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RÉPUBLIQUE FRANÇAISE

MINISTÈRE DE LA DÉFENSE

Toulouse Aeronautical Test Centre (CEAT)

« Fire Safety Department »

FIRE BEHAVIOUR OF STRUCTURAL COMPOSITE MATERIALS

DGA

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FIRE BEHAVIOUR OF STRUCTURAL COMPOSITE MATERIALS

➔ **Development of Hidden Fire Source**

➔ **Burnthrough, Smoke & Toxicity of structural composite materials**

DGAC
CEAT
AIRBUS

➔Reminder of the full test program

FIRE BEHAVIOUR OF STRUCTURAL COMPOSITE MATERIALS

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 manufacturer are required to demonstrate that polymer structural composites provide an equivalent safety level to the current material (aluminium alloy)**

FIRE BEHAVIOUR OF STRUCTURAL COMPOSITE MATERIALS

- **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**

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 cabin side (smoke / toxicity / heat release)

FIRE BEHAVIOUR OF STRUCTURAL COMPOSITE MATERIALS

FIRE TEST MEANS TO BE DEVELOPED

To define or adapt
various specific test means & procedures

- **Hidden Fire source (development of the test mean in progress / fire scenario to be defined)**
- **Burnthrough smoke box test (in progress)**
- **Under load fire test (mean test and method to be defined)**
- **Electric arc effects (method to be defined)**

FIRE BEHAVIOUR OF STRUCTURAL COMPOSITE MATERIALS

▸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
Bunsen burner test (FAR 25.853)	**Exposure to the hidden fire source**
OSU test chamber (Heat Release) (FAR 25.853)	**+ NDI & mechanical tests**
NBS test chamber (Smoke / Toxicity) (FAR 25.853 / ABD0031)	**Under load fire tests** (hidden fire source)
Cone calorimeter (7,5 & 10 W/cm²)	**Burnthrough smoke box tests**
	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**

BURNTHROUGH
SMOKE & TOXICITY
of
STRUCTURAL COMPOSITE MATERIALS

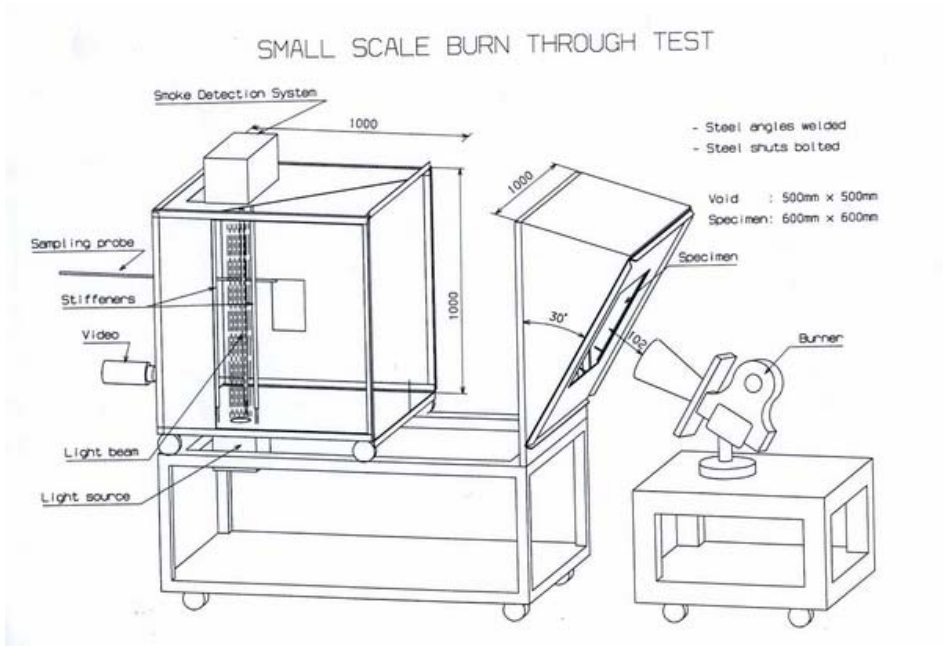
Burnthrough / Smoke box

- A small scale test was developed by the CEAT in 1996 to assess the fire behaviour of thermal insulation blankets.
- Many tests were carried out on assemblies including aluminium skin & insulation blankets which gave a good repeatability on burnthrough time, smoke density and toxicity.

- In 2002, this test device was widely used to assess the fire behaviour of GLARE (Glass-Epoxy / Aluminium composite) for fuselage skin (partially used on A380).

Burnthrough / Smoke box

- **Smoke box size : 1,2m^3**
- **Burner configuration in accordance with the burnthrough test requirements (App F Part VI)**
- **Photometer system (= NBS test chamber)**
- **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)

Materials / configurations to be tested

➢ **Various materials will be tested**
civil / military applications for airplane or helicopter

- ➔ **Various resins, fibbers, thicknesses, with & without honeycomb**
- ➔ **Tests will be carried out on assemblies “composite / insulation blanket / wall panel”**

Toxicity

- **Species to be analysed**

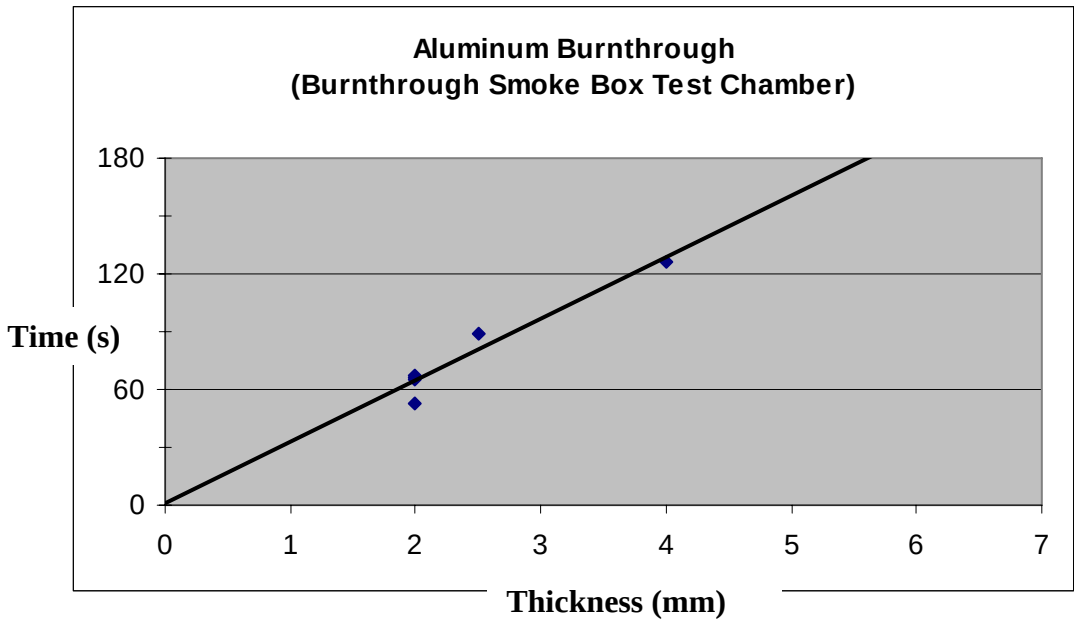
Gas Component		
Carbon monoxide/dioxide	CO / CO_2	FTIR
Oxides of nitrogen	NO_x (NO + NO_2)	FTIR
Sulphur dioxide	SO_2	FTIR
Hydrogen fluoride	HF	
Hydrogen bromide	HBr	?
Hydrogen chloride	HCl	FTIR
Hydrogen cyanide	HCN	FTIR
Hydrogen sulphide	H_2S	
Ammonia	NH_3	FTIR
Phenol	C_6H_5OH	?

- **Choice of the species results from :**

  - **effect on Toxicity Index (recent works from a NATO working group on standardization of the fire test methods for naval ships)**
  - **Our capabilities …**

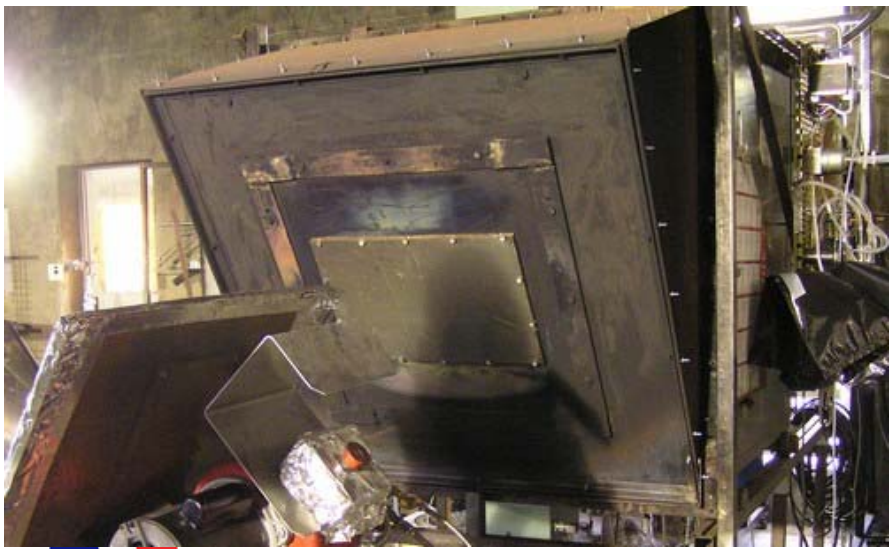
Preliminary tests

- **Tests on aluminium plates**



Preliminary tests

- **Composite materials / Test procedure**
  - **Burner settings : Calibration in accordance with the burnthrough test requirements**
  - **Test duration : 5mn**
  - **Gas analysis : FTIR & sampling (90s 4 mn & 5 mn)**

