EXPERIMENTAL AEROELASTICITY
WIND TUNNEL TESTING

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Presented as part of a short course on
Application of Adaptive Structures in Active Aeroelastic Control
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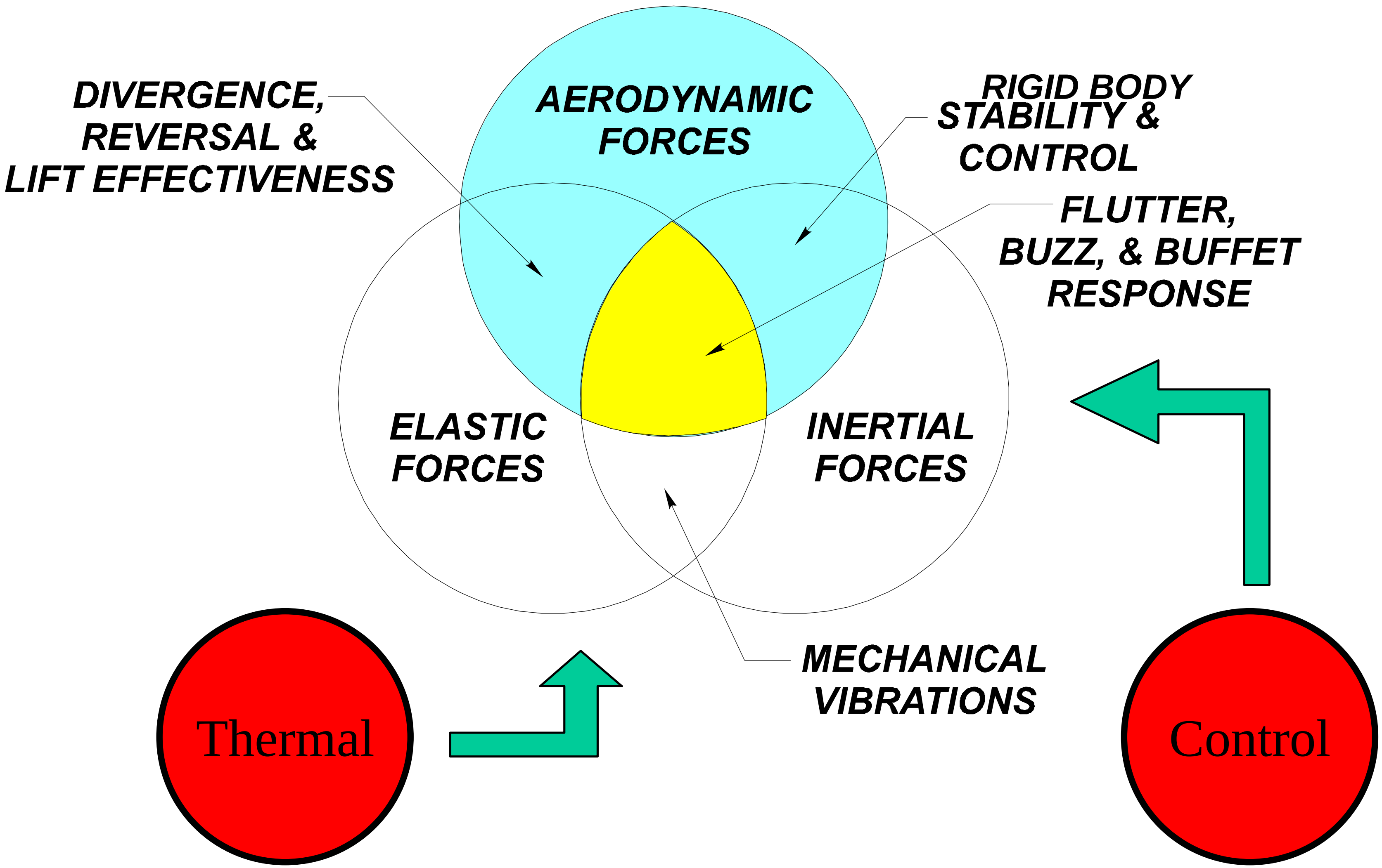
Ankara, Turkey

EXPERIMENTAL AEROELASTICITY AGENDA

- Session 1- Background on aeroelasticity and wind tunnels
  – Historical overview of aeroelastic testing
  – Overview of experimental research at NASA LaRC
  – Introduction to aeroelastic wind-tunnel testing
- Session 2 - Tunnel calibrations; the Transonic Dynamics Tunnel
- Session 3 - Model design, fabrication
- Session 4 - Wind tunnel testing and case studies
- Session 5- Active control and smart structure tests

