

Lunar Landing MFD

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INTRODUCTION

The purpose of this MFD is to aid a pilot in making a precision landing at a specified location on the moon (base locations are specified by the user in a configuration file). It has three major functions:

- 1) Provide relevant state information (distance, speed, acceleration, etc)
- 2) Provide targeting information in the form of require velocity/acceleration values necessary to reach a specific target within certain altitude/speed constraints
- 3) To provide a level of automatic over the spacecraft. This takes the form of both an Autothrottle, as well as an autopilot for certain portions of flight.

REQUIREMENTS

The genesis of this project was Joel "CaptainJoel" Rogers' Apollo 15 landing scenario. He has kindly allowed me to include versions of his scenario files as part of this package, thus saving everyone one more additional download. However, it does require that you download ACSOFT's AMSO add-on (www.acsoft.ch/orbiter/apollobeta.zip) and Christoph Kopp's Hadley-Apennine scenery (available at <http://nav.to/orbitmods>).

INSTALLATION

Simply unzip into your orbiter directory. From the Launchpad, activate the module "LunarLandingMFD" and have fun :-)

CHANGES 06/18/02

Modified the format of the latitude/longitude in the config file to be consistent with the format used in the other Orbiter config files; also corrected some bugs in the config file itself. Bug fixes to prevent uncontrolled thrusting when switching between throttle and MFD modes. Modified the descent rate logic so that the rate change (that is, the acceleration applied) is based on the difference between the actual and desired rates (previously, all changes were 0.5 m/s^2).

As far as major changes, modified the DAP to control the spacecraft through Approach mode (Landing is now the only portion that must be done manually). The other major change is with the LPD. In the real LM, the LPD not only displayed the target landing location, but also allowed the pilot to manually reposition the target; the MFD now does the same.

CHANGES 06/10/02

Separated guidance/control functionality from output functionality. This means that Autothrottle/DAP now operates independently of the MFD redraw, allowing it

to continue operating even while using an external camera view. Also removed the hard-coded target - now target bases can be added by the user by editing the file Config/LunarLandingMFD.cfg.

BACKGROUND

The flight path generated by the MFD is based on that flown during the actual Apollo landings, so a little discussion about them seems fitting (an excellent source for information about the LM descent and ascent can be found in Dr Floyd Bennett's "Lunar Module Descent and Ascent Trajectories", which can be found at <http://www.hq.nasa.gov/alsj/alsj-descent.html>). Prior to the final landing approach, the LM was in an elliptical orbit, with an apolune of 60 nm and a perilune of 50,000 feet. The approach begins at a low point in the orbit, when the LM's descent engine ignites. For the next eight minutes, the Lunar Module's computer, the PNGS (Primary Navigation and Guidance System), guides the spacecraft through the Braking Phase towards a target in space, called the High Gate. The High Gate is located about 4.5 miles up range from the intended landing site, at an altitude of about 7,000 feet (and includes velocity/acceleration constraints). At High Gate, the spacecraft pitches forward, enabling the crew to see their intended landing site. A new landing target, Low Gate, now guides the LM through the Approach Phase to an altitude of 500 feet, and 2000 feet up range. During this phase, the commander can maneuver to select a new landing if it appears that the computer is bringing them down into a bad spot. At Low Gate, the Landing Phase begins - horizontal velocities are nulled out, and the LM descends vertically down the last 100 feet.

MODES OF OPERATION

The MFD operates in one of six separate modes:

- 1) Monitor - Prior to engine ignition
- 2) Braking - From engine ignition to High Gate
- 3) Pitchover - Occurs at High Gate
- 4) Approach - From Pitchover to Low Gate
- 5) Landing - From Low Gate until touchdown
- 6) Contact - On the surface

The MFD automatically transitions between modes based on certain criteria - the pilot has no direct control over the mode.

AUTOTHROTTLE MODES

Although its capabilities are more limited than that of the PNGS, the MFD is able to provide some automatic control over spacecraft function in the form of an Autothrottle. Additionally, during certain portions of flight, pitch control is also provided. The Autothrottle operates in one of four separate modes:

- 1) Horizontal Guidance - Control is based on arriving at the High Gate with the correct horizontal velocity. In essence, the computer controls the horizontal portion of flight, and the pilot controls the vertical.
- 2) Digital Auto Pilot (DAP) - Identical to Horizontal Guidance except that pitch control is also provided. This enables the computer to control both the horizontal and vertical components of flight; the pilot just sits back and enjoys a nice cold one :-)

3) Rate of Descent (Auto) - The opposite of Horizontal Guidance - the pilot controls the horizontal and the computer controls the vertical. The required rate of descent to reach of the target is automatically provided to the Autothrottle (hence the name, Auto).

