INVESTIGATION OF THE PERFORMANCE OF A 200 N SATTELITE THRUSTER OPERATING IN DIFFERENT ALTITUDES

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Abstract. *This work presents results obtained in tests performed with a 200 N thrust, bipropellant satellite thruster. Tests were conducted at INPE (National Institute for Space Research), in its tests facilities with altitude simulations, at Cachoeira Paulista, Brazil. The main objective of the tests was to obtain data to compare thruster performance during fire tests in various simulated altitudes. Results of tests are presented hereby and shows how plume temperatures and thrust varies as altitude also does. It is shown that thrust, temperatures in plume and shape of plume change with environment pressure, as expected, while combustion chamber pressure do not. This kind of tests were never made before in Brazil. The observed results will allow validation and improvement of models used to analyze supersonic multiphase reactive flows.*

***Keywords**: plume, thruster, bipropellant, pressure.*

1. Introduction

Working life of satellites depends almost uniquely of their capacity to remain on its correct orbit, with a correct attitude. Communication and observation satellites are good examples: with occurrence of small changes in their attitude, their mission can be lost. To keep orbit and attitude, satellites utilize a on board propulsive system. CFD and computing codes are, each day, more and more utilized to analyze plume behavior of this propulsive system. Meanwhile, due to the computational intensity and interdisciplinarity of the plume chemistry problems, there are needs to check some computational methods by means of experimental proceedings.

Rocket missions can take place in various altitudes, with different surrounding pressures. In this work, the changes in performance of a 200 Newton, bipropellant thruster is investigated on different environment pressures. All fire tests were performed in the test bench with altitude simulation (BTSA) of the National Institute for Space Research (INPE), in Cachoeira Paulista, Brazil. Data of thrust, propellant mass flow rate, combustion chamber pressure, combustion chamber and plume temperatures and environment pressure were collected. All collected data can be used to validate and improve models utilized to analyze multiphase supersonic reactive flows. One example of multiphase supersonic reactive flow is the plume of bipropellant thrusters with excess of fuel in contact with free oxygen in atmosphere. This situation can occur with our specimen in simulated low altitudes.

2. Tests apparatus

Tests facilities are described in 2.2. For this work, a 200 N, bipropellant thruster was used. Thruster utilizes MMH (monometyl hydrazine) as fuel and NO (nitrogen tetroxide) as oxidant. This specimen is a development thruster, designed by INPE, and made by Brazilian industry. It is briefly described below.

2.1. Jet system

The jet system combines fuel and oxidizer to produce hypergolic combustion. The system's major components are: fuel and oxidizer valves, injector head assembly, combustion chamber and nozzle.

Each thruster of the system has one fuel and one oxidizer solenoid operated valve that is energized open by one electrical command, permitting the respective propellant to flow through the injector to the combustion chamber. When the electrical command is terminated, the valves are deenergized and closed by means of a spring load.

The injector assembly directs the flow of propellants to the combustion chamber. The thruster utilized in this work tests has one pair of concentric injector (one fuel, one oxidizer) for stream impingement of propellants in the combustion chamber. Additional fuel holes are provided near the outer edge of the injector assembly for cooling the combustion chamber walls. The combustion chamber and the nozzle of this thruster are constructed of steel alloy. The nozzle is radiating cooled. A simplified view of thruster is shown in the figure 1.

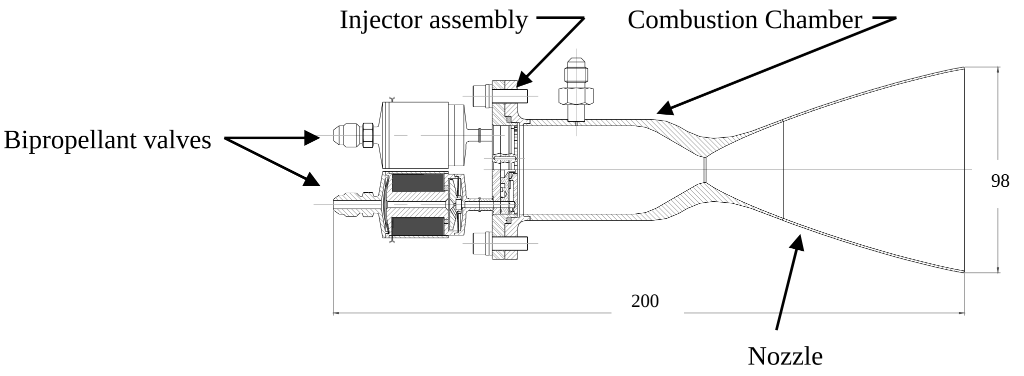


Figure 1 – Bipropellant thruster utilized in the tests (dimensions in mm).

