AircraftFire Project

Fire risks assessment and increase of passenger survivability

FP7 EASN Project - EU Grant Agreement n° 265612

2011 - 2013

www.aircraftfire.eu

INSA ROUEN
TU Delft Delft University of Technology
INSTITUT P'
EADS
The University of Edinburgh
Civil Aviation Authority
AIRBUS

Fraunhofer
I2M BORDEAUX INSTITUT DE MECANIQUE ET D'INGENIERIE
University of Patras
Universitatis Islandiae
University of Ulster
University of Greenwich

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Summary

1/ Presentation of the AircraftFire project and first results

2/ Fire performance of aeronautical composites

- New experimental setup
- Fire behaviour of composite materials

The AircraftFire Project

AcF Research Objective

Evaluation of fire threats and passenger survivability in new generation of aircrafts

- Characterisation of the fire performance of composite materials (physical/chemical/thermal flammability and burning properties) for aircraft design and fire safety analysis (modelling)
- Development and validation physical models correlated to the evolution of the fire scenarios,
- Modelling of the cabin fire growth and passenger evacuation
- Recommendations for efficient industrial technologies

The fire threat in new generation of aircrafts

Aluminium is substituted by flammable composites for decorative panels, hull, wing, cowling, structure, etc.

The fire threat can significantly increase due to…

- The flammability of materials in high temperature environment
- The toxicity of the smokes
- The total aircraft fuel load

With impact on the fire development and the passenger evacuation

Higher energy supply for *avionics and electronics*

➔ *fire risks (ignition,…)*

CAA, Airbus, EADS

Material fire performance
Fire Growth and Evacuation

1/ Material performance during fire (experimental)

- ✓ Material characterisation and behaviour during fire
- ✓ Ranking of material performances
- ✓ Behaviour under low pressure (partly simulation of altitude)
- ✓ Behaviour under load

Work Package 3

Fire Behaviour of materials
Ranking

Work Package 4

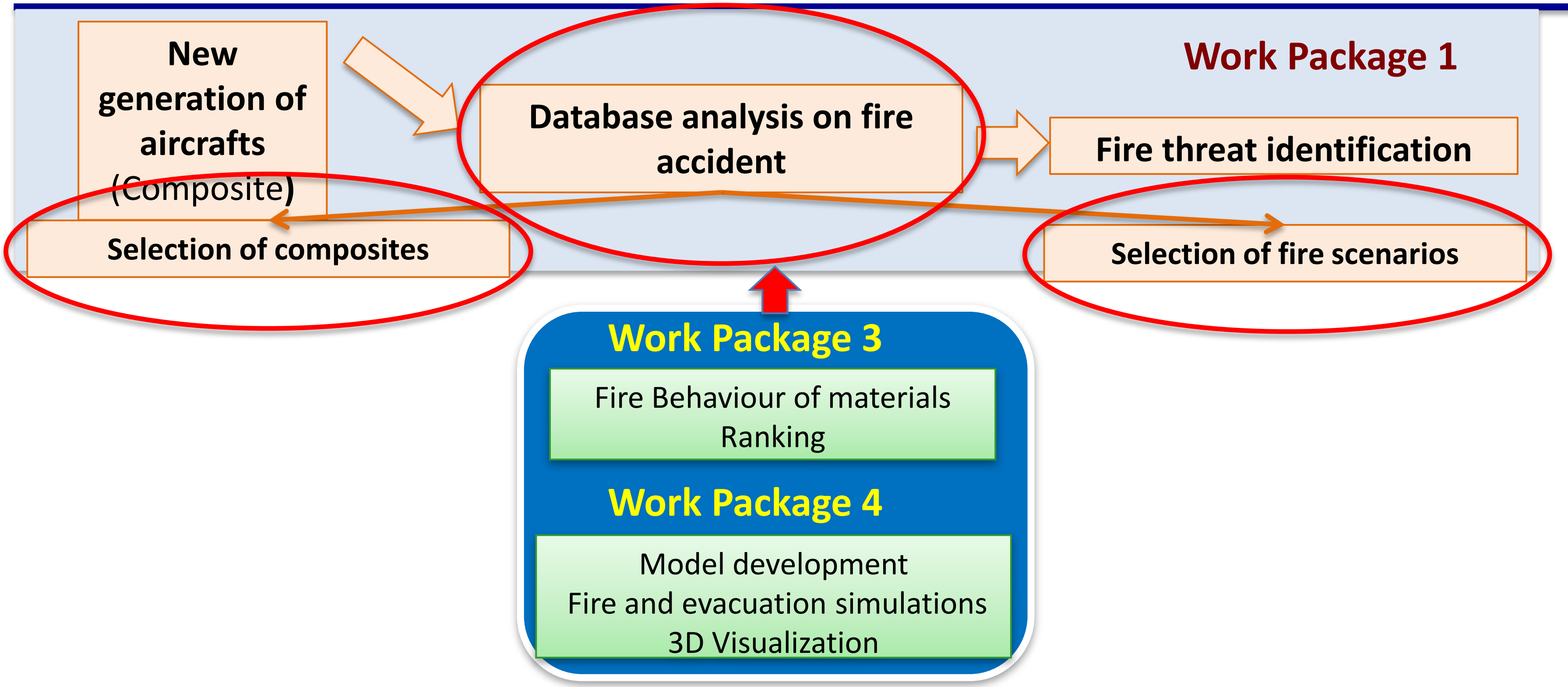
Model development
Fire and evacuation simulations
3D Visualization

2/ Fire growth and evacuation (modelling)

- ➢ The enhancement of a full scale modelling of fire development (**SMARTFIRE**) in new generation of aircrafts;
- ➢ The adaptation and enhancement of a numerical evacuation model (**airEXODUS**) during post-crash.
- ➢ 3D Visualisations

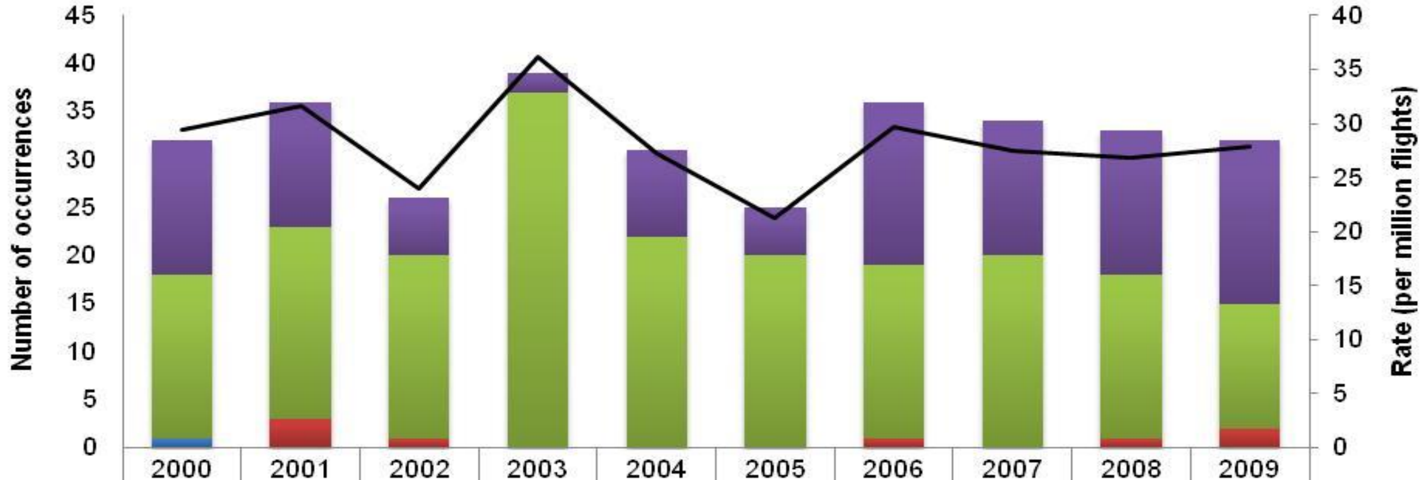
Univ. Greenwich, EADS, Univ. Iceland

AircraftFire: Organisation



Fire occurrences by severity grade

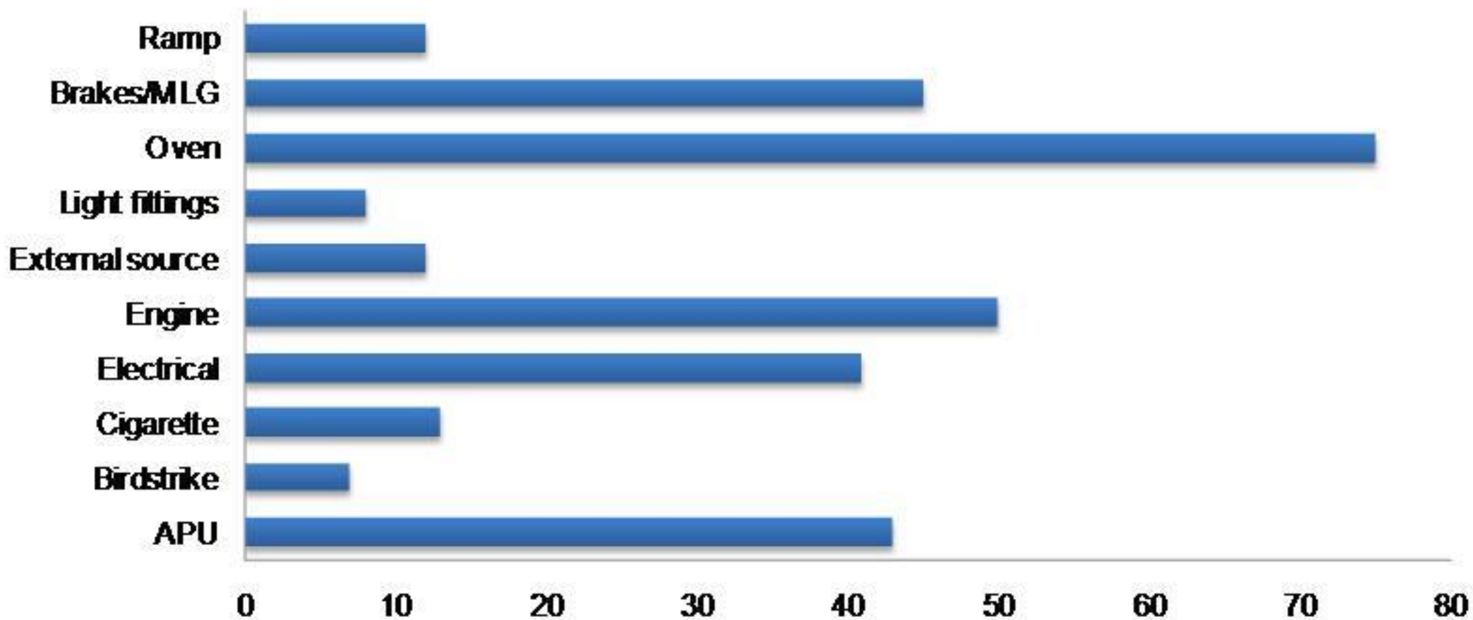
Number and Rate of Fire Related Occurrences (UK Fleet)
A-High Severity and D Low Severity



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
D	14	13	6	2	9	5	17	14	15	17
C	17	20	19	37	22	20	18	20	17	13
B	0	3	1	0	0	0	1	0	1	2
A	1	0	0	0	0	0	0	0	0	0
Rate per million flights	29.42	31.69	24.01	36.17	27.27	21.28	29.74	27.46	26.89	27.82

CAA, Fraunhofer

Causal factors for Fire occurrences

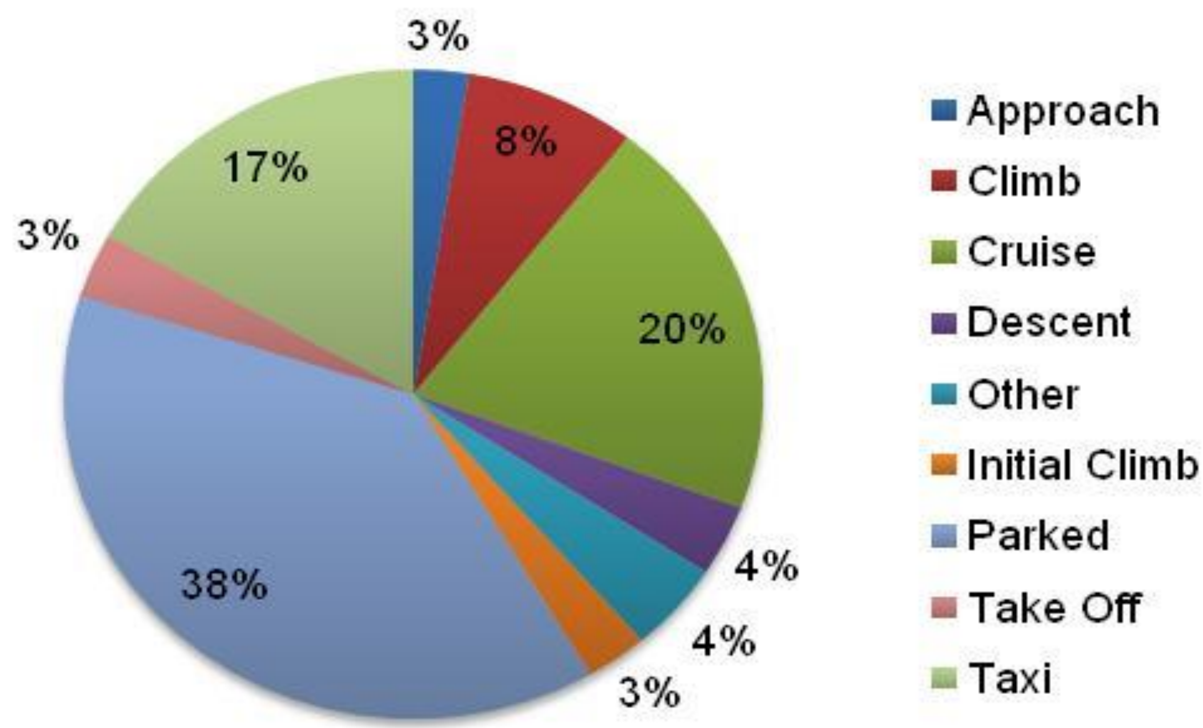


	APU	Birdstrike	Cigarette	Electrical	Engine	External source	Light fittings	Oven	Brakes/MLG	Ramp
Total	43	7	13	41	50	12	8	75	45	12

number of occurrences

CAA, Fraunhofer

Distribution of Fire occurrences by phase of flight



CAA, Fraunhofer

Composite materials in aircrafts

A composite material =
Matrix + Fibres
(1D fibres or wooden fabric)

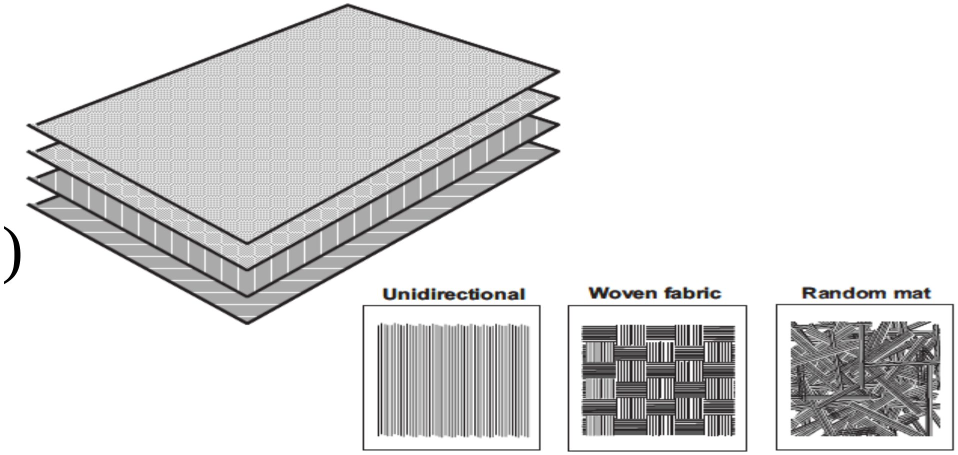


Figure 6.1. Ply structure of laminated composites and common examples of ply architecture.