4) Rate of Descent (Manual) - The same as the previous mode, except that the rate of descent is manually selected and modified by the pilot.

The Autothrottle mode can be selected automatically or manually. For each MFD mode, the Autothrottle has a default mode, as well as other acceptable modes. Not all MFD/Autothrottle mode combinations are valid (most of obvious reasons); the MFD will not allow a user to select an invalid mode, so there is no problem with accidentally selecting a mode that is incompatible with the MFD mode. A following list includes each MFD mode and it's associated Autothrottle modes (the first in the list is the default):

- 1) Monitor:
 - Horizontal Guidance (High Gate)
 - DAP - The only mode in which the Autothrottle is actually utilized; in this case, to control the pitch. Aside from that, the Autothrottle mode is fairly meaningless.
- 2) Braking:
 - Horizontal Guidance (High Gate)
 - DAP
- 3) Pitchover:
 - Horizontal Guidance
 - DAP - This mode only lasts a few seconds, so, like Monitor mode, the Autothrottle mode is fairly meaningless
- 4) Approach:
 - Rate of Descent (Auto)
 - Rate of Descent (Manual)
 - Horizontal Guidance (Low Gate)
 - DAP
- 5) Landing:
 - Rate of Descent (Manual) - The initial rate is set at 3 m/s

Note that while DAP is not the default mode for any of the MFD modes, once engaged, it will stay engaged until Landing mode, or until it is manually changed; for example, if DAP is used for Braking mode, it will continue to operate for Approach mode.

In order for the Autothrottle to have any effect, it must be engaged. This is the default option for the MFD, but it can also be disengaged in order to provide manual control of the throttle (I would not recommend this for your first few approaches ;-)). All the discussion regarding procedures within this file assumes that the Autothrottle are engaged - if you disengage it, you're on your own :-)

BASIC COMMANDS

The MFD is activated with SHIFT + ESCAPE (sorry, folks, I'm running out of meaningful keys that aren't used by other MFDs!). Additionally, the MFD has the following commands:

Key	Description
SHIFT + T	Engage/Disengage Autothrottle
SHIFT + M	Cycle through available Autothrottle modes
SHIFT + N	Select the next target base
SHIFT + P	Select the previous target base
SHIFT + MINUS	Increase your rate of descent. If the Autothrottle is currently in Auto mode, it will automatically be changed to Manual mode (reduces keystrokes during critical times). The initial rate will be the current, automatically selected rate (rounded down to an integer value)
SHIFT + EQUALS	Decrease your rate of descent. Like the previous command, it will automatically change Auto mode to Manual.
SHIFT + B	Override the computer and initiate the Braking phase. The benefit of this command is that the Autothrottle still maintains control of the burn.
SHIFT + A	Change the precision on the relative bearing display (described below). The default precision is two decimal places, but four can also be displayed with more accuracy is needed (say, for a plane change to align with a target). For current applications, the normal user will probably never need to use this command.
SHIFT + NUMPAD 8	Shift target downrange (away from the spacecraft) by 100 m
SHIFT + NUMPAD 2	Shift target uprange (towards the spacecraft) by 100 m
SHIFT + NUMPAD 6	Shift target right (away from the spacecraft) by 100 m
SHIFT + NUMPAD 4	Shift target left (away from the spacecraft) by 100 m
SHIFT + NUMPAD 5	Reset target to the original location (defined in the config file)

For purposes of shifting the landing target, the directions are defined with respect to the spacecraft's heading (not the velocity vector).

OPERATION

Landing a Lunar Module within 1 km (and hopefully much closer!) of a selected point starting from almost 500 km away is a complicated task, and therefore, so is the MFD :-). Seriously, the actual flying is amazingly simple and straightforward, once you get used to the basic procedure.

For those of you (like me :-)), who are impatient and want to jump right in, read the next section (Monitor Mode). If you follow the procedure, and activate the DAP, the computer will take care of you - in fact, if you let it, the computer will do most of the flying (at least the hard parts) throughout the whole flight :-).

Based on the nature of the MFD, I figure the best description of operation is to run through a sample landing.

MONITOR MODE

First, start Orbiter with an appropriate scenario. You will be in a descent orbit, attached to the CSM - separate and move into the LM. The first order of business is maneuver the LM to a level attitude (I recommend the HLEVEL Navmode) and aligned with your velocity vector. Since you will soon be pitching up to 90 degrees, and errors could result in unwanted roll, be precise about this (I use the Attitude MFD, but then again, I'm biased :-)). If you are planning on using the DAP, you can select it now - you will be pitched up to +90 and held in that attitude as you orbit; if you plan on flying manually, you must pitch yourself.