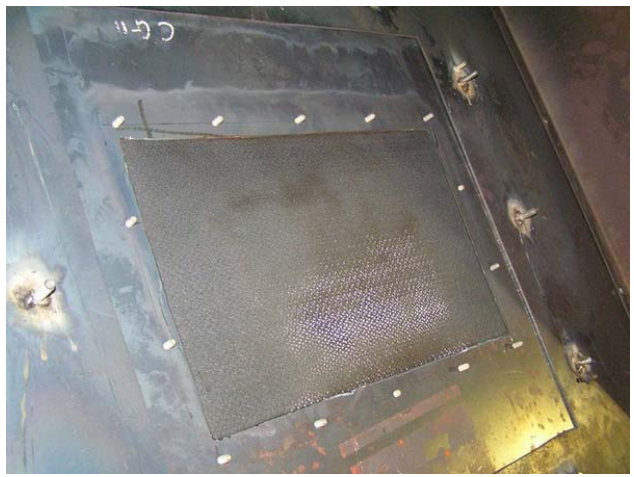


Preliminary tests

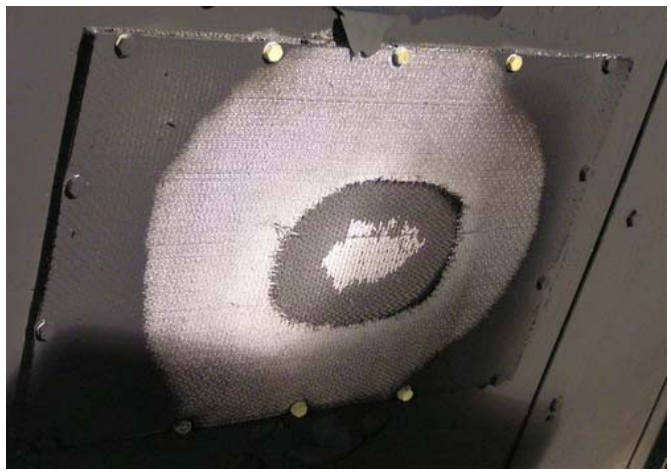
- **Preliminary tests were carried out on various small specimens (window box : 400 mm x 250 mm)**
  - **Composite : carbon - epoxy (M18-1/G939)+ NOMEX honeycomb**
    Total thickness : 11.5 mm . (Resin 180)

Outer face

Inner face

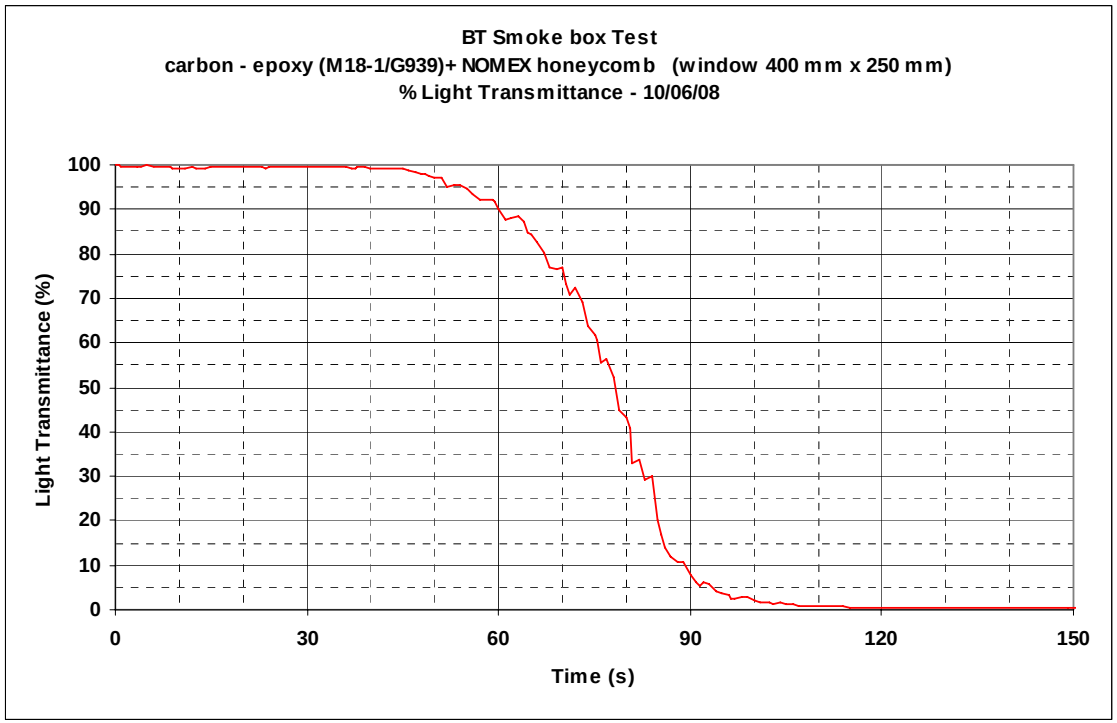


After test



Preliminary tests

- **Smoke Opacity**



- **Smoke release started at 40s**
- **The majority of the loss of visibility happened before the 90s**

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

Development tests

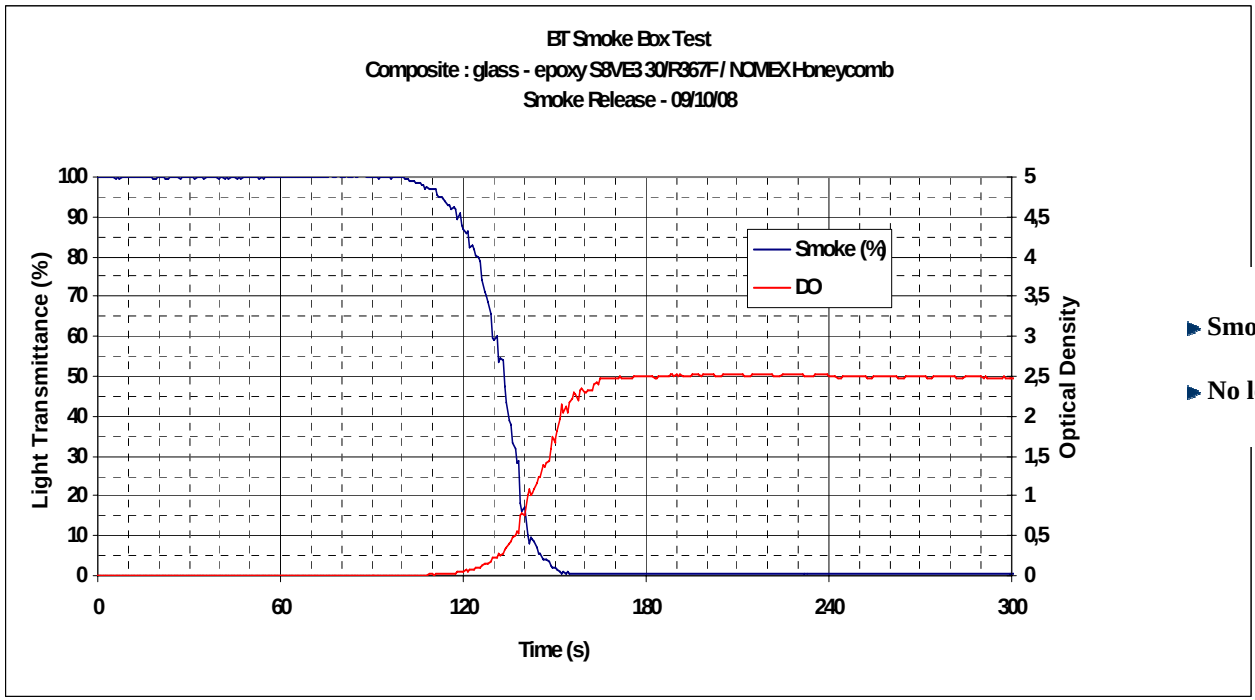
- **Development tests were carried out on various large specimens (window box : 500 mm x 500 mm)**
  - **Composite : Glass Epoxy S8VE3 30/R367F / NOMEX Honeycomb (Resin 120)**

Inner face – After test

Outer face – After test

Development tests

- **Smoke Opacity**



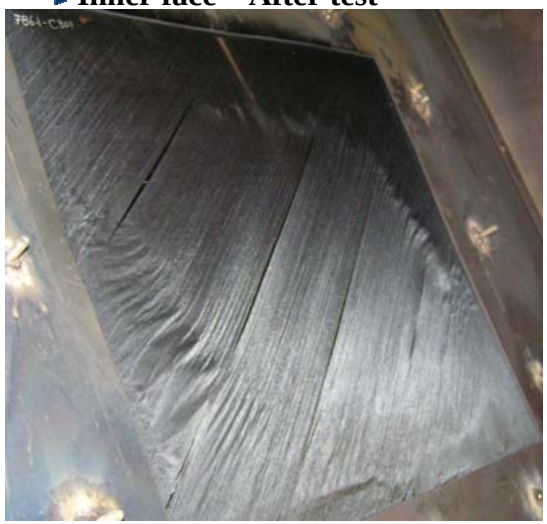
- Smoke release started at 1mn 40s
- No loss of visibility before the 90s

Development tests

- **Composite : Carbon - Epoxy T300/914 - 16 plies - Thickness : 2,5 mm (Resin 180)**

Inner face – After test

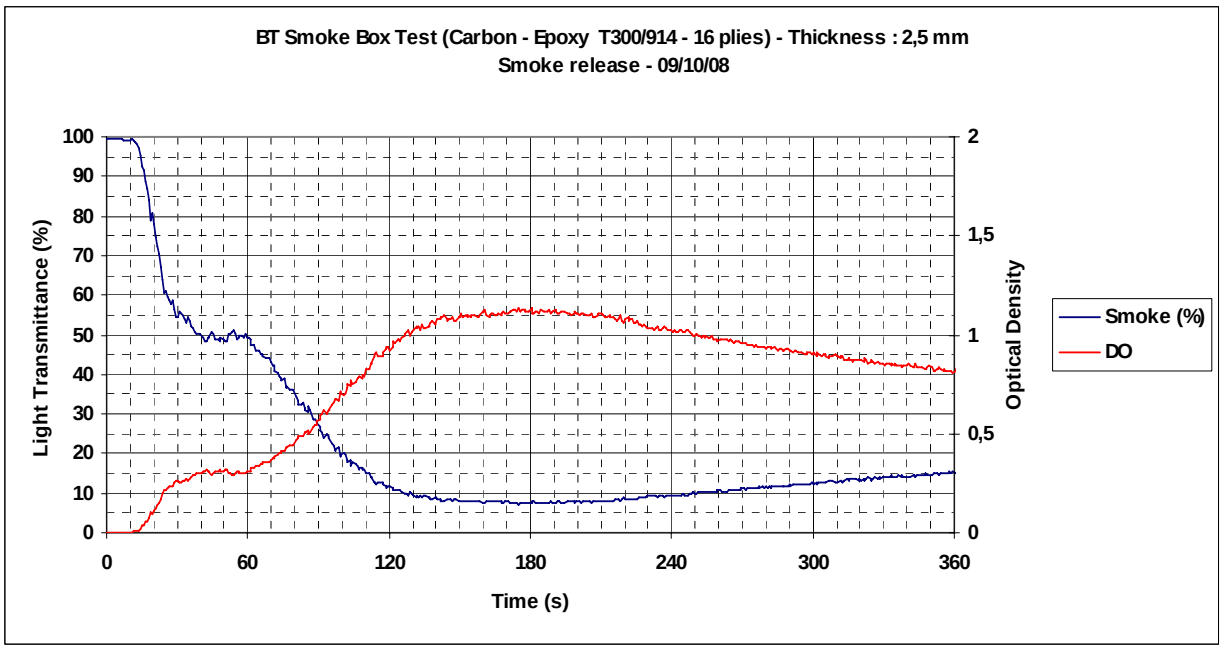
Inner face – After test



Outer face – After test

Development tests

- **Smoke Opacity**



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

Development tests

- Composite :
  - Carbon - Epoxy T300/914 - 16 plies - Thickness : 2,5 mm (Resin 180)
  - Thermal acoustic insulation : (Microlite, Nextel + térul 18)

