FIRE PROPERTIES AND BEHAVIOUR OF COMPOSITE MATERIALS:

WP7.1 “Understanding and characterising the fire behaviour of primary structure composite materials”

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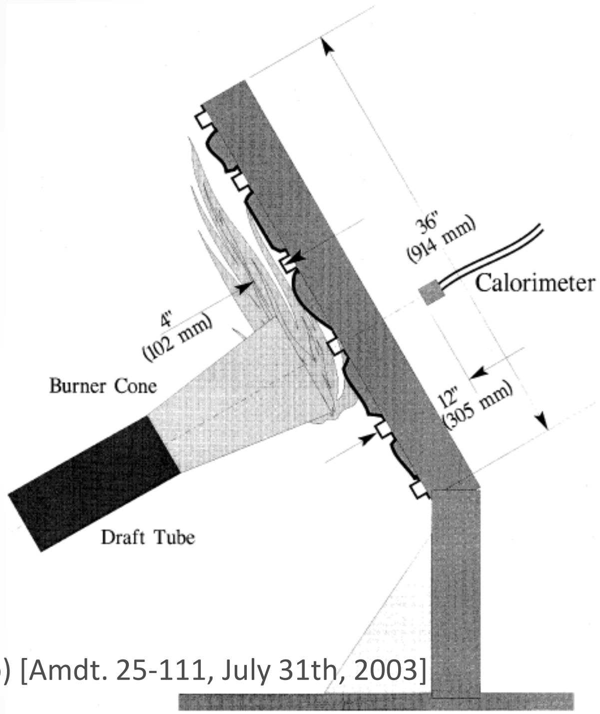
Outlines

- Aviation safety regulation
- Fire behaviour of composite materials
- Future Sky Safety: Project 7 Objectives
- Work Package 7.1 Approach
- Methodology of investigation
- Thermo-chemical kinetics and energetics
- Anisotropic thermal behaviour

Aviation safety regulation

Burnthrough resistance of aircraft structures

Burnthrough test: fire behaviour of composite materials



FAR 25.856(b) [Amdt. 25-111, July 31th, 2003]

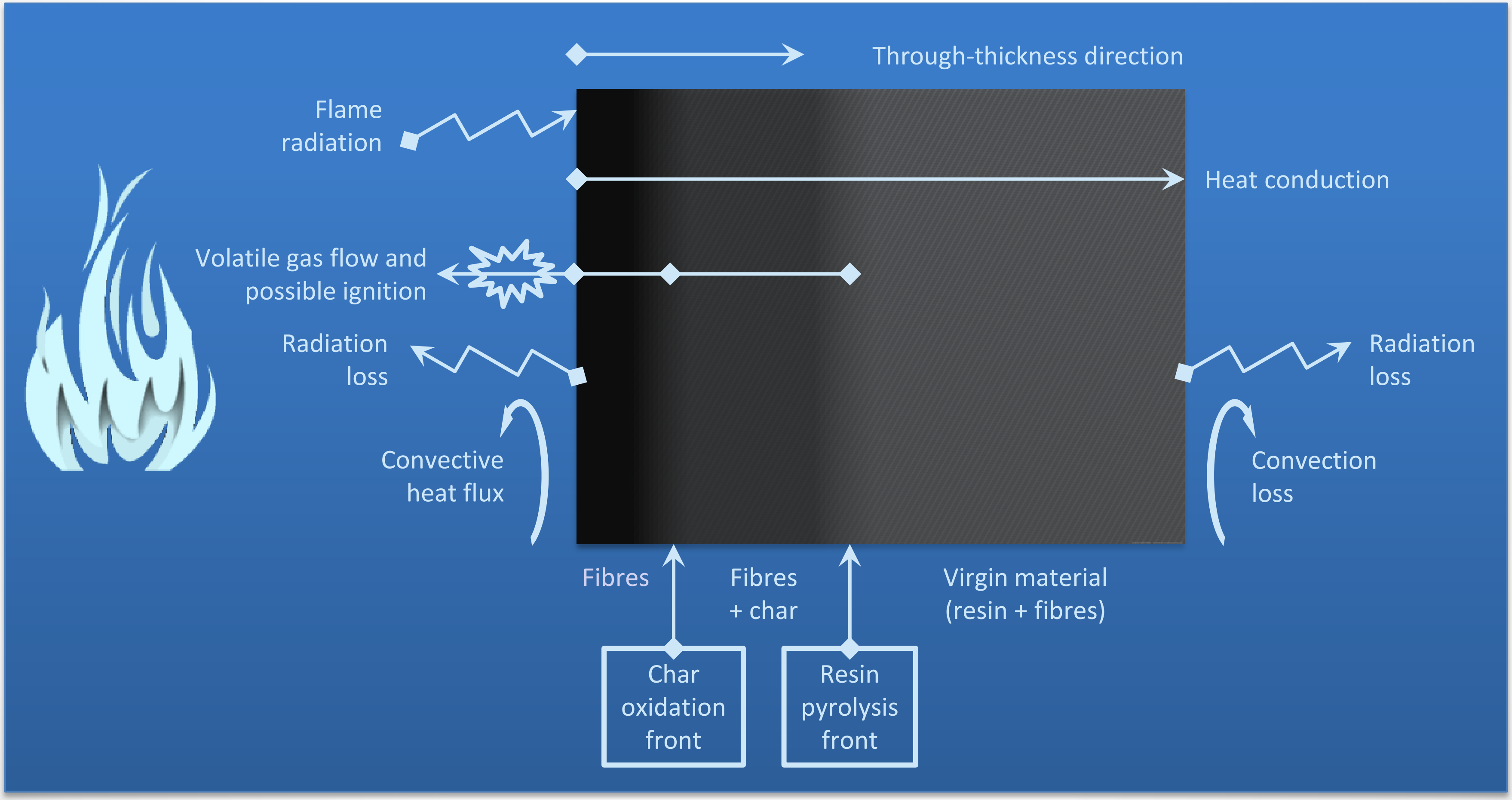
Unlike some metallic structures, composite structures generally do not experience burnthrough after 4 or 5 minutes of fire exposure

