GTOC 7

Solution Descriptoin for Team 2

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1. Description of Methods Used

Our approach consisted of parallel efforts using several types of tools and methods. In all efforts, the same main scenario was used. In this scenario, the mothership releases and captures all probes directly at the asteroids. The timeline of events for the mothership is always in the same order: release probe 1 at asteroid A, release probe 2 at asteroid B, release probe 3 at asteroid C, capture probe 1 at asteroid D, capture probe 2 and 3 at asteroid E. Where asteroids A-E are unique. This scheme was chosen in order to maximize the number of possible asteroids that each probe could visit within the time constraint. This scheme was also a result of the restriction that only 10 impulses are allowed for the mothership. Otherwise a sequence of 6 would be possible.

1.1. Trajectory Calculation Methods

A Lambert Solver method was used to compute all transfer trajectories for the mothership. Several low-thrust trajectory algorithms were used for the probe trajectories. The shape-based method from [1] was used as a quick way to check if a transfer orbit using a set of given parameters and no thrust constraints was even possible. A constrained trajectory solved with the optimal control package SPARTAN was then used to refine and improve the shape-based trajectory.

DLR's in-house optimizer SPARTAN (SHefex-3 Pseudospectral Algorithm for Reentry Trajectory ANalysis) implements the global flipped radau pseudospectral methods to solve constrained or unconstrained optimal control problems, which can have a fixed or variable final time. It belongs to the class of direct methods and has a highly exploited Jacobian structure, as well as routines for automatic linear/nonlinear scaling and auto-validation using the Runge-Kutta 45 scheme. It is the reference tool for the development of the entry guidance for SHEFEX-3 mission and has been validated with several well-known literature examples.

1.2. Search Methods

The search problem was tackled from two directions independently. On one side, a grid search over all launch times and asteroids was used to find all possible mothership trajectories that fit the scheme and the constraints. On the other side, several different types of searches were used to find all possible probe trajectories which maximize the number of unique asteroids visited. In both cases the search space was sometimes restricted at each search step by filtering the asteroids based on orbital parameters; selecting asteroids which were less costly to reach at each step.

For one search method, an entire grid search was performed for the mothership over the possible launch periods with step size equal to the synodic periods of two asteroids and a stepsize of 10 days. The first asteroid solutions had been used to get the second, third and fourth. The sequence of 4 asteroids had been optimized by the Matlab function fmincon with delta-v as a function and several linear time constraints, e.g. time between release of probe1 to prick up of probe1 is less than 6 years. The optimized 4-sequence was used to start the grid search for the 5th one. A total of 113 solutions for the mothership had been found, which served as an input for the probe tree search.

The list of all possible mothership trajectories was parsed to find a list of asteroid IDs and starting times for the probes. Using these starting conditions a greedy algorithm similar to the A* algorithm was used with a fine grid search to search through the entire tree of possible paths through the asteroids. At each level in the tree, the top N paths with the shortest trajectory times were chosen to be further considered and the rest of the paths were discarded. A full search through the next level of the tree was done for each of these N paths. At this next level the top N paths were then selected and the rest were discarded. This process was repeated until the probe's time of flight and/or mass constraints were reached. The algorithm then backtracked through each found path to see if the mothership could be reached from any of the last asteroids in the path.

Another search method started with a coarse full grid search through all possible asteroids and starting times. The entire tree of asteroids was searched with a depth-first approach and a list of all tree paths was collected. The list of paths was then parsed to find all combinations of three paths which fit the scheme. We then tried to reach the end points of the paths in each combination using the mothership.

The final tree was a greedy tree having different values as cost-function depending on the depth of the problem (mass, time of flight, both). That tree searches for a fixed number of asteroids. If a bush is not possible to get to the "mothership-asteroid" it is deleted and the tree goes one level back. Inside the tree some branch and bound is performed (dv needed for the plane change, the phasing between the two asteroids). It still needs to be investigated if the phasing has not stolen some solutions, where the probe first goes inbound and than outbound again. The transfers in tree were calculated by pagmo mbh (see Dario Izzo).