Before test

Development tests

After test

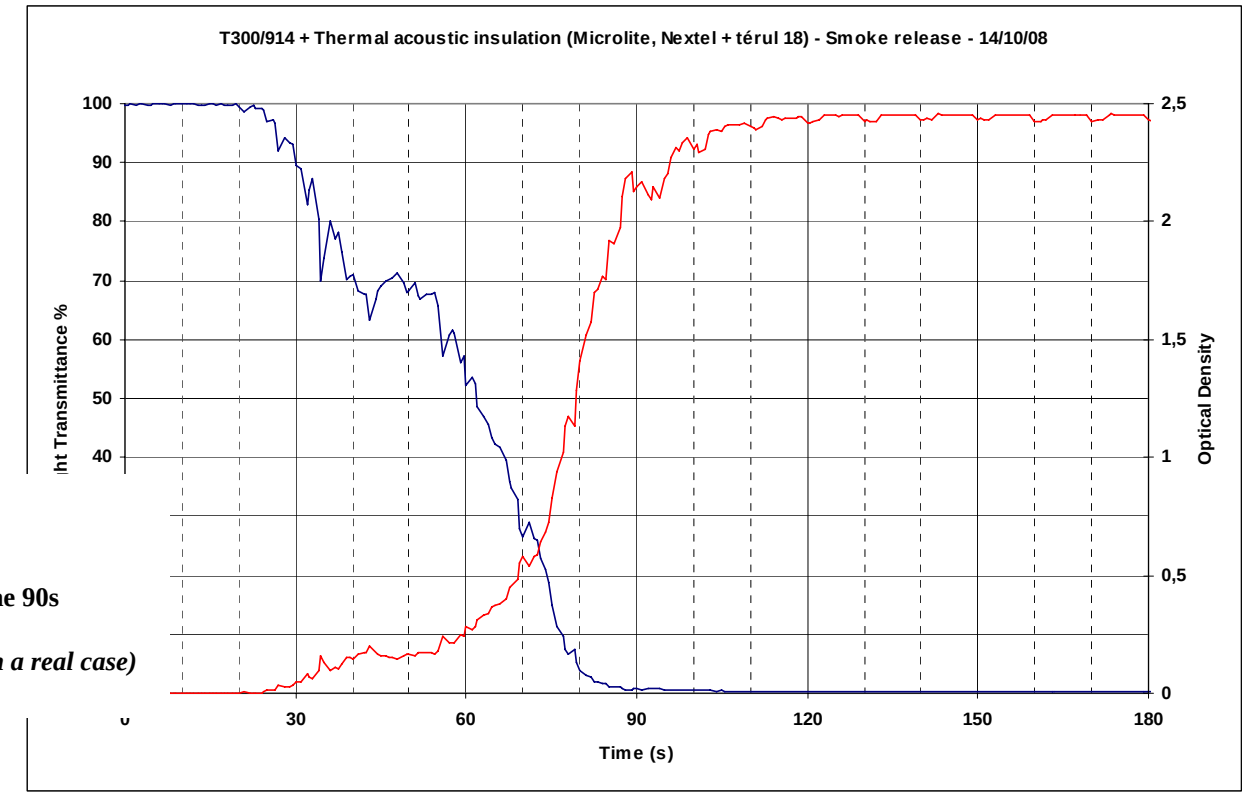
Inner side

Outer side

Thermal insulation removed

Development tests

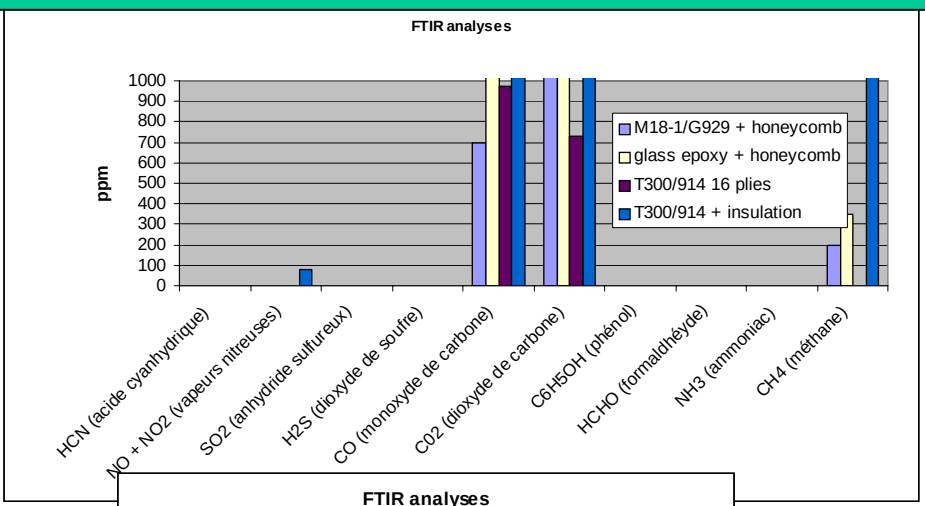
- **Smoke Opacity**

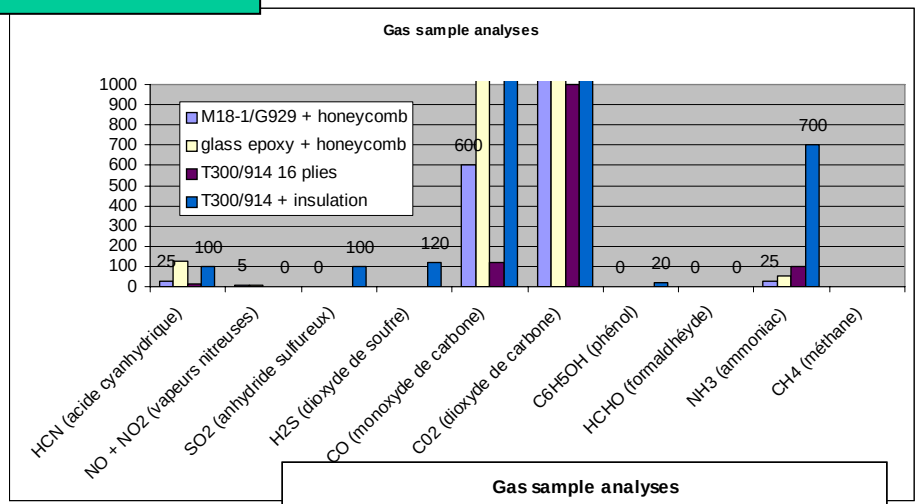


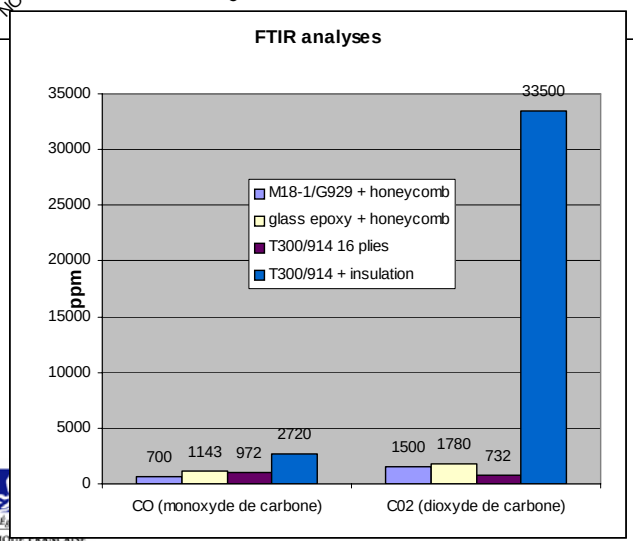
- **Smoke release started early again ~ 20 s**
- **Total loss of visibility happened before the 90s**

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

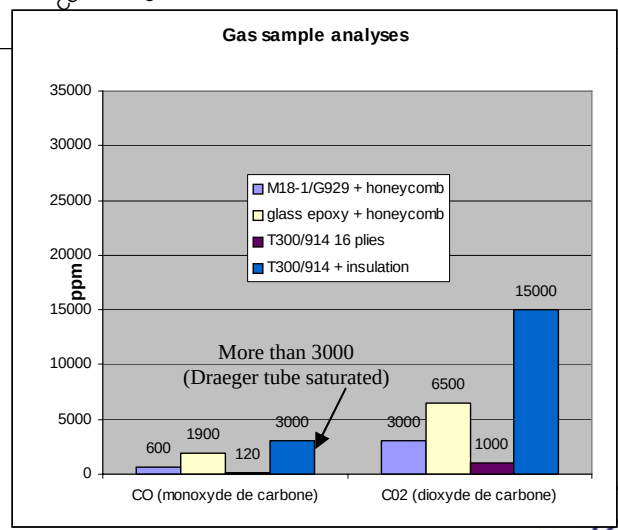
Development tests







- few species are currently analysed by FTIR
- Some differences between FTIR & gas sample analyses
- need to buy other standard gas mixtures
- need to improve the procedure of measurement



- Toxicity results

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

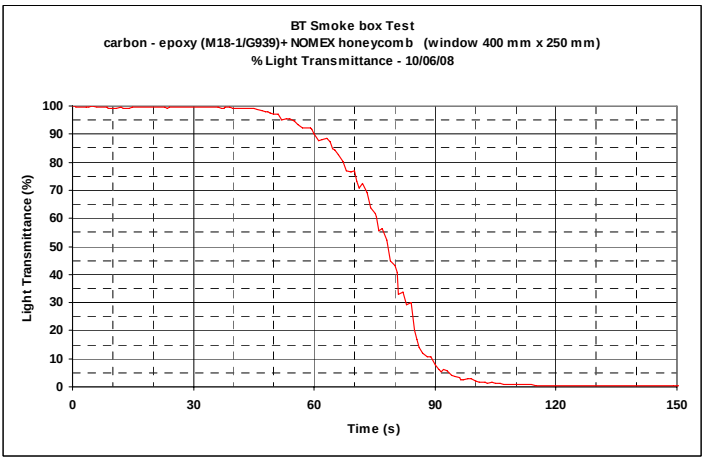
T_m = minimum percent light transmission