5 Thermosets

- **Carbon fibres reinforced epoxy composites** (hull, wing, structure)
  flammable and decompose when exposed to fire
- **Glass fibres reinforced phenolic composites** (decorative panels)
  low flammability and good fire resistance

2 Thermoplasts

- **Seats, next aircraft generation**
  better mechanical properties, recycling

5 Cabin Materials

- **Cabling, seating, thermo-acoustic, carpet,…**

CAA, EADS, Airbus

3 Fire scenarios

➢ **Hidden zone fire**

✓Fire spread, fire propagation

➢ **In-flight fire**

✓Flammability of materials under load and at low pressure + flame impact

✓Sustainability of flame in altitude

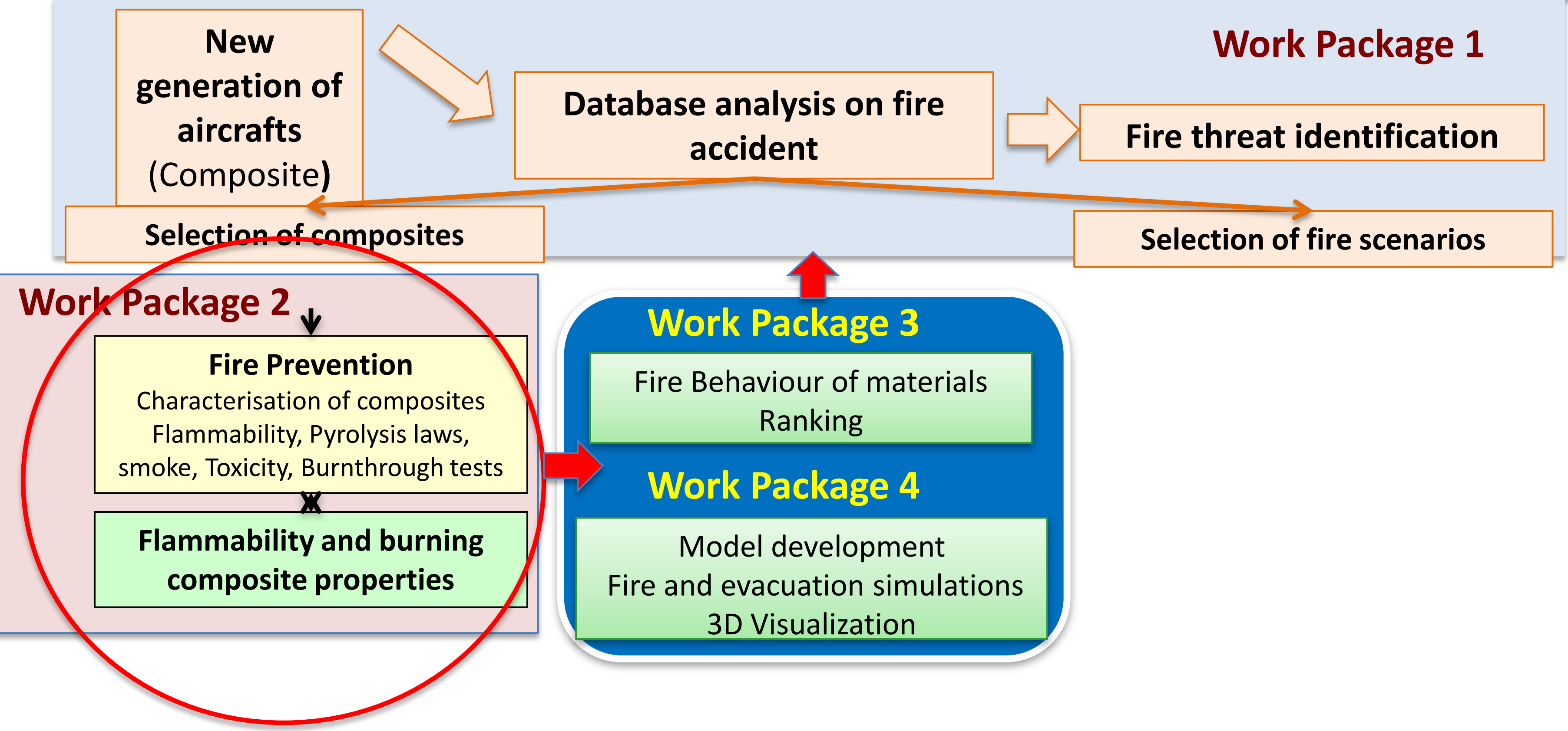
➢ **Post-crash fire**

✓ Kerosene pool fire modelling

✓ Fire growth and evacuation

- Post-crash fire with cabin integrity
- Post-crash fire with rupture of the cabin or cracks of the skin

AircraftFire: Organisation

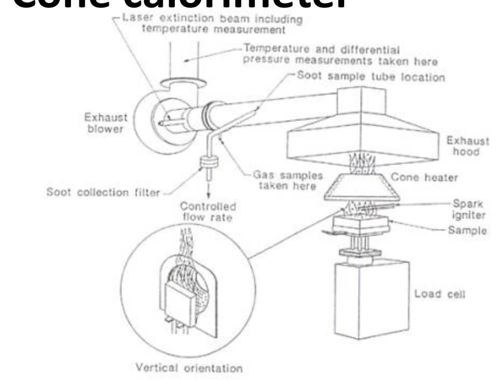


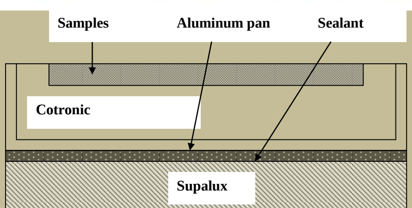
Methodology to determine material flammability properties

Key Flammability properties	Techniques
Conductivity, Specific heat, Heat of pyrolysis	MDSC
Glass transition temperature, Melting temperature, Heat of melting, Heat of pyrolysis, Specific heat	DSC
Ignition temperature (or the critical heat flux) % of residues, Kinetic parameters for reaction (i.e. activation energy and pre-exponential factor)	TGA
Quantification and history of gases emission	TGA - FTIR
Heat of combustion, efficiency of combustion Heat released rate / mass loss rate, CO, CO2, smoke fields Smoke point height	Cone calorimeter
Influence of the ambiant medium, equivalence ratio	Universal flammability apparatus (UFA)
Optical density of smoke	Smoke chamber

Methodology to determine material flammability

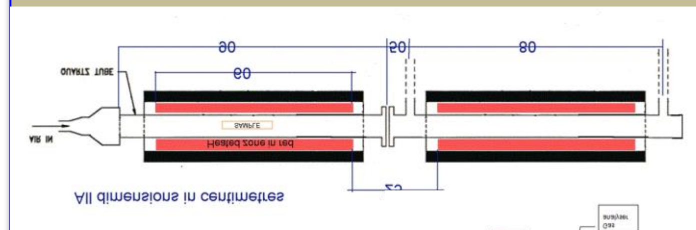
Cone calorimeter

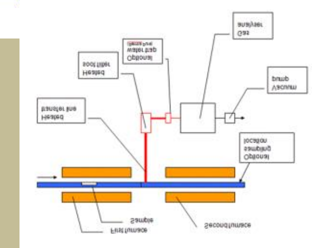


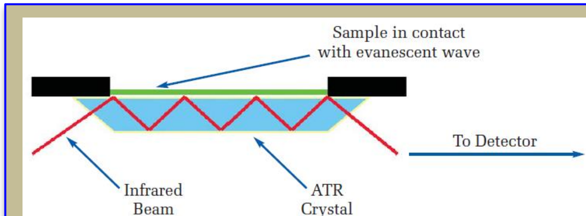


Universal Flammability Apparatus

Tube furnace







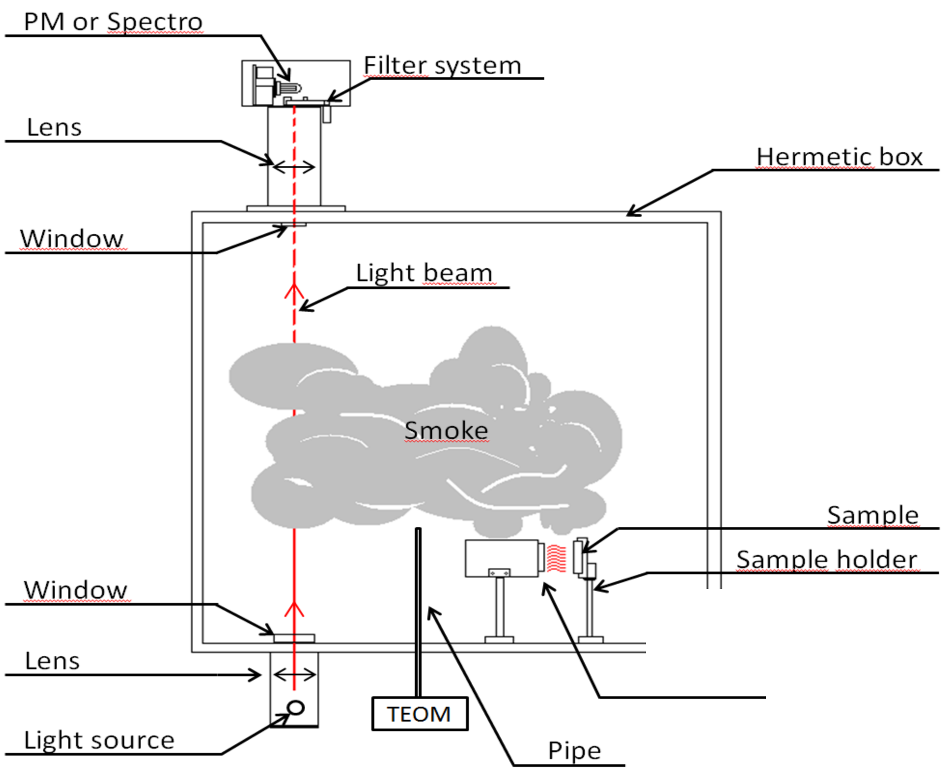
FTIR Spectroscopy: Attenuated Total Reflectance (ATR)

Thermogravimetric analysis (TGA)

Firesert, Univ. Patras, CNRS P'

Optical density of smoke

Objectives: measurement of the optical properties of smokes
===> correlation with their concentration and size



Transmittance: $T = \dfrac{I}{I_0}$

optical density $D = \log\left(\dfrac{1}{T}\right)$

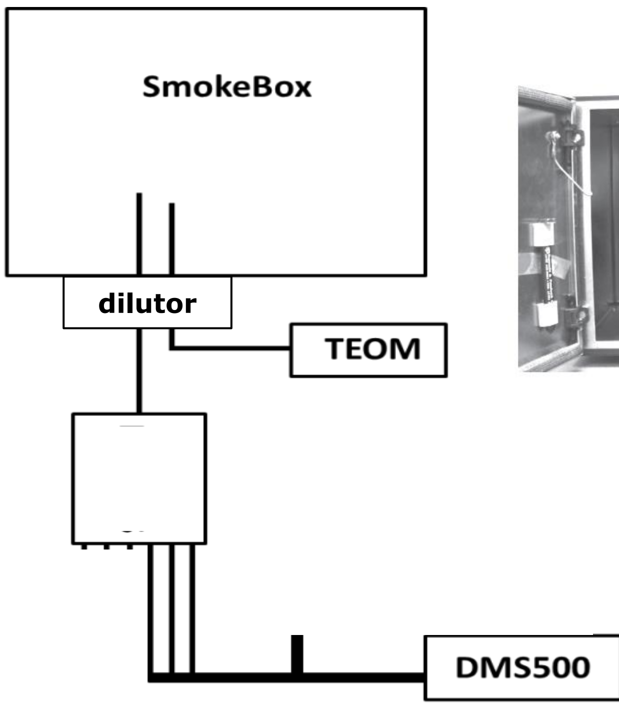
Specific optical density: $D_s = \dfrac{V}{AL} D$

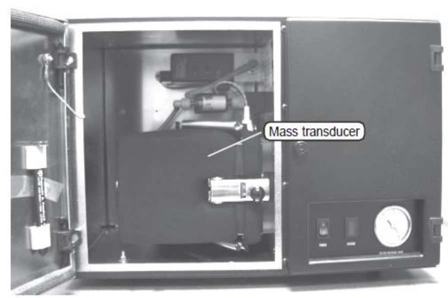
Extinction coefficient $K_{ext} = \dfrac{1}{L}\ln\left(\dfrac{1}{T}\right)$

CORIA

Optical density of smoke

Smoke sampling and devices for measuring particle parameters





TEOM: Mass concentration
(tapered element oscillating microbalance)

DMS: particles size distribution

CORIA

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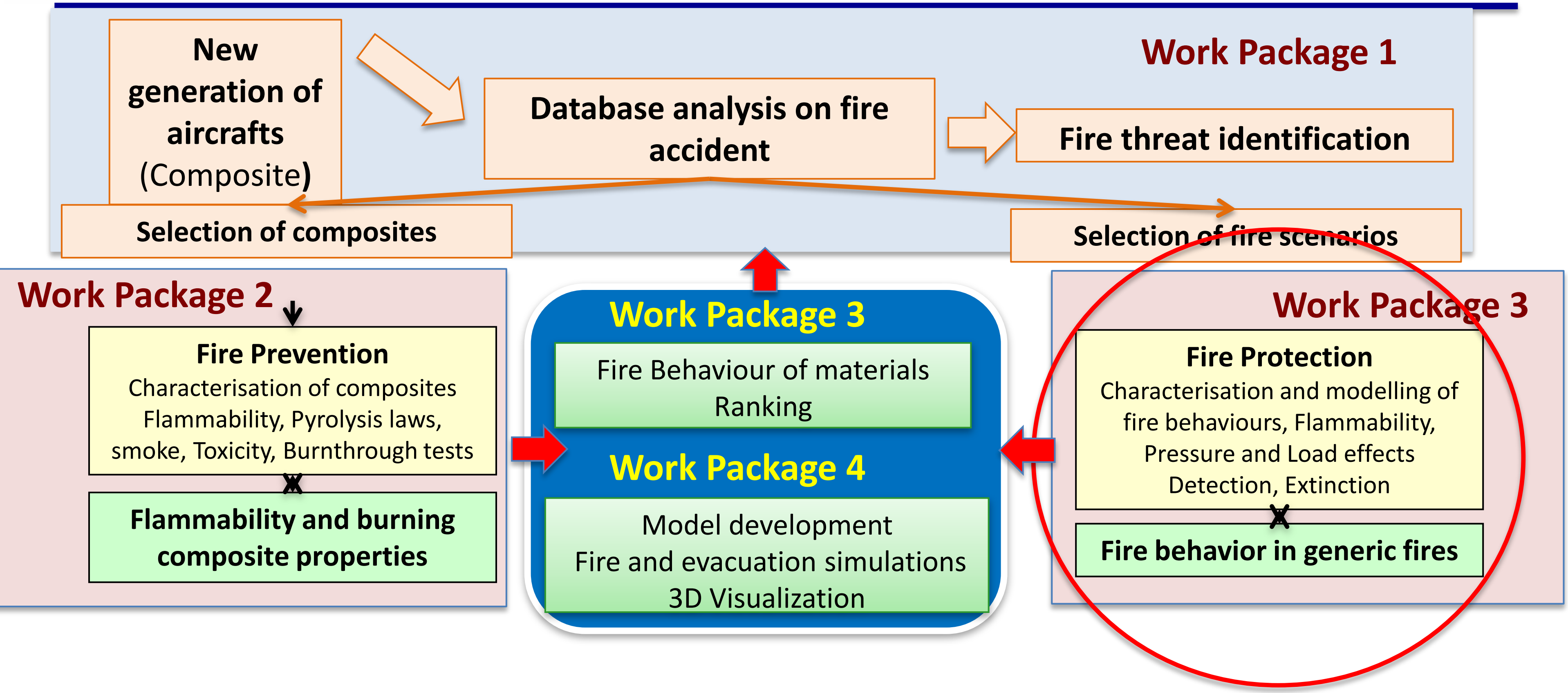


