

Earth to Moon

An Orbiter Tutorial

by David Courtney

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Orbiter is a free and realistic space flight simulation program by Martin Schweiger

Orbiter home: orbit.medphys.ucl.ac.uk/

Orbiter community: www.orbiter-forum.com

My orbiter-forum contact name: [blixel](#)

Warning: This document includes many colorful screenshots to help illustrate the various concepts that are being discussed. PRINTING THIS TUTORIAL IS NOT RECOMMENDED. Note however there is a checklist at the end of the tutorial that is suitable for printing.

Credit: I learned the fundamentals of Orbiter by reading the outstanding documentation that comes with Orbiter, by reading [Go Play in Space](#) by Bruce Irving, by watching the tutorial playbacks that come with Orbiter (specifically, the “DG to the moon” playback), by looking at several [tutorials and videos](#) on orbiter-forum.com, and finally, by spending a tremendous amount of time enthusiastically pursuing a greater understanding of this wonderful space simulator.

Motivation: This tutorial started as a simple plain text document wherein I jotted down a few important reminders so I wouldn’t forget what I was learning. That plain text document grew organically over the course of an entire year. I eventually realized that I had a compilation of fantastic information that would be beneficial to others, so long as I took the time to format it in a presentable fashion. This tutorial is the result of that formatting effort.

Audience: This tutorial is intended to help beginners who want to learn how to fly from the earth to the moon without using automated methods that do most of the work for you (but leave you clueless as to how or why anything works.)

Every effort has been made to make this tutorial as simple, yet all-inclusive as possible, but it is not intended to serve as an installation guide for the Orbiter program, nor is it intended to serve as a guide for familiarizing beginners with the user interface of Orbiter. (Refer to the Orbiter.pdf document in the Doc folder to familiarize yourself with the fundamentals.)

It is assumed that you have already installed Orbiter, have it working, and have spent at least enough time to understand how to get into space and how to interact with the multi-function displays (MFD’s).

This tutorial utilizes the Delta-glider space vessel that comes with the default installation of Orbiter. This tutorial does not require any Orbiter add-ons. However, I highly recommend [Orbiter Sound](#) 3.5 by Dan Steph so you will have engine and thruster sounds.

Now that all of that is out of the way, let’s fly to the moon!

Quickstart

Let's get right to it shall we.

Orbiter comes with quite a few scenario files. The best built-in scenario to use to follow along with this tutorial is the aptly named Quickstart scenario located in the Checklists folder.

This is a great starting scenario because it puts you on Runway 33, during the day, at the Kennedy Space Center, in the basic Delta-glider which is fueled up and ready to go.

Note, once Orbiter is loaded, pressing F8 will toggle to the 2D cockpit view that I'm using in this tutorial.

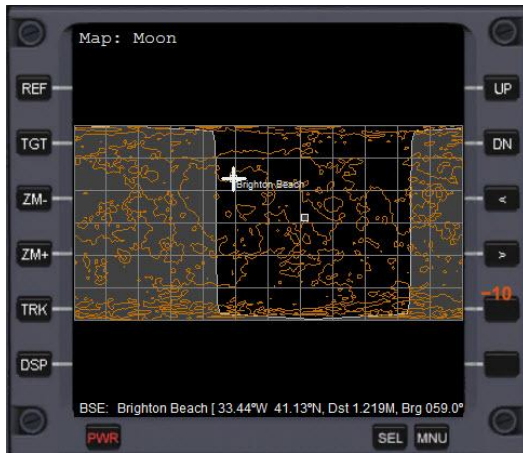
We'll start by setting up a couple of our MFD's. In one of the MFD displays, we'll open the Align plane MFD, on the other, we'll open Map MFD. On both MFD's, click TGT and select the moon as the target.



To see the orbital planes on Map MFD, you have to click DSP to bring up the display parameters and click MOD to change the Orbit lines value. The value needs to be set to Orbit plane. Once it is set, click OK.



Planning the Time of Arrival



The moon rotates on its axis once every 29.5 days. This means a day on the moon lasts about 14.75 days. If you want to arrive at your target base when the sun is shining, you need to depart Earth at the appropriate time of the month.

On your Map MFD, click REF, and select the moon as the reference. Now you will be able to see which part of the moon is in the sun, and which part is in the dark.

Click TGT and select Brighton Beach as the target.

In the image above, you can see that Brighton Beach just entered the dark of the moon. If we were to depart for the moon now, we would arrive at night.

Using time acceleration, we can skip ahead several days so that Brighton Beach is back in the sunlight (as in the image to the right.) If we were to depart for the moon on this day, we would arrive when the sun is still shining at Brighton Beach.

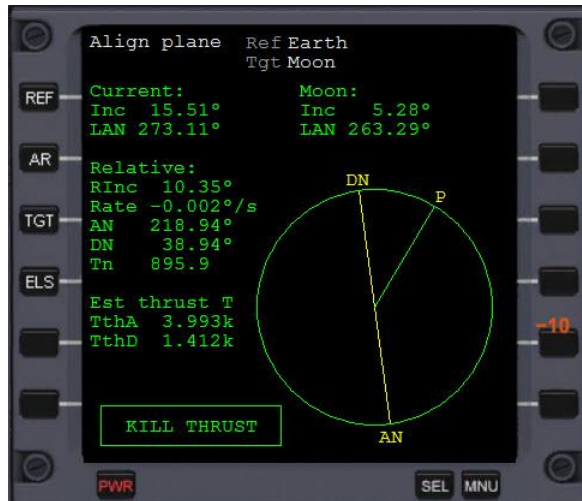
There is no particular advantage to landing when the sun is up. It's a matter of personal preference. But taking such things into consideration is something you should include as part of your planning. Thinking ahead is always important!

Realizing that it takes several days to get to the moon, you could depart Earth when your target base was still in the dark and arrive just as the sun was coming up over the lunar horizon. If you were planning a fictional mission that required solar energy, then arriving at lunar sunrise would give your crew maximum sunlight exposure for the duration of the mission.



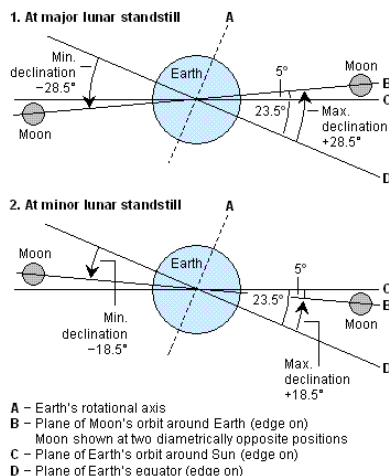
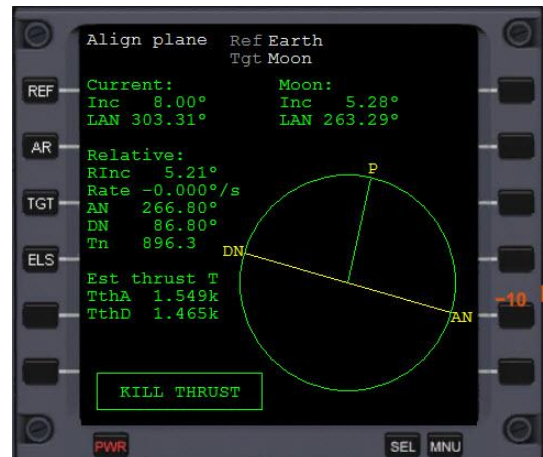
Once you have determined your arrival time at the target base, click REF on Map MFD and select Earth as the reference.

The Launch Window



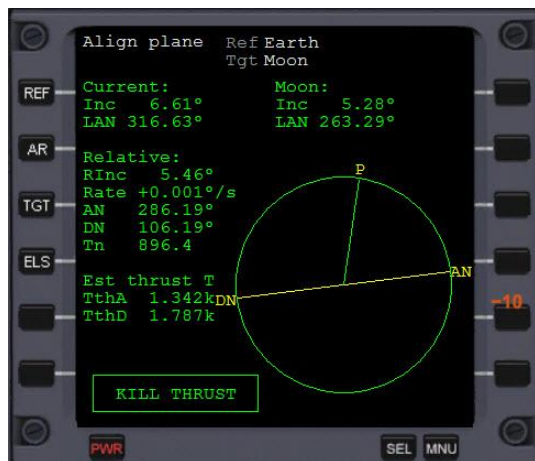
When the moon's orbit most closely matches our projected orbit, that is when it's best to take off. The number displayed on the Align plane MFD's RInc (Relative Inclination) indicator will get lower as the launch window gets closer.

It is time to take off when the RInc value reaches its lowest number. If you watch the Align plane MFD, you can anticipate the lowest RInc by watching the Rate (right below the RInc). You'll see that it shows something like -0.002 or -0.001. Eventually this will show as -0.000. When this happens, you are near the lowest RInc - in other words, your launch window has arrived.



Note that the RInc value will never reach zero. The best RInc you can achieve will depend on the date of your launch.

The moon moves "up and down" relative to the earth's ecliptic plane, so this means as you fly to the moon on various dates, the best (i.e. lowest) RInc will vary from one flight to the next.



If you continue to wait, the Rate will go from -0.000 to +0.000; if you continue to wait beyond that, the RInc will start to rise again. (Note in the image to the left, the RInc has started going up.)

If the RInc is getting higher, it means the last launch window has already gone by. You just have to sit and wait – or, more practically, accelerate time to the next launch window.

You can always align your orbital plane once you're in orbit, but in so doing, you are wasting fuel. In real-life space flights, fuel is a precious commodity. In terms of realistic space flight, it is an absolute requirement to launch at the most fuel efficient time.

The Ride to Orbit

Explaining the details of taking off and getting into orbit is outside the scope of this tutorial. However, I do have a couple of thoughts to share with the absolute beginners.

When you take off from the runway, turn and head straight east (90 degrees) and hold that heading all the way to orbit. The primary reason you want to head straight east is so that you will have a proper orbital plane. If you take off and fly the runway heading of 330 degrees (or 150 degrees – the other runway direction), your orbital plane is going to be way off and is going to require an enormous amount of correction.

If you get to orbit with a heading of approximately 90 degrees, the amount of plane change you will be required to make will be very low. Now - having said that, I at least want to get you thinking about improving your efficiency for your future flights.

In the "DG to the moon" tutorial that comes with Orbiter, it says "The plane alignment MFD provides a rough guide for the correct ascent heading. Try to keep the relative inclination between your orbit and the Moon's orbit at a minimum (indicated by the RInc readout)."

What that means is after you take off and get to the initial heading of 90 degrees, you can watch the Align plane MFD and bank left/right so that your RInc will stay at the lowest possible number during your ascent to orbit. Taking off and holding a heading of 90 degrees is slightly inefficient. If you can make small banking corrections on the ride up, you will have a smaller Align plane correction to make in the forthcoming steps.

