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TITLE: Test Case RCM-2. Mascotte Single Injector -10 Bar-

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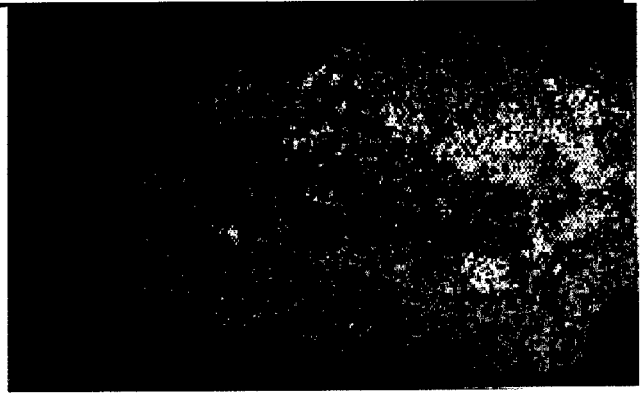
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*2nd International
Workshop*

***ROCKET
COMBUSTION
MODELING***



TEST CASE RCM-2
Mascotte single injector
- 10 bar -

March 25 – 27, 2001
DLR, Lampoldshausen

French-German Research on Liquid Rocket Combustion

I- GENERAL PRESENTATION

The MASCOTTE cryogenic combustion test facility was developed by ONERA to study fundamental processes which are involved in the combustion of cryogenic propellants, namely liquid oxygen (LOX) and gaseous hydrogen (GH2). Three versions of this test facility have been built since the project was started in 1991. The first tests at atmospheric pressure were performed in January 1994, while pressures up to 10 bar were achieved in fall 1995. Test case RCM2 will consist of modeling the MASCOTTE combustor at a chamber pressure of 10 bar. The details for both the test facility geometry and the operating conditions required for the numerical simulations are listed below.

II- GEOMETRY

a) Test combustor

The MASCOTTE test combustor has a square section of 50 mm x 50 mm (Figure 1).

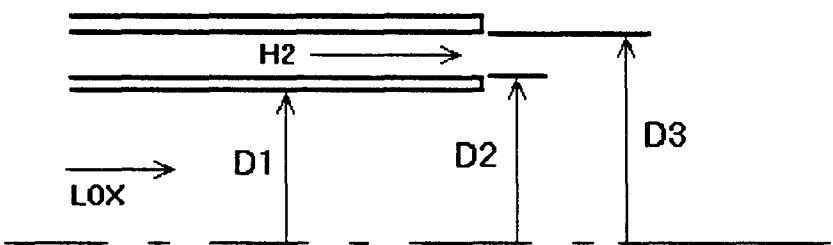
The injector head consists of a single coaxial injector element.

Combustion is initiated by using an H2/O2 igniter (O/F = 4) for roughly 2 seconds.

Figure 2 summarizes the geometry of the combustion chamber used for tests at 10 bar . The black dots indicate the locations of wall temperature transducers.

b) Injector

The MASCOTTE injector is a shear-coaxial element consisting of a core of liquid oxygen surrounded by a high speed flow of gaseous hydrogen to provide good atomization properties.



The dimensions of the injector are listed below.

	D1	D2	D3
DIAMETER	5.0 mm	5.6 mm	12.0 mm

Figure 3 shows the actual injector head geometry. However, computations may be performed with the above simplified geometry.

III- TEST OPERATING CONDITIONS

a) Operating point

The operating point chosen for this test case is a 10 bar case which has been extensively investigated experimentally. The operating conditions are defined in the following table:

PRESSURE	O/F	$\dot{m}$ (LOX)	$\dot{m}$ (H2)
10 bar	2.11	50 g/s	23.7 g/s

b) Propellants

Oxygen is injected under liquid conditions at 85 K, while hydrogen is injected under gaseous conditions at a temperature of approximately 287 K.