The top portion of the MFD display is the same, regardless of mode. First, there are three status displays indicating the mode of the MFD and the Autothrottle (Engaged/Disengaged as well as the Autothrottle mode). Below that is the target location - name, latitude, longitude, and relative bearing. The pilot can select a landing site using SHIFT + N and SHIFT + P to cycle through the list of available sites. Since the approach path should be aligned to a fairly high degree, the bearing should be close to zero and should not be of much concern during the approach (the error will increase as you get closer, so don't worry too much when it does).

Below that is the basic state information - distance, velocity, and acceleration - broken down into horizontal and vertical components. Note that the horizontal distance is the distance over the surface between your location and the landing target, and the vertical distance is your altitude. Also, the distance is to the landing target, not the next guidance target (High or Low Gate).

While the top portion of the screen remains constant, the bottom half changes based on what the current mode is. The primary data displayed throughout the flight is the results of the guidance calculations. In essence, the horizontal position of the approach is one long brake from 1.6 km/s to zero; the vertical is a controlled descent, with braking occurring primarily in the later phases. Because of this, horizontal information is displayed in terms of acceleration/deceleration, and vertical information in terms of speed. Let me repeat that so there is no confusion - horizontal guidance is in terms of acceleration, and vertical guidance in terms of velocity. The primary result of the guidance calculations are "Required" values. Simply put, they tell the pilot that if you hold this acceleration and this velocity, you will arrive at the next target within the correct constraints (horizontal velocity is the primary constraint - vertical velocity is much easier to manage so it is left up to the pilot's discretion).

The final part of the display during Monitor mode is the maximum acceleration. This is the maximum acceleration that the descent engine can generate (the product of its max thrust and current mass). Since the LM is at +90 pitch, this means that all of its thrust is horizontal. As the LM approaches the landing site, the required acceleration will increase; when it reaches 95% of the max acceleration, the maximum acceleration display will turn white and begin to flash - just a warning that things are about to get exciting :-). When the acceleration required equals the max possible, the engine will ignite and the MFD will enter Brake mode. Note that the engine can be manually started earlier using SHIFT + B.

BRAKE MODE

Brake mode starts with ignition and ends with pitchover at High Gate. The default Autothrottle mode is Horizontal Guidance, but DAP can also be selected. If in Horizontal Guidance, the computer will use the throttle to control your deceleration. The pilot will have to use the vertical velocity readouts (velocity required, actual velocity, and acceleration) to control the descent. It's actually very easy (so easy, that I designed the DAP because it was getting tedious with all my testing :-)) to fly, provided that you remember to make gentle pitch changes and watch your acceleration - letting it get too high will cause you to shoot back and forth around the target velocity instead of holding it closely. If the DAP is flying, enjoy the ride :-). In either case, I recommend opening up the Ascent Profile MFD to watch the altitude/pitch profile - the pitch profile with the DAP flying is pretty cool :-)

It's important to realize that this MFD operates only in two dimensions - horizontal and vertical. No automatic lateral targeting is currently supported (give it some time), so the MFD assumes that you are aligned with the target. If for some reason you decide to apply a lateral motion, please be aware that the MFD will not compensate for this - the further you are away from your target alignment, the more inaccurate the MFD becomes. However, for small adjustments, this is usually not noticeable. Still, I would recommend waiting until Approach mode before attempting to make any lateral movement, if for no other reason than that you can see your landing site.

The display during Brake mode is similar to that during Monitor. In addition to the required acceleration/velocity data, there is also a delta display, showing the difference between the required and actual values. If the error becomes greater than 25% of the required value, the delta value turns red. Additionally, maximum acceleration is replaced with the Time To Go until High Gate. When the time is under a minute, the display turns white and begins flashing. Time zero should be reached at High Gate, and Pitchover should begin. For this approach, High Gate is 7.3 km up range, and an altitude of 2.1 km. Horizontal speed at High Gate should be 100 m/s.

PITCHOVER MODE

Pitchover is the transition between Brake and Approach mode. It pitches the LM forward to about 30 degrees, enabling you to see the landing site. It's more of an event rather than a guidance mode - simply sit there for the few seconds it takes to complete.

