LunarTransferMFD

(LTMFD)

Version 1.4

for

Orbiter Space Flight Simulator 2010

June 21, 2010

Copying / Warranty

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This software is created for Martin Schweiger's Orbiter space flight simulator 2010.

The Internet

The Internet home page of LTMFD is located in *http://koti.mbnet.fi/jarmonik/Orbiter.html*
Software author can be contacted via e-mail *jarmonik@mbnet.fi*

System Requirements

The Orbiter space flight simulator 2010. (Orbiter 2006 isn't supported).

Installation

Unpack the software package in the Orbiter installation folder. Maintain directory structure.

Usage with AMSO or NASSP

LTMFD shouldn't be used simultaneously with IMFD versions 5.0 or 5.1 in AMSO or NASSP. However, there is no problem using LTMFD and IMFD 5.3 at the same time.

New in Version 1.4

Graphics

LTMFD is now supporting simple graphics to present trajectories. The green graph is presenting your current trajectory and the Blue graph is presenting your planned/desired trajectory that will be archived by making a burn.

When a flight plan doesn't exist the screen may be blank. TLI and TEI programs will show the green initial trajectory only in "Eject" view mode.

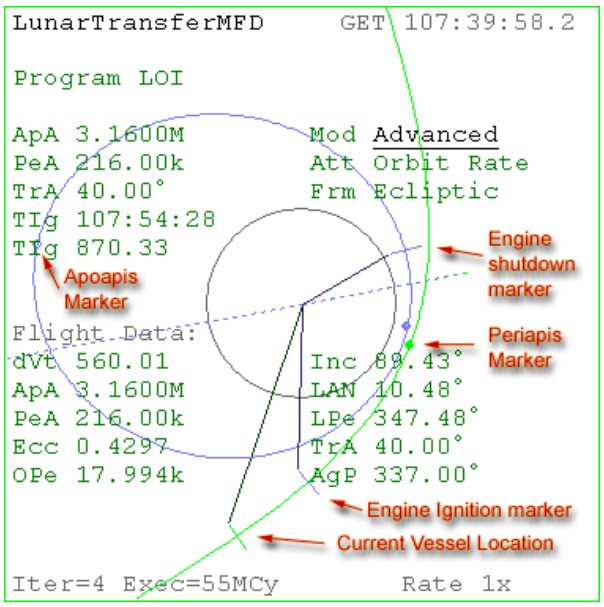

Figure 1: Orbit graph

Graphics settings can be modified by using the action menu [ACT]. The setting can be used to disable graphs, change graph intensity and graphics projection. The projection can be either the active vessel or the same as the frame [Frm] setting.

View Modes [VM]

Other significant feature in LTMFD 1.4 is a View Modes [VM]. The view mode button [VM] can be used to view different flight stages. Sometimes some view modes are disabled when a trajectory doesn't meet the certain criteria.

Flight Monitor has following view modes:

- Main View
- Fly-by Earth rel.
- Earth Return

Main View will always display flight data related to the next periapis passage and the reference can be either the Earth or the Moon. When the vessel is in elliptical lunar orbit the *Main View* is the only available view mode. *Fly-by Earth rel.* will display the same information as the *Main View* except that the graphics is plotted in the Earth relative coordinate system making it a proper view mode to display free-return trajectories. The same will apply in TLI program that is using the same view mode. *Earth Return* can be used to take a close-up view of the Earth and to display flight data related to the Earth return.

TLI Program has following view modes:

- Eject
- Fly-by Moon rel.
- Fly-by Earth rel.
- Earth Return

The first three modes will display flight data related to lunar fly-by. The last view mode "Earth Return" will display data related to the Earth return for an example in a case of a free return trajectory.

TEI Program has following view modes:

- Eject
- Earth Return

LOI Program has no view modes

General information

What is LTMFD ?