The physical properties of the propellants are summarized below:

Conditions	H2	O2
Pressure	1 MPa	1 MPa
Massflow	23.7 g/s	50 g/s
Temperature	287 K	85 K
Density	0.84 kg/m ³	1170 kg/m ³
C _p	14300 J/kg/K	1690 J/kg/K
Velocity	319 m/s	2.18 m/s
Viscosity	8.6x10 ⁻⁶ kg/m/s	1.94x10 ⁻⁴ kg/m/s
Surface tension	-	1.44x10 ⁻² N/m

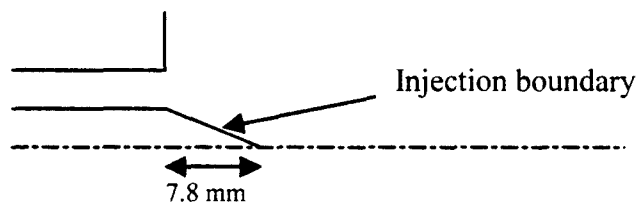
c) Turbulence

No data are yet available regarding the turbulence level at the injector exit. However, in order to make the comparison between various computations easier, we propose fixing the kinetic energy level at $\tau = 5 \%$ ($\tau^2 = 2/3 \text{ k} / U_{inj}^2$), where U_{inj} is the hydrogen injection velocity. In addition, we recommend deriving the value of turbulence dissipation ϵ at the inlet using a turbulence length of 4 mm as a representative scale of the GH2 injection ring.

IV- GENERAL DATA FOR COMPUTATIONS

The list below describes the methods which should be used for this simulation.

- Although the chamber has a square cross section, computations may be performed in an axisymmetrical cylindrical geometry with the same cross section as the actual chamber.
- Computational Domain
 - A computation of the entire chamber (i.e., including the nozzle) is preferred.
 - If there are problems, computations may be performed for a shorter chamber (without the nozzle) with the following characteristics:
 - Chamber length = 400 mm
 - Exit boundary condition: Constant pressure, $p = 10$ bar.
 - An adiabatic wall boundary condition may be used.
- Droplet Injection
 - Injection on conical solid boundary representing the liquid core: length of core - 7.8 mm (if not possible, droplets may be injected at the injector exit).



Flow visualizations and optical particle sizing have been achieved at 10 bar, which show that the atomization process is very complex and far from being complete (presence of ligaments). Nevertheless, some data could be obtained by means of a one-component PDPA (Phase Doppler Particle Analyzer) at 30 mm from the injector with an acceptable validation rate (47%). These measurements represent the droplet data at the closest location from the injector exit and can be used as inlet boundary condition. In order to fit these data with a Rosin-Rammler distribution, the PDPA distribution has been truncated at 250 μm by removing a small number of big droplets. This leads to the following distribution :

Rosin-Rammler distribution : $1 - v_c(D) = \exp[-(D/D_{RR})^N]$, where $v_c(D)$ is the cumulative volume undersize distribution, with $D_{RR} = 130$ micron, $N = 2.25$

Participants may choose from the following :

- the above distribution with the initial axial velocity of drops, $V_{inj} = 10$ m/s for all drops
- one single droplet size of $D_{32} = 82$ micron (which is the Sauter Mean Diameter of the above distribution), initial axial velocity of drops, $V_{inj} = 10$ m/s

- For the angle of injection, the following function derived from experimental results (Ref. 6) can be used: $\theta(x) = \arctan[R_i(1 - x/L_c)/(x + R_i/\tan\theta_i)]$

$$\text{where } \theta_i = \theta(0), \tan\theta_i = 0.68(U_{gas}/U_{liq} - 1)\sqrt{\rho_{gas}/\rho_{liq}},$$

$R_i = D_1/2$ (see section II-b), L_c is the length of the core, and x is the axial distance from the injector exit to the point of injection.

▪ Physical Models

- Combustion, turbulence, and evaporation models are not specified. Participants are free to choose these models as they see fit.

V- EXAMPLES OF AVAILABLE DATA

Each test run performed on MASCOTTE provides a set of standard temporal data, such as propellant mass flow rate, pressures, wall temperatures, and propellant temperature at the inlet.

In addition to classical measurements, several test campaigns have been carried out on MASCOTTE using non-intrusive or intrusive combustion diagnostics: laser-induced fluorescence of OH, fluorescence of gaseous oxygen, laser tomography, Phase Doppler Particle Analysis, measurement of liquid/gas mass fraction by a fiber optic device.

Figure 4 summarizes the locations where these various diagnostics have been applied.

