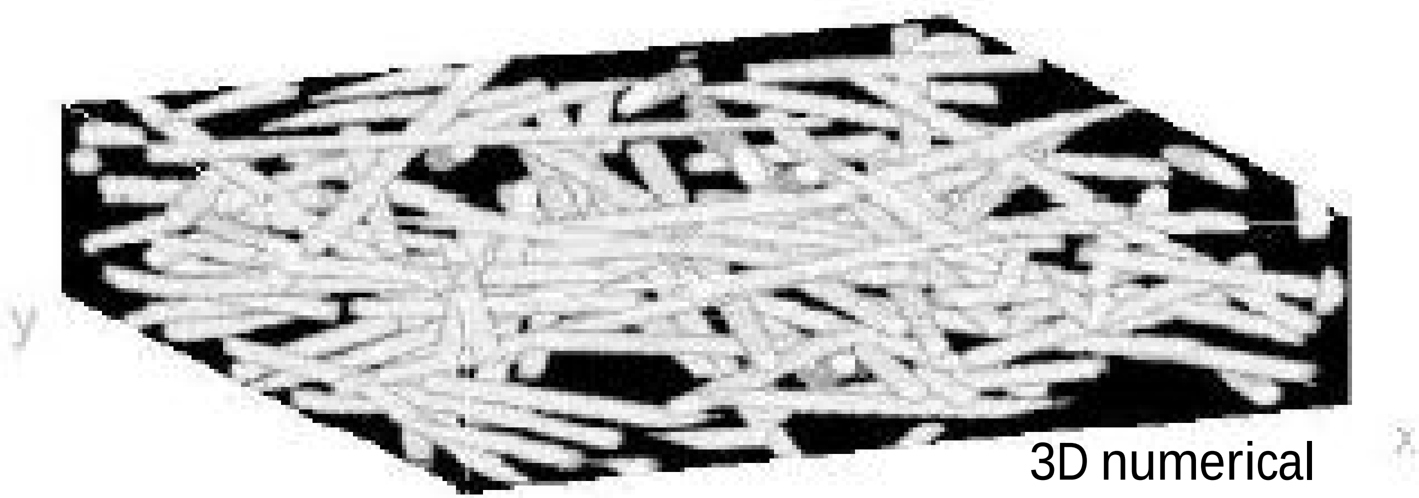
Presentation of the 2011 Ablation Test Case

Jean Lachaud*, Alexandre Martin#, Ioana Cozmuta[x], and Bernie Laub[+]

*UARC/Univ. of California Santa Cruz, Jean.Lachaud@nasa.gov
#University of Kentucky, Alexandre.Martin@uky.edu
[x] ERC Inc., Ioana.Cozmuta@nasa.gov
[+] NASA Ames Research Center, Bernard.Laub@nasa.gov



3D numerical reconstruction of TACOT

Session : *Ablation model/code inter-calibration*

4th AF/SNL/NASA Ablation Workshop – March 1-3, 2011, Albuquerque, NM

. Outline

1. Objectives
2. Test case definition
3. Material of the test case
4. Required Code Output

. Objectives

Calibration & Comparison

Three types of material-response codes have been identified in the community

Type 1: CMA-type codes (heat transfer, pyrolysis decomposition, simplified transport of the pyrolysis gases, equilibrium chemistry);
Type 2: CMA model augmented with an averaged momentum equation for the transport of the pyrolysis gases;
Type 3: Higher fidelity codes (possibly including finite-rate chemistry, multi-component diffusion, in-depth ablation/cocking, etc).

A test case with two objectives has been defined

1. **Inter-calibration** of codes of the same type (focus: numerical methods and data interpretation)

2. **Comparison** of codes of different types (focus: modeling approach).

. 2011 Test case

Open, Focused, Simple.

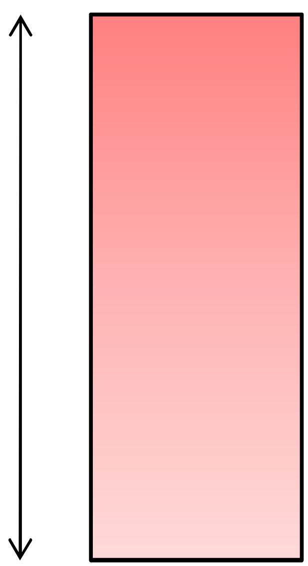
- ✓ **Open :** configuration and material unclassified
- ✓ **Focused :** comparison of the "in-depth physics and chemistry"
- ✓ **Simple :** 1D, no recession, simple boundary conditions (BC), simple environment.

