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Corresponding author: PARAVAN Christian
e-mail of corresponding author: christian.paravan@polimi.it
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Title
Liquid Film Cooling: Open-Literature Review, Modeling and Efforts Towards Validation

Authors
Federico GIAMBELLI [1], Riccardo BISIN [2], Enrico BRAGALLI [3] and Christian PARAVAN [4]*

** Corresponding author*
[1]Research Fellow, Space Propulsion Laboratory (SPLab), Via La Masa 34, federico.giambelli@mail.polimi.it
[2]Post-Doctoral Research Fellow, Space Propulsion Laboratory (SPLab), Via La Masa 34, riccardo.bisin@polimi.it
[3]Master Thesis Student, Space Propulsion Laboratory (SPLab), Via La Masa 34, enrico.bragalli@mail.polimi.it
[4]Assistant Professor, Space Propulsion Laboratory (SPLab), Via La Masa 34, christian.paravan@polimi.it

Abstract
Liquid Rocket Engines (LREs) have always embodied a preeminent role in thermo-chemical propulsion, largely employed in multiple applications: from space access to in-space propulsion. Depending on the mission type, these engines feature different thrust classes and burning times. The basic principle of functioning relies upon the conversion of enthalpy (generated from combustion) into kinetic energy via a gas-dynamic nozzle. As an effect, large heat fluxes are developed in the thrust chamber, with its peak at the throat region, hence the need for a cooling technique implementation [1].

Film cooling is one of the possible solutions being first studied by [2–4]. Recently, most efforts on this topic are reviewed by [5], with detailed numerical and experimental analyses reported in [6, 7]. The underlying mechanism lies in the interposition of a thin coolant layer (I.e. fuel) to protect the chamber wall beneath. Transpiration and slow diffusion of the film in the core stream are exploited, persisting in the form of a protective layer [5]. For this aspect, liquid film cooling (LFC) is generally preferred with respect to gaseous film cooling (GFC), being more effective due to the aggregation state transition. Focusing on liquid film cooling, one of the crucial aspects is the determination of its maximum possible extension, namely the Film Cooled Length (FCL), at which the thin layer still endures in the liquid state. In this framework, the thrust chamber walls are safely protected, with their temperature far below the core stream one. The governing physical mechanism is primarily based on heat and mass transfer occurring at the film interface. The liquid coolant is consumed by the enthalpy exchanged via forced convection and radiation, transferred from the propellant stream [8]. Additional coolant mass may be lost due to a possible entrainment mechanism, as an effect of the shearing nature of the core stream which destabilizes the film [9].

This paper aims to provide an extended revision of already-existing analytical models for film cooling [8], simulating lab-scale tests and comparing their results in terms of protected length (FCL). The fundamental principle foresees tracking the evolution of a one-dimensional thin liquid layer along the longitudinal axis of the engine, under the influence of a high enthalpy core stream. Eventually, the extended model is deeply validated with a vast data set, including results deriving from experimental campaigns.

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