# Proof of Structure

Laurent PINSARD
Structures Senior Expert GA

**General Aviation Structures workshop**
16-17 October 2017

# Content

- CS XX.307 Proof of structure
- CS XX.XXX “must be tested”
- AMC & ASTM
  - AMC VLA.307
  - ASTM F3114 – 15
  - CM-S-006 Certification, Type Design Definition, Material and Process Qualification for Composite Light Aircraft.
- AMC 23.307 Proof of structure
  - Criteria for determination of Acceptable Means Of Compliance (simulations/analysis, tests or combination)
- CS & AMC 25.307 Proof of Structure
- Conclusion
- Examples

# CS 23.305 Strength and deformation

The structure must be able to support

(a) **Limit loads** without detrimental permanent deformation, and:

(b) **Ultimate loads** without failure.

**CS 305**
**Strength & deformation**

←

**CS 307**
**Proof of structure**

# CS 23.307 Proof of Structure

(a) Compliance with the strength and deformation requirements (**CS 23.305)** must be shown for each critical load condition.

- Structural analysis may be used only if the structure conforms to those for which experience has shown this method to be reliable.
- In other cases, substantiating load tests must be made.

(b) Certain parts of the structure must be tested as specified in Subpart D of CS-23.

**Analysis or Test**

# CS 23.XXX "must be tested"

- **Wing - CS 23.641 Proof of strength**
- **ASTM Designation: F3114 – 15. 4.9.1 Wings**
- **Control surfaces - CS 23.651 Proof of strength**
- **CS 23.723 Shock absorption tests**
- **CS 23.843 Pressurisation tests**
- **CS 23.562 Emergency landing dynamic conditions**
- **TSO qualification tests are required**

# CS-xx.307 Proof of Structure

- **CS-LSA ASTM Designation: F2245 – 12d (*)**
- **CS 22.307 Proof of structure**
- **CS-VLA.307 Proof of Structure**
- **CS 23.2235 Structural strength (Amdt 5)**
- **ASTM Designation: F3114 – 15. 4.4 Proof of Structure:**

## 3.2.3.3. Special factors for ultimate load testing

It is possible to certify small aircraft mainly based on static structural testing without detailed analyses of the complete structure and prediction of failure modes. (see also AMC 23.307)

# AMC 23.307 Proof of Structure

d) “Static testing to ultimate load may be considered an adequate substitute for formal stress analysis where static loads are critical in the design of the component. “

# CS XX.307 Proof of structure - Conclusion

- Same objective in CS 22, VLA, CS 23 Amdt <5 or 5
- New organization of the proof of structure (transfer to ASTM)
- When specified, “test must be performed”
- Factors to be considered when analysis only is used but **Test correction factors** should also be considered to cover process and material variability.
- CM-S-006 for CS 22 and VLA (for composites) certification possible based on *static structural testing without detailed analyses of the complete structure and prediction of failure modes…*

# CS XX.307 Proof of structure - Conclusion

CS xx.307 refers to CS XX.305 “Strength and deformation” (static)

Valid for metallic, composite, wood construction (including additive manufacturing?)

CS XX.307 “Proof of structure” (Analysis, test or both) can be extended with some adaptations to

- Loads (XX.301)
- **Fatigue (XX.571)**
- Flutter (XX.629)
- Dynamic impact (XX.631 Bird Strike)
- Crashworthiness (XX.562 seat)
- Fire condition (XX.853)
- High energy fragments (23.2240(d))

**Simulation/analysis Vs test (static, fatigue, dynamic, vibrations, flight…)**

# AMC to 23.571 and 23.572 Fatigue evaluation

**(Fatigue) Metallic pressurised cabin structures, metallic wing, empennage and associated structures**

Any method used in the analyses should be supported, as necessary, by tests or service experience.

The nature and extent of tests on complete structures or on portions of the primary structure will depend upon evidence from applicable previous design and structural tests, and service experience

# Proof of Structure. AMC 23.307

Determination of the

Acceptable

Means

Of Compliance

(simulations/analysis, tests or both)

AMC 23.307 Proof of Structure

# AMC 23.307 Proof of Structure

Means of Compliance by test or by analysis if the structure is of **similar characteristics** which have been previously been tested.

In deciding the need for and the extent of testing including the load levels to be achieved the following factors will be considered by the Agency.

- Test specimen
- Loads level
- Instrumentation

# AMC 23.307 Proof of Structure

a. The confidence which can be attached to the constructors' overall experience in respect to certain types of aeroplanes in designing, building and testing aeroplanes.

CONFIDENCE - RELIABILITY

*Establishing confidence is difficult as even the most experienced manufacturers experience test failures.*

*Experience needs to be properly recorded to be considered.*

# AMC 23.307 Proof of Structure

b. Whether the aeroplane in question is a new type or a development of an existing type having the **same basic structural design** and having been previously tested, and how far static strength testing can be extrapolated to allow for development of the particular type of aeroplane.

**SIMILARITY**

# AMC 23.307 Proof of Structure

c) The importance and value of detail and/or component testing including representation of parts of structure not being tested, and

**value of detail and/or component testing**
**“CLASSIFICATION OF THE STRUCTURE ”**

c) The degree to which credit can be given for operating experience.

