EXTENDED GAS GENERATOR CYCLE FOR RE-IGNITABLE CRYOGENIC ROCKET PROPULSION SYSTEMS

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ABSTRACT

Liquid rocket propulsion systems are able to provide thrust at high specific impulse. Especially for upper stage propulsion systems this high efficiency is strongly wanted. A high ratio of thrust to weight is obtained by rocket engines based on the gas generator cycle. Another wanted characteristic of an upper stage engine is the ability of re-ignition. An extended gas generator cycle is presented in this paper which includes the ability of several re-ignitions of the propulsion system. The main components of this extension are two high pressure bottles for the gas generator supply only during start up transient. Due to the self-pressurisation effect the modules can restart the gas generator several times during flight. The switch over from the high pressure bottles to the pump supply during transient is investigated in this study by means of the software package EcoSimPro. This study was performed as a Diploma-Thesis in the frame of the project Turbomachines in Rocket Engines (TIR) supported by the Institute of Space Propulsion, DLR-Lampoldshausen. The simulation proves the feasibility of the extended gas generator cycle and indicates in which applications it has significant advantages.

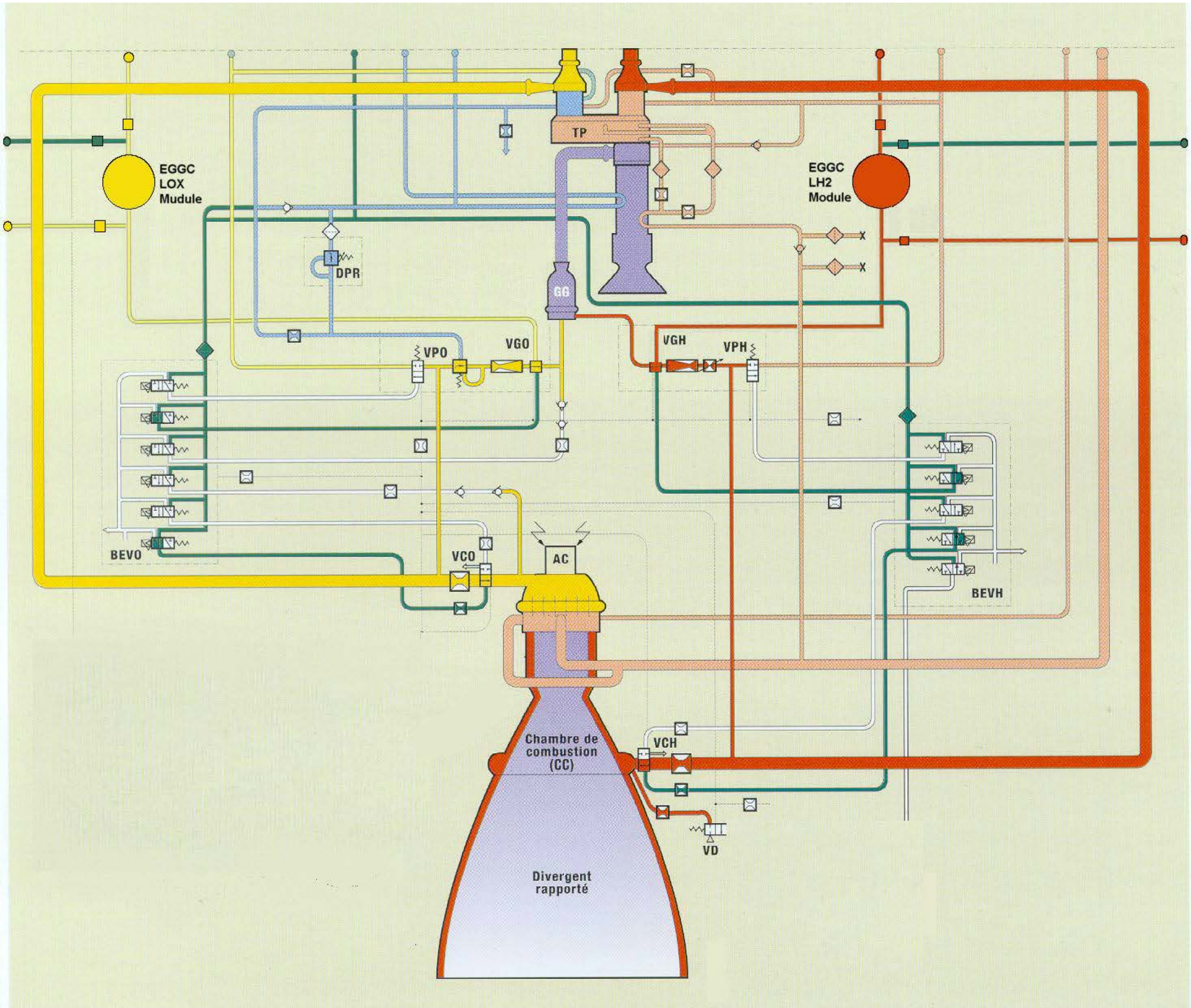

Figure 1 : Extended Gas Generator Cycle Engine (EGGC), Photo Origin, SNECMA

INTRODUCTION

Re-ignition is a standard characteristic of upper stage rocket engines in an expander cycle or in a pressure fed cycle. A gas generator cycle (GGC) engine was proposed [1], which has two (plus two back-up) pyrotechnical turbo pump starters (TPS) for one re-ignition of the propulsion system. In [2] a multiple use turbo machine starter (MUTMAS) was proposed which runs on cold gas. Such a MUTMAS enables almost arbitrary numbers of re-ignition for an engine in GGC. The disadvantage of the MUTMAS is a switch from cold gas to hot gas supply of the turbines during the start up transient.

In the *extended gas generator cycle* (EGGC) which is presented here (fig.1) the gas generator (GG) is supplied by two complementary fuel/oxidiser modules during start up transient. After the start up the GG is switched to the pump supply and the engine runs as in the normal GGC mode. In the EGGC the turbines are always supplied by hot gas. The switch over phase of the EGGC is in the focus of this study and its influence to the overall start up transient has to be investigated by a simulation of the dynamic behaviour of the complete rocket engine. This simulation was made with the software package EcoSimPro [5] and is described in detail in [3].