Much of the test data obtained in the MASCOTTE test facility has been reported in the literature (see references). Figures 5-9 show some typical results (reference [5]).

An instantaneous OH emission image is presented in Figure 5, whereas Figure 6 presents the probability distribution of the flame location based on O2 LIF results.

Figure 7 shows typical OH images. Figure 8 shows the radial distribution of mean temperature, as well as the standard deviation, near the injector exit. Figure 9 displays the axial evolution of temperature at a fixed radial position for both 1 and 10 bar.

VI- REQUESTED RESULTS

The results of numerical computations must be presented in such a way that they can be compared to experimental data. For this reason, the participants are requested to provide the following information (to the extent possible depending on the output of the numerical code):

- Radial profiles of mean temperature and standard deviation at CARS measurement locations ($x/D_1 = 2; 10; 16; 20; 36; 40; 43; 50; 60$) (Figures 4 and 8). x represents the axial distance from the injector exit (see Figure 2), $D_1 = 5$ mm.
- Mean temperature as a function of distance from the injector exit at four radial locations ($y/D_1 = 1; 2; 3; 4$) (see Fig. 9).
- OH mass fraction contours in the near field of the injector (up to 150 mm downstream); see Fig. 7.

- Gaseous oxygen contours in the near field of the injector (up to 150 mm downstream). An example of the probability distribution of flame location is given for an 8 bar case in Figure 6.
- Axial profile of mean wall temperature (adiabatic wall temperature).

VII- REFERENCES

- [1] Habiballah. M, Vingert. L, Traineau. JC, Vuillermoz. P, "MASCOTTE : a test bench for cryogenic combustion research", IAF-96-S.2.03, *47th International Astronautical Congress*, (Beijing, China), October 7-10, 1996.
- [2] Bazile. R, Guerre. S and Stepowski. D, "Planar Laser Induced Fluorescence of Hot O₂ in MASCOTTE", *Second French-German Colloquium on Research on Liquid Rocket Propulsion*, (Aachen, Germany), 1996.
- [3] Herding. G, Snyder. R, Scoufflaire. P, Rolon. C and Candel. S, "Emission and Laser Induced Fluorescence Imaging of Cryogenic Propellant Combustion", *Conference on Propulsive Flows in Space Transportation Systems*, (Bordeaux, France), pp 1-14, 1995.
- [4] Brummund. U et al, Péalat. M et al and Candel. S et al "Laser Diagnostics for Cryogenic Propellant Combustion Studies", *Proceeding of the 2nd International Symposium on Liquid Rocket Propulsion* (Châtillon, France), 1995, pp. 19.1-19.22.
- [5] Candel. S, Herding. G, Snyder. R, Scoufflaire. P, Rolon. C, Vingert. L, Habiballah. M, Grish. F, Péalat. M, Bouchardy. P, Stepowski. D, Cessou. A, Colin. P, "Experimental investigation of shear-coaxial cryogenic jet flame", *Third International Symposium on Space Propulsion*, (Beijing, China), August 11-13, 1997.
- [6] Caré, I. Etude d'un injecteur coaxial assisté. Thèse de doctorat. Université de Rouen, 1990.

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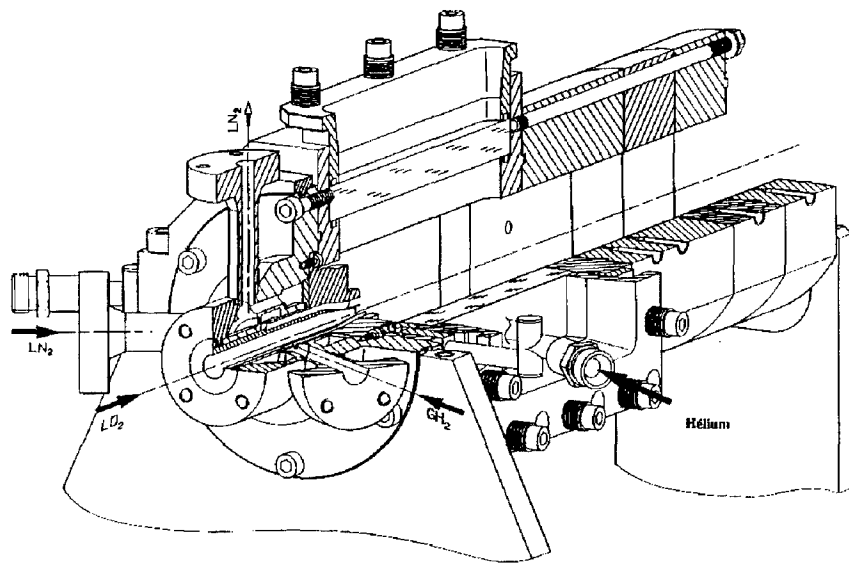


