Cryotechnics

Since 1987, the 'Laboratoire de Chimie industrielle' has had contractual and research activities in the space field and especially with the manipulation of liquid oxygen often used in rocket propulsion. This work led to the development, the construction and the improvement of a cryotechnic test bench, allowing to use liquid oxygen under pressures as high as 50 bar. This bench is remotely controlled by a dedicated software able to manage control sequences with a precision of less than one millisecond. This software is also in charge of data acquisition from up to 128 channels, with frequencies higher than 10 kHz.

This bench, actually very versatile, has allowed the realisation of various studies related to the use of liquid oxygen in space cryotechnic engines, among which the following are the most important:

- study of the ignition sequence of the gas generator of the HM7B engine, which is a part of the third stage of the Ariane IV rocket launcher,
- characterization of a liquid oxygen spray in the gas generator of the HM7B engine,
- behaviour of the flooded ball bearings of the oxygen pump used in the HM7B engine.

Other research, less important owing to the amount of work realised, were also driven out of the field of use of liquid oxygen :

- cooling of two gates of the Vulcain engine, which is the main engine of the new Ariane V rocket launcher,
- measurement of the pressure drop across the injectors of the combustion chamber of the HM7B engine.

All of these researches were realised mainly on behalf of the Société Européenne de Propulsion, in collaboration with other university departments. Some of them were led on behalf of other companies, like ONERA in France, or Techspace Aero in Belgium.

Since our experience is mainly in the field of liquid oxygen, we will describe the researches made in this area.

Study of the ignition sequence of the gas generator of the HM7B engine

The aim of this study was to determine a valid sequence for the starting up of the gas generator of the HM7B engine. To start up the gas generator, a pyrotechnic device is ignited. Eventually, the released gases activate the engine's turbine allowing to drive the pumps which inject first liquid oxygen, and thereafter hydrogen, in the combustion chamber of the gas generator. The oxygen reacts with the hot powder's gases, and provides a flame which will ignite the hydrogen. After ignition, the gas turbine runs autonomously. In our work, we studied the complete starting up sequence, except for the injection of hydrogen. We investigated the parameters of this sequence, in order to find valid one, that is a sequence where the powder's gases burn with oxygen inside the combustion chamber without generating a peak of pressure.

The test bench was fitted in order to respect to the configuration of the actual gas generator and its equipment:

- even if the pyrotechnic device used is not the same as the one which is used in the HM7B engine, it is equivalent and provides the same dynamic response,
- the combustion room has the same volume and shape as the actual one; the only difference is the wall thickness, which is more generous on the bench in order to allow the insertion of probes,

- the increase of pressure due to the starting up of the liquid oxygen turbopump is reproduced rather well by filling and emptying fast remote controlled buffer containers.

The testing bench and the studied material are equipped with a high number of fast temperature and pressure probes. The combustion room is also equipped with very fast photodiodes, used to detect the flame front when the powder's gases burns with oxygen, and with a sampling probe connected to a mass spectrometer. This one allows to determine the chemical composition of the gases.

Many experimental parameters were varied during the experiments : the length of the pyrotechnic device, and then the duration of its combustion, the pressure and duration of the preventing of the combustion room with helium, the oxygen injection pressure, the moment at which this injection is made, the duration of the cooling of the liquid oxygen injection system,...

research duration: 3 years

Characterization of a liquid oxygen spray in the HM7B gas generator chamber

These experiments were done in order to characterize the dynamic evolution of the liquid oxygen spray in the combustion room of the gas generator of the HM7B engine, after the opening of the injection gate. For these experiments, the injection head of the gas generator was fitted on a display box equipped with perfectly plane windows. This box was filled with pressurized helium, to simulate the combustion gases, and an helium stream could be injected convergently with the liquid oxygen spray, to simulate the hydrogen flow.

The main parameters which were varied during these testings were the pressure in the combustion chamber, the cooling time used for the liquid oxygen injection system, and the flow of helium, simulating the hydrogen injection in the combustion room. Qualitative and semi-quantitative information was obtained with fast camera and high definition snapshots, using direct spray visualization or *shlieren* technique. Some pictures taken by these methods were analyzed by computer. More quantitative information were obtained using the PDPA technique (Phase Doppler Particle Analysis). It was the first time that such a technique was used to characterize the size and the velocity of liquid oxygen droplets. With such techniques, we characterized the dynamic evolution in size and velocity of the oxygen droplets in the spray since the opening of the injection gate.

The data obtained by the PDPA technique were also analyzed using the neural networks computation methods. By this way, we were able to model the behaviour of this liquid oxygen spray, and to reproduce the influence of each operating parameter. The results obtained by the neural networks were relevant with the observations taken during the experiments, and gave valuable information about the phenomena occurring during the starting up of the liquid oxygen injectors. Neural network computation seems to be a promising technique to model such kind of highly complex, strongly non-linear phenomena.

research duration: 2 years

Behaviour of the flooded ball bearings of the HM7B oxygen pump

The HM7B engine is equipped with turbopumps, used to feed the cryotechnic engine with liquid oxygen and gaseous hydrogen. The gear of the liquid oxygen pump is supported a ball bearing located in the liquid oxygen flow, so the liquid oxygen cools and lubricates this bearing. This configuration is simple and light, but if some hot spot appears on the bearing, it will vaporize oxygen near it, so it will no longer be cooled and lubricated. The hot spot will extend and, if its temperature reach a critical value, the metal will react with oxygen and burn. We had to determine a safe range of operating conditions for this ball bearing.

In order to realize these experiments, a special testing box has been built for the Université de Liège. This one allows to study the influence of the axial and radial loading of the ball bearings, induced in the actual engine by pressure of the liquid oxygen on the pump gear, the flow of this fluid inside the

bearing, the pressure, the temperature, and the dimensional and metallographics characteristics of the bearings.

The test device is fitted with a high number of temperature, pressure, strength and flow probes. The ball bearing itself is fitted with two temperature probes on its inside ring, an three other ones on the outside ring. The data measured on the rotating part are sent from the rotating shaft by a modulated frequency induction transmitter.

The experiments determined the maximum loading that the original ball bearing can sustain, and to qualify the new surface-treated ball bearing which is used at the present time in the HM7B engine, since the failure of flight 63. At the present time, comprehensive tests are made in order to understand the thermal divergence phenomenon for the ball bearings.

research duration: 3 years