NASA Armstrong Flight Research Center

Aerostructures X-Plane Airworthiness Guidelines and Best Practices

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NEW AVIATION HORIZONS

Understand Airworthiness

- … As applicable to flight research
- Definition
  – NASA Procedural Requirements 7900.3C
  – “The capability of an aircraft to be operated within a **prescribed flight envelope** in a **safe manner**.”
- X-planes and research aircraft are not normally fleet “certified” operational systems (neither FAA or DoD)
  – NASA provides own airworthiness
  – Each aircraft has unique requirements, research, mission, flight envelope, airframe and systems, etc.
- Tailor design and airworthiness methodology to meet unique research/mission requirements
  – Designs adequate (not perfectly optimized) for experiment needs
  – Multiple paths to airworthiness
  – Higher unmitigated risk → additional mitigation is possible (testing, instrumentation and monitoring, shorter life, more inspections, etc.)

Static Structures

- **Big picture: Confidence in strength & confidence in loads**
- **Many approaches to design, test, and operate "one-of-a-kind" aircraft or to modify certified aircraft**
- **Guidelines for entire vehicle or only for certain area(s)**
- **Guidelines are starting points for tailorable approaches to address strength and loads**
  - Certification approach from Mil-A-8860
  - NASA AFRC Approach #1 – “No-Test & No-Data” Factor of Safety
  - NASA AFRC Approach #2 – “Test & Data” Factor of Safety
  - NASA AFRC Approach #3 – “Test & No-Data” Factor of Safety
  - Other approaches…

Static Structures (Cont.)

- **FAA/DoD Approach for Fleet Certification**
  - Factor of Safety = 1.5 FS on ultimate
  - Proof Test = Dedicated, full-scale, equivalent article to 150% DLL
  - Instrumentation = Fully instrumented and calibrated flight-test aircraft
  - Loads Predictions = Well understood (e.g. wind tunnel derived)
  - Flight Level = Methodical envelope expansion up to 100% DLL

Static Structures (Cont.)

- **Approach #1 ("No-Test & No-Data" Factor of Safety)**
  - Factor of Safety = 2.25 FS on ultimate
  - Proof Test = None
  - Instrumentation = No loads instrumentation
  - Loads Predictions = Well understood and conservative
  - Flight Level = 100% DLL

G-III Adaptive Compliant Trailing Edge (ACTE)

AFTI/F-16XL2 Supersonic Laminar Flow Control Glove and Attachments

F-106/C-141 Tow Launch Demonstration

AFTI/F-111 MAW Cambered LE & TE

Static Structures (Cont.)

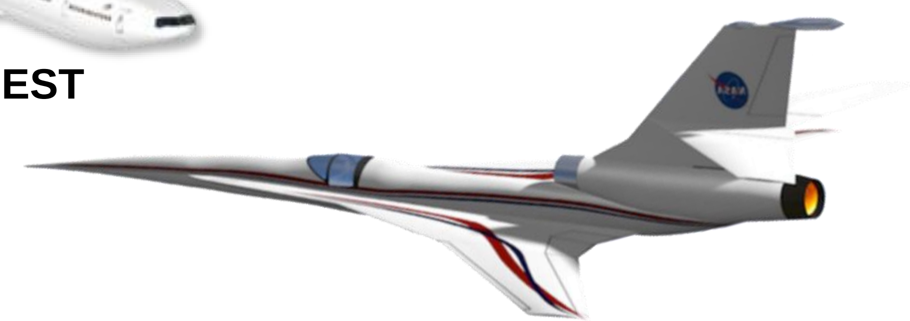
- **Approach #2 ("Test & Data" Factor of Safety)**
  - Factor of Safety = 1.5 FS on ultimate
  - Proof Test = 100% LL (Flight-test aircraft is proof test aircraft)
  - Instrumentation = Fully instrumented and calibrated flight-test aircraft
  - Loads Predictions = Low confidence in loads
  - Flight Level = 80% LL (100% LL on a case-by-case basis)
  - Proof test = 1.25 of flight limit → 1.875 equivalent design FS

Static Structures (Cont.)

