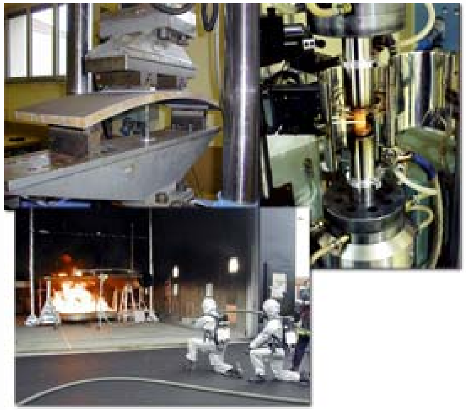


Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

MINISTÈRE DE LA DÉFENSE

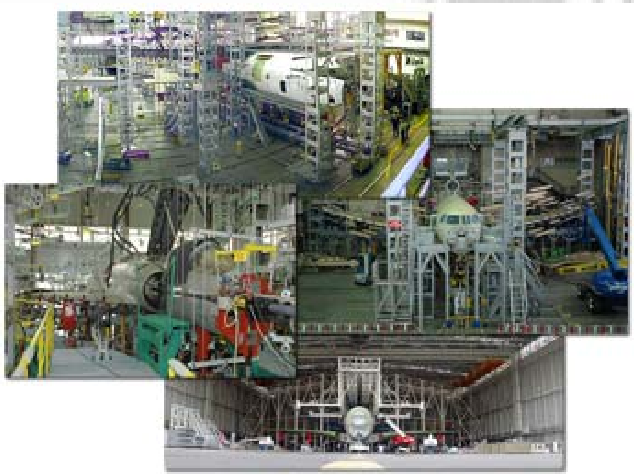
DGA Aeronautical Systems

(ex. CEAT)

« Fire Safety Department »

Fire Behaviour Of Structural Composite Materials

(progress of the work)



DGA

Serge LE NEVE
E-mail : Serge.le-neve@dga.defense.gouv.fr

- ➔ **Objectives of the works**
- ➔ **Test Program**
- ➔ **Post-crash Fire Behaviour**
  - ➔ **Burnthrough**
    - ➔ **Smoke box & test method**
    - ➔ **First test results**
  - ➔ **Release of Smoke & Toxicity**
    - ➔ **Species to be analysed**
    - ➔ **First test results**
  - ➔ **Conclusion**
- ➔ **Inflight Fire Behaviour**
  - ➔ **Development of various Hidden Fire sources**
    - ➔ **Propane Hidden Fire Source**
      - ➔ **First test results & next works**
    - ➔ **Radiant Heat Source**
      - ➔ **First test results & next works**
  - ➔ **Underload Fire Behaviour**
    - ➔ **4-point-bending test method**
  - ➔ **Conclusion**

Increase in the use of composite materials in new aircraft programs (structural applications and fuselages)

- The use of composite structures has been increased because of the advantages composites offer over metal

- Boeing 787 or Airbus 350 will have about 50 % of the structural weight including wings and fuselage

- Currently, there is no fire requirement on composite materials used outside the cabin, cargo compartment and fire zones

➔The aircraft manufacturers are required to demonstrate that polymer structural composites provide an equivalent safety level to the current material (aluminium alloy)

► MANY TESTS HAVE BEEN DEVELOPPED FOR FIRE SAFETY REQUIREMENTS

CABINE LAYOUT
HIDDEN AREA
CARGO COMPARTMENTS
FIRE AREAS or POWERPLANT INSTALLATIONS

► works will allow to determine if the current aeronautical fire tests are sufficient to assess the fire behaviour of structural composite materials

TEST PROGRAM

- **To assess the fire behaviour of structural composite materials faced with the following threats :**

In-flight thermal damaging

- **Hidden fire damaging**
- **Electric arc effects**
- **Check the residual mechanical properties**

Post-crash fire effects

- **Burnthrough behaviour**
- **Environmental effects on the cabin side (smoke / toxicity / heat release)**

TESTS

Following the development of the new test means & test methods, all the following tests will be performed on each kind of composite materials

Standard tests	New tests

Standard tests

- <u>Bunsen burner test (FAR 25.853)</u>
- <u>OSU</u> test chamber (Heat Release) (FAR 25.853)
- <u>NBS</u> test chamber (Smoke / Toxicity) (FAR 25.853 / ABD0031)
- <u>Cone calorimeter (7,5 & 10 W/cm²)</u>

New tests

- <u>Exposure to the hidden fire source</u>
  + NDI & mechanical tests
- <u>Under load fire tests</u> (hidden fire source)
- <u>Burnthrough smoke box tests</u>
- Electrical arc effect

Comparison of all the test results will be made to determine if the current tests are relevant to characterize the fire behaviour of composite materials

Materials / configurations to be tested

➢ <u>Various materials are to be tested</u>

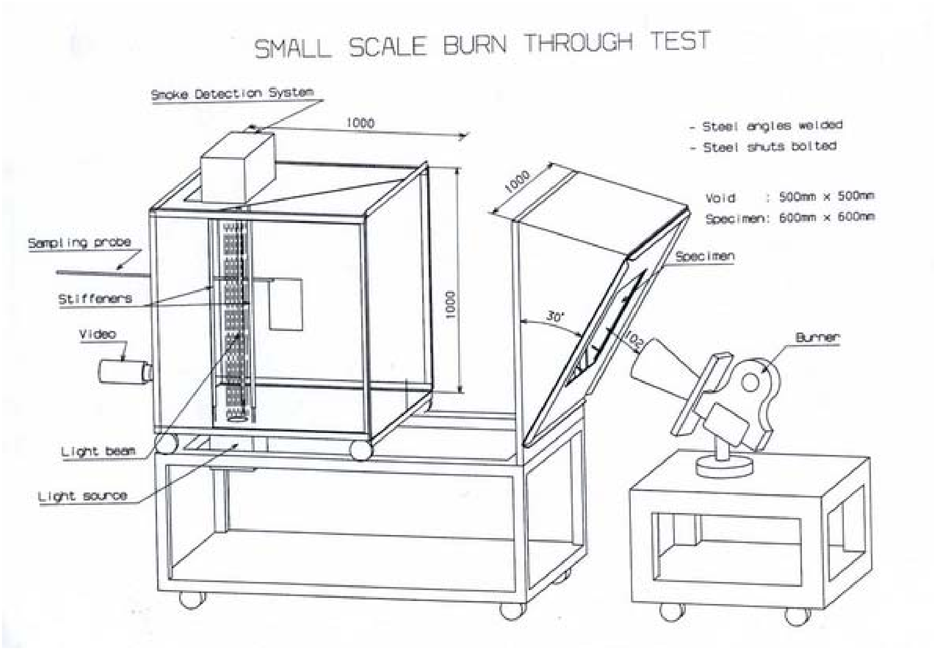
From civil / military applications for airplane and helicopter

- **➔ Various resins, fibbers, thicknesses, with & without honeycomb**
- **➔ Burnthrough / Smoke / Toxicity: The tests will be carried out on assemblies “composite / insulation blanket / wall panel”**

BURNTHROUGH
SMOKE & TOXICITY
of
STRUCTURAL COMPOSITE MATERIALS

Burnthrough / Smoke box

- **Smoke box size : 1,2m³**
- **The burner & flame calibrations are in accordance with the FAR 25.856 AppF PartVI requirements (HF: 18,2 W/cm² ; T°: 1038°C)**
- **Photometer system (= NBS test chamber)**
- **Toxicity measurement: FTIR gas analyzer & gas sampling (=> IC or colorimetric analysis)**
- **Test sample is fitted on the outer side of the specimen holder to avoid that the released smoke from the edges of the sample penetrates inside the smoke box**



- **<u>Test samples</u> : Smoke box window = 500 mm x 500 mm**

  (tests sample : 600 mm x 600 mm)

