AEROELASTICITY BRANCH OVERVIEW

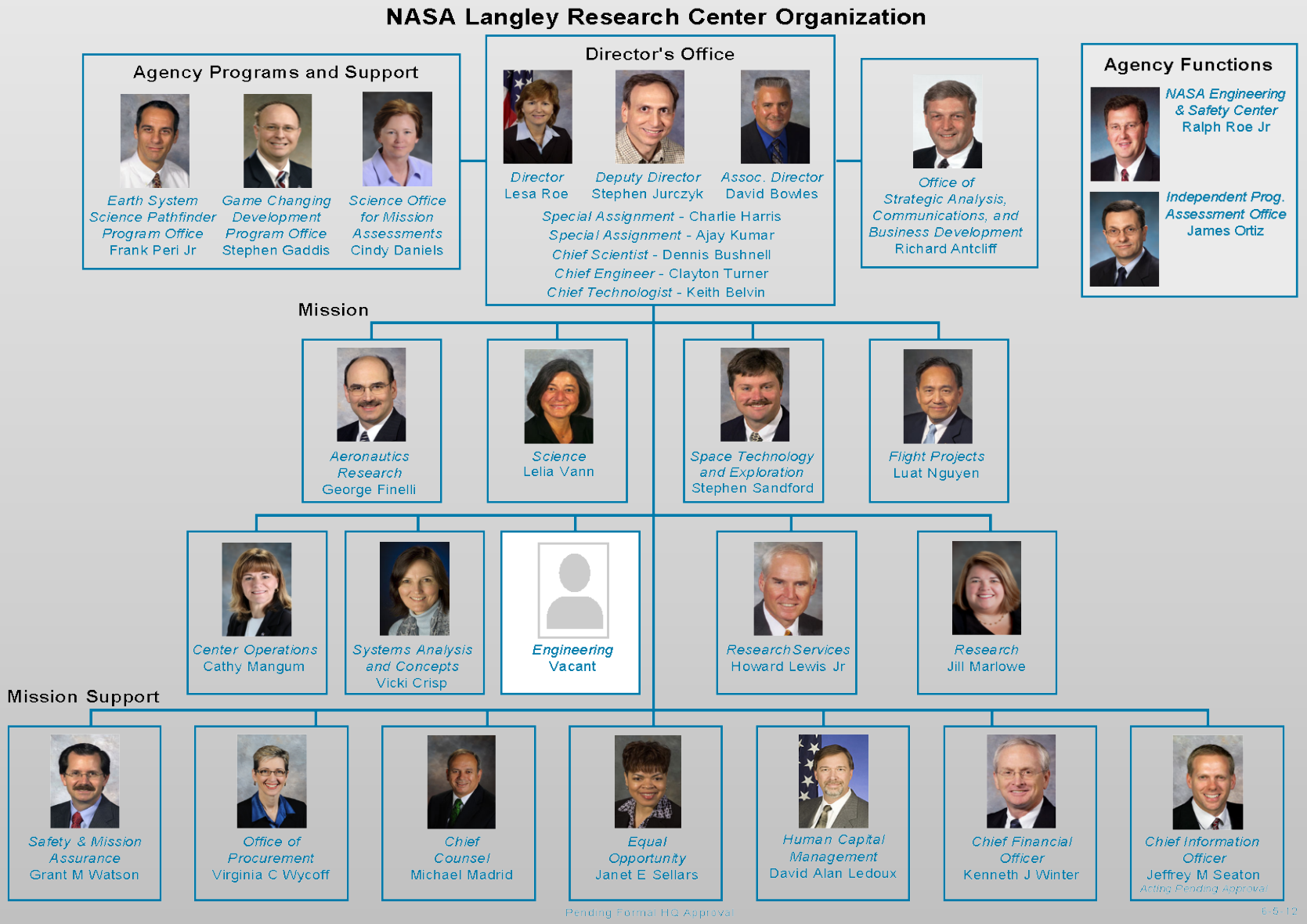
Stanley R. Cole, Branch Head
Boyd Perry III, Assistant Branch Head

Aeroelasticity Branch
NASA Langley Research Center
Hampton, Virginia

OUTLINE

- Our place within NASA
- Our vision
- Our branch and discipline
- Our mission
- Our realm of influence
- Our technical program
- Our recent successes
- Our bottom line (summary)

NASA Langley Research Center Organization



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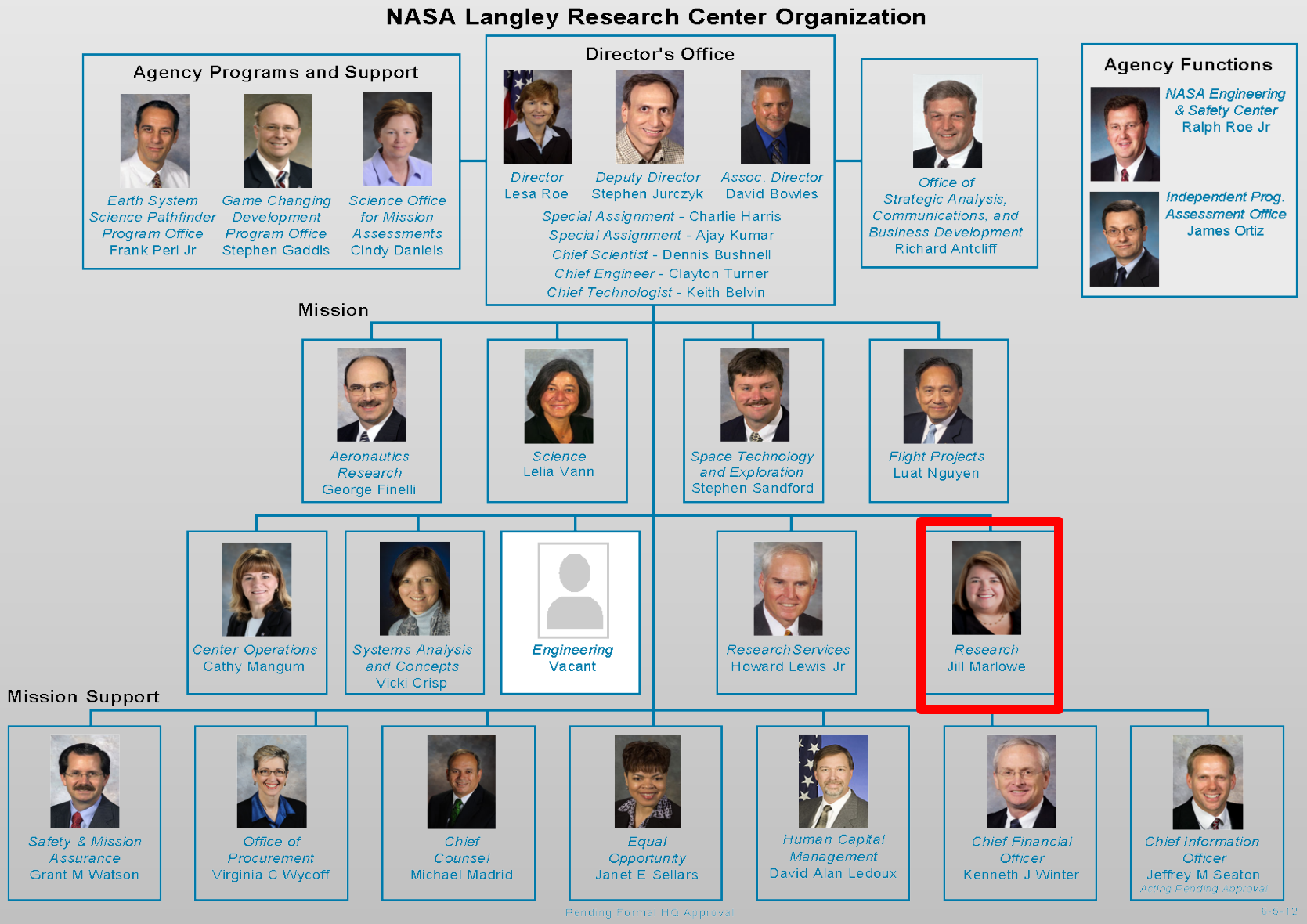

