Armstrong Flight Research Center

X-Plane Structures Challenges/Lessons Learned

Briefing to the 2016 NESC Structures TDT F2F Meeting

Randy Thompson, Chief, Aerostructures Branch

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Outline

- **X-planes introduction**
- **Recent (30 years) of structures related X-planes and research aircraft**
- **ARMD New Aviation Horizons Plan**
- **Structures lessons learned (four of many)**
- **Summary**

X-Plane Designation

- **70 years of X-planes (Bell X-1 First flight – 19 Jan 1946)**
- **Original designation – “XS” for eXperimental Supersonic**
- **“X” identifies research craft designed for experimental and developmental research programs which are not intended for production beyond a limited number built solely for flight research**

“Recent” Research Aircraft

- **Flight research just not with X-planes**
- **Research aircraft include purpose-built aircraft without an “X” designation and aircraft (significantly) modified for specific research**


NEW AVIATION HORIZONS

ARMD New Aviation Horizons Plan

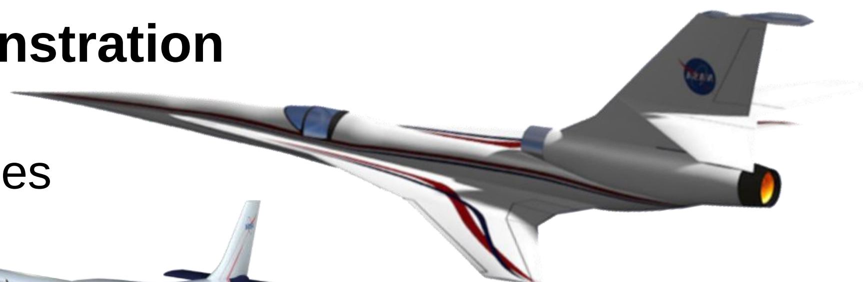
- **2014 → 2034 (est) Global Aviation Industry**
  - 3.3B → 7B Passenger Trips; 58M → 105M Jobs; \$2.4T → \$6T GDP
- **ARMD 10 Year X-Plane Plan**
  - Research/Demonstrate new airframe and propulsion technologies
  - Distributed ~\$4.25B budget increase over next 10 years
- **Ultra-Efficient Subsonic Transports (UEST)**

D-8: Prop/AF integration enables reduced drag

HWB: Aerodynamically efficient shape enables reduced drag

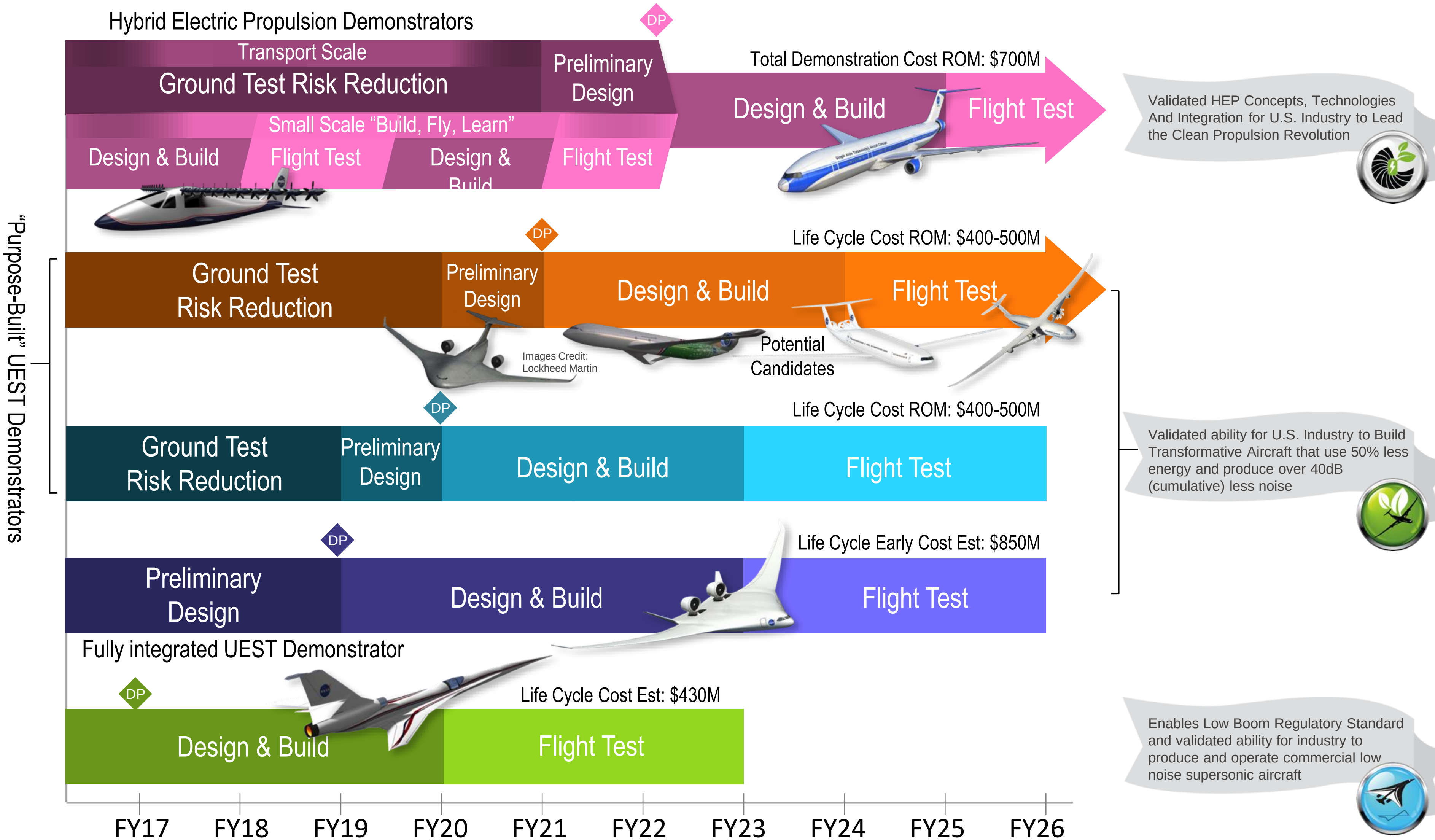
TBW: Very high AR substantially increases wing efficiency

