Composite Modification Workshop
Breakout Session: Materials and Processes

Wichita, KS
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Relevant Regulations for M&P

2x.601 General
2x.603 Materials
2x.605 Fabrication Methods
2x.609 Protection of Structure
2x.613 Material Strength Properties and Design Values

• Regulations 2x.603, 2x.605, and 2x.613 have interplay
  ➢ Compliance with one affects the others
  ➢ Many times compliance with these regulations is done concurrently
Modifying Structure

- **Material Requirements (2x.603)**

Modifications to composite structure may be limited to attachment of separate parts such that no new composite materials are incorporated onto the base structure. More commonly, however, modifications to composite structure involve creating new composite structure, such as with doubler plies, scarfed joints, or bonded assemblies. When new composite structure is fabricated, the modifier must recognize that they are creating the composite material at the same time they are creating the part. They are therefore responsible for creating appropriate material standards. A composite material standard has no significance without an accompanying process specification. This leads to coupling the requirements for material and process control.
Modifying Structure

• Material Requirements (2x.603)

Two considerations regarding materials used on modifying composite structures are to (1) control the material used in the modification and (2) ensure suitability of the modification material, including compatibility between modification materials and the base structure. Materials used to modify existing structure must conform to approved specifications as described in § 2x.603. These specifications may be industry standards (almost always the case for metal) or may be written by the modifier.

➢ Reference existing guidance for creating a composite material specification
Modifying Structure

• **Material Requirements (2x.603)**

The suitability of the material to withstand the operational environment must be assessed by the applicant. For example, for composite baseline structure, if the base materials were a 250°F cure resin system, and the modification involves using 350°F cure resin systems, the processing involved in base structure modifications (e.g., addition of bonded doublers) may damage the base structure. Consumable materials, such as release films and bagging materials must also be appropriate and compatible with the base structure. Many of these materials also require specifications for material procurement and proper process control.
Modifying Structure

• Material Requirements (2x.603)

If the base materials and associated processes are known, including specifications and other supporting data, compatibility tests may be limited to those needed for specific processing envelops (e.g., cure cycle details for new materials used as bonded doublers). If the base materials are not known, work is needed to identify the material and associated fabrication process through some form of verification testing. Tests to identify base materials include resin content, specific gravity/density, chemical analysis – typically with a spectrometer (e.g., FTIR, EDR), dynamic mechanical analysis (DMA), differential scanning calorimetry (DSC), and microscopic evaluation. The preferred method is to test samples of the base material taken from structure removed as part of the modification. Costly repairs may be needed to get sufficient quantity of the material from the base structure for reverse engineering testing. Best practice is to confirm the reverse-engineered material findings with materials listed in the maintenance instructions for the base structure. Once the base material is identified, raw materials will need to be purchased for purposes of qualification and specification development. If the base material identified has an international shared database, equivalency testing may be appropriate to use the available data and associated material & process specifications.
A note about shared databases

• Does this audience see any potential in the following:
  
  ➢ If we pool data from different equivalency programs of a given material, and show some level of insensitivity to processing, could we eliminate equivalency exercises?
    
    – Keep in mind failure of composite structure is normally due to BVID. The static and fatigue strength of the components are severely reduced by the presence of BVID and minor processing variations combined with BVID are within the scatter of BVID strength effects.
Modifying Structure

• Fabrication Methods (2x.605)

As discussed in the previous section, composite materials and processes are often coupled for purposes of ensuring a repeatable and reliable modification when developing designs and structural substantiation data. The challenge with reverse-engineered materials is that it is technically feasible to identify resin and reinforcement materials, but it is nearly impossible to reverse-engineer process instructions. This leads to a situation where it is most efficient and cost-effective to work closely with the OEM.
Modifying Structure

• Fabrication Methods (2x.605)

The methods of modifying existing structure must produce a consistently sound structure per § 2x.605. Composite modifications require close control and must be performed under an approved process specification. Processes must be shown to be repeatable and reliable. Long-term aging effects and environmental degradation must be accounted for. In some instances, processes that were effective during initial part manufacture may not be suitable for the modification.
Modifying Structure

• Fabrication Methods (2x.605)
• Should we include guidance on modification process specs like:
  ➢ Use witness coupons for bonded areas using base material substrate or strong rationale showing similarity and same failure modes.
  ➢ Control consumable materials and tooling as well to ensure repeatability.
  ➢ Consider thickest areas that will require thermocouple monitoring for complete cure assurance. Demonstrate heat blanket in-situ modifications with TC placement on similar stacking with similar heat sink as base structure using a subcomponent (Building Block-like approach)
Modifying Structure

• Fabrication Methods (2x.605)

If all details of the base structure fabrication processes are known, alterations may be made as needed for increased internal loads or other structural modifications without process qualification trials. If some or all details of the base structure fabrication processes are not known, appropriate process qualification trials will be needed to ensure sound structure. Of particular concern is the development of bonded structural joints where individual processing steps (e.g., surface preparation and cure cycle details) have unique relationships with the base substrate and any new bonded materials (doubler and/or adhesive).