Having said all that, it is my opinion that making those corrections on the ride up is a slightly advanced strategy. In my opinion, if you are new to Orbiter, you shouldn't worry about trying to keep your relative inclination at a minimum during the ascent to orbit. Instead, focus on holding a heading of 90 degrees; you'll make a plane alignment burn once you are in orbit in any event.

Keeping your relative inclination at a minimum is a matter of efficiency. It is indeed better to make flight adjustments as you're ascending to orbit, but when you're just getting started with Orbiter, the issue of watching your pitch, vertical speed, altitude, and velocity is far more important. So, for your first few attempts, don't worry about the relative inclination as you're ascending. The added distraction of watching the relative inclination in addition to everything else is a bit too much for beginners.

Prioritizing Plane Alignment and Orbit Circularization

Once you reach orbital velocity and cut the main engines, one of the more pressing matters to address is circularizing your orbit. However, it is often the case that you will cross the descending node before you reach Apoapsis. When that happens, it is usually in your best interest to make the necessary plane change prior to circularizing your orbit.



The above screenshot was taken immediately after I reached orbital velocity. I need to circularize my orbit, but I won't reach Apoapsis for another 1,546 seconds. Note the ApT (time to Apoapsis) value that says 1.546k. That is almost 26 minutes from now. In looking at the Align plane MFD, I see that I will reach the descending node in 1,025 seconds. Note the Tn (time to node) value that says 1.025k. That is only 17 minutes from now.

It is sometimes the case that you reach the node and Apoapsis at, or very near, the same moment. When that happens, circularizing your orbit takes priority. It won't do any good to make a plane change if you miss the Apoapsis burn opportunity and end up re-entering the atmosphere half an orbit later as a result.

IMPORTANT: If you use time acceleration, always turn off your autopilots before you start accelerating time. Pressing the Kill Rotation button will shut off the autopilot and eliminate most of the ship's angular momentum.

Since I have the time to spare, I will do the plane alignment burn first.



Before doing the plane alignment burn, let's take a look at what the **current** orbital plane looks like.

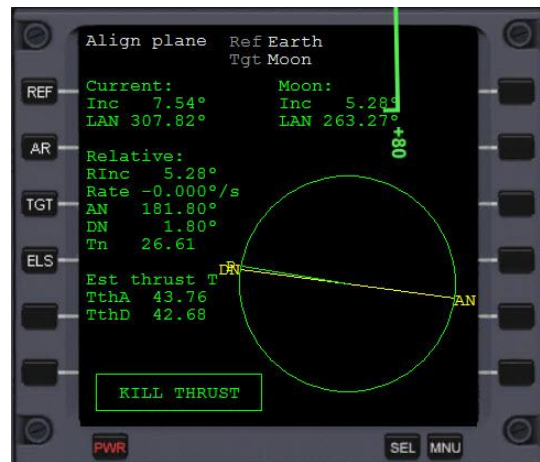
If you open Map MFD, you can press ZM+ to zoom in a couple of clicks so you can get a close look at your orbital plane around the earth. (Remember, the orbital plane is displayed by clicking DSP and adjusting the Orbit lines value.)

For now, I am just observing. In a moment, I will compare this image to what my orbital plane looks like after I complete the plane alignment burn.

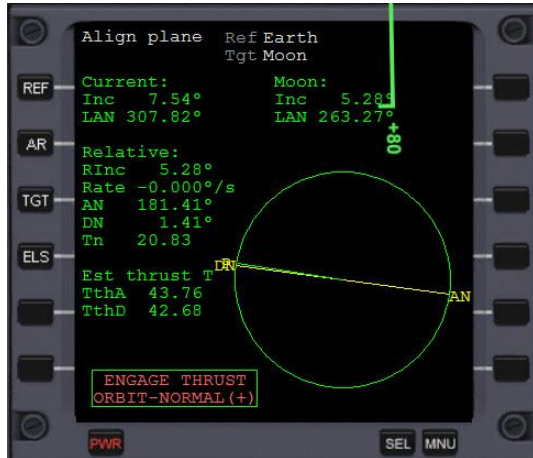
Plane Alignment

If you don't know the *secret formula* behind the Align plane MFD, then knowing when to burn, how long to burn, and what the acceptable margin for error is can be a total mystery.

In the image to the right, we see that we are just 26.61 seconds away from the Descending Node. Currently, the Align plane MFD is on the "Kill Thrust" mode. In a moment, it will change from "Kill Thrust" to "Engage Thrust Orbit-Normal (+)".



The time at which this message changes seems totally random when you are new to Orbiter. However, there is a very easy to understand method for anticipating when the Engage Thrust message will come on.



Toward the bottom left of the Align plane MFD, there are a couple of numbers next to the TthA and TthD variables. When the Tn (time to node) is just about half of the TthA/TthD number, the Engage Thrust message will come on.

In the image to the left, we can see that Tn is just under 21. (21 is just about half of 43.) As I was accelerating time forward to get to this point, I slowed down to 1x when Tn was getting down below 75 so I would have time to orient my Delta-glider to the Normal+ position before it was time to engage the thrusters.

If you are new to Orbiter, you are probably wondering, “When do I use the Orbit Normal (+) autopilot, and when do I use the Orbit Normal (-) autopilot?” You probably realize that you don’t want to have to wait for the Engage Thrust message to come up and tell you which orientation to use. If you wait for the Align plane MFD to tell you which orientation to use, you may very well pass the node entirely by the time the autopilot is done orienting the ship. Therefore, you need to know how to anticipate the direction of orientation in advance.

Fortunately, there is an easy memory trick for knowing which way to orient your ship.

Ascending Node = Anti-Normal (or AN = AN)

If you can remember that, then you can always deduce that the Descending Node is *the other one*.

When I was doing this burn, I knew that I needed to use the NML+ autopilot because I was coming up on the Descending Node. I briefly thought to myself “AN=AN (Ascending Node = Anti-Normal) and therefore Descending Node is *the other one*. Conclusion: Use the NML+ autopilot.”

When doing any kind of burn, you always want to keep an eye on what is going on so you can back off the throttle in time so you don’t overshoot. Overshooting is sloppy and it wastes fuel. (Bad form.)

To prevent yourself from overshooting when making a plane alignment burn, it is best to keep an eye on the Tn value.

As Tn reaches 0 and passes by, that means the Time to node has come and gone, and very shortly thereafter, you will actually cause your RInc to increase if you continue burning.



Ideally, you want to reduce the RInc to 0.00, but it's not always possible to do that in a single node passage. Once the Engage Thrust message goes away, you should kill your engines even if the RInc has not yet reached 0.00. If necessary, you can make another correction at the next node passage. However, in going to the moon, a RInc of 0.01 is *more than* acceptable. Due to the fact that the moon is so close to the earth (relatively speaking), we will still easily get to the moon with a Relative Inclination of 0.05 or lower. (See technical note at the bottom of this page.)

Note that when you need to execute very small burns, it is better to use translation thrusters than to use the main engines. The main engines are too powerful, even at their lowest increment, when all you need is a small burst of thrust. If I wanted to bring my RInc all the way to 0.00 at the next node passage, I would eliminate that last 0.06 TthA/TthA with the 10% translation thrusters by holding down the CTRL key. (If you don't know about the translation thrusters, it is critical that you read section 15.2 of Orbiter.pdf in the Doc folder.)

Now that the burn is complete, if you bring up Map MFD, you can see how your orbital plane looks as compared to before.



Looks great! Let's move on to the all-important orbit circularization burn.

Technical Point: A plane alignment burn isn't even necessary when going to the moon. If you use more precise navigation equipment than the standard Transfer MFD (more about Transfer MFD later), you can get to the moon by combining your ejection burn and plane alignment burn into one action. This is especially important in the event you want to go directly from the International Space Station (ISS) to the moon. The ISS will be about 70 degrees off plane, so if you were to undock from the ISS and use the Align plane MFD to get lined up with the moon prior to making the ejection burn, that massive 70 degree plane change would require an enormous amount of fuel.

Once you learn the more rudimentary method of getting to the moon as outlined in this tutorial, you will eventually want to explore the more sophisticated (more complex) method(s).

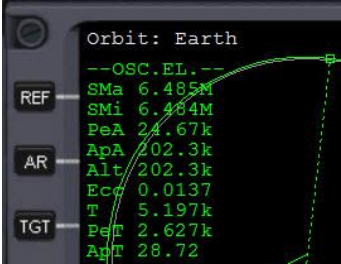

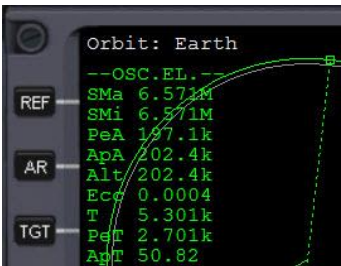

Orbit Circularization

When you are circularizing your orbit after launch, this is best done by performing a series of PROGRADE burns (as opposed to trying to bring your eccentricity down to 0.0000 in one single burn.) When the time to Apoapsis (ApT) is down to about 10 to 15 seconds, burn the main engines at full throttle by pressing + on the numeric keypad. Watch the PeA value (the Periapsis) increase, but notice that your ApT is also increasing.

This happens because you are *pushing* your highest point of orbit slightly forward as a result of the powerful main engine burn. When the ApT rises to 30 or 40 seconds, let go of the + key and wait for the time to count down to 10 to 15 again. The second burn may not require the full power of the main engines. You may want to use CTRL+ for the second burn so you don't overshoot the orbit circularization.

The idea is to burn a little to raise the PeA, wait for the ApT to count down, burn a little more, wait for ApT to count down again, burn a little more, and so on. Each burn will require less engine thrust than the one before it. When you are within a few kilometers of having a circular orbit, you want to switch to translation thrusters to work out the last little bit of eccentricity.

Performing a series of burns will ensure that your Apoapsis is not affected. (See the table on the next page.)

Before		Before the orbit circularization burn, the eccentricity is 0.0137 and the PeA (lowest point of orbit) is 24.67 kilometers.
Burn 1		After the first orbit circularization burn with the main engines burning at full thrust, the eccentricity is down to 0.0024, the PeA is up to 171.5k, and I am now 60.28 seconds away from Apoapsis. Notice that I am further away from Apoapsis now than I was before I started the burn. Now I wait for the ApT timer to count down to about 10 seconds again.
Burn 2		<p>After the second orbit circularization burn with the main engines burning at <u>partial thrust</u>, the eccentricity is down to 0.0004, the PeA is up to 197.1k, and I am 50.82 seconds away from Apoapsis.</p> <p><i>Note that correcting the eccentricity beyond this point is completely unnecessary.</i></p>
Burn 3		<p>After a final burn with <u>translation thrusters only</u>, I brought the eccentricity all the way down to 0.0000.</p> <p>Notice the ApA (Apoapsis) only increased by 0.1k during the series of burns.</p>

Assessing the Situation

I think it's important to fully understand what your present situation is each step of the way. Prior to the orbit circularization burn, your situation was that you needed to take action within a relatively short period to prevent yourself from re-entering the atmosphere. Now that the orbit circularization burn is complete, your present situation is more relaxed. You can happily orbit the earth indefinitely before moving on to the next action.