Understand complex physical phenomena → Get better safety margin management → Anticipate next fundamental issues

Fire behaviour of composite materials

Fundamental issues

Multiphysics problems with coupled phenomena*



* Review of fire structural modelling of polymer composites
A.P. Mouritz et al. Composites: Part A 40 (2009) 1800-1814

Future Sky Safety: Project 7 objectives

Mitigate the risk of fire, smoke and fumes

Work Package 7.1:

Understanding and characterising the fire behaviour of primary structure composite materials

- Enhance knowledge concerning the fire behaviour and performance of CFRP primary structure materials
- Produce a comprehensive experimental database on a reference composite material (T700GC/M21)
- Share the results within the European research community
- Confront experimental results to state-of-the-art models and simulation tools

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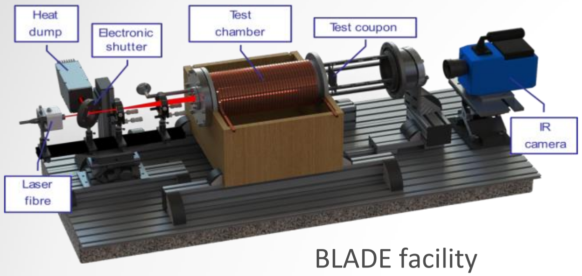
Work Package 7.1 Approach

Understanding and characterising the fire behaviour of primary structure composite materials



BLADE facility

Thermal properties
Pyrolysis behaviour

Chemical properties

METTLER TOLEDO TGA/DSC3+

Produce a comprehensive experimental database on a reference material (T700GC/M21)

FIRE facility

Fire behaviour

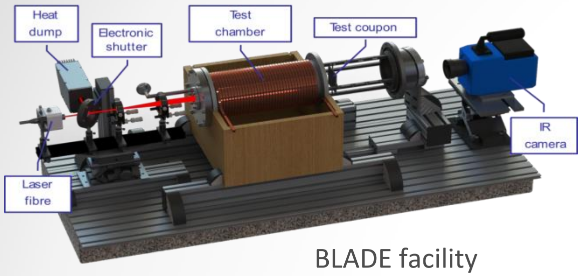
Mechanical and Thermo-mechanical behaviour

DMA testing device

Numerical simulation tools

Work Package 7.1 Approach

Understanding and characterising the fire behaviour of primary structure composite materials



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Methodology of investigation

Independent experiments to isolate a single (set of) parameter(s)

Required input parameters for pyrolysis model

Parameter	Method	Reaction	Species	Temperature	Decomposition state	Fibres orientation
Arrhenius coefficients	TGA	✓				
Heat of reaction	DSC	✓				
Stoichiometric coefficients	TGA	✓				
Permeability tensor	X-ray µtomography				✓	✓
Gas properties	Gas chromotography Mass spectrometry	✓	✓	✓		
Density	Hydrostatic balance	✓			✓	
Mass fractions, volume fractions, partial densities	Homogenisation X-ray µtomography		✓		✓	
Specific heat	DSC / $BLADE^{ONERA}$		✓	✓	✓	
Thermal conductivity tensor	LFM / $BLADE^{ONERA}$		✓	✓	✓	✓

Method of identification and variable dependency of each input parameter

Methodology of investigation

Independent experiments to isolate a single (set of) parameter(s)

Thermo-chemical kinetics and energetics

METTLER TOLEDO TGA/DSC3+

TGA measurements $T = [25 - 1100\ °C]$ → Mass loss rate = fct(T, heating rate, atmosphere) → Arrhenius modelling of pyrolysis and oxidation reactions

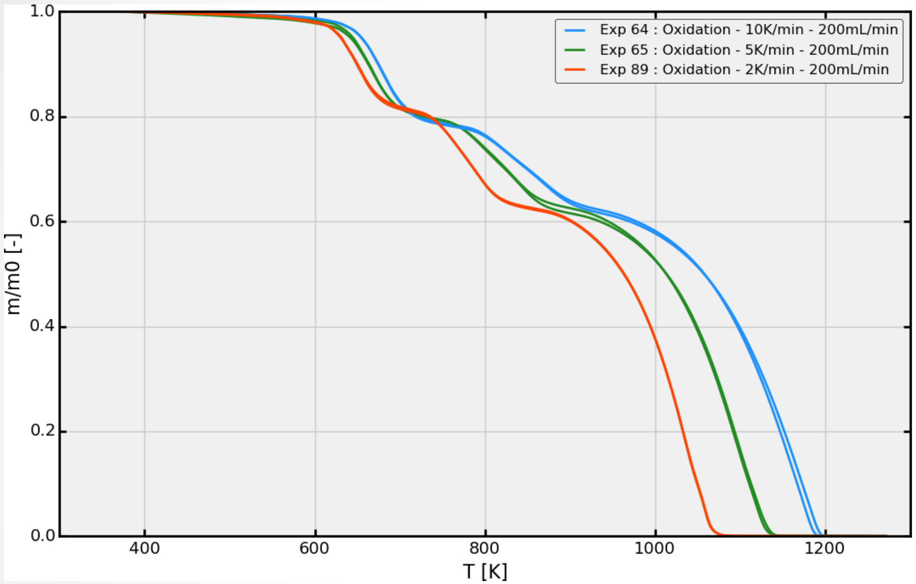
DSC measurements $T = [25 - 1100\ °C]$ → Heat flux = fct(T, heating rate, atmosphere) → Heat released or produced of each reaction

