

# Steady State and Dynamic Simulation of Cryogenic Rocket Propulsion Systems

## Abstract

Selection of thermodynamic cycle, equipment specifications and operating parameters of a pump-fed liquid rocket engine is guided by the mission requirements. The designer has to analyse several competing alternatives before arriving at the best-suited design. A steady-state analysis, producing performance data of competing cycles under varying operating conditions, helps narrow down this choice. A transient or dynamic analysis, on the other hand, is used to predict the state variables as functions of time, particularly during startup and shutdown and while responding to changes in operating conditions. It is also useful in implementing automatic control where several basic controllers work in parallel.

A flexible structure flowsheet simulator is necessary to address to the wide variety of propulsion cycles and the vast range of equipment specifications used in rocket propulsion. The user can define and simulate any process architecture by selecting equipment modules from a library, declaring the way they are connected and specifying their characteristics. Such a simulator, named CRESP-LP (*C*Ryogenic *E*ngineering *S*imulation *P*rograms - *L*iquid *P*ropulsion), designed specifically for propulsion systems, has been developed. The package has two distinct components: CRESP-LP-SS for analysing the steady state behaviour and CRESP-LP-DN for analysing the dynamic or transient behaviour of liquid propulsion rocket engines. The work presented here describes the constitutional structure and the software architecture of the two components of CRESP-LP. Example problems solved both in steady state and dynamic regimes have been presented to demonstrate the applicability of the softwares.

The work has been divided into four different parts. The first part describes the *Foundation* of the subject. It gives a general introduction to the subject and reviews the literature published in the field of liquid propulsion and chemical engineering process

simulation. In the second part we give a detailed account of the scientific principles behind CRESP-LP-SS. We discuss the mathematical models of the equipment types used in the software and describe the executive program that implements the flowsheet structure. The architecture of the software has been presented along with a brief description of the component C++ classes. The flexible structure software has been used to perform a parametric study on the thermodynamic cycles commonly employed in liquid rocket propulsion.

The third part of the thesis describes the dynamic simulator CRESP-LP-DN. It presents the mathematical models of the equipment types and the approach to solving the complete set of differential-algebraic equations as function of time. The fourth and the final part of the thesis contains the concluding chapter where the strengths and limitations of CRESP-LP have been discussed and some possible future work has been suggested.

Keywords: Liquid propulsion rocket engine, steady state analysis, dynamic analysis, flexible structure simulator.