Visitor Research Report

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Area of Research: **Advanced Earth-to-Orbit Concept Development**

Period of Visit: **June 1, 2009 – August 21, 2009**

Context description:

Currently, spaceflight is very expensive compared to other methods of transportation. The costs of access to space can be lowered significantly by using a fully reusable launch vehicle capable of re-launching within a couple of days. However, for reusability to be effective at reducing costs, maintenance between flights must be kept to a minimum. Two main factors that influence maintenance requirements are system complexity and robustness. System complexity can be reduced through design simplification enabled by application of advanced technologies. Reducing the number of vehicle stages required to achieve orbit at reasonable take-off mass is an example of this. Designing vehicle systems and components that have design limits that are much higher than required for the operating environments (large operating margins, i.e., robustness) can also result in substantially reduced maintenance needs. Large operating margins have not been applied yet, since large penalties in mass and size would result for launch vehicles designed with current technologies. New technologies (i.e. nuclear propulsion and carbon nanotubes) that might reduce the launch vehicle mass and size can also be used to increase operating margins and enable efficient reusability. Research is needed to develop these technologies to the level that they can actually be implemented. Due to budget limitations, choices need to be made regarding investments in new technologies. Technologies that lead to large reduction in overall vehicle mass and complexity are worth the investments. A model is needed that can identify the effect of the new technologies on the total vehicle. Such a model exists for a single-stage-to-orbit, rocket-propelled concept. This simplified performance model determines the effect of changes in two of the most important vehicle performance parameters, $(T/W)_{sys}$ and Isp, on the vehicle mass. In this model it is assumed as an approximation that the required delta-V to get to orbit is independent of these engine parameters. To make the model more accurate, the relation between the engine parameters and the required delta-V needed to be determined.

Goal: To determine the effect of the specific impulse and the thrust-to-weight ratio of the launch vehicle on the required delta-V to get to a low Earth orbit (LEO).

Strategy: The Launch trajectory of a reference vehicle with different combinations of specific impulse and thrust-to-weight ratio is optimized (lowest delta-V), resulting in a delta-V budget for that combination. Next an equation is derived that fits these predicted delta-V nicely. A combination of two optimizers are used. First, a genetic optimizer looks for a near optimum trajectory. Then, a gradient optimizer fine-tunes the trajectory to obtain the optimum trajectory and the accompanying delta-V requirement. The trajectory that is optimized consists of a vertical acceleration, an uncontrolled gravity turn, and a controlled gravity turn followed by a Hohmann transfer for orbit insertion.

Accomplishments: A relation was derived based on the model's output. The following conclusions can be drawn from the relation:

- Ideal DV increases as Isp increases and (T/W)sys decreases
- Sensitivity to Isp is highest at low (T/W)sys
- Sensitivity to (T/W)sys is highest at high Isp
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Future Work: This relation can be used to make the mass and size estimation model more accurate. Future projects might improve the model even more. Further, it is also possible to make the relation more accurate by looking at different types of launch trajectories.

Pending Publications: None

Seminar Presented: '*Single Stage to Orbit Launch Trajectory Optimization'* on August 20, 2009 at NIA and NASA Vehicle Analysis Branch Meeting.