The Active Flutter Suppression (AFS) Technology Evaluation Project

Eli Livne, Ph.D.

The William E. Boeing Department of Aeronautics and Astronautics

University of Washington, Seattle, WA

eli@aa.washington.edu

The Active Flutter Suppression (AFS) Technology Evaluation Project

FAA technical monitors / collaborators:

David R. Westlund

FAA - Advanced Materials and Structures

John Bakuckas, Ph. D.

FAA - Structures and Materials Section, ANG-E231

Carl J. Niedermeyer

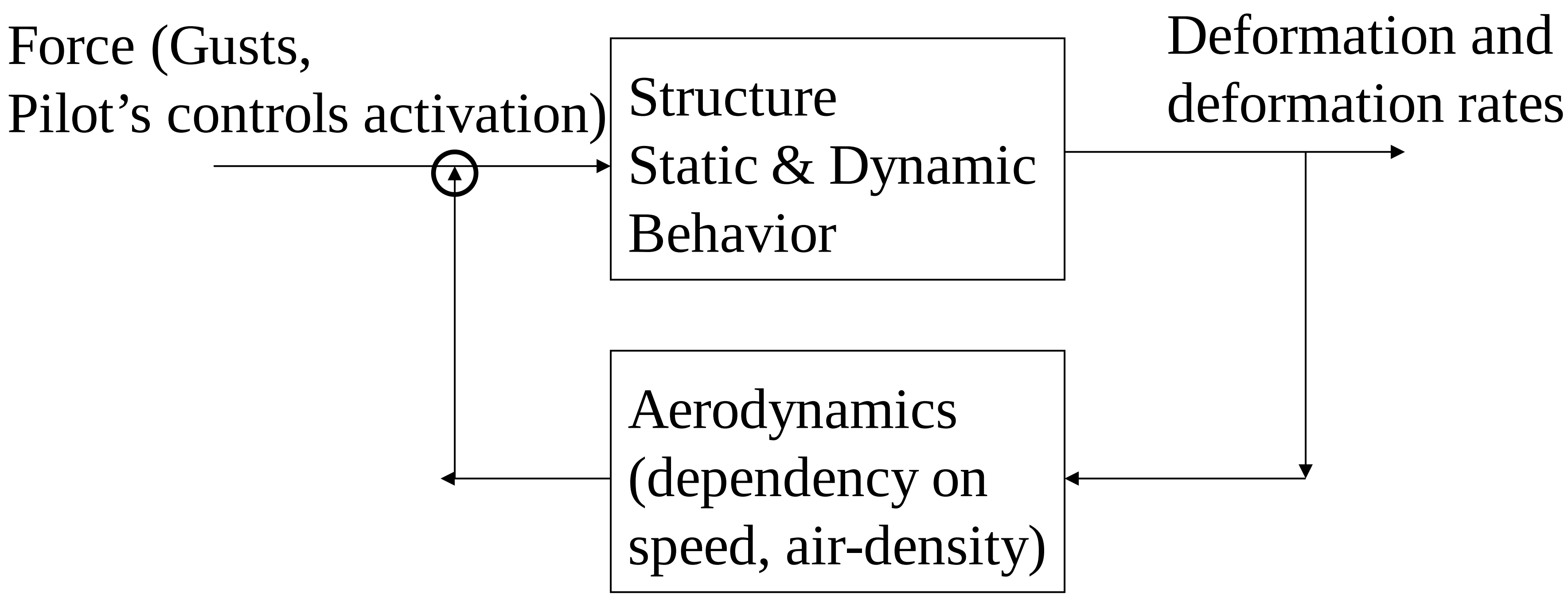
FAA - Airframe and Cabin Safety Branch (ANM-115)