AircraftFire

cnrs advancing the frontiers

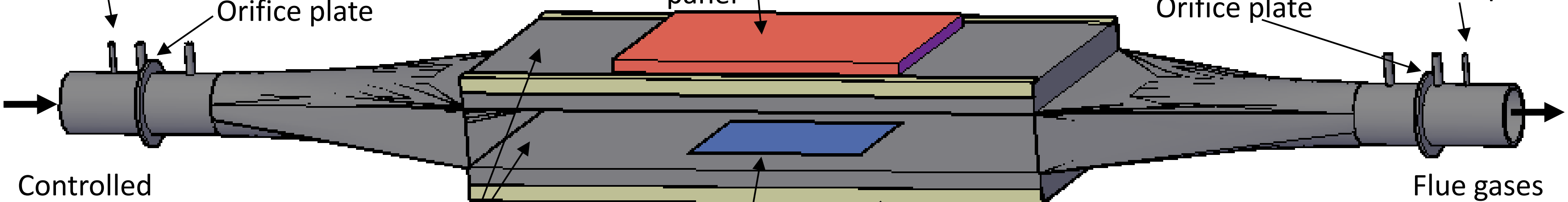
SEVENTH FRAMEWORK PROGRAMME

Generic Hidden Zone Fire

Experimental and Numerical studies

Objective: To evaluate the consequences of fire in hidden zones, and its propagation into cabin and cockpit

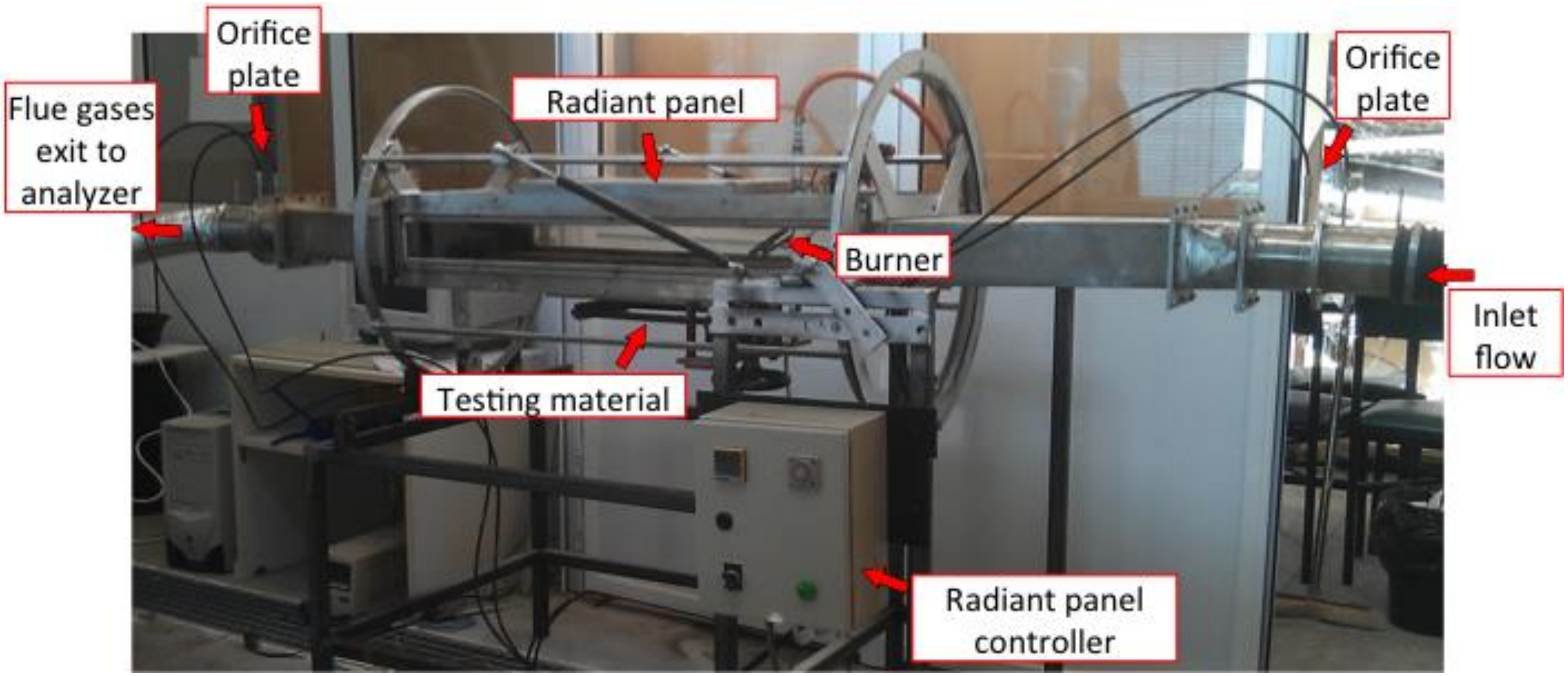
- The effect of under ventilation and of the depletion of oxygen
- Smouldering
- Fire spreading from a local initial fire
- Presence of unburned pyrolysis gases which may ignite if oxygen concentration is increased
- Burnthrough related phenomena



Univ. PATRAS

Generic Hidden Zone Fire

Univ. of Patras Experimental device



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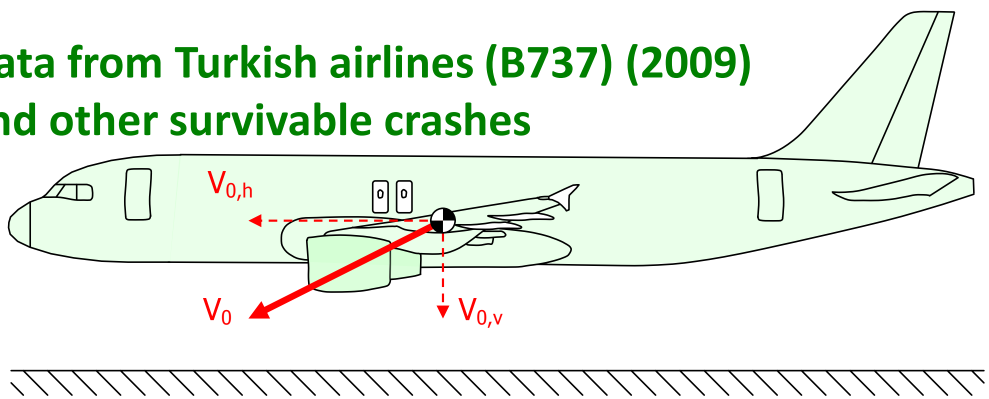
Create dynamic models to compare crash between metallic and composite aircrafts

- Therefore compare existing metallic body with composite
- Can compare the crash characteristics of an A320/B737 with simulated performance of a composite
- Examine forward velocity effects
  - Certification vertical drop only
  - Confirm model with actual crash response

Data from Turkish airlines (B737) (2009) and other survivable crashes



TUDelft

AircraftFire: Organisation

AircraftFire

advancing the frontiers

SEVENTH FRAMEWORK PROGRAMME

Work Package 1

New generation of aircrafts (Composite)

Database analysis on fire accident

Fire threat identification

Selection of composites

Selection of fire scenarios

Work Package 2

Fire Prevention
Characterisation of composites
Flammability, Pyrolysis laws,
smoke, Toxicity, Burnthrough tests

Flammability and burning composite properties

Work Package 3

Fire Behaviour of materials
Ranking

Work Package 4

Model development
Fire and evacuation simulations
3D Visualization

Work Package 3

Fire Protection
Characterisation and modelling of fire behaviours, Flammability,
Pressure and Load effects
Detection, Extinction

Fire behavior in generic fires

Model development and fire and evacuation simulations
3D Visualization

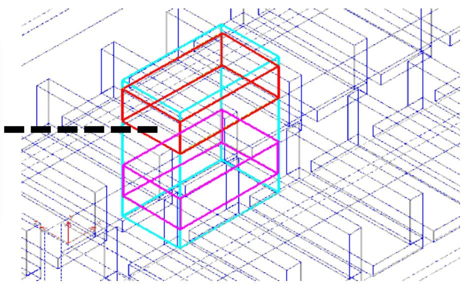
Joint Fire and Evacuation Simulation Method

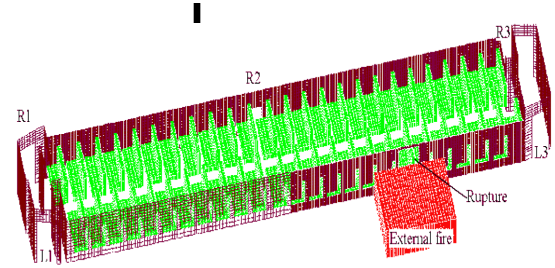
An Application of the Fire/Evacuation Methodology: Manchester Airport B737 Fire August 22sd, 1985

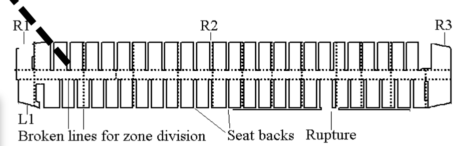
SMARTFIRE CFD Fire Simulation

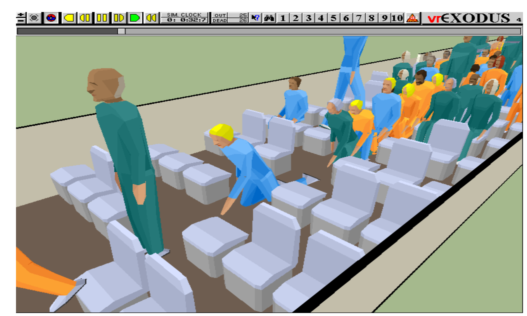
Fire Hazards at Specified Zones

airEXODUS Evacuation Simulation









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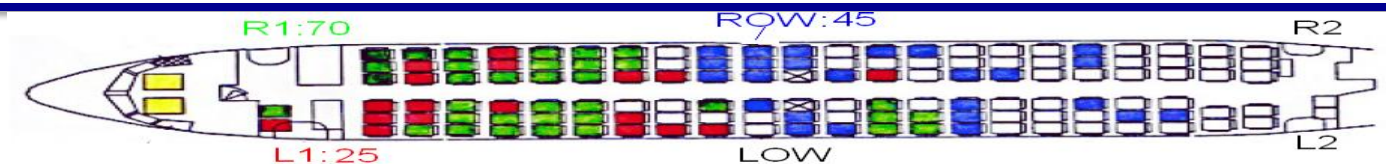
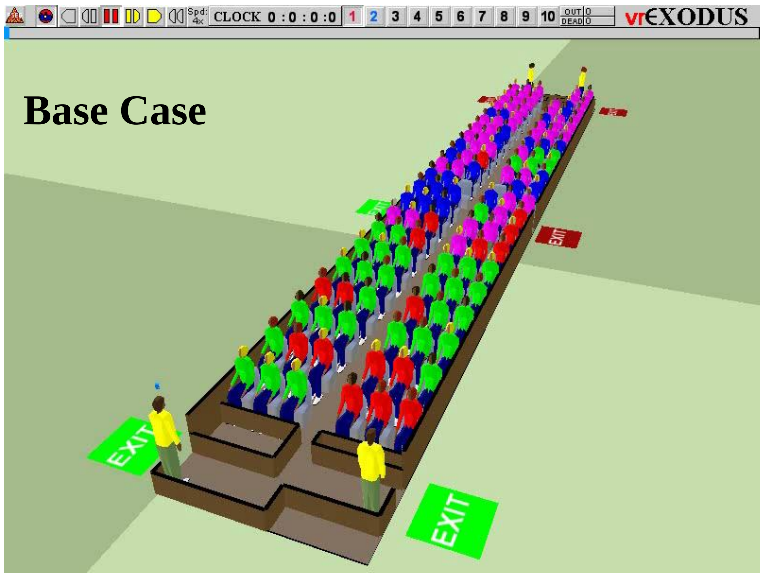
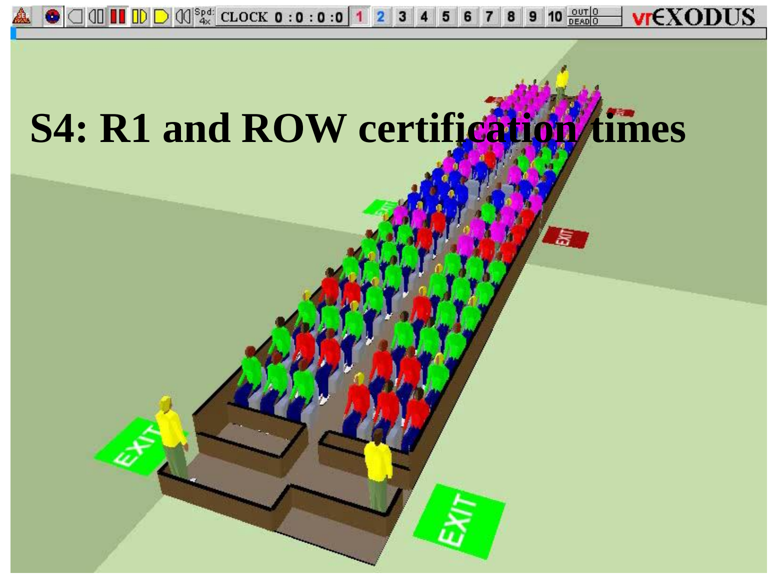
Impact of Exit Opening Times On Evacuation





Base Case: the reconstruction with the actual times to open the exits in the accident **L1(25s), R1 (70s), ROW (45s), R2 (0s)**



Scenario 4: 10s for R1 and 12s for ROW – ideal case, all exits opened as planned

Could the loss of life have been significantly reduced if the R1 exit was opened earlier?
Did the delay in opening the ROW exit impact survivability?