- **Supersonic Low Boom Flight Demonstration**
  - Demonstrate boom noise reduction
  - Support international regulation changes



- **Hybrid Electric Propulsion**
  - Integration and demonstration

New Aviation Horizons Flight Demo Plan



Structures Lessons Learned

- Executing fwd → Remembering the past to succeed in the future
- Lessons learned from programmatic to technical

X-3 (center), and clockwise from left:
X-1A, D-558-I, XF-92A, X-5, D-558-II, and X-4

Flight-Research vs. Developmental T&E

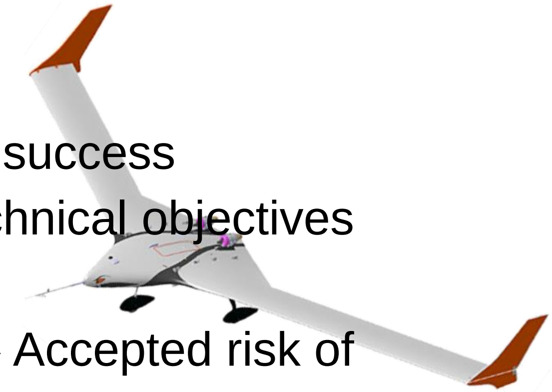
	Flight Research	DT&E
Purpose	Discover something new or validate a theoretical principle	Verify and validate proper operation in flight environment to show works as designed
Predicted outcomes	Typically high uncertainty	Typically high confidence
Measure of Success	Quality of data produced	Match predictions and validate operation

- **Changes perspective on technical risk →Take it! (more on that later)**
- **Changes perspective on "failure" → "Fail early, fail often."**
- **Changes perspective on scope → Limited vs. Complete**
- **Changes perspective on expected results → Data is key**
- **"Learn by doing" → Build, fly, learn…**

  "We will ask big questions, seek multi-disciplinary solutions, and demonstrate their feasibility in 18-36 months" – ARMD AA

Take the Right Kind of Risk

- **Programmatic Risk**
  - Unacceptable to fail due to inadequate planning, management, etc.
- **Technical Risk**
  - Technical failure is OK
  - Can learn as much from technical failure as technical success
  - Lean forward and accept risk of failing to meet the technical objectives
  - Take the right technical risk
  - Example: First X-56 flex-wing flight takeoff mishap → Accepted risk of mishap due to flutter, but not takeoff mishap



- **Safety Risk**
  - Edwards AFB, street names, conference room names, etc.
  - Hazards must be identified, mitigation implemented, and risk assessed and accepted
- **Misconception of taking risk in Convergent Aeronautics Solutions (CAS)**

Capt Glenn Edwards
Sat, 5 June 1948, AM
YB-49

Judson Brohmer
Tues, 17 July 2001, 0700
F-16

Understand Airworthiness

- **NASA granted authority to conduct airworthiness and safety review processes for "Public Use" aircraft outside of FAA regulations**
- **NPR7900.3C (Aircraft Operations Management Manual)**
  - 2.3.2 Center Directors shall establish airworthiness, flight safety, mission readiness, and configuration control review processes and procedures to identify any hazards, to manage the risks associated with flight programs, to ensure safe flight operations, to manage and thoroughly document aircraft configurations, and to ensure that flight objectives satisfy programmatic requirements.
- **Airworthiness = Capability of an aircraft to be operated within a prescribed flight envelope in accord with the project's safety risk posture**

Understand Airworthiness (Cont)