Toxicity

- **Species to be analysed**

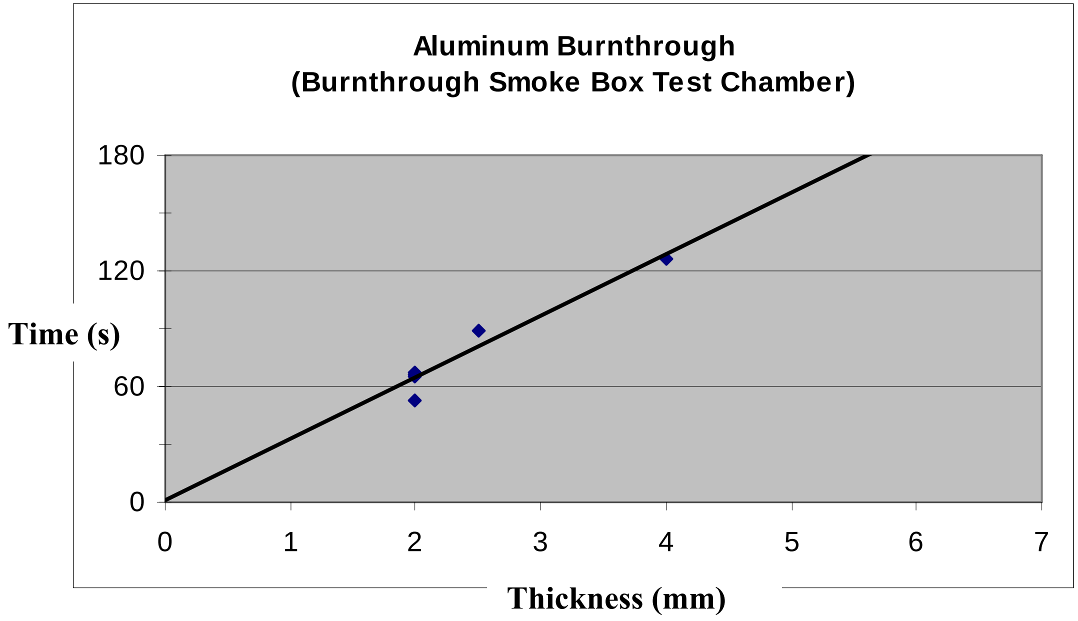
Gas Component		
Carbon monoxide/dioxide	CO / CO_2	FTIR
Oxides of nitrogen	NO_x ($NO + NO_2$)	FTIR
Sulphur dioxide	SO_2	FTIR
Hydrogen fluoride	HF	
Hydrogen bromide	HBr	?
Hydrogen chloride	HCl	FTIR
Hydrogen cyanide	HCN	FTIR
Hydrogen sulphide	H_2S	
Ammonia	NH_3	FTIR
Phenol	C_6H_5OH	?

NO TEST RESULTS
(FTIR test method still in development)

- **The choice of the species results from :**
  - **their effect on Toxicity Index (estimated in recent works from a NATO working group on standardization of fire test methods for naval ships)**
- **FTIR will be used for continuous analysis**

Preliminary tests

- **Tests on aluminium plates**



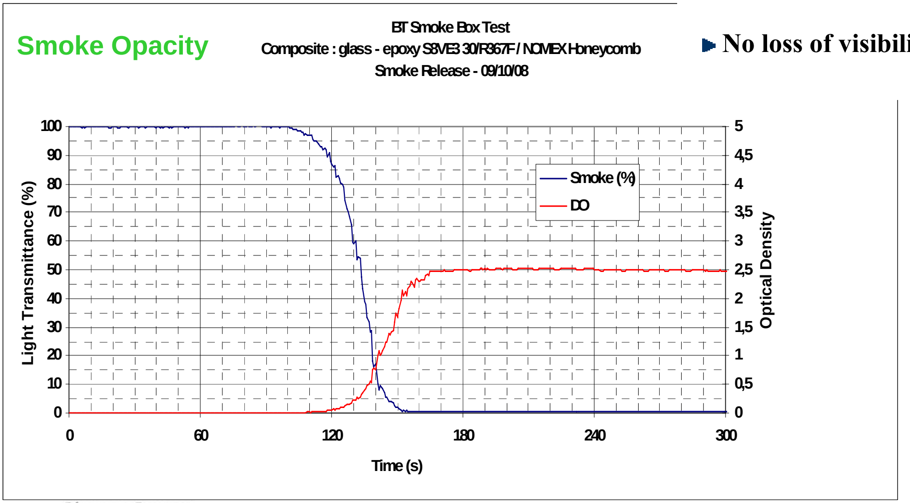
Development tests

- **Development tests were carried out on various large specimens (window box : 500 mm x 500 mm)**
  - **Composite : Glass Epoxy S8VE3 30/R367F / NOMEX Honeycomb (Resin 120)**

Inner face – After

Smoke release started at 1mn 40s

No loss of visibility before the 90s



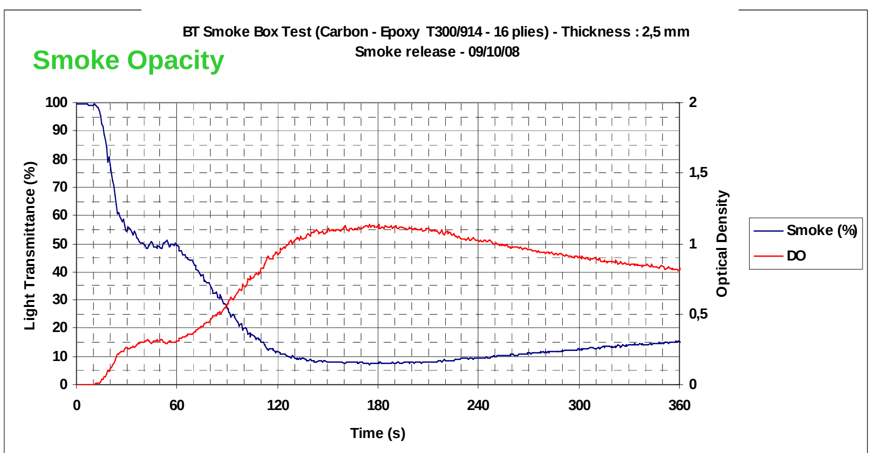
Outer face – After test

Development tests

- Composite : Carbon - Epoxy T300/914 - 16 plies - Thickness : 2,5 mm (Resin 190)

- Smoke release started very early ~ 15 s
- But the total smoke release was not very high

Inner face – After test



Inner face – After test

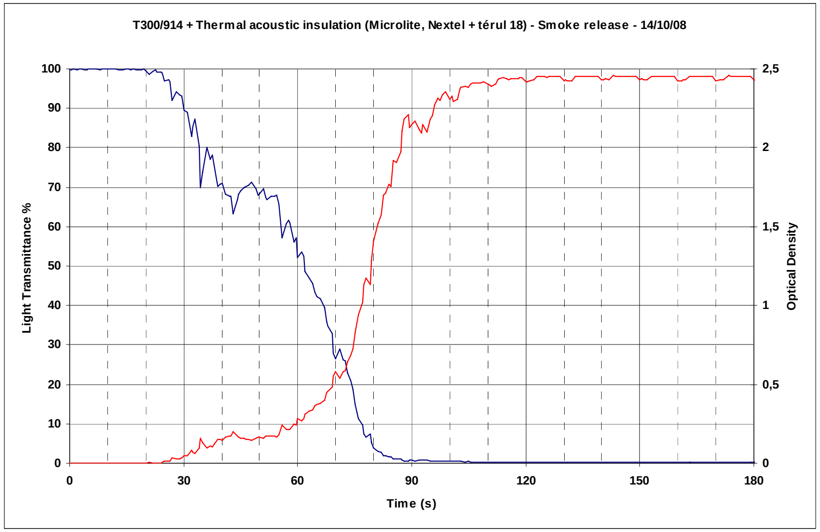
Outer face – After test

Fire Behaviour of Structural Composite Materials

BURNTHROUGH / SMOKE / TOXICITY

Development tests

- **Composite :**
  - **Carbon - Epoxy T300/914 - 16 plies - Thickness : 2,5 mm (Resin 190)**
  - **Thermal acoustic insulation : (Microlite, Nextel + térul 18)**

