CASE STUDY
SPACEFLIGHT

Rocket Engine Feed Cycles and Cooling Techniques in Flownex

CHALLENGE

South Africa and other African countries remain reliant on foreign launch providers for the deployment of satellites. This has negative cost and timeline implications in many cases. Thus, UKZN's Aerospace Research Institute (ASRI) started developing a Commercial Launch Vehicle (CLV) to provide South Africa with the capability to launch satellites weighing up to 200 kg into Low Earth Orbit (LEO). As part of this, a study was done to investigate the effect of propellant feed cycles and cooling techniques on rocket engine performance and resulting CLV performance.

SOLUTION

A 1-dimensional fluid flow simulation of the rocket engine in Flownex was used to predict the key performance parameters of each of the different engine configurations. Four different engine configurations were modelled. The results from the simulations were used to calculate the resultant payload that could be delivered to Low Earth Orbit by the CLV. From this, an optimal design could be selected. Thus, the flow simulation was a crucial part in deciding which engine configuration would provide the best performance of the CLV, and in predicting what this performance would be.

BENEFITS

By investigating different propellant feed cycles and cooling techniques, the optimal engine configuration and design for this launch vehicle can be determined. An optimal engine configuration maximizes payload capacity, optimizes the performance of the launch vehicle, and correspondingly reduces the cost per kilogram of satellite payload delivered to Low Earth Orbit.

UNIVERSITY OF KWAZULU-NATAL™
INYUVESI YAKWAZULU-NATALI

"Flownex is playing an important role in our rocket engine and launch vehicle development work, and I expect that the extent of this role will increase with time."

University of Kwazulu-Natal
***Jean Pitot –** Associate Professor*

INTRODUCTION

African countries remain reliant on foreign launch providers for the deployment of satellites. This often has negative cost and timeline implications. This problem has led UKZN's Aerospace Research Institute (ASRI) to investigate the development of a Commercial Launch Vehicle (CLV) to provide South Africa with the capability to independently launch satellites weighing up to 200 kg into a 500 km polar Low Earth Orbit (LEO). The CLV will be a 2-stage rocket with a 225kN thrust first stage and 28kN thrust second stage. Both stages will be powered by the South African First Rocket Engine (SAFFIRE), which is a liquid propellant rocket engine producing 25kN of thrust at sea level using LOX/RP-1 propellant.

A study was done to investigate the effect of propellant feed cycles and cooling techniques on rocket engine performance and resulting CLV capability. Electropump and Gas Generator feed cycles, and ablative and regenerative cooling techniques were investigated. Parameters to quantify the relative performance of the rocket engine include input power, pressure drop across subcomponents, and thrust. Flownex, a 1-dimensional simulation tool, was used to model a rocket engine with different feed cycles and cooling techniques to predict rocket engine performance and resulting CLV performance capability (payload to LEO).

METHODOLOGY

Two propellant feed cycles; electropumps and gas generators, were considered along with two cooling techniques; regenerative and ablative. The resultant engine configurations are: Electropumps with ablative cooling (Elec Ablative), Electropumps with regenerative cooling (Elec Regen), Gas generator with ablative cooling (GG Ablative), and Gas generator with regenerative cooling (GG Regen).

Diagrams of the two feed cycle configurations can be seen in Figure 1 and Figure 2 below. In Figure 2, the combustion chamber and nozzle are coated on the inside with an ablative layer.

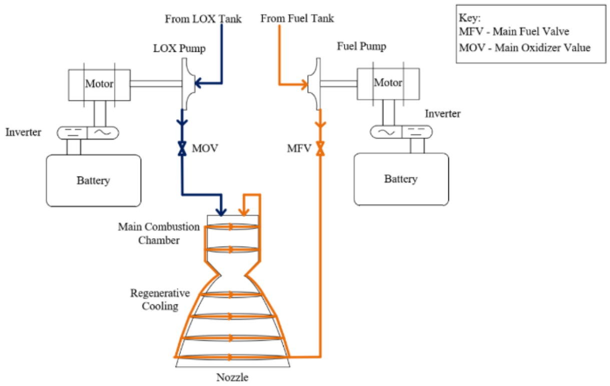

Figure 1: Electropump & Regenerative Cooling Configuration.