A = exposed specimen area

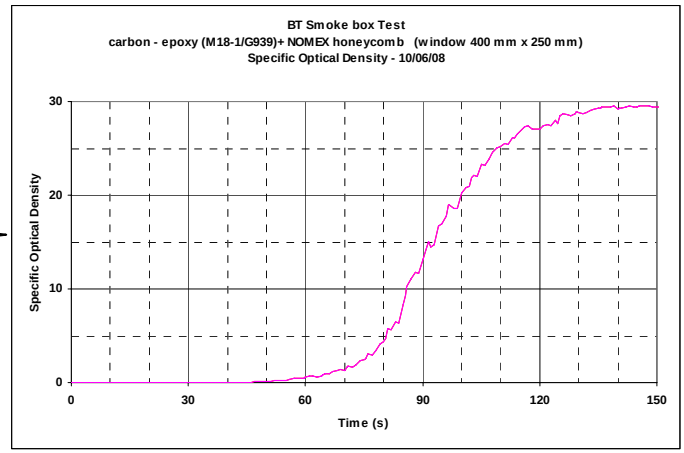
V = chamber volume

L = light path length

- **Due to the limitation of the photometric system and to the scale factor, it will 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 with NBS toxicity requirements Scale Factors

Gas concentration in the CEAT 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		

Smoke Toxicity : Comparison with FAA smoke box Scale Factor

Gas concentration in the CEAT smoke box is 1.36 more than in the FAA test chamber

$$\text{Ratio of Volume}_{Box} \text{ to Burn Area}_{Box} = 60.33\ ft^3 / 9.25\ ft^2 = 6.52$$

Burnthrough smoke box :

- **Volume of the smoke box : V_{SB} = 1.2 m3**
- **Exposed area of the regular test sample :**
  - **500mm x 500mm : S_{SB} = 0.25 m²**

- **Ratio of Volume to Exposed area = 4.80**

▸ 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**

- **Scale factor has been determined to compare the toxic gas concentrations from the CEAT BT smoke box and from the FAA BT smoke box**

- **Few toxic species are currently analyzed (we need to buy other standard gas mixtures)**

- **We need to perform more tests on various materials to compare the FTIR gas analysis to the sampling gas analysis**

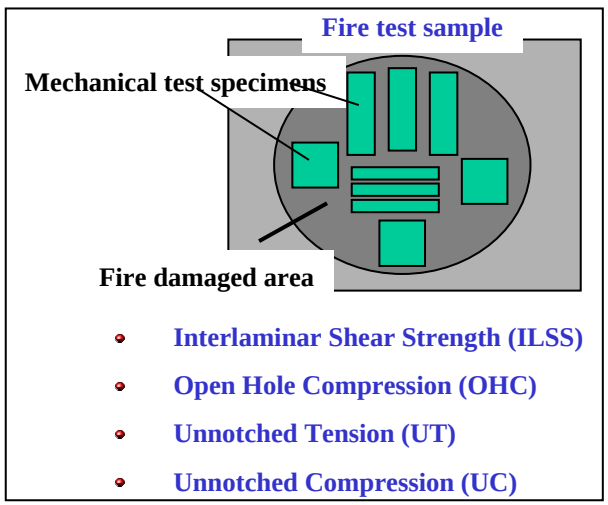
DEVELOPMENT
OF A REPEATABLE

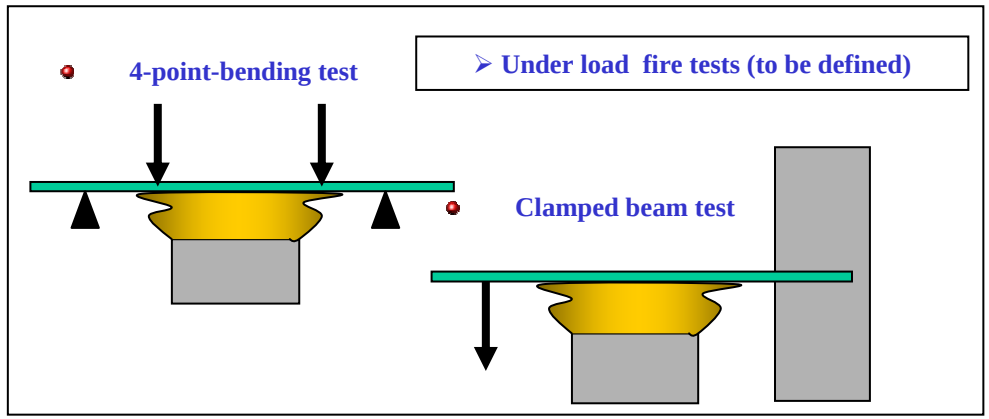
HIDDEN FIRE SOURCE

HIDDEN FIRE SOURCE

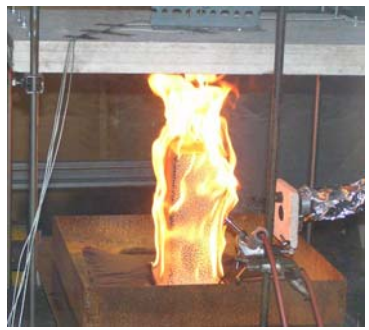
What's the need ?

- **Repeatable fire source simulating a hidden fire :**
  - **To expose the various composite test samples to various scenarios before mechanical tests**
  - **To perform the under-load fire tests**





HIDDEN FIRE SOURCE



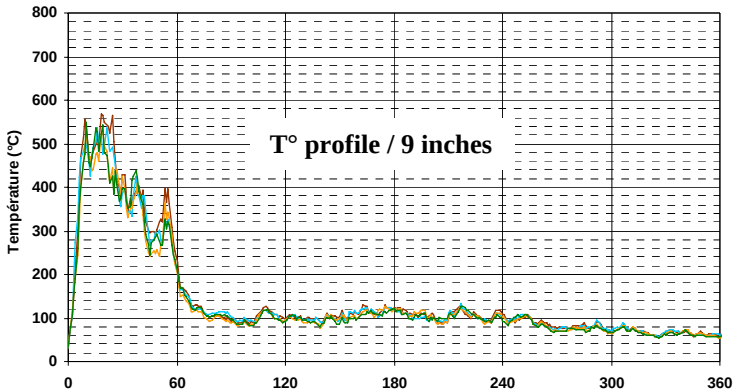
SPECIFICATIONS

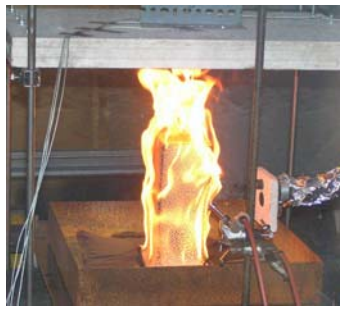
Assuming that the FAA foam block fire source is representative of a declared hidden fire :

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

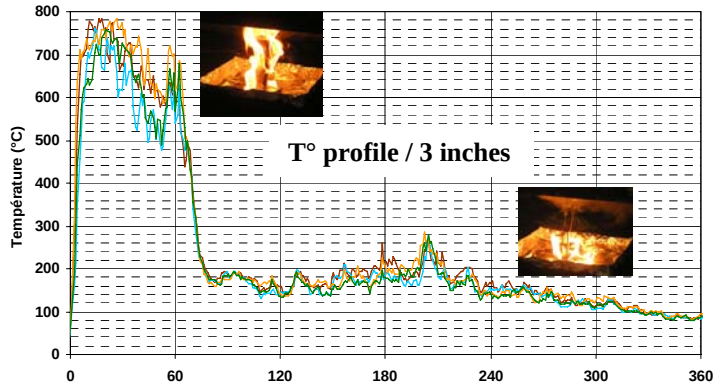
Characterisation of the FAA foam block fire source

T° at 9 inches from the foam top



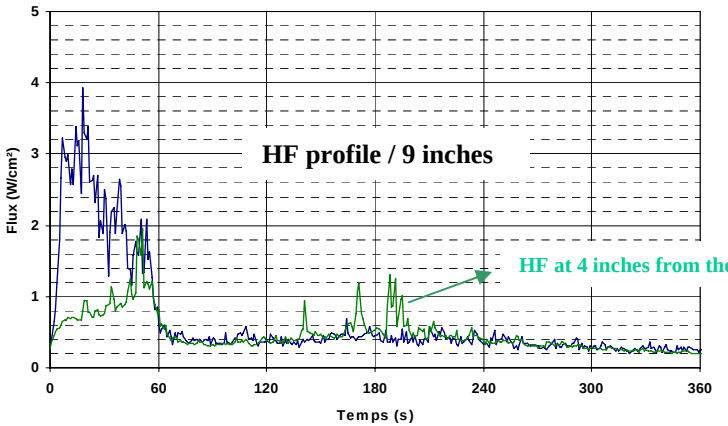


T° at 3 inches from the foam top



Foam 16kg/m3 + Heptane 10ml - Foam top to HF meter : 3 inches - 24/06/08

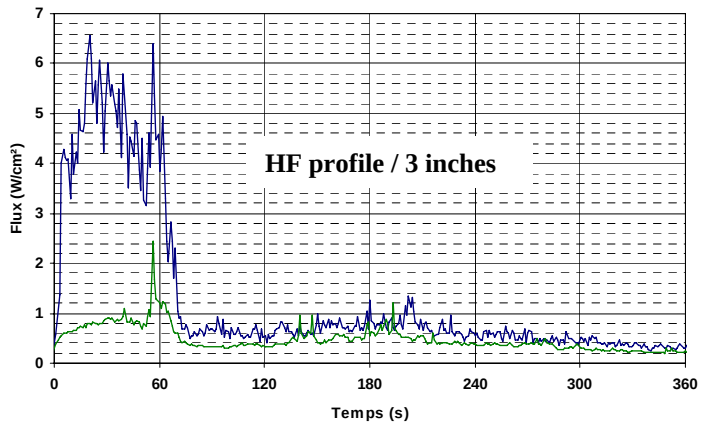
Heat fluxes at 9 inches from the top / 4 inches from the side



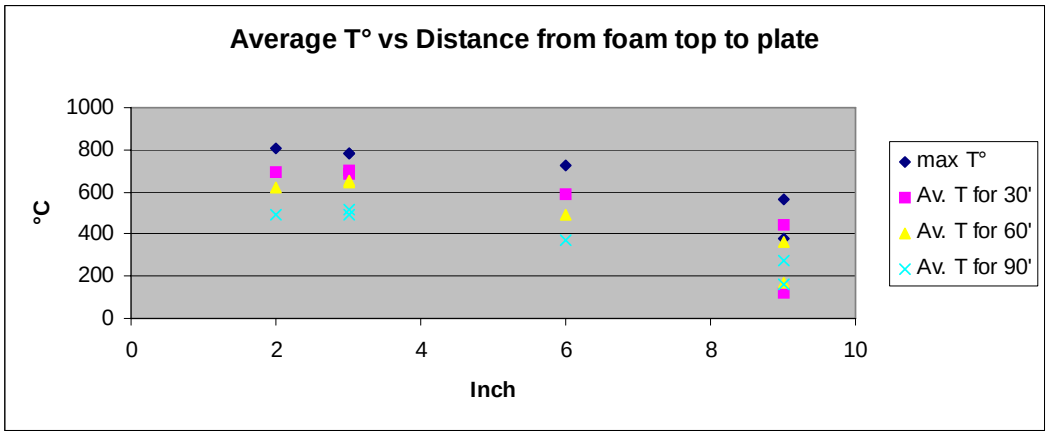
Various distances from the foam top to the plate were tested :