- Easy correlation between the mass loss rate and the heat of reaction
- Possibility to divide elementary chemical reactions occurring close to each other as the temperature increases
- Valuable input data for:
  - *chemical decomposition mechanism: number of reactions? reactants and products? onset temperatures?*
  - *Arrhenius reaction rate equations for pyrolysis models*
  - *Chemical source term in the energy equation for pyrolysis models*

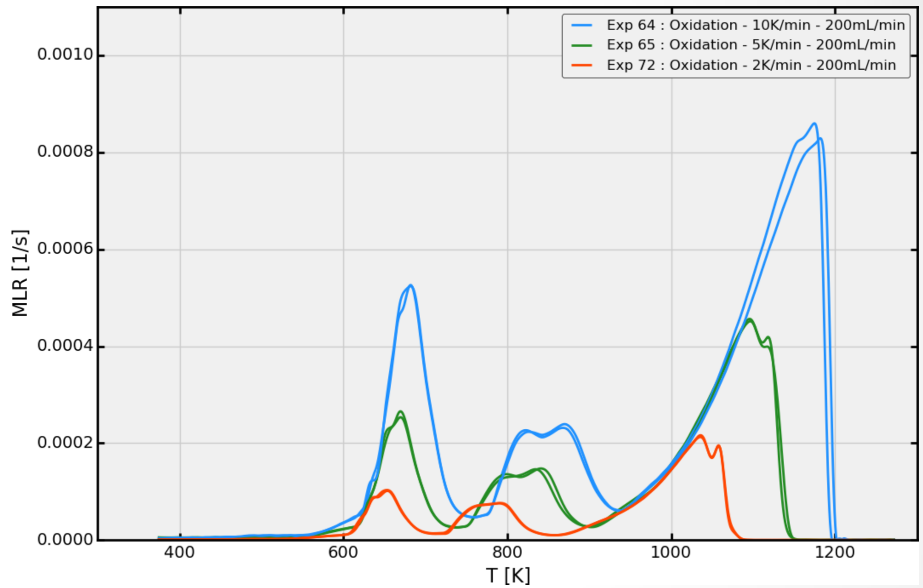
Thermo-chemical kinetics and energetics

Mass loss rate, Arrhenius coefficients, reaction enthalpies

Thermo Gravimetric Analysis (TGA) at different heating rates



Normalised mass loss as a function of temperature



Normalised mass loss rate as a function of temperature

- 3 different heating rate from $2\ K/min$ up to $10\ K/min$
- 2 repeatability measurements for each heating rate
- Air atmosphere
    - *pyrolysis AND oxidation reactions can occur*

Global decomposition mechanism

Resin pyrolysis: $resin\ \rightarrow \nu\ char + (1-\nu)\ gas_{pyro}$

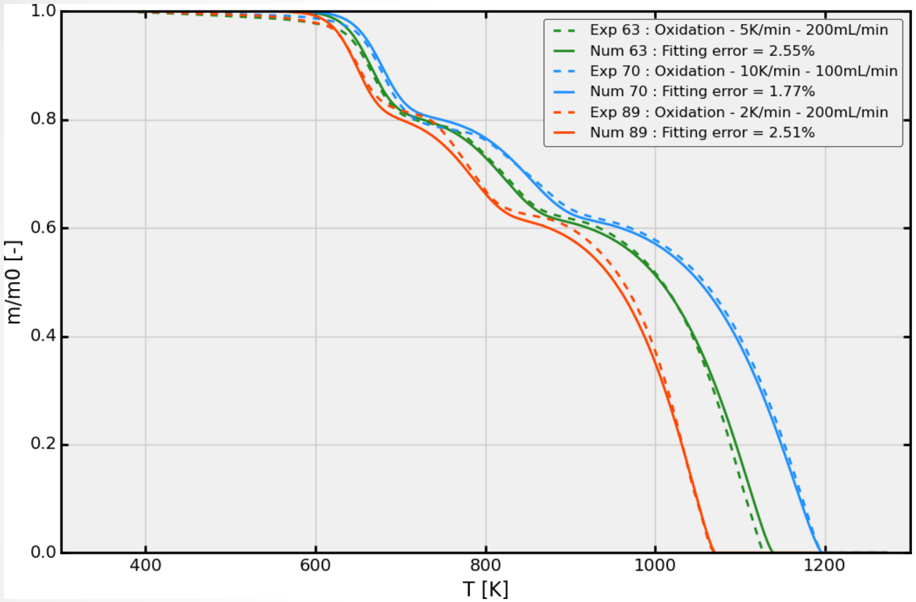
Char oxidation: $char\ +\ O_2\ \rightarrow Gas_{oxi}$

