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TITLE: Test Case RCM-1 Cryogenic Injection

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2nd International Workshop

ROCKET COMBUSTION MODELING

TEST CASE RCM-1

Cryogenic Injection

March 25 – 27, 2001
DLR, Lampoldshausen

French-German Research on Liquid Rocket Combustion

I- GENERAL PRESENTATION

The DLR Cryogenic Injector Facility M51 is used to study the jet break-up and mixing of cryogenic jets under high pressure conditions. The research is focused on the injection and mixing processes in cryogenic rocket engines with LOX (liquid oxygen) and GH2 (liquid hydrogen) as propellants (Ref. 1).

To study the fundamental processes of high pressure injection the propellants are replaced by non reacting simulation fluids (Ref 2 and 3). In the proposed test case LN2 (cold liquid nitrogen) is injected into a warm gaseous nitrogen environment. The LN2 jet is formed by a simple tube injector with an inner diameter of 2.2 mm.

The principal aim of the cold flow injection experiment is to understand the mixing process of a dense cryogenic jet in a light gas environment. The participant is free in the choice of the physical modeling. The idea is to have different approaches to finally find the most realistic simulation.

Shadow graph photography has been used for a preliminary flow field evaluation. Density profiles of the jet have been measured using two dimensional Raman scattering diagnostics.

II- GEOMETRY

a) Test chamber

The M51 test chamber consists of a cylindrical vessel with an inner diameter of 122 mm. The actual length of the vessel is 1000 mm (Figure 1). The test chamber has 4 windows for optical access. The injector is mounted in the center of the faceplate. The face plate has a ring slit of 5 mm.

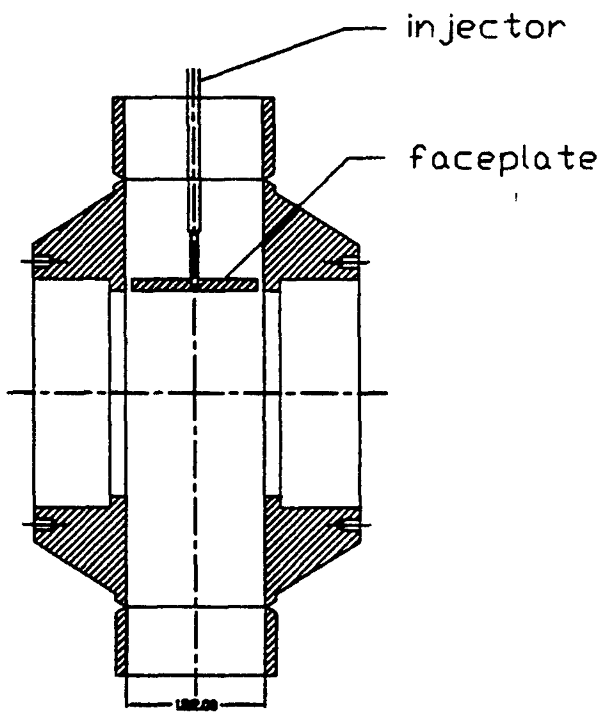

Figure 1: Test chamber with injector, faceplate and side walls (window section); the chamber inner diameter is 122 mm.

b) Injector

The tube injector is located in the center of the faceplate. The injector element's inner diameter is 2.2 mm. The tube length is 90.0 mm. As tube length to tube diameter ratio is more than 40 a fully developed turbulent velocity profile is to be expected at Position 2. The tube's inner walls are hydraulically smooth.

The injector manifold has an inner diameter of 6.0 mm.

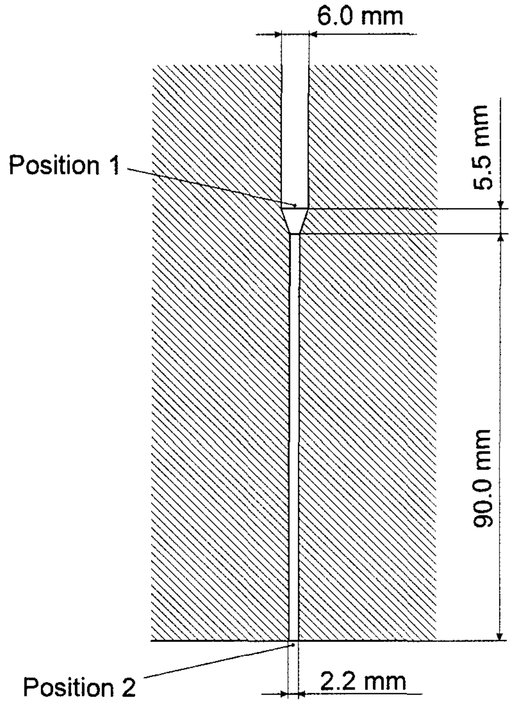

Figure 2: Injector baseline dimensions

III- TEST OPERATING CONDITIONS

a) Operating points

The operating points chosen for RCM-1-A and RCM-1-B are actual test data and listed in the following table (P1 = Position 1, see Fig. 2):

