CERTIFICATION PROBLEMS FOR COMPOSITE AIRPLANE STRUCTURES

Daniel CHAUMETTE

AVIONS MARCEL DASSAULT-BREGUET AVIATION

92 214 SAINT-CLOUD - FRANCE

ABSTRACT

In the last ten years the AVIONS MARCEL DASSAULT-BREGUET AVIATION have flight tested a number of aircraft components in composite materials.

These components went through a certification process (for civil airplanes) or qualification process (for the military) and a philosophy has been developed in FRANCE, as in some other european countries and the U.S.A.

In a first section this paper gives a short history of the regulation for composite material airframes, leading to a common document for application of the basic regulations (FAR in the U.S.A., JAR in EUROPE) to civil transport airplanes.

In a second section, some details will be given on the interpretation of the regulations for two important issues on composite structures :

- problems of damage tolerance of composites, in particular impact damages

- problems related to the scatter on the characteristics of composite materials and its consequences on design allowables and the requirements on static tests.

1 - BACKGROUND

The last decade had seen the introduction in service of high performance composite materials on airplane structures, both civil and military.

One typical example of this evolution is the work done at Avions Marcel DASSAULT-BREGUET AVIATION. Figure 1 is showing all the flight articles since the first experimental MIRAGE 3 rudder in 1975 to the ACX experimental fighter to be flown in 1986. On the civil side two significant steps are the certification and production of FALCON 50 carbon fiber ailerons in 1978 (200 shipsets produced) and the experimental carbon fiber wing for the FALCON 10.

During that period one of the problem was for AMD/BA (as for any other company) the definition of the certification philosophy applicable to composite structures, as the basic regulation, valid for metallic structures, did not cover some special aspects of composites.

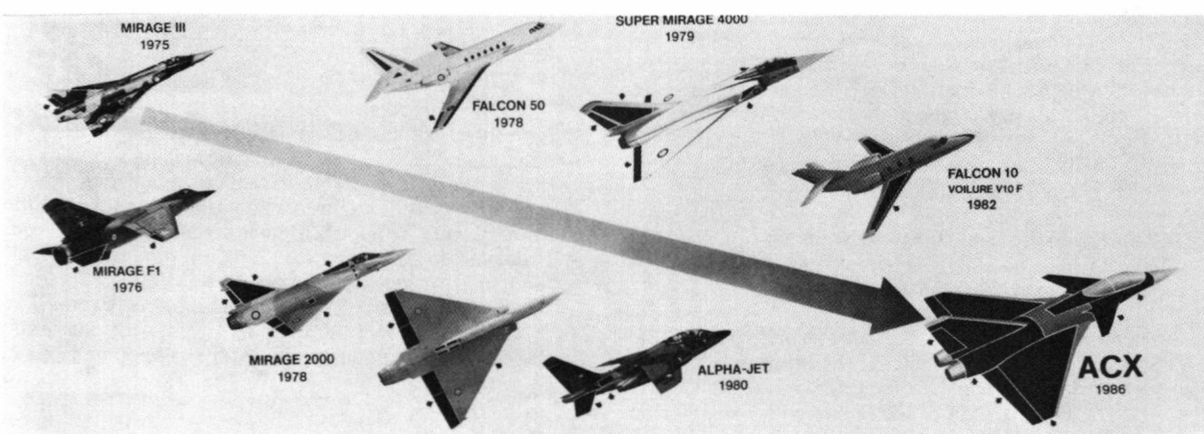

FIGURE 1 : COMPOSITE PROGRAMS OF AMD/BA

Extensive discussions on rulemaking did take place between the french industry and french authorities. Later these discussions extended to the european level, and subsequently became transatlantic for the definition of the new FAA Advisory Circular AC 20.107.

In this paper a first section will give an history of the regulations governing composite structures.

A second section will present the philosophy of AMD/BA on two problems of composite structures :

- damage tolerance after impact
- scatter in the static strength and the major fatigue test.

2 - A SHORT HISTORY ON COMPOSITE STRUCTURES REGULATIONS

At first, it is necessary to have a look on the basic regulations (metallic structures) applicable in the different countries (see figure 2). The cases covered are the fighter airplane and the civil transport-airplane.

