1/4 Scale Fire Penetration Testing of Composite Fuselage

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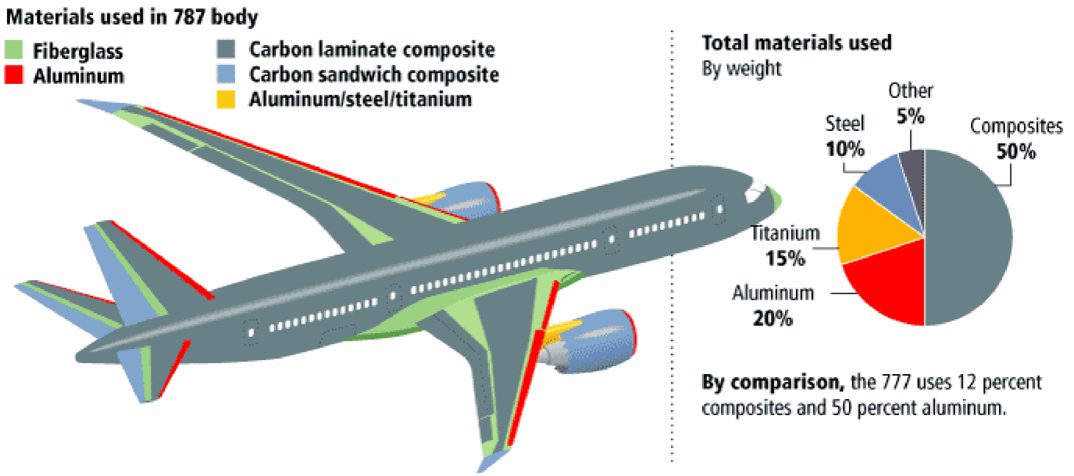
INTRODUCTION

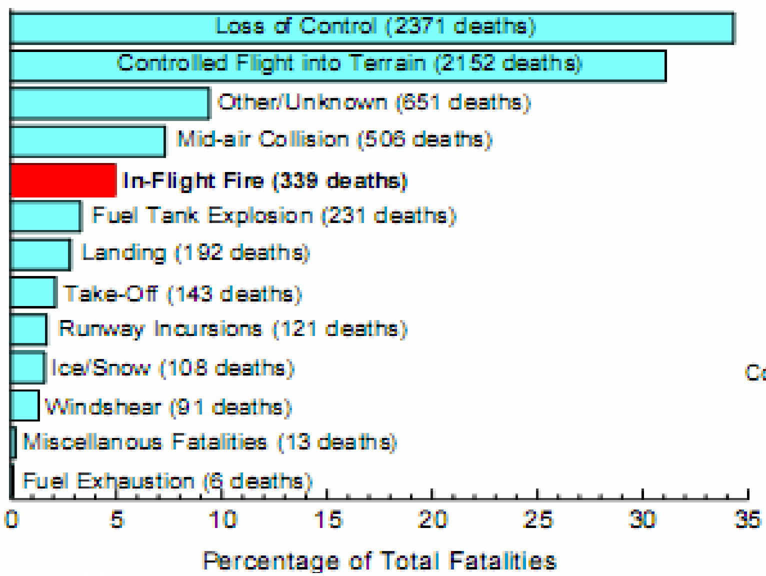
- In last decades **the fastest development** in aeronautical industry is the use of composite materials
- Comparing with metallic alloys they provide **lower density and higher strength** behavior
- This properties allow:
  - Weight savings
  - More passenger comfort
  - Lower aircraft maintainability costs
- New passenger aircraft designs are **increasing the composite materials** in their primary structural elements

