RE-IGNITABLE GAS GENERATOR CYCLE ROCKET ENGINE

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ABSTRACT

One of the most essential design features of a liquid rocket propulsion system is the cycle in which the propellant is processed. The strongest European main engine VULCAIN runs on liquid hydrogen and oxygen, it processes the propellant in a *gas generator cycle* (GGC). The new upcoming upper stage engine for the European launcher ARIANE will be an *expander cycle engine*. This upper stage engine will have the ability of *re-ignition.* Re-ignition must be considered as an essential aspect of *in-space propulsion.* So far the typical application of the GGC-engine is on the first stage, for lift off from ground. This paper presents a solution how to perform re-ignition also on a gas generator cycle engine. The advantages of a GGC-engine can be extended by this design feature and can be interesting especially for engines of high thrust and high specific impulse for orbital transfer and in-space propulsion.

1. INTRODUCTION

For in-space propulsion and re-ignition specific operational aspects of the propulsion system have to be considered. Reconditioning after the first burn phase and conditioning of the components for re-ignition requires a specific propellant and energy management. One operational aspect is the mode how to restart the combustion chamber, the turbo machines and (on a GGC engine) the gas generator. The GGC engine normally has three pyrotechnical starters, for the thrust chamber, for the gas generator and a third one to start the turbo machines. The first two are relative small, their purpose is to ignite the fuel/oxidiser mixture. Although it is also a pyrotechnical system the purpose of the turbo machine starter is not an ignition but to run up the turbo machines of the rocket engine. Therefore it is significantly stronger than the two other pyrotechnical elements. The technology of multiple ignition (re-ignition) of a chamber is already in progress at a fair level and it is as well applicable for multiple ignition of a gas generator. If the pyrotechnical turbo machine starter can also be replaced by a system for multiple application the gas generator engine can become re-ignitable as well.

2. GAS GENERATOR CYCLE

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 [5]. 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 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 [1,3].

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

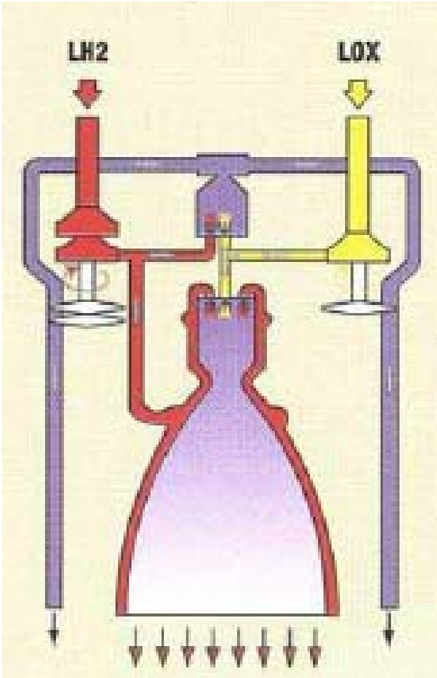

Figure 1 : Gas generator Cycle Engine (Photo SNECMA)

3. REQUEST FOR 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 (GSE) 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.

4. RE-IGNITION OF A GAS GENERATOR ENGINE

Heat exchangers for processing in space/orbit propulsion are already subject of studies [2,4]. These heat exchangers can be used as a part of a system for multiple start of the turbo machines of a GGC-engine. The main component of this system is a high pressure capacity. It is filled with a cryogenic fluid at low pressure, than the fluid is locked and solar heat is transferred by means of a heat exchanger. The effect will be a strong increase of pressure and temperature in the capacity. After the controlled heat transfer the capacity can provide high pressure gas flow for the turbines of the engine and hence run up the turbo pumps. The design of the system is fitted to the coast phase of a space craft with apogee-propulsion.

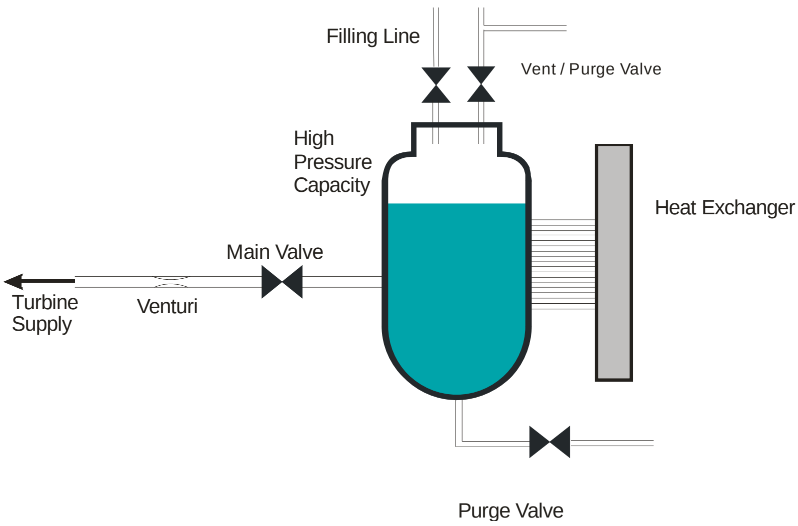

Figure 2 : Multiple Use Turbo Machine Starter (MUTMAS)

HP capacity		
Volume	0,01	m^3
Propellant	LN_2	
Pressure	200	bar
Power	120	kW
run time	3	s

Table 1 : Data Sheet of a MUTMAS

5. RESTART PREPARATION

During the coast phase of 90 min the MUTMAS is prepared for restart of the engine. The first step is to fill the high pressure (HP) capacity by means of a low pressure (LP) capacity to a certain level. Afterwards roughly half the time is available to transfer solar energy through the heat exchanger to the high pressure capacity and to the fluid inside. The pressure and temperature increase of the fluid in the capacity is shown in figure 3.

