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Derivation of Design Allowables at Airbus Filton Site

Background

- Over the last 25 years, the use of composite materials on Airbus aircraft has become steadily more widespread.
- Early uses such as fairings, spoilers and rudders for the A300/A310 have been steadily expanded and in-service applications for the A320 family, A330 and A340 now include primary structures such as the fin, horizontal tail plane, rear pressure bulkhead and keel beams.
- Data used for structural design and analysis must satisfy regulatory requirements.
- Design allowables are derived from generic specimens, i.e. elements and coupons, see Figure 1: Pyramid of test.
- The process selected to determine these data can have a significant effect on the material property values used in design.

The Test Matrix

- All materials used on Airbus aircraft must comply with the relevant Airbus material specification.

  The material specification defines:
  The types of test that must be carried out
  Laminate configurations
  Test methods to be used
  Environmental conditions
  Number of batches to be tested at each temperature and condition
  Number of coupons required per batch
- An extract from a typical material specification is shown in table 1.

Statistical Reduction of Test Results

- Once the testing has been carried out, statistical analysis is carried out in line with the airworthiness requirements to produce statistically-derived values.
- To remove the effect of variability in the coupon manufacture, some properties have the raw data normalised to a nominal cure ply thickness.
- Sample size has a significant effect on the B-basis value. For some properties, it may be possible to pool data from several batches and/or conditions. To pool the data:
  - the equality of variance of the raw data is checked – if this test is passed then the data can be considered to be from the same population and can be pooled.
  - where the data can be pooled, the individual results within a batch are normalised to the mean value for that condition.
  - if equality of variance test is failed then combinations of batches are compared to see if they can be pooled (e.g. if there are five batches from one environmental condition).
- The statistical method used depends on the number of batches and coupons in the population.
  - For single batch data, the Small Sample method is used for single-batch data, or where a batch-to-batch variability test (Analysis of variance) is failed.
  - For multiple batches conduct a batch-to-batch variability test (Analysis of variance):
    - Fail - use Small Sample method on each batch separately.
    - Pass- 18 or more results – use MIL-HDBK-17; Fewer than 18 results – use Small Sample method.

Determining Design Allowables for the material

- Engineering Judgement is applied to the statistical values calculated. The trends across different environments of the mean test data are reviewed for to identify any anomalous results.
- For Moduli and Poisson's ratio:
  - Where the difference in results are negligible across the range of environments, or if there are outiners identified (using AGATE process) and removed from the sample, the design value is the mean of all the environment value.
  - Otherwise the design values are determined for each environment separately.
- For Strengths:
  - The design allowables for any laminate tests carried out are compared with the predicted laminate properties using a laminate analysis calculation and the lamina properties. If the mean predicted strength is greater than the mean qualification test data, the ply data is modified such that the predicted laminate properties are the same as the test results. This ensures that either the lamina or laminate design allowables are consistent and either can be used in the design as appropriate.
  - For some materials, Environmental Knock-down Factors (EKDF) and B-basis Knock-down factors (K_B) are known from past experience. Where this is the case, the RT/AR data is used as a reference with the EKDFs and compared to the design allowables determined from the test results and the lowest factor is used.
  - Where EKDFs are not available, these are then determined using the calculated design allowables in conjunction with any suitable historic data. The EKDF is calculated for a type of failure mode, e.g tension, using all properties where there is an appropriate failure mode, e.g. tensile strength in 0° and 90° directions; plain, open-hole and filled hole tension results. The EKDF is the lowest factor from these.

Airworthiness Requirements

- In order for an aircraft to gain its Certificate of Airworthiness, the manufacturer must demonstrate that the relevant Airworthiness Requirements are met.
- The requirements are defined in JAR 25.613 Material Strength Properties And Design Values.
- Specifies the level of statistical confidence required for any design allowable value used.
- For redundant structure, in which the failure of individual elements would result in applied loads being safely distributed to other load carrying members, 90% probability with 95% confidence (see figure 2).
- All stress allowables must take into account the effects of temperature and environment (see figure 3).