Fibres oxidation: $fibres\ +\ O_2\ \rightarrow Gas_{oxi}$

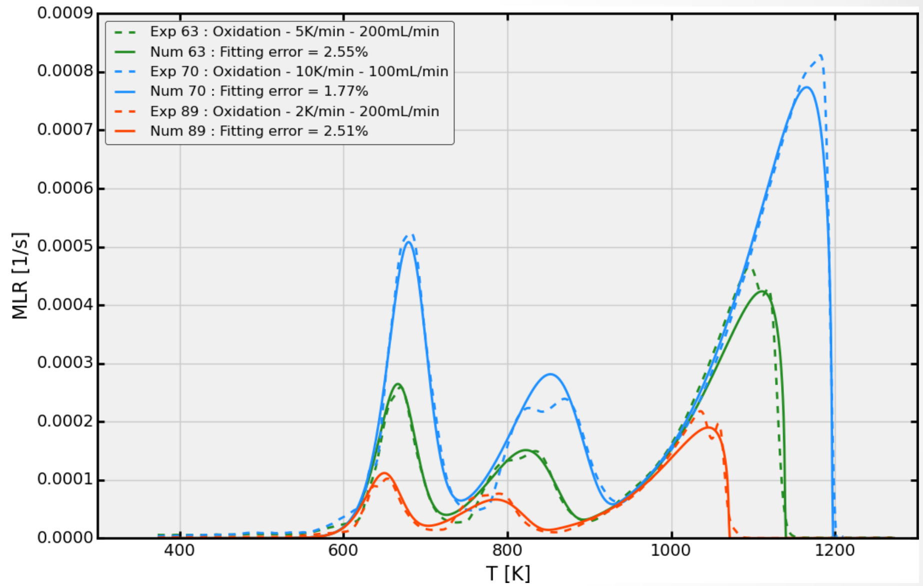
Thermo-chemical kinetics and energetics

Mass loss rate, Arrhenius coefficients, reaction enthalpies

Global kinetics models using Arrhenius reaction rate equations



Normalised mass loss as a function of temperature



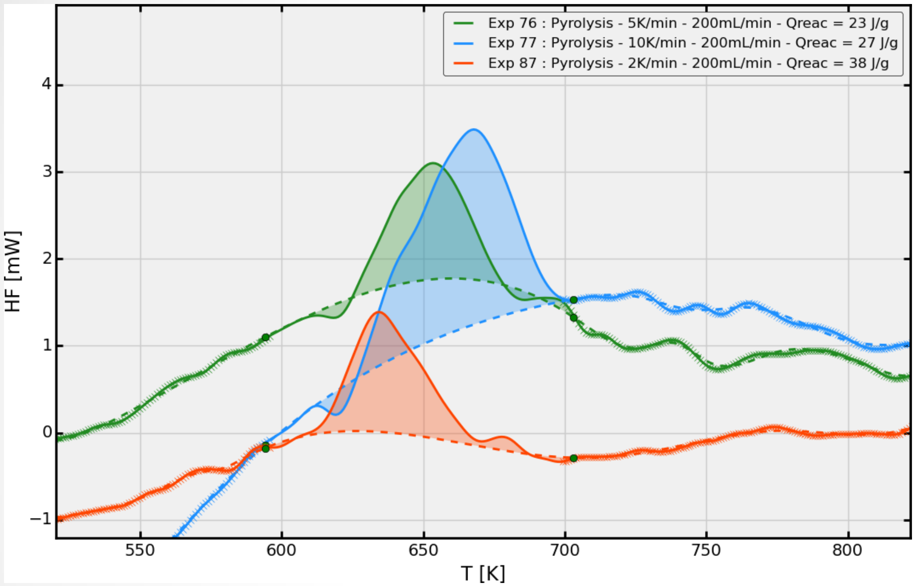
Normalised mass loss rate as a function of temperature

- 3-stage-model used to fit the 3 global reactions
- Good agreement whatever the heating rate
- 3-stage-model could be improved
  - *pre-oxidation before 1st pyrolysis reaction*
  - *char and fibre oxidation may be composed of 2 sub-reactions*

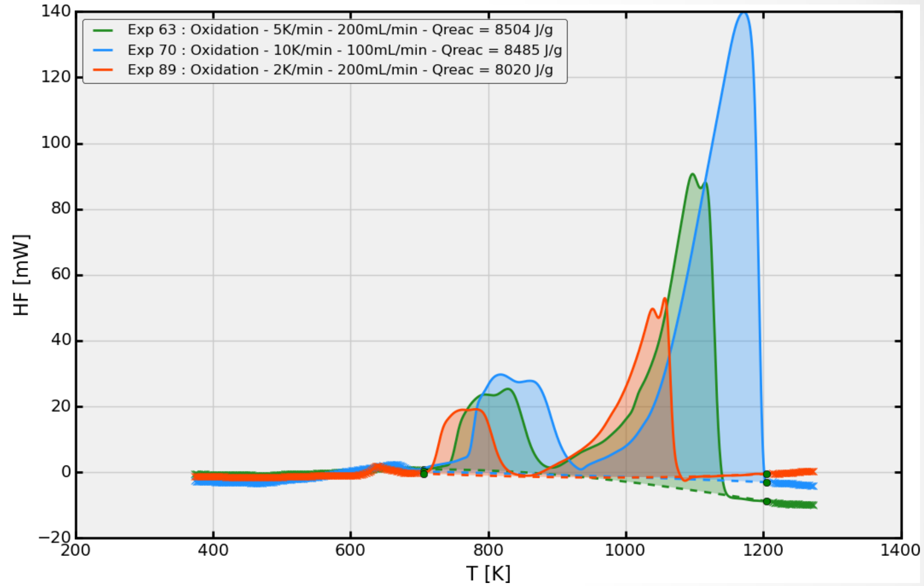
Thermo-chemical kinetics and energetics

Mass loss rate, Arrhenius coefficients, reaction enthalpies

Differential Scanning Calorimetry (DSC)



