TRAJECTORY OPTIMIZATION TO DELAY TURBULENT TRANSITION FOR MARS ENTRY VEHICLE

ROMAN JITS, DAVID SAUNDERS

ELORET Corporation

e-mail: ryjits@gmail.com

In Mars entry aeroshell shape optimization study[1], the spherical-segment shape (Apollo-like) was found to have lower heating for all flight regimes, as compared to 70 degree sphere-cone. Taking advantage of wide entry corridor for higher L/D (with reasonably high C_D) of this shape, allows reduction of peak heating rate and dynamic pressure and provides potential to shape entry trajectory in order to delay transition to turbulence. It is believed that the transition delay could enable a significantly more mass-efficient heat shield design due to the possibility of providing a laminar flow regime for a large portion of the heat shield. To realize such a potential in this study, the momentum thickness Reynolds number (Re_θ) based constraint was constructed in Velocity-Altitude space, spanning flyable envelope, and implemented as a lower bound constraint into trajectory optimization. It was used to keep Re_θ below the critical value of 200 above the apex of the spherical segment, thereby tending to delay transition upstream of that location.

For spherical-segment shape flown with ballistic coefficient of 146 kg/m^2, the entry trajectories were optimized using *POST3D*[2] capabilities, seeking a bank control schedule such that target Mach 2.1 at 10 km altitude was met, while peak dynamic pressure was minimized and the Velocity-Altitude constraint was not violated. The nominal entry angle was chosen to be just 1.5 deg to the overshoot boundary. Such a choice was driven by the desire to exploit the advantage of the wider entry corridor provided by the spherical segment trimmed at L/D = 0.39. This decision is supported by experience from recent Martian entries[3], where the corridor width between nominal and overshoot trajectories was as small as 1 degree. Thus, a nominal trajectory with this shallow entry angle was designed and optimized to be flown above the implemented Velocity-Altitude constraint for the nominal entry conditions.

To test the robustness of thus developed nominal trajectory, it was re-simulated in the presence of multiple off-nominal factors. The CFD calculations for peak heating and peak dynamic pressure points were performed for one off-nominal trajectory, which had the highest resulting peak dynamic pressure among all off-nominal cases. The calculated CFD results showed that Re_θ were, indeed, below 200 over more than half of the heat shield for both of these critical points.

This approach promises delayed transition if applied to much larger Mars entry vehicles, up to 100 MT, provided that they have similar heat shield configurations and ballistic coefficients around 140-150 kg/m^2. Similar methodology could be also applied to aerocapture trajectories for larger entry vehicles.

References

1. Jits, R., Saunders, D., “Aeroshell Shape & Trajectory Optimization”, Progress Report, NASA Ames Research Center, April 2008.
2. Striepe, S.A., Powell, R.W., et al, “Program To Optimize Simulated Trajectories (POST II)”, January 2004.
3. Private communication with Bobby Braun, Associate Professor at Georgia Tech, July 2008.