Research Directorate (RD)

Business Support Team

Darlene T. Baxter and Michelle L. Sample
Business Managers

Lori W. Brown and Bonnie J. Lumanog
Administrative Officer

Sherry L. Cox
Secretary

L. David Wall
Center Support Contracts Manager

Lori S. Rowland
IT and Computer Security Official

Senior Leadership Team

Charles E. Harris, Director, R&T
Steven G. Reznick, Deputy Director, R&T
Jerome T. Kegelman, Deputy Director for R&T Test Operations
Edward A. Healy, Jr., Deputy Director for R&T Program Implementation
Brenton W. Weathered, Chief Engineer for Airborne Systems
Larry Leavitt, Chief Engineer for Aerodynamics, Hypersonics, Acoustics
W. Keith Belvin, Chief Engineer for Structures and Materials
Edward R. Generazio, Agency NDE Specialist
Joe W. Posey, Senior Research Engineer for Acoustics

Safety Professionals

Peter M. Kjeldsen,
Internal Quality Assessment Specialist
Charles B. Zeitman,
Safety and Occup Health Manager
Clifford B. Williford,
Safety and Occup Health Manager

Configuration Aerodynamics Branch
vacant, Head
Zachart T. Applin, Assist. Head

Computational Aerosciences Branch
Mujeeb R. Malik, Head
Joseph H. Morrison, Assist Head

Flow Physics and Controls Branch
Anthony E. Washburn, Head
Catherine B. McGinley, Assist. Head

Advanced Sensing & Optical Measurement Branch
Kenneth D. Wright, Head
Gary A. Fleming, Assist. Head (Detail to SED)

Aerothermodynamics Branch
N. Ronald Merski, Head
Michael Difulvio, Assist. Head

Hypersonic Airbreathing Propulsion Branch
Kenneth E. Rock, Head
Shelly M. Ferlemann, Assist. Head
J. Philip Drummond, Associate Head

Advanced Materials and Processing Branch
Joycelyn S. Harrison, Head (Detail NSF)
Emilie J. Siochi , Assist. Head
Erik S. Weiser, Assist. Head

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Durability, Damage Tolerance and Reliability Branch
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Edward H. Glaessgen, Assist. Head

Gas, Fluid and Acoustics Research Support Branch
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Glenn A. Brehm, Section Head
William H. Presson, Jr. , Section Head
Richard D. White, Jr. , Section Head

Structural Mechanics and Concepts Branch
H. Kevin Rivers, Head (Detail Ares 1-X)
Stephen J. Scotti, acting Head
David Brewer, Assist. Head

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D. Michele Heath, Assist. Head

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Flight Dynamics Branch
Charles M. Fremaux, Head

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- Our recent successes
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OUR VISION

To carry out research and technology development to obtain a fundamental understanding of, to quantify, and to control complex unsteady aerodynamic flow and aeroelastic phenomena experienced by aerospace vehicles

To strive to maintain and improve the condition of mankind, starting with the United States, through aeronautical engineering collaboration, research, and development aimed at meeting national needs, desires, and the NASA mission

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AB WORK AREAS

Computational Aeroelasticity

Structured & Unstructured Grid CFD
Moderate Fidelity TSD Analysis
Unsteady Aerodynamics
Static and Dynamic Aeroelasticity
Reduced Order Modeling

Aeroservoelasticity

Aeroelastic / Aeroservoelastic Analysis
Active / Adaptive Controls
Exploiting Aeroelasticity
Smart Materials Applications

Aerospace Vehicle Aeroelasticity

Fixed-wing Aeroelastic Clearance
Steady/Unsteady Aerodynamics
Linear flutter calculations

Launch Vehicle Aeroelastic Stability
Ascent Buffet Loads
Ground Wind Loads

Helicopter Rotor Loads and Vibrations
Aeromechanical Stability
- Rotor Performance
- Tiltrotor Aeroelasticity

