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ROBUST TRANSIENT CONTROL OF REUSABLE LIQUID-PROPELLANT ROCKET ENGINES

Abstract

The current trend towards a more affordable access to space is generally materialising in reusable launchers and engines. From the control perspective, these reusable liquid-propellant rocket engines (LPRE) imply more demanding robustness requirements than expendable ones, mainly because of their multi-restart and thrust-modulation capabilities.

Classically, the control system handles LPRE operation at a finite set of predefined points. That approach reduces their throttability domain to a restricted interval in which they are designed to be safe in nominal conditions. Moreover, transient phases, which have a great impact on the duration of engine life, are not robustly operated. Hence, the goal of this work is to develop a control loop which is adapted to the whole set of operating phases, transient and steady-state, and which is robust to modelling uncertainties and to external-conditions variations.

Several blocks have been assembled to constitute the control loop: engine simulation, reference generation, controller and estimation. First, a simulator representative of the gas-generator-cycle (GG) *Vulcain 1* engine was built. That is the main target cycle because *Prometheus*, the potential engine application of these studies, is of this type. Nevertheless, the approach is not restricted to it.

The purely thermodynamic modelling of the engine was subsequently adapted to the control framework, obtaining a nonlinear state-space model. The considered states consist in shaft rotational speeds, pressures and mass flows. The available actuators are continuously-controllable valves, a binary igniter and a binary starter. These actuators are related to discrete events in transient phases. Regarding start-up, the igniter, starter and valves are activated during the first seconds. Up from the end of those activations, the whole system behaves in a fully continuous way.

Hence, there is a different control strategy for each sub-phase. The first and discrete sub-phase presents a discrete optimisation of events timing, in which the time differences between events are adapted according to operation criteria and constraints. This trajectory planning is performed off-line as a function of internal and external conditions. The subsequent continuous sub-phase is feedback controlled to track a pre-computed reference state. A model-based control method, Model-Predictive Control, has been applied in a linear manner with robustness guarantees to this complex system, which must respect a set of hard state and control constraints.

Tracking of pressure (thrust) and mixture-ratio operating points within the design envelope is achieved in simulation while respecting constraints. Robustness to perturbations and to variations in certain parameters is also demonstrated.