Top B.C.

$T_{surface}$ = f(time)

$p_{surface}$ = 1 atm

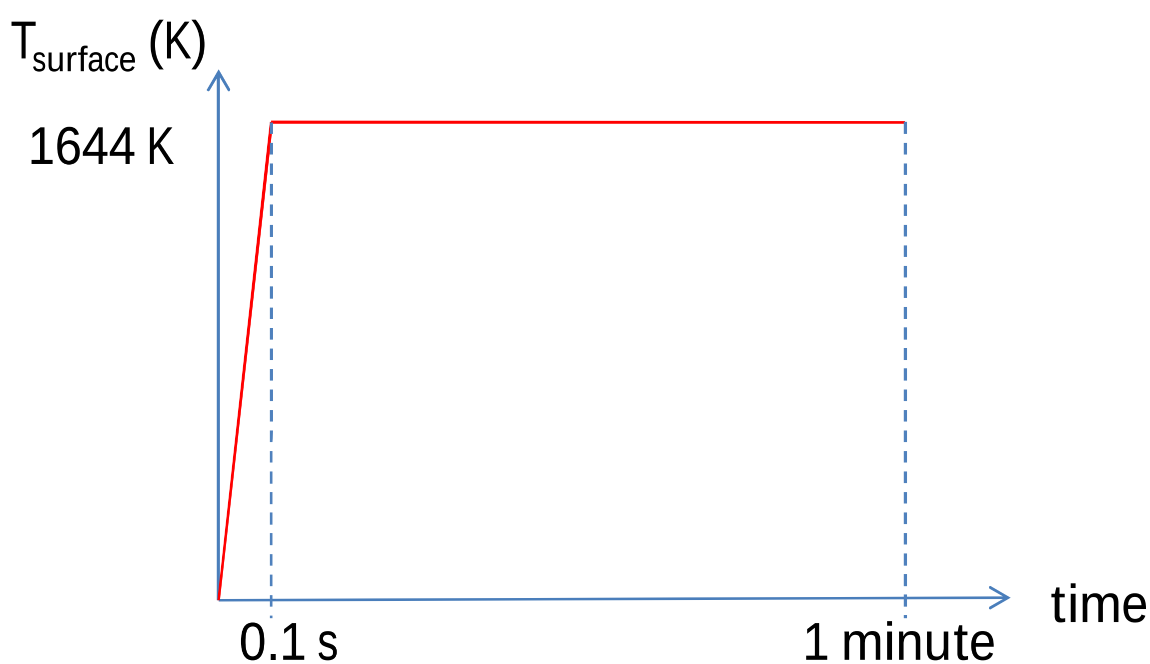
h = ??



Bottom B.C.

Adiabatic, impermeable

<u>Initial conditions</u>: T=298 K, p= 1 atm, initial gas composition left open (air, Ar, pyrolysis gas, …)



. Choice of a material

Open data, type 1-2-3 inputs, material of current interest.

Requirements

1- Open literature input data for codes of type 1, 2, and 3.

2- Thermo-chemical properties similar to current low-density ablators (for meaningful model comparison).

→ **NOT AVAILABLE**

Solution : develop a set of data, i.e. a theoretical material

3- Architecture and composition simple enough to allow for physics-based models development with reasonable time investment (for codes of type 2-3)

4- Realist architecture: fabrication for a reasonable cost if we decide to start testing the material and pushing the exercise further.

5- Fair mechanical properties for ground testing but insufficient mechanical properties for atmospheric entry. Should allow open access to test data.

. TACOT

Theoretical Ablative Composite for Open Testing

Elemental composition

o Reinforcement: ex-cellulose carbon fibers, heat treated at 2000 K, density 1600 kg/m^3, length: 1mm, diameter: 10 microns.