Experimental Aeroelasticity

Testing Expertise
- Transonic Dynamics Tunnel
- Mounting Systems

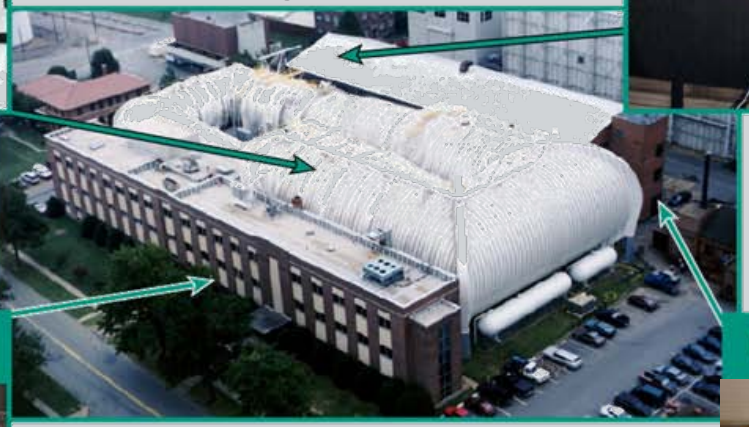
Operational Knowledge
- Airstream Oscillator Operations
- Oscillating Turntable
- TDT & Model Safety Features
- Data Acquisition Systems

Experimental Databases for Code Validation

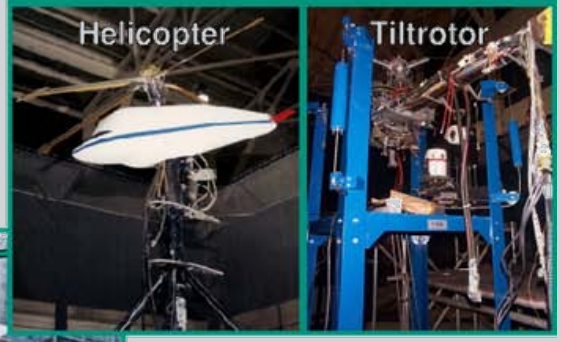
EXPERIMENTAL FACILITIES USED BY AB

TDT Test Section

Transonic Dynamics Tunnel



Rotorcraft Hover Test Facility



Model Preparation Area #1

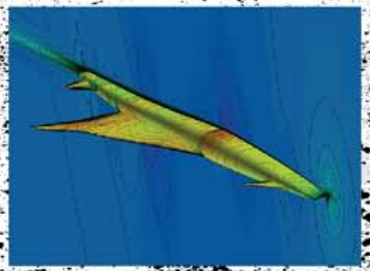
Model Preparation Area #2

AB MEMBERS

- 19 AB NASA civil servant engineers (6 PhD, 10 MS, 1 PE)
- 4 AB Army civil servant engineers (1 PhD, 1 MS)
- 2 National Institute of Aerospace (NIA) engineers (both Army)
- 1 Graduate Co-Op Student (Old Dominion University)
- 9.4 work-year equivalents under contract
    - 1 system administrator
    - 4 test engineers
    - ~3 engineers (research, control)
    - 1 mechanical technician (Army)
    - 0.4 Graphics illustrator

Aeroelasticity Branch
NASA Langley Research Center

MEMBERS



Stan Cole
Branch Head

Boyd Perry, III
Assistant Branch Head

Pam Bussey
Branch Secretary

Karen Myers
System Administrator

Lee Pollard
Sr. Graphic Designer

Bob Bartels
Sr. Research Aerospace Engineer

Pawel Chwalowski
Sr. Aerospace Engineer

Bob Doggett
Distinguished Research Associate

James Florance
Aerospace Engineer

Jennie Florance
Aerospace Engineer

Christie Funk
Graduate Co-Op Student

Jen Heeg
Sr. Research Aerospace Engineer

Ji Young Hur
Research Aerospace Engineer

Thomas G. Ivanco,
Research Aerospace Engineer

Don Keller
Sr. Aerospace Engineer

Ray Kvaternik
Distinguished Research Associate

Andrew Kreshock
Aerospace Engineer

Chester Langston
Electronics Engineer

Steve Massey
Sr. Research Aerospace Engineer

David J. Piatak
Sr. Research Aerospace Engineer

Tony Pototzky
Sr. Research Aerospace Engineer

Mike Ramsey
Mechanical Engineering Technician

Russ Rausch
Sr. Research Aerospace Engineer

Mark Sanetrik
Aerospace Engineer

Rob Scott
Sr. Research Aerospace Engineer

Martin Sekula
Research Aerospace Engineer

Jinwei Shen
Sr. Aeronautical Engineer

Walt Silva
Sr. Research Aerospace Engineer

Bill Stevens
Aerospace Engineer

Rob Thornburgh
Research Engineer

Carol Wieseman
Sr. Aerospace Engineer

Matt Wilbur
Sr. Research Engineer

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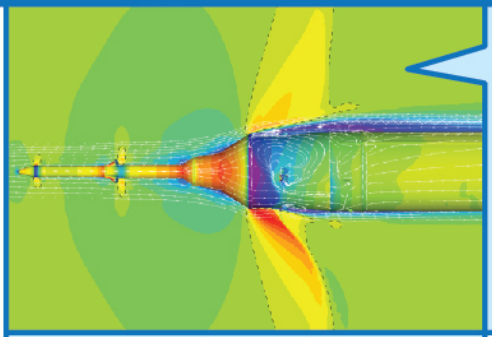
Aeroelasticity Branch

… an integrated research and technology organization offering comprehensive analysis and experimentation capabilities focused on obtaining a fundamental understanding of aeroelastic and unsteady-aerodynamic phenomena experienced by aerospace vehicles, especially in the transonic speed regime.

POC: Stan Cole 757.864.1267
Stanley.R.Cole@nasa.gov
http://aeroelasticity.larc.nasa.gov/

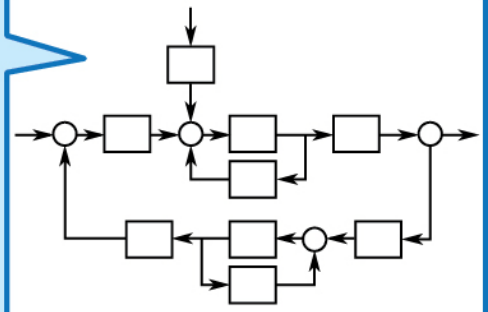


Launch Vehicle Aeroelasticity

- Aeroelastic Stability
- Ascent Buffet Loads
- Ground Wind Loads

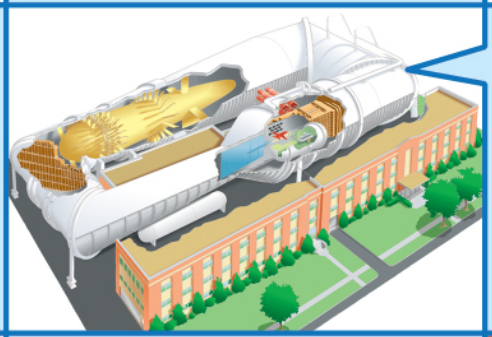
Aeroservoelasticity

- Flutter Suppression
- Gust Load Alleviation
- Ride Quality Control
- Relaxed Static Stability