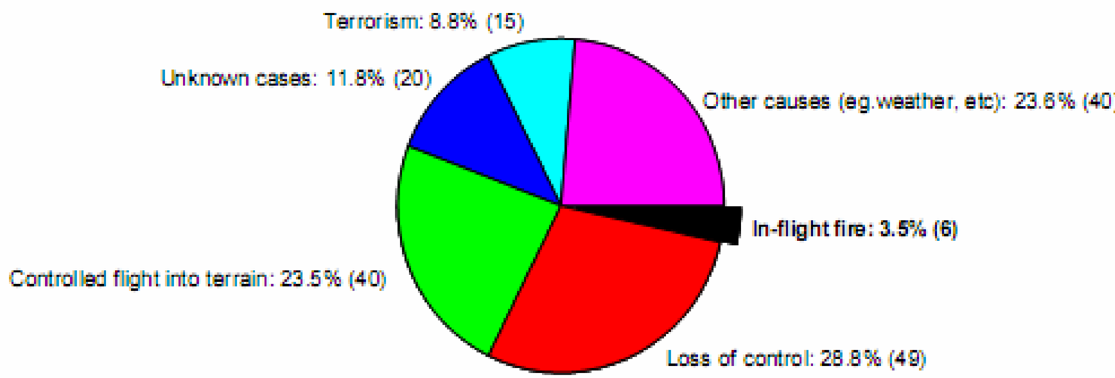


INTRODUCTION

- The main risk associated to composites is their flammability
- The resin disappears with heat emission, smoke and toxic gases when the composites are exposed to high temperatures.
- Composites strength decrease with the high temperatures

Reasons to avoid their usage in structural parts





RESEARCH GOALS AND BENEFITS

- The **cabin integrity** and the **ability to act as a barrier** against fire are the **main challenge** for crew and passenger survival

In a post craft accident → Critical factor → **Fire penetration time** → Beside have to considered →

- **Heat emission**
- **Smoke density**
- **Smoke toxicity**
- **Inside temperature**

- New fireworthiness **requirements (Special conditions AC 20-107B)**
- Manufacturers have to demonstrate that **composites = conventional metallic** alloys

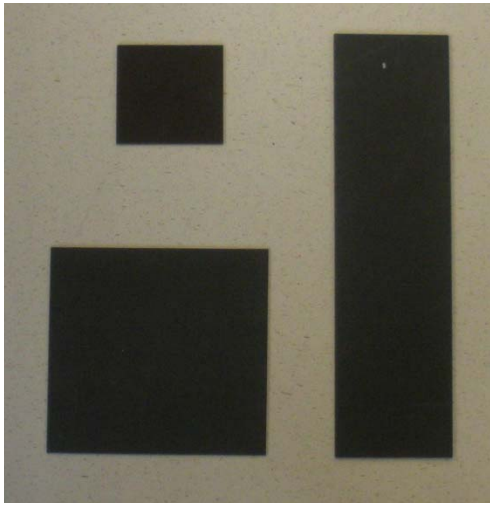
This preliminary research in flammability tries to analyze the behavior of the new composite materials against fire and the consequences of the increase in their use.

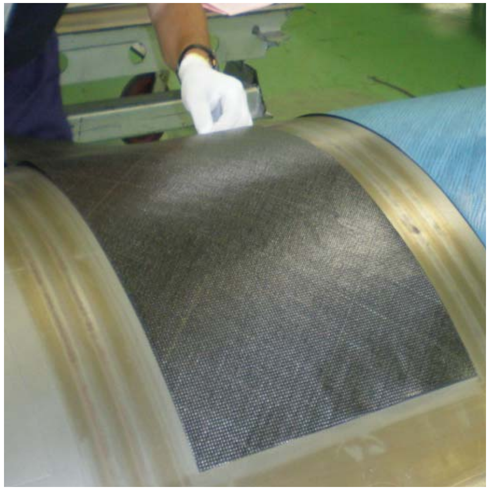
MATERIALS SELECTION AND TESTED SAMPLES

Selected materials

Typical composite materials used in aircraft structural parts

SAMPLE	MATERIALS	TAPE THICKNESS (mm)	Nº TAPES	TOTAL THICKNESS (mm)	LAMINATION SEQUENCE
PMC 1	carbon/epoxy UD tape	0.184	10	1.84	(+/0/-/90/0)s
PMC 2			14	2.58	(0/+/90/-/0/90/0)s
PMC 3			10	1.84	(0/90/0/90/0)s
PMC 4	carbon/epoxy fabric	0.178	10	1.78	(45/0/45/0/45)s
PMC 5			14	2.49	(45/0/45/0/45/0/45)s
PMC 6	carbon/BMI fabric	0.315	6	1.89	(45/0/45)s
PMC 7			8	2.52	(45/0/45/0)s





