DAMAGE TOLERANCE AND FATIGUE SUBSTANTIATION OF ROTORCRAFT COMPOSITE SANDWICH STRUCTURES

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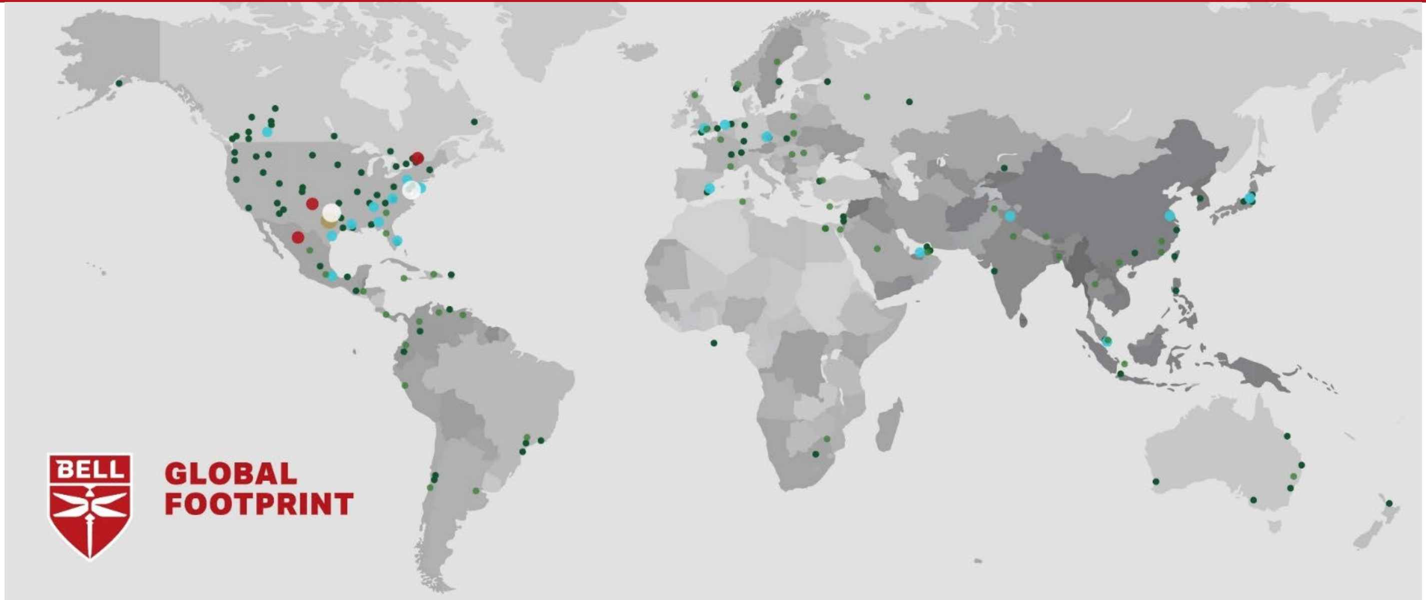
Bell Textron Inc.

Composite Sandwich Workshop | Geneva, Switzerland | September 23-25, 2025

Bell Textron - Worldwide Support Facilities



CORPORATE FACILITIES

Corporate Headquarters
Fort Worth, TX

Bell Training Academy
Fort Worth, TX

Advanced Vertical Lift Center
Arlington, VA

FABRICATION AND R&D

Advanced Composites Center
Fort Worth, TX

Rotor Systems Center
Fort Worth, TX

Drive Systems Center
Grand Prairie, TX

Flight Research Center
Arlington, TX

AIRCRAFT ASSEMBLY

Aircraft Assembly Center
Amarillo, TX

Commercial Aircraft Assembly Center
Mirabel, Quebec, Canada

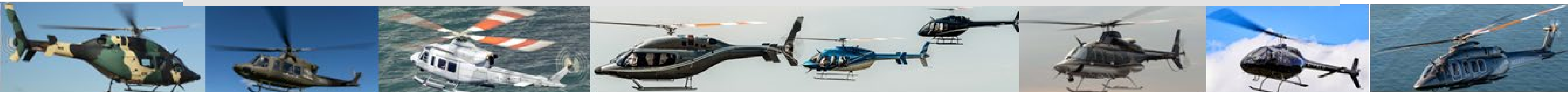
Textron International Mexico
Chihuahua, Mexico

SALES, SUPPORT AND SERVICE

Huntsville, AL
Ozark, AL
Patuxent River, MD
Broussard, LA
Miami, FL
Piney Flats, TN
Corpus Christi, TX
Washington, DC
New Delhi, India
Tokyo, Japan
Mexico City, Mexico
Abu Dhabi, UAE
Warminster, England
Singapore
Prague, Czech Republic
Amsterdam, Netherlands
Dubai, UAE
Calgary, Alberta, Canada
Valencia, Spain
Shanghai, China