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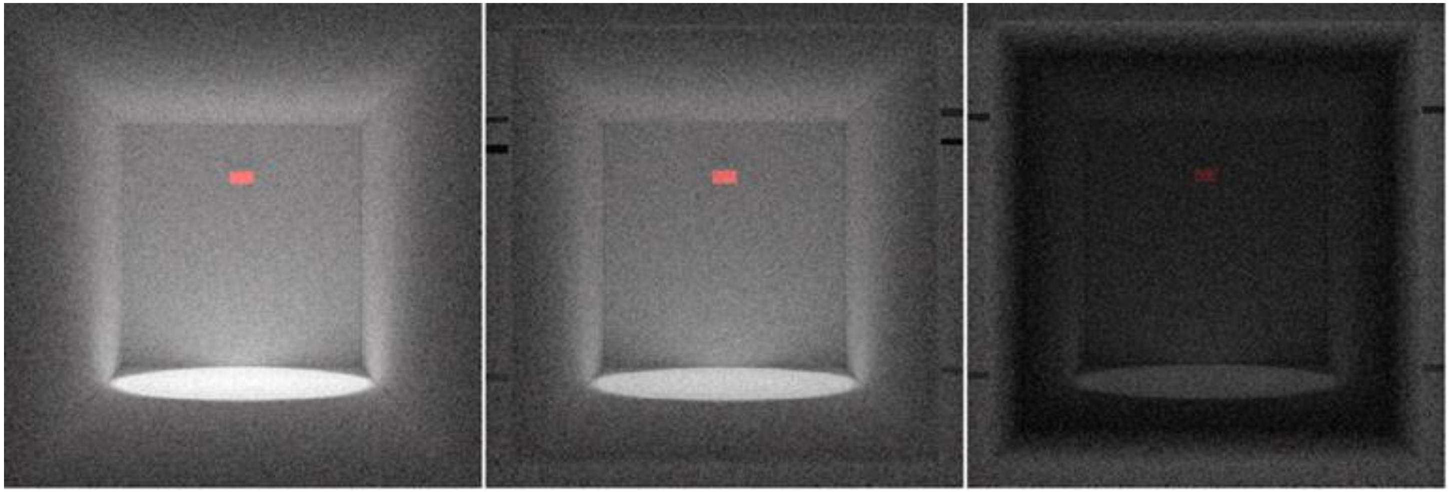
Smoke visualisation



Smoke visualisation: from left to right the density of smoke increased at same light source parameters

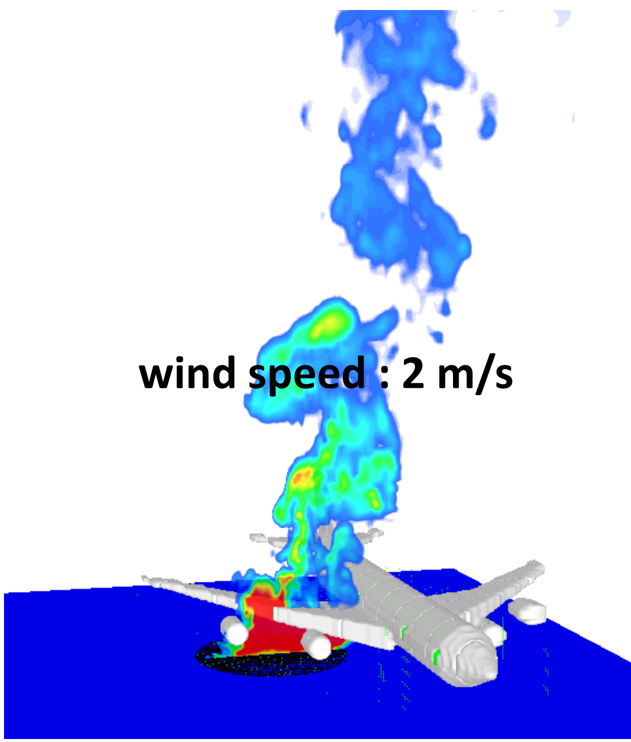
EADS

Kerosene pool fire engulfing a full-scale aircraft modelling

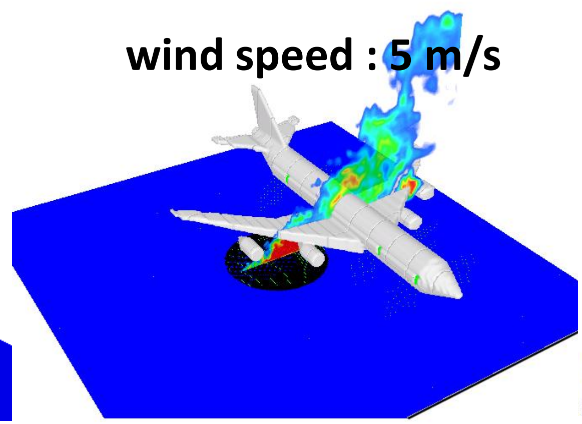
Temperature, flame spread rate, CO/soot over the composite fuselage

- ✓ Pool size from 10, 20, 30 to 40 m
- ✓ Fuel position : below one engine
- ✓ Burning rate of the liquid fuel : about 6 mm/min
- ✓ Heat release rate : higher than 800 MW
- ✓ Time to steady state : about 30 s

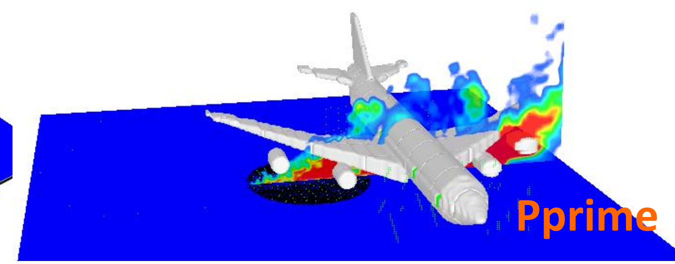
wind speed : 2 m/s



wind speed : 5 m/s



wind speed : 10 m/s



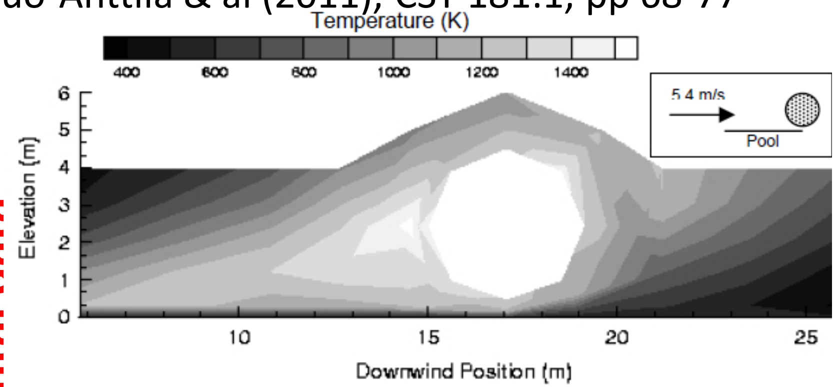
Temperature and heat flux on the fuselage surface

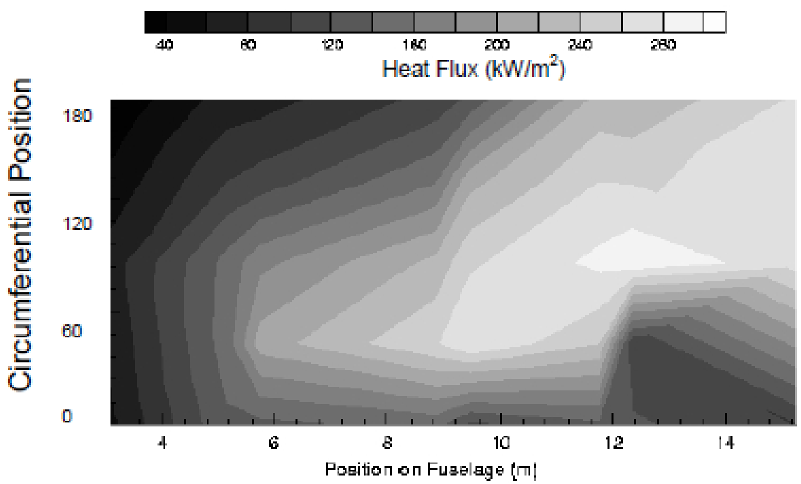
Experimental and Numerical fields

Wind - kerosene pool fire (D=19 m) engulfing a large cylinder object (d=3.7 m)

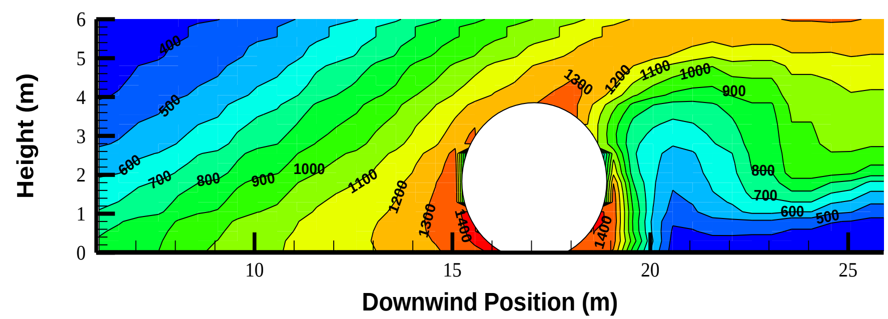
Suo-Anttila & al (2011), CST 181:1, pp 68-77

Experimental data

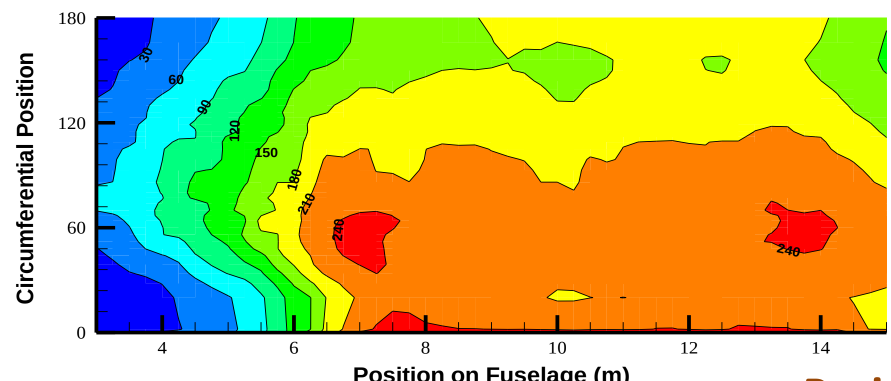




Temperature °C



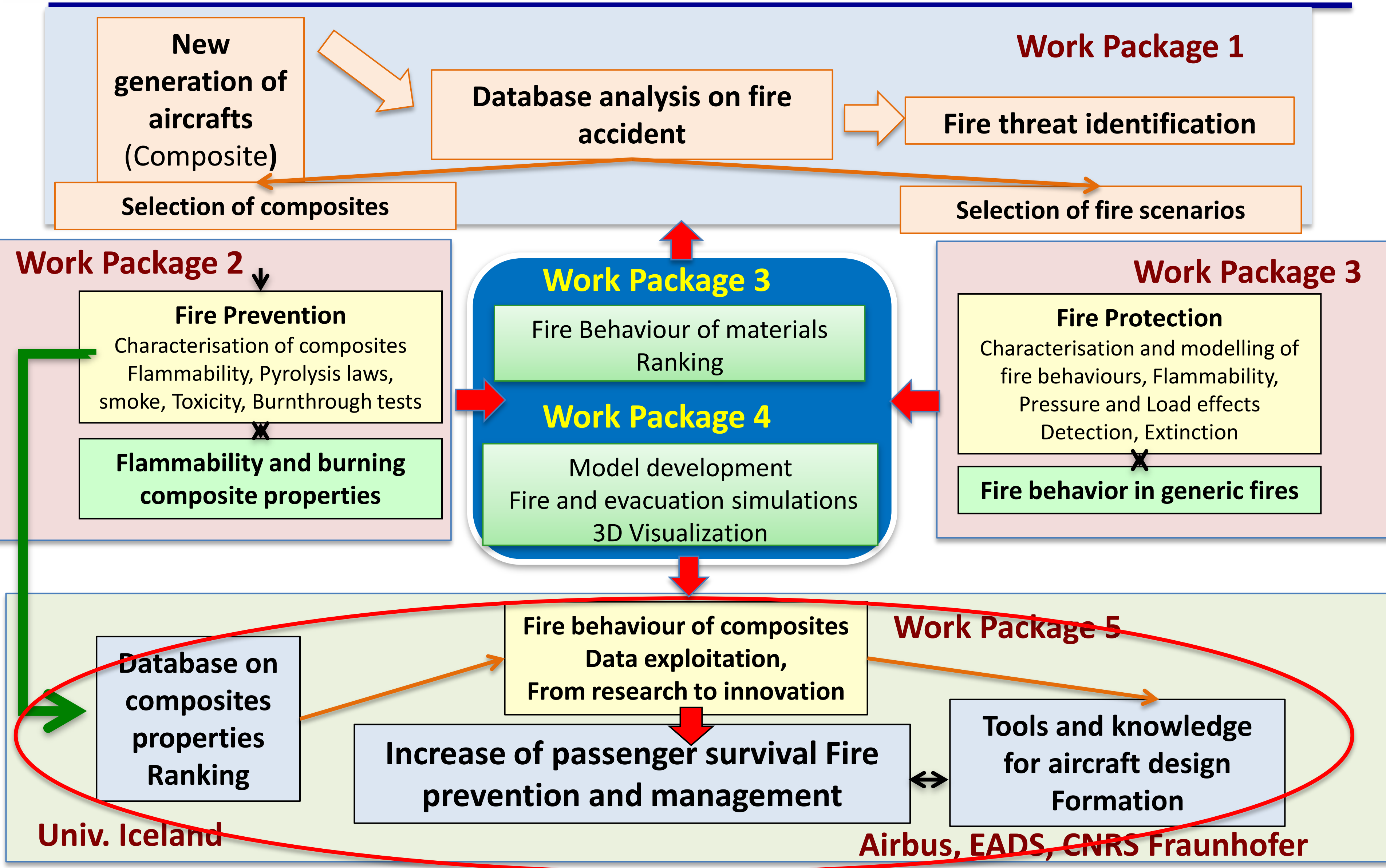
Heat Flux kW/m²



Modelling

Pprime

AircraftFire: CONCLUSIONS



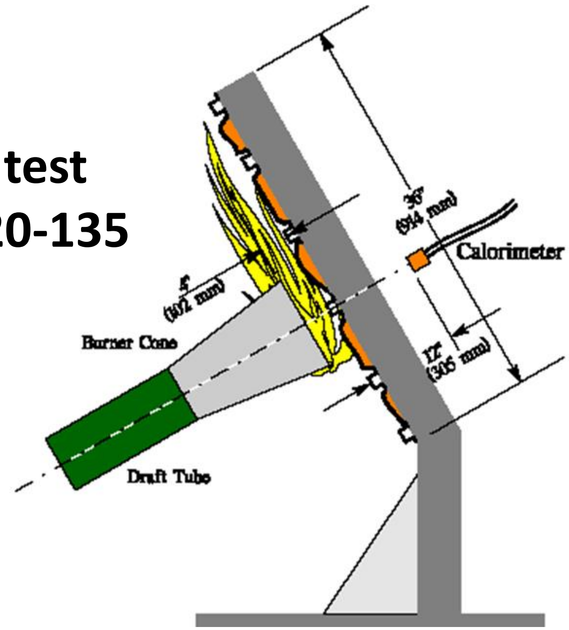
In-house Burnthrough test Facility

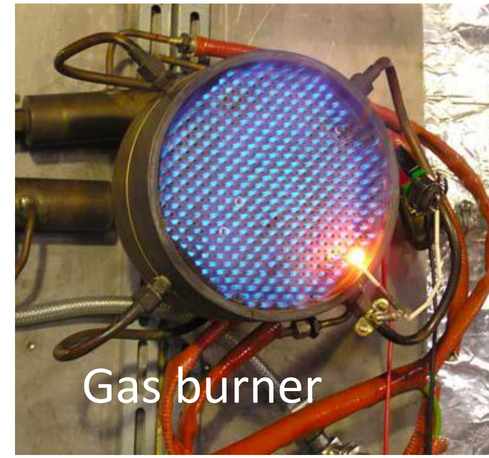
Pprime

Material qualification
Mimic of *Passed/Failed* standard tests

The burnthrough test: ➔Time of burnthrough
Efficiency of the barrier to the flame

FAA test
AC 20-135





Photos from FAA website

Flux 182kW/m² (fuselage, wing, structure)
Flux 106 kW/m² (engine)
Gas Temperature: 1100°C

Material Characterization with In-house Burnthrough Test Facility

❖ Features:

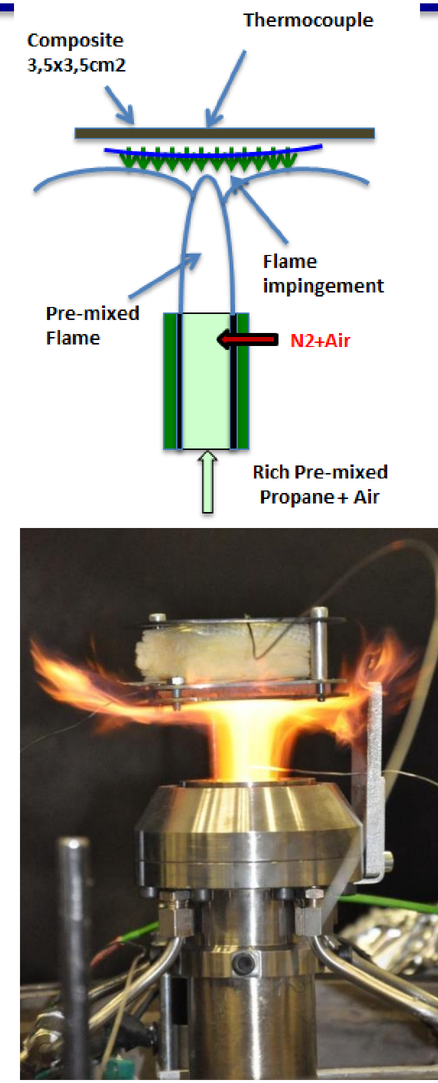
- ➢ Premixed burner
- ➢ Inside diameter injection D: 35 mm
- ➢ Burner / Sample distance 1.7, 3.5 and 5.2 cm
- ➢ Co-flow outside Nitrogen