TEST DESCRIPTION

Two different test campaigns:

- Characterization fire tests following the aeronautical standards
- Fire tests in the scale model demonstrator

<u>Characterization tests</u> (according to aeronautical requirements (FAR/CS 25.853)

•Vertical Flammability Tests 60 seconds (Bunsen Burner Test)

•Smoke density Test (NBS Chamber Test)

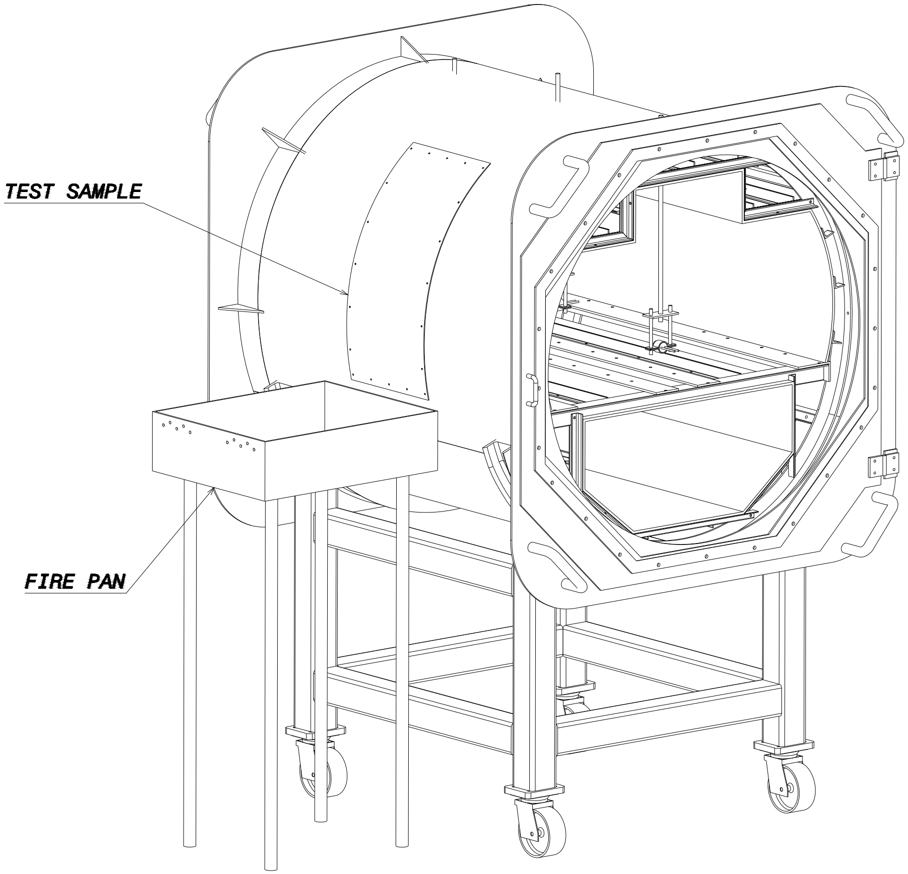
•Smoke Toxicity Analysis

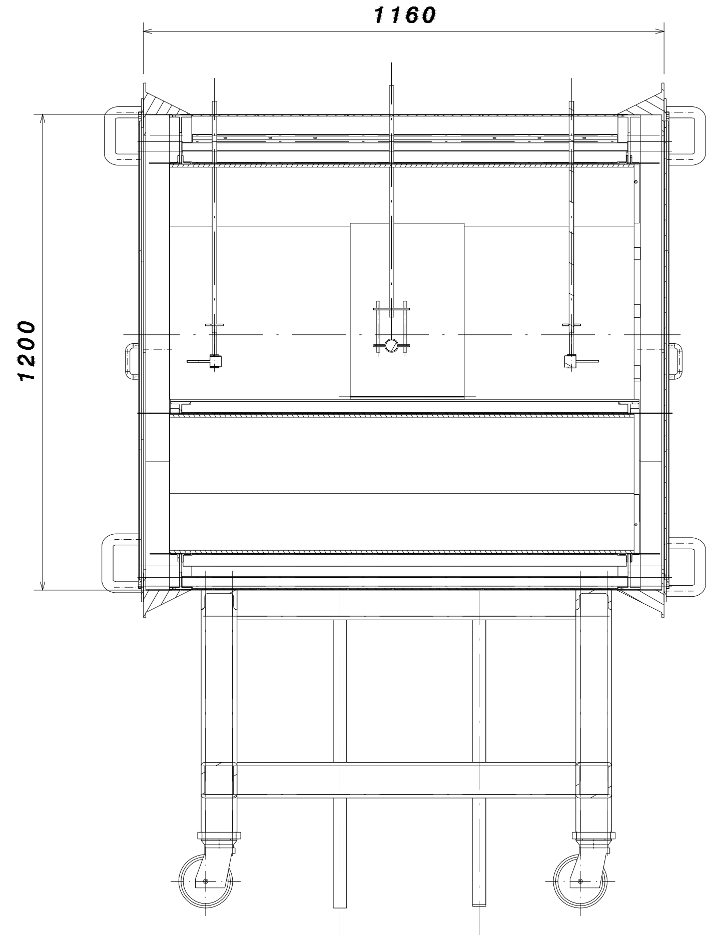
• Heat Release Rate Test (OSU Chamber Test)

Main parameters: Flame propagation characteristics, smoke density, toxicity of the gases generated during combustion and heat release

TEST DESCRIPTION

Fire test in scale demonstrator





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THEORICAL CONSIDERATIONS

<u>To simulate the ignition source Froude's scaled techniques have been considered:</u>

- ✓ Scaled mass loss rate for kerosene JP5:

$$\dot{m}_S = \dot{m}_F \cdot \left(\frac{L_S}{L_F}\right)^{5/2} = \dot{m}''_F \cdot A_F \cdot \left(\frac{L_S}{L_F}\right)^{5/2} = 0.054 \cdot 7.437 \cdot \left(\frac{1}{4}\right)^{5/2} = 0.01255\, kg/s$$

- ✓ Scaled firepan area:

$$\dot{m}_S = \dot{m}''_S \cdot A_S \Rightarrow A_S = \frac{\dot{m}_S}{\dot{m}''_S} = \frac{0.01255}{0.054} = 0.2324 m^2$$

- ✓ Scaled heat release:

$$Q_F = A_F \cdot \dot{m}''_F \cdot \chi \cdot \Delta H_c = 7.437 \cdot 0.054 \cdot 0.7 \cdot 42.8 = 11.94 MW$$

$$Q_S = Q_F \cdot \left(\frac{L_F}{L_S}\right)^{2/5} = \frac{11{,}944}{4^{5/2}} = 0{,}3732 MW$$

- ✓ Scaled time:

$$t_S = t_F \cdot \left(\frac{L_S}{L_F}\right)^{1/2} = \frac{m_F}{\dot{m}_F} \cdot \left(\frac{L_S}{L_F}\right)^{1/2} = \frac{\rho_F \cdot V_F}{\dot{m}_F} \cdot \left(\frac{L_S}{L_F}\right)^{1/2} = \frac{0.81 \cdot 208.197}{0.4016} \cdot \left(\frac{1}{4}\right)^{1/2} = 296.93 s \approx 5 \min$$