GLOBAL LOCATIONS

Customer Service Facilities
Independent Representatives



BELL HEADQUARTERS
FORT WORTH, TX

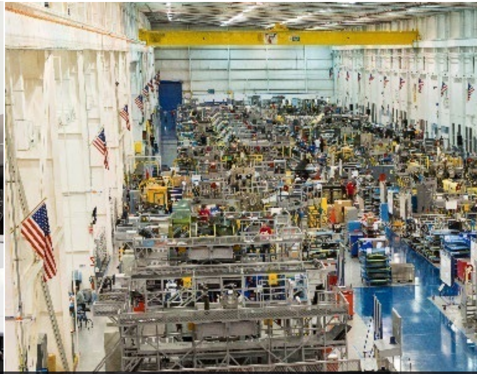
ADVANCED VERTICAL LIFT CENTER
WASHINGTON, D.C.

US FACILITIES

FLIGHT RESEARCH CENTER
ARLINGTON, TX

BELL PINEY FLATS
PINEY FLATS, TN

MANUFACTURING TECHNOLOGY CENTER
FORT WORTH, TX



BELL AMARILLO
AMARILLO, TX

BELL TEXTRON CANADA LTD.
MIRABEL, QUEBEC

BELL TEXTRON AUSTRALIA.
COFFS HARBOUR

Canada, Europe, and Asia Pacific

BELL PRAGUE
CZECHIA

BELL SINGAPORE
SINGAPORE

Industry-leading Producer of Commercial and Military Rotorcraft

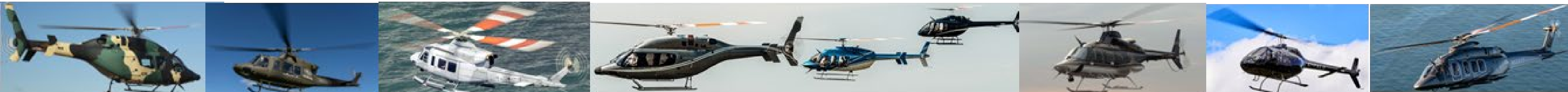
- World's first civil-certified helicopter
- Pioneered the revolutionary tiltrotor - winner of the US Army's Blackhawk replacement program (V-280)
- World-class customer service, serving customers flying Bell aircraft in more than 140 countries.
- *Popular Science* "Best of What's New in Aerospace" Award in 2019. Bell's Autonomous Pod Transport