NORMAL GAS GENERATOR CYCLE

The extension described in this paper is based on the normal GGC. This basic cycle and its motivation are briefly described by [2]:

A main target of rocket engine design is a high specific impulse. Therefore high pressure and temperature in the thrust chamber is requested. The latter automatically emerges if a fuel/oxidiser combination like liquid hydrogen/oxygen is applied. To establish high combustion pressure the rocket engine has its own turbo pumps. The pumps are driven by turbines on the same shaft. The turbines again are supplied by hot gas from a gas generator (GG). This cycle enables significantly higher chamber pressures than the expander cycle. The GG is a small combustion chamber (compared to the thrust chamber) and is supplied by a small part of the fuel/oxidiser of the rocket.

To start up this cycle a turbo machine starter is needed (fig. 2a) which runs up the pumps/turbines to e.g. 60% of rotational speed. Than the GG is ignited, provides now hot gas at high pressure and runs up the turbo machines to the reference point. Then the cycle maintains itself.

After a shut down the GGC engine normally cannot be re-started because all pyrotechnical elements (incl. the turbo pump starter) are burnt out.

REQUEST FOR RE-IGNITION

[2] also reminds briefly to the request of re-ignition : The task of the rocket main stage is to transport the upper stage and the payload through the atmosphere and to provide a high initial velocity for the flight of the upper stage. The latter continues the flight and finally deploys the payload when the requested orbit (altitude, velocity, inclination) is reached.

For energetic reasons the mission to orbits of high altitude (e.g. geo-stationary-orbit at 35,786 km) starts with an injection into an elliptical orbit. Again for energetic reasons the transfer to the final orbit is than reached by engine activation in the apogee. This procedure of orbital transfer with propulsion phases close to the apogee and free flight in the perigee requires a rocket engine with the ability of re-ignition.

