GTOC: Global Trajectory Optimisation Competition

- Like the “World Cup” in space orbit design
- A yearly / bi-yearly competition
- First organized by the Advanced Concepts Team of the European Space Agency (ESA) in 2005
- A common platform for researchers and engineers to test and improve their skills and tools
- HUMAN vs COMPUTER?

Contact

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More info:
http://sophia.estec.esa.int/gtoc_portal/
## The Past GTOCs

<table>
<thead>
<tr>
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Winner organizes the next competition…
Challenge

• Non-typical problem (no “can” solution / algorithm available)

• Very complex (many different possibilities)

3. Only 1 month to solve and return a solution

Methodology

1. Make smart approximation and decision in the tree search

2. Develop models to check whether a point is inside a soccer grid or not

3. Accurate calculations on the final low-thrust trajectory
Our Solution

Score 308
141 flybys at the moons

Io: 31/32 faces
Europa: 31/32 faces
Ganymede: 31/32 faces
Callisto: 23/32 faces

Departure: December 2020
Total flight time: 4 years
Mass expenditure: 999.6 kg

Red: high scores, Green: mid, Blue: low
Tour de Jupiter’s Moons

Score 308
141 flybys at the moons
Total time: 4 years
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<th>Team</th>
<th>Score</th>
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<tr>
<td>1</td>
<td>311</td>
<td>123</td>
<td>Team 5</td>
<td>Politecnico di Torino &amp; U. di Roma &quot;Sapienza&quot; Italy</td>
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<td>2</td>
<td>308</td>
<td>141</td>
<td>Team 6</td>
<td>ESA-ACT &amp; Hong Kong Univ. of Science and Technology</td>
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<td>3</td>
<td>267</td>
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<td>Team 2</td>
<td>University of Texas at Austin, USA</td>
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<td>246</td>
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<td>Team 4</td>
<td>DLR, Germany</td>
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<td>State Key Laboratory &amp; Chinese Academy of Sciences</td>
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<td>6</td>
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<td>Analytical Mechanics Associates, Inc., USA</td>
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<td>Team 14/9</td>
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<td>8</td>
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<td>Team 10</td>
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<td>9</td>
<td>154</td>
<td>83</td>
<td>Team 18</td>
<td>University of Colorado, Boulder, USA</td>
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<tr>
<td>10</td>
<td>87</td>
<td>53</td>
<td>Team 3</td>
<td>U. of Jena, Germany &amp; TU Delft, The Netherlands</td>
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<td>11</td>
<td>83</td>
<td>23</td>
<td>Team 21</td>
<td>Beihang University, Beijing, China</td>
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<tr>
<td>12</td>
<td>73</td>
<td>17</td>
<td>Team 15</td>
<td>University of Hawaii at Manoa, USA</td>
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<tr>
<td>13</td>
<td>15</td>
<td>3</td>
<td>Team 1</td>
<td>Michigan Technological University, USA</td>
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Consequential violations in altitudes and dynamics:
18 10 Team 26 Peking University, Beijing, China

Incomplete or discontinuous trajectories or other severe violations:
xx ~3 Team 13 University of Trento, Italy
xx 2 Team 24 Francesco Santilli, Turin, Italy
Possible Applications...

NASA’s Jupiter Europa Orbiter (JEO) Mission Concept
Proposed launch in 2020

Tour Phase Provides Almost 2.5 Years of Jovian System Science Opportunities

Close satellite flybys

Io monitoring

Jupiter atmosphere

Jupiter magnetosphere

Credit: NASA JEO mission concept:
http://opfm.jpl.nasa.gov/europajupitersystemmissionejsm/jupitereuropaorbiterconcept/
Advanced Concepts Team

European Space Agency:
Dario Izzo, Luis Felismino Simoes, Marcus Marteens, Guido de Croon, Aurelie Heritier

Center for Space Science Research

Hong Kong University of Science and Technology:
Chit Hong Yam, Tsz Yan So, Kin Chiu Chu, Kai Yin Leung, Hermanni Heimonen, Kwing Lam Chan, Kwok Yee Michael Wong
Some Key Contributions

Prof. Chan and Prof. Wong: develop algorithms based on linear algebra to check which face the spacecraft fly on during close encounter at the moons.

Herman: worked on first part of the trajectory, searched for many possibilities at the 4 moons.

Cathie: develop a “re-targeting” algorithm to accurately flyby at the desired grid.

Alan: programming, debugging, and mass calculations.

Lawrence: convert the guess solutions from ESA to an accurate low-thrust model.

Hippo: coordinate and try to manage...and submit the final trajectory.
1. First time participation in the GTOC: an international competition in the astrodynamics field

2. Undergraduate students with no prior background to compete against professional teams in the world

3. Excellent results given the difficulty of the problem

Future Plans
1. Organize workshops and seminars to share our experience and knowledge
2. Organize mini-competitions in HK
3. Continue the research in astronautics and space science
Center for Space Science Research 太空科學研究中心
Galilean moons 伽利略衛星
Europa 歐羅巴 (木衛二)
Close flyby 近距離飛越
European Space Agency (ESA) 歐洲太空總署
Jet Propulsion Laboratory (JPL) 噴射推進實驗室
Global Trajectory Optimisation Competition (GTOC) 國際太空軌道設計比賽

Team Members from HKUST
數學系陳烱林教授，物理學系王國彝教授，任哲航博士，數學系的蘇芷茵、物理學系的梁啟彥、朱建釗及 Heimonen, Hermanni Juuso Elias (Herman)
Prof Kwing-lam Chan, Prof Kwok-yee Wong, Dr Chit-hong Yam, Tsz-yan So, Kai-yin Leung, Kin-chiu Chu and Heimonen, Hermanni Juuso Elias

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The 4 Phases of the Trajectory

Scores

Departure in Dec 2020
Phase 1: Ganymede-Ganymede-Europa

TOF: 198 → 107 → 39 days

$\Delta V$ on chemical solution = $\sim 300$ m/s; required thrust level = 0.035N

Low-thrust optimization based on Sims-Flanagan model (MALTO/GALLOP): Trajectory is divided into segments of constant thrust, numerically integrated.

Departure: Dec 2020

Score: 3
Final mass: 1895 kg
Phase 2: Inner Moons Tour

46 Flybys:
16I, 12E, 16G, 2C

Score: 138

Io and Europa are visited by resonance transfers. Mostly 2:1 (Io) and (1:1) resonances

Time of flight: 303 days

Final mass: 1653 kg
Visiting high scoring faces on Ganymede (1:1 res.) and low scoring faces on Io (3:1 res.) and Europa.

Time of flight: 317 days

Final mass: 1252 kg

54 flybys: 20I, 14E, 20G

Score: 91
High-score faces of Callisto are mapped. Inclination is increased to map low-score faces of Europa (3:1 res.)

Time of flight: 418 days

54 flybys: 2I, 15E, 21C

Score: 76

Final mass: 1000.4 kg