Aircraft Aeroelasticity

- Flutter, Divergence
- Buffeting, Control Surface Buzz
- Turbulence Response
- Limit Cycle Oscillations

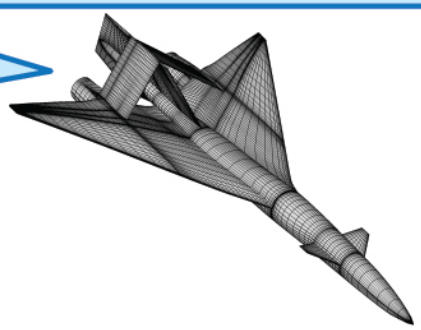


Experimental Aeroelasticity

- Transonic Dynamics Tunnel
  - Heavy gas test medium for better similitude
  - Many features for model safety
  - Variety of mounting systems
  - Airstream oscillator system

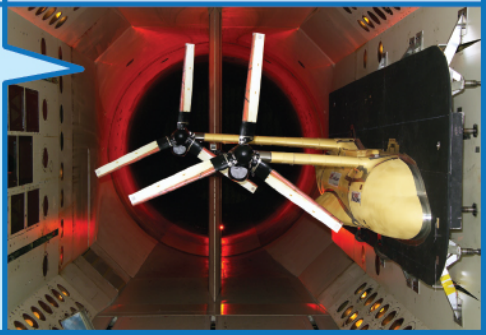
Computational Aeroelasticity

- State-of-The-Art Codes (FUN3D, CFL3D)
- Static and Dynamic Aeroelasticity
- Reduced Order Models
- Grid Generation



Rotorcraft Aeroelasticity

- Aeromechanical Stability
- Active Twist Rotor
- Tiltrotor Aeroelasticity



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OUR REALM OF INFLUENCE, 1 of 2

- **Technical / program committee membership**
  - International Forum on Aeroelasticity and Structural Dynamics (Org. Comm.)
  - NATO RTO AVT Mechanical Systems, Structures, and Materials (Chair)
  - TTCP Technical Panel – 4, Structures and Dynamics (Member)
  - AIAA Structural Dynamics TC (Member)
  - AHS Aircraft Design Committee (Chair)
  - AHS Design Competition Steering Committee (Member)
- **Technical society participation**
  - AIAA Aeroelastic Prediction Workshop (Chair & Org. Comm.)
  - Frequent participation in AIAA ASM, SDM, Applied Aero, IFASD conferences
  - Provide lecturers for bi-annual AIAA short course on aeroelasticity
  - Special sessions at national and international conferences
- **Technical expertise shared with technical community**
  - Teach invited short courses for industry (Boeing, Gulfstream, Embraer)
  - Provide invited speakers at major universities (Texas A&M, Michigan, Montreal)
  - Provide PhD dissertation committee members at major universities (UMich, W&M, VaTech, ODU, Delft, KTH)
  - Teach graduate courses in local universities (W&M, ODU)

OUR REALM OF INFLUENCE, 2 of 2

- **Cooperating with others in technical work**
  - Space Act Agreements (SAAs)
- **Monitoring the technical work of others**
  - Small Business Innovation Research (SBIR) contracts
  - NASA Research Announcement (NRA) contracts
- **Technical documentation / dissemination**
  - NASA TPs and TMs
  - Journal articles and conference papers
  - Engineering reports and databases of analyses and tests
  - Patents
- **NASA Educational program participation**
  - Cooperative Education (Co-Op) program
  - Graduate & Undergraduate Student Researchers (GSRP & USRP) programs
  - Langley Aerospace Research Summer Scholars (LARSS) program
  - Regular visits to local elementary schools

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OUR TECHNICAL WORK

- NASA organizations that directly support our work
  - Aeronautics Research Mission Directorate
    - Fundamental Aeronautics Program
      - Supersonics Project
      - Subsonic Fixed Wing Project
      - Subsonic Rotary Wing Project
    - Aviation Safety Program
      - Vehicle Systems Safety Technologies Project
    - Aeronautics Test Program
  - Human Exploration & Operations Mission Directorate
    - Commercial Space Flight Development
      - Commercial Crew Development
    - Exploration Systems Development
      - Space Launch System

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AB TECHNICAL WORK SUPPORTED BY FUNDAMENTAL AERONAUTICS

- Supersonics
  - Aeroservoelasticity
- Subsonic Fixed Wing
  - Efficient Aerodynamics
  - Lightweight Airframe & Propulsion Systems
- Subsonic Rotary Wing
  - Aeromechanics

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- Supersonics
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- Subsonic Fixed Wing
  - Efficient Aerodynamics
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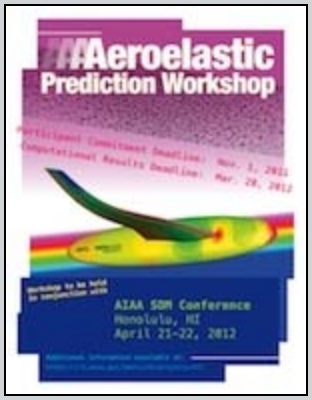
- Subsonic Rotary Wing
  - Aeromechanics

- Full-span aeroelastic (AE) and aeroservoelastic (ASE) analyses, with focus on a realistic structural definition of an N+2 configuration:
  - FEM development, sizing, etc (Lockheed-Martin, NASA)
  - Linear AE analyses (LM, NASA)
  - Nonlinear (FUN3D) AE analyses (NASA)
  - ROM development (FUN3D)
  - Linear and ROM ASE model development
  - APSE development
  - Structural optimization
  - Active controls

AB TECHNICAL WORK SUPPORTED BY FUNDAMENTAL AERONAUTICS

- Supersonics
  - Aeroservoelasticity



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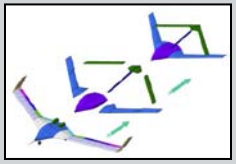


- Subsonic Fixed Wing
  - Efficient Aerodynamics
  - Lightweight Airframe & Propulsion Systems

