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HYBRID ROCKET PERFORMANCE

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A hybrid rocket is a system consisting of a solid fuel grain and a gaseous/or liquid oxidizer. Figure 1 shows three popular hybrid propulsion cycles that are under current consideration. NASA MSFC has teamed with industry to test two hybrid propulsion systems that will allow scaling to motors of potential interest for Titan and Atlas systems, as well as encompassing the range of interest for SEI lunar ascent stages and National Launch System Cargo Transfer Vehicle (NLS CTV) and NLS deorbit systems (1). Hybrid systems also offer advantages as moderate-cost, environmentally acceptable propulsion system. The objective of this work was to recommend a performance prediction methodology for hybrid rocket motors. The scope included completion of: a literature review, a general methodology, and a simplified performance model.

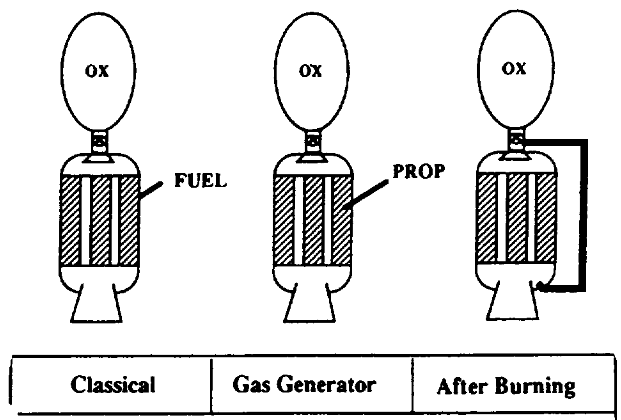

Figure 1. Hybrid Rocket Propulsion Cycles

A literature review team was established with three Master's students in conjunction with the University of Alabama in Huntsville. The literature review produced 450 citations on hybrid rocket motors and related technologies. From these, the team selected 120 papers for closer evaluation. The papers were catalogued and referenced. The following topics were examined in detail: Hybrid Rocket Performance, Hybrid Rocket Flight Vehicles - History, Hybrid Rocket Combustion Modeling, and Hybrid Rocket Testing Methodology. The results of the review are being developed into a lecture series that will be delivered at MSFC this fall entitled "Rediscovering Hybrids".

Hybrid rockets look like a combination of a liquid and a solid rocket. The hybrid rocket can borrow oxidizer tank, feed system, and injector technology from the liquid rocket. They also can use propellant grain, case, and nozzle hardware technologies from solid rockets.

However, when considering the internal combustion phenomena; liquids, solids, and hybrids are very different. Figure 2 compares the internal combustion phenomena of a liquid, solid, and hybrid rocket, and a solid fuel ramjet. In a liquid rocket, the fuel and oxidizer are essentially "completely" burned before they reach the entrance to the nozzle. In a solid rocket the gas phase combustion occurs within a millimeter of the propellant surface with only active metal droplet combustion occurring in the port or nozzle. For the hybrid rocket, the active combustion region is in the boundary layer above the fuel surface. The details of the combustion processes are important in the hybrid because they control the fuel production rate. The hybrid rocket really looks like a solid fuel ramjet when considering the internal combustion processes.