2. Description of Solution

The details of the solution submitted are as follows:

LaunchDate = 62360.10 ModJDate

v_inf_mag = 6.00 km/s
v_inf = 4.04 km/s 4.42 km/s -0.43 km/s

Probe 1 Release Date = 62902.60 ModJDate

Probe 2 Release Date = 63433.32 ModJDate

Probe 3 Release Date = 63780.44 ModJDate

Probe 1 final rendezvous with the mother ship = 65094.10 ModJDate
Probe 1 final mass = 1069.30 kg

Probe 2 final rendezvous with the mother ship = 65624.82 ModJDate
Probe 2 final mass = 1192.27 kg

Probe 3 final rendezvous with the mother ship = 65971.94 ModJDate
Probe 3 final mass = 999.51 kg

Mother ship final mass = 6284.84 kg

Secondary performance J_2 = 9545.92 kg

Asteroids visited by Probe 1

ID = 2417
Arrival = 62902.60 MJD
Departure = 62932.60 MJD

ID = 5312
Arrival = 63353.77 MJD
Departure = 63383.77 MJD

ID = 14542
Arrival = 63709.03 MJD
Departure = 63739.03 MJD

ID = 29
Arrival = 64014.82 MJD
Departure = 64044.82 MJD

ID = 7654
Arrival = 64295.50 MJD
Departure = 64325.50 MJD

ID = 2401
Arrival = 64803.21 MJD
Departure = 64833.21 MJD

ID = 9863
Arrival = 65027.23 MJD
Departure = 65057.23 MJD

Asteroids visited by Probe 2

ID = 11277
Arrival = 63433.32 MJD
Departure = 63463.32 MJD

ID = 5855
Arrival = 63827.54 MJD
Departure = 63857.54 MJD

ID = 11382
Arrival = 64190.58 MJD
Departure = 64220.58 MJD

ID = 1941
Arrival = 64610.68 MJD
Departure = 64640.68 MJD

ID = 4056
Arrival = 65080.98 MJD
Departure = 65110.98 MJD

ID = 1291
Arrival = 65557.08 MJD
Departure = 65587.08 MJD

Asteroids visited by Probe 3

ID = 12820
Arrival = 63780.44 MJD
Departure = 63810.44 MJD

ID = 4008

Arrival = 64161.06 MJD
Departure = 64191.06 MJD

ID = 3074
Arrival = 64487.04 MJD
Departure = 64517.04 MJD

ID = 14458
Arrival = 64859.43 MJD
Departure = 64889.43 MJD

ID = 14906
Arrival = 65249.36 MJD
Departure = 65279.36 MJD

ID = 1287
Arrival = 65699.94 MJD
Departure = 65729.94 MJD

J = 19

Legend for plots:
Dashed blue line : Mothership trajectory
Blue circles : Launch, probe release and probe capture events
Magenta circles : Asteroid visit start and stop events
Green line : Probe trajectory while visiting asteroids
Black line : Probe trajectory between asteroids