Pyrolysis enthalpy integration from DSC measurements



Oxidation enthalpy integration from DSC measurements

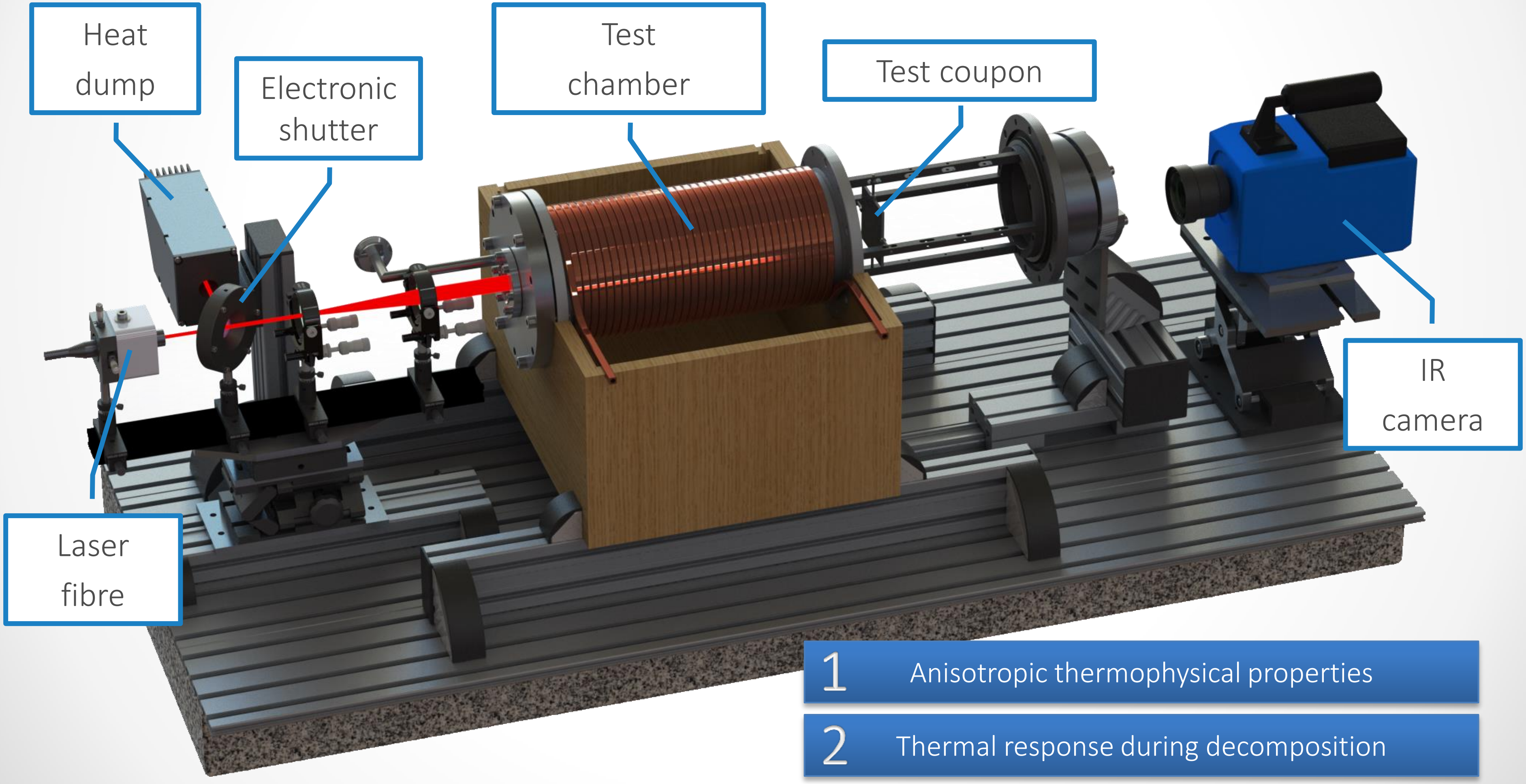
- Exothermal pyrolysis is measured with very low reaction enthalpy (and low accuracy as a consequence)
- Good agreement whatever the heating rate for the oxidations enthalpy
- Confirmation of the oxidation sub-reactions on the heat flux signal
  - *conventional DSC should be more accurate but not correlated with TGA measurements*

Methodology of investigation

Independent experiments to isolate a single (set of) parameter(s)

Anisotropic thermal behaviour analysis

BLADE facility



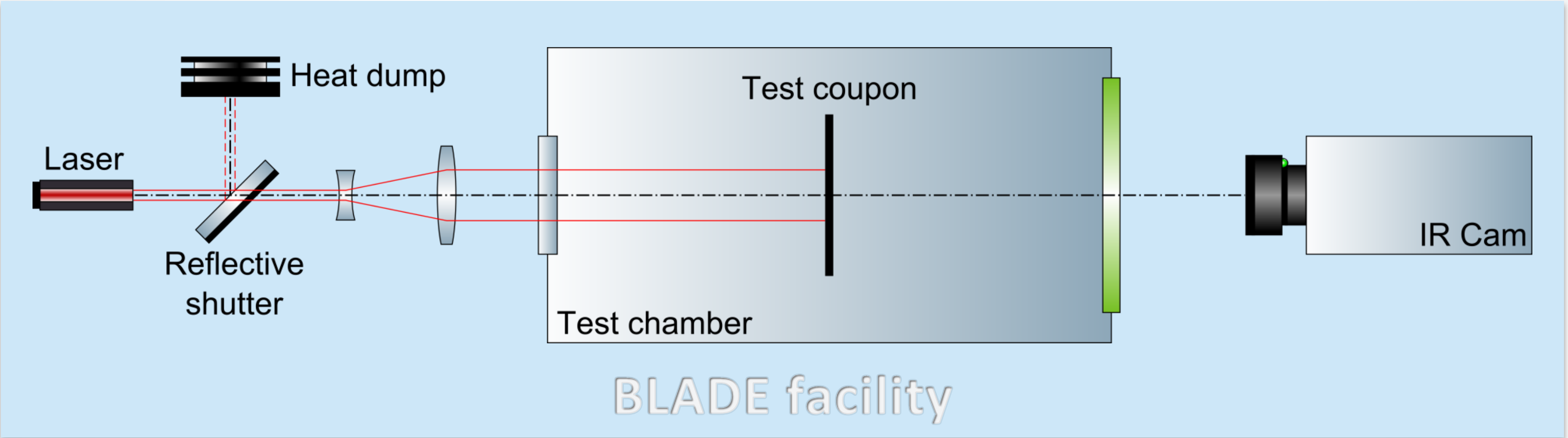
1 Anisotropic thermophysical properties

2 Thermal response during decomposition

Methodology of investigation

Independent experiments to isolate a single (set of) parameter(s)

