The Active Flutter Suppression (AFS) Technology Evaluation Project

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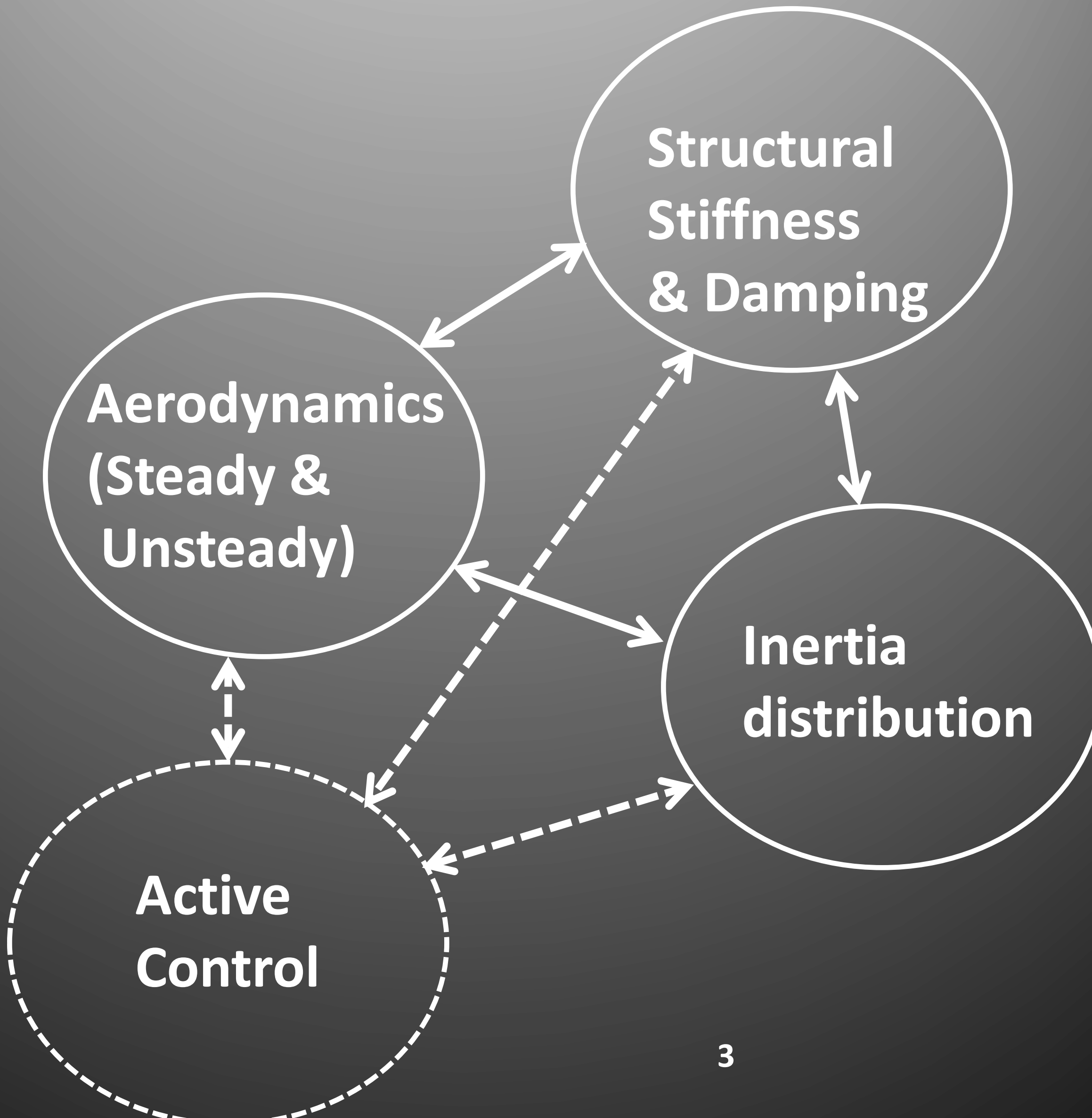
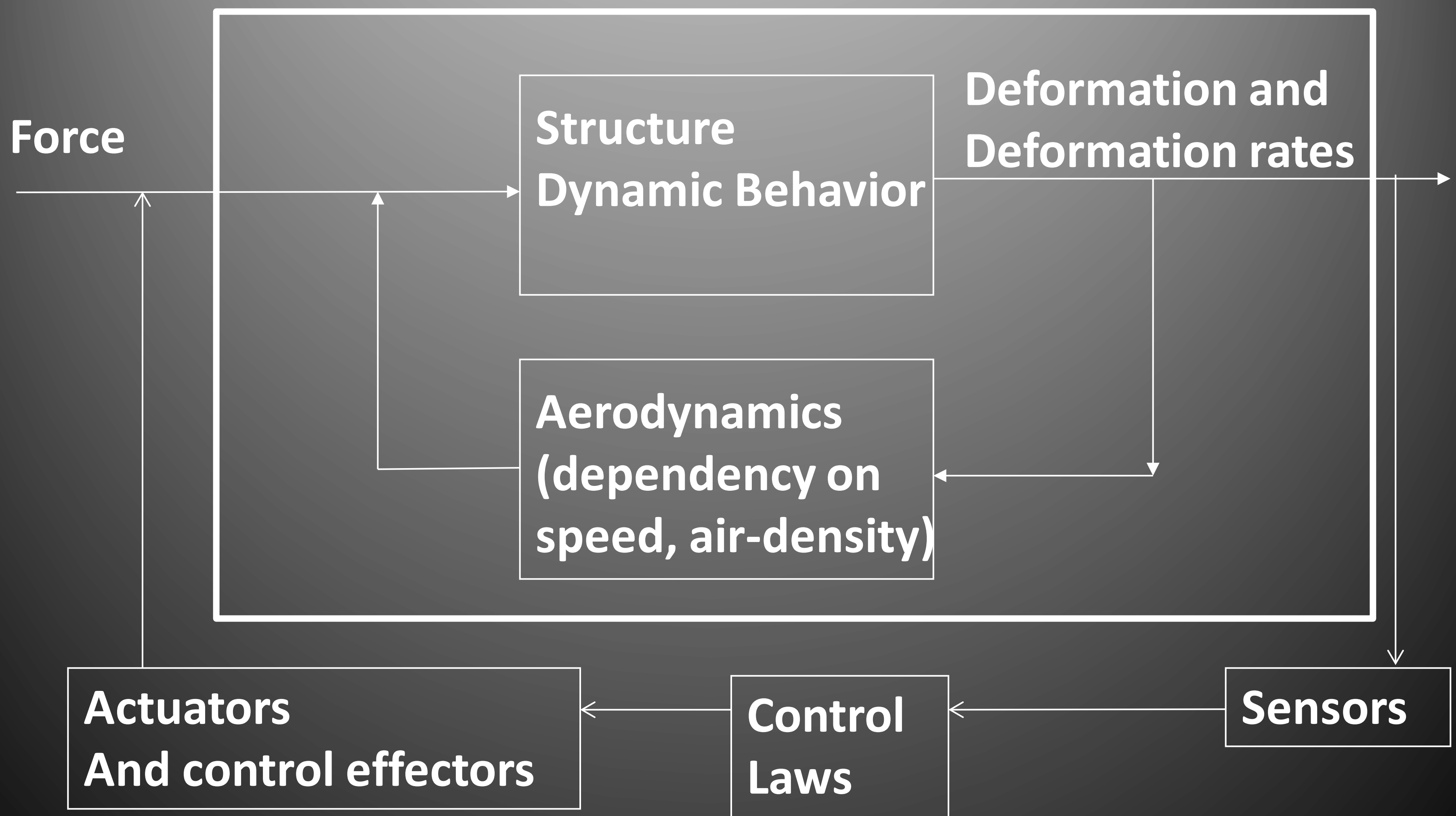

