EUROPEAN AVIATION SAFETY AGENCY
AGENCE EUROPÉENNE DE LA SÉCURITÉ AÉRIENNE
EUROPÄISCHE AGENTUR FUR FLUGSICHERHEIT

Additive Manufacturing (AM)

EASA

EASA Meeting
Koeln
September 2016

S.Waite
Senior Expert - Materials
Certification Directorate

Your safety is our mission.

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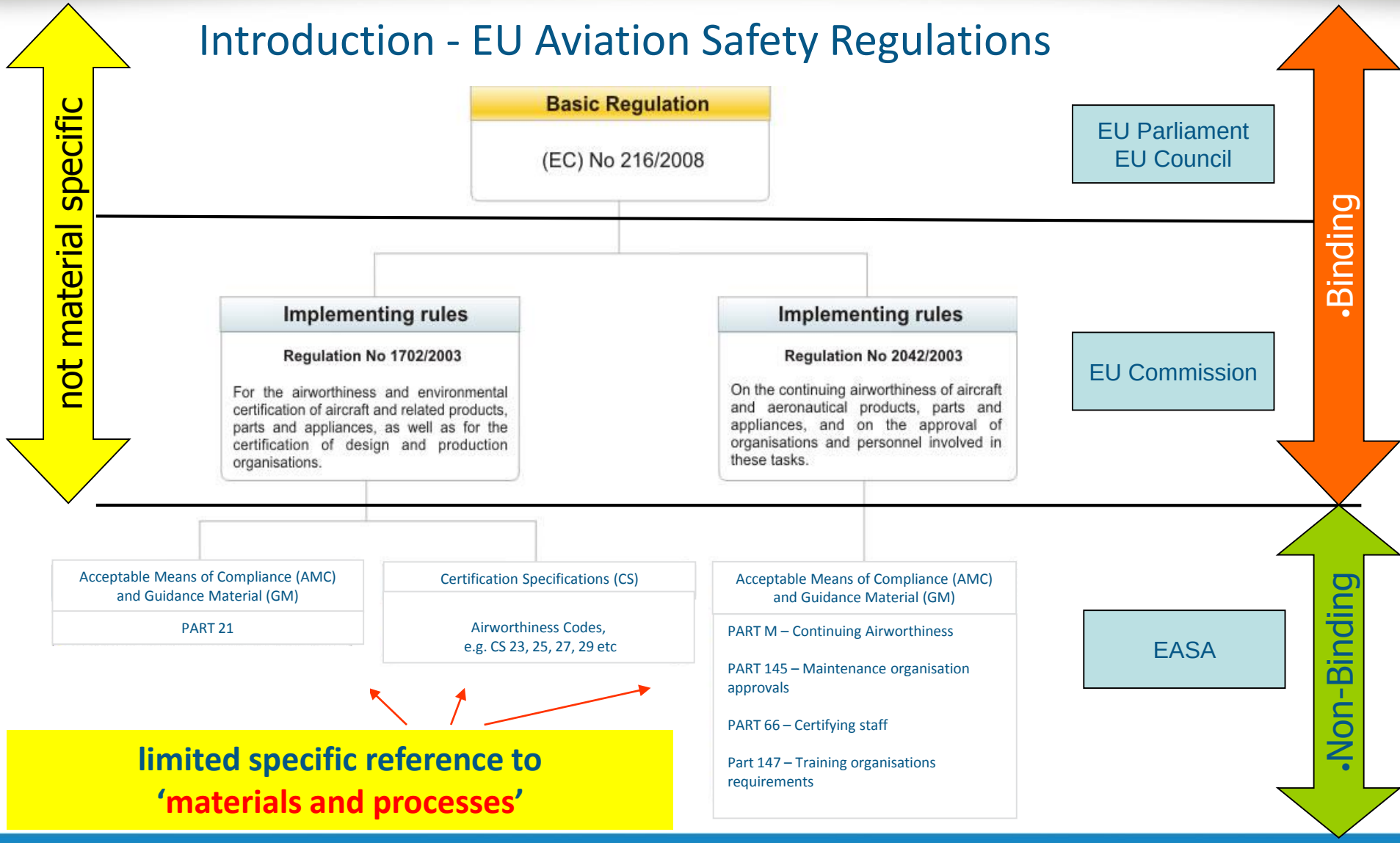
EASA AM – Introduction - rapidly developing technologies and applications :