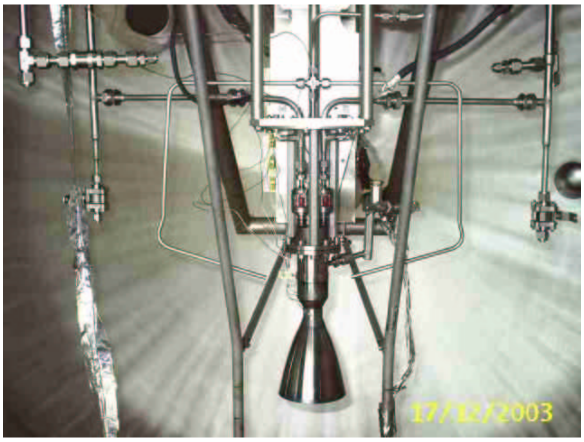
2.2 Test facilities

Specially designed and built to attend the needs of the Brazilian Space Program, INPE's Test Bench with Altitude Simulation, in Cachoeira Paulista, Brazil, is one of the most sophisticated instruments in qualification and development tests of satellite thrusters, with its convenient eight cubic meters chamber. It is suitable for testing up to 200 N bipropellant thrusters, or 150 N monopropellant hydrazine thrusters (INPE/BTSA folder).

The tests facilities have a data system with 46 acquisition channels, with rates up to 5000 points per second.

Test facilities have two propellant tanks, one for fuel and one for oxidizer. Each tank is pressurized with nitrogen, which expels the propellant to the thrusters in test. The tanks have pressure and temperature sensors, and gas traps to ensure proper propellants mass flow control. The tanks and vacuum chamber can be seen in figure 2.

(a)



(b)

Figure 2 – View of (a) test chamber and propellant tank and (b) thruster mounted in chamber.

2.3 Tests

All tests were performed with the same thruster, in the same day, with the same propellant mass flow rate to allow comparisons. Increase of vacuum chamber pressure during tests was done by opening service relief valves. Collected data used for graphics were taken from last 3 sec period of each 10 sec shot (100 points per second for pressure and force, and 100 points per second for temperature). All collected data, as well its variation and standard deviation, is part of INPE's test report B200N-14. This report is not available for public consult.

To measure temperatures inside the plume, three type B thermocouples (Pt 6% Rh/Pt 30% Rh) were installed. Figure 3 shows the support device to keep thermocouples in the right position, inside the plume. The thermocouples were positioned in the following position:

- Center of plume (O in distance from center, in graphics below);
- Border of plume (1 and -1 as above);
- Halfway between border and center (0.5 and -0.5 as above).

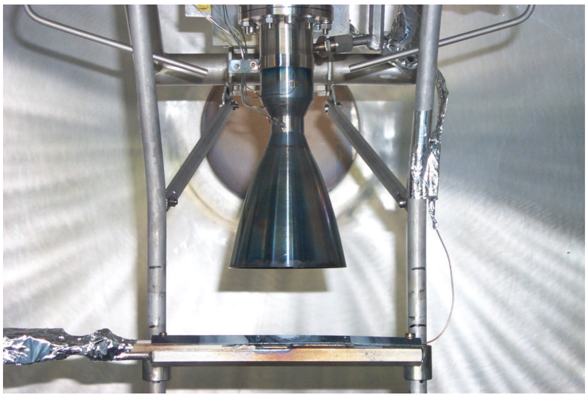


Figure 3: View of thermocouples and their support device under thruster.

The support device with mounted thermocouples had a variable position in height. This variation in height allows the mapping of temperatures inside the plume. For this work, the following positions in height for thermocouples (measures taken from nozzle exit plane)were used: 0, 50 mm, 120 mm and 200 mm.

For each position, three hot tests were made, with 10 seconds in duration and with different ambient pressure each, in a total of 20 hot shots. The campaign report was named B200N-14. The complete description of hot shots is in Tab.1.

Table 1 – Brief description of hot tests.

