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BIGLOBAL INSTABILITY OF COMPRESSIBLE TAYLOR-CULICK FLOW

Abstract

Most of large segmented grain solid rocket motors, such as Ariane V MPS, Space Shuttle SRB and Titan series SRM, exhibit low amplitude but sustained pressure oscillations at some working times. The resulting thrust oscillations are deleterious to performance of launcher and severely, resonate with natural frequencies of vehicle structure leading to failure of the program. Vortex shedding seems to be the major driving mechanism for these instabilities, strictly speaking the interactions between unsteady vortices created by the sheared flow and longitudinal acoustic modes of the combustion chamber.

Vortex shedding phenomena in solid rocket motors are divided into three forms: corner vortex, shedding from backward facing steps in the propellant profile; obstacle vortex, shedding from obstacles like inhibitors protruding into the flow; parietal vortex, shedding from unstable boundary layers at the burning surfaces. The information obtained from subscale hot and cold flow experiments seems to show that when the vortex shedding frequencies approach the frequencies of acoustic modes of the chamber, the resonance happens and the pressure oscillations appear.

The present paper focuses on the parietal vortex shedding case, which was latterly discovered in numerical simulations and validated in cold flow experiments afterward. In the theoretical aspect, a local non-parallel method and a biglobal method have been used to investigate the hydrodynamic instabilities of the internal flow of solid rocket motors (Taylor-Culick Flow). Some discrete eigen modes were found and the comparisons with experiments show a reasonable agreement. Due to incompressible linear Navier-Stokes equations adopted in previous literatures, the effects of sound were not included and the interaction between sound field and vortex shedding cannot be considered.

Compressible linear Navier-Stokes equations are introduced and the biglobal instability method is applied in this work. The resulting eigenvalue problems are solved by using a spectral collocation method. The results show that the eigen spectrums are also discrete and separated to sound part and hydrodynamic part. On the sound side, the eigenvalues are a little smaller than the classic values where no mean flow exists, and the mode shapes display the sound boundary layer effect obviously which plays an important role in estimating the total unsteady energy of solid rocket motors. On the hydrodynamic side, the mode shapes largely differ from those when incompressible linear Navier-Stokes equations were adopted, Partly owing to the boundary conditions used at flow outlet are reflectible.