Structural
Stiffness
& Damping
Aerodynamics
(Steady &
Unsteady)
Inertia
distribution
Active
Control

Aero-servo-elasticity (ASE)



Aeroservoelastic Systems: Benefits, Problems, and Opportunities

- Shape dynamic behavior of the flexible vehicle using active control:
  - Flight mechanics of the vehicle as a “rigid body”
  - Optimum cruise shape
  - Maneuver load / Gust load alleviation
  - Ride comfort (Vibrations)

- Adverse Interactions
  - Flutter and Divergence
  - A control system designed for flight mechanics control, gust alleviation, ride comfort, etc., may interact with the dynamic aeroelastic structure to produce instabilities.
  - Find ways to decouple the active control system from the dynamics of the aeroelastic system.

Opportunities – AFS as a response to flutter problems

If flutter or other dynamic aeroelastic problems show up late in the design process, when solution by revised stiffness / inertia / aerodynamic means becomes too costly / impractical

Use active control, through the action of control effectors driven by actuators and control laws, to solve the problems.

In this case Active Flutter Suppression is used as a fix of flutter problems.

Opportunities – AFS as part of the Integrated design from the START

Allow integrated optimization of the coupled structure / aerodynamic / control system from its early design stages, leading (potentially) to major weight savings and performance improvements.

Livne, E.,
“Future of Airplane Aeroelasticity”,
Journal of Aircraft, Vol. 40,
No. 6, 2003, pp. 1066-1092.

Livne, E.,
“Integrated Aeroservoelastic Optimization: Status and Progress”,
Journal of Aircraft,
Vol. 36, No. 1, 1999, pp. 122-145.

Technology State of the Art

- Gust alleviation systems are already certified on passenger airplanes as well as ride comfort augmentation and maneuver load control systems.

- Those aeroservoelastic systems operate in harmony with the aircraft flight control system (FCS).

- Active Flutter Suppression has been thoroughly researched since the mid 1960s (when flight control systems began to become powerful and high bandwidth).

Technology State of the Art (continued)

- Many academic / theoretical studies.
- Quite a number of wind tunnel tests using dynamically / aeroelastically scaled models of production or test aircraft with active controls.
- A few AFS flight tests of AFS-configured test vehicles – A B52 in the early 1970s, an F4F with external stores in the 1970s, NASA DAST UAV in the 1970s-early 1980s, Lockheed / USAF X56 UAV recently.

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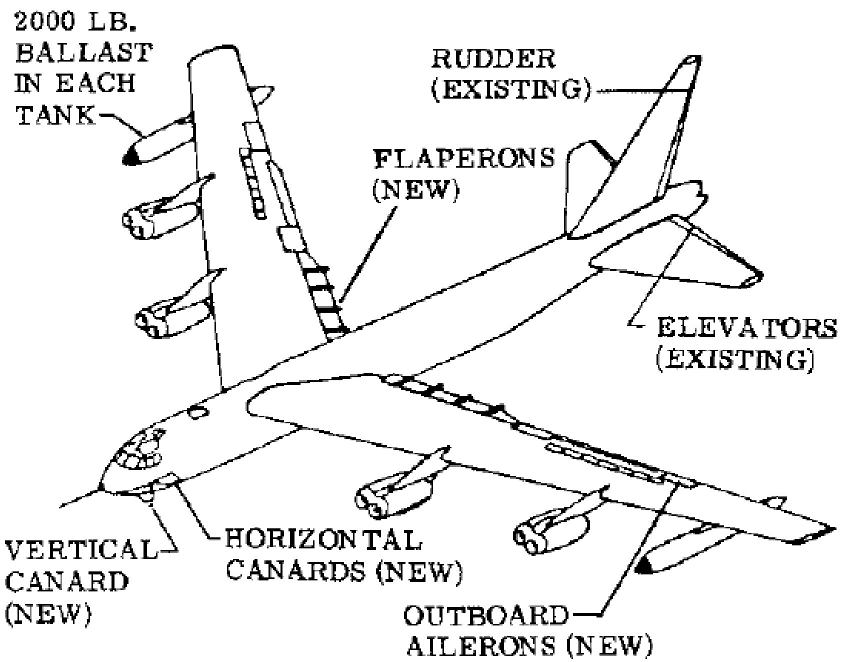
Past AFS Flight Testing Experiences – The CCV B-52



SURFACES	CCV CONCEPTS				
	RCS	FMC	MLC	AS	FR
RUDDER				X	
ELEVATOR			X	X	X
FLAPERON		1 SEGMENT	X		
OUTBOARD AILERON		X	X		X
HORIZONTAL CANARD	X				
VERTICAL CANARD	X				

Fig. 1 B-52 CCV control surfaces.