		BASIC REGULATION	
		CIVIL TRANSPORT	FIGHTER AIRCRAFT
USA		FAR 25	MIL.A 8860
EUROPE	FRANCE	JAR 25	AIR 2004 D (*) AIR 2004 E
	GERMANY	JAR 25	AIR 2004 D MIL.A 8860
	ITALY	JAR 25	AIR 2004 D MIL.A 8860
	NETHERLAND	JAR 25	
	UNITED KINGDOM	JAR 25	AVP 970 (*) AIR 2004 D MIL.A 8860

(*) By NOW OBSOLETE

FIGURE 2

For the civil airplane in most of the european countries the basic regulation is the JAR 25, itself a derivation from the FAR 25 regulation applicable in the U.S.A. For the military side the two main regulations are the US MIL A8860 applied to US airplanes and to some european designs (the most notable being the TORNADO) and the French AIR 2004 D and 2004 E applied to french designs and to cooperative designs such as the JAGUAR and the ALPHA JET.

By now these regulations are making no specific reference to composite materials (excepted a short reference in the AIR 2004 E).

Anyway they form the basic reference rules, and any new regulation on composites will be mostly a form of an "Acceptable mean of compliance" to the basic rules. And the aim of such a document will be to define practical methods to certify composite structures, with the basic objective to achieve at least the same overall level of safety than the metallic structures designed by the current regulations.

The first composite regulation to appear was the FAA Advisory Circular AC 20.107. This document was welcomed in FRANCE and used for the certification of the FALCON 50 ailerons. But it was felt that some important parts of it were unsatisfactory, in particular the sections dealing with the fatigue and damage tolerance.

In FRANCE extensive discussions between manufacturers and the Authorities, based on actual experience of flight qualification, have led to the establishment of a philosophy defined by the Technical Note 81/04 STPA/EG, based on AC 20.107 but with extensive changes. This paper was applicable to civil and military airframes.

In some other european countries similar discussions have taken place, but not to the point of producing an official document.

Then composites became the subject of discussions within the JAR Structures Group, leading to the production of a JAR Discussion Paper around the core of the STPA paper.

Meanwhile FAA and the US industry have developed a new draft of Advisory Circular AC 20.107 A.

Under the pressure of the manufacturers who where strongly in favor of using as far as possible a common set of rules and a common philosophy on both sides of the Atlantic, this was a good occasion of an EUROPE-USA discussion on this matter. After several meetings, complete agreement was reached on a common text under the form of a revised AC 20.107 A for the FAA and the corresponding ACJ for the JAR. The only small differences remaining being due to differences in the basic JAR and FAR rules which were beyond the scope of the discussions.

So for the civil transport airplane the situation by now is quite clear. For fighter aircraft work remains to be done, but in our opinion most of what is applicable to the civil transport composite structures can be applied as well to fighters.

3 - INTERPRETATION OF THE REGULATIONS FOR COMPOSITES : TWO EXAMPLES

IMPACT DAMAGE TOLERANCE OF CARBON EPOXY STRUCTURES.

One problem of composite materials such as carbon-epoxy is the sensitivity to low energy impact damages. For the metallic structures an impact damage has almost no immediate consequences on static strength, except for very large impacts which are immediately detectable during walk around inspections. However in the long run initial impact damages may lead to a fatigue crack, and that fatigue crack can grow to a critical size. This behaviour is exemplified by figure 3. Safety is maintained by inspections leading to the detection of the crack before it becomes critical.

On the other hand an impact on a carbon-epoxy panel may lead to an immediate strength reduction (mostly for compression panel) even for damages which are not visually detectable from the outer side. This kind of behaviour is shown on figure 4. Experiments have also shown that in most cases the initial impact damage is not growing further under fatigue loads.