It's important to understand that you don't have just one opportunity to make the large ejection burn that will take you out to the moon. You have a new opportunity to make the burn every time you go around the earth. When you are new to Orbiter, it's easy to get a bit of tunnel vision when reading step-by-step tutorials and watching step-by-step videos. You may think that because some action you took didn't match up exactly with what "*that guy in the video did*" that it somehow means you made an irrecoverable error, that you missed the "window" entirely, and the only way to fix it is to start over.

What you need to realize (and the sooner you realize this, the better), is that no two flights will ever be exactly the same. Period.

As an example of the varying ways to do things, in the previous steps, I made the Align plane burn prior to the orbit circularization burn, but I was not required to do things in that order. I could have skipped over the Descending Node and went straight to Apoapsis to do my orbit circularization burn. I could have done the Align plane burn at the next node passage after Apoapsis.

On the other hand, some things do indeed have to be done in a precise order. For example, we can't perform the ejection burn prior to doing our Align plane and orbit circularization burns. While that is obvious to someone who has a little experience, it certainly isn't obvious to someone who is brand new to Orbiter. Understanding the sequence of events and how you can vary the order of certain tasks comes with experience.

That is all I'm going to say about this point, but I wanted to bring it up because, again, I know how easy it is to get tunnel vision when you're trying to understand these things for the first time.

Transfer MFD

Once you have a reasonably circular orbit, and you have aligned your plane with the moon, it is time to prepare for the Trans Lunar Injection (TLI) burn which will raise your Apoapsis all the way out to the moon's orbital path around the earth.



Bring up Transfer MFD. By default, it will look like the image to the left. The default view of Transfer MFD is showing a similar graphic to what you would see if you were to look at Orbit MFD.

The circular graphic represents the earth, and the single radial line extending out to the edge of the circle is showing your ship's position in orbit around the earth.

For the sake of clarity, it can be useful to look at Transfer MFD side-by-side with Orbit MFD.

Notice how Orbit MFD shows the same situation as Transfer MFD.





The first thing we need to do is click TGT to select the moon as the target. Notice that the graphic has been updated.

The new graphic is showing a very tiny circle in the middle of a much larger orange outer circle. The very small circle in the middle is Earth. The large outer orange circle is the moon's orbital path around the earth.

The dark orange radial line that is pointing out to the edge of the circle is showing us where the moon is currently at in its orbit around the earth.

The dim greenish radial line doesn't have any relevant meaning at this point.

Click HTO to turn on Hypothetical Transfer Orbit. This allows us to create "What if?" scenarios (hypothetical scenarios.)

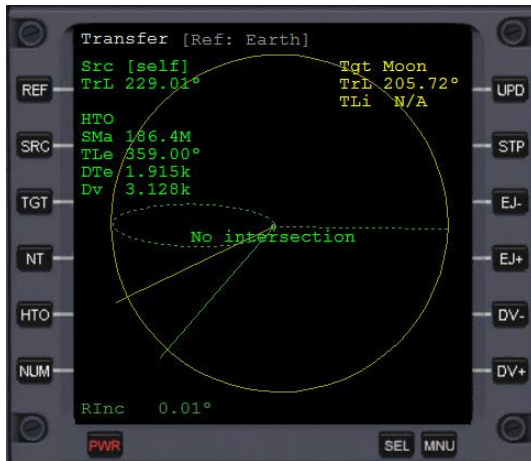
The goal here is to create a working solution that will take us to the moon. The two parameters we will adjust are the DV (delta-v – that is, how much *power* we need) and the EJ (Ejection point – that is *when* we will make the ejection burn.)

Start by clicking and holding DV+ to add some delta-v to your hypothetical plan. Watch the Dv value on the Transfer MFD as it increases.



When the Dv gets close to 3.000k, you will notice a dashed ellipse growing from the center and extending out toward the edge of the MFD. This growing ellipse represents your projected orbit around the earth. Remember, the tiny (almost imperceptible) circle in the middle is the earth itself.

If we consider the image to the left, it shows our orbit extending to about 1/3rd of the way out to the moon's orbital path. Clearly that isn't far enough, so I continue pressing DV+ to add even more Dv.

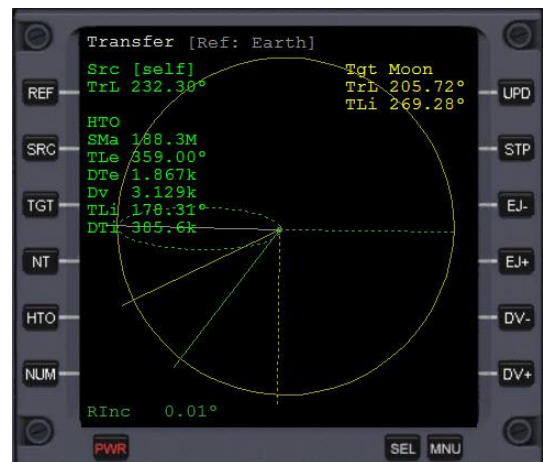


At 3.128k Dv, I have a hypothetical orbit that takes me *almost* to the moon, but the Transfer MFD is still reporting “No intersection.” This means I don’t have quite enough delta-v to get me there.

The amount of Dv that is required will vary (albeit slightly) from one flight to the next. The moon does not orbit the earth in a perfectly circular path, so the amount of delta-v that is required to get there will vary depending on the time of month and time of year.

One more click of DV+ is all I need for Transfer MFD to stop reporting “No intersection.” Once Transfer MFD stops reporting “No intersection”, it’s a good idea to add about 12 to 15 more clicks of DV+.

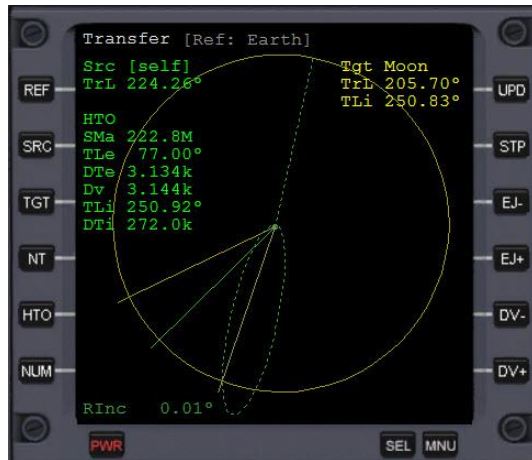
If we don’t have enough Dv, Transfer MFD will revert back to “No intersection” as we move the ejection point around the earth in the next step. Generally speaking, you need an extra dozen clicks of DV+ anyway.



When you have the minimal amount of Dv to keep Transfer MFD from reporting “No intersection”, you are actually on a crash course trajectory with the lunar surface. That isn’t necessarily a problem because you will make a mid-course correction in any event.

However, it is preferable to attempt to plan your arrival as a curved path around the far side of the moon with a positive periapsis. Due to the relative imprecision of Transfer MFD (and the fact that we will be controlling the timing of the burns by hand), our ability to plan a perfect path around the moon is extremely limited.

In the image above, I added 15 more clicks of DV+ beyond the 3.129k intersection. Without a more accurate calculation tool, I’m just guessing how much extra Dv I need. (But I know from experience that 12 to 15 extra clicks is usually a good estimate.)



The next thing we need to do is to find the point in our orbit around the earth where performing this burn will allow us to arrive at the moon's orbital path at the same time the moon is actually there. (If we are too late, or too early, the moon won't be at the same place in space we are.)

We find the correct Eject point by clicking EJ+ and/or EJ-. These buttons rotate our hypothetical Eject point clockwise (EJ-), or counterclockwise (EJ+).

The dashed greenish radial line that extends out to the top of the orange circle represents the point in our orbit where we will perform the ejection burn. As we rotate the ejection point using EJ+ and EJ-, it moves our hypothetical orbit accordingly. (Notice that the Eject point is on the exact opposite side of the planet.) The goal is to rotate our ejection burn point until our hypothetical orbit intercepts with the moon's predicted position.

The moon's predicted position is represented by the dashed orange radial line. We want the solid gray radial line to lay straight over top of the dashed orange radial line. (As in the image above.) Again, the moon's current position is the solid orange radial line. In the time it takes us to travel the roughly 385,000 kilometers between the earth and the moon, the moon will have orbited around the earth to the point represented by the dashed orange radial line. As we can see in the image, our hypothetical orbital path (the dashed green ellipse) intercepts the moon at that point in time.

Conclusion: we have a working solution.



As an aside, remember earlier when I added 15 extra clicks of DV+ even after Transfer MFD's "No intersection" message went away? If you look at the image to the left, you can see that 3.129k Dv was not enough after I adjusted the Eject point using EJ+.

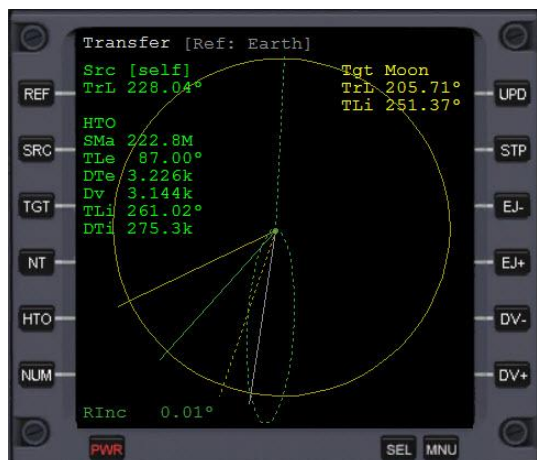
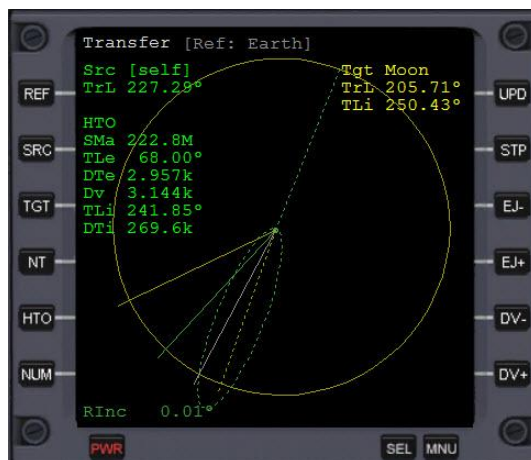
This is due to the fact that the moon is slightly further away from the earth at this point of its orbit than it was a few degrees earlier. Even though 3.129k gave us a working hypothetical scenario before, that amount of Dv is not quite sufficient at this new point.

For the sake of additional (perhaps even exhaustive) clarification about the hypothetical transfer orbit, here are some additional examples to consider.

In this example, our eject point is off by a significant amount. Notice the solid gray line is several degrees to the left of the dashed orange line.