Bell Model 47
First certified civil helicopter

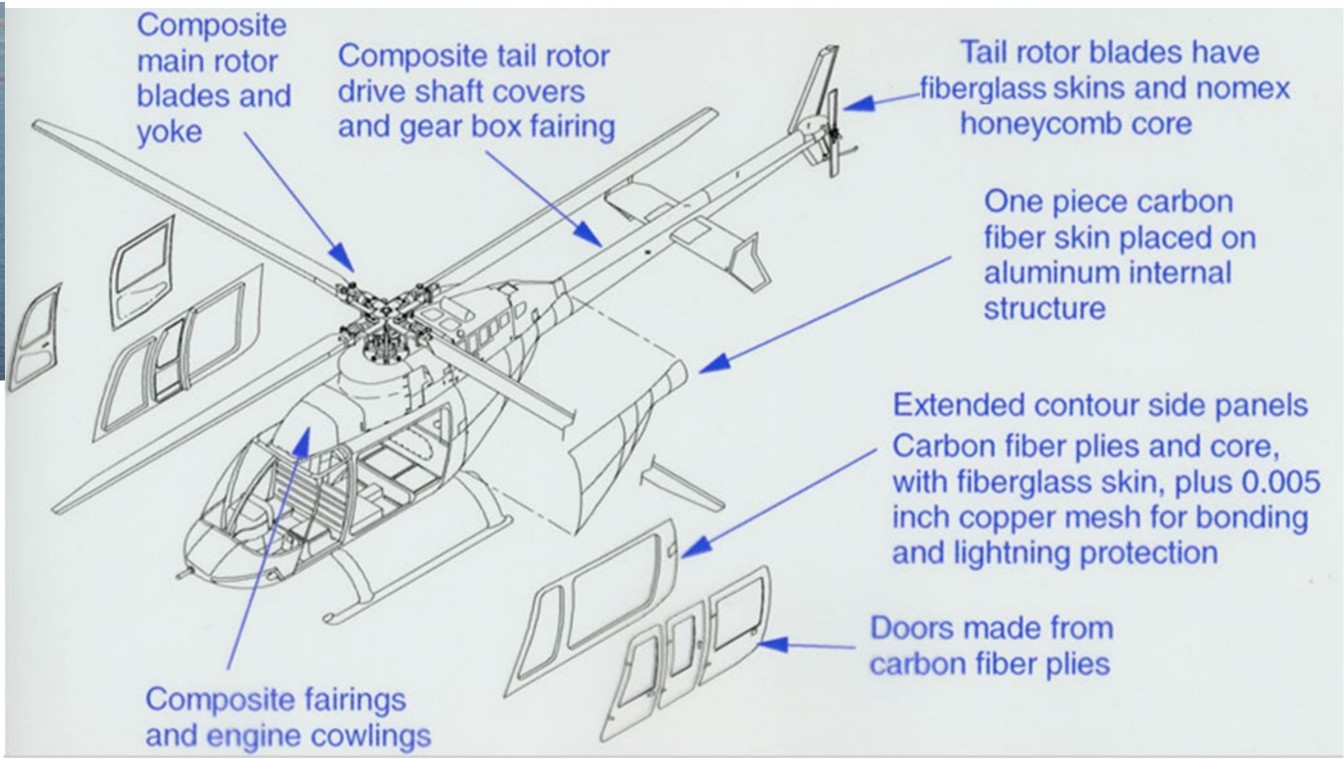
V-22 Tiltrotor

V-280 Valor

Bell 525 – Clean Sheet Design Certifying to §29.571[29-55] and §29.573[29-54]



Composites Structures (Example: Bell M407)



Bell 407 certified under FAR Part 27

Composites Structures (Example: Bell M429)

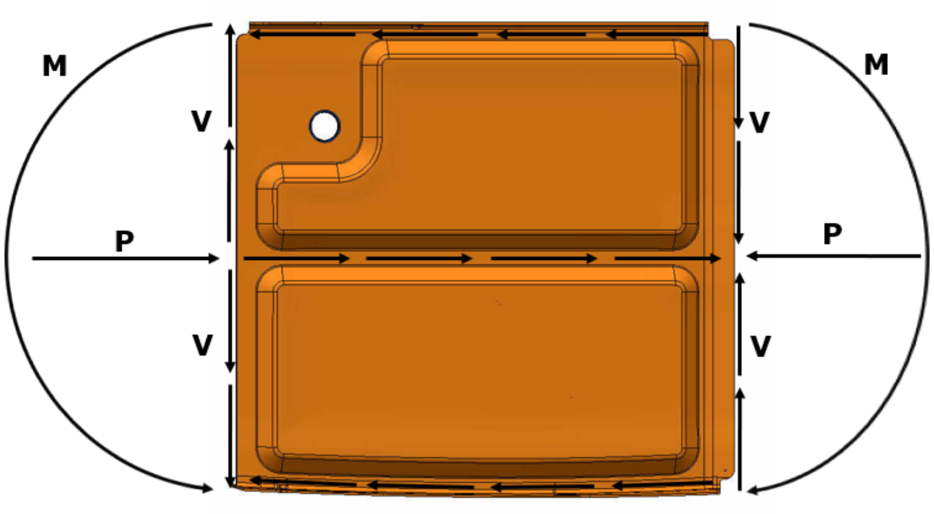
M429 Composite Structures (~80%)

- M/R Blades
- T/R Blades
- Yoke
- Cowlings
- Doors
- Side body
- Nose
- Floor
- Tail boom
- H-stabilizer
- V-stabilizer

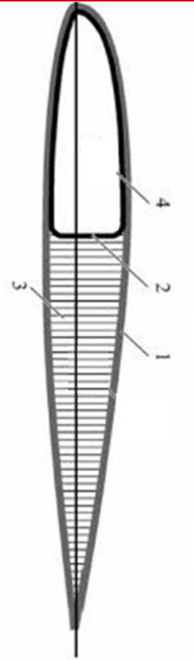
Bell 429 is certified under FAR Part 27

Primary Loads:

Typical A/F Loads, e.g., Compression, Shear, Bending, etc.