❖ Parameter Setting:

- ➢ Burner exit temperature, T_{exit}: 830 to 1172 °C
- ➢ Output speed constant cold: u_c = 2.3 m/s; hot: 12m/s
- ➢ Turbulent flow Re ≅ 4700
- ➢ Mass fraction of y_{O2} = 0 to 0.06 at the burner exit
- ➢ Pressure 0.2 to 1 atm, load effects

❖ Diagnostics during tests:

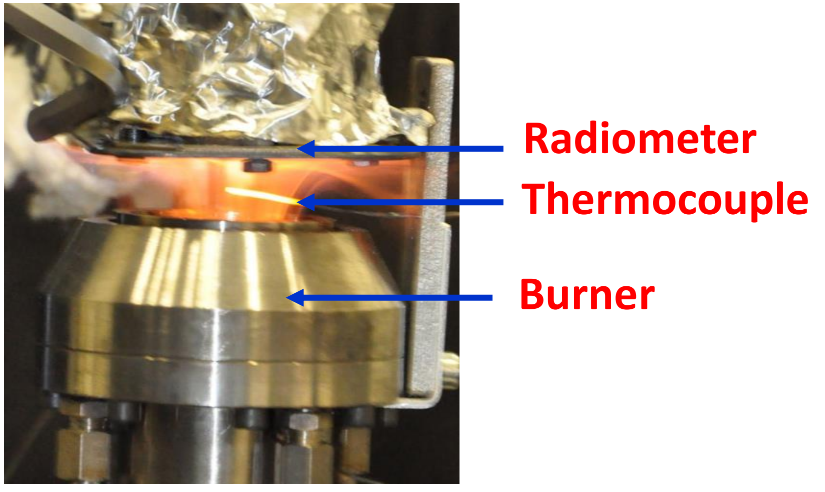
- ➢ Flowmeters for air, fuel gas, nitrogen
- ➢ Weight sensor ➔ Mass loss ➔ Mass Loss Rate MLR
- ➢ Thermocouples
- ➢ Video camera

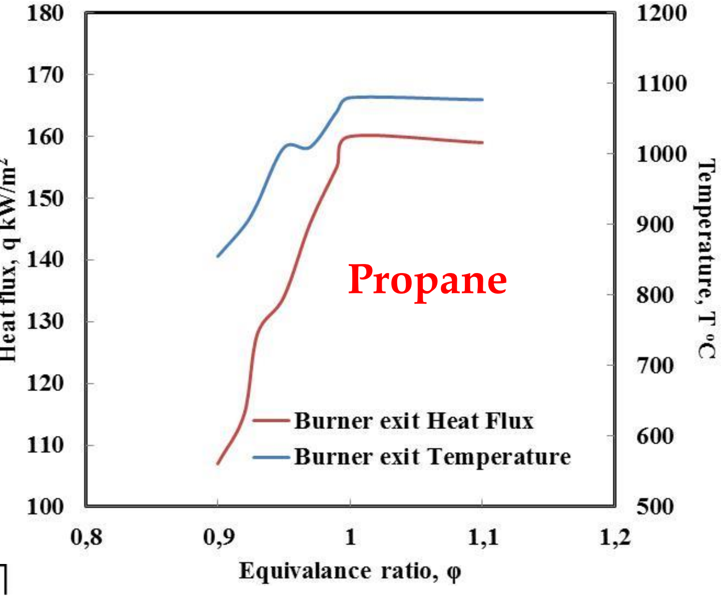


Schematic and snapshot of facility

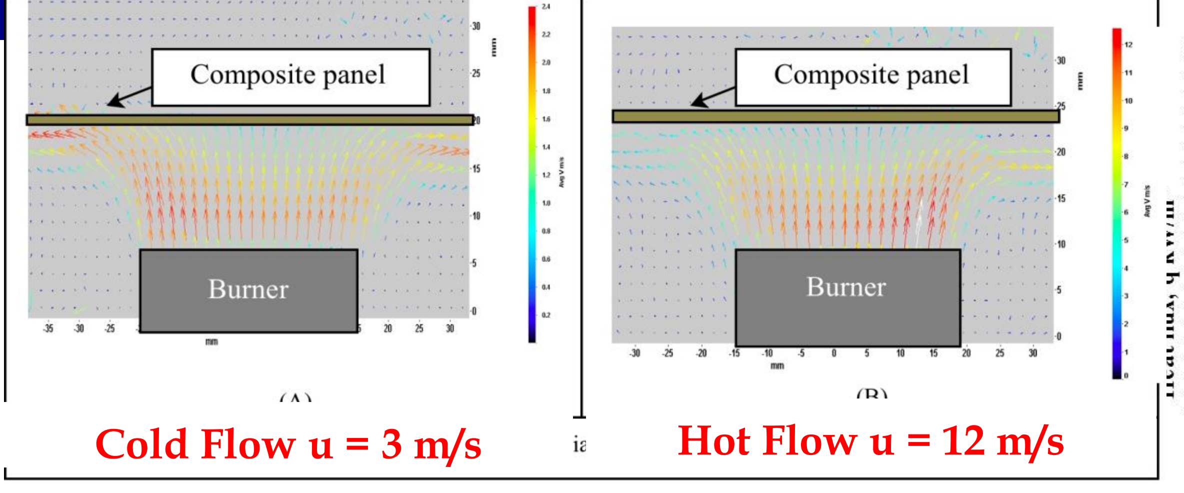
Heat Flux calibration

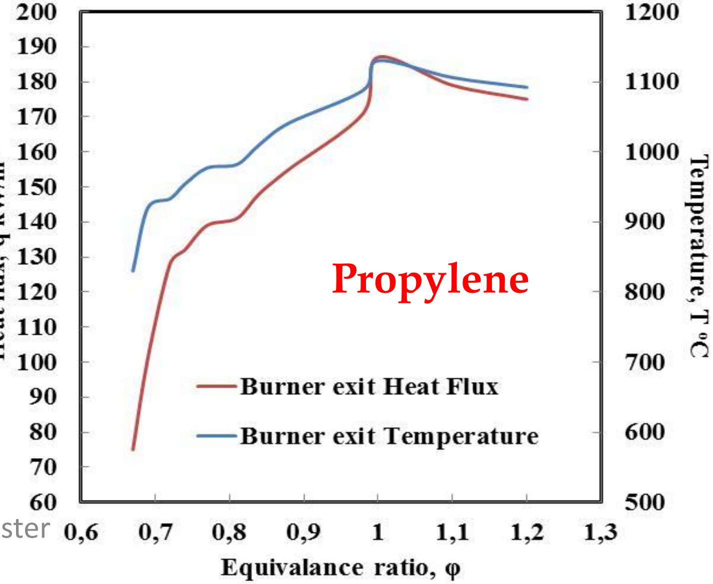
Radiometer – Tube calorimeter



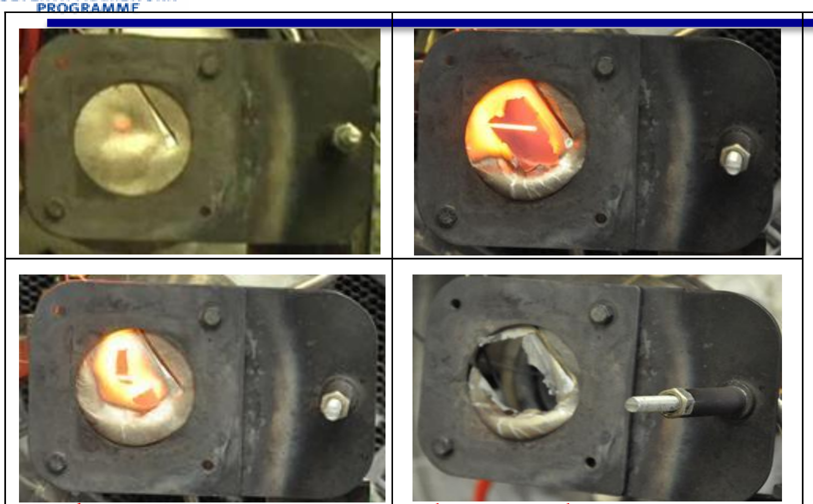


PIV



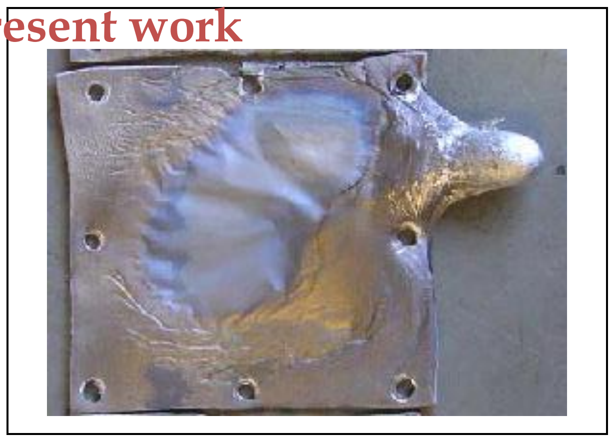


Aluminium (2mm thickness)



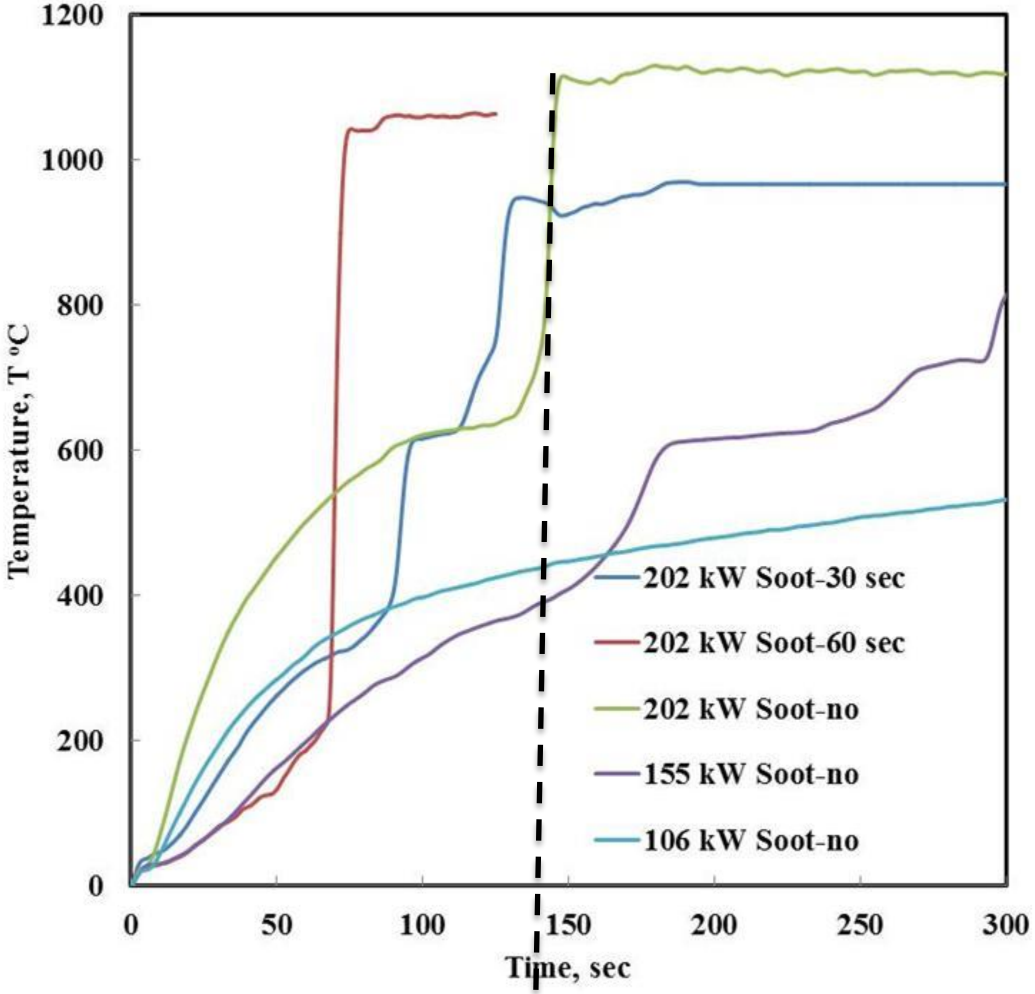
Aluminium Burnthrough Test:

Present work



Aluminium Burnthrough Test:

