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ANALYSIS OF FREQUENCY RESPONSE CHARACTERISTICS OF PRESSURE-COUPLED LIQUID PROPELLANT VAPORIZATION PROCESS

Abstract

Combustion instability in liquid rocket engine has haunted the development of high-performance combustion since 1940s. The problem severely impairs engine operation and often leads to catastrophic consequences. In almost all liquid-fueled systems, propellants are delivered into the combustion chamber as a spray. Since droplet vaporization represents a rate-controlling process in the system, the dynamic behavior of spray combustion is essentially a statistical consequence of the vaporization characteristics of liquid propellants. An understanding of vaporization process is thus a prerequisite in treating combustion instability particularly low-frequency pressure oscillations known as chugging experienced during start-transient and shutdown in the Liquid Rocket Engines (LRE). Low-frequency stability of liquid-propellant rocket engines has been the subject of many analyses during the past two decades. The analytical models currently in use to predict stability limits have been evolved from the contributions of many researchers. In the present paper, stability limits for chugging behavior in LRE are determined for a 1-inch diameter sub-scale rocket engine. Liquid oxygen and gaseous hydrogen are used as propellants. Initially, stability boundaries are determined using the modified dead-time model that includes a discrete vaporization time for each propellant, plus a mixing and reaction time common to both propellants. In order to determine the stability boundary, the characteristic equation in the form of $1 + H(s)$ (where s is the Laplace operator) has been solved for the pressure drop experienced across the fuel/oxidizer sides (Injection pressure - Chamber pressure). A point on the stability boundary is determined by those values of $\frac{\Delta P_f}{P_c}$ and $\frac{\Delta P_o}{P_c}$ which yield one or more conjugate pairs of roots of the characteristic equation 1+H(s) that lie on the imaginary axis with the condition that no roots exist to the right of the imaginary axis. The stability boundaries are presented as loci of these points. The stable operating region lies above the boundary. Stable and unstable zones are identified with the experimental test data that shows stable and unstable operating conditions. The study has clearly brought out the relevance of droplet size and associated change in vaporization time in contributing stability to a cryogenic engine. These type of analysis can be a good tool to identify the stable and unstable operating conditions for LREs.