- **9 inches**
- **6 inches**
- **3 inches**
- **2 inches**

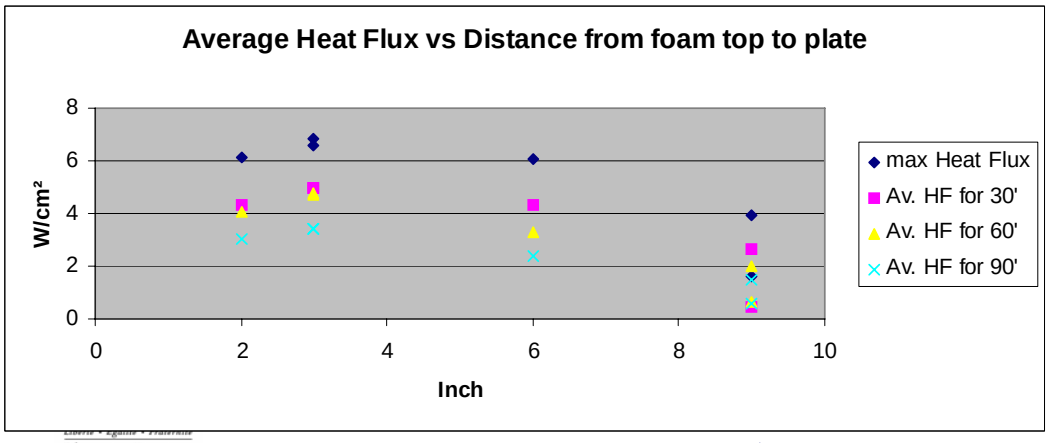
▸ **Active time of burning : ≃ 1mn**



Characterisation of the FAA foam block fire source

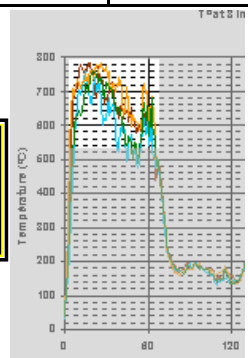


Av T°C	d = 2 inches	d = 3 inches	d = 6 inches	d = 9 inches
30"	697	700	588	447
60"	621	642	492	365
90"	494	495	375	278
Max :	805°C	781°C		



Fire source specifications :

- T° ≃ 650 to 700 °C
- Heat Flux Density ≃ 4 to 5 W/cm²

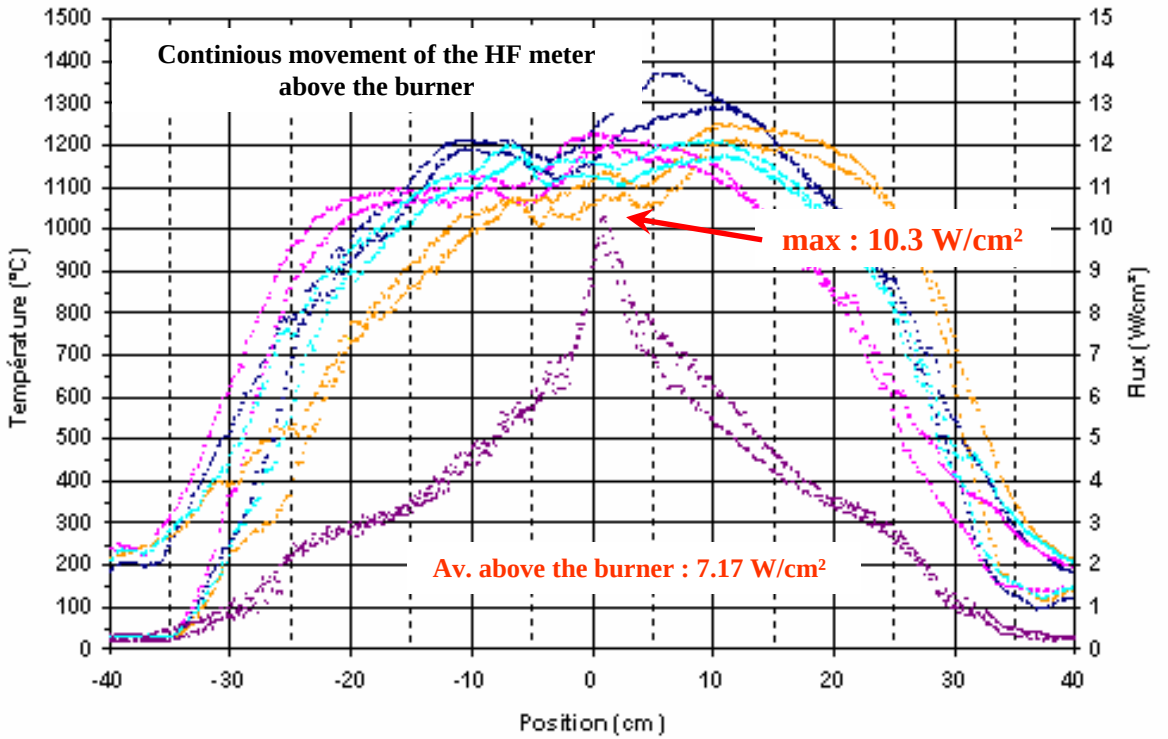


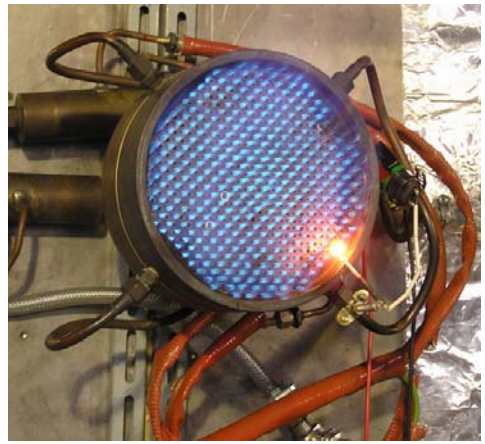
Av HF (W/cm²)	d = 2 inches	d = 3 inches	d = 6 inches	d = 9 inches
30"	4,35	5	4,33	1,60 to 3,90
60"	4,05	4,75	3,32	0,65 to 2
90"	3,01	3,44	2,4	0,60 to 1,5
Max :	6,14 W/cm²	6,84 W/cm²		

ISO 2685 Gas Burner

Characterisation of the ISO flame

Heat flux Mapping (3 inches above the burner)
(centre line (vertical impact position))





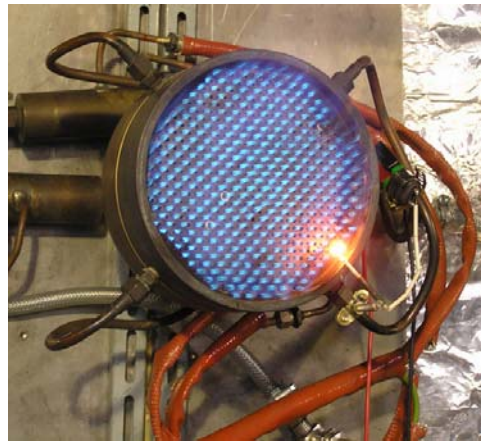
- Diameter = 152 mm

- ISO setting of the burner is too energetic (7,17 W/cm² / 1150 °C)

- Heat Flux is not homogeneous (very thin and high peak)

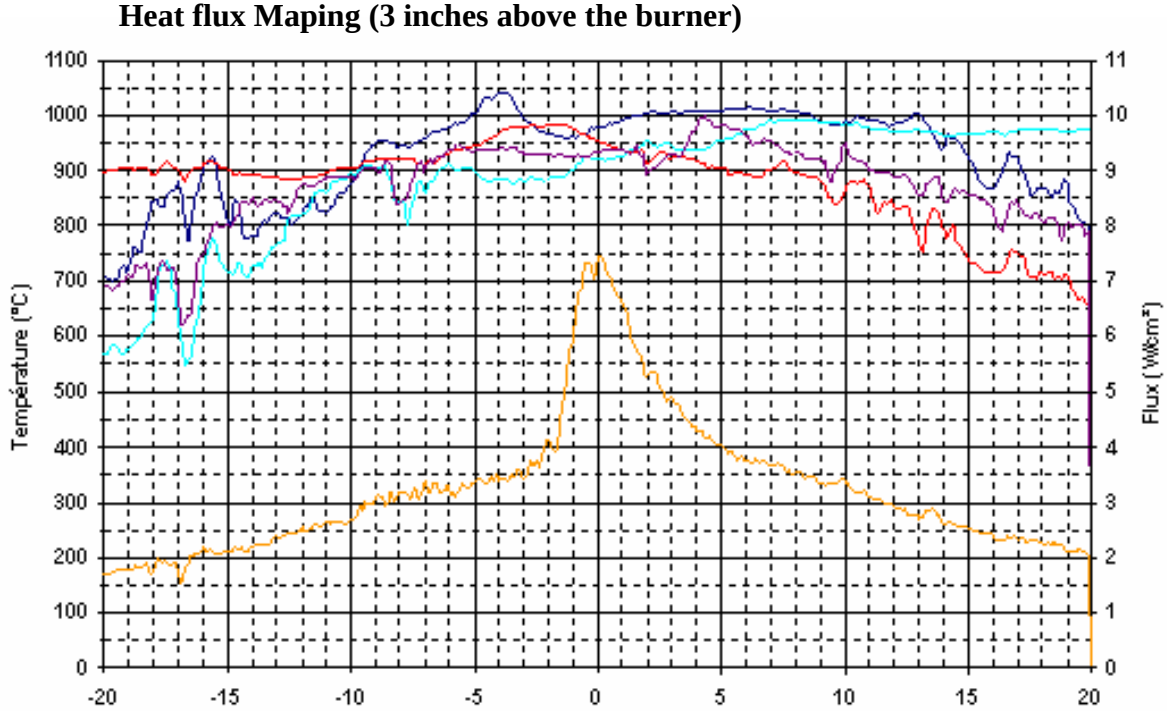
ISO 2685 Gas Burner — Lowest energetic flame

Several settings were tested, the lowest energetic flame was :