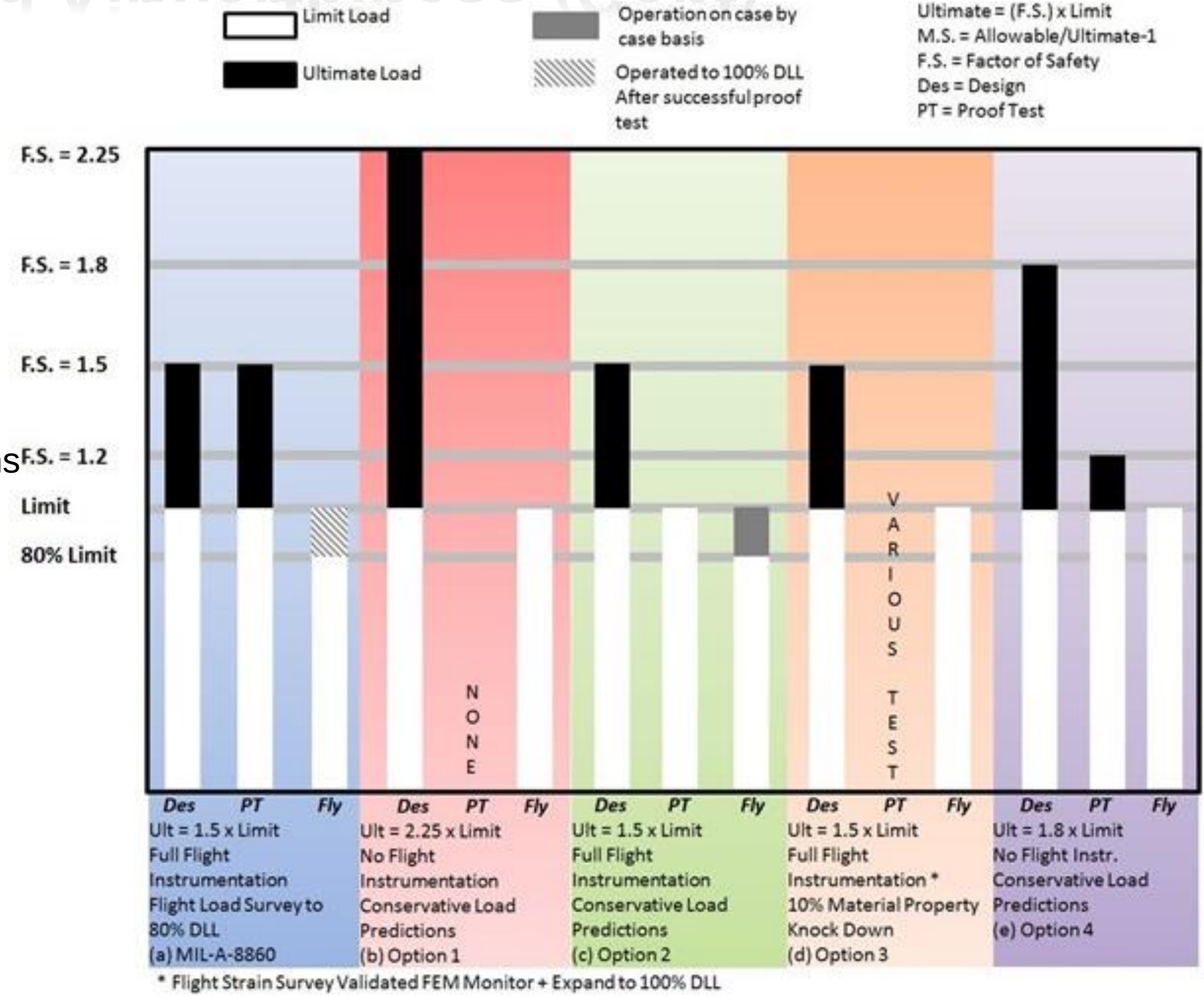
- **Big picture: Understand loads / Understand strength**
- **To support the airworthiness process, Structures Engineers gather airworthiness evidence through analysis and ground/flight-test to increase airworthiness confidence in accord with a project's safety risk posture**
- **X-planes and research aircraft are not normally "certified" operational systems (either FAA or DoD)**
  - Airworthiness guidelines are tailored to meet mission requirements
  - Multiple paths to airworthiness
  - Can accept higher risk (in many cases the higher risk is mitigated through shorter life, more inspections, instrumentation, ground test, etc.)
  - Can trade envelope for margin
  - Can trade real-time monitoring for margin
  - Can disregard (in many cases) fatigue concerns
  - Example:

Quiet SuperSonic Technology (QueSST) Aircraft (LBFD)	vs	Convergent Electric Propulsion Scalable Technology and Operations Research (SCEPTOR)

Understand Airworthiness (Cont)