o Matrix: ex-novolac/formaldehyde polymer, virgin density 1200 kg/m^3

Microstructure

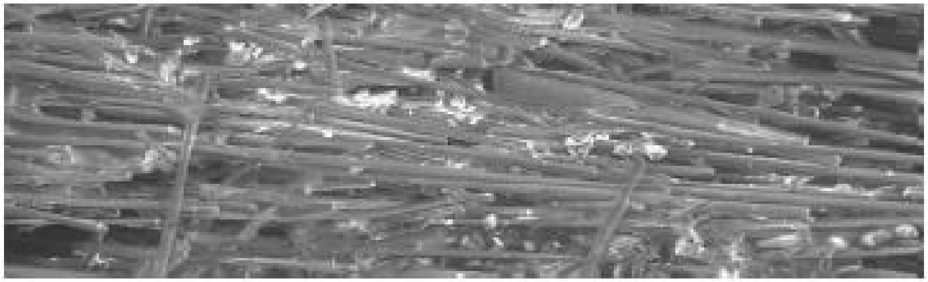
o Random fiber distribution and orientation, volume fraction: 10 %

o Fiber-coating matrix (homogeneous thin layer around the fibers), volume fraction: 10 %

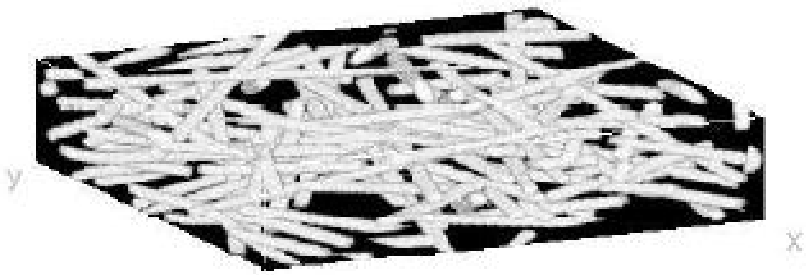
o Initial porosity: 80 %

Illustration of a quasi-random chopped-fiber structure

AQ60, EADS Astrium - fiberglass/phenolic (Huygens TPS, Titan 2005)



Scanning Electron Microscopy (SEM) image



3D numerical reconstruction

. **TACOT**

Tabulated properties provided in the spreadsheet (1/2)

Thermal properties of the solid [needed for **type 1** – **type 2** – **type 3**]

o conductivity, heat capacity

borrowed: *Performance of a Low Density Ablative Heat Shield Materi*al; Covington et al., JOURNAL OF SPACECRAFT AND ROCKETS, Vol. 45, No. 4, July–August 2008.

o char formation enthalpy at 298K = 0 J/kg [hyp. C(gr), cf. *CEA thermo-chemical tables*]

o virgin phenolic formation enthalpy at 298 K = -2e6 J/kg [average and rounding of literature data]

Mass transport properties [needed for **type 2** and **type 3** codes]

Hypothesis: the matrix losses 50% of its mass and 50% of its volume during pyrolysis, i.e. shrinkage without intrinsic change in density

❑ **Type 2** and **type 3**:

o porosity (virgin: 0.8; char: 0.85)

o permeability (virgin: 1.60e-11 m2; char: 2.00E-11 m2) – estimated by DNS.

❑ **Type 3 :**

o tortuosity (virgin: 1.2; char: 1.1) – estimated by DNS.

Tabulated properties provided in the spreadsheet (2/2)

Pyrolysis model

o Decomposition kinetics [needed for type 1 – type 2 – type 3]
Assumes the presence of two phases in the matrix (A and B) with two degradation reactions modeled by Arrhenius laws [Goldstein, 1965]

o Pyroloysis gas properties

- Average molar composition of the pyrolysis gases produced: **[type 3]**

species	CO2	CO	C6H6	C6H5OH	CH4	H2O	H2
mol fraction	0.016	0.058	0.005	0.089	0.100	0.234	0.499

[DECOMPOSITION CHARACTERISTICS OF A CHAR-FORMING PHENOLIC POLYMER USED FOR ABLATIVE COMPOSITES; George F. Sykes; NASA TN D 3810; 1967]

- corresponding elemental composition: C: 0.206; H=0.679; O=0.115 **[type 1&type 2]**
[computed from above molar composition]

- thermo-physical properties as a function of Temperature at Patm

Chemical-equilibrium assumption [output from CEA2 provided = f(T)]

o calorific capacity, enthalpy **[Type 1]**

o mean molar mass, viscosity **[Type 2]**

Finite-rate chemistry [integrated in type 3 codes]