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Active Flutter Suppression—A Flight Test Demonstration

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Recent Encounters

www.flightglobal.com 23 Mar 2011
FAA and Boeing agree on 747-8 OAMS special condition

Boeing and the US FAA have come to a final agreement on the regulatory special condition required for the 747-8's outboard aileron modal suppression (OAMS) system designed to dampen out a structural vibration in the wing.

The X-56A Multi-utility Aeroelastic Demonstration (MAD) is an innovative modular unmanned air vehicle designed to test active flutter suppression and gust load alleviation.
http://www.lockheedmartin.com/us/products/x-56.html

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The FAA / AMTAS Active Flutter Suppression Project

- **Assess the state of the art of the technology and its level of readiness for actual airplane implementation.**

- **Work with industry, government research agencies, government regulation & certification agencies in the U.S. and abroad, as well as academia to develop a plan of action that would lead, via development of analysis, design, tests, operations, and maintenance process to established FAA policies regarding AFS on civil aircraft.**

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The FAA / AMTAS Active Flutter Suppression Project

- Year 1: state of the art assessment and the development of an R&D plan.
- Years 2&3: Analysis and design studies followed by tests of representative configurations to study technology readiness, identify key issues, and create a data base of test results for future design & analysis methods validation.
- Conclusion: Revised FAA policies / certification requirements (or not…)

Project Status

- Study of the state of the art via a comprehensive literature survey and past-work technical source data base generation – almost completed, continuously being updated.

- Preparation of discussion points / guidelines for talks with industry – completed.

- Building a team that would represent industry / government research agencies / academia & gathering views from lead experts in this area as well as more information (unpublished) on existing industry experience
- – underway…

…..subject to difficulties due to:

IP concerns by industry, budget pressures in industry & government labs, the large geographic separation of centers of expertise involved.

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Multi-Organization Expert Team Building Effort
&
Technical Consultations

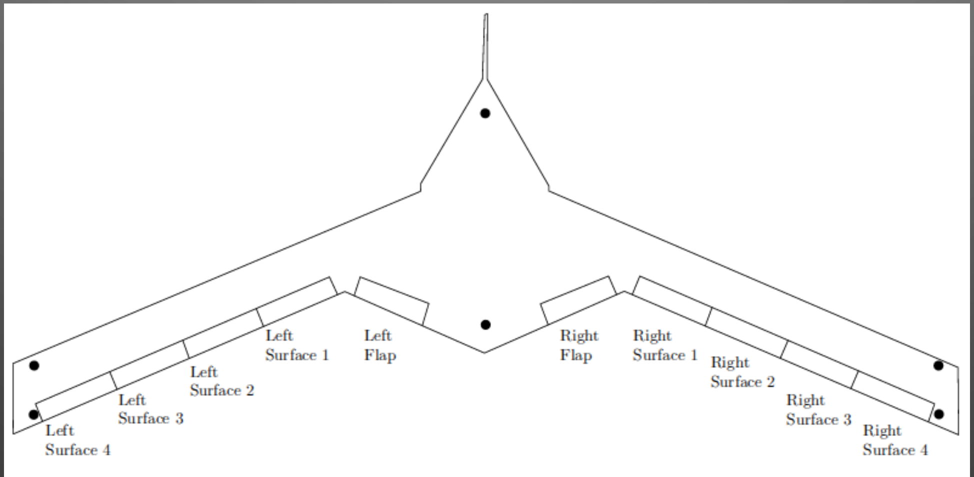
- NASA Langley – initial discussions. To be continued.
- US AFRL – initial discussions. To be continued.
- Boeing – discussions
- AIAA SciTech 2014 Conference - Discussions
- American Flutter and Dynamic Council (AFDC) – presentation, discussions.
- AIAA Aviation 2014 Conference – Discussions
- Lockheed Martin Skunkworks – Discussions, strong interest in collaboration.
- NASA Armstrong Flight Research Center – Discussions, strong interest in collaboration.
- International Council for the Aeronautical Sciences (ICAS) 2014 Conference – Discussions. Search for international collaboration.