- many methods, metallic and non-metallic
- rapidly increasing number of applications, i.e. baseline applications and repair
- significant commercial benefits, e.g. rapid prototype evolution, reduced part count etc
- potential safety considerations - are changes required in rules and/or guidance?
  - 'engineering properties', e.g. anisotropic, competing damage modes, repeatability etc
  - changes in relationship between design, production, continued airworthiness (CAW), more integrated than many typical metallic processes (some similarities wrt composites)
    - increasing process driven quality (relative to inspection)
  - pressure for utilisation in increasingly critical applications

Introduction - EU Aviation Safety Regulations



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EC No.216/2008 Annex 1**:**

1.a. Structures and materials: the integrity of the structure must be ensured throughout, and sufficiently beyond, the operational envelope for the aircraft, including its propulsion system, and maintained for the operational life of the aircraft.

21A.31 Type design … shall consist of:

1. The drawings and specifications, and a listing of those drawings and specifications, necessary to define the configuration and the design features of the product shown to comply with the applicable type-certification basis and environmental protection requirements;

2. Information on materials and processes and on methods of manufacture and assembly of the product necessary to ensure the conformity of the product;

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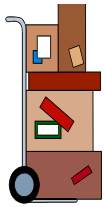
Material properties built into part, or repair…



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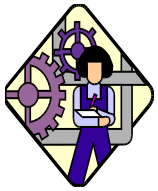

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Manufacturing Processes

Material Purchased

Internal Manufacturing Processes Controlled by site specific Process Documents

Production Certification (PC)

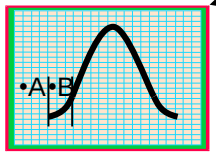
Material & Processing Standards

Material Specification

Process Specification

- close link between DOA, POA, and suppliers, mostly via specs

Engineering Processes



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Prediction of Material Behavior (Design Values)

Prediction of Structural Behavior (Design Analysis)

Verification & Certification Tests

Note: slide from a CMH-17 composite tutorial – similar for AM

Design philosophy changes:

Do not reduce the existing Level of Safety

- show 'equivalence' to existing technologies
- result of: experience, R&D, 'engineering judgement', reaction to incidents and accidents, and regulations existing at the time of certification, Type Certificate Holder in-house design practice

Maintain robust 'aircraft level' design concept

- address all identified threats, e.g. manufacture, in-service
- similar to established metallic structure, e.g. T. Swift philosophy etc
- local damage may be different, but structural level failure may be driven by the similar failure mode, e.g. buckling

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Standardisation of Certification Requirements Applicable to AM

- limited material specific specific rules/guidance
  (although significant to design and throughout CSs)

- governing rule is CS 2x.603:

CS 25.603: Materials (For Composite Materials see AMC 20-29*)

'The suitability and durability of materials used for parts, the failure of which could adversely affect safety, must…..'

- *be based upon experience/test*
- *conform to specifications (meeting design data)*
- *consider environmental effect (temperature, moisture etc)*

*AMC 20-29 - harmonised with FAA AC20-107B

CS 25.605: Fabrication Methods

(a) The methods of fabrication used must produce a consistently sound structure. If a fabrication process (such as gluing, spot welding, or heat treating) requires close control to reach this objective, the process must be performed under an approved process specification.

(b) Each new aircraft fabrication method must be substantiated by a test programme

CS 25.613: Mechanical Strength Properties and Design Values Materials

(a) Material strength properties must be based on enough tests of material meeting approved specifications to establish design values on a statistical basis. *(A and B-basis)*

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CS- E – different words, similar intent as CS 2x-603, 605

CS-E 70 Materials and Manufacturing Methods (See AMC E 70)

(a) The suitability and durability of materials used in the Engine must be established on the basis of experience or tests. The assumed design values of properties of materials must be suitably related to the minimum properties stated in the material specification.

(b) Manufacturing methods and processes must be such as to produce sound structure and mechanisms which retain the original mechanical properties under reasonable service conditions.