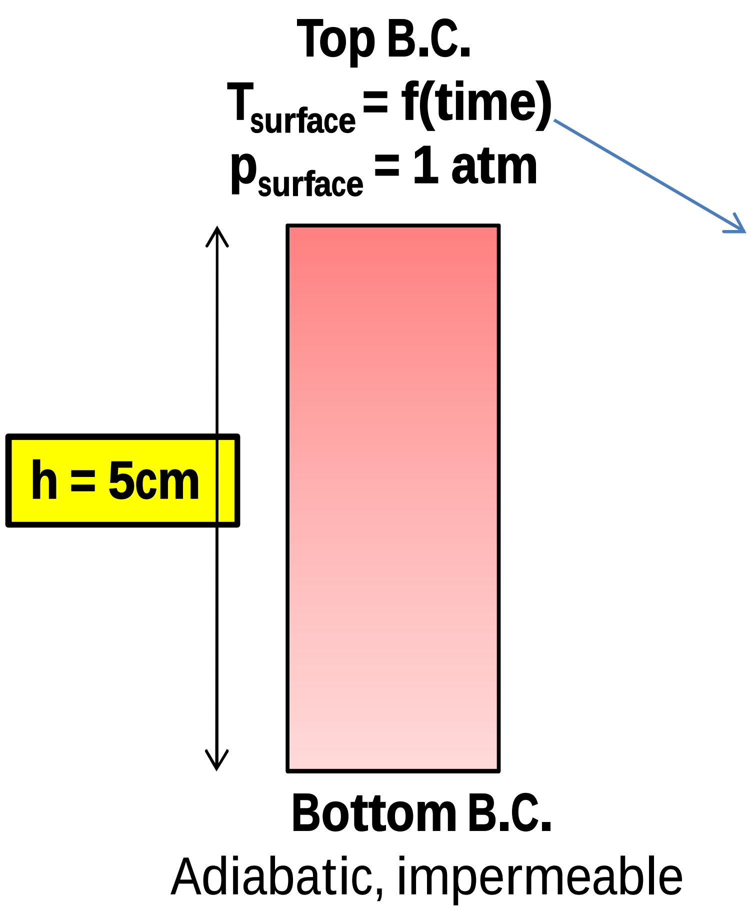
o mechanism (reactions, rates) [April69]

o calorific capacity, enthalpy, mean molar mass, viscosity, diffusion coefficients [inferred from composition given by the code = f(t, x)]

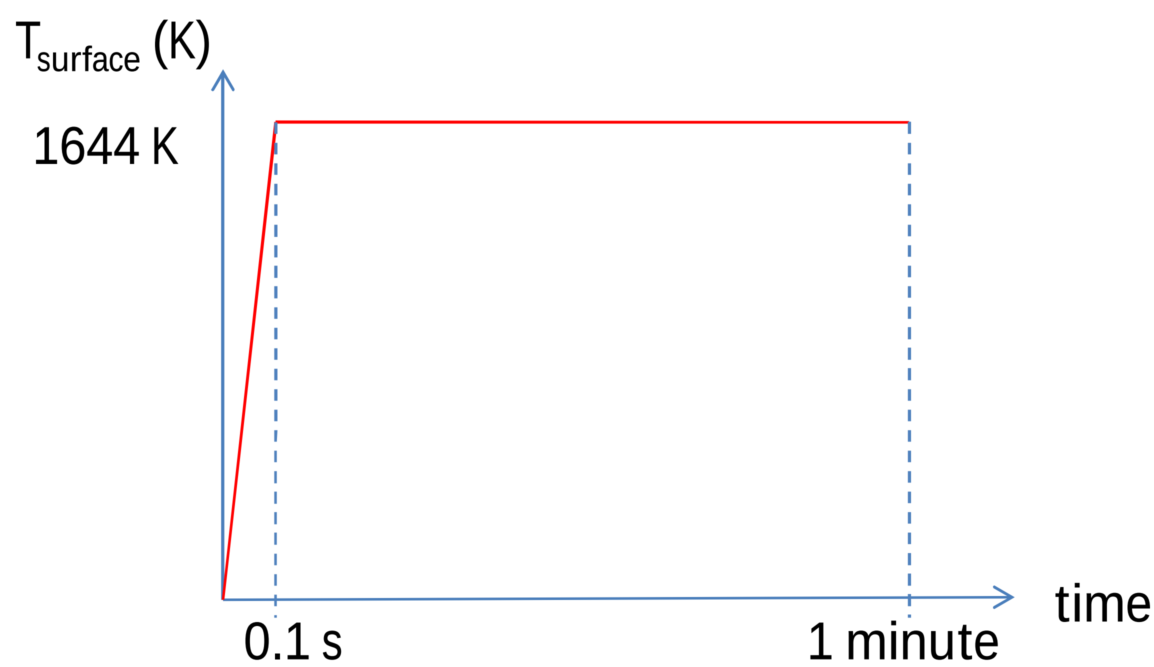
. 2011 Test case

Open, Focused, Simple.