AEROELASTICITY

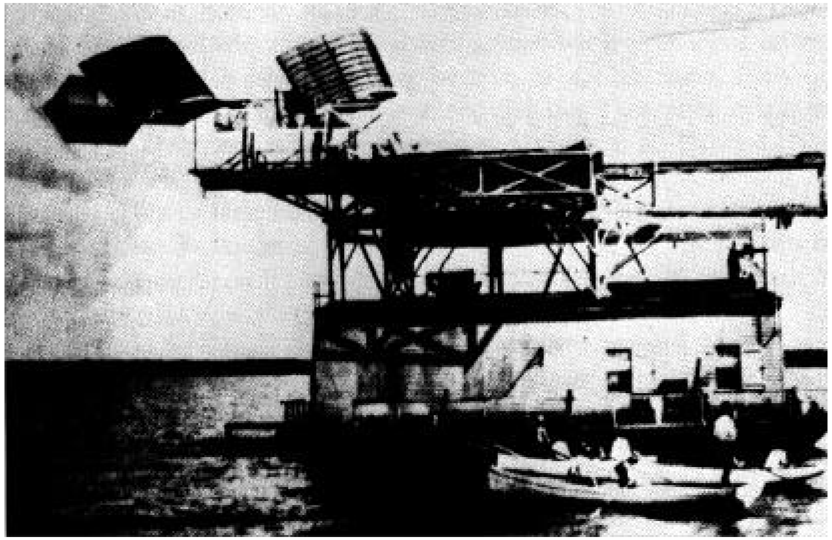


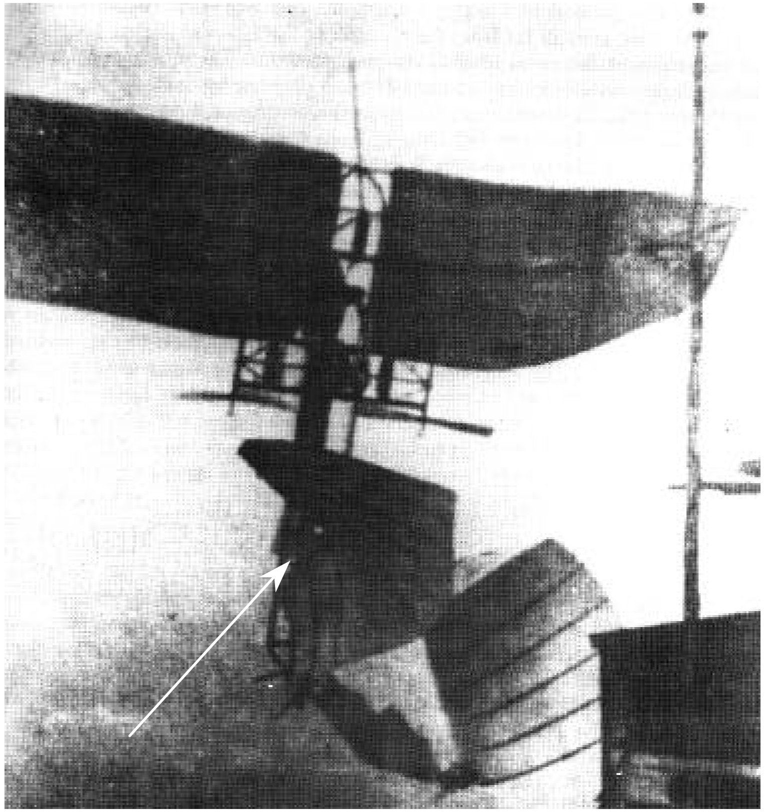
WHAT AFFECTS AEROELASTICITY?

HISTORY OF AEROELASTICITY

Airplane designs had aeroelastic problems from Day One !

Samuel Langley's monoplane launched (days before the Wright Flyer) from a houseboat in the Potomac River suffered a structural failure -- possibly aeroelastic divergence



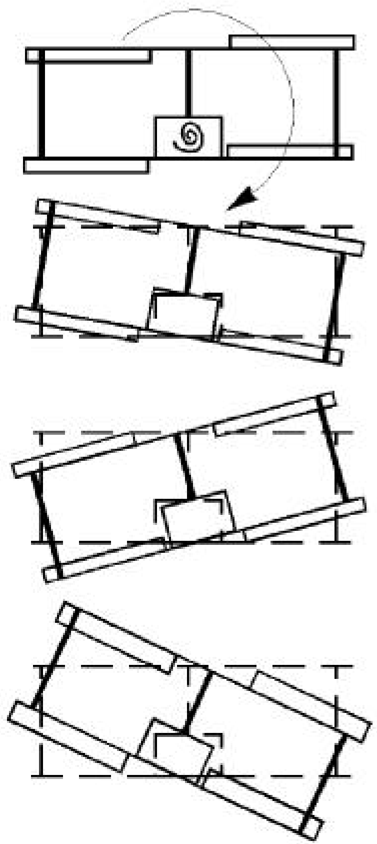


HISTORY OF AEROELASTICITY

Flutter was common during World War I

- The Handley Page 0-400 bomber had a coupling between the aft fuselage in torsion and an antisymmetric elevator motion
  - "… at certain critical speeds of flight a tail wobble is set up, involving heavy torsional stresses on the fuselage, the type of vibration being an angular oscillation approximately about the axis of the fuselage …

    … the angular magnitude of this oscillation amounts at times to something approaching 15°, and is undoubtedly extremely dangerous to the structure …"
  - The DH-9 had a similar problem in 1917
  - Design modifications were developed to eliminate such aeroelastic hazards … a stiff torque tube connecting the left and right elevators was introduced.

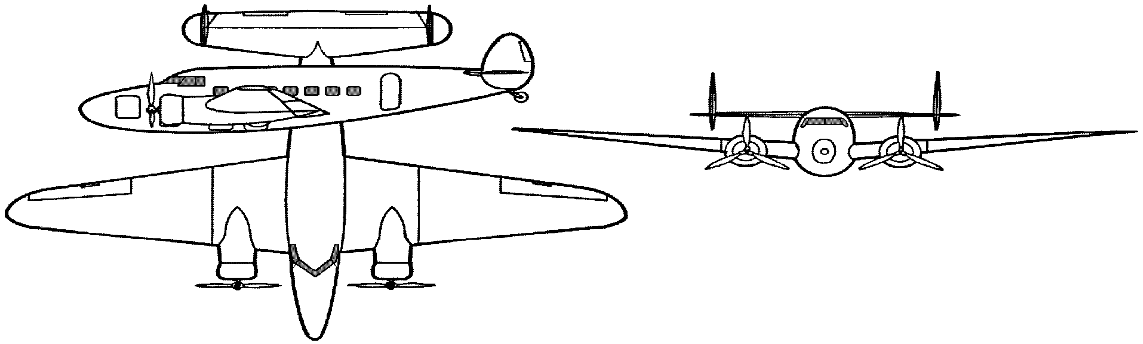


HISTORY OF AEROELASTICITY

The 30's provided more examples of flutter.

- **The Lockheed Model 14H (Super Electra) required significant effort to balance the tip-mounted rudders.**

- **KLM refused to accept the airplane without a better static aerodynamic balance for the rudder.**

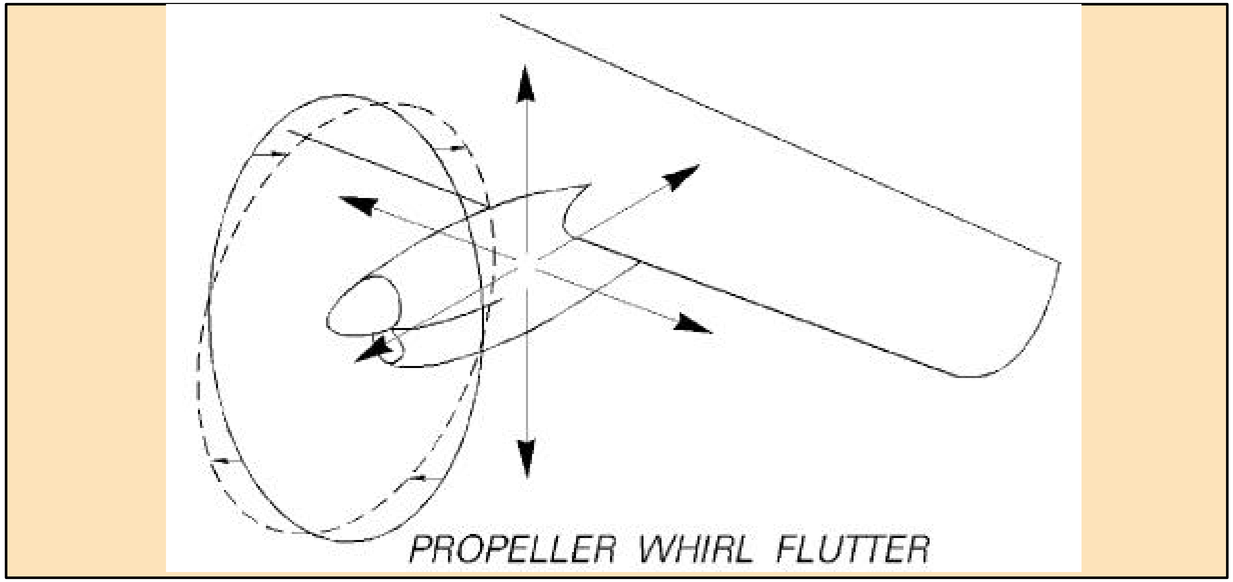


- **Eight airplanes were delivered to Northwest. Northwest suffered their first crash in company history near Bozeman, Montana, killing 10 people, in January 1938.**

HISTORY OF AEROELASTICITY

Other types of inherent aeroelastic problems . . .