Figure 1: MASCOTTE Combustor

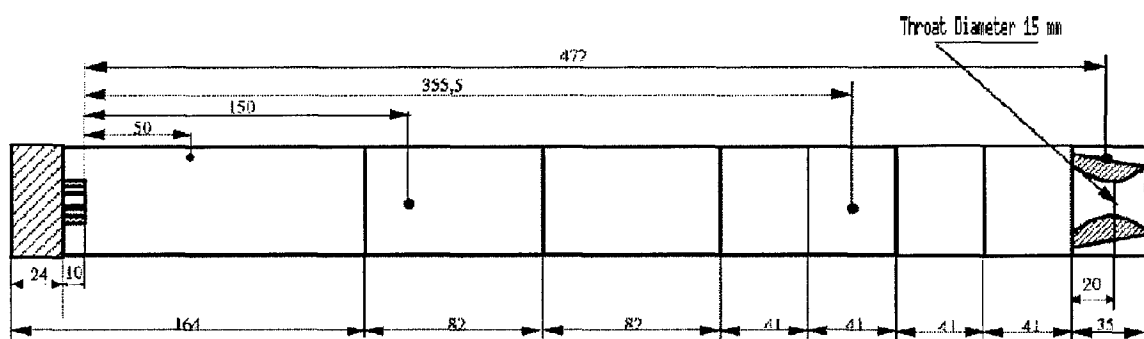


Figure 2: Combustor geometry (in mm) for the 10 bar case

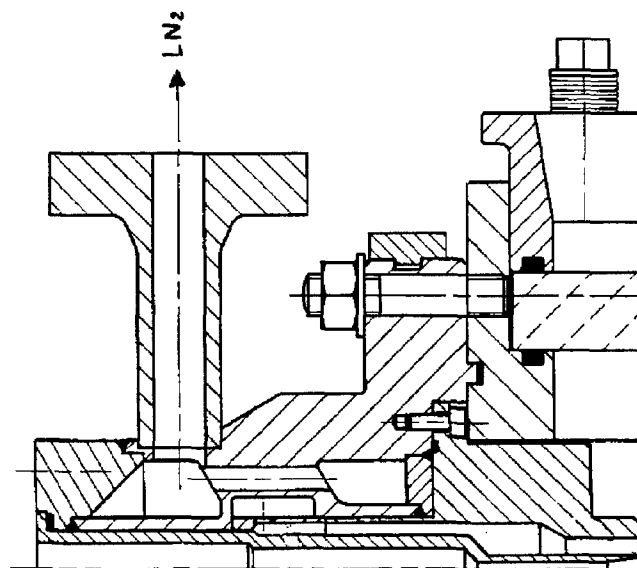


Figure 3: Injector head

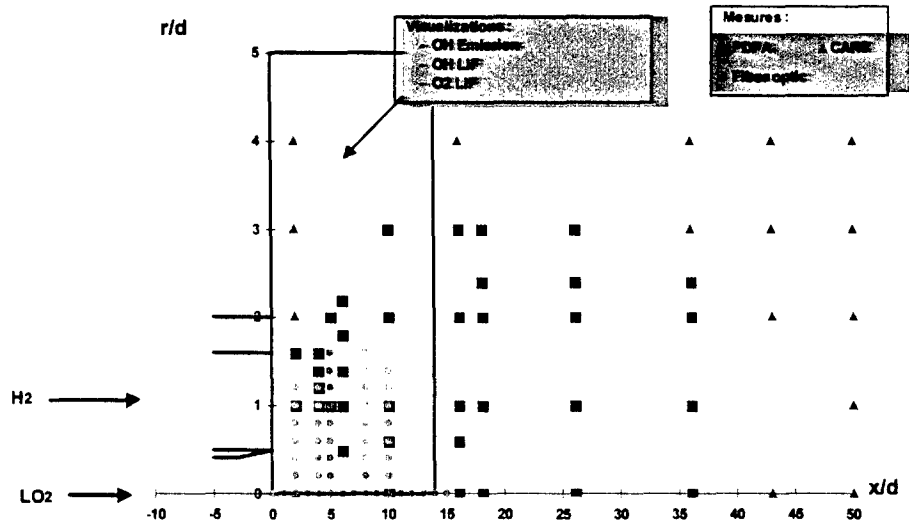


Figure 4: CARS, PDPA, and fiber optic measurement locations



