論 文 の 内 容 の 要 旨

論文題目　Characteristics of Combustion and Lean Blowout Limit in a Double Swirl Burner for a Bio-Jet Fuel

(ダブルスワールバーナーにおけるバイオジェット燃料の燃焼および希薄吹き消え限界特性)

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High demand for air transportation leads to future usage of new ultra-lean technologies paired with alternative fuels, which often show differences in properties compared to conventional jet fuels. These variations can lead to differences in combustion limits and combustion behavior, causing inappropriate influence onto stable operation of a jet engine, ending in malfunction or even damage of the system. Therefore, this research aims to explore experimentally differences in atomization and combustion behavior between conventional petroleum-derived Jet-A1 fuel and bioderived “Hydrotreated Esters and Fatty Acids” fuel (HEFA) in a non-premixed configuration of a dual swirl prefilm airblast injector, with the emphasis on physical properties.

Although, there exists several experimental data of different jet fuels used with different injector designs, Jet-A1 and Hydrotreated Ester and Fatty Acids were not compared in a dual swirl prefilm airblast injector yet, therefore it is one of this work’s original contribution to knowledge. The used analyzing methods in this study are well known, but the combination of the gathered experimental data and their analysis of characteristic combustion time in a jet engine model combustor has not been conducted, yet. Additionally, the difference in lean blowout of the two liquid fuels has not been addressed in a dual swirl prefilm airblast injector, especially not in regards to the fuels’ characteristic combustion time, hence it is another original contribution to knowledge.

To analyze if the difference in physical properties between Jet-A1 and HEFA influence atomization, droplet size measurement via Interferometric Laser Imaging for Droplet Sizing

(ILIDS) system were conducted. For the comparison of evaporation rate, both fuels were tested via single droplet experiments in a microgravity drop tower facility. The results showed no measurable difference in initial droplet size between Jet-A1 and HEFA in the used airblast injector. Evaporation rate showed significantly higher values for the tested biofuel of about 10%. Droplet size measurement at elevated heights from the injector during combustion showed slightly smaller droplets for HEFA compared to Jet-A1, confirming a better evaporation process.

Experiments at ambient condition and near jet engine condition with 630 K inlet temperature paired with 0.5 MPa pressure were conducted to test the stability limits of both fuels. HEFA showed in both cases strong advantages over Jet-A1 in Lean Blowout Limit. Several airflow rates were tested at ambient condition and the differences between the two fuels correlated well with the difference in evaporation rate. Optical observation with a high-speed camera and a CH* chemiluminescence filter showed nearly constant lift-off height over the whole tested condition in the ambient case. Detections of droplets close to initial droplet size near the flame leading edge indicated strong non-premixing conditions, which stabilized the flame at the same position for all tested cases. Jet engine condition showed on the contrary a remarkable difference, with Jet-A1 staying nearly constant at a specific lift-off height and HEFA moving further downstream when changing the condition close to LBO. Reason was given to the stronger evaporation rate of HEFA, which transformed the flame from non-premixed to premixed flame, lifting further off, due to possible lower laminar flame speed of the global condition, where the Jet-A1 flame was still stabilized by droplets like in the ambient condition cases. Pressure signal analysis of near jet condition experiments revealed a periodic fluctuation of both fuels near LBO at a frequency of approximately 120 Hz, which was identified as Helmholtz mode. Simultaneous observation of spray via Mie Scattering showed HEFA with a substantial longer characteristic combustion time of 1.55 ms than Jet-A1. This increased time delay correlated well with an additional convection time due to the increased lift-off height in HEFA and was therefore indirectly linked to the faster evaporation. Timescale analysis let to the assumption, that evaporation rate is the dominant factor for the lean blowout in ambient and near jet engine condition, which was shown by the LBO results. In both conditions, the difference in LBO limit between the two fuels exceeded the difference in evaporation rate, indicating an additional contributor, assumed to be the difference in calorific heat value.

The results of this research imply, that utmost care needs to be taken when developing new ultra-lean combustion technologies for multi-fuel usage. Well established fuels were used in this work to indicate, that known fuels with a small difference in evaporation rate can lead to a shift in flame position, with an accompanying increase in characteristic combustion time. Although not observable in this work, such an additional delay can lead to different periodic fluctuation or other combustion instability phenomena.