- **Approach #3 ("Test & No-Data" Factor of Safety)**
  - Factor of Safety = 1.8 FS on ultimate
  - Proof Test = 120% LL (Flight-test aircraft is proof test aircraft)
  - Instrumentation = None
  - Loads Predictions = Well understood & conservative load predictions
    - Rarely have well understood & conservative load predictions
    - This approach often coupled with instrumentation to gain confidence in loads → Becomes like approach #2
  - Flight Level = 100% LL

D-8 UEST

X-57

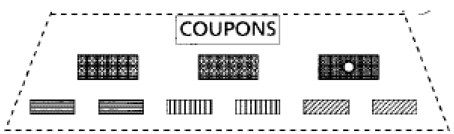


QueSST / LBFD

Composites

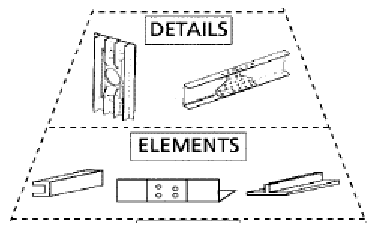
- **Building Block Approach for Experimental Flight**
  - Building block approach requires time and money but reduces risk (safety, technical, and programmatic)
  - Impractical to test everything → Balance between analysis and test
  - Testing supports analysis for critical and complex features
  - Appropriately scope building block approach for prototype flight

Destructive coupon testing



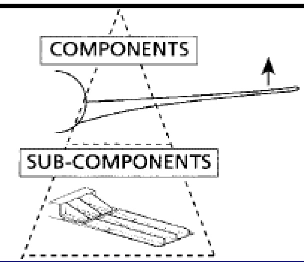
Gets the design started

Destructive testing of design features



Project risk reduction

On aircraft proof loading



Safety of flight

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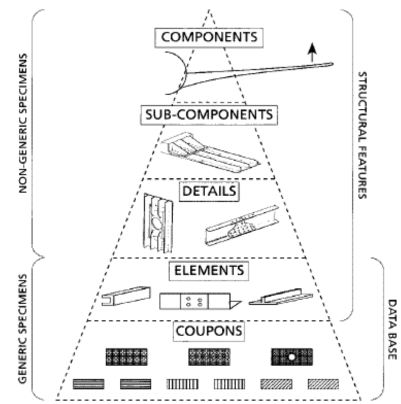


FIGURE 2.1.1 *The pyramid of tests (Reference 2.1.1(a)).*

Test here to provide a level of confidence failure does not occur here

Composites (Cont.)

- **Airworthiness requires close link between design, analysis, and manufacturing to understand "as built" performance**
  - Relationship easier to establish when working with high pedigree manufacturers with proven processes and ability to leverage design databases
  - Start-ups have a path to airworthiness at a cost of higher scrutiny
- **Many paths to airworthiness → Tailorable based on risk posture, design FS, test pedigree, M&P confidence, etc.**
- **AFRC best practices:**
  - If proven material equivalence, follow Static Structures approaches
  - FS=3.0 for secondary/tertiary structures with unknown equivalence

Aeroelasticity

- **Modified, previously-certified aircraft or new store or experiment carriage configurations**
- **Flutter Criteria: Minimum 15-20% margin on Equivalent Air Speed (EAS) and Mach Number**
- **AFRC process:**
  - Step #1: Gather historical aeroelastic information pertaining to aircraft/test article
  - Step #2: Choose clearance approach to show airworthiness = most efficient effort to provide sufficient evidence consistent w/risk posture
    1) Clearance by **flutter analysis, Ground Vibration Test (GVT)/Modal Test, and flight-testing**
       - Large margin (~ >100%) on high-confidence model, flutter testing normally not required
       - Low margin (~ <100%) on high-confidence model, flutter testing and/or monitoring may be required
    2) Clearance by **flutter sensitivity study**
    3) Clearance by **aeroelastic similarity**

    (2 and 3: Mainly used for smaller structural modification)

Aeroelasticity (Cont.)

- **Approach #1 (Flutter analysis, GVT, and flight-test)**
  - Standard approach for new aircraft/test article or previously certified aircraft with significant structural and/or mass modifications
  - GVT data used to validate or update Finite Element Model (FEM) and aid in flight flutter testing
  - Flutter analyses often conducted twice (depending on quality of FEM)
  - Flight flutter testing proves no aeroelastic instabilities exist within planned flight envelope and to extrapolated flutter criteria

G-III w/ Adaptive Compliant Trailing Edge (ACTE)

F-15B w/ Quiet Spike

X-53 Active Aeroelastic Wing (AAW)

