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ADVANCED CHEMICAL PROPULSION AT NASA LEWIS: METALLIZED AND HIGH ENERGY DENSITY PROPELLANTS

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ABSTRACT

Two of the programs at the NASA Lewis Research Center investigating advanced systems for future space missions are the Metallized Propellant Program and the Advanced Concepts Program. Each program includes both experimental and theoretical studies of future propellants and the associated vehicle impacts and significant payload benefits for many types of space transportation.

METALLIZED PROPELLANT PROGRAM

The technologies for using metal additives to increase engine specific impulse (I_{sp}) and propellant density are being developed. Metallized propellants can be customized to increase I_{sp} and reduce the tankage mass and the dry mass of the propulsion system to increase the vehicle performance. Typically, aluminum particles are suspended in a gelled fuel: hydrogen, RP-1, or monomethyl hydrazine. Over the last year, a series of vehicle systems analyses and experimental programs were conducted to identify the best applications for metallized propellants and demonstrate the technologies of propellant formulation and combustion.

Vehicle and System Performance Studies

Piloted missions to Mars and the Moon can derive several benefits from using metallized propellants instead of traditional chemical propellants. Using metallized $O_2/H_2/Al$, a piloted Mars mission can deliver 20 to 33 percent additional payload to the surface (Ref. 1). Propellants such as NTO/MMH/Al and O_2/MMH/Al can provide Earth- and space-storable options for a Mars ascent stage of a manned Mars mission. The higher boiling point of these propellants minimizes or eliminates propellant boiloff losses. The mass penalty for using these propellants over O_2/H_2 is minimal. The storability advantage of these metallized propellants is gained with only 3 to 5 percent additional mass in LEO (Ref. 1).

On lunar cargo missions using $O_2/H_2/Al$ instead of O_2/H_2, the added payload delivered is only a modest 2 to 3 percent (Ref. 2). This option does not demonstrate a large gain for metallized propellants, but the lunar mission might be used as a testbed for future more ambitious Mars missions.

For upper stages propelling robotic planetary missions, metallized $O_2/H_2/Al$ and NTO/MMH/Al have very significant potential, especially for high-energy fast planetary missions (Ref. 3). On an outer planet flyby, metallized propellants for an STS-C compatible upper stage can deliver 28 percent more injected mass onto a planetary trajectory (with an injection energy (C_3) of 150 km^2/s^2). For a Jupiter orbiter mission, an upper stage using NTO/MMH/Al can deliver 97 percent more injected mass than NTO/MMH (at a C_3 of 80 km^2/s^2).

Other high-density propellants for the Advanced Launch System were also analyzed (Ref. 4). Using metallized hydrocarbon propellants, significant increases in density and I_{sp} over non-metallized fuels are possible. With JP-10/Al and RJ-5/Al, the I_{sp} increases are 5.9 and 4.9 lb_f-s/lb_m, respectively.

Experimental Program

The spray characteristics of gelled propellants are being analyzed with cold flows of propellant simulants. The metallized fuel simulant is gelled water and the simulated "oxidizer" is nitrogen. A laser sheet illuminates the spray and helps identify the structure of the thixotropic gellant flow. By understanding the differences between the gelled and the non-gelled simulants will help understand mixing in the combustion chamber and potentially find ways to improve combustion efficiency.

Batches of RP-1/Al are now readily producible in large (gallon) quantities. The rheological properties of small batches of RP-1/Al have been characterized by Aerojet and TRW (Refs. 5 and 6) and there are no longer any barriers to scaling up production of this metallized fuel to that needed for space missions.

Experimental hot-firings of a subscale O_2/RP-1/Al engine are continuing at NASA Lewis (Ref. 7). A calorimeter chamber is being fabricated to determine the heat fluxes to the combustion chamber and nozzle. These experiments will aid the development of a combustion model for metallized propellants.

Cryogenic gellants for metallized fuels are being formulated and demonstrated at TRW, Inc. Fuels such as propane, methane and hydrogen may be important for future NASA launch vehicle and space transfer systems. Using silica-based gellants, hexane and propane have been gelled with and without added aluminum. The ultimate goal of this work is to gel hydrogen with a 60-percent aluminum loading (by mass).

University Research Program

The Pennsylvania State University is continuing their aluminum combustion research (Ref. 8). In this part of the program, the velocity and diameter of aluminum oxide agglomerations are measured using a laser sizing system and velocimeter. Approaches to reducing the formation and promoting the breakup of these agglomerations are of great importance to metallized propellant engine performance. Particle agglomerates reduce the predicted specific impulse of the rocket engine because of two-phase flow losses. Breakup of these agglomerations will minimize these losses.

ADVANCED CONCEPTS FOR CHEMICAL PROPULSION

In the Advanced Concepts Program at NASA Lewis, high energy density propellants are being studied. Both theoretical and experimental work is directed toward understanding methods of storing atomic hydrogen at high densities for launch vehicle and upper stage propulsion. At densities of 15 percent of atomic hydrogen (by mass) in solid hydrogen, a specific impulse of 750 lbf-s/lbm is possible. At this performance level, an atomic hydrogen launch vehicle can provide a 52- to 58-percent Gross Lift-Off Weight (GLOW) reduction over the Advanced Launch System using O_2/H_2 propulsion (Ref. 9). Additional vehicle, feed system and performance studies are underway to define the methods of using atomic hydrogen in an operational propulsion system.

University Research Program

The University of Iowa has completed a study of the specific impulse and energy density of over thirty high energy density materials, such as C_5 and Li_3H (Ref. 10). An important result of this survey was that many potential propellant materials exist with specific impulses between 500 and 600 lb_f-s/lb_m. Several newly-considered materials may produce performance levels near 1000 lb_f-s/lb_m.

Experiments studying the potential storage density of atomic hydrogen are underway at the University of Hawaii. The experiments include measurements of the thermal and optical energy release during atomic hydrogen recombination. Computer modelling of atomic hydrogen in a solid molecular hydrogen storage medium is also underway.

Other planned activities are the study of high field magnets for the long-term storage of atomic hydrogen and other free-radical propellants. Additional experimental work at the Lawrence Livermore National Laboratory will further analyze the energy distribution of atomic hydrogen recombinations.

CONCLUSIONS

Metallized propellant technology is a near-term option for potentially improving chemical propulsion performance. Significant payload increases are predicted and greater safety is enabled with gelled metallized propellants. Promising developments in propellant formulation, combustion research and system analysis will be critical to the future technology readiness of metallized propellants.

Extensive additional technology development work is certainly required to bring high energy density propellants to fruition. Both atomic hydrogen and other potential candidates are being analyzed. Continuing studies and experiments will determine the feasibility of using these compounds for useful propulsion.

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