PRELIMINARY DESIGN AND SIMULATION OF A LIQUID PROPELLANT ROCKET ENGINE

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Abstract

This paper synthesises the qualification project carried out by the authors. The main objectives of the project was to perform the preliminary design of a liquid propellant rocket engine in accordance with certain design specifications and simulate its actions. To use a practical application, we drew up a preliminary design for two rocket engines and simulated the actions of one of them using two different configurations.

It was neither the philosophy nor the intention of the authors to run simulations with a view to reducing the real costs of testing any particular rocket engine, which is a more typical objective of simulations. The goal was to build the foundations of some modules, modelling in the most general way possible all the elements that can constitute a rocket engine of this kind; to combine them so that the preliminary design of any liquid propellant rocket engine can be easily drawn up; and, through the simulation of different configurations, be able to determine in the real preliminary design how the actions and control can be modified according to the configuration. The result can give us the preliminary design of each component comprising the engine, as well as a suitable, verified, controlled outline of the final configuration.

In addition, such foundations constitute a good basis for possible simulations of real tests on a specific rocket engine.

Key Words: Design, simulation, rocket, liquid propellant.

1 INTRODUCTION

The simulation of the complete rocket engine has been developed on the basis of an independent study of the individual constituent components and their subsequent connection to form the complete assembly.
The individual modelling of each component consists of two parts: The geometrical (parametrical) design of the component and the study of its actions. In this way any rocket engine can be simulated by simply introducing the desired design requirements, and then both the geometrical calculation of the components and their actions can be obtained individually and within the complete operation of the engine.

2 APPLICATION OF THE DEVELOPED LIBRARIES

The project covered the design and study of the components of a liquid propellant rocket engine and their subsequent connection.
Since each component was studied separately and included in the library for reuse, other engines can be studied by simply taking the components required and connecting them accordingly.

The following components were modelled:

Tank
Pipe
Inducer
Pump
Reductant
Propeller shaft
Plato de inyectores Injector plate / disc
Combustion chamber
Turbine
Nozzle
Cooling system

A detailed explanation about these components would be too long for this presentation, but those who are interested are asked to refer to the original article.

Using the libraries developed, various rocket engines were designed changing their rated operating point.