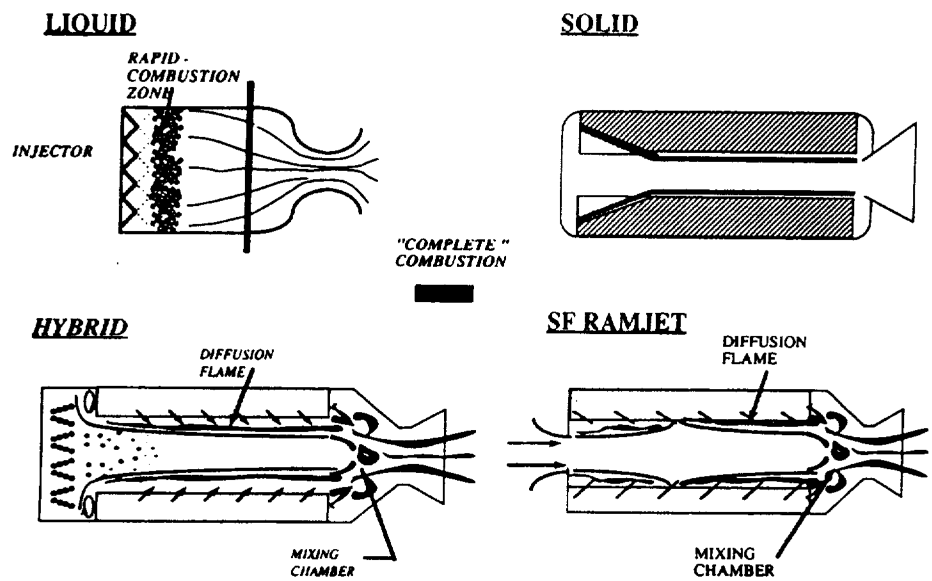

Figure 2. System Comparisons - Combustion Phenomena

The key performance analysis areas for a hybrid rocket are injector analysis, fuel regression rate analysis, grain evolution, mixing efficiency, and nozzle erosion rate. For a complete analysis, each of these areas must be coupled to an internal flowfield analysis. In simplified solutions, they are assumed to be uncoupled.

A general methodology for hybrid rocket performance would consist of three areas: a performance predictor, CFD analyses, and testing. An efficient performance program is required to make design trade studies and for the evaluation of test results. This predictive capability should embody, in a simplified form, the results of CFD analyses and testing. The performance predictor should be efficient enough that trade studies on particular parameters could be performed in a mater of hours. This would allow the designer to gain understanding of the underlying principles that are controlling the motor operation. CFD analyses and testing must be designed to provide essential global parameters to be used in the performance predictor.

Based on these premises, a very simple performance analysis code was developed for hybrid motors. The analysis had the following assumptions: 1) uniform gaseous oxygen injection, 2) fuel regression controlled by oxidizer mass flux, 3) multiple circular ports, 4) constant nozzle erosion rate, 5) a combustion efficiency of 0.95, and 6) one-dimensional equilibrium in the chamber an nozzle.

A PC version of the One Dimensional Equilibrium Code with Transport Properties (ODETRAN) (2) was modified to perform the thermochemical calculations. A sensitivity study was performed on product species to reduce the thermal property data deck by 171 species so that ODETRAN can now run practical problems on a personal computer. This effort also produced a TM applications document entitled "Running ODETRAN for Rocket applications.

This simple analysis method was programmed on a spreadsheet. The spreadsheet allowed input of the number of ports, port length, characteristic velocity as a function of oxidizer-to-fuel ratio, and a transient oxygen flow rate. Once the program was checked out, a concept study for the National Launch System (NLS) was performed.

Figure 3 shows the concept that was investigated. The hybrid motor would be mounted on top of the NLS stage-and-a-half booster. Residual oxygen from the booster tank would be "blown down" through a multi-port hybrid rocket motor. This low-cost concept could fulfill the total impulse requirements of 585,000 $lb_f sec$ to deorbit the stage. Using the spreadsheet and the results of the ODETRAN analysis, a concept was developed that has 30 ports, 750 pounds of fuel, a 36-in. length, and 517,000 $lb_f sec$ of total impulse. Figure 4 show results of the analysis. A graph of the oxidizer mass flow, motor oxidizer-to-fuel ratio, and thrust as a function of time are plotted. Also, the characteristic velocity as a function of oxidizer-to-fuel ratio is shown.