- ✓ **Open :** configuration and material unclassified
- ✓ **Focused :** comparison of the "in-depth physics and chemistry"
- ✓ **Simple :** 1D, no recession, simple boundary conditions (BC), simple environment.

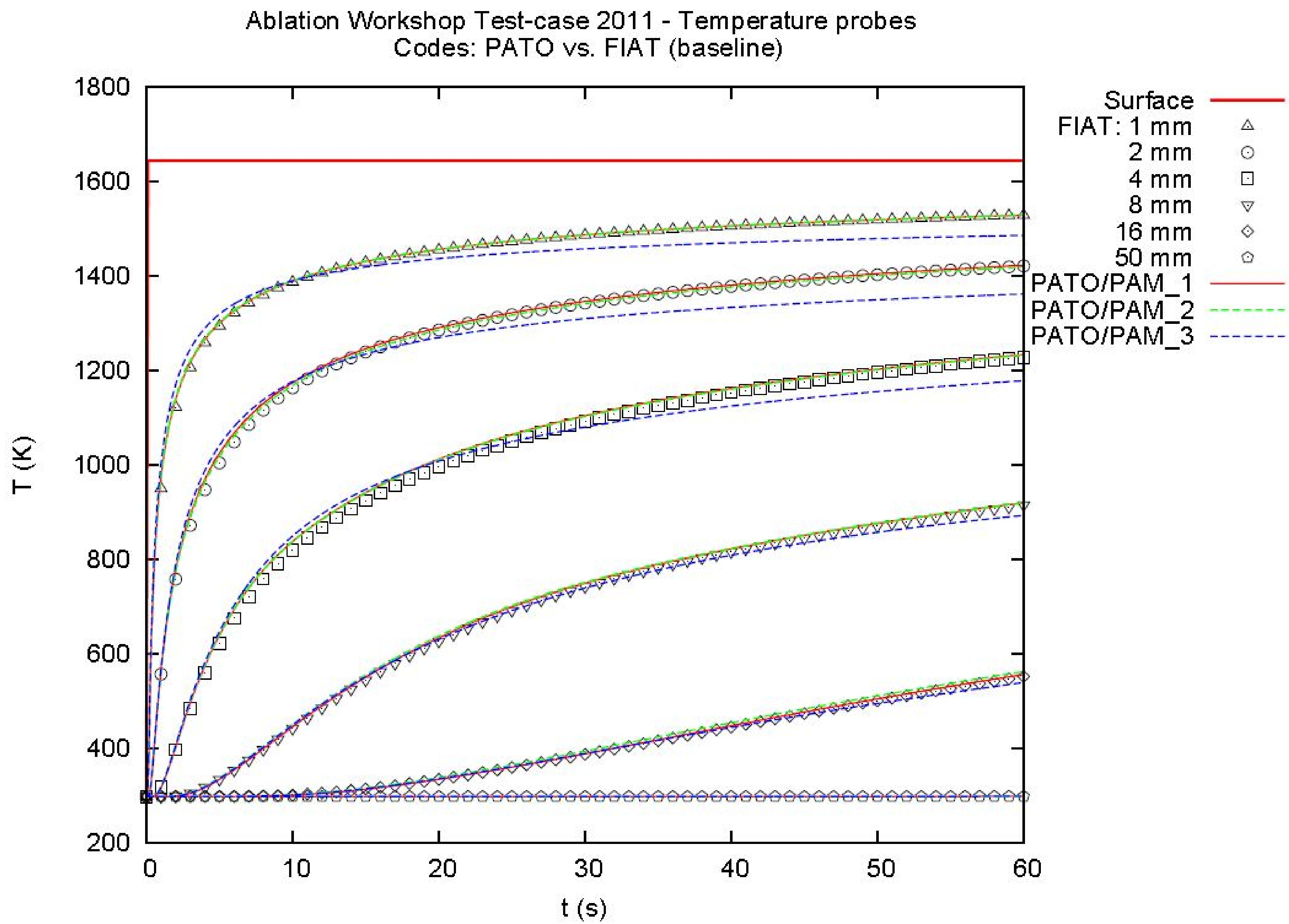


Initial conditions: T=298 K, p= 1 atm, initial gas composition left open (air, Ar, pyrolysis gas, …)