Ian Y. Won

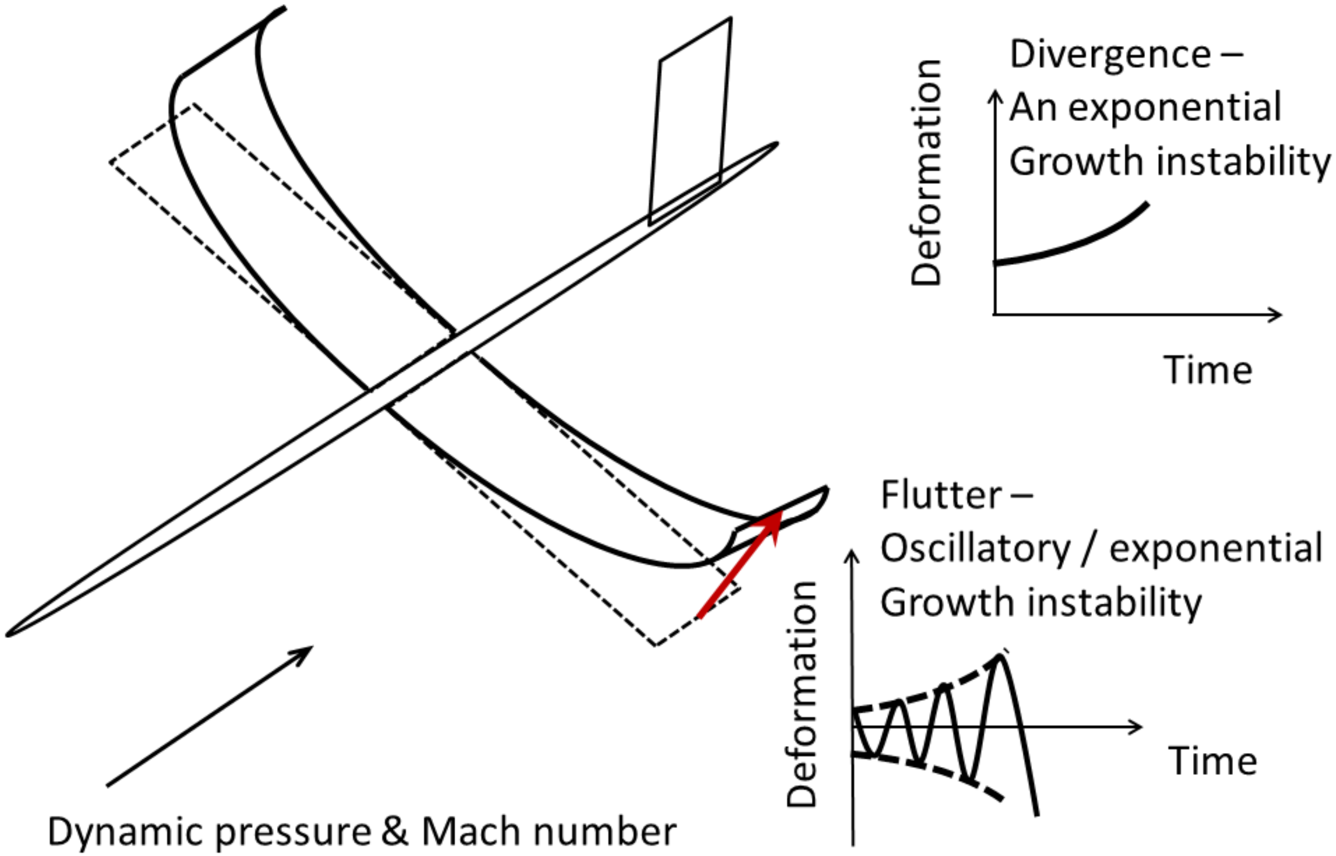
FAA - Airframe/Cabin Safety Branch (ANM-115)

