

STUDIES ON FILM COOLING IN ROCKET COMBUSTION CHAMBERS

*A thesis submitted
in partial fulfillment for the degree of*

Doctor of Philosophy

by

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April 2013

ABSTRACT

Film cooling is applied extensively to surfaces that are exposed to hot combustion gases. A review of literature revealed that studies on film cooling process have concentrated mainly on film cooling applied to gas turbine airfoils. In this study, an extensive program of work has been undertaken to understand the gaseous and liquid film cooling process applicable to rocket combustion chambers. The film cooling performance of various gaseous and liquid coolant injector configurations are investigated experimentally. Measurements using coolant injector orifices of straight and compound angles in two orientations are obtained for the gaseous coolant. Tangential and compound angle orientations are examined for the liquid coolant. The data is analysed based on film cooling effectiveness and film uniformity calculations at different blowing ratios. Beyond the fundamental importance of these analyses, the gaseous film cooling data sets are used to validate computational models developed using CFD. The computational models are used to document all of the pertinent flow physics and heat transfer characteristics associated with the film cooling flow field.

Experimental results showed that in case of gaseous coolant injection, compound angle holes produced better film cooling performance compared to straight holes. However, increasing tangential angle of the compound injector did not improve the performance and in-fact led to a rise in wall temperature. It is observed from the numerical simulations that at higher tangential angles, better distribution of coolant around the circumference is offset by the increased heat transfer coefficients created by the secondary flow structures downstream of injection. A local maximum value for Nusselt number is observed in the regions where the flow reversal occurs. Conjugate wall cooling simulation with highly conductive walls showed reversed heat transfer from the surface to the gas in the nearby injection regimes. The analysis shows that highly conductive wall is not a proper choice for film cooling applications. In case of liquid film injection, compound angle holes produced higher performance only in the neighbourhood of injection.

A thorough analysis of the liquid film cooling process is carried out in the present work incorporating all associated phenomenon as is currently understood. The interfacial mass and energy balance is discussed in detail, together with the phenomenon of coolant transpiration, free-stream turbulence, film instability and the entrainment of the liquid by the gas stream. The limitations of the existing analyses are noted, and a new correlation procedure is suggested that is applicable to rocket combustion chambers operating at subcritical conditions. The results of this study show that the effect of coolant entrainment is significant. Therefore a numerical model is developed

to investigate the liquid-gas interface characteristics and the associated entrainment mechanisms. Simulation results indicate that the disturbance waves are present at the liquid-gas interface for coolant flows above a critical value and these waves are formed after a finite distance from the inlet. The distance toward the wave inception point increased with the increase of momentum flux ratio. The coolant film thickness and the disturbance wave characteristics are not much affected by the changes in pipe diameter. Analysis indicates that the disturbance are dynamic, continuously growing and eventually the wave crests are sheared off by the incoming gas phase causing entrainment. It is also observed that the turbulent flow features in the gas core have strong effects on the interfacial waves.

Together, the results of this study have enhanced the understanding of the film cooling process applicable to rocket combustion chambers and have laid the groundwork for higher effective film coolant injector orientations.