초청강연

Recent research activities on hybrid rocket in Japan

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ABSTRACT

Hybrid rockets have lately attracted attention as a strong candidate of small, low cost, safe and reliable launch vehicles. A significant topic is that the first commercially sponsored space ship, SpaceShipOne vehicle chose a hybrid rocket. The main factors for the choice were safety of operation, system cost, quick turnaround, and thrust termination. In Japan, five universities including Hokkaido University and three private companies organized "Hybrid Rocket Research Group" from 1998 to 2002. Their main purpose was to downsize the cost and scale of rocket experiments. In 2002, UNISEC (University Space Engineering Consortium) and HASTIC (Hokkaido Aerospace Science and Technology Incubation Center) took over the educational and R&D rocket activities respectively and the research group dissolved. In 2008, JAXA/ISAS and eleven universities formed "Hybrid Rocket Research Working Group" as a subcommittee of the Steering Committee for Space Engineering in ISAS. Their goal is to demonstrate technical feasibility of lowcost and high frequency launches of nano/micro satellites into sun-synchronous orbits.

Hybrid rockets use a combination of solid and liquid propellants. Usually the fuel is in a solid phase. A serious problem of hybrid rockets is the low regression rate of the solid fuel. In single port hybrids the low regression rate below 1 mm/s causes large L/D exceeding a hundred and small fuel loading ratio falling below 0.3. Multi-port hybrids are a typical solution to solve this problem. However, this solution is not the mainstream in Japan. Another approach is to use high regression rate fuels. For example, a fuel regression rate of 4 mm/s decreases L/D to around 10 and increases the loading ratio to around 0.75.

Liquefying fuels such as paraffins are strong candidates for high regression fuels and subject of active research in Japan too. Nakagawa et al. in Tokai University employed EVA (Ethylene Vinyl Acetate) to modify viscosity of paraffin based fuels and investigated the effect of viscosity on regression rates. Wada et al. in Akita University employed LTP (Low melting ThermoPlastic) as another candidate of liquefying fuels and demonstrated high regression rates comparable to paraffin fuels. Hori et al. in JAXA/ISAS employed glycidylazide-poly(ethylene glycol) (GAP-PEG) copolymers as high regression rate fuels and modified the combustion characteristics by changing the PEG mixing ratio.

Regression rate improvement by changing internal ballistics is another stream of research. The author proposed a new fuel configuration named "CAMUI" in 1998. CAMUI comes from an abbreviation of "cascaded multistage impinging-jet" meaning the distinctive flow field. A CAMUI type fuel grain consists of several cylindrical fuel blocks with two ports in axial direction. The

port alignment shifts 90 degrees with each other to make jets out of ports impinge on the upstream end face of the downstream fuel block, resulting in intense heat transfer to the fuel. Yuasa et al. in Tokyo Metropolitan University employed swirling injection method and improved regression rates more than three times higher. However, regression rate distribution along the axis is not uniform due to the decay of the swirl strength. Aso et al. in Kyushu University employed multi-swirl injection to solve this problem. Combinations of swirling injection and paraffin based fuel have been tried and some results show very high regression rates exceeding ten times of conventional one.

High fuel regression rates by new fuel, new internal ballistics, or combination of them require faster fuel-oxidizer mixing to maintain combustion efficiency. Nakagawa et al. succeeded to improve combustion efficiency of a paraffin-based fuel from 77% to 96% by a baffle plate. Another effective approach some researchers are trying is to use an aft-chamber to increase residence time.

Better understanding of the new flow fields is necessary to reveal basic mechanisms of regression enhancement. Yuasa et al. visualized the combustion field in a swirling injection type motor. Nakagawa et al. observed boundary layer combustion of wax-based fuels. To understand detailed flow structures in swirling flow type hybrids, Sawada et al. (Tohoku Univ.), Teramoto et al. (Univ. of Tokyo), Shimada et al. (ISAS), and Tsuboi et al. (Kyushu Inst. Tech.) are trying to simulate the flow field numerically. Main challenges are turbulent reaction, stiffness due to low Mach number flow, fuel regression model, and other non-steady phenomena. Oshima et al. in Hokkaido University simulated CAMUI type flow fields and discussed correspondence relation between regression distribution of a burning surface and the vortex structure over the surface.