# Solution Entry for the 7th Global Trajectory Optimisation Competition (GTOC7)

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**Description of Methods:**

We take the route of solving the single sequence problem first. By ignoring the multiple sequences and any consideration of the mothership, an upper bound on the score is approximated. Using the methods described below we found that reasonable ballistic sequences existed with as many as 16 asteroids. When considering the requirement to converge in low-thrust, we found that ~14 (or possibly 15) is the most to be expected. Armed with this information we took a top down approach to consider the mothership and chaining the sequences together. First looking for feasible mothership trajectories that link three 14'ers with no repeats (to steal the term from labeling of Rocky mountains that exceed 14,000 feet…), we immediately found this architecture infeasible as the mothership delta-v constraints are much stronger than originally suspected. Then we progressively considered different architectures that would support lower scores, starting at 41 and going down. In the end, the architecture that obtained the greatest score was the simple approach of having the mothership drop off all three probes at one asteroid and picking them all up at another. In our approach, we used a fast lambert solver, custom tree search algorithms, ant colony optimization, a direct ballistic optimization software for the mothership trajectory, a direct low-thrust software for converging the end-to-end probe sequences, and a differential dynamic programming software (HDDP) for solving the final solutions using the full thrusting dynamics at high resolution. Note that we chose to use asteroids as waypoints for the mothership to make the problem more tractable. All of our codes were run on workstations with multiple CPU cores.

The rough details of our solution method are broken down into the following major phases

1. All-on-all Lambert Problems: Solve the lambert problems for the all-on-all connections of the earth and asteroids at all viable (discretized) times.
2. Ballistic Sequence Identification: Several techniques were investigated including A) a classic tree search algorithm with clever pruning and necessary discretization and B) Ant colony optimization. In the search the main pruning variables were flight time, mass, and the likelihood of converging in low thrust.
3. Low-thrust end-to-end convergence of the ballistic sequences. Only converge as many as necessary to properly tune the ballistic search, ensuring that most of the resulting solutions are feasible in low-thrust.
4. Mothership and sequence connections: The goal is to order 3 sequences (from the list generated in part 2) for the mothership to pursue. Again, tree search algorithms and other path planning ideas sorted thru the millions of candidate sequences identified in part 2.
5. Final low-thrust convergence and mothership optimization.
6. Iterate to maximize score

Our final solution has a score of J=35, and a combined final probe mass of J'= 2493.028 kg. Each probe consists of a 13 body sequence:

```
P1:   5736   7441   1052   2984   6545  15939  15935  11024   9639  15985   3452   5774   1717
P2:   5736   5715   1884  16006   6580  11008  12500   9678   8451   6577   5761    869   1717
P3:   5736   6579  14277   5029   3019   2086  12617  16022  14409  16162  12237    580   1717*
```

*NOTE: the P3 final asteroid is just an intercept. The mothership completes the P3-mothership rendezvous.

The second probe counts the first and last asteroids in the score as only the second probe has sufficient stay times at both. The first and third probes only count their interior asteroids in the score. The mothership drops all the probes off at the same asteroid, and returns to a single final asteroid for pickup. The third probe does not have sufficient mass to fully rendezvous with the final asteroid/mothership, so the mothership instead uses a ~200 m/s maneuver to rendezvous finally with the third probe. According to our verifications, all of the problem constraints are met to the stated tolerances.

The final masses are as follows:

$P1_m$=0.80122571797558E+03 kg
$P2_m$ =0.89133586644678E+03 kg
$P3_m$ =0.80046614508638E+03 kg
$M_m$ =8.51538692102472E+03 kg (including all three probes at the end)

The vinf at launch is `6 km/s` with a `855.6 m/s` maneuver by the mothership immediately at launch.

Relevant dates (MJD) are given below (subset of the M.txt file)

```
LAUNCH MOHTER SHIP:   6.0543395600998E+04
Release of probe 1:   6.1242721539790E+04
Release of probe 2:   6.1777870404550E+04
Release of probe 3:   6.2057017407382E+04
Return of  probe 1:   6.3434221539790E+04
Return of  probe 2:   6.3967870404549E+04
Return of  probe 3:   6.4248517407382E+04
```

The following pictures give visualizations of the mothership and probe trajectories. See the solution files for more details.