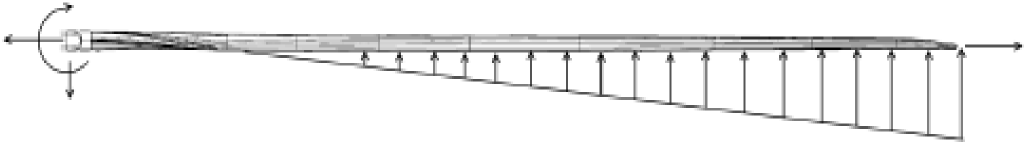
Typical Rotor Blade Composite Sandwich Structure

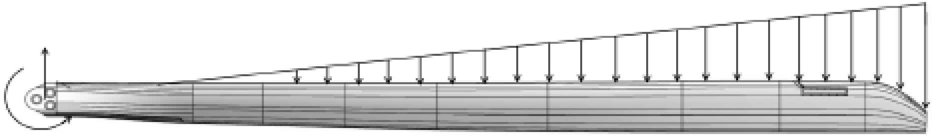


Typical Blade Cross Section

1. Composite Skin
2. Web
3. Core
4. Spar Tube
5. Abrasion Strip

Primary Loads: Centrifugal Force (CF), Beam and Chord Bending, Torsion





Reference: https://gallery.vtol.org

Helicopter vs Airplane

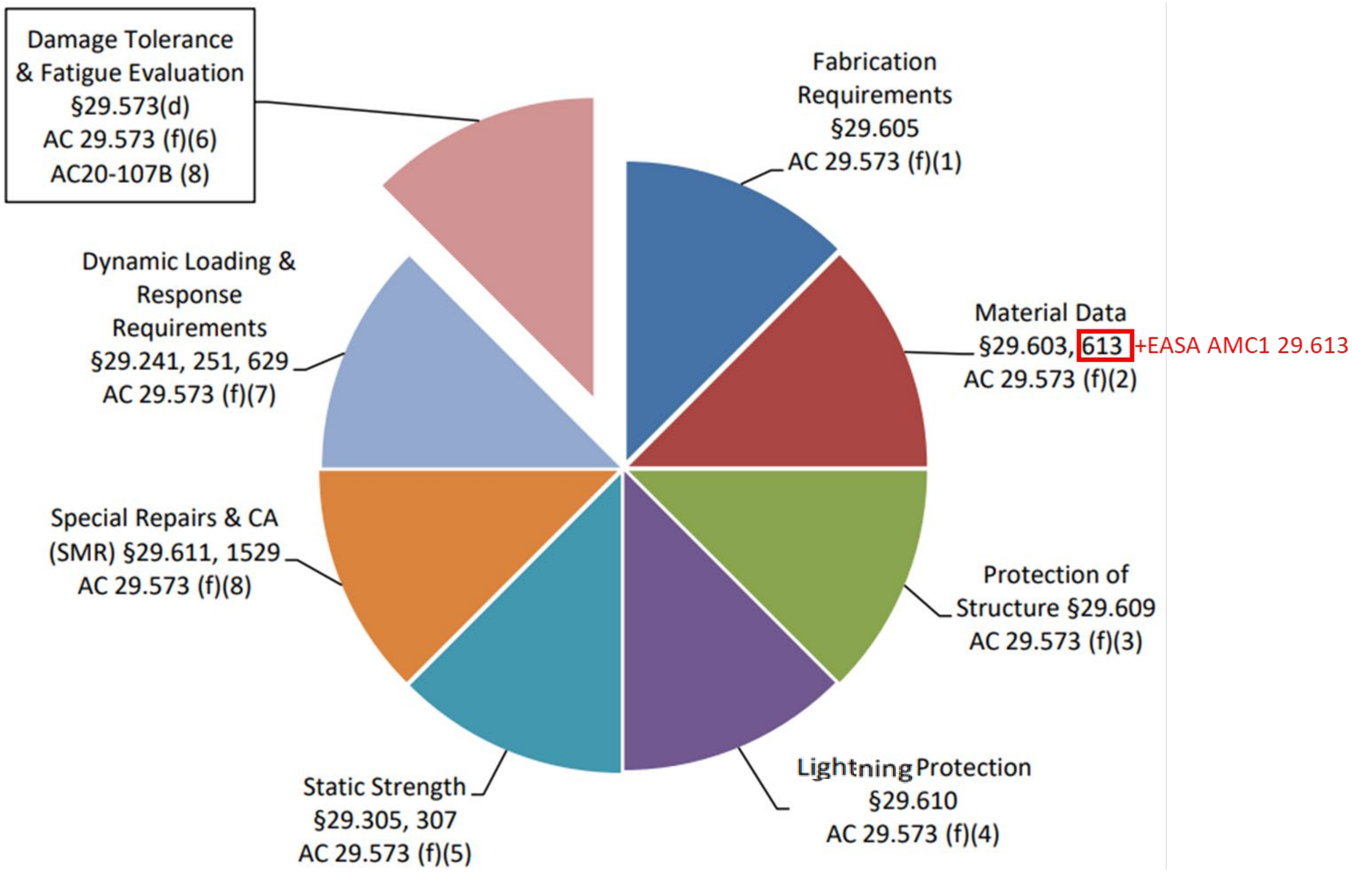
DT and Fatigue Feature	Airplane	Rotorcraft
Geometries	Large and nearly planar parts	Complex geometries of dynamic parts
Fatigue Loading	Occurs at takeoff and landing with a few smaller loading cycles in flight	Occurs during every rotor revolution in rotors and some areas of airframe structure. Airframe loading can respond to higher harmonic loads
Fatigue Cycles	Typical number of fatigue cycles in lifetime are usually 200,000	Accumulate 200,000 cycles in less than 10 hours
Damage Growth	Slow and gradual in the structure and inspections are practical before damage reaches critical size	Slow at beginning and rapid later due to high cycle loading
Design Consideration	Compression with damage	Damage tolerance safe-Life as a major consideration in the design