FAA Transport Airplane Directorate

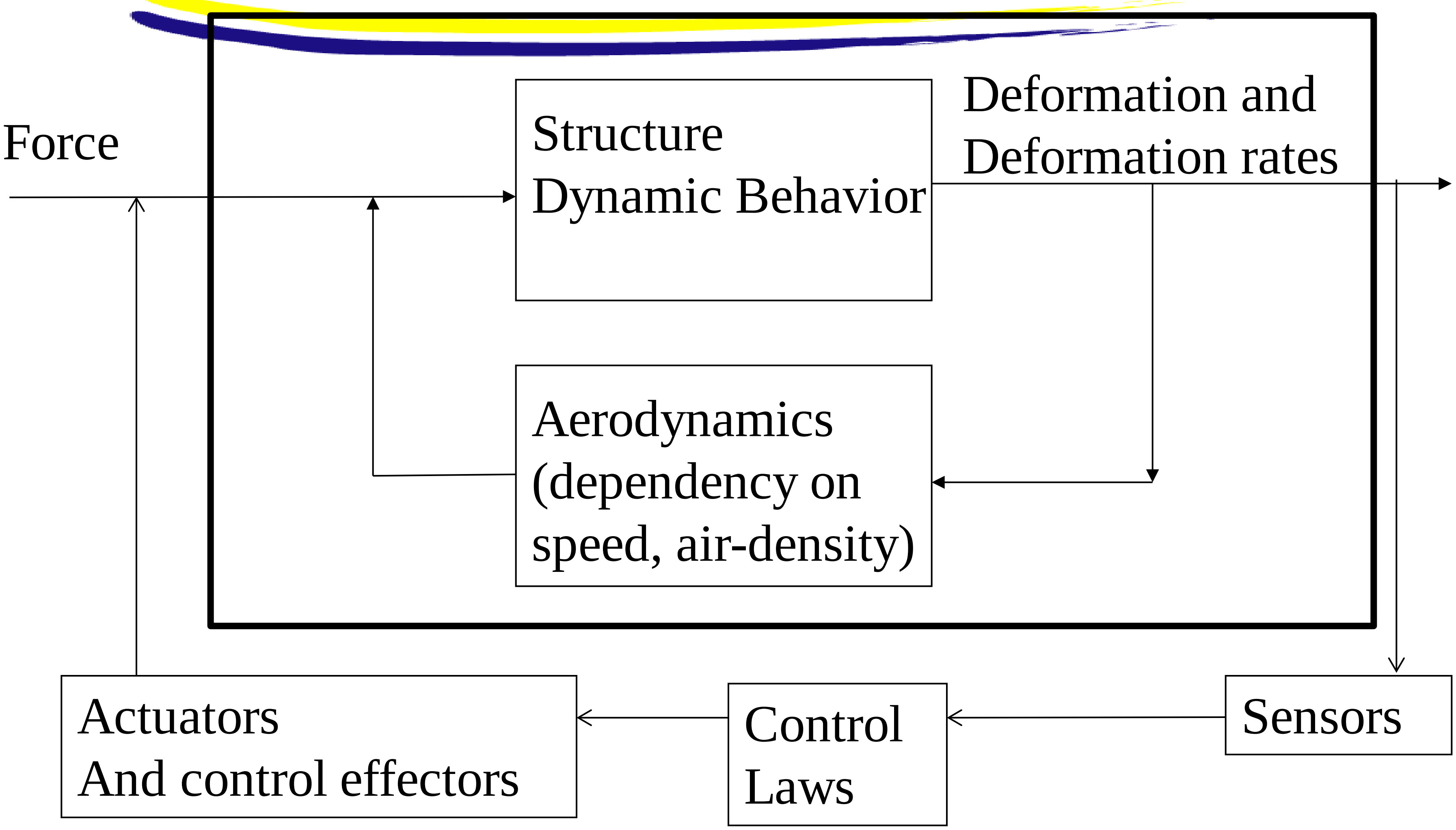
The Aeroelastic (AE) physical feedback loop and its associated stability: static & dynamic