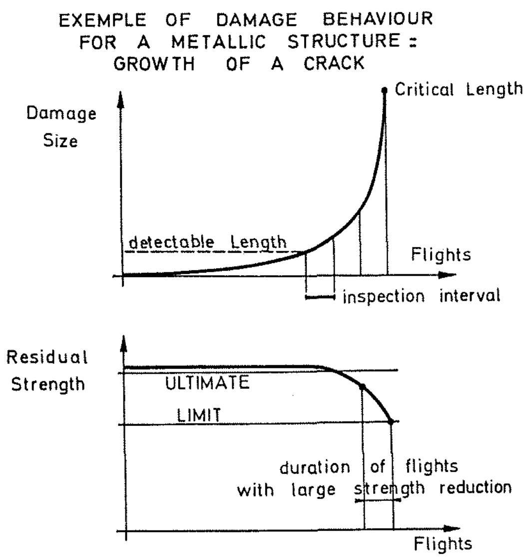

FIGURE 3

This double characteristic of composites : i.e

- sensitivity to impact damage
- existence of "no growth" types of damages

is not covered by basic regulations, nor in AC 20.107.

It was covered in Draft AC 20.107 A, but not to the satisfaction of the Europeans, who have developed their own philosophy in the JAR discussion paper. So it was an important item in the discussions between JAR and FAR specialists.

The basic rule asks for a residual strength level before detection of the damage equal or greater than limit loads. In practice, in case of a metallic structure critical damages are almost always of "growth" type (see figure 3) and the risk to have the structure flying for a long time with a residual strength close to limit load is low, and selection of inspection intervals is quite simple.

For the composite structure, to set the residual strength level for example at limit loads, with a damage level which can only be detected by elaborate non destructive inspections may very well allow the structure to dwell for a long time in the dangerous area close to limit loads.

So there was clearly a need to have a correlation between the inspection intervals and the residual strength in order to maintain the overall safety of metallic structures. And in the common FAR-JAR version of AC 20.107 A a paragraph was added to § 6.a.4 reading :

"For the case of no-growth design concept, inspection intervals should be established as part of the maintenance program. In selecting such intervals the residual strength level associated with the assumed damages should be considered".

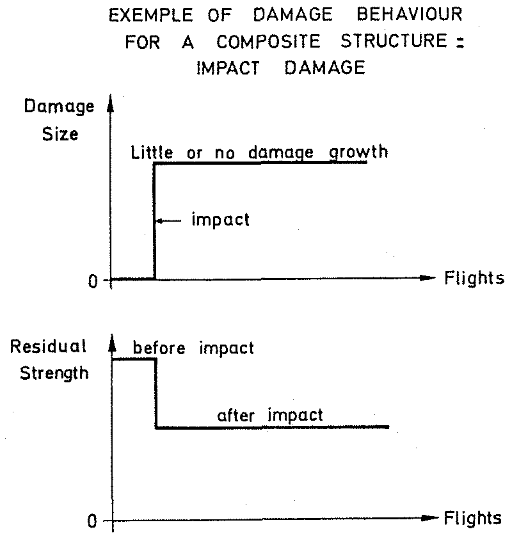

FIGURE 4

Combined with a new § 5.g :

"g. It should be shown that impact damage that can be realistically expected from manufacturing and service, but not more than the established threshold of detectability for the selected inspection procedure, will not reduce the structural strength below ultimate load capability. This can be shown by analysis supported by test evidence, or by tests at the coupon, element or subcomponent level".

Up to now manufacturers are using visual inspection and the size of the damage at the detection threshold is such than the ultimate strength requirement of § 5.g becomes the overriding factor, as the further reduction of strength with larger detectable damages is low (see figure 5) and so § 6.a.4 is automatically fulfilled.

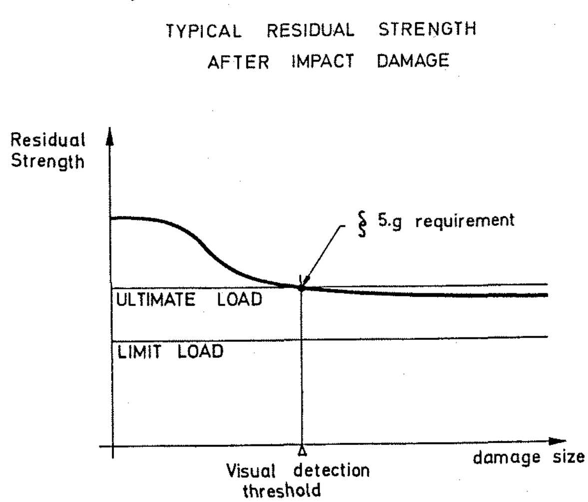

FIGURE 5

DESIGN VALUES AND THE ROLE OF THE MAJOR STATIC TEST -

The situation of metallic structures.