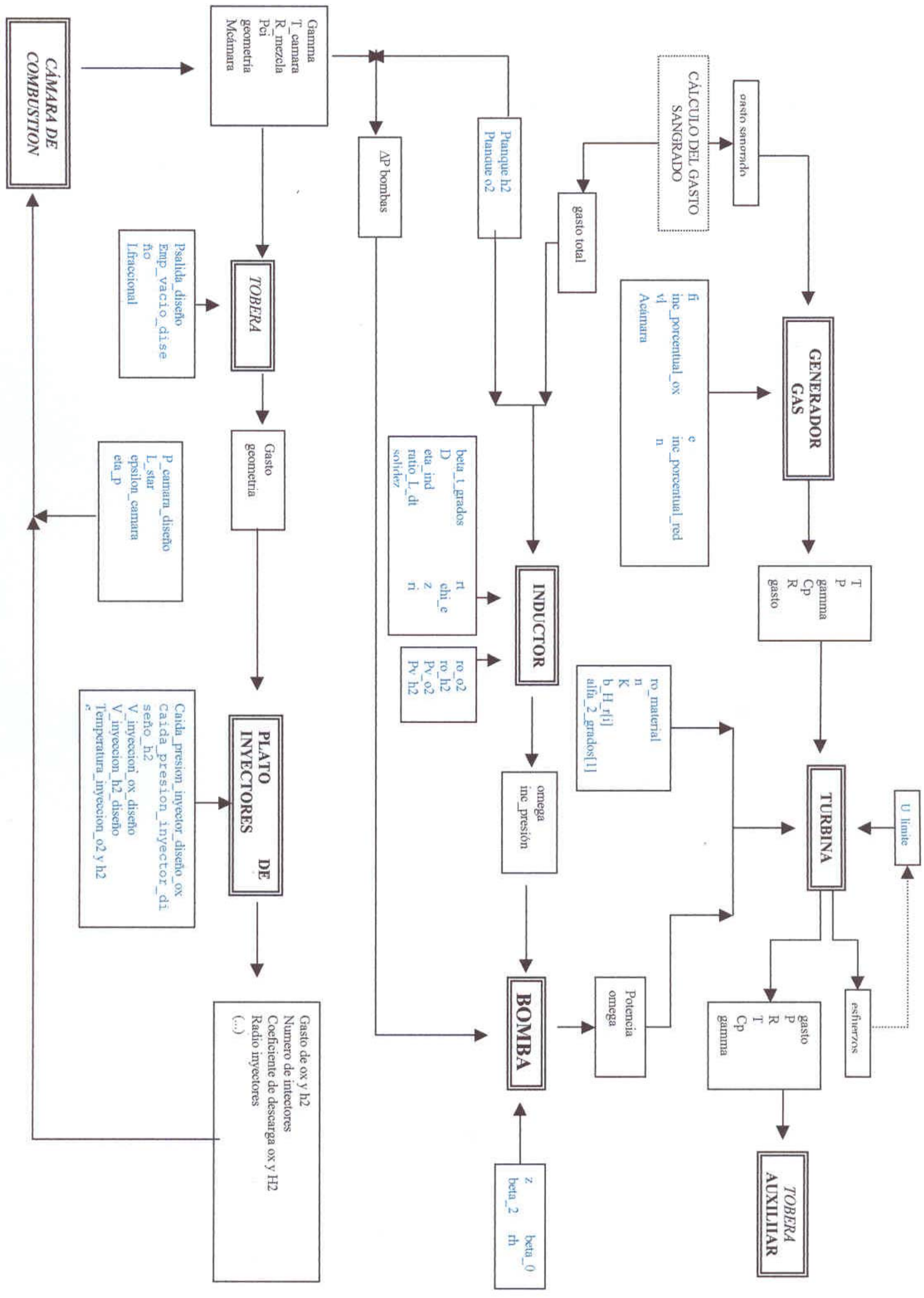

Figure 1 Design Properties

Parametric studies were also carried out of the different components, as well as of different configurations of one particular engine.

A liquid propellant rocket engine was conceptually designed with hydrogen as reductant and oxygen as oxidant. The engine has a mechanical pressurisation system which comprises two turbopumps (one for each fluid) and a one turbine which carries aloft the mechanical unit as a whole. The hydrogen pump is joined to the turbine, whereas there is a reductant between the oxygen turbopump and the turbine shaft -hydrogen turbopump.
An open cycle was chosen for the engine system, with a gas generator.

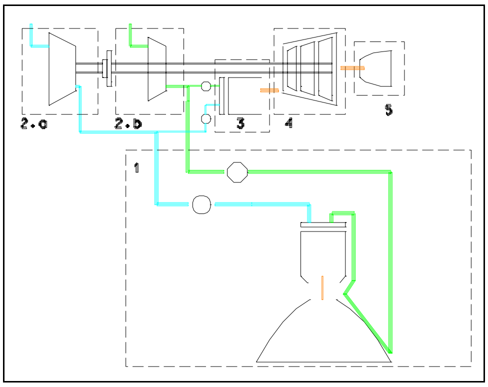

Figure 2 Sketch of the Simulated Rocket Engine

The complete engine design was based on the design of five main components or groups into which they were divided. The correctly connected individual components were used to represent them.

The five large design blocks referred to are:
1. <u>Propulsion unit</u>: Nozzle, main combustion chamber, main chamber injector plate. This unit gave rise to certain requirements for the mechanical unit
2. (2.a and 2.b) <u>Compression unit</u>: This unit gave rise to certain requirements for the drive unit.
3- <u>Gas generator</u>: This gives the input conditions for the drive unit
4- <u>Drive unit</u>: Turbine
5- <u>Auxiliary exhaust unit</u>: Auxiliary nozzle

A detailed description of the design process would be too long, so it is summarised in Figure 1 where we can see different, basically state-of-the-art design data and the relationship between the above-mentioned units.

The engine boundary conditions are those expected:

- Hydrogen compression system inlet pressure (Pa)
- Hydrogen compression system inlet temperature (K)
- Required power on the output shaft of the oxygen pump (W). Here it is possible to carry an auxiliary system which requires power
- Oxygen compression system inlet pressure (Pa)
- Oxygen compression system inlet temperature (K)
- "Extra" power supplied to the turbine input shaft (W). Here it is possible to add a certain amount of extra motive power by means of another motor system

Motor controls:
- Signal permitting user control of the output area to which the nozzle is to be fixed
- Signal permitting user control of the effective area of the main hydrogen valve
- Signal permitting user control of the effective area of the main oxygen valve
- Signal permitting user control over the effective area of the hydrogen bleed line valve
- Signal permitting user control over the effective area of the oxygen bleed line valve

2.1 SIMULATION OF THE RESPONSE OF A ROCKET ENGINE TO CHANGES IN THE CONTROL VARIABLES

After properly connecting the individual components, engine performance was simulated as shown in Figure 2.
Different experiments were carried out for the purpose of studying control of the engine by variation of a single signal.