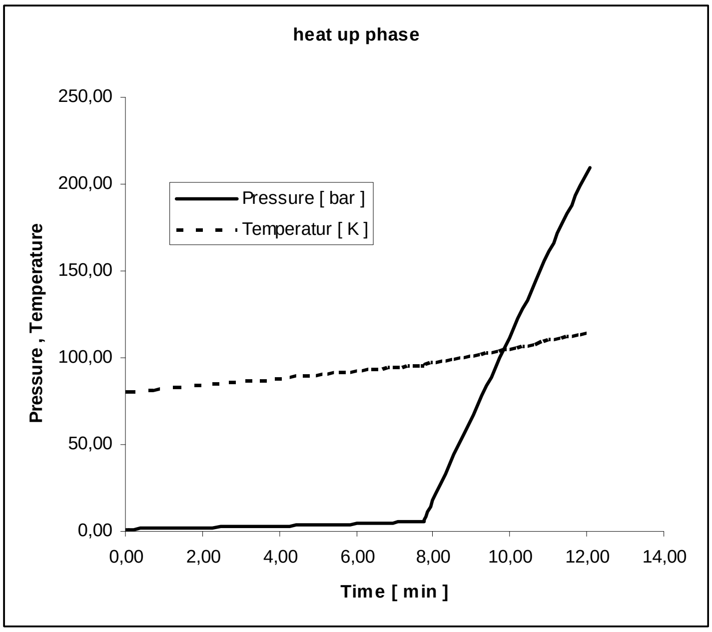

Figure 3 : Pressure, Temperature Increase in the HP Capacity during Heat up Phase

6. MUTMAS WORKING PHASE

The MUTMAS is activated by its main valve and provides high pressure gas flow for the turbines. The rapid expansion of the gas is adiabatic and the flow rate is restricted and smoothed by a venture (Laval-nozzle). Venturi and turbine inlet guide vanes have sonic flow conditions.
During the expansion (working phase) a good part of the energy gathered in the heat up phase of several minutes is released in some seconds. For the example of a MUTMAS given in table 1 the complete process is shown in an enthalpy-entropy-diagram (h-s-diagram, fig.4).

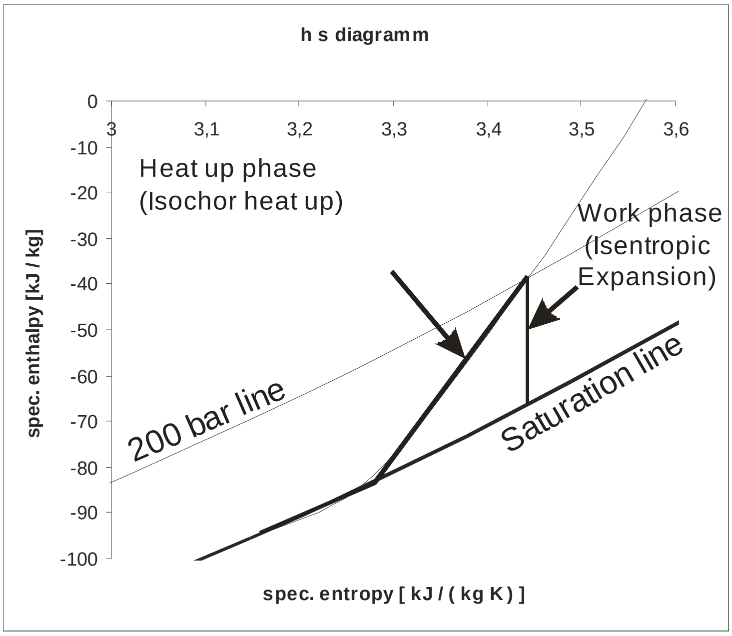

Figure 4 : Complete Process of the MUTMAS

7. RECONDITIONING

After engine burning time and shut-down the MUTMAS is vented/purged (reconditioning) and refilled for the next engine start. Instead of performing this reconditioning during the coast phase a refilling during engine operation phase should be considered. Because the acceleration during the propulsion phase facilitates the performance of the fluid process, particularly the filling of the HP capacity.

8. MUTMAS PROPELLANT

The propellant to start up the re-ignitable gas generator shall be a cryogenic fluid. The ARIANE 5 e.g. has liquid oxygen, hydrogen and helium onboard. For selection of the fluid for a MUTMAS three aspects have to be considered. The functional aspect is the application in the turbo machine. The selected fluid is close to the pumped fuel and oxidiser of the rocket engine. Therefore separation and sealing aspects have to be considered. The thermodynamic properties of the fluid are ruling the performance aspects of the MUTMAS. The profit of a fluid with high energy density is a small HP capacity, which means a lower weight of the complete system. The third aspect is a matter of logistic. It is favourable to select a fluid which is already used on the launcher. That means the MUTMAS can be fed by an existing source and needs no extra tank.

9. CONCLUSION

This article is a first step to demonstrate the feasibility of a multiple use turbo machine starter (MUTMAS) within the conditions of orbital flight. The case study (table 1) suits to the technical requirements of recent launcher propulsion systems and is a useful basis to introduce this design feature in future launcher propulsion systems.

10. OUTLOOK

The MUTMAS enables the use of the GGC engine with all its advantages as a re-ignitable upper stage and in-space propulsion system. The proposed MUTMAS is a system composed of components which are already available or in progress for space application. The more in weight for this system pays out more than enough in high thrust and high specific impulse.

The request for high thrust of the upper stage is not yet demanded. For the main stage the high thrust engine is already in studies and preparation. As a high thrust upper stage engine the re-ignitable gas generator cycle engine could be of great interest for the step after.

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