We would never make it to the moon with this scenario.

We could fix this hypothetical scenario by clicking EJ+ a few times to rotate the eject point counterclockwise.

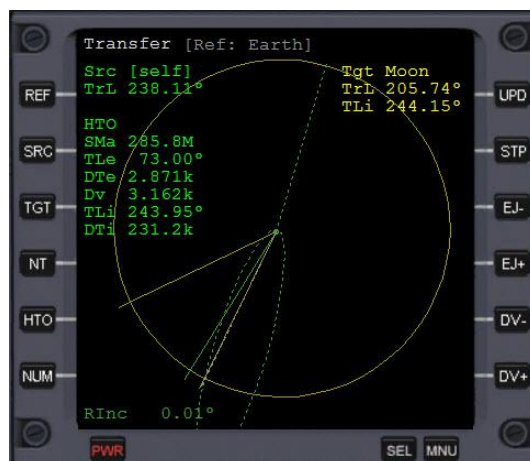


In this example, we have the exact opposite problem. Notice the solid gray line is several degrees to the right of the dashed orange line.

We could fix this hypothetical scenario by clicking EJ- a few times to rotate the eject point clockwise.

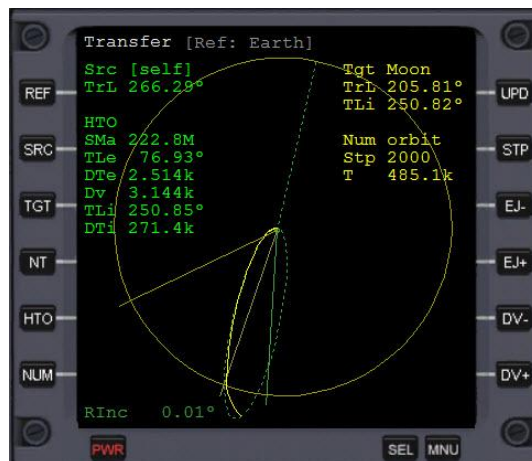
In this final example of what not to do, we have our eject point lined up correctly, but we have a relatively significant amount of extra Dv. Notice how the green dashed ellipse extends beyond the edge of the MFD.

We would still get to the moon with this scenario, and the extra Dv might technically speed up our trip ever so slightly, but there's usually no need to burn the extra fuel.



There is one other feature of Transfer MFD that can help us determine a more accurate amount of Dv to use. If you click NUM, it will draw a bold yellow line over top of your hypothetical orbital ellipse. This is the numerical trajectory.

You can control how many *steps* it will draw by clicking STP and typing in a new value. The default of 2000 steps is just right for our purposes, so there's no need to change it.



As you can see in the image to the right, the numerical trajectory shows that my Dv of 3.144k is dead-on. I have no reason to make any changes at this point. However, for the sake of comparison, let's see what the numerical trajectory looks like with a different amount of Dv.

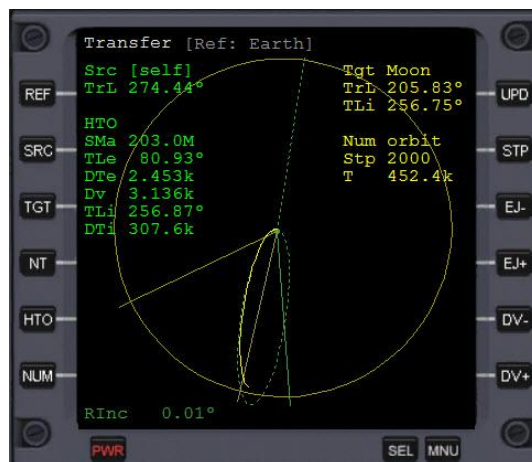


In the image to the left, I reconfigured Transfer MFD with the minimum amount of Dv that it would allow me to use without reverting back to "No interception."

Notice how the updated numerical trajectory seems to come up short. I know from experience that I would still make it to the moon with 3.131k of Dv. However, it would undoubtedly be a ballistic trajectory with the face of the lunar surface. (A mid-course correction would solve that problem though.)

In this last example, I reconfigured Transfer MFD by adding just a few more clicks beyond the 3.131k minimum. (An extra 5 clicks.)

When I update the numerical trajectory, it still seems to have me on a trajectory that is coming up short. Again, I would have no problem getting to the moon with this scenario, I would just have to make the appropriate burn at the mid-course correction. But the original trajectory (using 3.144k Dv) looked better, so I'm sticking with that.

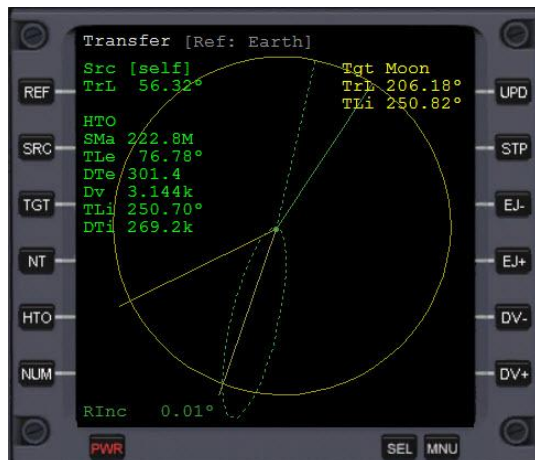


Ready for Trans Lunar Injection Burn

Once you are happy with the hypothetical solution you found using Transfer MFD, there is little to do but sit and wait until it is time to perform the burn. The DTe variable lets us know how many seconds there are until the burn. Using time acceleration, we can carefully fast forward until it is closer to the time to burn.

We are going to start our burn when DTe reaches 30 seconds. Furthermore, our ship needs to be in the prograde position when we perform the burn. Depending on the current orientation of your ship (and the amount of mass you are carrying), it can take several seconds to rotate to the prograde position. So don't wait until DTe is down to 35 or 40 seconds before you come out of time acceleration. You want to leave yourself more time than that in case it takes several seconds to orient your ship.

As you gain more experience, you won't have to think about each step as you're doing it, and therefore won't require as much time. But until things are second nature to you, make sure you leave yourself plenty of time to get set up for each action.

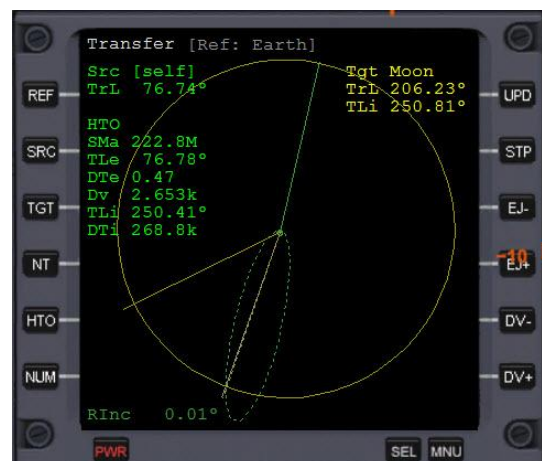


In the image to the left, I am down to 301.4 seconds until the burn. (I have about 5 minutes remaining.) Within the next couple of minutes, I will use the prograde autopilot to get my ship oriented in preparation for the burn. The exact moment I use the prograde autopilot depends how far out of orientation my ship is. If I am very close to the prograde position already, I may wait until DTe is all the way down to 40 seconds before I use the prograde autopilot. If I am way out of orientation, I will use the prograde autopilot when DTe is 60 seconds or higher.

As soon as DTe reaches 30 seconds, fire your main engines at full throttle. Keep an eye on the DTe countdown timer.



When DTe reaches 0 seconds, press the Kill Rotation button to shut off the prograde autopilot. (*Note: Don't turn off the main engines at this point. Continue burning until Dv is 0. You are just shutting off the prograde autopilot at this point.*)



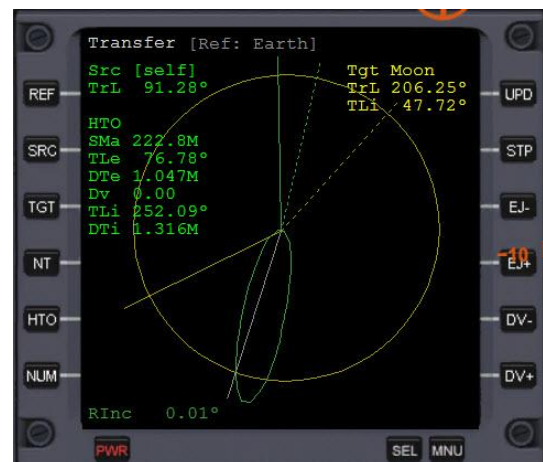
As you're burning the main engines for the TLI burn, you will notice your orbit around the earth become highly elliptical as the apoapsis rapidly increases. On the Orbit MFD in the image below, you can see my orbit growing as my velocity increases.



Continue burning the main engines until Dv reaches 0. As always, be ready to back off the throttle so you don't overshoot. When Dv gets down to around 500, you should lower your throttle to 75% and continue backing off the throttle incrementally as Dv gets closer to 0.

By the time Dv gets down to 1 or 2, you should shut off the main engines entirely and use translation thrusters to add the last bit of thrust to your trajectory.

If you happen to overshoot a little, don't panic - just use reverse translation thrusters to *clean up* the overage.



Once your TLI burn is complete, click HTO to shut off the dashed lines and HTO data. That information is no longer relevant after the burn is complete.

Congratulations, you're on your way to the moon!

Coasting to the Moon

Once the TLI burn is complete, you will spend about 3 days coasting toward the moon. When you are within a few hours of lunar periapsis (a.k.a. perilune), you will need to take the opportunity to make a couple of mid-course correction (MCC) burns. If we were using more sophisticated navigation equipment, we would perform the mid-course correction burn much earlier. It would be more efficient to make the mid-course correction burn approximately half-way to the moon. (About 36 hours into the flight - when Earth's gravitational influence is no longer the dominating force.) However, since we are using basic navigation equipment, we need to be within the moon's gravitational Sphere of Influence (SOI), and that won't be the case until we are almost all the way to the moon.



Use time acceleration to get yourself out to the moon. At 1,000x, it will take about 4 minutes to go from the earth to the mid-course correction point. That is a comfortable speed and you won't have to worry too much about overshooting.

IMPORTANT: It bears repeating that you must turn off your autopilots before you start accelerating time. Pressing the Kill Rotation button will shut off the autopilot and eliminate most of the ship's angular momentum.

As you are coasting to the moon, make sure you have Orbit MFD open. At the bottom of Orbit MFD, there is a gravitational indicator. (Notice the capital letter G.) The number tells you how much gravitational influence the reference body is exerting on your ship.

Using this information, you will be able to anticipate when you are getting close to the mid-course correction point so you can slow down the time acceleration without overshooting. When Earth's gravitational influence drops below 0.50 the indicator will turn red. (If we were using more sophisticated navigation equipment, that would be the time we would do our mid-course correction.)