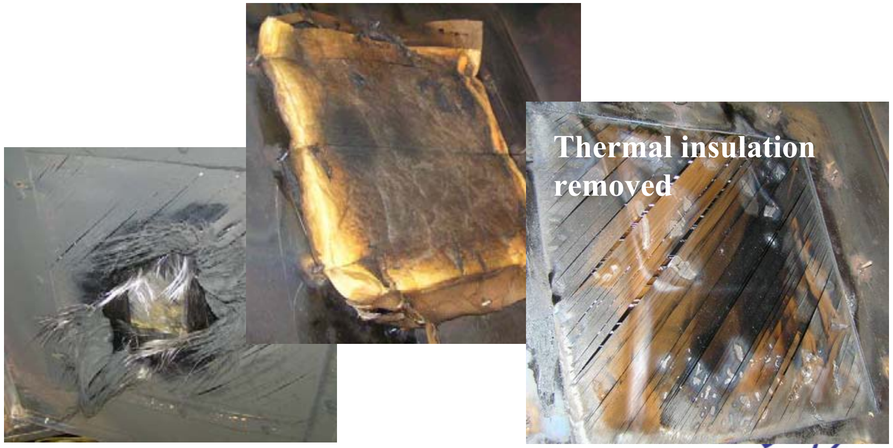


- **Smoke release started early again ~ 20 s**
- **Total loss of visibility happened before the 90s**

(But the gas concentration is higher than in a real case)

Before test

After test



Smoke Opacity : Comparison to NBS criteria (Max Specific Density (Dm) = 200)

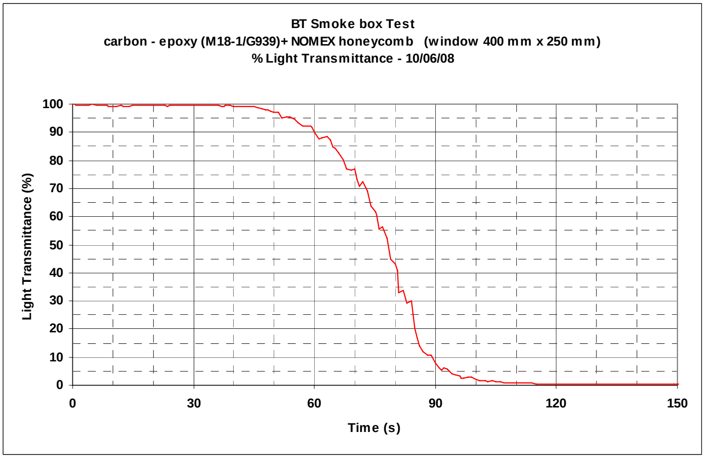
T_m = minimum percent light transmission

A = exposed specimen area

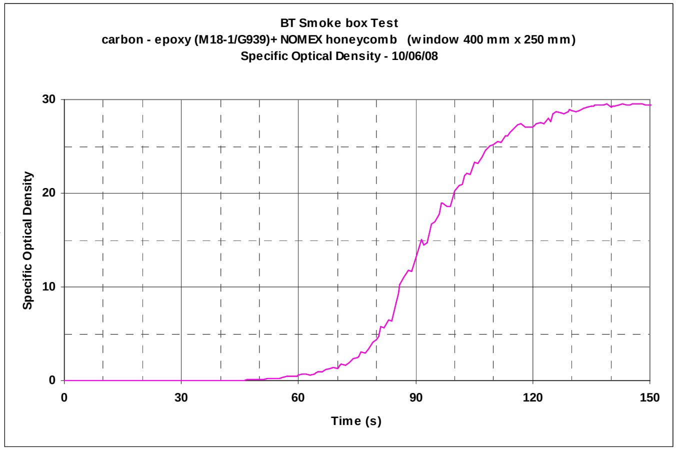
V = chamber volume

L = light path length

- **Due to the limitation of the photometric system and to the scale factor, it is not be possible to compare the smoke opacity with the NBS criteria (Specific Density < 200)**



$$D_m = (V / LA)\log_{10}(100 / T_m)$$



Test	Exposed Area		Test Chamber Vol	Light Path Lenght	Dm at 0,5% of Light Transmittance
Smoke Box	Small Size	400mm x 250mm	1,2m3	1m	**27,6**
Smoke Box	Regular Size	500mm x 500mm	1,2m3	1m	**11**
				NBS Requirement	**200**
NBS	Standard	65mm x 65mm	0,510m3	0,914m	**300**

Smoke Toxicity : Comparison to NBS toxicity requirements Scale Factors

We calculated the scale factors to compare the test results to the NBS toxicity requirements:

Gas concentration in the DGA smoke box is 25 more than in the NBS test chamber

Scale factors :

$$k = (S_{NBS}/S_{SB}) \times (V_{SB}/V_{NBS})$$

- small test sample : k = 1/10
- regular test sample : k = 1/25

NBS test chamber :

- Volume of the test chamber : $V_{NBS} = 0.510$ m3
- Exposed area of the test sample : $S_{NBS} = 0.00424$ m²

Burnthrough smoke box :

- Volume of the smoke box : $V_{SB} = 1.2$ m3
- Exposed area of the test samples :
  - 400mm x 250mm : $S_{SB} = 0.1$ m²
  - 500mm x 500mm : $S_{SB} = 0.25$ m²

NBS test chambre ABD0031 requirements (ppmm)			Corrected requirements ABD ➔ Smoke Box (ppm) Small sample /	Regular sample
1 000	CO	Carbone monoxyde	10 000	25 000
100	NOx (NO+NO2)	Oxides of nitrogen	1 000	2 500
100	SO2	Sulphur dioxide	1 000	2 500
100	HF	Hydrogen fluoride	1 000	2 500
	HBr	Hydrogen bromide		
150	HCl	Hydrogen chloride	1 500	3 750
150	HCN	Hydrogen cyanide	1 500	3 750
	H2S	Hydrogen sulphide		
	NH3	Amonia		
	C6H5OH	Phenol		

CONCLUSIONS & NEXT WORKS

- **Not possible to easily compare the smoke densities from the BT smoke box test to the acceptance criteria from the NBS test chamber**

- **Scale factor has been determined to compare the toxic gas concentrations from the BT smoke box to the acceptance criteria from the NBS test chamber**

- **Continuous FTIR gas analysis is still in development**

- **Various organic composite materials and aluminium will be tested under various configurations of assemblies (fuselage skin / insulation / wall panel)**

Fire Behaviour of Structural Composite Materials Submitted to a Hidden Fire Source

➔ Scope

➔ To check the <u>ability of structural composite materials to keep their integrity</u> when they are submitted to a <u>hidden fire source</u>

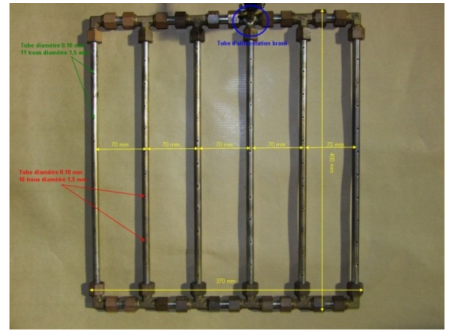
<u>AC 20-107 (Composite Aircraft Structure)</u> :
- § 11.b : « …The exposure of composite structures to high temperatures needs to extend beyond the direct flammability and fire protection issues to other thermal issues … »

➔ 3 different damaging sources will be used :

- **Propane fire source**
- **Radiant heat source**
- **Electric Arc source** ***(test method to be defined)***

<u>Note</u> : The main goal of the study is more to assess the mechanical behaviour of the structural composite materials than to assess their flammability behaviour.

