them

$$p_L + \frac{1}{2}\rho\cdot v_p{}^2 = p_R + \frac{1}{2}\rho\cdot V_{out}{}^2 \rightarrow \Delta p = p_R - p_L = \frac{1}{2}\rho\cdot(V_{out}{}^2 - v_p{}^2)$$

$$A_p\cdot v_p = A_{orifice}\cdot V_{out} \rightarrow V_{out} = \left(\frac{A_p}{A_{orifice}}\right)\cdot v_p = \frac{1}{\eta}\cdot v_p$$

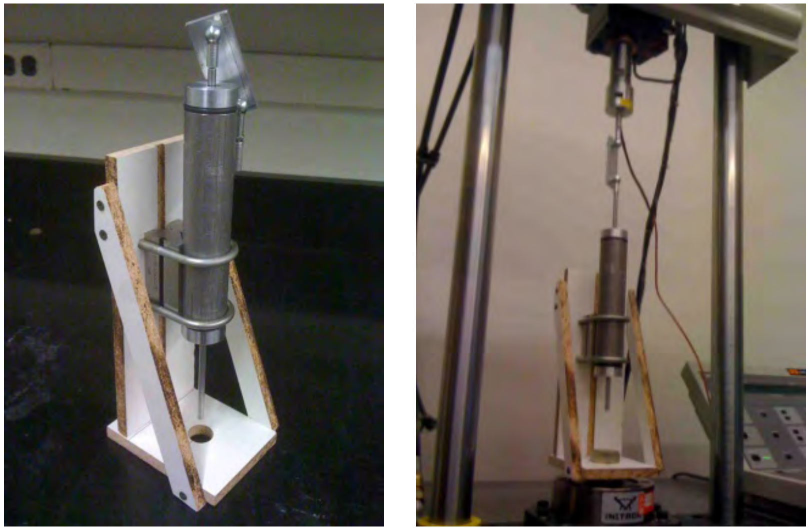
$$F_{tot} = F_{pressure} + F_{viscosity} + F_{inertial}$$