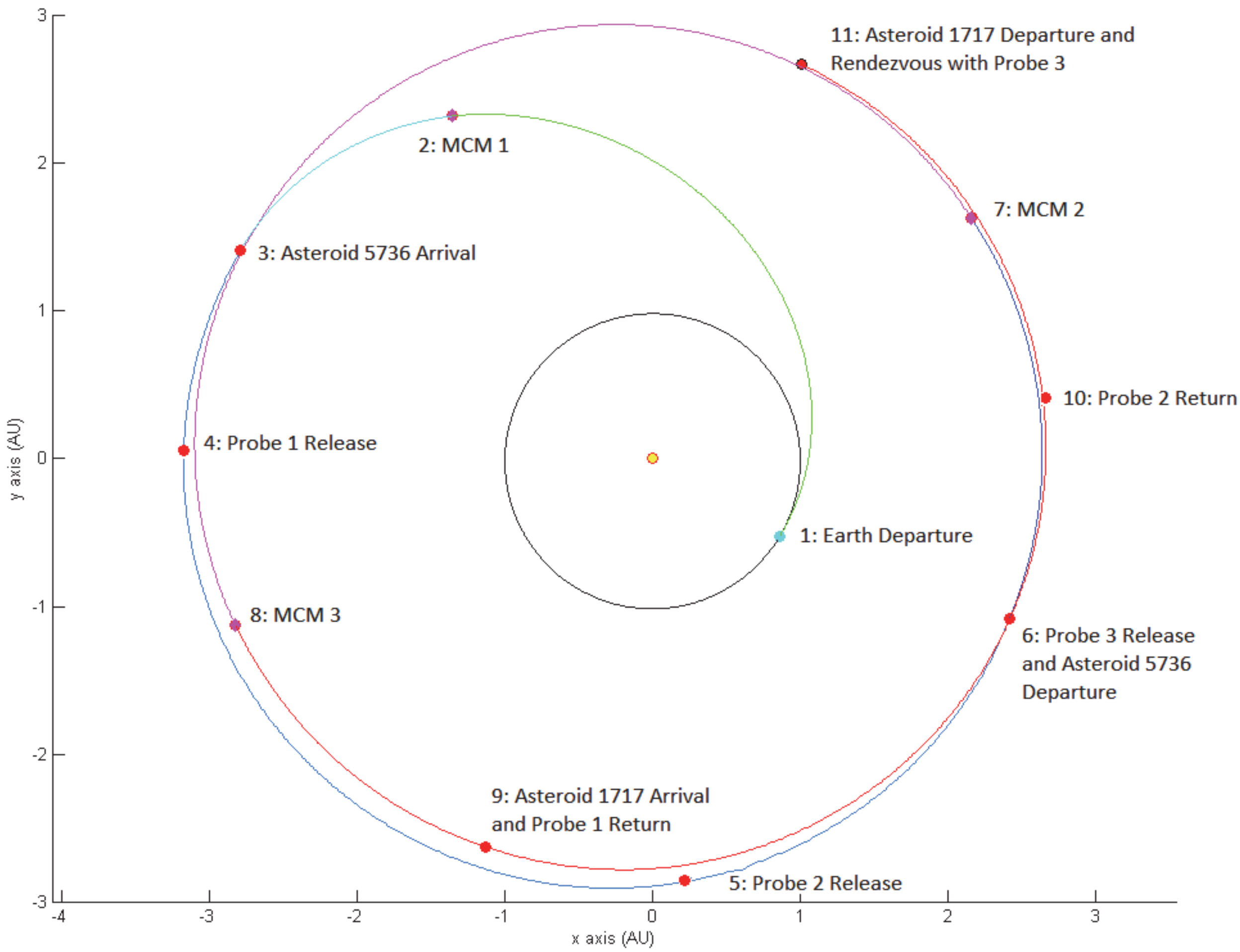


**Figure 1: Mothership trajectory and maneuvers.**

