FIRE SAFETY INVESTIGATIONS FOR MATERIAL SELECTION AND DESIGN OF A CARBON FIBRE REINFORCED FUSELAGE STRUCTURE

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ABSTRACT

In this paper a test program for carbon fibre reinforced composites is described, designed to provide suitable criteria for fire safety of composites, used for fuselage construction of civil aircraft. As till now, fuselage structures and skins for large airplanes have always been constructed of aluminium alloys, no certification procedures concerning fire safety of fuselages exist. Therefore a program has been performed to find criteria for selection of fire safe materials and constructions for composite fuselages.

1. INTRODUCTION

1.1 Background - Development Program for a CFRP Fuselage

Since 1983 at MBB a program is performed, which has the aim to constitute the technological premises for introduction of composite materials for future wide-body fuselage structures. The main topics are investigations on

- Design principles for composite fuselages
- Structural components
  - -- Development
  - -- Design
  - -- Test
- Materials and material selection

One of the major safety problems in aviation is fire. If now for large areas of the fuselage aluminium will be replaced by organic, i.e. combustible materials, the aspect of fire safety has to be considered under a completely new point of view. Selection of materials and constructions as well as definition of design criteria always has to take into account the consequences in the case of fire. So the risks have to be assessed and suitable safety criteria have to be established. The aim of this program is to find a suitable fire-safety standard, at least comparable to aluminium.

1.2 Fire Scenarios

For civil airplanes two fire scenarios are of major importance:
The INFLIGHT FIRE and the POSTCRASH FIRE.

An inflight fire generally originates inside the fuselage in an attended or unattended compartment. Development spread and consequences of this type of fires are mainly determined by materials and construction of equipment and furnishing. Only in the case of an engine fire, during flight structural components (especially wings) are expected to be affected by fire.

After a survivable crash often a so-called postcrash fire occurs. This scenario in most cases is determined by a big fuel fire outside the fuselage (caused by damage of a wing tank or fuel lines and subsequent release of fuel). This means that a fire of high temperature and intensity is affecting the fuselage. For survival of passengers under these circumstances the following criteria are important:

- time until the fire penetrates through the fuselage skin into the passenger cabin
- flame spread over the fuselage
- development of smoke and toxic gases inside the aircraft.

These parameters determine the passenger survival time inside the cabin and the possibility for safe evacuation.

1.3 Present Rules and Standard Tests for Civil Aircraft

For fire testing of materials and parts for civil aircraft the following test methods today are used either for certification or for material-qualification:

Flammability testing - bunsen burner test

All parts used inside the pressurized fuselage have to be subjected to a bunsen burner flame with a temperature of about 850 °C. Flammability, burn time, development of burning drips, flame spread velocity and burn through resistance can be determined. This test is requested for airworthyness certification of transport category aircraft.

Smoke density and toxic gas components - NBS-chamber

In the NBS chamber samples of materials and composites are subjected to radiant heat (2.5 W/cm^2) together with or without the influence of flames. The smoke development during pyrolysis of the sample is measured by light extinction. Simultaneously gas samples can be taken out of the test chamber and can be analyzed for toxic and irritant components. This test has been proposed in an NPRM (Notice of proposed rulemaking) by the FAA in 1975, but never was rendered mandatory. Nevertheless Airbus started to use it as a requirement for all parts inside the pressurized fuselage and now similar requirements are used by almost all suppliers of airplanes and aircraft equipment and furnishing.

Fire test for aircraft seat cushions

This test is the first certification test (mandatory since 1984) which takes into account that in some cases (ruptured fuselage) an external fuel fire might reach parts of the cabin interior and cause a severe fire inside the cabin. As the polyurethane seat cushions are a large fire load in the passenger cabin they are in this test subjected to a flame of a kerosene burner with a nominal fuel rating of 2.25 gallons per hour, a flame temperature of 1040 °C and a heat flux of 11.9 W/cm². Weight loss and flame spread are limited and no burning drips are allowed to occur.

Cargo compartment fire containment test

As a fire originating in a cargo compartment has to be kept contained inside the cargo compartment, to avoid endangering of aircraft functions and of the health of passengers the FAA recently introduced a burn through test for lining materials, using the above mentioned oil burner at a temperature of 930 °C and a heat flux of 9.12 W/cm².

2. TEST PROGRAM

2.1 Selection Criteria for Test Methods

As the short description of possible fire scenarios shows, for composite structural parts and fuselage skins the fire resistance i.e. the time until flame penetration occurs under the conditions of a postcrash fire can be considered as the most important criterion for passenger safety.
For realistic testing of the burnthrough resistance it is necessary to simulate:
- temperature
- intensity

and to a certain amount
- size, i.e. quantity of heat

of a large fuel fire.
Furthermore we have to consider that material temperature which is essential for material failure under the impact of a flame is not only determined by the flame temperature but also by:
- heat transfer coefficient between skin and flames
- density and specific heat of material
- radiative losses on both sides
- thermal conductivity of the material.