**OPERATING EXPERIENCE (?)**

# AMC 23.307 Proof of Structure

a) Confidence, Applicant's overall experience

b) New or derivative **similar d**esign previously tested. Extrapolation

c) Detail and/or component testing (classification of the structure)

d) operating experience (*)

Issue. Quantification of these criteria

# Proof of Structure

## EASA Comments

- *Tests without instrumentation does not allow the validation of the analysis and subsequent potential for extrapolation.*

- *(*)Operating experience is very rarely a valid substitute for static strength justification by analysis and test.*

- *justification by test only can rarely address all the critical elements of the structure*

# AMC 23.307 Proof of Structure

- Analyses including finite element model used in place of tests must be demonstrated to be reliable for the structure under evaluation and the load levels that have to be covered. This would normally be provided by correlation with experimental results on the same structure or through comparison with other known and accepted methods and results or through a combination of both.

# AMC 23.307 Proof of Structure

- Finite element validation

Information on the application of methods such as Finite Element Method or engineering formulas to complex structures in modern aircraft is considered reliable only when validated by full scale tests (ground and/or flight tests)

# AMC 23.307 Proof of Structure

If not supported.

The manufacturer should establish a strength test programme. In the case of a **wing, wing carry through, fuselage and empennage** this will usually involve ultimate load testing.

**Structure to be evaluated.**

**wing, wing carry through, fuselage and empennage**

# AMC 23.307 Proof of Structure

Where proof of structure is being shown by an ultimate load test, the test article should conform to the same design specifications as the production article.

The manufacturer should ensure through his quality assurance organisation that the strength of the component tested conservatively represents the strength of the components used in production (serial) aeroplanes.

**CONFORMITY**

# AMC 23.307 Proof of Structure

Any changes to be evaluated according to 21A.33

**CONFORMITY - CONFIGURATION**

# AMC 23.307 Proof of Structure

ELEMENTS TO CONSIDER. PRIMARY STRUCTURE: WING, WING CARRY WING THROUGH, FUSELAGE AND EMPENNAGE…

- fem VALIDATED IF **CORRELATION** WITH EXPERIMETAL RESULT ON **SIMILAR** STRUCTURE OR
- STATIC TEST CASES TO LIMIT – ULTIMATE
  - CORRECTION FACTORS (VARIABILITY, ENVIRONMENTAL…)
  - CRITICAL COMPONENTS LOADED
  - CONFORMITY
  - CHANGE 21A.33

# Proof of Structure - Simulation

## Advantages

- cheaper,
- faster response cycle resulting in the possibility of analysing different designs rapidly (development phase).
- Simulations of  various Loads cases

## Issues

- Validation/correlation needed (past test experience)
- modelling errors not apparent,
- Manufacturing damages not incorporated

# Proof of Structure – Tests

## Advantages

- Should be able detect failure modes
- Identification of stress levels at critical locations
- Demonstrate the capability of the TC holder to produce specimen (organisation of the production far before TC)

## Issues

- Expensive, test organisation,
  - Specimen to adapt (boundary conditions), instrumentation
- Configuration to be frozen early enough or changes to be evaluated (Par 21)
- Same manufacturing process as for TC design production
- Corrective factors to be considered
- **Determination/selection of the relevant critical load cases (envelope ?)**

# Proof of Structure – Tests

Alternative for cost reduction:

- produce specimen and test close to TC with the risk to identify structural issues to be corrected (cost of the retrofit, communication…).
- Reduce the specimen definition to be tested

# CS 25.307 Proof of Structure

## CS 25.307 Proof of Structure

AMC 25.307 provides further guidance on defining the need for test for new types and developments of existing designs.

# AMC 25.307 CLASSIFICATION OF STRUCTURE

- Structure Classification (step by step)
  - New Structure
  - Similar New Structure
  - Derivative/Similar Structure

# AMC 25.307 “Proof of Structure ”

## Structure Classification.

| Classification | Accepted approach |
|---|---|
| New Structure | Analysis, supported by new strength testing of the structure |
| Similar New Structure | Analysis validated by previous test evidence and supported with additional limited testing. |
| Derivative/Similar Structure | Analysis, supported by previous test evidence |

# AMC 25.307 “Proof of Structure ”

**Test only.**

test load conditions should be selected to ensure all critical design loads are encompassed.

- For single load path structure which carries flight loads (including pressurisation loads), the test loads must be increased to account for variability in material properties.
- for metallic materials,
  - a factor of 1.15 applied to the limit and ultimate flight loads may be used (single load path).
  - If the structure has multiple load paths, no material correction factor is required.

# AMC 25.307 “Proof of Structure ”

AMC 23.307 is not very detailed; however, the AMC 25.307 provide a more robust approach for the classification of the structure and to conclude on the level of test or analysis  to be performed.

A pyramid of testing is recommended, especially for complex composite structures. (See also AMC 20-29)

A full scale structural test is an opportunity for the applicant to demonstrate its capability to produce an aircraft conforming to the TC design and perform/organise a test according to a certification test plan.

EASA
European Aviation Safety Agency

# Questions ?

Your safety is our mission.

An agency of the European Union