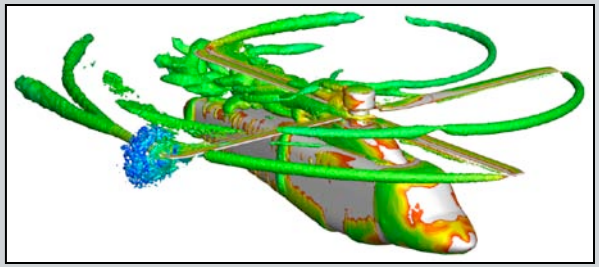
- Subsonic Rotary Wing
  - Aeromechanics

- TBW gust-load-alleviation TDT Test
- Nonlinear ASE control-centric method development
- Aeroelastic Prediction Workshop
- Probabilistic aeroelasticity
- FUN3D code enhancement
  - o ASE capability
  - o Gust capability
  - o Nonlinear structural models

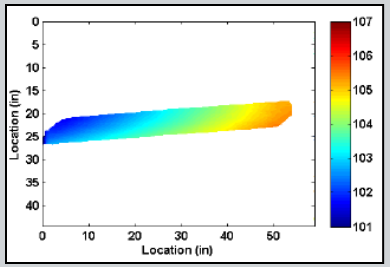
AB TECHNICAL WORK SUPPORTED BY FUNDAMENTAL AERONAUTICS

- Supersonics
  - Aeroservoelasticity
- Subsonic Fixed Wing
  - Efficient Aerodynamics
  - Lightweight Airframe & Propulsion Systems

CFD/CSD Analysis



PIV Capability



- Subsonic Rotary Wing
  - Aeromechanics

- Research and understand the characteristics and effectiveness of piezo-electrically actuated, actively controlled rotors
  - o Comprehensive and CFD/CSD analyses
  - o TDT Test
- Development of a full-rotor-disk Projection Moiré Interferometry (PIV) blade displacement measurement system
- GPC control-law development for tiltrotor applications

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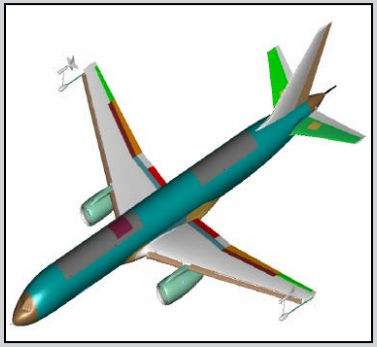
    - Aeronautics Test Program
  - Human Exploration & Operations Mission Directorate
    - Commercial Space Flight Development
      - Commercial Crew Development
    - Exploration Systems Development
      - Space Launch System

AB TECHNICAL WORK SUPPORTED BY AVIATION SAFETY

- Vehicle Systems Safety Technologies Project

Generic Transport Model (GTM)



- Dynamic stability derivatives
  - o Analytically predict dynamic stability derivatives for “intact” and “damaged” configurations
  - o Investigate improved data filtering techniques for dynamic stability derivative testing
- Extend correction factor methodology to static-aeroelastic configurations
- Add flexible modes to GTM 6-DOF simulation
- Asses the importance of modeling aeroelastic effects in aircraft simulations of loss-of-control events

OUR TECHNICAL WORK

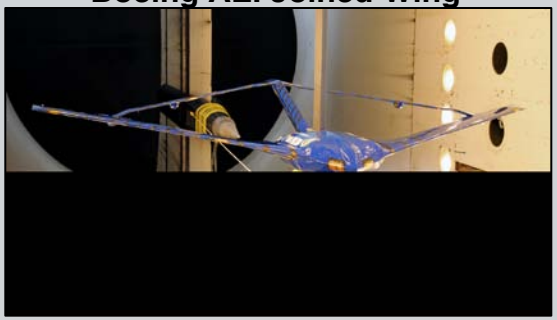
- NASA organizations that directly support our work
  - **Aeronautics Research Mission Directorate**
    - Fundamental Aeronautics Program
      - Supersonics Project
      - Subsonic Fixed Wing Project
      - Subsonic Rotary Wing Project
    - Aviation Safety Program
      - Vehicle Systems Safety Technologies Project
    - **Aeronautics Test Program**
  - Human Exploration & Operations Mission Directorate
    - Commercial Space Flight Development
      - Commercial Crew Development
    - Exploration Systems Development
      - Space Launch System

AB TECHNICAL WORK SUPPORTED BY AERONAUTICS TEST PROGRAM

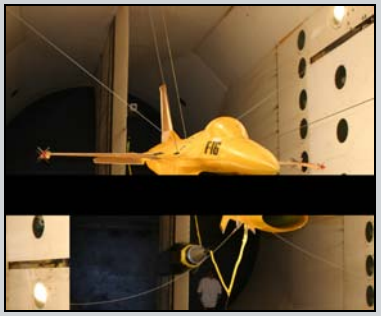
- AB provides experimental aeroelastic expertise for most tests conducted in the Langley Transonic Dynamics Tunnel (TDT)

