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RESURGES IN A 200N FUEL FILM COOLING BIPROPELLANT ENGINE

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Abstract

A 200N bipropellant engine under development was tested in the Test Bench with Altitude Simulation located at the National Institute for Space Research, Cachoeira Paulista, Brazil. During the firings very high amplitude pressure oscillations in the combustion chamber were observed. Pressure oscillations more than 40% of the chamber mean pressure imposed very high heat transfer rates to the wall, throat nozzle and injector face, leading to the overall engine failure. This work discusses the onset of the above behavior and relates it with the Resurge effect phenomenon described earlier during the development of the much larger F-1 Rocket Engine.

INTRODUCTION

Propulsion systems often present pressure oscillations which can be observed through the pressure recording in their combustion chambers and feeding lines[1]. Low frequency oscillations are usually associated to the coupling of phenomena taking place in the combustion chambers and their propellant feeding lines. High frequency oscillations, when observed, are linked to the coupling between the combustion process and the engine acoustic cavity properties.

In fact, longitudinal, tangential and radial acoustic modes or any of their combinations can take place during an engine firing[2]. This can be troublesome for their presence increases the amount of heat transferred to the chamber walls, possibly leading to its destruction. A well known wall cooling technique is the peripheric injection of some propellant (either fuel or oxydizer) to generate a liquid film on the wall, modifying the engine inner surface overall heat transfer coefficient, hence allowing larger firing times.

Test Facility

The engine under development is a 200N, bipropellant, NTO (Nitrogen Tetroxide)/MMH (Monomethil Hydrazine) unit, undergoing tests at the bench facility with altitude simulation, located at the Cachoeira Paulista Center of the National Institute for Space Research (INPE)[2].

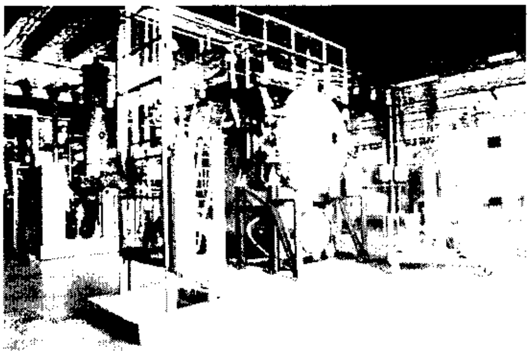

Figure 1 – Satellite Thruster Test Facility with Altitude Simulation – Partial View

This Bench has an 8.5m^3 vacuum chamber for testing monopropellant engines up to 150N and bipropellant engines up to 200N thrust. Figure 1 displays the engine coupled to the thrust balance after a firing sequence.

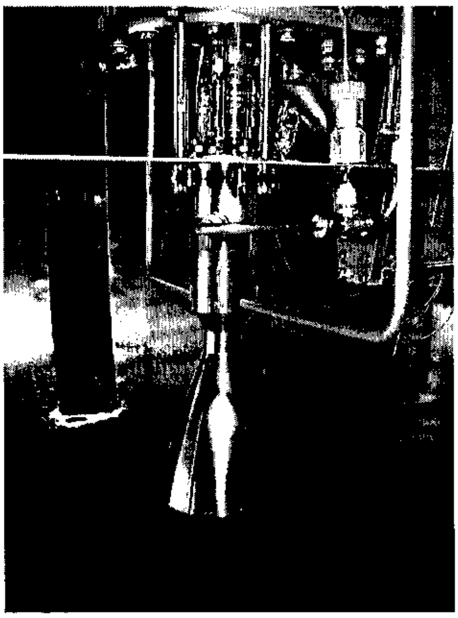

Figure 2 – Test Facility – 200N engine at the Thrust balance.

Injection Plate

This engine component consists of central coaxial swirling injectors where the oxydizer is injected at the center and the fuel is injected around the oxydizer stream. (in a counter – swirling mode). An outside ring with six equally spaced atomizers inject through slots 10% of the overall fuel mass flow rate for wall cooling and to generate a screen between the wall and the main central propellant flow. Figure 3 shows a scheme of the injection plate.

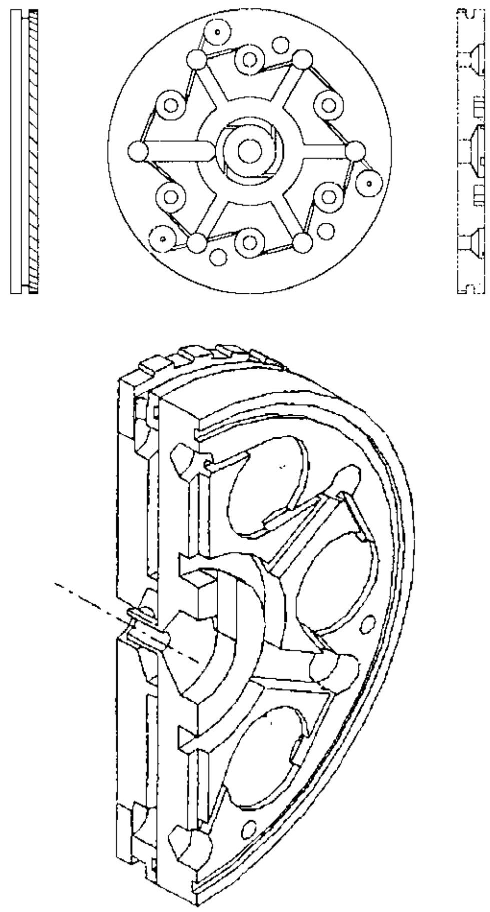

Figure 3 – Injection Head (schematics).

