Harnessing the Sun's Gravity for LEO to GEO Transfers

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The geosynchronous orbit (GEO) belt is in incredibly high demand, yet it requires a considerable amount of fuel to reach. Common launch sites for GEO satellites include Guiana Space Centre, Kennedy Space Center and Baikonur Cosmodrome. Without dog-leg maneuvers, the minimum inclination that may be reached are 5, 28.5 and 51° respectively. Therefore, for high latitude launch sites, a large part of the fuel budget is allocated for inclination changes (Δi). To minimize this additional cost, several strategies have been developed in the past, such as two-burn strategies where the Δi is optimally distributed over the two burns, three-burn bi-elliptic or super-synchronous transfers where the Δi is performed at high altitudes, etc.

In [1], a new strategy is proposed where the Δi and periapsis raise (Δr_p) from LEO to GEO is performed by third-body perturbations from the Sun. Transfers starting at a 51° inclined orbit have been found that require only 2.5% more ΔV than transfers from 28.5°. Hence, this technology facilitates flexibility in launch site selection to go to GEO. Such transfers depart LEO after an in-plane impulse in the velocity-direction to reach the required transfer orbit eccentricity and arrive back at periapsis at GEO altitude with the right inclination, after which another in-plane impulse in the anti-velocity direction re-circularises the orbit. Assuming the initial r_p and i are fixed, the design variables are time of year of launch, initial transfer eccentricity (e), argument of periapsis (ω) and longitude of ascending node (Ω). Every permutation of those four design variables result in different realizations for final r_p and final i. Given the size of the state space, and the sensitive maps between design variables and final r_p and i values, navigating the state space is not trivial.

In this paper, a robust way to find transfers for any time of year and initial orbit inclination is developed. For each time of year, with resolution one day, the combination of initial e, ω and Ω that satisfy the required Δi and Δr_p are determined for an orbit with 51° initial i. This means finding intersections between contour lines representing the correct Δr_p and correct Δi, at the smallest e they occur. By minimizing e, the required fuel to inject the spacecraft from LEO into its transfer orbit is minimized.

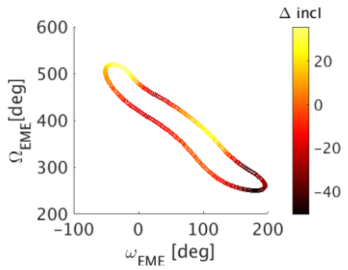

Fig. 1. Example Δr_p contour

The utilized method consists of two main steps. First of all, for a certain e, using a tangent-predictor, pseudo-arc length-corrector scheme [2], the required Δr_p contour shape is traced out [3]. An example of this can be found in Fig. 1. It has been observed that each of these contour shapes has four local minima of final i. The second step utilizes a slightly different predictor-corrector scheme to trace out the path of the four local minima on the Δr_p contour shapes through different values of e, without having to compute the entire Δr_p contour shapes. This step is repeated until a point has been found for which the final inclination is close to zero or a maximum e of 0.99 is reached. Finally, the design variables (e,ω,Ω) for the four local optima can be fed to the next day. This allows us to skip the first step and immediately trace out the minimum i on the contour surfaces. The lowest final i of the four families and its e are plotted in Fig. 2 for half a year.

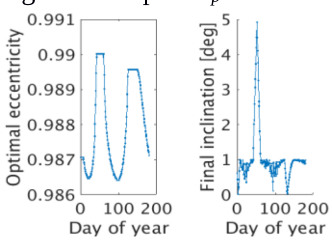

Fig. 2. Final results

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