▶ PROPANE FIRE SOURCE



A propane fire source has been designed on the basis of the FAA foam block fire source characteristics, <u>assuming that these characteristics are representative of a declared hidden fire</u> :

- 750°C
- 5,5 W/cm²

- **The Heat Flux Density & T° are similar to the flame characteristics produced by the FAA foam block**
- **The Flame size is wider to produce an <u>homogeneous damaged area</u> compatible with the mechanical test specimens to be removed (area ~ 150 mm X 300 mm)**

PROPANE FIRE SOURCE → COMPARISON OF THE 2 FIRE SOURCES

Comparison of the effects of the 2 fire sources on a composite material

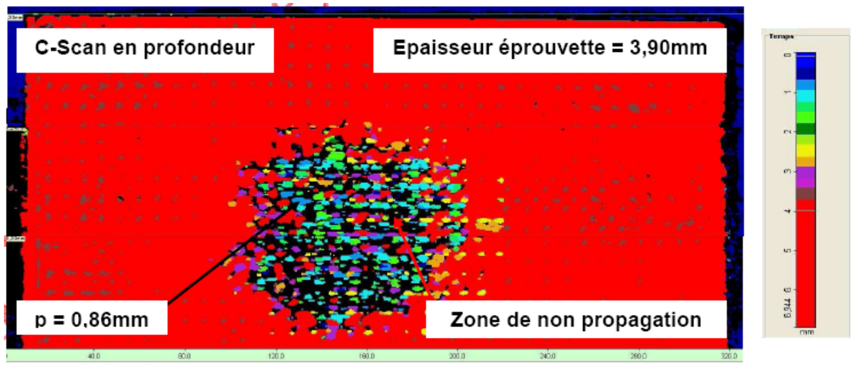
Foam Block Fire :

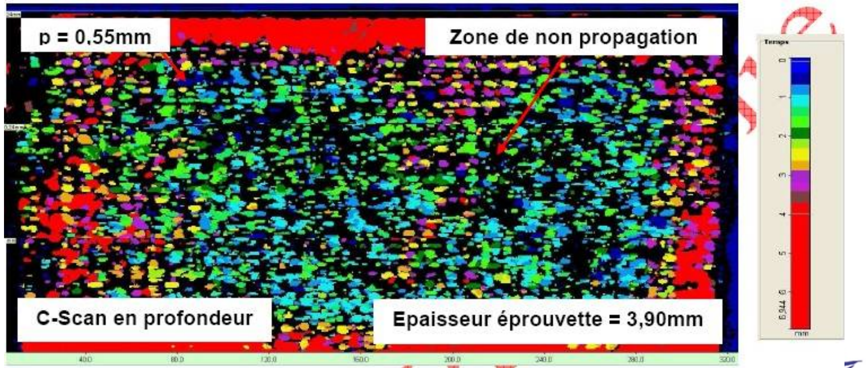
- **Time of exposure : complete burning** (but the major part of the damages are produced during the 1st stage of fire (1mn)
- **Distance burner / test sample : 3 inches**

- Very good homogeneity
- Very good agreement of the damages

Equivalent Scenario :

- **Time of exposure : 45 s**
- **Distance burner / test sample : 6 inches**



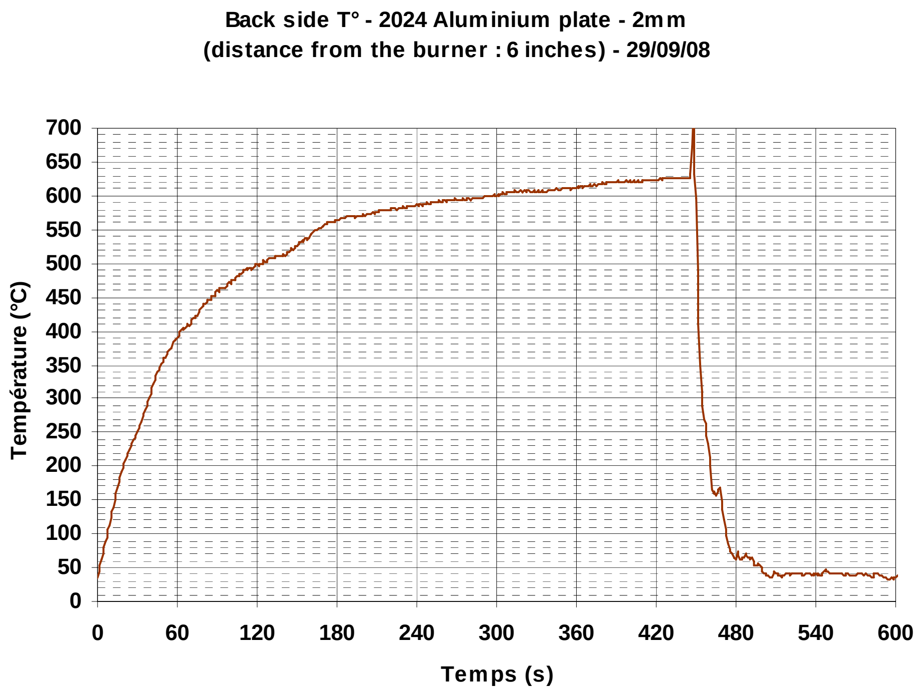


NDI of the damages

PROPANE FIRE SOURCE

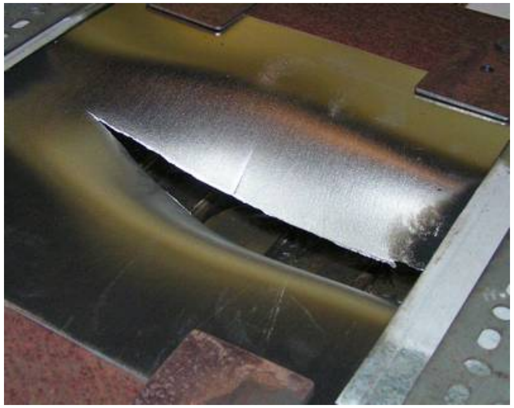
- **2024 Aluminium – 2 mm**

Gas burner
Damaging test on 2024 aluminium



Burnthrough time of a 2mm "2024 Aluminium plate"

7 mn 26 s



PROPANE FIRE SOURCE

FIRE TESTS

BASELINE TEST (representative of the foam block fire scenario) :
- Time of exposure : 45 s
- Distance burner / test sample : 6 inches

Test on :

T300 / 914 Carbon / Epoxy	16 plies / 2,4 mm
T800H / DA508 Carbon / Epoxy	16 plies / 2,4 mm
T800H / 5245 Carbon / Epoxy-Cyanate-Bismaleimid	16 plies / 3 mm
G939 / M18-1	8 plies / 2.2 mm
Aluminium 2024	2 mm ; 1,6 mm

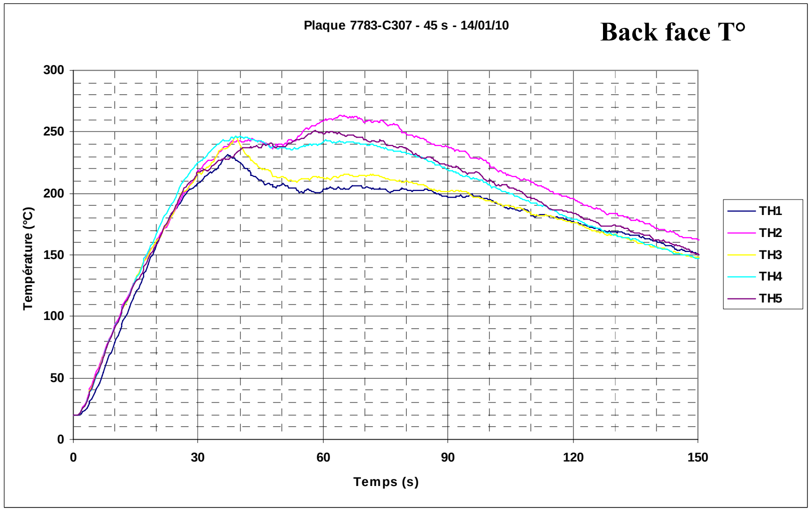
PROPANE FIRE SOURCE

FIRE TESTS

BASELINE TEST (representative of the foam block fire scenario) :