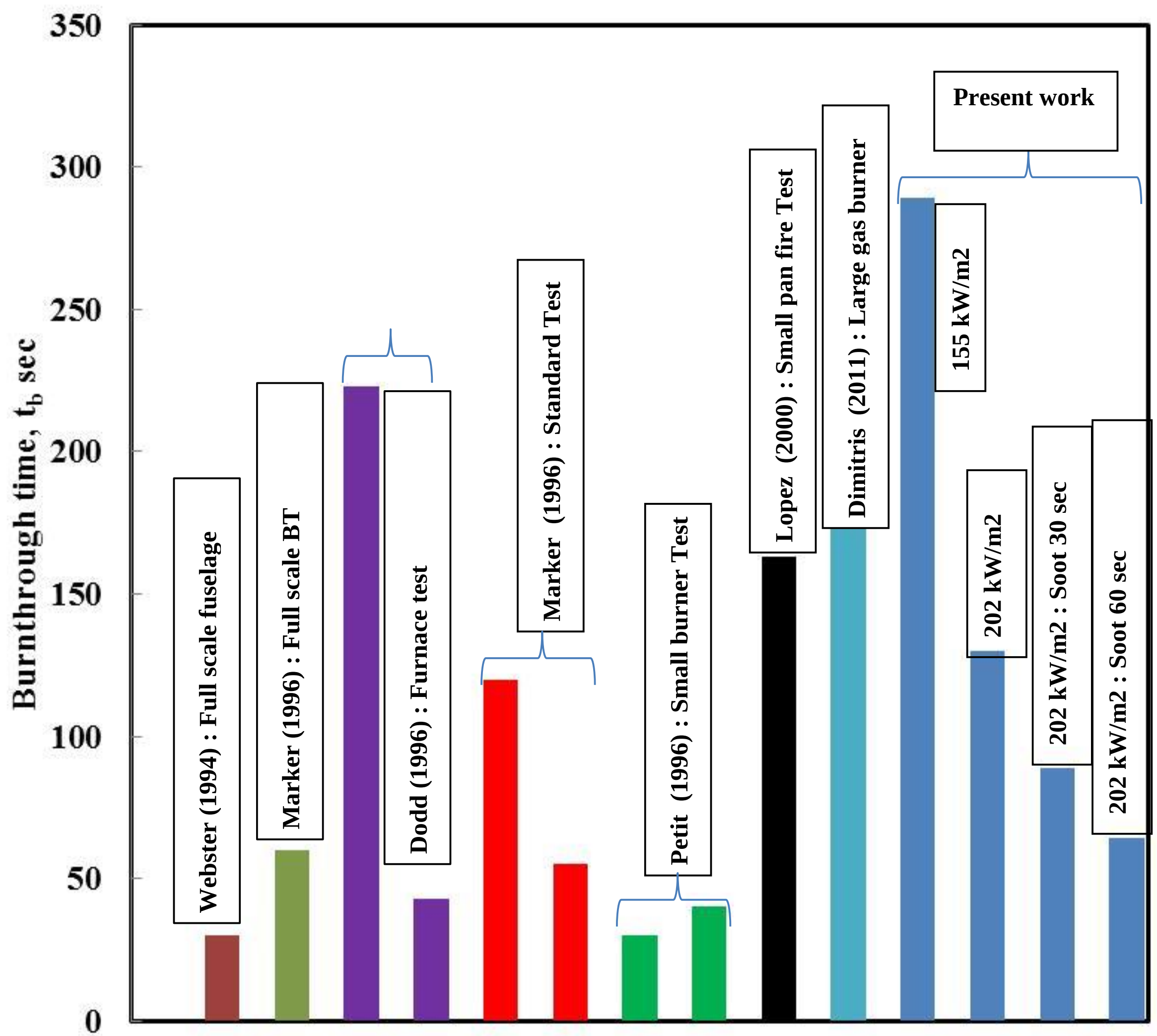
Literature



BT= 140s

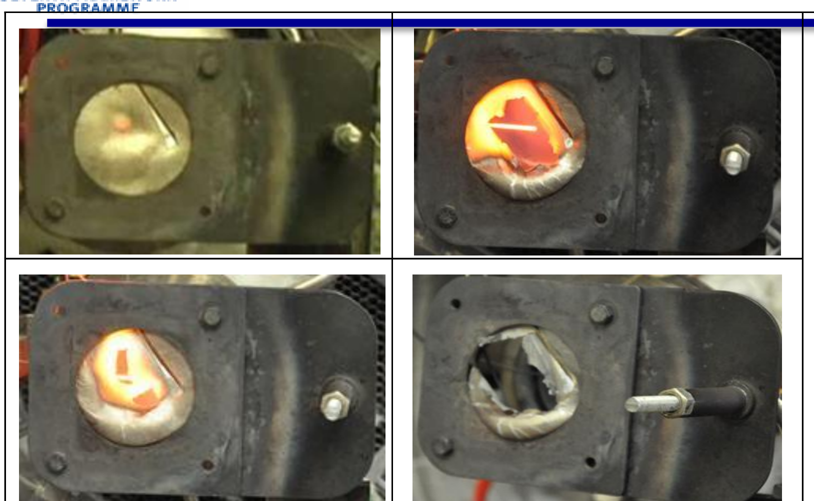
Aluminium: Burnthrough Data

Authors	Burnthrough time, t_b sec	Sample surface and Test No,	Device of tests
Webster, H (1994), FAA	30		Full scale fire test on aircraft fuselage
Marker (1996), FAA	60		Full scale burnthrough test
Dodd (1996), CAA	223	clean	Burnthrough furnace test
	43	sooted	
Marker (1996), FAA	120	1	Standard burnthrough test
	55	2	
Petit (1998), CEAT	30	1	Small burner burnthrough test
	40	2	
Lopez (2000)	163		Small scale pan fire
Dimitris et al. (2011)	173		Large In-house gas burner
Present work (Pprime)	289	1	Small In-house gas burner
	130	2	
	89	3	
	64	4	



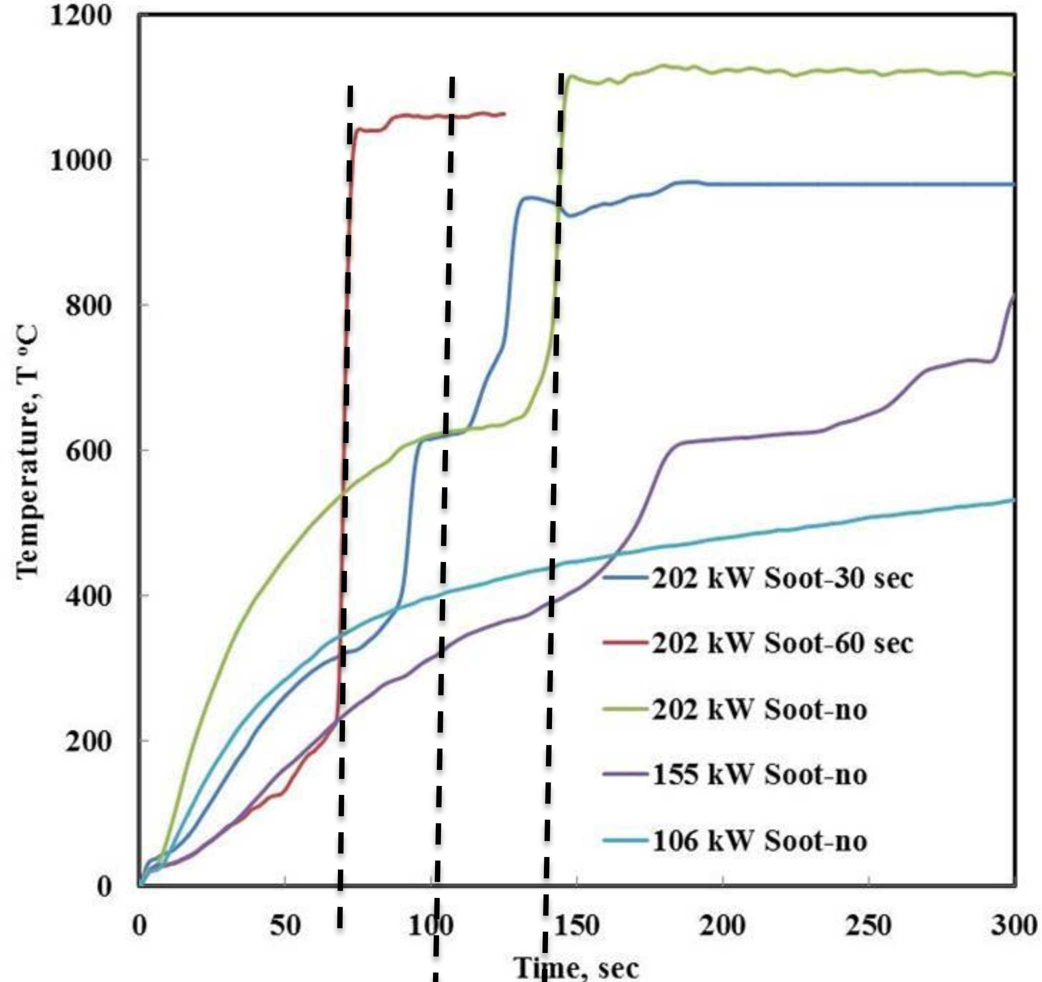
Complete burnthrough data for aluminium *b*=2 mm

Aluminium (2mm thickness)



Aluminium Burnthrough Test: Present work

Aluminium Burnthrough Test: Literature

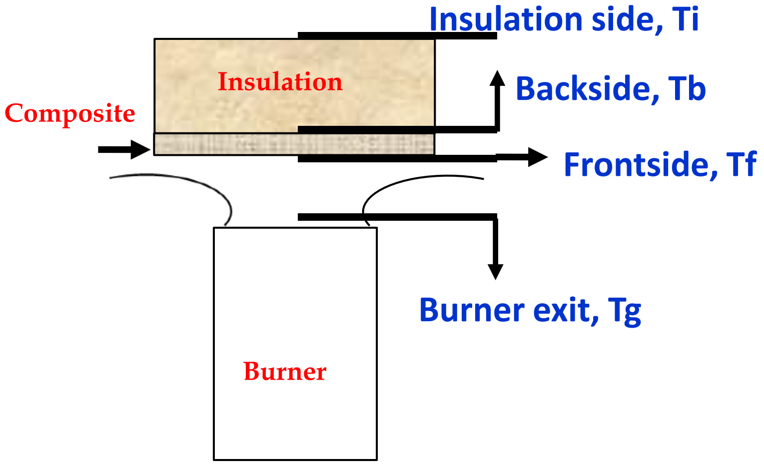


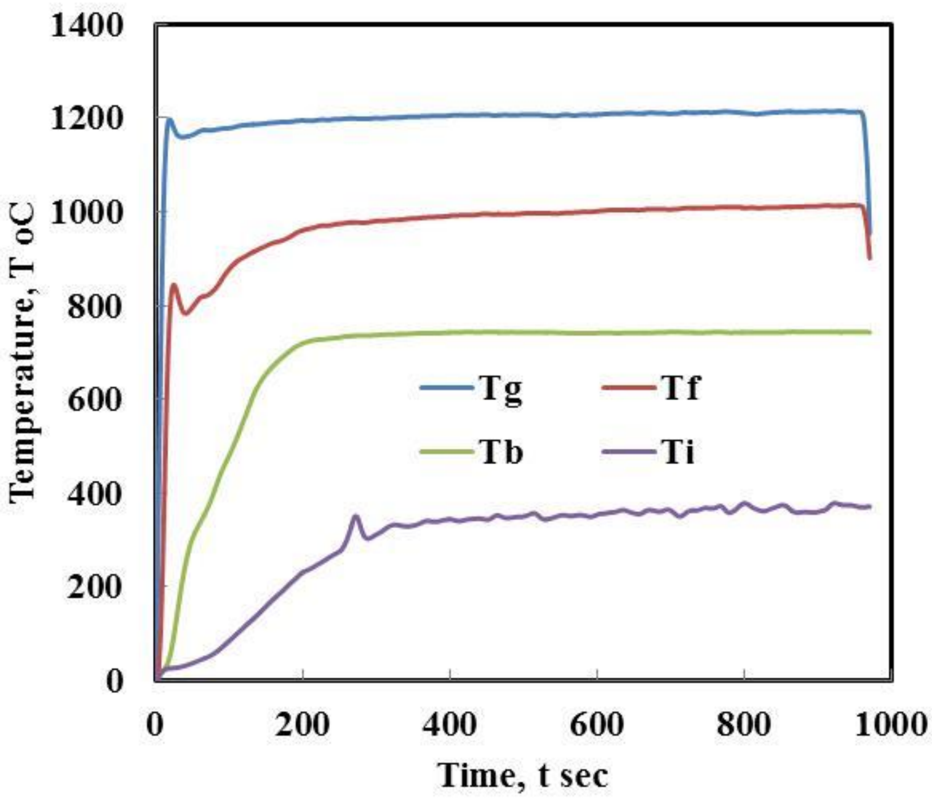
Soot dep.(60s), BT = 64 s

BT= 140s

Soot dep.(30s), BT = 100s

Burnthrough time for composite Material AcF2





Test conditions:

Total heat flux q = 70 to 202 kw/m2

Strain rate, $\tau = 430\ s^{-1}$

$yO2 = 0$ to 0.06

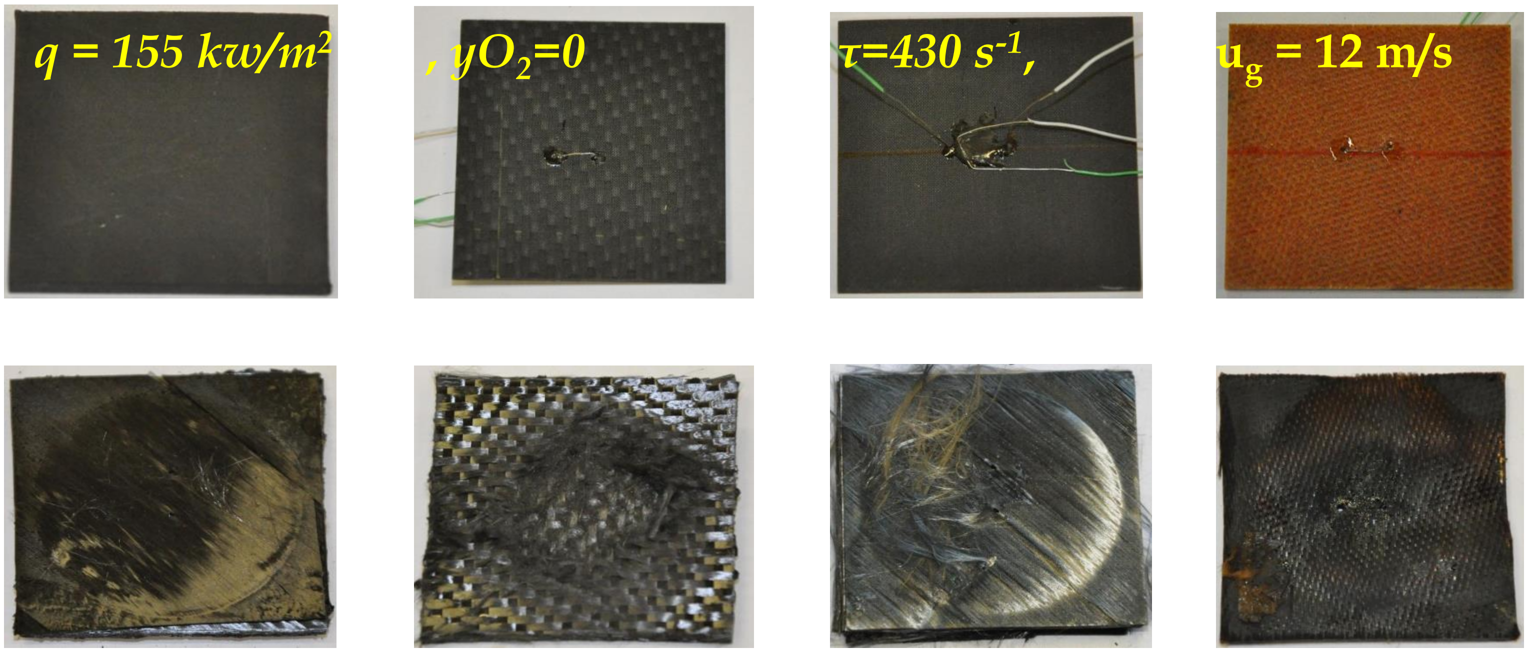
Sample thickness $b = 2 - 4$ mm

$u_g = 12$ m/s

Burnthrough time > 17 minutes (1000 seconds)

No Burnthrough is observed

Composites : Material Swelling



Virgin sample

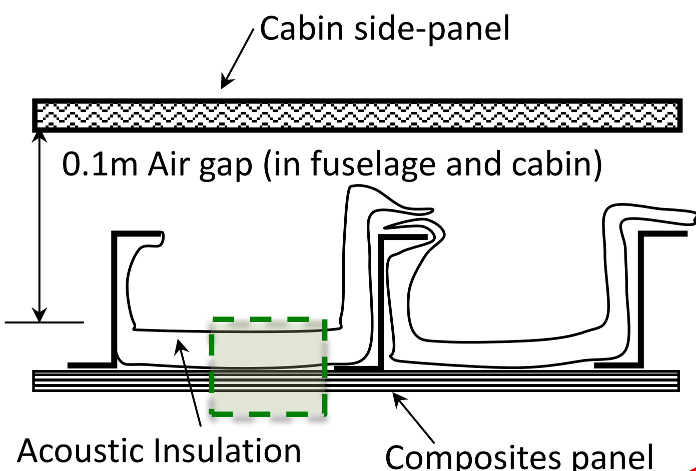
Sample swells expands

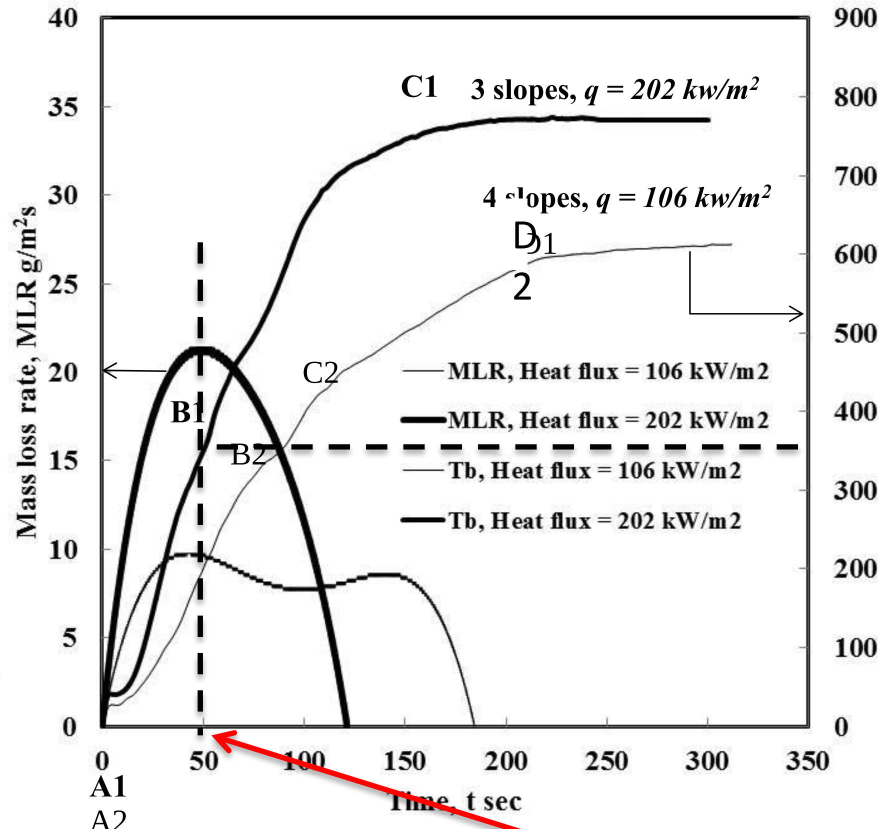
During resin vaporization, the resin escaped through closely spaced fibre (carbon or glass). This in turn produces internal pressure in the composites and therefore the sample swells i.e. the composite expands in response to internal pressure.

