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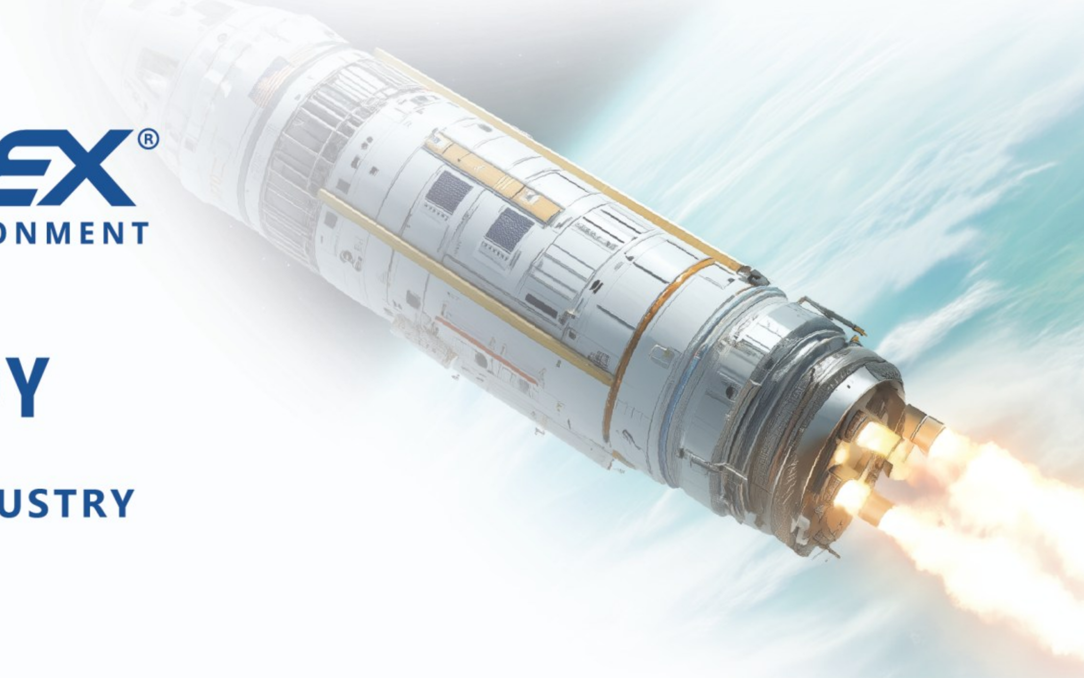
SIMULATION ENVIRONMENT



CASE STUDY

SPACEFLIGHT INDUSTRY

DESIGN OF A MOBILE LIQUID ROCKET ENGINE TEST FACILITY FUEL FEED SYSTEM USING FLOWNEX

CHALLENGE

As part of the University of KwaZulu-Natal's Aerospace Research Institute (ASRI) programme to develop the SAFFIRE liquid-fuelled rocket engine, a mobile liquid rocket engine test facility was designed and constructed. A critical part of the process of quantifying the performance of the rocket engine, such a facility is required to determine the performance, stability, and control characteristics of a rocket engine, and to validate the designs of the propellant feed and injector system. Design of such a system requires simulation of internal fluid flow through tanks, pipes, valves and venturis.

SOLUTION

Flownex was the simulation tool used to model the propellant feed system. The model was used to determine the required characteristics of the system components. The propellant feed system utilises pressure in the fuel tanks to drive propellant through the feed system and into the rocket engine. The simulation model determined the tank pressure required to achieve the required propellant flow rate into the engine. To characterise this essential parameter, flow through pipes, valves, and venturis had to be accurately modelled along the flow path. The Flownex simulation results were validated by cold flow test results, allowing it to be used as the verified design tool for the rocket engine propellant feed system.

BENEFITS

The success of the cold flow tests and flow simulation modelling allowed the rocket engine test facility to be used to perform a series of extended hot fire tests with on-target propellant mass flow rates. This successfully yielded data on the performance of the rocket engine as well as on the flow characteristics of the propellant feed system leading to the rocket engine. This data was used to validate the design of the rocket engine, as well as the propellant feed system and the analytical models used to simulate the propellant flow in the rocket engine test facility.

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

The Aerospace Research Institute (ASRI) is currently busy with the development of the SAFFIRE (South African First Rocket Engine) liquid-fuelled rocket engine, a Kerosene and Liquid Oxygen (LOX)-powered rocket engine that is to be used as a propulsion unit on South Africa's first small satellite launch vehicle. As part of the development process, a mobile liquid rocket engine test facility was designed and constructed. Since cold flow and static hot fire testing of a rocket engine is a critical part of the process of quantifying the performance of the rocket engine, construction of such a facility was a necessary step.

One important outcome of these tests is to validate the design of the rocket engine test facilities' propellant feed and injector system. Validation of the design is an important step both in qualifying the test facility and in development of the propellant feed systems for the rocket engine itself.