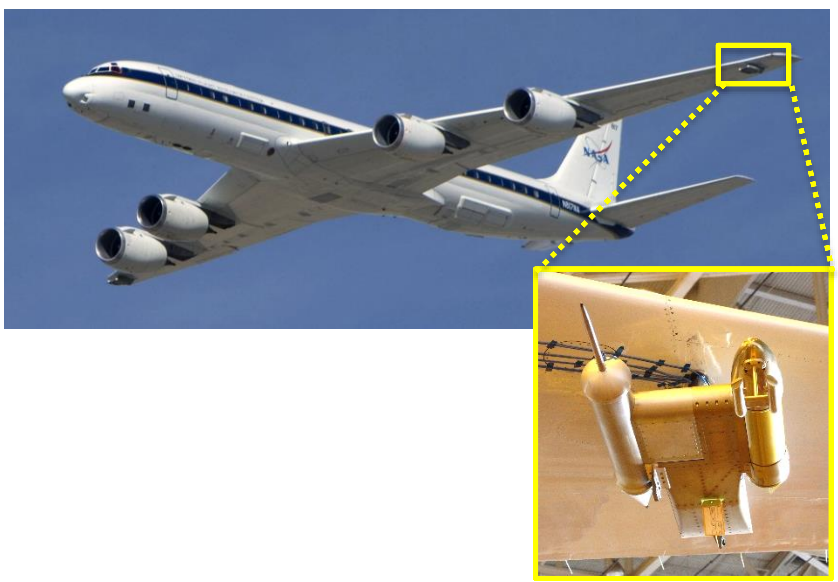
X-43 Hyper-X mated to B-52

Stratospheric Observatory for Infrared Astronomy (SOFIA)

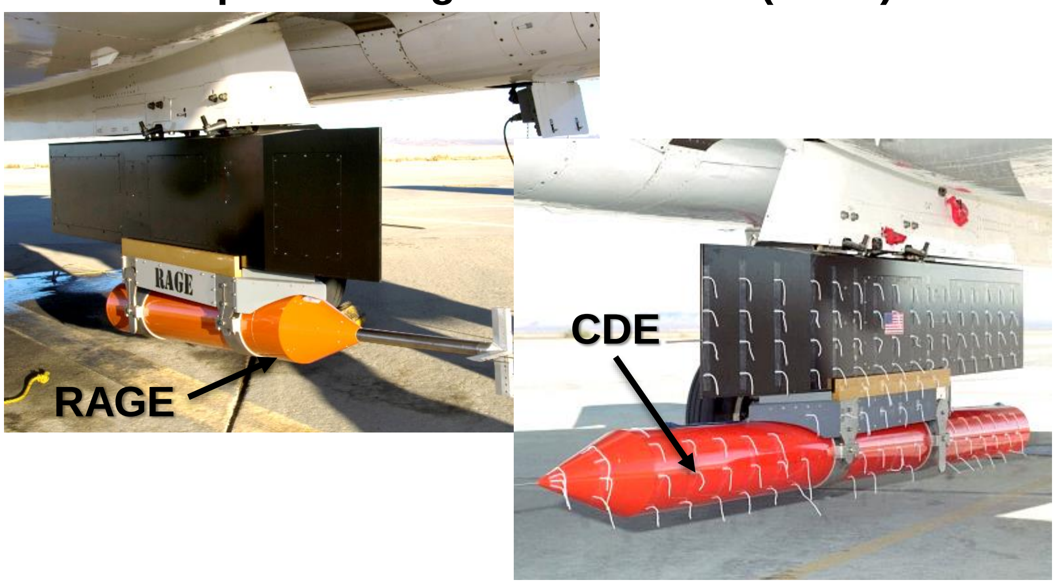
Aeroelasticity (Cont.)

- **Approach #2 (Flutter sensitivity study)**
  - When uncertainties in FEM parameters exist, flutter sensitivity study can capture variable combinations which bound the flutter envelope
    - Determine if large flutter margins exist with all variations
    - Identify flutter critical combinations & justify further investigation
  - If necessary, perform limited GVT to validate FEM

DC-8 High Ice Water Content (HIWC) Wingtip Pylon



F-15B Rake Airflow Gage Experiment (RAGE) & Cone Drag Experiment (CDE) attached to Propulsion Flight Test Fixture (PFTF)



Aeroelasticity (Cont.)

- **Approach #3 (Aeroelastic similarity)**
  - Minimum effort & low cost approach
  - Often used for new external stores when previously cleared on same pylon and same aircraft location
    - Similar mass & stiffness distributions and unsteady aerodynamic forces as previous flown and cleared configuration
    - Often, stores considered stiff & treated as rigid-bodies attached to a flexible pylon; Shape, mass, CG location, & inertias of old and new stores may be sufficient for comparison

