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TERMINAL AREA GUIDANCE USING THE ENERGY TUBE CONCEPT FOR A WINGED RE-ENTRY VEHICLE

Abstract

Because the Terminal Area Energy Management (TAEM) guidance of the Space Shuttle relies on pre-flight computed reference trajectories stored in the on-board computer, there is a lack of robustness to off-nominal conditions. However, nowadays also several guidance studies are performed in which the trajectories are calculated on-board. In these guidance studies, it is common to use a fixed strategy, in terms of a nominal dynamic pressure profile, for the motion in the vertical plane. Moreover, in these studies, the maximum range is calculated using the angle of attack profile for maximum lift-to-drag ratio, while the maximum dive is calculating by assuming a flight at maximum dynamic pressure. Further, it is common to specify only one specific value for the minimum required energy to reach a specific target range. If a guidance system needs to be able to cope with off-nominal conditions, it is important to know the correct capabilities of the vehicle at every instant during the flight. This paper investigates optimal guidance strategies to perform a maximum range and a maximum dive flight, the required energy and the influence of off-nominal conditions on both the guidance strategies and the required energy.

The optimal trajectories are calculated for a reference vehicle similar to the Space Shuttle, the HORUS-2B. The optimiser used in this study is a genetic algorithm.

The optimisation results show that the maximum range is obtained by flying at a minimum drag. For a subsonic flight, the minimum drag path in the (V,h) space or energy space can be visualised by calculating contours of constant drag, using an equilibrium flight situation. If the vehicle starts at an initial state, which is not situated on the minimum drag path, transient maneuvers are performed to intercept the maximum range glide path. But if the vehicle starts at a supersonic velocity, the optimal solution does not follow the equilibrium minimum drag valley because the transient maneuvers have a large impact on the optimal maximum range trajectory of a winged re-entry vehicle with poor gliding capabilities at supersonic velocities. The maximum range strategy differs significantly from the solution using the angle of attack profile for maximum lift-to-drag ratio.

The optimal strategy for a maximum dive using the HORUS is to fly at a minimum dynamic pressure, because this yields the largest drag. This is in contrast to a dive at maximum dynamic pressure.

The above strategies are valid for all off-nominal conditions, but the obtained dynamic pressure profile differs for different initial states. Hence, if the guidance algorithm needs to be able with off-nominal conditions, it is not possible to use only one reference profile.

Although several combinations of altitude and velocity are possible that yield the same total energy, the obtained maximum range differs. Hence it is not possible to only specify the minimum required energy for a specific target range, but it is also necessary to specify the corresponding combination of altitude and velocity. This leads to the energy tube concept. A cross-section of the energy tube contains all the combinations of altitude and velocity for which it is possible to fly a desired range. The larger the cross-section, the more off-nominal conditions the vehicle is able to deal with.

The optimal strategies and the energy tube concept can be extended to the complete TAEM by incorporating turning flights. The energy tube concept can be used in an on-board planning and guidance algorithm that is able to cope with off-nominal conditions.