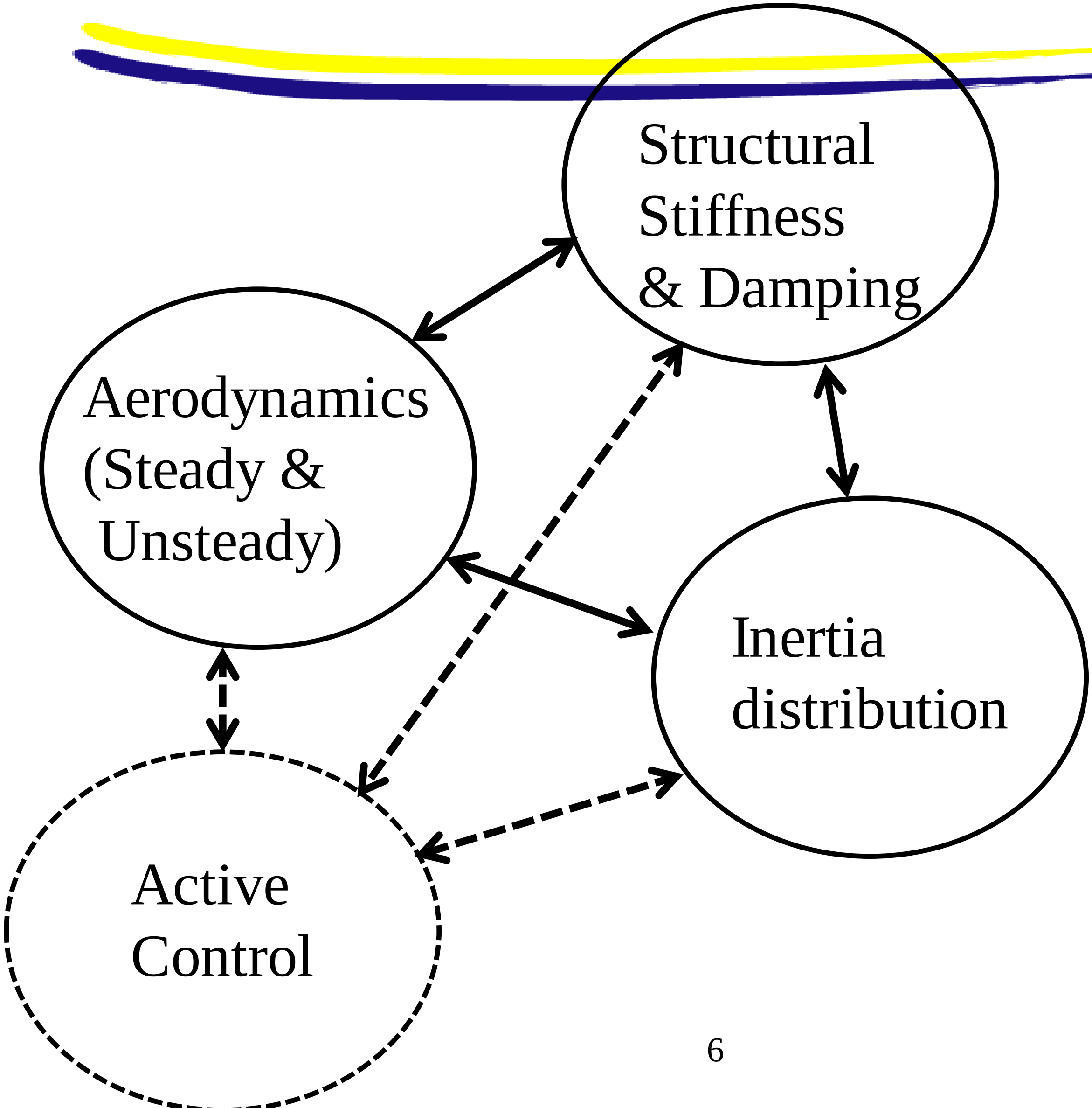


Divergence & Flutter Instabilities



Aero-servo-elasticity (ASE)




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

Aeroservoelastic Systems
Benefits and Opportunities

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

Aeroservoelasic Systems – Adverse Interactions

- 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

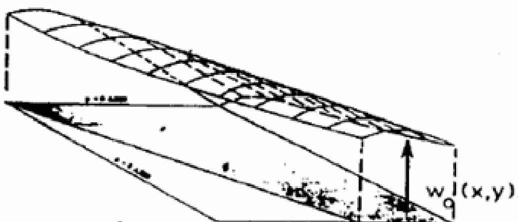
If flutter or other dynamic aeroelastic problems show up late in the design process, when solution by revised stiffness / inertia / aerodynamic means becomes too costly / impractical:

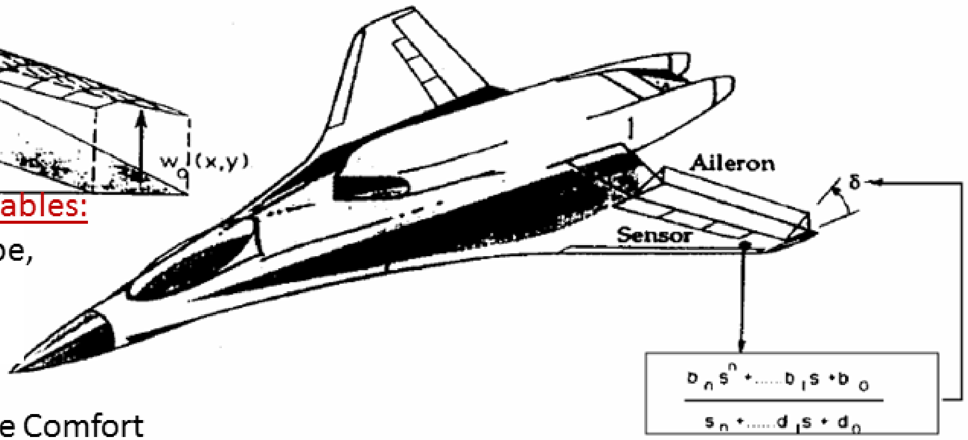
- Use active control, through the action of control effectors driven by actuators and control laws, to solve the problems.

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.

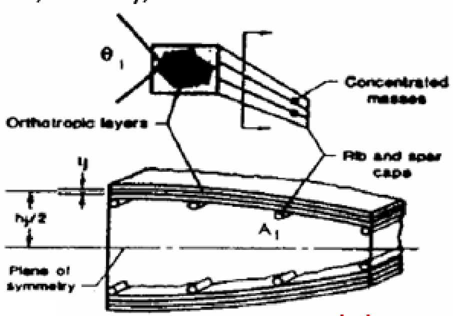




Aerodynamic design variables:
Planform and airfoil shape, twist, camber, jig shape, controls motions
Constraints: Lift / Drag / Performance, Safety, Ride Comfort

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.



Control system design variables (depending on Control system topology and parametrization)
Constraints on aeroservoelastic stability, flight stability and control, handling qualities, maneuver loads, gust loads, ride comfort.