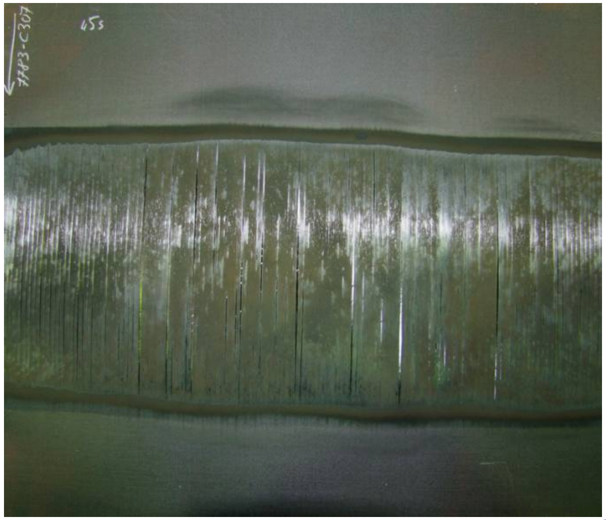
- **Time of exposure : 45 s**
- **Distance burner / test sample : 6 inches**

T300 / 914 Carbon / Epoxy 16 plies / 2.4 mm



2.4 mm Totally delaminated

➔ *No mechanical test*

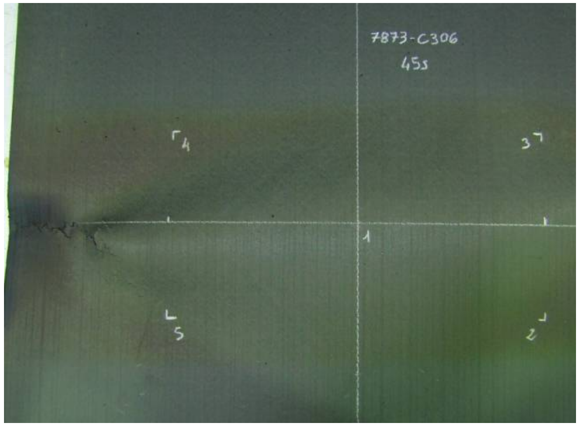


PROPANE FIRE SOURCE

FIRE TESTS

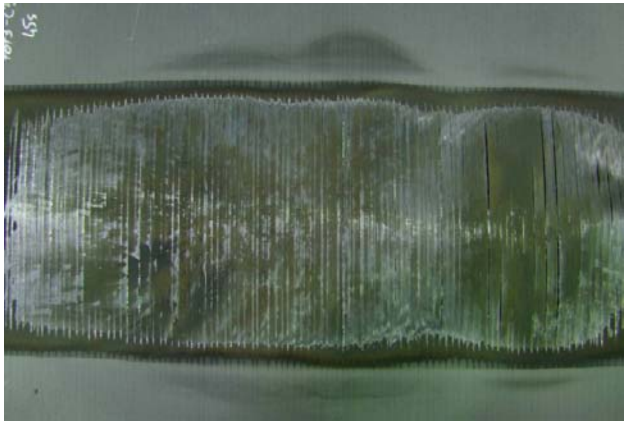
BASELINE TEST (representative of the foam block fire scenario) :
- **Time of exposure : 45 s**
- **Distance burner / test sample : 6 inches**

- **T800H / DA508 Carbon / Epoxy 16 plies / 2.4 mm**



2.4mm Totally delaminated

➔ ***No mechanical test***



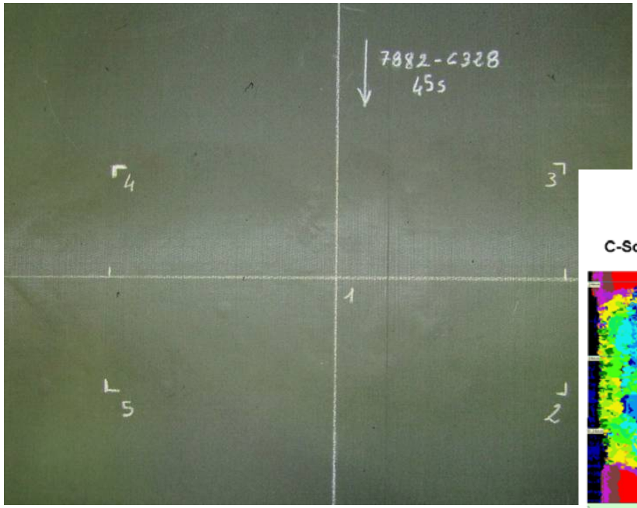
PROPANE FIRE SOURCE

FIRE TESTS

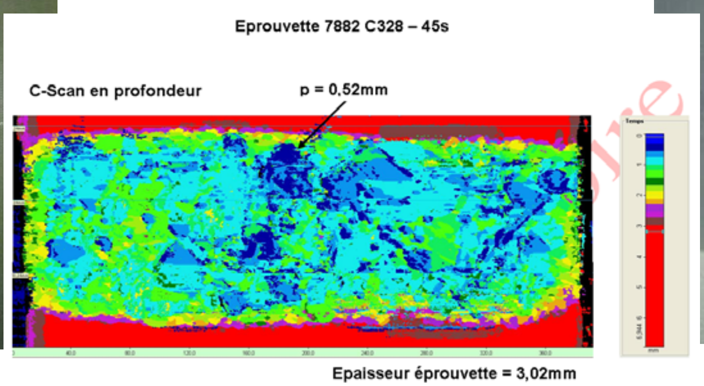
BASELINE TEST (representative of the foam block fire scenario) :

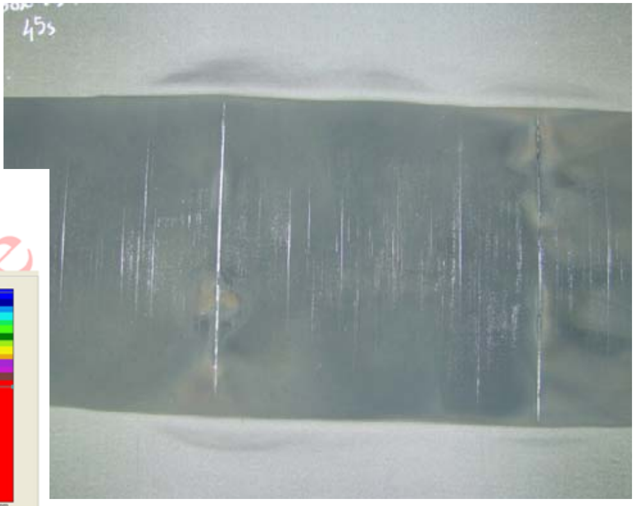
- **Time of exposure : 45 s**
- **Distance burner / test sample : 6 inches**

- **T800H / 5245 Carbon / Epoxy-Cyanate-Bismaleimid 16 plies / 3 mm**



80% delaminated
Better but Thicker





PROPANE FIRE SOURCE

FIRST TEST RESULTS

BASELINE TEST (representative of the foam block fire scenario) :
- **Time of exposure : 45 s**
- **Distance burner / test sample : 6 inches**

- **The fire tests shown that :**

Under the baseline test conditions (representative of the foam block fire scenario used for the ignition time on the intermediate scale hidden fire test):

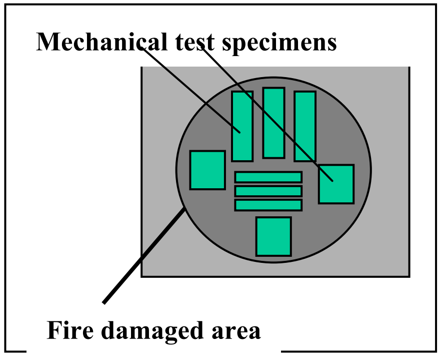
✓ **A 16 plies composite material supposed to be used for a fuselage skin application is at least 80% delaminated**

