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A NOVEL APPROACH TO COOLING AND SERVICE LIFE EXTENSION IN REUSABLE ROCKET ENGINE THRUST CHAMBERS

Abstract

Reducing engine maintenance burdens will be crucial to improving the cost efficiency of future reusable launch vehicle operations. One method to reduce engine maintenance is to extend the service life of critical components, such that intervals between maintenance for such components can be increased. Previous studies have indicated that thrust chamber wall ligaments are among the components in liquid rocket engines which fail most often. These components typically fail due to temperature-dependent failure modes, specifically creep deformation and thermal ratcheting. Thus, the high temperatures inside the thrust chamber are likely contributing factors to thrust chamber wall ligament failure. Reducing the temperature at the wall may mitigate or delay the onset of failure due to creep deformation and thermal ratcheting.

Typically, liquid rocket engines are cooled using regenerative cooling: cryogenic fuel is pumped through channels in the thrust chamber walls to remove heat. However, the hot gas side of the wall is still exposed to extreme temperatures from the combustion reaction. In some cases, film cooling (the generation of a fuel-rich fluid layer at the wall to reduce the wall temperature) is also used to cool the hot gas side of the wall. However, this method is known to reduce specific impulse. A new method for cooling the hot gas side of the wall is therefore proposed. Reducing combustion temperature itself will result in a flow-on effect of reduced temperature at the wall. Combustion temperature can be changed by modifying the oxidiser to fuel mixture ratio at which the engine operates. A simple preliminary analysis applied to the RL10 rocket engine indicated that the maximum wall temperature could be reduced below the creep threshold by altering the oxidiser to fuel mixture ratio, with a subsequent small (4.1%) loss in thrust, and a negligible change in specific impulse.

This study expands upon the preliminary analysis, using the Reusable Sounding Rocket engine currently under development by JAXA's Institute of Space and Astronautical Science as a case study. Numerical simulations of combustion, exhaust nozzle flow, thrust chamber wall heat transfer and cyclic creep deformation have been conducted. The operation of the Reusable Sounding Rocket engine was simulated at a wide variety of mixture ratios. Film cooling was also simulated for comparison to the proposed mixture ratio control method for cooling the wall ligaments. The impacts on engine performance and component service life were then investigated based on the simulation results.