Semi-Span Supersonic Transport

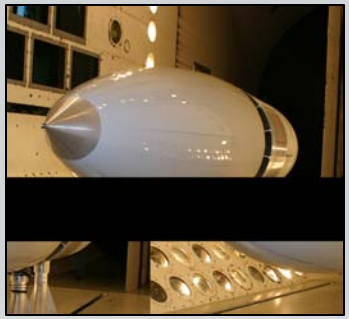
Boeing AEI Joined Wing



Cable-Mount Checkout

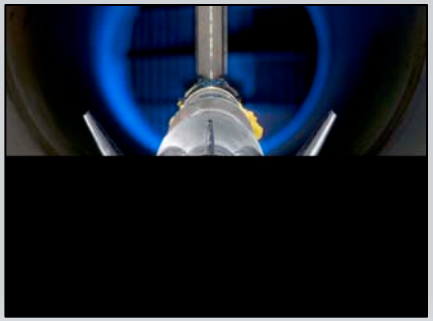


ATGI Ram Air Turbine Pod



Gulfstream Horizontal Tail on OTT

SNC/ULA Dream Chaser



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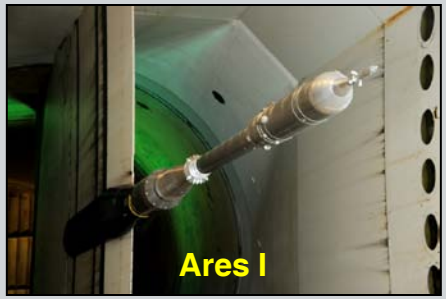
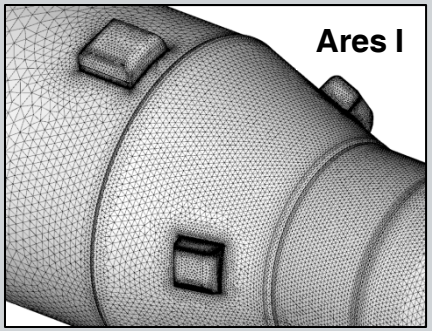
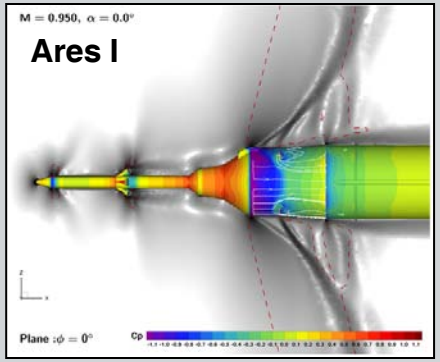
    - Commercial Space Flight Development
      - Commercial Crew Development
    - Exploration Systems Development
      - Space Launch System

AB TECHNICAL WORK SUPPORTED BY HUMAN EXPLORATION & OPERATIONS

- AB performs analytical and experimental work on commercial space flight development and exploration systems development







OUTLINE

- Our place within NASA
- Our vision
- Our branch and discipline
- Our mission
- Our realm of influence
- Our technical program
- **Our recent successes**
- Our bottom line (summary)

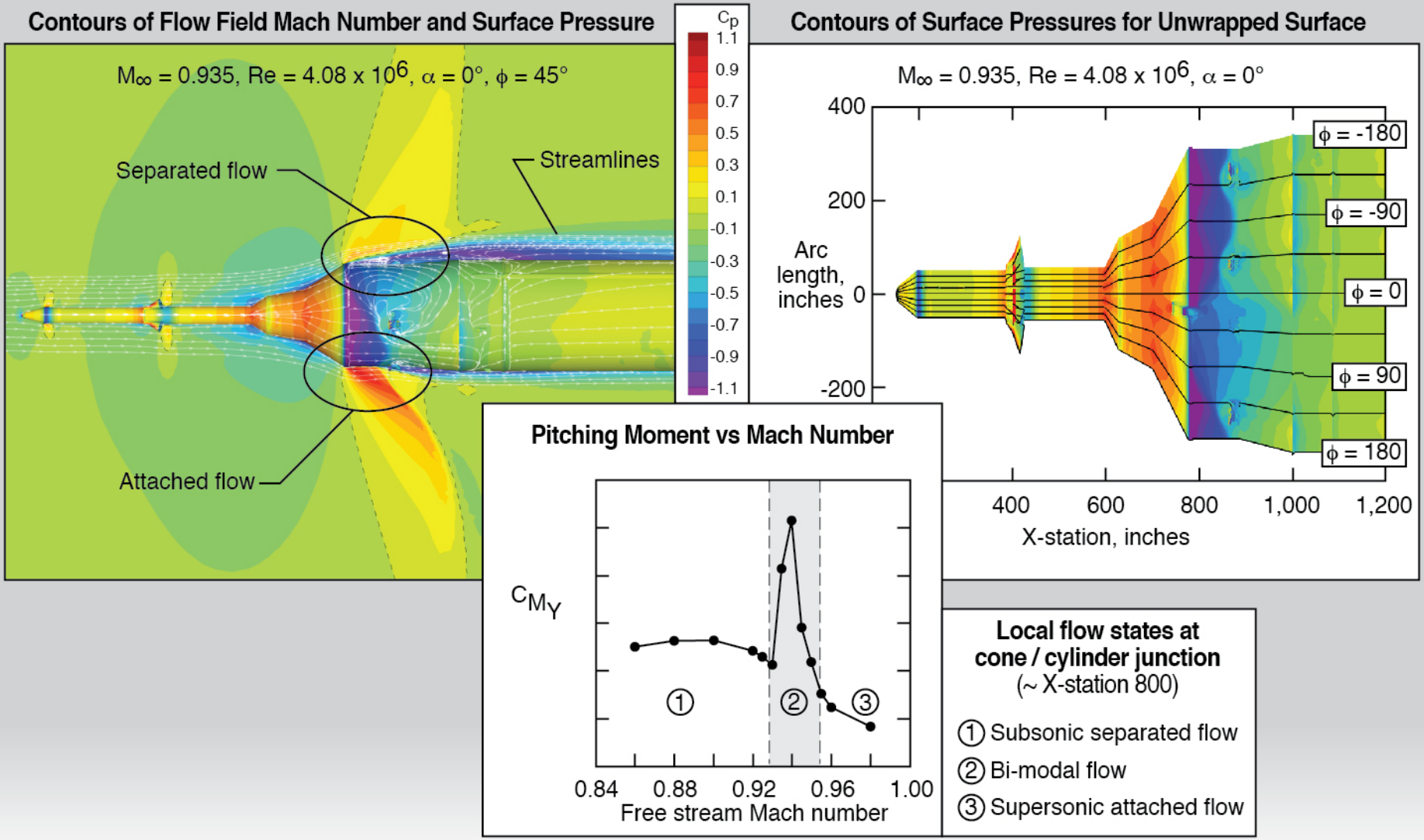
OUR RECENT SUCCESSES, 1 of 2

- **Comprehensive aeroelastic assessments of Ares I-X and Ares I launch vehicles**
  - Computational – stability, bi-modal loading, ground-wind loads
  - Experimental / Wind Tunnel – buffet loads, ground-wind loads
  - Experimental / Flight – buffet loads, ground-wind loads, instrumentation
- **Special sessions at major conferences**
  - 2010 AIAA Applied Aero Conf – on Ares Aeroelasticity
  - 2011 IFASD – on preparations for the Aeroelastic Prediction Workshop
  - 2012 AIAA SDM Conf – on Semi-Span Supersonic Transport project
- **First AIAA Aeroelastic Prediction Workshop (AePW-1)**
- **Patents**
  - Method of performing computational aeroelastic analyses (Silva, Pat. No. 8,060,350)
  - Compact Vibration Damper (Ivanco, Pat. Pend.)
- **Enhancements to computational aeroelasticity codes (CFL3D and FUN3D)**
  - Active controls capability
  - Gust capability