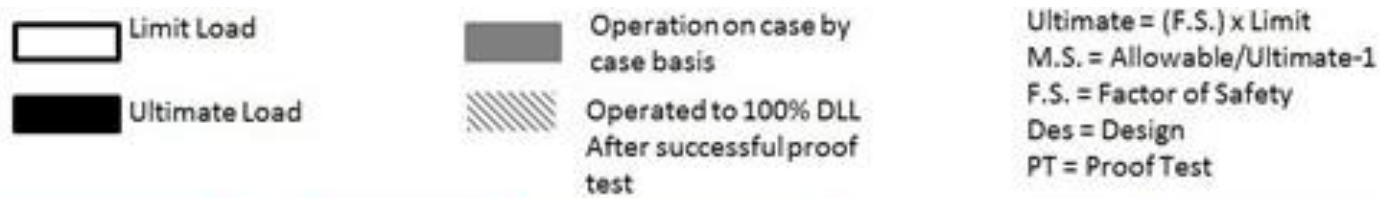
Considerations

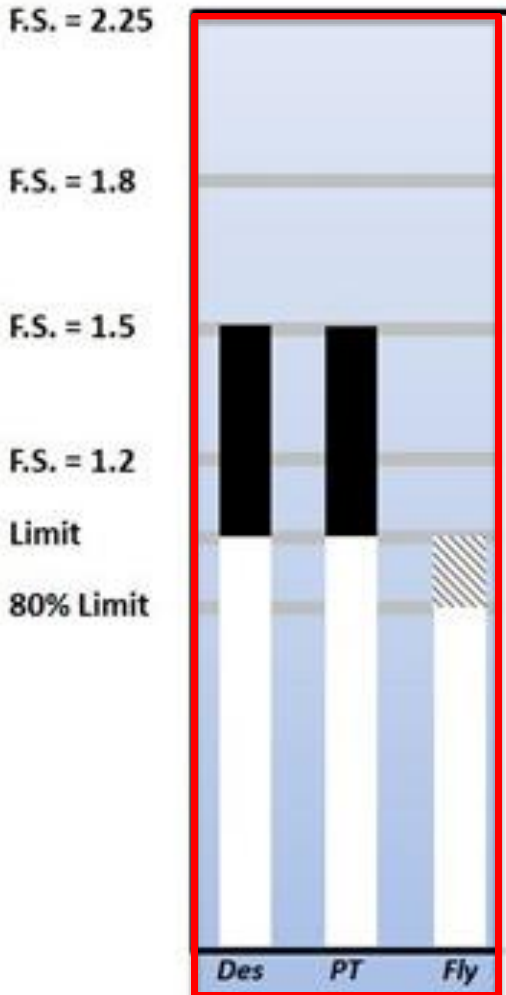
- Design FS
- Confidence in external, internal, and thermal loads analysis
- Instrumentation ?
- Ground/flight testing
- Structural inspections (type & intervals)
- Flight envelope limitations
- Flight environment limitations
- Control law tailoring
- Fatigue considerations (usually of little concern)



Ref: G-7123.1-001B2 (Aircraft Structural Safety of Flight Guidelines)

Understand Airworthiness (Cont)





- Mil-A-8860 Approach
- Utilized for a "certified" airframe
- Design to 1.5 FS (Ultimate = 1.5 x Design)
- Dedicated (sacrificial) static test article to 150% LL
- Fully instrumented and calibrated flight-test aircraft
- Methodical envelop expansion to 80% LL (loads survey) then to 100% LL (demonstration) [modern = gather data to correlate a model to clear an envelope]

Understand Airworthiness (Cont)

