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The Use of Optimization Techniques in the Calculation of Dynamic Loads Due to Random Vibration Environments in Rocket Engine Systems

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Summary

An important part of rocket engine design is the calculation of the dynamic loads that act on the engine. These loads can greatly influence the weight of engine components and thus affect overall engine performance, so it is important to be able to calculate them as accurately as possible. Recent NASA engine programs have indicated the need for improved methodologies for calculating the dynamic loads due to random noise excitation sources in the engine. The major dynamic forces acting on a rocket engine are the result of extremely complex processes inside the engine such as combustion pressures, fluid flow, etc. These loads are random in nature and because of their complexity cannot be quantified with enough precision to allow a true dynamic response analysis to be done. That is, we can't simply take an engine system finite element model, apply these forces as functions of time or frequency, and calculate the response because we don't know what the forces are. However, it is possible to measure the accelerations at various locations on the engine during a hot-fire test. These accelerations (or, in the case of a new design, accelerations from testing of a similar engine) can then be used to define a dynamic environment for the engine in the form of acceleration power spectral density functions at specific points in the engine. The problem then becomes one of trying to reproduce the engine environment by exciting the engine system in some way. There are several ways of doing this including direct enforced acceleration methods in which enforced accelerations are imposed at the points in the engine where the environments are defined, system equivalent applied force methods in which we seek to determine a set of applied forces that will reproduce the measured environment as closely as possible, and component methods in which loads are calculated on a component by component basis. This paper discusses the advantages and disadvantages of each method and then presents an equivalent force method in which the equivalent forces are derived using a gradient-based optimization approach. The equivalent applied loads include cross-correlation between locations and are derived so as to minimize the difference between the accelerations resulting from the applied forces and the specified acceleration environment but with the conservative constraint that these accelerations always exceed the environment. The method has been applied to the J2-X rocket engine currently being designed as the upper stage

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engine in the new NASA Ares lunar launch vehicle. The numerical results indicate that the optimization approach yields more accurate values for the loads in major engine components than the other methodologies.