Test case	**RCM-1-A**	**RCM-1-B**
Chamber Pressure	3.97 MPa	5.98 MPa
Temperature P1	126.9 K	128.7 K
Density P1	457.5 kg/m^3	514.0 kg/m^3

Mass flow P1	0.00995 Kg/s	0.01069 kg/s
Velocity P1	0.769 m/s	0.736 m/s
Viscosity P1	28.8×10^{-6} kg/m/s	35.8×10^{-6} kg/m/s

The mass flows and velocities are specified for the injector manifold at Position 1. The injector outlet velocity is then around 5.6 m/s in both cases (Position 2, see Fig. 2).

b) Fluid data

Liquid nitrogen (LN2) is injected. The physical properties of the LN2 for Position 1 (P 1, inlet boundary) are summarized in the table.

IV- GENERAL DATA FOR COMPUTATIONS

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

Computational Domain:

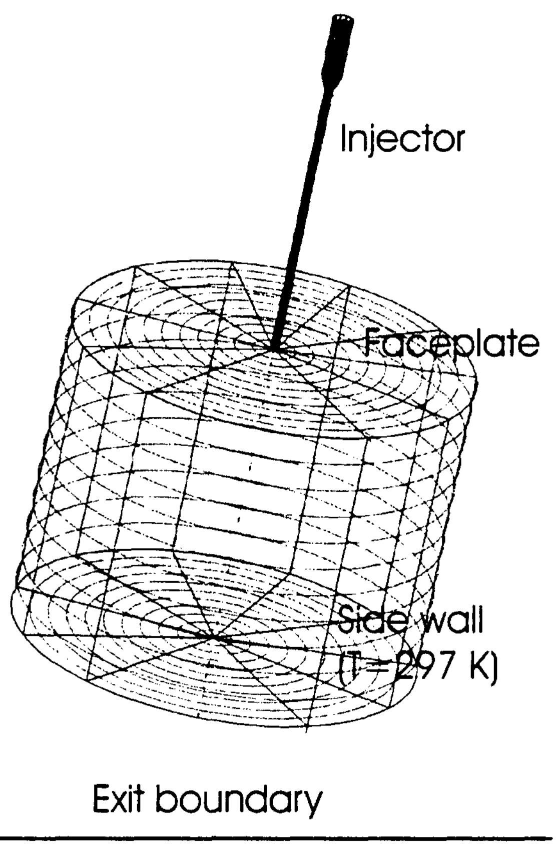

Figure 3: Principal sketch of computational domain (not in scale).

- The test chamber is a cylinder with an inner diameter of 122 mm.

- Computation of the entire chamber is preferred. The computed chamber length should be between 600 - 1000 mm. The length of the calculation regime may be less than the real length but should be long enough to ensure decoupling of the outflow boundary condition from the injector flow field.
- The ring slit should be neglected and wall boundary conditions should be set.
- The injector flow has to be simulated starting at Position 1 and using the data as specified in the table (fixed mass flow **inlet boundary**). This will result in an injector outlet mean velocity of around 5.6 m/s.
- All **wall boundary conditions** (injector inner walls, faceplate) are no slip and adiabatic except the chamber side wall. The chamber side wall has a constant temperature of 297 K.
- **Exit boundary** condition (chamber bottom): zero gradients in axial direction or extrapolated conditions exit at the specified chamber pressure (3.97 MPa or 5.98 MPa for RCM-1-A and RCM-1-B, respectively).
- **Initial condition:** The test chamber is filled with gaseous nitrogen at specified chamber pressure (3.97 MPa or 5.98 MPa for RCM-1-A and RCM-1-B, respectively) and at ambient temperature (297 K).

Physical Models

- Fluid: Nitrogen, pressure range 3.9 MPa - 6.2 MPa and temperature range 125 K - 300 K.
- Physical models for the turbulent flow calculation are not specified. Participants are free to choose these models. To study the influence of different models is one aim of this workshop. Therefore different solutions for the test cases may be presented.
- A real gas equation or appropriate fluid property data for nitrogen are necessary.

