Go Play In Space

Fun With Martin Schweiger's Orbiter Space Flight Simulator

Second Edition

Bruce Irving
with
Andy McSorley

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Fun with Martin Schweiger's *Orbiter* Space Flight Simulator

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Second Edition for Orbiter 2006
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PDF available for free download:

Virtual Spaceflight
(http://www.aovi93.dsl.pipex.com/play_in_space.htm)

MiGMan's Flight Simulation Museum
(www.migman.com/orbiter/orbiter.htm)

Go Play in Space (Second Edition)
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All screen captures in this book are from Orbiter 2006, captured and annotated by the authors unless otherwise noted and credited. Diagrams by the authors. Cover design by Betty Sunter.

Cover graphic includes add-on "ESAS CEV" by Franz 'francisdrake' Berner (http://www.orbithangar.com/advsearch.php?search=name&text=ESAS+CEV) and the astronaut "EMU Mesh" by Jógvan 'C3PO' Trondesen (http://www.orbithangar.com/advsearch.php?search=name&text=EMU+Mesh), both used with permission.

Thanks again to Martin Schweiger for creating Orbiter. It still rocks. Thanks also to the many add-on developers and "orbinauts" around the world who help to keep Earth's virtual space program growing, changing, and fun.

Dedicated to the children of today – you will be the first truly spacefaring generation, explorers and citizens of the Solar System. We hope that Orbiter and this book will help to launch you on your way to a future we can barely imagine today (though we still try!).

Go Play In Space

Table of Contents

Introduction

Would you like to fly in space?

Chapter 1: **Before you get started**

Learn how to download, install, configure, and run Orbiter 2006.

Chapter 2: **Smack! Rescue**

After docking with another Delta Glider, undock, separate, and fix up a bad orbit.

Chapter 3: **Hovering at the Beach**

A day at Brighton Beach, hovering and polishing your thruster control skills.

Chapter 4: **Fly Me to the Moon**

Sinatra? Apollo 8? No, just fly the trusty DG from KSC to the Moon.

Chapter 5: **Dancing in the Dark**

Rendezvous (or orbit synchronization) and docking.

Chapter 6: **Mars Awaits** by Andy McSorley

Fly to the Red Planet in 2033 with IMFD.

Chapter 7: **Learning and Doing More**

Tutorials, web sites, and books to expand your space flight skills.

Chapter 8: **A Bit About Add-ons**

Learn about some of the many add-ons available to enhance your Orbiter experience.

Chapter 9: **I Was Just Wondering…**

Answers for selected questions about orbits, Orbiter, and other space stuff.

Epilogue: **Your Future In Space**

Thoughts about the future and the need for people to pursue real space careers.

Appendices

Would you like to fly in space?

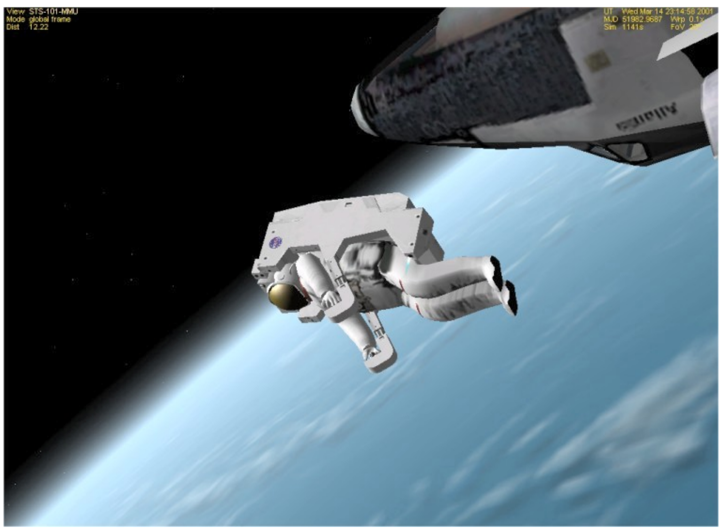
When I was a kid, I was obsessed with flight, especially space flight. It was the sixties, so it was a good time to be a "space kid" – I read everything I could about the Gemini and Apollo flights; built models; wrote to NASA and received huge envelopes of "NASA Facts" and colorful posters; and collected LIFE magazine issues with their amazing color photos and their exclusive astronaut stories. More than anything, I wanted to become a military jet pilot and eventually an astronaut – perhaps one of the more common career goals of kids in that exciting time. When I got glasses around age 12, I knew my plans for the Air Force Academy wouldn't pan out. I got interested in computers but ended up majoring in physics in college, and following a later interest in lasers, I got a masters degree in optical engineering. This led to a very interesting and satisfying career that has combined computers and optics, but I never lost my interest in flying and space. I spent a lot of time playing with flight simulators in the nineties and finally got my real pilot's license in 2001.

With this background, you can imagine how excited I was when I discovered Orbiter. If I could have had such a thing as a kid, I would have been ecstatic. I really like Orbiter, and I wanted to share my enthusiasm with today's "space kids," whether they are actual kids, or other *old* space kids like myself. So with the help of Andy McSorley on this second edition (updated from Orbiter 2005 to 2006), I've written what I hope is a *relatively* gentle introduction to Orbiter, and I hope it helps you or your favorite "space kid" to have fun playing in space.

Apollo 11 as simulated in Orbiter – The Lunar Module (LM) *Eagle* is about to touch down at Tranquility Base on the Moon, July 20, 1969. The Apollo spacecraft are not part of the basic Orbiter installation, but are available through an amazing add-on package that defines additional spacecraft, scenery, sounds, and flight instruments. The add-on for Apollo (which, like Orbiter and all other Orbiter add-ons, is freeware available for download through the web) is pretty complex and should probably not be the first thing you try! Flying a simulated LM is just one of many cool things you can do in Orbiter. See Chapter 6 for more information on this and other add-ons.

Welcome to Orbiter!

Would you like to fly in space? As I write this in late July 2005, only about 450 men and women have ever flown in space (generally defined as flight above 100 kilometers [62 miles] in altitude). As it happens, nine of them are in space right now, two in the International Space Station (ISS), and seven aboard the Space Shuttle *Discovery,* which is currently docked with the ISS (STS-114). Human space flight *is* a pretty specialized job, though there are many other people whose jobs are connected to space flight. Some help to design and build spacecraft, others help to plan or support space missions in a variety of ways, working for government space agencies or private companies in many different countries. Although there haven't been all that many "manned" (and "wo-manned") space flights (let's just say "piloted"), there have been thousands of satellites and space probes launched, and more are launched every year. Space flight is important as well as exciting, and it will be even more important in the future. Maybe someday you will have a job that involves space flight, perhaps even become an astronaut or cosmonaut and fly on a mission to Mars. Maybe not — but it's still fun to think about.



Flying in Space – The smallest spacecraft in Orbiter is just "you" in a space suit, simulating the MMU (Manned Maneuvering Unit) used by Space Shuttle astronauts. It's a good way to practice using attitude thrusters (the tiny blue jet firing on the lower left front of the MMU backpack in this picture). This scenario ("Atlantis MMU Satellite Repair") is found in the "Space Shuttle Atlantis" folder. Select the scenario in the Launchpad window and read the brief instructions there for starting your EVA (extra-vehicular activity, or space walk). You may want to check out Chapter 3 first, to learn how to operate your thrusters with the keypad keys.

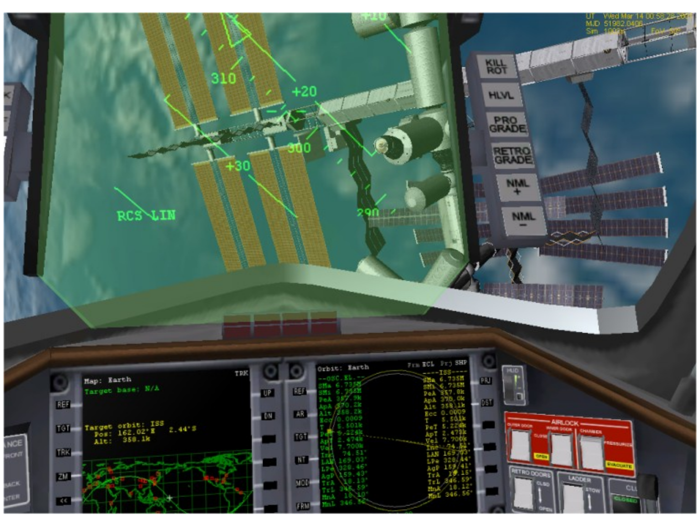
In the meantime, there's Orbiter. Orbiter is a free space flight simulator for the PC. Although you won't experience "zero G" or need a space suit to breathe, Orbiter is realistic in many ways. So you can use Orbiter to "play in space," but unlike a "space shooter" or a game based on *Star Wars* or *Star Trek*, the science that controls Orbiter is real and quite accurate. What does this mean? It means that if it takes a lot of fuel to do a certain orbit change in real life, it will take a lot of fuel in Orbiter. A mission that takes three days in real life (such as a typical Earth-Moon trip) will take three days in Orbiter too (but Orbiter lets you accelerate time by 10 to 100,000 times to greatly speed up such a mission so you can do it in around 45 minutes if you average 100x time acceleration). Orbiter comes with spacecraft that are much more powerful and fuel-efficient than current real spacecraft, though they are still physically possible (with future advances in material and engine technologies). This means that many space voyages that are not yet possible can be simulated in Orbiter. Orbiter also includes one standard realistic spacecraft (the Space Shuttle *Atlantis*), and there are add-ons for nearly any historical or fictional spacecraft you can imagine, from Gemini and Apollo to the *Star Wars* Millennium Falcon (but without warp drives).

Learning about gravity, rocket engines, thrust, orbits, trajectories, attitudes, and more could be called "rocket science," but once you know a bit about these subjects, you can do some really cool things in Orbiter, and you don't have to be a rocket scientist. You can just do it for fun. Figuring out orbits and trajectories in space is called "orbital mechanics," and it certainly involves math and physics, but thanks to Orbiter, you can start to learn and experiment with the basics of space flight without a lot of math (the math is still there, but Orbiter does most of it for you). As you do more advanced flight planning for missions to Mars and the like, you will find that some math (and more "geometrical thinking") is needed. But in this manual, although there are a lot of numbers, there's not much math.

Is it a game? Some Orbiter users make the point that "Orbiter is a simulator, not a game." Well, it certainly is a simulator, and anything you use mainly to have fun could arguably be called a game, although in the case of Orbiter, while there are real challenges and skills to master, there aren't really any enemies or scores. Maybe it's a "space flight simulation game." Whatever you call it, Orbiter is a lot of fun, and it can be enjoyed on a variety of levels, from simple flying and sightseeing to complex and realistic interplanetary flight planning for future missions to Mars. This manual is just a start, but once you go through these missions, you will be ready to understand the various more advanced tutorials you can find on the web. Just do the parts that interest you and don't worry about the rest. You might learn some things along the way, but don't worry about that either – this kind of interactive learning is really fun.

A Note to Parents and Teachers

Orbiter is a freeware space flight simulator created for the PC by Dr. Martin Schweiger primarily as an educational tool (although Dr. Schweiger is the author, he credits a number of other talented people who have contributed 3D models, planetary graphics, and special instruments that are now included as part of Orbiter). It allows students to demonstrate and experiment with various aspects of physics that are involved in space flight. It uses detailed physical and mathematical models to simulate flight in powerful, futuristic, but still physically realistic spacecraft, as well as in a simulated version of the current Space Shuttle with its realistically tight fuel and payload margins (easily installed third-party add-ons provide access to many other historical, current, proposed, and even fictional spacecraft – add-ons for the Apollo Moon landing missions and more detailed versions of the Space Shuttle are especially impressive).



You Are There – The 3D graphics in Orbiter help to make it quite believable. In this "virtual cockpit" (VC) view from the futuristic Delta Glider, we are orbiting 358 km above New Guinea and have just undocked from the International Space Station (ISS) which we can see through the greenish tint of the HUD (head up display). The two MFD screens (multi-function displays) show our position (Map MFD) and orbital information (Orbit MFD). The right mouse button "moves your head" for view control, while the left mouse button can operate any of the controls you see here. Only a few Orbiter spacecraft have this VC feature, but other views and menus also support mouse interaction for many program functions.

Stealth Learning – Although there are books and even other software tools to help students learn about the physics of space flight, it is Orbiter's first-person perspective that really makes it compelling. The idea that you are piloting the spacecraft is backed up by excellent 3D graphics and well-designed controls and instruments for flight planning, navigation, and "situational awareness." These instruments (including a multi-mode head-up display or HUD, as used in modern military aircraft) allow you to pilot the spacecraft from takeoff or launch to orbit; to make modifications of orbits as needed to rendezvous and dock with other spacecraft; to transfer from Earth orbit to the Moon or to Mars or other planets (and to orbit or land on these other bodies); and finally to return to Earth, reenter the atmosphere, and land on a runway like the Space Shuttle does today. This may seem like a lot to learn and handle, and it certainly can be – Orbiter's learning curve can be pretty steep. But for people who have experience with today's complex video games (as many young and some not-so-young people do), it may be just another challenge to master, one that carries with it a solid dose of Newtonian physics, mathematics, astronomy, and space technology and a wide range of simulated experiences that are literally out of this world.

Safe and Effective – Dr. Schweiger develops and distributes Orbiter for free, which is a great contribution to space flight enthusiasts and science educators everywhere. The adage "you get what you pay for" is luckily not true in this case – Orbiter has been carefully designed and programmed and is remarkably stable for any complex 3D simulation, let alone a free one (add-ons can sometimes cause stability problems, most often when an add-on is installed that was intended for an earlier version of Orbiter – be sure any add-ons you install are meant for the current version). The downside of all this is that since you can't buy it, you have to download and install it yourself, there's no printed manual (though there is a detailed PDF manual you can print yourself), and there is no direct or official support.

But Orbiter is pretty easy to download and install, and the installation is contained in one main folder and makes no modifications to your Windows environment as many programs do. There is also a great "support group" on the Orbiter Web Forum, Orbiter enthusiasts who are often willing to give some of their spare time to answering questions posted by new users. See Chapter 1 for more information on installation, configuration, basic operations, and support.

How to Use This Manual

Orbiter is a great program, and you can do a lot of different things with it, depending on your level of interest in space flight. But because it has so many features, and is also expandable through add-ons, there's a lot to learn, and it can take some time to master Orbiter's features. The good news is that you don't have to master *all* of Orbiter's features to have fun with it, and this manual is intended to guide you through the basics that most people want to learn to do right away. Here are some tips for using this book to get what you want out of Orbiter.

Follow Your Interests – Although you will probably find it useful to go through chapters 2 and 3 to learn the basics of spacecraft and MFD operations, you don't have to follow the chapter order to get something good out of this book. Feel free to skip around. The steps in each chapter are usually pretty detailed, so if you want to work on docking with the space station first thing, try out chapter 5. Some later chapters do refer back to procedures explained in earlier chapters to avoid excessive repetition.

Watch the Movie First – For several chapters, there are flight recordings of some or all of the steps in the flight, so you can "watch the movie" before you even try to execute the steps yourself. In some cases the flight recording scenario is provided in the basic Orbiter installation (in Scenarios – Playback and

Scenarios – Tutorials), while for others there may be playback files from the web you can install in your Scenarios – Playback folder. This will be described in each chapter. In the Tutorials folder, the flight recordings include on-screen annotation, sometimes quite detailed (you can turn the notes off with a checkbox, see below). You may find that you can learn everything you need just by watching the movie one or more times and following along with the on-screen notes. Whenever you are ready, you can press Control-**F5** to bring up the record/playback control panel, press the STOP button, and take over the rest of the flight manually.

Note that you can also control the playback speed of the flight recording. If you uncheck the "Play at recording speed" box, you can use the normal time acceleration keys (**T** to speed up time, **R** to slow it down) to control the playback. You can also pause the simulation any time (Control-**P**). Note too that the Scenario – Tutorials folder includes several annotated flight recordings that are not referenced in this book (e.g., landing the Space Shuttle *Atlantis*). The Playback folder holds non-annotated recordings and any that are recorded by you (you also use Control-**F5** to turn on record mode).

Skip the Details (Use the Summaries) – There are a lot of explanations, warnings, background comments, etc. in this book, on the theory that you will probably want to learn when and why you should do something, not just the particular exact steps. But maybe you'd like to skip the details at first and just run through the steps on your own. No problem – at the end of most flight chapters is a numbered summary or checklist of the steps used in the chapter, with little or no extra explanation.

Just a Start – This manual covers a lot of ground, but it doesn't cover everything there is to know about Orbiter – it is intended to introduce basic techniques and information in a fun way to get you started on the learning curve. This can help you to better know what to look for when experimenting, and to make better use of other documentation as discussed in Chapter 7, "Learning and Doing More."

For Users of Previous Orbiter Versions

If you used the 2005 or earlier versions of Orbiter, you can enjoy or ignore most of the new 2006 features as you wish, but one thing you will need to adjust to is the lack of shift keys for switching between different MFDs. For example, if you are accustomed to using Right-Shift-O to open the Orbit MFD on the right side, you will have to adjust to using the mouse to click the [**SEL**] button and then the [**Orbit**] button. On the other hand, you will probably like the fact that the no-panel view now has its own MFD, autopilot, and RCS control buttons on screen. This makes flying no-panel add-on ships a lot easier – you can fly without needing to remember key commands (except a few like Control-D for undocking).

Cautions and Disclaimers

There are just a few important points to make here...

Orbiter version – This manual was originally developed and tested with Orbiter 2005, and has now been updated for and tested with the 2006 version (see Chapter 1 for download information). There are earlier versions of Orbiter (development started in 2000), and although I don't know Dr. Schweiger's development plans, there could quite possibly be more updates in the future. Some parts of this manual might work with earlier or later Orbiter versions, but I can only vouch for the 2006 version, and I suggest you use that one with this manual (most procedures will probably still work with the 2005 version, but various features of the 2006 version have been integrated into most of the examples). When a newer version of Orbiter comes out, I will consider updating this manual again, but since this is a spare time project, I can't make any promises!

No guarantees – As with most things in life, there are no guarantees with this manual. I don't think there's much chance of anyone using it to try to operate real spacecraft (if there is, please don't, or at least send me an email and invite me along for the ride!). Even within the intended scope of a PC simulator for entertainment purposes, I can't say that the procedures described here are the best ones or that they are even completely correct. They are just things that I've found that more or less work and that I've decided to share to help other people get started with Orbiter. Although I now have substantial Orbiter experience, I am far from being a top Orbiter expert (some users on the Orbiter Forum have been using it since its first release in late 2000!). Consider me a grown up space kid who found something cool and wanted to share it with others. If you like it and find it useful, please share it with other parents, teachers, or students. If you have some good experiences with it, please visit the Orbiter Forum (click the Forum link at http://www.orbitersim.com) and share your stories with other Orbiter fans.

So welcome!

Thanks to the Web, Orbiter is a truly international venture – Martin Schweiger is British, but Orbiter and its wide range of add-ons include contributions from people in many countries. Its user base is even more international (see http://orbinauts.dansteph.com), and that's as it should be – space is of interest to many, and important to the future of us all, so it's natural that we share our interests and ideas regardless of where we happen to live. I hope that real future space ventures will enjoy a similar spirit of cooperation in a common cause.

I certainly am open to corrections and suggestions for this manual. If you find mistakes, or you have an idea for a better way to do something, or for additional examples or chapters in future editions, please send an email to bruce.irving@marsdrive.com.

New Co-Author – I'm happy to welcome my friend Andy McSorley as a co-author for this second edition. Andy contributed ideas, proofreading, and testing to the first edition, and this time he has also created a new chapter on using the Interplanetary MFD add-on to plan and fly a trip to Mars. Although I have not changed all the "me" references to "we" in the background material, Andy has been a real contributor from the start of this project and has really helped the whole book. Thanks, Andy!

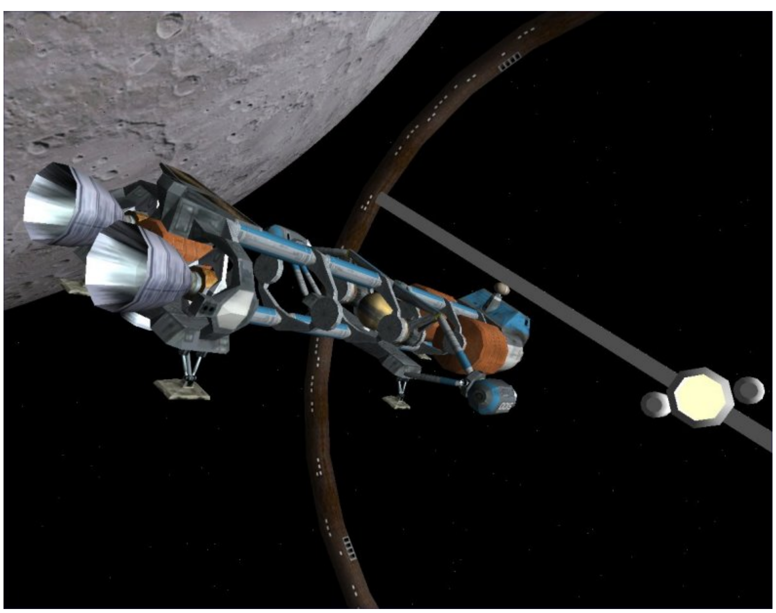
Enjoy,

Bruce Irving
("FlyingSinger" on the Orbiter Web Forum)
http://flyingsinger.blogspot.com

Andy McSorley
("AndyMc" on the Orbiter Web Forum)
http://www.virtualspaceflight.com

Before You Get Started

The goal of this chapter is to help you get Orbiter installed and configured so you can quickly start to play. It will give basic information, tips, and advice but will refer you to the Orbiter manual for some details. Fortunately Orbiter is pretty easy to install and configure so you shouldn't have too much trouble. Note that you will need a Windows-based PC (there is no Mac version of Orbiter). While you can make some installation and configuration choices to reduce the demands on your PC, and you don't need the *very* latest and fastest PC and graphics accelerator card, Orbiter is a fairly complex real-time simulator with detailed 3D graphics. Some older PCs may not be able to keep up.



Space Bug – The Shuttle-A cargo transport (with no payload modules) in lunar orbit, approaching the rotating Lunar Wheel Station for docking. The fictitious Shuttle-A is one of Orbiter's standard spacecraft, a space freighter made to operate mainly outside the Earth's atmosphere. It would be used to haul freight between Earth orbit and the Moon, making use of its hover engines (smaller engines visible here) and rotating auxiliary engines (center mounted pods) to take off and land horizontally from the Moon's surface. This "Blue Danube" scenario can be found in the Space Stations folder.

Before you install Orbiter on your PC, you will need to be sure you have what you need to succeed with the installation. That might start with **getting permission** to download and install some new software if the PC in question is your family or school PC, or if it is your PC, but family or school rules require getting permission. Orbiter is quite harmless – it is free software developed and released purely for educational and entertainment purposes, but you should follow the rules of your home or school (if you're an adult reading this, you might not need permission, but give your parents a call anyway, they'll be happy to hear from you – and tell them about Orbiter while you're at it).

Orbiter is safe! Note that Orbiter is a better PC "citizen" than many commercial and even freeware or shareware PC programs – it installs its files only into the directory you specify, not into various Windows system directories as many programs do. This means the files generally will not affect other programs on your PC, and they can be removed when necessary by simply deleting the installation directory with all its files. This also means that you can easily have multiple installations of Orbiter on the same PC, which is useful when you want to try out different sets of add-ons (as long as you have disk space since each is at least 116 MB, up to 665 MB with all high-resolution files, before any add-ons!).

The information below is a summary of the important points and should help to get you going. If you have problems, first check the Orbiter manual. This file (**orbiter.pdf**) is installed with Orbiter in the /Doc folder, but you can also download the manual from the web before you even install Orbiter (go to www.orbitersim.com and click on the link labeled "Manual" – there are several download sites for this PDF file). See especially chapters 2 (Installation), 3 (the Launch Pad), and 5 (Getting Help).

What You Need

Here's what you need to install Orbiter 2006. These are *my* guidelines, not absolute minimums – check the Orbiter web site and manual (orbiter.pdf) for the latest information on requirements. It's always a good idea to review the installation page at www.orbitersim.com in case there have been changes or patches.

- **A Windows PC** (Windows 98, ME, 2000, XP – sorry, no Mac version) with at least 200 megabytes of free disk space. For best results with Orbiter 2006, your CPU speed should be 1 GHz or better, you should have at least 256 MB of RAM, and a graphics accelerator card with 32 MB or more graphics memory. Most PC's sold since 2001 probably meet these guidelines, although in some, the built-in graphics accelerator may not be very good. You also need a fairly up to date version of Microsoft's DirectX graphics utilities (search www.microsoft.com for **directx** – most commercial games will check and install a new version if needed, so you may be up to date already). If your PC can run graphics-heavy games such as *The Sims*, *Halo*, or *Microsoft Flight Simulator* OK, it should be OK for Orbiter. See the Orbiter manual for more details.

- **A keyboard with a numeric keypad.** Orbiter makes frequent use of the numeric keypad keys. Most desktop PCs include such a keypad as a standard part of the keyboard, but if you are using a notebook PC, you may not have such a keypad, or it may be "embedded" in the standard keys and require awkward shift keys to access. You can usually plug in an external keyboard to a notebook, and you can also buy separate numeric keypads that plug into the USB port.

  Orbiter can also use a joy stick for some controls, which is most useful for flying in the atmosphere in airplane-like space craft. It's nice to have, though in space operations, the keypad generally works better, and even for atmospheric flight, you can usually do OK with the keypad.

- **A web connection** to download the Orbiter files. These files are pretty large and could take quite a while to download if you are using a 56K dialup modem connection. Orbiter doesn't require access to the Internet while it runs (it does not yet have any multiplayer capability, and even if it gets this in a future version, it would be optional to use).

- **A Zip file application** to "unzip" the compressed Orbiter files (file names of the form name.zip). Windows XP includes direct support for "zipped" (specially compressed) file archives. Other versions of Windows require use of a utility such as WinZip – you can find free evaluation versions or basic versions of this or other zip utilities on the Web (search Google for "free zip file utility").

Downloading Orbiter Files

If you have the requirements above, you can download the Orbiter files and get started. You will download and save the files to a directory on your PC. But first you have to find them. Note that web sites **DO** change, so use Google (www.google.com) to search if a site mentioned seems not to work.

- **Go to www.orbitersim.com** - The central web site for Orbiter is maintained by its creator, Dr. Martin Schweiger, http://www.orbitersim.com. This web site has a lot of information about Orbiter including FAQ's and descriptions of the latest versions and updates (the Gallery page also has a lot of great screen shots) . This site does not directly host the download files for Orbiter, but it includes links (on the Download page) to several "mirror" web sites that do host the Orbiter files (there are still other web sites for the many add-ons developed for Orbiter, but you should start out with the basics for now – except for Orbiter Sound).

- **Mirror Sites** – Read any notes on the Download page of www.orbitersim.com, choose a mirror site, and read any notes there before downloading. Note that the files are named by release date (e.g., orbiter060426_base.zip would be Base Files of April 26, 2006 – shown as 06*mmdd* below).

- **Basic Distribution** (**Base** file zipped ~50 MB, unpacked ~120 MB, contains the basic, required Orbiter files, orbiter06*mmdd*_base.zip) – Install and try the basic files before installing extensions or add-ons. Note that the Orbiter SDK is only needed if you plan to make your own add-ons.

- **Planetary Extension Packages** – These are optional but recommended if your PC is fast and has a good graphics card. High resolution texture files make the Earth and some other planets look much nicer, but new level 10 (L10) textures for Earth and Mars unpack to *very* large files.

  Earth L10 (zip ~79 MB => ~187 MB, Earth06*mmdd*_L10.zip)
  Mars L10 (zip ~177 MB => ~256 MB, Mars06*mmdd*_L10.zip)
  Planets/Moons (zip ~69 MB => ~104 MB, individual files also available, PlanetHires06*mmdd*.zip)
  Vessel Extensions (very small files, hi-res textures for Delta Glider and Dragonfly ships – get these)

- **Orbiter Sound 3.0** – This is an optional add-on, but it improves the Orbiter experience so much, it is essentially required. It adds a variety of sound effects and MP3 music support to Orbiter and is only available from "Dan's Orbiter Page," the web site of its author "DanSteph":

  http://orbiter.dansteph.com (click ***DOWNLOAD***, then first download link, about 10.4 MB)

  The download file is an executable (OrbiterSound30.exe) file, not a Zip file – you must download and save the file, then after Orbiter is installed, run this executable file to install Orbiter Sound 3.0

(it has an installer but the installer does not write anything to the Windows Registry or other places, only to the Orbiter installation directory).

But wait! There's actually no sound in space, right?

You're right – above the Earth's atmosphere, in the near-vacuum of space, there is nothing to carry sound waves, so no sound. But inside a piloted space craft, there *is* air, and there are lots of sounds and vibrations that carry through the metal parts of the craft and into the air around the astronauts, from the air conditioning fans, fuel pumps, reaction control thrusters, and other systems. There are also sounds from radio transmissions. And since external views in Orbiter often look like scenes from a space movie, why not have a sound track? Orbiter Sound 3.0 supports MP3 playback so you can replace the silence of space with your favorite tunes. Think of it as an MP3 player with 3D graphics. And rocket engines.

Installing from the Zip Files

Once you have the Zip files saved in a directory on your PC, you can install Orbiter.

- **Create an installation directory (folder).** You can do this anywhere on your PC, but most people put their programs under Program Files, often on the C: drive. In a Windows Explorer window, select the "parent" folder (e.g., C:\Program Files), choose **File > New > Folder**, and then type a name to replace the default name "New Folder" (e.g., Orbiter2006).

- **Folders Are Very Important!** Orbiter installation is a simple matter of extracting or copying the files from the compressed Zip file to the new directory where you want it to run. The most important point of this is to keep and use the directories that are defined inside the Zip file when you extract or copy the files in the Zip file. Orbiter depends on the files it needs being in the correct folders when it runs. If you are using WinZip, there is a check box in the Extract dialog that says "Use folder names" – **you need to check this box**. If you are using XP, Zip files look like folders. Select all the files AND subfolders in this (/Config, /Modules, /Textures, etc.) and drag them to the installation folder. This will preserve the directory structure as required.

- **Extract the Files** – Extract or copy the files and folders to your installation folder as described above for your Zip method. You will find a file **orbiter.exe** in the top level of your installation folder. You can double click this file to launch Orbiter.

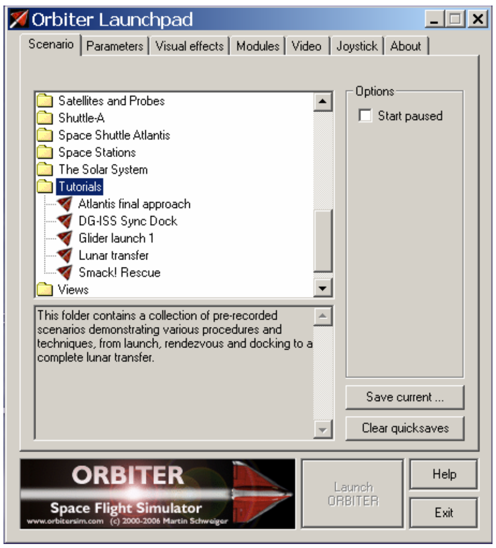
- **Make a Desktop Shortcut** – To avoid having to open the installation folder whenever you want to run Orbiter, you can make a desktop shortcut icon. Right click on the file orbiter.exe and choose **Send To > Desktop (Create Shortcut)** from the pop-up menu. Then you can launch Orbiter by double clicking the new desktop shortcut.

- **Install Orbiter Sound** – Once Orbiter is installed, you can install Orbiter Sound 3.0 as well. Go to the folder where you saved OrbiterSound30.exe and double click to run it. It will prompt you to locate the folder where Orbiter is installed. Click the Browse… button and locate the Orbiter installation folder, then click the button that appears, Install OrbiterSound 3.0, and wait. The installer will install all the needed folders and files and will prompt you for how to customize your sound levels and features (optional for now, its defaults will work without customization).

- **Tip: Save Your Install Files!** – If you really get involved with Orbiter, you will probably need to reinstall it someday, perhaps after installing a troublesome add-on (most add-ons work well, but some don't). It will be much easier if you save (on your hard drive and/or burned to CD) the installation Zip files, as well as the Orbiter Sound installation program and any other add-ons you download and would like to keep. It's also a good idea to save a copy of the entire basic Orbiter installation folder once it's installed and you are sure it is working. You can save it on the hard drive or on a CD as a quick way to get back to a working configuration if an add-on or an accidentally deleted file causes things to break.

Run and Configure Orbiter (Launchpad Settings)

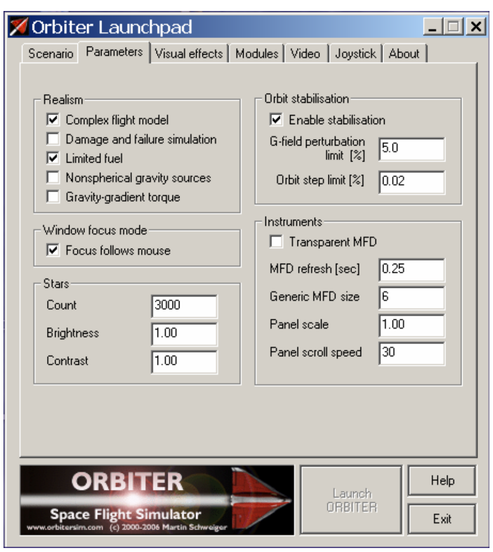
Double click **orbiter.exe** or your desktop shortcut to run Orbiter – it starts out with a tabbed dialog box called Orbiter Launchpad. You need to check and probably change some of the settings Orbiter will use, at least the first time (Orbiter remembers your settings for subsequent sessions). For details of all settings, see Chapter 3 of the Orbiter.pdf manual (in the /Doc folder).



Scenario Tab – This is more or less the "home screen" when you start Orbiter. Here are listed scenario files you can run, most of them organized into folders by spacecraft type or theme. Double click a folder to open it. Most folders and scenarios have explanatory text that shows up below the list. Quicksaves are scenarios saved by you while running Orbiter (using Control-S). The basic procedure is:

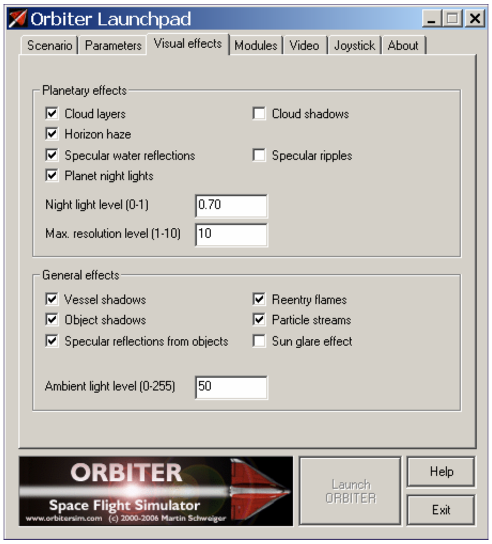
- Locate and click on a scenario file to select it
- Click the **Launch ORBITER** button

The **Save current…** button is used just after you quit a scenario you'd like to use again someday.



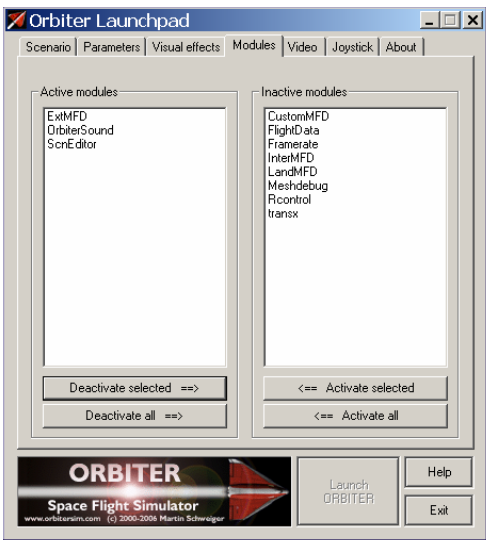
Parameters control various aspects of the simulation. Default settings are mostly OK (you should keep **Complex flight model** and **Limited fuel** checked – it's really better this way), but don't use **Nonspherical gravity** or **Gravity-gradient torque** just yet. Two useful but optional changes:

- **Stars** – Defaults (shown) are OK, but 4000 stars with Brightness 0.9 and Contrast 4.0 may look better than the default settings.
- **MFD refresh rate** – MFDs are the two "computer screen" instruments on the panel. Change to 0.25 sec (default is 1 sec) for more responsive updating, helpful with getting more accurate engine burn times.



Visual effects are cool, but some of them can hurt the frame rate on a PC without a good enough graphics card. These settings work well for me, although "Specular water reflections" can sometimes make the earth a bit too plastic/shiny looking. It's all up to your taste and frame rate tolerance. Try the settings here (essentially default settings) and see how they work for you. You may have to do some trial and error if your frame rate is hit badly.

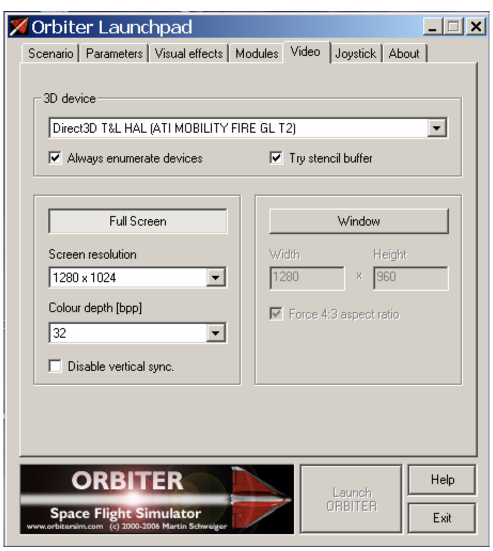
Ambient light level determines how dark it is when it's dark (e.g., planet night side). The default level (8) is realistically (really) dark, but for practical things like seeing the ISS for docking, or landing at night, a level like 50 can be very helpful and still fairly dark.



Modules are additional controls and MFDs that have been installed and can be activated on request from this tab before running a scenario. Using more active modules can mean more CPU time and a slower frame rate (screen update), so only activate what you need.

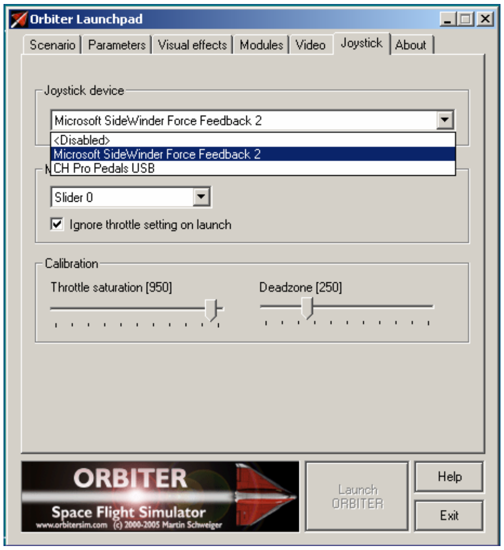
Add-ons such as Orbiter Sound will add more items on the right side. Orbiter Sound 3.0 works very efficiently with Orbiter, so you should install and activate it. If Orbiter Sound is still in your right "Inactive" list, click to select it, then click **Activate selected** (as shown).

Some modules are supplied (all shown here except InterMFD and LandMFD, which are add-ons). ExtMFD (allows additional MFDs) and ScnEditor (integrated scenario editor) are very useful and are active here.



Video settings are very important to a good Orbiter experience. You usually want the highest resolution that your CPU, graphics card, and monitor can handle with a good frame rate. If you have a notebook or LCD monitor that is (say) 1280 x 1024, you should choose that same Screen resolution setting here for best picture quality. Use 32 bit Colour Depth if your graphics card allows (better looking planets).

Try settings like the ones shown, and if you have problems, refer to Chapter 3 of the Orbiter PDF manual. It may save a little time and flashing to run Orbiter in the same resolution you normally use in Windows (even on a CRT), since otherwise the system has to reset video modes when you start and stop Orbiter, but use what looks best and runs well.



Joystick settings are made on this tab. If you have any joysticks installed that are recognized by Windows, they should show up here. These settings work OK for the Microsoft stick listed here. If you don't have a joystick, don't worry much – the keypad works better for most things anyway (with the exception of airplane-like flight inside the atmosphere, when a joystick "just feels right," especially for scenarios like "Atlantis Final Approach," which is in the Space Shuttle Atlantis folder, with an annotated playback version in the Tutorials folder).

TIP: When using just the keyboard/keypad, if you get odd effects like a spacecraft that won't stop rotating, check to see if your joystick or its throttle is jammed against something, giving a series of "commanded" actions you don't know about.

About Numbers, Units, and Time

One thing you will notice about Orbiter is that in addition to nice graphics, it displays a lot of numbers. Orbiter uses the metric system exclusively. Distances are in meters (abbreviated m), velocity (speed) is in meters/second (m/s), and lengths of time are in seconds (s or sec). If you are not that familiar with metric values, note that a meter is a little over 3 feet, and 1 mile is about 1600 m. For velocity, 1 m/s is the speed of a slow walk, 30 m/s is about highway driving speed (67 mph or 108 kph), and 200 m/s is about the speed of a (slightly slow) jet airliner (447 mph or 720 kph).

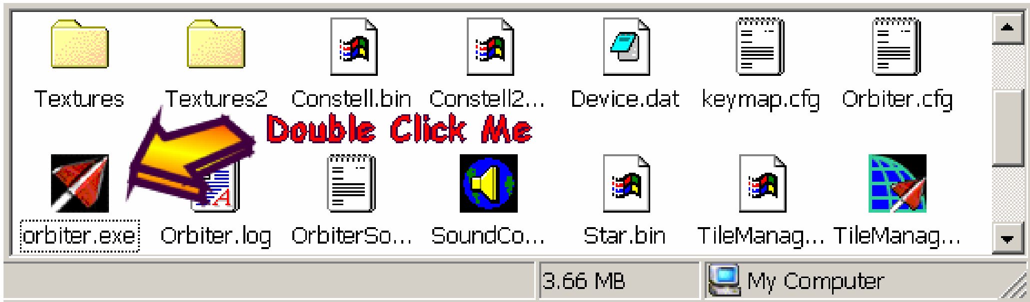
TIP: You should try to "think metric," but if you need to, you can roughly *double* m/s values to get mph (a better estimate is to multiply the m/s value by 2.2 to get miles/hour).

Because Orbiter has to display a wide range of numbers, from fractions of a meter or a few seconds, to millions of meters, it has a special form of "scientific notation" using letters. In this system, **k** means thousands (10^3), **M** means millions (10^6), and **G** means billions (10^9). For example, the distance from New York to Paris is 5,793,638 meters, which is 5793.7 kilometers (km) or 3600 miles. Orbiter would display this as **5.7937M** (read this as 5.7937 **M**illion meters – a million meters is 1,000 kilometers). Time periods in seconds can seem odd when they get large, but just remember that there are 60 seconds in a minute, 3600 seconds (**3.600k**) per hour, 86,400 (**86.400k**) seconds per day. One week = 7 days = 604,800 s (**604.8k**). One month = 30 days = 2,592,000 s (**2.5920M**). You'll get used to it (but you may want to keep a calculator handy at first!). We sometimes need to discuss mass and force (or thrust). The metric unit for mass is kilogram (kg) and the unit of force or thrust is the Newton (N) rather than pounds which are commonly used (rather confusingly) for both mass and force in the English system of units.

Time and Date – Orbiter expresses date and time as **UT** (Universal Time, sometimes called Zulu time), which is the time of day (and date) in Greenwich, England (near London). This system is also used by airplane pilots because when everyone uses the time in a standard single place for everything, it reduces problems with and confusion over time zone differences. Orbiter also uses a system based on counting days and fractions of a day (the fractions give the time) called "Modified Julian Date" or **MJD**. MJD is the number of days since a particular reference day. It makes many orbital calculations easier (and is used in scenario files), but you don't need to know much more about it now.

Running Orbiter

Once it's installed and configured, running Orbiter is easy. Double-click the **orbiter.exe** file in the installation folder or the desktop shortcut you created (see "Run and Configure" above for more info).



From the Launchpad, choose a scenario to run, then click the **Launch Orbiter** button (it's grayed-out until you select a scenario). With a default installation, the load time should be pretty fast. Hi-resolution textures and various add-ons (when you choose to install them) can make the load time take longer.

Quitting Orbiter

From Launchpad – To quit from the Launchpad, just click the [**Exit**] button.

From Inside Orbiter Itself – If you have launched a scenario and want to quit, you have to at least wait for the scenario to finish loading, and then you can press F4 for the main menu and click [**Exit**], or you can type alt F4 or CONTROL Q to exit directly

Getting Help

The first place to look for help is in the Orbiter help files and/or documentation. The Orbiter manual (orbiter.pdf in the installation /Doc folder) is the key reference and is quite thorough (you need the free Acrobat Reader, www.adobe.com) . Help files have a lot of useful information you can even access while running the sim (from the main menu F4).

If you have looked in the manual and are still stuck, you can try the Orbiter Web Forum (click the Web Forum link on www.orbitersim.com to reach the forum). You can use the Search link on the forum to search for past questions and answers, and you can also register and post questions in the forum. Also be sure to check the two or three "sticky" posts that stay at the top of the list (including one about FAQs – many people have the same basic questions). If you are using add-ons, you can also check the Addons Forum. As a freeware program, Orbiter has no official support, but members of the Forum are pretty friendly and will usually respond to reasonable and polite questions from "newbies."

TIP: Keep in mind that it is nobody's job to answer Orbiter questions on the Forum – members do this in their spare time to encourage and help people who share their interests in space flight and Orbiter. Please try to be polite and patient with your questions, and try to include enough information about your problem so an experienced person has a chance of figuring out what might be wrong. If you just say "it doesn't work," people have to guess what's wrong and it's frustrating for everyone.

Go Play in Space!

Smack! Rescue

The goal of this chapter is to get familiar with the basic operations and displays of Orbiter using mainly the mouse with on-screen controls and menu picks as much as possible (there may be a few keyboard operations). We start with a scenario that comes with Orbiter, building a little story around it, and explaining how to deal with the "emergency" this scenario presents. The idea that you would notice a critical orbit problem just minutes before you would need to take action is pretty unlikely, but unlikely situations are something that simulators are great for! For the story part, imagine that you are the pilot, and that the instructions and suggestions are coming from an instructor on the radio who can see all your flight data via telemetry. You can also start out by viewing an annotated playback of the mission instead of flying it yourself.

Nose to Nose – Two sleek "Delta Glider" rocket planes have opened their docking port covers, lined up, synchronized their roll rates, and are about to dock nose to nose in low Earth orbit. In this view, you can clearly see the two large main engines in the tail of GL-01 as well as its three bottom-mounted hover engines. The main engines will figure heavily in this scenario, while the hover engines will be the centerpiece of Chapter 3 when you will be training at sunny Brighton Beach. A small Shuttle PB spacecraft is orbiting nearby (just visible near bottom of picture).

You've had some fun testing out the new "Delta Glider" (DG) rocket plane in low Earth orbit (LEO) the last few days. That's a funny name for this spacecraft – with its powerful main and hover rocket engines, it's hardly a glider, but whatever. Your tail number is GL-01, and you're seconds away from docking with GL-02 flown by another pilot, Martin. It was Martin's idea to add the synchronized rotation once the ships were lined up nose to nose – kinda cool. Not strictly regulation, but it's no big deal – you quickly learn in space that it's mainly relative motion that matters anyway, and *relative* to GL-02, your ship isn't really rotating.

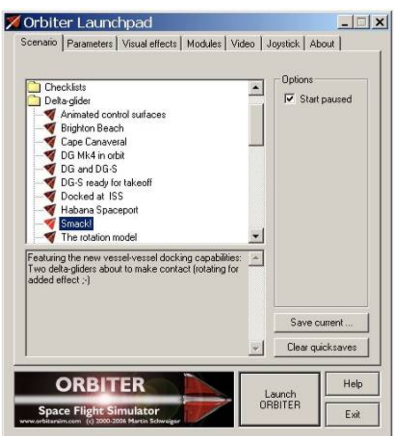
Two Ways To Start

Thanks to Orbiter's "flight recorder" feature, there are two ways to start out with this chapter. You can follow the instructions in the text, opening the standard supplied file "Smack!" and flying the mission exactly as described. Or you can open a different version of the scenario file that automatically runs a playback of the mission with on-screen comments telling you what is happening and what to do (you can still change views and some other things during playback). This playback is something like a movie or video except that it actually runs in Orbiter. Although the motion of the spacecraft is prerecorded, you can interrupt the playback at any time with [CONTROL] p and take over control yourself. To run the playback version, launch Orbiter and run the scenario **Smack! Rescue** found in the **Tutorials** scenario folder.

Docking and Checking Status

With a closing velocity (CVEL) of 0.69 meters/second on the Docking MFD, you'd be coming in a bit hot for space station docking (recommended CVEL of 0.1 m/s), but the DG docking ports are plenty strong. This is barely a slow walk (that's about 1 meter/second), though these ships have a lot of mass, and you don't want to bump the other ship *too* fast. The fact that both ships are traveling at a velocity (**Vel**) of 7388 m/s (7.388k in Orbiter format, 16,500 mph, 26,597 kph) relative to the *Earth* is important for a lot of things (like staying in orbit!), but it doesn't affect much in the final seconds before docking.

- **Start Orbiter and launch the scenario *Smack!* that you'll find in the supplied "Delta Glider" scenario folder.**
  Review Chapter One, "Before You Begin," if you need any help doing this. This will put you in the cockpit of Delta Glider GL-01 with GL-02 quickly approaching and the Earth in the background appearing to rotate. You will need to follow and do all steps manually if you start with this scenario rather than with the one in the Playback folder.



- **You start out in the external view – hold down the RIGHT mouse button and move the mouse to pan the view, and use the mouse wheel to move the "virtual camera" in and out.**
  Use [page up] and [page down] keys for camera control if you don't have a wheel mouse – you can also pan the view from the keyboard by holding the Control key and using the arrow keys.
  NOTE: If nothing is rotating, you may have started in pause mode (as shown in the Launchpad dialog above) – press [CONTROL][P] to toggle out of pause mode. You can press [CONTROL][P] again any time you'd like to pause Orbiter.

- **Press [F1] if you want to switch to/from the cockpit view, but don't touch any other controls yet.**
  It's all lined up so just wait a few seconds for the spacecraft to dock, for the docking sounds and confirmation, and for the message DOCKED to display in the lower left corner of the left multi-function display (MFDs are basically computer screens – the left and right MFDs can be changed to display many types of information, depending on what you need to do, but the Docking and Orbit MFDs are all you need for this chapter).

  NOTE: Other than with docking ports and with planet surfaces, Orbiter currently has no "collision detection." If you miss the docking port, your spacecraft will pass through the other one without effect! Sorry, no explosions. If docking doesn't automatically happen, start with the playback scenario and interrupt it with [CONTROL] p after it docks.

SMACK! That was a solid bump, but you're safely docked. Time to review your status and prepare for some additional tests. First a quick look at the orbital elements on the Orbit MFD on the right – and right away something looks wrong. The orbital diagram shows that your periapsis is *inside* the circle representing the Earth's radius - **PeR** is 6.156M meters, 6.156 **M**illion meters, or 6156 km, and Earth's radius is 6371 km. You do the math – the low point of this orbit is *really* low, about 200 km below the surface, and that's not going to fly for long! Better double check with altitude mode on the Orbit MFD.

Peri-*WHAT?*

Orbits are usually ellipses (sort of egg shaped, an elongated circle). *Periapsis* is the lowest point in an orbit around any body (also called *perigee* in the case of an Earth orbit), apoapsis is the highest point (also called *apogee* for the Earth case). In the Orbit MFD diagram, periapsis is shown as a closed circle, apoapsis is an open circle. The labeled Orbit MFD and 3D "fixing up our orbit" graphics below should make this more clear. There is also a section on understanding orbits in Chapter 9, "I Was Just Wondering." This section explains the shapes of orbits and what the numbers that describe them mean.

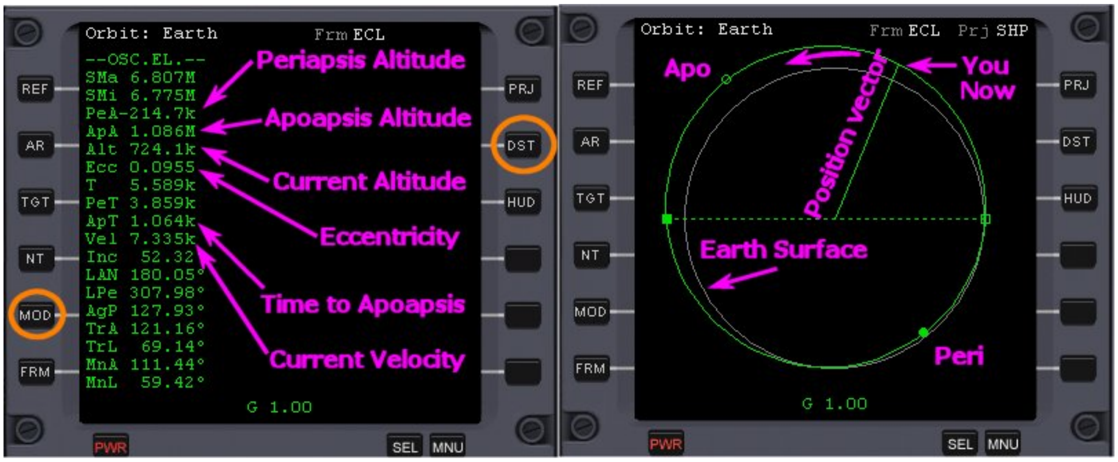
How could you have missed *that*? It must have happened as you changed orbits to rendezvous and dock. Altitude mode shows you are 706.6 km above the surface now, but with a periapsis altitude (**PeA**) of -214.7k meters – mathematically below the surface. You need to raise that periapsis or you will be reentering the Earth's atmosphere sooner than planned!

- **Press F1 to go to the internal (cockpit) view if you are not there already.**
  There are actually three cockpit views for the DG, the instrument panel view, a no-panel view, and a 3D "virtual cockpit" view (you can cycle these with the F8 key, but note that not all Orbiter spacecraft have panels). **TIP:** You can "raise your seat" (lower the panel) in the panel view with the ↑ key (lower it with ↓). In our screen shots, we have put the lower edge of the MFDs at the bottom of the screen.

- **Click the distance [DST] button on the right side of the Orbit MFD to switch to altitude mode.**
  This on-screen button is circled in orange in the picture below. It changes the display from radius (**Rad**, distance from center of Earth) to altitude above the surface (**Alt**), and **PeR** becomes **PeA** with a value of –217.4k m (below the surface!).

- **Click the mode [MOD] button on the Orbit MFD to cycle display modes.**
  Also circled below, this lets you display the orbit diagram, the numbers (orbital elements), or both. In the figures below we have labeled the orbital parameters that are most useful in this scenario. Other orbital parameters are important too but are not directly needed in this situation. For example **T** is the orbital period, the amount of time needed for one complete revolution around the Earth. For this orbit, that period is 5.589k seconds or about 93 minutes, but it's rather theoretical since if you don't fix up this orbit soon, you won't complete the next one anyway!

  In the right hand diagram you can better see the dots for periapsis (Peri) and apoapsis (Apo) as well as the gray outline of the Earth's surface and the green line ("Position vector") which indicates your position. This is a typical "prograde" orbit so the position vector sweeps around counterclockwise as shown by the curved arrow at the top, in the same direction as the Earth's rotation. We'll discuss the square dots (called nodes) in a later chapter.



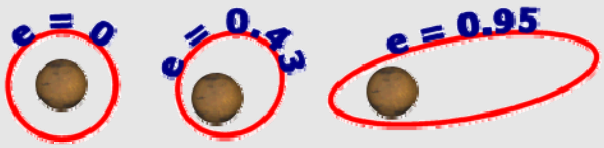
Fixing Up Your Orbit

The best way to raise the periapsis is to make a prograde main engine burn (accelerating in the direction we are orbiting) when you reach apoapsis as shown in the graphic above. When will that be? Check the labeled Orbit MFD shown above – **ApT** is time to apoapsis, and it's 1092 seconds from now (1.092k, k meaning "thousands", which is about 18 minutes), so you better get ready to make that burn! Here are the steps you'll need to follow.

- ✓ Kill the rotation that still has the docked ships spinning relative to the Earth.
- ✓ Undock, use thrusters to separate by 30-40 m, and hold relative position (you want to try to stay close together so you could re-dock quickly with GL-02 after both orbits are fixed, though you won't actually dock in this chapter).
- ✓ Turn both ships in the prograde direction using the prograde autopilot button.

✓ Wait until "time to apoapsis" (**ApT**) is about 60 seconds and fire the main engines for both ships until eccentricity is as small as possible (maybe around 0.008 or smaller), which will raise the periapsis to a safe altitude and create a nearly circular orbit.

Eccen-*WHAT?*



Eccentricity (eck-sen-TRI-sitty, **Ecc** in the Orbit MFD, often called just **e**) is a number that measures how "stretched out" your orbit is from a perfect circle. A value of zero indicates a circle, larger values less than 1.0 indicate more and more elongated elliptical shapes. Values of 1 or greater indicate an orbit that isn't closed – which means you escape from the planet's gravity. This can be good news if you're trying to go to the Moon or to Mars, not such good news otherwise! See chapter 9 for more about orbits.

Kill Rotation and Undock – Start by killing your rotation and undocking. "Kill rotation" means to apply whatever rotational thrusters are necessary to cancel out rotations in all directions. It's a very common operation, and though it can be done manually, the Kill Rotation autopilot is normally used. Since you are docked and the DG thrusters are pretty powerful, the autopilot in your ship will kill the rotation of both ships.

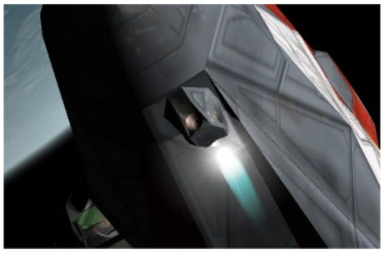
One small thing – there's really no pilot in GL-02, so once you separate, you will have to pilot both ships! This is actually a cool feature of Orbiter – you can switch ships at any time (be sure the ship is in a stable situation before leaving it, especially if you plan to use time acceleration), and you can slow down or speed up time at will, which can really help you multitask.