CS- E – different words, similar intent as CS 2x-613 (statistical credibility - safe-life - metal assumption)

CS-E 515 Engine Critical Parts

…the factors used to account for scatter should be justified. In order to utilise this approach the test should be designed to be representative of the critical engine conditions in terms of the temperature and stress at the specific features…

…test data should be reduced statistically in order to express the results in terms of minimum LCF capability (1/1000 or alternately -3 sigma). The fatigue life should be determined as a minimum life to initiation of a fatigue crack, defined typically as a crack length of 0.75mm.

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CS25.571: ***Damage-tolerance & fatigue evaluation of structure***

'(a) General. An evaluation of the strength, detail design, and fabrication must show that catastrophic failure due to fatigue, corrosion, or accidental damage, will be avoided throughout the operational life of the aeroplane…'

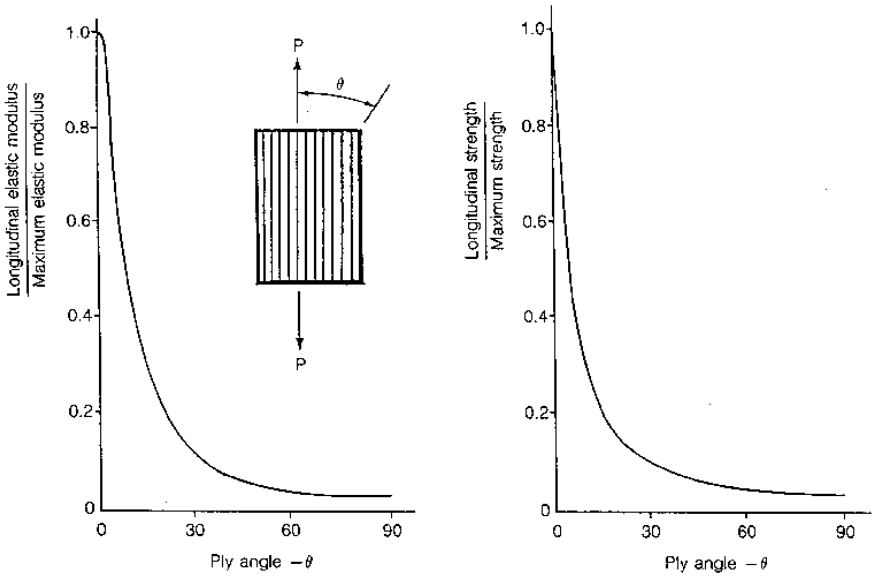
Environmental Damage - ED

Accidental Damage - AD

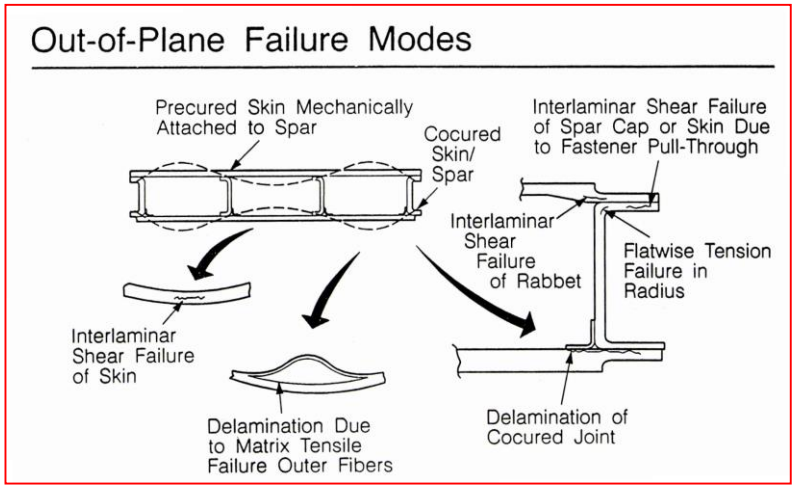
Historically: metal/fatigue/corrosion focused

What are the potentially significant differences between existing typical metallic structures and AM?