➢ Where is guidance on process qualification trials?
Modifying Structure

• Protection of Structure (2x.609)

Modified structure must be protected against environmental deterioration. For metals, this most often manifests in corrosion. Galvanic corrosion is a concern where certain composite and metallic materials are placed in contact, such as aluminum and carbon. (See additional discussion under Installation Considerations) Modified composite structure must be properly protected against environmental effects such as UV degradation. This typically requires paint, primer, coatings, and other surface layers known to be compatible with a particular substrate and themselves.

Environmental protection is expected to be part of the modification design, and not something that is managed through inspections alone.
Modifying Structure

• Material Strength Properties and Design Values (2x.613)

Material strength properties and design values must exist for both the base material and modification materials. Metallic material strength properties and design values may come from established literature sources such as MMPDS. Composite strength properties and design values must be established on a statistical basis as described in § 2x.613. The applicant must take into account the operational environmental condition (including temperature and moisture) when defining design values for modification materials. For composite materials this includes identifying the effects of reduced strength and stiffness at maximum and minimum operating temperatures. Furthermore, composites are known to have greater statistical coefficients of variation than traditional metallic materials. Variability must be quantified and considered during structural substantiation.
Modifying Structure

- **Material Strength Properties and Design Values (2x.613)**

This regulation is most easily met when the original equipment manufacturer provides the design values for the base structure. When that is not the case, the applicant may apply reverse engineering practices as explained to identify the material and processes. Tests will need to be performed to define the upper and lower bounds of base material properties within statistical requirements. Note design values do not have to be generated at the lamina level for the base structure, but can be developed at higher levels of the building block, such as elements and details.
Modifying Structure

• **Material Strength Properties and Design Values (2x.613)**

Bonded joint design values should be characterized as a function of the adhesive, substrate material, surface preparation technique, processing (cure), and design details. In order to demonstrate redundant structure and use B-basis design allowables under § 25.613(b)(2), bonded structural details should be assessed with a complete bondline failure between arresting features, so that the remaining structure can sustain limit load.
Modifying Structure

• FAA Concerns
  ➢ Did we emphasize difficulty of reverse engineering enough?
  ➢ Can we provide means of reverse engineering?
  ➢ Should we further describe ways to develop design allowables (test matrices)?

• Audience Thoughts
  ➢ Appropriate level of detail?
  ➢ Did we identify all relevant considerations?
Modifying Structure

Did we address the challenges?

➢ Define what you are working with
  - Reverse engineer material
  - Reverse engineer process
  - Reverse engineer design values

➢ Define new material to be added
  - Material definition / control
  - Material process definition / control
  - Generate design values

➢ Determine compatibility with new material and process
  - Surface preparation, if applicable
  - Effect of new cure cycle, if applicable
  - Process control for drilling and similar procedures
  - Protection of Structure
  - NDI procedures
Composite Parts

• Material Requirements (2x.603)

The composite part manufacturer is also the material manufacturer. The part manufacturer must have material control under § 2x.603 for any part whose failure could adversely affect safety. This includes non-structural parts that have other regulatory performance requirements, such as flammability or electrical conductivity. Therefore, the composite manufacturer is always starting at a level that requires developing material properties and understanding the material system characteristics. To obtain statistically meaningful results and to gain confidence in the correlation between testing and analysis, the manufacturer must have sufficient material and process control to ensure statistically consistent material properties. This will ensure a reliable repeatable manufacturing process.
Composite Parts

• Material Requirements (2x.603)

Materials must be controlled for all composite parts whose failure could affect safety. This includes all parts (structural and non-structural) who have requirements for material properties such as strength, stiffness, conductivity, flammability, etc. This entails qualifying materials and controlling them under material specifications.
Composite Parts

• **Material Requirements (2x.603)**

Material qualification is the process of defining material properties. Standards must be set based on experience or test. Qualification must account for the effects of environmental conditions, such as temperature and humidity, expected in service. Qualification tests are generally performed as part of the process to develop design allowables, as required under §2x.613 for structures. However, material qualification should focus only on the material properties that are critical to the design. For non-structural parts this may include properties such as flammability or conductivity.
Composite Parts