➢ **Stop the rotation of the docked ships by clicking the [Kill Rotation] button on the right side of the control panel. Wait for rotation to stop (a few seconds).**

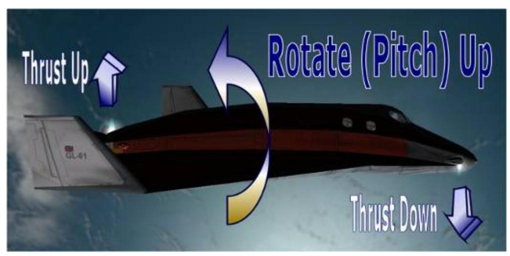
This can also be done with the keypad-[5] key (5 on the numeric keypad). This is one of several special purpose "autopilot" controls for doing common orbital tasks. Orbiter doesn't have a standard general autopilot, but the special ones are usually enough. You can install add-ons from the web to automate many other tasks including even launching to orbit and landing on the Moon or Mars (see chapter 6 on add-ons).

➢ **Undock by pressing the [CONTROL][D] command on the keyboard.**
You can do almost all actions in this chapter using the mouse to click controls and menus. Undocking has a screen button, but it's on the lower 2D instrument panel which is reached with [CONTROL][↓] (use [CONTROL][↑] to go up a panel – the DG has an overhead panel too). Most operations in Orbiter are done with keyboard commands and most also have mouse/screen controls. Undocking gives you a small kick away from the target ship.

RCS Thruster Operations – You need to slowly back off from GL-02 then stop and hold position at about 30-40 m. So we will review thruster operations, concentrating on just three things for now, switching between rotation and translation modes, and the key commands for thrusting forward and backward.




Thrusters are small rocket engines installed at several points on the spacecraft to be able to fire or “thrust” up, down, left, right, forward, and backward (picture above shows the right forward RCS cluster on the DG). They are also called attitude thrusters or reaction controls and are labeled RCS on the panel (RCS = reaction control system). By firing the RCS thrusters in various combinations, the spacecraft can be accurately rotated to point in any direction, or “translated” for small movements in any direction. You can rotate the ship up/down (pitch), sideways left/right (yaw), and right/left around the central axis of the ship (roll or bank). The directions for translation are up/down, left/right, and forward/backward.



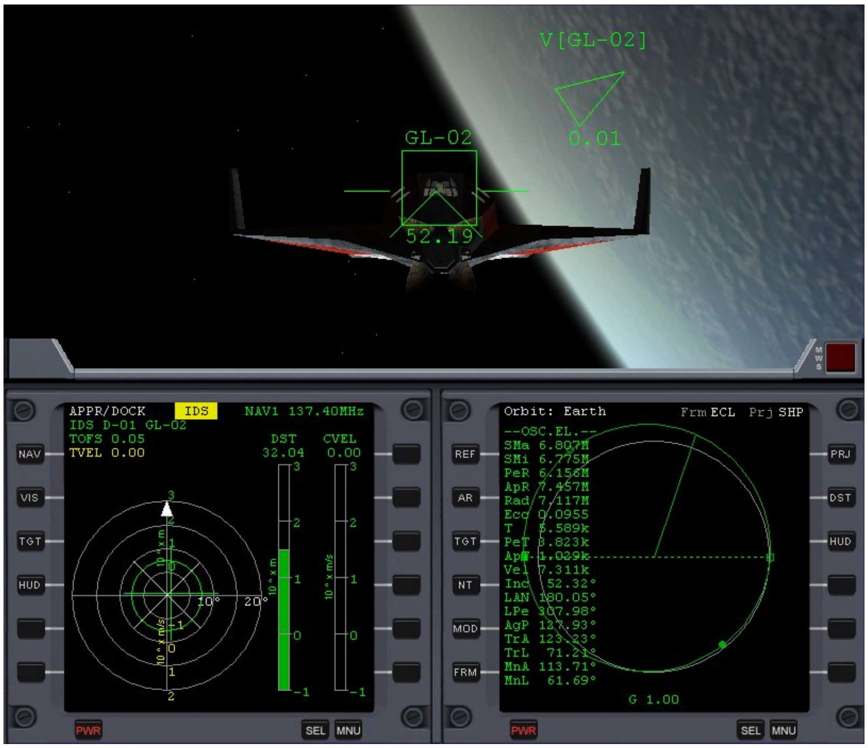
RCS control is done with the numeric keypad on the right side of your keyboard. You’ll learn more operations in the next chapter but for this one, you only need three keys. The Orbiter manual (PDF file Orbiter.pdf installed with Orbiter in its /Doc folder) also has some good diagrams and explanations (see section 14.2 “Attitude Thrusters”). The whole RCS and engine control keypad will be explained in the next chapter.

- **Press the keypad-/ key (not the main keyboard key) to switch from rotation to translation thruster mode.**
  The keypad number keys control both rotation and translation, and the keypad-/ key cycles between the two modes. The RCS mode is shown as a rotary switch at the upper right corner of the panel (it says OFF, ROT, or LIN – you can also change modes here with the mouse, but the keypad is better since you often have to switch modes repeatedly when docking etc.). With Orbiter Sound installed, you will also hear a voice say “Translation” or “Rotation” to confirm the mode when you change it.

- **Press the keypad-9 (thrust back) key a few times to get a CVEL of about –0.70 m/s or so on the Docking MFD.**
  The Docking MFD will also show a **green bar** when you are moving away from the “target” and a **yellow bar** (or **red**, which means you are closing too fast!) when you are moving toward the target.

- **When the Docking MFD shows a distance (DST) of about 30-40 m, press the keypad-[6] key (thrust forward) a few times to try to get CVEL to zero.**
  A CVEL of -0.01 to +0.01 is OK but zero is the goal. If you overshoot, use [9] to thrust back a little again (see Tip below). Alternate between [6] and [9] as needed to zero it out. Now you are holding position at a fairly safe distance relative to GL-02 so you can both maneuver a bit. The Docking MFD below shows DST 32.04 m, CVEL 0.0, and TVEL (transverse or sideways velocity) of 0.0 m/s – so GL-02 is at 32 meters and holding.

  TIP: Holding down the [CONTROL] key while pressing thruster keys applies "fine thrust" of 1/10th the normal value, ideal for making small corrections in your speed.



  Note: This and later screen shots are taken with a wider FOV (field of view) than the earlier shot (now 50° vs. 30°, shown in upper right corner of screen) to show more of the outside world. Press the [X] key to zoom out (bigger FOV, wider view) or the [Z] key to zoom in (smaller FOV, more magnified, narrow view). Range is 10° to 90°. "Normal vision" range is roughly 40° to 60° depending on monitor size and other factors, but you should use what looks good to you.

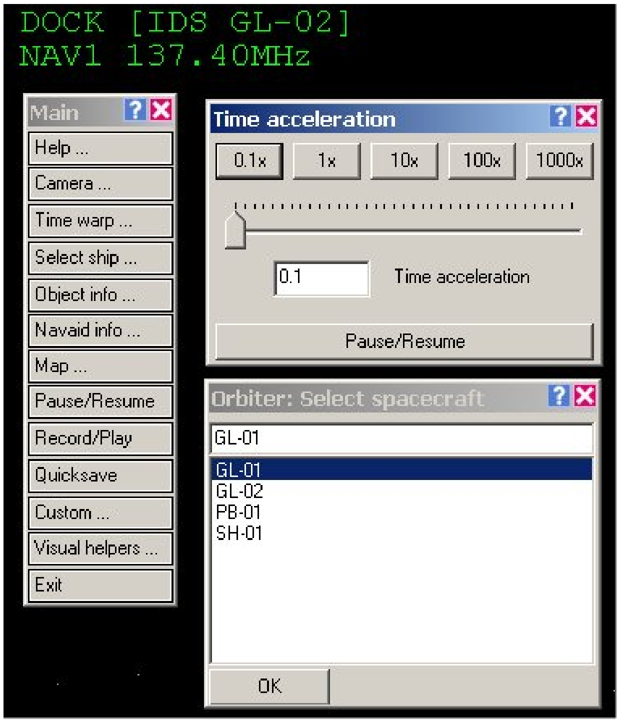
Turn Prograde for the Burn – This is really just a single button click on the RCS panel, but for fun, you can slow down time so you can switch ships and get both GL-01 and GL-02 to start rotating into position at nearly the same time. There's no real need for this, it just looks cool in the external view! The [**Pro Grade**] button is another one of Orbiter's special purpose autopilots. It automatically fires RCS thrusters as needed to point the ship's nose in the "prograde" direction and to keep it pointed there if corrections are needed (prograde means pointing the nose in the direction of orbital motion – pointing tail-first is called retrograde and is also handled by a simple autopilot button).

- **Press [F4] to open the main menu panel in the upper left corner of the screen.**
  Drag the menu panel down a little so you can read the text in the upper left corner of the screen (shows HUD mode and sometimes view and other information).

➢ **Click the [Select Ship...] button.**
Move this small "Orbiter: Select Spacecraft" panel out of the way near the main menu panel in the upper left corner.

➢ **Click the [Time Warp...] button.**
Move this "Time Acceleration" panel out of the way too.

➢ **On the Time Acceleration panel, click the [0.1x] button.**
This slows everything in the simulation down to 1/10th of real time (i.e., 1 second of real time now takes 10 seconds of "Orbiter time").



➢ **On the ship's panel, click the [Pro Grade] button.**
You can press the [[ ] (left bracket) key instead. The ship will start turning to line up with the orbital direction, but in slow motion due to the 0.1x time setting.

➢ **On the Select Spacecraft panel, quickly click GL-02 in the list, then click [OK].**
You are now in the other ship! Move the mouse pointer off the ship panel.

➢ **On the GL-02's panel, click the [Pro Grade] button.**

➢ **On Select Spacecraft, click GL-01 and click OK.**

➢ **Press [F1] to go to the external view, then click [1x] on the Time Acceleration panel to return to real time.**
Watch the two ships rotate in near synchronization to line up for the burn. Leave the panels for the main menu, select ship, and time acceleration open for later use.

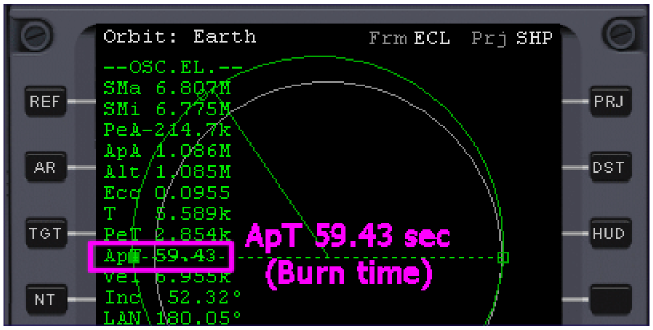
Mouse Note

The panels for the main menu ([F4]), time acceleration, ship selection, etc. can stay open while you do other things, which is very convenient for quick access (though it doesn't help the outside view). By default they are activated by a "mouse over" rather than with a mouse click, so be careful not to accidentally leave the mouse pointer over one of these panels when you try to type keyboard commands to Orbiter – Orbiter won't "hear" you.

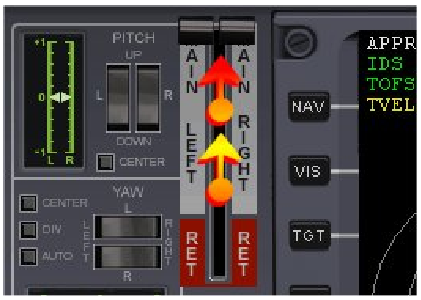
Make the Apoapsis Burn – You need to wait a little while now to reach apoapsis. Once there, since you are using the prograde autopilot to stay pointed in the right direction (along the orbital "velocity vector" – basically the direction of our orbit), you can then just fire the main engines as you monitor the eccentricity (**Ecc**) of your orbit.

Look at the value of **ApT** in the Orbit MFD. This is the time in seconds until you reach the next apoapsis point (times are always in seconds, 600 s = 10 minutes, 3600 s = 1 hour, etc.). Look also at the eccentricity value (**Ecc**). This is what you hope to drive to zero to make your orbit circular.

- **Carefully use time acceleration if desired to get close to apoapsis faster - click the [10x] button in the Time Acceleration panel.**
  Watch the ApT carefully in the Orbit MFD and switch back to [**1x**] when ApT reaches about 100 s. You don't want to miss the burn position in this situation.



➢ **At ApT = 60 s, press the [0.1x] button in the Time Acceleration panel.**
This will slow things down so you can get the burn set up in both spacecraft.

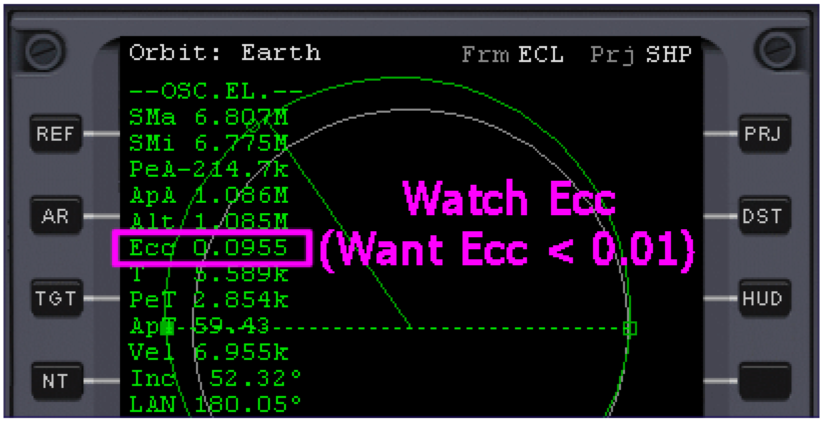


➢ **Use the mouse to drag the main engine controls to the top (full thrust).**
The main engine throttle handles are on the left side of the panel. Be careful to position and drag the mouse between the handles – this will drag both throttles at the same time (if one engine's thrust is higher, you won't accelerate in the right direction).
TIP: Keypad-[+] gives full main engine thrust and the [CONTROL] key will lock it in.

➢ **In the Select Spacecraft panel, click on GL-02 and click OK to switch ships.**

➢ **In the GL-02 cockpit, quickly drag the main engine controls to full thrust, then switch back to GL-01 in Select Spacecraft.**
You should first confirm that you are still in prograde mode in GL-02 (it should be OK). While still in 0.1x time, you may want to switch to external view [F1] and see both ships with their engines burning on the night side of the Earth (see picture below – the white patches in the background are city lights in South Africa, surface labels are on – click **Visual Helpers…** on the main menu to see how to turn on surface and other labels).

➢ **Click the [1x] button in Time Acceleration and watch the Ecc value carefully in the Orbit MFD.**



TIP: The keyboard commands for time acceleration are [T] to increase by a factor of 10 with each press (1x, 10x, 100x, 1000x, 10000x, 100000x) and [R] to decrease by a factor of 10 on each key press, down to 0.1x. High time compression (1000+) makes long flights (like Earth-Mars) possible, but use with care especially near planets – even simple autopilot features such as Prograde can cause trouble with 1000x or higher acceleration (e.g., uncontrolled spinning which causes the autopilot to use up all of your RCS fuel as it keeps firing thrusters to try to stop the spin!).

➢ **When Ecc reaches around 0.01, click [0.1x] again to slow down time.**
With time at 1/10th, the Ecc value will drop slowly – just wait for it.

➢ **When Ecc reaches about 0.008 or lower and stops dropping, cut the engines (drag down to the stop position).**
TIP: You can cut the main engines instantly by pressing the keypad-[*] (*) key.

➢ **Switch to GL-02 and check the Ecc value – it should be smaller too, but won't be identical to that of GL-01.**

➢ **Cut GL-02's engines when Ecc stops dropping (very soon).**

➢ **Switch between ships one more time to confirm that engines are shut down, then return time to [1x]**
Congratulations, it looks like you saved the ship! The orbit looks safe (altitude 1059 by 1139 km, e = 0.0053 in our case, not quite circular which would be e=0). Your orbit will be somewhat different, and it's not too critical here – as long as it's well above 200 km and roughly circular, it's OK in this case, though it certainly is possible and often necessary to reach more exact orbital parameters. The GL-02 should be pretty close at the moment, probably close enough to dock fairly quickly again if required. What are those green boxes? You never turned off the Docking MFD and Docking HUD (head up display) – the boxes are displayed by the Docking HUD as a "road in the sky" leading to the docking port of the designated docking target. GL-02 is facing the wrong way for docking right now, but you aren't going to try that in this chapter anyway. There's more about HUD modes in a later chapter. Time for a little sightseeing!

What's up with that nose cone?

The DG has a "flower petal" nose cone that opens for docking and is closed for atmospheric operations (flying in the air). Above 200 km the nose cone petals won't cause any drag, so they could be left open, though it's probably better (and looks cooler) to close them. You can find a handle for this on the lower control panel. Use [CONTROL][↓] (down arrow) to switch to that panel (there's an upper panel too, that's [CONTROL][↑]). Or you can just type [K] to toggle the nose cone doors (K is for kone?). Both nose cones were closed in the flight recording.

Quick Save the Scenario – This would be a good time to "quick save" the current situation for later use, and to either end the mission or to go do some sightseeing around the Solar System.

Some users might have "quick saved" already in case of a mistake. This saves the current state of the simulation in a scenario (.scn) file in the Quicksave folder found in the Launchpad dialog. This allows you to later load and run that scenario to return to this exact time and space location instead of starting the scenario again from scratch. Orbiter scenario (.scn) files are very small text files so feel free to quick save often.

- If the main menu ([F4]) is open, click the [**Quicksave…**] button, otherwise, you can press [CONTROL][S]. A time stamped copy the current situation is saved.
- If you want to exit from Orbiter now, click [**Exit**] on the main menu, or press [alt][F4].

When to Change What – An Important Orbit Rule

Under “Fixing Up Your Orbit,” we made the statement “the best way to raise the periapsis is to make a prograde main engine burn when you reach apoapsis.” This is true, but there’s a more general rule that’s worth learning. Remember that periapsis is the closest point, and apoapsis is the farthest point…

- To change your **periapsis** height, burn at **apoapsis** – prograde to **RAISE** periapsis, retrograde to **lower** periapsis.
- To change your **apoapsis** height, burn at **periapsis** – prograde to **RAISE** apoapsis, retrograde to **lower** apoapsis.

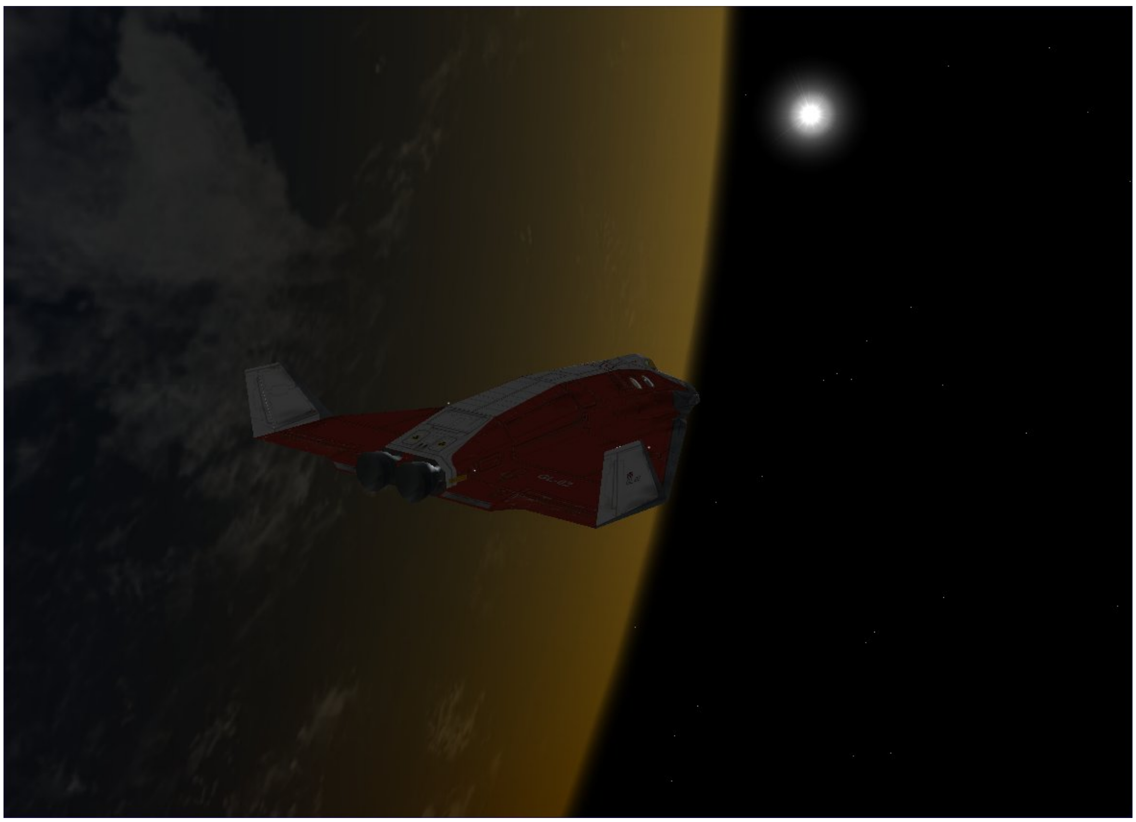
That might seem kind of backwards at first, but that’s how it works. Why? One key point to note is that any point at which you fire your engines must still be a point on your new orbit. So although your speed will change at this point, your ship won’t instantly “jump” to a new position, and any change in the height of the orbit must occur elsewhere. If your burn point is the periapsis, it will still be the periapsis after a prograde burn, and usually after a retrograde burn, though if you burn long enough retrograde, the apoapsis could get low enough to become the new periapsis, flipping the roles of the two points.

Of course the speed and height of the orbit after a burn will change everywhere, not only at apoapsis or periapsis, and you could choose to fire your engines at any point in your orbit, and in any direction. The special thing about burning prograde or retrograde at periapsis or apoapsis is that the positions of these critical orbital points will not change, while burning at an arbitrary point or direction can change everything about the orbit.

If the term “retro” sounds familiar, note that lowering your periapsis by the right amount and in the right place can set you up for reentry. Early spacecraft such as Mercury and Gemini had rocket packs dedicated to re-entry which were sometimes called “retro rockets.”

Space Tourist Time

That wasn't really too bad, was it? Now that you're in a better orbit, it's time to figure out where you are exactly and to get ready for a little sightseeing. The Earth is the obvious view, but thanks to Orbiter's amazing camera system, ship jumping, and planetarium features, you can really view almost anything in the Solar System in just a few mouse clicks, and even have a good idea of what you're looking at. Your current spacecraft won't go there just because you move the camera (think of it as a view from a possibly distant space probe) – your craft has to fly to get to other places (or you can "cheat" by switching to a spacecraft that is already in some distant location, or by using the Scenario Editor). There are no "warp drives" in Orbiter – but it does make good use of good old basic (Newtonian) physics, supplemented by a lot of time acceleration (often referred to as "time warping")!



So How's That New Orbit? Check the Orbit MFD in each ship and see what the new orbit looks like. What are the new periapsis and apoapsis (**PeA**, **ApA**)? As long as periapsis is well above 200 km (2.000M), it should be stable for quite a while. How fast are you going (**Vel**)? What's your period of rotation (T is in seconds – divide by 60 for minutes)? Press the [DST] button and check the distance from the center of the Earth (**Rad** instead of **Alt, PeR** instead of **PeA,** etc.). After that, unbuckle your seat belt, float over to a window, and stare at the Earth for a while like the real astronauts do.

Where Are We Now? (Changing MFDs) – So far you have done well with the two MFDs that were open when the scenario started, but there are a lot of other MFDs in the basic Orbiter, and many more available as "add-ons" created by Orbiter user-programmers and posted on the web. In later chapters you will learn about more of these, but for now, you can just bring up the Map MFD to see what your orbit is passing over.

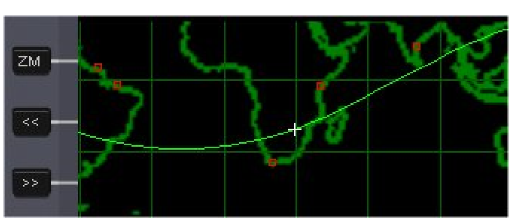
MFDs are controlled with on-screen buttons, and within a specific MFD, most operations can also be done with key commands. MFD key commands are based on the Shift keys, but with a special twist. **The <u>left</u> Shift key controls the <u>left</u> MFD, and the *right* Shift key controls the *right* MFD.**

- **Bring up the left MFD selection list by clicking the [SEL] button**.
  This button is the only way to switch MFDs (no keyboard shortcut to switch*).

- **Select the Map MFD by clicking the button next to its name.**

About the Map MFD
The Map MFD shows where you are above the planet or moon you are orbiting. It also shows useful information like your ground track and base positions (with added info about your target base if you define one for landing) as well as information about your target orbit (if specified). For Earth, the target orbit could be the orbit of the Moon or of a space station or other ship you intend to dock with.

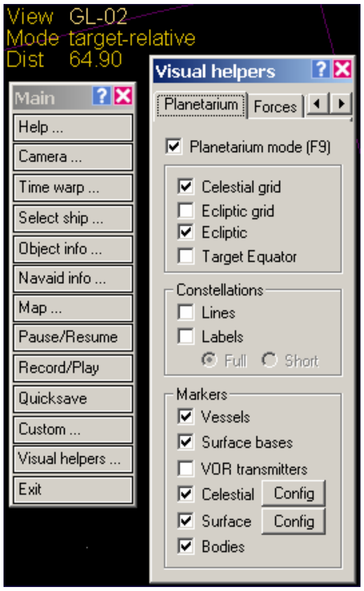
The Map MFD shows the track of your current orbit over a map of the Earth. Where are you now? It looks like you are over Zimbabwe in Southeast Africa. Try out some of the MFD buttons, especially [**ZM**] (below left) and [**TRK**]. You can also use the [**TGT**] button to select another orbiting object as your potential rendezvous "target" and display its orbit as well (your orbit is green, target orbit is yellow, below right). Use the arrow keys and the Enter key on your keyboard to select a target from the list that pops up when you click [**TGT**] (the mouse doesn't work on this list). The [**MNU**] button (next to [**SEL**] button) brings up brief descriptions for the buttons used by the current MFD.



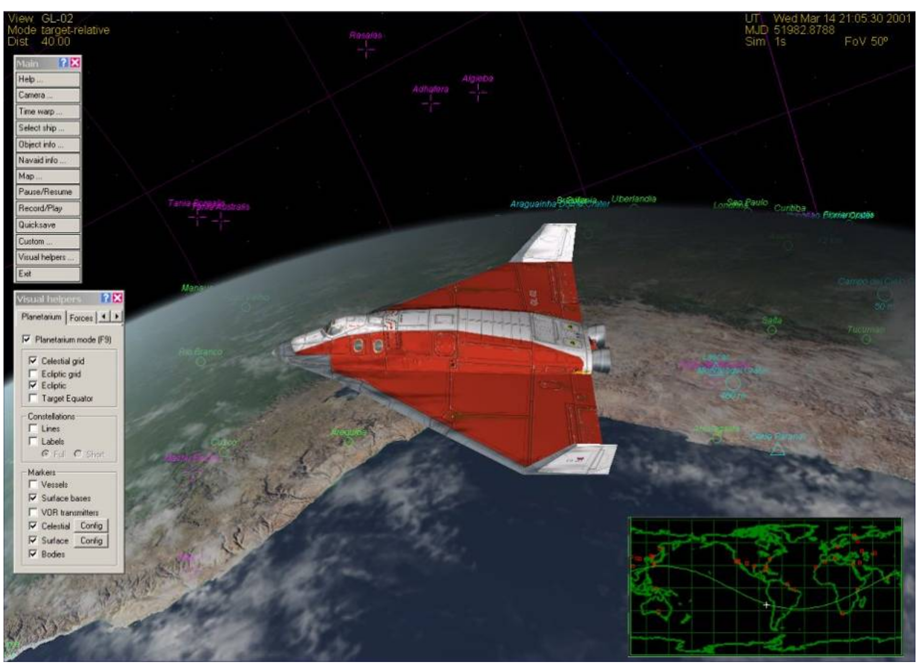
* Earlier versions of Orbiter provided Shift-Letter keys to switch between MFDs, but this is no longer supported in the 2006 version.

Visual Helpers (Planetarium) – If you want to know what you are orbiting over in more detail, or whether that bright dot is a planet, a star, or the International Space Station (ISS), take a look at Visual Helpers. This brings up a panel with check boxes to control the display of all sorts of labels.

- **On the main menu, click on [Visual Helpers...]**
  You can also press CONTROL F9 to bring up this panel. "Forces" allows display of lift, thrust, drag, etc. vectors on external views of spacecraft (labeled with dynamic force values).

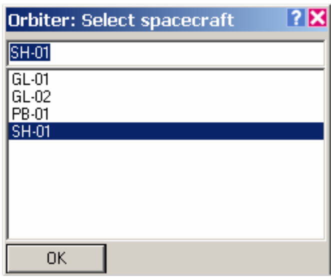


- **Check the boxes for the items you want to see.**
  Once you have selected the labels you want, you can close the panel or move it out of the way (though it's pretty big). You can then turn labels on and off with the F9 key alone. The labeled picture below shows the DG nearing the coast of Peru (map from Map MFD was added by hand in a graphics program).

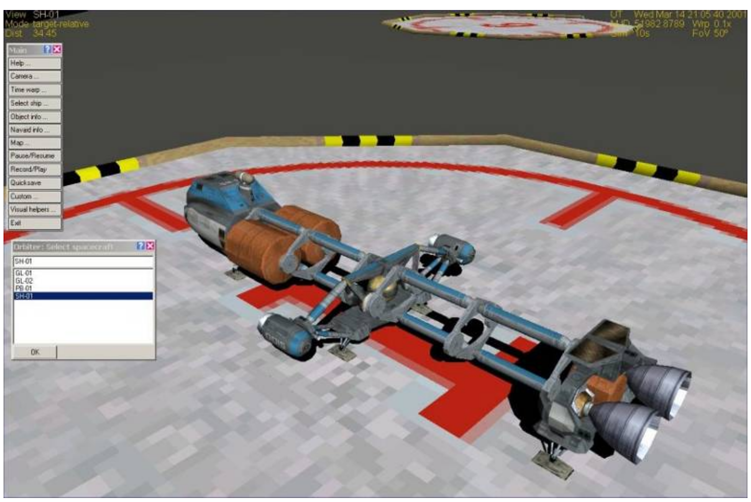


Visit Brighton Beach – This is a preview of some things from the next few chapters. Did you notice some other spacecraft listed in the Select Spacecraft panel? Some scenarios have spacecraft spread all over the Solar System, and you can jump to any of them with the Select Spacecraft (or F3) panel.

➢ **In the Select Spacecraft panel, select SH-01 and click OK.**
SH-01 is a Shuttle-A, a rather bug-like spacecraft made for hauling freight in space (it doesn't do too well in the Earth's atmosphere – it has hover engines but no wings and not much streamlining – it can make it to Earth orbit if it's lightly loaded).



➢ **Use the right mouse button to pan around the SH-01**.
It's parked on a pad at Brighton Beach. Isn't that near New York City? Use your mouse wheel or [page up] key to pull the camera back as far as you like and see where this Brighton Beach actually is. You'll be flying a DG there in the next chapter.



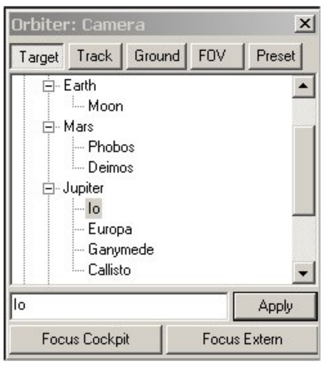
Visit the Planets – If you bring up one more main menu panel, you can take a quick tour of the Solar System courtesy of Orbiter's camera controls. You can also view some spacecraft and space stations, but the available ones will depend on what is defined in the scenario file.

➢ **On the main menu bar ([F4] if it's not open), click on [Camera...]**
This panel has several "pages" but the front page is what you need now. Click the plus sign labeled "Sun" to open the Solar System list, select a planet or spacecraft from the list (click the plus sign in front of a planet name to display a list of its moons if it has any), then click the [**Apply**] button. Your camera (but not your spacecraft) instantly jumps to a view of that planet or spacecraft (listed as Ships). Once displayed, you can use the normal viewing controls – right mouse button (or Alt-Arrows) to pan the view,

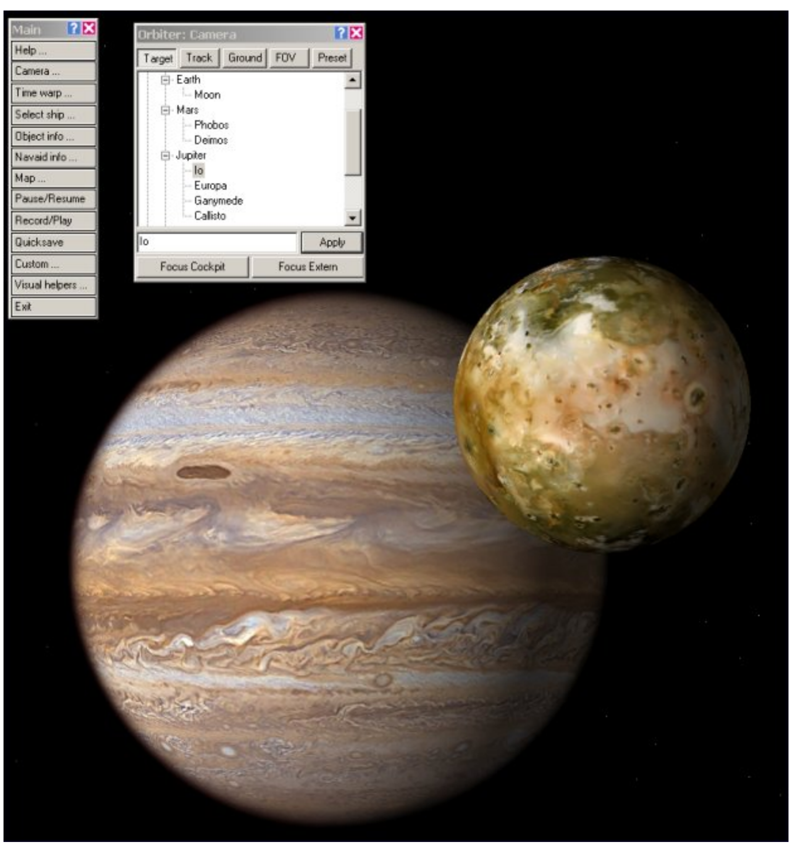
the mouse wheel (or **PageUp** / **PageDown** keys) to change the camera distance. Depending on your previous camera and zoom settings, you may have to adjust something to see a new object that you jump to (you may be too close or too far).

The other pages in the Camera panel are useful too. The [**Track**] button shows you the options for setting your camera position with respect to the target. The [**Ground**] button lets you set ground-based positions on some planets (especially Earth, good for watching launches and sunsets). The [**FOV**] page allows you to change the camera's field of view (FOV) (you can also use the [Z] and [X] keys).

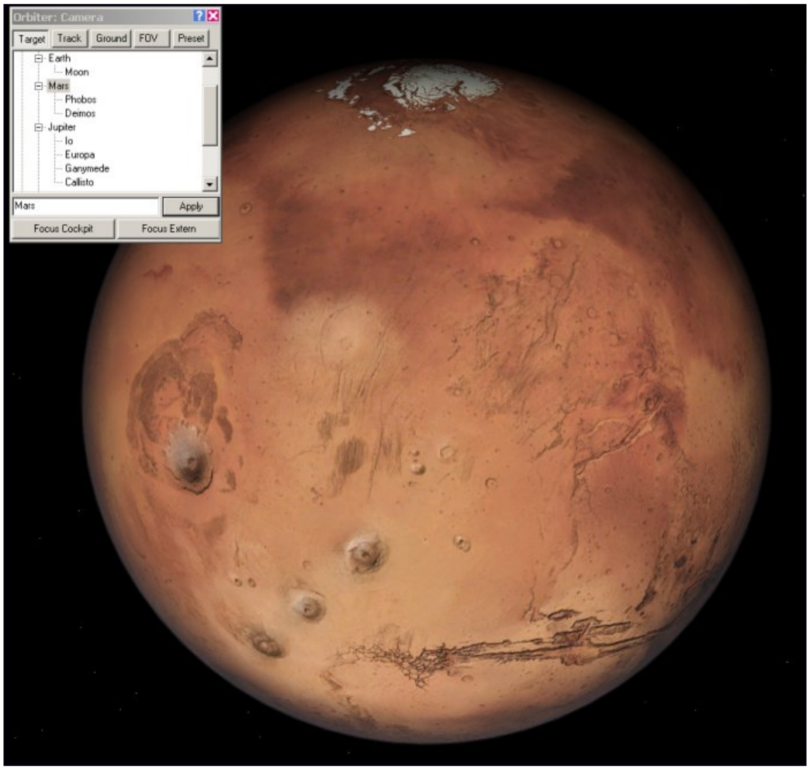
Finally, some scenarios include pre-defined positions that provide useful or interesting points of view – access these (or define your own) through the [**Preset**] page.



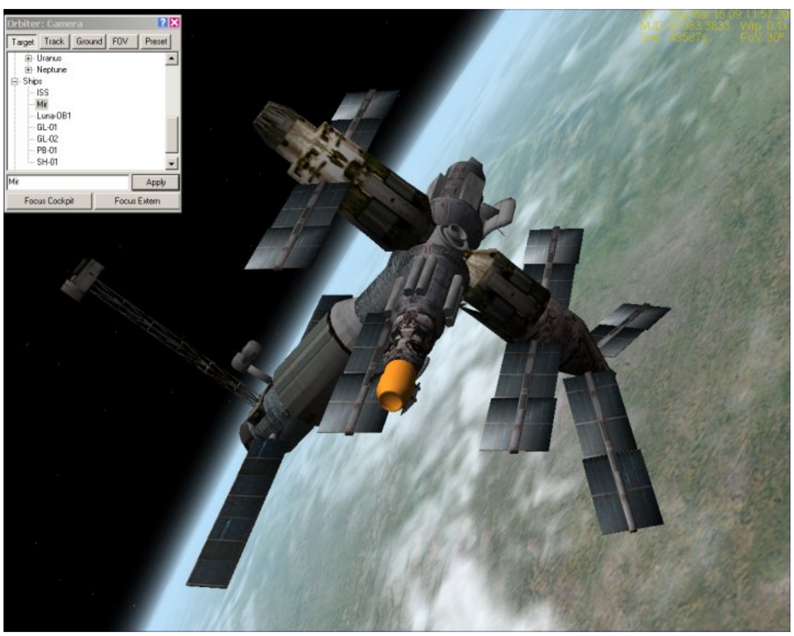
- **Here are a few examples of Orbiter views in the Solar System…**



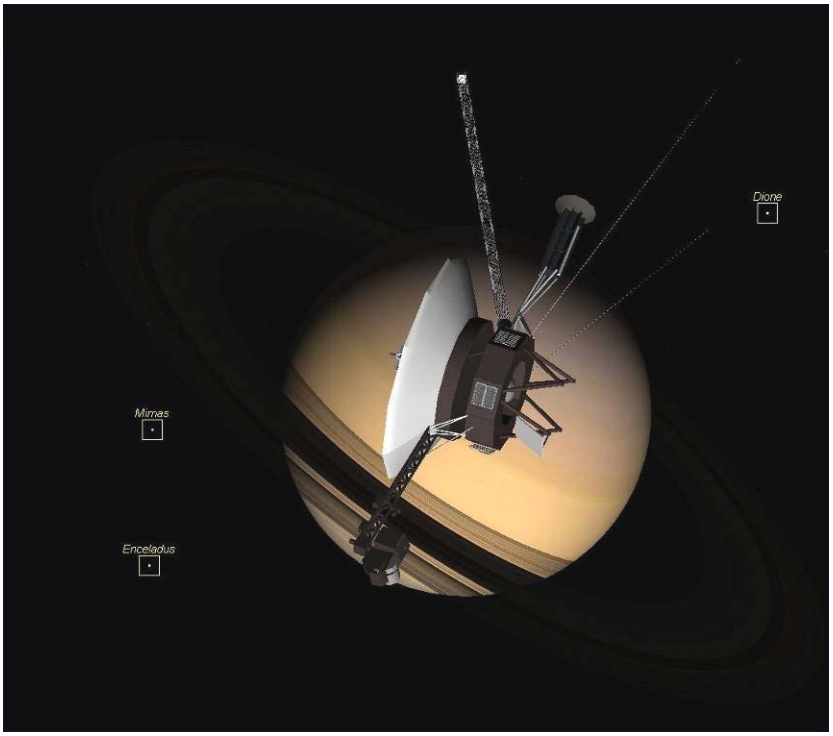
Jupiter and Io – Here is Jupiter's volcanic moon Io with Jupiter in the background (Io is much smaller than Jupiter but is closer to the camera in this view). Orbiter includes the four largest moons of Jupiter that have been known since Galileo observed them with his simple telescope in 1610 (they are called the Galilean moons – Callisto, Europa, Ganymede, and Io). There are add-ons available to define many additional moons of Jupiter and the other outer planets (Saturn, Uranus, Neptune) that have been discovered since, including a large number of small moons discovered by Voyager and other exploration craft. Distant Pluto is not defined in the standard Orbiter installation, though it is also available as an add-on.



Mars - This is a view of Mars with Orbiter's standard hi-resolution textures (level 8 for most of the planet, level 10 around Olympus Mons). A level 10 texture for all of Mars' surface is available as an optional download at some Orbiter download sites, but it is huge (175 MB zip file!) and requires a fast PC and a modern graphics accelerator with a lot of video memory to run with good frame rates.



Mir Lives! This is a view of the Russian Mir space station, which still exists in Orbiter, though in real life, it reentered the atmosphere on March 23, 2001 after a long and successful career and many visitors (http://en.wikipedia.org/wiki/Mir). Mir was built from sections launched between 1986 and 1996 and was occupied for 4,594 days by 28 long duration crews. Many Orbiter scenarios include Mir as well as the International Space Station (ISS), and you can learn to adjust the orbit of your ship to rendezvous and dock with either space station (see chapter 5 for information on docking and other tutorials on the web).



Saturn - This is Voyager 1 visiting Saturn in Orbiter, much as it did for real in November of 1980. Visual Helpers are turned on to show labels for a few of Saturn's many moons (by default, Orbiter defines 8 moons for Saturn, although more are known and can be defined with add-ons). The Voyager spacecraft model is not supplied with Orbiter but is an add-on by John Graves (at www.orbithanger.com, search for "voyager" by missleman01). There are Orbiter add-ons for many historic spacecraft and missions.

Speeding Up the Planets

When you are out with your Orbiter virtual camera touring the Solar System, it's really cool to speed up time and experiment with different views (mainly the [F2] key, but [CONTROL][F1] gives more viewing options). First make sure you have all your spacecraft safely parked on something solid or in stable orbits with no autopilot buttons pressed (to avoid problems like uncontrollable spins and running out of thruster fuel when you're not looking), unless you don't care what happens to them – that's OK, they bounce, and you can always start over with a new scenario.

First look at the Earth from a few thousand kilometers out. Speed up time with [T] to 1,000x or even 10,000x and watch the Earth spin, watch the clouds move around, and watch the Sun set and rise every few seconds (slow down with [R]). Use the right mouse button to spin your view around. Depending on what the target is and what you hold fixed ([F2] cycles between target relative, absolute direction, and global direction), you will see these features change in different ways. Experiment! The orbits of the multiple moons of Jupiter and Saturn are interesting to watch when speeded up (use planetarium mode [CONTROL][F9] to turn on labels for "Bodies"). The effects of rotations and changing Sun angles on the appearance of Saturn's rings can be pretty amazing. It's also cool to put the camera on one of their moons (Io at Jupiter is always nice) and target the view towards or away from something else, like another moon, or Jupiter, or the Sun.

It's your Solar System, make it work for you.

Summary of Steps (for Smack! Rescue)

Here is a summary of the main operations of this chapter (not including the "Space Tourist" section).

1. Start Orbiter and launch the Delta Glider (DG) scenario called "Smack!"

2. The two spacecraft are lined up and closing nose to nose, a few seconds from docking, which is automatic (hands off at this point). Switch between internal and external views as desired ([F1] key) and rotate the view with the right mouse button.

3. Go to the cockpit view ([F1]) – Orbit MFD shows current orbit is not stable (its low point or periapsis is too low and must be raised or you will reenter the atmosphere, click [DST] to view altitude, -214 km).

4. Kill rotation (keypad-[5]), undock ([CONTROL][D]), switch to linear thrusters (keypad-[/]), and thrust backward (keypad-[9]) to a CVEL of around –0.70 m/s or slower.

5. At a distance (DST) of 30-40 m, use forward thrust (keypad-[6]) to zero out CVEL.

6. Open the main menu panel ([F4]), then open [**Time Warp…**] and [**Select Ship**] panels.

7. Click the [**0.1x**] button on the time acceleration panel to slow down time.

8. Click the [**Pro Grade**] button on the right side of the main instrument panel to point the DG along its orbital direction.

9. In the spacecraft selection panel, choose GL-02 and click OK to switch to it.

10. Click the [**Pro Grade**] button in GL-02, then switch back to GL-01.

11. Go to external view ([F1]), restore time to **1x**, and watch the ships rotate to prograde.

12. In the internal view ([F1]), watch the value of ApT (time to apoapsis) in the Orbit (right) MFD, carefully speeding time to **10x** if desired. Go to **1x** time when ApT reaches about 100 seconds.

13. When ApT reaches about 60 seconds, slow time to **0.1x**, and push main engine throttles (right main panel) to the top (full thrust).

14. Switch to GL-02 on spacecraft selection panel, advance its engines to full thrust, and return to GL-01.

15. Carefully watch the value of Ecc on the Orbit MFD as you return time to 1x.

16. When Ecc reaches a value of about 0.01 or smaller, slow time to **0.1x** again, and watch as Ecc continues to drop (very slowly at 1/10th time).

17. When Ecc reaches a minimum value (0.006 or smaller), cut the main engines by dragging the throttles down to the stop point.

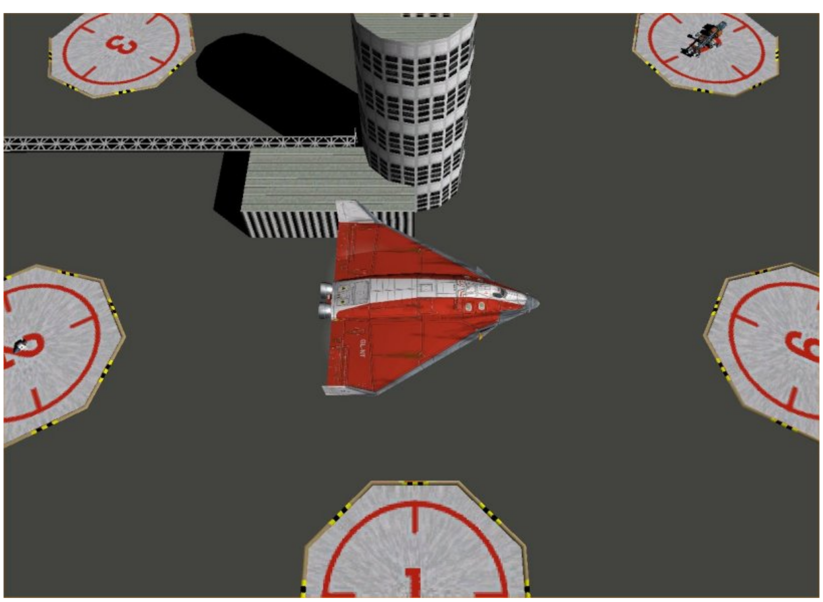
18. Switch to GL-02 and check its Ecc value. If it is still slowly dropping, keep burning (at 0.1x time), cutting engines when it gets small enough (below 0.01).

19. Switch back to GL-01, click time acceleration to 1x, and enjoy your new orbit!

Hovering at the Beach

You won't be flying *to* the Moon just yet, but this exercise will have you flying *on* the Moon to practice hover takeoffs and landings, near-surface maneuvers and navigation, and a few other things. Why the Moon? With no atmospheric drag to slow things down, and with gravity only one-sixth that of Earth, the Moon is a great place to practice hover flight and low-speed maneuvers. It's also very easy to achieve orbit on the Moon, but hover-to-orbit is not on the training schedule just yet (OK, I know you'll do it anyway, but just get through the basic stuff first!).

In this exercise, you will again fly the Delta Glider, using its hover engines, auto-level, and auto-hover features to maintain an altitude of around 20 m. You will then use translation and rotation thrusters to move slowly (no more than 10 m/s) around the base, following instructions on which landing pads to use. You will also make use of radio beacons to help judge distance and direction to the correct pad.



Brighton Beach is Orbiter's default Moon base (add-on developers can and have defined other, more elaborate Moon bases that you can find on line). Brighton Beach is located at 33° West longitude, 41° North latitude, on the southwest edge of a bay-like plane of basaltic lava called *Sinus Iridum* ("Bay of Rainbows"). You can use Orbiter's Visual Helpers (Planetarium) feature to turn on surface labels for features on the Moon and other bodies in the Solar System.

Welcome to Brighton Beach, our first and so far only Moon base! There's not much water, true, but you can still get a tan. OK, it's just an astronaut's tan (a visor shaped area around the eyes). The base is not as small as it looks from up here – in addition to the tower and the six landing pads you see, there are six underground levels. Quite a bit of living space, but not much of a view down below. There is a McDonald's on level U3 South. Yeah, they are everywhere. Tastes the same too.

Preflight & Com

OK, time to get started. You will still be flying the Delta Glider, though its wings and streamlined shape won't help you here. There's no atmosphere on this rock. But the DG is also a great hover machine with powerful thrusters. Today will be basic hover (VTOL for Vertical Takeoff and Landing), thruster, and surface-referenced navigation exercises using the Surface HUD and the Surface MFD. You won't be going very far or very fast – it's thrusters and hover-engines only within 500 meters of the base.

- **Start Orbiter, open the Delta-Glider folder on the Scenario tab of the Launchpad, and launch the scenario "Brighton Beach."**
  The scenario starts with an ground-based view from the tower. Press F2 to switch to a target-relative view and move the camera in close to have a look at the DG sitting on Pad-04. The F2 key will cycle through the common external views; you can use the Camera dialog (from the F4 main menu or CONTROL F1) to get more view options.

- **Press F1 to go to the internal view, then F8 to cycle to the panel view. Use ↑ to raise your seat for a better view if you want.**
  As in the *Smack!* scenario, you will use the MFD and control panel buttons to make it easier to set things up. In this scenario, you will also use the no-panel view for better ground visibility. Although buttons for almost all the common operations (MFDs and autopilot commands such as prograde) are also available on the no-panel view, a few are only on the panel, so use the panel for initial setup. In a real spacecraft or aircraft, you would also have made a thorough external preflight inspection, and used a checklist to make sure every switch and gage in the cockpit is correctly set. But you get to skip that in a PC simulator.

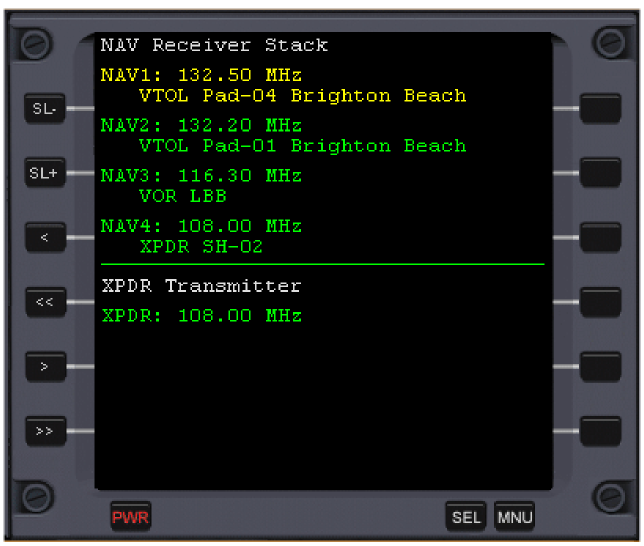
- **Click the left [SEL] button to display the list of MFDs and select [Surface] from the list.**
  It doesn't really matter which MFD you use for what. The scenario starts with the VOR/VTOL (Landing) MFD on the left displaying "No signal." You will open this MFD on the right after you set up the radio beacon frequencies for your pads.

  The Surface MFD displays important information about your orientation (pitch and bank or roll) as well as Ground Speed (GS, m/s – you can actually configure this for other types of speed, see the Orbiter manual), altitude (ALT, **km**), vertical speed (VS, m/s, plus is moving up, minus is moving down), acceleration (ACC, m/s^2, current "G-force" where 1G is about 10 m/s^2). There is also some atmosphere information that's not applicable here (marked N/A). EQU POS and RATE can be useful – they show your current ground position (latitude and longitude) and how it is changing. AOA is angle of attack (only needed in air). VACC is vertical acceleration in m/s^2. It reads zero on the ground, but in flight it will tell you how much you are accelerating up (+) or down (-), and in lunar free fall, it will read -1.62 m/s^2, the Moon's gravitational acceleration.

About the Surface MFD

The Surface MFD is modeled on the "glass cockpit" computer displays used in modern commercial aircraft (and which are actually called MFDs). The center instrument is an attitude indicator (blue for sky, brown for ground, horizon between), and this is surrounded by various numerical flight data in "data tape" format which gives a visual impression of how each value is changing instead of just showing the current value. When flying in the Earth's atmosphere, airspeed (IAS or TAS) would usually be displayed instead of ground speed.

➢ **On the right MFD, click [SEL] then [COM/NAV] so you can tune the radio beacons for the landing pads.**
Use the [**<<**] and [**>>**] buttons to tune the NAV1 frequency (top one, highlighted yellow) to 132-something, then use the [**<**] and [**>**] buttons to tune the fractional part to get **132.50** kHz (kilohertz). The text should say "VTOL Pad-04 Brighton Beach." Next use the [**SL+**] button to highlight NAV2 and similarly tune it to **132.20** kHz, the frequency for Pad-01 (needed later). Finally click [SL+] again and tune NAV3 to **116.3** kHz which is the long-range VOR beacon for Brighton Beach (LBB), just in case.



About the COM/NAV MFD

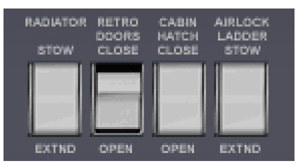
Aircraft usually have a "stack" of several radio transceivers for voice communication (COM) and for radio navigation (NAV). Orbiter doesn't really have voice coms, so its four radios are all used to tune in radio beacons that help you find bases, pads, runways, docking ports, etc. according to their assigned frequencies (channels). You tune the frequencies here, and they are used by other MFDs like the VOR/VTOL and Docking MFDs. XPDR means transponder, a radio beacon that is sent out by your own ship for tracking purposes.

➢ **On the right MFD, click [SEL] then [VOR/VTOL] – it should now indicate that it is receiving the signal from Pad-04 (if not, click [NAV] until it does).**
Since you are sitting on Pad-04, the MFD should show distance (DIST) 0.0, horizontal (ground) speed (HSPD) 0.0, vertical speed (VSPD) 0.0, and altitude (ALT) 2.57 m (the pad is slightly raised above the average lunar surface level). The set of circles indicates distance from the pad center, the inner circle indicating the pad size, with green to indicate you are within the pad radius. The green cross shows the position of the center of the pad, and the yellow arrow shows the direction of your ground speed.

About the VOR/VTOL MFD
Sometimes called simply the "landing MFD," this instrument is quite similar to the Docking MFD shown in Chapter 2. It conveniently collects and displays the most critical information you need when you are close to the ground and trying to land precisely on a pad. Some (real) military helicopters have a similar display since they have similar problems with the need to be precise in hovering over and landing on a small target, often with poor direct downward visibility.

(If your MFD doesn't show NAV1 and Pad-04, click the [**NAV**] button until it does.)

The vertical bars graphically show ALT and VSPD. For VSPD, green indicates increasing altitude (i.e., rising), yellow indicates a safely decreasing altitude (descent, i.e., falling), and red indicates an **unsafe** rate of descent (i.e., slow down or crash). This instrument can help you take off and land safely even when you can't see the pad.

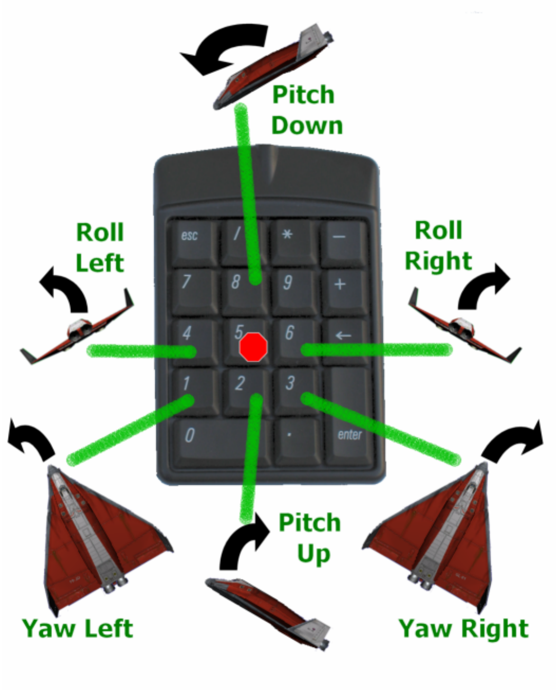


- **Open the Retro Doors by clicking the lower half of the white RETRO DOORS button on the lower right side of the panel.**
  This allows the forward-aimed retro engines (mounted in the leading edges of the wings) to be used if needed. You should not use main OR retro engines for this exercise, but if you get yourself going a bit too fast with the translation thrusters, you might need a quick burst of forward (main) or reverse (retro) thrust to slow down quicker. You can also open retro doors with a dialog box (Control-Spacebar).