Anisotropy: Significant strength/stiffness reduction with orientation relative to load



Strength/Stiffness v Ply Angle
(non-dimensionalised)



Anisotropy: potentially difficult to predict:

- **failure loads**
- **damage modes**
- **damage locations**

Existing CS25 Structures Regulations of particular interest and potential relevance include:

CS 25.571: Damage Tolerance and Fatigue Evaluation of Structure:

'(3).....inspections or other procedures must be established as necessary to prevent catastrophic failure, and must be included in the Airworthiness Limitations Section of the Instructions for Continued Airworthiness required by CS 25.1529'

Does not need to be visual,
Note: 80-90% of inspections are visual
ref. also CS25.611

Does not need to be an 'inspection'

Notes:

1/ EASA does not approve inspection standards, but accepts them as part of a process, project etc - provided that they are shown to be validated, applicable, and repeatable

2/ technology and technology application changes must not reduce the existing 'acceptable level of safety'

Example AM challenge…*

CS 25.613: Mechanical Strength Properties and Design Values Materials

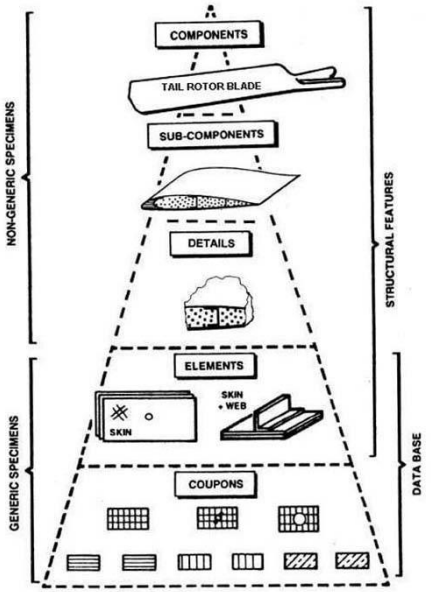
How do we statistically manage inaccessible free edges in complex laser melt parts?

- free edge coupons produced in parallel with parts

- coupons produced from part cut-up

- use higher pyramid component testing (small data set statistics?)

** similarities to how castings are addressed in CS25.621 'Castings Factors'?*



AMC 20-29 Figure 2 - Schematic diagram of building block tests for a tail rotor blade

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Example AM challenge – existing requirements/awareness**…*

PART 145.A.42 Acceptance of components:

'…organisation may fabricate a restricted range of parts to be used in the course of undergoing work within its own facilities provided procedures are identified in the exposition.'

AMC 145.A.42 Acceptance of components:

'All necessary data to fabricate the part should be approved either by the competent authority or the type certificate (TC) holder or Part-21 design organisation approval holder, or supplemental type certificate (STC) holder;'

* *AM similarities wrt composites*

** *applies to industry and regulators*

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*Example AM challenge – existing requirements/awareness***

PART 145.A.42 Acceptance of components:

'7. Examples of fabrication under the scope of an Part-145 approval can include but are not limited to the following:

a) Fabrication of bushes, sleeves and shims.
b) Fabrication of secondary structural elements and skin panels.
c) Fabrication of control cables.
d) Fabrication of flexible and rigid pipes.
e) Fabrication of electrical cable looms and assemblies.
f) Formed or machined sheet metal panels for repairs.

changed material:
changed damage mode/debris?
- consider downstream critical part consequences…

All the above fabricated parts, should be in accordance with data provided in overhaul or repair manuals, modification schemes and service bulletins, drawings or otherwise approved by the competent authority. Note: It is not acceptable to fabricate any item to pattern unless an engineering drawing of the item is produced which includes any necessary fabrication processes and which is acceptable to the competent authority.'

EASA AM: Strategy:

1 - Understand the technology / process / product and its actual, planned or potential uses.

2 - Identify potential safety / environmental risks.

3 - Define and implement means to mitigate risks working closely with industry and NAAs.

4 - Monitor evolution of technology / product / process and effectiveness of mitigation.

5 - Review and revise implementation of strategy as necessary.