F-15B Aeronautics Research Testbed

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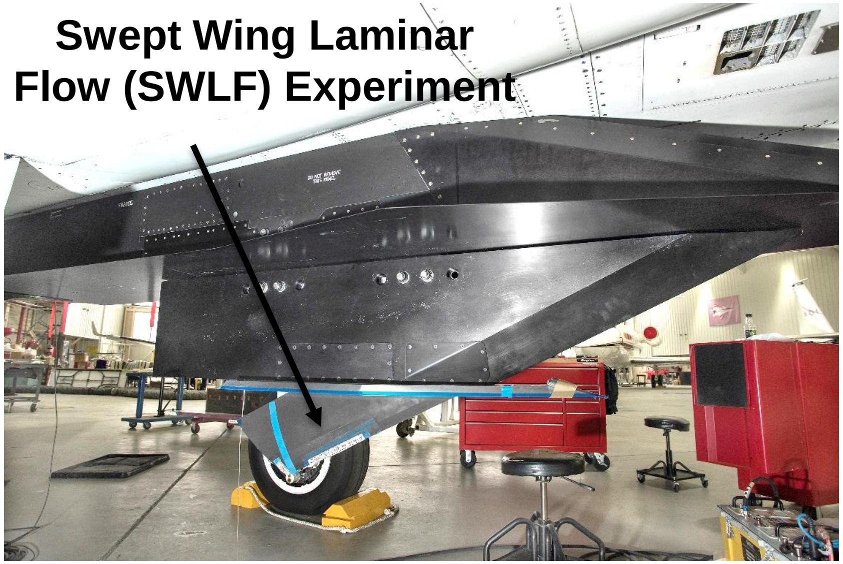
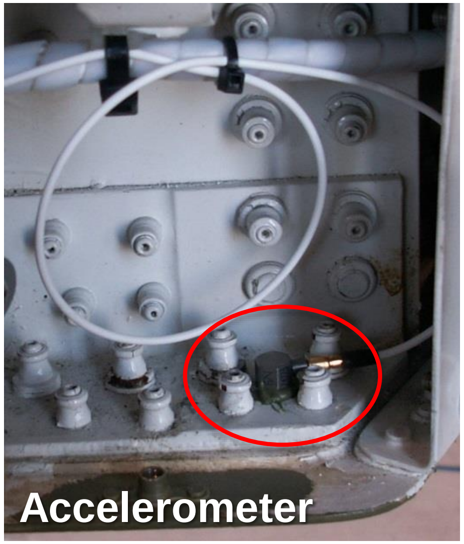
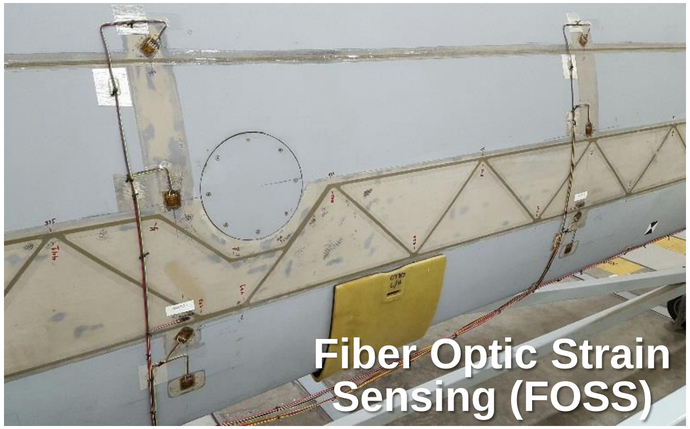
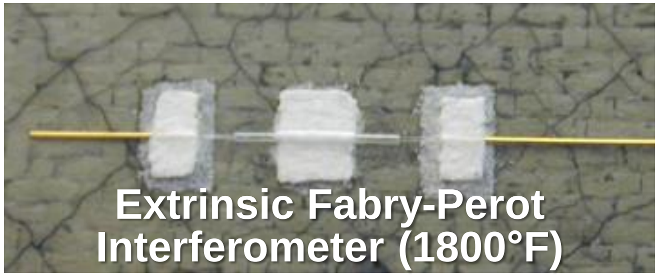


Structural Instrumentation

- **Instrumentation required to understand performance…**
  - Safety
  - Experiment success
  - Experiment failure
- **Flight research requires a combination of COTS and unique purpose-developed instrumentation**







- **Early involvement critical to experiment success**

Structural Instrumentation (Cont.)

- **Purposed and opportune → Need strategic view to develop measurement and test technologies/techniques as a priority for future X-planes**

Strain gage loads measurement techniques on composites proven on HiMAT then utilized on X-29

Highly Maneuverable Aircraft Technology (HiMAT) 1979-83

$\Rightarrow$

Electro-optical Flight Deflection Measurement System (FDMS) developed for HiMAT then utilized on AFTI/F-111 MAW, X-29, and X-53 AAW

Summary

- **X-planes and modified vehicles for flight research require a unique perspective compared to fleet certified airframes**
- **Aerostructures Lessons Learned / Best Practices**

  #1 – Understand tailorable/adequate airworthiness processes applicable to flight research

  #2 – Modified structure requires special considerations (e.g. modified inspection plans)

  #3 – Tailor Static Structures airworthiness methodology to gain confidence in strength and loads

  #4 – Understand the use of composites in non-certified, research airframes

  #5 – Tailor Aeroelasticity airworthiness methodology to gain confidence in flutter margins

  #6 – Make sure you have the ability to learn the right information from the research; Work instrumentation early in development

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