LunarTransferMFD is a numerical lunar transfer trajectory calculator. It can be used to compute single impulse lunar transfer trajectories with better accuracy than typical patched conic applications such as IMFD. LunarTransferMFD is based on Broyden's method with numerical forward trajectory model (RKF56).

Typical user input parameters are desired Time of periapis passage, Altitude and flight heading in periapis.

In the current version, operation is limited in Apollo style flights from the Earth's surface to lunar surface and back. Missions starting from unaligned orbits are not yet supported and many other advanced features are still under work.

LunarTransferMFD can be used only with high thrust vehicles such as Apollo. Low thrust propulsion systems such as ion-engines or science fiction style nuclear propulsion systems won't work with LTMFD.

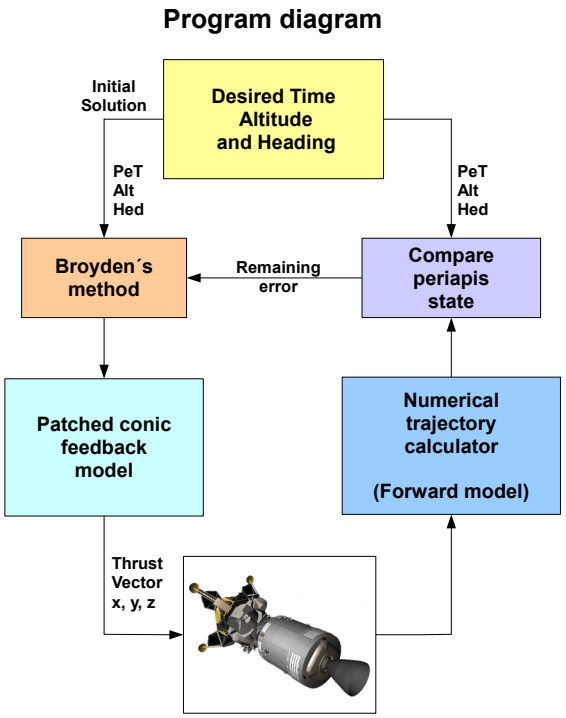

Figure 2: Operation Principle

Currently only a fixed attitude maneuver is supported. It becomes highly inefficient while the burn time increases but it works well enough with the Apollo in the Orbiter for now.

User Interface

User input parameters are located in upper portion of the screen and can be selected with [NXT] and [PRV] buttons. Selected parameter is highlighted and underlined. Configuration and mode parameters in right column can be toggled/modified with [+] and [-] buttons. Data parameters in left column can be adjusted with [+] and [-] buttons. Rate of adjustment is displayed in lower-right corner and can be cycled with [ADJ] button. However, true rate of adjustment is depended from type of the parameter being adjusted. Data parameters can be set directly from the keyboard by pressing [SET] button. (***See section:*** *Setting values from keyboard*)

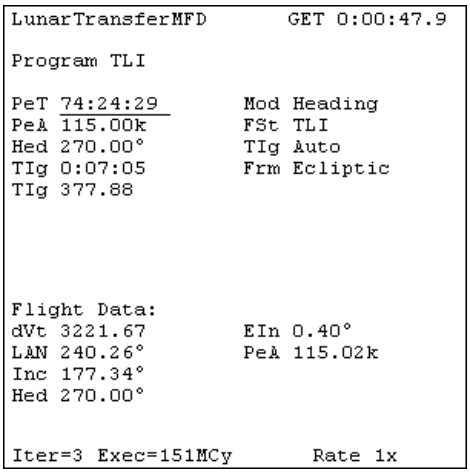

Figure 3: User Interface

Current ground elapsed time (GET) is shown in upper-right corner of the screen. "Iter" and "Exec" items are not important from user point of view. They are presenting iteration count and program execution time in cycles of CPU time-stamp counter (rdtsc).