Figure 5: Instantaneous LIF image of OH emission

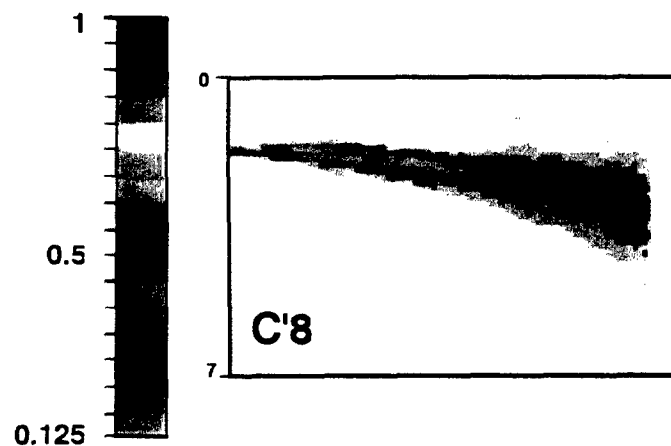


Figure 6: Probability distribution of flame location based on O_2 LIF results (8 bar)

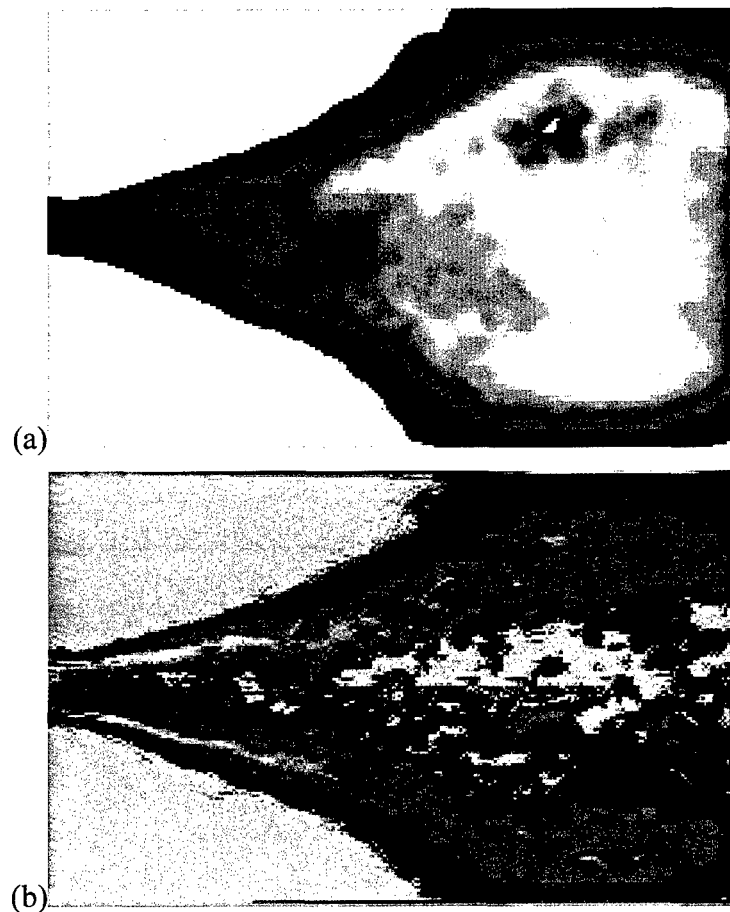


Fig. 7: Average emission image a) and Abel-transformed emission image b) for operating point A-10, $p = 10$ bar.