Test Results

This campaign consisted of a series of short duration firings for several F/O ratios with the firing time ranging from 5 up to 35 sec. each.
Obviously the external wall temperature increases with the firing time. Figures

4-6 show the behavior of the combustion chamber pressure, the engine thrust and the propellants flow rate for a 35 sec. firing.

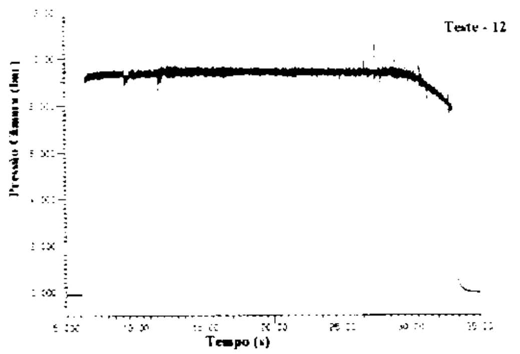

Figure 4 – Combustion Chamber Pressure

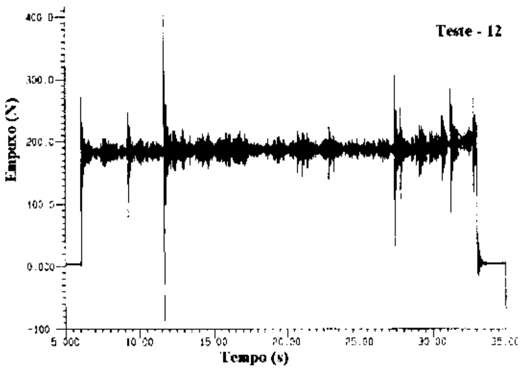

Figure 5 – Thrust

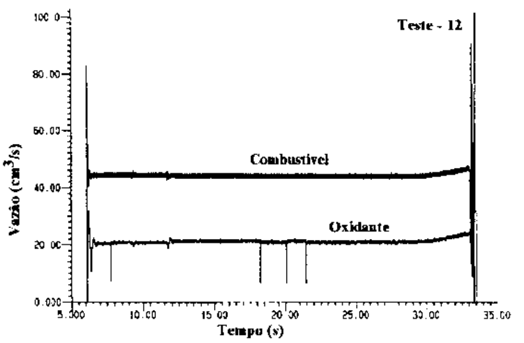

Figure 6 – Propellants flow rate

The sequence of pictures in Figure 7 displays the setting up of an excessive lateral overheating taking place during this 35 sec firing, while Figure 8 shows the nozzle throat failure which led to the immediate chamber pressure decrease with the increasing of the thrust and of the propellants flow rate depicted in Figures 4-6.