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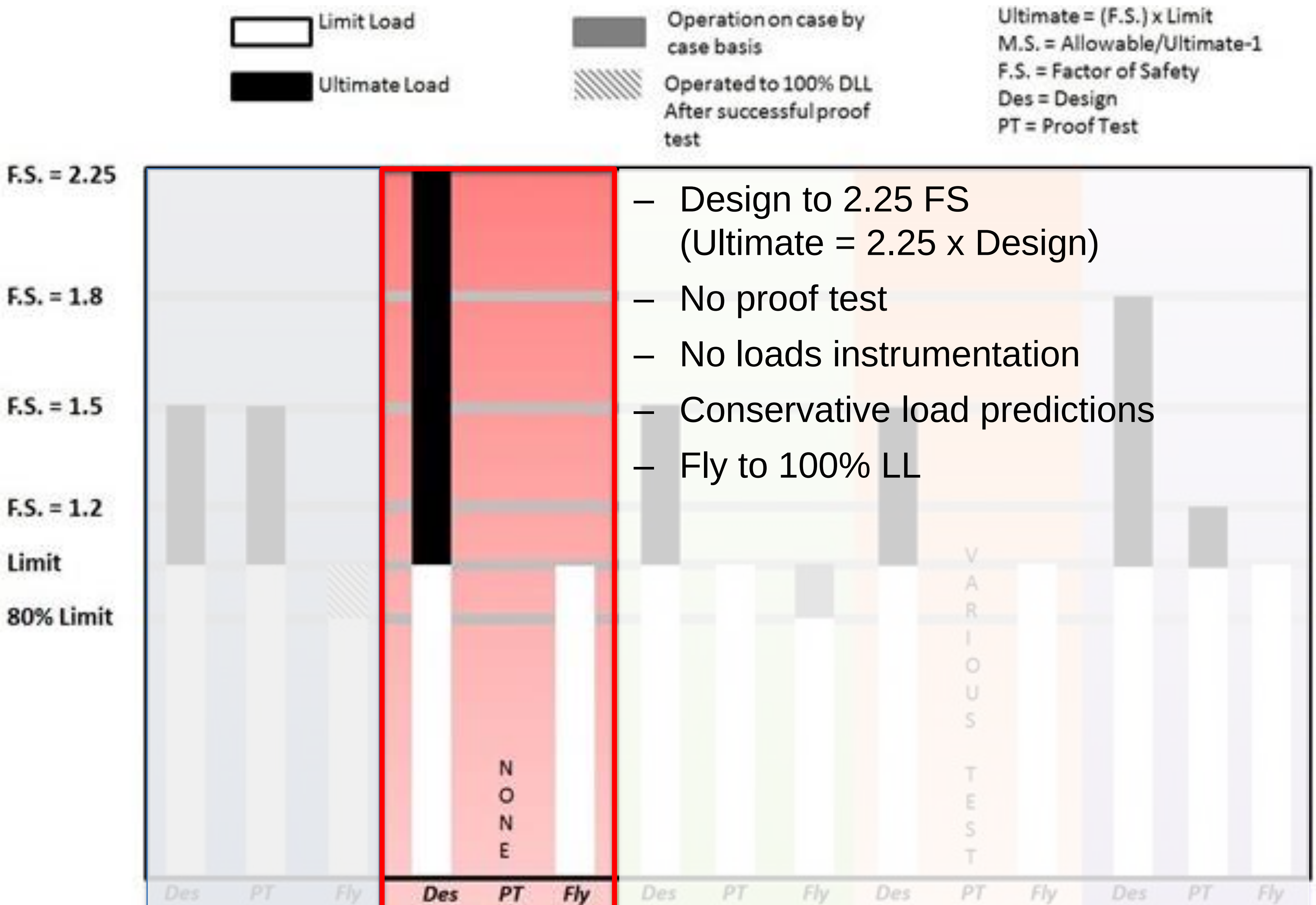


- Design to 2.25 FS
  (Ultimate = 2.25 x Design)
- No proof test
- No loads instrumentation
- Conservative load predictions
- Fly to 100% LL

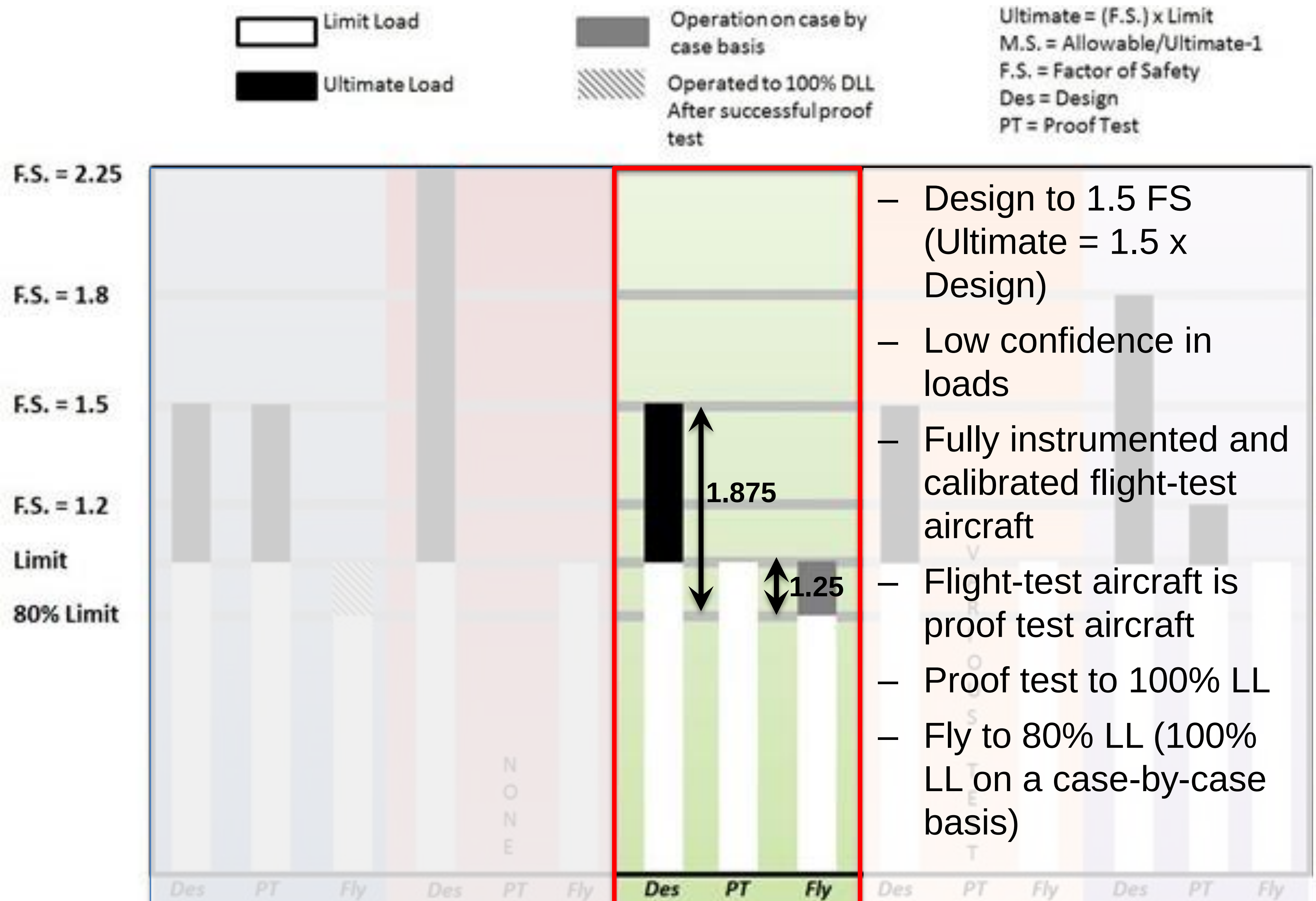
Understand Airworthiness (Cont)