Program Selection

Program selection menu can be opened with [PRG] button. New program can be selected with [NXT] and [PRV] buttons and activated with [+] or [EXE] buttons. When a program is activated from the program menu existing configuration will be replaced by auto-configuration. This should ensure that meaningful pre-configuration exist when a program screen appears.

Executing programs

[EXE] button is used to perform different actions like executing/selecting programs and activating/disabling autoburn from delta-velocity display. Most of the programs of LTMFD are computationally heavy therefore execution must be triggered manually by pressing [EXE]. After that a transfer solution will appear in lower portion of the screen. Sometimes "*Unable to find solution*" message will appear indicating that trajectory search algorithm was not able to find suitable solution. This doesn't mean that no solution exists.

Existing transfer solution will be cleared after modifying operation mode parameters such as (Mod) or (FSt).

Setting values from keyboard

You can setup input parameters from the keyboard by pressing [SET] button. Exponent form can be used like "12.4e3" or "11.45e-2". Also the exponent can be replaced by a postfix like "12.4k". Where 'k' is equal to "e3" and so on.

Postfix	Multiplier	Description
G	1e9	giga
M	1e6	mega
k	1e3	kilo
m	1e-3	milli
u	1e-6	micro
d	86400	day
h	3600	hour
A,AU	AU	astronomical unit
f,ft	0.3048	feet or ft/s
N,Nm	1852	nautical mile

Table 1: Keyborad input postfixes

In the LTMFD dates are expressed either in Ground Elapsed Time (GET) or Modified Julian Date (MJD) format. A format displayed on a screen will depend from date configuration option. (***See section:*** *Configuration menu*).

It is possible to enter dates from the keyboard in GET, MJD or UT formats. Syntax of valid GET input string is "hhhh:mm:ss.s" (e.g. 26:06:12.21). Note that preceding zeros must be entered if no hours or minutes has elapsed (e.g. 0:30:10). Universal Time (UT) input format requires "UT" prefix in front of the line like "UT 04-May-2009" or "UT 04-May-2009 18:00:00". Time of day is optional but when used must be entered completely. (*i.e. in 24h format including minutes and seconds.*)

Valid names for the months are *Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov and Dec* (these are not case sensitive).

Free-return Trajectory

Currently there is no auto-plan program for a free-return trajectory. The free-return trajectory can be configured using the TLI program in "Heading" mode. First, set the Heading (Hed) into 270 deg, Pericynthion altitude (PeA) into 120k and Time of Periapis passage (PeT) into GET 70:00:00. Execute the program by presseing [EXE] and select "Earth Return" view mode by pressing [VM]. Then adjust the (PeT) setting to reach proper altitude for Earth return. Of course, you need to press [EXE] to re-plot the trajectory. This procedure isn't always guaranteed to success but should do that most of the time.

TEI Program

TEI program is designed for Apollo style earth return purposes. TEI program can be used for lifting off from lunar surface, executing TEI burn and making all necessary course corrections. Below is a screen shot from TEI program.

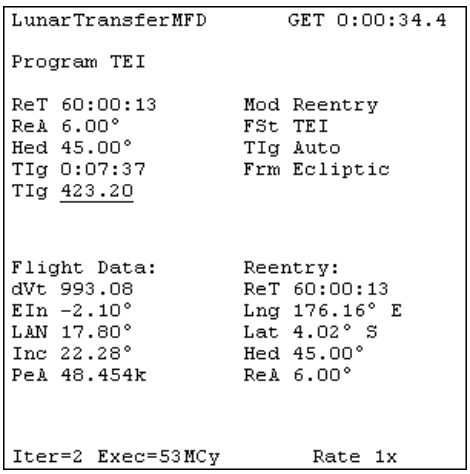

Figure 4: TEI Program

Input Parameters

The top most parameter, (Mod), in right column is targeting mode selector, it will effect in configuration of targeting parameters in left column. Available modes are "Periapis" and "Reentry". (FSt) is a flight state selector. Flight stage is automatically identified during program auto-configuration but can be manually selected. (***See section:*** *Flight stages*). (TIg) parameter in right column is ignition mode selector, it can be either set to "Auto" or "Manual". In "Auto" mode time of ignition is automatically computed using conic approximation and in "Manual" mode time of ignition is user configurable. (Frm) Parameter is a reference

frame selector. It will effect in (Inc) and (LAN) values displayed in a data output area in lower portion of the screen.