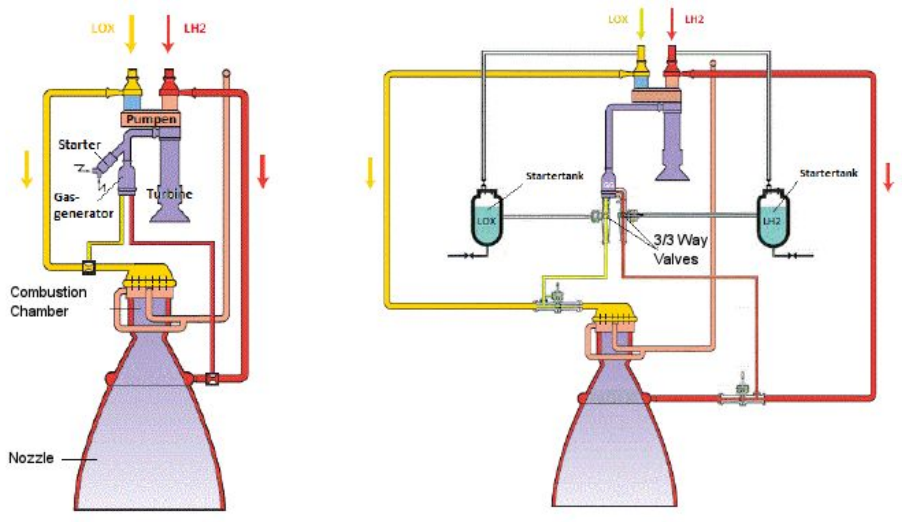

Figure 2 : GG Cycle and Extended GG Cycle, Photo Origin, SNECMA

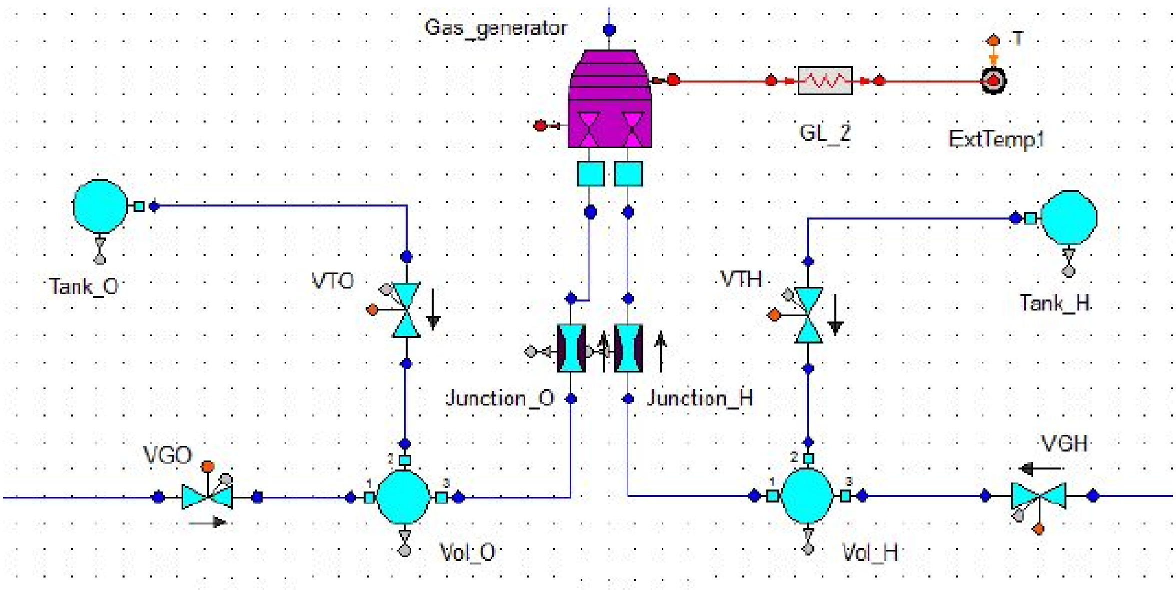

Figure 3 : Supply Module of the EGGC in the EcoSimPro Simulation

RE-IGNITION OF AN EXTENDED GAS GENERATOR CYCLE ROCKET ENGINE

During steady state operation the GG of the propulsion system is well supplied with a part of the fuel and oxidiser provided by the pumps at a high pressure level. At the start of the engine the turbo pumps deliver not yet the requested pressure level. Therefor two complementary modules are used to supply the GG during start up transient. The main components of the modules are the high pressure bottles (fig.4) in which the cryogenic fuel/oxidiser is locked and increased in pressure due to self-pressurisation before the start up transient.
For engine start the fuel/oxidiser is released from the high pressure bottles via a three-way valve to the GG (fig. 2b). At that moment the GG is ignited and produces by combustion the hot gas for the turbines. After the modules are emptied the three-way valves switch to the normal supply from the pumps which have sufficient speed and pressure level at that instant.
The modules can be filled again during flight and are available for the next start-up of the propulsion system, a cycle which can be repeated almost arbitrarily.

COMPLEMENTARY MODULES IN THE EGGC

The principle process of the modules (fig. 4) within the EGGC was already studied in [2]. The phases of the process are :

- the reconditioning of the high pressure bottles,
- the filling of the bottles,
- the self-pressurisation of the fluids
- and the expansion of the fluids.

The expansion of the fluids within this application means the supply of the GG.