Diameter = 152 mm

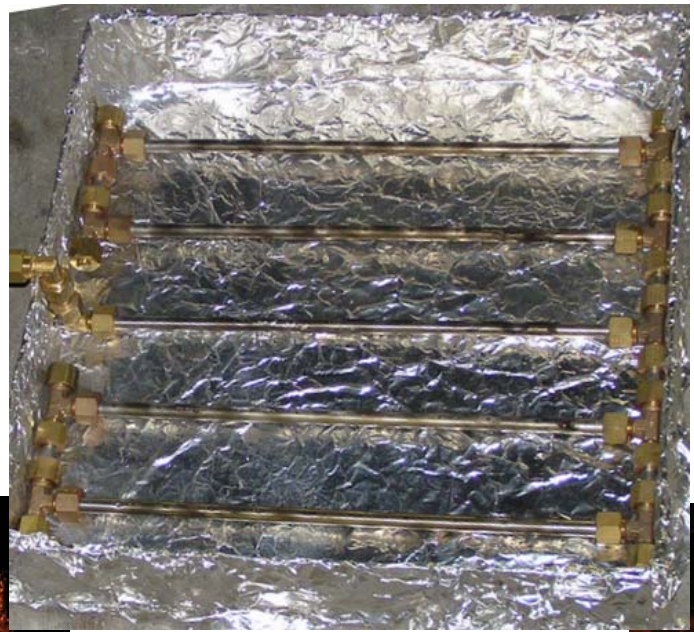
Heat flux Maping (3 inches above the burner)



The flame T° is too high (950 °C)

The Heat Flux is not homogeneous

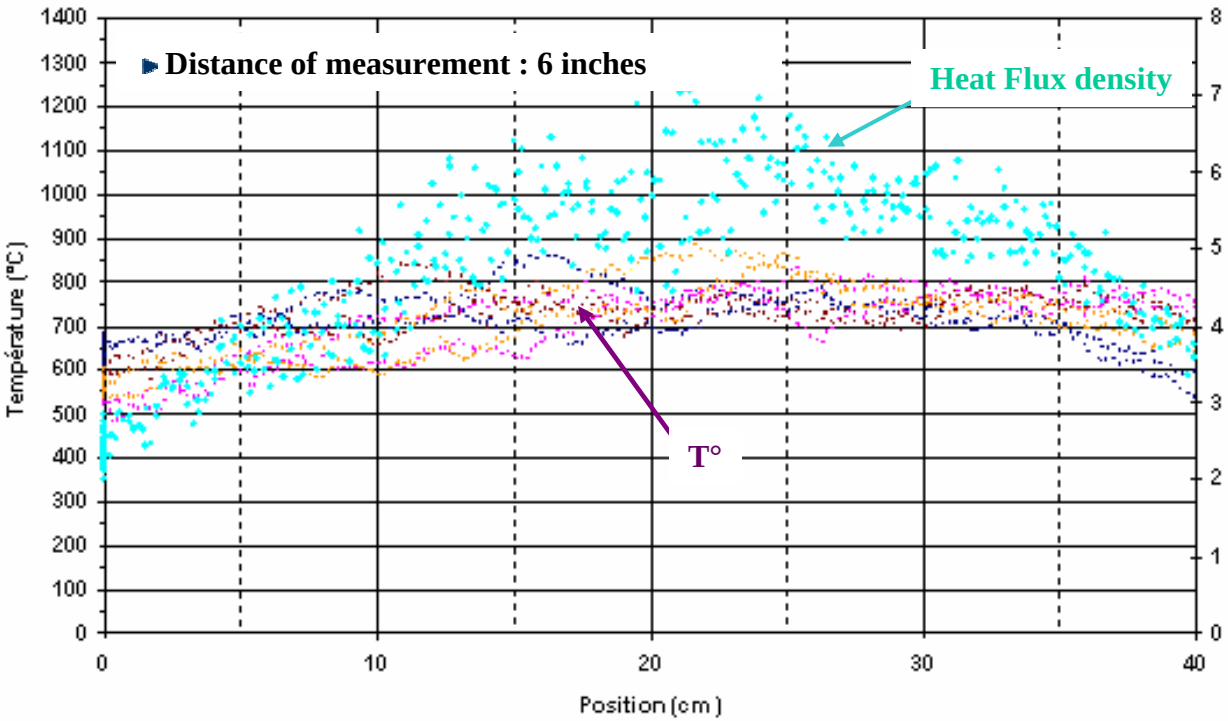
CEAT Hidden Fire Source



Simple experimental gas burner made with 5 bored tubes

CEAT Hidden Fire Source

Characterisation of the CEAT gas burner's flame



Flame characteristics are homogeneous & very close to the flame of the foam block

- **Flame T° ~ 750 °C**
- **Heat Flux ~ 5,5 W/cm²**

CEAT Hidden Fire Source

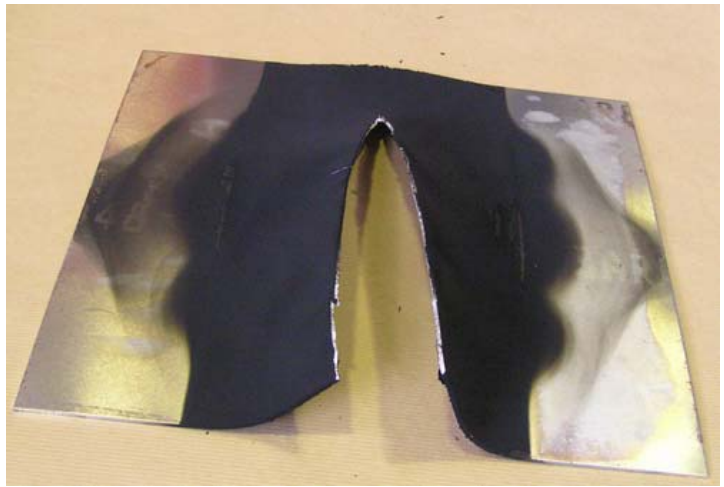
T300 / 914 Epoxy Carbon and T300J or HTA / RTM6 Epoxy Carbon were used to compare the damages generated by the 2 fire sources (Foam block / Gas burner)

Surface exposed to the flame :

150 x 400 mm

Comparison of the damage tests : Foam block / Gas burner

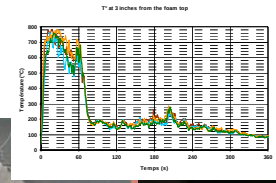
2024 Aluminium plate was used as reference to determine the burnthrough time

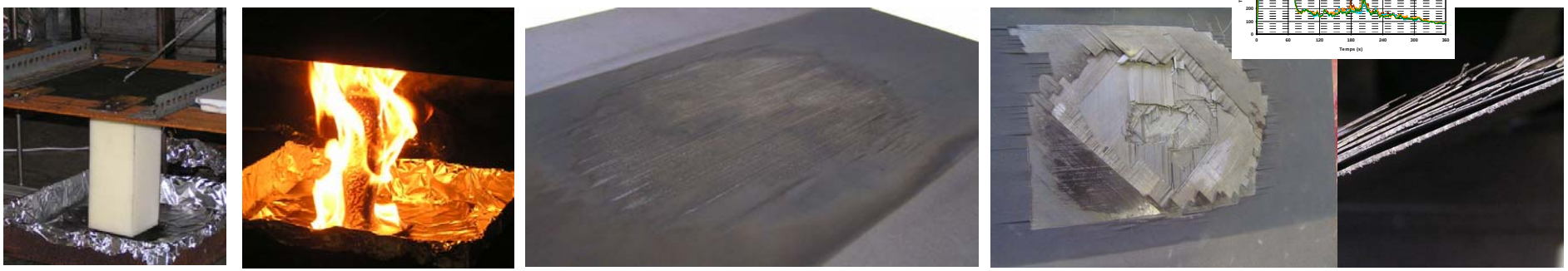


CEAT Hidden Fire Source

Comparison of the damage tests : Foam block / Gas burner

- **Foam block test / d = 3 inches (exposure time : 7 mn (complete burning of the foam))**



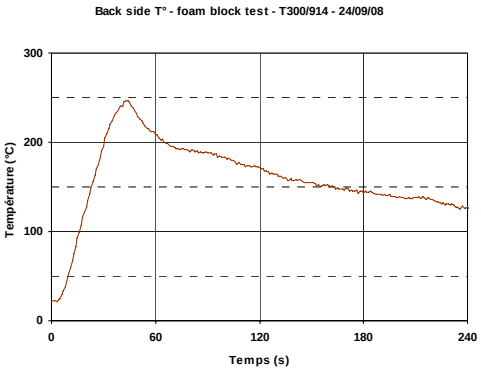


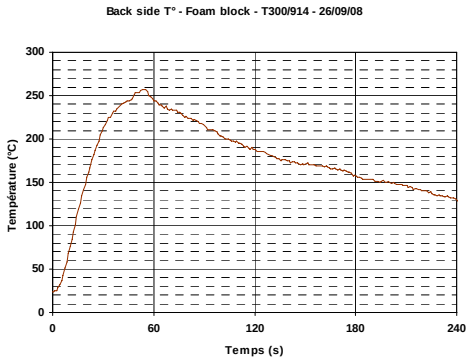
- **Gas burner test / d = 6 inches (exposure time : 1 mn 30 s) /**

CEAT Hidden Fire Source

Comparison of the damage tests : Foam block / Gas burner

- **Foam block tests (exposure time : 7 mn (complete burning of the foam))** d = 3 inches

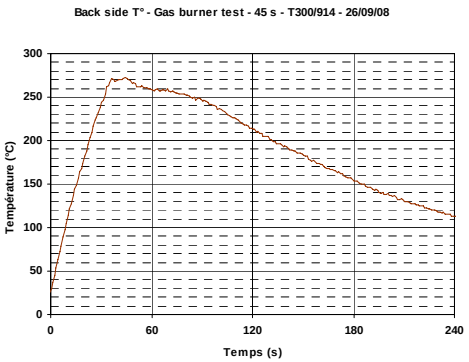


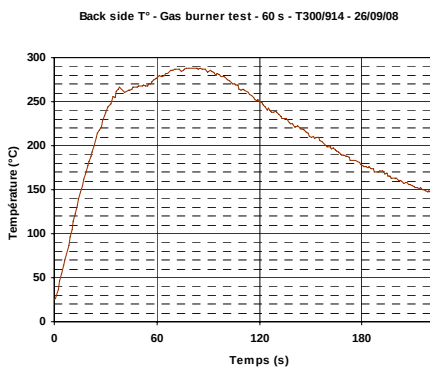


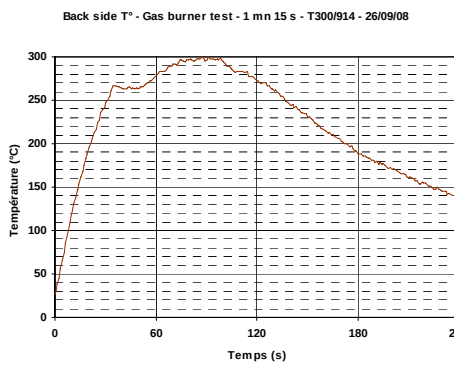
For both fire sources :