Mod	Periapis	Reentry	
FSt	Launch	TEI	TECC
TIg	Auto	Manual	
Frm	Ecliptic	Earth Equ	Moon Equ

Table 2: TEI Mode parameters

Targeting or Data parameters in left column are used for describing desired transfer orbit or goal. Meanings of the parameters are described in a following table below. Once the targeting parameters are set user must execute the program by pressing [EXE].

PeT	Time to perigee passage
PeA	Altitude of perigee
Hed	Desired flight heading in perigee
TiG	Time of ignition
TiG	Time to ignition

Table 3: TEI Periapis Mode

ReT	Time of reentry interface passage
ReA	Reentry angle
Hed	Flight heading in the reentry interface

Table 4: TEI Reentry Mode

Heading as an input parameter

I am not exactly sure how good idea is to use desired flight heading as an input parameter. At least in TEI program it do work pretty well. If a polar orbit is desired it can be archived with flight headings of 0 and 180 degrees leading to orbits with opposite LANs. Also flight headings of 90 and 270 degrees should lead in lowest and highest inclinations relative to equator.

Most of the time flight heading can be defined in range [0 to 360]. However, in some flight stages this is not possible. For an example if a vessel is located directly above the north pole only possible flight heading is directly to south.

Flight heading can be defined in a range [0 to 360] as long as:

$$\left| \frac{\tan(\pi/2 - \beta)}{\tan(2\pi - \vartheta)} \right| > 1.0$$

Where, β is geocentric latitude of a vessel and ϑ is true anomaly. This means that problems may occur when true anomaly (TrA) is somewhere around 270 degrees or the vessel is near polar regions.

If flight heading is out of valid range LTMFD will notify user about it.

Flight Stages

Flight stage selector (FSt) must be set to correspond current flight stage.

Launch stage will compute necessary information required to archive properly aligned lunar orbit for TEI burn. There is no countdown in launch mode and user may launch when ready. (***See section:*** *Launching to Orbit*)

TEI mode must be selected when making TEI burn.

TECC mode must be selected when making a course corrections after TEI or computing PC+2 burn data or aborting a mission after failed TLI.

Data Output Area

Lower portion of the screen is so called transfer solution display or data output area. This area often repeats some information already existing in input parameters, this will only ensure that transfer solution was properly computed. (*a verification*)

In the TEI program left column of lower portion of the screen is displaying some general information and right column is displaying information related to reentry interface. If the reentry interface doesn't exist due to high perigee altitude, this information will be replaced by perigee related information. Note that altitude of reentry interface must set from the configuration menu. Default altitude is 120km

dVt	Total amount of delta velocity required
EIn	Initial orbit miss alignment
Inc	Inclination in selected reference frame (Frm)
LAN	LAN in selected reference frame (Frm)
PeA	Perigee altitude
ReT	Time of passage of entry interface
Lng	Geocentric longitude of entry interface
Lat	Geocentric latitude of entry interface
Hed	Flight heading in the entry interface
ReA	Reentry angle
PeT	Time to periapis passage
Lng	Geocentric longitude of periapis
Lat	Geocentric latitude of periapis
Hed	Flight heading in the periapis

Table 5: TEI Output Information

Mathematical notation of EIn in TEI and TLI programs is:

$$\sin^{-1}\frac{(\vec{\mathbf{r}}\times\vec{\mathbf{v}})\cdot\vec{\mathbf{x}}}{|\vec{\mathbf{r}}\times\vec{\mathbf{v}}||\vec{\mathbf{x}}|}$$

Where, $\vec{\mathbf{x}}$ is escape vector or position vector of the Moon.

