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Interdependent Figure-of-Merit Software Development

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This program was undertaken in order to understand the complex nature of interdependent performance in space missions. As the *first step* in a planned sequence of progress, a "spread sheet" program has been developed to evaluate different fuel/oxidizer combinations for a specific Martian mission. This program is to be linked with output attained using sophisticated software produced by Gordon and McBride. The data must be input by hand at this time. The programming to date makes use of 11 independent parameters. While the work is somewhat developed, some modifications such as the inclusion of aerobraking, in-situ propellant, output presentation, and automation of the data feed are still necessary. The program should prove to be quite valuable, even under its early stages of development.

Optimization is essential when faced with the incredible magnitude of costs, risks, and benefits involved with space exploration. We must decide not only what to use, but how to utilize it most effectively. Making the most of what we have and what we find is the essence of our NASA Center. A system of weights needs to be devised on which to measure our options. It is the goal of this work to devise a Figure of Merit (FoM) on which different choices can be presented and made (Fig. 3.1). The plan is to model typical missions to Mars, identify the parameters, and vary them until the best one is found. Initially, most of the focus is placed on propellant selection.

There has been some work done in the past and some currently under investigation which will prove crucial to our goals. Dr. Frisbee at JPL has been working on autonomous oxygen and carbon monoxide production from the Martian atmosphere for a number of years. He has provided his most current papers on the subject. They include the modeling information for power requirements, production rates, and system mass breakdown. There is a group willing to provide us with very reliable incremental velocity requirements for many different scenarios. There is a group in Austin, Texas, who have been doing feasibility studies for different lunar missions. They have neglected some important parameters regarding propellant selection, but their input still may prove useful. The tasks ahead are open for investigation.

The study utilizes current spread sheet technology and effectively demonstrates how changing a single parameter influences the feasibility of a mission. An IBM PC is currently being used to run LOTUS 123 Version 201. The plan is to keep the programming simple at first, building on the complexity with time. The first run of the program is for a specific mission, starting at LEO, making a landing on Mars, and from

- INDIVIDUAL FIGURES OF MERIT MISLEADING

  - Specific Impulse

  - Energy Density

  - Expansion Ratio

  - . . . .

- OVERALL MISSION IMPACT IMPORTANT

- MULTIVARIABLE PARAMETRIC PROBLEM

- EACH PARAMETER AFFECTS OTHERS

- COLOR-CODED QUANTITATIVE DISPLAY IS BEING DEVELOPED

  - I_{sp}, Transport, Energy Use (T, E), Storage, Refrigeration Needs, Products,

    . . . .

  (Recall Successful LP Program)

Figure 3.1. "Figure of merit" optimizations.

there placing a given payload into a Martian satellite orbit. The rocket staging was developed from the velocity requirements using Newton's laws and a minimum-energy transfer. This approach will utilize CET 86, Gordon and McBride's software for unconventional fuel performance. The current input parameters are made up of those placed on the fuel/oxidizer combination, the nozzle, the structural mass coefficient (tanks, pumps, refrigeration units, motors, etc.), and the payload itself. To date, they include the selection of the fuel and the oxidizer, whether the expansion is modeled as frozen or equilibrium flow, the mixture ratio, the chamber pressure, the ambient pressure, the expansion ratio, the nozzle's material density, its average thickness, the structural coefficient, and the payload mass. From this information, some useful quantities are found for each stage of the rocket and for the vehicle as a whole. They are made up of the following: exhaust velocities, mass flow rates, vehicular thrusts, throat areas, exit plane areas, nozzle coefficients, payload coefficients, initial masses, final masses, structural masses, fuel/oxidizer masses, and FoM. Currently, the FoM for each stage, as well as for the vehicle, is defined as the total initial mass divided by the mission payload. This will be modified to include risk, reliability, support hardware, etc. The real beauty of this approach to programming is the ease of immediate updating of the results.

To date, some runs have been accomplished. The last two months have been spent developing the basic logic for the program. A few additional parameters must be examined before the more visual aspects of the work can be effectively presented. The first is automating the data entry. All changes in the input have been entered by hand; a more efficient manner is under investigation. The LOTUS software is equipped with "macros" which allow complex, yet tedious tasks to be performed. The results should prove to be very powerful, especially when considering that over ten thousand points of propellant data have already been generated using CET 86. Having a subroutine to enter the data into the main program is not only feasible but also necessary for computer processing. The next step is to include an "aeroshell" in the model. The huge mass savings will prove to be a major factor in the minimization of the FoM. It will also make the mission profile much more realistic. Once these tasks have been accomplished, the real motivation for this initial spread sheet can be more effectively explored. In-situ propellant production will also start off simply, with the extraction of oxygen from the Martian atmosphere. These additions will make the data more presentable, both to those interested in finding an optimal solution and to others interested in viewing families of curves generated from other output data.

The research and complexity of the program are developing at a steady rate. The first major run of the spread sheet will come after the inclusion of "aerocapture" into

the model. The basic program will continue to evolve. The FoM must also contain a reliability factor. Leakage rates for all Earth-carried oxygen need to be included. The structural factor needs to be calculated using fuel density, chamber pressure, and cryogenic requirements. The different possibilities for in-situ propellant production must be examined. Oxygen can be produced from the atmosphere or from the polar ice cap. Other possibilities include hydrocarbons from water and CO_2. Further complexities will enhance the value of the work but will slow the computation speed. I have been in communication with the people at LOTUS regarding their Version 3; it is due to be released in the second quarter of 1989. Their newsletter claims that it meets their goals for speed and performance and, "123 Release 3 features significant power and performance enhancements including true three-dimensional spreadsheets, external database access, new recalculation techniques and graphics and printing improvements." We should be able to purchase an upgrade of the current version for about $200 and run the software on either of the SUN386i computers currently at the Center. The three-dimensional version would be a very useful means of storing both inputs and outputs.

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