MANEUVERS AROUND JUPITER WITH AUTOMATIC CORRECTION OF THE TRAJECTORY CONSIDERING GRAVITATIONAL DISTURBANCES GENERATED BY THE GALILEAN MOONS: IO, EUROPA GANYMEDE AND CALLISTO

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Abstract:

This study aims to evaluate the influence of the gravitational attraction of the Sun, Io, Europa, Ganymede and Callisto, during orbital maneuvers of a spacecraft orbiting Jupiter. In the simulations some constructive aspects of the propulsion system were considered. Initially ideal thrusters, capable of applying infinite magnitude of the thrust, were used. Thus, impulsive optimal maneuvers were obtained by scanning the solutions of the Two Point Boundary Value Problem (TPBVP)) for various values of transfer time in order to select the maneuver of minimum fuel consumption. Then, the selected maneuver was simulated considering a more realistic model of the propulsion system. In fact is not possible to accomplish an impulsive maneuver because to perform this kind of maneuver it would be necessary an infinite capacity for the thrusters, because the entire velocity change of the spacecraft should occur instantly. Thus, the orbital maneuver must be distributed in a propulsive arc around the position of the impulse given by the solution of the TPBVP. In this arc was used a continuous thrust, limited to the capacity of the thrusters. However the effect of the propulsive arc is not exactly equivalent to the application of an impulse due to the errors in magnitude and direction of applied thrust. The difference between these approaches produces a deviation in the trajectory. The evaluation of deviation is extremely relevant in the mission analysis and spacecraft design of the trajectory control system. Therefore, the influence of the capacity of thrusters in the trajectory was evaluated for a more realistic model instead of the ideal case represented by the impulsive approach. Thus, initially the bi-impulsive maneuver, which consists of finding the transfer orbit that connects a point on the initial orbit to another point in the final orbit spending a certain amount of time, is accomplished. An algorithm for solving this problem by universal variables was used. Then, the optimum maneuver is selected and simulated using the Spacecraft Trajectory Simulator (STRS). In the STRS the orbital movement is obtained by the solution of Kepler's equation for each simulation step. Thus, given an initial state, the Keplerian elements are obtained and propagated to the next step, to be converted into the new state. In the STRS simulator, the reference state is defined by guidance subsystem providing the ideal trajectory to be followed, according to the solution of the TPBVP. This reference is continuously compared with the current position of the vehicle generating an error signal, which is inserted into proportional-integral-derivative controller, generating a signal capable of reducing errors in transition and stationary regimes. This signal is sent to the actuators to generate a signal to be applied in the dynamics model of the movement, added to the disturbing signal due to the gravitational forces of the Sun, Io, Europa, Ganymede and Callisto. Therefore, the evolution of the vehicle can be simulated and analyzed.

Due to the impossibility of application of an infinite thrust the orbital maneuver must be distributed in a propulsive arc around the position of the impulse determined by solution of the TPBVP. In this propulsive arc continuous thrust is applied, limited to the maximum capacity of the thrusters. However, the effect of the propulsive arc is not exactly equivalent to the application of an impulsive thrust. The difference produces a deviation in the final orbit with respect to the reference orbit. To minimize this deviation, the flight angle formed between the direction of the velocity and the thruster pointing direction, could be maintained near to zero by controlling the pointing direction of the thruster, ensuring that the thrust is always applied in the direction tangential to the path. However, this solution is more complex because it requires the use of the attitude control system, and in fact, this approach is not capable to reduce the error in the final orbit reached by the vehicle.

Therefore, to optimize the propulsive maneuvers distributed in an arc it must be considered the optimization procedure for orbital maneuvers with continuous thrust. However this optimization procedure is a difficult task, since in most of the cases it requires numerical methods and the definition of initial values for obtaining the solution. A simple possibility to minimize the effect caused by the error in the thrust direction would be executing the maneuver in several stages, each one applying just a fraction of the total velocity increment, to reduce each propulsive arc and thereby reduce the flight angle. In this case the error in the trajectory is minimized but the total *time spent to reach the final orbit is maximized, characterizing a problem of multi-objective optimization with conflicting objectives. Another possibility to minimize the error in the trajectory after the application of the main thrust could be the use of an automatic correction of the orbital elements using continuous low thrust controlled in closed loop. In this approach, the final orbital elements are defined, then control loops for each of these elements determine, at each step of the simulation, the magnitudes and directions of application of thrust necessary to reach the desired orbital elements. The variations of elements occur gradually until the difference between the current and reference signals do not generate errors. Then, the propulsion system is turned off automatically.*

To illustrate the necessity of split the maneuver in several propulsive arcs, or use the automatic correction approach, some cases are studied. Hence this work represents an effort in the design of the propulsion system of space vehicles. It was confirmed that the effect of a propulsive arc is not exactly equivalent to the application of an impulse. The difference produces a deviation of the final orbit relative to the reference orbit. This deviation depends on the magnitude of the impulse required for the maneuver, the maximum capacity of the propulsion system and the characteristics of the trajectory control system. The evaluation of the trajectory deviations is relevant to the analysis of a space mission and in the design of the trajectory control system if a more realistic model is considered instead of the ideal case represented by the impulsive approach. The automatic correction of the orbital elements, which utilizes an innovative approach to reduce the errors in the spacecraft path, controlling the continuous thrust in closed loop, was tested with success in the presence of some environmental perturbation forces.

Keywords: *Astrodynamics, Orbital Maneuvers, Continuous Thrust, Automatic Correction*.