Thruster Briefing

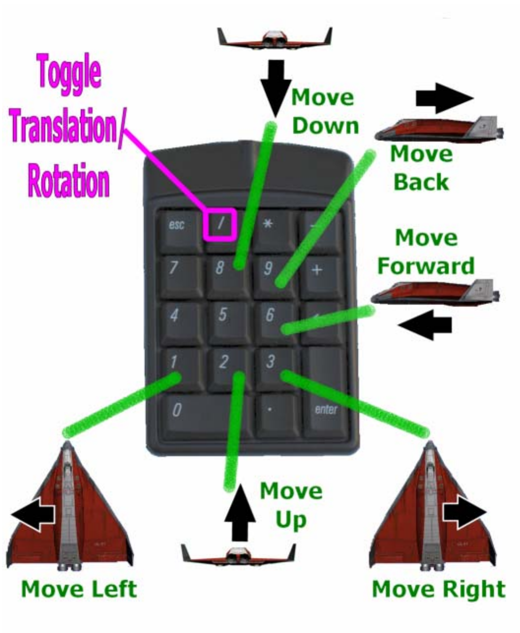
OK, time for the thruster briefing. You probably heard it all before, but pay attention anyway. You can't imagine the number of student pilots who say "but I *thought* it *was* in linear mode" when explaining why they missed the pad by 300 meters.

Thrusters in Orbiter are controlled by the numeric keypad (you can use a joystick, but the keypad is generally more precise and useful, except for atmospheric flight on Earth). There are two modes, rotation and translation, and the mode is controlled with the keypad [/] key. You used translation mode a bit in *Smack!* (remember the [6] and [9] keys for forward and back?). Start with rotation mode, checking out the diagram below. Note that rotation occurs around the spacecraft's center of gravity (CG), which you can think of as its balance point.



ROTATION MODE KEYPAD
Pitch: [2] is nose **up**, [8] is nose **down**
Yaw: [1] is nose left, [3] is nose right
Roll or bank: [4] is roll left, [6] is roll right
Kill (**stop**) rotation: press the [5] key

USEFUL TIP: For smaller corrections, hold down the [CONTROL] key while pressing thruster keys (in rotation or linear mode). This reduces thrust to 1/10th of its normal value when finer control is needed.



TRANSLATION (or LINEAR) MODE

Remember: Press the keypad [/] key to toggle (switch) modes back and forth between rotation and translation.

TRANSLATION (or LINEAR) MODE KEYPAD
Move vertically: [2] is UP, [8] is DOWN
Move laterally: [1] is LEFT, [3] is RIGHT
Front/back move: [6] is FORWARD, [9] is BACKWARD

Note that there is no standard "kill translation" autopilot as there is for "kill rotation" (there is an add-on MFD that does this and some other cool functions, the Attitude MFD).

Now remember, you still have gravity here (1/6th of Earth, light, but you still know which way is down), but there's no air. And no air means no air friction (drag). Once you are hovering or flying, when you apply thrusters, you are applying forces which will move parts of the spacecraft in certain directions. When thruster pairs fire in the same direction, the whole spacecraft moves in the opposite direction (so to shift or translate RIGHT, the thrusters on the LEFT side will fire). When thrusters are fired in "crossed" pairs (say left in front, right in back), the front of the ship moves RIGHT, the back of the ship moves LEFT, and as long as it doesn't bend (it won't), you rotate or YAW to the right.

No friction – And what about that "no friction" thing? Of course that means that once you start moving or rotating in some direction, you will keep moving or rotating that way at a constant speed, unless you add or subtract another force. When flying on Earth or with a ground-rolling vehicle, air or ground friction provides the force that slows you down – you have to keep applying thrust or other power to keep going. For vertical motion near a planet or moon, gravity provides a force that pulls you down, and you need to apply vertical thrust to compensate (for hover) or exceed (for takeoff or launch) that gravitational force.

Today you will be using the automatic hover [A] and automatic level [L] settings which will keep you "floating" at a constant altitude and level with the ground, with the upward force from the hover engines' thrust exactly compensating for the downward force or "pull" of gravity. Then you will use your left, right, front, and rear thrusters to move your DG around in a simple pattern around Brighton Beach.

So once you are in hover, you will use thrusters (NOT main engines) to start moving, but how will you stop moving? Hit the brakes? NO, you know better than that – brakes work by friction, and you only have wheel brakes anyway. The only way to stop the motion from a force you apply with a thruster is to apply an equal force in the opposite direction. You saw that in the Smack! scenario with the forward [6] and rear [9] thrusters in translation mode. Same thing here, except you will need to combine rotations and translations to get around the simple course.

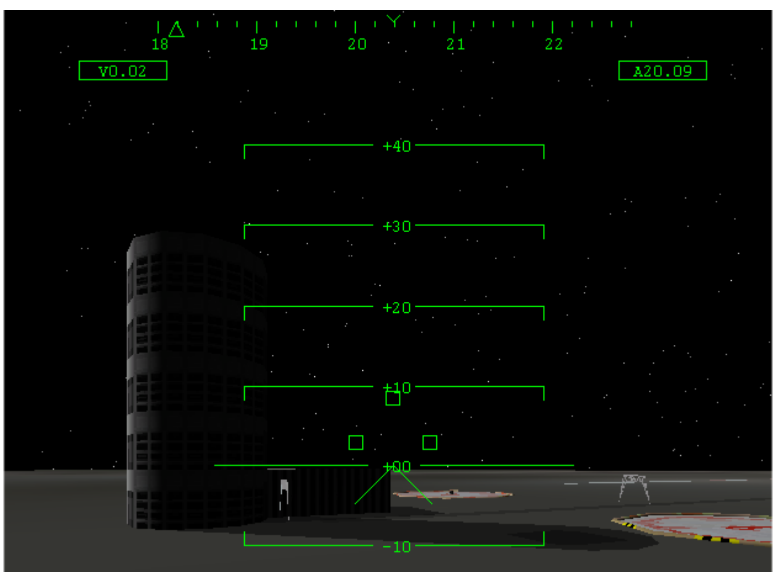
Lost in Translation – Stopping any rotation is pretty simple – just use the Kill Rotation button ([5] **num**), but stopping translation is a different matter. The trick is to keep it slow at first, to try as much as possible to only apply thrust in one direction at a time, and to not rotate until you have canceled out that translation. Why? Because when you rotate, your thrusters will point in new directions, and it's hard to apply canceling thrust that is exactly opposite your original thrust. With practice, you will develop a better feel for the combined motions, although it's always better to think in "components" – left/right, up/down, forward/back, and to try to solve one problem at a time. If you just try random thruster directions, you may end up moving fast in some unexpected direction – lost in translation, so to speak (you *can* try a burst in the direction you think you need and see how the velocity changes – if it was the wrong way, press the key for the opposite direction to "take out" this test input). You will quickly learn that the direction you are pointing and the direction you are moving are completely independent.

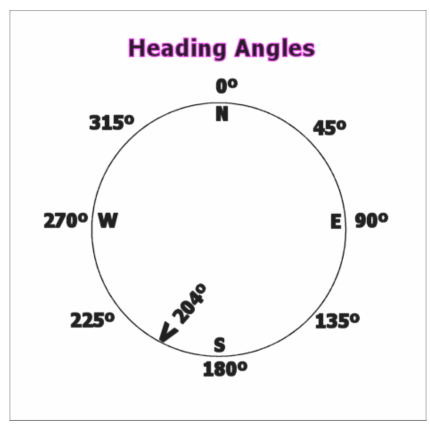
When you are near a pad and receiving its radio beacon signal, the VOR/VTOL MFD helps you a lot by showing you the distance and direction to the pad center, as well as the direction and value of your horizontal speed. You can use this to figure out how to cancel out that speed when you need to.

HUD Stuff

HUD stands for Head Up Display, which is an optical projector system that displays computer generated symbols and even images on a special transparent panel in front of the pilot. This system has been used in military fighters and other aircraft for many years because it allows the pilot to keep his or her "head up" and looking for other aircraft while still seeing important information about speed, altitude, targets, etc. There are also helmet-mounted displays (HMD) that allow the pilot to see the information while looking in any direction (in panel view, the Orbiter HUD is a little like an HMD because you can see HUD symbols over the panel – virtual cockpit mode shows the HUD most accurately). In Orbiter, the HUD has three modes which are switched with the [H] key or with panel buttons in some spacecraft (and special transfer-to-HUD buttons on the Surface, Orbit, and Docking MFDs).

The three modes are Surface, Orbit, and Dock. You've seen a little of the Dock mode in the Smack! scenario. This chapter mostly uses the Surface mode. When you display the panel, the surface HUD is displayed in its most basic form. In no-panel view, more information is displayed in the upper left corner to make up for the lack of panel (fuel, thrust level, RCS mode, etc.).



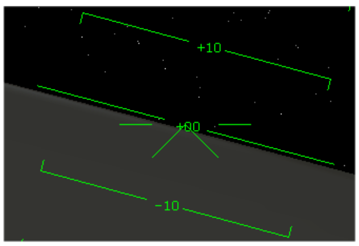


The basic information you need now is

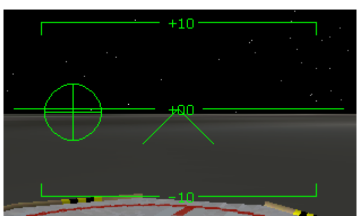
Heading ribbon – This is at the very top of the HUD and shows the direction your ship's nose is pointing (not necessarily the direction you are *moving*). It's basically a compass with north = 0º (or equivalently 360º since it "wraps around"), east =90º, south=180º, and west=270º. To save room, the final zero is dropped, so the heading ribbon shows these directions as 00, 09, 18, and 27, and of course intermediate directions are there too (e.g., southeast would be 135º, halfway between 13 and 14 on the ribbon). Small tick marks are in 2º steps. In the picture above, the heading caret (small v at top) is pointing at 204º, 24º west of south. If there is a target base defined, a small triangle (Δ base direction indicator) shows its direction (in this case, it's the center of Brighton Beach, and the triangle is right above the tower building at 182º).

Velocity (speed) and Altitude boxes – The boxed number with a **V** in front **V0.02** is your ground speed, regardless of direction (i.e., could be moving forward, sideways, backwards, etc.), and the **A** box **A20.09** shows altitude in meters above the average surface level (note: Surface MFD altitude is in km).

Pitch ladder – The set of parallel lines in the center is called the pitch ladder, though it also shows your roll (or bank). The spacecraft itself is shown as a fixed "airplane" symbol, an inverted V with two short horizontal lines like wings. The lines are numbered in steps of 10º from 0º (which is level pitch – note that you are level in the picture above with the zero line along the Moon's horizon). Positive values are nose-up pitch, with +90ºbeing straight up. Negative values are nose down. Roll or bank is shown by left and right tilting of the lines. If you roll left, the ladder lines tilt (like the horizon outside) to the RIGHT. Think of the little airplane symbol as your spacecraft and the pitch ladder zero line as the horizon and you'll get the picture. Here's what a roll of about 20º to the left looks like (pitch is still level at 0º):



Yaw is not directly shown but you can see it if you have forward motion so that the "velocity vector" (VV, the ⊕ symbol, sometimes called the flight path indicator) is visible right in front (note that you will only see this if your speed is at least 1 m/s and in the forward direction). If you then yaw RIGHT, the ⊕ will move LEFT of the airplane reference symbol as shown below.



The Velocity Vector is very useful because it shows exactly the point in space that you are moving toward. Keep the ⊕ on a particular point on the ground, and you will go there (but it's up to you whether you arrive there under control!). Note: the VV is defined a bit differently in the Docking HUD mode.

Three More Things: The triangle of three green boxes in the center of the HUD tells you that the landing gear are down. When you retract the gear with the handle on the lower panel (or press [G]), the boxes will flash while the gear are in motion. When they are safely stowed, the boxes disappear. No air drag on the Moon, so no real need to retract, but if you DO retract the landing gear, remember to extend them again to land! This is also done with [G].

Takeoff, Hover, Move, Land

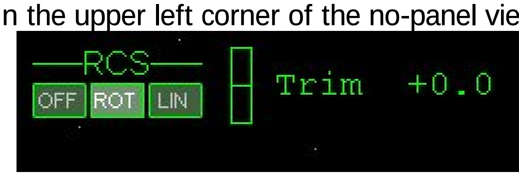
The first step is to go into a low hover. You can use the mouse with the hover engine throttle on the left side of the panel, but since you will need to go to the "no panel" view for better visibility, you probably should just get used to the keypad for this. The no-panel view also has an "expanded HUD" which directly displays the acceleration level each engine (main or hover) is supplying, which is quite useful (acceleration is in meters per second per second, or m/s^2, and is the thrust of the engine divided by the current mass of the vehicle – the mass goes down as you use up fuel, so the acceleration value is really more useful than thrust in this case).

- **Go to no-panel view (F8).**

- **Start hover engines by tapping the keypad-0 key several times until the acceleration value on the HUD reads 1.7 (use keypad-. to decrease thrust), and also press the L key to engage auto-leveling.**
  You can also press the HOR LVL button. The Moon's gravitational constant is 1.622 m/s^2, about 1/6th that of Earth (9.8 m/s^2), so you need to apply hover engine acceleration that exceeds this value. The keypad only allows you to control hover acceleration in steps of 0.1 (i.e., 1.6 or 1.7, nothing in between), so if you are not using auto-hover, you typically have to alternate between the keypad-0 and keypad-. keys to maintain altitude or rise/fall at a controlled rate. Auto-level helps to keep the hover thrust precisely vertical so you don't drift off the pad (if you rotate the spacecraft, you can get a small component of sideways thrust from the hover engines). *Keep thrust low so you rise slowly, trying not to overshoot.*

- **When your altitude reaches about 20 m, press the A key to engage auto-hover.**
  You can also press the HOLD ALT button. Altitude (in meters with the usual letter tags, k for kilo, etc.) is in a box labeled **A** at the top center-right of the HUD display. Auto-hover will try to hold you at the altitude displayed when you hit the A key. If you are rising fast, it will cut the engines and let you (eventually) free-fall back to the target altitude. If you are falling fast, it may apply full hover thrust to overcome the downward acceleration (there isn't always enough power to do this in time!). But once it reaches the target altitude and achieves near-zero vertical speed (VS on the Surface MFD), it will automatically adjust hover thrust over a small range to maintain altitude.

- **Make sure you are in ROTATION mode, and start a slow yaw rotation to the LEFT.**
  In the upper left corner of the no-panel view are buttons for RCS (reaction control system):



  You can click these buttons or toggle linear/rotation with the keypad-/ key and (with Orbiter Sound installed) you will hear the confirming voice say "rotation" (ROT) or "translation" (LIN for "linear motion") – it's important to be sure of your RCS mode before pressing any thruster keys. Yaw left is the keypad-1 key in rotation mode.

- **Stop your rotation when you reach a heading of 90 degrees.**
  Yes, I know left is the long way around from a 70º to a 90º heading (this is your clearing turn before leaving the pad). You can use opposite thruster to stop, or use the Kill Rotation (keypad-5) key.

- **Switch to LINEAR mode (keypad-/), and move about 50 meters to the LEFT, keeping your speed under 5 m/s.**
  Use the keypad-1 key to start this, watching the DIST value on the VTOL MFD for a value of 50, then use opposite thrust (the keypad-3 key) to zero out your horizontal velocity. Note how the length and direction of the arrow on the MFD change as you move away from the pad.

- **Use ROTATION to point your nose back at Pad-04, then use LINEAR as needed to move and get centered (DIST = 0.0) and stopped over the pad.**
  As you get close, you will lose sight of the pad under the nose and will need to rely upon the VOR/VTOL MFD to determine when you are centered over the pad.

- **Once over the pad, press [A] to turn off auto-hover, and apply hover thrust keypad-[0] and keypad-[.] to slowly drop back onto the pad.**
  Keep an eye on the VS (vertical speed) in the Surface MFD to keep a small negative (downward) speed as you descend to the pad (below –1.0 m/s). You should also use the VOR/VTOL MFD vertical speed bar – the VSPD value should be small and the bar yellow (not red) for a safe descent speed. Be sure auto-level is still active and only use front/back (6/9) and left/right (1/3) translation (plus hover engines). Congratulations, you landed!

Moving to a New Pad

Follow the diagram below to fly a low-hover pattern from Pad-04 to Pad-01. Note that you should not go directly to it, you need to go around the base area. Here are the basic steps, quite similar to the steps above, but you need to pay attention to your heading and distance from Pad-01, and stop at each waypoint (WP1, WP2, WP3 in the diagram below).

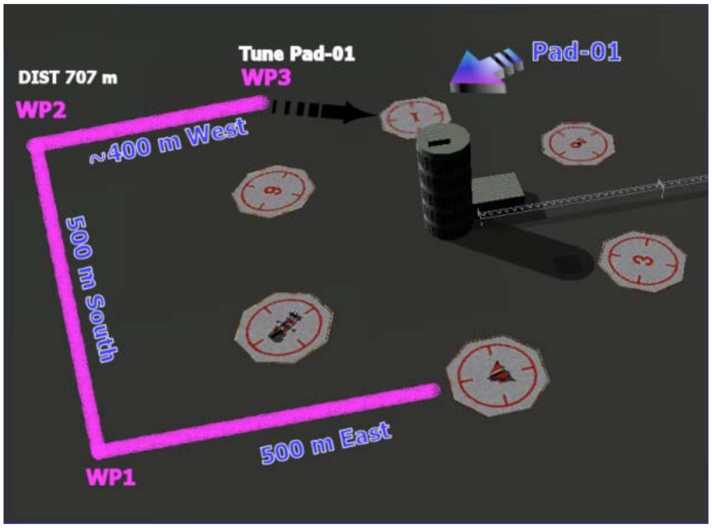
- **Go back to the panel view (cycle [F8]) and check that the frequency for the Pad-04 radio beacon is still selected**.
  If it's not, click [NAV] on the VTOL MFD to re-select the frequency (should be NAV1).

- **Lift off with hover thrust as before, use auto-level ([L]) and auto-hover ([A]) to hold 20 m altitude.**

- **Use the VOR/VTOL MFD for guidance with rotation and linear thrusters as needed to follow the course as shown in the diagram.**

  Start with rotation mode and turn to your initial heading of 90°, then use Translation to thrust forward **at less than 10 m/s** (remember to start reverse thrusters early enough to slow down and stop without overshooting the waypoint). Stay within the defined course and distances to avoid losing the pad radio signal. WP3 is actually "abeam" Pad-06 (i.e., stop when Pad-06 is directly to your right).

  TIP: You can "turn your head" in the cockpit with the mouse by holding down the right mouse button. Return to the front view with the [home] (home) key. This is more realistic looking in the virtual cockpit view but works in the other cockpit views too.



- **When you reach WP3 on the diagram, hover and hold position while you switch the landing MFD com to the Pad-01 frequency.**
  Use the [**NAV**] button or Right [SHIFT][N] to cycle through the four nav frequencies.

- **Use the front view and Pad-01 signal to go directly to the new pad and land.**
  Use the arrow's length and direction and DIST value on the MFD to get as close as possible to the center of the pad before landing (pad is big, but DIST 0.0 is the goal).

Once Around the Block (First Orbit)

So now you've got the feel of the hover thing, and you want to orbit. OK, one quick trip around the Moon, then back to Pad-01. Since you pretty much know what to look for now, I'll outline the procedures in a bit less detail than before. We call this the elevator takeoff and it's really kinda fun.

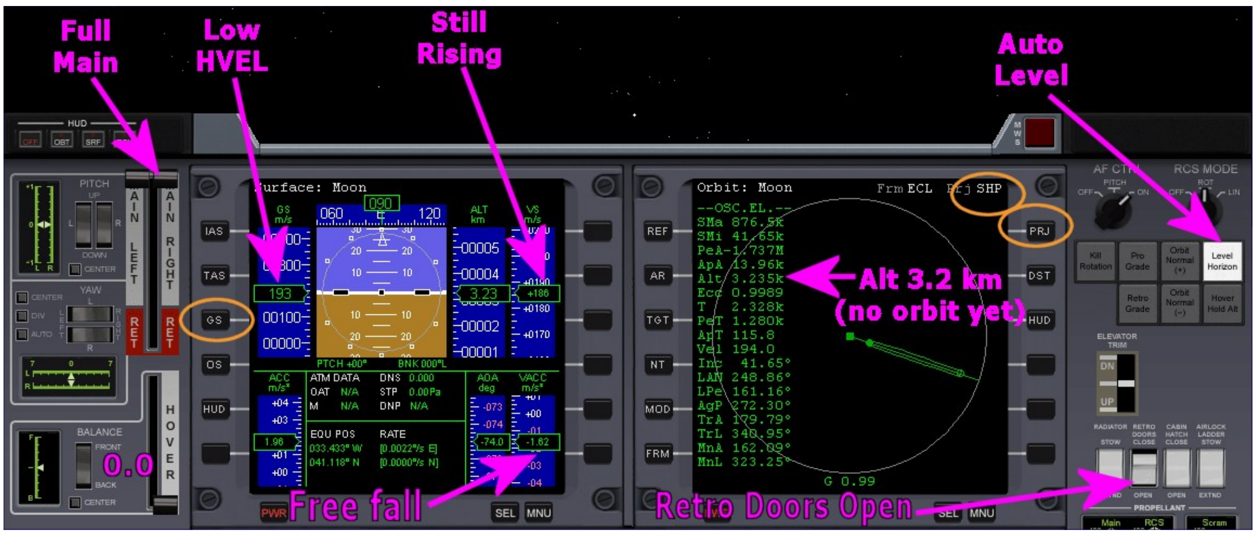
- **Start out the same as before, go into a hover at about 20 m and make a clearing turn the long way around to 90° degrees heading (make sure auto-level [L] is engaged so you don't drift away from the pad).**
  A 90° launch azimuth (heading) gives you the most velocity from the Moon's rotation (not much actually, the Moon rotates pretty slowly, once every 27 days) and also gives you the minimum orbital inclination (tilt of your orbit with respect to the equator), which for 90° launch azimuth is equal to the latitude of your launch point (41.1° in this case). This is important because that inclination will bring you right back over the base on your first orbit, when you better plan to land. ***Aim for exactly 90° heading.***

- **Switch to the Orbit MFD on the right, then click [PRJ] button (projection) to display SHP and also click the [DST] button to display altitude.**
  You can also restore the panel view ([F8]) if you like, though all the important buttons are also available on the no-panel view. "Projection ship" (SHP) displays the orbit information relative to your own ship's orbital plane. DST will display altitude (Alt, PeA, ApA) above the surface rather than radius from the Moon's center (Rad, PeR, ApR).

- **After final pre-orbit checks, apply full hover thrust ([A] to kill the hover hold then keypad [0] to maximum) and watch your altitude in the HUD.**
  Just make sure auto-level is still on and that your heading is exactly 90°.

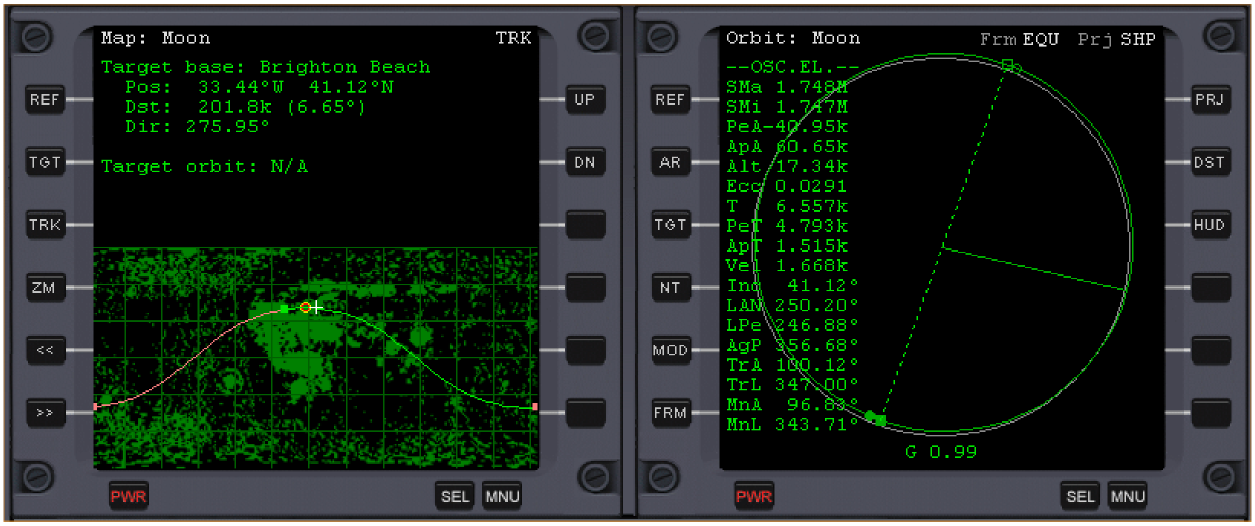
- **When ALT reaches 2000 m, hit the R key to slow time to 0.1x and get ready to use the mouse to quickly increase your main engine throttles to maximum and drag your hover throttle to zero thrust as soon as you reach 2200 m.** Why? You want to quickly turn on maximum horizontal thrust (to build orbit speed quickly) and simultaneously cut the hover thrust to zero. Unlike with the main engines which have the special "cut engines" keypad-* (*) key, there is no single key to cut the hover thrust. It's not essential to switch engines simultaneously, but it makes it a little easier to get a good orbit without a very high apoapsis. Slow-motion is optional though – if you've got video game mouse skills, there's no need to use 0.1x.

- **Then press T to return to normal (1x) time.** The picture below is just after hover engine cutoff (but still rising) and full main thrust has been applied, with horizontal velocity (GS on Surface MFD) still low.



Still rising? Yes, even after cutting the hover thrust, you will continue to rise – just like throwing a ball in the air, it rises until gravity (and air friction on Earth) overcomes the "thrust" you gave the ball with your arm. Notice in the Surface MFD that after hover engine cutoff (HECO), the vertical acceleration (VACC) will show -1.62 m/s^2 (free fall on Moon), while vertical speed (VS) will drop to zero and then become negative (falling). Your spacecraft will reach a maximum height then start to fall – but in the meantime, your main engines are building up the horizontal speed needed to achieve orbit – which means you will continue to fall, but you will also go forward fast enough to "stay ahead" of the Moon's downward-curving surface as you are pulled towards its center by gravity, so you "fall around" the Moon, which is what an orbit is, just a very long fall (see Chapter 9, "I Was Just Wondering…" for more on this).

- **When your eccentricity (Ecc on the Orbit MFD) reaches about 0.03, press the R key to again slow down time to 0.1x.** Slow motion is again optional but will allow you to better see when the Ecc value reaches its smallest value and starts to rise again. **When it does, MECO!** This stands for "main engine cutoff" and you can do it by quickly pulling the main engine throttles down to zero power with the mouse (if you have the panel up), or by pressing the keypad * key.



Is your orbit good enough? Probably not. Your apoapsis should be OK (ApA 40-100 km depending on when you did MECO). But periapsis altitude is probably still negative (note the red below-surface path on the Map MFD above, and the negative PeA on the Orbit MFD). Even if this occurs near Brighton Beach where you need to land, you will want to start with positive PeA, 20-30 km to avoid terrain (though planet and moon surfaces in Orbiter are actually smooth). Do you remember what to do from Chapter 2?

- **That's right, a few seconds before apoapsis (watch ApT for the number of seconds to go), make a prograde burn to raise the periapsis.**
  If you are in no-panel, use the PRO GRD button or the [key (left square bracket) to start the prograde autopilot. It doesn't matter if this orbit is not quite circular since you plan to de-orbit (i.e., slow down and land) after the first orbit anyway. Burn until you raise PeA to 25-30 km (probably just a few short bursts of the main engine, the keypad + key). **Vel** will probably be about 1600-1700 m/s, varying slightly since the orbit won't be quite circular.

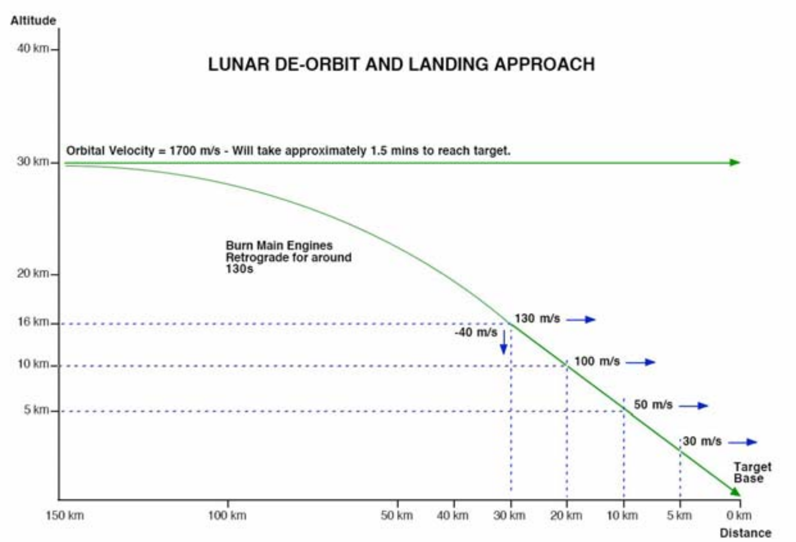
Your first lunar orbit will go fast (especially if you use time acceleration). The view is not actually that great when you're moving fast down low, but you'll be busy preparing for your de-orbit burn anyway.

Orbit Mode HUD

This would be a good time to try out the orbit mode of the HUD. Press H until you see Orbit: Moon in the upper left corner (you can also click the [HUD] button on the Orbit MFD to transfer its settings to the HUD). In orbit mode, the "pitch ladder" is referenced to your orbital plane instead of the planet surface. This allows you to manually position for pro grade, retro grade, and other special attitudes (though you can still use the auto-pilot buttons). When you are prograde, the velocity vector symbol (circle with plus sign in it) is directly in front of you (there is also a retrograde HUD symbol, a big plus sign). Note that the Orbit HUD does not display altitude or velocity as does the Surface HUD. If you need this information while viewing the Orbit HUD, display the Surface MFD which lets you choose to display ground speed (GS), orbital speed (OS), and a couple of atmospheric (airspeed) options that don't apply on the airless Moon.

Bringing It All Back Home (De-orbit)

Time to think about the de-orbit procedure. De-orbit (or reentry) is basically simple – burn in the retro direction to slow down, then fly back to the pad. The trick is knowing when to slow down and by how much! On Earth, you've got a nice thick atmosphere to slow you down and provide lift when you get down low enough (this is why the Space Shuttle can slow down and glide to a landing with no power after the initial retro reentry burn). But reentry on Earth is also tricky, because friction with the air heats up the spacecraft, and this has to be controlled with precise flying. On the Moon, there's no atmosphere to help *or* hurt you, but the DG has powerful hover engines that can control the rate of descent, as well as the main engines which are used (retro) to kill most of your orbital speed. In this case, you will start the full-power de-orbit burn when you reach 150 km distance from Brighton Beach. This works well in this case, and the diagram below summarizes the approach. See the next chapter for a simple physics-based (formula) method to figure out when to start slowing down.



You can think of three phases for the de-orbit procedure:

- **Phase One:** Prepare MFDs, determine what things to watch, turn retrograde for the burn.
- **Phase Two:** Burn to a slow enough approach speed, turn prograde and level, slow your descent.
- **Phase Three:** "Get down" to the pad by managing your direction, speed, and descent rate.

Don't Panic!

There are a lot of steps and explanations here, and it may take you a few tries to get it all working. This is the most "interactive" task so far, many things will depend on other things, so we can't give you exact numbers or steps, and it may seem like things happen fast. Start out by doing a Quick Save (CONTROL S) at an early point (say after you burn main engines to slow down), then you can easily quit from Orbiter and return to that point for another try. Feel free to slow down time or to use pause to give yourself time to figure something out. And there will be a summary of steps at the end of the chapter that may be easier to follow once you know the main ideas.

- **Phase One, Prepare: First configure your MFDs.**
  You will need to change these a couple of times as things happen. Start out with the **Map MFD** (use [SEL] button and click [Map]) and the **Orbit MFD** ([SEL] and [Orbit]). You need to set your target base on the Map MFD. Click the [**TGT**] button, then use arrow keys to choose **Spaceports** and **Brighton Beach**.

- **Turn off any autopilots (prograde or auto-level) and use [T] to bump time acceleration up to 10x or 100x (remember [R] to slow down time).**
  The period of your orbit will be over 6000 seconds (100 minutes), so speed up time a bit until the distance (Dst) to Brighton Beach is about 300 km or so on the Map MFD. Your orbit path on the Map should go right through the base circle for Brighton Beach (if it doesn't, you didn't have a 90° heading when you fired main engines to enter orbit). If it's only off a little, you may still be able to make it back (or change orbital planes to line it up, see next chapter). Otherwise, start over with the takeoff and aim for exactly 90°.

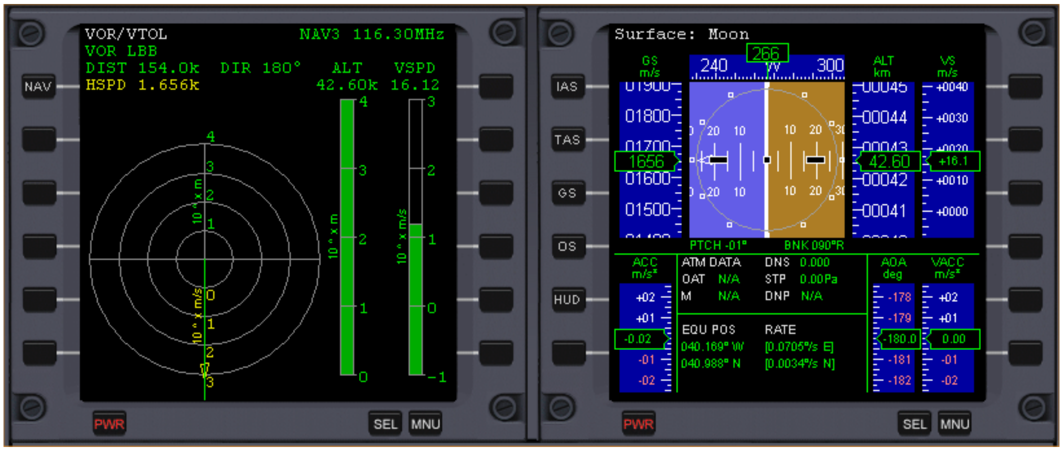
> **TIP:** You may still want to have the main menu panel ([F4]) open in your upper left screen as you did in Chapter 2. Feel free to use the menu Pause button or key ([CONTROL] [P]) or slow to 0.1x time any time you need to check that things are OK. Slow speed is a little better because you can still use MFDs and other controls. In Pause you can only change views.

- **Slow to real time (1x) when you get about 300 km or so from the base.**
  Note that this is given by the Dst: figure on the Map MFD.

- **Immediately click the Retro Grade [RETRO GRD] button (or press []] right square bracket) in preparation for the de-orbit burn.**
  Turning retrograde means aiming your engines in the direction you are moving so they will slow you down when you fire them (flying tail-first). At 1700 m/s, it only takes about one minute to go 100 km (100,000 m ÷ 1700 m/s = 59 s), so start to turn retro right away.

- **Switch the Map MFD to the VOR/VTOL MFD and select NAV3.**
  Click [SEL] then [VOR/VTOL] and [NAV] to get to NAV3. NAV3 is the VOR beacon for Brighton Beach (LBB, 116.3 MHz) which you programmed in early in the tutorial "just in case." The VOR has a range of 500 km so you should be receiving it now, giving you distance and directional information more conveniently than the Map MFD.

- **Switch the Orbit MFD to the Surface MFD (click [SEL] then [Surface]).**
  The Orbit MFD won't be too useful once you slow down enough to de-orbit, and the Surface MFD shows you ground speed (GS) and vertical speed (VS, with negative values indicating descent). This will allow you to keep the Orbit HUD up which will be useful in a few moments. The picture below is just before the retro burn, 154 km from base, which is directly behind us, moving at 1656 m/s (orbital speed).



- **Phase Two, Burn & Turn: When you reach 150 km from base on the VOR/VTOL MFD (DIST), apply full main engine thrust.**
  Drag the main engine throttles to the top if you are in panel view. If you are in no-panel, hold down the keypad-+ key, touch the CONTROL key, then release both to quickly lock in full power. If you noticed the full thrust acceleration value during the orbit burn (on the expanded no-panel HUD), it was probably about 13 m/s^2 (about 1.3g), so you will lose ~13 m/s for each second you fire the engine in the retro direction. You can divide your speed by this value to estimate the burn time, 1700/13 = 131 seconds (over 2 minutes - your speed and acceleration can be different depending on your orbit, amount of fuel, etc.). You actually won't drive speed to zero just yet.

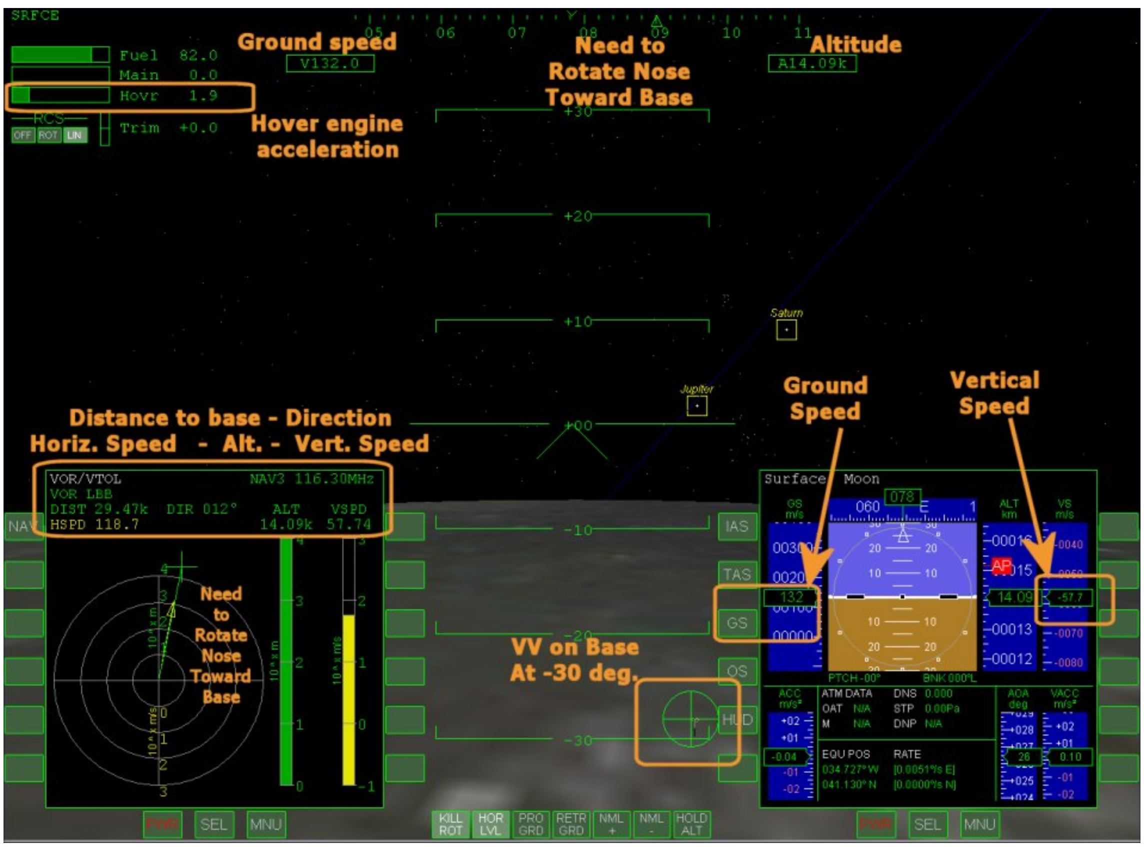
- **Keep burning until the velocity (ground speed) shown on the Surface MFD reads close to 130 m/s, then cut your main engines (MECO).**
  Drag throttles to zero or press keypad-*. This should put you ~40-50 km from base.

- **Press R to slow time to 0.1x , click the Pro Grade button, and switch back to Orbit HUD (H) if it is not there already (upper left should say Orbit [Moon]).**
  The ship will slowly start to turn to pro grade. The Orbit HUD is needed so you can tell when you are very close to pro grade so you can kill rotation and start to level the spacecraft as soon as possible (you need to get the hover engines facing down to slow the descent). You can correct your lineup with the base a little later.

- **Turn off the panel if it's displayed (F8) and press X a few times to "zoom out" to a wider field of view (FoV 70° should work well).**
  FoV is shown in the upper right corner. A wider FoV along with no-panel allows better downward visibility for approach and landing. A FoV of 90° shows the most but also distorts the view and distances, something like a fisheye lens or a car side mirror.

- **Press T for 1x time, wait for Pro Grade to <u>nearly</u> complete, *then* Kill Rotation (keypad-5), press L to roll level, and show Surface HUD (H).**
  You want to be pretty close to the pro grade direction, but you *really* need to get the hover engines facing down as soon as possible so they can start to slow your descent. You don't need to be exactly pro grade now, just looking toward the base **as shown in the labeled picture on the next page** (yaw left or right if needed to point near the heading ribbon's triangle base indicator if you can't see the VV – slight rotation in this case).

- **Phase Three, Get Down: As soon as you are level (or very close), start adding hover thrust with keypad-0, but keep VS negative (i.e., keep going down).** You will probably need quite a lot of downward thrust at first, because you will see in the Surface MFD that your VS (vertical speed) is pretty large and negative (e.g., -135 m/s), and you don't want to lose too much altitude yet. This causes your velocity vector (⊕ symbol) to be below you and out of sight even with no panel and a wide FOV. You want VS to be negative (going down since you are landing), but you want a much smaller number. You also want to get the ⊕ symbol on or near the base (remember, the ⊕ shows the point you are moving toward, and Brighton Beach would be a good choice now). On the VOR/VTOL MFD, a red VSPD bar will remind you if you are falling too fast (yellow is OK). **Remember that keypad-0 increases hover thrust (slows descent) and keypad-. decreases thrust.** You will need to constantly use these two keys.



In this no-panel shot, we have already applied hover thrust to slow our descent. We are level in pitch but descending at -57.7 m/s (VS) with ground speed 132 m/s (GS), 14 km altitude, 29 km from base (roughly half rules OK). We have zoomed out (X) to FoV 70° and the base is in sight and close to the desired -30° pitch line (30 degrees down). We are applying 1.9 m/s^2 hover thrust. The nose is rotated a little to the left, with both the VV and the direction indicator on the VOR/VTOL MFD showing the need to rotate right to line up with the VOR signal direction (though we are moving toward the base since the VV is right on it).

- **Click or press Pause (CONTROL P) and read the following "landing plan."**

The Roughly Half Plan – Now that you are level and have slowed the descent for the ride back to Brighton Beach, you need to plan your final approach. While the basic idea is to keep the VV on the base, you may need some guidance on how to do this. You have four main things to work with:

- ✓ Main engines (probably not needed any more unless you decide to "re-orbit")
- ✓ Hover engines (very important control)
- ✓ Retro engines (important for slowing down as you get closer)
- ✓ Thrusters (important for directional control and fine-tuning the descent)

How can you use these controls to keep everything "happy?" There are various ways that will work, but to start with, a rule of thumb might help. If you keep your altitude *roughly* one-half of your distance to the base, and also keep vertical speed (VS on Surface MFD) at *roughly* one-half of ground speed (GS on Surface MFD), this will give a controllable descent until you are within 3-5 km of the base. As long as you didn't start too high (25-35 km should be OK), this "half the distance" rule should keep Brighton Beach at just about -30° on the Surface HUD, which will be visible near the bottom of the screen (in no-panel view with 70° FoV). In the picture above, the "half rule" is OK for altitude and distance (14 km altitude, 29 km distance) and for velocity (-58 m/s should be about -66 m/s for GS of 132 m/s, close enough for now), and you can see that the ⊕ symbol is on the target base, with hover thrust 1.9 which will soon raise the VV above the target. Remember, this is the ***roughly*** half rule, so don't worry if things drift off a bit – don't "chase the numbers" to try to keep them exact. You have some time to make corrections. Pause or slow down time if you need to think about it.

Note that as you get closer to the base, you will want to use retro engines (keypad [-] key as long as retro doors are open) to start to slow down so you arrive near the base at maybe 10-20 m/s ground speed which you can quickly burn off at the last minute. But note that as you decrease your forward speed, you will also have to decrease your descent (VS) as well to follow the "roughly half" plan. Actually if you keep Brighton Base at the -30° line and keep the ⊕ symbol mostly on it, the velocity part should be OK.

- ➢ **Use keypad hover keys [0] and [.] to keep the ⊕ (VV) on or near the base.**
  Try to follow the roughly half rule as you do this.

- ➢ **Use translation thrusters (mainly left/right) to move the VV onto the base if it drifts right or left.**
  It needn't be exact since you can correct it later, but you want to keep the base in sight and keep moving toward it.

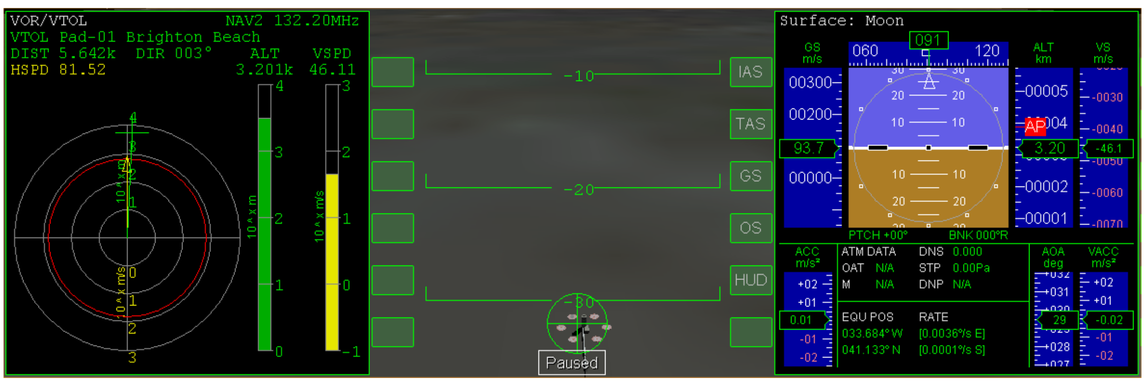
- ➢ **Use rotation thrusters (mainly yaw) to keep the nose aligned with the VV.**
  Not essential but it helps to keep the base and the VV both in sight if they are front and center. If the VV is on the base but the base isn't straight ahead, you are moving toward the based but not pointing at it (as in the picture above); yaw to correct.

- ➢ **If you get confused and can't even see the VV, press [A] (also kill rotation, keypad-[5], if necessary) and [L] to auto-hover and auto level.**
  This will stop your descent as long as you aren't too low and descending too fast (if this happens, you will hit the surface – quit and start over from your Quick Saved starting point or the beginning if necessary). It isn't especially fuel efficient, but you can worry about that another time. It also will not stop your horizontal motion (you can use retro engines and linear thrusters for that). With these, you can even stop and hover at high

altitude while you figure out where the base is and whether to continue or start over.

- **When distance to base is less than 50 km, switch the VOR/VTOL MFD to NAV2 with the [NAV] button**
  This is the frequency for Pad-01. The MFD gives distance to base (DIST), horizontal speed (HSPD), vertical speed (VSPD), and direction arrow as in hover practice.

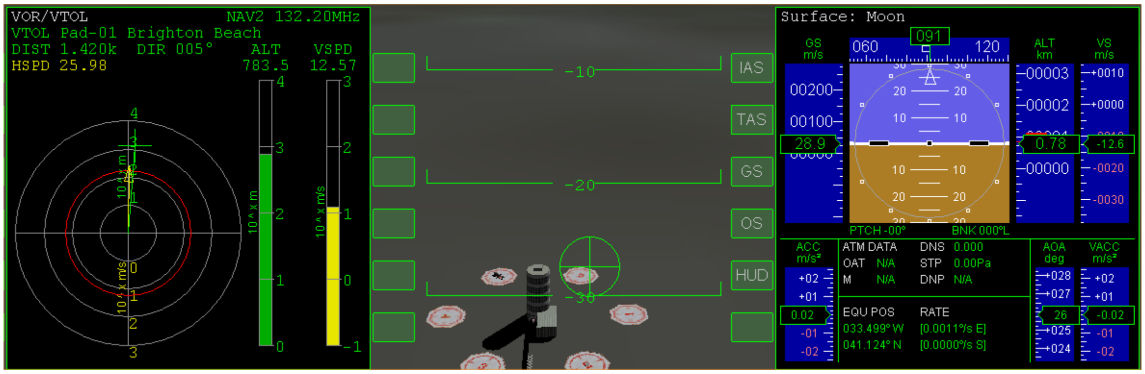
- **When you get within 20 km from the base, slow down to about 100 m/s ground speed.**
  Use your retro engines (keypad-[-] key). You will also need to adjust hover engines to keep the VV on the base. In the picture below, we are 5.6 km from the base, a bit fast at 94 m/s ground speed, so getting ready to slow down. The VV is on the base, the target (+) and yellow direction of motion arrow on the VOR/VTOL MFD (Pad-01 selected) are nearly straight ahead (up), altitude is roughly half of distance (3.2 km vs. 5.6 km), vertical speed (VS) is about half of GS (-46.1 m/s vs. 93.7 m/s), so everything is pretty "happy" in this situation. Hover thrust (upper left corner, not shown) is 1.3 m/s^2, a little below lunar G.



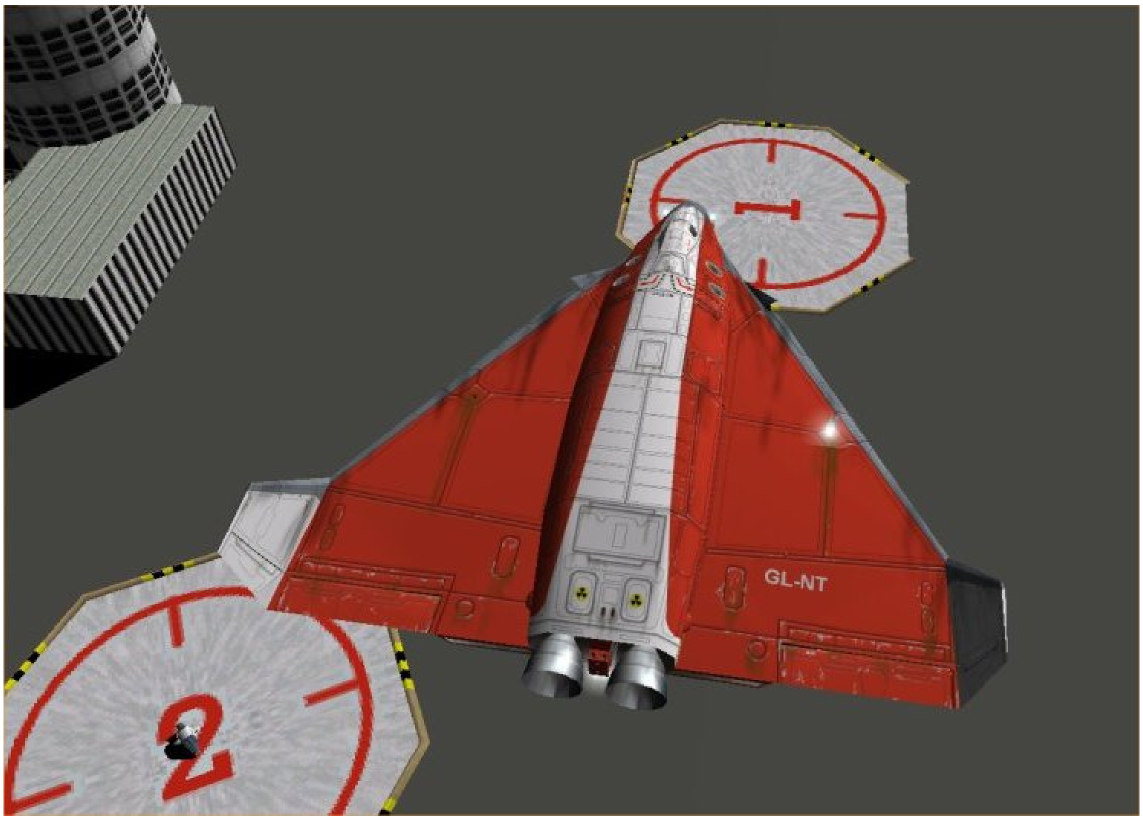
- **When you get about 5 km from the base, slow to about 30 m/s ground speed.**
  Use retro engines and slow your VS accordingly with hover engines to keep the VV on the base. You should be at about 2.5 km (2500 m) altitude at this point and will soon hear a voice say "twenty-five hundred." This is landing assistance from Orbiter Sound (based only on altitude, it will call out lower altitudes more often starting with 1000 m).

- **Lower landing gear with [G] if you raised the gear earlier.**
  Recall that the HUD will show three small squares in a triangle shape when gear are down (these will flash when gear is in motion). You can also see the status of the gear and raise or lower it with the control on the lower panel ([SHIFT] [↓]) if the panel is displayed, or just use the [G] key.

- **Within 1-2 km of the base, slow down to 10 m/s.**
  At 500-1000 m altitude, the base should look pretty big, and it should start to look and feel much like hover practice. Use auto-hover and auto-level from here if you like, and maneuver over the pad just like before (except a little higher up). In the picture below (next page), we are still fast but about to slow down for final approach. Note the values: 1.4 km DIST, 794 m ALT, 26 m/s HSPD, 12.56 m/s VSPD down, with VV moving toward Pad-01. **Hovr** value (not shown) is 1.6 m/s^2 (just about cancels lunar G).



➢ **Use your Landing MFD to guide you back to Pad-01 and land.**
Remember that even with the no-panel view and the widest FoV, the pad eventually disappears under the nose, and you will need to use the VOR/VTOL and Surface MFDs to get centered on the pad and land. You made it back!



Summary of Steps (Hovering at the Beach)

Preflight and Com

1. Start Orbiter, open the Delta-Glider folder on the Scenario tab of the Launchpad, and launch the scenario "Brighton Beach."
2. Press [F1] to go to the internal view, then [F8] to cycle to the panel view.
3. Select the Surface MFD on the left with [SEL] and [Surface]
4. Select the COM/NAV MFD ([**SEL**] [**COM/NAV**]) and tune the navigation radio frequencies NAV1 to 132.50, NAV2 to 132.20, NAV3 to 116.3.
5. Select the VOR/VTOL MFD ([**SEL**] [**VOR/VTOL**]) – it should now show the signal from Pad-04.
6. Open the Retro Doors (button on lower right of main panel, or use Control-Space bar for dialog).

Thrusters – See diagrams on page 3-5.

Takeoff, Hover, Move, Land

7. Press [F8] until you are in the no-panel view.
8. Press [L] for auto-level and tap keypad [0] key to get value of 1.7 for hover acceleration.
9. At altitude of 20 m, press [A] to engage auto-hover.
10. In rotation mode ([/]$_{num}$ to toggle), yaw <u>left</u> (the long way around as a clearing turn, [1]$_{num}$) to a heading of 90 degrees (use Kill Rotation button or [5]$_{num}$ to stop).
11. In translation mode ([/]$_{num}$ to toggle), translate (move) left 50 m ([1]$_{num}$ to start, [3]$_{num}$ to stop). Toggle modes and rotate (yaw, [1]$_{num}$ or [3]$_{num}$) to point nose at Pad-04, then use translation thrusters (toggle [/]$_{num}$ then [6]$_{num}$ forward and [9]$_{num}$ back) to move back to the pad.
12. When stopped over the pad, press [A] to release auto-hover, then alternate hover thruster keys (keypad [0]$_{num}$ for plus and [.]$_{num}$ for minus) to slowly drop to the pad.

Moving to a New Pad

13. In panel view [F8], check that Pad-04 radio beacon is still active on VOR/VTOL MFD.
14. Lift off with hover engines and hold 20 m altitude with [A] and [L] as before.
15. Use translation and rotation thrusters as needed to follow the diagram on page 3-11 to Pad-01.

Once Around the Block (Orbit)

16. Takeoff, auto-level [L], auto-hover [A] at 20 m as before, and rotate to exactly 90° heading.
17. Restore panel view (cycle [F8]) and switch to the Orbit MFD on the right, then click [PRJ] button (projection) to display SHP and also click the [DST] button to display altitude values.
18. Disengage auto-hover [A] and apply full hover thrust [0]$_{num}$ – then press [R] to slow time when altitude reaches 2000 m.
19. When altitude reaches 2200 m, pull hover engine throttle to zero thrust and push main engine throttles to full thrust. Then restore 1x time with [T].

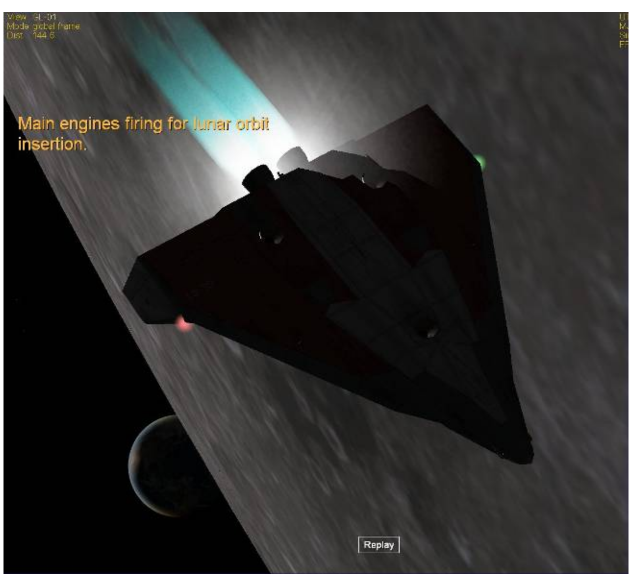
20. When eccentricity (**Ecc** on the Orbit MFD) reaches about 0.03, press [R] to slow time to 0.1x. Watch the slowly dropping Ecc value and when it starts to rise, kill main engine thrust ([*] num). Periapsis (PeA) will probably be negative and will require a small burn at apoapsis to raise this. Accelerate time if desired to ApT ~ 60 s and turn Pro Grade (panel button).
21. When you are close to apoapsis (ApT ~ 10 s), use [+] num to fire 2 or 3 very short bursts of main engine thrust to raise PeA to 25-30 km (use retro engine [-] num to adjust if you overshoot this).