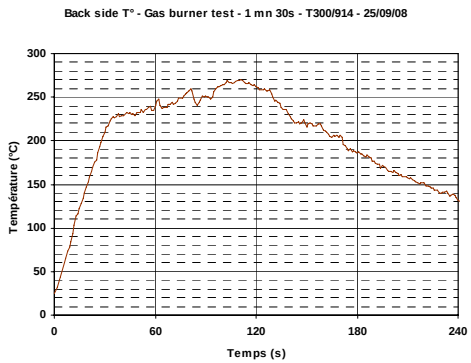
- **Back side T° ~ 250 / 300 °C (insulating effect of the delaminations)**
- **Profile rise T° are very similar until the first delaminations**
- **Gas burner tests : an after flame time (~ 20 s) was observed**
- **45 s gas burner test shows the more similar profile of T°**

- **Gas burner tests (exposure time : 45 s to 1 mn 30 s)** d = 6 inches





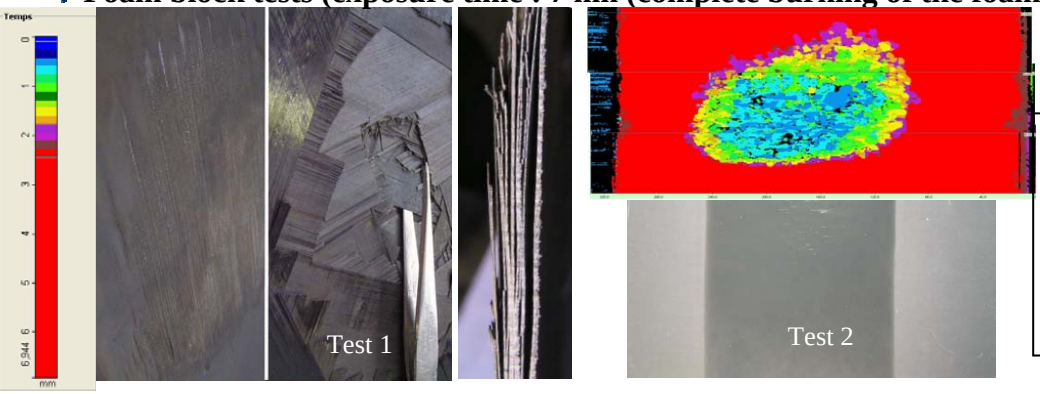




CEAT Hidden Fire Source

Comparison of the damage tests : Foam block / Gas burner

- T300 / 914 Epoxy Carbon
  - Foam block tests (exposure time : 7 mn (complete burning of the foam))

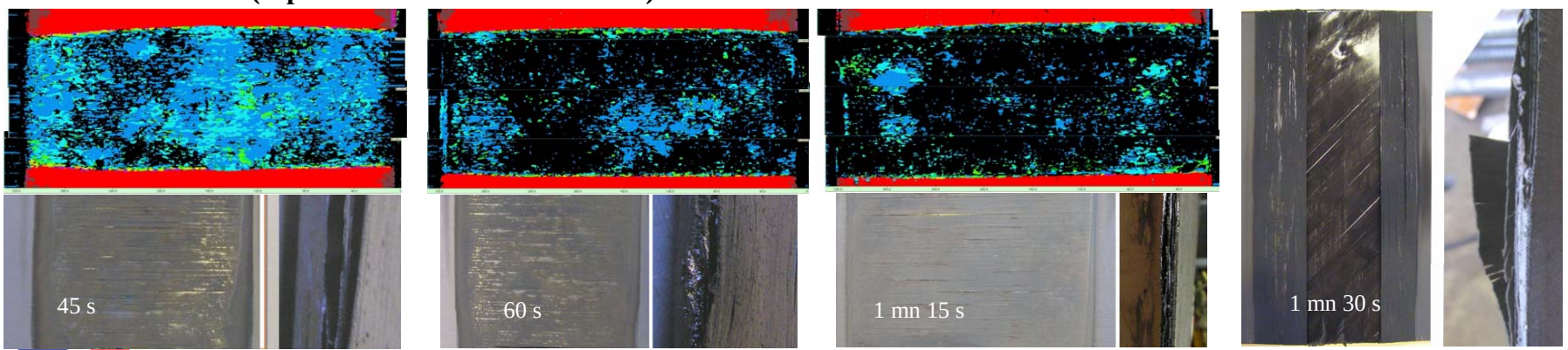


- Non Destructive Investigation (Visual & Ultrasonic Phased Array Analysis)

Foam block tests :
- Destructive analyse showed more than 11 delaminated plies (composite plate was constituted of 16 plies)

CEAT hidden Fire Source tests :
- 45s fire test is closer than the others to the Foam block test

  - Gas burner tests (exposure time : 45 s to 1 mn 30 s)

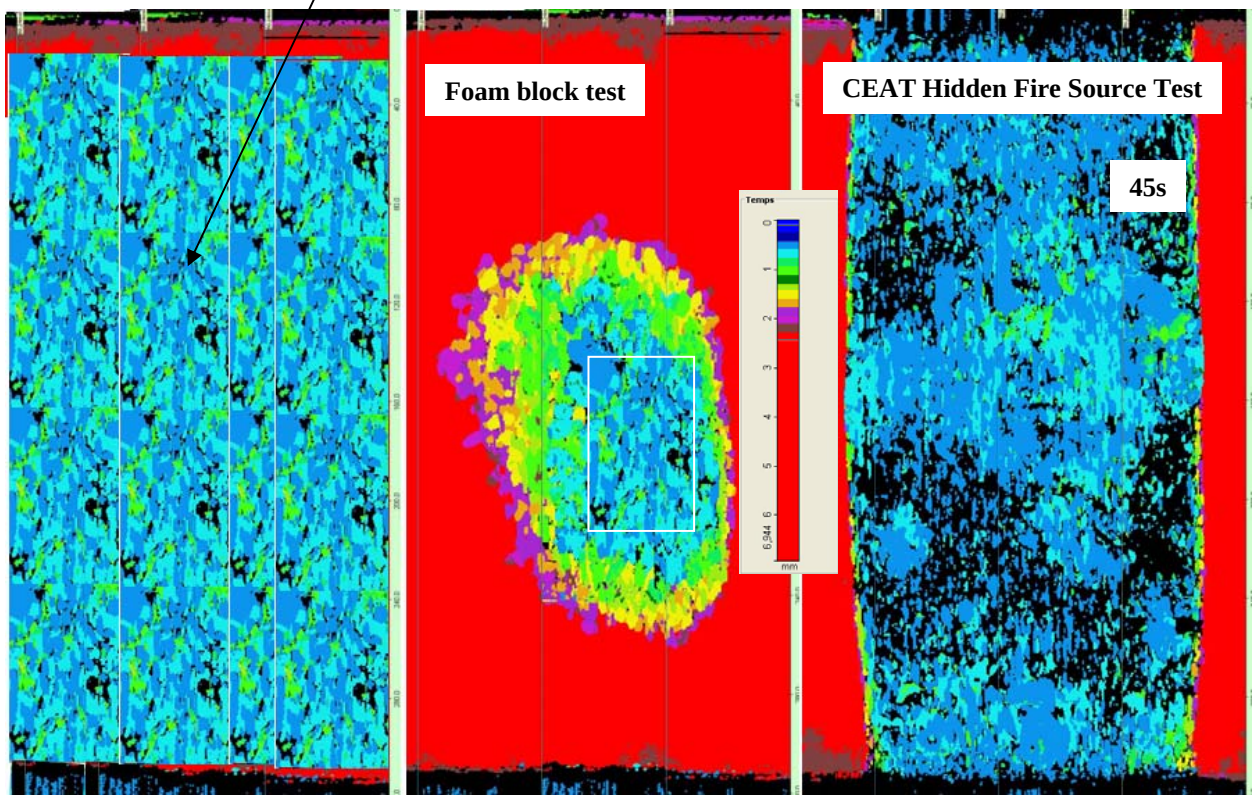


CEAT Hidden Fire Source

Comparison of the damage tests : Foam block / Gas burner

- T300 / 914 Epoxy Carbon (2.5 mm)
- Non Destructive Investigation

Duplication of the central image (maximum damage) of the foam block test



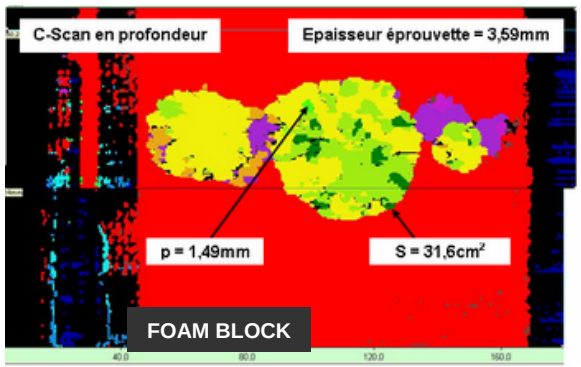
- **Damages created by the foam block and the hidden fire sources are rather similar**
- **The hidden fire source seems a little more severe (black areas are totally delaminated)**

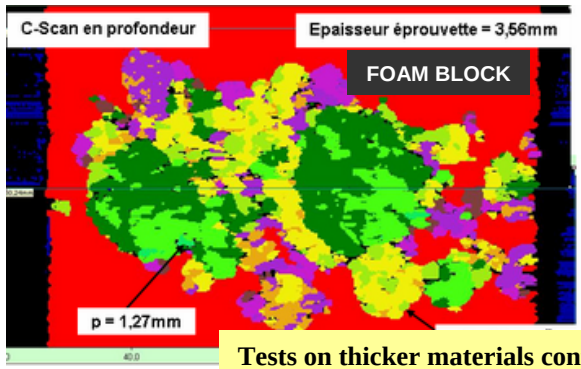
CEAT Hidden Fire Source

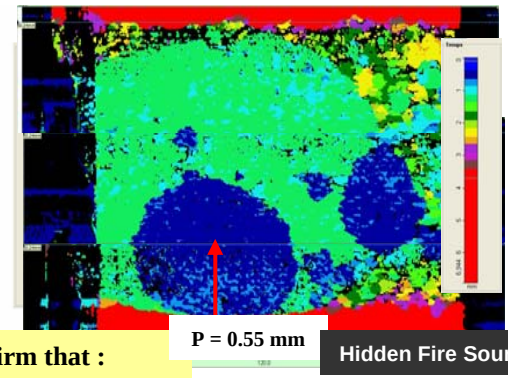
Comparison of the damage tests : Foam block / Gas burner

- Non Destructive Investigation

HTA / RTM6 Epoxy Carbon ("Sergé 2/2" weaving) (3.6 mm)