These complex interconnections imply the necessity of using a relatively large fire source and samples which are far larger than those normally used for bench testing. Additionally the influence of insulation materials (as used in the aircraft close to the fuselage) on material temperature may not be neglected.

Burn through without mechanical loads alone might give as unrealistic feature of the performance of an aircraft fuselage subjected to a fire as the mechanism of material failure is completely different looking for example at an aluminium alloy on one side and at a carbon fibre reinforced composite on the other side.

Theoretical predictions on the mechanism of failure of composites under the influence of fire together with mechanical loads don't exist at the moment and so realistic loads for an airplane lying on the ground have to be simulated. The worst assumption that should be taken into account is an aircraft fuselage lying on the ground with a broken landing gear.

Complementary to testing of burn through resistance development of smoke and toxic gases as well as flammability and flame spread velocity have to be evaluated for selection of materials and constructions. For a first screening of these parameters the hard criteria of a postcrash fire have not necessarily to be applied. Existing standard test methods combined with the observations in the larger scale (kerosene burner) test are able to give a good tool for assessment of these problems.

2.2 Description of tests performed

As the FAA has proven in a lot of large scale tests, tests with the kerosene burner as performed for seats showed a good correlation between bench test and realistic fuel fires. So this burner was chosen for the burn through tests. Samples representing possible fuselage constructions where produced in a size of 500 mm x 500 mm. Figure 1 shows the test assembly for the burnthrough tests without mechanical load.

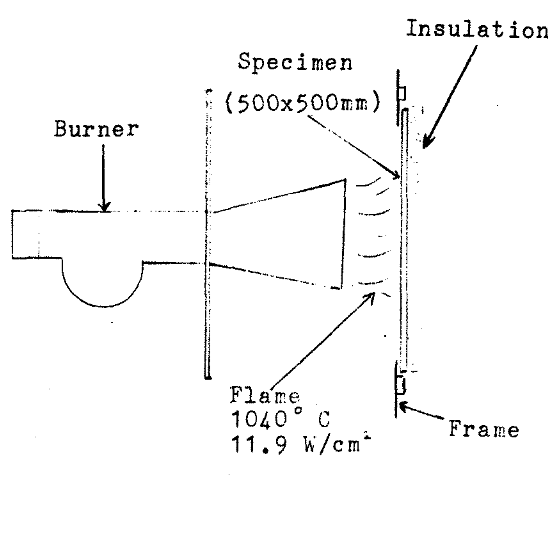

Figure 1: Burn-through Test

The specimen were mounted in a watercooled steel frame. This was necessary to prevent warping of the frame and subsequent flame penetration between the sample and the frame. Aluminium alloy samples, representing a state of the art fuselage structure and different composite samples were tested in this assembly with and without insulation material on the backside. The insulation thickness was defined according to the currently used insulations for civil transport aircraft.

For testing under load, an assembly as shown in figure 2 was used.

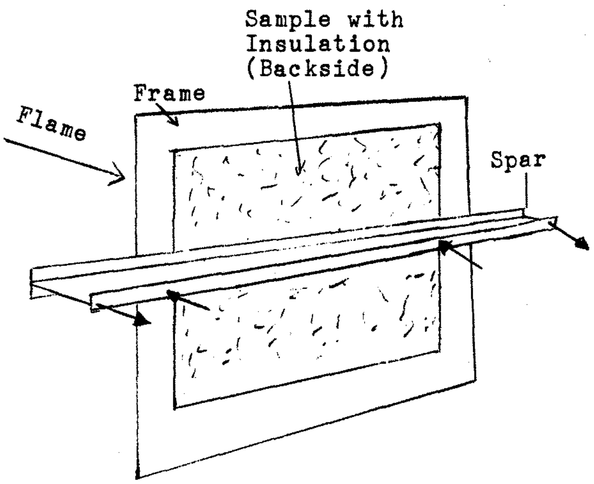

Figure 2: Burn-through Test under mechanical load

The spar was subjected to a momentum of 475 Nm by four - point - bending. This simulates the load on a fuselage structure of a wide-body airplane, lying on the ground with a broken landing gear. The load was produced by weights.

Additionally flammability tests were performed with a bunsen burner and smoke density and gas tests were conducted in the NBS-chamber (see short-description of standard tests).

3. TEST RESULTS

3.1 Burn through tests

The first burn through tests were performed without load and had the aim of comparison of the performance of the following fuselage constructions under postcrash-fire conditions:

- Aluminium
- Monolithic CFRP structure
- Sandwich structure, CFRP

The tested CFRP panels had an Epoxy matrix.

Typical results are shown in table 1.

Material	Thickness [mm]	Insulation	Time to burnthrough [sec]
Al 3.1364	1.6	no	190
Al 3.1364	1.6	Yes	110
CFRP-fabric monolithic	2.72	no	2160
CFRP-fabric monolithic	2.72	yes	1800
CFRP-sandwich Nomex-honeycomb	2.72 (2x) 30	no	2520

Table 1: Typical burn through times

These experiments, evaluating simply burn through characteristics, showed a superior behaviour of composites. If thermal insulation is provided on the backside, especially metallic structures perform worse because of their high thermal conductivity. The difference between sandwich- and monolithic constructions is not very impressive for non-loaded specimen.