TLI Program

TLI program can be used for launching from the Earth to low earth orbit, executing TLI burn and making all necessary course corrections during trans lunar flight. Operational principles of TLI program are exactly the same as with TEI program, therefore, I'll keep this short.

Mod	Heading	Surface	
FSt	Launch	TLI	TLCC
TIg	Auto	Manual	
Frm	Ecliptic	Earth Equ	Moon Equ

Table 6: TLI Mode parameters

Below is a screen shot from the TLI program in "Surface" targeting mode. Surface target (Tgt) can be entered by pressing [SET] button. Available surface targets can be cycled by pressing [+] or [-] buttons. In "Surface" mode TLI program will always compute a solution that will lead in retro-grade lunar orbit.

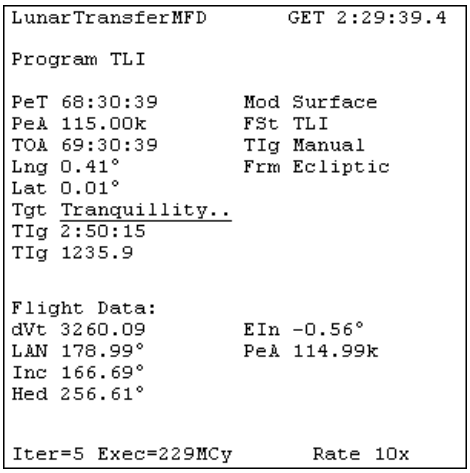

Figure 5: TLI Surface Mode

TOA	Time of orbit alignment with target
Lng	Geocentric longitude of target site
Lat	Geocentric latitude of target site
Tgt	Name of the target site

Table 7: TLI Surface mode parameters

LOI Program

LOI program is created for Lunar Orbit Insertion and can not be used for Earth orbit insertion. Targeting priority selector (Pri) is used to select orbit shape parameter. It can be either Ecc, OPe, ApA or SMa in the "'Simpple"' operation mode.

Ecc	Ecc	Desired orbit eccentricity
Period	OPe	Desired orbit period in seconds
Ap.Alt	ApA	Desired apoapis altitude
SMa	SMa	Desired orbit semi-major axis

Table 8: LOI Targeting Priorities

LOI program can be used only within lunar sphere of influence. It can be also used for orbit circularization burn in lunar orbit. Time of Ignition (TIg) isn't user input parameter in this program.

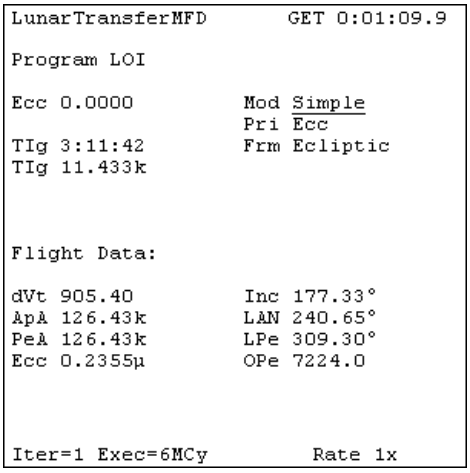

Figure 6: LOI Program

Advanced Mode

The advanced mode of the lunar orbit insertion program will allow user to define a periapis altitude (PeA) and an apoapis altitude (ApA) for the desired target orbit. Ability to change (PeA) during a lunar orbit insertion burn is highly limited, especially, if the burn time is short. Here are some examples for valid adjustment ranges for some vessels from the initial fly-by altitude.

dVt	Total amount of delta velocity required
ApA	Apoapis altitude
PeA	Periapis altitude
Ecc	Orbit eccentricity
Inc	Inclination in selected reference frame (Frm)
LAN	LAN in selected reference frame (Frm)
LPe	Longitude of periapis in selected frame (Frm)
AgP	Argument of periapis in selected frame (Frm)
TrA	True Anomaly in engine shutdown
OPe	Orbit period in seconds

Table 9: LOI Data output description

[DeltaGlider ±1km], [Apollo ±5km], [LRO ±300km].