Reference: D.J. Reddy on DER Conference, May 2006

Airframe vs Rotors and Drives

Airframe	Rotor and Drives
Highly Redundant Structure	Single load path for each assembly as a whole.
Sensitive to Low-Cycle Loading (GAG, Power Thrust, Extreme Maneuvers)	Structures of individual component can be redundant structure in details
Areas adjacent to dynamic systems subject to significant high-cycle loading	Sensitive to both low-cycle and high-cycle loading
Subject to tension, compression, bending, and shear; any may have torsion	Subject to tension, torsion, bendings, and shear
Primary failure modes are compression/buckling and shear	Rotor components operate in tension dominated field due to CF. Drives composite component operate in torsion dominated field

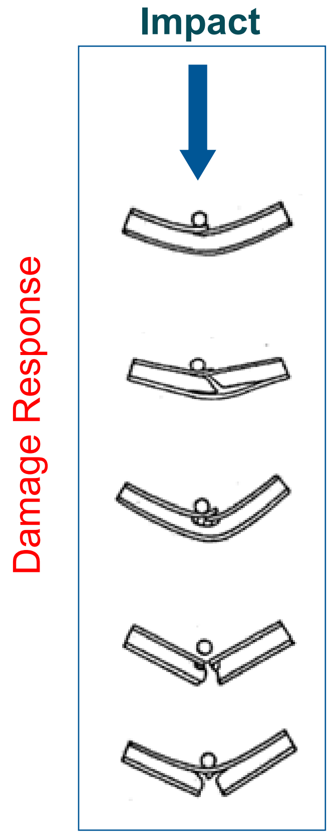
Certification Requirements for Damage Tolerance and Fatigue