Bringing It All Back Home (De-orbit)

22. Select the Map MFD, click [**TGT**], and define target base as Brighton Beach. Place or keep the Orbit MFD on the other side for now.
23. Accelerate time ([T]) until Map MFD shows distance (**Dst**) to Brighton Beach (BB) as ~300 km. Then restore normal time [R] and immediately turn Retro Grade (panel button) for de-orbit burn.
24. Replace the Map MFD with the VOR/VTOL MFD and use [NAV] to select NAV3 (LBB), and also replace the Orbit MFD with the Surface MFD.
25. When you reach **150** km, push main engine throttles to full thrust for ~2 minute burn until ground speed (GS) on Surface MFD is reduced to about **130**, then cut main engines ([*] num). Slow time to 0.1x ([R]).
26. Immediately click the Pro Grade button (starts in slow motion) and switch to Orbit HUD (use [H]) if it is not already displayed.
27. Turn off the panel (cycle [F8]) and press [X] a couple of times to get wider-angle FoV 70° for better landing view.
28. Restore normal time [T], wait for Pro Grade to nearly complete, Kill Rotation ([5] num), press [L] to roll level, and cycle back to Surface HUD [H]. If you should lose sight of the velocity vector (⊕ symbol), yaw left or right ([1] num or [3] num) to point the nose at the base direction indicator (triangle) on the heading ribbon.
29. As soon as you are close to level, start applying hover thrust ([0] num increase, [.] num decrease) to slow your descent. It may take a lot of thrust at first, but VS should stay negative (i.e., don't start to rise).
30. For final approach, try to keep Brighton Beach at about -30° on the Surface HUD, and the VV (⊕ symbol) on or very close to the base. Also try to keep altitude at about ½ the distance to the base as shown on the Map MFD or (soon) the VOR/VTOL MFD.
31. Use translation thrusters (mostly lateral, [1] num and [3] num) to center the VV on the base, and rotation thrusters (mostly yaw, [1] num and [3] num) to keep the nose left-right aligned with VV. The pitch should still be level (nose position indicator at 0° pitch line) though the VV will be below the 0° pitch line (at around -30°). The nose should not be pointing at the base (attitude is level, flight path is sloping down).
32. Within 30 km of the base, you should have the pad-01 radio beacon, so switch VOR/VTOL frequency to NAV2.
33. Within 20 km, slow to about 100 m/s, and at 5 km, slow to ~30 m/s, slowing descent to maintain the "roughly half" rule (VS about half of GS, and altitude about half of distance). Use retro engines ([-] num) to slow down, and hover engines to keep VV on the base as you do.
34. Within 5 km of the base, use [G] to lower your landing gear if you raised them earlier.
35. Within 1-2 km of the base, slow to 10 m/s or slower, stopping when you are over the pad. Use auto-hover [A] and auto-level [L] to get stable over the pad, use LIN thrusters to adjust your position over the pad, then turn off altitude hover-hold [A] and use hover engines to lower the ship slowly onto the pad.

Fly Me To The Moon

This chapter will teach you to fly to another world. The Moon is the closest body other than Earth that you can actually orbit and land on, and it's really not all that hard to get to in Orbiter, especially with the powerful and fuel-efficient Delta Glider. But we will introduce a few challenges along the way, such as launching to low Earth orbit (LEO) from a runway, flying to an orbit that is well aligned with the Moon's orbital plane (most or all of the alignment will be done by waiting for a "launch window" that has pretty good alignment to begin with), using the Transfer MFD to determine how to "eject" from LEO at the right time to intercept the Moon, and making mid-course corrections to enter briefly into lunar orbit and get set up for a landing on pad-02 at Brighton Beach. There's a summary checklist at the end.



Earthrise – The Moon is the final destination for this chapter, and here we are burning retro for lunar orbit insertion, with Earth just rising. It's back to Brighton Beach but this time you've got to fly there all the way from KSC (Kennedy Space Center), and you've also got an expert guide along for the ride, Dr. Martin Schweiger, the author of Orbiter. His recorded flight and extensive on-screen playback notes (along with this chapter) will guide you all the way from takeoff to touchdown, and whenever you are ready, you can take over the controls and fly the rest of the mission on your own. If you play back the complete flight with the time accelerations included in the replay file, the whole thing will take about one hour.

This chapter will make use of your previous experience with changing orbits and controlling your attitude with thrusters, and you will learn some important new skills as well. With this experience, you will be ready to try some interplanetary flights, using either the Transfer MFD or one of the other flight planning MFDs that are available (TransX is supplied with Orbiter, and the newer Interplanetary MFD is available as an add-on – see chapters 6 & 8). You will still have some important skills to master before you can consider yourself a full-fledged "Orbinaut," including rendezvous and docking with a space station (see chapter 5), atmospheric (Earth or Mars) reentry, and a few others. In chapter 7, we will refer you to some good tutorials by others to help you complete your Orbiter education.

Launch Window Waiting

Welcome back to Earth and to your fast-track Delta Glider training – third lesson and you're flying to the Moon! Not bad. Time for some more action. So the very first thing you'll have to do is… wait a while. For the launch window, that is. A launch window is the date and time (or range of dates and time) during which a particular flight is feasible or favorable in terms of the position of the target, length of time required, the required and available fuel, and sometimes other factors, such as the desire for daylight at the starting point or destination. With the DG, you actually have a lot of available energy or delta-V (see chapter 9, "I Was Just Wondering…" for a discussion of delta-V), so you could really ignore some of these things – launch pretty much when you like and use extra fuel to make up for it. But this time you will fly a simple and reasonably fuel-efficient trip to low Earth orbit and then on to the Moon (though the four day flight won't be especially fast). The Transfer MFD will only work if you and the target share the same orbital plane. That's what you'll have to take care of first, making sure your orbit is aligned with the Moon's orbit.

Want to Skip the Details for Now? If you'd rather just get set up and flying and learn the details of the alignment issues later, skip for now to where it says "OK, time to fly" and follow those directions.

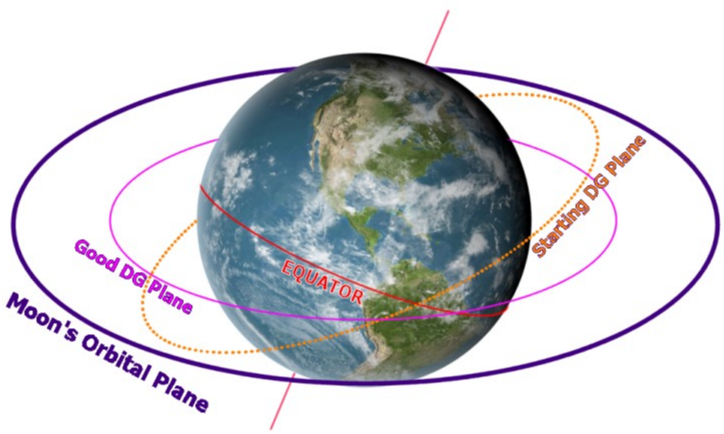
Orbital Alignment – The big issue for the launch window is orbital alignment, and you will be looking at it with the Align MFD. If the orbital inclination of the target (the Moon in this case) and the inclination of your brief LEO "parking orbit" are very different, you will have to use a lot of fuel to get aligned for the transfer orbit. You *could* do that in the DG, but ships like the Space Shuttle don't have this option when they launch (say) for the ISS – they have to launch to an orbit that is well aligned with the orbit of the target, or they won't have enough delta-V to rendezvous and dock with it (of course the Shuttle has nowhere near the delta-V needed to go to the Moon – it's purely a LEO machine).

Inclination, Ecliptic, Equator, Reference, Huh?

Inclination is the tilt of the orbit, normally measured relative to the equator of the Earth. We haven't worried about it too much, but you can reference orbital information shown in the Orbit MFD (such as inclination, **Inc**) to different bodies ([**REF**] button, e.g., Sun, Earth, Moon), from different reference planes ([**FRM**] button, with options ECL, ecliptic plane, which is the plane of the Earth's orbit around the Sun; or EQU, the plane of the Earth's equator). The orbit diagram can also be projected in different planes ([**PRJ**] button). Projection choices are the ecliptic plane [Prj ECL], which is the plane of the Earth's orbit around the Sun; the plane of the Earth's equator [Prj EQU]; and your own ship's orbital plane [Prj SHP]). Often this is just a matter of convenience, but if you are transferring from one body to another, it becomes more important, and it's easier to compare two quantities if they are measured in the same way (with some math or the Orbit MFD, it's easy to switch these references).

You will start out sitting on the ground, on runway 33 (heading 330° or northwest), but remember the Earth is rotating, and you move along with it. So if you were to look at the Orbit MFD, you would see you already have orbital elements, including orbital inclination! If you measure that orbital inclination relative to the ecliptic (the plane of the Earth's orbit around the Sun), and you also define your target orbit as the Moon, you will be able to see what the relative inclination would be if you were to launch now. It won't be very close right now, but you can fix that by just waiting a while.

The Power of Sitting and Waiting – Earth's Moon is unusual in the Solar System in that its orbit is nearly aligned with its planet's orbital plane around the Sun (the ecliptic) rather than with the plane of the equator. Furthermore, the Earth's rotational axis is tilted relative to the ecliptic by about 23.5° (this causes the seasons, among other things), and it rotates every 24 hours. The result of all this is that the Moon's orbital inclination with respect to the equator varies between 28.60° and 18.30° depending on the time of year, time of month, and time of day (for more on the Moon, see http://en.wikipedia.org/wiki/Moon). If you can launch and get a small relative inclination for your orbit (which you can within a range of about 0° to 10° – note that 28.5° is the minimum equatorial inclination available to launches from KSC's latitude), you will need only a small plane alignment burn (or possibly none) before transfer.



Getting in plane is important for using the Transfer MFD to set up the transfer orbit to the Moon. **Earth's equator** is tilted relative to the **Moon's orbital plane**. If you launch now, the resultant "**starting DG plane**" is tilted too much relative to the Moon. By waiting about 1 hour (in this case), the rotation of the tilted Earth changes the geometry and allows you to launch into a "**good DG plane**" which is nearly parallel to the Moon's orbital plane (small relative inclination or Rinc value). Note that these orbits are not drawn to scale.

Another way to look at this is to measure both orbits from the ecliptic (ECL) instead of the equator (EQU). The Align MFD does this, and you can set the Orbit MFD to do it too with the [**FRM**] button.

OK, time to fly. The instructions and MFD information should make things a bit more clear.

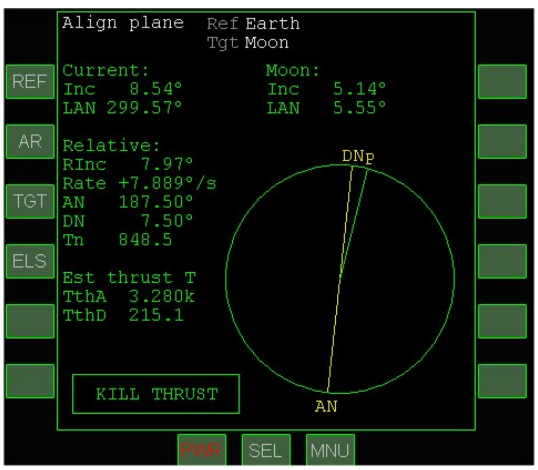
Learning from Orbiter's Author

This chapter is based on a flight recording of an Earth to Moon flight by Orbiter's author, Dr. Martin Schweiger. The scenario and its flight recorder files are included in the Orbiter installation, and Dr. Schweiger has added on-screen text notes to the playback file to explain what is going on. So even before you read this chapter, you may want to "watch the movie" to have an idea of how it will all work. You can use the [CONTROL] p dialog to either play back with the time acceleration that was recorded (about one hour total), or turn this off and use [T] and [R] keys to speed up or slow down the playback as desired. You can also use the dialog to interrupt the playback and take control of the rest of the flight from any desired point, following these instructions (note that you can't resume playback once you interrupt it).

- **Start Orbiter, and open the scenario folder called Tutorials. From this folder, launch the scenario called Lunar Transfer.**
  You will start out in REPLAY mode in the cockpit of your Delta Glider sitting on runway 33 at Kennedy Space Center (KSC). Note the date and time (UT) in the upper right corner of the screen.

  It's about 01:15 UT on Monday, February 6, 2006 (about 8:15 pm Sunday in Florida). The playback starts out in the no-panel view for best visibility. Most buttons you need are available in this view, so it will be used for all screen shots in this chapter.

- **Notice the Map MFD on the right side (below right).**
  It is already set up with the Moon as the target orbit. The yellow line updates to show the Moon's ground track. Notice that it is not yet lined up very well with the current "orbital" track (you're sitting on the ground, revolving with the Earth).



- **Notice the Align MFD on the left side (above left).**
  This MFD is new for you – it is designed to help align your orbit with a target orbit (already set to the Moon). "Align" means to make the inclinations the same, or relative inclination (Rinc) close to zero. Right now it's about 8° which is why you must wait a bit before takeoff. In about one hour it will get down to around 0.3° and you can launch.

- **Watch and read the screen notes, or accelerate time with the T key until just before 02:19 UT on February 6.**
  If you are reading the screen notes, you might as well use the scenario's own playback speed (it will eventually accelerate you to takeoff time). If you are manually controlling the time, you can use 10-1000x, but be careful not to overshoot. Watch the orbital tracks get closer on the Map MFD and the RInc value approach zero on the Align MFD as you approach the optimum launch time, just about 02:20 UT on February 6.

Cleared for Takeoff

OK, it's your first runway takeoff, it's night, and you're going to the Moon. But no pressure. Just take it easy and don't try to make the turn to heading too fast or too steep – it's easy to over-bank and end up heading west instead of east (you start out on the runway heading 330° and need to turn **right** to 90° as you climb out). Note: If you have a joystick, you can use it, but don't "yank and bank" too hard – keep the turns gentle.

> ### Takeoff and Climb Goals
>
> There are several things you need to achieve with a runway takeoff and climb to Earth orbit in a space plane like the Delta Glider. You need to get airborne and turn quickly to the target heading, which is due east (90°) in the case, since this direction gives you the most help you can get from the Earth's rotation speed. You need to quickly gain altitude to get above the dense, drag-inducing lower atmosphere as soon as possible, though with a winged craft, the lower atmosphere also provides lift that helps us gain altitude (unlike a vertically launched rocket for which the engines must provide all the lifting force). And you need to gain a lot of horizontal speed to achieve orbit at the desired altitude. This is mainly controlled with the pitch of the spacecraft, which affects how much lift you get from the wings, and also affects how much engine thrust is directed downward and how much is horizontal. Elevators on the wings control pitch at first, but above 30-40 km, you may need the RCS thrusters (though in the recorded flight, the RCS thrusters were not needed until orbit was achieved).

You will use the Surface HUD for most of the information you need on the ascent. ***Note that if you take over and fly the ascent manually, whether you use the keypad or joystick, the DG can be a bit tricky to fly in the atmosphere – so it may take a few tries to get right.*** The replay makes it look easy, but the person flying it has had lots of practice! With the exception of instructions to change and adjust settings on the MFDs, most of the following instructions will apply only if you take control. The recording incorporates all the actual flight operations.

- **Apply full main engine thrust.**
  Press the keypad [+] key, then the [CONTROL] key to lock at full thrust, or drag the main engine throttles to the top on the panel (if displayed). You should not have to steer.

- **Watch the HUD for V100.0 which is rotation speed (time to raise the nose for liftoff).**
  No-panel helps forward visibility, but there really isn't that much to see until you reach orbit, so you can display the panel if you prefer (F8 key). Rotation speed needn't be exactly 100 (90-110 m/s is OK).

- **Apply gentle back stick or press and hold keypad [2] to raise the nose and fly off the runway (pitch up to about 30°).**
  Watch the HUD for pitch, roll, altitude, and speed. Some people like to apply some nose-up trim for the climb, though the recording does not use trim. The trim control is on the right panel below the autopilot buttons (you can also use the [del] key for nose up, and the [ins] key for nose down trim). While optional, elevator trim provides most of the

aerodynamic "back stick pressure" (or keypad [2] key) needed to keep the nose up for the early part of the climb, so it's quite useful.

- **Raise the gear ([G]) and start a gentle (~30°) roll (bank) to the right.**
  Use the keypad [6] key (or right stick). Maintain slight stick back pressure or 2-key taps to keep the pitch at around 30° while you make the turn to 90° heading. You can increase back pressure somewhat to speed up the turn. When you reach a heading of about 75° you should start to reduce your bank ([4] key or left stick) to avoid overshooting the required 90° heading. This can be tricky especially with the keypad, so it may take you several tries to get everything right.

- **At 90° heading, set the pitch to about 30° and continue climbing.**
  Recall that the direction indicator (the -^- symbol) shows where the nose is pointing, and its position on the pitch ladder shows your pitch angle. The position of the velocity vector (VV, the ⊕ symbol) on the pitch ladder shows the direction you are actually moving, which is usually not exactly where you are pointing. Keeping VV above the zero pitch line will keep a positive rate of climb.

  Make small bank adjustments (keypad [6]/[4] keys) as needed to hold approximately 90° heading. You will see that your heading affects the RInc value shown in the Align MFD, which you want to make as close to zero as possible. So you can make small adjustments to minimize this value instead of holding exactly 90° (in the recording, the heading ends up closer to 100°).

- **At 30-40 km, you may want to activate the rotational RCS thrusters with [CONTROL] [/] on the keypad (if you are flying manually).**
  The recording does not do this, and the VV starts to drift downward even with constant back pressure, meaning that the climb angle is reduced. This is because the air density has dropped. You can also activate this with [ROT] button (upper left in no-panel view) or with the RCS rotary switch on the upper right panel (if displayed).

- **Above 40 km, allow pitch to fall to about 20° to start to build horizontal velocity, but keep varying pitch slightly as needed to keep climbing.**
  You will continue to climb but with a smaller vertical speed which is OK. Once you are above the dense part of the atmosphere, drag is lower, and you can accelerate more efficiently to gain orbital speed. Keep your VV above the 0° pitch – you will typically have to adjust the pitch up and down slightly as you climb to do so.

- **On the left MFD, click [SEL] and then [Orbit], then set projection to "ship" with the [PRJ] button, and set altitude mode with the [DST] button.**
  This displays the Orbit MFD so you can see how your orbit is developing. It's still mostly below the surface now (ballistic trajectory) but it will rise quickly once you reach orbital speed. As you get close to this orbital speed, the orbital values will change fast.

- **Keep burning until HUD velocity is around 7500 m/s and ApA is above 300 km, then kill main thrust with keypad [*] (or drag throttles to zero).**
  For a stable orbit, PeA should be above 200 km, and ApA is not especially critical, but the recorded flight has a PeA below 90 km and you may as well. This is OK for the short time you will be in this parking orbit. Note also that the Surface HUD shows ground speed (about 7500 m/s) while the Orbit MFD Vel value is orbital speed (about

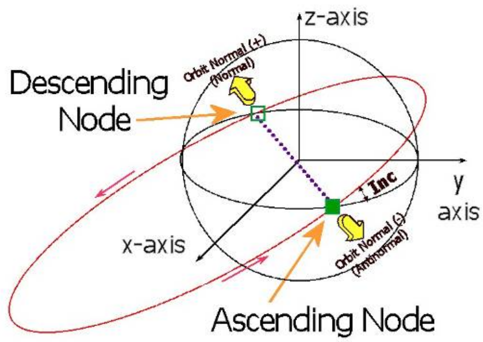
7900 m/s, below left). Both speeds are correct, but they are measured differently. The Surface MFD has buttons to show four different speeds (IAS, TAS, GS, OS). The first two are only valid in the atmosphere (indicated and true airspeed), GS is ground speed, and OS is orbital speed.

- **Switch HUD to orbital mode by clicking the [HUD] button on the Orbit MFD.** Orbital mode shows your attitude relative to your orbital plane rather than relative to the surface. The [HUD] button transfers any settings (such as reference planet) from the MFD to the HUD.

Tweak and Align the Orbit

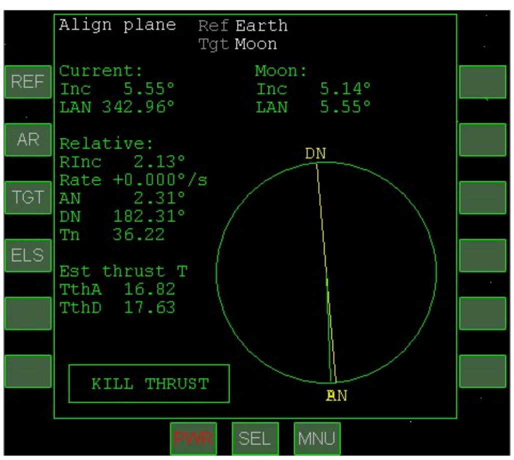
Now that you've reached orbit, you can see what adjustments (if any) are needed. As mentioned above, the exact orbit shape isn't too important since you will be leaving shortly for the Moon anyway, but if you have hand-flown to orbit, some adjustment may still be needed. The recorded flight was quite accurate in terms of relative inclination (RInc about 0.2°), but if you end up with more than 0.5° RInc, you will need to do a plane change to reduce this in order for the Transfer MFD to work well. The Transfer MFD assumes that the target orbit is in the same plane as you are, or at least very close. ***If you are following the recorded flight, note that the steps in this section will not be needed now***, but the concept of a plane change is still important, and the recorded flight will perform a plane change near the Moon in order to align the orbital plane with the target base for landing.

Alignment Issues – Recall that when you needed to change the size of the orbit (periapsis or apoapsis), there was a special point in the orbit to do this (which is at the "opposite end" of the orbit, e.g., burn at apoapsis to change periapsis, retrograde to lower it, prograde to raise it). A similar thing applies to orbital inclination – you burn in a special place and in a special direction to change the "tilt" of the orbit. Remember the square symbols on the Orbit MFD? Those are called nodes, and they show where one orbit crosses a target orbit (or a target plane, typically the equatorial plane if there is no target orbit).

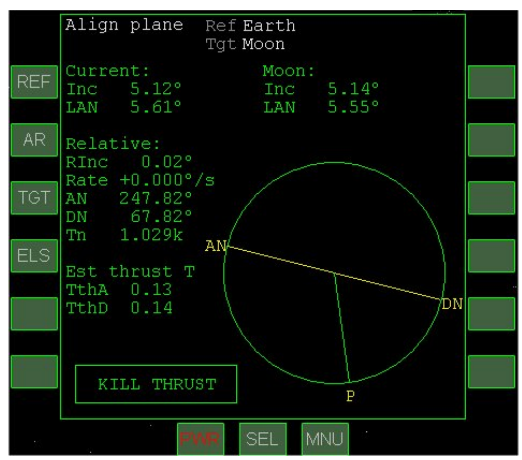


Nodes - The node at which you are going uphill or north as you cross is called the ascending node (AN), and the downhill/south crossing is the descending node (DN, sort of like "downhill"). In the Orbit MFD (labeled above), these are connected by a dotted line called "the line of nodes." You can think of this as a kind of "axle" around which the inclination with respect to the equator (Inc, as shown here, or relative inclination RInc in the case of a target orbit) can be tilted.

To change the orbital inclination, you point the ship in a special direction and burn. The directions (yellow arrows, figure above) are called **orbit normal** (or normal **+**) and **orbit anti-normal** (or normal **-**). To reduce your relative inclination (RInc) with the target orbit, the mnemonic (memory hint) is "**AN for AN**," meaning "Turn **A**nti-**N**ormal at **A**scending **N**ode." The descending node is opposite (turn Orbit Normal). The Align MFD gives you a lot of help with this – it actually tells you which direction to turn, how long until you start the burn (**Tn**), and how long to apply thrust (**Tth**). The message actually flashes when you need to fire main engines at full thrust! *The following screens are NOT from the recorded flight, but from a hand-fly to orbit that left a 2° alignment difference, too large for a good transfer.*



Alignment 2°off after achieving orbit, ascending node is next plane change opportunity



After normal (-) burn, RInc reduced to 0.02° for accurate use of Transfer MFD

- **Restore the Align MFD to one of the displays with target Moon if you have closed it (click [SEL] then [Align Planes]).**
  You will still want the Orbit MFD on one display (no target for now, [**NT**] button). Depending on how it was flown, you may be approaching either descending or ascending node. Just after achieving orbit in the recorded flight (Sim 4543s), the Time to Node (**Tn**) was 78 s and the Descending Node Thrust Time (**TthD**) on the Align MFD was 2 s. With RInc of 0.24°, this small burn wasn't needed in the recorded flight, but in the above screens, alignment was off by 2.1°, with ascending node coming up next. The left screen shot is somewhat after orbit insertion, already very close to the AN. The right screen shot is after the 16.82 s anti-normal burn (0.02° RInc is very good).

- **For AN Case: Click the Orbit Antinormal (-) autopilot button (NML - at bottom of no-panel or ['] key) and watch for Tn to reach around 60 s.**
  This will position you correctly for the burn at the ascending node (AN). You can carefully time accelerate with [T] until Tn is about 60 s, then slow to 1x with [R]. The flashing message on the Align MFD will tell you to start the burn when Tn is half of TthA, so when Tn is just over half of TthA, you may slow to 0.1x to start the burn more precisely (the burn is likely to be short, so you may choose to stay in 0.1x).

- **When Tn reaches half of TthA (time to thrust), apply full main thrust (throttles or keypad [+] key).**
  It is more accurate to apply half of the burn time before reaching DN and half after passing it. The "engage thrust" message will flash.

- **When RInc reaches ~0° and TthA reaches zero, kill the main engines.**
  You may again find it useful to briefly use 0.1x time for more precise cutoff timing. If the RInc is still off a little, try using **linear** RCS thrusters (forward and back, keypad [6] and [9]) to tweak it. If it's too far off (more than a degree), wait to reach DN and make a small normal (+) burn – use the **NML +** button for this case. In this case, you may also have to raise your periapsis with a prograde burn at apoapsis if PeA is less than 200 km so you can safely complete an orbit.

Transfer MFD and Eject Burn

Now that your orbital plane is aligned with the Moon's orbital plane, you are ready to plan and execute the transfer orbit, using the Transfer MFD. The Transfer MFD displays the spacecraft orbit (green, too small to see clearly if the target is the Moon's much larger orbit) and target orbit (yellow), something like the Orbit MFD, but with some special features (see the Orbiter PDF manual section 13.10 for more details on the Transfer MFD). *Note that if you are following the recorded flight, you can still enter a transfer solution in the Transfer MFD for practice, but the solution will not affect the playback.* If you are hand flying the scenario, you will use the Transfer MFD to time your TLI (trans-lunar injection) burn.

The key feature is the "hypothetical transfer orbit" (**[HTO]** button) that simulates the approximate transfer orbit as a dotted ellipse that you can change in size (with **[DV+]** or **[DV-]** , for delta-V) and/or direction (with **[EJ+]** or **[EJ-]** for eject location). This is the key to transfer orbit planning, the ability to estimate the effect of a certain burn (DV) and certain eject direction (EJ) before you make the burn. It's not exact, but it's a pretty good estimate, and you can always make a mid-course correction if needed when you get fairly close to the Moon. *Note that if you hand-fly, your starting orbit will be at least slightly different so your pictures and numbers will not exactly match the ones shown here.*

The Transfer Idea – The idea of the Transfer MFD comes from the need to "lead" a moving target. If you want to throw a ball to someone who is running, you need to throw it to where the runner will be when the ball gets there, estimating how far they will move, and controlling the direction and speed of the thrown ball to make it get there at the right time. In the case of the Moon, the "target" moves in a predictable path (orbit), and if you could try out different energy amounts (delta-V) to get the right distance (size of the transfer orbit), and different starting locations (EJ) in your own orbit, you could eventually find a combination that reaches the Moon's orbital distance at the same time and place as the

Moon. This is what you do with the "hypothetical transfer orbit" (HTO), "hypothetical" meaning "what if?" What if I apply this much delta-V starting at this orbital position? What would my orbit look like? Would it arrive at the Moon's orbital distance? Where would the Moon be at this arrival time?

A Lot of Lines but basically simple. **DG Now** is your current position (green), **Moon Now** is the Moon's current position (yellow). Use **DV** buttons to extend the dotted hypothetical transfer orbit to touch or pass the target orbit as shown, then you can use the **EJ** (eject) buttons to rotate the **DG Later** (gray) line to line up with the **Moon Later** line (the yellow dotted line – you may have to add some DV as you rotate the transfer orbit since the Moon's orbit is not a perfect circle). You will make your eject burn when you reach the green dotted **Eject Pos.** and DTe is zero. Burn until Dv is zero and you're on the way to the Moon.

The clever part of the Transfer MFD is that as you tweak the orbit size with delta-V, and vary the "eject" position (time or angular position around your orbit), you can graphically see the changes in the hypothetical orbit. By making a couple of lines coincide (the "LATER" positions of you and the target), you force the MFD to solve the transfer equations for the desired result (the place where you and the Moon arrive at the same time). It's easier to use than to explain!

Transfer MFD – The MFD has a number of controls, of which you need just a few right now. It's easiest just to walk through the steps and explain as you go along.

- **Select the Transfer MFD on the right side (click [SEL] then [Transfer]).**

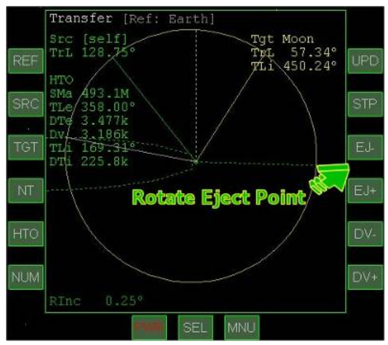
- **Click the target button [TGT], select Enter by Name, type <u>moon</u>, and press the enter key.**
  The Moon's orbit (target) is yellow, and yours is green, but too small to see at this scale.

- **Click the [HTO] button to enter hypothetical transfer orbit mode.**
  Some new values will appear on the left side of the MFD (HTO block).

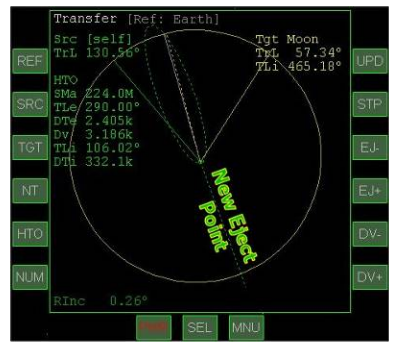
- **Start to add delta-V by clicking the [DV+] button.**
  Note that you are not really adding delta-V yet (that comes later with the burn), you are just entering assumed values to predict the hypothetical effect. You will need to click it quite a few times before it grows enough to see (the delta-V added is displayed as Dv, and you will need over 3000 m/s of delta-V for the transfer). The HTO is shown as a dotted ellipse. When this ellipse reaches or passes the Moon's orbit, you have an intercept solution, but not at the right place (i.e., you would reach the Moon's orbital distance, but not when the Moon is there). ***If you are following the recorded flight, you will use the [DV+] button until Dv reaches 3.186k.*** This will extend the dotted ellipse well past the Moon's orbit at first.

➢ **Use [EJ -] and/or [EJ +] to rotate the gray “later position” line to coincide with the yellow dotted line representing the Moon’s later position.**
All the lines will move as you try to get a solution, and sometimes you can get close and then it “jumps.” Try increasing the DV in this case, or clicking [**EJ-**] and [**EJ+**] slowly to try to get closer to the solution. You can also get “No intercept” as you rotate the gray line – again, just use [**DV+**] to enlarge the HTO ellipse a bit until it intercepts again. ***If you are following the recorded flight, you will use the [EJ+] and [EJ-] buttons until TLe reaches 290°.*** TLe is the angular position at which the burn will take place. Note that these values place the intersection point of the HTO slightly ahead of the Moon's target position. Passing the Moon on the leading side will allow you to later enter into a retrograde lunar orbit (opposite the Moon’s rotation direction).

HTO selected, ellipse grows (**DV+** until intersect)



Gray line ⇨ yellow dotted (**EJ- or +** to line up)



Gray and yellow dotted lines are close (DG slight lead)

Wait for Eject Position – With a good HTO solution, all that’s left is to wait for the eject time (**DTe**, which is about 2405 s in the above right picture, about 40 minutes). When you get to within a minute or so of that position, you’ll turn prograde and prepare for full thrust on the main engines 30 seconds before **DTe** reaches zero. A burn providing over 3000 m/s of delta-V will take several minutes, and the **Dv** value will continuously show the remaining delta-V needed to complete the calculated burn. When it reaches zero, it’s time for main engine cutoff (MECO).

➢ **Wait or accelerate time until DTe (eject time) is about 60 s.**
It’s best to stay at 100x or slower when close to a planet (if you choose to use 1000x, at least turn off any autopilot function first). The recording uses 10x in this phase.

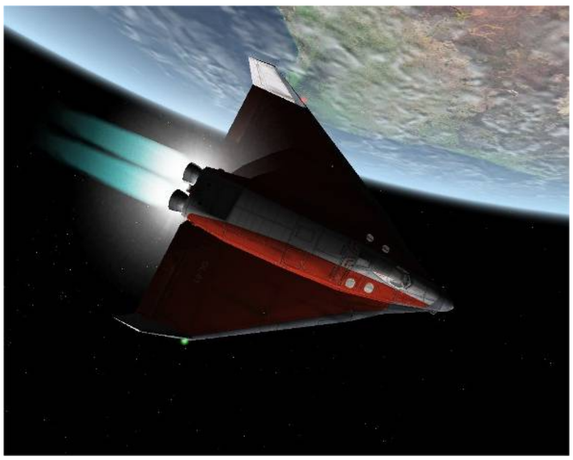
➢ **Use PRO GRD autopilot button or [key to turn prograde for the eject burn.**
You are adding to your orbital velocity, so prograde is the correct direction.

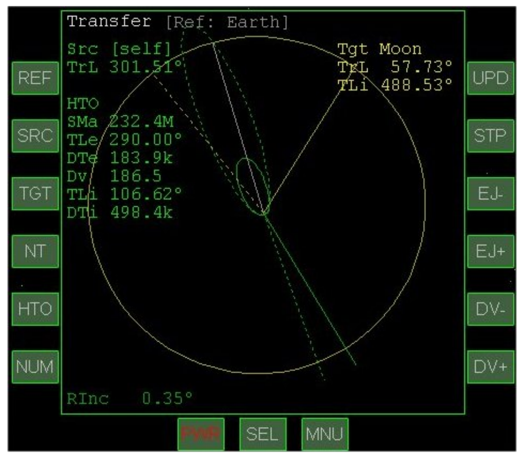
➢ **When DTe reaches about 30 s, apply full main thrust.**
This will be a little before the ship’s radius vector (solid green line) reaches the ejection point (dotted green line). Use throttles or keypad as you have done before. This will be a long burn (around 3 minutes), but keep an eye on the Dv value. It changes fast especially at the end (picture below right has remaining Dv of 186.5 m/s and the real (green solid ellipse) transfer orbit is starting to approach the dotted HTO orbit.

- **When DTe reaches zero, press the [Kill Rot] button (or keypad 5 key).**
  This turns off the prograde autopilot to keep it from recalculating and changing the prograde direction to follow the new orbit (the correct direction for the whole burn is the prograde direction at the ejection position, or DTe = 0).

- **When remaining Dv drops to ~600, start reducing thrust.**
  This is to avoid overshooting the HTO target (dotted) ellipse, since the shape changes fast in the last few hundred m/s of Dv. Drag throttle down or use keypad [-] key with the [CONTROL] key to reduce thrust. Bring it down to zero when the ellipse matches the target (or when Dv is close to zero).

- **Click the [HTO] button to turn off HTO mode.**
  This allows you to see the actual orbit information (not shown).





You are on your way to the Moon! But there are still a few things to look after before you get there.

Cruise and Correct

Now all you have to do is wait for a few days and watch the Moon get closer and closer. While the transfer orbit you've planned is a bit faster than the energy-minimum Hohmann transfer, it is still a fairly slow way to go to the Moon – roughly 4 days and 6 hours (for comparison, Apollo 11 took about 76 hours from mission start to lunar orbit insertion, 3 days and 4 hours). Faster transfers take more fuel for the TLI burn and more fuel to slow down when you get there. Fortunately you can use time acceleration in Orbiter, so it's not too bad. You can safely use up to 100x time acceleration for the first few hours (until maybe 40,000 km from the Earth), then you can use 1000x or so time acceleration until the Moon's gravity really starts to kick in (see below). You should not use any autopilots with 1000x – if you want to turn retro or prograde or something, you should first set time acceleration to 1x or 10x then turn off the autopilot before going back to 1000x. Be sure to take a good look back at Earth (external views are best). *If you are following the recorded flight with time acceleration as recorded, it will speed time up considerably during the cruise portion (up to 2000x once you get some distance from Earth).*

This might be a good time to mention that there are other tools available for planning flights away from the Earth (Moon, Mars, or other planets). Many Orbiter users find the Transfer MFD to be all they need for Moon flights, and even for Mars journeys and beyond (there are some "tricks" for interplanetary flights, see the Orbiter manual section 13.10). TransX is an add-on MFD developed by Duncan Sharpe that is now supplied with Orbiter (it has its own PDF manual in the /Doc folder). Interplanetary MFD is a newer add-on available on the web (see chapter 6 for an Earth-Mars flight using IMFD).

The plan now is to fly directly to Brighton Beach, entering lunar orbit only briefly in the process. To enter an orbit with the proper inclination and periapsis to pass low over Brighton Beach, several burns will be needed, all fairly close to the Moon: (1) a plane change burn to change the orbital inclination to pass over the base, (2) a retrograde lunar capture burn to slow down, lower the periapsis, and enter an eccentric but closed temporary orbit, and (3) another retrograde burn, this time at periapsis, to lower the height of the orbit on the opposite side of the Moon (above the base) to under 10 km.

Plane Change Burn – To get the needed plane change with minimum fuel use, it's best to perform this burn fairly far from the Moon, but at a point where the Moon's gravity dominates (within the Moon's sphere of influence or SOI). You can tell this from the G indicator at the bottom of an Orbit MFD with reference set to the Moon. For accurate orbital elements, this should be above 0.5 (it's 0.64 in the case of the recorded flight). Plane change burns are usually done at one of the nodes (ascending or descending), which changes the inclination but not the periapsis or apoapsis. In this case, the burn will be done in the normal-plus direction but not at a node, as you can see in the Orbit MFD view of the burn position below left. This means that the periapsis will also change, but this will need further adjustment anyway (PeA is negative, i.e., 165.6 km below the Moon's surface in this case, but this will soon be raised).

As you can see in the zoomed-in Map view (below right), at the time of the correction burn, the orbital plane is approximately in the equatorial plane of the Moon, and Brighton Beach is northeast of the current equatorial position. A Normal(+) burn will make the burn position an ascending node with respect to the Moon's equatorial plane, i.e. will raise the eastern part of the trajectory to higher latitudes, as required.

- ➢ **On the Orbit MFD, click [AR] (auto reference) to select the strongest gravitational source, which is now the Moon.**
  This is shown above left. Then click [HUD] to copy the new reference to the HUD.

- ➢ **Switch the right MFD to the Map (click [SEL], [Map], then [REF] and choose Earth -> Moon from the list of bodies that pops up.**
  The red square is Brighton Beach, your destination (above right). Note that the ground track is near the equator (inclination is 174.88°, about 5° from a retrograde equatorial orbit which would be 180°). The inclination needs to be changed for the ground track to "ascend" to the northeast and pass over Brighton Beach (~41° north latitude). Use

[ZM] to toggle the two zoom settings as desired (whole Moon or small area).

- **Click the [TGT] button on the Orbit MFD and select Brighton Beach.**
  This is to define your target base. Use the arrow keys to choose Spaceports and then Brighton Beach, the only base on the (default) Moon.

- **Click the NML + button to orient in the normal-plus direction.**
  This is labeled "Orbit Normal +" in the control panel view (or use ; key). A burn in this direction will make this point an ascending node (with new orbit rising north of the equator as required to reach Brighton Beach to the northeast).

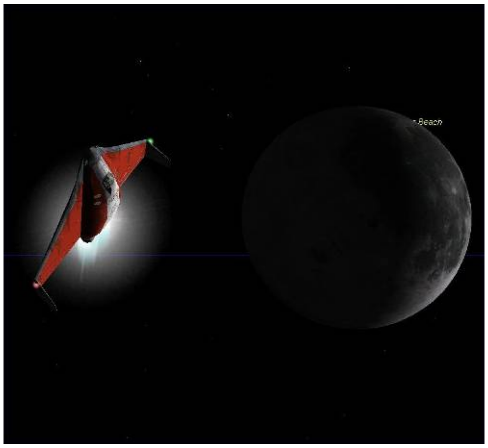
- **Start a main engine burn, keeping an eye on the Map MFD.**
  Try low thrusts or brief bursts. The orbital track will start to rise to the north – prepare to stop burning when the orbital track approaches Brighton Beach.

- **Reduce and cut off main engine thrust.**
  Burn time in recorded flight was about 23 s. In the recorded flight, the resulting inclination was about 126°. Adjust with linear or retro thrust if needed. Note that PeA as well as inclination have changed and PeA is too high (over 3000 km).

Periapsis Adjustment Burn – Since the plane change did not occur at a node, the burn also changed the periapsis altitude (PeA), though the orbit is still hyperbolic (Ecc > 1, not a closed orbit around the Moon). A retro burn is needed to reduce the PeA and allow capture into an initially eccentric but closed orbit. The position of this retro burn is not critical as long as it results in a closed orbit and PeA around 200 km. This is just an interim orbit and will need to be adjusted further for approach and landing.

- **Click the RETR GRD button to orient in the retrograde direction.**
  A retrograde burn will slow you down, allow capture into lunar orbit, and lower the periapsis height in initial preparation for approach and landing.

- **Apply full main engine thrust while monitoring PeA.**
  When PeA reaches about 200 km, stop the burn. In the recorded flight, this burn was about 30 s and resulted in PeA of about 186 km (ApA > 50,000 km, Ecc 0.93). Moon-relative velocity fell from around 1160 m/s to 610 m/s, a delta-V of about -550 m/s.



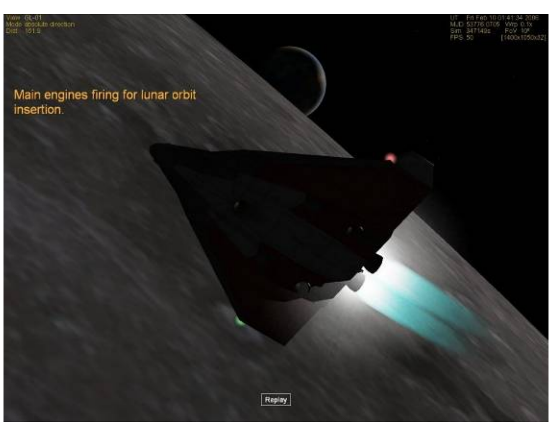
- ➢ **Turn prograde PRO GRD so you can watch the approach to the Moon.**
  In the recorded flight, this burn was completed some 20,000 s or over 5.5 hours (PeT 21.00k s above) before periapsis, so there is some time to kill (or time accelerate). Note that in the “upside down” prograde cockpit view, the lunar south pole is “up” so it looks like you are entering “behind” the Moon rather than “ahead” of it as you actually are.

Approach Orbit Insertion Burn – This retrograde burn will be made at the initial periapsis position to lower the orbit on the other side of the Moon, setting a very low new periapsis near the target base in preparation for approach and landing. Watch the PeT (periapsis time) value while you time accelerate to the burn position (the recorded flight uses 200x time acceleration).

- ➢ **When PeT reaches about 120 s, click the RETR GRD button to orient in the retrograde direction again.**
  Make sure you are at 1x time. This retro burn will lower the current, high apoapsis to set a new, much lower periapsis on the opposite side of the Moon, near Brighton Beach.

- ➢ **When PeT reaches 35 s, apply full main thrust.**
  This turns out to be about a 35 s burn in the recorded flight, so be prepared to pull back the thrust pretty quickly since you want a small (under 10 km) but positive PeA.

- ➢ **Turn prograde again if desired for the forward view.**
  You will need to turn retrograde yet again during the approach in order to use main engines for most of the deceleration for approach and landing.



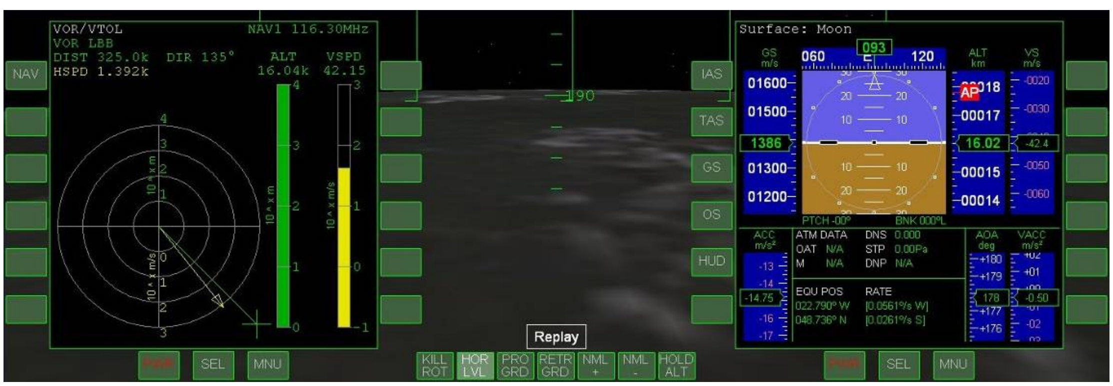
Approach and Landing

You are now in orbit around the Moon, but you won't complete a full orbit before starting the approach to land at pad 02 at Brighton Beach. The approach to Brighton Beach is much the same as that described in detail in chapter 3, although Dr. Schweiger's recorded flight does do a few things a bit differently. You can best follow and learn the details by watching the replay and reading and following his comments. Just be sure to set up the MFDs per instructions so it will all make sense (the playback will land you no matter what views or MFDs are displayed, but the comments will only make sense if you have the correct instruments and settings). Here are some key points to note. The times (in seconds) are the Sim counter times from the recorded flight, shown in the upper right screen corner. For reference, the landing time is 350740 s (just over 4 days from simulation start) so the time covered in this section is about 3500 s or just under one hour before landing:

- **Fast forward** to base approach (Sim 347261 to 349840 s) – Recording uses 20x.

- **Use Main Engines** – At about 400 km from base (349850 s), turn retrograde RETR GRD again to prepare for deceleration and path adjustment burns (you will approach the base tail first until just under 100 km in order to use main engines for this), and also turn level to the horizon HOR LVL for better control and orientation with the surface. Slow to around 1200 m/s to start.

- **Set Up MFDs** – Switch the left MFD to VOR/VTOL (landing), where the long range VOR beacon for Brighton Base (LBB) has already been set up as NAV1. Also switch the right MFD to Surface and click its [HUD] button to sync the HUD to the surface data. The Surface MFD provides a lot of information, most usefully the vertical speed (VS). You will need this to determine how much hover thrust you will need as your horizontal speed is decreased.



- **When to burn?** As mentioned in screen notes, main engines provide about 20 m/s^2 of acceleration, and if current ground speed is about 1200 m/s, it will take $t = v/a = 60$ s to kill all ground speed, and the distance would be $d = vt - \frac{1}{2}at^2$ or about 40 km. You generally will decelerate in stages rather than stopping and dropping straight down to the pad from high altitude, so you will start decelerating before this (as shown in the flight recording).

- **Use Retros** – Once you have slowed down to under 500 m/s and get within 100 km from the base (DIST value on VOR/VTOL MFD), you can rotate to face the base PRO GRD, and also open your retro engine doors with the panel switch (if visible) or by calling up the DG Controls dialog with Control-Spacebar and clicking the Retro Doors button there. Further slowing will be done with the low-thrust retro engines. Also switch to the Pad-02 ILS beacon (stored as NAV2) by clicking the [NAV] button on the VOR/VTOL MFD.

- **Watch Your Speed** – As you get closer to the base, continue to monitor and adjust both VS (with hover thrust) and ground speed (GS, with retro thrust), and to adjust your line up with LIN mode thrusters. At 10 km, you should slow to 200 m/s or slower, 100 m/s at 4 km, and under 20 m/s when you are within 1000 m of the base. Keep the VV (velocity vector or flight path marker ⊕ symbol) on or very close to the base.

- **Line Up and Hover** – You will lose sight of the pad before reaching it even with no-panel view, and you must then rely on the VOR/VTOL display to guide you to a landing. Stop over the pad and use hover thrust (and linear thrusters as needed to stay lined up) to establish a slow descent onto the pad. A small burst of hover thrust in the last few meters will soften the landing.

That's it – you made it back to the Moon!

Summary of Steps (Fly Me to the Moon)

Note: If you have the LandMFD add-on (LazyD's landing autopilot, LandMFD0514.zip), it may cause a problem with this scenario (when you cross the Moon's SOI) if it is activated in the Launchpad, even if you are not using its MFD in the current scenario. This problem may be fixed with a later version of LandMFD. We're not sure of the exact cause – it's just something that showed up in testing.

Launch Window Waiting

1. Start Orbiter, and open the scenario folder called Tutorials. From this folder, launch the scenario called Lunar Transfer.

2. Notice the Map MFD on the right side (below right). It is already set up with the Moon as the target orbit.

3. Notice the Align MFD on the left side

4. Watch and read the screen notes, or accelerate time with the [T] key until just before 02:19 UT on February 6.

Cleared for Takeoff

5. Apply full main engine thrust. Press the keypad [+] key, then the [CONTROL] key or use the throttles in panel view.

6. Watch the HUD for V100.0 which is rotation speed (time to raise the nose for liftoff).

7. Apply gentle back stick or press and hold keypad 2 to raise the nose and fly off the runway (pitch up to about 30°).

8. Raise the gear ([G]) and start a gentle (~30°) roll (bank) to the right.

9. At 90° heading, set the pitch to about 30° and continue climbing. You can actually adjust the heading to try to drive RInc as close to zero as possible (maybe 90°-100°).

10. (Optional but can be helpful) At 30-40 km, you may want to activate the rotational RCS thrusters with [/] on the keypad (if you are flying manually).

11. Above 40 km, allow pitch to fall to about 20° to start to build horizontal velocity, but keep varying pitch slightly as needed to keep climbing.

12. On the left MFD, click [**SEL**] and then [Orbit], then set projection to "ship" with the [**PRJ**] button, and set altitude mode with the [**DST**] button.

13. Keep burning until HUD velocity is around 7500 m/s and ApA is above 300 km, then kill main thrust with keypad ***** (or drag throttles to zero).

14. Switch HUD to orbital mode by clicking the [**HUD**] button on the Orbit MFD.

Tweak and Align the Orbit

Note: These steps not needed if following recorded flight or if hand-flown and RInc is around 0.4° or smaller

15. Restore the Align MFD to one of the displays with target Moon if you have closed it (click [**SEL**] then [**Align Planes**]).

16. For AN (Ascending Node) Case: Click the Orbit Antinormal (-) autopilot button (**NML -** at bottom of no-panel or ' key) and watch for Tn to reach around 60 s.

17. When Tn reaches half of TthA (time to thrust), apply full main thrust (throttles or keypad **+** key).

18. When RInc reaches ~0° and TthA reaches zero, kill the main engines.

Transfer MFD and Eject Burn

19. Select the Transfer MFD on the right side (click [**SEL**] then [**Transfer**]).

20. Click the target button [**TGT**], select Enter by Name, type moon, and press the enter key.

21. Click the [**HTO**] button to enter hypothetical transfer orbit mode.

22. Start to add delta-V by clicking the [**DV+**] button.

23. Use [**EJ -**] and/or [**EJ +**] to rotate the gray "later position" line to coincide with the yellow dotted line representing the Moon's later position.

24. Wait or accelerate time until DTe (eject time) is about 60 s.

25. Use **PRO GRD** autopilot button or [key to turn prograde for the eject burn.

26. When DTe reaches about 30 s, apply full main thrust.

27. When DTe reaches zero, press the [**Kill Rot**] button (or keypad 5 key).

28. When remaining Dv drops to ~600, start reducing thrust until Dv is close to zero.

29. Click the [**HTO**] button to turn off HTO mode.

Cruise and Correct

Once you are around 40,000 km or so from Earth and have all autopilots off, you can use up to 1000x time acceleration to speed up the cruise phase to the Moon.

30. **Base Alignment Burn** – Once the Moon becomes a significant gravity source (G 0.5 or greater at bottom of Moon-referenced Orbit MFD), a plane change burn will be needed to align orbit with Brighton Beach Moon Base.

31. On the Orbit MFD, click [**AR**] (auto reference) to select the strongest gravitational source, which is now the Moon.

32. Switch the right MFD to the Map (click [**SEL**], [**Map**], then [**REF**] and choose **Earth -> Moon** from the list of bodies that pops up.

33. Click the [**TGT**] button on the Orbit MFD and select Brighton Beach.

34. Click the **NML +** button to orient in the normal-plus direction.

35. Start a low-thrust main engine burn, keeping an eye on the Map MFD.

36. As the orbital track approaches Brighton Beach, reduce and cut off main engine thrust (fairly short burn, probably under 30 s).

37. **Periapsis Adjustment Burn** – A retro burn is needed to adjust to a PeA of ~200 km and to create a closed but very elliptical parking orbit.

38. Click the **RETR GRD** button to orient in the retrograde direction.

39. Apply full main engine thrust while monitoring PeA for a value of about 200 km (short burn, ~30 s).

40. Turn prograde **PRO GRD** so you can watch the approach to the Moon.

41. **Landing Approach Orbit Insertion Burn** – At periapsis, another retro burn is needed to lower the high apoapsis to a new very low periapsis (~10 km) on the other side of the Moon near the base.

42. When PeT reaches about 120 s, click the **RETR GRD** button to orient in the retrograde direction again.

43. When PeT reaches 35 s, apply main thrust (another short burn, ~30-40 s), watching PeA for a value just under 10 km.

44. Turn prograde again if desired for the forward view (although you will need to use the main engines for your main retro burns to slow down for the approach and landing).

Approach and Landing

Approach and landing are not described in detailed steps in this chapter. See the Moon landing instructions in chapter 3, which are very similar to this situation, or watch the playback (with comments) of the landing supplied for this chapter.

Dancing in the Dark

Rendezvous & docking is a fundamental and practical application of orbital mechanics. The Apollo Moon landing missions (1969-1972) depended on the ability of the Lunar Module (LM) to launch from the Moon and rendezvous and dock with the Command and Service Module (CSM) waiting in lunar orbit. A major goal of the earlier Gemini program (1964-1966) was to prove the feasibility of this key technique for the Apollo program. Dr. Edwin E. "Buzz" Aldrin actually did research and development on rendezvous and docking techniques in his 1963 doctoral degree work at MIT before becoming an astronaut and putting the techniques to the test on Gemini 12 (1966) and on Apollo 11 (1969), when he became the second man to walk on the Moon. Nowadays, U.S. Space Shuttles and Russian Soyuz and Progress unmanned supply ships rendezvous and dock with the International Space Station (ISS) to transfer crews and supplies.

In this chapter, you will again fly the Delta Glider to learn how to rendezvous and dock with the ISS in Orbiter. You will use the Scenario Editor to create the starting point for the mission, and the Synchronize Orbit and Docking MFD's will guide your way to the ISS. There is also a 36 minute annotated flight recording that you can watch to get a feel for the whole process, interrupting it at any time you feel like taking the controls yourself to complete the process.

Two and half meters to go and all lined up for docking with port D-01 of the future (completed) ISS. We've got it made. Getting here is the main goal of this chapter. The title "Dancing in the Dark" is the title of a chapter on orbital maneuvering in Wayne Lee's excellent book on space flight, *To Rise From Earth* (it's also a pretty cool song by Bruce Springsteen). I liked the title so well, I borrowed it for this chapter. For more information on Lee's book, see chapter 7, "Learning and Doing More."

Requirements for Rendezvous

To rendezvous with an orbiting target spacecraft, there are several important requirements:

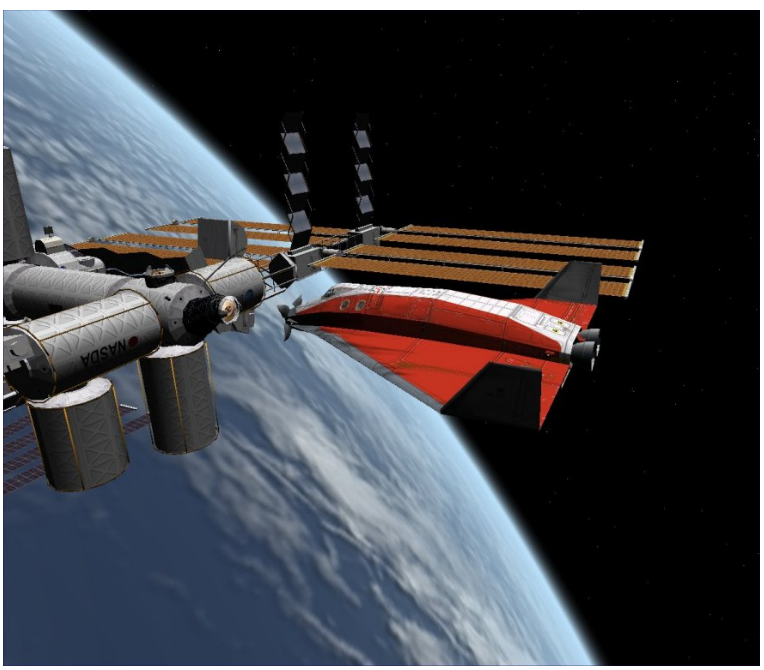
1. Orbital planes must be aligned to within 1° and preferably to 0.5° or smaller. This is accomplished with the help of the Align MFD as shown in earlier chapters, or in this case by setting the orbital inclination directly with the Scenario Editor.

2. The orbits of your ship and the target must be made to intersect at some point.

3. Your orbit must be adjusted to "synchronize" with the target's orbit, meaning that the orbits not only intersect, but that both ships reach the intersection point at very close to the same time.

Although these requirements could be met by trial and error using only the Orbit MFD, the Synchronize Orbits MFD (Sync MFD for short) allows you to choose from several intersection options and to "look ahead" several orbits to check for intersections or near-intersections. The Orbit MFD is still important because the Sync MFD only considers angular position around your orbit, not orbital height. It could show you at the intersection point even if the target is many kilometers directly above or below you (this is a fairly common error in learning to rendezvous and dock).

One question you might have is why we're not using the Transfer MFD as was done to "rendezvous" with the Moon. In fact you could and probably would want to do this to start with if you needed to rendezvous with a target in an extremely different orbit from your starting orbit, such as LEO (low Earth orbit) to GEO (geosynchronous orbit). In that case you might start out with the Transfer MFD and then use the Sync MFD to guide you in making the adjustments required to achieve the precise intercept necessary for rendezvous with a small target.