Structural design variables:
Toplogy, shape, sizing
(skin panel layup and thickness, Spar / rib caps and webs)
Constraints: stress, strength, buckling, Fatigue, damage tolerance

Objectives:
Weight, cost, performance or some mix of those

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).

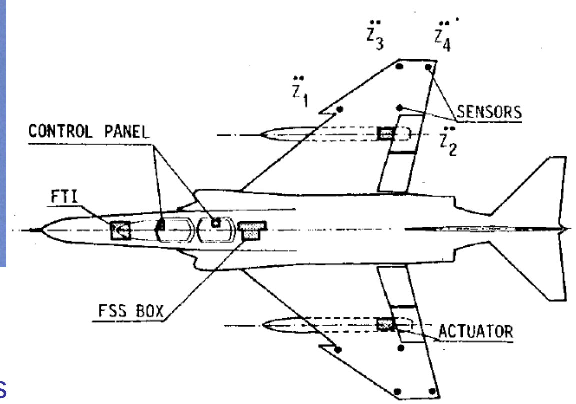
Technology State of the Art (continued)

- 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.

Past AFS Flight Testing Experiences

NASA DAST (Drones for Aeroelastic & Structural Testing) Program – Late 1970s Early 1980s .

12 June 1980, shows the DAST-1 (Serial #72-1557) immediately after it lost its right wing after suffering severe wing flutter.



US-AFFDL & Germany's MBB F4F with external stores AFS research vehicle Late 1970s

B-52 CCV Research Vehicle Early to mid 1970s

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

354 J. AIRCRAFT VOL. 19, NO. 5

AIAA 80-0770R

Active Flutter Suppression on an F-4F Aircraft

O. Sensburg* and H. Hönlinger†
Messerschmitt-Bölkow-Blohm, West Germany
and
T.E. Noll‡ and L.J. Huttsell‡
Air Force Wright Aeronautical Laboratories, Wright Patterson Air Force Base, Ohio

