

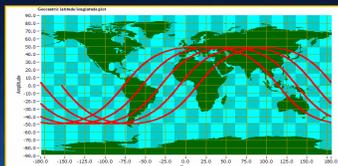
Propulsion Systems Integration into an Aero-Assist Orbital Transfer Vehicle

Patrick Jolley
 Utah State University
 4130 Old Main Hill
 Logan, Utah 84322
 prjolley@cc.usu.edu

Dr. Stephen Whitmore
 Utah State University
 4130 Old Main Hill
 Logan, Utah 84322
 swhitmdr@engineering.usu.edu

California Space Grant Foundation
 INTEGRATION - FACILITATION - INNOVATION

Known Fixed Orbits



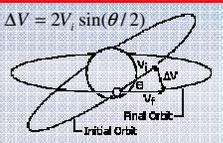
The Need for Responsive Space

Responsive – Ability to respond within hours
Maneuverable – Have maneuverability to rapidly achieve any Earth-centered orbit
Operable, Economical, Survivable, Flexible
 * 2001 AFSPC ORS MNS
Currently -
 - Easy for hostile forces to predict the footprint of orbiting platform
 - Space Shuttle can change inclination only by few tenths of a degree



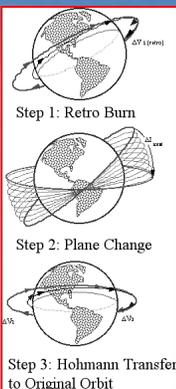
$$\epsilon_{orbit} = -\frac{\mu}{2a_{orbit}} = -\frac{\mu}{2a_{orbit0}} + \frac{\text{Energy added}}{m \text{ satellite}}$$

Cost of Orbital Agility



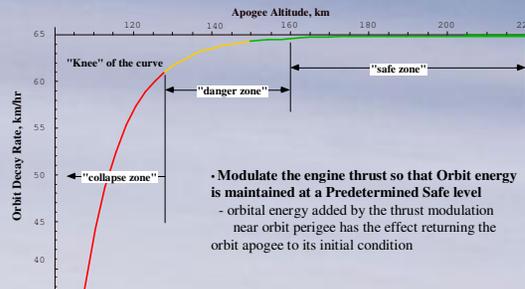
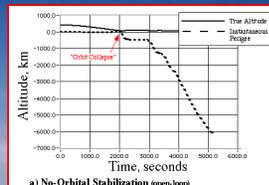
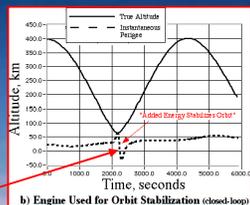
Because of the high energy associated with LEO, a purely propulsive maneuver requires almost as much energy as was used during launch.

The aero-assist maneuver takes advantage of the aerodynamic lift vector to change the inclination of the orbit.



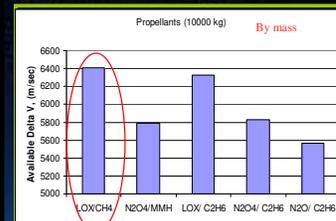
Key Needed Technologies

- 1) High L/D Hypersonic Airframe Configurations
- 2) Sharp Leading Edges and High Temperature Leading Edge Material
- 3) Precision Restartable, Deep-Throttled Orbital Maneuvering Engines

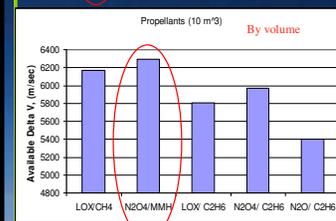


Modulate the engine thrust so that Orbit energy is maintained at a Predetermined Safe level - orbital energy added by the thrust modulation near orbit perigee has the effect returning the orbit apogee to its initial condition

Propellant Choice: N₂O₄/MMH



When selecting propellants it is usually best to pick the propellant with the highest Isp. The higher the specific impulse the lower the mass required to achieve the required mission delta-v.
 LOX/CH₄ has an Isp of 365 sec

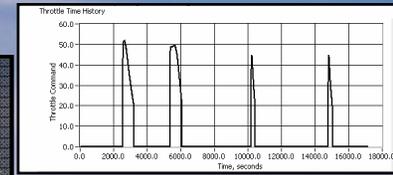


Waveriders are more likely to be constrained by their available volume than mass due to their slim vehicle design and low packaging factor.
 N₂O₄/MMH has an Isp of 330 sec

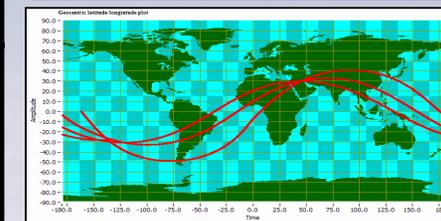
Additionally, N₂O₄/MMH is hypergolic - meaning it ignites upon contact and it has the advantage of storability for years without a cooling system to prevent boil off.

Results

Each aero pass will require a different amount of thrust from the engine to overcome the energy loss due to drag. Additionally, different amounts of throttling can change the way the spacecraft will enter its next pass.



Aero-Assisted Modified Orbit

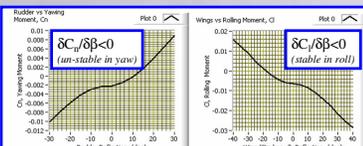
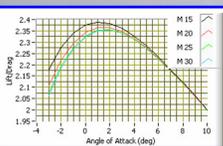
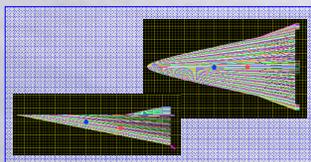


Three successive overhead passes occurring in different time intervals.

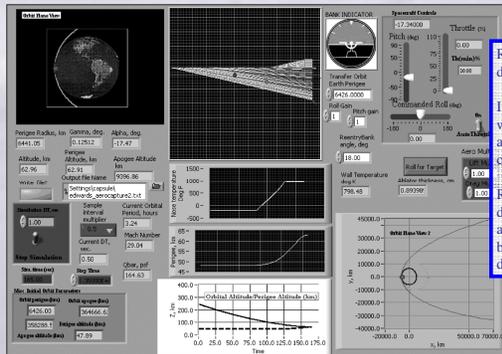
Making A Conical Power Law Waverider Fly

The waverider was equipped with control surfaces like wings, rudder, and elevator to make the vehicle flight worthy. There is sufficient control authority for trim flight.

A 6 DOF aerodynamic database was generated using incidence angle techniques and modified Newtonian flow theory.



Simulation Model



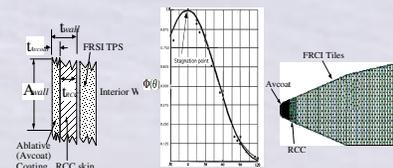
Results were generated by a USU 3 degrees-of-freedom (DOF) simulator

Interactive simulations allowed for a wide variety of trajectories to be analyzed and compared for all flight configurations.

Real time feedback of heating, deceleration, and orbital state allowed for a rapid response and better understanding of the affects of different parameters.

Future Work

- Thermal Modeling
- Solid Modeling
- Mass Budgets
- Hybrid Propulsion System



As the vehicle enters the atmosphere, shockwaves compress the air in front of the vehicle, making the air hot enough to melt aluminum and steel. The vehicle must survive this blast of hot air. Ceramics, felt insulators, and special carbon based materials are typically used to protect against such high temperatures. Ablatives, which chemically react to absorb heat, were also used on Apollo. These thermal effects will be simulated using radiation, the Fay-Riddell method, and real-gas table lookups.