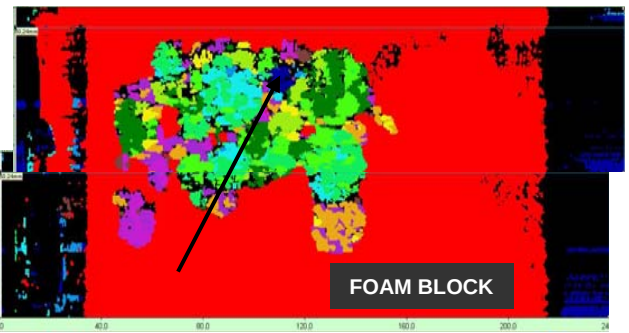


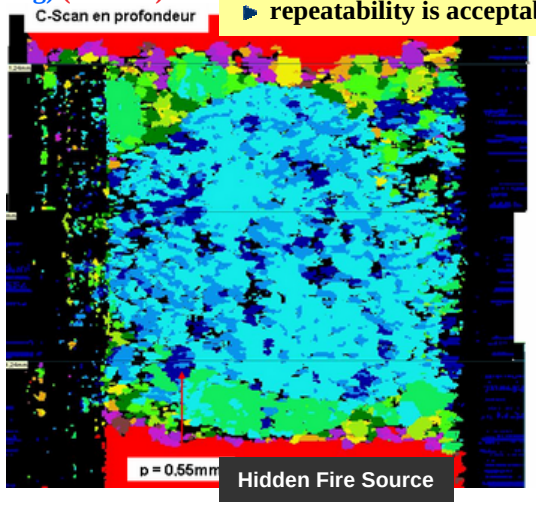


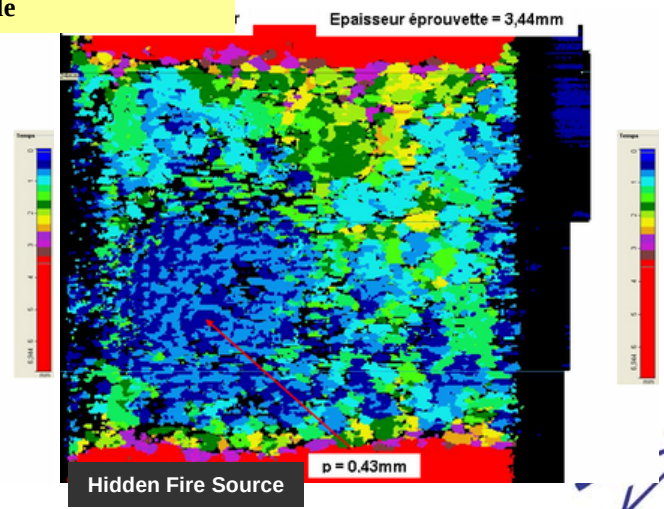


Tests on thicker materials confirm that :
- hidden fire source is a little more severe
- repeatability is acceptable

T300J / RTM6 Epoxy Carbon ("Satin 4" weaving) (3.6 mm)



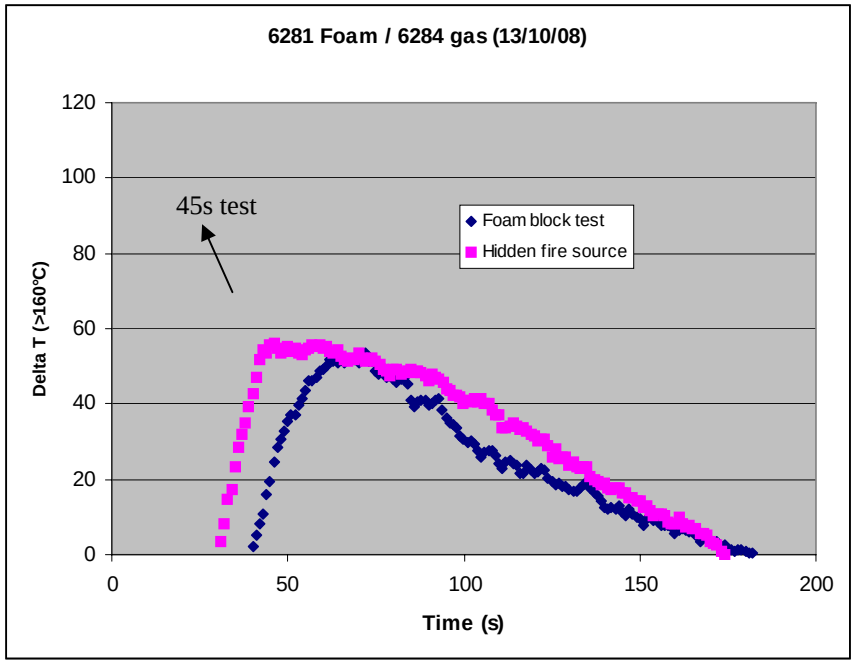




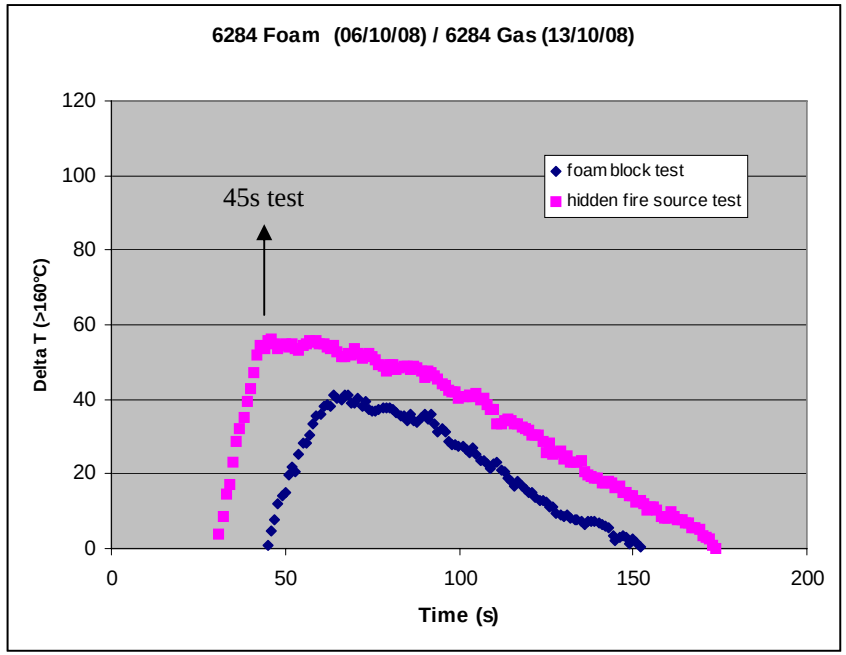
CEAT Hidden Fire Source

Comparison of the damage tests : Foam block / Gas burner

- Non Destructive Investigation



Back side T° (over 160°C)



Despite the differences shown by NDI, these curves show that the fire sources are probably quite similar.

- **Should be possible to do better by modifying the burner settings**

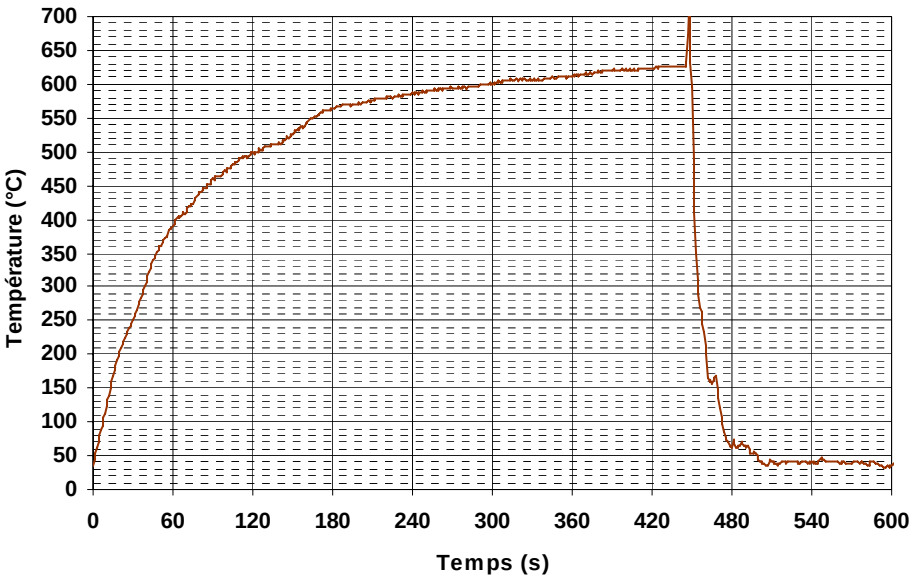
CEAT Hidden Fire Source

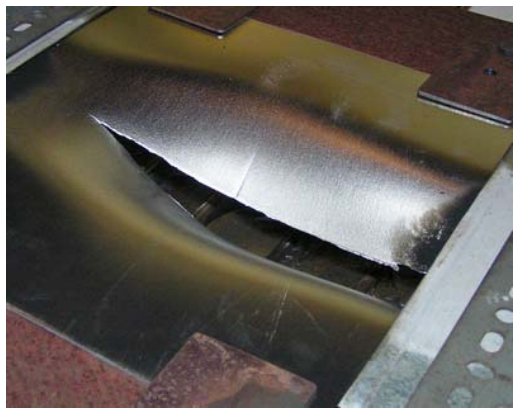
2024 Aluminium – 2 mm

Gas burner
Damaging test on 2024 aluminium

Burnthrough time of a 2mm "2024 Aluminium plate"

7 mn 26 s





Burnthrough time : this fire source is probably very close to the FAA fire source used on wind tunnel test (FAA burnthrough time : 9 to 10 mn (thickness 3.175 mm (1/4 inch)):

• an estimation of the burnthrough time using our fire source on an aluminum plate of this thickness is in the same range.

CONCLUSIONS

- **The flame characteristics (T° / Heat Flux) of the gas burner and the FAA foam block fire sources are very close**

- **The damages generated on composite material (epoxy/carbon) by the CEAT's hidden fire source** (exposure time : 45s (close to the duration of the active combustion of the foam block) **and by the foam block fire source are rather similar**

- **The hidden fire source seems a little more severe. (should be easily corrected by modifications of the burner settings)**

- **Burnthrough of aluminum : The effect of the CEAT hidden Fire Source and the FAA fire source used for the wind tunnel fire test (under static conditions) are similar**

SOON APPROVED FOR THE NEXT WORKS

NEXT WORKS

- ✓ **To define various scenarios of exposure to fire**

  (from 45s (ignition stage) to a duration to be determined simulating a declared hidden fire)

- ✓ **To define the test procedures for the under load fire test**

- ✓ **To run the fabrication of various composite materials**

- ✓ **To run the fire tests and mechanical characterisations**

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MINISTÈRE DE LA DÉFENSE

Toulouse Aeronautical Test Centre (CEAT)

« Fire Safety Department »

FIRE BEHAVIOUR OF STRUCTURAL COMPOSITE MATERIALS

DGA

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