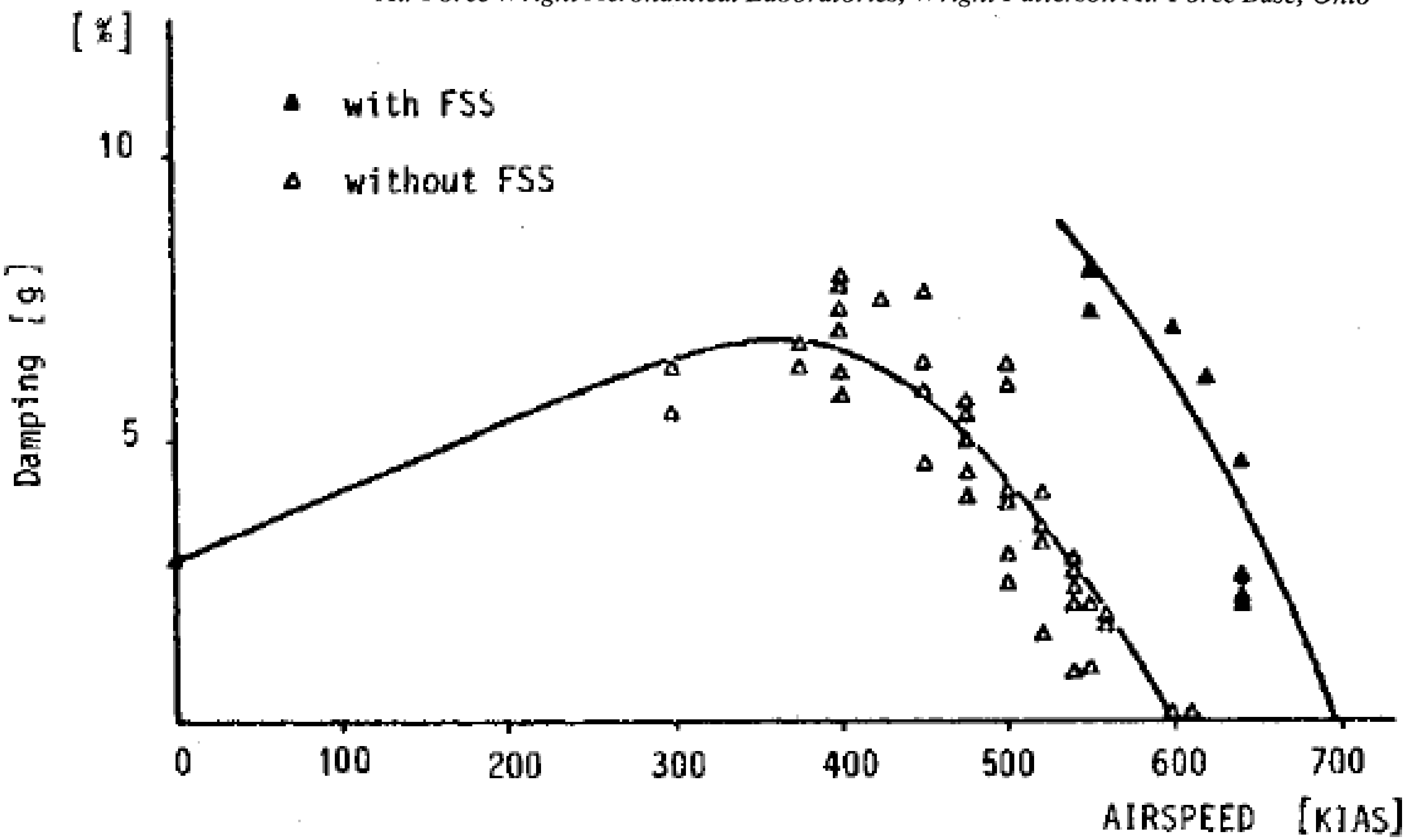


Fig. 24 Increase of flutter speed with FSS.

VOL. 12, NO. 6, JUNE 1975 J. AIRCRAFT 551

Active Flutter Suppression—A Flight Test Demonstration

Kenneth L. Roger* and Garold E. Hodges†
The Boeing Company, Wichita, Kansas

and

Larry Felt‡
Wright Patterson Air Force Base, Ohio

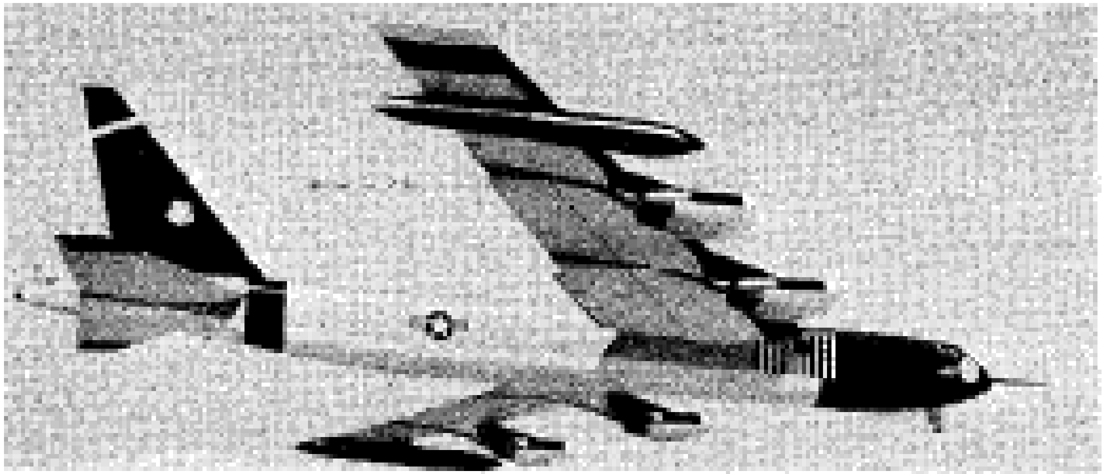
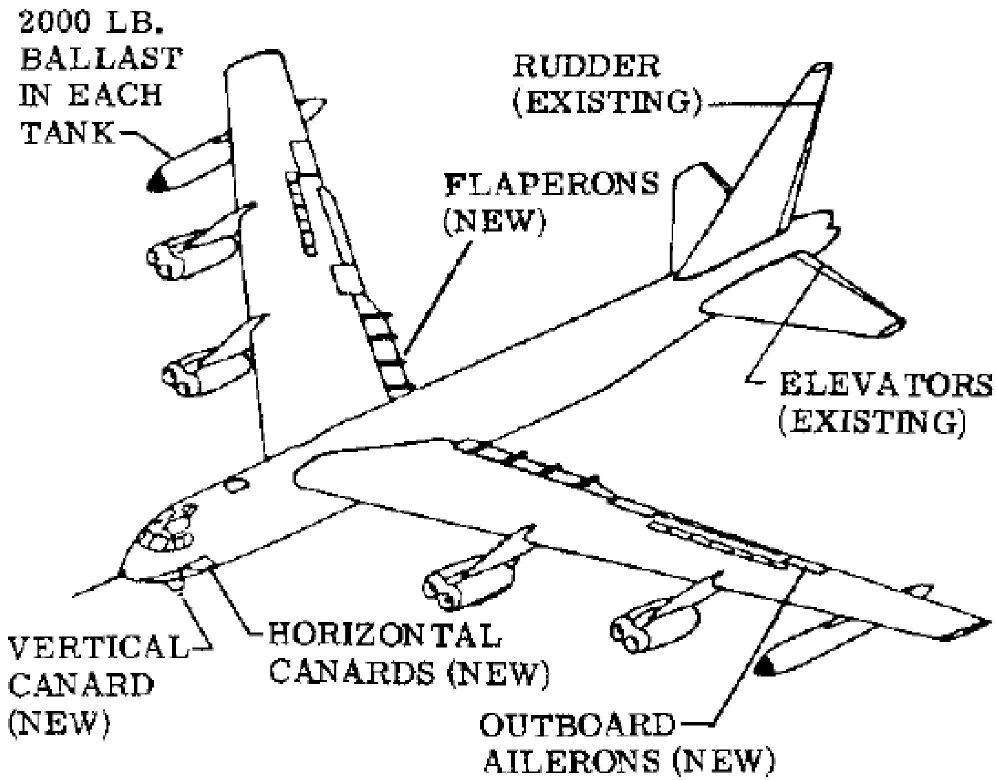