Temperature and Mass Loss Rate (AcF2)

Backside Temperature / MLR correlation

Test condition: **Strain rate, $\tau=430\ s^{-1}$ and sample thickness $b=4\ mm$, $u_g=12\ m/s$**





$A_i \rightarrow B_i$ Burning of resin – heat penetration

B: Maximum of MLR (or HRR) $T_{backside}=T_{degradation}$

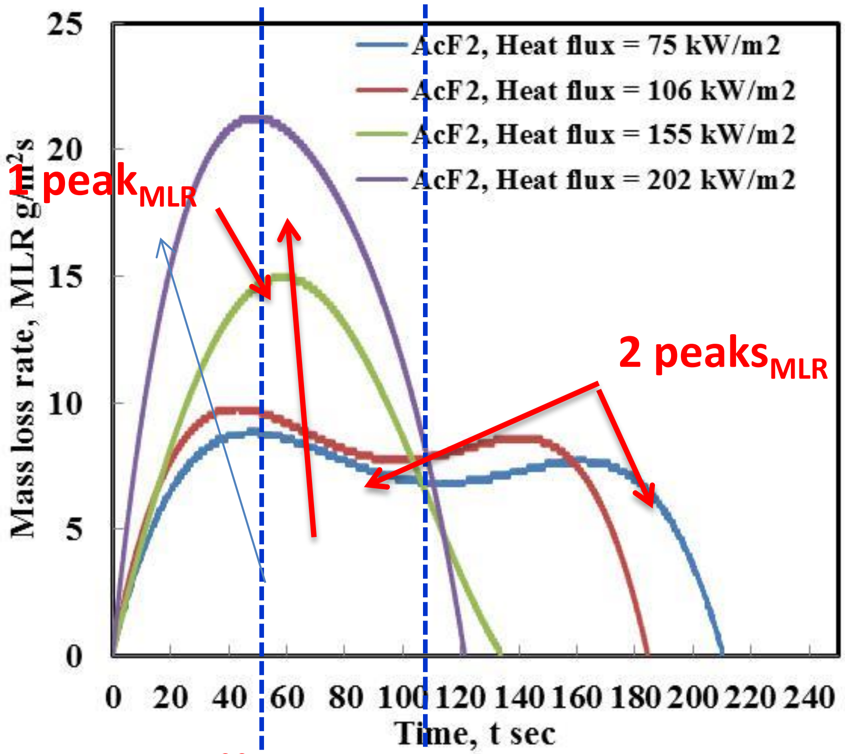
C: End of resin burning

Off gassing : Toxicity and Potential ignition

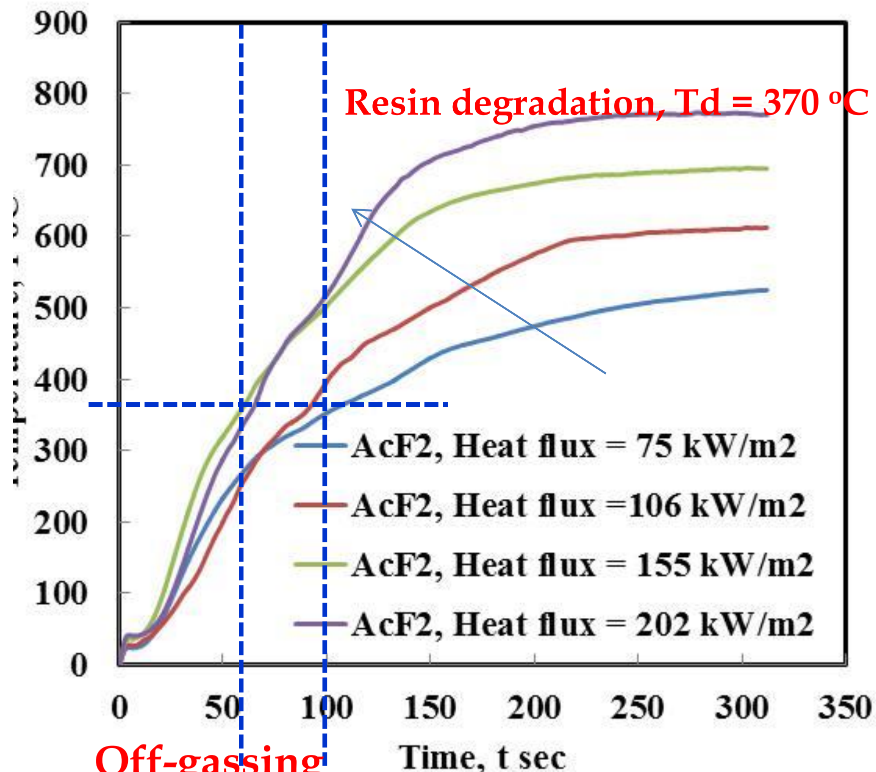
Video

Mass Loss Rate - Temperature Material AcF2

$O_2=0.06$ (excess O_2)
Strain rate, $\tau=430\ s^{-1}$
$u_g = 12\ m/s$



MLR



Backside Temperature, Tb

q ↑ => MLR (V_{comb}) ↑ and $T_{backside}$ ↑

Higher heat flux => 1 $peak_{MLR}$: Formation and oxydation of char

Lower heat flux => 2 $peaks_{MLR}$: Combustion, formation of protective char layer, char oxydation, resin burning

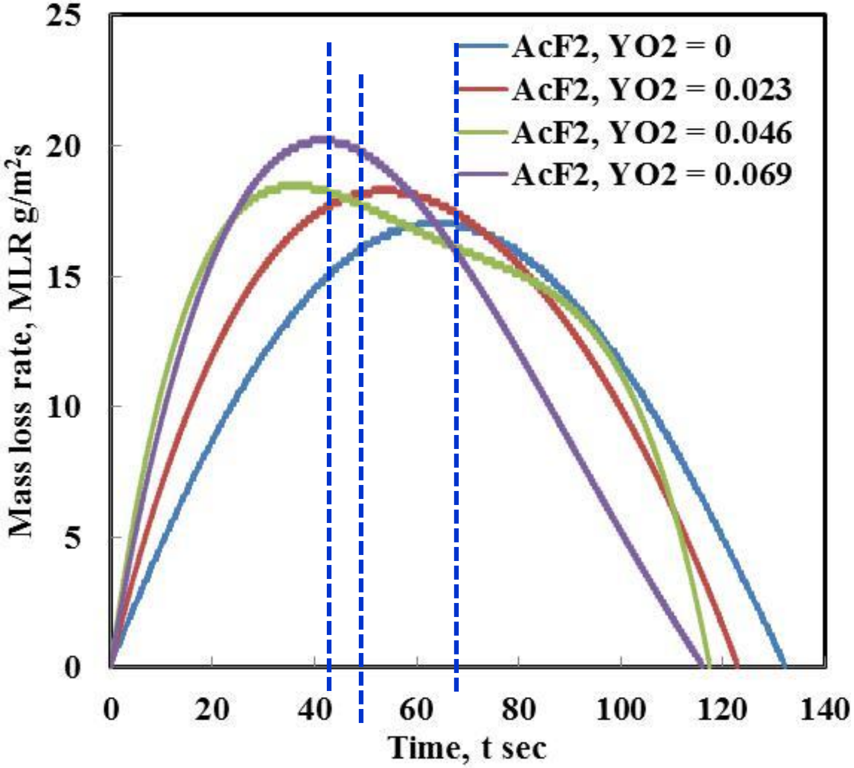
Influence of Y_{O2}

AircraftFire

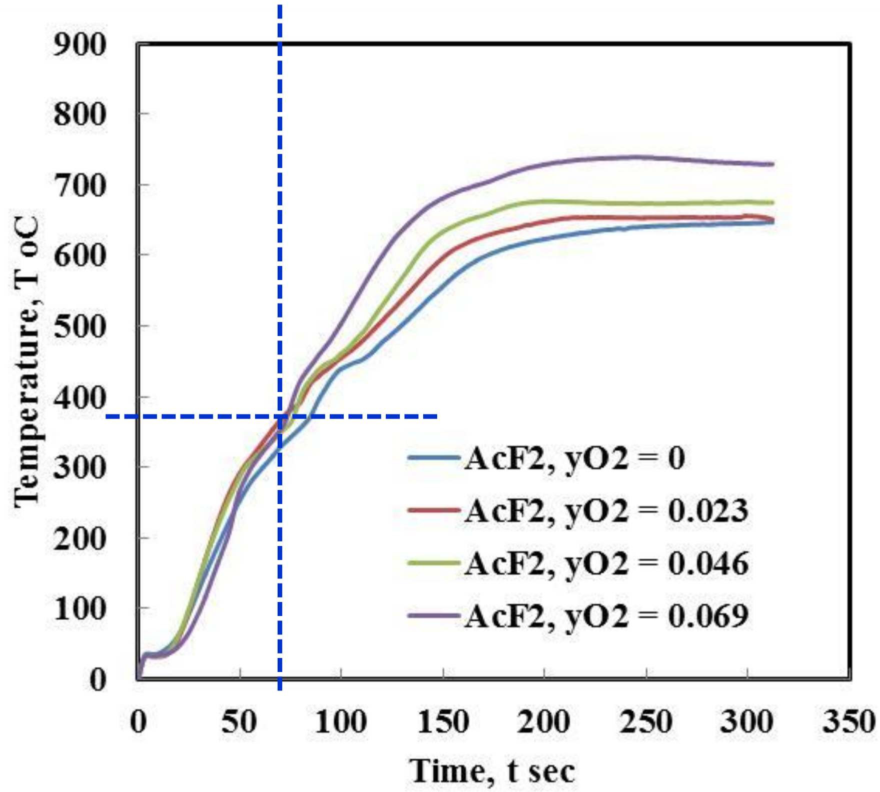
SEVENTH FRAMEWORK PROGRAMME

cnrs advancing the frontiers

$q = 155\ kw/m^2$, $\tau=430\ s^{-1}$, $u_g = 12\ m/s$



MLR

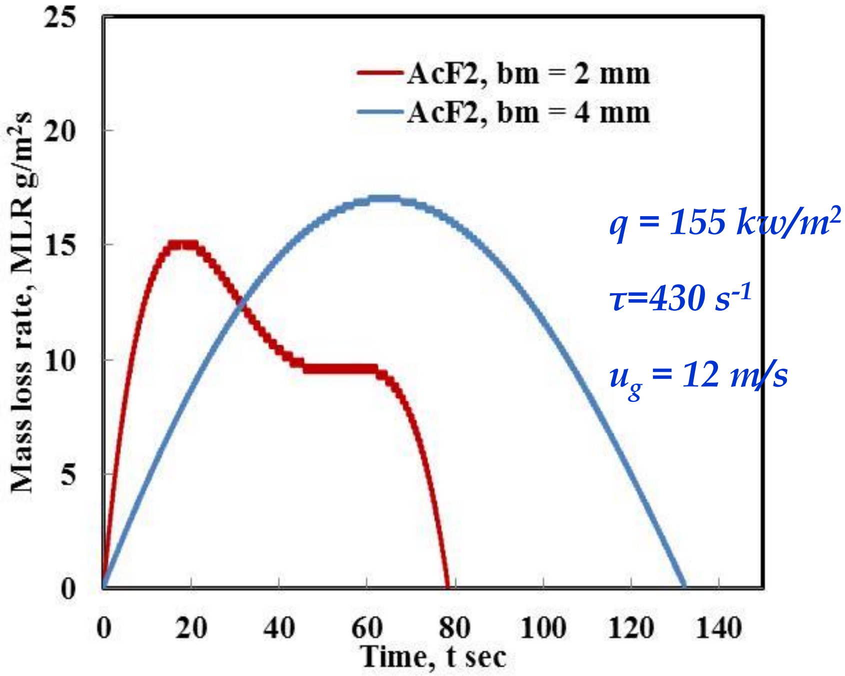


Backside Temperature

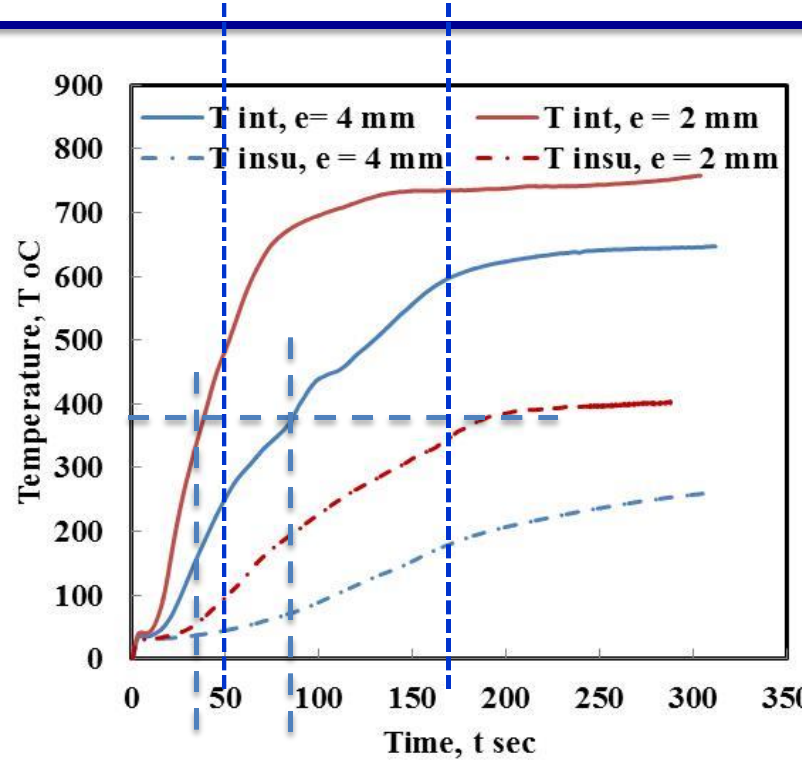
Y_{O2} ↑ => MLR: V_{comb} ↑ and $T_{backside}$ ↑

- Pyrolyis and burning of resin degradation products
- Maximum of MLR peak ↑ with Y_{O2} ↑
- Strong influence of O_2 due to high temperature reaction (T=1100°C)