The whole process can be repeated several times. The period of repetition is typically ten minutes which is short enough for all apogee activations and enough for many dual-satellite-launch applications.

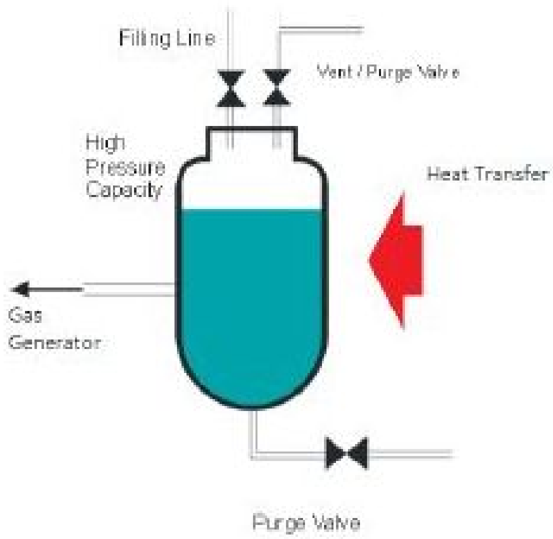

Figure 4 : Elements of a Supply Module

TRANSIENT BEHAVIOUR

Compared to the EGCC in [2] the cycle in this investigation has an additional phase, the switch over of the GG supply from the high pressure bottles to pump supply while the GG is burning. The question is whether we can guarantee an undisturbed function of the GG during this switch over. To investigate the dynamic behaviour the start up of the complete rocket engine is simulated by the software package EcoSimPro. It is a simulation software for continuous and discrete 0D and 1D systems. EcoSimPro uses symbols for flow components which can be arranged in flow schemes (fig. 3) and it converts the arrangement into a system of algebraic and ordinary differential equations.

SIMULATION OF START UP TRANSIENT

The reference model of the HM7b in [5] was extended by the modules of the EGGC (fig. 3). At first the implemented extension was not activated in the simulation and the behaviour of the extended configuration was compared to the reference configuration. To obtain the same behaviour the implemented throttles (see below) had to be adjusted to match the pressures of the reference model. The simulation was started with already filled start tanks at 31.8 bar on the LH_2 side and 32.4 bar on the LOX side, which corresponds to the pump outlet pressures in steady state. The ignition of the GG was at the time as in the reference model, at 2.0 s. The opening of the 3-way valves started (fig. 6) at 1.6 s in order to have sufficient fluid in the GG for ignition. Due to this flow short after opening (at 1.7 s) the turbine (and pumps) started to rotate.

