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INVESTIGATION OF INTEGRATION OF ANNULAR FIN CONFIGURATION AND GEOMETRY FOR IMPROVED THERMAL MANAGEMENT OF ROCKET NOZZLES: DESIGN, ANALYSIS, AND OPTIMIZATION

Abstract

Rocket nozzles are an intrinsic part of rocket propulsion that directly influences the efficiency of the rocket and the entire mission. These rocket nozzles are subjected to high temperatures up to 3500K. Thus it is evident that sophisticated cooling systems are required in order to prevent the nozzles from thermal breakdown. Conventional cooling systems like film cooling, regenerative cooling, ablative cooling, etc, require additional subsystems or components that ultimately lead to higher costs for this system alone. Moreover, as the cooling system is an independent unit, any malfunction in the control systems corresponds to a high chance of thermal breakdown of the nozzle. Thus, introducing an effective cooling system with high reliability and less cost of implementation will be highly beneficial.

In light of these challenges, the presented study was undertaken to evaluate the efficacy of incorporating small, protruding structures, referred to as fins, on the external surface of a rocket nozzle to enhance cooling performance. A comprehensive analysis was performed to evaluate the impact of different fin design profiles on thermal efficiency. A three-dimensional design and thermal analysis were performed utilizing the SpaceX MERLIN 1D engine as a reference. A prototype nozzle model was then fabricated from a stainless steel 304 billet and subjected to thermal testing. In this proposed research, The fin profile design was approached as a series of discrete annular fin systems, with each fin's profile and diameter altering in accordance with its location on the nozzle's exterior surface. A combination of finite element approximation and annular fin heat transfer computations were used to evaluate the cooling and heat transfer rate of the finned nozzle. The study's findings show an accelerating rise in the rate of heat transfer to about 36.5 percent from the nozzle's exterior without affecting the weight constraints of the nozzle and demonstrate the potential to cut the price and weight of cooling systems by more than 50 percent while simultaneously improving cooling prospects and nozzle performance in scorching environments.