T300 / 914 Carbon / Epoxy	2.4 mm (16 plies)	Totally delaminated
T800H / DA508 Carbon / Epoxy	2.4 mm (16 plies)	Totally delaminated
T800H / 5245 Epoxy-Cyanate-Bismaleimid	3 mm (16 plies)	80% delaminated

➔ **These test conditions are too severe to make a study of the mechanical behaviour of composite materials for fuselage applications**

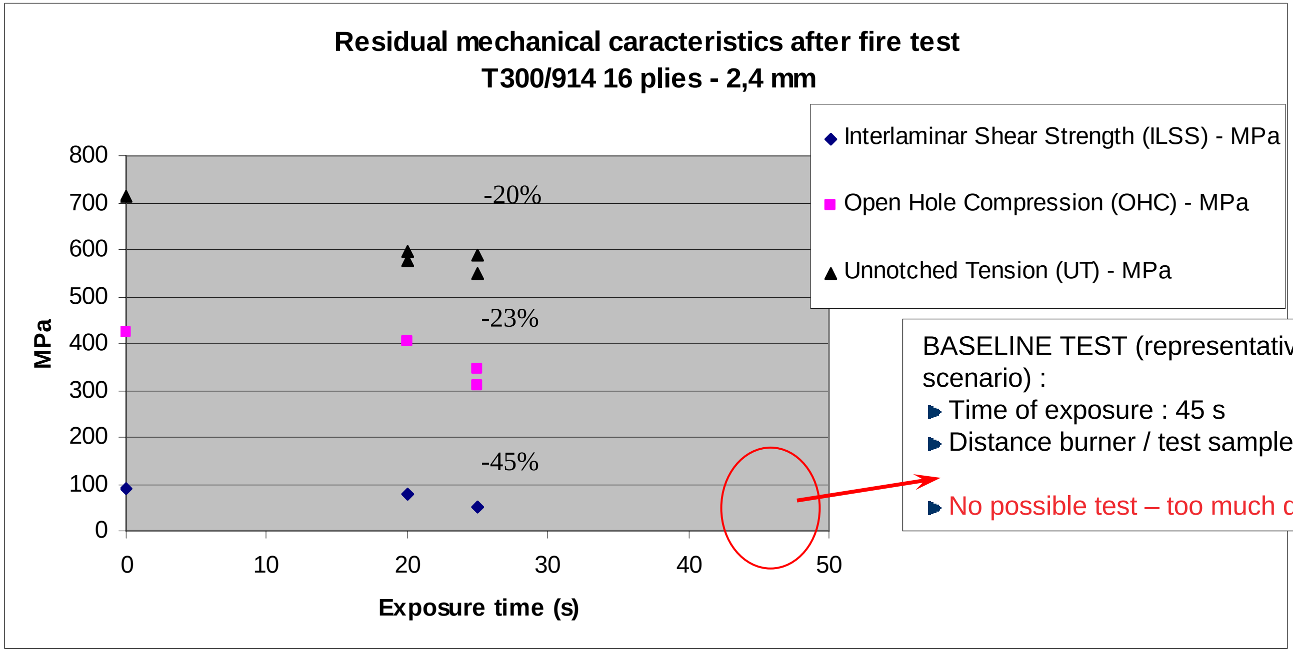
PROPANE FIRE SOURCE

FIRST TEST RESULTS



2 other scenarios were tested with a reduced time of exposure

➔ **The loss of mechanical properties is already very significant after only 25s of exposure to the fire source**



BASELINE TEST (representative of the foam block fire scenario) :

- Time of exposure : 45 s
- Distance burner / test sample : 6 inches
- No possible test – too much damage

PROPANE FIRE SOURCE

- **The next step will be to determine less severe scenarios which will be able to discriminate and classify the composite materials :**

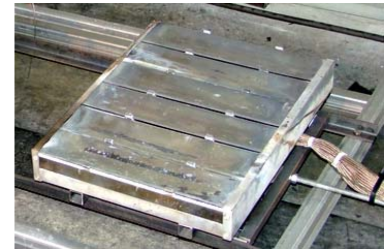
  - ✓ **By reducing the gas flow-rate**
  - ✓ **without reducing the baseline time of exposure which is already very short (45s)**

▶ RADIANT HEAT SOURCE

We have designed a damaging test rig using a radiant panel :

- **The composite test sample is 10 cm above the horizontal radiant panel**

RADIANT HEAT SOURCE

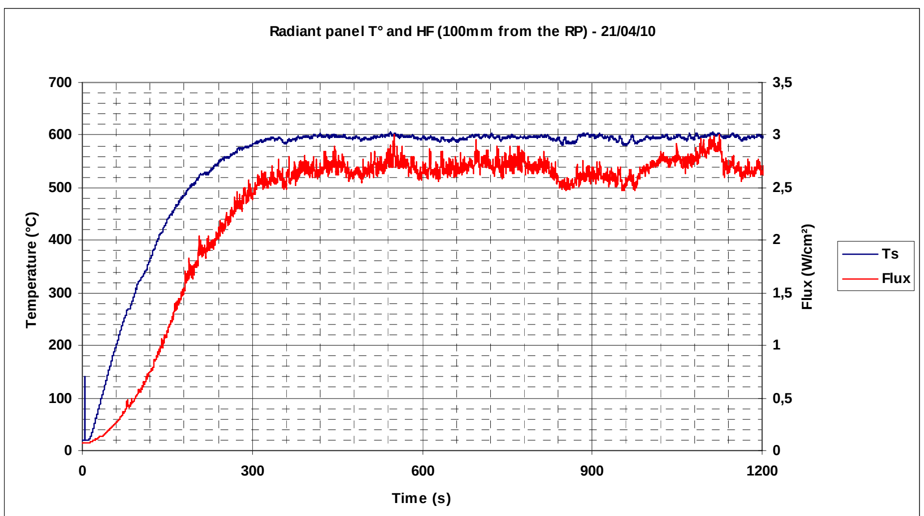


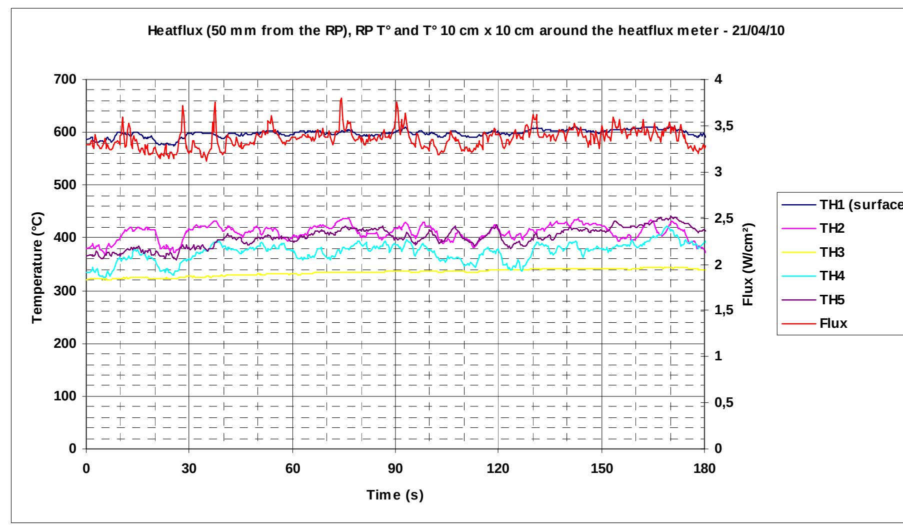
Characterisation of the radiant heat source (d = 10 cm)

Radiant Panel setting T° : 600°C
Heat Flux : 2.7 W/cm²

Characterisation of the radiant heat source (d = 5 cm)

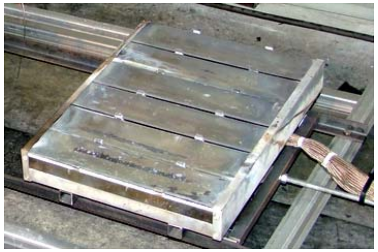
Radiant Panel setting T° : 600°C
Heat Flux : 3.5 W/cm²