- Table 6 presents a comparison concerning static strength requirements of the four main regulations, civil and military.

  There is a general agreement on the factor between limit and ultimate loads and on the derivation of design allowables. There are some divergences on pressurization loads. Apparent divergences seem to be quite large between the civil and the military on the subject of correction of the results of the static test (that is ratio between the actual strength of the material and the minimal design value, and ratio of the actual thickness of the part tested and the minimum of manufacturing tolerances). In fact as these corrections are very difficult (or impossible) to apply in many practical cases (for example a compression failure) and as the military regulations have not the same legal status as the civil ones, these correction factors are very often not applied to military planes. So in the most frequent cases no correction factor is applied to static test results.

- A further issue is the need to do a full scale static test up to ultimate loads (on a complete structure or on major components). Initially the practice was to subject all new designs to ultimate loads tests. This was related to the rather limited accuracy of stress computations at that time. Nevertheless the service experience on these airplanes has shown that their static strength was sufficient (except for a few cases which were due to inadequate design cases, not to static strength substantiation).

Since the mid sixties advances in finite element methods have provided a huge increase in the accuracy of stress computations. Then it seemed feasible to maintain the same safety while replacing the ultimate load static test by the combination of refined computation (using in general B type design values) and a static test to limit loads to check the computed stress distribution.

The objective being to save the cost of the static test articles.

This new method for strength substantiation has not received the same degree of acceptance on both sides of the Atlantic, JAR authorities being much more reluctant than Federal Aviation Administration. And a difference remains between the two codes for paragraph 25.307(a) JAR reading : "Where substantiating load tests are made these must cover loads up to the ultimate load unless it is agreed with the Authority that in the circumstances of the case, equivalent substantiation can be obtained from tests to agreed lower levels (see ACJ 25.307)".

While FAR is reading : "The Administrator may require ultimate load tests in cases where limit load tests may be inadequate".

This is one of the difference remaining between JAR and FAR regulations, even after the agreement on AC 20.107A on composites.

ULTIMATE LOADS , DESIGN ALLOWABLES
AND CORRECTION OF STATIC TEST RESULTS

		CIVIL REGULATIONS		MILITARY REGULATIONS	
		JAR 25	FAR 25	AIR 2004 E	MIL.A.8860
SAFETY FACTOR = ULTIMATE LOAD / LIMIT LOAD		1,5	1,5	1,5	1,5
PRESSURIZED FUSELAGE = ULTIMATE LOAD CASE		2 ΔP	2 ΔP	2,25 ΔP	1,5 to 2ΔP
ALLOWABLES	SINGLE LOAD PATH	A.VALUES	A.VALUES OF HDBK 5	MINIMAL VALUES OF AIR 9050	A or S VALUES OF HDBK 5
	MULTIPLE LOAD PATH	B.VALUES	B.VALUES OF HDBK5		B.VALUES OF HDBK 5
CORRECTION OF STATIC TEST RESULTS	MATERIAL PROPERTIES	ONLY IN THE SINGLE LOAD PATH CASE		YES	YES
	THICKNESS	NO	NO	NO (PENDING ON APPROVAL)	YES

TABLE 6

Scatter of Composite Materials Structures.

Initially the high strength composites had the reputation to have a large scatter on static strength (for identical parts subjected to the same conditions). With the experience of full scale production, our own experience combined with the data available in the litterature shows that this scatter is not so large. Typically there is a general agreement on a scatter of about 5 % (standard deviation) for the strength of Metallic structures. And the scatter for composites will be about 5 % for tension type failure, and 8 % for compression type failures. The only structural details giving higher scatter are some metal to composite bonded lap joints. So the scatter of composites is slightly higher than the scatter of metallic structures.

Static Strength Substantiation for Composites.

In meeting the general objective of an equivalent overall safety with metallic structures the question is how to take into account the differences in scatter between composites and metallic structures.