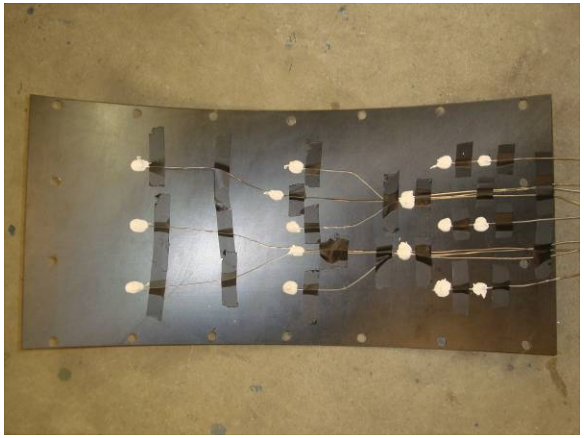
- ✓ Scaled total fuel volume:

$$t_S = \frac{m_S}{\dot{m}_S} = \frac{\rho_S \cdot V_S}{\dot{m}_S} \Rightarrow V_S = \frac{\dot{m}_S \cdot t_S}{\rho_S} = \frac{0.01255 \cdot 296.93}{0.81} = 4.6 l$$

TEST DESCRIPTION

Scale demonstrator test instrumentation

- Test samples surface thermocouples (9 TCP)
- Vertical thermocouple rig (5 TCP)
- Combustion gas analyzer (O_2, CO, H_2, SO_2, H_2S, NO, NO_2 and NO_x)
- Sampling gas equipment for colorimetric analysis
- Water cooled heater flux meters (2 HFM)
- Video camera (2 VC)
- Infrared thermography camera



Scale demonstrator ignition source

- Kerosene (4.7 L)
- Petrol (225 ml)

TEST DESCRIPTION

Test layout

TEST RESULTS

1. Characterization tests

	Heat release test		Optical density tests	Vertical flammability test		
Sample	PHRR (kW/m^2)	THR ($kW\ min/m^2$)	Smoke optical density (Ds)	Flame time (s)	Drip flame time (s)	Burn length (mm)
PMC 1	110.02	99.32	85	8	No drips	85.71
PMC 2	109.03	113.6	49.23	12	No drips	63.61
PMC 3	108.57	83.42	81.15	4	No drips	70.9
PMC 4	150.28	139.02	106	24	No drips	31.69
PMC 5	157.99	140.97	154	13	No drips	13.43
PMC 6	62.72	74.71	65	3	No drips	12.36
PMC 7	61.39	56.93	54.56	4	No drips	6.41

Sample	CO (ppm)	HCN (ppm)	HF (ppm)	HCl (ppm)	SO2 + H2S (ppm)	NOx (ppm)
PMC 1	85	5	< 0.5	< 0.5	106	16
PMC 2	113	9	< 0.5	< 0.5	141	27
PMC 3	92	3	< 0.5	< 0.5	106	9
PMC 4	133	25	< 0.5	< 0.5	176	33
PMC 5	167	53	< 0.5	< 0.5	243	43
PMC 6	93	2	< 0.5	< 0.5	< 5	17
PMC 7	75	2	< 0.5	< 0.5	< 5	19

TEST RESULTS

1. Characterization tests

-**Carbon/BMI** results confirmed the **best behavior against fire** due to its performances to resist higher temperatures.

- In **Carbon/Epoxy fabric** panels the **flame time is larger due to is larger resin content**

- In **Carbon/Epoxy tape** panels the **burnt length is larger due to they are made of unidirectional tapes**

- **Carbon/Epoxy** fabric panels have **more toxic gases emissions due to is larger resin content**

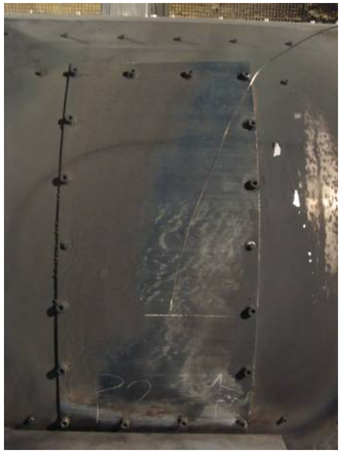
- These kind of tests allow to qualify and compare the fire behavior of different materials.