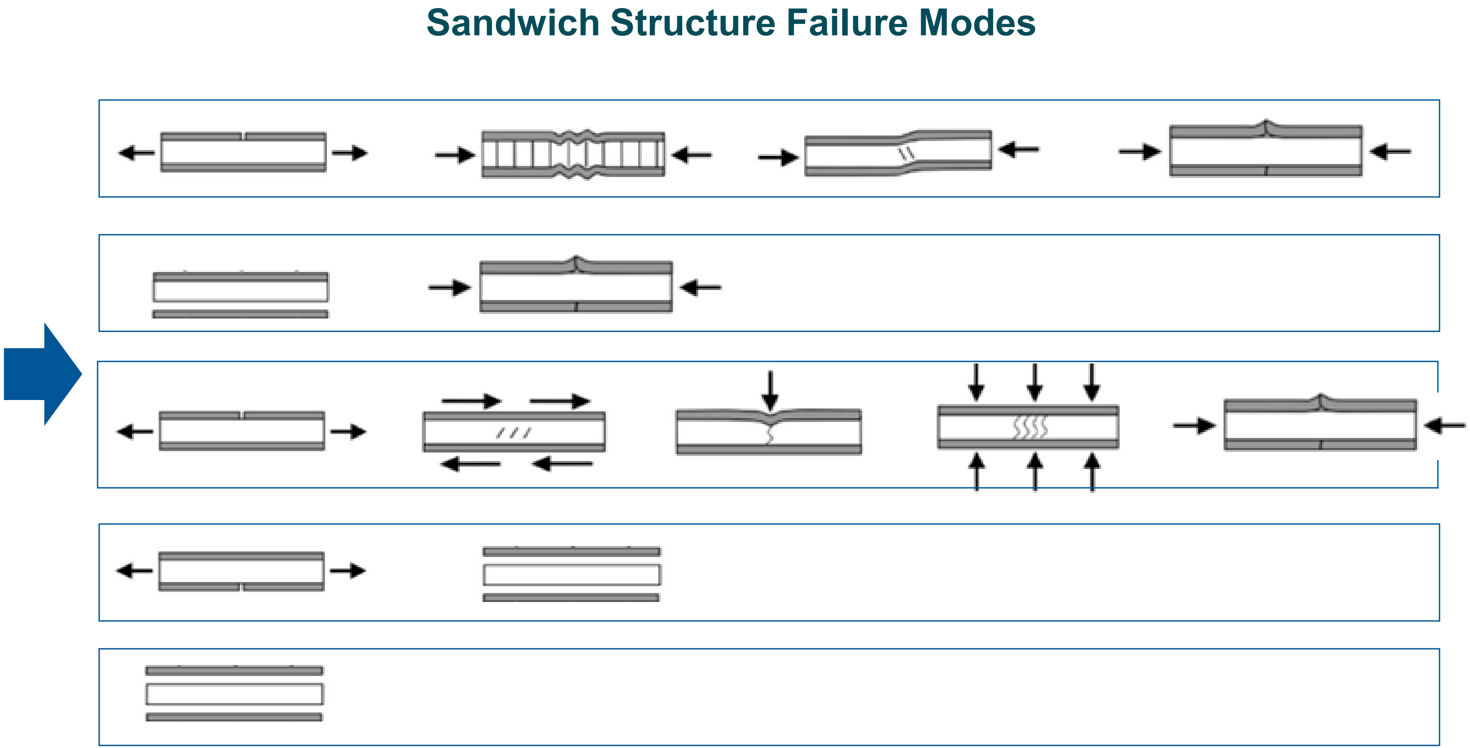


- Example shown: §29.573
- §27.573 is same
- Added on 27th Jan 2023:
  - EASA AMC1 29.613

    On material strength and design value of **Composite Sandwich Panel**

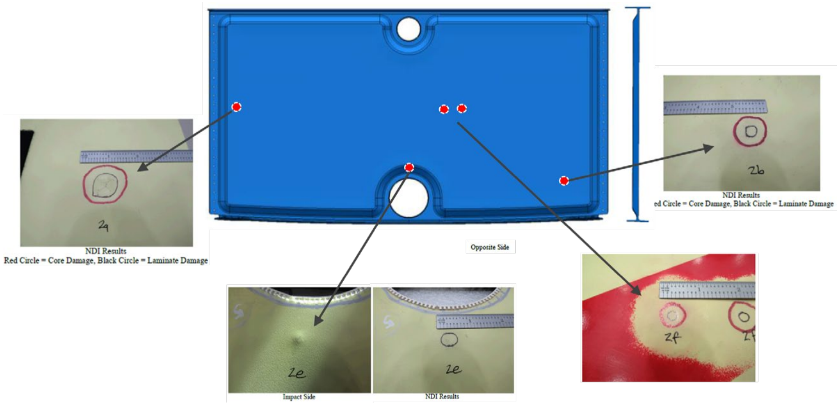
Typical Damage and Failure Modes of Sandwich Structure





Reference: CMH-17 Volume 6

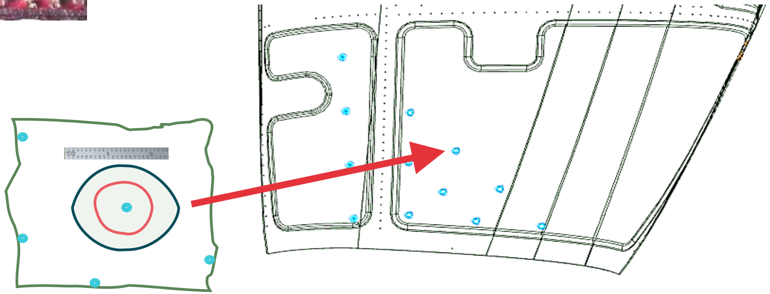
Threat Assessment and Damage Response in Airframe Composite Sandwich Panel