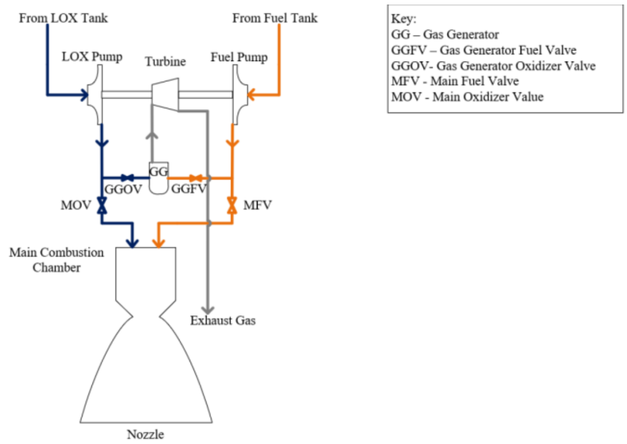

Figure 2: Gas Generator & Ablative Cooling Configuration.

The operating principles of the two cooling techniques are shown in Figure 3 below:

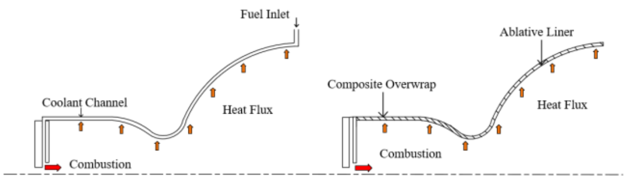

Figure 3: Engine Cooling Operation: Regenerative & Ablative.

A single rocket engine for each of the four different configurations was modelled in Flownex, corresponding to the working principles shown in the diagrams above. Two of the four modelled Flownex networks are shown in Figure 4 and Figure 5 below:

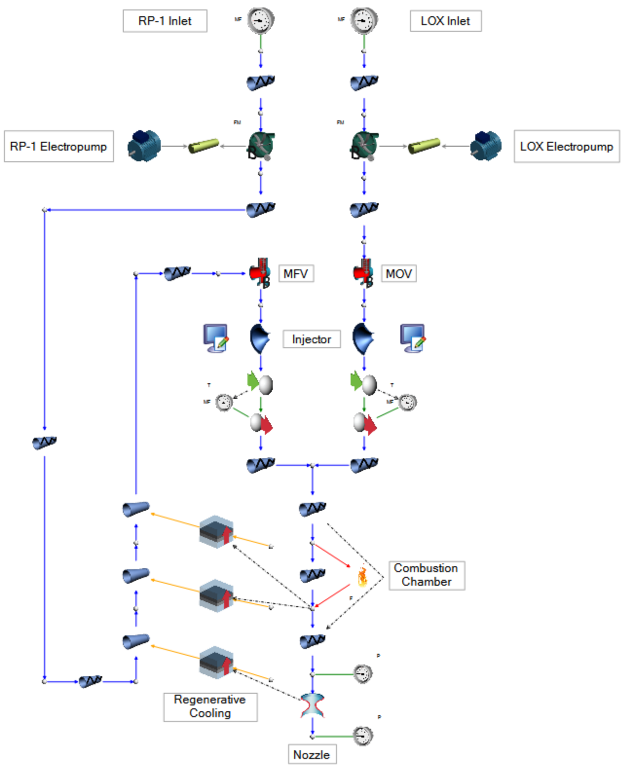

Figure 4: Electropump Regenerative Engine Flownex Model.

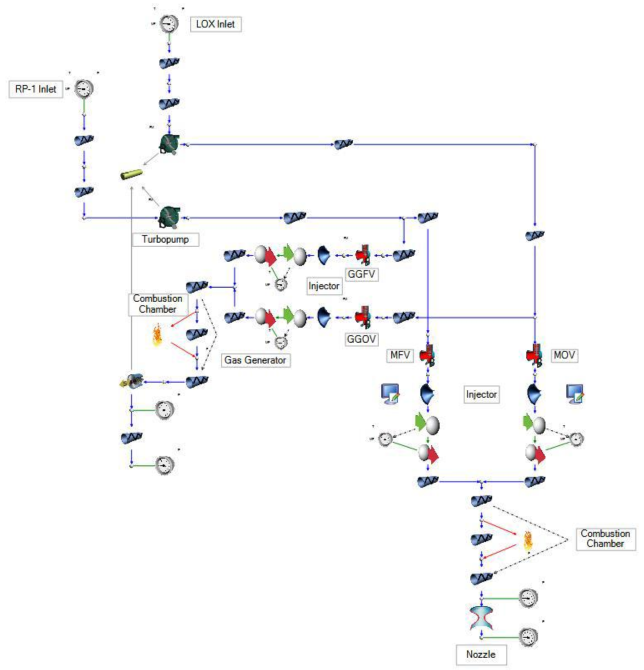

Figure 5: Gas Generator Regenerative Engine Flownex Model.