TEST RESULTS

2. Fire test in scale demonstrator

Summary of scale tests materials

Sample	Material	Fiber	Resin	Layers	Sample thickness (mm)
PMC 1	CARBON/EPOXY UD TAPE	AS4	8552	10	1.84
PMC 2				14	2.58
PMC 3	CARBON/EPOXY FABRIC	AS4	8552	10	2.05
PMC 4				14	2.87
PMC 5	CARBON/BMI FABRIC	T300	F655	6	1.8
PMC 6				8	2.4
Al	7075 - T651 ALUMINIUM ALLOY	N/A	N/A	N/A	2.4



-**Flame do not penetrate in a fuselage made in composite** material due to after resin burnt the tapes itself still maintain their capabilities as a fire barrier

- Flame arrives in the cabin of aluminum metallic fuselages immediately after the event

TEST RESULTS

Test Video

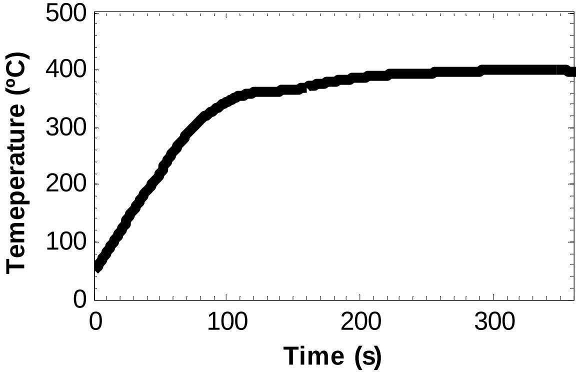
TEST RESULTS

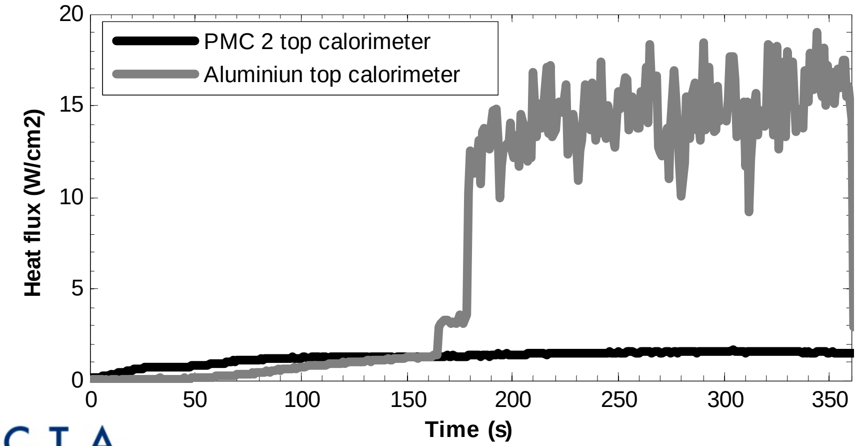
2. Fire test in scale demonstrator. Temperature and Heat Flux analysis

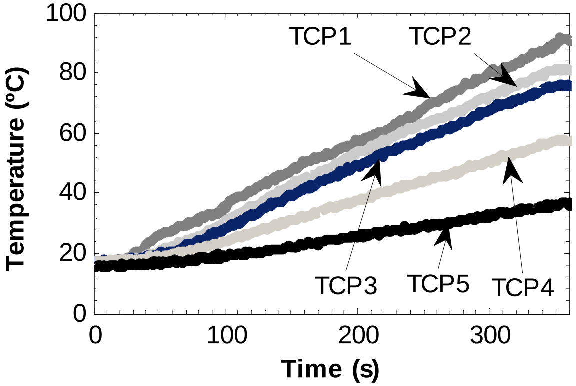
Temperatures and heat fluxes measured for different samples

Sample	Max temperature [ºC] (Thermocouple Rake)	Heat flux [W/cm2] (bottom calorimeter)	Heat flux [W/cm2] (top calorimeter)
PMC1	97.35	0.62	1.74
PMC2	90.05	0.57	1.62
PMC3	91.2	0.67	1.77
PMC4	86.85	0.61	1.49
PMC5	94.55	0.7	1.85
PMC6	90.85	0.61	1.65
Aluminium	247.6	5.35	17.32