Test	**Duration**	**Vacuum Chamber Pressure**	**Thermocouples height**	**Mass flow rate)**	**(cm^3/s)**
	(Second)	**(mbar)**	**(mm from nozzle)**	**Fuel**	**Oxidant**
B200N-14-02-01	5	4,5	0	47	26
B200N-14-03-01	10	4,5	0	47	26
B200N-14-04-01	10	4,5	0	47	26
B200N-14-05-01	10	250	0	47	26
B200N-14-06-01	10	320>280	0	47	26
B200N-14-07-01	10	Atmospheric	0	47	26
B200N-14-08-01	10	4,5	50	47	26
B200N-14-09-01	10	250	50	47	26
B200N-14-10-01	10	320>280	50	47	26
B200N-14-11-01	10	4,5	120	47	26
B200N-14-12-01	10	250	120	47	26
B200N-14-13-01	10	320>280	120	47	26
B200N-14-14-01	10	4,5	200	47	26
B200N-14-15-01	10	250	200	47	26
B200N-14-16-01	10	320>280	200	47	26
B200N-14-17-01	15	4,5	200	47	26
B200N-14-18-01	10	4,5	200	47	26
B200N-14-19-01	10	250	200	47	26
B200N-14-20-01	10	320>280	200	47	26

2.4. Tests results

Main tests results are presented in Fig. 4 to 8. Figure 4 shows the variation of thrust as test chamber pressure, what means, thrust as function of altitude. Figures 5 to 8 shows increase of temperature as pressure grows up. These graphs are discussed in Conclusions.

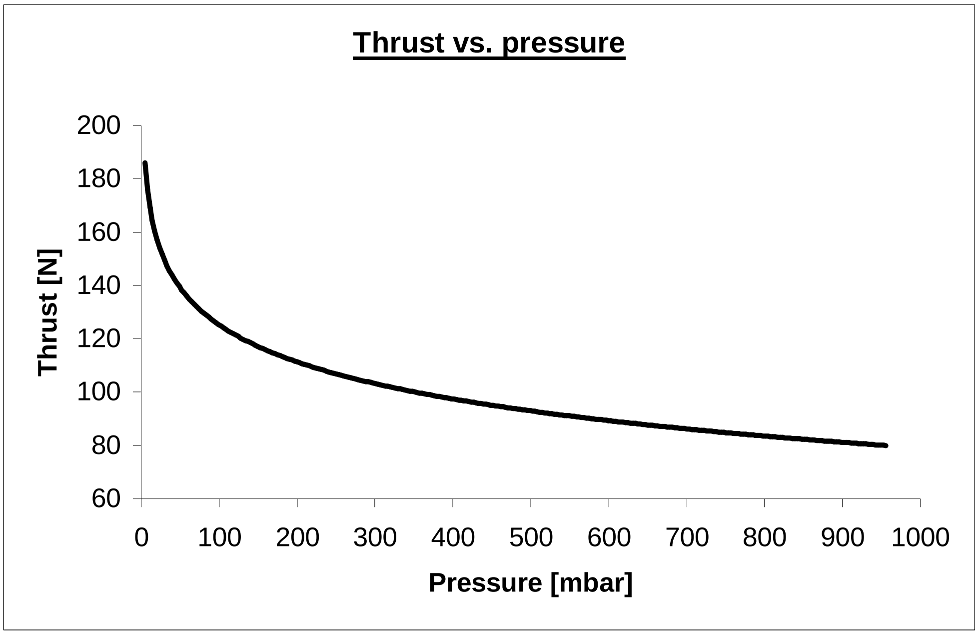


Figure 4 – Variation of thrust with environmental pressure

For all figures below, solid line indicates experiments in 5 mbar pressure, medium dashed line indicates 255 mbar and very dashed line indicates experiments in 288 mbar. As above, tests results are discussed in Conclusions. For all figures, unity is nozzle exit diameter, positive to the right and negative to left from centerline.