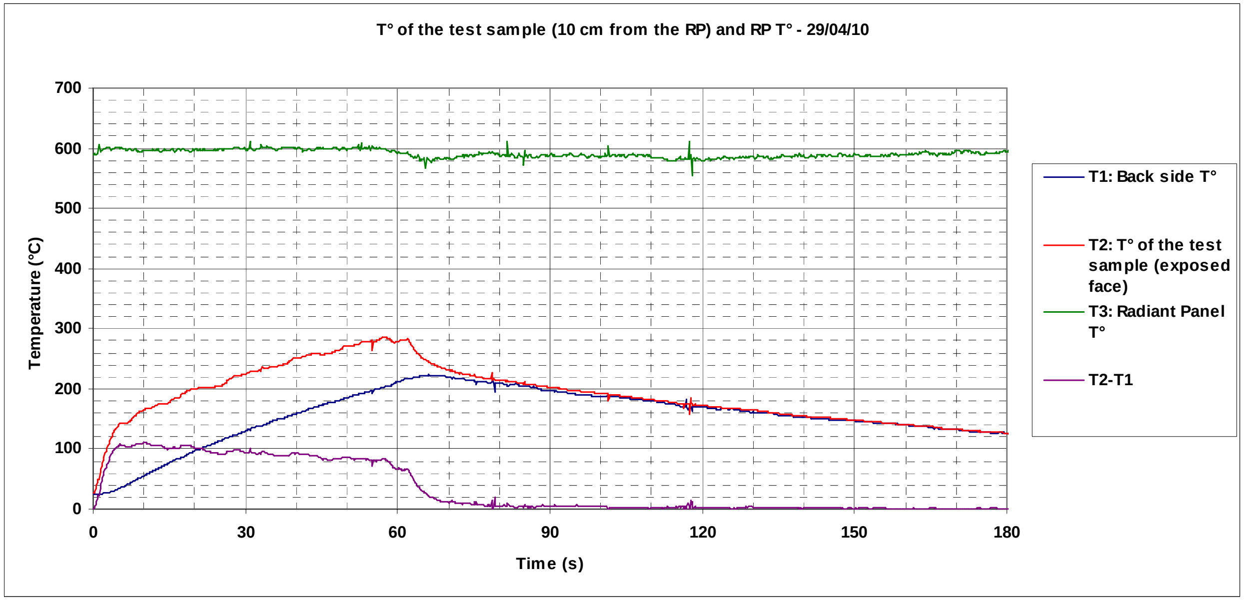
RADIANT HEAT SOURCE

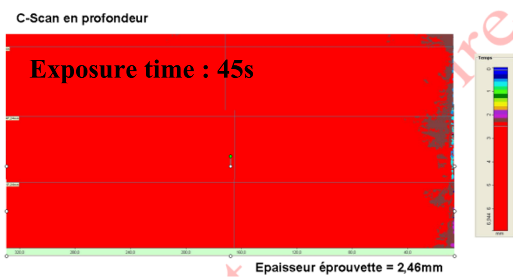
FIRST TEST RESULTS

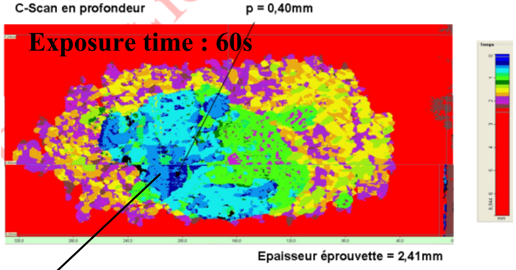


- **T300 / 914 Carbon / Epoxy 16 plies / 2.4 mm**

The test sample is 10 cm above the Radiant Panel







80% of the thickness is delaminated after 1 mn of exposure

RADIANT HEAT SOURCE

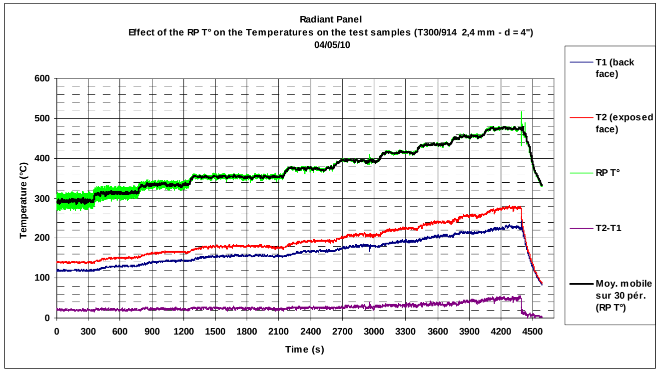
FIRST TEST RESULTS

- **The first test results show that :**

Under exposure conditions (1mn under 2.7 W/cm^2) **less severe than the conditions used for the Radiant Panel Test under development for electrical wiring** (1mn under $\gtrsim$3 W/cm^2)**:**

✓ **A 16 plies composite material representative of a fuselage skin is 80% delaminated**

➔ **These test conditions are too severe to make a study of the mechanical behaviour of composite materials for fuselage applications**



▶ RADIANT HEAT SOURCE

- **The next step was to find the setting T° of the radiant panel which generates surface temperatures of the composite material close to the resin glass transition T° (190 / 200°C):**

We found that:

✓ **380°C / 3mn generates a T° of ~ 200°C on the exposed face (170°C on the opposite face)**

(no visible damages by NDI)

✓ **460°C / 2mn generates a T° of ~ 255°C on the exposed face (200°C on the opposite face)**

(beginning of the damages visible by NDI)

➔ We have now to determine the best scenarios of exposure around these settings to compare the residual mechanical properties of tye various composite materials

UNDERLOAD FIRE BEHAVIOUR

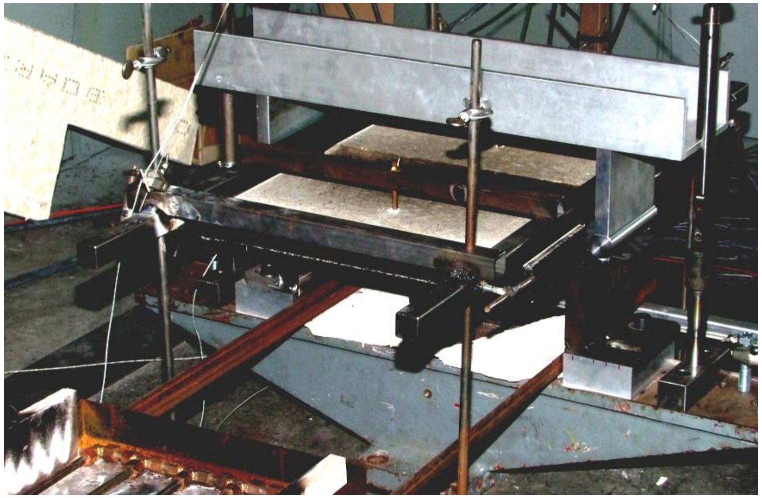
To assess the mechanical behaviour of composite materials <u>during the exposition to a hidden fire</u> :

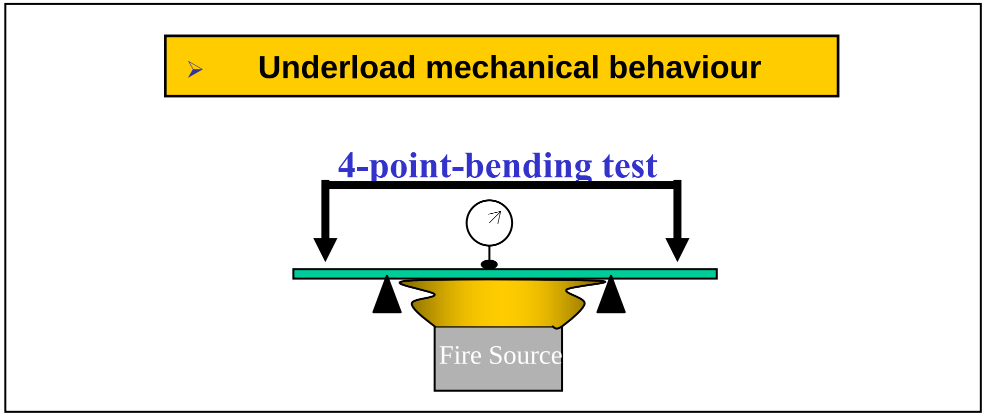
- We designed a 4-point-bending test rig capable of using the gas fire source and the radiant source