It's recommended to set the (TrA) to -20deg when using a DeltaGlider or Apollo, this will slightly increase the operational range of the (PeA) paramater. Note that (TrA) setting is only valid when the target orbit is elliptical. (TrA) setting has also an effect in longitude of periapis (LPe). It can be used to adjust the alignment of orbit's apsides.

The (**Att**) parameter is controlling the guidance method during orbit insertion. "Star Fixed" will hold a fixed attitude during the maneuver and "Orbit Rate" will rotate the vessel during the maneuver. This mode has a better operational range and it's more fuel efficient.

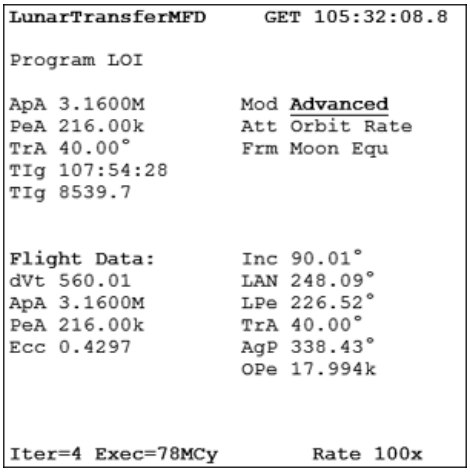

Figure 7: Advanced mode of LOI Program

Flight Monitor

Flight Monitor is a similar program as Map program in IMFD. Flight Monitor numerically propagates the trajectory in the first periapis passage. If the trajectory passes through the reentry interface vessel status in the interface is also printed on the screen. Left column contains a status of the periapis and right column contains a status of the reentry interface.

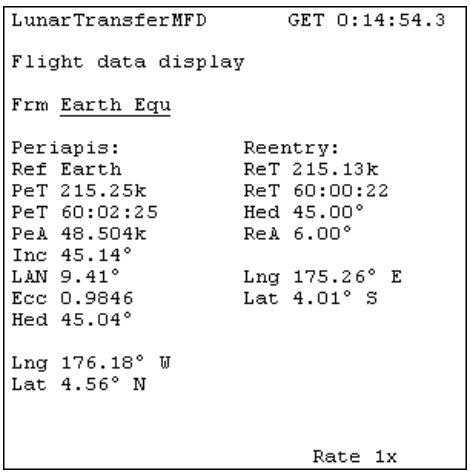

Figure 8: Flight Monitor program

Ref	Reference planet of the periapis
PeT	Time to periapis passage
IpT	Time to surface impact
PeA	Periapis altitude
Inc	Inclination in selected reference frame (Frm)
LAN	LAN in selected reference frame (Frm)
Ecc	Orbit eccentricity in the periapis
Hed	Flight heading in the periapis
Lng	Geocentric longitude of periapis
Lat	Geocentric latitude of periapis

Table 10: Periapis state parameters

ReT	Time to reentry interface
ReT	Time of passage of the interface
Hed	Flight heading in the interface
ReA	Reentry angle
Lng	Geocentric longitude of the interface
Lat	Geocentric latitude of the interface

Table 11: Reentry interface parameters

Launching from surface

Launch mode of TLI and TEI programs can be used for surface launch. Launch heading display (Hed) is indicating launch direction from the current position at a time of lift-off. When launching from the Earth launch heading is most often 90 degrees. It is normal that required flight heading will change slowly during lift-off. (TLn) is counting down the launch and it can't

be modified by user. When launching from the Earth the Launch countdown will continue from 0 to -60 and after that the countdown will move to next launch window if the vessel is still landed. [EXE] button is not used in launch mode neither is the autoburn.

