	INTERNSHIP 6 MONTHS **YEAR 2021-2022**
Internship tutors: Annafederica URBANO Email: annafederica.urbano@isae-supaero.fr	-Internship with ISAE SUPAERO – Toulouse - April – October 2022 Location: **ISAE SUPAERO - Toulouse** Grant: 3,60 €/hour ⇨ 554,40 €/months (22 days, 7 hours/day)

TITLE: Multi-Disciplinary Analysis and Optimization of Reusable Liquid Rocket Engines

Context

Liquid Rocket Engines (LRE) are complex systems composed by several sub-systems (feed system, cooling system, combustion chamber, etc.) that need to be designed conjointly [1]. The purpose of the LRE is to provide the thrust to a launcher. Its design directly impacts the specific impulse (Isp), which is the driving parameter in the mission analysis, but also the overall mass of the launcher which is strongly affected by the propellant mass. The development of suitable tools for the design and optimization of LRE, linked with the overall launch system design, is of primary importance to reduce the cost of future space launchers. Multi-disciplinary analysis and optimization (MDAO) permits to solve complex coupled optimization problems under constraints involving several inter connected sub-systems. MDAO approaches have been successfully applied to aeronautical and space systems [2,3,4], including LRE [6,7], but there is no example available in the literature of generic MDAO tools for LRE, considering categorical variables for the optimization (propellant, cycle, ect.).

Goals of the internship

The objective of the present research project is the development of a system analysis tool for LRE, named LAST-PROP (launcher analysis sizing tool – propulsion) based on a MDAO model. LAST PROP has been developed in the framework of previous student's research projects and in its current form describes a gas generator cycle based on the Vulcain 2 engine. LAST PROP includes 3 disciplines: combustion, feed system and cooling system. The optimization can be carried out with 3 input parameters: the oxidizer to fuel ratios of the main combustion chamber $(O/F)_c$ and of the gas generator $(O/F)_{gg}$ and the pressure chamber p_c . The objective function is either the dry mass of the propulsive system m_d (to be minimized) or the *Isp* (to be maximized).

Work plan

- *Bibliography* on LRE cycles and MDAO approaches;
- *Learning:* use of the actual version of LAST PROP.
- *Development*: integration of a continuous formulation for the combustion discipline, providing analytical derivatives, making use of the PyCycle framework [5];
- *Development*: implementation of different LRE open and closed cycles (expander, staged combustion, full flow …) and generalization to different propellants. Comparison against available data;
- *Development*: integrating a variable atmospheric pressure which allows to carry out an optimization over a whole trajectory. Development of a variable thrust to control the trajectory and in particular to land.
- *Results*: for a specific target mission, use the developed framework to carry out an optimization for a virtual LRE considering, as additional inputs, two categorical variables, namely the propellant and the cycle.

Team

The internship will be at the SaCLab (Space Advanced Concept Laboratory) in the DCAS department at ISAE SUPAERO. The intern will collaborate with 3 other students working on LAST PROP in other projects and with one PhD student working on surrogate models for coaxial injectors. The work is carried out in collaboration with ONERA (L. Brevault and M. Balesdent).

[1] Sutton,G.P.,andBiblarz,O.,RocketPropulsionElements,7thEdition,Wiley-Interscience,2000.

[2] J. R. R. A. Martins, "A short course on multidisciplinary design optimization", http://mdolab.engin.umich.edu/sites/default/files/Martins-MDO-course-notes.pdf, 2012

[3] L. Brevault, M. Balesdant and S. Defoort, "Preliminary study on launch vehicle design – applications of Multidisciplinary Design Optimization methodologies", Concurrent Engineering: Research and Applications, SAGE Publications, 2017, 26 (1), pp.1-11.

[4] J. S. Gray, J. T. Hwang, J. R. R. A. Martins, K. T. Moore and B. A. Naylor, "OpenMDAO: An open-source framework for multidisciplinary design, analysis, and optimization". Structural and Multidisciplinary Optimization, 2019

[5] J. Gray, J. Chin, T. Hearn, E. Hendricks, T. Lavelle and J.R.R.A.Martins "Chemical-Equilibrium Analysis with Adjoint Derivatives for Propulsion Cycle Analysis", *J. Prop. and Power* , 2017.

[6] G. Cai, J. Fang, X. Tong, J. Chen and J. Wang, Optimization of System Parameters for Liquid Rocket Engines with Gas-Generator Cycles, *J. Prop. Power*, 26:1, 2010

[7]M.J.Montazeri and R. Ebrahimi « Multidisciplinary optimization of a pump–fed system in a cryogenic LPE using a systematic approach based on genetic algorithm », *Aero. Sci. and Tech.*, 49, p185-196, 2016

STUDENT PROFILE

Master 2 student.
Skills: Basics in LRE. Basic in optimization under constraints. Python scripting.
Soft skills: autonomy, innovation, curiosity.