OUR RECENT SUCCESSES, 2 of 2

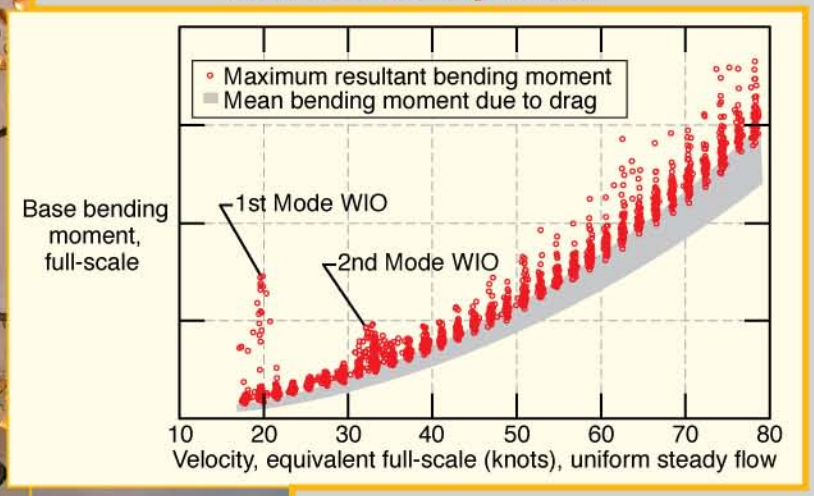
- **Testing in the Langley Transonic Dynamics Tunnel**
  - S^4T Flutter-Suppression / Gust-Load-Alleviation / Ride-Quality-Control (2)
  - Boeing AEI Joined Wing Gust-Load-Alleviation (2)
  - TDT Cable Mount System Checkout (using Lockheed-Martin F-16)
  - ATGI Ram Air Turbine Pod
  - Boeing Next Generation Jammer Pod
  - Gulfstream Horizontal Tail
  - Bell Tiltrotor
  - SNC/ULA Dream Chaser Buffet

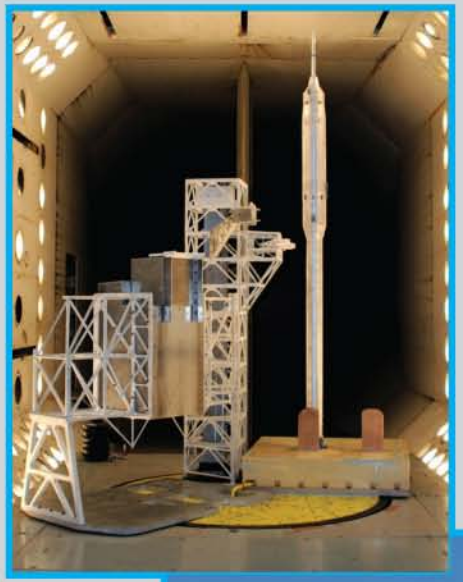
Computational Aeroelastic Analysis of Ares I-X Bi-Modal Flow Field



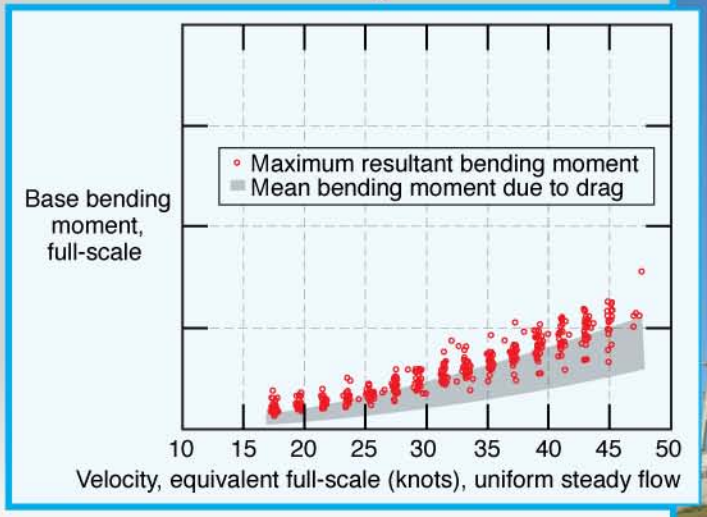
Ares I-X Ground Wind Loads Investigated in Langley Transonic Dynamics Tunnel

Roll-Out Configuration





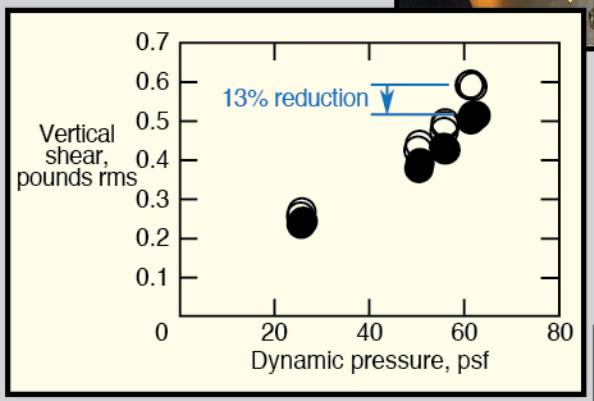
On-Pad-Launch Configuration

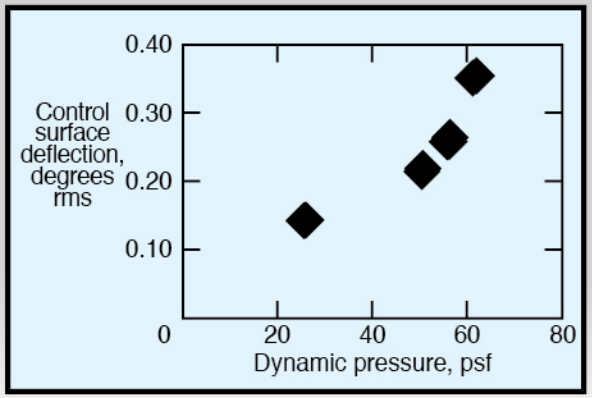


Gust-Load-Alleviation Systems Reduce Transonic Gust Loads on S4T Wind-Tunnel Model