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EASA current activities:

- EASA AM WG:

- Cert. Directorate (Chief Expert - Airframe)	R. Minter – richard.minter@easa.Europa.eu
- Structures	S. Waite (AM WG chair) – simon.waite@easa.europ.eu
	W. Hoffmann - wolfgang.hoffmann@easa.europa.eu
- Propulsion	M. Mercy - matthew.mercy@easa.europa.eu
- Systems	TBD
- Cabin Safety	T. Ohnimus - thomas.ohnimus@easa.europa.eu
- DOA	A. Enache - alexandru.enache@easa.europa.eu
- POA	D. Lamothe - dominique.lamothe@easa.europa.eu
- Maintenance	R. Tajas - rosa.tajes@easa.europa.eu

- Risk and Mitigation Matrix
- Certification Memo
- Workshops (first meeting - September 2016)
- Regular communication with other regulators

Risk and Mitigations Matrix:

Preliminary (initial) areas of risk list (under EASA AM WG review/development*):

Scope and definition of AM not standardised
New materials
Many process parameters to control (see Appendix)
Anisotropic properties of finished part
Variation in the types of AM equipment / processes and lack of standardization
Limited understanding of acceptable ranges of variation for key manufacturing parameters
Limited understanding of key failure mechanisms
Transfer from small scale manufacture to high levels of production
Lack of broad industry databases / allowables (each implementation is unique)
Development of capable NDI methods
Repairs
Current rules: Note: ARAC Composite and Metallics group also has to consider new technology in F&DT recommendations)
Insufficient guidance (Likely)
POA related
DOA related
DOA and POA link
Certification related
Higher risk of bogus parts

* including identification of existing mitigations and the need for new additional actions

Certification Memo: **Additive Manufacturing**

EASA Proposed CM No.: Proposed CM–S-008 Issue 01 (in CRD process)

Requirements:
CS X.571, CS X.603, CS X.605, CS X.613, CS-E 70, CS-E 100 (a), CS-P 170, CS-P 240, CS-APU 60, GM 21.A.91, 21.A.101, 21.A.133, 21.A.433, GM 21.A.435, 21.A.437, 21.A.447, 21.A.805, AMC 145.A.42(c)

Purpose/Scope: …provide guidance regarding regulator expectations relating to the usage of AM technologies in products (Aircraft, Rotorcraft and Propulsion) subject to EASA Type Certification

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CM:

EASA Certification Policy and Guidance for DOA and POA Holders

applicants to demonstrate:

- complies with appropriate CS's
- suitable for intended use
- source materials purchased to spec
- produce consistent product to process spec
- statistically significant design values wrt defined facilities/equipment
- control of equipment/process

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CM:

EASA Certification Policy and Guidance for DOA and POA Holders

use of AM:

- is a change of material or/and process iaw GM 21A.91
- in repair and repair design would normally be classified Major, applicants are advised to consult EASA when introducing AM in repairs including cases where they hold a privilege for repair approval.
- **Design Organisation Approval Holders** are advised to involve the Agency at the earliest opportunity during the development and implementation of AM. ….AM will be subject to increased oversight by the agency and that specific audits will be scheduled to examine the introduction and use of AM within the scope of the design organisation audit cycle. … audits may take place concurrently with the review of AM applications rather than post approval.

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CM:

EASA Certification Policy and Guidance for DOA and POA Holders

use of AM:

- Production Organisation Approval holders are advised to inform their respective competent authorities at the earliest opportunity before the implementation of AM processes. ...implementation of a new AM process by a POA holder is a change which may be identified as a significant change in accordance with Part 21.A.147 + GM

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Conclusions: AM is rapidly evolving:

- EASA does not approve materials or processes, but accepts them as part of a project - provided that they are shown to be validated, applicable, and repeatable

- Technology, and technology application, changes must not reduce the existing 'acceptable' level of safety

- EASA Working Group formed to review and assess risk, and risk mitigation, and to work with other regulators and industry (CM) to help ensure safe integration of the evolving technologies into aviation

Rules: EASA suspects that limited/possibly no rule change will be required (TBD)…

Conclusions: AM is rapidly evolving:

Guidance: some guidance change will be required, any need being a function of:

- criticality of applications
- identification of any common underlying philosophy development* associated with maturing technologies (icw international standards bodies etc, e.g. SAE, ASTM). It is impractical and inefficient for regulators to provide regulatory guidance regarding all and everyone of the many evolving methods

* it is understood that IP will not be shared. However, applicants are required to meet the requirements, e.g. show stable process, repeatable 'engineering properties' etc

Conclusions:

POA/DOA/Maintenance:

- possible need to increase awareness of closer relationship between design, production, continued airworthiness (CAW), more integrated than many typical metallic processes (some similarities wrt composites)
- need to increase awareness of existing rules, particularly at interfaces between design, production, and maintenance, e.g. link between non-TCH DOA, PART 145 (AMC 145.A.42 para.7), and the need for TCH data for extensive repair and 'replacement' (also similarities wrt composites)

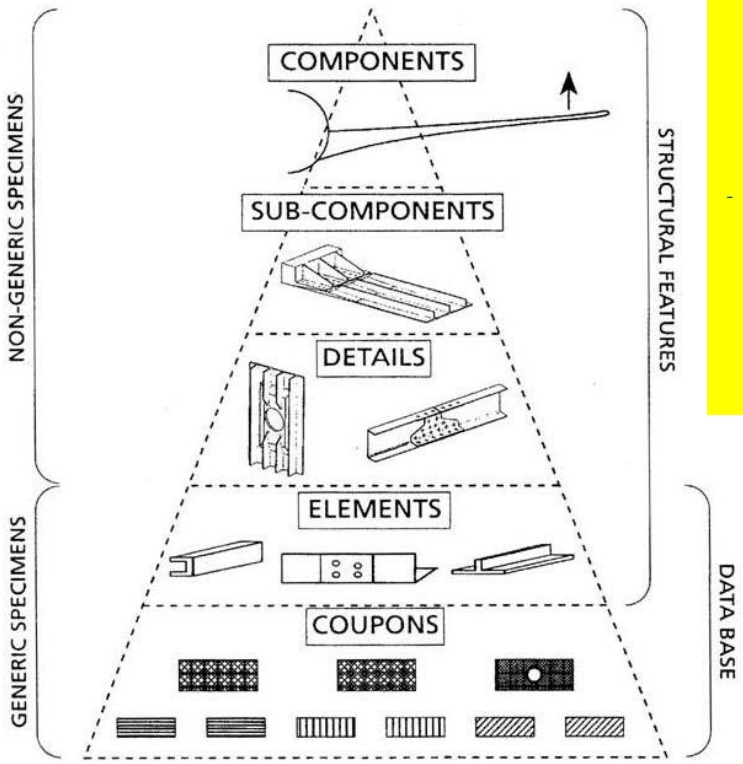
R&D:

EASA strategy to work with EU funded projects and industry to ensure regulatory resource is efficiently focused upon maturing methods and applications

Questions?

Support Slides

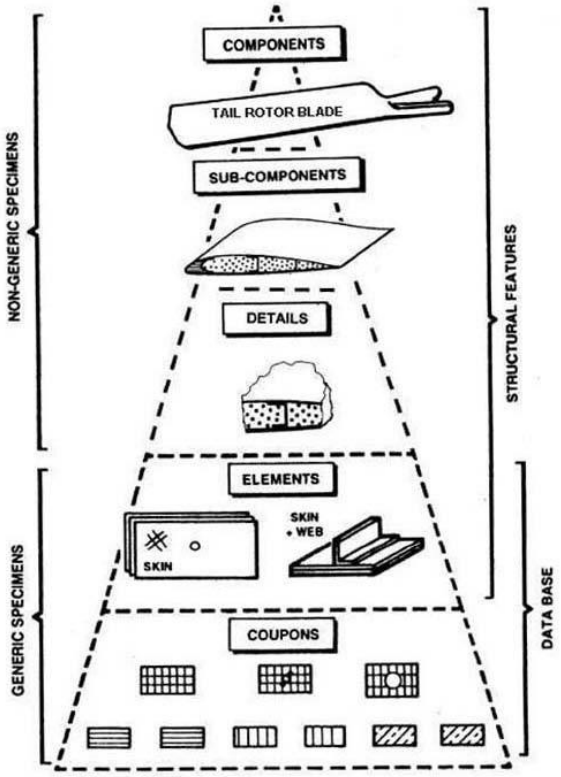
Substantiation: Test/Analysis Pyramid (Building Block)?



AMC 20-29 Figure 1 - Schematic diagram of building block tests for a fixed wing.