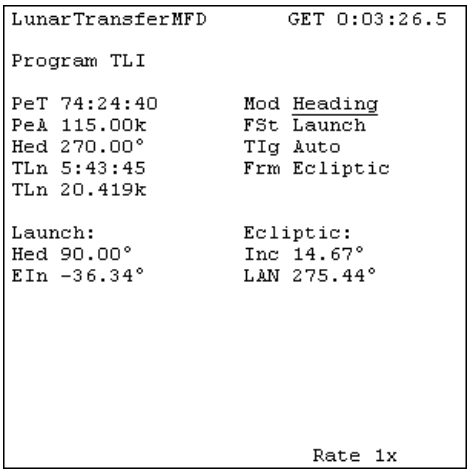

Figure 9: Surface launch mode

When launching from the Moon there is no countdown because it could take long time to get in the optimal launch window and the benefit from it would be very small. Therefore it's not worth of waiting.

During surface launch note that launch heading displayed in LTMFD or IMFD is indicating required direction of movement when in the SurfaceMFD or HUD heading is indicating orientation of the vessel.

Orbital alignment indicator (EIn) displays current miss alignment of vessel's orbital plane. In other words it's the angle between required direction of movement and actual direction of movement. The (EIn) should be near zero before reaching the orbit. The (EIn) can be controlled by turning the vessel few degrees to left or right form the flight heading pointed by (Hed). It's like heading towards VOR beacon with airplane. Target isn't an orbital plane therefore you can always correct your course and hit it dead center. Launching to ISS is more complicated.

It's also possible to use LaunchMFD (*by Simon "Enjo" Ender*) to reach the low orbit. Required orbit alignment items (Inc) and (LAN) are displayed on the screen.

When using Apollo launch autopilots or LaunchMFD the time of launch may not be exacyly the same as the one computed by LTMFD. There are alternative launch windows leading in parking orbits with different inclination and can be still used properly for TLI. Lowest possible inclination is preferred in LTMFD.

Thrust Monitor

The Thrust Monitor or in other words Delta Velocity Display can be opened or closed at any given time by pressing [DV] button. This doesn't interfere in execution of any other programs.

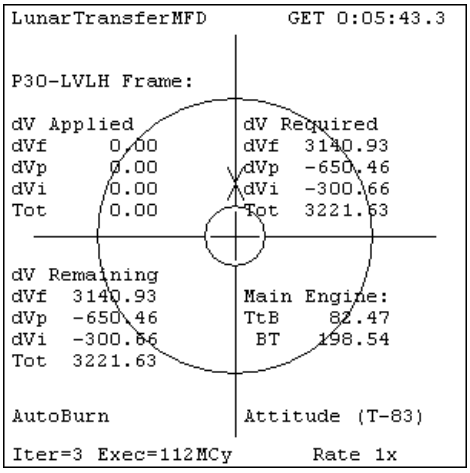

Figure 10: Thrust Monitor

dVf	dV in forward flight direction
dVp	Plane change dV
dVi	Inbound direction (i.e towards planet)

Table 12: Delta volocities

When the Thrust Monitor is open, Autoburn can be activated and disabled by pressing [EXE]. When pressing [EXE] anywhere while the autoburn is active it will always disabled it. When the autoburn is active, status display will appear in lower-right corner of the screen.

Selected engine is displayed above remaining burn time (BT) and time to ignition (TIg).

Delta velocities can be displayed in ft/s by switching "dV Display" item from configuration menu to "Imperial". This doesn't effect in behaviour of any other programs or displays.

Action Menu

In current implementation of LTMFD action menu contains only a few items but more will come in the

future. Action menu is used to trigger special actions such as Auto Configuration and GET Synchronization. There are also parameters those are more often require than the parameters in configuration menu. Action menu can be accessed from anywhere, without effecting existing program configurations, by pressing [ACT]. Selected action can be triggered by pressing [EXE] button, this will also close the menu automatically. Parameters in the Action menu can be modified with [+] and [-] buttons. You can close the Action menu without executing any actions by pressing [ACT].