- **“Propeller whirl flutter” (wing flutter due to propeller-nacelle-wing interaction) led to the loss of several lives in the Lockheed Electra (a 4-engine turboprop transport).**



- **Several people were killed in the crash of the Israeli ARAVA tactical transport when the wing fluttered catastrophically because a wing strut attaching bolt was improperly torqued -- unfortunately this problem reoccurs (e.g., F-117).**

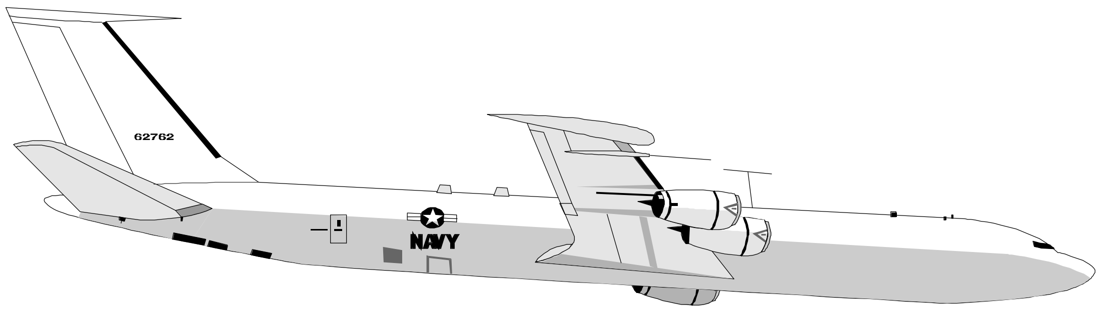
HISTORY OF AEROELASTICITY

- Jet - age incidents still occur . . .

  – wing bending-torsion flutter, encountered in testing of wing-tip fuel tanks for the T-33 (unplanned high speed test points) damaged the airplane beyond repair.

  – initial flutter testing on the KC-135 showed a limited amplitude (LCO) flutter of the vertical tail (24 to 36 in. motion at the top for 46 seconds)

  – E-6A TACAMO (Boeing 707-320) lost the upper half of the fin and rudder; “solved” the problem; and, repeated the failure on the next flight !



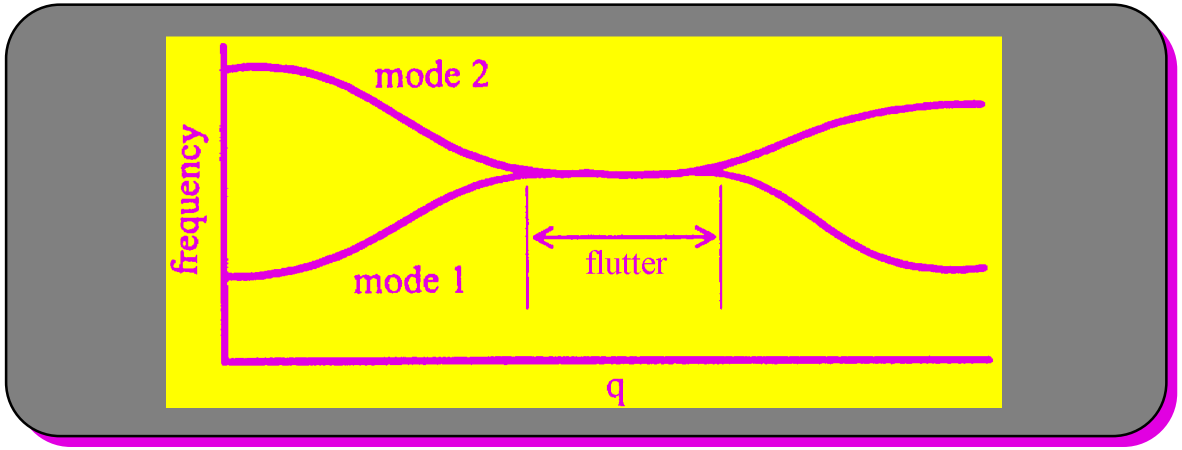
SOME TYPES OF AEROELASTIC PHENOMENA

- STATIC (involves the interaction of aerodynamic and elastic forces)
  - DIVERGENCE -- deformation - dependent aerodynamic forces exceed the elastic restoring capability of the structure
  - CONTROL SURFACE REVERSAL -- control loss or reversal of expected response due to structural deformation (stiffness) of the primary surface
  - LIFT EFFECTIVENESS ----change in magnitude and distribution of aerodynamic loads due to the structural stiffness of the aerodynamic surface

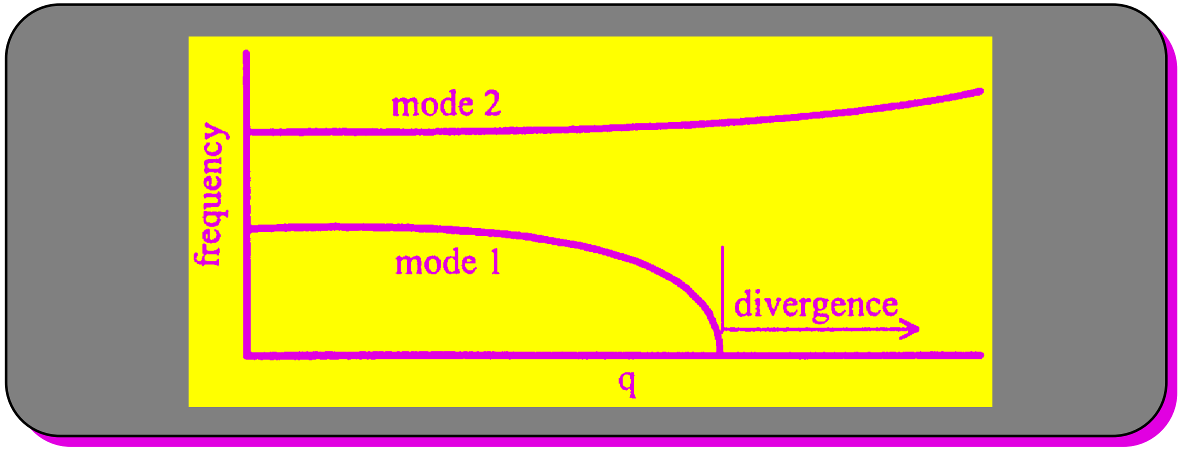
- DYNAMIC (involves the interaction of aerodynamic and elastic and inertial forces)
  - FLUTTER -- an oscillatory instability where one ”mode of motion” is driven to resonance by a second mode. Both modes have coalesced to the same frequency (includes ‘bending-torsion’, propeller whirl, and panel flutter)
  - ‘BUZZ’ and ‘BUFFET’ -- high frequency instabilities caused by flow separations, wakes from forward structures, shock wave oscillations
  - ‘DYNAMIC RESPONSE’ due to gusts, turbulence, and other such atmospheric disturbances that affect aircraft performance