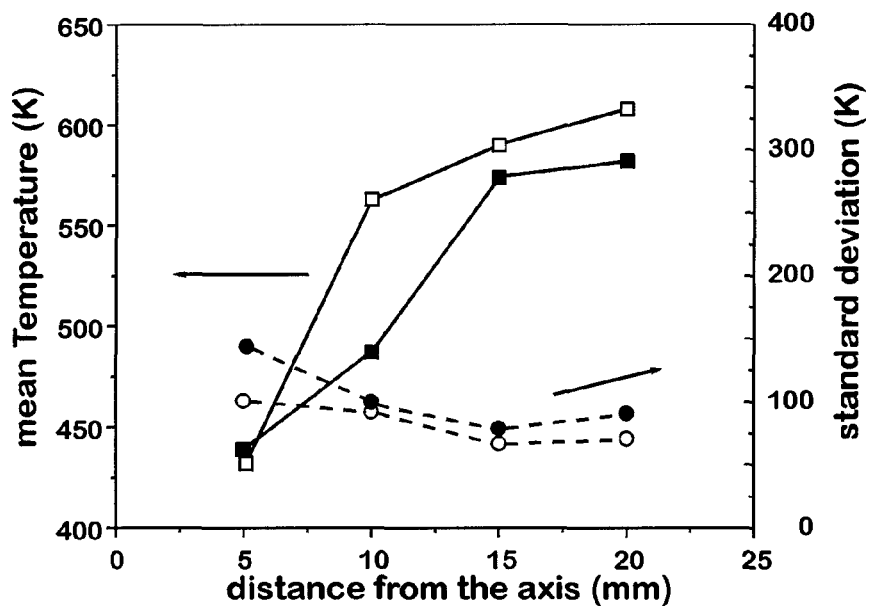


Fig 8: Mean temperature (squares) and standard deviation of temperature (circles) recorded as a function of distance from axis. The black symbols correspond to the operating conditions specified for this test case.

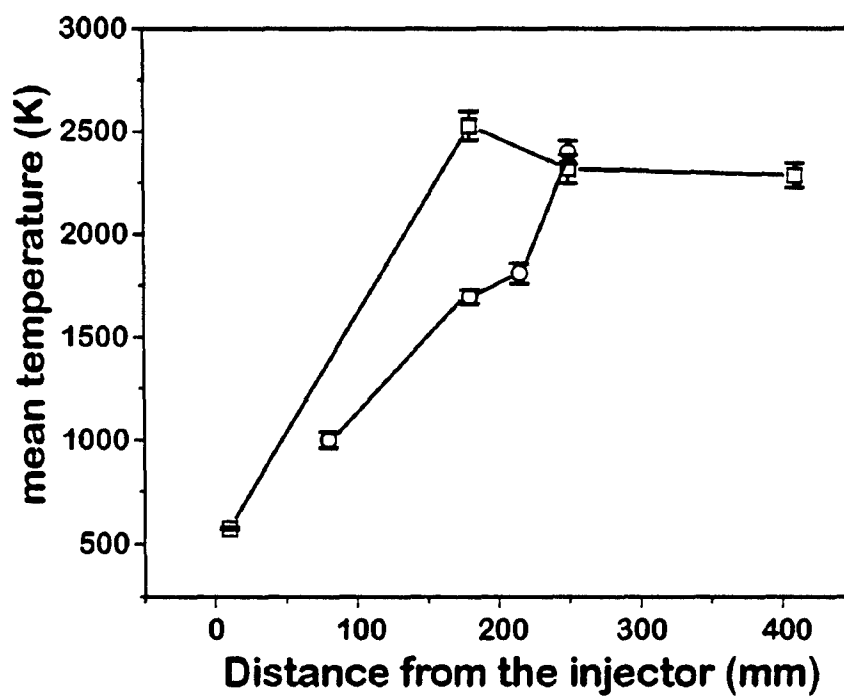


Fig 9: Mean temperature profiles recorded as a function of distance from the injector. The circles correspond to $p = 1$ bar and squares to $p = 10$ bar