GET Sync: Synchronize GET with simulation elapsed time, time of launch or with external source like AMSO/NASSP.

Engine: An engine that will be used in calculations and autoburn.

AGC dV Ref This parameter can be used to override the default reference of delta velocity. This is important only when a burn data is transfered to some other application, other than the LTMFD it-self, like in the vAGC that's used by the NASSP. By default the LTMFD is configured to switch the reference at the same with the vAGC.

AB Steering This paramater can be used to select preferred steering or powered flight guidance method. There are two modes available. "**Fixed dV**" Maneuvers are based on raw delta velocity computations carried out by navigation programs. "**Prefer LAP**" If Lambert Aim Point (LAP) information is provided by navigation program, Maneuver is executed by using LAP targeting.

Configuration Menu

Configuration Menu is a place for rarely needed configuration parameters and options.

Countdown: Start date of the GET countdown.

Engine: An engine that will be used in calculations and autoburn.

Date Format: Dates are expressed in this format. (GET or MJD)

dV Display: Units used in dV display. (Metric or Imperial)

EI Altitude: Altitude of reentry interface.

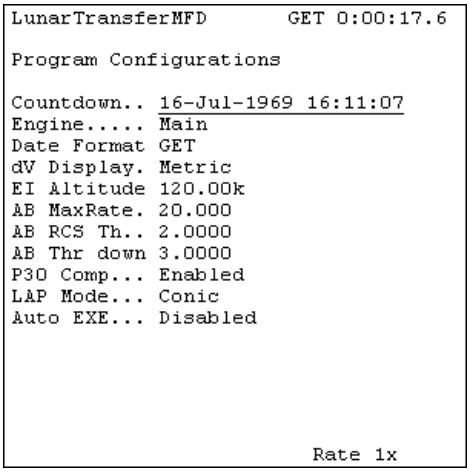

Figure 11: Configuration Menu

AB MaxRate: Maximum angular velocity used in autoburn.

AB RCS Th: Linear RCS Threshold. Switch to linear RCS when remaining dV is less than this amount.

AB Thr down: Throttle down when remaining dV is less than this.

P30 Comp: Enable P30 compensation in Local Vertical. (*Required in NASSP*)

LAP Mode: Lambert Aim Point computation method.(*Not in use*)

Auto EXE: Automatically press EXE after modifying input parameters.

Some Notes

- The LTMFD requires that Time to Ignition (TIg) is at least 300.0 seconds when executing a program.
- Computed transfer solution is not saved in scenarios only the user input parameters are.

Acronyms

ApA	Apoapis Altitude
Att	Attitude (i.e. orientation)
BT	Remaining Burn Time
dV	Delta Velocity
dVt	Total dV
dVf	dV in forward direction of flight
dVi	dV in inbound direction. (towards planet)
dVp	dV in plane change direction
Ecc	Orbit Eccentricity
EIn	Orbit alignment indicator
Frm	Reference Frame
FSt	Flight stage selector (a mode selector)
Hed	Flight Heading
Inc	Inclination in selected frame (FRm)
LAN	LAN in selected reference frame (FRm)
Lat	Geocentric Latitude
Lng	Geocentric Longitude
LPe	Longitude of Periapis
Mod	Program mode selector
OPe	Orbit period in seconds
PeT	Time to Periapis
PeA	Periapis Altitude
ReT	Time to reentry interface
ReA	Reentry Angle
Ref	Reference Planet or Moon
SMa	Semi-Major axis
Tgt	Target Base, Planet or Moon
TOA	Time of orbit alignment with target
TIg	Time to Ignition
TrA	True Anomaly
TtB	Time to Burn (same as TIg)