Ascent Trajectory Guidance for an Impulsive Orbit Injection

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Abstract

The ultimate objective is to inject a satellite into a target orbit with the required inclination and eccentricity, at the required perigee altitude of the target orbit. The orbit injection is performed by means of a last stage of a launcher vehicle, with prescribed thrust time-history and characteristic speed but with no control on the thrust intensity, direction, and interruption; thus an impulsive transfer approach is used to model the orbit injection. The appropriate fixed longitudinal attitude of the launcher vehicle along the last stage as well as the burning start-up time of this stage are calculated (pointing algorithm) and set up during a Keplerian trajectory (coasting phase) with attitude control capability, between the end of the previous ascent stage and the start-up of the orbit injection stage, already after leaving the Earth's atmosphere. Using the impulsive transfer model and the conservation of energy and of angular momentum along the Keplerian trajectory, the required conditions at the end of the previous ascent stage are deduced starting from the required parameters of the target orbit and the characteristic speed of the orbit injection stage.

This work presents a method for the trajectory guidance in the ascent stage, with the goal of the fulfillment of its required end conditions. One purpose is to reach the dynamic conditions appropriate for further performing the required plane geometry of the target orbit. Another purpose is to reach the required inclination of the target orbit already at the end of the ascent stage. The ascent stage is a solid-propellant stage with control on the thrust direction. The guidance method uses the ongoing actual dynamic conditions data provided by the on-board navigation system and the expected performance data available from ground tests for the ascent stage engine. The engine actual performance is also assessed during the flight and may be used to adjust the expected performance data, following the criterion and procedure established for the eventual adjustment. The actual inertial position and velocity data are used to identify the ongoing flight plane inclination. Using spherical trigonometry and a piece-wise linear approximation, the necessary azimuth change and the consequent yaw attitude program are established in order to achieve the required inclination at the end of the ascent stage. The pitch attitude program is established by means of a gradient-type iterative optimization method in order to achieve the required dynamic conditions at the end of the ascent stage. A best timely solution is produced in a periodical basis. For the pitch program, each periodical solution becomes the initial guess for the next periodical search procedure which, combined with an adjustable control step size, enhances the convergence to the solution. Both theoretical and algorithmic aspects are included.

Key features of the developed guidance method are its capabilities of mitigating the effects of dispersions in the thrust performance of the ascent stage engine. An additional end of stage condition is set in order to shape the trajectory as it approaches the end, so that the end requirements are satisfactorily fulfilled if the actual burnout time diverges from the expected one. Special state variables are set based on the end conditions, enhancing the requirements fulfillment capability in the case of an earlier burnout. After the expected burnout time, the control law is changed in a way to preserve the attained end conditions even in the case of the existence of any remaining amount of burning propellant.

Following the above concepts, a software prototype was built to enable the assessment of the guidance method. The prototype was set to run within an existing flight simulator which simulates the dynamics and flight attributions of a target launcher vehicle. This simulation arrangement provides appropriate conditions for a fair assessment of the guidance method. Diverse test cases have been run with variations on the input target orbit requirements and on the input actual performance of the ascent stage engine. In all test cases, a suitable solution has been achieved through the guidance method, and the predicted orbit injection has been further accomplished by the flight simulator.

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The results testify the suitable performance and reliability of the proposed guidance method. The yaw guidance model is effective yet simple. For the pitch guidance model, the usual convergence difficulties in dealing with gradient-type applications are overcome by using periodical feedback and adjustable control step size. The features of mitigating the effects of dispersions in the engine thrust performance proved to be effective; they are worthwhile mainly for solid-propellant stages.

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