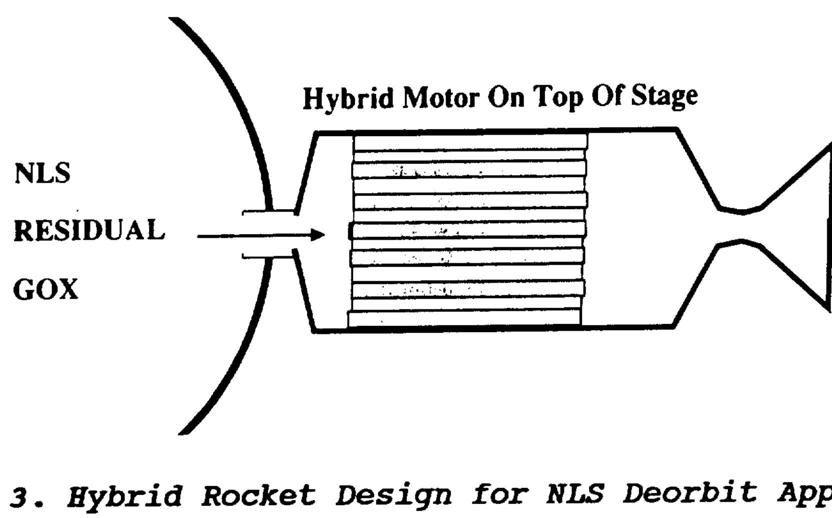

Figure 3. Hybrid Rocket Design for NLS Deorbit Application

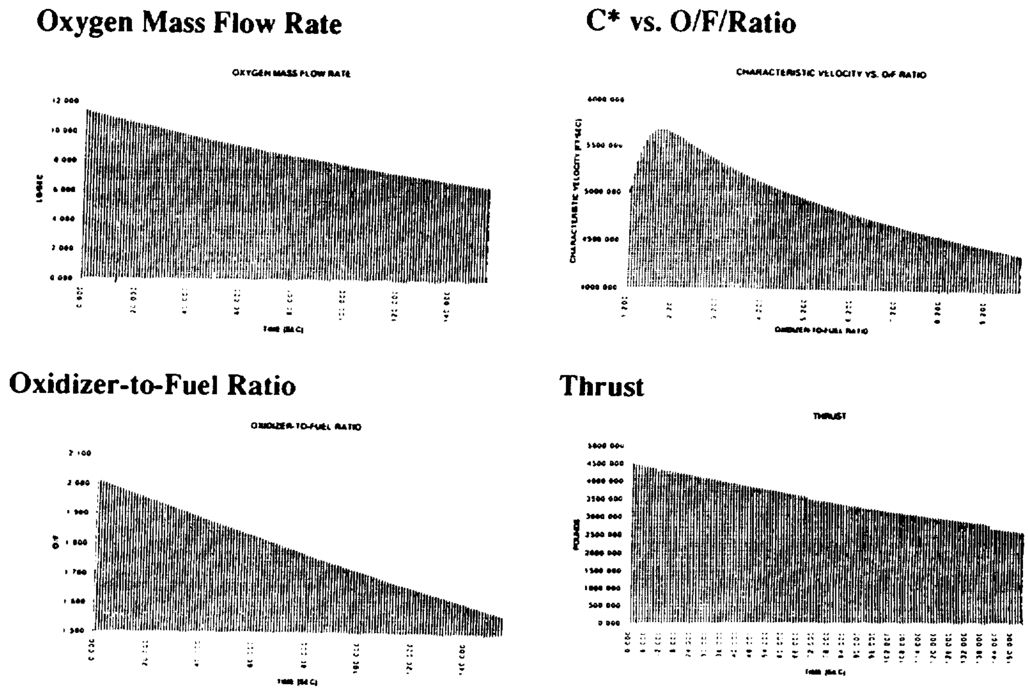

Figure 4. Results of Analysis of NLS Hybrid Deorbit Motor

The conclusions of this work are as follows: 1) the literature indicates moderate existing capability in hybrid ballistics, 2) thinking must be expanded to include performance tools from solid fuel ramjets, 3) component ballistic analyses must be coupled to the internal flowfied analyses, 4) mixing efficiency and nozzle/insulator erosion analyses for hybrids are slightly beyond existing practice, 5) a general performance methodology should embody results of CFD analyses, test data, and general ballistic analysis, and 6) concept studies can be performed with a simple spreadsheet program.

1. Goldberg,B. and Cook, J.,"Preliminary Results of NASA/Industry Hybrid Propulsion Program," AIAA 92-3299, AIAA/SAE/ASME/ASEE 28th Joint Propulsion Conference, Nashville, TN July 6-8, 1992.

2. Maser,K.,"ODETRAN-One-Dimensional Equilibrium and Transport Properties Program, Ver. 2.0," NASA MSFC, Users Document, Prepared for K.Gross/EP53/MSFC.

3. Greiner,B and Frederick,R.A.,Jr.,"Results of Labscale Hybrid Rocket Motor Investigation," AIAA 92-3301, AIAA/SAE/ASME/ASEE 28th Joint Propulsion Conference, Nashville, TN July 6-8, 1992.