The start up transient of the EGGC was simulated with different valve characteristics. The simplest characteristic is the linear opening (fig.5) of the three-way-valve for the flow between the high pressure modules and the GG and a linear switch over from the modules to the pumps.

The parameter which shows best the influence of the switch over phase is the mass flow at the GG outlet (fig.7). A smooth decrease and recovery of the flow can be observed.

In an advanced valve characteristic (fig.8) the opening and switch over course goes along a polynomial (valve angle versus time). This improve can keep the mass flow almost constant (fig.9). In both cases there was no risk for the GG to distinguish.

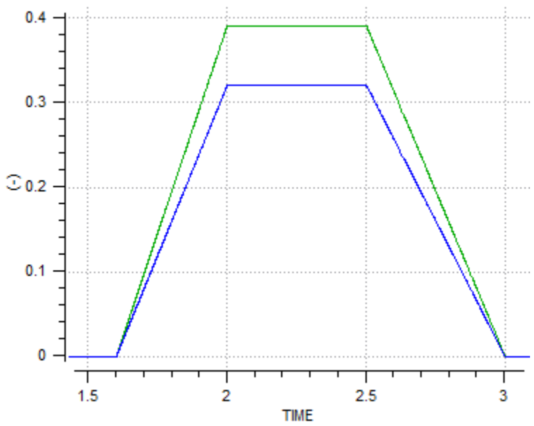

Figure 5 : Linear Characteristic for the Three-Way Valve (blue, LOX valve, green LH2 valve)

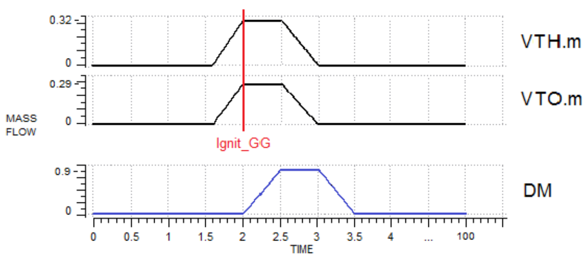

Figure 6 : Massflow versus Time from Supply Modules Compared to the Pyrotechnical Starter

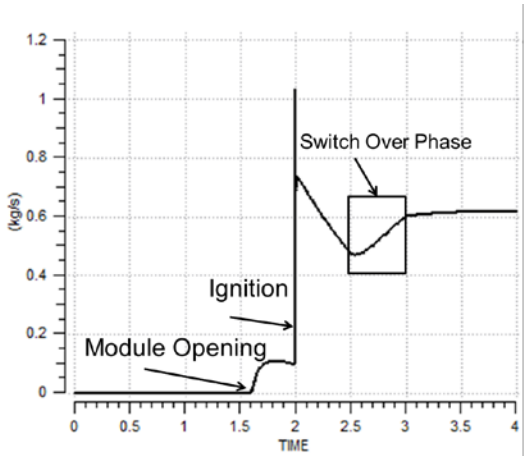

Figure 7 : Mass Flow at GG Outlet during Start up Transient at Linear Valve Characteristic

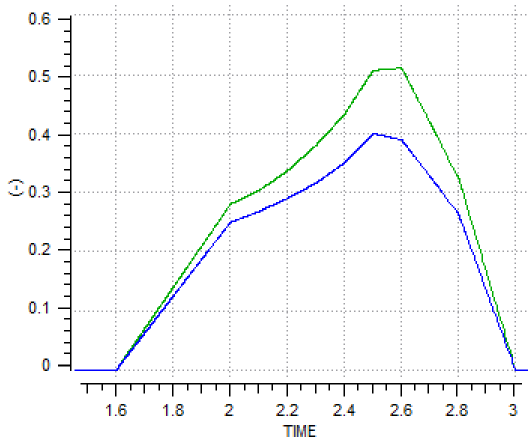

Figure 8 : Advanced Characteristic for the Three-Way Valve (blue, LOX valve, green LH2 valve)