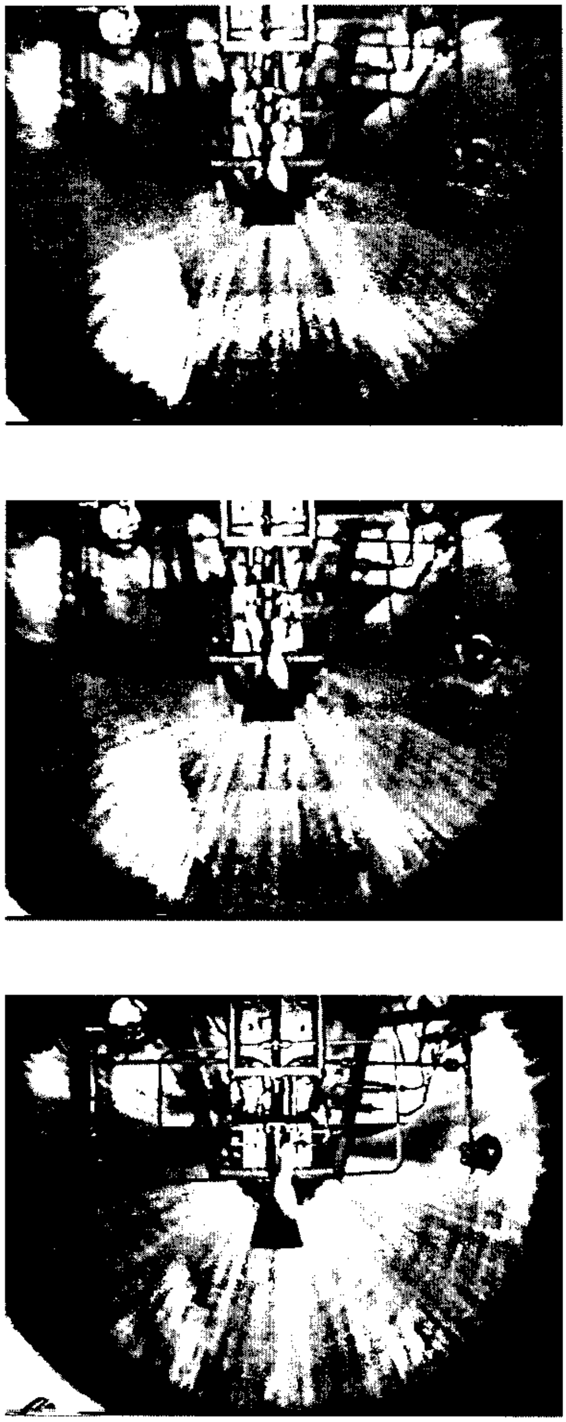

Figure 7 – Lateral overheating.

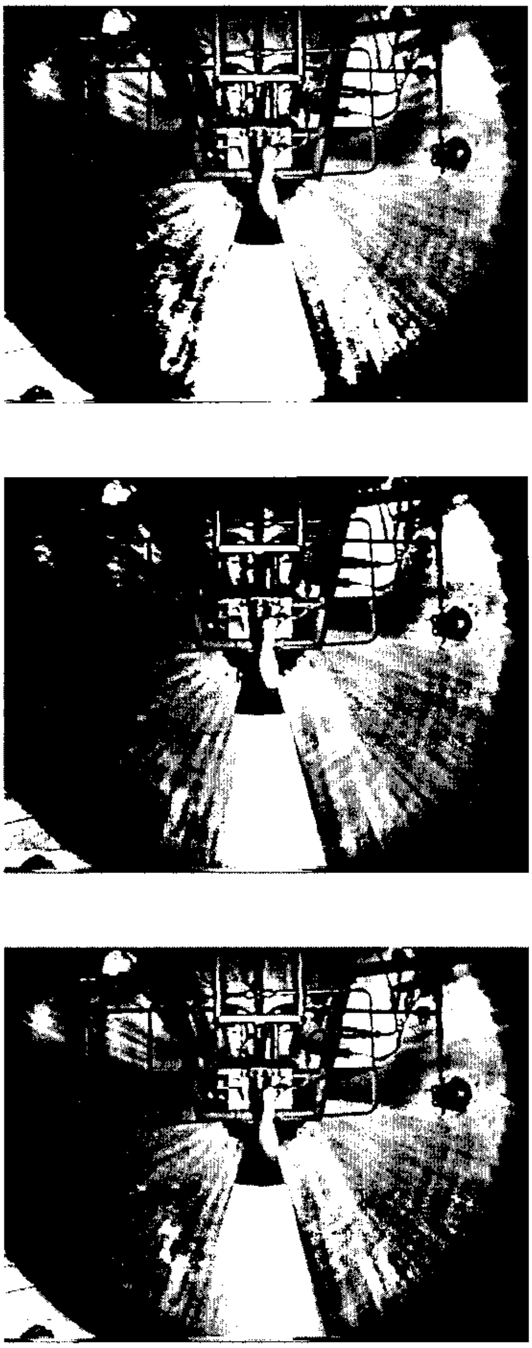

Figure 8 – Nozzle throat failure

Figure 9 – Nozzle throat and injection plate failure

CONCLUDING REMARKS

Noticing the random peaks as well as the sharp decreasing of the chamber pressure along with the increasing of the thrust (Figures 4 and 5) while the propellants flow rate go up near the end of the firing time (Figure 6), one may consider the occurrence of a phenomenon known as "resurge", first described back in the sixties during the development of the F-1 engine of the Apollo Program.

It is known that this engine presented combustion instabilities during its development phase. This led to the so called Project First, during which that engine underwent over 2000 firing tests exclusively dedicated to deal with its combustion instability problems[4]. The F-1 wall cooling was regenerative, using the fuel as cooling agent. Fuel was also used at the inner combustion chamber wall for its film cooling process. Oefelein and Yang (1993)[5] described this Project very carefully. The mechanisms responsible for its instabilities were located in three regions close to its injection plate face and in a fourth region, close to the walls, which had the cooling film protection. This region was identified as the main reason for the phenomenon then labeled resurge to take place, its cause being the pulsating combustion of the liquid fuel separated from the liquid layer used in the wall cooling. This was solved by finding an optimum cooling film thickness to maximize performance. The random peaks observed in this 200N combustion chamber pressure and thrust curves are quite similar to the ones observed in the F- 1 engine. Finally, the high temperatures in the 200N combustion chamber and nozzle led to the failures of the nozzle throat and of the injection plate as shown in Figures 8 and 9, respectively.

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