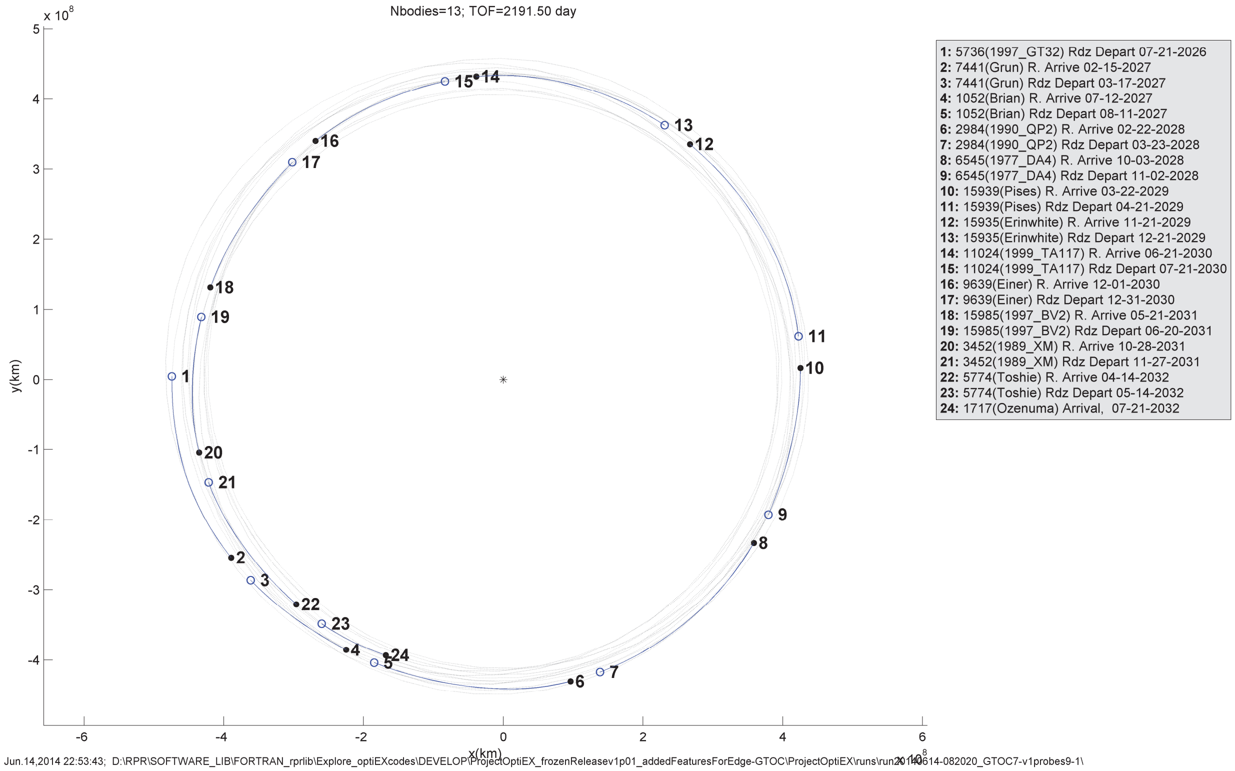


**Figure 2: Probe 1 trajectory**

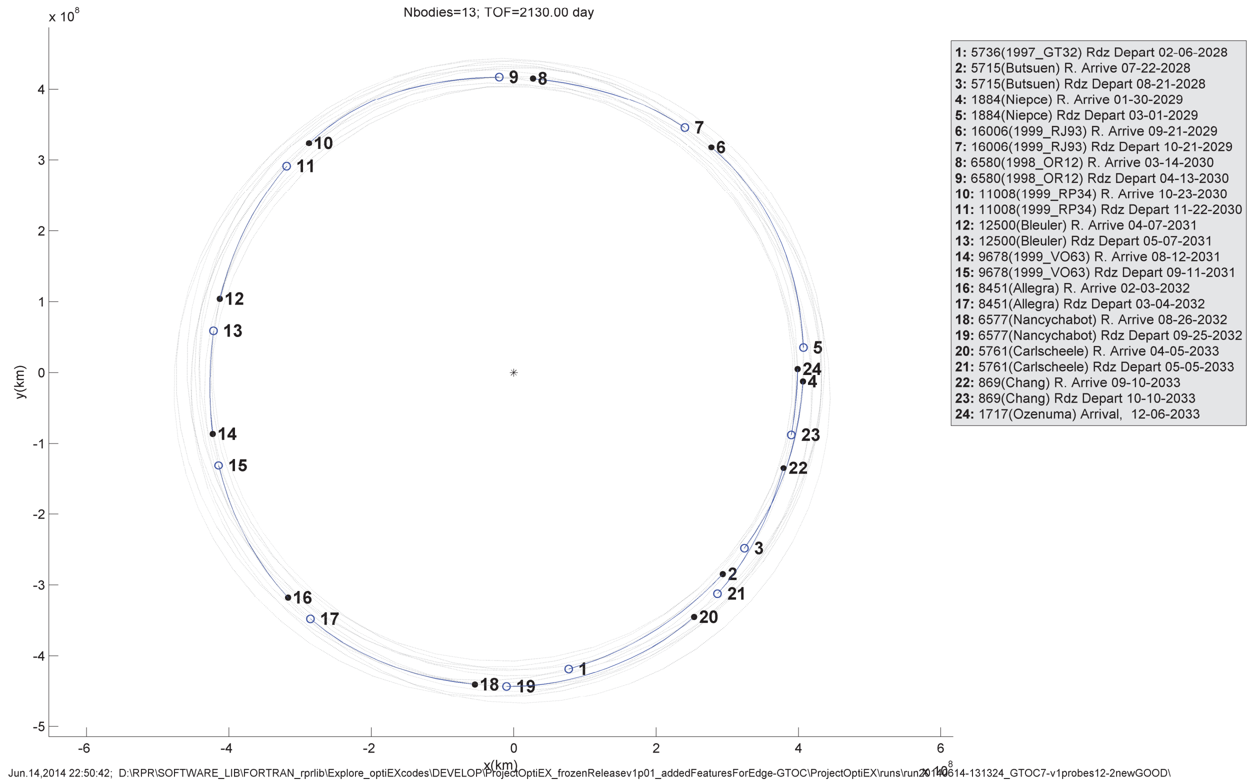