PMC 2 results







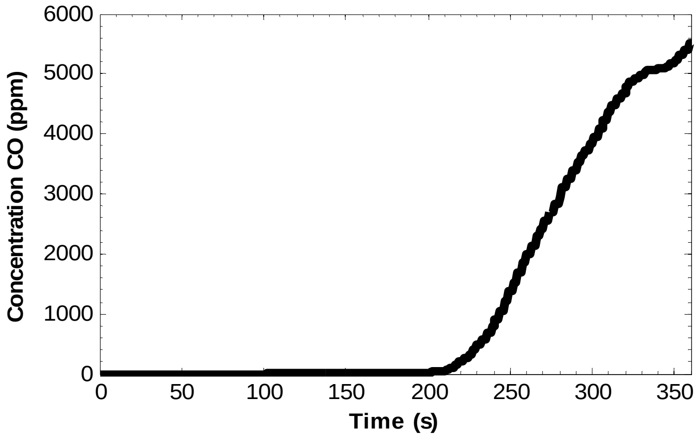
TEST RESULTS

2. Fire test in scale demonstrator. Smoke Toxicity analysis

Summary of maximum gases concentration measured inside the cabin

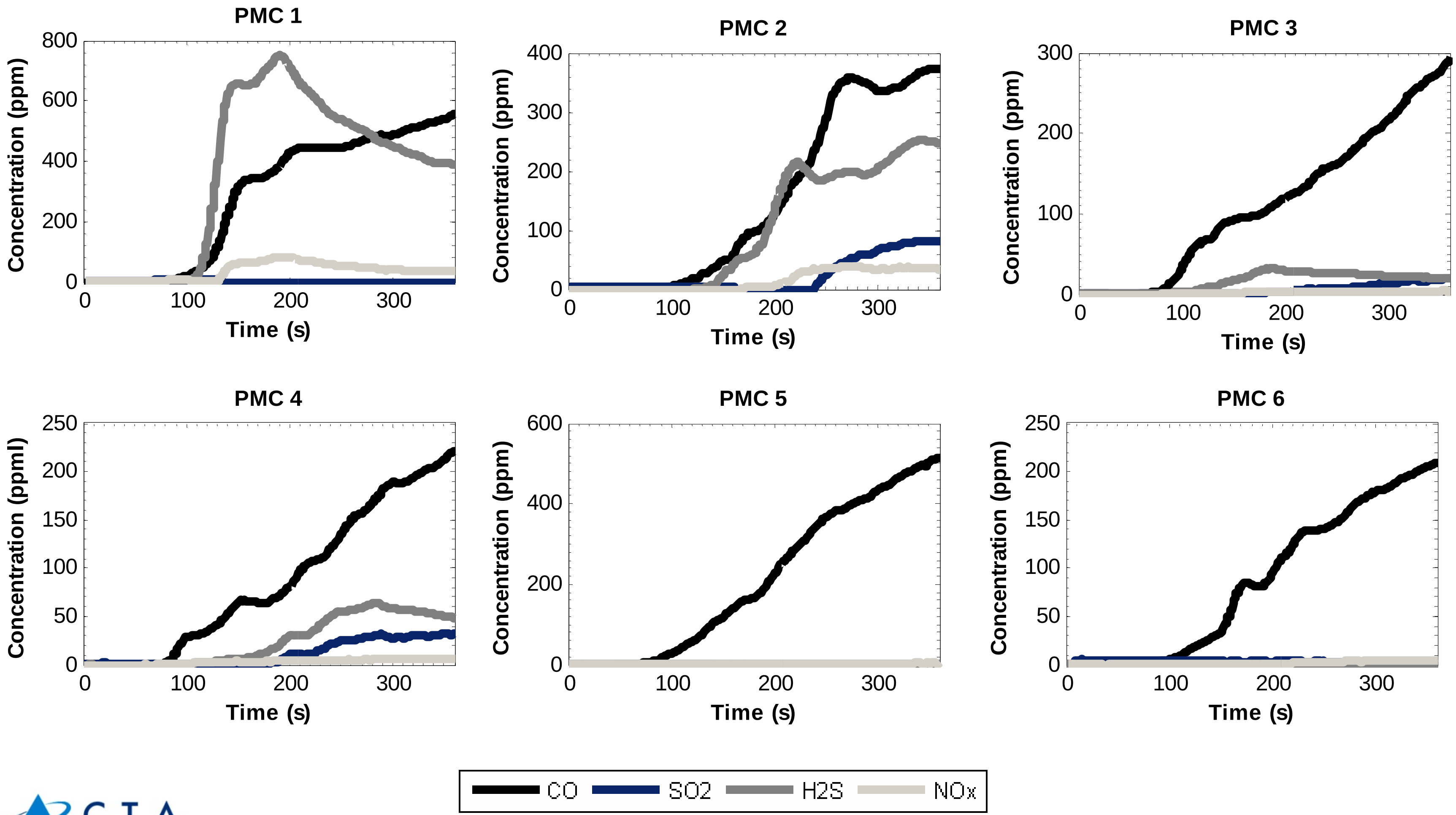
Sample	% O2	ppm CO	ppm SO2	ppm H2S	ppm NOx	ppm HCN
PMC 1	18	558	6	752,5	83	240
PMC 2	17	374	81	252,3	38	60
PMC 3	--	294	19	31,9	4,5	9
PMC 4	20,9	222	32	64,2	6,5	12,5
PMC 5	20,875	515,5	4	1,45	4,5	15
PMC 6	20,915	209,5	5,5	1,2	4,5	4,5
AL	13,5	5498	9	23,2	39	5