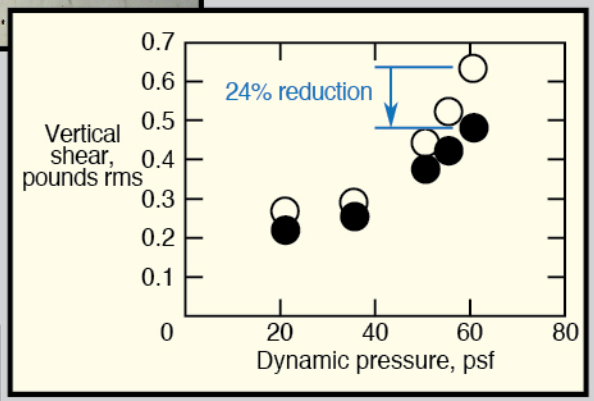
Mach Number = 0.95

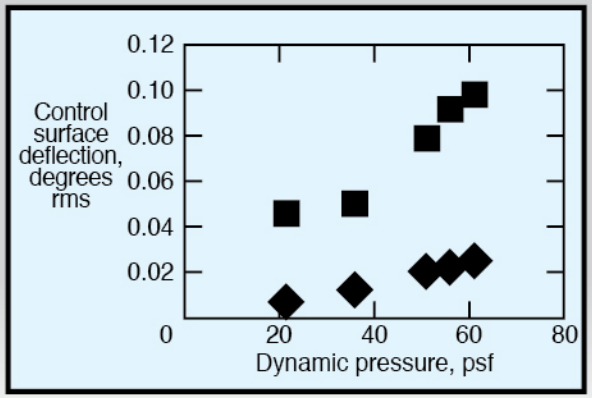
GLA Results for NRA Partner #1





GLA Results for NRA Partner #2





Open loop
Closed loop

Performance measurement sensors (mid-wing strain gages)
GLA sensors (vertical accelerometers)
GLA control surfaces

Aileron
Horizontal tail

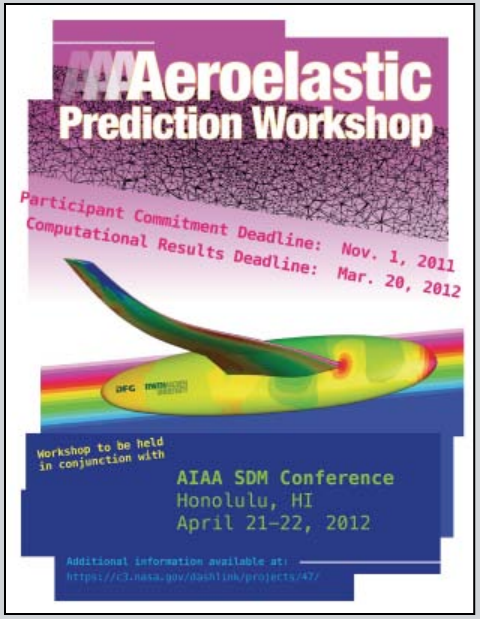
First Aeroelastic Prediction Workshop (AePW-1)

Problem:
The fundamental technical challenge in computational aeroelasticity (CAe) is the accurate prediction of unsteady aerodynamic phenomena and their effect on the aeroelastic behavior and response of a vehicle. Currently, a benchmarking "standard" for use in validating the accuracy of CAe codes does not exist.

Objective:
Obtain accurate analytical predictions of unsteady aerodynamic phenomena and their effect on the aeroelastic behavior and response of a vehicle.

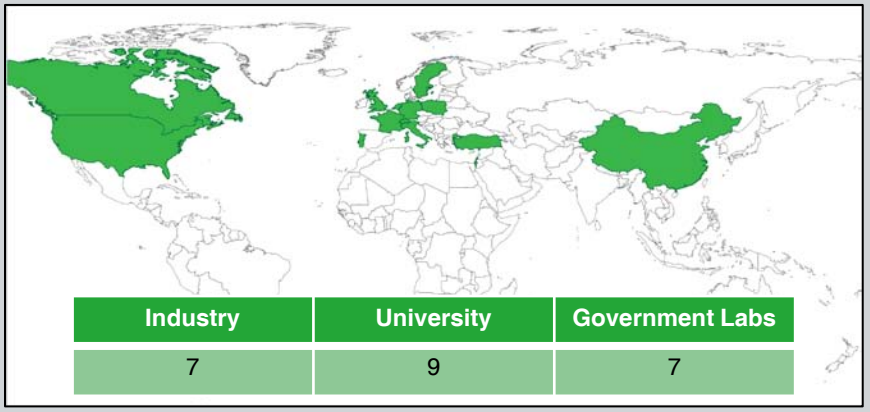
Approach:

- Evaluate experimental data sets available for benchmarking
- Perform computational evaluations of selected configurations
- Initiate an Aeroelastic Prediction Workshop (AePW) series to provide a forum for international code-to-code comparisons / improvements
- Formulate future research directions



AePW-1 Major Lessons Learned
as of 8/3/12

- RANS appears to be state of the art based on participants' code selection
- Seemingly simple AePW-1 cases capture complex and important flow phenomena
- Substantial variations were observed among CFD results
- Substantial differences were observed between analyses and experiment
- Contributing issues to differences:
  - Wall effects & wall modeling
  - Convergence criteria is not standardized
  - Methodologies for producing unsteady oscillatory responses is not standardized
  - "Steady" is a misnomer both experimentally and computationally
  - Postprocessing methods are not consistent among participants
- Most challenging phenomena to model pertinent to AePW-1 cases
  - Oscillatory shock behavior
  - Shock-induced separated flow
  - Tunnel wall boundary layer influences



AePW Analysis Teams (23)
AePW Analysis Contributor Nations (11)

Bartels Gust Highlight Goes Here

OUTLINE

- Our place within NASA
- Our vision
- Our branch and discipline
- Our mission
- Our realm of influence
- Our technical program
- Our recent successes
- **Our bottom line (summary)**

OUR BOTTOM LINE

- **Strengths and capabilities**
  - Engineering and technician staff
    - Dedication
    - Desire
    - Responsiveness
  - Diverse aeroelasticity knowledge
    - Aeroelasticity / unsteady aerodynamics code types
    - Aeroservoelasticity experience and application capability
    - Experimental experience
  - Wind tunnel and associated ground / lab testing