Overview of the Development for A Suite of Low-Thrust Trajectory Analysis Tools

Larry D. Kos
Primary author and point of contact
Marshall Space Flight Center
Mail Code VP11
Huntsville, AL 35812
phone: 256-544-1522, fax: 256-544-4225
Larry.Kos@msfc.nasa.gov

Tara P. Polsgrove
Marshall Space Flight Center
phone: 256-544-1274, fax: 256-544-4225
Tara.Polsgrove@nasa.gov

Randall C. Hopkins
Marshall Space Flight Center
phone: 256-544-4977, fax: 256-544-4225
Randall.Hopkins@nasa.gov

Dr. Dan Thomas
Marshall Space Flight Center
phone: 256-544-4493, fax: 256-544-4225
Herbert.D.Thomas@nasa.gov

Dr. Jon A. Sims
Jet Propulsion Laboratory
phone: (818) 354-0313, fax: (818) 393-6388
Jon.A.Sims@jpl.nasa.gov

Condensed Abstract

A NASA intercenter team has developed a suite of low-thrust (LT) trajectory analysis tools to make a significant improvement in three major facets of LT trajectory and mission analysis. These are: 1) ease of use, 2) ability to more robustly converge to solutions, and 3) higher fidelity modeling and accuracy of results. Due mostly to the short duration of the development, the team concluded that a suite of tools was preferred over having one integrated tool. This tool-suite, their characteristics and applicability will be described. Trajectory analysts can read this paper and determine which tool is most appropriate for their problem(s).

Extended Abstract

In this paper we review the development and completion of a suite of new low-thrust trajectory tools that will significantly increase the analytical capability of the LT community. This suite of will was [will be] As future missions are likely to continue the use of highly efficient electric propulsion, maybe even in an increasingly manner, analytical capabilities show grow to support this need.

Purpose and Goals

The purpose of this LT trajectory tool activity was to produce a tool or suite of tools that allows the LT mission design community to do LT trajectory analyses that: 1) are consistent (between analysts), 2) can be quick turn-around at times when needed (e.g. in hours or days), and 3) is rigorous, but still with fidelity levels that can be somewhat "dialed in", determined by time allowed. Goals for the actual tools themselves included that they be easier to use than previous tools, they provide better and/or faster results than previous tools – both if possible, and provide for more accurate modeling of the force model and environment than previous tools.

Tools

For an "at-a-glance" view to better understand the suite of tools and make a comparison of them, a simplified capability overlap graphic in Figure 1 shows that while the tools each have some niche for their application, there is also some amount of common analysis capability resident in each. ...

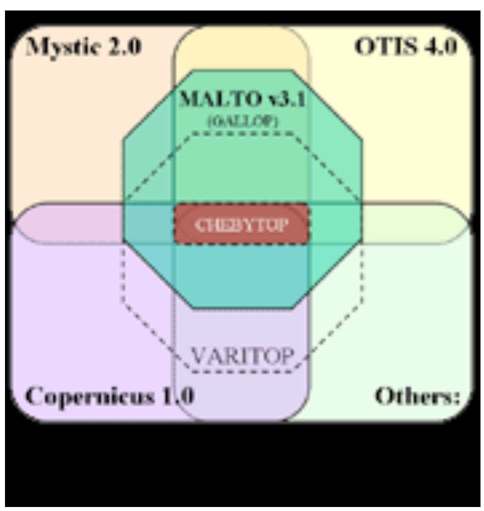

Figure 1. LTTT Suite Overlap *("iconized" for abstract)*

The process an analyst would use to determine the appropriate tool for their needs could follow the following process as an example. The first step is to determine which tool has applicability for their problem. The comparison table, shown following in Figure 1, is a starting point for this process.

Low Thrust Code/Tool Comparison/Summary Table

Bold entry is "Best in Category"

Code: \ Feature:	Direct/ Indirect	Method / submethod:	User-Friendly	Appli-cation	Turn-around Capability	Easily Converged	Self-starting	Fide-lity
CHEBYTOP	Indirect	Chebyshev polynomial approx. for traj. segments	4	Narrow	Small	Yes	Yes	Low
CHEBYTOP / ss	Indirect	Chebyshev polynomial approx. for traj. segments	5	Narrow	**VeryLarge**	**Yes**	**Yes**	Low
CHEBYTOP/MdlC	Indirect	Chebyshev polynomial approx. for traj. segments	5	Very Narrow	Large	Yes	Yes	Low

Figure 2. LT Trajectory Tool Comparison Table *(upper-left partial snapshot)*

Projected problem turn-around time for a problem solution will also determine which tool is selected. The faster the answer is needed the more likely it will be for an analyst to select the medium or even the low fidelity tool. Note that while the low fidelity tool is available, it is not considered part of the newly developed suite of five tools.