If you are impatient, you can speed up your trip by using a little 10,000x time acceleration. At 10,000x, it will take about 30 seconds to get to the mid-course correction point. However, it is very easy to overshoot when using 10,000x. You must pay extremely close attention to Orbit MFD so you can slow down when you see Earth's gravitational influence drop down below 0.25

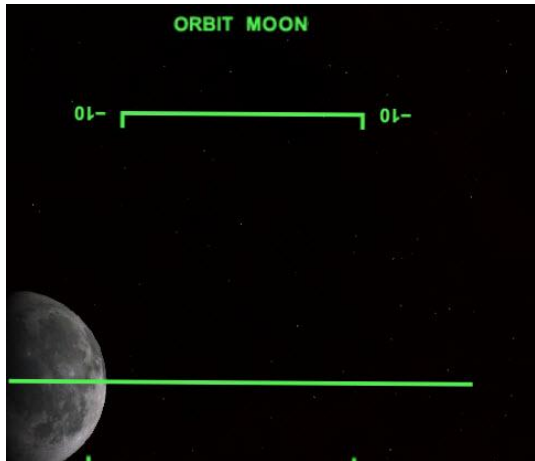
Continue coasting to the moon until the moon itself becomes the dominating gravitational body. This will happen when Earth's gravitational influence drops to approximately 0.20. In the image below, I have Orbit MFD open on both sides. On the right, I have Earth as the reference body, and on the left, I have the moon as the reference body. This is a great way to keep track of your progress as you are coasting out to the moon.

In the image below, you can see that the moon's gravitational influence is still red. That means the moon is not yet the dominating influence. (At this point in the journey, the sun is actually the dominating influence.)



After coasting just a little further, Orbit MFD reports that the moon is now the dominating gravitational influence. Notice that the gravitational indicator changed from red to green. The exact moment this occurs will vary from one flight to the next. When you reach this crossover point, you want to slow down to 1x acceleration so you can perform the mid-course correction burn.





When the moon becomes the dominating gravitational body, your HUD should automatically update. (It should say “Orbit Moon”, as in the image to the left.)

However, if you notice that the moon’s gravitational indicator has changed from red to green and the HUD is still referencing the earth or the sun, click the AR button. The AR button tells Orbit MFD to use the strongest gravitational body as the reference. Then click the HUD button to copy the moon’s reference data to the HUD.

Base Alignment

The first mid-course correction burn we are going to make is to get our ship aligned with the base we want to land at. The default Orbiter installation only has one base, Brighton Beach, so that is the base we are going to line up with. Bring up Orbit MFD on one side and Map MFD on the other. On the Orbit MFD, clicking FRM will toggle between EQU and ECL. (Equatorial view and Ecliptic view.) We want the EQU view. On Map MFD, click TGT to set the target as Brighton Beach, and click DSP to set Orbit lines as Orbit plane.



In the image above, I can see that my orbital path around the moon does not pass over top of Brighton Beach. In order to fix that, I need to do a plane change burn which will bend my orbital path. In looking at Orbit MFD, I see that my Inclination (Inc) is almost 180 degrees. That means I am on a retrograde orbit around the moon. Instead of orbiting West to East like you do when orbiting the earth, I am on an East to West orbital path. (If the Inclination was close to 0 degrees, then it would mean I was on a normal West to East orbit.)

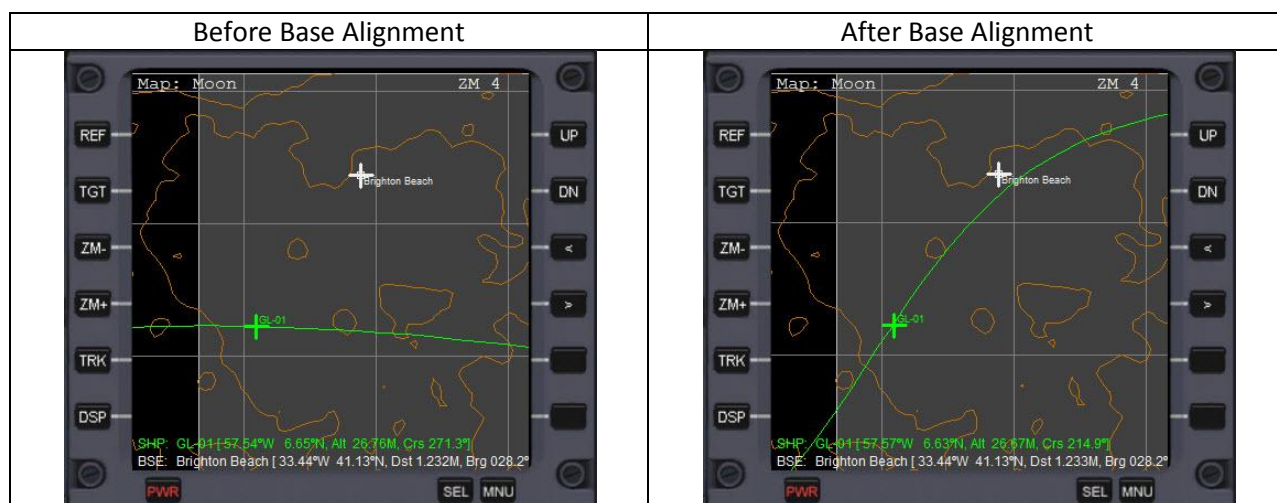
Since I am in an East to West orbit, I need to pitch my ship up +90 degrees from the direction of forward motion so that when I burn, the western part of my orbit will bend south and the eastern half will bend north. (If I were in a West to East orbit, it would be the other way around. I would need to pitch down -90 degrees.)

Using the ship's Orbit Normal (+) autopilot will orient the ship for me.

Once the ship has settled into position, I press CTRL+ 3 or 4 times to apply some main engine thrust. Continue the burn until the orbit line is near Brighton Beach.



Note that you don't want to apply full throttle because the Orbit Normal (+) autopilot has to make small corrections to your orientation during the burn. If you burn at full throttle, it will throw your ship out of orientation.



When aligning with Brighton Beach, it doesn't need to be perfect. As we close in on the moon, our orbital path is going to be disrupted a bit, so getting perfectly lined up with Brighton Beach at this step doesn't do us any good. We just want to get reasonably close.

Advanced tip: It's actually better if you don't line up perfectly during this alignment burn. If you can anticipate how much your orbital path will change as you approach the moon during the final few hours of coasting, then you can work it out where you will be almost perfectly lined up with the base after you arrive at lunar periapsis. However, that is a fairly advanced concept and is not something a beginner would have much luck at figuring out. But it's something to keep in mind for your future efforts.

Perilune Correction

Next we have to adjust our projected orbit around the moon. This is done by raising or lowering the PeA (periapsis). *The technical term for the lunar periapsis is perilune.*

Bring up Orbit MFD and make sure it is showing distance measurements above the surface of the moon, as opposed to distances from the center of the moon. Clicking DST will toggle between the two different measurement types (indicated as PeA and PeR respectively.) We want the PeA measurement.

In the image to the right, I can see that my PeA is -71.66 kilometers. This means despite my best effort to plan for a positive PeA during the Transfer MFD set up stage, I am still on a collision course with the lunar surface. (Oh well.)



I need to raise my PeA so that it is high enough to orbit the moon without crashing into any lunar mountains. The [highest elevation on the moon](#) is 10,786 meters, so it would be wise to have a periapsis of at least 13 to 15 kilometers. (Orbiter's default planet and moon surfaces are completely flat, so we could get away with a PeA of just a few meters above the surface (since there's no atmosphere to worry about), but it's more realistic if we take the real-world elevation of the terrain into consideration.)

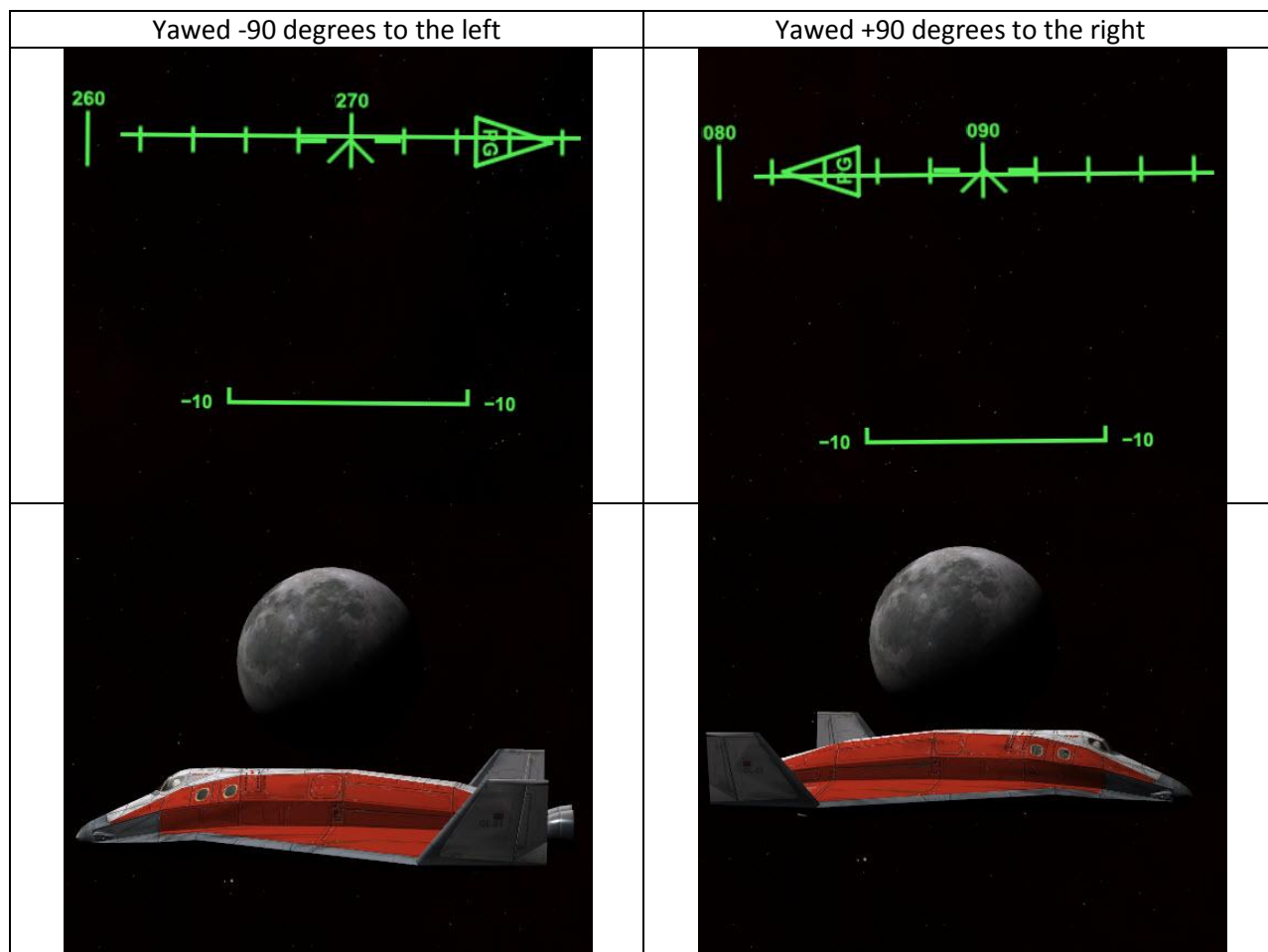
There is one other thing to take into consideration before we decide how we are going to manage this burn. Remember after the burn is complete, we still have a few hours of coasting until we reach perilune. During that time, our PeA is going to drop considerably as compared to what Orbit MFD reports out at this distance. If we don't account for that difference (more on that in a moment), we will crash into the moon.