Each experiment corresponds to a test in which all the boundary conditions are kept constant with the exception of one which we take as control:

- Main hydrogen valve control
- Main oxygen valve control
- Hydrogen bleed line valve control
- Oxygen bleed line valve control
- Main nozzle output area control

Owing to the extensive nature of the experiments, only the <u>final conclusions</u> reached are included here.

It was observed that system control was very limited with respect to engine operation. It was generally seen that valve opening in excess of the rated value has very little effect on engine performance, since it is always a "non-hazardous" and smooth action. On the other hand, valve closure has a greater impact which could result in engine destruction.

The safest and most effective form of thrust control is by controlling the hydrogen bleed line valve so that thrust is kept almost constant.

Varying this valve control signal from 70 to 140 (where 100 is the rated value), we can obtain a thrust variation 10% lower than the rated value when the valve opens and 5% higher when it closes, over a **thrust range of 1550 to 1850 kN within an appropriate safety range** of all variables.

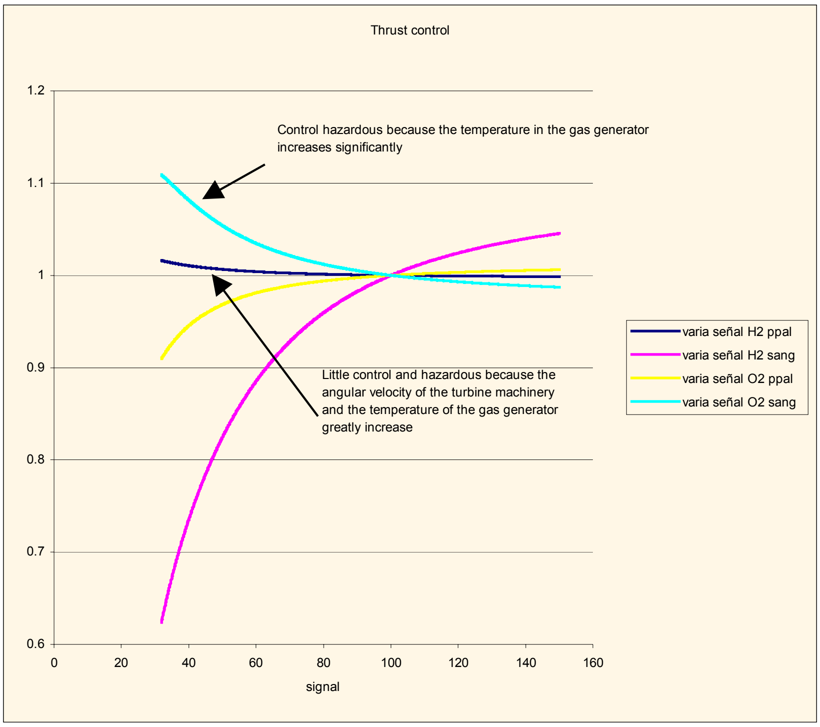

Figure 3

2.2 ANALYSIS OF TEST USING AN ENGINE WITH A DIFFERENT GAS GENERATOR

In addition to studying the variations in the engine fuel control valves, a study was carried out of the same engine with a hydrogen/oxygen-rich gas generator.

This change in turn gave rise to a change in the gas generator injector plate and to a modification in the release and injection areas of the bleed line valves (maintaining their identical discharge characteristics) to allow the release of the new bleed flow rates.

The changes made are shown in Table I and the rated operating point is given in Table II

	rico_o2	rico_h2
H_2 injection radius (mm)	2.78	3.19
O_2 injection radius	2.53	2.33
H_2 valve effective area (m^2)	5.791e-5	0.0019
O_2 valve effective area (m^2)	0.0021062	0.001036

TABLE I

	rico_o2	rico_h2
Thrust (kN)	1750	1750
Chamber pressure (bar)	150	150.5
Chamber temperature (K)	3538.3	3504.7
Gas generator pressure (bar)	184.5	148.5
Gas generator temperature (K)	1200	1243

TABLE II

Tests analogous with the previous ones but performed on an engine with a hydrogen-rich gas generator led to the conclusion that the safest and most effective form of thrust control was via control of the oxygen valves.

Curiously, we can see that engine performance (with regard to thrust) is identical when either of the two oxygen valves are varied, although the decrease in thrust is less when control is via the main oxygen valve (the difference is in any case very slight).

By varying either of these two control signals from 70-140 (where 100 is the rated value), we can obtain a thrust variation 15% lower than the rated value when the valve opens and 8% higher when it closes, over a **thrust range of 1475 to 1900 kN within an appropriate safety range** of all variables.

It can be seen that it is impossible to obtain identical conditions in the gas generator if "the same engine" is maintained, with the same propulsion unit in the same conditions and with the same turbine machinery and bleed line valve discharge characteristics (discharge coefficients) and injector characteristics. This would require appropriate changes in the exhaust characteristics of such components.