- Tests have been performed considering only fuselage skin. Not insulation material or other interior materials have been included in the study.



TEST RESULTS

2. Fire test in scale demonstrator. Smoke Toxicity analysis



CONCLUSIONS

Characterization conclusions

- Carbon/epoxy tape samples show a better behavior in smoke density, toxicity and heat emission tests comparing with carbon/epoxy fabric samples.

- The use of Carbon/BMI materials, although present better fire performances, must be restricted due to its high cost and weight penalty.

Scaled tests conclusions

- **Fuselages made in composite** materials **protect the cabin against flame penetration**.

- To enlarge the passenger survival after a fire event in a cabin made in typical aeronautical composite materials **adequate insulation** must be studied **to content the toxic gases emissions** and to prevent high transfer heat.

CONCLUSIONS

Final conclusions

In a potential cabin passenger fuselage made in composite materials **deeply investigations should be continue** to:

- Obtain **better material** candidates against flammability, heat transfer and toxic gases emissions, without compromise the aircraft cost and weight.

- Define the adequate **insulation** that prevent the fire effects goes directly to the passengers

- **Establish** if a specific **standard** for airworthiness certification of these materials is required

Composite materials present a better behavior against flame penetration in a cabin **than the standard aluminums** metallic fuselages but **further studies** about smoke emission or flame propagation are required.

FUTURE RESEARCH

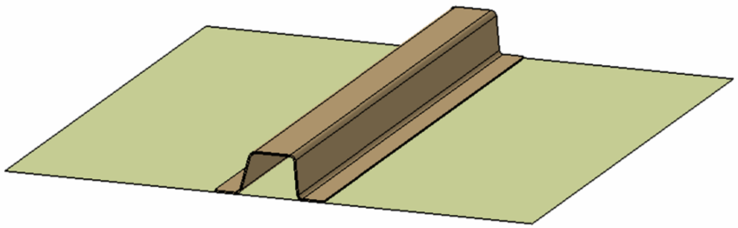
-To enlarge the composite materials candidates to be used in aircraft cabin passengers, **thermoplastic, Carbon/Epoxy doped with nanomaterials and even CNT's, carbon nanotubes materials will be investigated.**

- As the aircraft in flight must maintain the structural capabilities during a fire event, special attention should be paid to **test fire with get home loads**, and to designed the structure accordingly, to assure a safety landing.

- In the future composite structures will be designed as much bonded as possible, the fire effects in these bonded structure **should be tested and investigated** and proposed adequate **bonded surfaces and materials**.

- In order to reduce the amount of tests during future fire researchs, adequate **fire numerical modeling** must be establish.

- Complete fuselage barrel should be manufactured and fire tested to establish the best materials candidates and sizing for a composite cabin passenger aircraft.



Typical bonded structure

Thank you ...

Questions ?

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