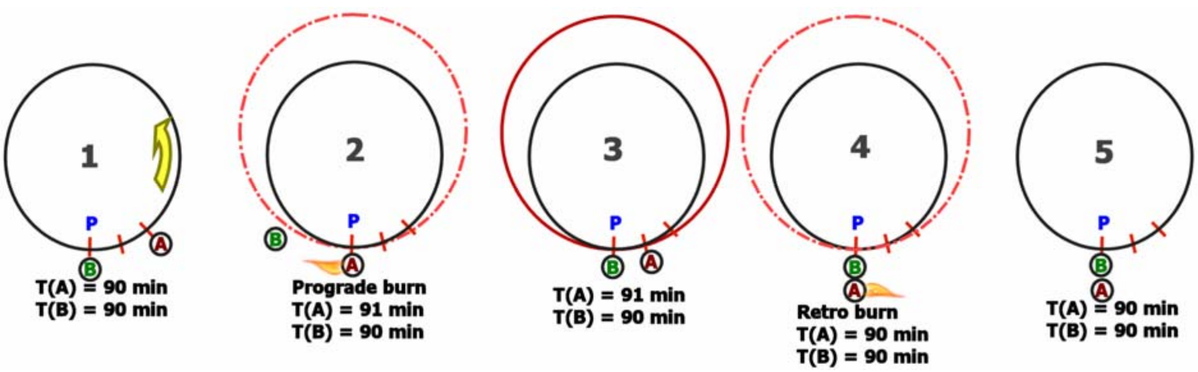


Another view of final approach – A systematic approach, attention to detail, a bit of patience, and judicious use of time acceleration will get you here from almost any orbit in 45 minutes of real time, maybe even less. The flight recording that demonstrates this chapter takes about 36 minutes to play back if you use the recorded time acceleration. Feel free to turn that feature off with Control-**F5** and control time acceleration yourself. This allows you to take more time to understand the details or enjoy the view. Or speed it up if you find some parts going too slowly for your taste (be careful not to overshoot as there is no rewind for the playback files).

A Basic Rendezvous Method

As with most things in Orbiter, there are several ways to rendezvous and dock, and the Sync MFD provides multiple intersection options to support these multiple methods, although all the methods are generally similar to use. We have decided to follow the example of Jared "Smitty" Smith's excellent "Orbital Operations" tutorial (http://smithplanet.com/stuff/orbiter/orbitaloperations.htm) and use the periapsis/apoapsis method. This has the advantage that it cleanly separates the setting of the intersection point and the orbital adjustments needed to achieve "sync." It is not necessarily the fastest method, since one or more orbits might be "wasted" getting to periapsis or apoapsis when an alternate intersection point might be available sooner. But it builds on your knowledge of the properties of burns at periapsis and apoapsis and uses only prograde or retrograde burns (assuming that orbital planes have already been aligned). In this case, periapsis is chosen, but apoapsis also works well as a reference point.

In the figures below (assumed in-plane, not to scale), ship **A** is *you*, and ship **B** is the *target* (ISS), which is assumed to not maneuver at all. The sync problem is shown schematically. In figure 1, the two ships are in the same circular orbit, but at different angular positions (orbital longitudes) such that your ship **A** always passes reference point **P** **two minutes** sooner than ship **B** (the target).



It's clear that with the same orbital period , T(A)=T(B)=90 minutes, the two ships will never "catch up" with each other. Something has to change. If your ship **A** makes a small prograde burn at P (figure 2), this burn point becomes its periapsis, and its orbital period is increased by (say) one minute. The other figures show what happens as a result on the next two orbits. By "speeding up" with a prograde burn, you now have a bigger elliptical orbit that takes one minute longer to complete than the target's (**B**) still-original orbit. So on each orbit you "fall back" by one minute. After two orbits, you have fallen back by two minutes and now reach the point P at the same time as the target ship **B** (figure 4). To prevent falling back further, you would need to make a small retro burn at P to return to the original smaller circular orbit (velocity as well as position matched or "synced" with the target, figure 5).

In general, it won't be quite this simple. Both orbits would probably be elliptical, the difference in arrival time won't be a simple number like 2 minutes, and the adjustment burn to match orbits with the target when you get near it won't be a simple retro burn. But the Sync MFD handles the numbers to allow you to line up the times pretty easily for the general case.

Docking Notes

Rendezvous or orbit synchronization can get you close to your target (within a few kilometers or even closer), and then the docking HUD and Docking MFD will help you with the rest. The first job once you are close in *position* is to also get yourself close in *speed*, adjusting your relative velocity to make your orbit closely match that of the target . Symbols projected on the docking HUD show you relative velocity as well as position information, giving you visual cues on where to point and thrust to reduce your relative velocity, and on where you are heading relative to the target. Unless your orbit is almost exactly the same as the target's when you get close to the target, you will find that it can take several cycles of reducing relative velocity, pointing and thrusting toward the target, adjusting alignment, and again fixing up the velocity. Although the HUD and MFD give you good feedback, "keeping everything happy" can seem like a juggling act at first. The details are easier to explain with an actual example, coming up shortly. It can also help to watch the flight recording, which realistically shows how this can all work. An expert could probably make a faster, more efficient, and more accurate approach than what is shown in this recording, but this way you can learn from those mistakes as well!

Setting Up

In the case of the Space Shuttle docking with the ISS, available delta-V is very limited and orbital plane alignment with the target and preparing for a close intersection are done mainly by choosing the right launch window and flying a precise ascent. Using the Delta Glider, you have plenty of delta-V, and you could start with nearly any LEO situation and make the necessary burns to align orbits, rendezvous, and dock with the ISS. But in this case we will show you a different set up method that's possible only in Orbiter – the Scenario Editor.

The Scenario Editor has many capabilities and is explained in more detail in Appendix B and in its own PDF manual installed in the Orbiter /Doc folder. In this case you will use its ability to directly change the orbital elements of any spacecraft in the currently running scenario, starting with a scenario where you are already docked and modifying it to put the DG in a different starting orbit. We will give the basic steps here without explaining too much about the orbital elements or the Scenario Editor.

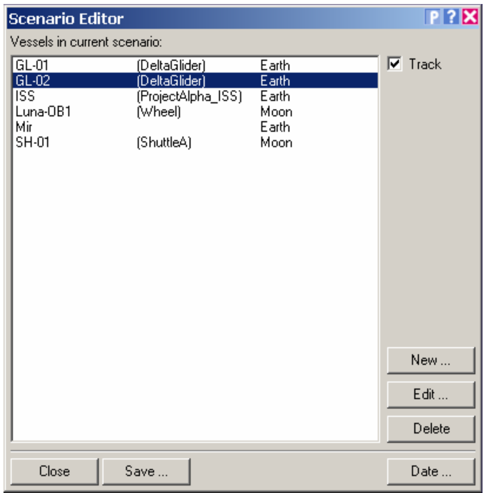
Flight Recording

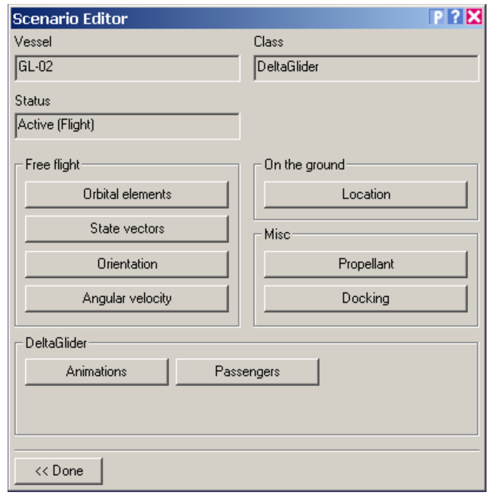
An annotated flight recording of this chapter (**DG-ISS Sync-Dock.scn**) is installed with Orbiter in the Scenarios/Tutorials folder. This scenario already includes the setup steps shown here, so if you wish to skip the setup steps, you can start with the playback scenario instead, using the Control-F5 "Stop" button to interrupt playback at any time you wish to take over manually and follow the steps in this chapter yourself. If you play back the whole thing with the time acceleration as recorded, it will take 36 minutes.

- **Start Orbiter and activate the Scenario Editor in the Modules tab.**
  The module is called ScnEditor and it is not active by default. Select it in the list of available modules and click the button to add it to the active list on the left. Once you do this, Orbiter will remember this setting for future sessions.

- **On the Scenarios page, check the "Start paused" check box and launch the scenario "DG Docked with ISS," in Delta-glider folder.**
  Yes, it's already docked, but you will soon change that. Starting in pause will allow you to change the conditions of the scenario before anything moves.

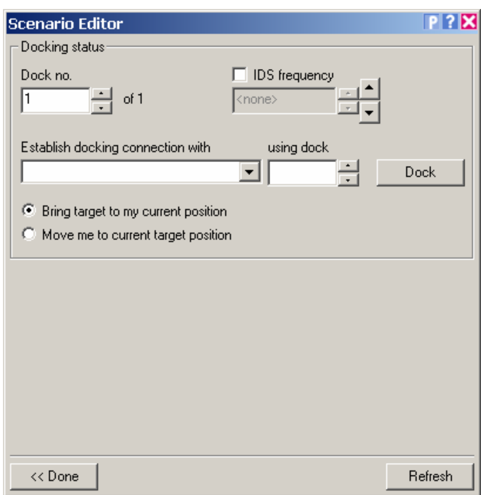
- **Press Control-F4 and launch the ScnEditor module from the dialog box.**
  See below left (main page). Note that the current ship GL-02 is already selected for editing.

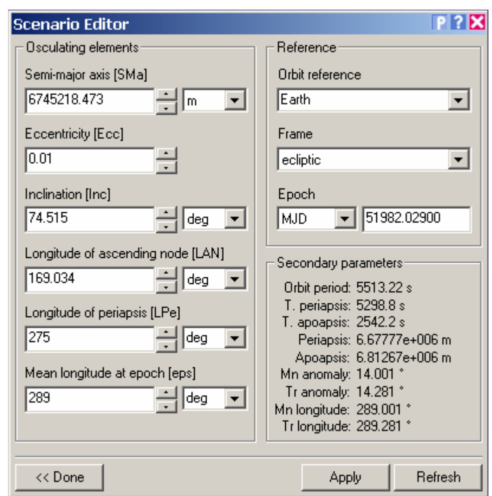




- **Click the Edit button, then on the edit page, click the Docking button.**
  The edit page is shown above right – it's mostly selector buttons.

- **On the Docking page, click the Undock button, then click <<Done.**
  See below left (after clicking Undock). Nothing visible happens yet (simulation started paused) but Orbiter can now move the DG independently of the ISS.





- **Back on the edit page, click the Orbital elements button.**

- **Enter the numbers in the table below.**
  Be careful to keep the text cursor in the editor window. Note that most of these values are pretty small changes from the starting (ISS) orbital elements, since we are keeping the new orbit pretty similar, as if we had launched from a good launch window to give good alignment and a fairly small (8°) angular difference in orbital position. Since you will need only relatively small burns to complete the rendezvous, a similar setup could also be used for docking practice with the Space Shuttle Atlantis (which could even be added in the Scenario Editor). You might want to practice with the DG first since the Shuttle has a few special challenges for docking, including a docking port that is on top instead of in the nose.

SMa	Semi-major axis (orbit size parameter, meters)	6745218.473
Ecc	Eccentricity (deviation from circular)	0.01
Inc	Orbital inclination ("tilt" of orbital plane)	74.515°
LPe	Longitude of periapsis (angular position of periapsis)	275°
eps	Mean longitude (measure of position around orbit)	289°

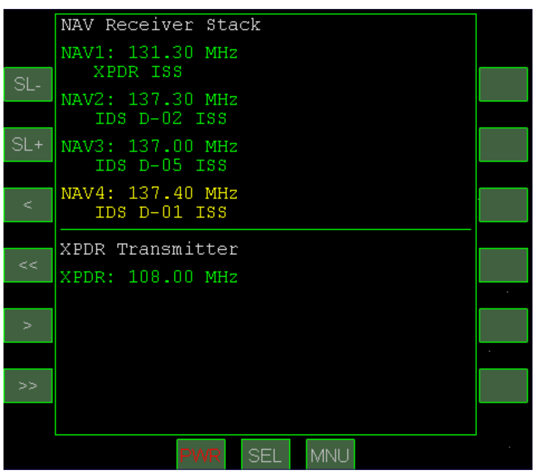
- **Click Apply, then << Done and finally the Close button to exit the editor.**
  Before you close, you may want to click the Save… button and save a copy of this starting point for later use. The Save dialog allows you to enter a name and description for the scenario.

- **Press Control-P to take Orbiter out of pause.**

- **Press F8 to change to the no-panel view.**
  This is not critical, so use the 2D panel or virtual cockpit view if you prefer, but visibility for docking is a lot better with the no-panel view, and all the critical buttons are available there (the no-panel view is also available for any spacecraft – many add-on ships have no panels).

- **On the right (Orbit) MFD, click the [DST] button.**
  Orbit MFD is good to keep on the right to start, and DST sets it to display altitude (Alt, PeA, ApA) instead of radius (Rad, PeR, ApR), which is a little more convenient for most things.

- **On the left MFD, click [SEL] then [NAV/COM] and define radio frequencies.**
  Highlight a frequency with the [**SL-**] and [**SL+**] buttons, change the integer part (108 to 139) of the selected frequency with [<<] and [>>], and change the fractional digits (.00 to .95) with the [<] and [>] buttons to match the picture below (it may not display the IDS info now).

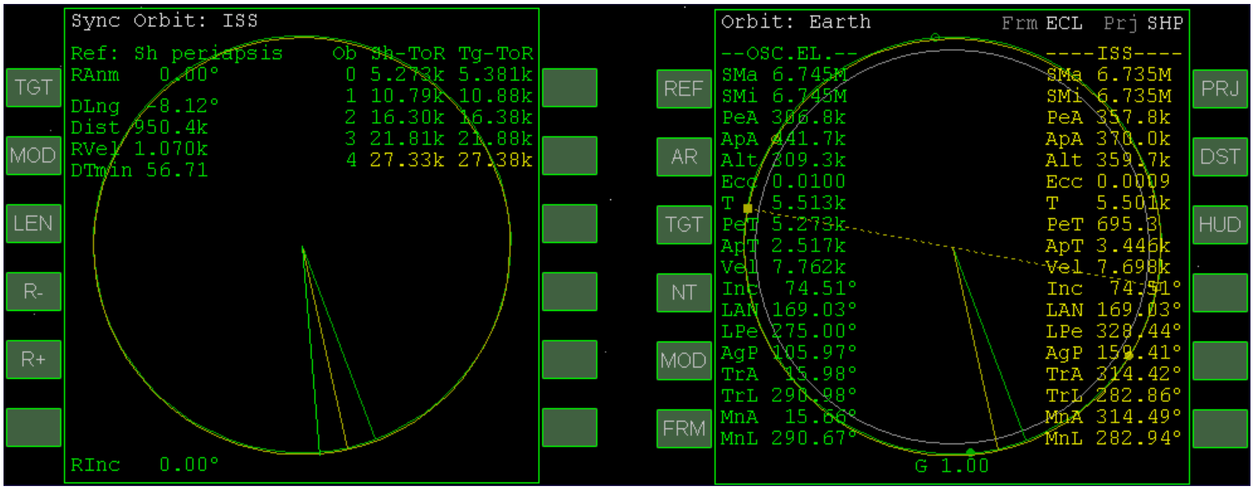


- **On the left MFD, click [SEL] then [Sync Orbit].**

- **On the Sync MFD, do the following two setup steps.**
  1. Click [**TGT**] then choose or enter **ISS**.
  2. Click [**MOD**] a few times until **Sh Periapsis** appears at the top left.

You may want to do a Quicksave (Control-S) now to include the MFD and frequency information. It's time to learn how to get back to the ISS where you started out a few minutes ago.

Rendezvous



Take a look at the Orbit MFD above right, and you'll see that as expected, your Delta Glider is now in a slightly different orbit from that of the ISS, giving you a couple of problems to solve. If you have done the scenarios in the earlier chapters (or have other Orbiter experience), you will see some familiar values on the Orbit MFD (note the differences between the DG and ISS orbits above, especially PeA, ApA, Ecc, and T). Note that the radius vector for your ship (green line) is a few degrees ahead of that of the ISS (yellow line), and both have just passed your periapsis (solid green dot).

That Syncing Feeling - In fact the Sync MFD tells you that in the recorded flight, your angular position is 8.12° ahead of the ISS position (difference in longitude, DLng). Note also that the ISS has already passed *your* periapsis, which we have chosen as the intercept reference point (Ref) in this case. This means you will have to go around almost a full orbit before the ISS will again reach your periapsis, where you will note and *write down* its altitude (Alt) so you can later adjust yours to match it. You will want to use time acceleration to speed through a couple of orbits before you will have everything set to dock.

Another important thing to note on the Sync MFD is the table on the upper right, with orbit numbers (Ob) zero to four, and columns for Sh-ToR (ship time on reference, your periapsis in this case) and Tg-ToR (target time on reference). None of the Sh and Tg values matches exactly, and we need them to match somewhere in order to dock. In the screen above, they come closest four orbits (or five, depending on whether you count orbit zero) in the future, on Ob 4. How close? That's the value DTMin (delta-time minimum), which is 56.71 seconds at the moment. Close, but not quite close enough to dock (actually you probably could use the docking HUD from 56 seconds, but it might take a while to close on the target).

The instructions in this chapter will be a little briefer than earlier chapters, and we will show somewhat fewer screen shots, since you've got the entire flight recorder playback to watch if you want to check on any details. The playback has the further advantage that you can slow it down or pause, change views or MFD's, and view it as many times as you need to understand what was done and why. And you can take control at any time you wish. We will assume you are in the no-panel view for best visibility.

- **Carefully accelerate time (10-1000x) until the ISS is approaching your periapsis, then slow to 1x.**
  Your periapsis is the green solid dot in the Orbit MFD. Use [T] and [R] to accelerate and slow time, being careful not to overshoot, though if you do, just go around another orbit.

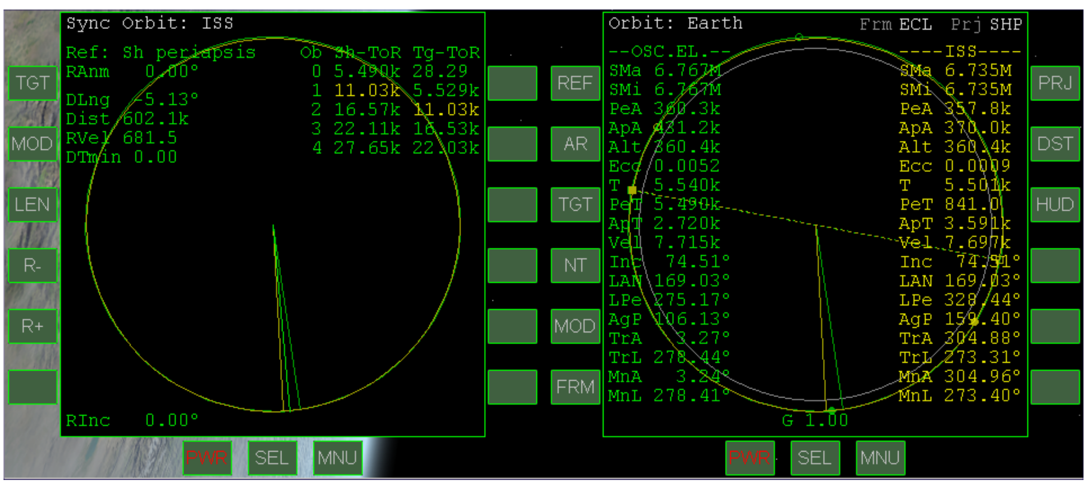
- **When the ISS reaches your periapsis, pause or slow to 0.1x and <u>write down</u> the Alt (altitude) value of the ISS there.**
  In the recorded flight this value was 360.3k and yours should be similar if you used the set up above. But record whatever value you actually have when the yellow line hits the green dot.

- **Accelerate time again until your ship is close to apoapsis (e.g., ApT ~60), go to 1x, and turn prograde.**
  Be careful not to overshoot, and use the [PRO GRD] button.

- **When you reach apoapsis, apply several short bursts of main thrust to raise your periapsis (PeA) to exactly match the ISS altitude you wrote down.**
  Use keypad [+] with very brief pulses. You will be raising your periapsis altitude (PeA) to match the ISS altitude you noted above. If you overshoot, use forward/backward (keypad [6]/[9]) linear thrusters to adjust PeA to the ISS altitude you noted earlier. Turn off prograde to save fuel. It's really not critical in this case, but on longer flights, you might use time acceleration for a long time, and if the ship is holding prograde, the thrusters could use up all your fuel!

- **Accelerate time again until your ship is close to periapsis (e.g., PeT ~60), go to 1x, and turn prograde.**

- **When you reach periapsis, watch the DTMin value in the Sync MFD, and use forward/backward linear thrusters to adjust it to zero.**
  The adjustment in this case is quite small (DTMin in the recording was only about 13 seconds), so be sure you are in translation (LIN) RCS mode, and use only forward/backward (keypad [6]/[9]) linear thrusters to adjust PeA to drive DTMin as close to zero as possible. Again turn off prograde to save fuel. Take a look at the MFD's below, just after DTMin adjustment for the recorded flight. Note that DTMin is 0.00 as expected, and that the ship time on reference point (Sh-ToR) value is 11.03k seconds, or just about two orbital periods away (T = 5.540k).

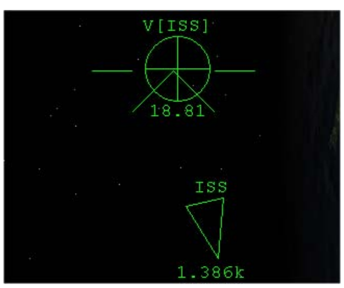


- **Carefully accelerate time (10-1000x) until the top line of the Sync MFD is yellow.**
  This will be about two orbits. The yellow line represents the orbit where the target will be closest among those listed. Recall that Sh-ToR is your time to the reference line, so when you get to about 900 for this value (15 minutes from intercept), go to 1x time and prepare for docking. On the final two orbits, the green and yellow radius vectors will converge, and the angular difference DLng will get smaller, as will the distance (Dist) and relative velocity (RVel). You will also be happy to see the sun rising around 600 seconds before intercept, so you can dock in daylight.

Docking

It's important to pay attention in space! In the recorded flight, I think I got a bit carried away with the scenery or something, because as I reached 190 seconds Sh-ToR (3 minutes to intercept!), I was over the coast of England waving hello to Dr. Schweiger in London instead of thinking about slowing my approach to the ISS which was only 3.5 km away and closing at about 18 m/s. Actually I wanted to end up stabilized (zero relative velocity) about 1 km from the ISS to avoid an overly long approach, but I started my tail-first approach burn late (as above, looking at Italy) and I ended up stopping at 800 m instead. A bit close, but it worked out OK. Here are the steps to follow, with suggestions for a bit more safety margin. Note that not all Sync MFD approaches work out quite this precisely, and your nearest approach to the target may be several kilometers. The Docking HUD and Docking MFD can still work in such cases (see Smitty's Orbital Operations Tutorial for more general instructions).

- **At around 5 km from the ISS, rotate your nose to the V[ISS] symbol as shown.**



If you are pointed at the ISS as you close in the last few minutes, you will see the –V[ISS] (plus sign) symbol which indicates the direction of your closing velocity. The V[ISS] is 180° from this direction and therefore "behind" you, so you will need to rotate (pitch or yaw) and point your *tail* at the ISS. Pointing at the V[ISS] HUD symbol and thrusting ***forward*** will reduce the relative (closing) velocity, the value of which is displayed under the symbol (18.81 m/s here). Note that when the target is off-screen, an arrow shows its direction and distance (1.386 km in this case).

- **At around 2 km, start to thrust toward the V[ISS] symbol.**
You could start sooner and use linear RCS thrusters, but a couple of careful main engine pulses will kill most of the relative velocity in this case. In other docking situations, you may have a larger closing velocity and may need to be more aggressive with the main engines. You can then

use linear thrusters (forward/back) to reduce it further. The goal is to get very close to zero (0.01-0.03 is OK) at about 1 km distance from this ISS. Note that as you get closer, the direction will change, and you may need to switch back to rotation to re-point the nose at the velocity indicator before applying further linear forward/back thrust to zero it out (shown in the recording).

- **Rotate to put the nose on the ISS, then set up for docking as follows.**

If you are only a kilometer or so from the ISS with zero RVel, the Sync MFD has done its job and you can power it down to give better visibility for docking (assuming you are using the no-panel view). But if you have Orbiter Sound installed, you may be hearing an annoying beep now – the radar proximity warning. You can turn it off before closing the left MFD.

1. On the left MFD, click [**SEL**], [**Radio/MP3 panel**], [**RAD**], and [**PWR**] (off).
2. On the right MFD, click [**SEL**], [**Docking**], [**NAV**] (three times), then [**HUD**].

This will set up the docking MFD to use NAV4 which has been set to 137.40 MHz, the IDS (instrument docking system) frequency for ISS docking port D-01. The ISS in Orbiter has five docking ports – you can find this and other detailed information in the Control-I (info) dialog box. Why port D-01? It worked out OK in the recording, although it was not pointing in my approach direction. Feel free to try out other ports and see if they seem easier to approach (you can cycle through the four defined frequencies with [**NAV**] and send the port info to the HUD with the [**HUD**] button).

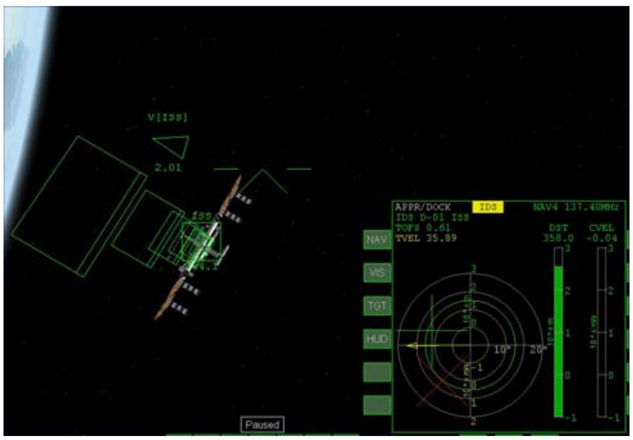
- **Use lateral LIN (left/right, up/down) thrusters to move the –V[ISS] symbol onto the outer docking boxes as shown below.**

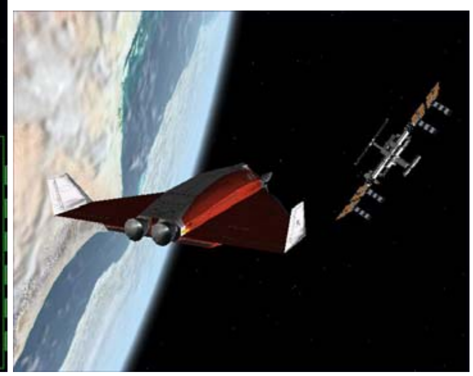
The docking boxes are like a "road in the sky" leading to the selected docking port. If you just head directly for the ISS, it will be hard to get lined up with the docking port. The docking boxes are like an ILS glide path for a runway (if you are familiar with instrument approaches!).

- **Use forward RCS thrust to start closing on the boxes.**

Here's where you need some patience (or some 10x warp), since 740 m at 1.5 m/s will take 8 minutes to cover. This is nothing in real world docking (the Space Shuttle takes days to rendezvous with the ISS, hours for the final few hundred meters and docking), but you can get tired of waiting. You can stay fairly slow and use 10x time acceleration, or you can try some small bursts of main and retro engines (better open the retro doors to be ready, Control-Space).

- **When you get near one of the outer docking boxes, switch to rotation and turn and face the ISS.**
  Recall that keypad-/ toggles between LIN and ROT (or you can use the screen buttons in the upper left corner of the no-panel view). You may not really be "inside" a box at first – you may be above or below or otherwise offset from it. You will probably need more lateral translation as well as rotation to get into position to "slide down" the docking boxes, and you may pass the ISS at some point and see your closing velocity (CVEL) go from positive to negative – this is OK since you are going to one of the outer docking boxes to get lined up before trying to close the range for docking (you could also get lucky sometimes and pick a docking port whose IDS boxes point right toward you, saving you a lot of maneuvering). Don't worry about perfect alignment or position now – just pointing at the ISS with the docking boxes somewhere in front of you is OK for starters (as in the example below).

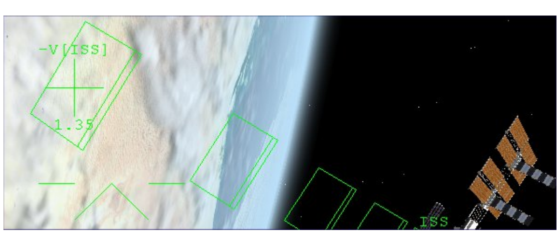




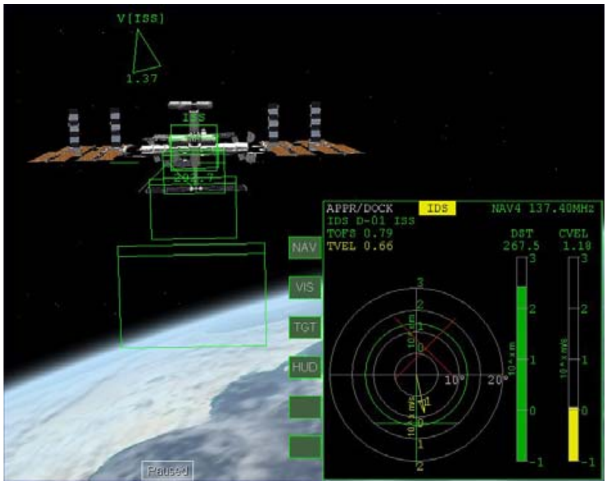
  This maneuvering can be confusing at first. Feel free to use the outside view to get a better feel for the 3D geometry of your approach. You won't see the docking boxes, but by spinning your view with the right mouse button, you may be able to better visualize the situation.

- **If your closing velocity (CVEL) is positive, use forward or backward LIN thrust (keypad 6/9) to drive it close to zero.**
  CVEL of around 0.02 or 0.04 is OK – you just don't want to close the range much more until you can really get the IDS boxes in front of you, and start to get aligned rotationally (this is the X symbol shown in red in the Docking MFD above), and somewhat aligned laterally (that's the green plus sign). Just having the X and the + appear on the MFD is good enough for now.

- **Use lateral (left/right/up/down) LIN thrusting to put the –V[ISS] HUD symbol inside one of the outer boxes and thrust toward it.**
  Remember that this symbol shows where you are heading relative to the ISS. It's OK to have a positive CVEL if it's taking you into one of the boxes (the picture is intentionally cropped to show mainly the boxes, showing only part of the ISS itself).

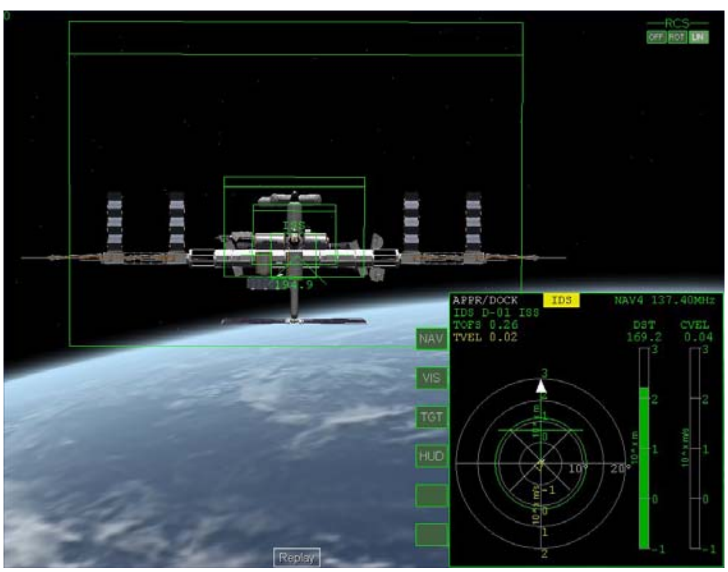


- **When you get nearly inside one of the boxes, switch to ROT and use pitch, yaw, and roll to point at the ISS and get lined up with the boxes (double-line at top).** Once you get in the "right" orientation things will seem a lot less confusing and you can begin to mentally separate your problems as rotational (pointing, shown by the MFD **X**) and lateral alignment (shown by the MFD **+** sign). Rotation should be solved first, even if you feel you are too high or too low as a result. Closing a bit fast in this view (1.18 m/s), need to slow down.



- **Use linear RCS thrusters to slow CVEL to nearly zero again.** You need to stabilize several hundred meters away to complete your alignment with the HUD boxes and get ready to fine tune the alignment with the Docking MFD.

- **Use rotational RCS thrusters to get the Docking MFD X symbol lined up with the center of the rings (angular alignment).** ***Rotate toward the X*** – if it's above the center in the MFD, pitch the nose up (keypad 2), if it's to the left, yaw left (use Kill Rotation as needed). It can be a little off now, but get it mostly lined up (the X will turn white). This will make your nose-tail axis parallel with a line sticking straight out of the docking port. With this solved, you will know that any deviation you see is due to lateral shifts and not due to looking from a skewed direction.

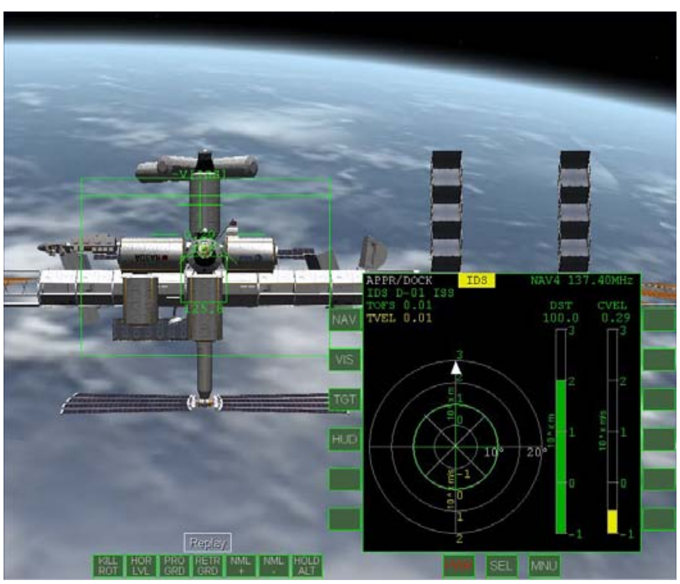


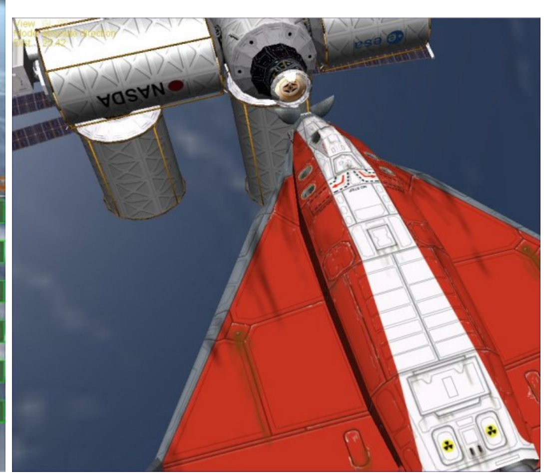
- **With angular alignment solved, use linear thrusters to line up the MFD "plus sign" with the center of the rings for lateral alignment**.
  Thrust toward the MFD cross to move it – think of this as the target, and if the target is to the left, you thrust to the left. You will also notice an arrow that appears on the MFD to show the direction and magnitude of your lateral motion. This will usually take a number of tries and constant adjustment until you get a feel for it. You may also find that the angular alignment drifts a little – if so, switch to ROT and correct it, using fine thrusters (Control-keypad) if necessary to really center it (it should stay centered pretty well on its own unless you have gravity gradient torque and/or nonspherical gravity sources checked in the Launchpad Parameters page – these settings are more realistic but can make docking a bit more challenging). *Don't forget to switch back to translation (LIN) RCS mode.*

- **When angular and lateral alignment are both good and relatively stable, use LIN forward thrust (keypad-6, not main engines) to start to close on the port.**
  You can close at 0.3-0.5 m/s or so, slow enough to make corrections but fast enough to see progress. When you get within 5 m or so, you should slow to about 0.10 m/s for final docking. When you are stable, you will find that the -V[ISS] cross will sit just a bit higher than the docking port (because the DG's docking port in the nose is lower than your eye point). The key point is "when you are stable" because if there is any lateral velocity, the cross will drift. Use both the outside view and the Docking MFD to keep track of what's happening and try to keep everything "happy." *Unless the MFD **X** gets off-center, use only LIN thrusters from now on – **no rotations**.*

- **Open the nosecone with [K] to expose the docking port (if you ever closed it).**
  In the recorded flight, I never did close it. Bad form! Check the outside view to be sure whether it's open or closed (there is no nose cone position indicator on the no-panel cockpit view).

- **Slow to around CVEL 0.1 m/s to close and dock.**
  If you get substantially out of alignment when within DST 75 m or closer, it's best to back up to 100 m or so, reduce separation rate to near zero, and fix your line-up, then start to move in again. It's quite hard to fix a bad alignment when you are very close – as with a good landing in an airplane, the secret of good docking is a good approach. Congratulations on docking!





Summary of Steps (Dancing in the Dark)

These summary steps are relatively brief, so refer to the main text and/or pictures if any points are not clear. This is mainly to prompt you in the steps once you are familiar with the procedure. Note that this is not the only way to do rendezvous and docking, but this is a good start.

Setup

Follow the steps on page 5-3 through 5-6 to set up the starting point with the Scenario Editor

OR

Skip the setup by starting with the playback scenario **`DG-ISS Sync-Dock.scn`** located in the Scenarios/Tutorials folder, using Control-F5 to interrupt the playback whenever you wish to start doing the following steps yourself.

Rendezvous/Sync

1. Carefully accelerate time (10-1000x) until the ISS is approaching your periapsis, then slow to 1x.

2. When the ISS reaches your periapsis, pause or slow to 0.1x and *write down* the Alt (altitude) value of the ISS there (On Orbit MFD, the ISS altitude when yellow line aligns with solid green dot).

3. Accelerate time again until your ship is close to apoapsis (e.g., ApT ~60), go to 1x, and turn prograde.

4. When you reach apoapsis, apply several short bursts of main thrust to raise your periapsis (PeA) to exactly match the ISS altitude you wrote down (use linear 6/9 thrusters to fine tune the value).

5. Accelerate time again until your ship is close to periapsis (e.g., PeT ~60), go to 1x, and turn prograde.

6. When you reach periapsis, watch the DTMin value (minimum time separation at reference point, which is your ship's periapsis in this case) in the Sync MFD, and use forward/backward linear thrusters to adjust DTMin to zero.

7. Carefully accelerate time (10-1000x) until the top line (orbit 0) of the Sync MFD is yellow. Slow to 1x time and prepare to slow down for docking (pause or slow to 0.1x while you read docking steps).

Docking

8. At around 5 km from the ISS, rotate your nose direction symbol to point directly at the V[ISS] symbol (circle with plus sign). This will be behind your ship, so your engines will be pointing at the ISS.

9. At around 2 km, start to thrust toward the V[ISS] symbol (short bursts of main engines) until V[ISS] is close to zero (0 to 0.02). Use linear thrusters to fine tune so you are not closing significantly with the ISS, but "hovering" about 1 km away.

10. Rotate to put the nose on the ISS, then set up for docking as follows (1) Power off the left MFD (2) Display the Docking MFD on the right with [SEL] and [Docking]. Click [NAV] three times then [HUD]. You should see the HUD docking boxes leading to port D-01.

11. Use lateral LIN (left/right, up/down) RCS thrusters to move the –V[ISS] HUD symbol onto the outer docking boxes.

12. Use forward RCS (linear) thrust to start closing on the boxes.

13. When you get near one of the outer docking boxes, switch to rotation RCS and turn and face the ISS.

14. If your closing velocity (CVEL) is positive, use forward or backward LIN thrust (keypad 6/9) to drive it close to zero.

15. Use lateral (left/right/up/down) LIN thrusting to put the –V[ISS] HUD symbol inside one of the outer boxes and thrust toward it.

16. When you get nearly inside one of the boxes, switch to ROT and use pitch, yaw, and roll to point at the ISS and get lined up with the boxes (double-line at top).

17. Use linear RCS thrusters to slow CVEL to nearly zero again.

18. Use rotational RCS thrusters to get the Docking MFD X symbol (which may not be visible if you are badly misaligned with the port) lined up with the center of the rings (angular alignment, it will turn from red to white when lined up). Rotate toward the X in the MFD to center it.

19. With angular alignment solved, use linear thrusters to line up the MFD "plus sign" with the center of the rings for lateral alignment. Thrust toward the MFD cross (+) to center it.

20. When angular and lateral alignment are both good and relatively stable, use LIN forward thrust (keypad-6, not main engines) to start to close on the port.

21. Open the nose cone (if closed) with K to expose the docking port.

22. Slow down to around CVEL 0.1 m/s to finally close and dock.

Mars Awaits

For centuries human beings have dreamt of one day making a journey to Earth's mysterious neighbor - Mars. This chapter will attempt to guide you on that journey, all the way from the surface of the Earth, to Martian orbit over Olympus base. From there you can take the final step of your journey to the surface of Mars. The flight will take place in a standard Delta Glider, planned and guided with the optional add-on IMFD by Jarmo Nikkanen, starting with the scenario "1. Awaiting Take-off from Canaveral" that comes with this tutorial. Upon arrival in Martian orbit you will have the choice of making a manual or an automatic landing using LandMFD. Either way I will describe what actions to take when the time comes. The flight time in the real world is around 6 months, so I have packed a number of zero-G board games and other activities back in the passenger compartment so you won't get bored.

The Scenarios necessary for this tutorial can also be downloaded here:
http://www.aovi93.dsl.pipex.com/scenarios/From_Earth_to_Mars.zip

IMFD v4.2.1 (minor 2006 update, by Jarmo Nikkanen) can be downloaded from here:
http://koti.mbnet.fi/jarmonik/Orbiter.html

LandMFD (by LazyD) can be downloaded here:
http://www.aovi93.dsl.pipex.com/others_addons/LandMFD0514.zip

Delta Glider in LEO, just before departure to Mars. Say 'Goodbye to Blighty!'.

The scenarios and the steps needed to fly to Mars were designed, written, and tested by Andy McSorley, while Bruce Irving provided nagging, additional testing, and a bit of interplanetary background material that you will probably skip.

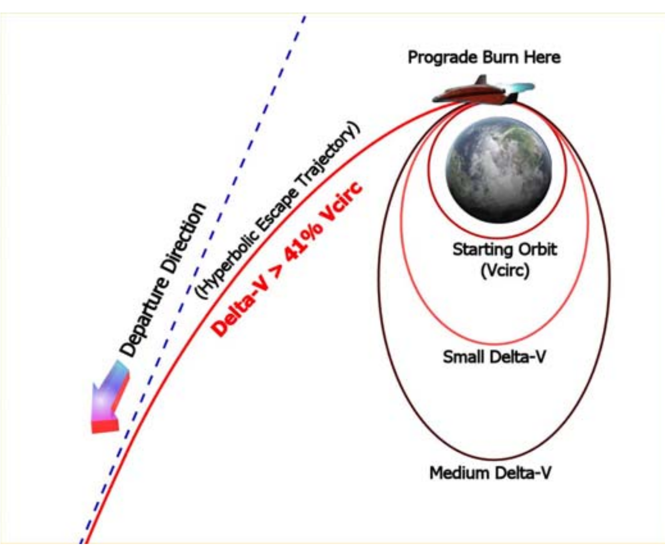
The formatting of this chapter is a little different from earlier chapters but should still be easy to follow.

Background – Interplanetary Trajectories

If you are anxious to get flying and want to skip this background material for now, just jump to the heading "Let's Get Flying." Make sure you have IMFD installed and activated before launching one of the supplied scenarios.

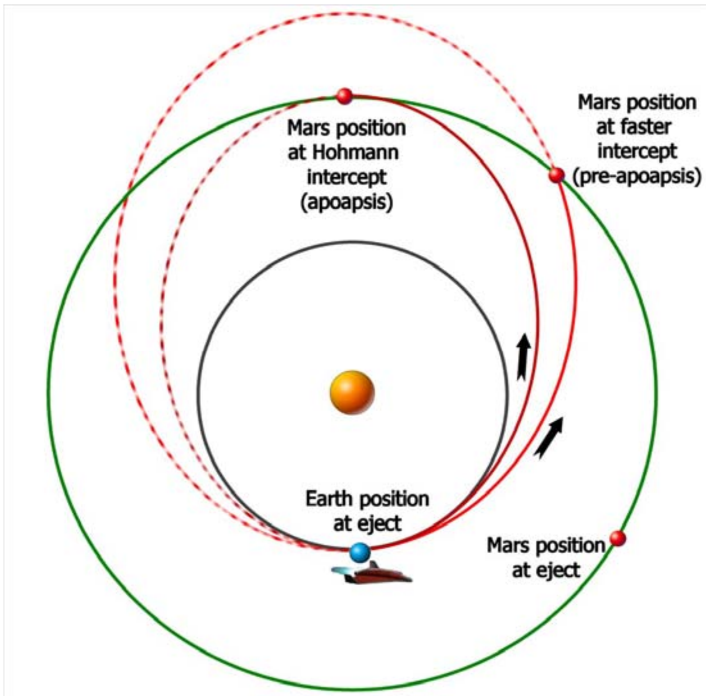
Are you sitting still? Of course not. Even if you're not reading this in some sort of moving vehicle, you are rotating with the Earth's surface (464 m/s at the equator), and traveling around the Sun with the Earth in its orbit (29,800 m/s on average). These non-apparent motions give you a much needed boost when you make interplanetary flights, for which you first must typically achieve low Earth orbit (LEO, around 7500 m/s), then fire your engines at the right time and direction to achieve escape velocity. This leads to a transfer orbit around the Sun, carefully planned and timed to intercept the orbit of the target planet just when the target planet arrives at that point in space. As with other orbits, once the transfer orbit is established with the eject burn, you will just coast to your destination (other than a small course correction burn or two). Additional steps are needed to enter into orbit and land at the desired spot on the planet. Orbiter includes tools to support all these steps, but the optional add-on Interplanetary MFD (or IMFD) by Jarmo Nikkanen incorporates most of the required tools and makes the process somewhat easier. But before you start pressing the buttons, you will want to have an idea of what you will be doing.

Planning Your Escape - If you have tried the Moon flight in Chapter 4, you might think you have already escaped from Earth's gravity, but you haven't quite. The Moon is also in orbit around the Earth, so a Moon flight is really just a transfer from one Earth orbit to another (very high) Earth orbit. But to go to another planet, you must escape Earth's gravity and go into orbit around the Sun. If you are already in Earth orbit, you can achieve escape velocity by making a prograde burn that adds at least 41% to your circular orbital velocity (Vcirc). For example, for a circular orbit of 300 km altitude, orbital speed is 7.73 km/s, and to just reach escape velocity, you must add 3.17 km/s for a total of about 11 km/s relative to the Earth. Note that this 41% rule means it takes less absolute ΔV to escape from a high orbit than from a low one, but of course it took more ΔV in the first place to reach the high orbit, so there is no free lunch. In practice, you will add more ΔV than minimum to have some remaining speed ("hyperbolic excess velocity") when you pass the Earth's sphere of influence (SOI). Note that upon escape, you will be in orbit around the Sun, and your excess ΔV will add to the orbital velocity of the Earth that you start out with (around 30 km/s).



Escape Velocity – You know from earlier flights that burning prograde at periapsis increases your apoapsis, and the longer you burn, the higher it is raised, making your orbit's eccentricity increase. When eccentricity exceeds 1.0 (parabolic), the path becomes a hyperbola that approaches but mathematically never reaches a line (asymptote) which is also the departure direction. For a more complete, well-illustrated, and very easy to understand discussion of escape trajectories and many other aspects of orbital mechanics and space flight, see Wayne Lee's book *To Rise From Earth* (reference details can be found at the end of chapter 7).

Transfer Orbits and Launch Window – The minimum energy trajectory to travel from one planet's orbit to another is an elliptical orbit around the Sun which just touches both orbits; this is called a Hohmann transfer orbit. The Hohmann transfer is also generally the slowest trajectory. For travel to inner planets, the Earth's orbit is the apoapsis point, and the target planet (e.g., Venus) is the periapsis. If the target planet is farther out, the periapsis of the transfer orbit is at the Earth, and the apoapsis is at (in our case) Mars, as shown in the figure below. A spacecraft on a Hohmann transfer will take 259 days to reach Mars and will move through precisely half an orbit (180°) around the Sun. If you have more available ΔV, non-Hohmann transfers are possible, and these are generally faster. In the figure below, the Hohmann transfer is shown in brown, and the higher- ΔV transfer orbit is red. Note that for the Hohmann case, the intercept occurs at the apoapsis of the transfer orbit, where the orbital speed is minimum, thus requiring less ΔV to slow down for Mars capture than the non-Hohmann case. With the Delta Glider, we can largely ignore such issues, since there is plenty of fuel, but with real current boosters, these energy issues are very important for interplanetary flights.



Transfer Orbits – The sizes and shapes of these sample orbits are exaggerated for illustrative purposes. The Hohmann transfer is well known as the minimum energy and slowest transfer orbit, but other transfer orbits are possible. Faster transfers typically require more energy (ΔV) for both eject and orbital capture, but depending on the relative positions of the planets, the amount of additional ΔV may be small enough even for current technology launch vehicles to handle. Faster trajectories are better for piloted missions in terms of consumables, exposure to radiation, exposure to microgravity conditions (if the spacecraft is not rotated to provide artificial gravity), and other factors. The 2033 date used in this chapter was suggested by a 2004 ESA study of human Mars missions.* In addition to being favorable in terms of relatively low ΔV, the positions of the planets allow for some free return possibilities (for safety/backup purposes) which are not explored here.

* ftp://ftp.estec.esa.nl/pub/aurora/Human_Missions_to_Mars/HMM_Executive_Summary_Final_Version.pdf (1 MB PDF).

The other important point about transfer orbits is their direction and timing, both of which are closely linked to the relative positions and motions of the planets involved. Since Mars takes 687 (Earth) days to complete one orbit, while the Earth's year is 365 days, it's clear that the relative positions of these two planets will change constantly. As with the chapter 4 Moon trip, it is necessary to "lead" the target in order to arrive at its predicted future position, and there are only certain ranges of dates and corresponding planetary positions for which the relative positions of the planets are favorable for an energy efficient Hohmann (or near Hohmann) transfer. These establish the feasible launch windows. For the Earth and Mars, launch windows for such energy favored transfers occur about every 25-26 months (the period varies because the orbits of Earth and Mars are elliptical). Once again the futuristic Delta Glider gives you a wider range of options, and IMFD can plan high-energy flights for situations that would not even be considered for a real flight with current technology. The example flight here is a faster-than-Hohmann case (178 days).

Background – About IMFD

Interplanetary MFD (IMFD 4.2) is a "space navigation computer" created as an add-on module for Orbiter by Jarmo Nikkanen (http://koti.mbnet.fi/jarmonik/Orbiter.html, version 4.2.1 is a slight modification for Orbiter 2006). It is more advanced than the basic Transfer MFD, and similar in most ways to Duncan Sharp's TransX MFD, which was originally an add-on but is now included with the standard Orbiter release package. Both TransX and IMFD allow you to do simple or complex interplanetary flights, and although IMFD has a few special features that TransX does not have, which to use is largely a matter of taste and which one you happened to learn first. There are a number of tutorials for both programs around the web, and many Orbiter web forum members who are familiar with both programs.

We won't try to summarize all of IMFD's features, but there are enough to require a more elaborate interface than most MFDs, including a menu selection page for the various programs. These include:

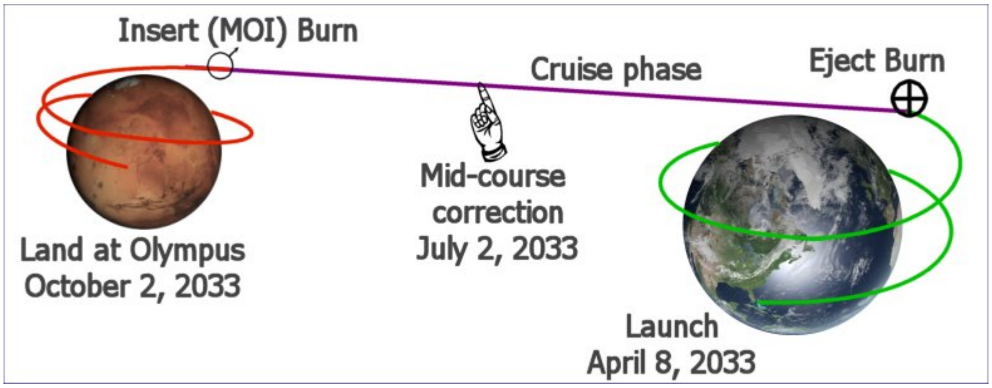
- **Course Program** – Collection of navigation tools including co-planar intercept, off-plane intercept, planet approach, orbit insert, and a few others less commonly used
- **Orbit Eject** – Used to plan departure from the starting planet, from either the surface or from a parking orbit
- **Map** – A powerful and flexible trajectory display and analysis tool based on accurate and fast numerical integration techniques
- **Base Approach** – A special program for setting up to land at a specific base on the target planet
- **Sling Shot** – A special program for planning and executing gravitational "sling shot" maneuvers

Only a few of IMFD's features are used in this tutorial. One that is used a lot is the AB (auto-burn) button found in most of the programs. It will automatically orient and hold the ship in the right direction and fire the engines for the burn. Quite amazing. There are other tutorials that get into more depth, but this chapter will give you a good idea of how powerful yet still easy IMFD can be. There is some "danger" in treating IMFD as a black box that magically gets you to Mars when you press certain buttons, but if you find it fun to plan trips to other planets, you may find yourself digging deeper into more advanced tutorials and background materials, and learning some real orbital mechanics in the process.

IMFD Interface and Terminology – IMFD starts with a menu page that allows you to choose from its main features or "programs" – IMFD is in effect a suite of related MFDs that can share data. Most or all IMFD screens include a **PG** button that toggles a second set of buttons on the right side of the MFD. Since you may have multiple things to plan and monitor, IMFD also supports a "shared" mode which allows you to display different IMFD screens on the left and right MFD, both based on the same data. Although it is common to have two instances of the same MFD displayed in Orbiter (e.g., two Orbit MFDs referenced to Earth and to Sun), these instances are normally independent.

Many of the terms and abbreviations used by IMFD are common to Orbiter (e.g., PeT, time to periapsis), but some are unique, and at least one is an "old" Orbiter term (PeD for periapsis distance from center of body, which is now PeR for periapsis radius in Orbiter). Any needed terms will be explained as needed in the tutorial steps. Pictures of most of the needed screens will also be shown. In this chapter, buttons to press are indicated by **Bold** text.

Mars Flight Game Plan – The "game plan" for this 2033 flight to Mars is to use IMFD in both the left and right MFD slots for most of the flight, and to use the modules in the list below. You may find it useful to open up an additional MFD window to hold a copy of the Orbit or Map MFD for general orientation. To do this, you must first activate the ExtMFD module in the Launchpad dialog. Once in Orbiter, press Control-F4 and choose ExtMFD from the list of modules. You can then re-size and move this window anywhere on the screen and set it to any built-in MFD you like (but not IMFD).



Several intermediate scenario files are provided, so you can start where you like.

- **General flight plan** – This is done with the Off-plane Intercept module of the Course program and will be used to establish your launch time and arrival date at Mars. The information established here will be shared with the other IMFD programs as needed.

- **Launch from Earth** (scenarios 1 and 1.1) – This phase is guided by the surface mode of the Orbit Eject program (gives you optimal launch time and heading).

- **Eject Burn from Orbit** (scenarios 2 and 3) – This phase is guided by the Orbit Eject program, where the auto-burn (AB) feature will automatically orient the ship and fire the engines at the proper time for the planned eject to Mars. Delta-V is about 3600 km/s.

- **Cruise Phase, Accurate Flight Tracking** – This is done with the Map program.

- **Mid-course Correction** (scenario 4) - This is handled with an auto-burn in the Course program, using the Map program to see the effect at Mars. Small delta-V.

- **Base Approach** (scenario 5) – The Base Approach program lets you set up an auto-burn for an arrival orbit that will pass over Olympus Base in preparation for landing.

- **Orbit Insert Burn** (scenario 6) – The Orbit Insert program actually performs the orbital entry burn that was set up by Base Approach. Delta-V will be almost 2800 km/sec.

- **Entry and Landing** (scenario 7) – Once you are in an orbit that passes over Olympus Base, IMFD is no longer needed. Steps are provided for landing manually (similar to the chapter 3 and 4 Moon landings) or automatically with the optional LandMFD add-on.

With proper use of time acceleration (discussed in the tutorial steps), this entire six-month flight to Mars can be accomplished in under one hour. Although this chapter and many aspects of this book are a team effort, Andy McSorley is your instructor pilot for the following detailed steps, so follow carefully.