• Material Requirements (2x.603)
The material specification is used to control procurement, shipping, and receiving of qualified materials. The material specification should require chemical, physical, and mechanical tests of each batch of material to be performed by the supplier and/or the part manufacturer at the time of receipt. Statistical sampling may be used when shown to be reliable. Guidance on material specifications may be found in FAA Policy Statement PS-ACE-100-2002-06. Although the policy is written for part 23 aircraft, it may be used as guidance for all product types.
Composite Parts

• Fabrication Methods (2x.605)

The type design of a composite part cannot be defined without a process specification. Additionally, composite part fabrication is a process that requires close control to produce consistently sound structure. The modifier must therefore create a process specification under §§ 21.31(a) and 2x.605. These are generally unique to each manufacturer, as there are few processing standards published by industry. The methods of fabrication used must produce consistent quality. Each new fabrication method must be substantiated by a test program.
Composite Parts

• Fabrication Methods (2x.605)

All composite materials and processes used in structures are qualified through enough fabrication trials and tests to demonstrate a reproducible and reliable design. The final mechanical behavior of a given composite material may vary greatly depending on the processing methods employed to fabricate production parts. The process specification must control the key process parameters that will govern final part performance. When generating a process specification, the manufacturer must consider the limits of the processing envelope and account for any changes in performance (e.g., environmental and variability effects) permitted by the process specifications.
Composite Parts

• Protection of Structure (2x.609)

Each part of the structure must be suitably protected against deterioration or loss of strength in service and must have provisions for ventilation and drainage where necessary for protection. Combinations of some metallic and composite materials require protection to prevent galvanic corrosion. Carbon and aluminum are one combination known to be susceptible to galvanic corrosion, which must be actively protected. Common practice is to use a layer of fiberglass between the carbon and metallic structure. It is insufficient to put those two materials in contact, and manage corrosion protection solely through inspections.
Composite Parts

• Material Strength Properties and Design Values (2x.613)

The applicant must establish statistical design values for structural parts (both critical and secondary structure) as described in § 2x.613. The applicant must take into account the operational temperature when establishing design values. For composite materials this includes evaluating the effects of reduced strength and stiffness at maximum and minimum temperatures within the operating envelope, including the effects of absorbed moisture. The effects of various paint colors and other design details that affect heat transfer must be considered when defining maximum operating temperature. As described in Policy Statement PS-ACE100-2001-006, for most paint colors, a default critical structural temperature of 180°F can be assumed without supporting tests or analyses. Dark colors or black, which may yield higher structural temperatures, are an exception.
How Basic Should Our Guidance on Issues Be?

FAA Thermal Analysis Research
Composite Parts

- **Material Strength Properties and Design Values (2x.613)**

Furthermore, composites are known to have greater statistical coefficients of variation than traditional metallic materials. The effects of variability must be quantified and later considered during structural substantiation. The effects of acceptable manufacturing defects (Category 1 damage, as defined in AC 20-107B), should be considered during the establishment of design values, to support future production and service events.
Composite Parts

- Material Strength Properties and Design Values (2x.613)

Bonded joints should be characterized as a function of the adhesive, substrate material, surface preparation technique, processing (cure), and design details. In order to demonstrate redundant structure and use B-basis design allowables under § 25.613(b)(2), bondlines should be assessed with a complete bondline failure between arresting features, so that the remaining structure can sustain limit load.

Although this policy applies to part 23 aircraft, it may be used for modifications on other product types.
Composite Parts

• Material Strength Properties and Design Values (2x.613)

  ➢ Material Properties for Critical Structure

If the part is critical structure and has a single load path, then A-basis design values need to be determined for the material system. If the installation includes redundant load paths, then B-basis allowables need to be determined. More specimens and batches are required for A-basis allowables than B-basis allowables. Material Equivalency testing is also acceptable if there is an existing database for the material.