APPROACH MODE

Now you can finally size up the situation :-). If you were careful (or if you let the DAP fly), you should be sitting pretty for a landing. When Approach mode begins, the guidance target switching from High to Low Gate - 610 m up range, 150 m altitude, with a horizontal velocity of 15 m/s. If you are in DAP mode, the computer will continue to automatically fly the spacecraft until Landing mode. If you're flying manually, here's the time where you get to show your stuff as a pilot :-). The Autothrottle switches into Rate of Descent (Auto) mode, and the pilot is left in charge of the horizontal deceleration. Here's where you must make decisions about where to land.

The display is identical to Brake mode, with the addition of the Landing Point Designator (LPD) display. This provides a reference angle to see where the

landing target is located. The angle is sighted on the HUD as degrees below the horizon (in the real LM, the angles were etched into the window). You can manually retarget the landing site using the SHIFT + numeric keypad commands. If you change the horizontal position, you should notice that the LPD angle changes; if you move the target to either side, the direction display changes. While the computer/DAP will compensate for horizontal changes, you must manually correct for lateral ones. This can be done using spacecraft roll/yaw in conjunction with the direction display. If the DAP is flying, be aware that it may use KILLROT to stop its own pitch rotation, thereby interfering with your control inputs. You can compensate for this using small, well planned, corrections.

When Low Gate is reached, the MFD switches into Landing mode (note that if you wind up bringing it in short, Landing mode will automatically engage at 100 m, regardless of your velocity or horizontal position). The Autothrottle is set to manual descent with a rate of 3 m/s.

LANDING MODE *****

The sole purpose of Landing mode is to null out all horizontal velocity and begin a slow, vertical descent to the surface. This display now provides four pieces of critical information: commanded rate of descent and the velocity in 3 dimensions (including laterally). It's just a matter of patience and finesse in order to slowly bring the LM down until...

CONTACT MODE *****

When lunar contact is made, the engine shuts down and the Autothrottle disengages (in case you need to make an abort). Finally, the location of your landing site is displayed.

The Falcon is on the plain at Hadley :-)

SCENARIOS *****

As I mentioned, the thing that spurred me into this project was CaptainJoel's Apollo 15 scenario. This distribution contains two versions of that scenario file. The first, "Apollo 15 Approach", is the original scenario. While probably more historically accurate, I found that - at least with this scenery - the albedo of the surface isn't correctly modeled, leaving the landing site very dark (even for lunar morning). Consequently, I advanced the scenario one day, which gives much brighter conditions. Since different people may prefer different conditions, I've included the second scenario as "Apollo 15 Approach - Day". Play with both and see which you prefer.

CONFIGURATION FILE *****

The MFD gets target base information from the file "Config/LunarLandingMFD.cfg", allowing users to add, delete, and modify landing sites. There is a maximum limit of 50 bases, all of which must be on the moon. Each line of the configuration file describes a different base (lines that begin with a ';' are comments) and has the following format: <base name> <longitude> <latitude>. The base name has a limit of 25 characters and cannot contain whitespace; the latitude/longitude are in degrees (not degrees/minutes/seconds).

KNOWN BUGS AND LIMITATIONS

When resetting the target to the original location, I've encountered garbage data that lasts for the first update, and then is immediately fixed. This doesn't happen every time, so I haven't isolated the exact conditions that cause it. However, it doesn't seem to have any real effect on spacecraft control so it appears to be just a very minor inconvenience.

Please note that this is NOT a sophisticated guidance algorithm (I'm working on that, though :-)). It flies well under normal conditions (better than even I expected), but I haven't do anything too wild (the occasional swooping descent to High Gate, maybe, nothing really taxing :-)). Be aware that if you let it get too far away from you, I can't promise you that the MFD will help you get it back (though, if it does, let me know!).

FUTURE WORK

Aside from removing some of the limitations that I've previously mentioned, some ideas for improvements in the near future include:

- An Abort mode (once I can figure out how to automatically jettison the descent stage)
- Sound at a couple key places
- Any other good ideas that users might have :-)

SOURCE CODE

Being a strong believer in Open Source, I've included the source files for the MFD. You are free to use, modify, and redistribute the code within certain, fairly loose, guidelines. Please read Copyright.txt that is included with the source files for full details.

FEEDBACK

Please, please, please! Any and all feedback is appreciated - comments, questions, problems, suggestions - anything. I'm sure this code is not bug free, so bug reports are important :-)

THANKS

My deepest thanks to Joel Rogers. He not only created the original scenario file and was gracious enough to let me include it, but also served as beta-tester and reference, and even provided a bit of unprompted promotion :-)

Also thanks to Encopo for the bug fix! :-)

Enjoy!

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