The type of burn we need to do at this point is an "outward" burn. We need to make a change to our outward velocity. This is done by yawing the ship 90 degrees from the direction of movement. Start by pressing the Pro Grade button, and then wait for the ship to settle.

Once the ship has settled, press Kill Rotation and then use the rotation thrusters to roll the ship upright. (As in the image to the left.)

Next, use the rotation thrusters to yaw the ship 90 degrees off the center line. If you need to raise your PeA (like I do in my situation), you want to yaw the ship to the right. If you need to lower your PeA, you want to yaw the ship to the left.



Once the ship is settled into position, press Kill Rotation and then apply a little main engine thrust by pressing CTRL+. Note this burn will not require much engine thrust. Do not use the full power of the main engines for this burn.

Since there is no autopilot to keep your ship locked in this orientation, it may yaw or pitch slightly during the burn. That is ok. This burn is short, and we are so close to the moon at this point that we don't have to be meticulously precise.

If you're planning to land at Brighton Beach, you should aim for a PeA that is approximately 60 kilometers. This *should* account for the 20-25 kilometers you will probably lose as you approach perilune (leaving you with a final PeA of about 35 to 40 kilometers.) If you find yourself approaching the moon with a PeA that is looking like it's going to be too low, you can make another outward burn after this point by repeating these steps.

In the image to the right, you can see that I brought my PeA up to about 60 kilometers. As long as the PeA doesn't drop by more than 45 kilometers during the final few hours of coasting to the moon, then I will be sufficiently far above the surface to not have to worry about crashing into any mountains.

Once you have raised (or lowered) your PeA as needed, it will immediately start counting down. Don't worry about that. We anticipated this would happen which is why we left ourselves adequate altitude above and beyond what was necessary.



Now you can coast ahead to perilune.

You may want to press Pro Grade so your ship is facing forward. (It will be more visually appealing if you are facing the moon.) Once your ship has settled, press Kill Rotation. If needed, use the rotation thrusters to roll your ship level with the horizontal indicator on the HUD, then press Kill Rotation again to kill off the angular momentum.

At this point, you are done with the mid-course correction burns. Use time acceleration to fast forward to perilune. Be especially careful with the time acceleration feature at this point as you are very close to the moon. It will only take about 3 ½ minutes to reach perilune at 100x; that is a comfortable speed and you won't have to worry too much about overshooting, but if you're in a hurry, you can use 1,000x.

At 1,000x, it will take less than 30 seconds to reach perilune. When PeT gets down below 2,000k, slow down to 100x or you will most assuredly overshoot. This is not a situation you can afford to overshoot. If you miss perilune, you are going to end up in a very messy situation that will be difficult to correct. (At the very least, you will waste a bunch of fuel. At worst, you will sling past the moon and end up orbiting the sun.)

Lunar Orbit Insertion



The next thing you need to do is the Lunar Orbit Insertion (LOI) burn. Our current trajectory has us slinging around the moon out into empty space. (This would be a real bad time for main engine failure.)

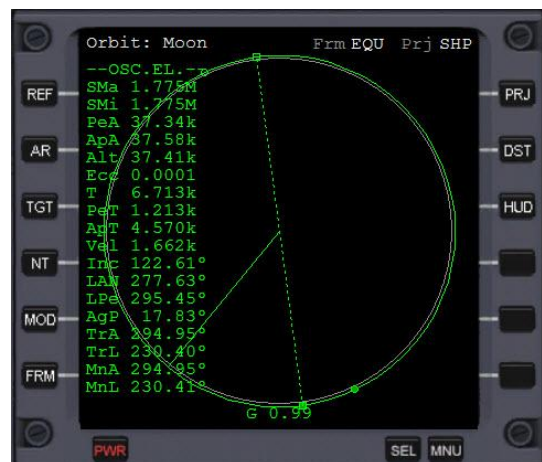
In the image to the left, I see that upon reaching perilune, my PeA is 38.19k. If I had adjusted my PeA to 15k during the mid-course correction burn, I would now have a PeA of about -7k which means I would be crashing into the moon soon.

The LOI burn is very straight forward. You simply press the Retro Grade button so the autopilot will put your ship into the proper orientation, and then you burn the main engines until you have a circular lunar orbit.

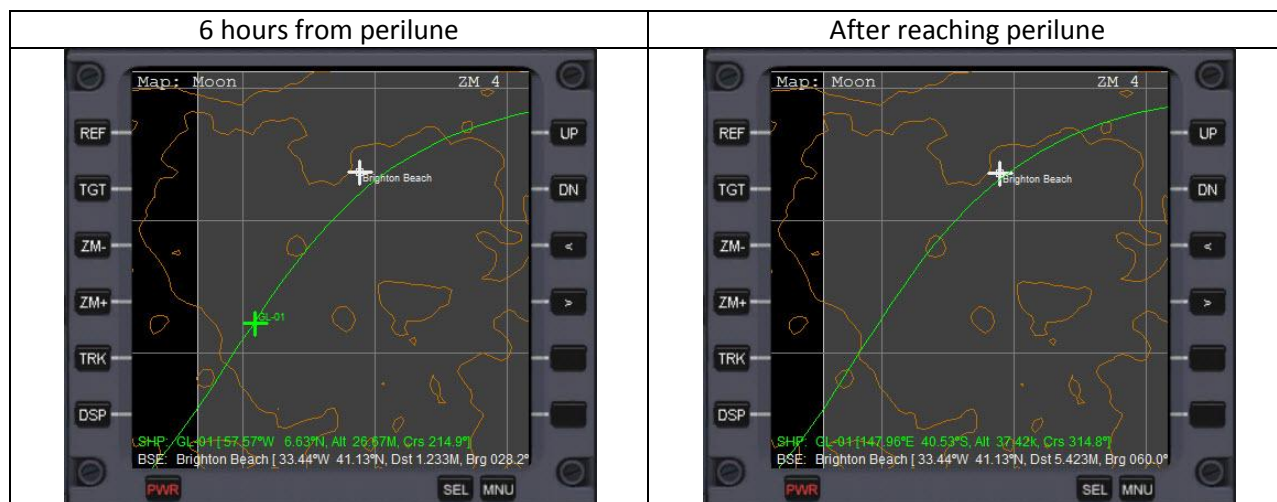
It is assumed you understand basic orbital mechanics, so I'm not going to elaborate on this step. However, as in the Orbit Circularization burn that we did back at Earth, it is again recommended that you perform the LOI burn as a series of retrograde burns. Note, for this burn, you need to do the first burn (using the full power of the main engines) when PeT is still at about 50 or 60 seconds. If you wait until PeT is all the way down to 10 or 15 seconds, you will pass perilune before the orbit is completely circularized.

Keep an eye on the PeT value. When it starts to rise above 60 seconds, kill the main engines and wait for it to count down again. As your orbit becomes more circular, you can wait for PeT to get to 30 seconds (and then 20, and then 10.)

After performing a series of burns, I have a nice circular orbit around the moon and my PeA is pretty close to what it was when I started.



Now that the LOI burn is complete, it is time to plan our landing at Brighton Beach. If you recall, back at the Base Alignment mid-course correction burn, I intentionally left my orbital path slightly south of Brighton Beach. Let's see what the alignment looks like now.



As you can see in the image above, if I had lined up my orbital path directly down the middle of Brighton Beach during the base alignment burn, my orbital path would now be off to the north. By intentionally leaving it skewed a little to the south, the orbital path is now closer to the center of Brighton Beach as a result. (Obviously it wouldn't have made that much of a difference, but these kinds of forward-thinking strategies will help you grasp Orbiter more fully overall.)

Ready to Land at Brighton Beach

Now that you are in orbit around the moon, and you are on a path that takes you near Brighton Beach, it's time to figure out how to de-orbit and land. De-orbiting in an environment like the moon that has no atmosphere is actually very simple. In short, all you have to do is turn your ship into the retrograde position, level your ship with the horizon, fire the main engines at full throttle until your horizontal speed is zero, and use the hover engines to descend gracefully to the lunar surface.

The relative difficulty of landing at Brighton Beach comes from trying to land precisely in the middle of one of the landing pads. When you are new to Orbiter, flying your ship with the translation thrusters in a zero-friction environment can be very difficult – at first. This final part of the trip will probably take a few tries to get it right, and it will probably take many, many tries before it feels like second nature.

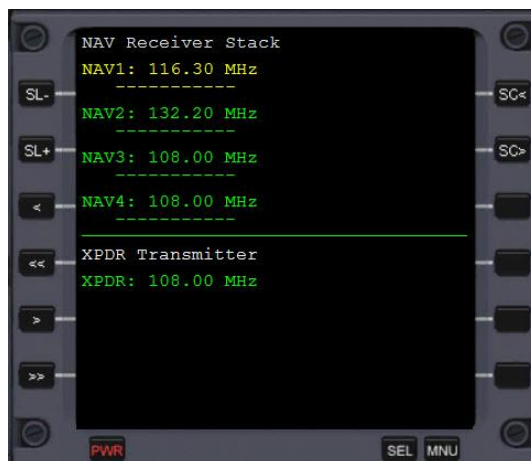
Switching between rotation and translation thrusters, keeping an eye on your vertical descent, and making sure you are lining up with the landing pad will seem impossible at first. But I will try to outline a method that will break this down into logical steps that will hopefully make it a bit easier for you.

Tuning the Navigation Equipment

To help us plan our approach at Brighton Beach, we need to tune our navigation equipment to the proper frequencies. Open the NAV/COM MFD and tune NAV1 to 116.30. That is the frequency of the long-range radio beacon at Brighton Beach.

We will use that radio beacon to get our ship perfectly lined up and to plan our engine burns which will reduce our velocity.

Tune NAV2 to 132.20. That is the frequency for landing pad 1.



You will get a signal from the radio beacon when you get within about 500 kilometers of Brighton Beach. The landing pads, on the other hand, have very short-range signals. You won't get a signal from the landing pad until you are within a couple dozen kilometers of Brighton Beach.