Anisotropic thermal behaviour analysis



- Test coupon size: 80 x 80mm (16 plies = 4.16mm thick)
- Test chamber controlled in pressure and temperature
- 50W continuous IR laser Gaussian beam collimated to Ø21.8mm @ $1/e^2$
- Exposure time accurately controlled with a reflective electronic shutter
- Transient temperature maps measured on the back surface using IR thermography

1 Anisotropic thermophysical properties

- Laser: 5W
- Heating duration: 5s

2 Thermal response during decomposition

- Laser: 50W
- Heating duration: 300s

Anisotropic thermal behaviour

Thermal conductivity tensor and specific heat

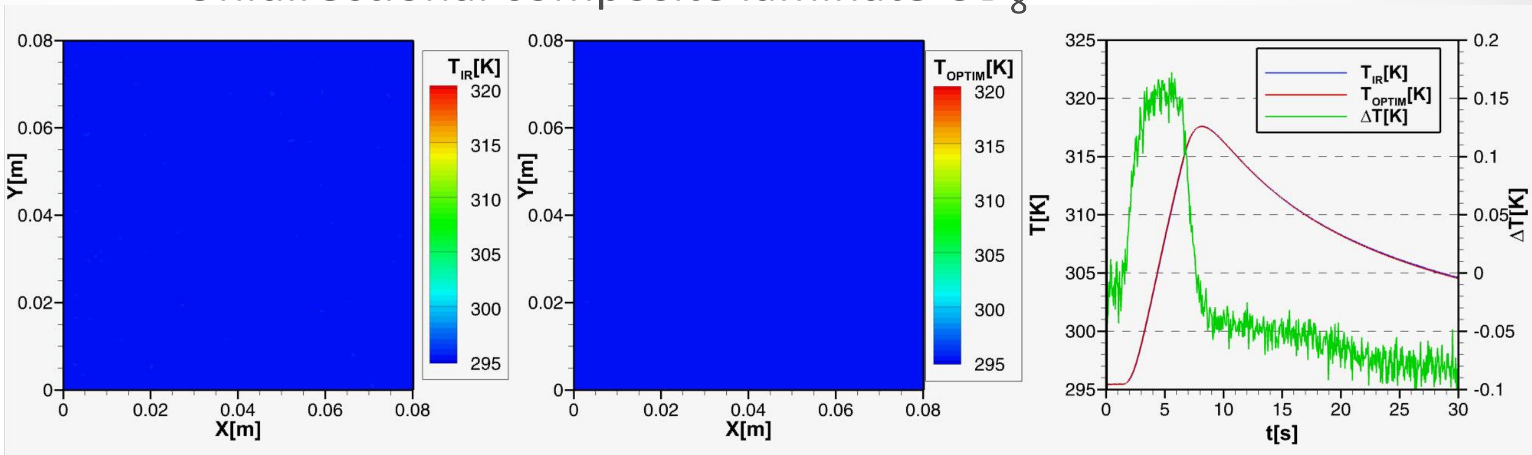
Initial

temperature

22°C

295K

Unidirectional composite laminate UD_8



Back surface IR measurement — *Optimal computation* — *Temperature evolution at the centre*