FLUTTER

- Frequency domain solutions may reveal . . .
  - flutter as a coalescence of aeroelastic frequencies of 2 or more modes



  - or, aeroelastic divergence as a “zero frequency” mode



FLUTTER

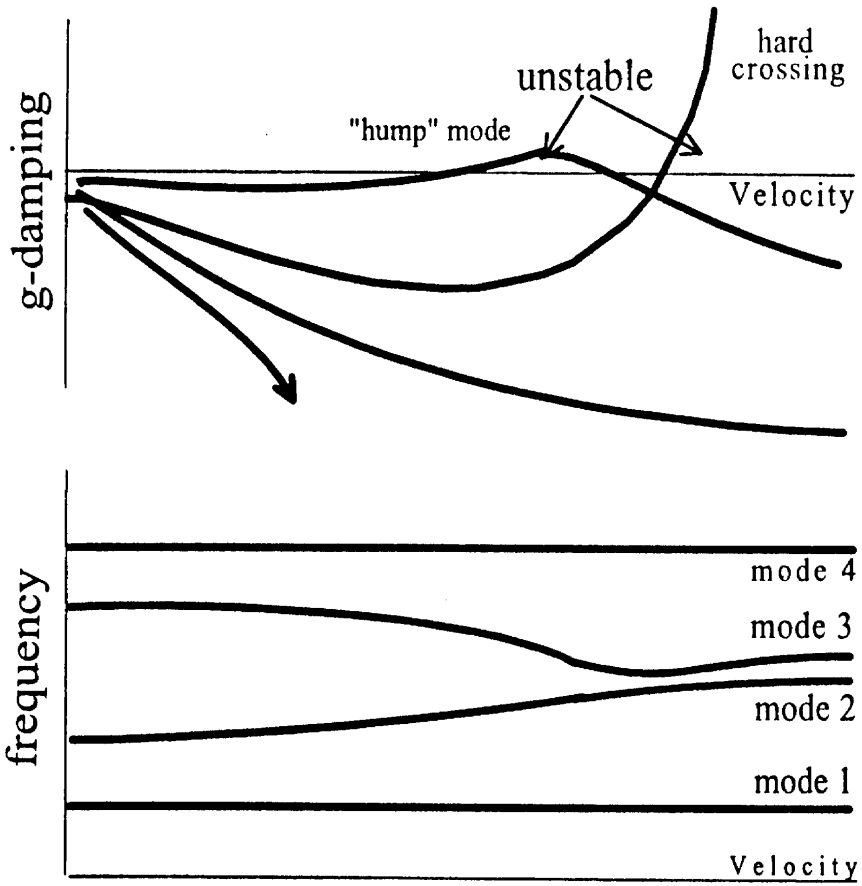
- The V-*g* (Velocity-damping) chart is a popular way to present frequency domain solutions

- **A V-g Diagram is constructed for each altitude and Mach no., the V-g diagram shows damping for increasing freestream velocity.**

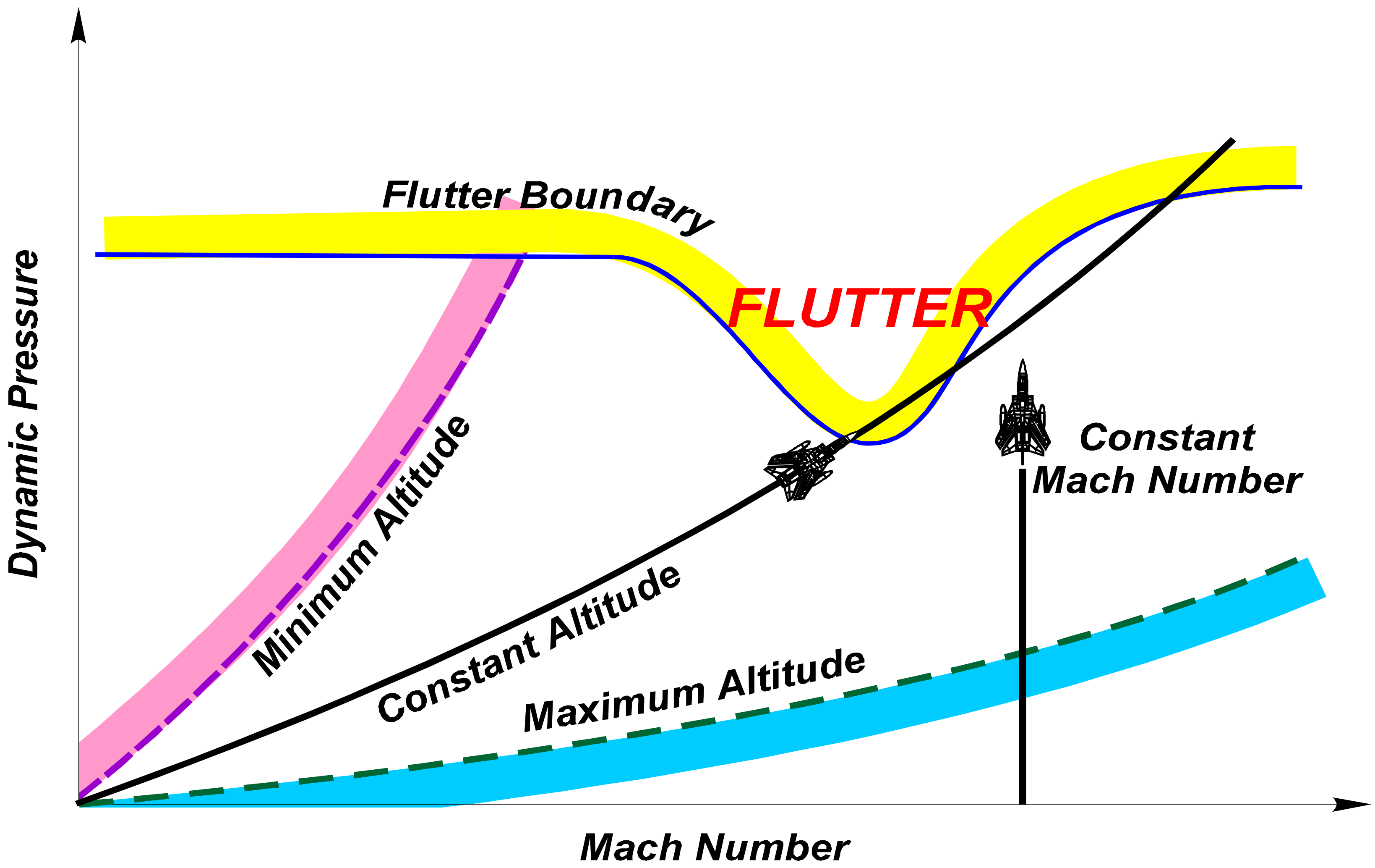
- **Critical modes may be sensitive to damping, the path (somewhat) indicates the nature and severity of the instability.**