Let’s Get Flying

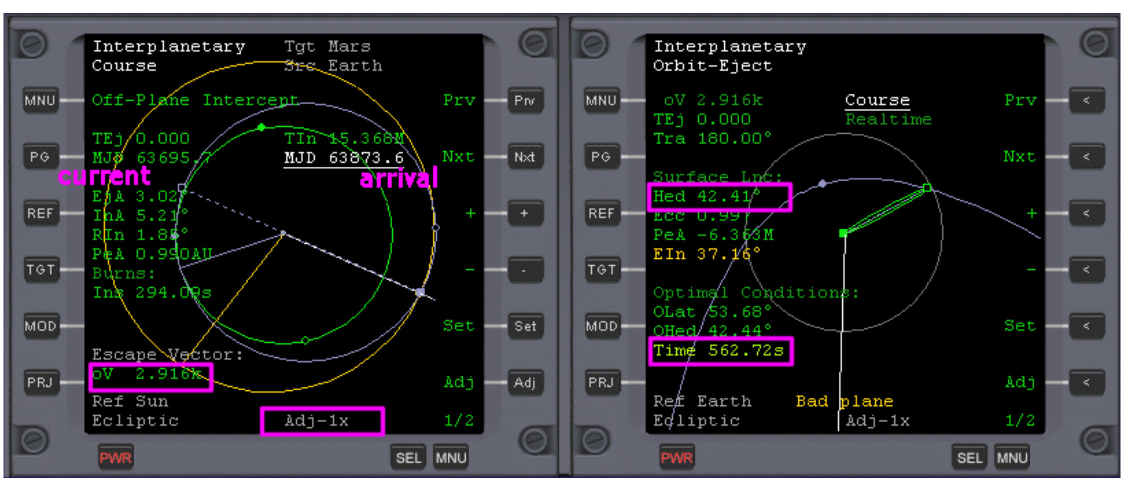
To use the supplied scenarios just place the folder ‘From Earth to Mars’ into your Orbiter installations scenario folder. You must also be sure that the two add-ons used in this tutorial have been installed into the Orbiter folder, and have been activated on the “Modules” tab of the Launchpad dialog. If this is not done, MFD screens that should display IMFD will instead be blank (need to quit, activate, and restart).

This tutorial can also be started from Earth orbit, using either Scenario 2 or 3. I have also included an additional scenario 1.1 Awaiting Take-off from Canaveral, which has IMFD already set up. **The buttons to click are in bold type**. Note that while displayed numbers and times can vary slightly from the ones shown in the screen shots, you should enter inputs as shown (IMFD adjusts for small changes). Be aware that if you begin your flight with Scenario 1.0, the values you see thereafter in IMFD will likely vary from the ones given in this chapter. This is due to the fact that no two users will achieve LEO with identical orbital parameters.

Scenario 1. Awaiting Take-off from Canaveral (April 8, 2033, 1723 UT)

1. Open IMFD in the left MFD screen, **PWR, SEL, Interplanetary**
2. Select Menu, switch mode to ‘Shared’ (if not set already), and select the Interplanetary Course program ‘Off Plane Intercept’, **MNU, PG, Course, Prv, Set**
3. Target Mars, **TGT** – Enter **mars** into dialogue box – **Return**
4. Select ***arrival*** MJD (under TIn), **Nxt** (x4)
5. Set **Adj** to 10x and use the **–** button (and + button if necessary) to reduce oV to a minimum value. When you reach the minimum level of oV at the Adj x10 setting, set Adj to x1 and reduce oV further. When you’re finished oV should equal 2.916k and arrival MJD should equal approximately 63873.5. Change it to **63873.6** (for better arrival conditions, same oV).
6. Open IMFD in the right MFD screen, **PWR, SEL, Interplanetary**
7. Select Orbit Eject program, and set it to Course, **MNU, Orbit-Eject**, then’**+**’ to change ‘Higher Orbit’ to ‘Course’.
8. Select **MOD** (mode) to see the surface take-off heading ‘Hed’ and time to launch ‘Time’.

There are two values of interest here. The first is the nominal heading to fly to orbit on, ‘Hed’, which a few minutes after opening the scenario is about 42.41 degrees (Fig. 1). The second value of interest is the time to launch, ‘Time’, which is counting down at the bottom of the right MFD, and which should be about 700 – 750s (700 - 750 seconds). The aim is to fly to orbit on the given heading, reducing EIn (escape Inclination) to zero (or as near as you can get it) as you ascend.



(Fig. 1)

For take-off you can switch the left side to the standard Surface MFD. For details on how to fly to orbit in the Delta Glider refer to the Earth-to-Moon launch in chapter 4.

Wait, or warp time (10x max) until time to launch, 'Time' is zero, and take off.

After take-off point the DG towards the heading shown by 'Hed' in the right MFD and fly to orbit (you can vary from Hed by 1° to 5° to try to reduce EIn to zero). ***Don't use the right MFD for anything else during the flight to orbit or you will lose the values it contains for heading etc.***

Your final orbit doesn't have to be perfect, just so long as it's above the atmosphere. As you ascend, the Escape Inclination 'EIn' figure will start to reduce in the right MFD. If you fly perfectly it should be very close to zero by the time you reach orbit. If you don't, you can adjust it later in orbit.

Scenario 2. In Earth Orbit (April 8, 2033, 1848 UT)

This scenario opens with IMFD open and set, but you have to reduce EIn to zero as described below, before setting off to Mars. See Fig.2.

If surface mode data (Hed etc.) are still displayed, select **MOD** to switch it off and display PlC, TtB (time to burn), and BT (burn time, i.e., duration) instead. If EIn is much above zero, you will first need a plane change burn, indicated by PlC (seconds). The **+** or **–** next to the PlC (magnitude of plane change burn) denotes the direction in which to make the burn. Turn your spacecraft's attitude to '+Normal' or '-Normal' (in this case it's +). Wait until Tn (Time to node) has counted down to zero before firing the main engines to drive EIn to zero (or very close).

An example of this is provided in scenario '2. In Earth Orbit'. Here EIn is 2.51 degrees. To reduce this to zero as described above, you will complete about a quarter of an orbit (818.74 seconds in Figure 2 below, with about a 20 second +Normal burn required.

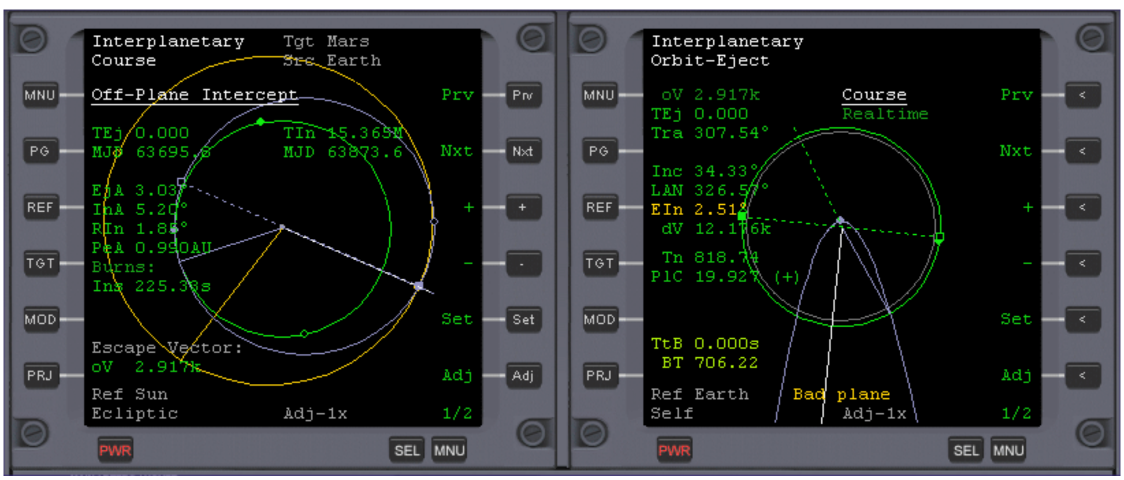


Fig. 2

Make the burn when Tn reaches zero, for the duration (PlC) seconds at full thrust, but be aware that full thrust may not be necessary when only a small burn is needed, as it increases your chances of overshooting your target, so go easy on the gas here. Cut the burn when the Escape Inclination 'EIn' has reached zero.

You are now ready to continue to the next stage of the flight, which is to eject from Earth orbit towards Mars, beginning at step 1 below.

Scenario 3. In Earth Orbit, EIn Zero (April 8, 2033, 1904 UT)

Assuming that you have ascended to Orbit and EIn (escape inclination) is zero, carry on beginning at step 1 below. If you want to just fly to Mars with a minimum of set-up then use this scenario to begin your mission at step 2 below.

1. If you had closed IMFD in the left MFD screen, reopen it, **Select, Interplanetary**
2. Select **MOD** – only if Hed, etc. (surface mode) are still displayed on the right MFD
3. On the right MFD select <u>Realtime</u> and change it to <u>Prograde</u>, **Nxt**, '**+**'
4. Orbit Eject now displays updated Time to Burn (TtB) and Burn Time (BT) values.
5. In the Orbit Eject (right MFD) program select Auto-burn, **PG, AB**

Now wait, or warp time (100x max) until about 30 seconds before TtB equals zero, then return to normal time. See Fig. 3. Note that as early as three minutes (T-180) before burn time, the auto-burn controller will start to fire RCS thrusters to orient the ship for the burn. This is normal. You can view the burn alignment cross-hair display with the **BV** button (click it again to return). This can also be used to manually set and hold orientation in cases where AB doesn't work well (e.g. for some slowly-responding add-on ships).

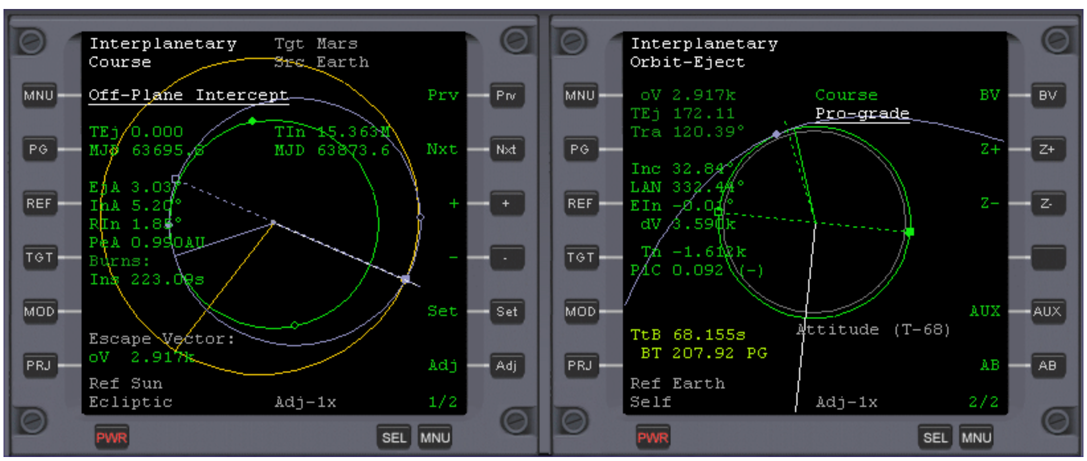


Fig. 3

The eject burn for Mars will begin automatically. When the burn has completed, warp time (1000x max) until you have left Earth's gravitational sphere of influence, 'Soi'. You will be able to tell when this has happened when the RH MFD displays the message 'Have a nice voyage!'

When you see the "nice voyage" message, return to normal time.

1. In the left MFD set the source 'SRC' to self, **PG, Src, Enter 'x'.**

   This is important: you will need to use the Course program to make a correction burn later, and it must know the source object to make the correct burn calculations.

This updates the Course program's source orbit from Earth to your own spacecraft. Now you can see your actual trajectory (green), superimposed over the calculated HTO hypothetical transfer orbit (blue). You will now be able to monitor the progress of your voyage using the Course program, and later use it to make a small mid-course burn to correct your trajectory. See Fig. 4.

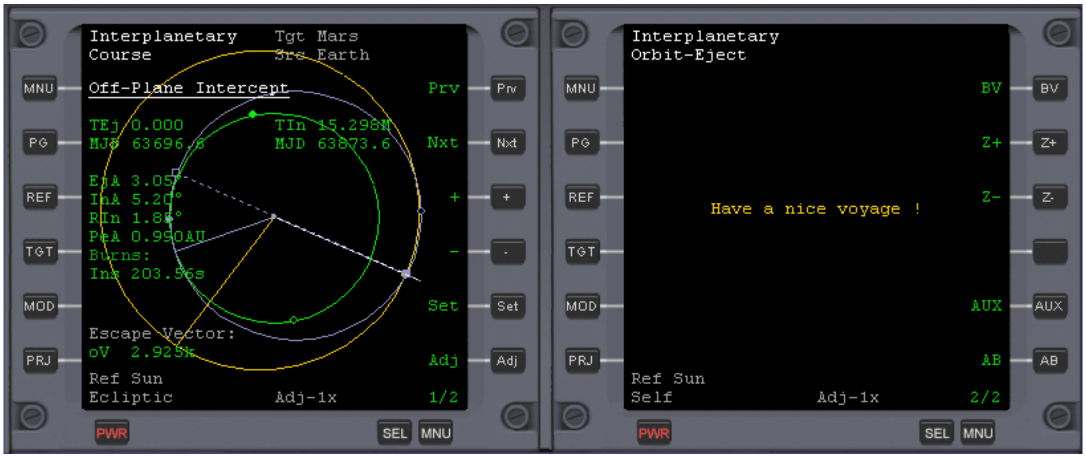


Fig. 4

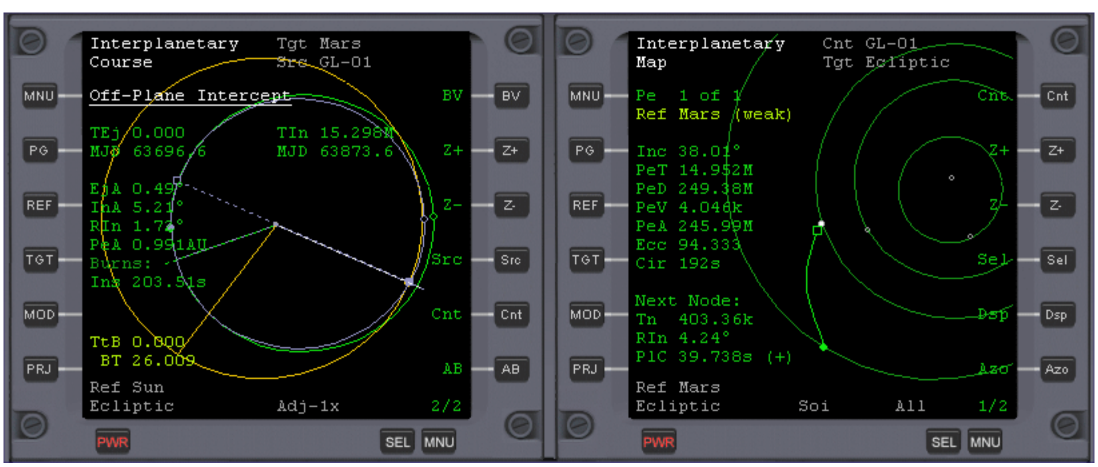
We have no further need of the Orbit Eject program in the right MFD so we can replace it with IMFD's Map program, an extremely powerful and accurate tool. So let's do that.

1. **MNU, Map, Ref (enter 'mars'), Cnt Enter 'x'**
2. Display the orbits of the planets and their spheres of influence, **Dsp, PG, Soi**

Here are the main buttons for the Map program:

- **PG** - Toggles button functions
- **Z+ Z-** - Zooms in and out of the Solar System map
- **Cnt** – Lets you choose what object (planet, Moon or Spacecraft) is at the center of the display
- **Dsp** - Toggles the display of the planetary orbits
- **Soi** - Toggles the display of the planet's gravitational sphere of influence
- **Azo** - Auto-zoom On/Off. Lets you choose whether the Map program adjusts its display automatically when changing Reference, Source etc.
- **Ref** - Sets the reference object from which the orbits and trajectories are displayed.

Make yourself familiar with this now; you will need to be able to use it as you approach Mars. When you've finished, your MFD should look something like this below. See Fig. 5.



(Fig. 5)

As a matter of interest, if you zoom out the Map, you may notice a slight discontinuity in your trajectory at the point where the Earth's influence begins to diminish and the influence of Mars begins to take over. Changing 'reference' in the map program enables you to see your orbit from the 'referenced object's' position. Change the reference to Sun, and you will see a trajectory similar to that in the Course program, but more clearly. It's roughly at the slight bend of your trajectory, where the effect of Mars' gravity begins to be felt, that you will make a correction burn.

Now let's make some progress towards Mars. ***Warp time*** (**T x 5**, 100,000x) until just before the halfway stage of the flight, around MJD 63780. Use Map **Z-** to zoom out to see your progress.

Using Time Warp

At time warp 100,000x, each second is roughly equivalent to about one day of real time (which is actually 86,400 seconds). So from the time of leaving Earth's SOI to the time when you need to make the correction burn, it takes about 73 seconds of simulator time. In the real world this is equivalent to 84 earth days. The total 'real' time for the journey is 178 days (about 6 months). You can't do the whole thing at 100000x, of course – such extreme time warp is only safe in cruise phases (no burns or autopilots). Orbiter can't keep up!

During the time warp you will also notice that from the point where you set the course program source to 'x' - your spacecraft, the BT displayed has decreased from about 26 seconds (see figure 5) to around 3 seconds then begun to increase again to around 5-10 seconds.

Slow time warp to 100x as **current** MJD approaches MJD **63780** (upper right corner of Orbiter display), and then return to normal time once it is reached.

Scenario 4. - Correction Burn (July 2, 2033, 84 days into flight)

Now it's time to make another burn to correct the errors that will have inevitably occurred on a trip of this distance. You can see the duration of the burn that's necessary, by observing the value BT at the bottom of the left MFD, usually somewhere between 5-10 seconds. See Fig. 6.

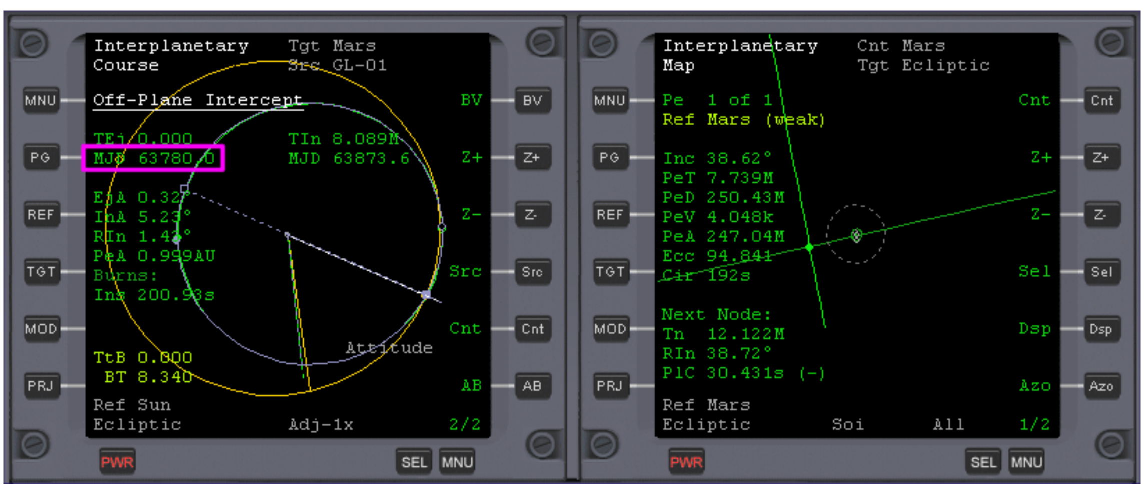


Fig. 6

Before you do though, set the Map program to reference Mars (if not already, **REF**), and also center the display to Mars (**Cnt**) to see the resultant effect of the correction burn. Zoom in a few times with the map and you will notice that your trajectory is some way off from the position of Mars.

To make the burn just click **AB**, and IMFD's Course program will do the rest.

The accuracy of the burn may vary, but it will usually place your trajectory close to or within the orbit of Mars's outer satellite Deimos. If you're lucky, you will see your trajectory heading straight towards Mars. See Fig. 7.

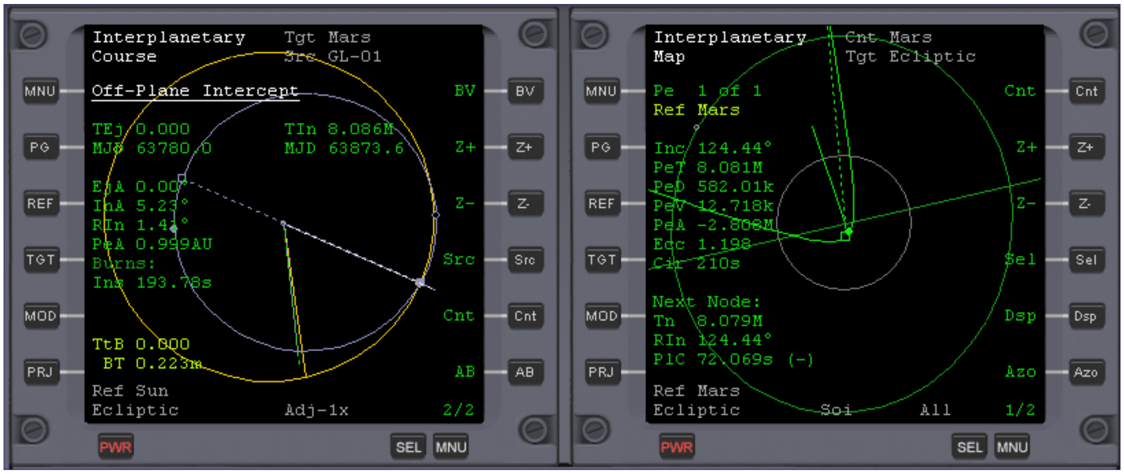
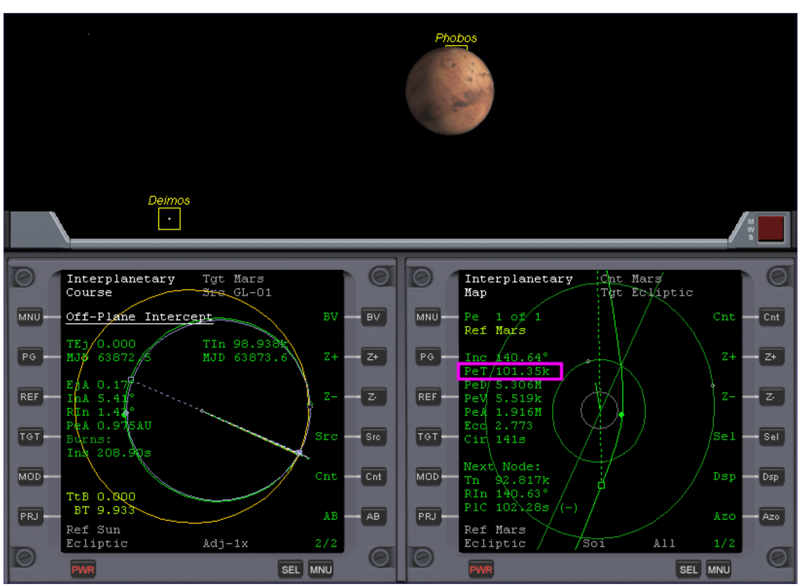


Fig. 7

After the burn is complete, set the screen to visual aids ("planetarium") mode **F9** (to show labels for the planets, use Control-**F9** to select which object labels are displayed, displaying the blue line of the ecliptic can be very helpful) and place the spacecraft in a prograde attitude. Now switch off prograde and rotate your spacecraft to the left. Mars should come into view. Kill-rotation when it is in the center of your screen. If you don't see Mars, you will have to hunt for it (check the external view), but eventually you'll find it. When you do locate it kill-rot.

Now warp time (100,000x), until Time to Periapsis (at Mars) PeT in the right MFD is around **500k** (seconds). Then slow time warp to 10,000x and then lower still as you approach 100k. Be very careful, as it's easy to overshoot your target. When PeT is **100k**, return to normal time. Now if you are still facing towards Mars, and you zoom the field of view to 10 degrees, you will be presented with your first sight of Mars (see Fig. 8, PeT 101.35k). Return zoom level to its previous setting.



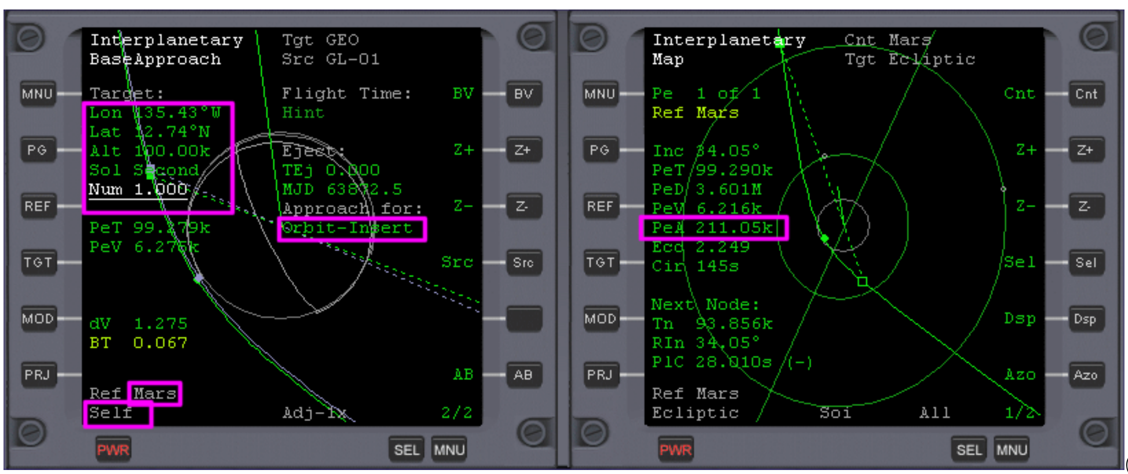
(Fig. 8)

The Course program in the left MFD is now finished with, so we can use the MFD on this side to plan a low parking orbit around Mars that will place us over Olympus base.

To do this you need to enter the coordinates of the base into IMFD's Base Approach program as well as some other data. The Base Approach program will set your periapsis distance (for either a prograde or retrograde orbit), orbital alignment (with the base), and the number of orbits to complete after insertion, before you pass over the base.

Open the Base Approach program in the left MFD, **MNU, Base Approach, Nxt** (x3), then **'+'** (x2) until 'Approach for:' changes to 'Orbit Insert'. Then (see notes at end of the chapter),

1. Reference Planet: **REF**, enter <u>**mars**</u>
2. Projection: **PRJ** – Change to 'Self'
3. Longitude: **Nxt, Set (enter <u>224.57</u>)** [1]
4. Latitude: **Nxt, Set (enter <u>12.74</u>)**
5. Altititude: **Nxt, Set (enter <u>100k</u>)** to set Altitude of Periapsis (don't forget the k!)
6. Sol: **Nxt, '+'** Change Sol from 'First' to 'Second'. This changes the approach from a retrograde one to a prograde one. For a prograde approach, the blue HTO will be on the left of the planet. 'First' and 'Second' refer to the two solutions that are possible.
7. Num: **Nxt, '+'** Change Num from '0' to '1'. This allows us to make <u>one</u> complete orbit of Mars before we are perfectly aligned with the base [2].
8. Engage auto-burn: **PG, AB**



(Fig. 10)

After the burn has taken place (see fig. 10), note how the Map program displays a different (and more accurate) value for PeA, compared to 'Alt' (Altitude), which you set in the Base Approach program. We will refine the base approach when we are closer to Mars with another burn.

Fine Adjustments
Outside of a planet's sphere of influence, the planet approach program is less accurate at setting your PeA, but the map program gives a very accurate reading. So maintaining the attitude set by the last burn, use linear thrusters (6/9) to fine-tune the PeA value shown in the Map program to 100k (100 km). See how your spacecraft's trajectory (green) now aligns perfectly with the HTO (blue) trajectory in the Base Approach program.

Face towards Mars like before. Zoom out the Map in the right MFD 5 times, until you see your spacecraft's marker (the white dot) and Mars' SOI. Warp time (10,000x max) until you see the white dot enter Mars's sphere of influence. Slow down time warp to 1000x. Zoom in with the Map program as you approach Mars. When the white dot reaches the orbit of Mars's outer moon Deimos, slow to normal time. Now perform another auto-burn **AB** to refine your base alignment. See Fig. 11.

Note how the Map program's PeA reading is still slightly different from the 'Alt' figure set in the Base Approach program. You can use linear thrusters to refine this to the required number as described in 'Fine Adjustments' above.

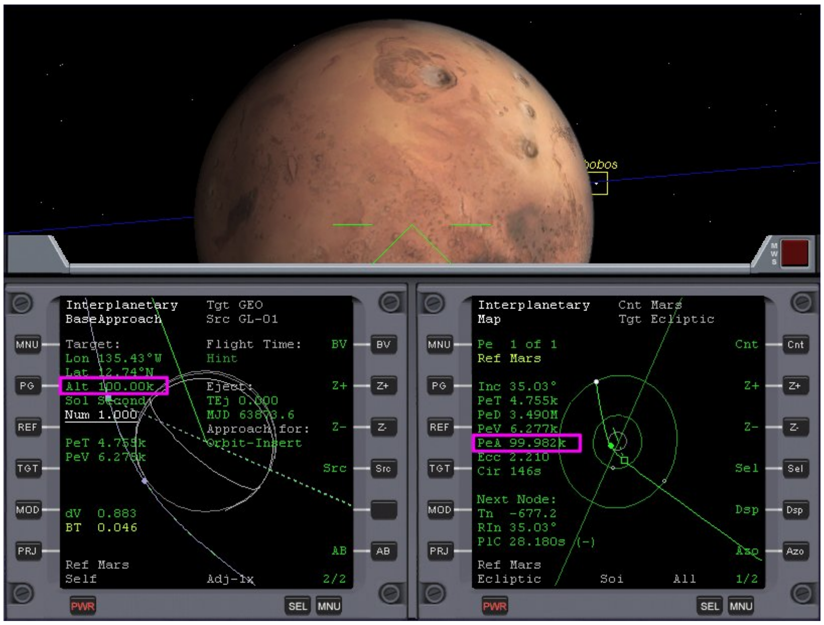
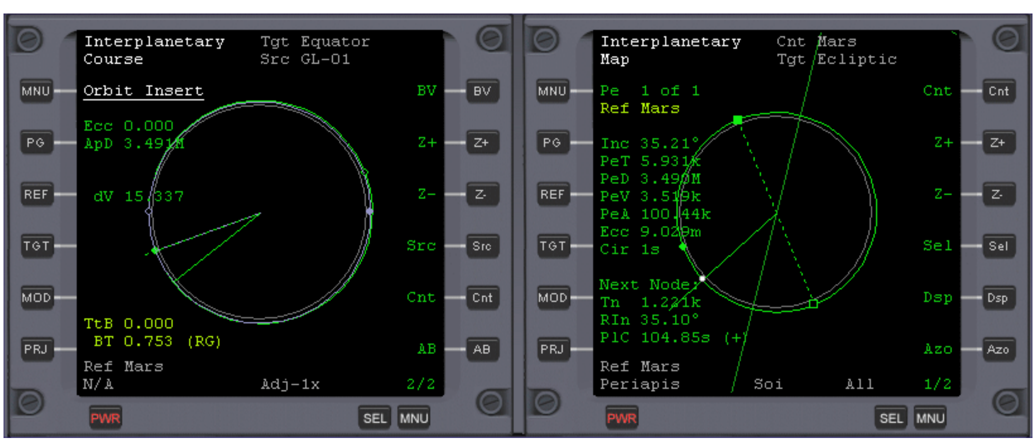


Fig. 11

Scenario 6. Orbit Insert (October 2, 2033, 176 days into flight)

Open the Orbit Insert program in the left MFD, **MNU, Course**, **Nxt** (x3) (underline Orbit Insert), **Set, PG, AB.** Set map to Periapsis, **PRJ.** See Fig. 12 (next page).

Warp time (100x max), zooming the Map program as you approach Mars. Sixty seconds before the insert burn time is reached (TtB), return to normal time (IMFD will reduce warp to 10x before 60s). RCS thrusters will fire before the burn, and after it's complete, you're in Martian orbit. See Fig. 13.



(Fig. 13)

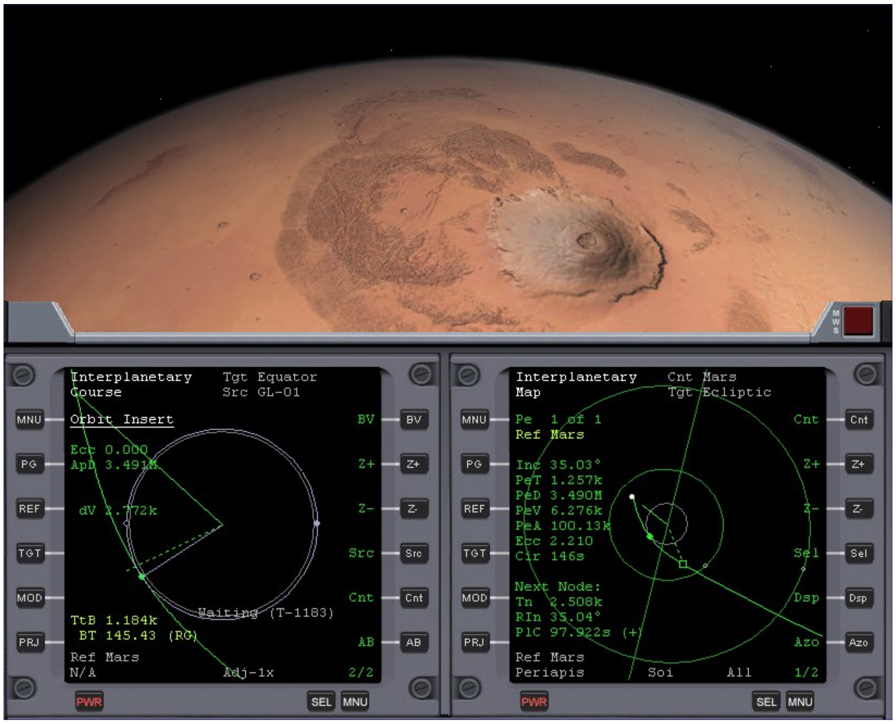


Fig. 12 - Spectacular view of the extinct volcano Olympus Mons, as you approach Mars.
Three times the height of Mt. Everest at 27km; it is the largest mountain in the Solar System.

The following scenario options begin at the state shown in fig.13, just after orbit insert. For a manual landing follow the procedure as outlined in the section "Bringing It All Back Home (De-orbit)" of Chapter 3, using the figures in the paragraph below to time the retrograde burn. You may want to display the Surface HUD and/or Surface MFD even for automated landings.

Scenario 7. Preparing to Land (Manual)

Make a retrograde burn at full thrust when 400 km from Olympus Base until your velocity is about 130-150m/s. The descent will be steeper than that used for the Moon as we begin at a higher altitude due to Mars's atmosphere. The IDS and XPDR frequencies for pad 1 Olympus base have been set in all the scenarios, so opening the VOR/VTOL (Landing) MFD will show you everything you need to know, to make a successful landing. It will begin to give you readings when you get to within 25km of the base. Be sure to lower the gear (G) just before landing.

Note also that Mars's atmosphere is very thin and it's not much use to us as an aero-brake. The Delta Glider has plenty of fuel to slow down with anyway.

Scenario 7. Preparing to Land (Using LandMFD)

1. Open LandMFD on the left side, **SEL** (two times), **LandMFD**
2. Warp time (100x max) until LandMFD, which until now has displayed a message in red 'Too far off plane' changes to 'Waiting for PDI …' 'Press <shift> 0 to select Autopilot'. Now slow to normal time (PDI is 'powered descent initiation,' an Apollo era term).
3. Engage LandMFD with **Shift** + '**0**' (zero) and warp time (10x max) until PDI Time: = 120 (seconds) when LandMFD will begin to commence the landing. Slow to normal time (Figure 14 shows LandMFD in the braking phase, about 648 km from Olympus Base).
4. When very near the base, lower the landing gear with the G key (not automatic).

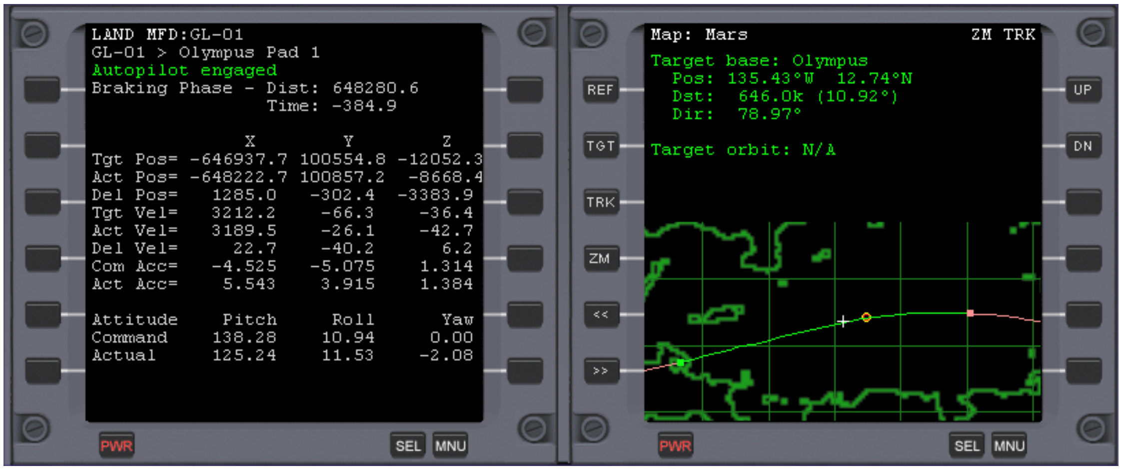


Fig. 14 (Note: Use LEFT-shift-0 to engage autopilot if LandMFD is on the left as shown here)

A Couple of Things About LandMFD

Even though your orbit appears to pass over Olympus base, LandMFD will probably tell you otherwise, with the message 'too far off plane'. Don't worry about this, as after one orbit the problem will right itself, usually when you are about 2-3 squares on the Map MFD away from the base.

Also note that even when the base alignment is correct and you are more than half an orbit away from passing over the base, LandMFD gives the message that you are moving away from the base. Just bear with this until you finally reach the half orbit before your final descent.

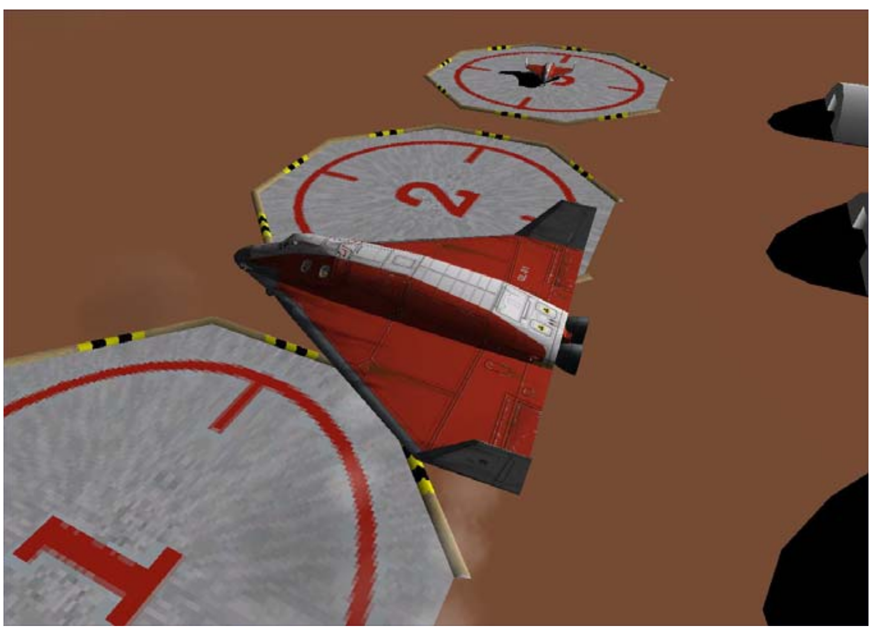


Fig. 15 - The Delta Glider arriving at its destination Olympus Base – Mars.

So now you've arrived, and there's two months leave to take. But what's this? "All leave cancelled!?!" You're to immediately take the DG 2, waiting on pad 3, to transport two mining engineers to the asteroid "3200 Phaethon." And what's more, you first need to find* and install the add-on to place this and two other Mercury-crossing asteroids in Orbiter's Solar System so you can fly them there. Great joy!

*http://www.orbithangar.com/advsearch.php?search=name&text=crosser (Mercury Crosser Asteroids by NightHawke)

Bonus Scenarios

Scenario 8. LandMFD Engaged

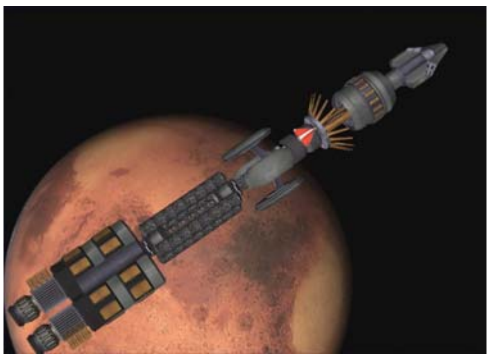
Launch this scenario and watch LandMFD make the complete landing.

Scenario 9. Final Approach

Launch this scenario and watch LandMFD make the final approach to Pad 1. The landing gear is already down. With this, you can see the Delta Glider just about to land at Olympus base (Fig. 15).

Things to Try

You may have noticed that the DG is a pretty small spacecraft for a 6 month flight. You may also wonder if it's possible to save fuel at any point – ever hear of aerobraking? Here are a couple of ideas for things to try using additional add-ons that are available on the web.



Fly Something Big – Long space voyages will require more living space than the DG has, and eventually there will be some really big ships. Care to upgrade to something in a full-size fusion-powered ship? The Vespucci-D by John McCain and "Oz" is cool, though the propulsion system has a learning curve (read the manual!). Yes, that's a Delta Glider docked near the rotating habitat modules (for surface ops). Another big interplanetary ship is Deepstar 1.0 by Alain Hosking. With the Scenario Editor and IMFD, you can cruise the Solar System…
http://www.orbithangar.com/advsearch.php?search=name&text=vespucci_D
http://www.orbithangar.com/advsearch.php?search=name&text=deepstar

Use Mars' Atmosphere - Unmanned probes can save fuel by using Mars' atmosphere to adjust their orbits (aerobraking – aerocapture is also possible but as yet untried). The AeroBrake MFD by 'gp' (Gregorio Piccoli) can help with this. We haven't tried it yet, but you can! Note that Mars' atmosphere ends at 100 km in Orbiter (there's not such a sharp cutoff in real life).
http://www.orbithangar.com/advsearch.php?search=name&text=aerobrak.

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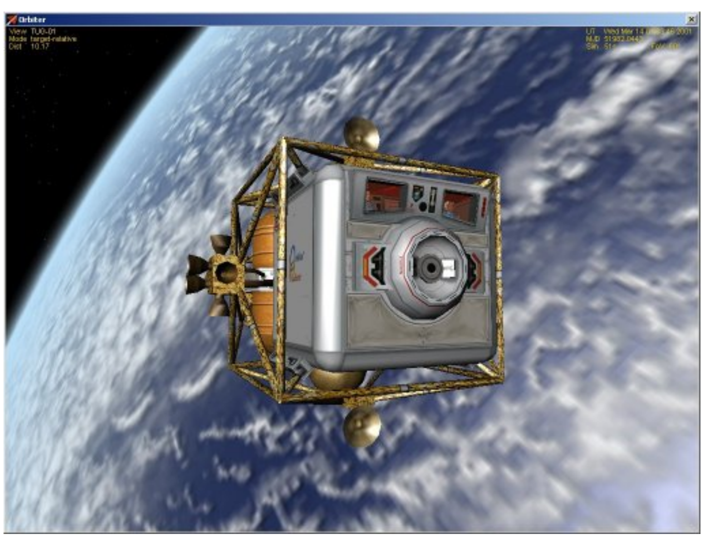
[1] Olympus base co-ordinates are 135.43W, 12.74N, so why enter 224.57 instead of 135.43? Well, IMFD only accepts coordinates in an Easterly direction, so we have to subtract 135.43 from 360 (degrees) to give us 224.57E, which is the same as 135.43W.

[2] In other situations I have left this set to zero (the default setting) and the Base Approach program placed me over Olympus ready to make a descent just after orbit insert was complete. However I find that with this particular scenario, IMFD can't quite find the burn vector and begins to hunt, never quite making it. This may be because the orbit insert burn occurs to close to the base co-ordinates.

Learning and Doing More

When you have finished the “test flights” in this manual, maybe you will just want to play and experiment on your own. You can also look around for cool add-ons to download and try (see next chapter), or maybe practice and get really efficient with takeoffs, orbits, and landings on the Moon, on Earth, or both. Fluency is always good. But there are also many other things you can learn, and many ways to learn them.

This chapter has some tips on other “goodies” that come with Orbiter, as well as information on additional tutorials (there are some really good ones out there). It will also point out a few web sites and books that you can use to add to your knowledge of how this space stuff works. NASA has some really good general web sites as well as some great sites for kids (of all ages). JPL (Jet Propulsion Laboratory, affiliated with NASA and with the California Institute of Technology, or Caltech, in Pasadena) has some of the best material on the basics of space flight. It’s called (logically enough) “Basics of Space Flight.” You could also go *really* unconventional and read the Orbiter manual. Once you have an interest in Orbiter, you’d be amazed at the useful stuff you’ll find in that PDF file.



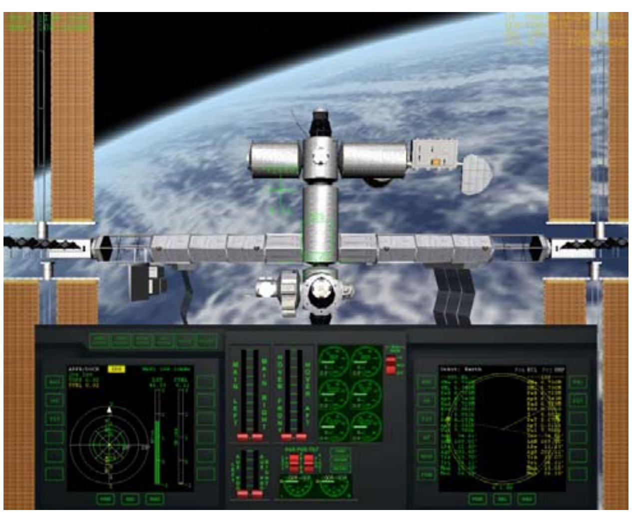
Dragonfly is another one of the spacecraft supplied with Orbiter. Rather boxy and utilitarian in design, it is an orbital “space tug” for use in construction and for short-haul trips around space stations. It would really need a “mother ship” since it has only thrusters, no main engines, making it difficult to make any large orbital changes. Definitely NOT for reentry or landing – it has no heat protection, no hover engines, not even any legs or other landing gear! It does have an excellent control panel with just a single MFD (though it does have a dedicated radar display for keeping track of its position when near space stations, ships, and construction components and debris).

Explore What You Have

Orbiter comes with an amazing amount of stuff, so once you have learned the basic operations covered in chapters 2-6, you may just want to explore for a bit.

Variations on a Theme – By this I mean modifying the exercises in this manual in some way. Think "replay value." For example, can you keep the two DG's in chapter 2 docked together and boost them together into a higher orbit? Flight test the thrusters and hover engines in chapter 3 – how good is auto-hover at saving you from a fall? How accurately can you stop over a pad on a high speed run into Brighton Beach? Can you orient yourself pro grade or retro grade without using the autopilot buttons (just using the Orbit HUD and manual thrusters)? Can you launch into a polar orbit of the Moon by launching on a different azimuth (heading, like maybe 0°)? Can you still get back to the Beach from that orbit? Same thing in chapter 4 – fly to Earth orbit on the runway heading (330° or northwest) and see what orbit you get? Can you still align with the Moon from that orbit (big delta-V for that)? Can you still achieve Moon orbit if you add more delta-V (DV+ button) in the Transfer MFD, so the transfer orbit goes even farther beyond the Moon's orbit? How much time can you save on a Moon trip this way?

Supplied Scenarios – Orbiter comes with over 100 pre-defined scenarios organized in a number of themed folders available from the Launchpad. There are scenarios that demonstrate features added to the 2006 edition; scenarios based on supplied spacecraft (Delta Glider, Shuttle-A, Dragonfly, Space Shuttle Atlantis, Shuttle-PB); and others that are based on supplied space stations and satellites (International Space Station, Mir, Lunar Wheel, Hubble Space Telescope – see chapter 9 of the Orbiter manual for information on supplied ships and stations). There are also scenarios for the "checklist" tutorials in the Orbiter manual, navigation scenarios for learning the Transfer and TransX MFDs, and a number of demo and playback scenarios (the ones in the /Tutorials folder are annotated). Finally there are a number of scenarios that show off the Solar System and the precision of Orbiter's planetary motion calculations, which are good enough to demonstrate eclipses and to allow recreation of historic fly-by missions to the outer planets, such those of the Voyager and Galileo probes.



Shuttle-A at ISS – Lined up about 46 meters from docking with the ISS, the Shuttle-A is a cool supplied spacecraft (this is from scenario "Shuttle-A Docked at ISS.scn"). It has a pretty nice instrument panel with a different look but with most of the same controls as the Delta Glider. One difference is the "AUX POD" controls in the lower center. The auxiliary engines are located amidships on tilting pods (change the angle then jump to the outside view and watch them rotate). They can be rotated to the rear for extra forward thrust, down to add to hover thrust, or straight ahead for retro thrust – or anywhere in between. Panel controls are the only way to operate the pod engines. There is an overhead panel (CONTROL ↑) with more functions including cargo pod controls.

There is also a "Legacy Scenario" folder with a few scenarios that use the "old" ISS model. Most scenarios use a newer and more detailed model of the ISS than the one used in Orbiter versions prior to 2005. This ISS model looks great, but its high detail can slow down the frame rate on lower-end PC's. Legacy scenarios may work better on these machines.

Supplied Documentation – The Orbiter manual is a 100+ page PDF file that installs with the program (in the /Doc folder). The manual is well written and well organized, but it still may seem rather overwhelming to a new user, since it has to cover everything about the program, in contrast to a tutorial manual like this one which can pick and choose what to cover (though you may think this manual is pretty dense too!). After you have played with Orbiter a bit and learned that you can accomplish some things without months of study, you should spend some time with the manual, exploring little bits at a time. For example, take a look at the section on the Transfer MFD (section 13.10). It has a lot of useful features not covered in chapter 4 of this book, and there are diagrams that illustrate the screen symbols and the interface.

Checklist Tutorials - You may also want to try out some of the "Checklist" tutorials in the Orbiter manual (chapter 18 plus Quickstart, chapter 4, scenarios in the Checklists subfolder) – although these long lists of steps are basically text-only, once you have gone through the examples in this manual, the steps will make a lot of sense to you, and you will find that these are really quite good tutorials (as you might expect from the author of the program). There are also flight recordings related to some of these tutorials (e.g., annotated playbacks are in the /Tutorials folder, non-annotated and your own playbacks are in the /Playback folder).

Space Shuttle with HST – In the supplied *Atlantis* scenario "HST Orbit Deployment.scn," you can use the Shuttle's remote manipulator arm to deploy the Hubble Space Telescope. Here are the notes from the scenario, which is found under "Satellites and Probes":

"The Hubble Space Telescope is being pulled out of the Shuttle Cargo Bay. Complete the deployment operation using the Manipulator Arm control pad (Ctrl-Space). After detaching the telescope, switch focus (F3) to the HST and unfold the solar arrays (Ctrl-3), deploy the high-gain antennae (Ctrl-1), and open the main telescope hatch (Ctrl-2)."

There are other manuals in the /Doc folder as well. There are specific PDF manuals for the Shuttle Atlantis (including the MMU, the spacesuit propulsion system shown in the introduction of this book), and for the Shuttle-A and Dragonfly spacecraft (these ships have panels, and the internal systems of the Dragonfly are modeled in greater detail than any other craft I know of other than the add-on Delta Glider III). There is also a separate PDF manual for Duncan Sharpe's powerful TransX MFD (included but must be activated on the Modules tab of the Launchpad). You will also find PDF's for the scenario editor and the flight recording feature (this is in the /Doc/Technotes sub-folder).

Curriculum for Learning Orbiter

Some people like to simply explore, while others may want more structure, to know what they "should" study. Here is my take on this for Orbiter – others may have different opinions on what the key topics are and in what order they should be learned. Many people (including Dr. Schweiger in the Orbiter Manual "quick start") start out with taking off in the Delta Glider from the runway at KSC and flying it around a bit and then to orbit. Many people find this difficult and frustrating at first, so I saved this task for chapter 4 of this manual. My reasoning is that Orbiter is a *space* simulator, not a flight simulator. It seems more natural and rewarding to me to start out in space, even though all real space missions to date have started by launching from Earth (but none has yet launched from a runway, except for air-dropped sub-orbital missions such as the X-15 in the 1960's and the more recent SpaceShipOne, which won the X-Prize in 2004). That's the power of a simulator – you can start out in any situation you like, and save the hard or boring parts for another time!

So here is my "curriculum" for Orbiter. You can see that this manual pretty much follows the first few steps of this outline. This list will be followed by an expanded section on each item with information on key concepts, the needed skills, and relevant tutorials. Note that LEO is low Earth orbit.

- Basic spacecraft operation
- Basic orbital operations (orientation, orbit changes)
- Launch to orbit (no atmosphere)
- Reentry/Landing (no atmosphere)
- Launch to Orbit (Earth runway)
- Transfer to Moon from LEO (Basic)
- Rendezvous (Synchronize Orbit)/Dock (LEO to LEO)
- Atmospheric Reentry (Earth)
- Runway Landing (DG and/or Space Shuttle)
- Transfer to Moon and Planets from LEO (Precision)
- Flying the Space Shuttle

In the following, tutorials on the web are referenced by the author's name or nickname – the web site links and tutorials (listed by these names) are described in the later section "Tutorials on the Web." "Chapter 2" (etc.) without further qualification means this manual. Note that these are not *all* the tutorials that cover these subjects, just ones I happen to know. "Resources/Skills" for each topic generally assumes you have mastered the skills of the earlier topics. "Orbiter 4" means Orbiter Manual, chapter 4.

Basic spacecraft operation

Key Concepts: Basic Orbiter user interface, use of engines and thrusters, translation vs. rotation, the concept and interface for MFDs, and the use of basic keyboard commands.

Resources/Skills Needed: Orbiter installed, basic mouse and keyboard skills, Surface MFD, VOR/VTOL (Landing) MFD, Com/Nav MFD

Tutorials: Chapters 2 & 3; Trevor Johns; Harmsway (Orbiter Basic Training); Orbiter 14

Basic orbital operations (orientation, orbit changes)

Key Concepts: Properties of orbits (periapsis, apoapsis, nodes, inclination), spacecraft orientation (pro/retro grade, normal/anti-normal), when and where to modify an orbit.

Resources/Skills Needed: Thrusters, autopilots, Orbit & Align MFDs, Surface & Orbit HUD

Tutorials: Chapters 2, 3, 4; Trevor Johns; Harmsway (Orbiter Instrument Training); Poons

Launch to orbit (no atmosphere)

Key Concepts: Launch azimuth/heading, orientation, vertical vs. horizontal velocity, why east is best launch direction.

Resources/Skills Needed: Surface, Orbit, & Map MFDs

Tutorials: Chapter 3; Trevor Johns; Harmsway (Orbiter Instrument Training); Poons

Reentry/Landing (no atmosphere)

Key Concepts: Target base, alignment, timing, retrograde burn, velocity vector.

Resources/Skills Needed: Orbit & Surface HUD, Orbit & Surface MFD

Tutorials: Chapters 3 & 4; Harmsway (Orbiter Instrument Training); Poons

Launch to Orbit (Earth runway)

Key Concepts: Runway heading, rotation speed, aerodynamic controls, atmospheric drag, RCS controls, use of pitch to control vertical speed, MECO.

Resources/Skills Needed: Targets for Map, Surface, Align, & Orbit MFDs

Tutorials: Chapter 4; Orbiter 4, 18; Poons; Duncan Sharpe ("Old stuff" link); Harmsway (Orbiter Instrument Training)

Transfer to Moon from LEO (Basic)

Key Concepts: Launch window for alignment with target, orbit alignment, transfer orbit, delta-V, eject timing, course corrections, capture by Moon, retro burn for orbital entry/landing.

Resources/Skills Needed: Align, Orbit, & Transfer MFDs, Orbit MFD referenced to Moon

Tutorials: Chapter 4; Harmsway (Orbiter Instrument Training); Trevor Johns (Mars/Phobos); Andy (Transfer MFD Tutorial); Poons (includes transfer *back* to Earth, and Earth reentry in DG)

Synchronize Orbit (Rendezvous) / Dock (LEO to LEO)

Key Concepts: Alignment of orbital planes, orbit synchronization (and MFD), docking approach.

Resources/Skills Needed: Synchronize Orbit MFD, Orbit HUD, Docking MFD, Docking HUD

Tutorials: Chapter 5; Smitty; Poons; Orbiter 4, 18; Harmsway (Orbiter Instrument Training)

Atmospheric Reentry (Earth)

Key Concepts: Reentry timing and geometry, retro burn, pitch/bank angle control in reentry phases, atmospheric friction heating, alignment with base, energy management, lift forces.

Resources/Skills Needed: Nav/Com MFD, Map MFD (target base)

Tutorials: After Columbia; Poons; Harmsway (Orbiter Instrument Training); Orbiter 18.3

Runway Approach & Landing (DG and / or Space Shuttle)

Key Concepts: Energy management, angle of attack, use of Surface HUD, navigational/approach aids, visual alignment cues.

Resources/Skills Needed: HSI MFD, runway approach aids (VASI, PAPI)

Tutorials: Poons; Harmsway (Orbiter Instrument Training); Orbiter 18.3

Transfer to Moon and Planets from LEO (Precision)

Key Concepts: Launch window, delta-V, eject timing, orbital alignment (in plane vs. out of plane transfers), course corrections, time vs. energy, orbital entry vs. direct reentry, aerobraking.

Resources/Skills Needed: Transfer MFD, TransX MFD, IMFD (add-on, see chapter 6)

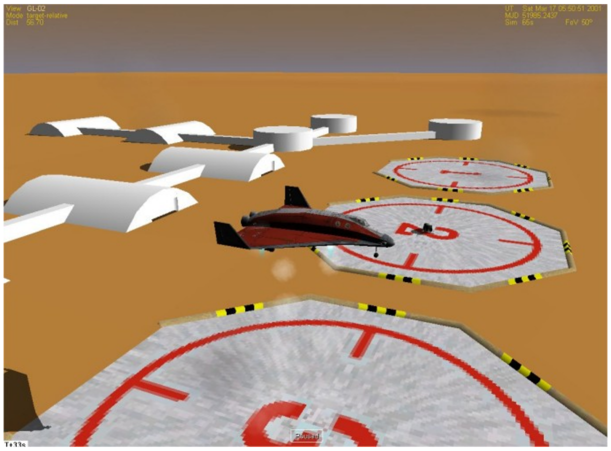
Tutorials: Chapter 6 (IMFD); Duncan Sharpe (TransX); Andy (TTM24); Rob Denny; Jarmo Nikkanen (IMFD)

Flying the Space Shuttle

Key Concepts: Vertical launch with roll/pitch control, OMS system, special docking issues (docking port not in nose), EVA/MMU, robot arm tasks, reentry requirements, energy management.