AFTI/F-11 Mission Adaptive Wing (MAW)
Variable camber LE & TE

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

F-106/C-141 Tow Launch Demonstration

Understand Airworthiness (Cont)



- Design to 1.5 FS (Ultimate = 1.5 x Design)
- Low confidence in loads
- Fully instrumented and calibrated flight-test aircraft
- Flight-test aircraft is proof test aircraft
- Proof test to 100% LL
- Fly to 80% LL (100% LL on a case-by-case basis)

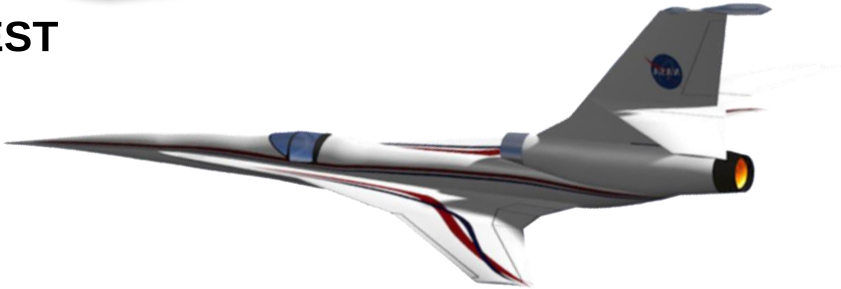
Understand Airworthiness (Cont)

F-8 Supercritical Wing Research Aircraft

X-29 Advanced Technology Demonstrator

D-8 UEST

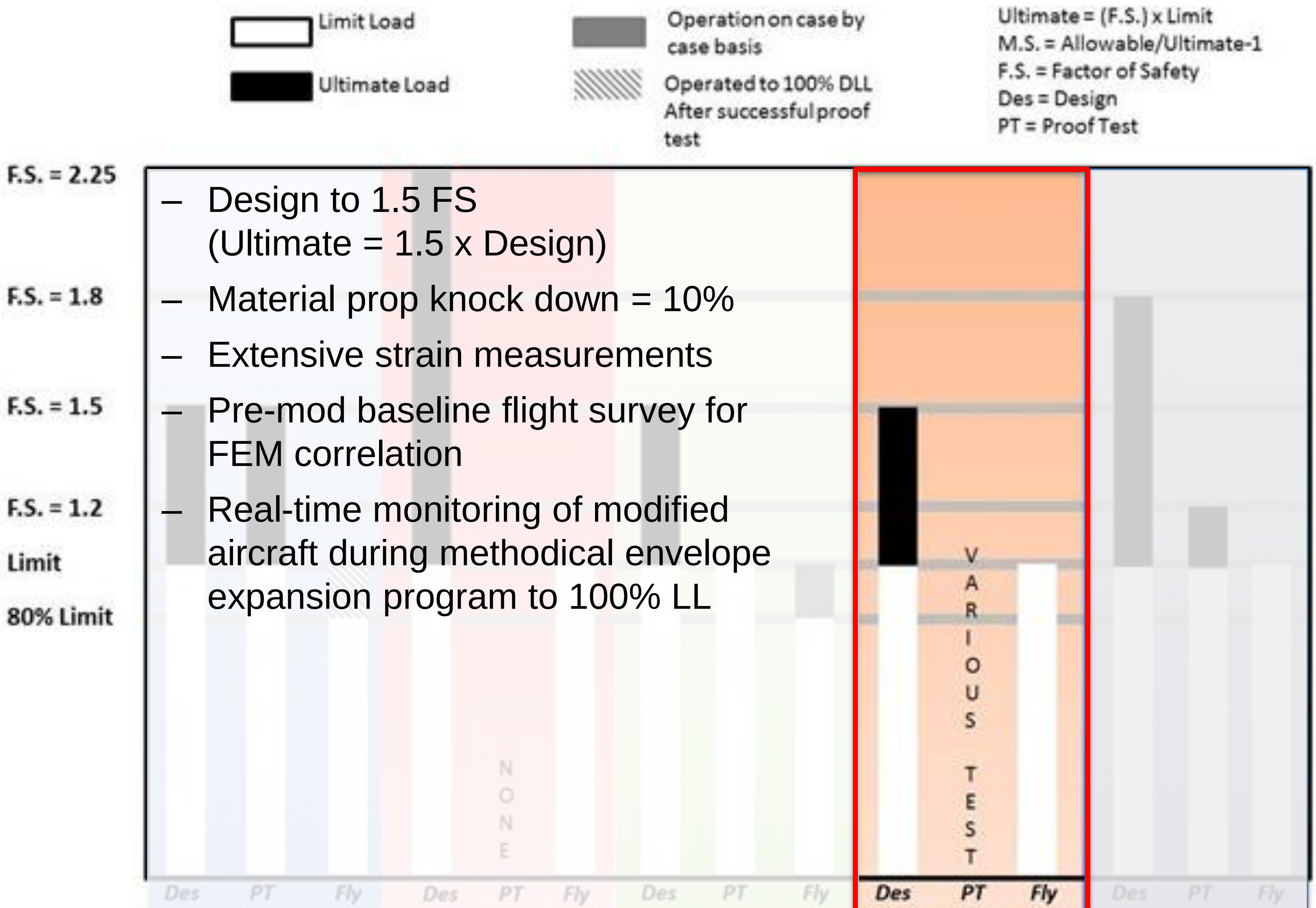
Scalable Convergent Electric Propulsion Technology and Operations Research (SCEPTOR)