Orbiter has a convenient utility built-in to help you find information about ships, spaceports, and planets/moons. If you press CTRL+I (I for Information), it will open a small information window. From there you can select Spaceport in the left dropdown and Brighton Beach in the right dropdown.

You will then have a list of all the frequencies for the landing pads, and the frequency for the radio beacon at Brighton Beach.

Note in the image above, this utility shows me all the landing pads at Brighton Beach are free.

If there are ships already sitting at a particular landing pad, you need to make sure you choose a different landing pad. In the image to the right, you can see that landing pads 4 and 5 are in use.

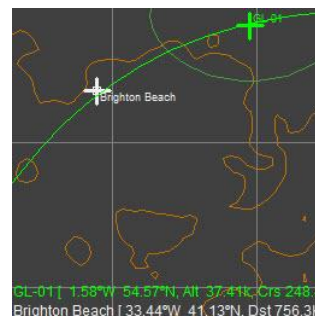


VOR/VTOL MFD

Once you tuned your navigation equipment to the proper frequencies, open the VOR/VTOL MFD and make sure it is set to NAV1. The MFD won't display any information until you are within range of the radio beacon.

If you look at the bottom of Map MFD, you can see how far away you are from Brighton Beach by looking at the Dst (Distance) value. (If you don't have Brighton Beach selected as the target, you won't see this information.)

In the Map MFD image to the right, I see that I am 756.3 kilometers from Brighton Beach. At the rate I'm traveling (1,664 meters/second), the radio beacon will be in range in just over 2 ½ minutes.



This is a good time to get the ship oriented for the upcoming base alignment burn. Press the Level Horizon button to have the ship's autopilot roll the ship upright. At this point, we still want the Orbit HUD, so don't change to the surface HUD just yet.

Next, use the rotation thrusters to yaw the ship so that it is facing exactly opposite of the direction of movement. You can tell when the ship is facing backwards by looking for the bulls-eye velocity vector at the 180 degree mark.



In the image to the left, the VOR/VTOL MFD is now showing the information I need to set up my landing.

The first thing to note is that we have to plan our actions carefully so we don't blow past Brighton Beach.

$$492.4 / 1.664 = 295.91$$

That is how many seconds it will take to arrive at Brighton Beach at my current velocity. (295 seconds is, of course, equal to about 5 minutes.)

We don't want to start reducing our velocity too early though. The main engines are quite powerful and can eliminate that entire 1,664 meters/second of velocity in roughly 90 seconds. (It depends how much fuel you have on board. The more fuel you have, the more mass you are carrying, the more mass you are carrying, the longer it will take to eliminate your velocity.)

If I were to apply the full power of the main engines as soon as the radio beacon came online and continued burning until my velocity was down to a comfortable 100 meters/second, I would end up about 400 to 420 kilometers from Brighton Beach.

At that speed and distance, it would take about 65 to 70 minutes to hover to the landing pad. During that time, you would burn a lot of fuel using the hover engines to keep yourself off the surface. Depending on your fuel usage up to that point, you may even run out before you made it to the landing pad. On the other hand, if we wait too long, we'll fly right over top of Brighton Beach and we'll have to turn around and come back. (That can be even more frustrating than coming in too slow.)

Getting this part of the landing process figured out requires a bit of practice. Eventually you'll get a feel for the distances and speeds. I suppose if you're good at mental arithmetic, you can make the appropriate calculations on the fly. But for the rest of us, we just tend to feel it out.



Before we eliminate any of our velocity, we want to get ourselves perfectly lined up with the radio beacon. The way we do that is by yawing our ship so that the radio beacon is exactly 90 degrees to one side or the other.

If you are on an orbital path where you are passing south of Brighton Beach, you need to yaw your ship so the radio beacon is at the -90 degree marker as indicated on your HUD.

In the image above, notice that the green line inside the VOR/VTOL targeting graphic is perfectly lined up with the center line on the left. The yellow arrow represents my direction of movement. By orienting the ship to this position, I can apply main engine thrust to get myself lined up with the radio beacon at Brighton Beach.

Note if your orbital path has you passing north of Brighton Beach, you would need to yaw your ship so the radio beacon was at the +90 degree marker instead. In other words, the green line inside the VOR/VTOL targeting graphic would need to be perfectly lined up with the center line on the right.

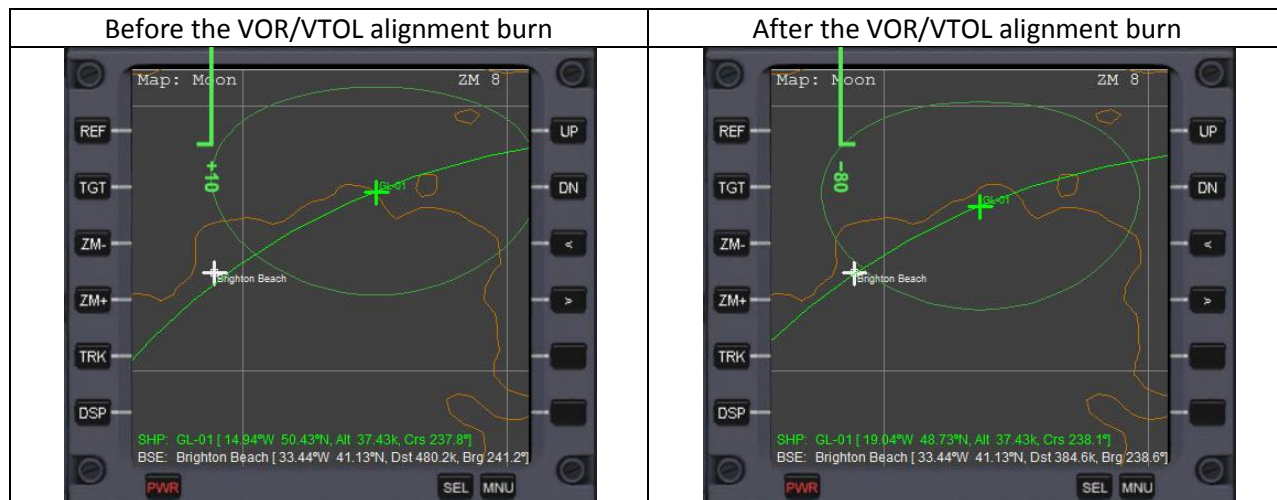
Once my burn is complete, the yellow arrow (which again is the indicator that represents my direction of movement) is perfectly lined up with the green line.

This means I am now precisely lined up with Brighton Beach. Note that in the few seconds it took me to orient the ship and make this burn, I have already traveled 100 kilometers!



I am now less than 400 kilometers from Brighton Beach. (About 4 minutes away at my current velocity.) It's important to work out this base alignment carefully, but expeditiously.

To further illustrate the purpose of this burn, look at the following before and after images taken from Map MFD.



Now that we are lined up with the radio beacon, we need to yaw the ship so that it is facing backwards again. Line up with the bulls-eye velocity vector at the 180 degree marker.

With your ship in this orientation, the main engines will act as a brake, allowing you to slow down in a series of steps so you can plan your descent toward Brighton Beach.

As soon as you begin decelerating, you'll need to start watching your vertical speed. Note the VSPD indicator in the image to the right.



The moon's gravity is relatively weak, but there is no atmosphere to slow your descent, so it's important not to let your vertical speed get out of control. I don't want to arrive at Brighton Beach at an altitude of 37.43 kilometers, so I'm not going to use the hover hold autopilot at this point. By the time I am near the landing pad, I want to be at an altitude of just 300 to 500 meters.

When you're new to Orbiter, the easiest way to work out your arrival at Brighton Beach is by observing action and reaction. Burn the main engines for a few seconds to eliminate some velocity, then kill the engines and wait a couple of seconds to observe how quickly the distance indicator is ticking by. Repeat the process until your distance is down to around 30 kilometers and your velocity is down to about 100 meters/second.

At 30 kilometers from Brighton Beach traveling at 100 meters/second, it will take 5 minutes to reach the landing pad, and you will be traveling slow enough to use the retro engines and translation thrusters as needed.

When you are within 5 kilometers of Brighton Beach, you want to begin slowing down even further. 25 meters per second at 5 kilometers is a good goal to aim for.

During all this time, don't forget to watch your vertical speed! As your ship begins to descend, you will need to use the hover engines to keep your sync rate from getting out of control. When you get down to about 3 kilometers, use the hover hold autopilot. That will free you from having to worry about your descent rate so you can focus on lining up with the landing pad.

The final approach to the landing pad is done with translation thrusters when you are traveling at a mere 5 to 10 meters per second. And the final positioning when you are over top of the landing pad is done with 10% thrusters. (That is, you hold down the CTRL key while using the translation thrusters.) At that point, your horizontal speed (HSPD) should be no more than 1 meter per second. When you are finally lined up over the pad, you use 10% translation thrusters to bring your HSPD all the way down to 0.00.

Most things about Orbiter can be learned by reading, looking at still images, and/or watching videos and/or Orbiter playbacks. However, in my opinion, landing is a very hands-on experience and can only be learned by doing it yourself as many times as is necessary to get the feel for it. (This is true for landing on the moon, or landing in atmospheric conditions like on Earth.)

Having said that, I will walk through the landing I did while making this tutorial just to explain a few things that are going through my mind while doing these landings.



When I got to a distance of 250 kilometers, I used the full power of the main engines to decelerate down to about 1,000 meters/second.

I realized that I needed more time to allow my ship to descend from altitude, so I engaged the main engines again to decelerate down to 600 meters/second.

After coasting a little further to the base, I could see that the radio beacon was a little out of alignment with my direction of movement. In looking at Map MFD, I could see that my orbital path was still a bit south, so I rotated the ship 90 degrees (as before), and applied a little main engine thrust to straighten out the alignment.

The key to a good approach is to keep your ship perfectly lined up with the radio beacon.



Continuing a gradual slow down as I get ever closer to the base.

Notice my altitude has dropped 1/3rd by this point. I am now applying hover thrust to keep my descent from getting out of control.





Notice I have switched to the landing pad radio frequency. I don't want to land on top of the radio beacon, so it's important to switch to the landing pad frequency when you are within a couple kilometers of Brighton Beach.

Notice that my altitude is all the way down to 2 kilometers and my vertical speed is well under control.

It is time to open the retro engine doors and rotate the ship 180 degrees.



The switch for the retro engine doors is located at the bottom of the 2D panel. You have to use the down arrow key to scroll the panel down to reveal this row of switches.



I have rotated the ship 180 degrees so the landing pad is now directly in front of me.

After dropping below 1,000 meters in altitude, I engaged the hover hold altitude autopilot so I wouldn't have to think about my altitude while trying to line up over the landing pad.