Influence of material Thickness *b*



MLR



Backside Temperature

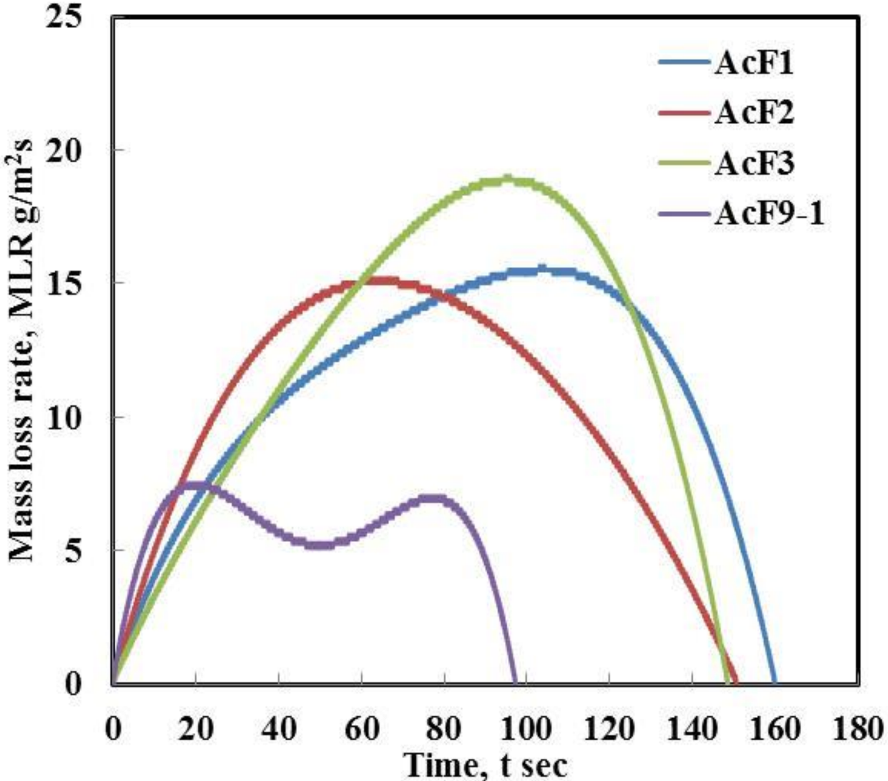
b ↑ => MLR: V_{comb} ≈ and $T_{backside}$ ↓

- ✓ *b*=2mm: 2 peaks_{MLR} (low heat flux) e=4mm: 1 peak_{MLR}
- ✓ $V_{comb,\ b=2mm} \approx V_{comb,\ b=4mm}$ (thermal effect)
- ✓ *b* ↑ => Fire Resistance ↑
- ✓ *b*=2mm : insulation effect on backside with higher dT/dt

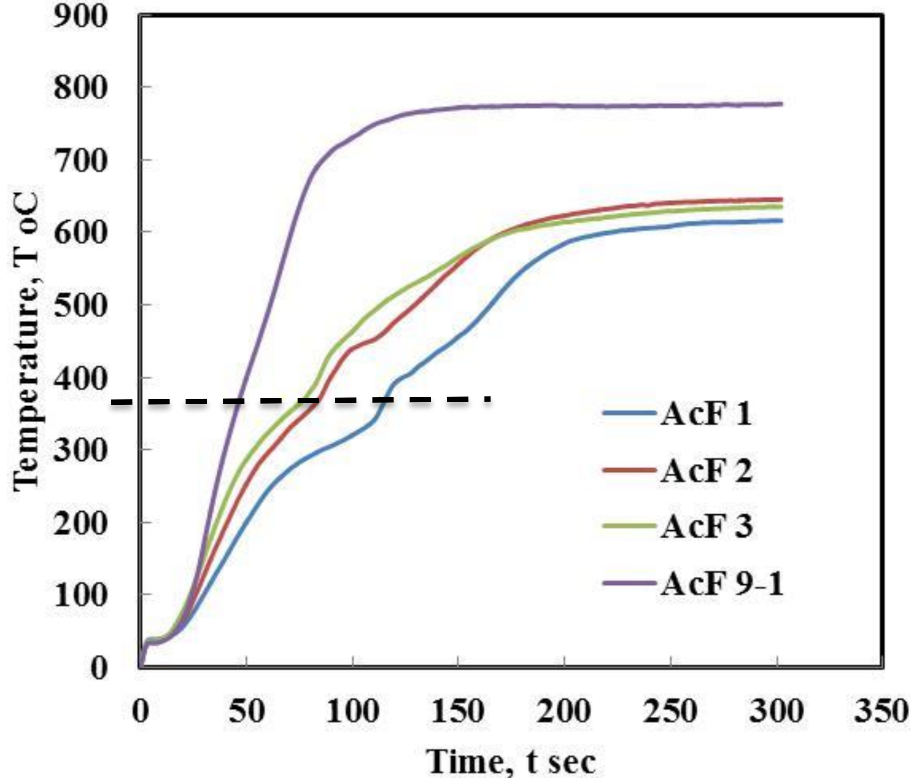
Comparison AcF1, AcF2, AcF3 (Epoxy/graphite fibers)

AcF9-1 (Phenolic/Glass fibers)

q = 155 kw/m², yO_2=0.06 τ=430 s^{-1}, u_g = 12 m/s



MLR



Backside Temperature

- ✓ $V_{comb\ epoxy+FC} > V_{comb\ phenolic+FV}$
- ✓ $T_{int\ epoxy+FC} < T_{int\ phenolic+FV}$ (thermal conductivity)
- ✓ Always char layer formation with phenolic resin

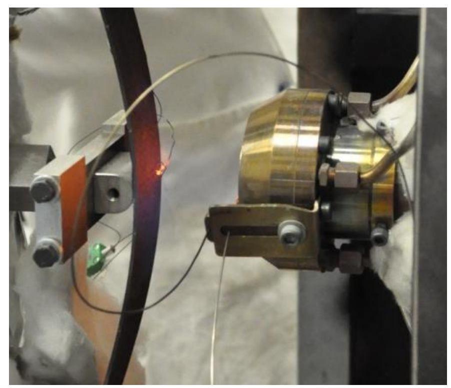
Degradation times and respective peaks of MLR

Sr. No.	Experimental Parameters variations		Aluminium Burnthrough time (seconds)	Composite Time for backside degradation (seconds)	Composite Maxima of MLR (g/m^2s)
1	Heat Flux, q (kW/m^2)	75	-	115	7.26
		106	infini	100	7.84
		155	175	60	16.96
		202 (no soot deposition)	130	46	21.12
		202 (soot deposition during 30s)	85	-	-
		202 (soot deposition during 30s)	64	-	-
2	Thickness b_m (m) (Heat Flux, q = 202 kW/m^2)	0.002		20	15.5
		0.004		60	16.96

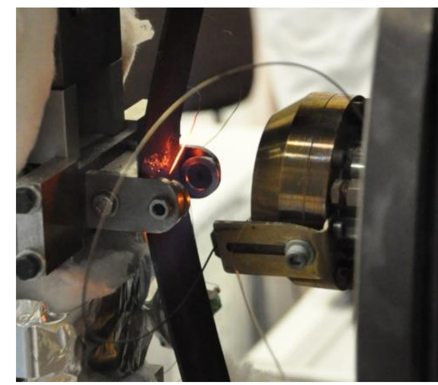
Material burning under load

Experiment consists of exposing a sample of composite material to a flow of hot gases generated in the burner while applying a bending load

Experimental device

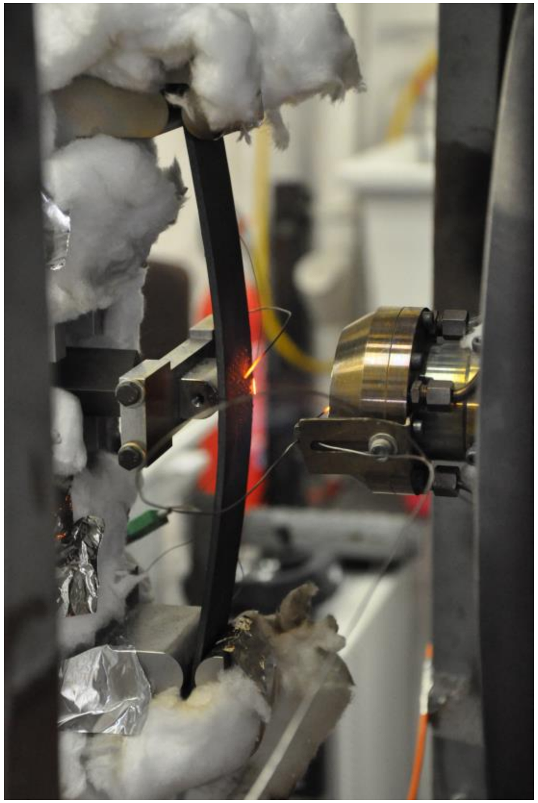


Contraint in fibers exposed to the flame: Tension stress

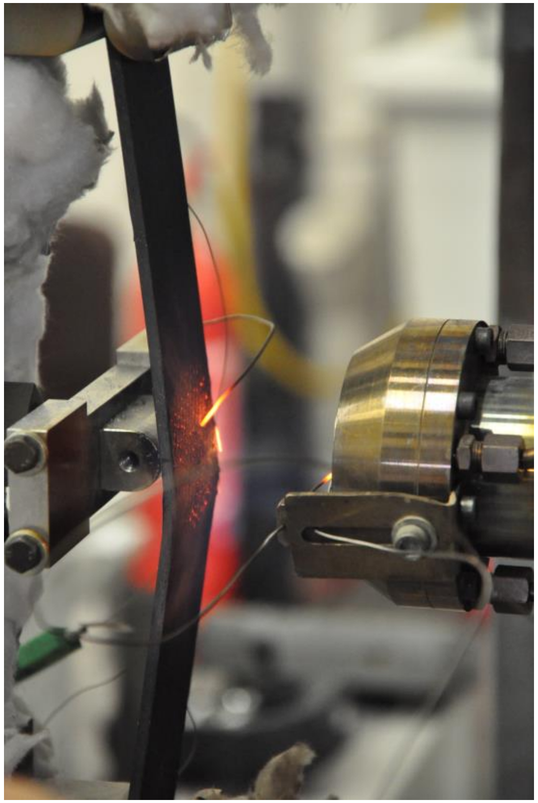


Contraint in fibers exposed to the flame: Compression stress

Material burning under load



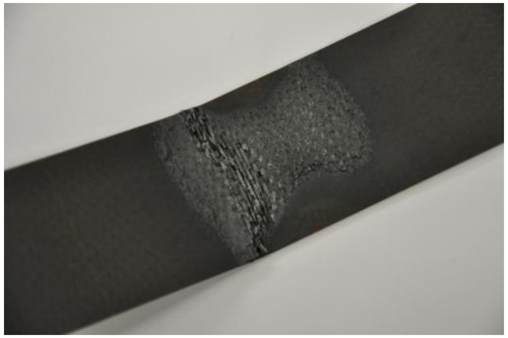
Before crack

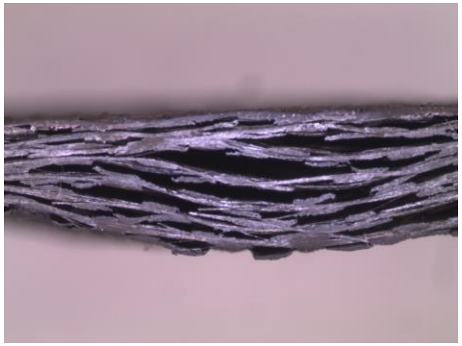


After crack

Material burning under load

Sample after testing

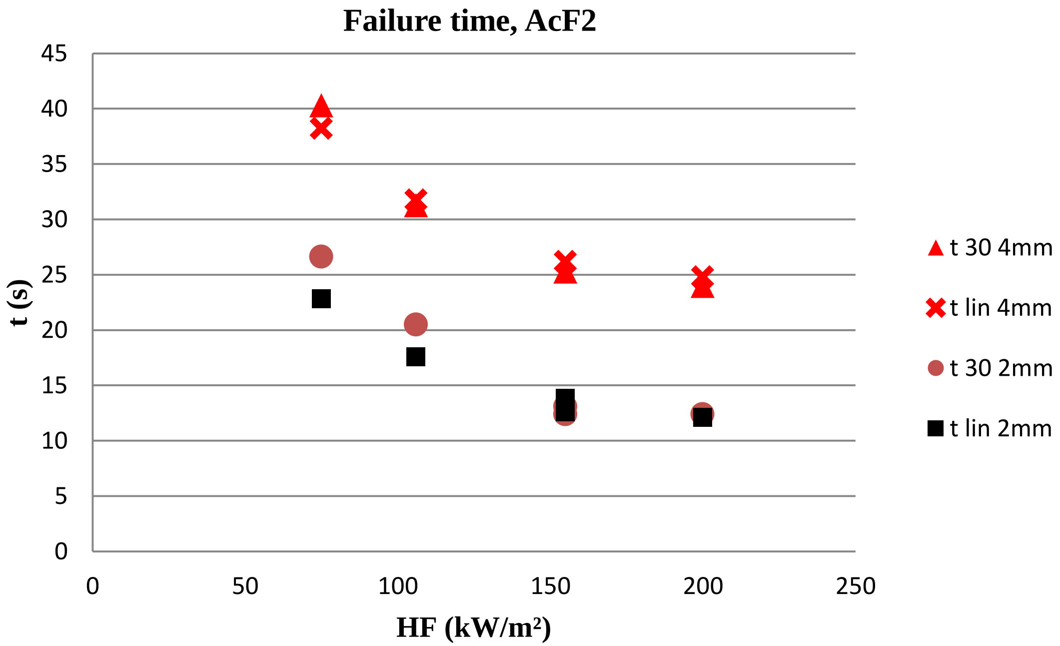




AcF2 Failure Time (HF)

b=2mm (Deflection 30mm)

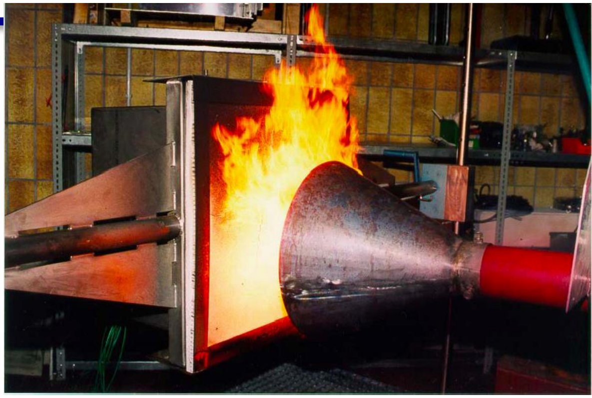
b=4mm (Deflection 15mm)



Burner – composite distance: 5.2cm

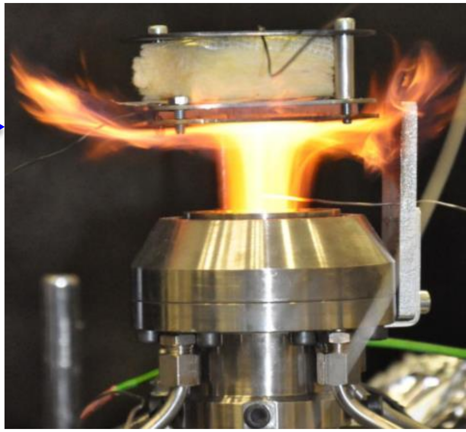
Conclusion

Burnthrough standard test burner



- **Parameters**:
  - Temperature and heat flux at the material location, imposed geometry
  - Type and Material thickness
- **Main Result**: burnthrough time (passed/failed tests)

Burnthrough AircraftFire burner



- **Parameters**:
  - Temperature and heat flux at the material location
  - Material thickness, Y_{O2}, τ, Pressure, Load, etc.
- **Results**:
  - Burnthrough time!
  - Burning rate (combustion regimes (char), effects of additives)
  - Measurements of interface temperatures (heat flux inside the composite)

Fast and low cost tests for materials (composites)

Conclusion

- **No burnthrough observed for composites in the studied conditions** (up to 15minutes)
  - Heat flux: 182kW/m^2 Gas Temperature: 1100°C

- **Main results**
  - ✓ $V_{combustion}$ mass loss of 24-30% in mass of the sample resin

Peak 1 of MLR
- Pyrolysis and combustion
- End of resin combustion (less than 3 minutes)
- Fibres oxidation

✓ Peaks 2 of MLR
- Protective char formation
- Char combustion

- **Fire propagation in the cabin consequences**
  - ◆ **Aluminium** : Time for Burnthrough
  - ◆ **Composite**: Time for beginning of backside off gassing $T_{back}=T_{deg}$
    - ➔ Potential diffusion of toxic gases in the cabin
    - ➔ Ignition of fuel degradation products

AircraftFire partners

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THANK YOU FOR YOUR ATTENTION