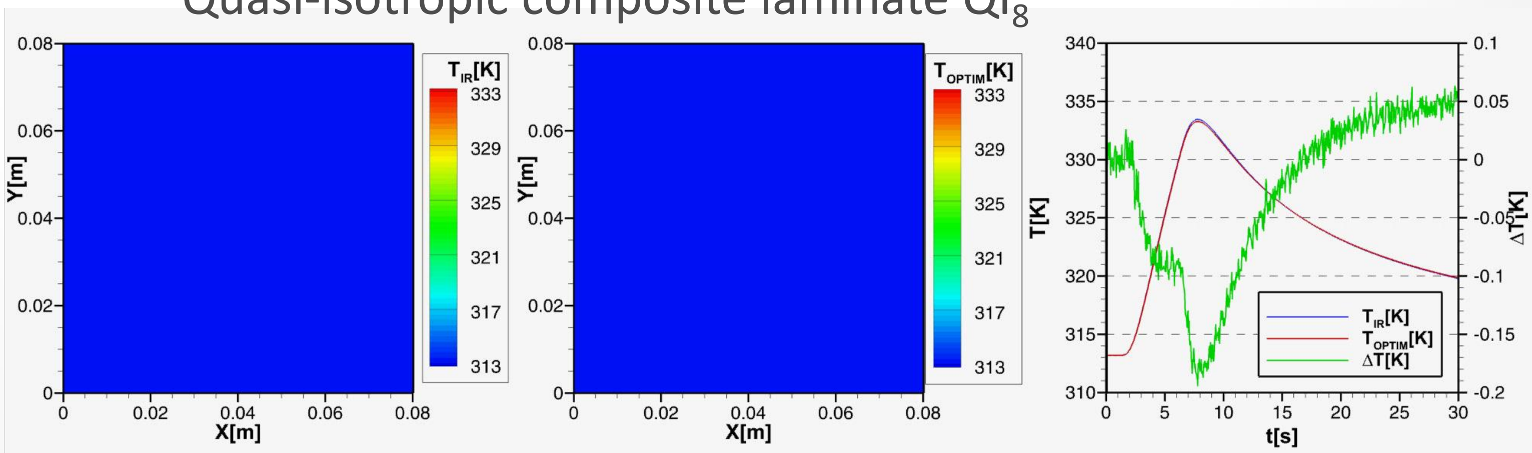
Initial

temperature

40°C

313K

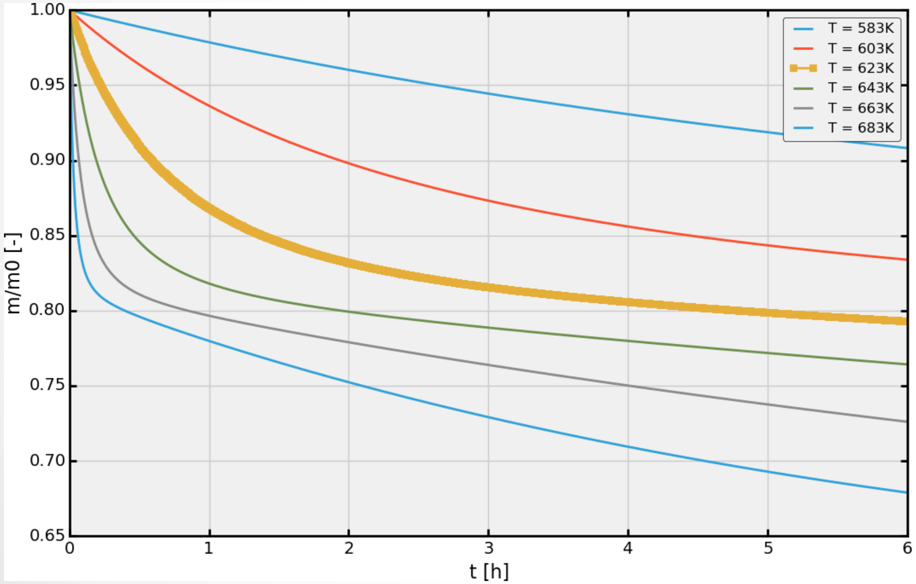
Quasi-isotropic composite laminate QI_8



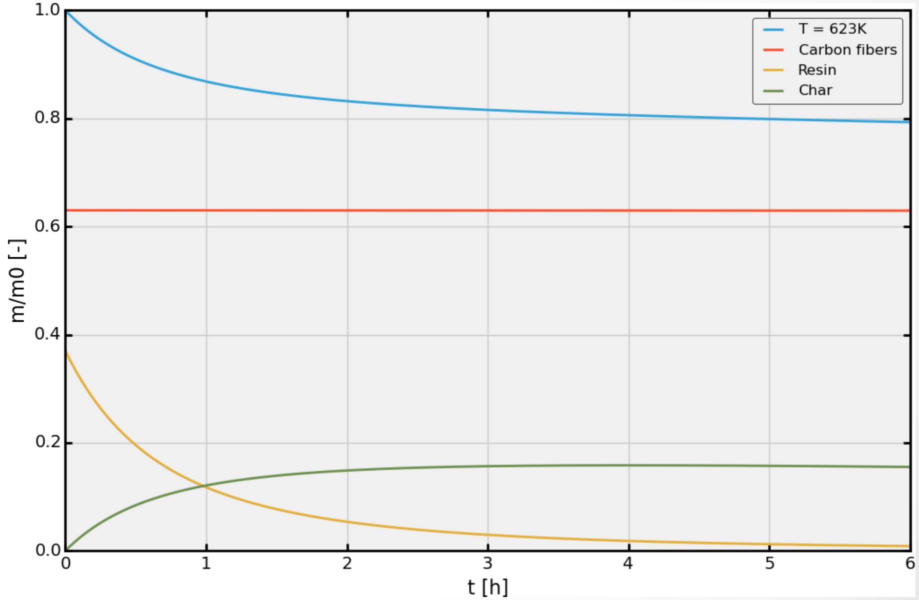
Back surface IR measurement — *Optimal computation* — *Temperature evolution at the centre*

Characterising the charred material properties

- Define experimental protocol to prepare charred sample materials to be tested in the BLADE facility
  - *from thermogravimetric analysis and Arrhenius kinetics*
  - *slow isothermal decomposition in a furnace for homogeneous decomposition within the material*



Isothermal mass loss computed from Arrhenius kinetics



Species mass fractions time evolution for $T = 623\ K = 350\ °C$

- Perform experimental measurements in the BLADE facility similar to the virgin material

Anisotropic thermal behaviour

Thermal response during laser-induced decomposition

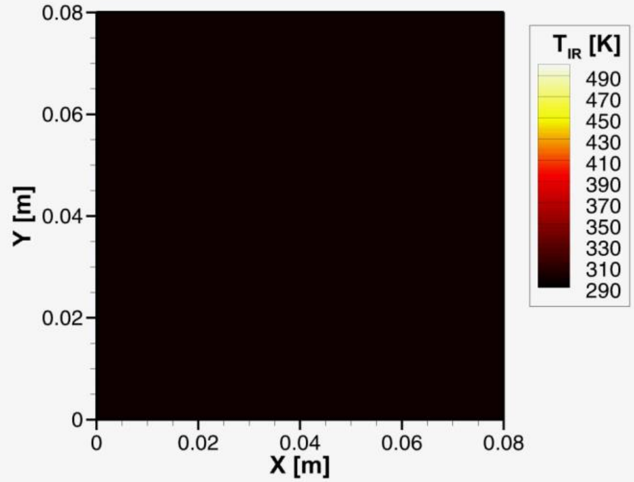
FUTURE SKY SAFETY

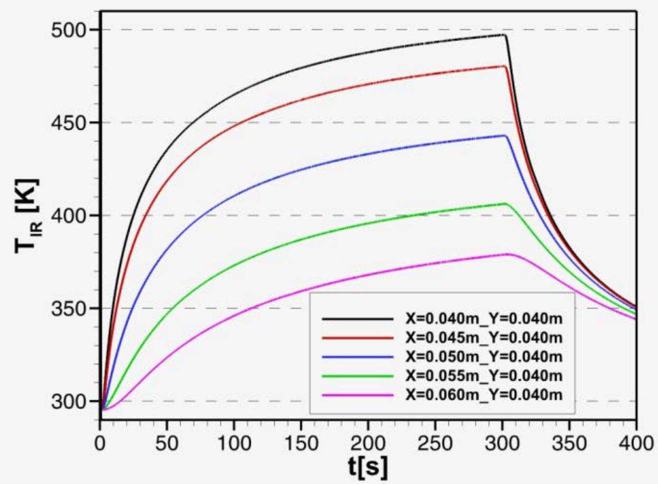
IR thermography measurements on the unexposed surface