**Figure 3: Probe 2 trajectory**

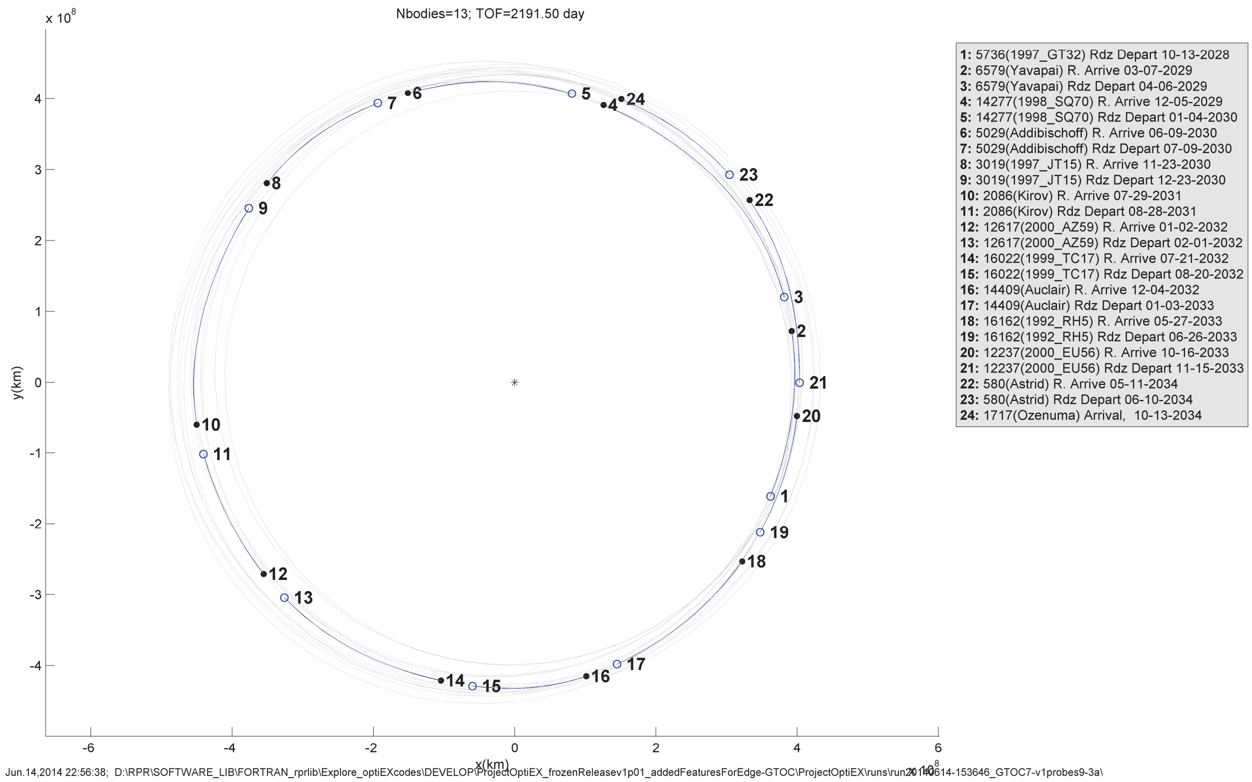


**Figure 4: Probe 3 trajectory**