Static and F&DT substantiation in mid-upper test/analysis pyramid

- typically, representative Boundary Conditions are essential



AMC 20-29 Figure 2 - Schematic diagram of building block tests for a tail rotor blade

Design Philosophy: robust design concept, e.g. Large Damage Capability (LDC)

- to be similar to established metallic structure except:
  - potentially different/more competing damage modes,
  - some damage modes not so readily detected

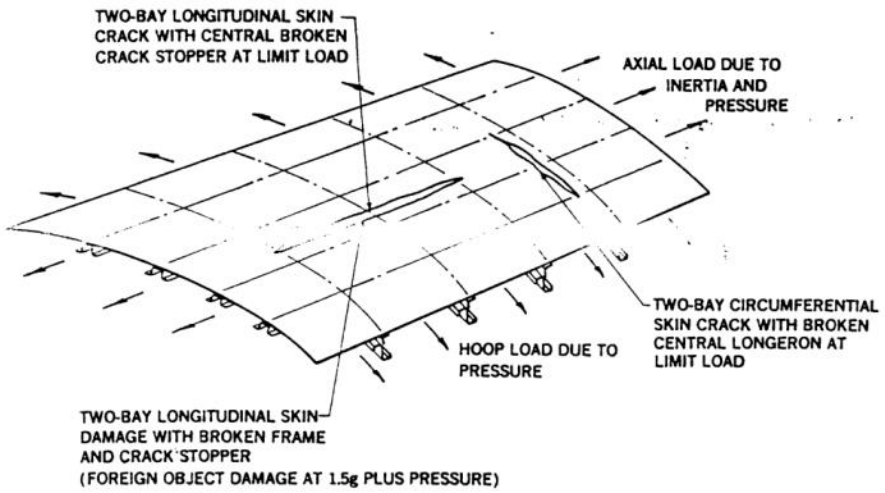
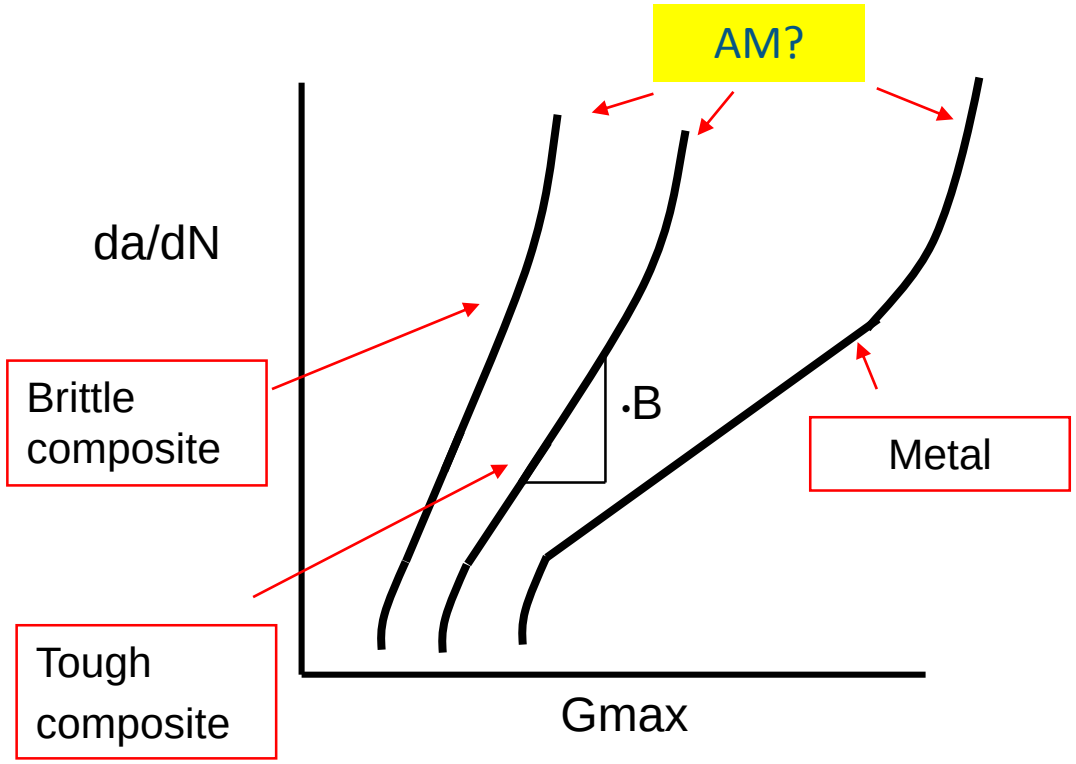