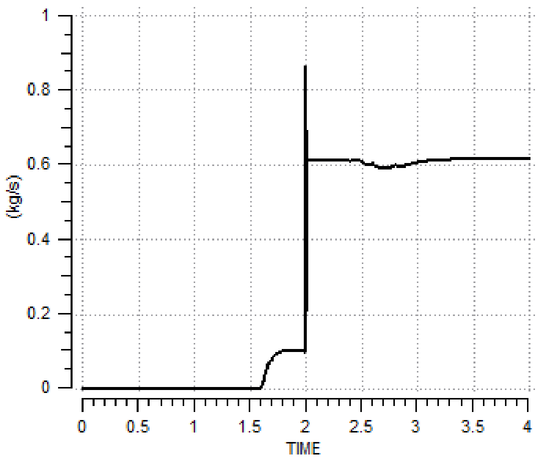

Figure 9 : Mass Flow at GG Outlet during Start up Transient at Advanced Valve Characteristic

Results

The investigation was performed for a GGC engine of relative low combustion pressure [4]; it revealed not only the transient behaviour (fig. 10, fig.11) but also the required dimensions of the EGGC modules. The simulation predicts a higher pressure (12.4 bar) during the GG ignition compared to the ignition by pyrotechnical starter (8 bar). Hence the start up duration until steady state of the rocket engine is also shorter (3.5 s) than in the GGC. Nevertheless at steady state the same parameters are reached in both cycles. The result shows an advantage of the EGGC in rocket engines with high combustion pressure (although not treated her). Because the higher the engine pressure level, the higher is the power provided by the self pressurisation process and the volume of the starter tanks become smaller.

The simulation of 6 s time period took 30 min of computation time on a standard personal computer. The 3 way valves were not standard in the ESPSS 2.0 library of used EcoSimPro version, therefor each 3 way valve was simulated by two valves, a volume and a throttle. The 3-way valve in later libraries can be used from EcoSim 5.4.14 upwards.