Other major factors that will determine tool selection is the platform it runs on , the additional software licenses needed by the tool, and ITAR restrictions. Other characteristics of interest, and lesser ones that may affect the tool selection is the main or most commonly used mathematical algorithm used in the tool, and the main or most commonly used optimizer (e.g. SNOPT in three of the five new tools). It should be pointed out that ... . See Figure 3 for the table summary of these criteria.

(in progress)

Figure 3. Other Selection Criteria

Testing

Developer testing, yearly live demonstrations, beta testing ...

Example Comparison Table for Reference Mission 1 (w/ all 6 tools): Earth-Mars Flyby

Parameter	Units	CHEBYTOP	VARITOP	MALTO	Copernicus	OTIS	Mystic
Heliocentric Departure Date	n/a						
Escape Spiral Time	days						
Heliocentric Flight Time	days						
Initial Mass in Earth Orbit	kg						
Mass at Earth SOI	kg						
Mass at Mars Periapsis	kg						
Heliocentric Thrusting Time	days						
Specific Impulse	sec						
Input Power	kWe						
Efficiency	n.d.						

Figure 4. Mars Flyby Comparison Table w/ All 6 Tools

Reference Mission List for LT Traj. Tools

1) Earth - Mars Flyby
2) Earth - Mars Rendezvous
3) Earth - Mars Flyby - Vesta Flyby
4) Earth - Mars Flyby - Vesta Rendezvous
5) Earth - Jupiter Flyby
6) Earth - Venus Flyby - Jupiter Flyby
7) Earth - Tempel 1 Rendezvous
8) Earth - Venus Flyby - Venus Flyby - Jupiter Flyby - Pluto Flyt
9) Earth - [more than 1 rev around the Sun] - Jupiter Flyby
10) Earth - Venus Flyby - Mercury Rendezvous
11) 1 AU Polar (inclined 90° to the ecliptic) Orbiter mission
12) Earth - Tempel 1 Rendezvous - Earth Flyby
13) Classic minimum (optimum?) time to Mars (circ, coplanar)
14) Mars Sample Return
15) Comet sample return
16) Multiple asteroid Rendezvous
17) 5-years to Jupiter/Europa Orbiter
18) 8-years to Saturn/Titan Orbiter
19) 10-years to Uranus/Titania Orbiter
20) 12-years to Neptune/Triton Orbiter
21) 12-years to Pluto/Charon Orbiter
22) 6-years to Jupiter (Moon) Tour
23) 9-years to Saturn (Moon) Tour
24) 11-years to Uranus (Moon) Tour
25) 13-years to Neptune (Moon) Tour
26) 12-years to Pluto Tour
27) Kuiper Belt - Pluto Explorer
28) Earth - Moon (low thrust)
29) Earth-Sun Libration Point mission(s)
30) MW to GW interplanetary mission(s)
31) Earth/Sun/Moon 4-body/other “n-body” mission(s)
32) Non-Keplerian/Other Orbits

Figure 5. Reference Missions List (32)

Tool: / Reference Missions:	Low	E-C	E-C	mid	mid	mid	mid	mid	high	high	high
	CHEBYTOP	SEPSPOT	SNAP	VARITOP	SEPTOP	NEWSEP	Sail	MALTO	Copernicus	Mystic	OTIS
1) Classic minimum time to Mars, circ/coplanar	✓	n/a	??	✓	✓	✓	??	✓	✓	✓	✓
2) Earth - Mars flyby	✓	n/a	✓	✓	✓	✓	✓	✓	✓	✓	✓
3) Earth - Mars rendezvous	✓	n/a	n/a	✓	✓	✓	??	✓	✓	✓	✓
4) Earth - Mars flyby - Vesta (7°) flyby	n/a	n/a	n/a	✓	✓	✓	??	✓	✓	✓	✓

Figure 6. Reference Mission Check List *(partial snapshot)*

Web Site

Sections/Outline (description of pages & subpages)

(undecided which graphic will be used)

Figure 7. (Web site outline/site map [Riehl/Hack] or home site snapshot?)

Availability

As seen in Figure 3, tools will be available to the following extent ...

Acquisition Procedure

To obtain a tool described herein, the following processes have been developed. Efforts were made to make all tools available for download through the LTTT, but some restrictions were unavoidable.

MALTO: Go to the LTTT web site ad download it.

Mystic: JPL NASA Management Office? ...

Copernicus: TBD (LTTT web site download?) ...

SNAP: Follow the GRC CTO Guidelines at http;//www.grc.../ ...

OTIS: Follow ITAR Tool Acquisition process at http;//www.grc.../ ...

CHEBYTOP: Go to the LTTT web site and download it.

Conclusions

The LTTT suite of five new state-of-the-art tools is now released and available through various channels for minimum costs. ...

Acknowledgements

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