論 文 の 内 容 の 要 旨

論文題目　Reusable Rocket Engine Thrust Chamber Life Extension Analysis
（再使用ロケットエンジン燃焼室の寿命延長に関する考察）

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Extending the life of thrust chambers is considered crucial to improving the reusability of RLVs. Since the mid-1970's many studies have focused on analysing, testing and extending thrust chamber life. Many concepts and solutions for extending thrust chamber life have been proposed in the decades since. However, these concepts and improvements tend to focus on the design of the thrust chamber: using better materials, developing better structures, and so on. It is also important to consider the operating conditions to which the thrust chamber is exposed.

The aim of this study is to identify which operating conditions affect thrust chamber life and engine performance, and how these operating conditions have an effect. The reusable rocket engine developed at ISAS/JAXA is used as a case study to investigate this problem. A preliminary analysis of all possible variables which could affect thrust chamber life or engine performance was undertaken.　Through a logical process of elimination and a sensitivity analysis, five variables were identified as potentially having an effect on either engine performance, thrust chamber life, or both. These variables are cooling channel pressure, cooling channel flow rate, mixture ratio, propellant flow rate and combustion pressure. It was established that combustion pressure and propellant flow rate are intrinsically coupled. Thus, they were treated as a single variable.

To investigate the effects of these operating conditions in detail, a model was developed to simulate engine performance and thrust chamber life. The engine plant model comprises CFD models for the thrust chamber and cooling channels, and simple analytical models for all other components. A structural model for the thrust chamber wall was sourced from a NASA study. The structural model accounts for three failure modes: plastic instability, low-cycle fatigue and creep deformation. These models were integrated together and used to analyse the effects of varying the

above-mentioned operating conditions individually. The models were also used to determine the limits of engine operation.

The results of this analysis indicate that coolant pressure has only a marginal effect on plastic instability & creep deformation, and no significant effect on low-cycle fatigue. Coolant flow rate has similar negligible effects, with the notable exception of its effect on maximum wall temperature. If coolant flow rate is significantly reduced, the maximum wall temperature may increase above the creep threshold for the thrust chamber wall material. This in turn dramatically increases plastic deformation and reduces thrust chamber life. Both mixture ratio and combustion pressure were found to be effective methods of reducing heat flux into the thrust chamber wall, thereby reducing thermal loads and extending life. Such improvements usually lead to losses in engine performance, however. For example, by reducing propellant flow rate, it was assessed that a 50% increase in thrust chamber fatigue life could be achieved. However, this would also reduce engine thrust by 16%, and specific impulse by 3%.

An optimization of the above-mentioned operating condition variables was conducted, to improve thrust chamber life as much as possible without sacrificing engine performance. This optimization determined that life could be extended by 18.3–26.6% (depending on the failure mode being considered) without any loss in thrust or specific impulse. A sensitivity analysis was conducted on these results by relaxing the specific impulse requirement. By relaxing the specific impulse requirement by 3.6%, thrust chamber life could be extended by 24.3–38.5% (depending on the failure mode being considered) over the baseline value.

The key findings of this study include the importance of finding the “critical failure point” in the thrust chamber, the effectiveness of regenerative cooling for thrust chamber life extension, the effect of changing mixture ratio on gas properties, temperature and wall heat transfer, and the trade-off between mixture ratio and propellant flow rate in terms of both engine performance and thrust chamber life. Generally speaking, some of the qualitative results of this study can inform future reusable liquid rocket engine thrust chamber design. Specifically, key findings related to the location of the critical failure point, the effect of mixture ratio on heat transfer, and the trade-off between mixture ratio and combustion pressure (in terms of thrust chamber life and engine performance) are applicable to other engine designs. Future work will focus on improving the models developed for this project, investigating critical failure point location in more detail, quantifying the effects of mixture ratio on thrust chamber heat transfer for a variety of propellant types, and investigating previously-proposed design improvements for reusable rocket engine thrust chambers.