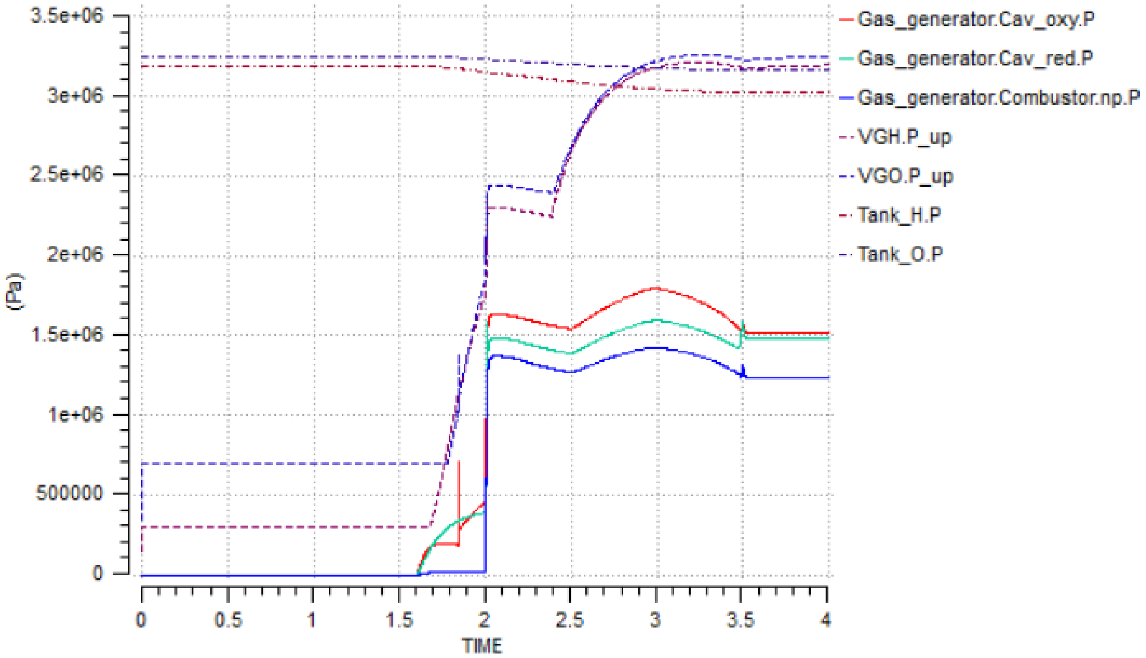

Figure 10 : GG Pressure during Start up

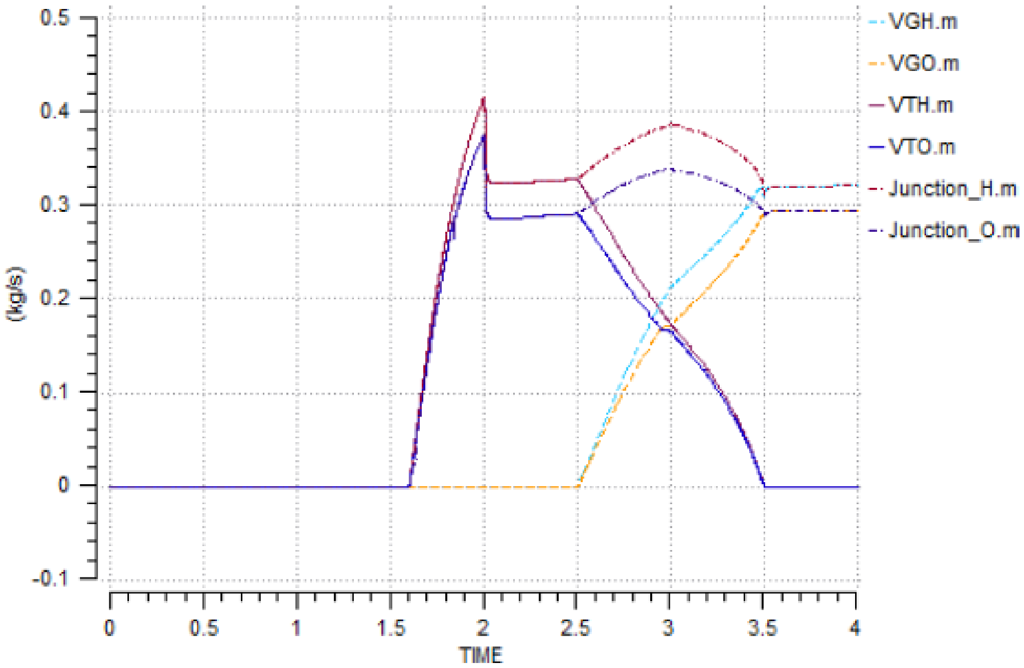

Figure 11 : Mass Flow to GG during Start up

CONCLUSION

The extension of the gas generator cycle with two modules is a small hardware modification. Their main valves (three-way valves) will only replace the normal gas generator valves (open/close valves); the high pressure bottles are of moderate size and mass and we can delete the weight of the normal turbo pump starter. Especially for rocket engines with combustion pressure of more than 10 MPa the high pressure modules provide sufficient power at small volumes. The functional aspect of the EGGC mainly depends on the type and characteristic of the three-way valves. A well optimised valve characteristic promises an undisturbed switch over of the GG supply from high pressure modules to pump supply.

For the functional aspects of the rocket engine we also have the profit that the turbines do not have to deal with pollution from a pyrotechnical turbo pump starter. Furthermore we have one pyrotechnical component less which means an increase of reliability of the propulsion system.

Altogether the extended gas generator cycle rocket engine is an important improvement for a cryogenic upper stage propulsion system.

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