- **Aerodynamic loads affect both frequency & damping, but some modes are insensitive to aerodynamics.**

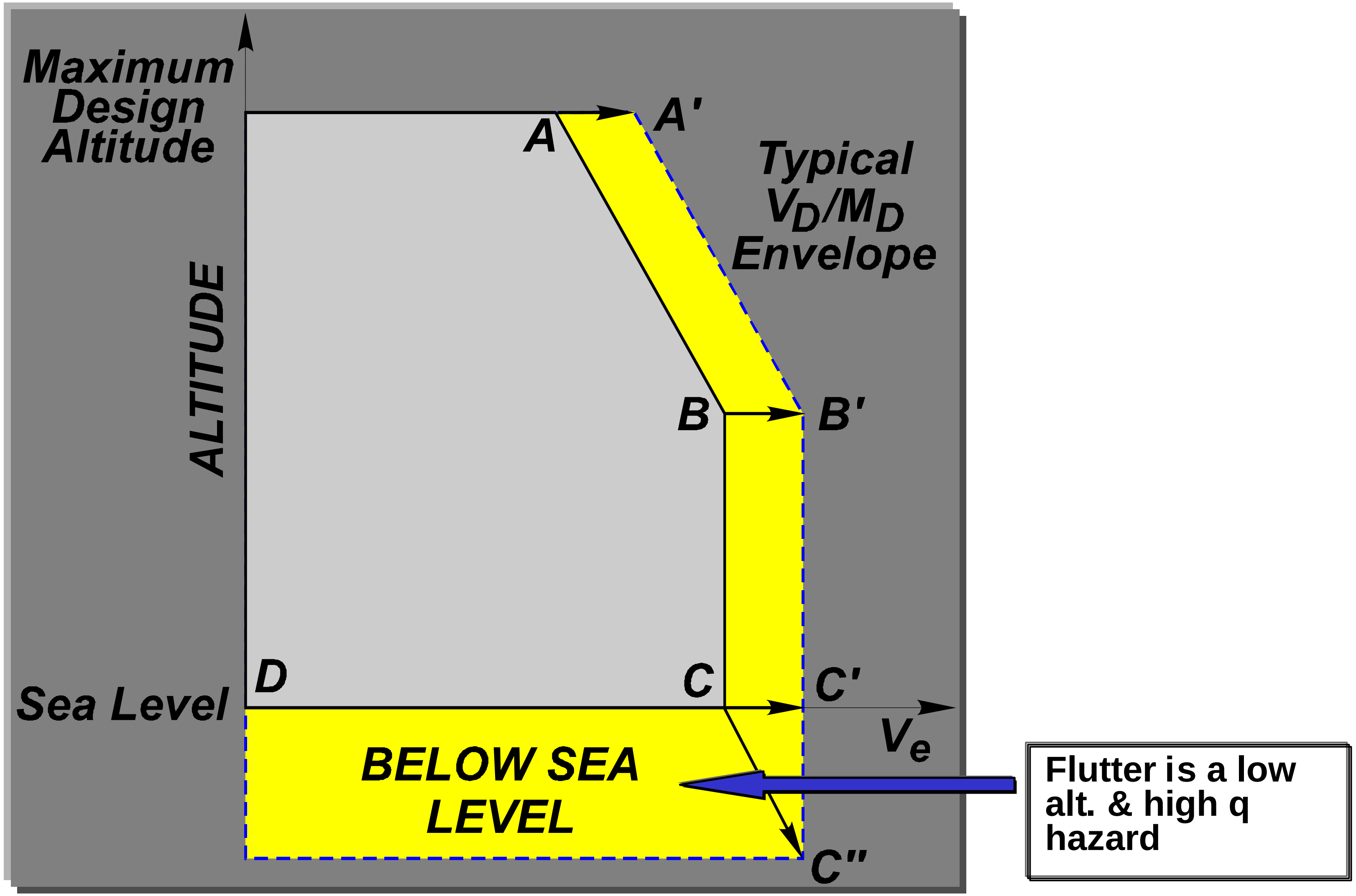
- **The number of roots depends upon the number of D.O.F. in the system or modes of vibration used in the solution.**



IMPACT OF FLUTTER ON FLIGHT



FLIGHT FLUTTER CLEARANCE REQUIREMENTS



DOCUMENTS OF INTEREST INCLUDE:

- Military Specifications
  - MIL-A-8870A, airplane strength, rigidity, flutter divergence, March 31, 1971.
  - MIL-F-9490D, flight control system - design, installation and test of piloted aircraft
- Civilian Specifications
  - FAR 23.629 Applies To Normal, Utility, Aerobatic, And Commuter Aircraft
  - FAR 25.629 Applies To Transport Category Airplanes
- Other documents that may prove helpful
  - "Structures Flight Test Handbook," Norton, W.J., AFFTC-TIH-90-001, Air Force Flight Test Center, Edwards AFB, California, Nov. 1990.
  - "Aeroelastic Flight Test Techniques and Instrumentation," Van Nunen, J. W. G., and Piazzoli, G., AGARD-AG-160, Vol. 9, AGARD, London, England, Feb. 1979.
  - "Aeroelasticity / aircraft structures," Chapter 12, Flying Qualities Phase, USAF Test Pilot School, Edwards AFB, California.
  - "Flight Control System Structural Response and Limit Cycle Oscillation," Kirsten, P. W., AGARD Conf. Proc. No. 233, Flight Test Techniques, London, England

AEROELASTICITY BRANCH
Structures and Materials Competency
NASA LaRC

<u>Vision Statement</u>: Our Vision Is to Be the World's Leader in Performing Innovative Aeroelastic Research, in Developing Cost-Effective Aeroelasticity Methods and Unique Advanced Concepts, in Conducting High Quality Wind-Tunnel Tests, and in Serving as a Technology Resource for the U.S. Aerospace Industry, the Department of Defense, Academia, and NASA.