Resources/Skills Needed: Launch procedures (roll, pitch control, *Atlantis*), launch autopilot (add-on Shuttle Fleet); reentry and landing procedures, special key commands for Shuttle systems

Tutorials: Harmsway (various), Kevin Stoffel (landing Shuttle, at eHarm.net); After Columbia (uses DG but explains many details about Shuttle reentry, approach, and landing); Orbiter Manual and the supplied *Atlantis* PDF manual.



Trevor Johns' tutorial starts at Olympus Base...

...and ends about 50 km from Phobos.

Tutorials on the Web

There are quite a few web sites providing support for Orbiter, and this section is not a complete list (usual disclaimer: web sites move, etc.). You can find more sites through the "Related Sites" link on the main site (www.orbitersim.com), and you can find more tutorials in the "sticky" post of the main Orbiter Web Forum ("Web Forum" link at the main Orbiter site, or http://www.orbitersim.com/Forum/default.aspx) to reach this site). Note that the Web Forum has a Search feature, very useful for finding tips, scenarios, procedures, informal tutorials, etc. Choose "Any date" in the search form (the default is "last 30 days.")

PeD/ApD and MFD Shift Key Commands – Note that many of the tutorials were written for pre-2005 Orbiter versions and use the names **PeD** and **ApD** which are *now* called **PeR** (periapsis radius) and **ApR** (apoapsis radius). Since the altitude feature ([**DST**] button on Orbit MFD) did not yet exist, older tutorials often give you a particular PeR value to compare to the radius of the planet or moon to be sure you are high enough above the surface of the planet. This is still OK, though you can also switch to altitude mode and directly display PeA and ApA as I have often shown in this manual (below surface is negative PeA, usually bad).

Many older tutorials also provide shift-key commands for switching MFDs (e.g., Shift-S for Surface MFD), and these no longer work. You must use the [**SEL**] (select) button to bring up the list of available MFDs and choose one from the list with the mouse. This is always possible now that the no-panel view includes MFD buttons (some add-on ships have a virtual cockpit with no buttons). Shift keys *within* MFDs still work (one reason the MFD switch keys were removed is that they often conflicted with internal keys, e.g., Shift-M could mean "mode" and it would not switch you to the Map MFD).

Trevor Johns' Mars Tutorial – This 2002 tutorial has a friendly conversational style and is still considered to be one of the best for learning the basics of Orbiter. It suggests you fly the Shuttle-PB from Olympus Base on Mars which has no panel, though you can use the buttons in the no-panel view for most things, or you can use key commands (which are given in the tutorial text, although some of them won't work in the 2006, mainly the commands to switch MFDs which must now be done with the mouse and the [SEL] button). Another choice is to use F3 to switch to a Delta Glider sitting on a nearby pad (GL-02, picture above left) and follow the same instructions with a familiar panel available. The "flight instructor" will talk you to Phobos (above right).

When you download and unzip the file to your Orbiter directory (use folders!), it will put several scenarios (but not the starting scenario) in the /Scenario folder. It will also create a new folder /T3G which will contain help files and a PDF (T3.PDF). I recommend printing the PDF and working from that. One slight problem is that the Olympus Spaceport scenario it uses as a starting point isn't supplied any more. But the supplied scenario "Martian atmosphere colours.scn" (found under 2006 Edition, Visual Effects) is nearly the same (starting time MJD is off by just 2.6 minutes) and works just fine.

Download (bottom of page): http://orbiter.dansteph.com/index.php?disp=d

Harmsway Tutorials – "Harmsway" (on Orbiter Forums) is actually Eugene Harm, and he has a fantastic Orbiter web site with a lot of great content (he works at Kennedy Space Center as an Environmental Professional, so his involvement with space goes beyond Orbiter – his web site also has a lot of great information about astronomy and the real Space Shuttle). His Orbiter tutorials cover almost all Orbiter operations. They are essentially text-only, but they explain things well and are easy to follow. There is also a page with various "adventures," which are story lines with associated Orbiter scenarios. The "missions" are often involved and challenging, so if you are looking for something to do with Orbiter once you know it better, here you go (most of the adventures require various specified add-on ships and bases in addition to the scenario files that you can download here in some cases) . Gene also has a lot of information about add-ons (see chapter 8). His FAQ is also quite good.

Main Orbiter Page: http://www.eharm.net/shop/freeware/orbiter/orbiter.html

Tutorial Links Page: www.eharm.net/shop/freeware/orbiter/tutorials/tutorials.html

Adventure/Mission Page: http://www.eharm.net/shop/freeware/orbiter/adventure/adventure.html

Poons' "Rocket Science for Dummies" – This 2004 tutorial by "Poons"(actually a small set of tutorials) is also light in tone, easy to follow, and covers a lot of ground (er, space). It is written as a series of posts in an on-line forum, but it includes some good graphics, not just text. The first tutorial starts in a Shuttle-A on the Moon and uses what I now call the "elevator takeoff" (which I "borrowed" from Poons and used in chapter 3), then brings you back with the help of an add-on, the Reentry MFD (available from Duncan Sharpe's web site, see below). Then you fly a DG from the Earth to lunar orbit, much like chapter 4 of this book. But Poons goes the extra mile (or quarter-million) and guides you back to Earth and reentry in the final section – well done! Some steps are explained only briefly, and the tutorials are not updated to Orbiter 2005/2006 (recall PeD=PeR) but they still worked for me when I tried them in 2005.

Starting page:
http://www.gpforums.co.nz/showthread.php?s=4f5e4191a2ba7a24ba4026d529a064a2&threadid=234067&perpa

Andy McSorley's "Virtual Spaceflight" – Andy is a long-time Orbiter user who maintains a fine Orbiter support site with a variety of tutorials, add-ons he has developed, scenarios, and even downloadable DVD and CD case inserts for your backup copies of Orbiter files (very cool!). Andy seems to be quite keen on the Moon, especially the "TTM24" add-on (To The Moon in 24 Hours, see his site for more information on this excellent add-on). Andy is also a contributing author for this second edition of *Go Play In Space* (primary author for the chapter 6 Earth-Mars mission).

Home Page: http://www.aovi93.dsl.pipex.com/index.htm

TTM24 Main Page: http://www.aovi93.dsl.pipex.com/ttm24_tutorials_index.htm

Links to Other Tutorials: http://www.aovi93.dsl.pipex.com/orbiter_tutorials.htm

Smitty's "Orbital Operations Manual" by Jared 'Smitty' Smith – One of the best tutorials around (and probably the most direct inspiration for this book), this one will teach you how to synchronize orbits and dock with the another spacecraft or space station. It goes into more detail than chapter 5 of this book. It includes clear explanations, extensive graphics, and more. This is how I finally managed to rendezvous and dock with the ISS. His "Grand Tour of the Solar System" is also cool. (http://smithplanet.com/stuff/orbiter/grandtour.htm).

Tutorial (including PDF Link): http://smithplanet.com/stuff/orbiter/orbitaloperations.htm

Rob Denny's Space Navigation Tutorials & Tools – Robert Denny's web site is just a single page, but it includes two useful add-ons (the essential Attitude MFD v3.0 and the Rendezvous MFD) as well as his excellent tutorial for Interplanetary MFD v4.2 (see chapters 6 and 8).

Home Page: http://solo.dc3.com/orbiter/

After Columbia's Entry Tutorial – Very detailed, illustrated tutorial on atmospheric (Earth) reentry. Uses the DG (in Orbiter 2003) but has many comments relating to reentry by the Space Shuttle, and aimed at helping to explain the difficulties of reentry and how these relate to the loss of the *Columbia* in 2003. Includes a lot of screen shoots and discussion, not just procedures.

Web page: http://aftercolumbia.tripod.com/entrytutorial/

Duncan Sharpe's "Orbiter Mars" Site - Duncan Sharpe is the author of TransX, an advanced orbital transfer tool suitable for Moon and interplanetary flights. His web site has links to a number of TransX tutorials and other tools (also his Reentry MFD which helps in planning and executing reentries). His "old stuff" page has older but still useful topics, including a nice runway takeoff explanation and an Earth-to-Mars tutorial using only standard MFDs (i.e., Transfer, not even TransX).

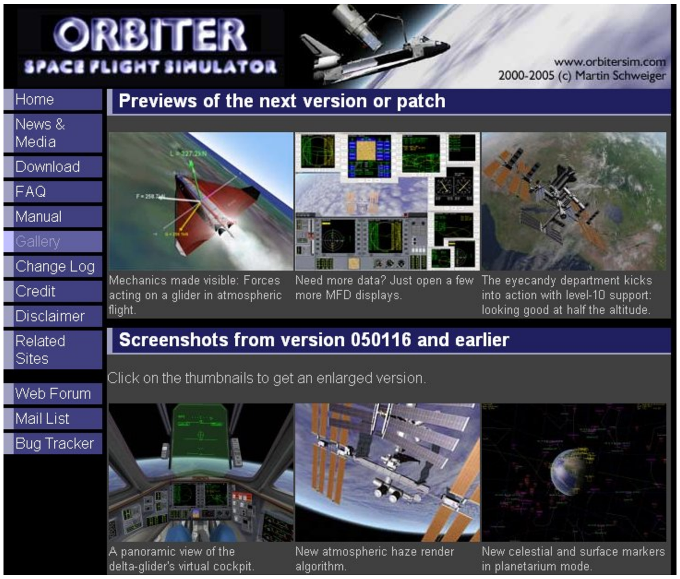
Home Page: http://www.orbitermars.co.uk/

Jarmo Nikkanen's IMFD 4.2 – Jarmo's IMFD 4.2 add-on (version 4.2.1 for Orbiter 2006) is another good option for a comprehensive precision navigation and flight planning tool for interplanetary flights, although it is an optional add-on. See chapters 6 and 8 for more on this powerful tool.

Home Page: http://koti.mbnet.fi/jarmonik/Orbiter.html

Other Web Sites

In addition to the web sites mentioned above mainly for their tutorial contents, there are other web sites devoted to various aspects of Orbiter, as well as web sites with space or orbital mechanics content that could be useful to Orbiter users. Since I am not trying to provide a comprehensive list of Orbiter or space related web sites (thousands of those!), and links can get out of date, I will list only two "clearinghouse" Orbiter sites here, and a small number of key space flight sites (mainly NASA and JPL). Note that chapter 8 (add-ons) has links to additional sites that specialize in Orbiter add-ons.



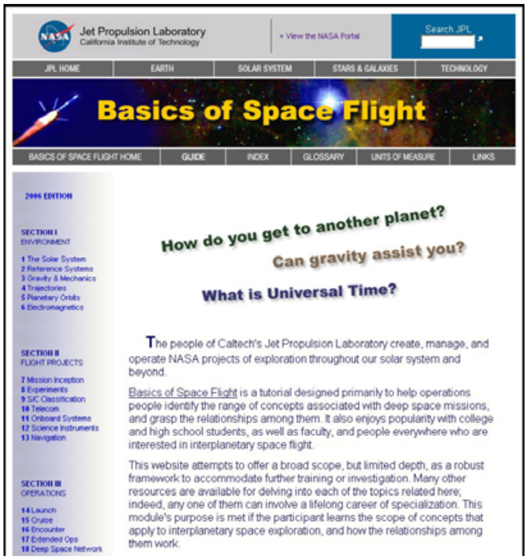
Orbiter Home Page and Web Forum (www.orbitersim.com)

Visit Dr. Schweiger's main web site for information on current versions and patches, download links (mirror sites), a gallery of Orbiter images (shown above), as well as links to related sites, and especially the link to the Orbiter Web Forum. The Web Forum (http://www.orbitersim.com/Forum/default.aspx) is where you can get all the latest information on developments and add-ons as well as advice and help with problems. As I said earlier, learn to use the Search feature on the Forum, because many questions have been asked before. But feel free to post a question that really has you stumped, or to share interesting information or experiences. On the "News & Media" page, there is a link to download a technical briefing on Orbiter 2005 that Dr. Schweiger presented at an ESA Astrodynamics Workshop in late 2004. This presentation (http://download.orbit.m6.net/news/orbiter.pdf) proves that it really *is* rocket science (but it's still fun).

SIMCOSMOS Orbiter Community Links (http://simcosmos.planetaclix.pt/)

This site has a LOT of Orbiter web links, more than I have ever seen elsewhere, including some obsolete sites, but also many recent ones. Quite amazing, but because the site uses frames and has links at several levels (and links to things other than Orbiter), the interface is a bit confusing and the Orbiter content can be hard to find (this is often a problem with framed web sites). So I will provide a direct link to its internal (non-frame content) page that lists hundreds of Orbiter related web sites:

http://simcosmos.planetaclix.pt/01_orbiter/SC_atlaslinks/00_orblinks/orblinks.htm



JPL's Basics of Space Flight (http://www2.jpl.nasa.gov/basics/)

This web site is **essential reading** if you want to understand space flight. It is really, really good, and I recommend that you work through the web-based version rather than the PDF version because the web version has interactive and animated content that is not possible in the PDF. Do the quizzes rather than skip them – your reading will be more engaged if you know there's a small test. Very well done.

NASA Educational Web Content (http://www.nasa.gov)

NASA has a lot of pretty pictures and a lot of educational content on the web, but it's spread around various sites, categories, and educational levels and can be hard to find. Of course they have search capability, but you may have better luck with www.google.com by using the "site" qualifier (e.g., type **`orbital elements site:nasa.gov`** in the Google search box,). This often puts more useful pages at the top of the list (this is Google's big trick!), while NASA's own site search may bunch together a lot of similar pages. You can also use this technique with Google's "Images" link to directly find graphics on NASA web pages (there must be millions).

Human Spaceflight: http://spaceflight.nasa.gov/home/index.html (excellent entry point)
NASA Kids: http://kids.msfc.nasa.gov/ (not just for kids, lots of good content and multimedia)
JPL Education Gateway: http://education.jpl.nasa.gov/k12/index.html

Rocket and Space Technology (http://www.braeunig.us/space/index.htm)

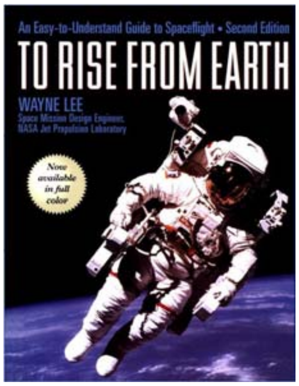
This is a great site with tutorial material (including problems and solutions) and information on orbital mechanics, rockets, spacecraft systems, tables of space missions, and much more. The orbital mechanics material is mathematical (at the level of algebraic expressions and geometry) but not extremely complex. It has many useful equations for calculating the effects of changes of velocity and the like.

Wikipedia (www.wikipedia.org)

My favorite general reference on the web, built by people who care about the subjects!

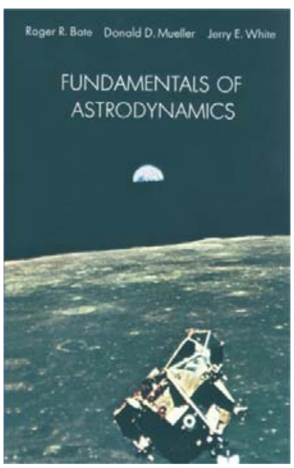
Books for Learning More

There are many books about space, at many reading levels and degrees of detail and technical content. Many of the children's books about "space" are mainly about astronomy, which is fine, but there is usually very little content on space flight (this is one of the reasons I wrote this book). So I will keep this list short and refer you to www.amazon.com (a great search tool even if you don't choose to buy your books there) and of course Google and other general search tools and on-line book stores to find other books.



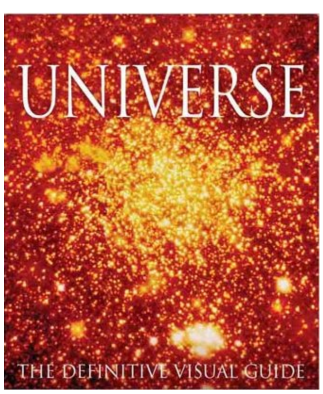
To Rise From Earth by Wayne Lee (Second Edition, Facts on File, 1999)

This book is fantastic! It is the best basic introduction to space flight and orbital mechanics I have ever seen, written by a space flight mission planning engineer and project manager for NASA's famous Jet Propulsion Laboratory in Pasadena (really La Cañada), California. Unfortunately it is out of print, but you may be able to get a used copy (as I did) through www.amazon.com.



Fundamentals of Astrodynamics (Paperback) by Roger R. Bate, Donald D. Mueller, Jerry E. White (Dover Books, 1971)

Yes, 1971, and I've had this book since my days as a physics major in that very same decade. It's still in print and is one of the best introductions to orbital mechanics, with simple but effective graphics, good explanations, examples, and a number of equations (it was first written as an undergraduate text at the U.S. Air Force Academy). It assumes familiarity with geometry, vectors, algebra, and some calculus. You don't need this book to use Orbiter, but if you want to dig deeper into orbital mechanics, this is a good (and cheap) place to start.



UNIVERSE - Martin Rees, General Editor (Dorling-Kindersly, 2005)

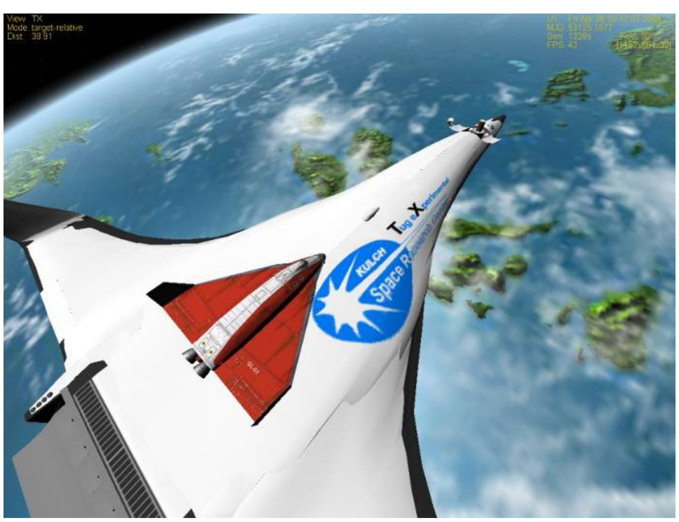
Of course I after talking about how so many "space" books are mainly astronomy books, I go and recommend a huge US$50 book that is primarily an astronomy book! But it does include a number of pages on space flight, and a fantastic collection of up-to-date (as of late 2004) planetary images from various spacecraft, as well as great descriptive text, astronomical star charts, and much more. If you decide to have just one book on space and astronomy, this could be it (get it on-line for a discount).

A Bit About Add-ons

One of the clever things that Martin Schweiger has done in designing and implementing Orbiter is to provide a flexible interface so that programmers and 3D graphic designers can create new features for Orbiter without his help. These are commonly called add-ons, and there are hundreds if not thousands of them in existence. This is a real gold mine for Orbiter users with special space interests. Chances are good that if it has something to do with space flight, past, present, future, or fictional, someone has created an add-on for it. If not, create your own (see http://www.eharm.net/shop/freeware/orbiter/developer/developer.html).

So in addition to the basic and optional high resolution graphics file downloads needed to install and run Orbiter, there is also a downloadable "SDK" (software developer's kit) with examples, utilities, documentation, etc. that programmers can use to implement new spacecraft, textures, MFDs, 3D objects, help files, etc. Note that this does *not* mean that Orbiter is "open source" – Dr. Schweiger provides a free license for anyone to use the Orbiter software, but he retains all intellectual property rights to it. The SDK only defines the interfaces that programmers can use so their code can be linked to and understood by Orbiter. But it is flexible enough to allow, for example, not only new rocket engines, but even totally new forms of propulsion.

So this chapter is just an introduction to a few add-ons I believe to be especially useful, amazing, or just cool. It's not really a how-to, but it does include some tips.



TX winged space launcher – A Delta Glider is pretty big. So imagine how big this hypothetical winged launcher is. Yury Kulchitsky ("Kulch," http://kulch.spb.ru/,) has developed a number of innovative propulsion and launch systems for Orbiter including an electromagnetic lunar mass driver and a "space elevator" (a cable to lift payloads to orbit – should be possible with carbon nanotubes). These add-ons go beyond mere rockets to show advanced concepts discussed in the space literature. The winged launcher concept was used on a smaller scale with SpaceShipOne (also available as an add-on) which won the X-Prize in 2004. Aerodynamic lift and the ability to land on a runway are big advantages that may well be used in future launch systems (straight up on a rocket is not the only way to go).

Add-on Mania

There is a certain danger in add-ons for Orbiter if you have any sort of inclination to collect things. There are just so many cool add-ons to find, download, and try (nowhere near Microsoft Flight Simulator, of course, but amazing nonetheless, and all free). So whatever your special interest in space, you can probably find add-ons related to it, though another slight danger is that add-ons are not always up to date and compatible with the latest Orbiter version. This is no one's fault and no one's responsibility – like Orbiter itself, add-ons are free, developed by Orbiter fans with programming and graphics skills for their own enjoyment, and shared for the benefit of other fans. But it's not always as much fun to update something you developed two years ago – you may be busy with other things, or you may want to develop something new. But many older add-ons continue to work with the latest Orbiter, so you can at least try them if you are interested.

This chapter has profiles of some Orbiter add-ons I've chosen to feature because I think they are good – not necessarily the "top 10" add-ons or anything (though some certainly are) – I'm sure there are others I've never even tried that are fantastic. These are only my opinions of course. It's a starting point.

Some of these profiles are more in-depth than others, and may even seem to be in the nature of a review, with notes on "cool things" and "cautions." Add-on developers put a lot of time and work into these free "products" and I hate to criticize anything, since they don't have to share their work in the first place (and no one forces anyone to use it). "Cautions" are mentioned mainly for the benefit of new users who may appreciate knowing that some add-ons don't have extensive documentation and may assume more Orbiter experience and space knowledge than a typical new user may have.

Where and How to Get Add-Ons?

I've tried to give search and usage tips for most of the individual add-ons mentioned below, but here's some general advice on finding and using add-ons:

- ✓ The main sites for add-ons are www.orbithangar.com (smaller add-ons, good search features, pages for latest and most popular downloads), www.spacesimmods.com (larger add-on files, good search features), and www.avsim.com (although this is mostly for flight simulators, it has a special Orbiter area in the File Library, and good search features). There are also files available on www.sourceforge.net, especially NASSP/Apollo (http://sourceforge.net/projects/nassp).

- ✓ Some authors choose to host their add-ons at their own web sites, or at friends' web sites, or at other web sites of one sort or another. Check the "related sites" page of the main Orbiter web site for other possible download sites.

- ✓ Web sites and files can change, move, or even go away completely. Use Google.com to do general searches with as much information as you have about the add-on you are seeking. **Any file names and versions mentioned are correct to the best of my knowledge as of the date of this writing, but these things may change also.**

- ✓ Visit the Orbiter Web Forum, especially the Addons Forum (Web Forum is linked from www.orbitersim.com). There you can see posts about new add-ons and discussions about add-on issues, and you can request information about an add-on you can't locate. You will also find several "sticky" posts at the top of the main and Addon Forums with frequently asked information (where to download files, tutorial locations, tips for add-on developers, etc.). This information should be up to date, but if you find something that's not, please post a comment on the forum. Someone else may know what the problem is.

- ✓ Most add-ons are supplied in zip files, and since most of them will include multiple files that must go into the right Orbiter folders to work right, most add-on makers follow the Orbiter convention of organizing the files into folders with the same names as the Orbiter installation folders (e.g., /config, /modules, /scenarios, /texture, etc.). If this is the case, you will see the folders (or the folder names in WinZip) when you open the zip file. You just need to unzip into Orbiter installation folder in a way that preserves the folder structure (e.g., check the "use folder names" button in the case of WinZip).

- ✓ A few add-ons will not have folders in the zip file and will require you to put the add-on files in the correct Orbiter folders yourself. Be sure to read the readme file or other documentation to make sure you know what to do in this case.

- ✓ Before you install an add-on, always check for a readme.txt or similar file and review it before installing. Make sure the add-on is compatible with your version of Orbiter, or be prepared to do a "clean" test installation with it to see if it will install and work.

- ✓ Keep in mind that while some add-ons replace existing files with an improved version, most will add files to the Orbiter installation. Some of these files can be large, and the main effect of this is typically to increase the load time when you start Orbiter. This is one reason it can be better to have several Orbiter installation folders where you install different types of add-ons, rather than install everything on top of one big Orbiter folder.

- ✓ There is at least one program which can be used to manage your add-ons. It is called Add-on Installer V1.1 by Thomas Kisiel. It is available on www.avsim.com (you can search for the file **orbiteraddoninstallerv110.zip**) and it can be quite useful. It allows you to keep track of which add-ons are installed, and even to selectively remove them. But to allow this, it keeps backup copies of all the old files, which can greatly increase the size of your Orbiter installation folder. It has a few limitations, but you may want to give it a try if you start using a lot of Orbiter add-ons (I have only tested this program with Orbiter 2005).

Have fun collecting and playing with the many add-ons for Orbiter!

Multiple Orbiter Installations

You can have multiple installations of Orbiter on one PC. It's just another folder and 80-300+ MB of disk space. This is especially useful if you want to try out an add-on that has not been updated for the latest Orbiter. You can make a clean installation of Orbiter, install the add-on, and try it out. If it works, great. If it doesn't, you know it's not compatible without having to consider whether the problem might be due to a conflict with another add-on (which sometimes happens). If you have lots of disk space, keep a basic installation of Orbiter installed with no add-ons (or maybe just Orbiter Sound), and copy this folder to a new folder when you need a "fresh" copy to try out an add-on. If you are short of disk space, burn this "master" install file to a CD to copy when you need to.

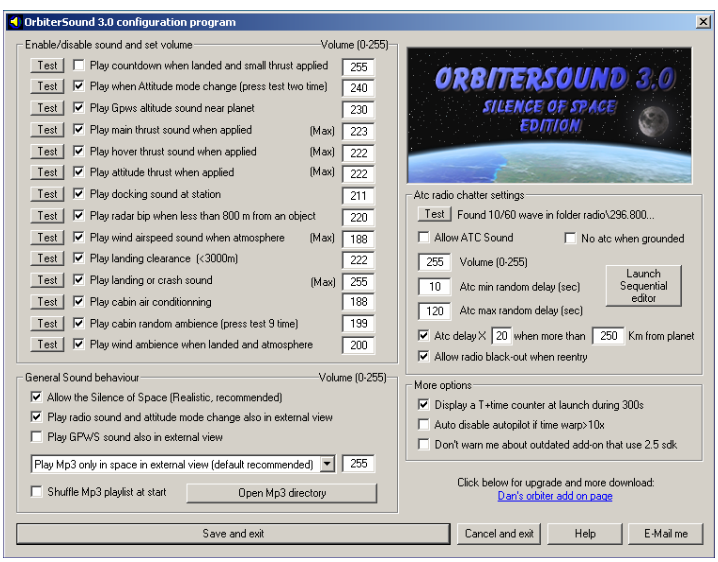
Orbiter Sound 3.0

As discussed in Chapter 1, Orbiter Sound 3.0 is the closest thing to a "required" add-on for Orbiter (it was developed for Orbiter 2005 but works well with the 2006 version). It is available from its author's web site, http://orbiter.dansteph.com. Dan has created a wonderful enhancement to Orbiter. It just adds so much to the experience and can't really be compared with other add-ons. So I hope you are already "sold" and I will talk a bit about configuring Orbiter Sound.

Orbiter Sound installs its own configuration utility which is very useful (below left). Here you can choose the types of sounds you want to hear and set the audio volume and test each type of sound.

I personally like hearing almost all the sounds, but I like to turn down the relative volume of some of the background noises so I can hear the MP3's better. I also tend to turn off "ATC" (air traffic control radio messages) since these are really only playing recordings from historical space missions (including Apollo 11) on a random basis (not connected with what you are doing). They are fun to hear a few times (and there are other "sound packs" available which I have never tried).

Note that you have a folder under the main /sound folder where MP3's can be copied to hear in Orbiter. A better option is to use the WinAmp playlist file found in that same folder to define the songs you want to hear regardless of where the MP3 files are on your PC. WinAmp is a widely used media player with a lot of powerful features (free version available, see http://www.winamp.com). The WinAmp playlist is actually a text file, so it's possible to modify it with a text editor to add song files to it without even using WinAmp as long as you follow the format (I think Dan chose to use this as a convenient, text-based way to define a playlist – Orbiter Sound does not use WinAmp itself to play music, it makes use of media service routines that are available to applications running under Windows).

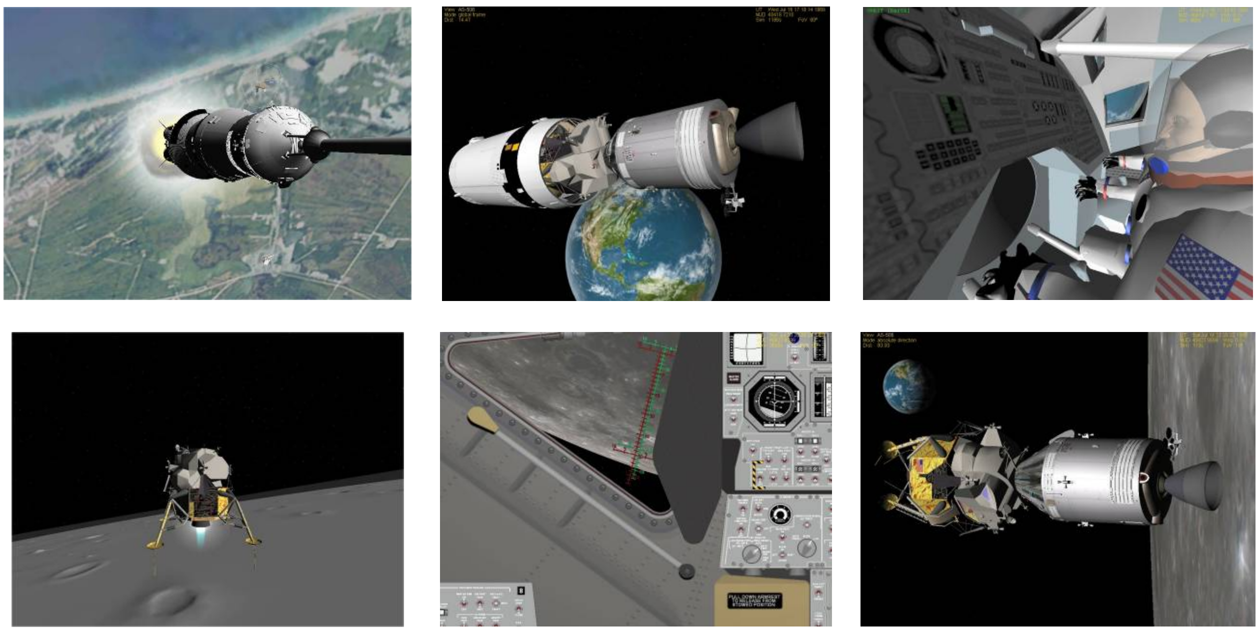


When you are in Orbiter, you can also change some settings of Orbiter Sound from its MFD (click [**SEL**] then [**Radio/MP3 panel** – above right). Here you can control some individual sounds (e.g., you can disable the landing or docking proximity beep, which can get a bit annoying at times). You can also control when MP3's are played (internal vs. external views) and you can skip tracks. Notice the CD-player-like sound control buttons (PRV, NXT, MUT, etc.) around the MFD in the screen shot above.

The Big Iron (Apollo, Shuttle Fleet)

These add-ons are projects that involve more than a single spacecraft, scenery addition, MFD, or special scenario. They involve all of these things and more and generally represent the work of teams made up of programmers, graphic artists, and others with a keen (some might say obsessive!) interest in a particular space program. Orbiter users get to share the fruits of their obsession and attention to detail.

NASSP 6.4.2 (Apollo) This is a truly amazing add-on. NASSP stands for "NASA's Apollo Space Simulation Project" and this project has been under way for several years. The current version allows you to simulate every important aspect of the Apollo Moon missions of 1968-1972, from the Saturn V launch to the astronauts walking on the Moon. It includes vehicles (Saturn V, Command/Service Module [CSM], and Lunar Module [LM]), panels, sounds, lunar bases (with 3D craters and hills), and scenarios. The Apollo 11 screen captures below are in intended to show the range of things you can experience with this add-on, but they are too small to show the incredible detail (clockwise from top left: Saturn V launch, docked with LM near Earth, CSM virtual cockpit view, lunar orbit, panel view from LM Commander's window, close to touchdown at Tranquility Base).



Primary Author(s): The NASSP Team (administrator Markus Joachim, "tschachim")

Where to Find It: The main link is http://sourceforge.net/projects/nassp/ which includes a link to the actual download page (download full 6.4.0 zip file plus patch files for 6.4.1 and 6.4.2, and install them in this order into an Orbiter folder, preferably one with Orbiter Sound and the Land MFD as the only other add-ons). Check the main page for possible references to further patches and upgrades.

Cool Things: Too many to mention. It really has it all from super detailed spacecraft models to real radio recordings keyed to some mission events to clickable panels for both the CSM and LM to 3D bases to simulate the terrain found at the actual landing sites for each Apollo mission.

Cautions: The main one is complexity. Although there is a launch sequencer/autopilot that is easy to use to start the launch, other tasks are done with a simulation of the AGC (Apollo Guidance Computer), entering strings of numbers like the real astronauts did. Cool, but complicated. Of course you can still use the regular Orbiter MFDs (e.g., Transfer MFD), and you can use the Land MFD autopilot (available but not included in NASSP) to land the LM on the Moon. Another caution is that I have not personally tried out NASSP 6.4.2 with Orbiter 2006 as I had done for Orbiter 2005, but I have been assured by other Orbiter beta testers that it works OK.

Things to Try: Although conducting a full Moon mission with all the steps is a real challenge, there are easy things to try from supplied scenarios. There are mission scenarios for all the Apollo missions in the "Project Apollo – NASSP" folder, but the "Apollo 11" subfolder has scenarios for many steps of the mission. Launch of the Saturn V is automated as in real life (go to the internal panel view and watch the mission clock – just accelerate time 10x or 100x until about T-20 seconds, then go to 1x, listen to the countdown, and watch from various viewpoints). If you have the Land MFD, it's fun to experience the Apollo 11 LM automatically landing at Tranquility Base (it seems best to start with one of the Apollo scenarios that come with the Land MFD itself).

Tutorials: There are several quite detailed tutorials around written for earlier NASSP versions. I have "spot checked" a few parts of these, and they seem to still work with the 6.4.2 version, but there may be some small differences. In any case, they are still quite helpful and will teach you a lot about how Apollo missions were done. As a tiny example, to extend the LM landing legs, you click the **LDG GEAR DEPLOY FREE/SAFE** switch on the "Explosive Devices" panel of the LM – the G key won't work! How would you know this? Read all the (PDF) manuals! The switch location would be in the "NCPP LM Instrument Panel Manual.pdf" and the procedure is in "NCPP LM checklist.pdf". Also check the Orbiter Web Forum "sticky" post on tutorials for additional information.

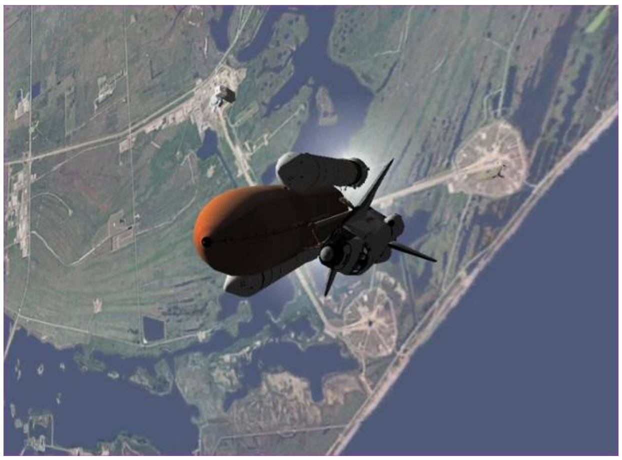
Note For Older Tutorials: Before Orbiter 2005, **PeR** (periapsis radius) was called **PeD** (periapsis distance, I guess). Similarly **ApD** is now **ApR**. This was changed when the altitude feature (DST button) was added, probably to avoid confusion on "distance from what?" (PeA is altitude from surface, PeR is radius from planet center). Older tutorials often refer to PeD and ApD – just think PeR and ApR instead.

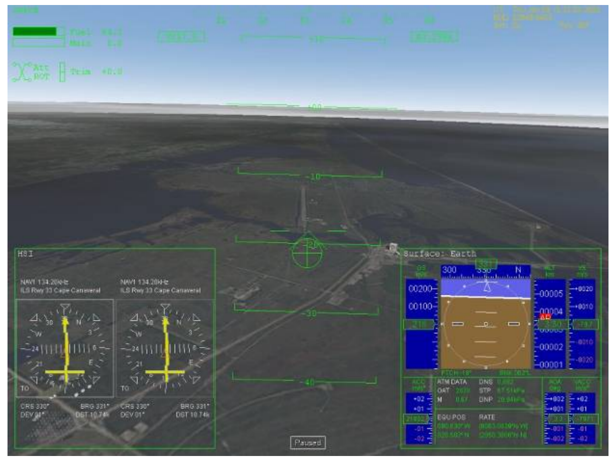
- **Apollo Lunar Mission Tutorial** by John Dunn (http://www.jdkbph.com/ALMT/index.htm) - Written for NASSP v4, it is very detailed, with background info and screen shots as well as procedures. Uses the standard Transfer MFD (as in chapter 4 here) for the first part of the mission (to the Moon) and the TransX MFD for the Moon-Earth phase. PDF files available for download on each page.

- **Orbiter Apollo11 Tutorial** (by "SaturnV" – search www.orbithangar.com for **tutorial**, file name OrbiterApollo11Tutorial.pdf) - Written for NASSP v5, also is very detailed, well illustrated, and informative. Uses the TransX MFD which has not been covered in this book.

- **How to get to lunar orbit the easy way tutorial** (by "Bob7" – search www.orbithangar.com for **tutorial**, file name to_the_moon_the_easy_way2.pdf) - For NASSP 5.2, shorter and simpler than the other two, but only goes as far as LOI (lunar orbit insertion, not the landing and return to Earth).

Space Shuttle Fleet (current version as of April 2006 is 3.8.5) – Although Orbiter includes a version of the Space Shuttle *Atlantis* which is quite good, the "Shuttle Fleet" add-on series is much more complete and detailed in many ways, including an excellent launch autopilot (the default *Atlantis* must be hand-flown to orbit, which is actually not that realistic). It's called the "fleet" because it includes separate downloads for *Atlantis*, *Challenger*, *Columbia*, *Discovery*, and *Endeavor* (*Challenger* and *Columbia* were of course lost in real life, but since many Shuttle fans like to re-create historic missions and payloads, they are still included in the Orbiter fleet). Each download includes payload objects, configuration files, graphical textures, authentic sounds, and scenarios appropriate to the Shuttle in question. This means that during an *Endeavor* mission, you will hear authentic radio calls for mission events such as, “Endeavor, Houston, negative return,” (meaning that the Shuttle has reached the altitude and distance from launch that is beyond the range for returning to Kennedy Space Center in the event of a serious problem, so it would have to land in Europe or North Africa or “abort to orbit” for any problem after this point). Screen shots: looking back at Kennedy Space Center (KSC) shortly after launching *Endeavor* (left), and a no-panel view on final approach for runway 33 at KSC, with the HSI MFD for instrument landing guidance, and the Surface MFD for general flight information (MFDs are transparent in this view, which is an option you can set in the Launchpad).





Primary Authors: Don Gallagher, Dave Hopkins

Where to find it: Try www.orbithangar.com and search (by author) for **david413** or (by name) **Shuttle** (this will find other types of “shuttles” as well) to find the five current Shuttle Fleet downloads (6-8 MB each) and any special add-ons (e.g., additional payload files). There have occasionally been some hosting problems, so check the Orbiter forum if you have trouble finding the Shuttle Fleet.

Cool Things: Authentic and detailed in so many ways. Excellent graphical modeling including virtual cockpits (unfortunately non-clickable); autopilot for realistic launch sequencing (be sure to activate the GPC MFD from the Launchpad since this is the launch autopilot); working “robot arm” for manipulating payloads. Atmospheric flight modeling (for landings) seems to be good. Excellent integration of sounds captured from actual missions. Up to date (e.g., payload and other information were available for the July 2005 STS-114 flight of *Discovery* at the time it actually took place).

Cautions: The major one is that there is no mouse-enabled panel, so you need to use key commands for most things (you can use the no-panel MFD and autopilot buttons). The documentation is also somewhat limited. A PDF with all key commands and some other information is included, but not much else. Some of the Shuttle information in the Orbiter main manual (orbiter.pdf) and in the two *Atlantis* PDF files supplied in the Orbiter /Doc folder can be useful with the Shuttle Fleet, though key commands can be different. You can find tips in the Orbiter Forum on flying the Shuttle Fleet, but you will find it easier to first get familiar with Orbiter using the Delta Glider (etc.) before trying a lot of things with the Shuttle. A realistic fact of life for the actual *and* simulated Shuttles is that the fuel load is very limited – unlike the DG, you typically can’t make big orbit changes with the Shuttle (even getting to orbit can be tricky without the launch autopilot – almost no fuel margin for mistakes). You can’t even make up for this by using Orbiter’s “unlimited fuel” option, because the Shuttle must lose a lot of mass by burning fuel during its ascent, or its engines won’t have enough thrust to raise it to orbit!

Things to try: Any of the launch missions is easy to do with the launch autopilot and fun to watch and listen to (but see tip below). It is also fun and easy to play with *trying* to land the Shuttle from a final approach scenario (watch the tutorial playback first), though doing a full re-entry to landing is quite a bit harder. It's not included with the Shuttle Fleet, but there is a reentry autopilot add-on for Shuttle reentry. It is called AutoFCS (file is http://www.rmnorman.com/Orbiter/AFCS2p1.zip by author Mike Norman, "Mikey451" on the Orbiter forums). This can control the reentry from the de-orbit burn (typically over Western Australia for KSC landing) all the way to stopping on the runway. Pretty amazing.

Easy But Semi-Cryptic Launch Codes

The special autopilot for the Shuttle Fleet is called GPCMFD 3.0 and it is installed with the Shuttle Fleet files. First activate it in the Modules tab of Launchpad. Run a Shuttle launch scenario and open GPCMFD with [**SEL**] and [**GPC MFD**]. You will see MFD buttons [**OPS**] and [**ITEM**]. Click [OPS] and enter 1 for mode 1 (Ascent). Then click [ITEM] and enter the special item 777 followed by the Enter key. This will start the launch countdown at T-10 (10 seconds to launch). See the supplied manual (GPCMFD V3 Manual.pdf) for more details. It's automatic up to MECO except you will need to make a small OMS engine burn near apoapsis to raise the periapsis and circularize the orbit.

Tutorials: I haven't found any full tutorials specifically for this latest release of the Shuttle Fleet, but several pages at Eugene Harm's site are very helpful.

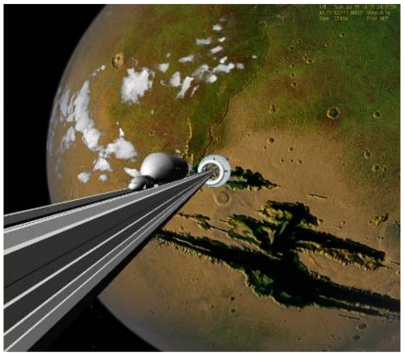
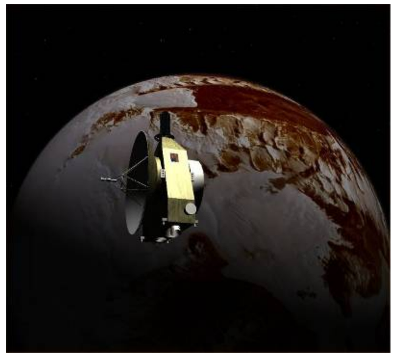
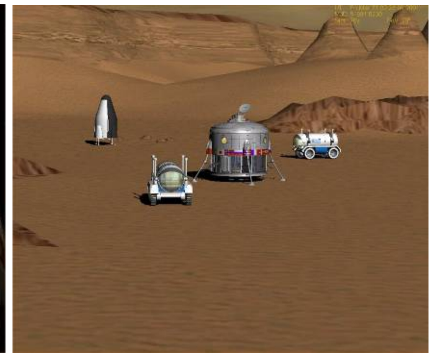
Installation tips and zip file with some scenarios and a PDF "Shuttle Launch Guide" – This really is a sort of mini-tutorial since it includes both the real Shuttle timeline events and the few Orbiter procedures that are needed (it assumes the add-ons he recommends are installed):
http://www.eharm.net/shop/freeware/orbiter/addons/atlantismod/atlantismod.html

A very informative review and discussion of the previous 3.8.2 Shuttle Fleet:
http://www.eharm.net/shop/freeware/orbiter/addons/endeavour/endeavour.html

A description of how to de-orbit and land the Space Shuttle (by Kevin Stoffel):
http://www.eharm.net/shop/freeware/orbiter/tutorials/orbiter_instrument/deorbit.html

ET Sep at the Cape – That's "the Cape" for Massachusetts people, Cape Cod, just above the nose of the ET (not Cape Canaveral). Here the 3.8.5 Space Shuttle *Endeavor* is approaching orbit and has just separated from the External Tank. The GPC MFD will fly the Shuttle all the way to low Earth orbit, although if an OMS burn (Orbiter Maneuvering System) is required to raise the periapsis and circularize the orbit, you will need to do this manually just as you would for the Delta Glider.

Toward a Better Looking Universe

Orbiter comes with some nice looking planet textures in the default installation, and there are standard high-resolution textures available for download and installation, now up to level 10 for Earth and Mars, with lower resolution levels for other planets and moons. Orbiter also allows add-on developers to define new surface and cloud textures for existing planets, and many have used data from NASA and other sources to create alternate surface textures for the Earth, Mars, and other Solar System planets (such as the futuristic terra-formed Green Mars*, above left, with Kulch's space elevator* - see footnote on next page for file information). Orbiter add-on developers can also add additional planets such as Pluto* (above center with New Horizons* spacecraft add-on), various asteroids, and many smaller moons of the Outer Planets which are not included by default. Orbiter add-on developers (or even users who choose to edit various "config" files – OK if you really know what you are doing) can even modify the properties or the Sun or the planets. This can be useful if you want to define scenarios that take place in much earlier or far future times (the orbital elements of the planets change slightly over time).

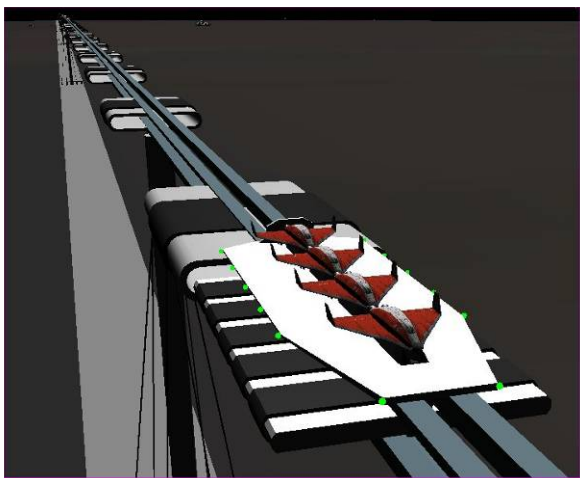
You can even completely redefine the Solar System to represent a hypothetical one for a different star (and define a whole new set of hypothetical planets to go with it). Developers can also define special highly-detailed textures for small areas (such as the default detailed area around Kennedy Space Center), as well as additional surface bases that can include 3D features (buildings, launch pads, craters, hills, lunar cities, etc., such as the detailed Vallis Dao* region of Mars, above right, with Mars Direct* development vehicles). You could call all of this stuff "scenery" and there is quite a lot of it on the web.

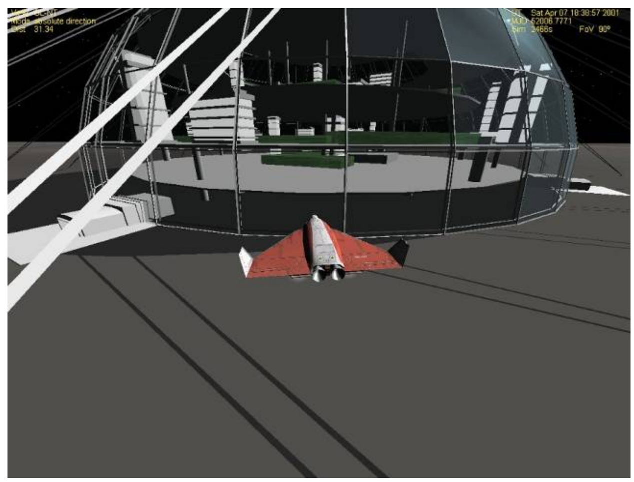
Changes in 2006 – Scenery (especially textures) is relatively "static" and may not be quite as version dependent as some other sorts of add-ons (such as spacecraft) that interact more extensively with the Orbiter "engine," although there is an important exception to this statement in the 2006 version of Orbiter. In order to support higher level textures more efficiently, Dr. Schweiger changed the structure of some of the planetary the texture files. This affects mainly planets with reflecting (water) areas and night lights (mainly Earth) for resolution levels 9 and above (9 was the highest resolution in Orbiter 2005, while Orbiter 2006 supports level 10). Planets without reflecting areas and night lights and with resolution levels of 8 and below are not affected. Cloud maps are also not affected.

This means that alternate high-resolution textures of Earth will need to be re-done, but the good news is that that new L10 Earth texture available for optional installation with Orbiter is quite good, as is the new L10 Mars texture (although that one is huge, 175 megabytes compressed as a zip file, much more when installed – this needs a good graphics card to run well). The other good news is that since most other planets and moons do not have water and lights, most existing texture add-ons for other planets (which tend to be level 8 at most due to limited available data from space probes) should work fine. Orbiter does not include Pluto by default, so a nice addition is Pluto/Charon 2.0* by NightHawke. It is visually quite cool, although the surface details are necessarily conjectural since the first spacecraft that will visit Pluto (NASA's New Horizons*) launched in January 2006 and will not reach its target until 2015.

It is better to use add-ons that are intended for Orbiter 2006 when possible (with 2005 as a second choice that will often work). Some really old add-ons may not work at all, although they sometimes can be made to work with some fairly small but technical changes (e.g., editing something in a configuration or scenario file may be easy to do, but only if you know what you're doing).

Finding New Scenery – The site www.orbithangar.com hosts many smaller scenery files (bases, planets, asteroids, launch pads – 189 files in a recent search). The companion site www.spacesimmods.com hosts many of the larger files, especially high-res planet and moon textures (do a search for Category Scenery, Sub-category Textures to find them). Although it doesn't have specific scenery categories, you can also try searching the Orbiter area of the AVSIM File Library for the words **textures** or **planet** (these produce quite a few hits – see www.avsim.com – registration may be required to download).





LMD & Luna City – There are many Earth bases and some for other planets, but one of my favorite base add-ons is Yury Kulchitsky's Lunar Mass Driver (LMD) and the domed "Luna City" that installs with it as a big expansion of Brighton Beach. This is a bit of a hybrid between a base and a propulsion system, because the mass driver is an electromagnetic rail system on a very long track. Spacecraft are mounted to a "train car" (shuttle) which is driven down the track by a series of powerful magnets. After several kilometers of acceleration, the shuttle reaches orbital speed and the craft are released at the end of the track (starts at low altitude, but OK, no air drag). This is very cool to see. Go to www.orbithangar.com (search for **kulch**, file MassDriver3.zip – see readme.txt file before installing).

Note: Kulch includes a real installer for this and his other add-ons, so unlike Orbiter and most add-ons, it will make entries in your Windows Registry and Start Menu. There's no harm in this, but in some situations, the owner of the PC may not want such software installed, or it may require admin privileges that you may not have.

* Orbit Hangar (www.orbithangar.com) files for other add-ons mentioned above:

Vallis Dao Mars terrain by jtiberius (VallisDao.zip) ; **Space Elevator** by Kulch (SpaceElevator4.zip); **Pluto/Charon 2.0** by NightHawke (Pluto-Charon_v2.0.zip); **New Horizons** by castorp (New Horizons.zip); **Mars Direct** 2004 version by jgrillo (Mars Direct Project.zip – HAB and Rovers shown are in development for a new Mars Direct add-on and are not yet generally available); **Green Mars** by Schimz is available only at www.avsim.com (greenmars.zip)

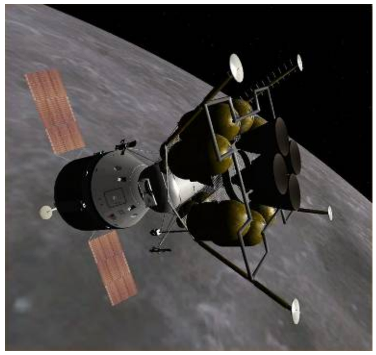
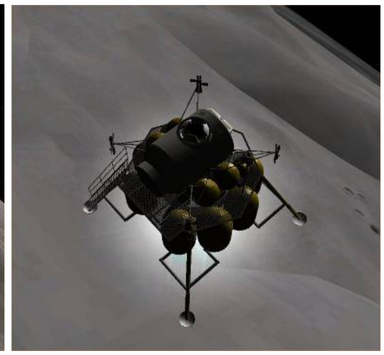
Spacecraft and Space Stations Galore

Add-on developers seem to really like making spacecraft, and they have been greatly helped by "Vinka" (http://users.swing.be/vinka/) who developed the "old" (but still used with many add-ons) spacecraft.dll and multistage.dll plug-in modules (and newer spacecraft2.dll and spacecraft3.dll) which allow physical, performance, and even animation properties to be defined in text files rather than by custom programming. This makes it easier for people whose skills and interests are mostly in the development of 3D models to turn these into operating spacecraft. Note that simple spacecraft can be defined in Orbiter without customized DLL's or even Vinka's DLL's. Such "config file" spacecraft require only a 3D model and a .cfg text file to define its properties.

Historical Spacecraft – This is a category that includes both piloted and unpiloted spacecraft. In the piloted category you can find Project Mercury, Gemini, Apollo (see NASSP above), Soyuz, Space Shuttle, X-15, and SpaceShipOne, as well as some that were designed but never built, such as the U.S. Air Force DynaSoar "space plane" from the sixties. Unpiloted craft start with the pioneers – Sputnik, Explorer 1, Vanguard, and include many lunar and planetary probes (Ranger, Surveyor, the Pioneers, the Mariners, Viking, Voyager, Galileo, many more). There are also launch vehicles from various periods from the US, USSR/Russia, Europe, and a few others (e.g., WWII era German V2). There is even an add-on featuring the small test rockets flown by Robert Goddard in the 1920's and 1930's (this Early Rockets add-on was developed by Mark Paton, who has done a number of excellent add-ons for Orbiter, search for **Paton** at www.orbithangar.com). Most of the spacecraft mentioned above are also at Orbit Hangar.

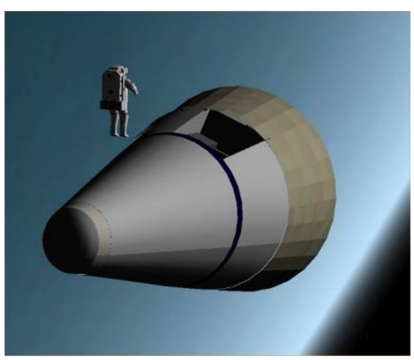
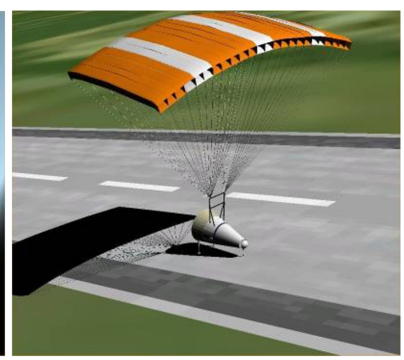
"Godspeed, John Glenn!" Mercury was the first piloted U.S. spacecraft to orbit the Earth. Rob Conley's Project Mercury add-on (panel/window view, above left) is an amazingly detailed recreation of this historic project (file project_mercury_050116.zip, available at www.orbithangar.com, search for author **estar**). Jim Williams has developed many historical add-ons, including Explorer 1 (shown above right), Vanguard, Surveyor, and others. Go to www.orbithangar.com and search for author **Jim Williams** to find these and other add-ons by Jim. Jim's own site http://www.moonport.org has additional information on Jim's developments and support for Orbiter.

Future Spacecraft – This category includes spacecraft and space stations that attempt to realistically portray some future propulsion system or other technology – a spacecraft that *could* possibly be designed and built someday, at least within the laws of physics, even if the technology does not yet exist. You could still call these ships "fictional" since neither the ship nor in most cases the needed technologies actually exist. These include ships with nuclear rocket engines (fission or fusion), ion engines, solar sails, mass drivers, space planes, space elevator cables (perhaps more likely at first on the low-G Moon), various space colony concepts, and even "star ships" based on some of these technologies and perhaps capable of a few percent of the speed of light. Some of these ideas are pretty "far out," but this still differs from various clearly fictional ships that use "warp drives" or other methods to equal or exceed the speed of light. Under the physics that we know today, it is not possible for an object of non-zero mass to travel at light speed, let alone exceed it. New laws and "loopholes" (or maybe "wormholes") may someday be discovered to change this. Until then, warp drives and such can be considered fiction.

ESAS CEV – ESAS is NASA's "Exploration Systems Architecture Study," which defines its future plans for the Moon and eventually Mars (part of the Vision for Space Exploration, VSE). CEV is "Crew Exploration Vehicle," and the late 2005 ESAS study pinned down the basic architecture and design of these post-2010 spacecraft to be at least superficially similar to the Apollo command and lunar modules (but quite a bit larger). The ESAS CEV add-on by "Francisdrake" is a very nice implementation of the design as currently envisioned by NASA (the detailed design will be determined by the winning contractor team). The author recommends another add-on by Simcosmos (António Maia) that implements several variations on the proposed CLV (Crew Launch Vehicle, above left). Both are available at Orbit Hangar. The ESAS final report is available from www.nasa.gov (search for ESAS).