3.2 Material Failure under mechanical load

Prior to testing under mechanical load a first screening of samples with spars on the backside was performed by measuring temperatures. Temperatures in the middle of the samples (under the spar) showed significant differences between aluminium, monolothic and sandwich constructions.

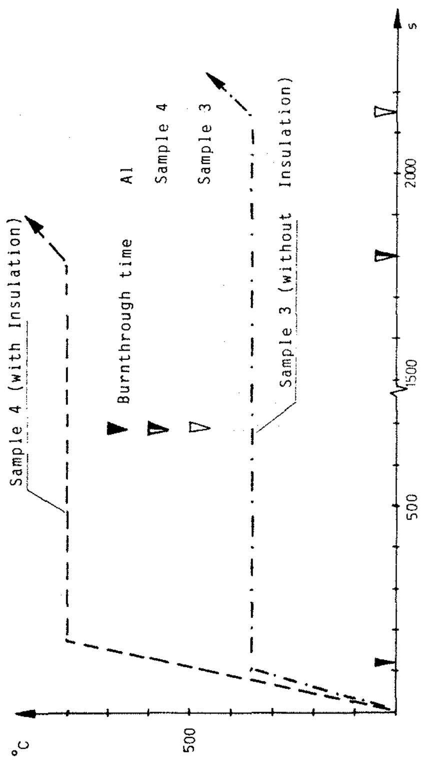

Figure 3: Idealized backside-temperatures (below spar) Aluminium, Monolithic CFRP structure

Testing under load showed a significant difference between monolithic and sandwich structures. Figure 4 shows some typical results.

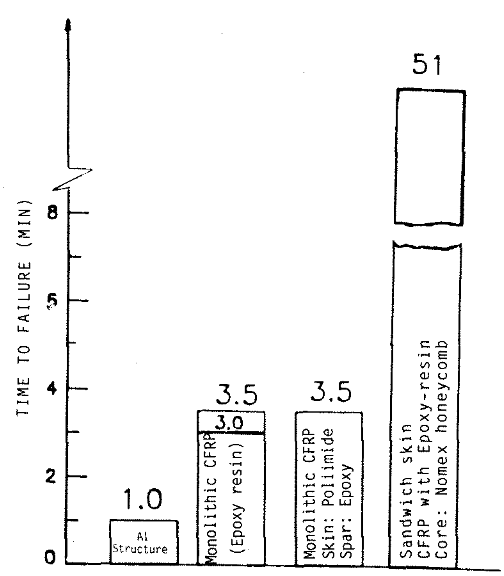

Figure 4: Time to mechanical failure

Obviously the inner surface layer and the spar are well protected against heat and flames as long as the outer surface layer (flame side) is not burnt through. This is effected by the low thermal conductivity of the composite material and the insulation effect of the honeycomb core. So testing under load allows obviously a much more realistic assessment of different constructions than simple burn through tests. Additional tests showed, that also the type of laminate (for example use of fabric or of tapes) may be of big influence on time to material failure. The type of resin, core material and surface protection (paint etc.) proved to be of minor importance.

3.3 Tests on smoke, toxic gas emission and flammability

For a complete assessment of the fire risks, caused by use of certain materials and constructions, flammability as well as development of smoke and toxic gases under the influence of fire may not be neglected.

Here also the following criteria have to be considered:
- type of resin
- surface protection
- lightning protection

In table 2 flammability values according to FAR 25.853 a) are shown.

Sample	Burnlength [mm]	Burntime (after extinction of impinging flame) [sec]
CFRP	11	11
CFRP lightning prot. paint	18	8
CFRP paint	25	10
Acceptable max. values	152	15

Table 2: Flammability values for Epoxy-CFRP samples with and without paint and lightning protection (Al-mesh)

Similar materials and combinations were tested in the NBS chamber for smoke and toxic gases. The results for the materials which had been chosen as candidates for fuselage structures all were below the limits today applied even to critical parts of the cabin interior (for instance for hoses for air condition).

4. OUTLOOK

When the test program described in this paper was started, the aim was to avoid additional safety risks in the case of fire, if aluminium is replaced by composite materials for large areas of the fuselage skin and structure. The results show clearly that it even is possible to get a significant improvement of safety especially for the post crash fire scenario using composite fuselage constructions. While aluminium has a melting point far below the temperature of a fuel fire, carbon fibre reinforced composite constructions are able to withstand those temperatures and heat-flux levels for a significantly higher period of time. The additional development of smoke and toxic gases seems not to be intolerably high even for Epoxy resins and, as experience from other programs shows, can be minimized using for example Poliimides.

During further progress of the composite fuselage program these conclusions will be verified by testing of larger parts of fuselages in real fuel fires.