<u>Mission Statement</u>: Our Mission Is to Provide a Strategic and Critical Role to the U.S Aerospace Community by Conducting Pioneering Research to Obtain a Fundamental Understanding of Complex Unsteady Aerodynamic Flow and Aeroelastic Phenomena Experienced by Flight Vehicles, in Developing and Validating Methods and Innovative Concepts, and in Performing Ground and Wind-Tunnel Tests.

GOALS

- Develop basic fundamental knowledge, analytical methods, & advanced concepts
- Define aeroelastic & aeroservoelastic characteristics of advanced aircraft & r/c
- Control and exploit aeroelastic response through active and passive means
- Maintain Transonic Dynamics Tunnel as a unique national facility
- Validate wind tunnel test results for prediction of flight aeroelastic events
- Through wind tunnel testing identify the aeroelastic properties of DOD and industry flight vehicles
- Acquire experimental data for method validation and advanced concept verification
- Provide aeroelastic expertise to DOD, industry, and NASA projects

FUNCTIONAL STATEMENT

Engineers and scientists in the Aeroelasticity Branch are able to perform research to:

- Develop fundamental knowledge & understanding of complex steady/unsteady aerodynamic flow & aeroelastic phenomena, especially in the transonic speed range

- Develop analytical methods that accurately predict aeroelastic phenomena including flutter, buffet, buzz, limit cycle oscillations, and gust response, and steady and unsteady aerodynamic flow phenomena that include viscous effects, vortex flows, separated flows, transonic nonlinearities, and unsteady shock motions

- Apply analytical methods to solve relevant aeroelastic problems related to fixed- and rotary-wing aircraft and launch vehicles

- Investigate, develop, and demonstrate unique concepts that employ smart materials and/or aerodynamic surfaces to prevent aeroelastic instabilities, reduce loads and vibrations, and alleviate adverse structural response

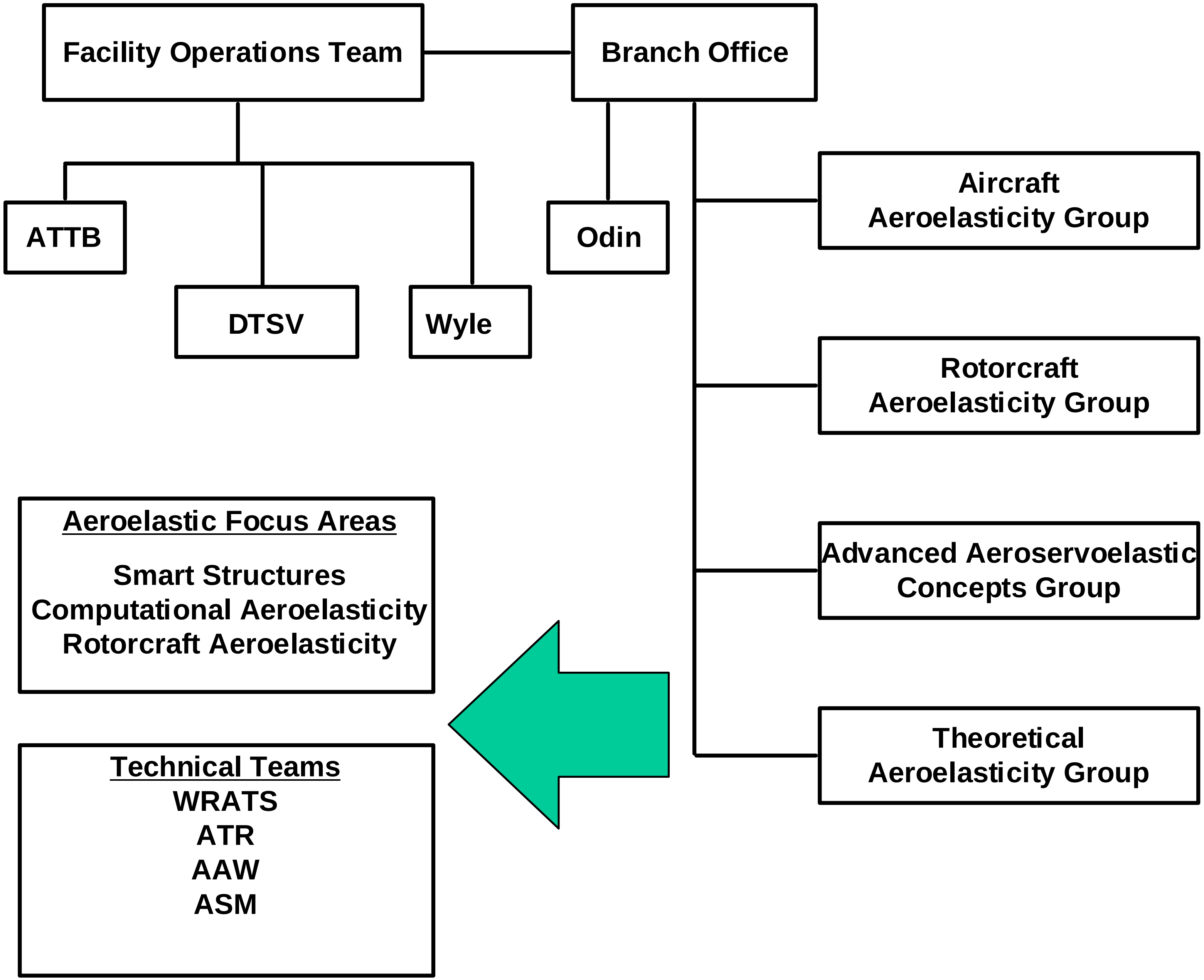
- Operate and maintain the Transonic Dynamics Tunnel and the Rotorcraft Hover Test Facility, and perform model tests to support industry, NASA, and other programs

- Provide technical expertise to support simulations, ground testing, wind-tunnel tests, and flight experiments of current and future flight vehicles