Quiet SuperSonic Technology (QueSST) Low Boom Flight Demonstrator (LBFD)

Understand Airworthiness (Cont)

- Design to 1.5 FS
  (Ultimate = 1.5 x Design)
- Material prop knock down = 10%
- Extensive strain measurements
- Pre-mod baseline flight survey for FEM correlation
- Real-time monitoring of modified aircraft during methodical envelope expansion program to 100% LL

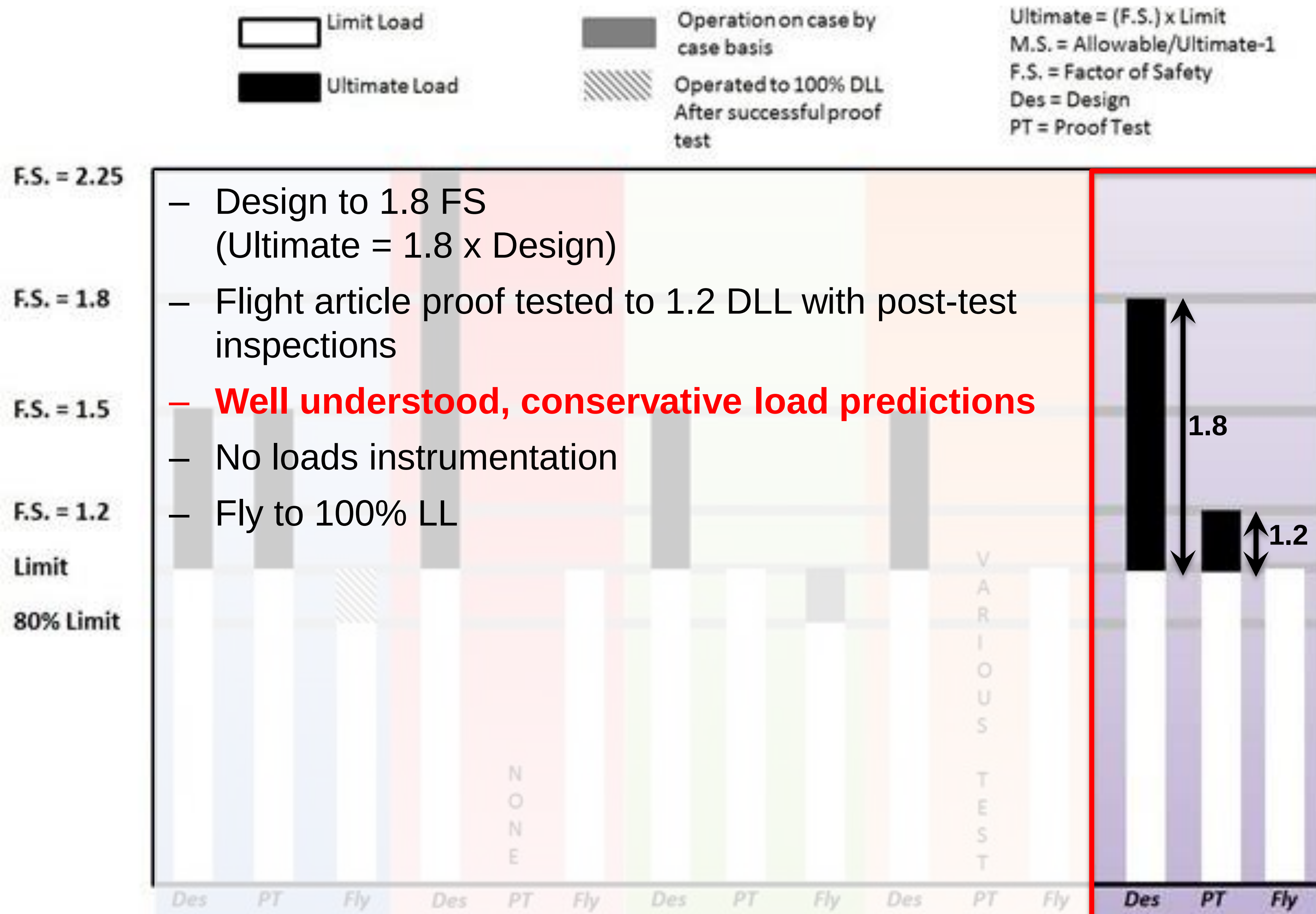


Understand Airworthiness (Cont)

Stratospheric Observatory for Infrared Astronomy (SOFIA)

Understand Airworthiness (Cont)

- Design to 1.8 FS
  (Ultimate = 1.8 x Design)
- Flight article proof tested to 1.2 DLL with post-test inspections
- **Well understood, conservative load predictions**
- No loads instrumentation
- Fly to 100% LL



Understand Airworthiness (Cont)

?

Understand Airworthiness (Cont)

- **A Word About Composites…**
- **Difficulty of Composites**
  - Mechanical performance VERY dependent upon Materials and Processes (M&P)
  - Variance of material properties
  - Requires characterization of material properties and structural features
- **AFRC Aerostructures Philosophy**
  - Airworthiness requires a close link between design, analysis, and manufacturing (including material perf) to understand “as built” performance
  - Relationship easier to establish when working with high pedigree OEMs
    - Proven processes and ability to leverage design databases
  - Employ a “building block approach” appropriately scoped for prototype flight
  - Many paths to airworthiness → Tailorable based on risk posture, M&P, etc.

Understand the Requirements

- **X-planes/Research aircraft have unique requirements**
  - Unique research
  - Unique mission
  - Unique flight envelope
  - Unique airframe and systems
- **Design and airworthiness methodology should be tailored to meet unique research/mission requirements**
  - Not held to Federal Aviation Regulations (FAR), Joint Service Specification Guides (JSSG), etc.
- **Structures design and airworthiness methodology needs to be technically adequate (not technically meticulous) to meet the experiment's intent in accord with the project's safety risk posture**
- **Example**
  - SCEPTOR – An electric-aero-propulsion integration experiment; Expected flight time of 30 min within EDW restricted area with EDW lakebed as landing mitigation
  - QueSST – Expected flight time of 90-120 min over multiple CONUS metro areas including ferry to those locations (ferry OCONUS???)

Have the Ability to Learn the Right Info