Fig. 9 Modified test airplane.



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.

Past Flutter Flight Testing with AFS - Safety

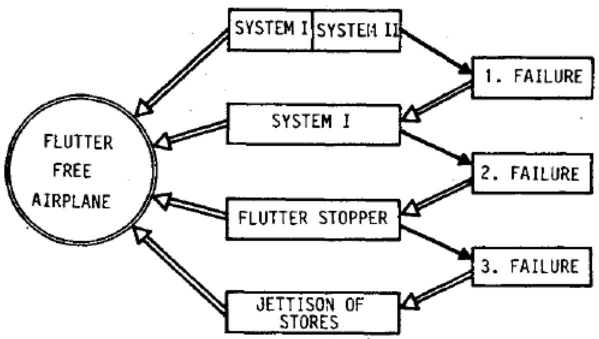


Fig. 16 Safety concept for the flight test program.

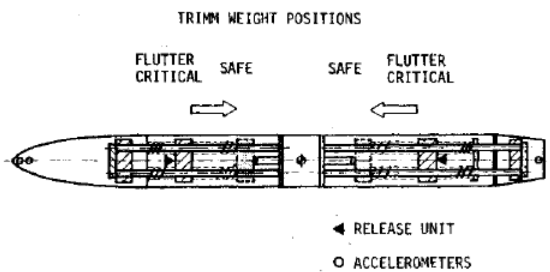
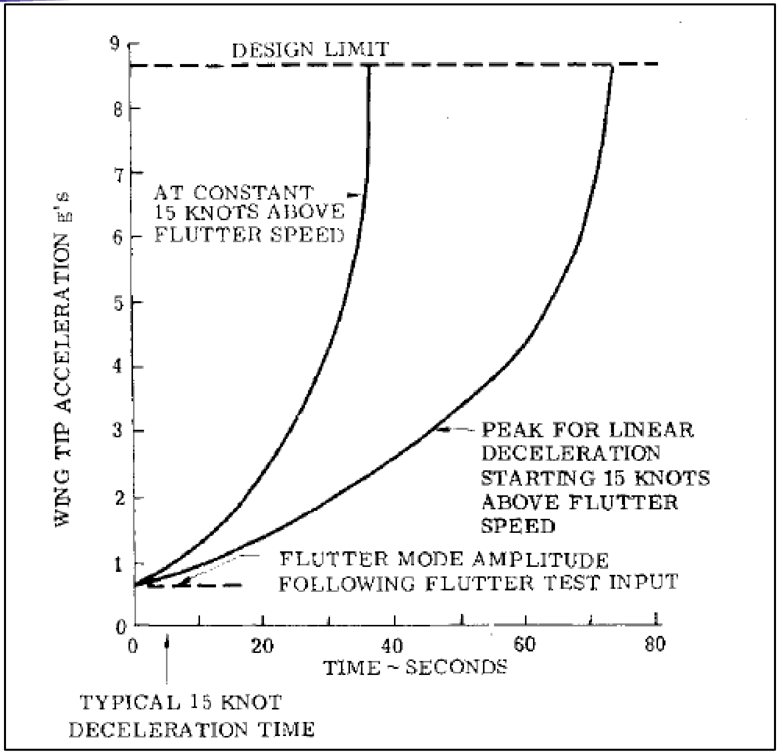


Fig. 17 Scheme of the flutter stopper.

AFFDL/MBB F4F – Flutter Stopper

Upon failure of both AFS systems, external store

Inertia is rapidly changed to a safe, stable configuration.