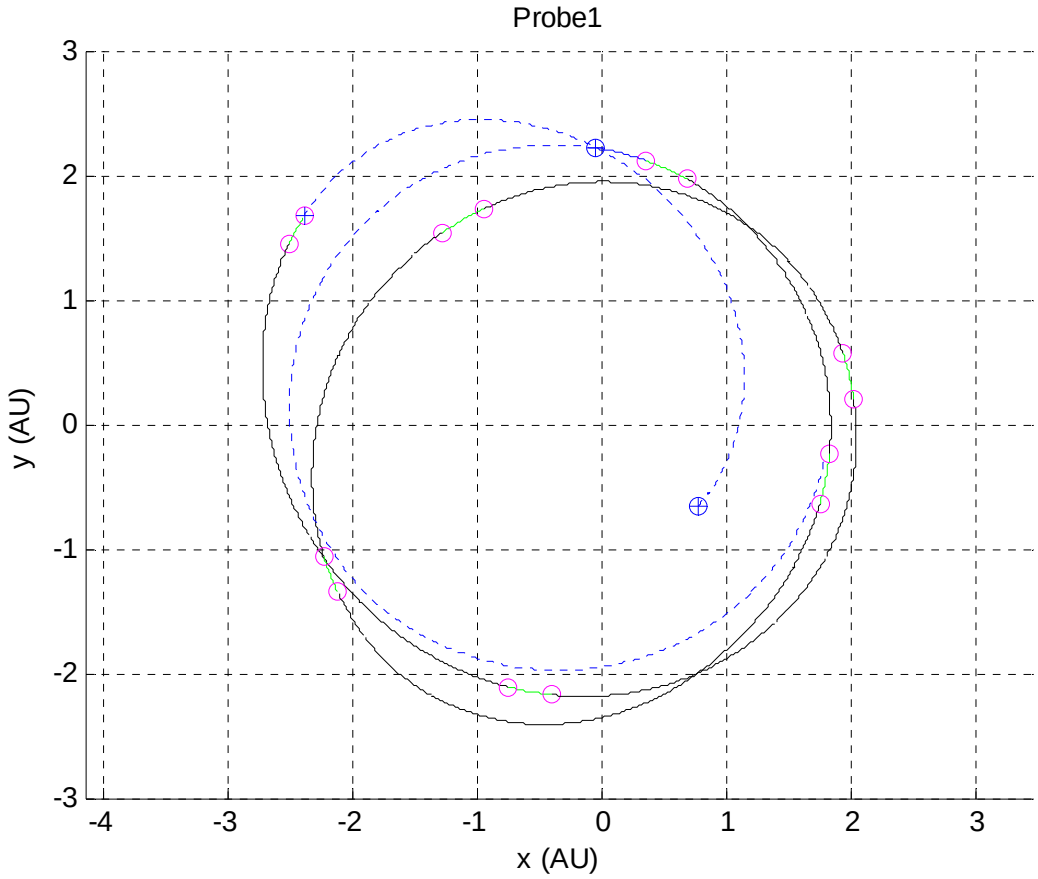

Figure 1: Trajectory of Probe 1 in the ecliptic plane.