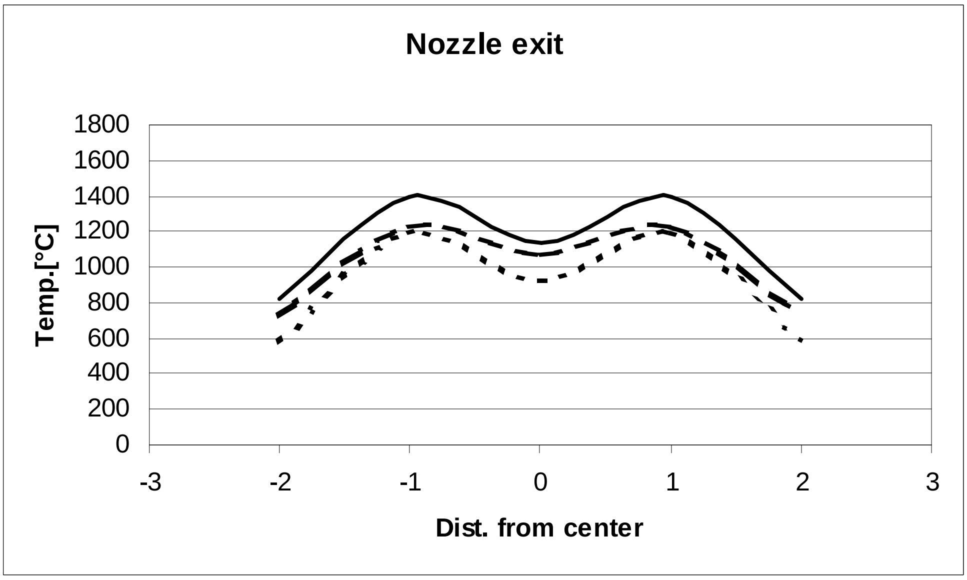


Figure 5 – Temperature measures in the section right at nozzle exit.

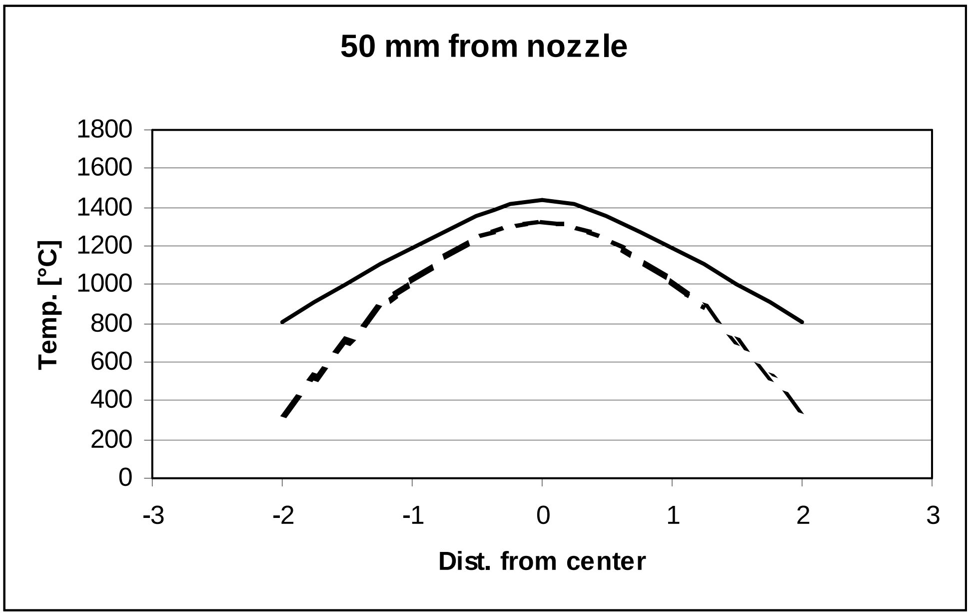


Figure 6 – Temperature measured at 50 mm from nozzle exit.

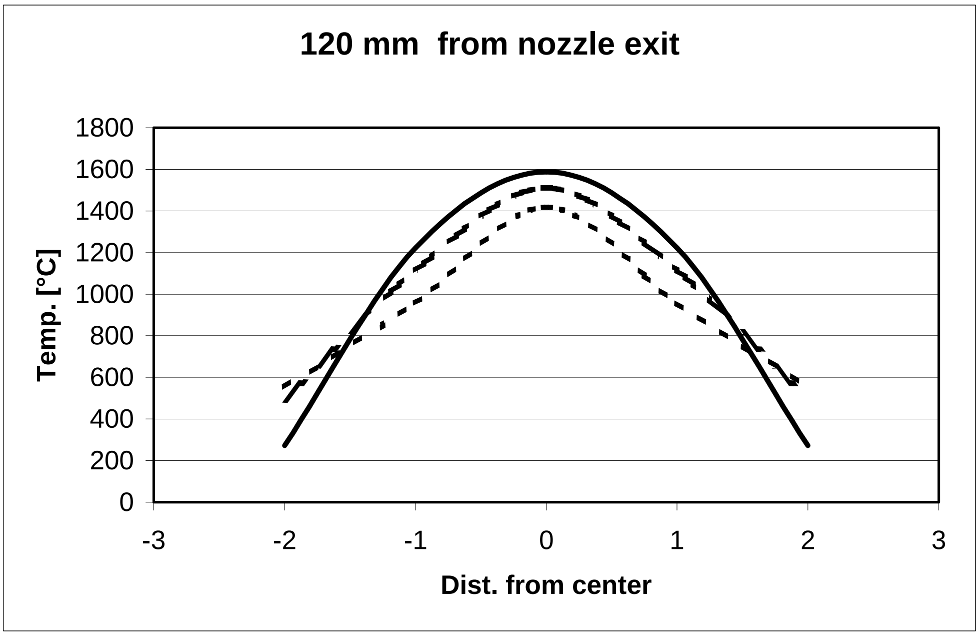


Figure 7 – Temperature measured at 120 mm from nozzle exit.

