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
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
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

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Destructive coupon testing

- Gets the design started

Destructive testing of design features

- Project risk reduction

On aircraft proof loading

- Safety of flight

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

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FIGURE 2.1.1 The pyramid of tests (Reference 2.1.1(a)).
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**
       o Large margin (~ >100%) on high-confidence model, flutter testing normally not required
       o 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**  
       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
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

Supersonic Boundary Layer Transition (SBLT) Experiment

Swept Wing Laminar Flow (SWLF) Experiment
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

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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