The rocket engine was split into eight subcomponents in Flownex using the built-in library elements. These components comprised the inlet and exit boundary conditions, the turbopump, the electropump, the injectors, the gas generator, the main combustion chamber, the nozzle, and the regenerative cooling. Previous studies and independent theoretical derivations provided input information and design parameters for the Flownex model components, such as fuel fluid properties, component masses, sub-equipment performance specifications, flow rates, etc.

Each configuration could then be calibrated and simulated in Flownex to predict the engine's performance.

RESULTS

The results obtained from the simulation included thrust of the rocket engine, electric power consumption by the electropumps, power produced, and fuel consumed by the gas generator. Secondary results essential for engine performance calculation such as operating temperatures and pressures throughout the engine were calculated by Flownex but not directly reported.

The thrust of the rocket engine, as calculated by Flownex, is given below:

Table 1: Thrust of different rocket engine cycle configurations.

Engine Cycle Configuration & Cooling	Thrust, Sea Level [kN]	Thrust, Vacuum [kN]
Electropump, Ablative	25.82	33.77
Electropump, Regenerative	26.86	34.02
Gas Generator, Ablative	25.85	33.80
Gas Generator, Regenerative	26.88	34.04

These results were used to calculate the payload capabilities to LEO of the CLV for each of the engine configurations and can be seen in Figure 6 below.

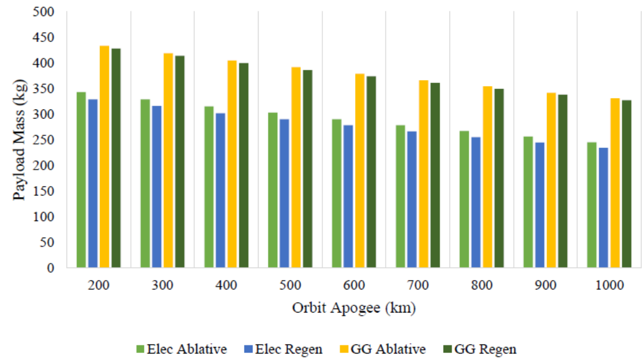

Figure 6: CLV Payload Mass using different engine configurations.

Two expansion ratios for the rocket engine were modelled: for the regeneratively cooled rocket engines an expansion ratio of 10.5 was used to ensure sufficient cooling of the engine without the fuel changing phase, and for the ablatively cooled engines a larger expansion ratio of 13.5 was used. When a common expansion ratio of 13.5 was used for the sake of comparison, the resultant payload capacities can be seen in Figure 7 below.

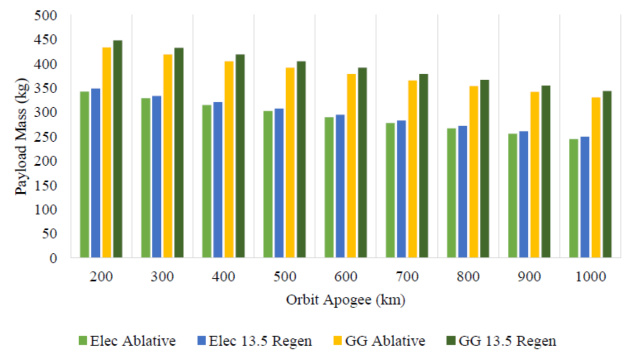

Figure 7: CLV Payload Mass using different engine configurations & same expansion ratio.

The results above indicate that the CLV can place anything in the range of a 250 kg payload into a 1000 km altitude Low Earth Orbit to 450 kg into a 200 km Low Earth Orbit, depending on the engine configuration used.

All these results allow the CLV designers to select the engine configuration with the best balance between performance, cost, and complexity.

CONCLUSION

A study was done to investigate the effect of propellant feed cycles and cooling techniques on rocket engine performance and resulting CLV capability. Flownex was used to model the different engine configurations, and the flow simulation results were used to predict engine configuration performance and resulting impact on the CLV performance. All these results allow the designers to select the engine configuration with the best performance for the CLV.