The material qualification must account for the operational environment and any fluids the parts may come in contact with. Besides coupon tests at lamina and laminate levels, point design (e.g., subcomponent) tests may be needed for areas where it is difficult to predict loads. The point design and subcomponent test articles are larger than coupons and are representative of the aircraft. The values determined from these point design tests establish design allowables that may be used in analysis to determine margins of safety. Testing at a larger scale than the coupon level helps validate the repeatability and reliability of the fabrication process as well as determine environmental factors.
Composite Parts

• Material Strength Properties and Design Values (2x.613)

➤ Material Properties for Secondary Structure

If the composite part is secondary structure, B-basis material allowables need to be determined. The material qualification should focus only on the material properties that are critical to the design. As mentioned above for critical structures, coupon-level testing should account for the operational environment of the part and any fluids that the parts come in contact with. Equivalency testing is also accepted if the material has an existing database as described above for primary structures. In most cases structural integrity of composite secondary parts is only shown based on full scale testing with no analysis. Therefore in some cases no point design tests or subcomponent test are required if a full scale test is done.
Composite Parts

- **Material Strength Properties and Design Values (2x.613)**
  - Material qualification by a component supplier/contractor

Material qualification tests must be performed by the manufacturer of the parts which may be the applicant or a part supplier. Regardless of the source, applicants remain responsible for showing that all components installed are compliant with all applicable regulatory requirements. In the case where the applicant wishes to install a component designed by a component contractor, the applicant must have access to the data which details how the design values were derived and maintained to ensure applicability of that data to their product and to show compliance to the regulations.
Composite Parts

• Material Strength Properties and Design Values (2x.613)

➢ Environmental and Variability Factors

In accordance with §§ 25.603 and 25.613, the applicant must account for the statistical variability of composite materials and also for environmental effects. When certifying by test, applicants for critical structural components, as well as secondary structure, apply overload factors to assure structural strength in all operating conditions. When certifying by analysis supported by test, design values must be used that correspond to worst-case environmental conditions and statistically lowest properties while maintaining positive margins of safety. Overload factors may be determined by coupon or element level test. Coupon level tests for determining an environmental factor results in a higher overload factor versus a factor determined at the element level test. Typically environmental factors for secondary structural parts are determined at the coupon level.
Composite Parts

• Material Strength Properties and Design Values (2x.613)
  ➢ Environmental and Variability Factors

Environmental factors may conservatively be calculated as the ratio of the strength at the full-scale test environment divided by the strength at the worst-case environment. The variability factor may conservatively be calculated as the ratio of the mean strength divided by the A- or B-basis strength, as appropriate. The highest factors should be selected, unless the applicant can validate the actual failure mode and apply the environmental and variability factors that applies to that failure mode.
A note about point designs

- Point designed structural substantiation usually refers to a substructure that has different test requirements than full scale or coupons.
  - In the past, full scale required 1 test, point design required 3 tests, and coupons required A/B-basis testing, which could be as low as 12 coupons for b-basis.
  - If the point designed structure is referring to the three subcomponents for strength testing, the obvious requirement is to use the same materials/processes/tooling, as the full scale article. Deviations to "the same" would have to be evaluated on a case by case basis.
  - In some cases, we fabricate the test structure to the most adverse tolerances, if we believe this will cause a significant strength variation. Normally the adverse tolerances are a fatigue issue, but in rare circumstances, it can be a static strength issue.
Composite Parts

• FAA Concerns
  ➢ Appropriate use of critical/non-critical definitions?
  ➢ Does reader understand requirements for non-structural parts?

• Audience Thoughts
  ➢ Appropriate level of detail?
  ➢ Did we identify all relevant considerations?
Composite Parts

Did we address the challenges?:

- Relatively straight-forward – not much is affected by the application being a “modification” versus any new design criteria
  - Few differences from AC 20-107B
  - Material specification, process specification, protection of structure, NDI

- Unique information in design allowables (§ 2x.613)
  - Use of A- or B-basis
  - Point design allowables
  - Data necessary to support certification by test versus certification by analysis supported by test
Installation Considerations

• **Protection of Structure (2x.609)**

The modification must be suitably protected against deterioration or loss of strength in service and must have provisions for ventilation and drainage where necessary for protection. Combinations of some metallic and composite materials, such as with the installation of a composite part on a metallic baseline structure, require protection to prevent galvanic corrosion. For a thorough description of this phenomena, please refer to reference [xyz]. Carbon and aluminum are one combination known to be susceptible to galvanic corrosion, which must be actively protected. It is insufficient to put those two materials in contact, and manage corrosion protection solely through inspections.
Installation Considerations

• FAA Concerns
  ➢ Too repetitive?
  ➢ Include or not?

• Audience Thoughts
  ➢ Appropriate level of detail?
  ➢ Did we identify all relevant considerations?
Installation Considerations

Did we address the challenges?:

- Only additional unique consideration is protection of structure, i.e. galvanic corrosion
Further Discussions

• What has challenged the audience in M&P in the past?
  ➢ Inconsistencies in FAA oversight for a particular issue
  ➢ Expectations that seem beyond the regulations
  ➢ Areas of safety concern not properly addressed

• General thoughts on how to judge criticality?

• Specific examples of greatest relevance for Appendix?