The AC 20.107A gives two options :

1) Analysis using appropriate design value supplemented by a static test.

2) Static test alone to ultimate load with eventually an extra factor to cover differences in scatter.

In option 1 the differences in scatter are accounted for in the derivation of design allowables, and the computations have to use methods demonstrated by a large data base of experience. So the role of the static test is mainly to check the computed stresses (if measured stresses extrapolated to ultimate loads exceed the design values further justification has to be provided), and when an ultimate load test is required no extra factor is necessary as the differences in scatter (if any) are already taken into account in the computation.

Option 1 is the normal way for large FAR 25 transports.

Option 2 is mostly an opportunity for FAR 23 airplane manufacturers who cannot afford the computing expertise and the test data base necessary for option 1.

Probabilistic approach.

To provide some insight of what can be a probabilistic approach on the question of design values (option 1) and extra factors on the static test (option 2), some results of a study done by AMD/BA are given hereafter. (The results are a function of the assumptions made and are just an indication).

- The reference safety level is the safety of a metallic structure with an overall scatter of 5 % and a mean static strength of just ultimate load (no correction of the test results).

- Two cases of load exceedence curves are considered one for the civil transport wing, one for the fighter aircraft wing.

- The composite structure is represented by the combination of n identical elements, working in series, the weakest one causing the failure.

CIVIL TRANSPORT WING =
MEAN STRENGTH REQUIRED FOR AN ELEMENT
OF A STRUCTURE COMPRISING N IDENTICAL ELEMENTS
WORKING IN SERIE

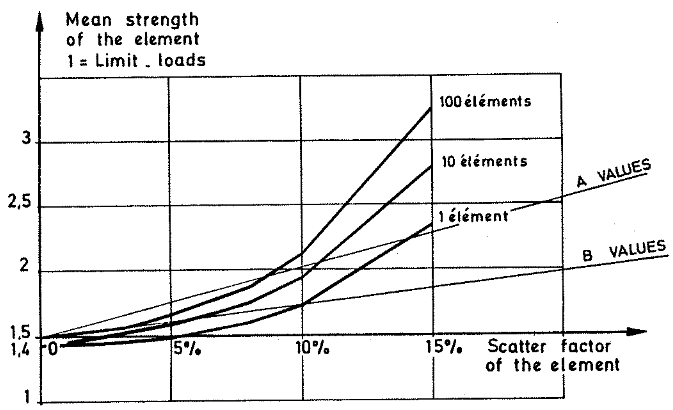

FIGURE 7

- Table 7 shows the design values to be used as a function of the scatter of each individual element and as a function of the number of elements working in series. Taking into account that due to some averaging effect the equivalent value of n seems to be between 1 and 10, the conclusion is that B type design values are acceptable for structures with element scatter equal or below 8 % typical of most composite structures, and that for structures with large scatter even A values may be unconservative.

For the option 2 (static test alone) figure 8 shows the factor to be used on the static test as a function of the scatter of the complete structure tested.

In this option one of the problems is that for a structure with several potential failure modes, it will be necessary to beef up structural details of low scatter (for example metallic fittings) in order to withstand the extra factor necessary for the structural details with high scatter, with a severe weight penalty. So option 1 has to be preferred as far as practical.

STRENGTH JUSTIFICATION BY STATIC TEST ALONE : REQUIRED FAILURE STRENGTH LEVEL TO KEEP THE SAME SAFETY THAN THE REFERENCE METALLIC STRUCTURE

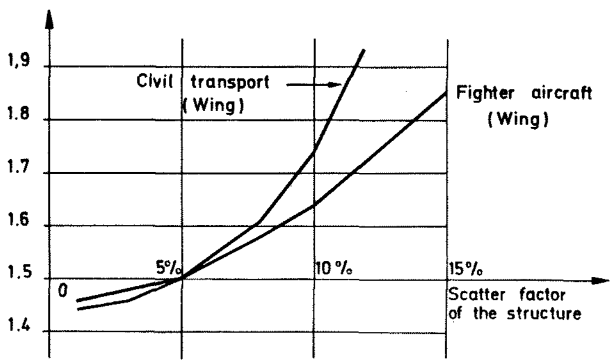

FIGURE 8