- The load (100 MPa) is representative of the fuselage in-flight stress

- The test sample is 6 inches above the heat source

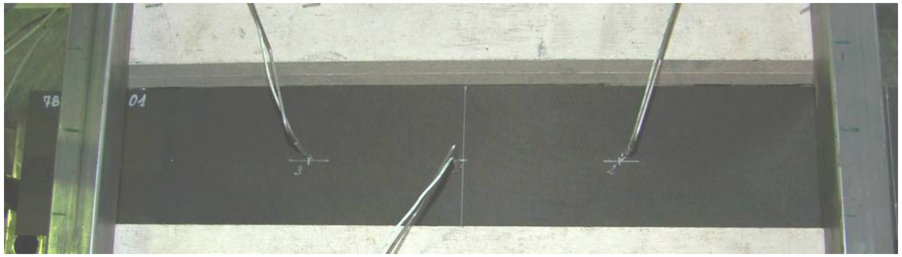
- The continuous recording of the bending displacement is measured at the centre of the test sample





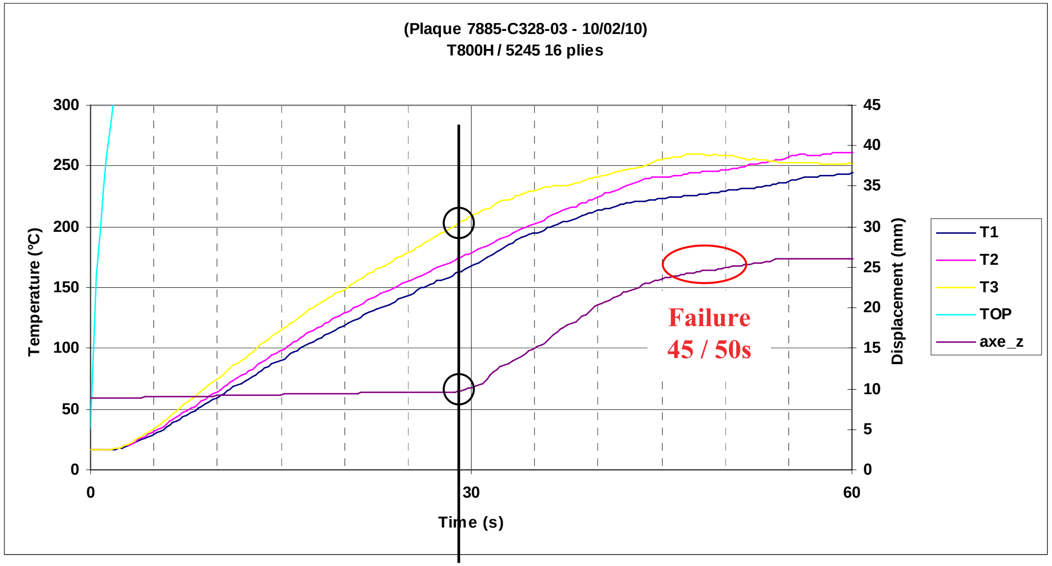
UNDERLOAD FIRE BEHAVIOUR

FIRST TEST RESULTS

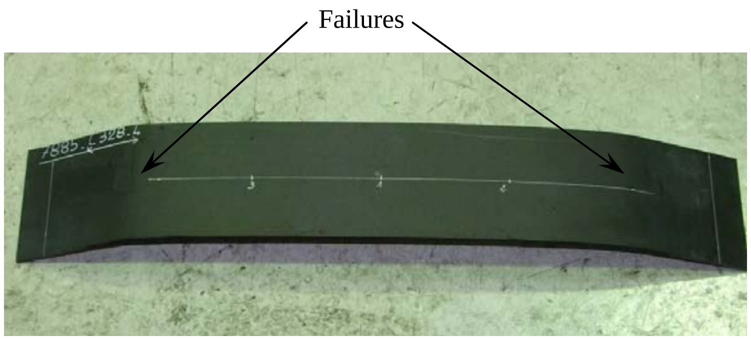


Thermocouples on the back side

- **T300 / 914 Carbon / Epoxy 16 plies / 2.4 mm**



Fire source :
Gas fire source (BASELINE setting (representative of the foam block fire scenario)) :
Distance burner / test sample : 6 inches



Test sample after test

The test sample began to bend after 29s at ≈ 200°C on the opposite face (close to the Glass Transition T°) and failed at ≈ 45s

CONCLUSIONS

We have designed

- **a propane fire source representative of the FAA foam block fire source used for the ignition of the intermediate scale fire test**
- **a radiant heat source to assess the behaviour of materials submitted to a heat source without flame**

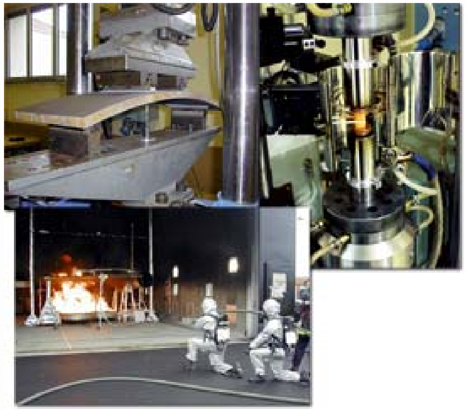
(➔But the first tests shown that the fire scenarios are to severe to make a study of the mechanical behaviour of composite materials for fuselage applications)

- **a 4-point-bending test rig to assess the underload behaviour of materials submitted to a thermal threat with or without flame**

CONCLUSIONS

REPRESENTATIVITY OF THE THREAT

- **We thought that the hidden fire source or the heat source used to test the cabin materials would have been a good source for the assessment of the fire and mechanical behaviours of composite materials for fuselage.**
- **We are surprised that these fire sources are too severe, leading to a delamination of (at least) 80% of the thickness (16 plies of carbon-epoxy, 2.4mm, representative of a fuselage skin).**
- **If a fire would propagate with the same characteristics, all the exposed parts of the composite fuselage would lose most of their mechanical properties within less than 1 minute?**
- **Are they realistic scenarios for the assessment of the flammability behaviour (propagation) but not realistic for the assessment of the mechanical behaviour?**
- **Or are they only intended to be representative of a local ignition source but not intended to be representative of a realistic larger in-flight fire?**



Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

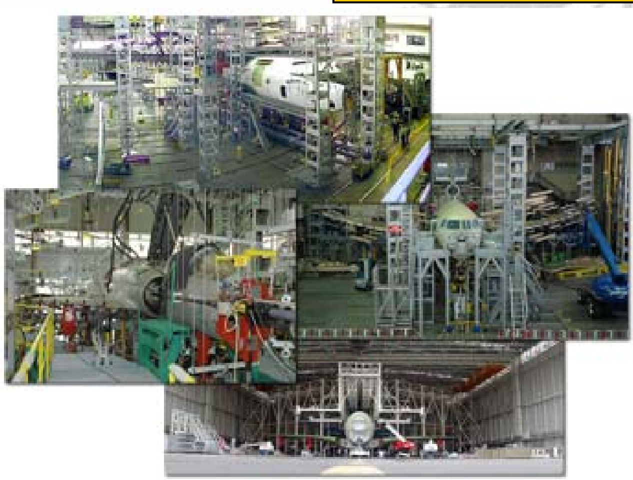
MINISTÈRE DE LA DÉFENSE

DGA Aeronautical Systems

(ex. CEAT)

« Fire Safety Department »

Fire Behaviour
Of
Structural Composite Materials



DGA