Emerging Picture

- Strong collaboration with Lockheed-Martin Skunkworks and NASA Armstrong Research Center
- Still hope for collaboration with Boeing & Airbus
- Research plan preparation – underway. With technical literature studies complete, focus is now on current regulations / certification practices, civil and military, covering all aspects of ASE and AFS technology
- Utilization of the X-56 (despite some limitations) for modeling, design, and test demonstration studies

The X-56 UAV System

The X-56 aircraft system consists of two center-bodies, four wing sets, a ground control station, and a storage trailer.



Control surfaces and accelerometers of the X-56 aircraft. Accelerometer locations are indicated with large dots. Control surfaces are labeled.

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X-56 Recent References
(from which the figures are taken)

- Beranek, J., Nicolai, L., Buonanno, M., Burnett, E., Atkinson, C., Holm-Hansen, B., and Flick, P., "Conceptual Design of a Multi-Utility Aeroelastic Demonstrator", AIAA 2010-9350, 2010, doi: 10.2514/6.2010-9350

- Hjartarson, A., Seiler, P. J., and Balas, G. J., "LPV Aeroservoelastic Control Using the LPVTools Toolbox,", AIAA 2013-4742, 2013, doi: 10.2514/6.2013-4742.

- Ryan, J.J., Bosworth, J.T., "Current and Future Research in Active Control of Lightweight, Flexible Structures Using the X-56 Aircraft", AIAA 2014-0597, 52nd Aerospace Sciences Meeting, 2014, doi: 10.2514/6.2014-0597

- Li, W.W., Pak, C.-G., "Aeroelastic Optimization Study Based on the X-56A Model", AIAA 2014-2052, AIAA Atmospheric Flight Mechanics Conference, 2014, doi: 10.2514/6.2014-2052

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http://www.nasa.gov/centers/armstrong/research/X-56/#.VGKw0fnF98E

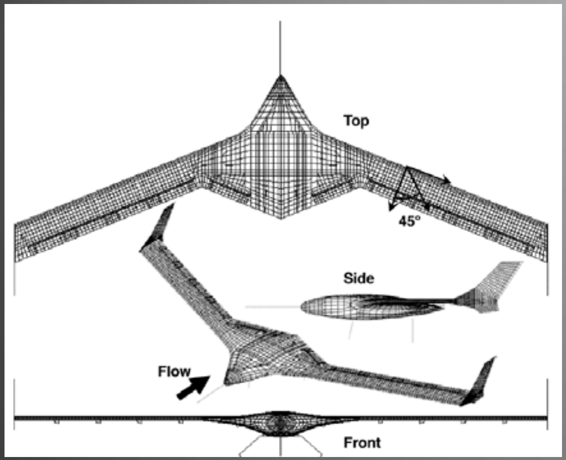
- The goal of the X-56A project is to advance aeroservoelastic technology through flight research using a low-cost, modular, remotely piloted aircraft. The aircraft is being tested using flight profiles where flutter occurs in order to demonstrate that onboard instrumentation can not only accurately predict and sense the onset of wing flutter, but also be used by the control system to actively suppress aeroelastic instabilities.

- Applied to future designs, such technologies will enable construction of longer, lighter, more flexible wings for a variety of crewed and remotely piloted aircraft. NASA engineers will explore issues related to active flutter suppression by adjusting software programs in the X-56A aircraft's flight control computer. Researchers also expect to learn how to better ease gust loads, which will make flexible airplanes safer during encounters with in-flight turbulence.