FIGURE 2. FUSELAGE DAMAGE TOLERANCE SIZES FOR STRUCTURAL DESIGN

Metal Design - Design for Redundant Structures' - T. Swift

- additional consideration may be required for technologies which change design concepts

Damage – Inspection and Damage Tolerance:



$$\frac{da}{dN} = AG^{B} \qquad G \propto P^{2}$$

$$\Rightarrow \frac{da}{dN} \propto P^{2B}$$

Material	B
Steel	1.6
Aluminium	2.2
Carbon/Thermoplastic	6.1
Carbon/Epoxy	12.2

Solution :- ensure that when damage is present, G is below a threshold value for crack growth

AM – potential for a broad range of Fatigue and Damage Tolerance philosophies
- safe life, flaw tolerant safe life, fail-safe, damage tolerant?

Composite Safety Issues

AMC 20-29 - Composites:

3. APPLICABILITY

This AMC provides Acceptable Means of Compliance with the provisions of CS-23, CS-25, CS- 27 and CS-29. Many of the concepts included in this AMC may also be applicable in part or in full to other CSs. However, when using this AMC as an Acceptable Means of Compliance for these other CSs, appropriate engineering judgement should be exercised and early agreement with the Agency sought.

This AMC applies to: applicants for a type-certificate, restricted type-certificate or supplemental type-certificate; certificate/approval holders; parts manufacturers; material suppliers; and maintenance and repair organisations.

– similar for AM

Composite Safety Issues

Standardisation of Certification Requirements for Composites

Composite Certification - existing rules and guidance

EASA AMC 20-29/FAA AC20-107B – 'COMPOSITE AIRFRAME STRUCTURE'

CONTENTS (expanded 12 to 36 pages, new sections – red)

1. PURPOSE
2. CANCELLATION
3. TO WHOM THIS AMC APPLIES
4. RELATED REGULATIONS AND GUIDANCE
5. GENERAL
6. **MATERIAL AND FABRICATION DEVELOPMENT**
7. PROOF OF STRUCTURE – STATIC
8. **PROOF OF STRUCTURE – FATIGUE AND DAMAGE TOLERANCE**
9. PROOF OF STRUCTURE – FLUTTER
10. CONTINUED AIRWORTHINESS
11. ADDITIONAL CONSIDERATIONS (crashworthiness, fire/flammability, lightning)

APPENDIX 1 Requirement Table
APPENDIX 2 Definitions
APPENDIX 3 Material Change

1984 document

applicable to PMC composite fan blade

– similar for AM

Composite Safety Issues

Safety Management System

Standardisation of Certification Requirements for Composites:

AMC 20-29 includes clear linkage between design requirements and many material, production, and continued airworthiness related requirements…

Regulations:	CS23	CS25	CS27*	CS29*
Material and Fabrication	603 613 619	603 613 619	603 613 619	603 613 619
Proof of Structure – Static	305 307(a)	305 307(a)	305 307(a)	305 307(a)
Proof of Structure – F&DT	573**	571	573	573
Proof of Structure – Flight	629	629	629	629
Additional Considerations				
Impact Dynamics	561	561	561	561

Works for CS-P CS-E

table continues with other requirements linked to flammability, lightning strike, production specifications, continued airworthiness etc.

* Rotorcraft

** Many similar code numbers, but some differences in content

– similar for AM

Production Organisation Approval PART 21, Sub. G:

21.A.147 Changes to the approved production organisation

(a) ….each change to the approved production organisation … significant to the showing of conformity or to the airworthiness … particularly changes to the quality system, shall be approved by the competent authority

GM 21.A.147(a) Changes to the approved production organisation – Significant changes

1 Changes to be approved by the competent authority include:

- significant changes to production capacity or methods…
- changes in the production or quality systems …important impact on the conformity/airworthiness of each product, part or appliance.

2 …ensure that changes do not result in non-compliance … competent authority and approval holder to establish a relationship … will permit the necessary evaluation work to be conducted before the implementation of a change