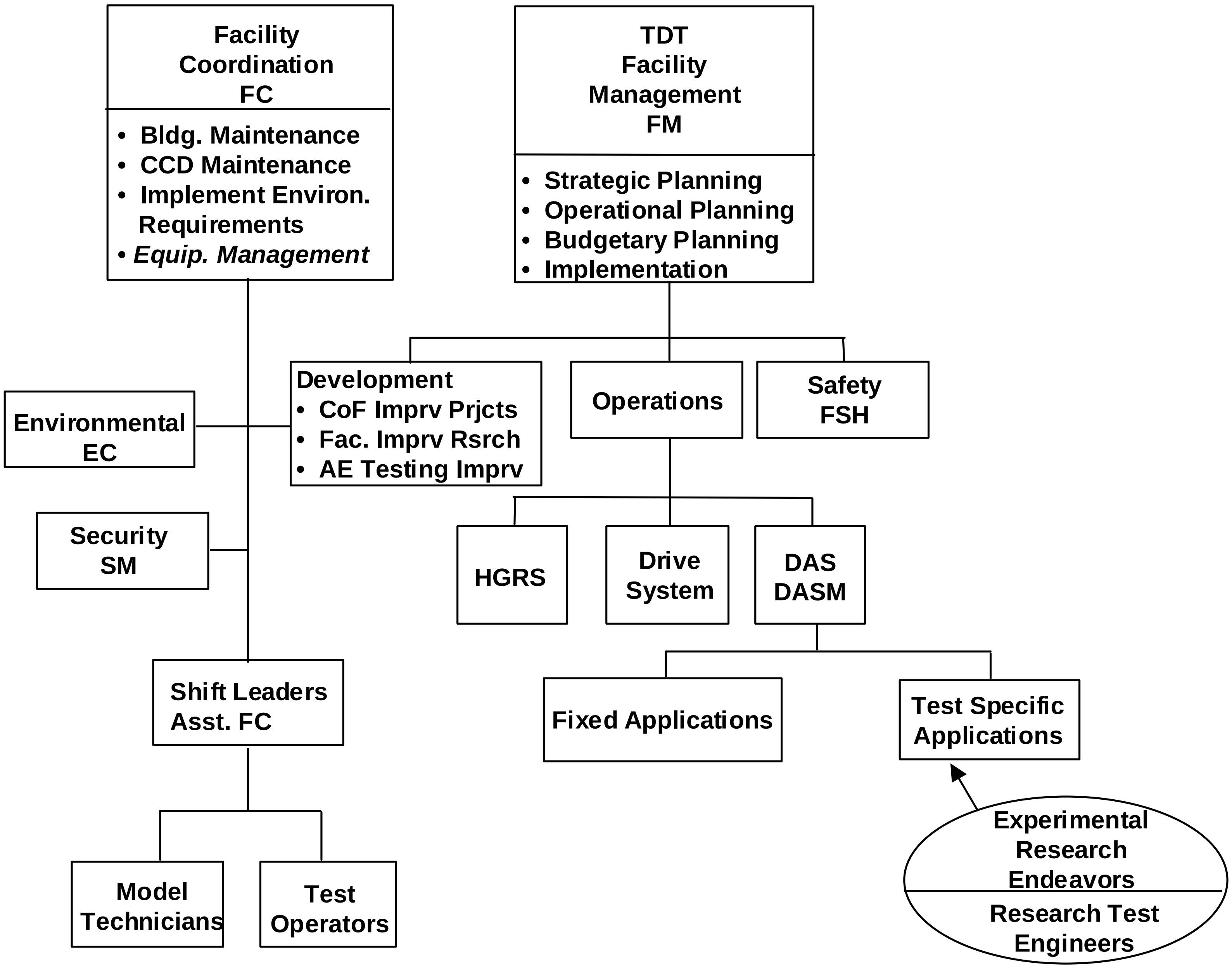
MAJOR AREAS OF RESEARCH EMPHASIS

- Smart Materials Applications to Aerodynamic/Aeroelastic Problems
- Active Controls Applications to Aeroelastic Problems
- Computational Aerodynamics/Aeroelasticity
- Twin-Tail Buffeting Control
- Active Aeroelastic Wing/Maneuver Loads
- Helicopter Rotor Aeroelasticity
- Tiltrotor Aeroelasticity
- High Speed Transport Aeroelasticity
- Blended Wing Body Aeroelasticity
- Flow Characteristics of Transonic Dynamics Tunnel (TDT)
- Testing in the TDT and in the Rotorcraft Hover Test Facility

AEROELASTICITY BRANCH - ORGANIZATION



FACILITY MANAGEMENT



AEROELASTICITY BRANCH - AFFILIATIONS

Branch Office

Tom Noll, Branch Head (detailed to SMC)
Boyd Perry, Assistant Branch Head (acting BH)
Stan Cole, Facility Manager (acting ABH)
Jerry Garcia, Data Acquisition Manager
Wesley Goodman, Facility Safety Head

Theoretical Aeroelasticity

Dave Schuster (Ld)
Bob Bartels
John Edwards
Ray Kvaternik
Walt Silva

Advanced Aeroservoelastic Concepts

Rob Scott (Ld)
Jennifer Heeg
Bob Moses
Dave Piatak
Carol Wieseman

Aircraft Aeroelasticity

Tony Rivera (Ld)
James Florance
Jennifer Florance
Don Keller
Robert Sleeper

Rotorcraft Aeroelasticity

Bill Yeager (Ld, A)
Renee Lake (A)
Chester Langston (A)
Mark Nixon (A)
Jeff Singleton (A)
Matt Wilbur (A)

A - Army
Ld - Leader

AEROELASTICITY BRANCH - TECHNICAL TEAMS

Aeroservoelastic Semispan Model

Scott - Technical Leader
JRFlorance
Keller
Kvaternik
Schuster
Silva
Wieseman

Active Aeroelastic Wing

Heeg - Technical Leader
JPFlorance
Schuster
Wieseman
Perry (NASA-Langley AAW Board Member)

WRATS

Nixon - Technical Leader
Kvaternik
Lake
Langston
Piatak
Singleton

Active Twist Rotor

Wilbur - Technical Leader
Lake
Langston
Yeager

GROUP FUNCTIONS

<u>THEORETICAL AEROELASTICITY</u>

CFD Unsteady Aerodynamics
Computational Aeroelasticity
Nonlinear Aeroelasticity
Aeroelastic Analyses
Aeroservoelastic Analyses

<u>ADVANCED AEROSERVOELASTIC CONCEPTS</u>

Aeroservoelasticity
Active/Adaptive Controls
Exploiting Aeroelasticity
Smart Materials

<u>AIRCRAFT AEROELASTICITY</u>

Aeroelastic Characteristics
Flutter Clearance
Steady/Unsteady Aerodynamics

<u>ROTORCRAFT AEROELASTICITY</u>

Helicopter Loads/Vibration
Aeromechanical Stability
Rotor Performance
Tiltrotor Aeroelasticity
Army Requirements

GROUP LEADER RESPONSIBILITIES

Responsibilities To Group Members
- Technical Leadership
- Mentorship & Encouragement
- Performance Planning
- Participate in Assigning Tasks to Group Members
- Liaison to Branch Office (360^o Communication)