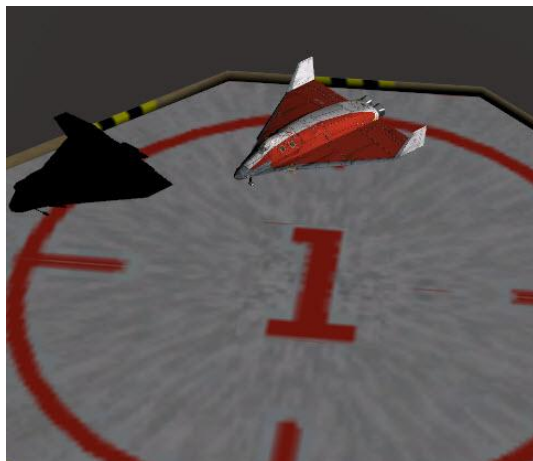
When you are new to Orbiter, a nice slow approach to the landing pad is the key to a successful landing. Never use the main engines when you are this close to the landing pad. You want to keep your horizontal speed nice and low so that no matter what happens, you don't end up drifting away from the landing pad at hundreds of meters per second.



Notice that I am a little out of alignment with the landing pad. When you are this close to the landing pad, and are traveling this slowly, you can correct these alignment errors by using left/right translation thrusters. (Pressing 1 or 3 on the numeric keypad as needed.)

You do not need to rotate the ship 90 degrees as we did before. At this very low speed, the translation thrusters are more than adequate to fix our alignment.

Once aligned, you can use rotation thrusters to point the ship directly toward the landing pad again. (In other words, make sure the green line is perfectly centered in the middle.)



In the image to the left, you can see that I am straight above the landing pad and have lowered my gear.

I am ready for touchdown.



Notice that my horizontal speed (HSPD) is effectively zero, my distance (DIST) from the center of the pad is less than 1 meter, and my vertical speed is about $\frac{1}{4}$ of a meter per second.

Note that the landing pad is quite large. If you are new to Orbiter and your distance is less than 30.00 meters when you touch down, you should consider your landing a smashing success. Fussing over the last few meters is not worth the time when you are new. You will just waste fuel hovering over the pad.

Touchdown and wheel stop.



Once you have touched down on the landing pad, turn off the Level Horizon autopilot and make sure your hover engines are completely off.

If this was your first successful landing on the moon, let me be the first to congratulate you on a job well done!

Earth to Moon Checklist

1. Plan your arrival time at Brighton Beach by using Map MFD. Set the Reference to moon and observe where Brighton Beach is at in relation to the sunrise/sunset terminator. If you want to arrive at a specific time, use time acceleration as needed.
2. Use Align plane MFD to determine the best time to take off from Earth. Set the target to the moon and watch for the lowest RInc.
3. While ascending to orbit, keep an eye on the RInc value in the Align plane MFD. Try to bank left/right to keep RInc at the lowest possible value.
4. After reaching orbital velocity, align your plane with the moon at the next node passage.
 - a. Use Align plane MFD to reduce RInc as much as possible. It will be time to fire the engines when Tn is half of the TthA/TthD numbers.
 - b. AN=AN (Ascending Node = Anti-Normal). Use Orbit-Normal (+) when burning at the Descending Node. Use Orbit-Normal (-) when burning at the Ascending Node.
 - c. Ideally, the RInc should be 0.00, but a RInc up to 0.05 is acceptable.
5. When you reach Apoapsis after launch, circularize your orbit by doing a series of Pro Grade burns.
 - a. When ApT is about 15 seconds, use the full power of the main engines to work out most of the orbit circularization.
 - b. When ApT begins to rise, stop burning and wait for ApT to count down to 15 again.
 - c. Repeat the process using less engine thrust at each burn.
 - d. Use translation thrusters to work out the last few kilometers.
6. Use Transfer MFD to plan the TLi (Trans Lunar Injection) burn.
 - a. Press TGT and choose the moon as the target.
 - b. Press HTO so we can plan a “What if?” (hypothetical) scenario.
 - c. Press DV+ to add delta-v to the hypothetical scenario.
 - i. It will require approximately 3.130k of delta-v before the computer will stop reporting “No intersection.”
 - ii. Add 15 additional clicks of delta-v after the computer stops reporting “No intersection.”
 - d. Use EJ+/EJ- to line up the solid gray radial line straight over top of the dashed orange radial line.
 - e. Press NUM to have a look at the numerical trajectory. If it appears you’re hypothetical plan is coming up a bit short, add another click or two of DV+ and adjust EJ as needed. Press UPD to update the numerical trajectory to test any changes you make.

7. The DTe value on Transfer MFD tells you how many seconds you have until it is time to burn.
 - a. Use time acceleration to carefully speed ahead to the TLi burn.
 - b. When DTe gets down below 100, make sure you slow down to 1x so you have time to orient your ship to the Pro Grade position before starting the burn.
 - c. When DTe reaches 30 seconds, burn the main engines at full power.
 - d. When DTe reaches 0, press Kill Rotation to shut off the Pro Grade autopilot.
 - e. When Dv drops below 500, begin backing off the throttle so you don't overshoot. Continue backing off the throttle as Dv gets lower.
 - f. By the time Dv is down into the single digits, be ready to kill the main engines entirely and finish up the burn with translation thrusters.
8. When the TLi burn is complete, press HTO to shut off the hypothetical data.
9. Press Kill Rotation and use time acceleration to fast forward to the mid-course correction.
 - a. Open Orbit MFD on both sides. Set the moon as the reference on one side and the earth as the reference on the other side.
 - b. When speeding away from the earth, keep an eye on the G indicator at the bottom of the Orbit MFDs to help you determine when you are approaching the mid-course.
 - c. At 1,000x, it will take about 4 minutes to get to the mid-course correction. At 10,000x, it will take about 30 seconds. If you use 10,000x, be sure to slow down when Earth's gravitation indicator drops below 0.25 or you will blow past the mid-course correction point.
 - d. When the G indicator at the bottom of the moon's Orbit MFD turns green, immediately slow down to 1x as you are now within the moon's SOI (Sphere of Influence.) It is time for the mid-course correction burns.
10. For the base alignment mid-course correction burn, open Map MFD and make sure Brighton Beach is selected as the target.
 - a. Make sure the moon's Orbit MFD is set to the EQU frame. If the Inclination (Inc) is close to 180 (which it will be in most cases), then you are approaching the moon in an East to West orbit. If the Inclination is closer to 0, then you have made a figure-8 type of trip to the moon and will be on a West to East orbit.
 - b. Assuming the normal situation (an inclination close to 180), you want to orient your ship using the Orbit-Normal (+) autopilot when aligning with the base. (If you did end up on a West to East orbit, use the Orbit-Normal (-) autopilot instead.)
 - c. When aligning with the base, do not use the full power of the main engines. Leave the orbital path slightly south of the target. As you approach the moon, the orbital path will probably drift a little to the north, so by leaving it skewed a bit to the south, it will be more accurate when you reach perilune.

11. For the perilune mid-course correction burn, keep in mind you want to end up orbiting the moon with a PeA of at least 13 to 15 kilometers.
 - a. The burn you make at this point needs to take into account the 20-25 kilometers you will probably lose as you spend the last few hours coasting to the moon.
 - b. Press Pro Grade to orient your ship toward the direction of forward movement.
 - c. Once the ship has settled, press Kill Rotation and use the rotation thrusters to roll your ship upright and level.
 - d. If you need to raise your PeA, yaw your ship to the right. If you need to lower your PeA, yaw your ship to the left.
 - e. This burn requires very little main engine thrust; do not use the full power of the main engines.
 - f. A reasonable PeA to aim for is 60 kilometers.
 - g. After the burn, press Pro Grade so you are facing the moon.
12. Press Kill Rotation to shut off the autopilot before coasting ahead to perilune.
 - a. It will only take about 3 ½ minutes to reach perilune at 100x.
 - b. At 1,000x, it will take less than 30 seconds to reach perilune. When PeT gets down below 2,000k, slow down to 100x or you will most assuredly overshoot.
13. When PeT gets down to about 100, slow time acceleration down to 1x if you haven't already done so. You can't afford to overshoot the LOI (Lunar Orbit Insertion) burn.
 - a. Press Retro Grade to get the ship oriented for LOI.
 - b. Do a series of retrograde burns to circularize the orbit.
14. Open the NAV/COM MFD and tune NAV1 to 116.30; tune NAV2 to 132.20. If you want additional information about the base, press CTRL+I.
15. Open the VOR/VTOL MFD and set it to NAV1.
 - a. You won't get a signal from Brighton Beach until you are within 500 kilometers of the base. Until then, if you look at the bottom of Map MFD, you can see how far away the base is by looking at the Dst (Distance) value.
16. When you are getting close to picking up the radio beacon signal, press the Level Horizon button to have the ship's autopilot roll the ship upright and then use the rotation thrusters to yaw the ship so that it is facing exactly opposite of the direction of movement. You can tell when the ship is facing backwards by looking for the bulls-eye velocity vector at the 180 degree mark.
17. When the VOR/VTOL MFD comes online, use the MFD to get your ship perfectly lined up with the base.
 - a. If you are on an orbital path where you are passing south of Brighton Beach, you need to yaw your ship so the radio beacon is at the -90 degree marker as indicated on your HUD. (The green line should be aimed left.)
 - b. If you are on an orbital path where you are passing north of Brighton Beach, you need to yaw your ship so the radio beacon is at the +90 degree marker as indicated on your HUD. (The green line should be aimed right.)
 - c. Once the ship is oriented, burn the main engines until the green and yellow lines are perfectly lined up.

18. Once you are perfectly lined up with the radio beacon, use the main engines to decelerate as you approach Brighton Beach.
 - a. If you decelerate too much too early on, it will take a very long time to reach Brighton Beach and you may run out of fuel before you get there.
 - b. If you wait too long to begin your deceleration burns, you will fly past Brighton Beach and will have to turn around and go back.
 - c. Remember to take your altitude into account as you are planning your deceleration burns. It is preferable to arrive at Brighton Beach at an altitude of about 300 to 500 meters.
19. Switch your VOR/VTOL MFD to NAV2 when you are within range of the landing pad. (If you don't, you will end up landing on the tower instead of the landing pad.)
20. Open the retro engine doors by pressing the down arrow to reveal the lower row of switches. When you are under 100 meters/second, rotate your ship so that it is facing the landing pad and use the retro engines for braking.
21. When your altitude drops to around 500 meters, use the Hover Hold autopilot to keep your altitude locked so you don't have to think about your vertical speed while trying to line up with the landing pad.
22. When the VOR/VTOL MFD says your distance is 30 meters, you are within the boundaries of the landing pad.
 - a. You should only use translation (or 10% translation) thrusters at that point.
 - b. Maintain a very low horizontal speed (HSPD) when you are close to the landing pad.
 - c. When you are as close to the center of the landing pad as you can get, use 10% translation thrusters to bring your HSPD down to 0.00
23. Shut off the Hover Hold autopilot, press G to lower the landing gear, and use 0 and . on the numeric keypad to lower the Delta-glider softly down onto the landing pad.
24. After touching down on the landing pad, press . several times to make sure the hover engines are completely off. Also, shut off the Level Horizon autopilot.