- Several key goals include:
  - Maturation of flutter-suppression technologies
  - Reduction of structural weight to improve fuel efficiency and range
  - Increase aspect ratio by 30 to 40 percent to reduce aerodynamic drag
  - Promote improved long-term structural integrity by reducing gust loads

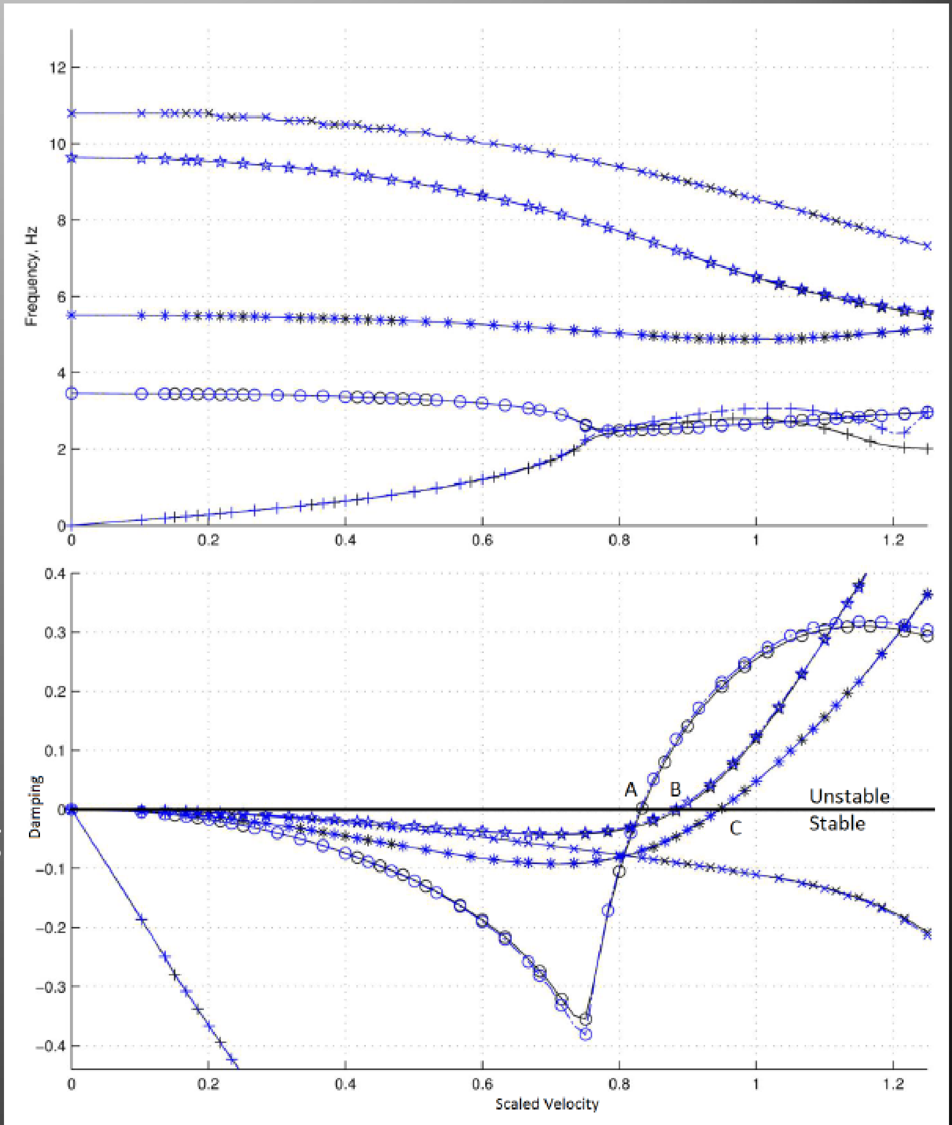
- Designing the next generation of aerospace vehicles will pose serious challenges in modeling, predicting, and controlling potentially destructive aeroservoelastic dynamics and finding ways to exploit efficiency gains from lighter, more flexible structures.

X-56 Finite Element Model and Flutter Mechanisms



A positive damping value indicates instability.

-Point A indicates the point of body-freedom-utter instability.
-Point B indicates the point of symmetric wing bending mode instability.
-Point C indicates the point of anti-symmetric wing bending mode instability.



Natural frequencies and damping values as a function of scaled velocity.

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In Test Flight

http://www.youtube.com/watch?v=jM1ns11VWS8

Benefits to Aviation

- Create a state of the art knowledge / experience base of Active Flutter Suppression (AFS) technology that would prepare the FAA and the industry for developments in AFS and its safe potential implementation for airplane efficiency benefits.