B-52 CCV

Mild flutter, low frequency

Analysis of time to destruction if AFS system fails

Enough time is available for pilots to correct

CCV B52 Flight Tests With and Without AFS

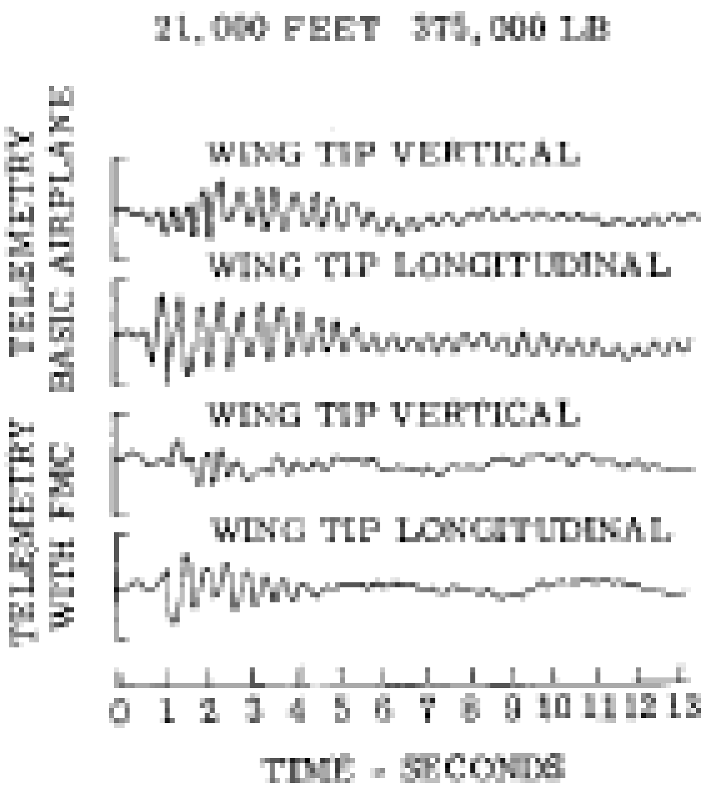


Fig. 18 Test transient response, 2 knots below flutter, with and without FMC.

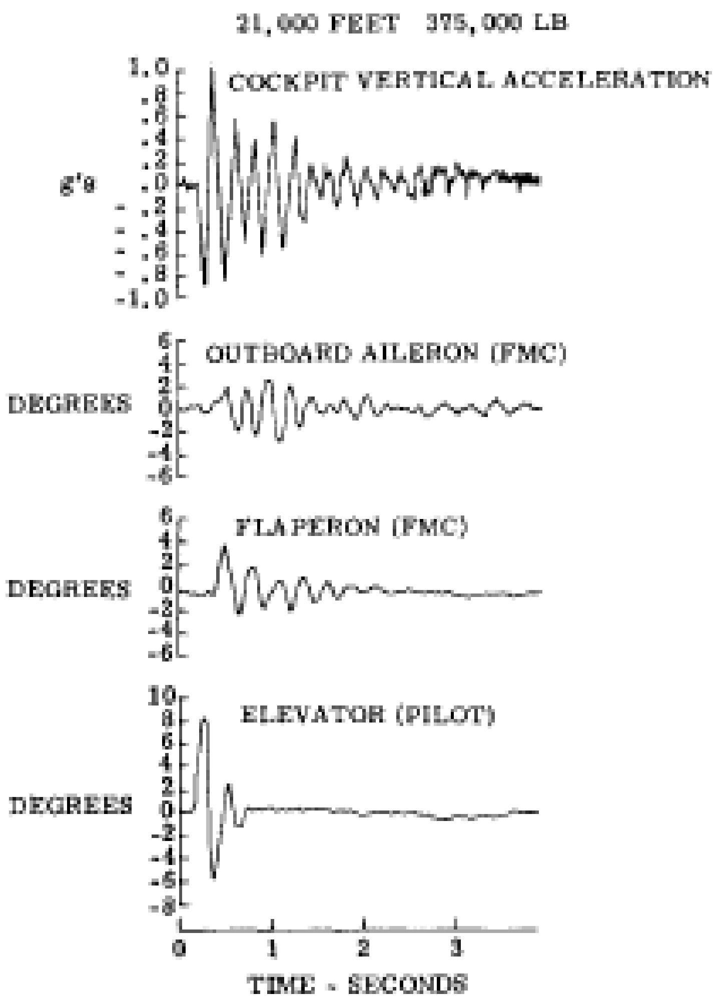


Fig. 19 FMC transient response, 12 knots above flutter.

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.

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.
- Preparation of discussion points / guidelines for talks with industry – completed.
- Currently, launching an industry / government research agencies consultation phase for gathering views from lead experts in this area as well as more information (unpublished) on existing industry experience.

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.