Design of these systems requires simulation of internal fluid flow through tanks, pipes, valves and venturis. Flownex specialises in simulations such as these, making it an important tool in the design process of the propellant feed systems.

METHODOLOGY

The diagram below illustrates the rocket engine test facility design, including the propellant feed system flow paths.

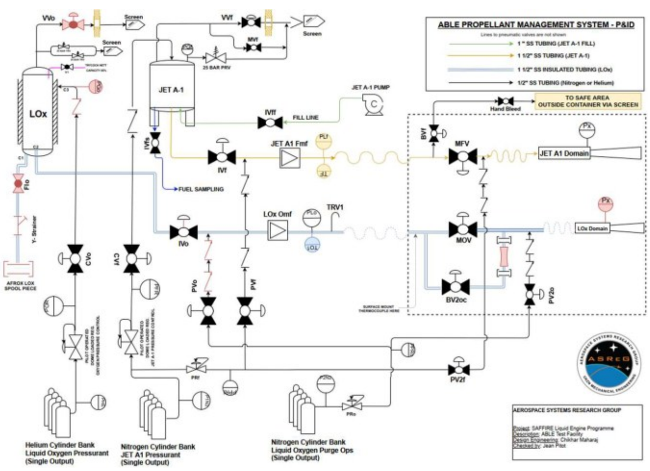


Figure 1: Rocket Engine Test Facility Flow Diagram.

There are two separate flow paths: the first transporting Jet A-1 (Kerosene) fuel from the tank to the rocket engine through a series of valves and a venturi, and the second transporting LOX from the tank to the rocket engine. Flownex was used to model the flow along these paths. The individual flow components were modelled in Flownex and characterised using manufacturer component data. Once all the flow components had been characterised, the Flownex model was used to determine the necessary LOX tank ullage pressure to maintain the required fuel flow rate through the system.

This was only a requirement for the LOX system as the feed line has no venturi to decouple the rocket engine combustion chamber pressure from the propellant feed system pressure. The required ullage pressure for the Kerosene tank was determined by defining the fuel line venturi discharge coefficient and subsequently determining the required venturi inlet and corresponding fuel tank pressure. For cold flow tests, a reduced tank pressure had to be used in the LOX system because there is no back pressure from the rocket engine combustion chamber.

Simulations of these processes allowed the system components to be sized and constructed. Once the system had been constructed and commissioned, a cold flow test was carried out to test the system and validate the Flownex model of the system.

RESULTS

Once the cold flow test had been completed, the results obtained from the cold flow test were compared to the Flownex model of the propellant feed system. The graph below shows an example of the flow rate measurements obtained during the cold flow test:

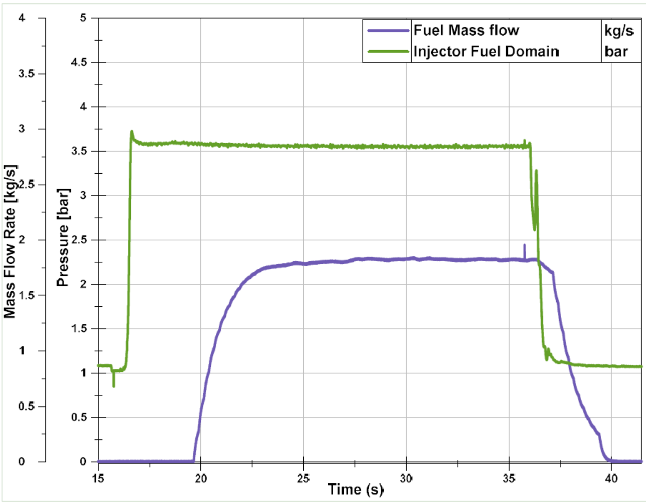


Figure 2: Fuel Flow Rate and Tank Pressure - Cold Flow Test.

The results of the test closely matched the results of the model, successfully validating the Flownex model. For example, a nominal LOX flow rate of 5.6 kg/s was measured, which was within 3.5% of the flow rate predicted by the Flownex model. Other flow characteristics, such as friction factors and loss coefficients of the flow components, were also derived from the test data and were found to compare well with the Flownex model results.

The success of the cold flow tests and flow simulation modelling allowed the Flownex model to be used as a design tool for further tests to be performed by the rocket engine test facility, including a series of extended hot fire tests with on-target propellant mass flow rates.

CONCLUSION

In this study[1], a liquid rocket engine mobile test facility was designed and constructed. The propellant feed system was designed and modelled in Flownex. The Flownex model and the test facility were successfully validated by a cold flow test. The successful validation of the design allowed hot fire tests to be conducted using the test facility, fulfilling the design intent of the test facility.

[1] Cooper, et al., 2024. Facility Design and Cold Flow Testing Operations for an 18 kN LOX/Kerosene Liquid Rocket Engine. *AIAA*.