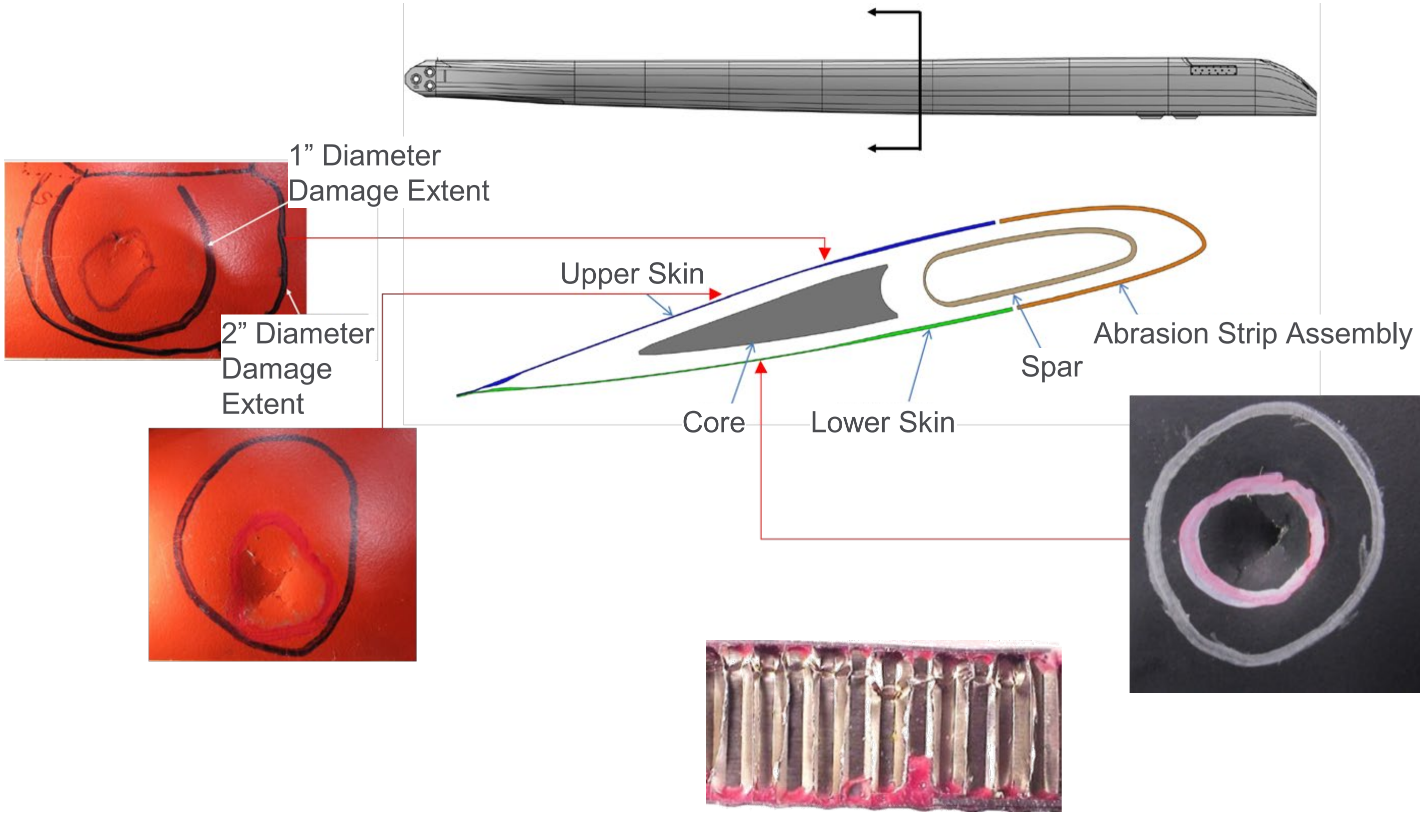


Large Diameter Impact

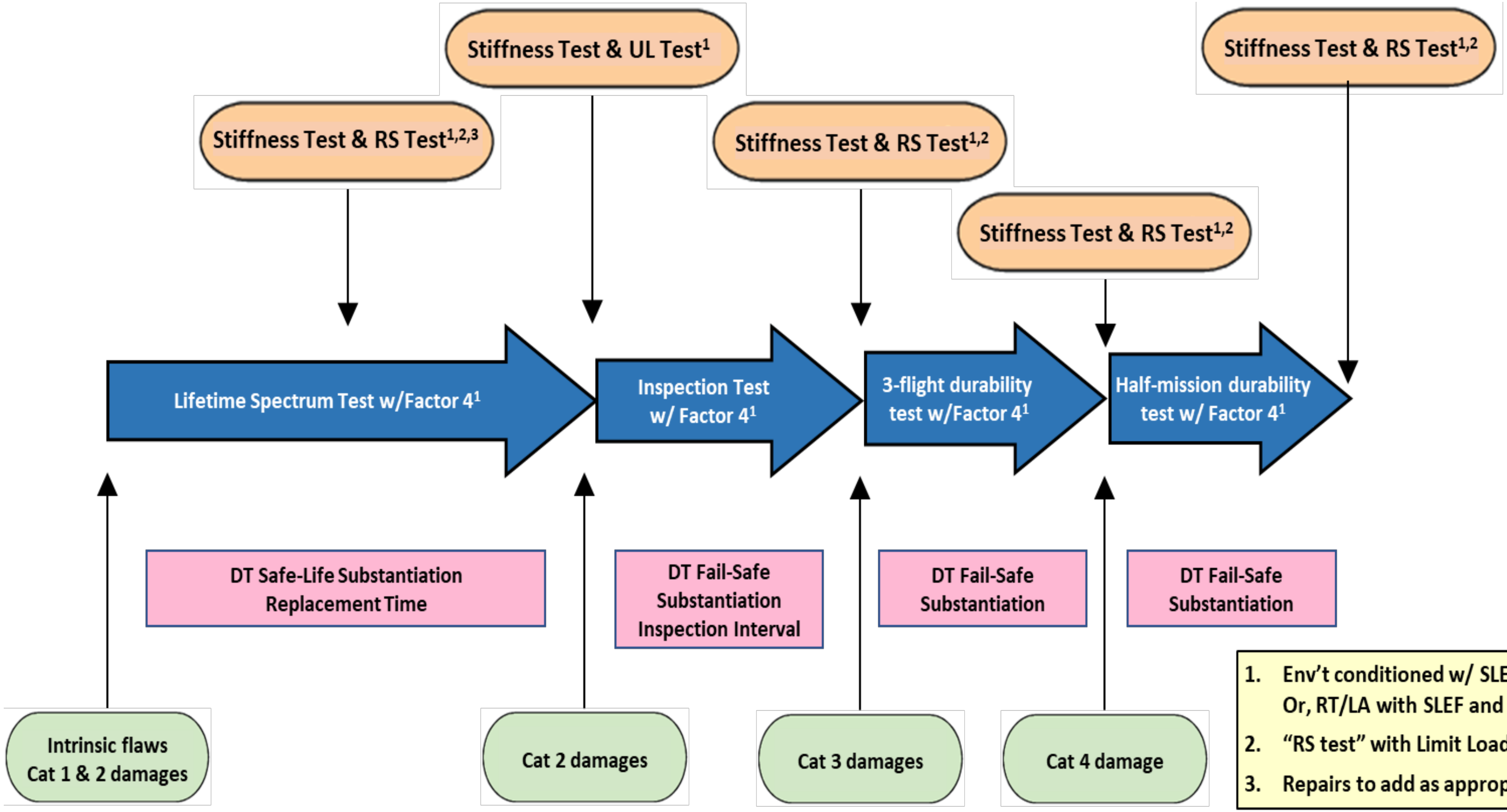
Core crush

- ❑ Threat Assessment
- ❑ Extensive impact survey on all PSEs
- ❑ Variables:
  - Impactor shape & size
  - Impact angle
  - Impact energy
  - Local geometries
  - Constraints



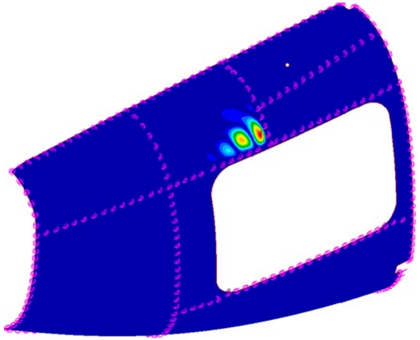

1” Diameter
Damage Extent
2” Diameter
Damage
Extent
Upper Skin
Abrasion Strip Assembly
Spar
Core
Lower Skin

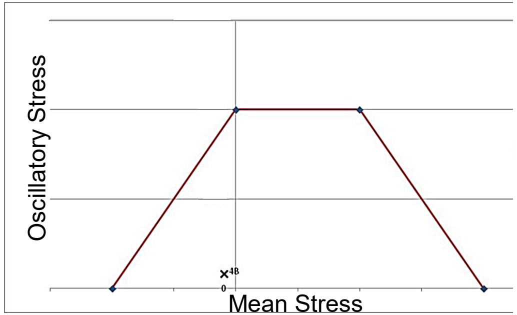
Substantiation per 27.573 and 29.573



1. Env't conditioned w/ SLEF Or, RT/LA with SLEF and ELF
2. "RS test" with Limit Loads
3. Repairs to add as appropriate

An Example: Airframe Sandwich Structure DT Fatigue Substantiation





Structure Static Sizing | Impact Survey | Test | Fatigue Loads or Strain

Structure RST assessment + Tool Validated by Testing

Progressive analysis approach validated by test evidence

Looking Forward

- <u>Fatigue</u> characterization of face sheet disbond
  - Constant amplitude loads
  - Variable amplitude loads

- Effect of <u>curvature</u> on buckling and fracture

- Effect of <u>environment</u> (temperature, humidity, moisture intrusion)

- Implementation of new available tools in new designs and substantiation effort

Take away slide

- Rotor sandwich components less likely to exhibit large disbonds from impact damages than airframe components
- No-growth design for rotor / drive and airframe components exposed to high cycle loads
- Impact damage response is greatly affected by local and global part stiffness
- More testing combined with reliable tools needed to optimize design for large disbond capability.
  - Conservative approaches / substantiation methods used until available