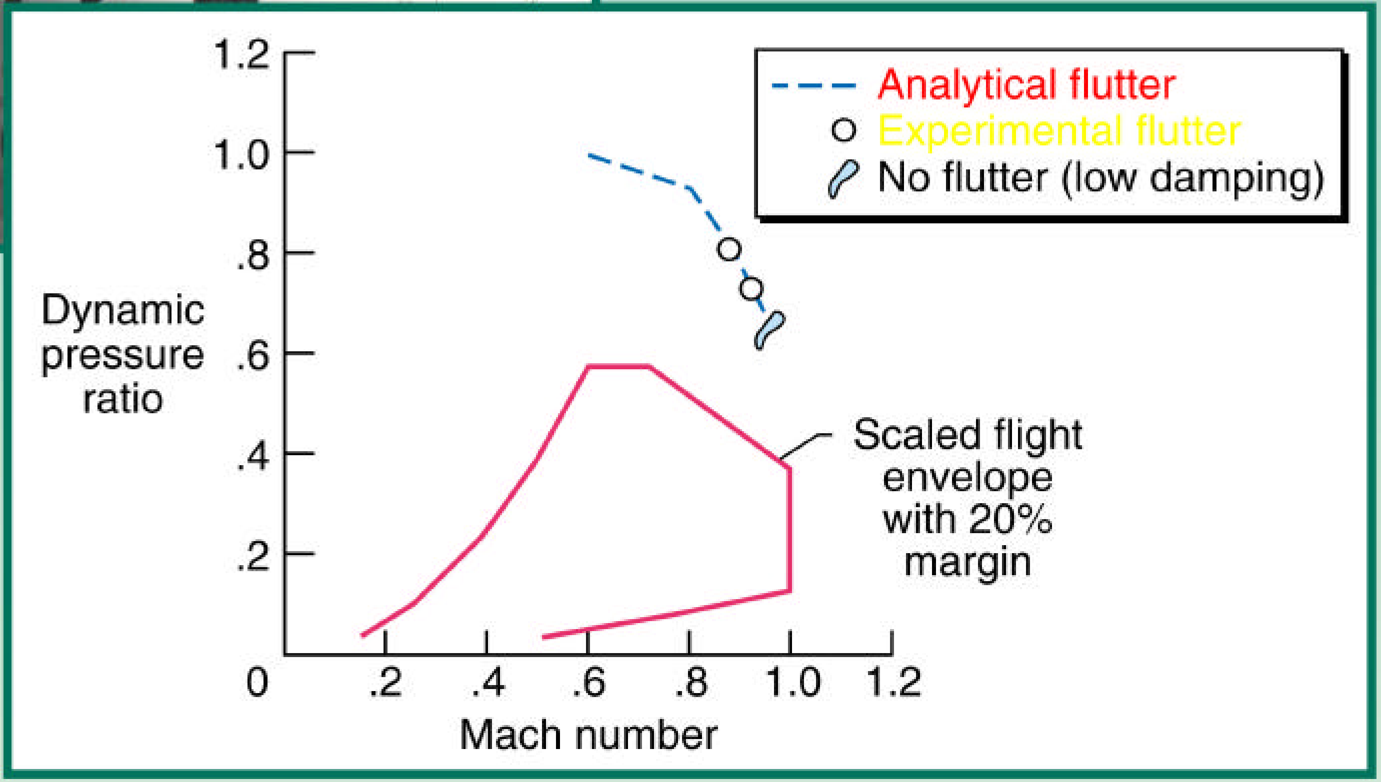
Responsibilities To Branch Office
- Liaison to Group (360^o Communication)
- Advocate for Group
- Research Planning
- Resource ($$ and WF) Budgeting

Responsibilities To Self
- CONDUCT RESEARCH

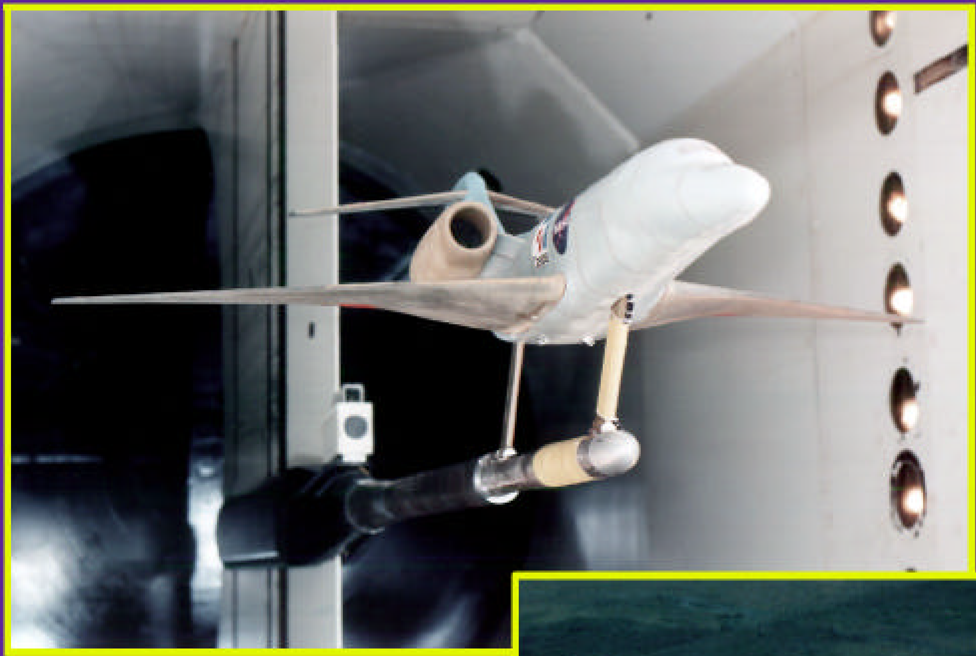
CHARACTERISTICS OF GROUPS, TEAMS, AND AEROELASTIC FOCUS AREAS

Group	Team	AFA
• Group Leader	• Team Leader	• Facilitator (Rotating)
• Collection of Individuals Supporting AB Core Capability	• Collection of Individuals Supporting Specific AB, LaRC ... Research Goals	• Collection of Individuals Interested in a Very Focused Area of Aeroelasticity
• Research $$ from RTAs	• Research $$ from an RTA	• No $$
• Research Workforce	• Team Members Assigned from Groups	• Membership Voluntary to All Branch Members
• Maintain AB Core Capabilities	• Team Research Performed	• No Research Performed
• Administrative Unit (e. g. Perf. Planning, Research Planning, etc)	• Technical Unit (Technical Planning Specific to Project)	• Open Forum for Planning and Coordinating Activities
• Accountable for Milestones and Deliverables	• Accountable for Milestones and Deliverables	• No Milestones or Deliverables
• Formal Entity	• Formal Entity	• Informal Entity

FIRST PHASE OF CESSNA CITATION X FLUTTER-CLEARANCE TESTS COMPLETED IN TDT



TDT TEST RESULTS PROVIDE GUIDANCE FOR CESSNA CITATION X FLIGHT FLUTTER CLEARANCE PROGRAM



STABILITY BOUNDARIES ESTABLISHED FOR BASELINE CONFIGURATION OF WRATS TILTROTOR MODEL