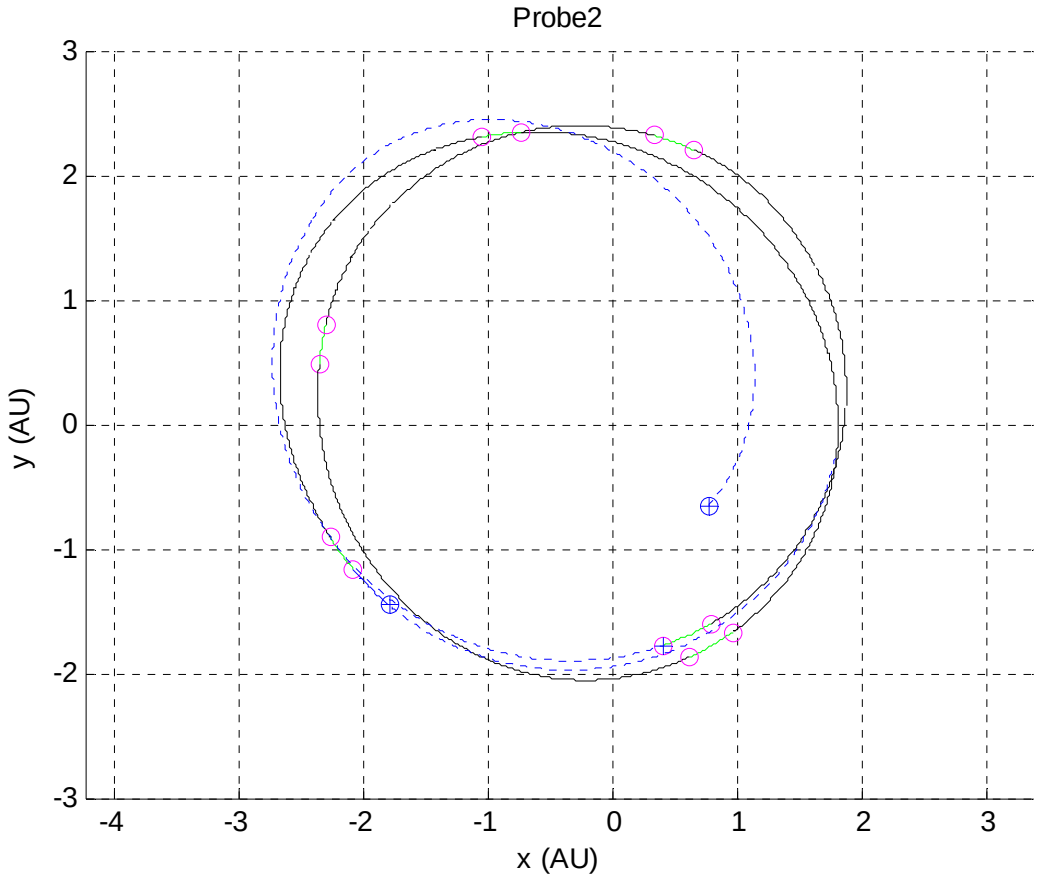

Figure 2: Trajectory of Probe 2 in the ecliptic plane.

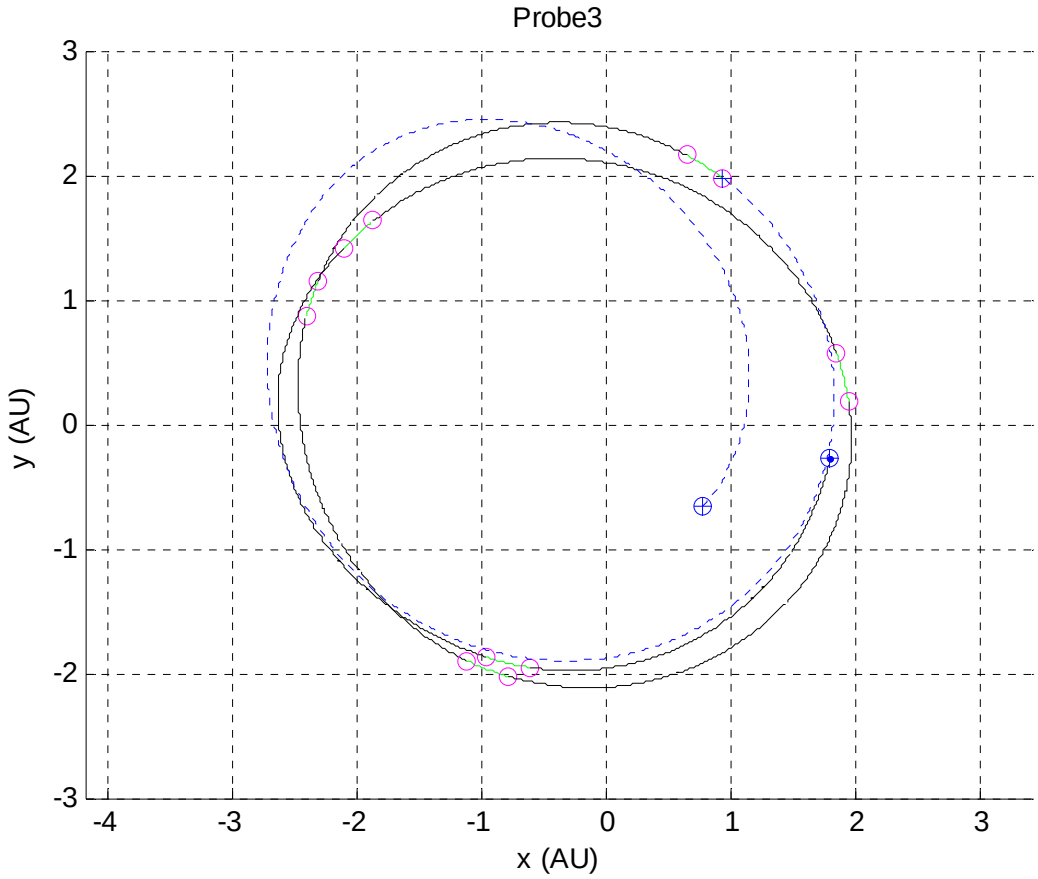

Figure 3: Trajectory of Probe 3 in the ecliptic plane.

3. References

1. B. J. Wall, B. A. Conway, "Shape-Based Approach to Low-Thrust Rendezvous Trajectory Design," Journal of Guidance, Control and Dynamics, Vol. 32, No. 1, January – February 2009, pg. 95 – 101.