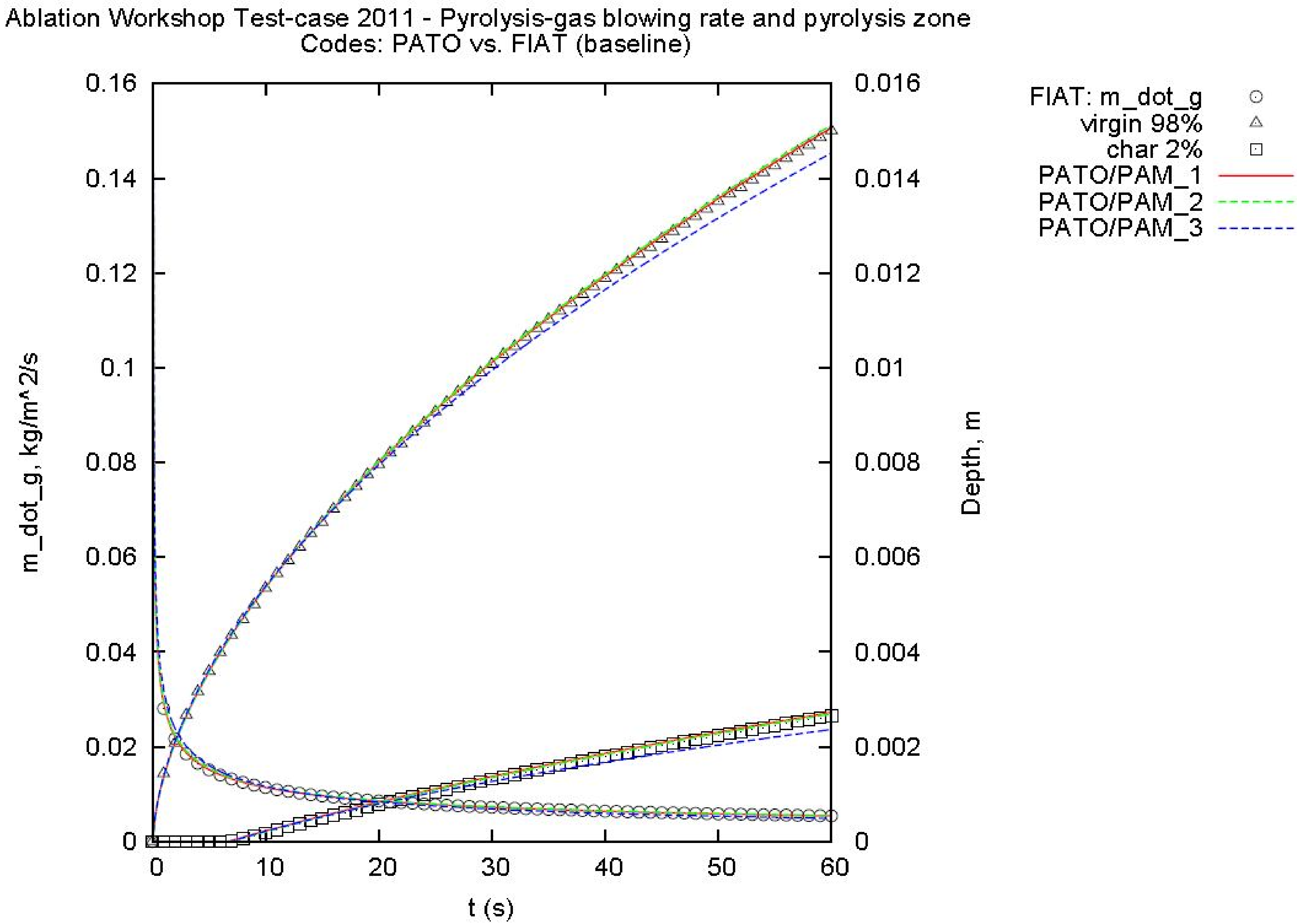
. Required code output

Temperature probes – excel file and plot against FIAT (baseline)



. Required code output

Pyrolysis data – excel file and plot against FIAT (baseline)



. Overview of the session..

1. FIAT baseline results [10 minutes]
2. Oral presentation of the results [5 minutes / participant]
3. Statistically analysis of the results by the
   Thermal Performance Data Base (TPDB) team [20 minutes]
4. Break around the posters (more details on the codes)
5. Discussion of Next Year test case [20 minutes]
6. Discussion of future experimental testing [40 minutes]