The Design of a Small Velocity Squared Damper



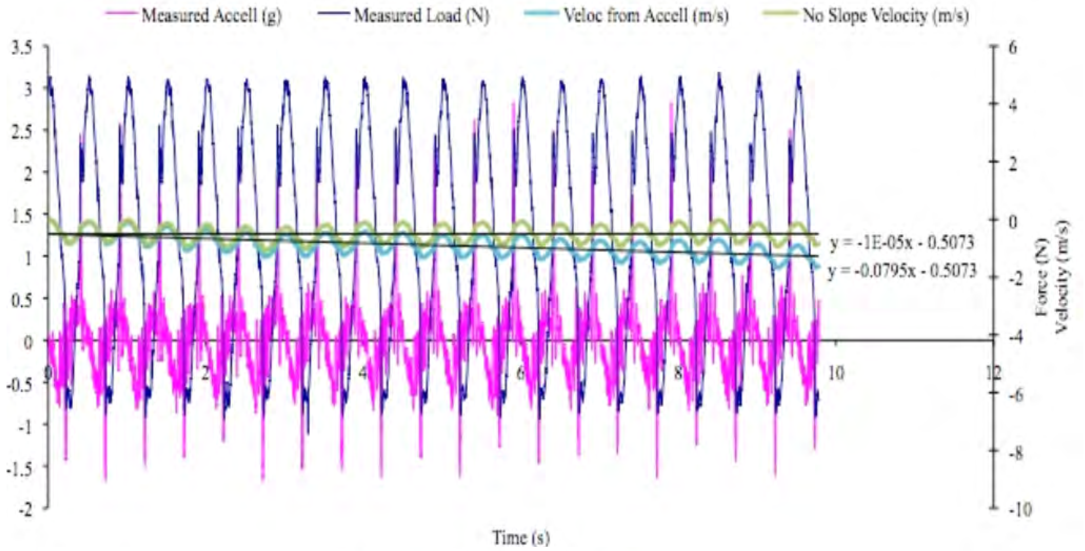
Early Ground Tests of the Damper

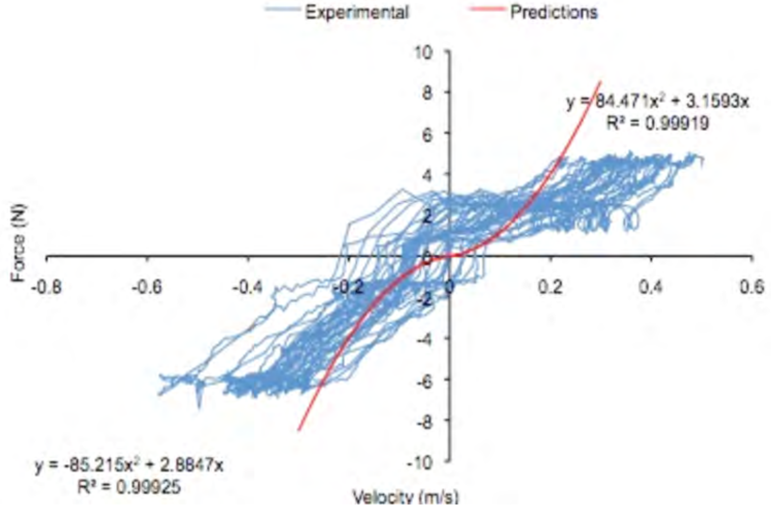
Direct attachment to the
Instron Machine



Attachment to the
Instron Machine through a lever system
To increase testing stroke

Early Damper Test Results





Test Fixture Problems:

Flexibility of lever system

Nonlinearity of the piston rod
Buckle (tendency to buckle
In compression)

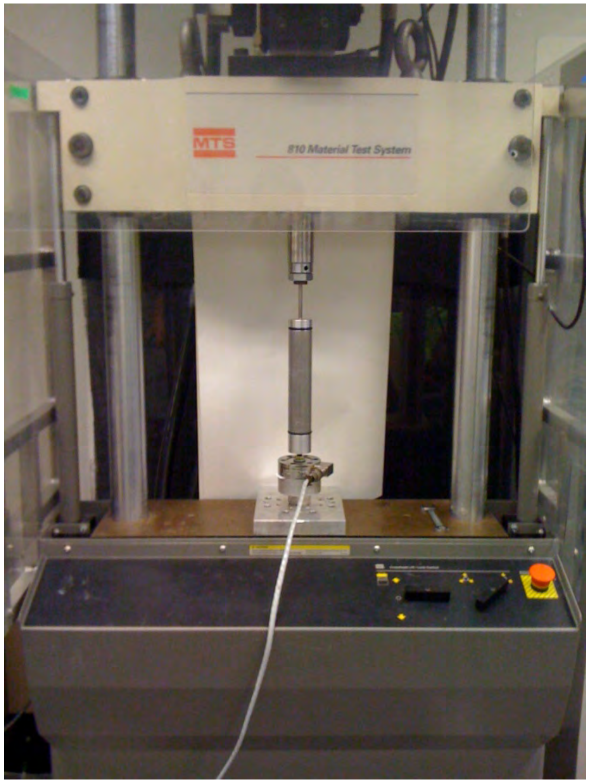
Short Term Plans Presented in May 2010

- Improve damper test fixture and carry out damper characterization tests
- Use CFD to simulate the internal flow field in the damper and optimize orifice shape and distribution.
- Attach dampers to the tail/rudder system and carry out aeroelastic wind tunnel tests at the UW’s 3 x 3 low speed wind tunnel.
- Correlate with Boeing results and validate Boeing and UW simulation codes.

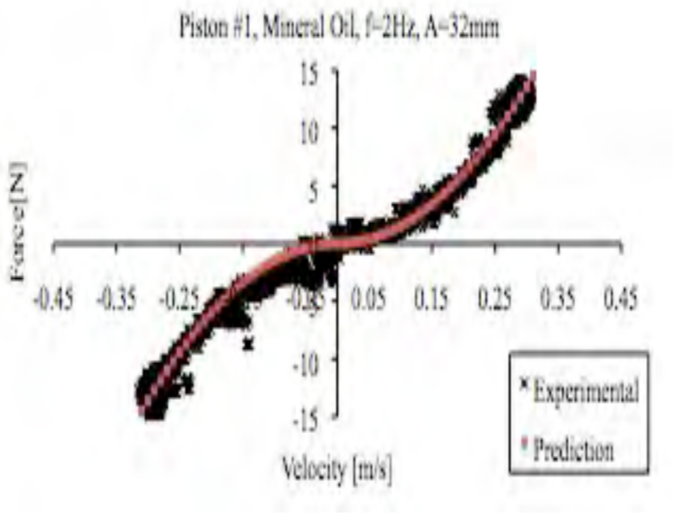
Accomplished

- Improve damper test fixture and carry out damper characterization tests
- Use CFD to simulate the internal flow field in the damper and optimize orifice shape and distribution.
- Attach dampers to the tail/rudder system and carry out aeroelastic wind tunnel tests at the UW’s 3 x 3 low speed wind tunnel.
- Correlate with Boeing results and validate Boeing and UW simulation codes.

