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Optimization out-of-orbit plane changes using aeroassisted maneuvers

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Abstract

The problem of optimizing the fuel consumption needed for orbital maneuvers is investigated. The normal to the orbit components of the atmospheric drag and lift forces are obtained. The temporal variations in the inclination using Lagrange planetary equation are derived, then are integrated over one revolution. A numerical example is given. The velocity variations required to perform the propulsive maneuvers due to engines on board the satellite are calculated. The performance gain using aerodynamic forces combined with propulsive ones is achieved. The comparison between the totally propulsive maneuvers and partly propulsive with atmospheric maneuvers are illustrated and discussed.
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1. Introduction

Plane changes are very expensive in terms of the required change in velocity and resulting fuel consumption. This situation motivated the specific technical development of orbital maneuvers using natural forces, replacing at least in

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part, propulsive forces. One of the natural forces that plays a crucial role in plane changes is that depends on the existence of an atmosphere. The maneuvers that use the atmosphere to modify a space vehicle velocity are referred to as "aeroassisted maneuver". The function of the atmosphere is to reduce the vehicle velocity causing an orbit transfer that can be coplanar or not.

It has been established, since 60s, that a substantial performance gain could be reached using aerodynamical forces together with the propulsive ones. Application examples for flight concepts related with aeroassisted maneuver include ballistic missiles, space probes (e.g. Gemini), lunar missions returned vehicles (e.g. Apollo) and the space shuttle.

The advantage of using the atmosphere is the fuel savings when compared with the equivalent exclusive propulsive maneuver. As an example, according to Miele [1], the fuel saving for a planar or quasi-planar aeroassisted transfer between a geostationary orbit and low Earth orbit can reach 60% of the fuel needed by Hohmann equivalent transfer. Atmospheric density variations, vehicle area-to-mass ratio, aerodynamical coefficients are the main causes of the deviations in the trajectory in vehicles entering the atmosphere.

2. Historical background

The study of the atmospheric maneuvers began in the mid-60s, when NASA started to think more seriously about a manned missions to Mars as the next step to the Apollo program. The Mars vehicle mass minimization was one of the project main goals. Therefore, the aerodynamic drag utilization, as the velocity reducer to provide the vehicle capture by the red planet was broadly studied and demonstrated a significant fuel economy that become initial to the project.

Wingrove [2] investigated several control methods for atmospheric crossing vehicles, and grouped them in three general classes (reference, prediction and closed form), in accordance with their advantages/disadvantages related with the initial conditions manipulation ability.

Walberg [3] compiled a survey of 33 other papers and technical notes about plane changes using aerodynamic and propulsive forces.

Mease [4] presented the state of art of the aeroassisted orbital transfer's optimization problem, emphasizing the fundamental principles that increase the knowledge with regard to this subject.

Calise [5], Hull et al. [6,7], Mease et al. [8], Miele et al. [9], Cochran et al. [10], Ma [11] and Mishne et al. [12] started to study several different approaches of the optimal plane change transfer problem using the atmosphere with closed-form and quasi-closed-form solution methods.

The modified TD88 thermospheric density model developed by Abd El-Salam and Sehnal [13] is used to estimate the performance gain that can be

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