Figure 1: Pyramid of Test

(Taken from MIL-HDBK-17F)

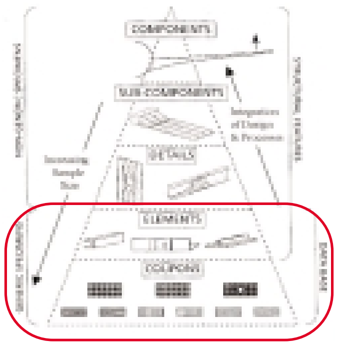

Figure 2: Normal Distribution Curve

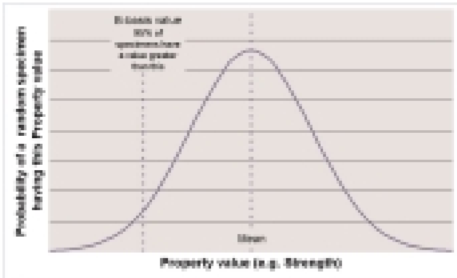

Figure 3: Effect of Environment

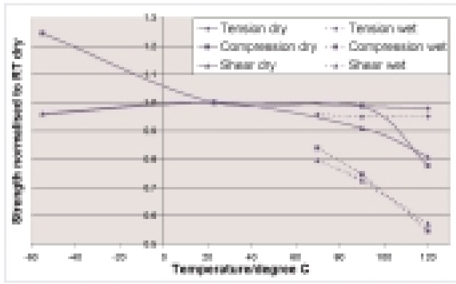

Table 1: Extract from typical test matrix

Properties	Number of batches to be tested normally six specimens per batch						
	Test Conditions						
	Dry				Wet (70°C/85% r.h.)		
Glass transition temperature	5				5		
	-55°C	RT	70°C	120°C	RT	70°C	90°C
Tensile Strength (0°)	1	5	1			1	1
Tensile Modulus (0°)	1	5	1			1	1
Poisson's Ratio (0/90°)		1				1	1
Tensile Strength (90°)	1	1				1	1
Tensile Modulus (90°)	1	1				1	1
Compression Strength (0°)	1	5	1			5	5
Compression Modulus (0°)	1	5	1			5	5
Compression Strength (90°)		1				1	1
Compression Modulus (90°)		1				1	1
In-Plane Shear Strength (45°)	1	5	1	1	1	5	1
In-Plane Shear Modulus (45°)	1	5	1	1	1	5	1
Interlaminar Shear Strength (0°)	1	5	1	5	1	5	5
Compression After Impact		5				5	5
G_{1C}		3			1		1
G_{2C}		3			1		1

Normalisation of data

- Scatter in the data may be due to variability in the material e.g. prepreg tape or in the manu facture e.g. coupon.
- Variability in tape – material scatter and it is the effect of this the B-basis allowable takes into account.
- Variability in the coupon manufacture does not need to be included and so this effect is normalised to a given nominal Volume Fraction (Vf) or Cured Ply Thickness (CPT).
- In general, properties that are fibre-dominated are normalised.
- Values are normalised using the following equation:

$$\text{Normalised value} = \frac{\text{test value} \times \text{measured thickness}}{\text{nominal thickness}}$$

Small Sample Method

- Method has been proposed for inclusion with MIL-HDBK-17.
- Assumes a normal distribution and a known coefficient of variation.
- The B-basis value for a small population is therefore calculated as follows:

$$V_B = \bar{V} \times \frac{1-k_b \times Cv}{1+Conf \times \frac{Cv}{\sqrt{n}}}$$

Where:
$\bar{v}$ mean value
n number of specimens
k_b = 1.2816, i.e. based on the use of a population
$Conf$ = 1.6449 for a 95% confidence level
C_v = coefficient of variation for the population

MIL-HDBK-17 Method

- The process outlined in MIL-HDBK-17 is:
  - Test for outliers (further investigation may allow removal of outliers).
  - Test for batch-to-batch variation – if so, use ANOVA method.
  - Test single groups for outliers (further investigation may allow removal of outliers).
  - Test for Weibullness – if so, use Weibull method.
  - Test for Normality – if so, use Normal method.
  - Test for Lognormailty – if so, use Lognormal method.
  - Use Non-Parametric method.

Determining Design Allowables for a group of materials

- For supply and cost reasons, it is necessary to be able to use multiple suppliers for materials.
- A material Group consists of materials that are similar in type and property;for instance 180° Cure Standard Modulus Carbon Fibre Epoxy Prepreg.
- The design must allow for any of the materials within the Group to be used on the aircraft.
- The Allowables for a given property are based on the property value from each member of the group.
- For Strengths:
  The B-basis design allowable for the group is the minimum value from the group; the mean design allowable is the mean associated with that B-basis design allowable.
- For Compression Modulii:
  The Mean design allowable is the average from all the suppliers.
  The B-basis allowable (used for buckling design calculations) is determined by applying the lowest KB factor from all the environments to the Mean as above.
- For other Modulii and Poisson's Ratio:
  The Mean design allowable is the average Modulii from all the members of the group. (B-basis not required)

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