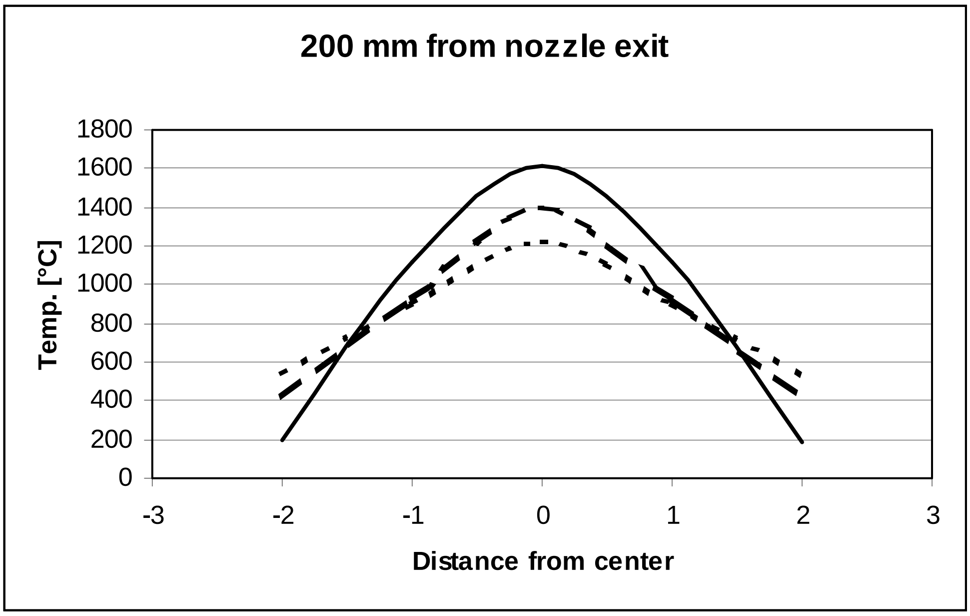


Figure 8 – Temperature measured at 200 mm from nozzle exit.

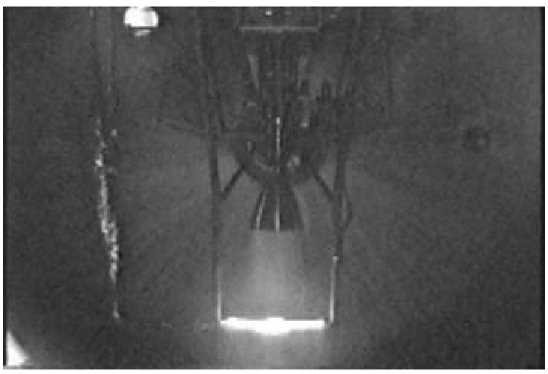
3. Conclusions

Satellites thruster operating in various simulated altitudes was never done before in Brazil, for any type and size of satellite thruster, as well as measurements of plume temperatures. It is known, and was seen, that thruster and plume temperatures varies as altitude changes.

It was observed, too, a small increase in combustion chamber mean pressure as altitude decreases, caused by interference of outside pressure increase. This combustion chamber pressure increase may cause a very slight decrease in fuel and oxidant mass flow rate. These two slight variations has no significance in overall results.

At plume border, a flame appears caused by combustion of excess of fuel. This excess of fuel, necessary to cool combustion chamber walls, leaves nozzle in a very high temperature, and when this unburned hot fuel meets outside oxygen in higher chamber pressures, far from nozzle exit, it will start a self-combustion process in the border of plume, which causes the observed flame. This phenomenon is easily observed in Fig. 9.

For future works, author's main suggestion is to built a suitable device to perform tests to measure plume dynamic pressure and velocity, in the same tests bench.



(a)

(b)

Figure 9 – In (a), test in low level ambient pressure, high simulated altitude; in (b), higher ambient pressure. It is seen in (b) hot fuel in a self-combustion process in border of plume when it meets free oxygen.

4. Responsibility notice

The authors are the only responsible for the printed material included in this paper. This work was extracted from first author's PhD thesis, to be presented.