T700GC/M21

[0/45/90/-45]s

$\Phi = 54\ kW/m^2$





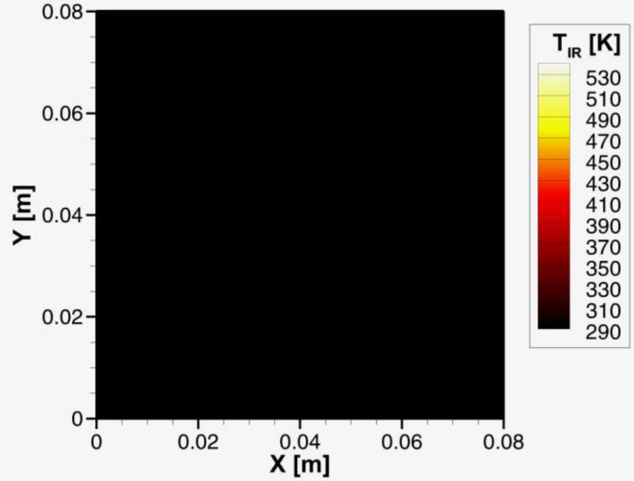
Back surface IR measurement

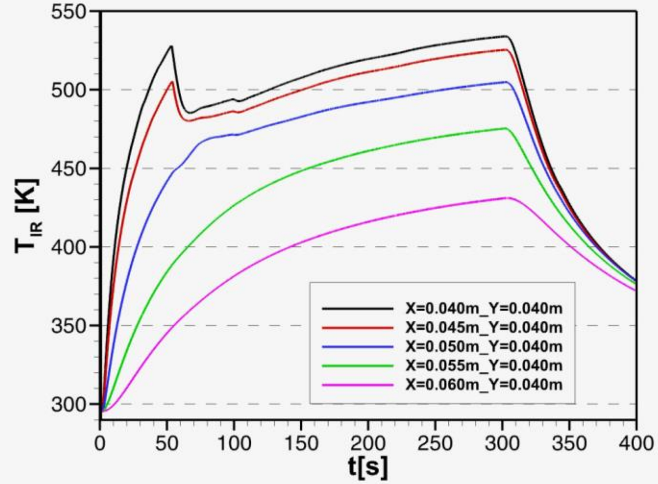
Temperature evolution at different locations from the centre

T700GC/M21

[0/45/90/-45]s

$\Phi = 100\ kW/m^2$





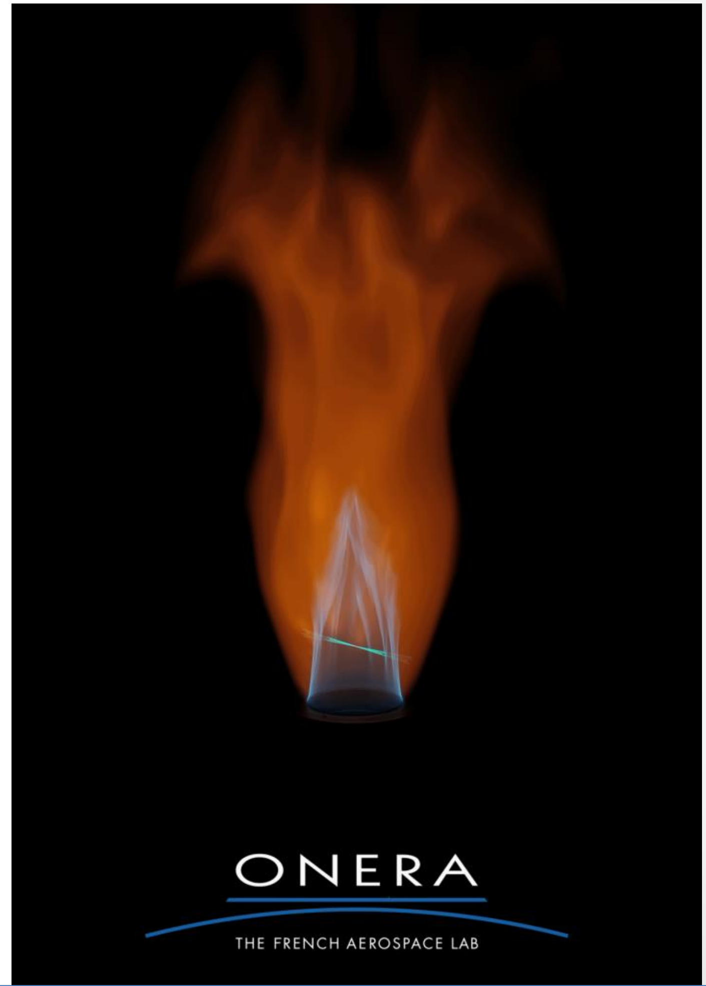
Anisotropic thermal behaviour

Thermal response during fire-induced decomposition

FIRE: Flame-wall Interaction Research Experiment

Anisotropic thermal response during fire decomposition

Interaction between fire and composite materials



Fire Dynamics measurements by LDV

Consortium

Stichting Nationaal Lucht- en Ruimtevaartlaboratorium
Deutsches Zentrum für Luft- und Raumfahrt
Office national d'études et de recherches aérospatiales
Centro para a Excelência e Inovação na Indústria Automóvel
Centro Italiano Ricerche Aerospaziali
Centre Suisse d'Electronique et Microtechnique SA
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http://www.futuresky-safety.eu

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