AUTOMATED SENSITIVITY ANALYSIS OF INTERPLANETARY TRAJECTORIES

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AGENDA

- Motivation
- Methodology
- Global Optimization
- Case Study 1
- Case Study 2
- Summary
**MOTIVATION**

- First task for mission designer is typically to create a nominal/baseline trajectory
- Second task is often to perform sensitivity analysis. The objective is to quantify the effects of changes to:
  - Operational constraints
  - Sub-system requirements
  - Off-nominal spacecraft performance
- Mission design is human-labor intensive and therefore expensive
- Computation time is not and is therefore cheap
- **Goals:**
  - Transfer as much work-load as possible to computers (automation!)
  - Quantify entire design space
  - Find better mission design solutions than possible otherwise
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METHODOLOGY

EMTG = Evolutionary Mission Trajectory Generator
SNOPT = Stanford Numerical OPTimizer
PEATSA = Python EMTG Automated Trade Study Application
METHODOLOGY

- Parse PEATSA options
  - Create EMTG cases
  - Run EMTG cases
  - Parse EMTG results
  - Has the case met stopping criteria?
    - Yes: Find an improved initial guess from the results
    - No: This case is done!
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GLOBAL OPTIMIZATION

- If trajectory solver has no global optimization capability (local only), then re-seeding with improved initial guesses is crucial.
- If trajectory solver DOES have global optimization capability, improved re-seeding is still helpful.
- EMTG uses monotonic basin-hopping for global optimization:
  - This process is stochastic.
  - No deterministic way to know if a global optimum has been reached. **trendlines can help**
  - No deterministic way to determine necessary run-time **frequent iterations can eliminated wasted run-time after optimal solution has been found**
  - Currently, EMTG hoppers are serial only **re-seeding effectively creates parallel hoppers**
- Global optimality also includes modify options that can be modified in a fixed local optimization:
  - **Between iterations, PEATSA can modify these fixed parameters**
    - Flyby sequence
    - Target small-body
GLOBAL OPTIMIZATION

Parse PEATSA options → Create EMTG cases → Run EMTG cases → Parse EMTG results → Has the case met stopping criteria?

- Yes → This case is done!
- No → Find an improved initial guess from the results

No → Randomly modify trajectory parameters (i.e. gravity assist sequence)
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Goal: Uranus moon tour
Assume that designer has zero knowledge of useful flyby sequence
Launch sometime in late 2024 or early 2025
Required 8 minutes of human labor for setup, and 12 wall clock-hours of computation time on a 64 core server
CASE STUDY 1 – URANUS MISSION

- Iteration 0
CASE STUDY 1 – URANUS MISSION
CASE STUDY 1 – URANUS MISSION

- Iteration 2

- Iteration 10
CASE STUDY 1 – URANUS MISSION

Iteration 80
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CASE STUDY 2 – LOW-THRUST ASTEROID SAMPLE RETURN

- Goal: quantify design space for return of a sample from asteroid 1949TG Daphne (ecc > .2, inclination > 10 deg)
- Launch sometime in late 2024 or early 2025
- Required 12 minutes of human labor for setup and 32 wall clock-minutes of computation time on a 64 core server

<table>
<thead>
<tr>
<th>Mission Parameters</th>
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<tbody>
<tr>
<td>Propulsion model</td>
<td>polynomial thrust, mass flow rate vs. power available</td>
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<tr>
<td>Propulsion system</td>
<td>2 NEXT engines$^7$</td>
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<tr>
<td>Maximum flight time</td>
<td>10 years</td>
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<tr>
<td>Earth return velocity</td>
<td>&lt; 10 km/s</td>
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<tr>
<td>Duty cycle</td>
<td>90%</td>
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<tr>
<td>Propellant margin</td>
<td>10%</td>
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<tr>
<td>Power margin</td>
<td>15%</td>
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<tr>
<td>Bus power</td>
<td>1 kW</td>
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<tr>
<td>Stay time</td>
<td>&gt; 500 days</td>
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<tr>
<td>EMTG run-time per iteration</td>
<td>20 seconds</td>
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<tr>
<td>Low-thrust transcription</td>
<td>Finite Burn$^8$</td>
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</table>

<table>
<thead>
<tr>
<th>PEATSA Options</th>
<th></th>
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<tbody>
<tr>
<td>run_type</td>
<td>trade study</td>
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<tr>
<td>comparison_criteria</td>
<td>maximum final mass</td>
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<td>wait_for_guess</td>
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<tr>
<td>flyby_bodies</td>
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<tr>
<td>options_to_vary</td>
<td>launch vehicle; solar array size; electric propellant load</td>
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<tr>
<td>option_ranges</td>
<td>Atlas V - 401 (0), 411 (1), 421 (2), 431 (3), 541 (9) or 551(10); 20 to 40 kW; 900 to 1500 kg</td>
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<tr>
<td>trade_study_type</td>
<td>vary each option separately</td>
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</table>
CASE STUDY I – URANUS MISSION

- Electric Propellant Tank Sizing
CASE STUDY 1 – URANUS MISSION

Launch vehicle selection
- 1 = Atlas V 401
- 2 = Atlas V 411
- 3 = Atlas V 421
- 4 = Atlas V 431
- 9 = Atlas V 541
- 10 = Atlas V 551
CASE STUDY 1 – URANUS MISSION

- Solar Array Sizing
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Sensitivity analysis is no longer a task that requires significant hands-on time for mission designer.

PEATSA allows simplified viewing of trade study effects, missed maneuver planning, etc.

Overall computation time decreases greatly, because individual runtime decreases.

PEATSA increases global optimization capability.