V- AVAILABLE DATA

- Two dimensional nitrogen density distribution in the chamber. The data have been measured using Raman scattering in a two dimensional laser light sheet set up. Instantaneous and averaged data are available. The time averaged data are used for reference of CFD simulations.

Figure 4: Typical flow field (shadow graph) of LN2 injection into gaseous nitrogen at 6.0 MPa chamber pressure.

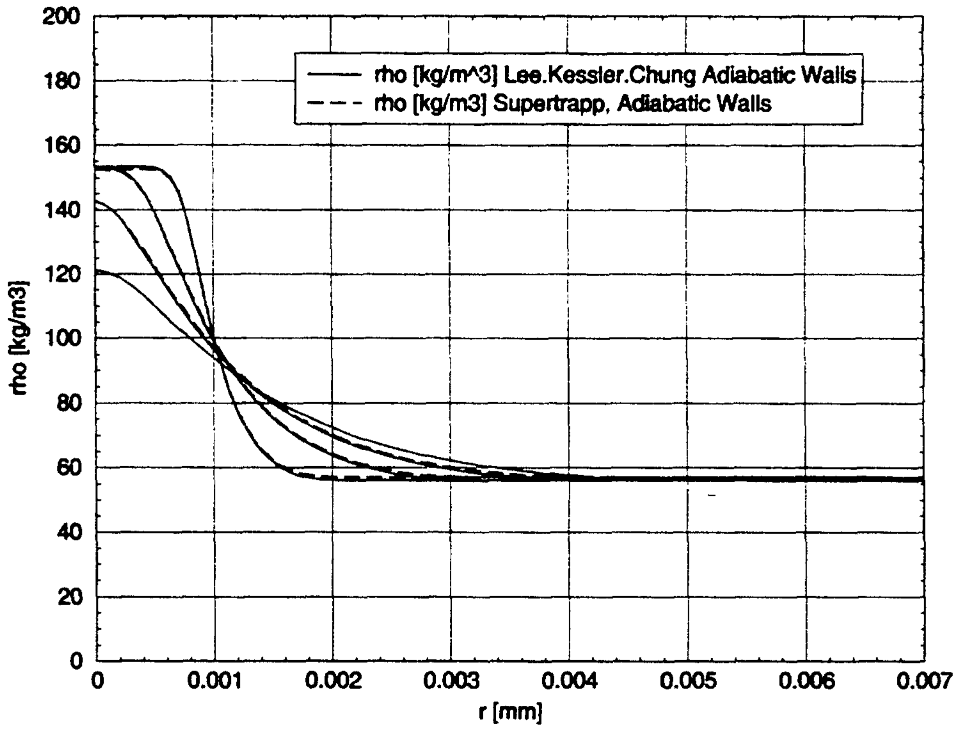

Figure 5:Typical time averaged density profiles of a LN2 Jet in gaseous nitrogen; parameter is the distance from the faceplate (principal tendency, data not for test case reference).

VI- REQUESTED RESULTS

- Injector exit condition (Position 2, see Fig. 2): velocity, density and turbulence profile.
- Radial density profiles for axial positions z = 5 mm, 15 mm, 25 mm, 35 mm, 45 mm, and 55mm downstream the faceplate (a sample is shown in Fig. 5, the data there are however from other injection conditions and therefore not for reference of this test case).
- Velocity field in chamber

II- REFERENCES

1. Mayer, W., Tamura, H., Propellant Injection in a Liquid Oxygen/Gaseous Hydrogen Rocket Engine, AIAA, Journal of Propulsion and Power, Vol. 12, No. 6, pp. 1137 - 1147, 1996

2. Oschwald, M., Schik, A., Klar, M., Mayer, W., Investigation of Coaxial LN2/GH2-Injection at Supercritical Pressure by Spontaneous Raman Scattering, 35th AIAA Joint Propulsion Conference, AIAA 99-2887, Los Angeles, CA, June 20-24, 1999

3. Mayer,W., Schik, A., Vielle B., Chaveau, C., Goekalp, I., Talley, D., Woodward, R., Atomization and Breakup of Cryogenic Propellants under High-Pressure Subcritical and Supercritical Conditions, Journal of Propulsion and Power, Vol. 14, No. 5, pp. 835-842, 1998

In case you need further information, you may contact: wolfgang.mayer@dlr.de