Not obtaining the same conditions in the gas generator means that the overall bleed flow rate must be greater than in the original case.

	M_1750_o2	M_1750_h2
Main critical intake (kg/s)	389	388
Critical bleed flow rate (kg/s)	50	68

TABLE III

As a conclusion with regard to the results, it may be said that for the same thrust with the same engine architecture as that used, the engine with a hydrogen-rich gas generator is more demanding that an engine with an oxygen-rich gas generator.

2.2.1 COMPARISON OF THE CONTROLS IN THE TWO VERSIONS

A study of the experiments shows that performance is different in the two versions. In both versions there are hazardous loads (the hazardous variable in all cases is the temperature in the gas generator which greatly increases, and in some it is also the great increase in angular velocity of the turbine machinery).

One curious aspect worth noting is that different controls have the same effects.

The effect that the main hydrogen control valve has on the reductant-rich version is the same as the effect that the hydrogen bleed control valve has on the oxidant-rich version.

The effect that the hydrogen bleed control valve has on the reductant-rich version when it opens is the same as it is in the case of the two valves referred to above.

The effect of the oxygen control valves on the reductant-rich motor is the same.

In general it may be said that the controls in the redact-rich version have more effects than those in the original oxidant-rich version.

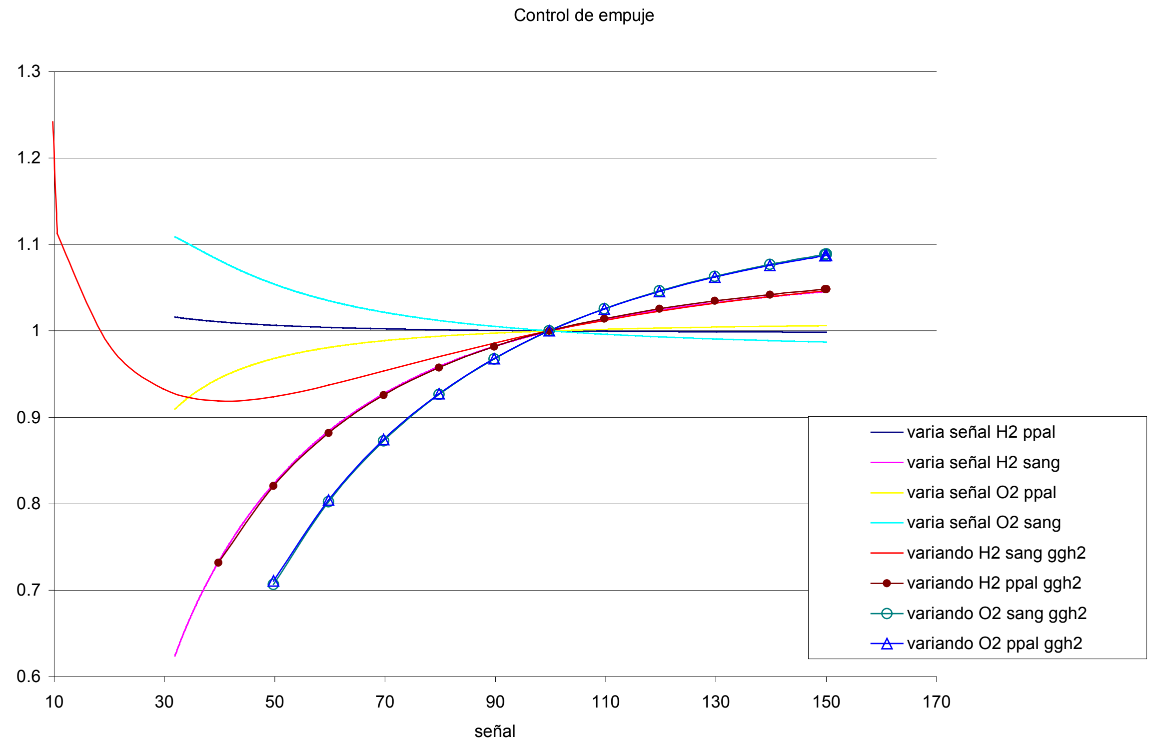

Figure 4 Thrust Control

3 FINAL COMMENTS

We have merely touched upon the project in this paper, but we would like to highlight its mainly academic nature in that improvement regarding qualitative results is, as it should be, immediate. We believe we have developed a tool which is sufficiently powerful and useful to serve as a guide in the initial stages of study and preliminary design of liquid propellant rocket engines.

The model, the simplifications in each of the components modelled, and possible improvements to the model are addressed in more detail in the original article. The practical applications are also described, giving details of the results and the conclusions reached.

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