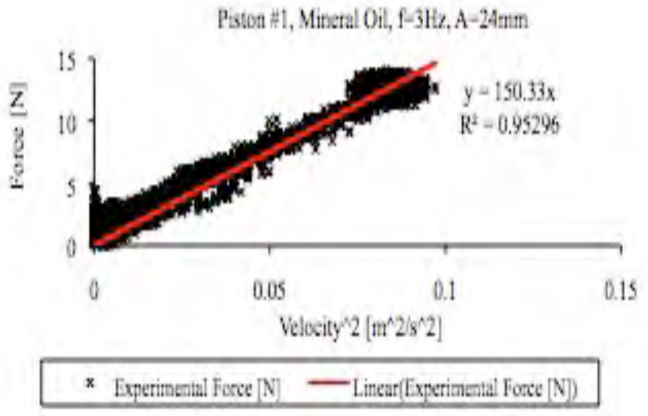
New Damper Tests

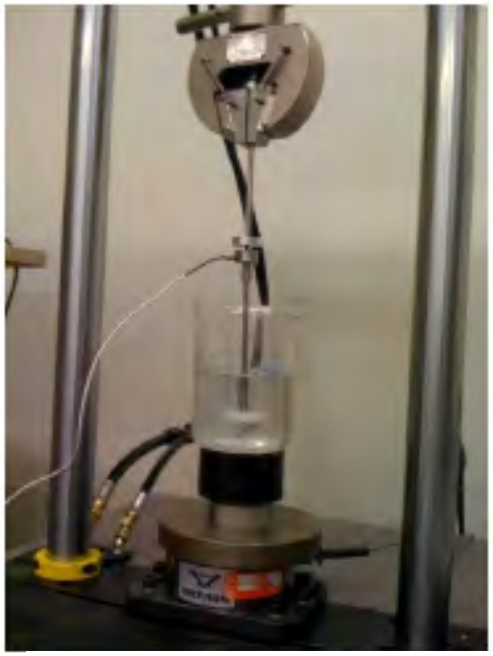


Damper in the Instron Machine



Typical end results





Testing for viscous force effects

Damper Attachment to Tail – Rudder System

Figure 92 Damper Airfoil Connection

Figure 93 Damper Aileron Connection

Damper Fairings

Figure 102 Waxing the Foam

Figure 104 Lay-up of Fiber Glass Plies

Figure 106 Final Two Painted Fairings

Figure 108 Damper Mounted on the Airfoil

Figure 109 Both Dampers Mounted on the Structure

2010 July-October Tests

- Mass and inertia measurements for all parts of the system
- Stiffness measurements
- Single degree of freedom uncoupled natural frequencies & damping ratio measurements
- Coupled natural frequencies & damping ratios
  - Clean tail / rudder system
  - With dampers (with and without oil)
  - With dampers + fairings
  - With fairings only
- Flutter tests – linear (evolution of frequencies and damping ratios, flow quality studies using tufts to assess the effect of the dampers and damper fairings
  - Clean tail / rudder system
  - Tail / rudder system with fairings

In Progress

- Replacement of the pitch springs system
- Replacement of the plunge springs
- Vibration tests of the modified system
- Development of numerical simulations and correlation with experiments – the linear cases

Short term plan

- Numerical simulation of the system with nonlinear dampers
- Correlation with Boeing predictions
- Wind tunnel tests of the nonlinear system with no hinge stiffness and with the nonlinear dampers

Longer Term Plans

- Test Tail/Rudder systems with composite rudder with various structural damage scenarios leading to local stiffness nonlinearity.

- Test Tail/Rudder system with small actuators and various hinge nonlinearities.

- Correlate with aeroelastic and aeroservoelastic simulation codes at Boeing and the UW.

- Proceed to more complex aeroelastic wind tunnel tests of composite airframe models.

Conclusion

- Major progress in the development of the UW's aeroelastic wind tunnel capabilities.
- Linear flutter as well as Limit Cycle Oscillations (LC) tested in the UW's 3 x 3 wind tunnel and used to validate UW's numerical modeling capabilities.
- A small velocity-squared damper was designed, built, and tested.
- Wind tunnel tests of tail / rudder systems with actuator failure and with nonlinear dampers – in development.
- Wind tunnel tests of representative tail / rudder systems with realistic rudder composite structures – in development.
- Results from this effort will provide valuable data for validation of simulation codes used by industry to certify composite airliners.