- **“Everyone” thinks Developmental Flight Instrumentation (DFI) is important**
- **“Everyone” wants DFI (Eng/Res always want more data)**
- **Projects need DFI (Eng/Res need some data)**
- **However …**
  - Instrumentation development is often a project’s afterthought and/or the last thing identified in the budget
  - Projects often want the minimum amount of DFI thus limiting understanding of **nominal** and **off-nominal** events
  - Projects want other projects to pay for their DFI development → Bad assumption that someone else is developing what you need
  - Projects often only want COTS DFI, but right DFI for the project’s application does not exist (because no one paid for it to be on the shelf & ready to use)
- **Early involvement integral to experiment success**
  - DFI can be long-lead procurement item
  - Design in structurally imbedded DFI
  - DFI development time/effort needed (sensors and packaging)
    - Example: Hypersonics – High temp sensors for flight → New sensor, minimum form factor, minimum weight, severe environment

Learn the Right Info (Cont)

- **Lucky or Good?**
  - Structural DFI needed to understand performance impacting experiment
    - Example: QueSST/LBFD – Primary experiment boom reduction/characterization → Need to understand airframe deflection to understand impact on boom → FOSS deflection and twist determination → Roadmap developed to meet project requirement while leveraging other efforts
  - Structural DFI needed to understand performance in event of mishap
    - Example: Hypersonics experiments where additional info would have been helpful in understanding event
- **Purposed and opportune → Need big picture view to develop meas and test technology/techniques as a priority for future NASA efforts**

Highly Maneuverable Aircraft Technology (HiMAT)

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

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

Summary

- Proposed budgets and research acknowledges need for USA to lead in aeronautics research – for nation and world
- If proposed budgets become reality → Very exciting time for NASA to significantly impact our nation’s economy for years to come
- Lessons Learned

  #1 – Understand the uniqueness of flight research vs. DT&E

  #2 – Understand risk; Take technical risk; Do not compromise on safety risk

  #3 – Understand tailorable/adequate airworthiness processes applicable to aeronautics research

  #4 – Make sure you have the ability to learn the right information from the research; Work DFI development early