BENEFITS OF HIGH AERODYNAMIC EFFICIENCY TO ORBITAL TRANSFER VEHICLES*  

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An analysis of the benefits and costs of high aerodynamic efficiency on aeroassisted orbital transfer vehicles (AOTV) is presented. These results show that a high lift-to-drag (L/D) AOTV can achieve significant velocity savings relative to low L/D aerobraked OTV's when traveling round trip between low Earth orbits (LEO) and alternate orbits as high as geosynchronous Earth orbit (GEO). Trajectory analysis is used to show the impact of thermal protection system technology and the importance of lift loading coefficient on vehicle performance. The possible improvements in AOTV subsystem technologies are assessed and their impact on vehicle inert weight and performance noted. Finally, the performance of high L/D AOTV concepts is compared with the performances of low L/D aeroassisted and all-propulsive OTV concepts to assess the benefits of aerodynamic efficiency on this class of vehicle.  

*Work supported by U.S. Air Force Wright Aeronautical Laboratories and Boeing Aerospace Company.
Figure 1. Synthesis of Optimum AOTV Mission Scenarios

Figure 2. Effect of Vehicle L/D on Plane-Change Capability
OBJECTIVE
FLY OVER SAME SPOT ON EARTH IN TWO SUCCESSIVE ORBITS

RESULTS
\[ \Delta u = 0.00481 \left( x^2 \cos \phi \sin (\phi - \phi_0) \right) \]
OR
\[ \Delta u = 0.7377 \cos \phi \sin (\phi - \phi_0) \]
FOR \( h = 100 \text{ NMI} \)

PERTINENT FORMULA
\[ H = f + r \]
\[ \delta L = 2\pi f \theta (T_{24} / 24 \cos \phi) \]
\[ x = \delta \sin (\phi - \phi_0) \]
\[ x = A \theta \]
\[ \delta A = 2\pi f \theta (T_{24} / 24 \cos \phi) \sin (\phi - \phi_0) \]
WHERE:
\( \delta A = \) INSTANTANEOUS AZIMUTH CHANGE
\( \phi \) = LATITUDE
\( f \) = ORBIT INCLINATION
\( h \) = AVERAGE ORBIT HEIGHT
\( r \) = EARTH RADIUS
\( T_{24} \) = ORBIT PERIOD = \( 2\pi \sqrt{3} / H_{24} \)

MAXIMUM PLANE CHANGE OF 21.4 DEGREES FOR ZERO LATITUDE AND POLAR INITIAL ORBIT

Figure 3. Synergistic Plane-Change Maneuver for Ground-Based AOTV

Figure 4. Ground-Based AOTV Insertion Weight
Figure 5. Ground-Based AOTV Configuration

Figure 6. Space-Based AOTV Configuration
Figure 7. Inflatable Chine AOTV 5xGEO Reentry Trajectory Comparison

Figure 8. Space-Based High L/D AOTV Optimized GEO Reentry Trajectory
Figure 8. Space-Based High L/D AOTV Optimized GEO Reentry Trajectory (Cont’d)

Figure 9. Aeromaneuver in Velocity Space
Figure 10. Impact of Heating Constraints on Aero Plane-Change Capability

Figure 11. Impact of Heating Constraints on Reentry L/D Ratio

Figure 12. Synergistic Atmospheric Phase
Figure 13. Ground-Based Sortie Mission

\[ \text{INCL} = 67 \, \text{DEG}, \Delta A = 17.8 \, \text{DEG}, \chi = 18 \, \text{DEG}, L/D = 2.08, \Delta_{\text{MAX}} = 100 \, \text{BTU/ft}^2\,\text{SEC}, W/C_{\text{LA}} = 242 \, \text{PSF} \]
Figure 15. Space-Based Sortie Mission

- CONSTANT ANGLE OF ATTACK FOR L/D MAX
- 150 BTU/FT²-SEC MAXIMUM HEATING RATE
- 45 DEGREE PLANE CHANGE USING SPACE-BASED AOTV

Figure 16. Variation in L/D Max Over Synergistic Plane-Change Trajectory

Δ INC = 45 DEG, L/D_MAX = 2.65, \( \frac{W}{C_L A} \) INITIAL = 205 psf

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Figure 17. Space-Based Sortie Mission

Figure 18. Synergistic Maneuver in Velocity Space
Figure 19. Impact of TPS Technology on Space-Based AOTV

Figure 20. Round Trip GEO Mission Performance Comparison

Figure 21. Round Trip 5xGEO (Polar) Mission Performance Comparison
Figure 22. Round Trip 6-Hour Polar Orbit Mission Comparison

Figure 23. Synergistic Plane-Change Mission Performance Comparison