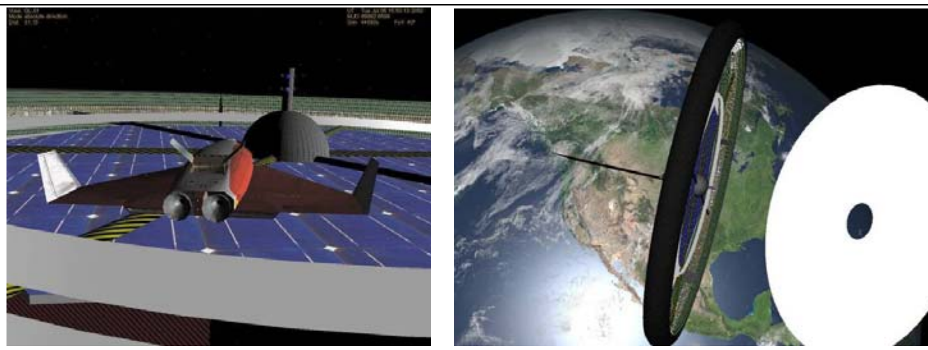
ESAS CEV: http://www.orbithangar.com/advsearch.php?search=name&text=ESAS
VSE CLV: http://www.orbithangar.com/advsearch.php?search=name&text=vse

The Rocket Company DH-1 – This add-on is based on the book **The Rocket Company** by Patrick J. G. Stiennon, David M. Hoerr, and Doug Birkholz (search at www.amazon.com). Although it is fiction, it is actually a technically detailed case study of the formation of a private space company that develops a unique, fully-reusable two-stage launch vehicle. The piloted first stage launches straight up so it can return to its pad with jet hover engines while the piloted second continues to orbit. It's a very cool concept, and I enlisted the help of Andy McSorley and later Mark Paton to develop an Orbiter add-on for the DH-1 so we could try out the concept (it works!). Download and read the included PDF to learn more.

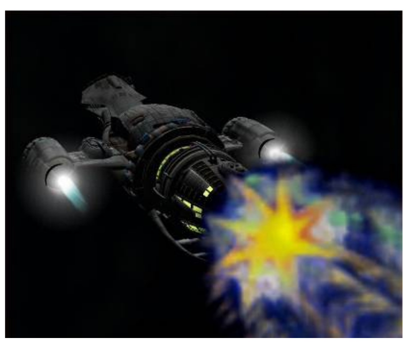
DH-1 "Final" Version (zip file): http://www.orbithangar.com/download.php?ID=2193

Others – Other Orbiter add-ons in this category include our familiar Delta Glider, Dan's greatly enhanced **Delta Glider III** (http://orbiter.dansteph.com); Kulch's **TX4** winged launcher (shown at the start of this chapter, www.orbithangar.com, search for author **kulch**); and Ken Bolli's excellent **TTM24** (To the Moon in 24 Hours, www.orbithangar.com, author **bolli**, and try the tutorials on TTM24 at the Virtual Spaceflight web site, http://www.aovi93.dsl.pipex.com/ttm24_tutorials_index.htm). **Greg Burch** has created a beautiful series of late-21st century ships, stations, and bases that are simply amazing, (http://www.orbithangar.com/searchauth.php?search=gregburch). These are must-have add-ons.

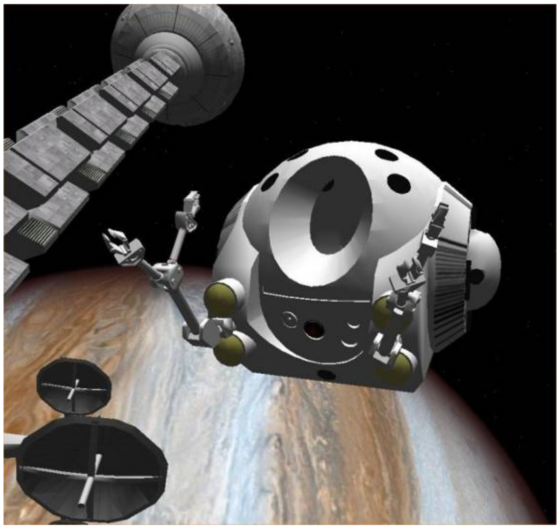
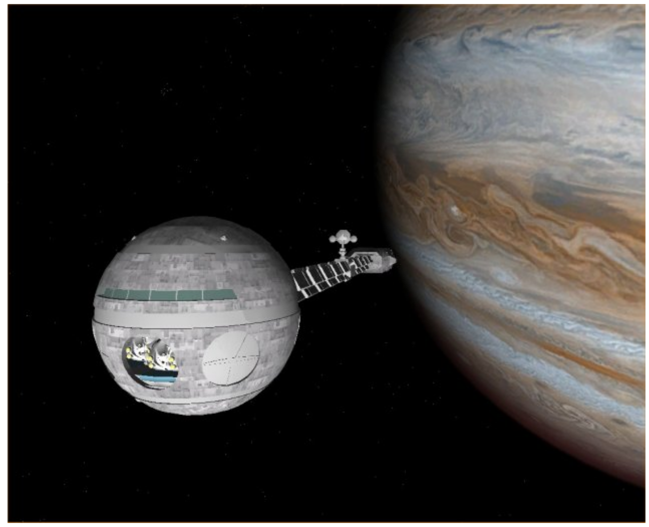


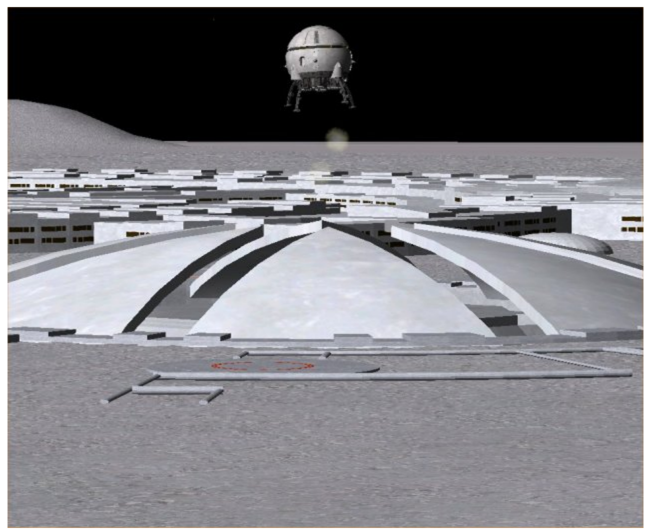
Stanford Torus Space Colony (v1.5 by Steven "Drake" Ouellette) – It may be hard to tell from these pictures, but this thing is *big*, about 1.6 km in diameter. Think of it as a large bicycle wheel that rotates (at 1 revolution/minute) to provide 1G of pseudo-gravity on its main living surface, which would be the inside of the "tire" surface. This area (perhaps 2 km^2) would support some 10,000 residents. To be built from lunar materials. The white disk is a huge solar mirror. Based on a 1975 NASA design study. See www.orbithangar.com, name search **stanford**, file name stanford_1_5.zip, plus habtexhires.zip for the high-resolution living area texture based on the developer's own town. Requires Vinka's spacecraft.dll (*not* spacecraft2 or 3) which is *not* included (http://users.swing.be/vinka/).

Fictional Spacecraft – A huge category that includes *Star Wars* (below right), *Star Trek*, and many others fictional worlds. There is certainly lot of material for inspiration, from golden oldies (*Space 1999*) to recent shows and films (*Firefly* space freighter from the TV show and the movie *Serenity*, below center).



It also includes what you might call "retro-future" systems such as the spacecraft that were illustrated in articles by Werner von Braun in *Colliers* magazine in the early 1950s (picture above left shows the "Wheel" space station and the "Ferry Rocket" multi-stage rocket). "World of Colliers" 2.01 is an incredible multi-vessel add-on with spinning space stations, classic pointy-nosed big-finned rockets, and bug-like lunar landers by Erik Anderson a.k.a. Sputnik and John Graves a.k.a. Missleman01 (search for **colliers** at orbithangar.com). Many of the concepts of modern space flight were laid out in the pages and paintings of those articles – and even if the designs are not practical by modern standards, they still look pretty cool. They really managed to capture in 3D the look and feel of Chesley Bonestell's classic paintings.



My personal favorites in the fictional spacecraft category are the various craft from *2001: A Space Odyssey* and its sequel, *2010* (the *Discovery* is shown near Jupiter, above, top right). Rip a copy of Strauss' "Blue Danube Waltz" (or the *2001* soundtrack) and listen while you recreate scenes from the movies.

World of 2001 – The team of Sputnik (yes, Erik Anderson again), 80mileshigh, and Nautilus created in 2005 what is perhaps the ultimate *2001* tribute with their massive 23 megabyte "World of 2001" multi-vessel, multi-base add-on. The 15 page PDF manual alone is 1.5 MB and describes the many ships (Orion, Titov, Aries, Moonbus, Polaris, and of course the massive rotating Space Station V, lower left above – some of the ships and bases are only mentioned in Clarke's books or the movie, not actually shown, except here). There is a separate manual for the many bases, including a beautifully done Clavius Moon base (lower right, above), complete with an animated retractable dome, as well as the Tycho excavation site with the mysterious TMA object. This add-on is a literally a work of art!

Download: http://www.orbithangar.com/advsearch.php?search=name&text=world+of+2001

2001/2010 Vessels – As fantastic as Wo2001 is, it doesn't let you ask HAL to open the pod bay doors. For that, you need the file **2001_2010vessels.zip** by David Bartles (dbartles2). This 2004 add-on seems to work fine with Orbiter 2006, and it fills out the world of *2001*, extending it into *2010* (the movie), with the *Discovery* (upper right, above), the *Leonov*, and yes, the famous pod bay doors and pods (Work Pod Betty shown above, upper left, apparently operated remotely by HAL). The arms are even animated, with numeric control keys for all the joints (read the PDF). Amazing work!

Download: http://www.orbithangar.com/advsearch.php?search=name&text=2010

MFDs for All Reasons

Add-on developers have created MFDs for all sorts of applications from the simple (e.g., a count down timer) to the very complex. I will discuss three examples that I find especially useful.

Attitude MFD - Attitude MFD V3.0 (050618, seems OK with Orbiter 2006)

Download: Go to www.orbithangar.com and search for **attitude** (file AttitudeMFD050618.zip).

Add-on Description: This is the MFD mentioned in chapter 3 that provides the translation equivalent of "kill rotation," but it does a lot more than this. Robert Denny updated the Attitude MFD for Orbiter 2005, and his orbithangar.com description is pretty concise, so I will quote an excerpt here.

> Updated version of Chris Knestrick's Attitude MFD. This is version 3.0. Attitude MFD provides the user with attitude information (pitch, yaw, and roll) with respect to a pre-selected reference attitude. It also provides an "Attitude Hold" mode to automatically hold the desired attitude. Finally, it provides the ability to "trim" velocity relative to a target to zero in each axis separately or in various combinations. It is really useful in the terminal phase of a rendezvous, where it can be used to orient toward a target and match its velocity precisely.

This really is a great add-on though some may feel that it makes docking a little "too easy." I believe there is no such thing as too easy when it comes to tools (but there's also something to be said for learning to do things manually and then to choosing to do them automatically – but it's up to you). The screen shots below show the Target Relative mode (left) from a docking scenario with the ISS nearby as the target. You can see that the distance is 38.43 m and the Fore/Aft velocity is +0.07 m/s (to "kill" this velocity, assuming the Attitude MFD is on the left side, type **Left** [SHIFT][5] (**keypad-5** - this is easy to remember since keypad 5 alone is "kill rotation" – clever idea). The right screen shows part of the built-in help added with version 3.0 (click the [**MNU**] button 3 times until you see the [**HLP**] button).

IMFD 4.2 – Interplanetary MFD - Space Navigation Computer Version 4.2.1 (patch for 2006)

Download: The author's web site, http://koti.mbnet.fi/jarmonik/Orbiter.html (file imfd.zip)

Add-on Description: Used in the Mars flight in chapter 6, this wonderful and still-improving add-on is extremely powerful and "deep" with many tools for all phases of navigation within the Solar System. Although it has many features and requires some study and practice with tutorials to master, its diagram-oriented interface is very well organized (within the constraints of the MFD screen/button interface). Its automated features can really help the beginner, including an auto-burn feature that will orient the spacecraft dynamically as it makes required burns for the various phases of a trip (orbit eject, course corrections, and even precision base approach that allows you to set up your arrival at a planet for convenient access to the desired surface base). The highly accurate Map program allows you to view the details of your trajectory at any desired point and scale. There's more information on IMFD on page 6-4, along with a number of screen shots showing its actual use for an Earth-Mars flight.

Tutorials: I recommend that you be pretty comfortable with general spacecraft and MFD operations and have one or two Transfer MFD Moon trips done before you tackle IMFD. Chapter 6 is then a logical next step. Then you might try one of the detailed tutorials listed under "Interplanetary MFD - Flight School" on Jarmo's web site (probably Habana to Brighton Beach for a look at a precision Moon flight, or Jarmo's Earth-Mars tutorial). The guest tutorials by "FlyBoy" (slingshot) and Rob Denny are quite good (Rob's IMFD tutorial is "Europa To Callisto" – the zip file has a detailed PDF and scenario files for all steps of the tutorial – Rob's own web site is http://solo.dc3.com/orbiter/). IMFD is worth some effort to master – it will unlock the Solar System and teach you a lot about orbital mechanics.

LandMFD — Landing Autopilot for No-atmosphere De-orbit by Dennis Hare a.k.a. LazyD

Download: At Andy's site (http://www.aovi93.dsl.pipex.com/others_addons/LandMFD0514.zip)

Add-on Description: This MFD is astounding to watch in action as it precisely de-orbits and lands the Apollo Lunar Module (if you have NASSP 6.4.2 installed, see above), up to 6 Shuttle-A cargo ships simultaneously approaching Brighton Beach from different orbits, or a number of other add-on ships I have yet to try (scenarios are provided for various add-ons, especially Apollo/NASSP, but you must install the corresponding add-ons first). All you really need is a hover-capable ship in an orbit that passes near the target base, and LandMFD can usually do the rest once you engage the autopilot.

Install and activate LandMFD in the Modules tab of Launchpad and read the readme.txt file for general instructions (important – while it needs few controls, it seems to have no MFD buttons, so you must know that shift-0 [zero] will engage or disengage the autopilot). Then run the one scenario in the LandMFD folder labeled "Orbiter" - "Brighton Beach Different Orbits" to see it control and land six ships at once (autopilot is engaged when scenario opens). You might then try it with the Mars landing in chapter 6 (see screen shot there – pre-landing scenarios are available so you don't have to fly the whole thing to see the landing).

Note: If LandMFD is installed, it may cause a problem with some scenarios. It seems to happen if you are using time acceleration when you cross the sphere of influence (SOI) of a planet or moon and if LandMFD is activated in the Launchpad, even if you are not using its MFD in the current scenario. Inside or outside the SOI, it seems OK. We're not sure this is it – it's just something that showed up in testing chapter 4 (Earth-Moon flight). If it happens, try de-activating LandMFD, fly until you get close to the target planet, quick-save the scenario, quit, activate LandMFD, and load and complete the saved scenario. LandMFD otherwise works well with Orbiter 2006.

I Was Just Wondering…

We all wonder about things, and with the abundance of information on the web, and with the availability of powerful and easy to use search engines like Google, anyone with an Internet connection needn't wonder for long. And yet… sometimes it's hard to find just the right question to get just the right answer for some special topic where you know more than the average "civilian" yet you really aren't an expert either. Sometimes there's too much information to sort through even with Google's help. When you find 7,437 needles in the haystack (in 0.07 seconds), which is the right needle?

I can't solve this problem in general, of course, but even after pointing you toward the books and web sites in chapter 5, I don't want to just say "you can find that for yourself on the web" for *everything* (though you probably can). I think I may know a few of the things you might be wondering about when it comes to space and Orbiter, because I was wondering about some of them myself not too long ago. So here are a few to get you started, with pointers to the web to help you get farther along. **Note that this information is all optional!** You don't need to know the information in this chapter to have fun and success with Orbiter!

"Is it safe to let the Wookie drive while you make the calculations for the jump to light speed?" is *not* one of the questions answered in this chapter, even though you might be wondering about that. But you can find a Millennium Falcon add-on for Orbiter on orbithangar.com (by Kyle Wiegers, search for **millennium**). And Wookies happen to be quite good spaceship drivers. A better question might be "can I get a spacecraft up to light speed in Orbiter?" (299792458 m/s, 299.8M in Orbiter notation), but you'll just have to try it for yourself. Note that Orbiter 2006 doesn't model the relativity effects which will prevent massive objects in real life from reaching the speed of light.
(Hint: you will need a LOT of fuel.)

You may consider this to be a pretty unusual selection of questions, since it does not include many that might truly be "frequently asked," such as "how do I install add-ons?" Aside from the fact that I've covered a number of such topics elsewhere in this book, I'm also not really trying to make a general purpose FAQ here. It's really more along the lines of "I wanted to discuss this but didn't want to clutter the main text any more than it already was!" There are some real Orbiter FAQ's on the web. Here are a few I have found (the usual disclaimer about web sites moving applies here – I actually found these just now by searching google.com for **orbiter simulator FAQ**).

http://www.medphys.ucl.ac.uk/~martins/orbit/faq.html (official FAQ, mainly troubleshooting)

http://orbit.m6.net/v2/read.asp?id=24924 ("sticky" topic for FAQ on the main Orbiter Web Forum)

http://www.eharm.net/shop/freeware/orbiter/orbiter_faq/orbiter_faq.html

Questions About Orbits and Zero-G

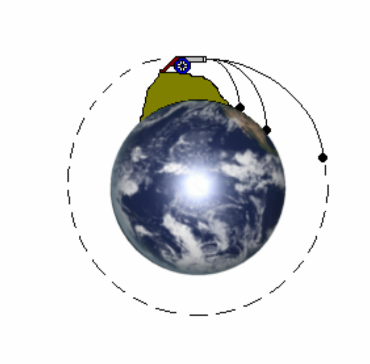
What is up with this orbit thing? And what about zero-G?

I've heard a lot of questions about orbits and about zero-G – and it turns out these are closely related. Here are a couple of more detailed variations that I was once asked by a Ph.D. in the life sciences:

This orbit thing bothers me – a spacecraft can circle the Earth for years at high speed without requiring power or slowing down? How does that work? And what about zero-G, is there really no gravity above some height like 300 km?

You can probably find dozens of answers to these questions on the web, and I will give it a shot too (the short answer: it's all just a really, really long fall). But instead of starting with the usual "cannon ball firing from a tall mountain" example, let's start with something you have actually experienced – throwing a ball. In this case, your arm provides the "thrust" (force) that accelerates the ball from zero speed (in your hand) to some final speed (40 m/s or even faster for a major league baseball pitcher, much slower for most people). If you throw a ball level (parallel to the ground), you are giving it a lot of horizontal velocity (HVEL). If you throw it straight up, it's mostly vertical velocity (VVEL). In either case, air drag slows it down, and gravity pulls it back to Earth in a few seconds. You probably know that if you throw it harder (faster initial speed), it will go a longer horizontal distance, or it will rise higher, or some combination (let's ignore cases like paper airplanes – these can generate lift from moving through the air, which is a force that opposes gravity and lets it stay up longer).

So NOW we will drag that old cannon up to the top of a really, really tall mountain that doesn't actually exist. Why? Because not even professional baseball pitchers can throw things fast enough, and by getting on a really big mountain, we imagine getting above most of the atmosphere so there's little air drag on the (cannon) ball. In this "thought experiment," we aim the cannon horizontally (level with the ground), and the throwing force comes from an explosion inside the cannon. The cannon is fired and the cannonball's path starts out horizontal but is pulled down by gravity, creating a curved path (it's actually pulled toward the center of the Earth, but for a short distance, this is close enough to "down"). With a small explosion, the cannonball travels a few kilometers before hitting. It's clear that it is falling toward the Earth and that its horizontal velocity (HVEL) has just carried it some distance from the mountain before gravity pulls it down. In this short distance, the Earth hasn't "curved away" very much, and the time to hit the Earth is almost the same as if we just dropped it straight down from the mountain (if the Earth were flat and had no air, it *would* be exactly the same time to reach the ground, dropping or throwing level).



Newton's mountain, although imaginary, has a distinguished history since Sir Isaac himself first presented the orbit idea with this thought experiment in the 1600's. He actually was trying to understand the motion of the Moon, the only satellite around at the time. Here you can see the basic idea that if you give the cannonball enough speed, the curve of the Earth will "outrace" the curve of the falling cannonball which will just keep falling around the Earth without hitting the surface.

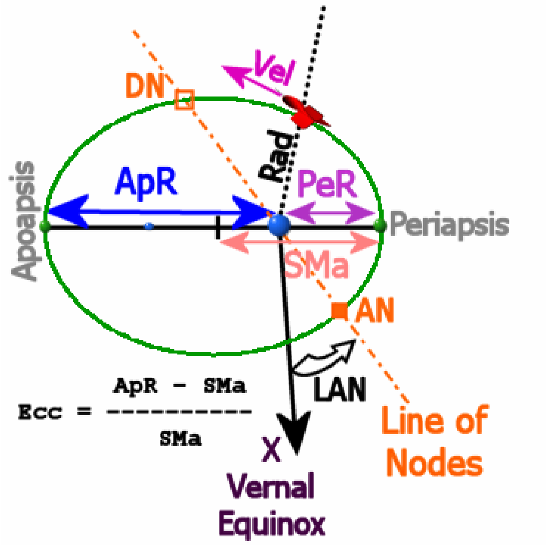
But the Earth is actually round, and let's say we get a really huge cannon that can make a huge explosion without disintegrating and we get that cannonball going at around 8000 m/s. What would happen then? Gravity would still pull the ball (let's forget the cannon part now) toward center of the Earth, creating a curved path as before. But traveling so fast, the ball goes several meters of "horizontal" distance for each meter of vertical distance that it falls. And the strange thing is, since the Earth is of course not flat, but "curves down" at about the same rate as the ball curves down, the falling ball doesn't hit the surface yet...

So what happens? The ball just keeps falling, but it never hits the Earth's surface! The "curving down" of the Earth's round surface means that the ball keeps falling, but sort of "down and around" the Earth. The ball is in orbit! That's why it's correct to say that an orbit is just a really, really long fall. Gravity has definitely NOT gone away – it is steadily pulling the ball toward the Earth's center. But the Earth's surface "curves down" faster than the ball falls down, and the ball never hits (unless air drag or something else "wears down" its orbit – remember this is just a thought experiment, but it's basically right).

But what about the zero-G thing? We're finally there! The key to THAT is the very same idea of falling. If you are in a spacecraft in orbit, you are in "free fall" and without the surface of the Earth to push back on you, or anything to slow you down, you feel no forces on your body, not even your weight (weight is actually a force, the force you feel normally just standing on Earth when gravity pulls you down against the ground or floor – you really feel the ground or your chair "pushing up" against your body). You feel no weight, so you are "weightless." Zero-G doesn't mean gravity has gone away or become zero. Gravity is still very much in the picture, pulling your spacecraft down and around the Earth.

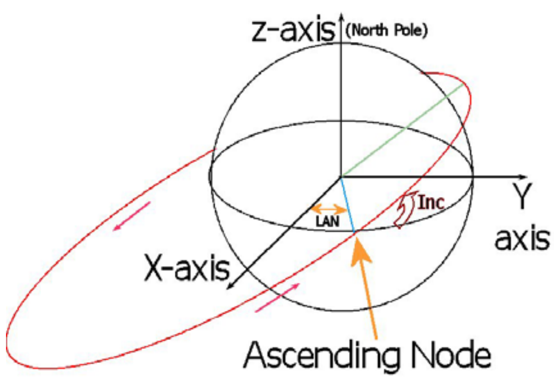
So how are orbits defined, and how do I interpret all those numbers that Orbiter displays?

Orbits are defined by orbital elements, and these are displayed on the Orbit MFD. The Orbit MFD buttons, abbreviations, and screen symbols are pictured and defined in section 13.2 (pages 50-52), and the orbital elements themselves are defined in mathematical detail in Appendix C (pages 109-110). Orbital elements are the numbers that define the an orbit in detail, and these are shown in several forms in the Orbit MFD. There are only 6 elements required to define an orbit, but the data can be expressed in several forms for convenience depending on what you want to do. The Orbit MFD actually shows 18 values. Here are some pictures which may clear things up a bit.



Some basic orbital elements given by the Orbit MFD are diagrammed here. The size of the orbit is given by apoapsis radius (**ApR**) and periapsis radius (**PeR**), and also by the semi-major axis (**SMa**), which is half of the long dimension of the ellipse. Eccentricity (**Ecc**) can be calculated from **ApR** and **SMa** as shown. The Line of Nodes shows where the orbit crosses the equator, ascending toward north (AN), or descending toward south (DN). Position "around" the orbit is usually measured as an angle from the defined x axis, which points toward the Vernal Equinox (the direction to a certain fixed star). **LAN** is one example (see next figure). Radius (**Rad**) from the Earth's center, and Velocity (**Vel**) are instantaneous values (constantly changing).

Inclination (**Inc**) defines the "tilt" of the orbit with respect to the equator, in degrees, and period (**T**) is the amount of time in seconds to complete one orbit. The rest of the listed elements are also measured in degrees, but they represent angular measures for various positions in the orbit, generally defined as "longitude" from a reference direction. I will give **LAN** (longitude of the ascending node) as an example and refer you to the Orbiter manual for the others.



Longitude of the Ascending Node (LAN) is used here as an example of a directional element, measured as an angle (labeled **LAN** in Orbit MFD) from the x-axis as defined in the figure above. Note that the z-axis goes through the North Pole, and the y-axis is defined to make the coordinate system "right handed." Also note that while information like this is important for working with equations in orbital mechanics, the Orbiter MFDs normally handle most of the calculations for you when you are changing orbits to intercept a space station or moon. You don't have to know this stuff in detail to use Orbiter!

Why is LAN important? You can perhaps see from the picture above that even if you change only the LAN for an orbit, the orbit will point to a different direction in space. So even if the sizes and shapes of two orbits are the same (apoapsis, periapsis, eccentricity), and even if their inclinations to the equator are the same, if the LAN is different, each will visit a different region in space.

For more information on orbital elements, I recommend the following web sites:

http://spaceflight.nasa.gov/realdata/elements/index.html

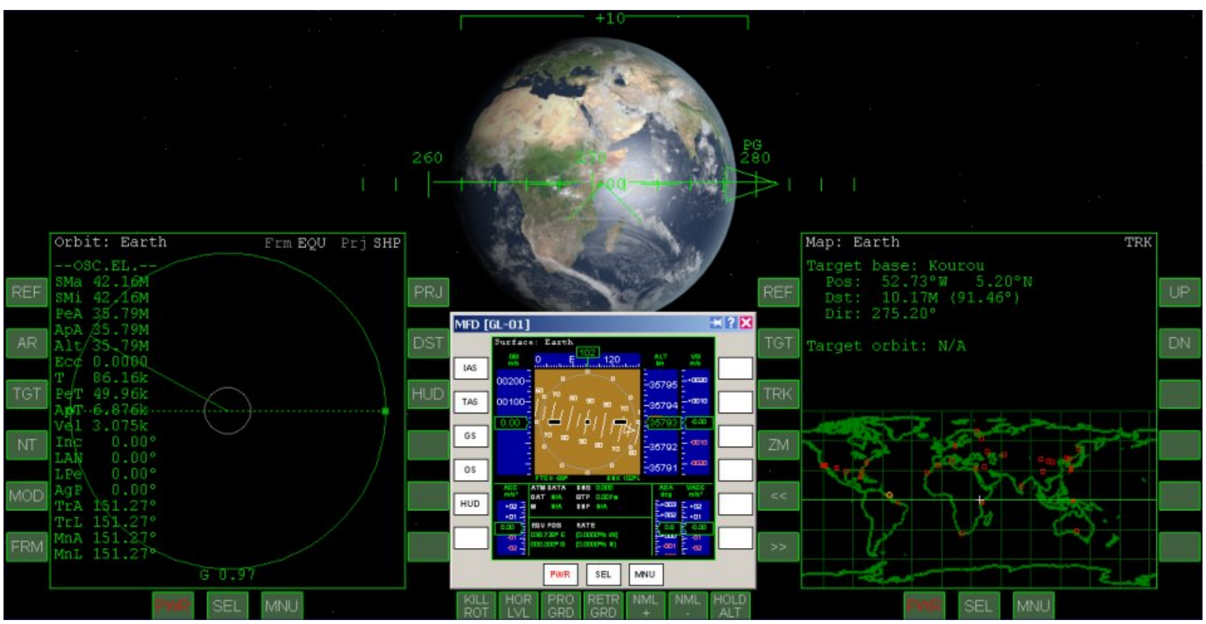
http://en.wikipedia.org/wiki/Orbital_element

Point of Confusion – What is "longitude?"

In common use, longitude refers to an east-west position on the surface of the Earth, used along with latitude for north-south position. We also use the term "longitude" in talking about orbits, but it's a different thing, not this surface-based longitude (referring orbital information to surface locations would be a bit of a problem since the Earth rotates every 24 hours). Longitude in orbital terms is still a sort-of east-west measure, but it refers to a fixed direction in space. Fixed how? Keep in mind that in addition to the Earth's daily rotation, the Earth travels around the Sun every 365 or so days. So we need to do something to define a coordinate system for orbital elements that stays (nearly) fixed (at least fixed for a long time, some years). This can be done by using the direction to a distant star as the reference direction (this does require adjustment every few years since even the stars are not exactly fixed relative to our Sun). The direction of the Vernal Equinox (spring position of the Sun with respect to the stars) in a certain year (2000 in Orbiter) is used as this reference direction.

What is a geostationary orbit?

A geosynchronous orbit is one whose orbital period matches the rotational period of the Earth (about 23 hours, 56 minutes or 86,164 seconds) . If the orbit also has zero inclination (i.e., it orbits directly above the equator), then the satellite will appear to hang stationary over one point on Earth, and it can also be called geostationary. Such an orbit is very useful for communication satellites. Current piloted spacecraft don't go anywhere near this height, but future space stations may also find these positions useful.



Orbiter includes a scenario that demonstrates a geostationary orbit, with a Delta Glider orbiting above a point in East Africa as shown above. This scenario is found in the folder **Special orbits**, which is inside the **Navigation** folder. Notice some interesting things about the above screen shot (an External MFD has been added to show the Surface MFD). The altitude is 35,790 km (22,400 miles), inclination and eccentricity are zero, period (T) is 86.16k seconds. The map shows the constant position above Africa, and the ground speed (GS) shown in the Surface MFD is 0.00 m/s. That's geostationary!

General Space Flight Questions

Why do most rockets have more than one stage?

This is due to a combination of necessity and efficiency. Most of the mass of any current technology rocket is fuel, and there also must be some structure and mechanism to make use of the fuel (fuel tanks, pipes, pumps, etc.) in addition to the rocket engines and the payload. As fuel is used up, weight is reduced, but it can be reduced even more by getting rid of any structures and mechanisms that are no longer needed. One way to do this is with stages – when the fuel for the first stage is exhausted, the entire stage is ejected, and the second stage engines can now be used more efficiently since they do not have to accelerate the unneeded mass of the discarded first stage.

There are variations on this, such as the Space Shuttle's use of two solid rocket boosters (SRB) that are "strapped on" and burn to provide a lot of additional thrust for the first 2 minutes of flight, along with the Space Shuttle Main Engines (SSME) that burn liquid fuel and oxidizer from the external tank. At 2 minutes, the SRB fuel is exhausted and the SRB canisters are dropped (parachutes allow them to be recovered at sea for refurbishment and reuse). The SSME's continue to burn, accelerating the now lighter Orbiter vehicle and external tank to orbit. This is sometimes called a "zero stage" method.

There are disadvantages in terms of complexity and costs of multi-stage rockets, but until advanced materials, propellants, and engines are developed that allow "single stage to orbit," variations of the multi-stage approach will continue to be used. This could include aircraft-type first stages such as the hypothetical "TX" shown in chapter 8. See http://en.wikipedia.org/wiki/Staging_%28rocketry%29 .

How does a real spacecraft know how fast it's going and where it is?

There are several ways that are used to keep track of the position, speed, and acceleration of spacecraft. One method is called an inertial navigation system (INS). In an INS, gyroscopes are used to keep track of the (x, y, z) directions in 3D space relative (say) to the stars, even as the spacecraft moves and rotates. Special sensors called accelerometers can continuously monitor any accelerations in each direction (from gravity, engines, thrusters, air drag while in the atmosphere, etc.). Since acceleration is defined as a change in velocity (speed and direction), and velocity is defined as a change in position, computers can use this constantly updating information to keep track of the acceleration, velocity, and position in real time.

For more details, see http://en.wikipedia.org/wiki/Inertial_navigation_system . By the way, Orbiter does much the same thing as this, but for Orbiter, the calculations are done many times a second to actually *determine* your simulated acceleration, velocity, and position as you fire thrusters or engines (thrust forces), fly through the atmosphere generating lift (aerodynamic forces), or get closer or farther from large bodies such as the Sun, planets, and moons (gravitational forces).

In addition to the INS, spacecraft near the Earth (or even quite far from Earth, even near Mars or Jupiter) are tracked by Earth-based radar systems. These systems send out high-power radio waves which reflect from the spacecraft. The reflected signal may be very faint, but they can still measure its direction, how long it took to get back, and any change in its frequency. From this information, they can accurately calculate the spacecraft's position and velocity. They can also do similar things with a radio signal that can be sent by the spacecraft (from a transponder or communication radio).

What is "Delta-V" and why is it important?

Delta-V (ΔV) is an abbreviation for "delta velocity." The Greek character delta (Δ) is used in mathematics to represent the change of some quantity, so delta-V means "change in velocity." Since velocity is directly related to energy (specifically kinetic energy), and a certain amount of energy is required to move from one state (a particular position and velocity) to another, delta-V is very useful in the planning of space missions. This is because each type of flight (e.g., Earth surface to low Earth orbit [LEO], LEO to the Moon, LEO to Mars, etc.) has a characteristic delta-V associated with it. Although the delta-V can vary somewhat depending on the dates and on the exact route taken, there is always a minimum delta-V for any direct flight, and if you know the available delta-V from your launch vehicle and spacecraft, this establishes whether a particular mission is possible. Here are typical delta-V values for some flights.

Starting point	End point	Delta-V (meters/second)
Earth surface	Low Earth Orbit (LEO)	9,300-10,000
LEO	Low Lunar Orbit (LLO)	4,200*
LEO	Lunar Surface	6,300
LLO	Lunar Surface	2,000
LEO	Trans-Mars Injection (TMI)	3,600
TMI	Mars Orbit (300 km circ.)	2,400
Mars Surface	Low Mars Orbit (LMO)	4,100
LEO	Ceres (central asteroid belt)	8,600

* includes delta-V for both Earth orbit eject and lunar orbit entry braking

What is "available delta-V?" This depends on the thrust of the engines, the amount of fuel carried, and the payload to be carried. For a given amount of thrust and fuel, you can give a small payload more delta-V than a large payload. This is why many satellites can be launched to orbit or even to the Moon or Mars with relatively small rocket boosters – unpiloted satellites can be made pretty small these days. There are equations for all this (the basic one is often called "the rocket equation," see references below) and they can be worked "backwards," meaning you start with the payload you want, say "100 metric tons on Mars" and from that you can figure out how much thrust and fuel you need to achieve the delta-V to reach Mars (probably concluding you don't have a big enough booster to achieve that mission yet). Or you can say "how much mass can we get to Mars with available boosters?"

For reference purposes, the Space Shuttle Main Engines (SSME) and the Solid Rocket Boosters (SRB) provide very close to the delta-V needed to reach a circular low Earth orbit (LEO) of about 400 km altitude (about 9700 m/s – note that this is more than the speed you will have in the Orbit MFD, around 7800 m/s, because it includes the delta-V needed to overcome atmospheric drag). Once it is in orbit, the

OMS engines (Orbital Maneuvering System) can provide the Shuttle with about 1300 m/s of additional delta-V for orbit changes (rendezvous with ISS, reentry burn, etc.). The (hypothetical and futuristic) Delta Glider, in contrast, has a very high main engine exhaust velocity (40,000 m/s – this seems to suggest a gas-core nuclear fission engine, and there's a hint of this in the yellow radiation warning symbols above the main engines, but the details of engines are not modeled anyway, only their performance). With this exhaust velocity and with only 58% of its mass as fuel, its available delta-V is about 36,000 m/s.

You can't fool Mother Nature when it comes to energy, but there are some "tricks." The basic trick is multiple stages – throw away mass you don't need (e.g., the empty first stage), giving a lower remaining mass that you can accelerate to a higher velocity. Another "trick" is gravitational assist – instead of going directly to the target planet, you calculate a path to pass close to another planet (without orbiting or hitting it) in a way that uses its gravity to speed up the craft and send it in the right direction for the target planet (sometimes called a "slingshot maneuver"). Venus can be used this way for Mars flights (for example).

For more on delta-V, see http://en.wikipedia.org/wiki/Delta-V and http://en.wikipedia.org/wiki/Delta-v_budget and the various links on those pages. There is also a very good web page on delta-V and rocketry here: http://www.pma.caltech.edu/~chirata/deltav.html (with a useful graph that relates fuel fraction, exhaust velocity, and delta-V, which I used in the Delta Glider estimates above).

Another great resource for interplanetary and lunar flight planning is the personal web site of Dr. Donald Rapp, http://www.mars-lunar.net/ and in particular for this question, his paper on the rocket equation and specific impulse (this three-page, 107 kB PDF file also includes a more extensive table of delta-V values for various flights): http://www.mars-lunar.net/Arch.Elements/1.Rocket.Equation.pdf. There are many other PDF files on trajectories and other technical planning issues, primarily for Moon and Mars missions. Dr. Rapp has extensive practical experience in space mission planning at JPL.

What about the risks of human space flight?

Every human activity has some risk – you could even get hurt climbing out of bed. But some things are clearly more risky than others, and many people think that flying in general, and space flight in particular, is especially risky. It is true that spacecraft use explosive fuels, fly very fast and high, and go where there is not enough air for humans to survive unprotected. These things can be dangerous if not handled carefully and correctly, but this is why space flight requires special hardware and software systems, extensive testing of the systems and procedures, and very intense training and practice for all the people involved. Even with these efforts, problems can occur, and in a few cases, the problems can be bad enough to kill people, as we know from the losses of Space Shuttles *Challenger* (1986) and *Columbia* (2003).

But consider that early airplanes were also very risky, and that when airline travel started in the 1930's, there were many crashes. Some people wanted the speed and convenience (and adventure, at that time) of flying – they were willing to take the risk even though the systems and procedures still had many problems. A lot of advanced technology was developed for World War II (things like radar and jet engines that allow planes to fly very high, above most of the bad weather), and since then (with many more developments), airline flying has become so safe that almost everyone trusts it. Of course there are still airplane crashes, but they are so unusual that each one is considered major news (unlike car crashes, which kill many people every day and are only local news if that).

Piloted space flight is still in its early stages – it is experimental flight, not routine flight. NASA and other space agencies work hard to make it as safe as possible, but it is not perfectly safe, and astronauts understand this. They choose to do it because they feel it is important (and for the adventure and other reasons too). Many people accept risky jobs such as high rise building construction because they need the work, and perhaps also enjoy it as a challenge. Other people enjoy risky hobbies such as mountain climbing. As space flight becomes more common, it will also become safer. There will also be more benefits from space flight over time, some of them not fully known yet. Many people (including me) believe that the known and potential benefits justify the risks of space flight. But there definitely are risks. For information on space disasters, see http://en.wikipedia.org/wiki/List_of_space_disasters

Questions About Orbiter

Why are you teaching space flight in a fictional rocket plane instead of in the Space Shuttle or Apollo or something else that's real?

You may know from chapter 8 that Orbiter allows you to install and fly add-ons for all sorts of realistic spacecraft, from historic unpiloted satellites and probes to Mercury, Gemini, Apollo, and the Space Shuttle (and even more when you consider available Russian spacecraft). "Realistic" is cool, but it is also limiting. These are all "early" spacecraft, though based on technology that was the best in the world at the time they were designed (even the Shuttle is "early" – it was designed in the 1970's). They typically have just enough fuel and payload to fly their specialized missions, and not much more (even the general-purpose Shuttle has a pretty narrow mission, "fly a cargo to low Earth orbit"). With weaker engines, they typically need multiple stages (see General Space Flight Questions), which makes them more complicated and expensive to operate.

To do much better than this requires advanced materials (super strong but light weight and heat resistant) and advanced engines that can provide more thrust for longer periods with less fuel. Such things are not prohibited by the laws of physics – they are under development but don't exist yet, except in the form of "fictional but physically realistic" simulated craft such as the Delta Glider. Such craft have been studied under the name "single stage to orbit" (SSTO), and we will have them eventually. In the meantime, they are simpler to operate in Orbiter, and they still teach you all the right stuff.

Isn't it cheating to use slowed-down time?

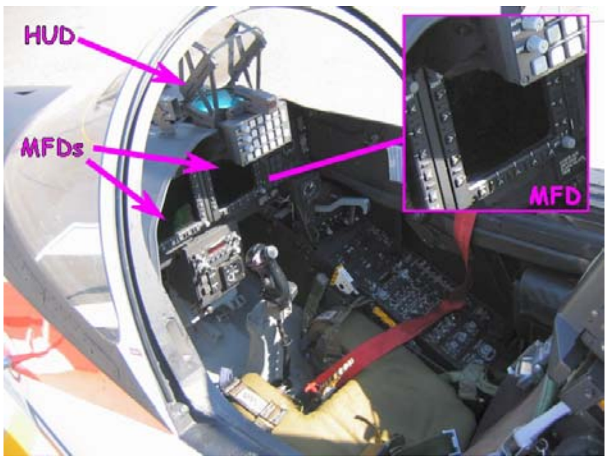
First of all, what is "cheating" in a single player simulation game anyway? The main goal of Orbiter is to provide a way to learn something about space flight in a realistic but fun way. One of the attributes of space flight is that some events happen very fast or require precision timing (like turning on a rocket engine for a maneuver), while other events take a very long time even for a fast spacecraft, like flying to the Moon (1-5 days) or to Mars (3-7 months or more). Orbiter lets you speed up or slow down time to deal with these different time scales. Of course you are free to define whatever you consider to be important in terms of realism – if you think it's better or more challenging to do everything in real time (1x), that's OK – though you probably won't be going very far from Earth at 1x time! You could even decide that speeding up time is OK, but slowing it down isn't – again, it's up to you, and you never have to slow down time to use Orbiter successfully. I just find it helpful sometime and wanted to let you know.

Questions About Other Stuff

I was wondering about the HUD and MFDs (multi-function displays) – what are they like in real life?

HUDs (head up displays) and MFDs (multifunction displays) started out in military aircraft, and HUDs are still most common in military aircraft where the pilot has many more things to worry about than even a commercial jet pilot (things like enemy aircraft and missiles), so keeping your "head up" and looking around is really critical. A few civilian aircraft (and the Space Shuttle) also use HUDs. MFDs are more common – they are used in virtually all modern military aircraft, nearly all civilian airliners, and even in some recent general aviation (small single/twin engine) airplanes.

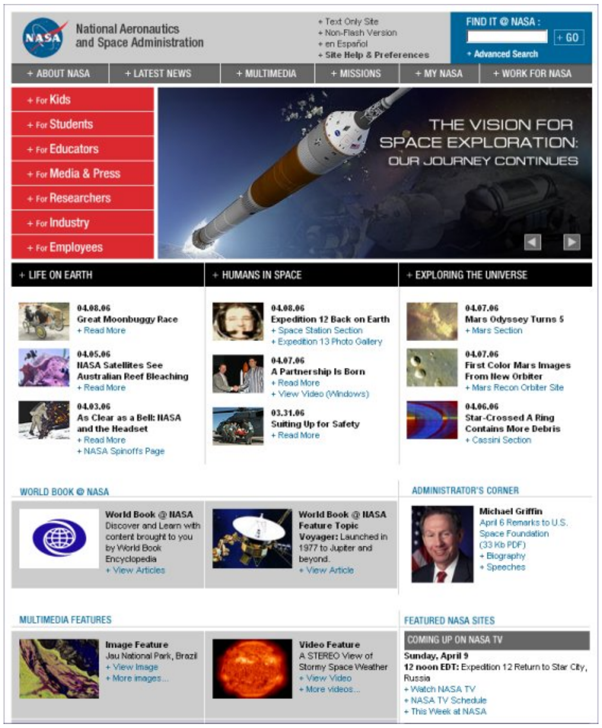
HUDs make use of optical lenses and mirrors that are something like a computer video projector. But instead of projecting onto a white screen for viewing, the computer images are projected onto a semi-transparent "combiner" plate. It's called a combiner because to the pilot, it combines the view of the outside world which is mostly far off ("at infinity") with the imagery (numbers, lines, icons, etc. called "symbology") generated by the flight computer. The optics are designed so that the symbology also appears to be projected "at infinity" so everything (real world and symbology) is in focus for the pilot.



Real HUD and MFDs in a U.S. Navy T-45 advanced jet trainer (photographed at an air show). The T-45 is used to teach aircraft carrier operations and the basic use of aerial weapons to Navy student pilots in advanced jet training. For this reason, the HUD is very valuable, just as it is in Navy combat aircraft. The pilot can see the most important flight information at all times, even as she concentrates on landing on the carrier or launching a training weapon. MFDs are special interactive computer screens that allow many types of flight, navigation, systems, etc. information to be displayed as needed. Notice the buttons around the edges of the screens.

MFDs are basically computer screens, most often LCD panels these days (they used to be CRT's), built to work reliably under all flight conditions (various G-loads, high/low temperatures, etc.) and with special illumination systems to allow them to be clearly visible in all light conditions (strong sunlight is especially challenging). They typically have buttons around the edges of the screen that are labeled on-screen by the software according to the function in use (e.g., maps need buttons to zoom in/out). Some modern MFDs are also touch-sensitive (to allow direct designation of an airport or a target), and those in some military craft also can be operated by special buttons on the throttle and control stick (a system called HOTAS for hands-on throttle and stick). Leaning forward to press buttons on the MFD is not a big problem in an airliner, but in a fighter where the pilot may be experiencing 6G or more on a regular basis, it's not as easy, and HOTAS is a very useful feature.

Wondering More



Of course Google.com and other search engines can help you find nearly anything, but here are a few more specific web sites you may find useful the next time you are just wondering about space stuff.

NASA has tons of information on everything related to space – dig around a little, and note that it's sometimes easier to search NASA sites with Google.com by adding **`site:nasa.gov`** to your search string (this will search across all the many available NASA web sites)
http://www.NASA.gov

Basics of Space Flight from JPL (JPL is part of NASA but is a very good starting point itself)
http://www2.jpl.nasa.gov/basics/

European Space Agency (NASA is not the only agency with great web content)
http://www.esa.int/esaCP/index.html

How Stuff Works (cool site for many topics, not just space, but this Hubble page is excellent)
http://science.howstuffworks.com/hubble.htm
http://science.howstuffworks.com/space-channel.htm (general space library, many topics)

Orbital Transfers between Planetary Orbits: An Example (a clever use of simple calculations)
http://www.go.ednet.ns.ca/~larry/orbits/orbitrnf.html

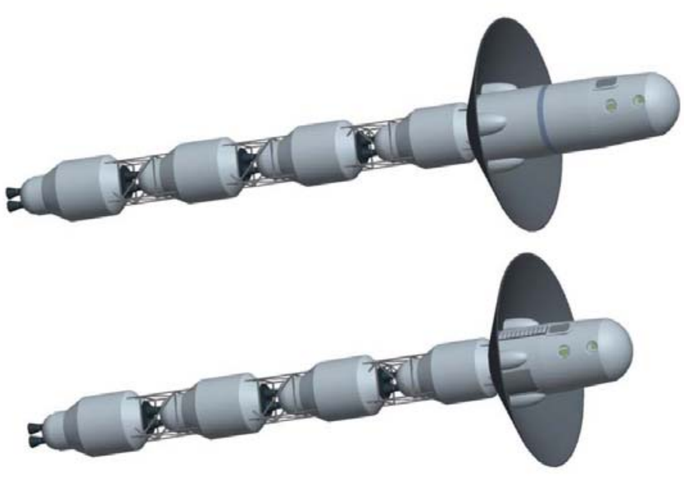
Mars and Moon Website (personal web site of Dr. Donald Rapp, formerly of JPL)
http://www.mars-lunar.net/

NOTES

Your Future In Space

This final chapter is different from the others, because it is concerned with real space flight, and with some of my own ideas and opinions about the future of space flight, and the future in general. The rest of this manual has been about simulated “playing in space,” using Orbiter for fun and as a framework to encourage you to explore certain aspects of space flight in a fairly realistic way. If you find this sort of thing to be interesting, and depending on where you are in your schooling or career plans, you might consider doing something that’s connected with real space flight. It could lead to involvement with some of the most interesting and important developments of the next 50 years or so. You could get involved now by joining a space advocacy group.

Opinions expressed here about the importance of space for the future of humanity, and on the feasibility of human flights to Mars in the near future, are my own take on various things I have read and thought about. But some aspects of this epilogue were inspired by several writers in particular. The nonfiction writings of Dr. Robert Zubrin and Dr. Raymond Kurzweil, and the writings of science fiction authors Kim Stanley Robinson, John Barnes, Stephen Baxter, and Gregory Benford have been particularly helpful. I will provide references and more detailed credits at the end of this chapter.



Mars for Less is a reference mission designed by Grant Bonin for MarsDrive Consortium, a group that is trying to organize other groups and individuals in support of human missions to Mars within the next twenty years. *Mars for Less* is a variation of Robert Zubrin’s *Mars Direct* that proposes to make use of existing medium-lift launch vehicles (MLLV) to place modular crew, utility, and propulsion units in low Earth orbit for assembly into complete vehicles for Mars injection. The MarsDrive ships (ERV, top, MTSV, bottom, graphic used with permission) are not (yet) an Orbiter add-on. There is more on MarsDrive and *Mars for Less* later in this epilogue, and even more at www.MarsDrive.com.

Space Is Real

While it's true that Orbiter is only a space flight simulation and in some respects a game, space is real, and you may have a real future in space. In fact, space may be more important than you may think. What is so important about space? For one thing, space truly is "the final frontier," and frontiers have been very important in human history. Think about the role of Columbus and other early explorers in discovering the Americas. The discovery of a "new world" previously unknown to the European trading nations of the 1500's stimulated technology to develop better sailing ships and navigation methods. It created new opportunities for trade and eventually for new places to live, allowing European colonists to escape religious and social oppression, or simply to start a new life. Of course this opportunity came at a cost – it was expensive and risky to cross the Atlantic Ocean in those early days. Those who made it faced many hardships (and the hardships for the native people they encountered were often worse – the treatment of native people by early explorers and settlers was terrible and sad even if we consider that at the time, there was nothing like our modern appreciation of the value of different cultures). The existence of the New World (today's North and South America) provided new sources and markets for goods and new places to live, but even more importantly, it opened the doors to new ways of thinking about everything.

Later (mainly in the 1800's) the American West became a New Frontier, and the challenges of expanding the United States from coast to coast became another major economic and social driver that created opportunities for many as well as new markets for goods, services, and ideas. Much has been written about the importance of frontiers in the development of the modern nations of Europe and North America. Dr. Robert Zubrin explores these and many other ideas in his books *The Case for Mars* and *Entering Space*. These are just a few examples, and while this is not a history book, I believe that one thing that is missing in today's world is a significant frontier. This is not to say that we lack challenges and problems to solve. We certainly have plenty of those. But some of history's most productive periods have occurred when there was a frontier to stimulate exploration and new ideas – and to provide focus or direction. This is related to a fundamental human trait – willingness to step out into unfamiliar territory in search of new ideas and opportunities and in spite of the uncertainties of such ventures.

Uncertain Future – The future IS uncertain, of course. Thirty years ago, some people believed that there was a "population bomb," that runaway human population growth would soon outpace our ability to grow food, leading to mass starvation. While there are still tragically bad conditions and even starvation in some regions of the world, it seems that when technology and social efforts lead to better living conditions, populations stabilize over time – people in more developed countries live longer lives, but under better conditions and with fewer children. Population is still a serious issue, but no bomb yet.

Of course we still face many risks – global warming and other environmental threats to the Earth's atmosphere and water; war and terrorism; various diseases, old and new; and a variety of natural disasters ranging from earthquakes and tsunamis to a possible giant asteroid strike. Technology and other human efforts can be used to reduce some of the risks and to help people when they are hurt by these things. Humans are very resourceful and there is reason for optimism in spite of the many challenges we face. But there are still many uncertainties.

OK, but what does this have to do with space? I'm getting to that, I promise! But first a case of good news and bad news. Consider the idea of living longer, healthier lives, which seems to be the result of improved nutrition, health care, education, and economic conditions in many parts of the world. Of course this is a good thing. There are some people who believe that molecular biology and medicine may be close to solving even the basic problems of aging, so that people could eventually have the chance to live much longer but still healthy lives, perhaps 120 years or more as a typical healthy and active lifespan. No one knows for sure yet if this is possible or how far it could go, but many people think it is plausible (some think we could reach this stage in the next 15-25 years, while others think it could happen but may take a hundred years or more to solve the many sub-problems of aging). But think about this – it means that if you were born in 1985, you might still be alive, healthy, and active in 2105. Is this a good thing?

Yes and no (yes for you personally, maybe no for society as a whole). While it's not quite the same as a "population bomb," consider a population of many millions of healthy 70-to-120-year-old people who in the past would have mostly been retired from their jobs (or in many cases, have died). What will we do with these people?

Send them into space? Not quite! My point is that the "good news" of greatly extending the lives of so many people could have unplanned consequences or "bad news" side effects. It could change the nature of our societies, of our working lives, and the nature of the opportunities that young people have. Not only is there no "new frontier" on Earth, but even the idea of a career that progresses over time from entry level to more complex, responsible, and better-paid positions could break down if the senior people remain on the job for many more years because they are still healthy and active and either need to or want to continue working. And this is not even considering the likelihood that we will develop computers and robots with something more similar to human intelligence which (who?) will also compete for some of the jobs that can only be done by humans today (robots already do much of the repetitive factory work that used to be done by people, and the Internet and advanced telecommunications are already changing the nature and distribution of work, entertainment, government, and more, changing every day).

Change will continue and accelerate, leading to a very different world in the future – maybe a better world, with chances for multiple careers, continuing education, creative pursuits, and more leisure time. Maybe the problems of a society where long, healthy lifetimes are the norm will take several generations to solve. No one really knows. Of course there are other scenarios too – what if a disease worse in its effects and harder to fight than AIDS becomes an epidemic? What if terrorism becomes more widespread and destructive? These are terrible prospects to consider – people will do everything they can to prevent such things from happening, and they probably will succeed – but maybe not.

I'm personally optimistic about the future, and I'm not trying to frighten anyone here. But I'm certainly not the first one to think about the unpredictable mix of good and bad changes that could come about in the next 10-50 years. This is making a pretty big leap on the basis of a lot of "what ifs," but some might even imagine the Earth becoming a boring place (in the "people live very long healthy lives without any special challenges" case), or a place that is quite terrible for many more people. Most likely it will be a mix, with some regions doing better than others, as is the case now. Science fiction (SF) and some nonfiction writers have explored many of these "what if" situations in books, and I will provide references for a couple of interesting examples later.

We need space – Finally we get back to space. What are some of the reasons space could become more important in the future? Here are a few that I have thought about based on my reading.

- **A new frontier** – Providing new challenges for people willing to leave the familiar world of Earth, as well as for the many who will stay here to develop and support the technology, the missions, and the eventual colonies. Mars would be the likely first step (we could revisit the Moon as well, but Mars offers many more useful resources), and I have a few notes about Mars exploration and colonization plans at the end of this chapter.

- **New places to live** – Colonies on Mars and perhaps other places in the Solar System (e.g., space colonies built from Moon materials or asteroids) could provide new and largely independent places to live, though for relatively few people within the first few years. Barring some unimaginable catastrophe, the vast majority of humans will probably continue to live on Earth for many years to come, even if space colonies are developed. Space is not likely to be a near future solution to excessive population growth on Earth.

- **New sources of materials and energy** – The Moon has a lot of material that could eventually be used for the construction of space colonies and satellites, possibly including solar power satellites that could collect solar energy and beam it to Earth as microwaves (there are some problems with the economics of such a system, but things could change). When nuclear fusion power plants are eventually developed, Helium-3 is an attractive fuel, and the Moon could be a good source of this substance. Materials on Mars will probably be used mainly there (at least at first), but Mars could also be a base for eventual asteroid mining (asteroids contain huge quantities of many valuable materials).

- **More options in case unexpected things happen** – This connects with the two points above. We certainly hope that we can preserve and even improve the Earth's environment, live in peace, solve any major medical problems that emerge, and wisely use, conserve, and share the resources we all need. We hope that if a large near-Earth asteroid (NEA) heads our way in the next hundred years or so that we will have the technology to detect and safely deflect it in time. We certainly will not give up the Earth easily to such disasters, but there is some benefit to having part of humankind's population living "off planet" as a sort of backup or insurance plan.

- **Science and Technology Spin-offs** – Science is often cited as the main reason for going into space, and it is important. The search for knowledge has long been one of humankind's fundamental drives as well as the source of basic knowledge that drives technology. We have also derived many side benefits from technology that was originally developed specifically for space flight, in addition to the direct benefits of satellites for communications, weather forecasting, navigation, etc.

  Many people say that science in space is best done by robotic spacecraft. For many missions, this is true, and robotic spacecraft certainly are essential for knowing what to expect and for planning piloted missions. But humans are still the best observers, opportunity-takers, and improvisers, and when we have humans on Mars and other planets, they will learn more, learn faster, and get more done than if we use only robots.

These are just a few reasons to consider space as the logical next step for mankind. Although there are some who say, "we should learn to limit what we want and to conserve, share, and use more wisely the resources of our only planet, the Earth," that is not the way it works in practice! Of course we should try to conserve and make the best use of limited resources, but as people become more prosperous, they soon want more options and more comfort, in the forms of cars, appliances, better heating and cooling, better health care, better education for their children, better entertainment, vacation travel, and just more of everything.

These are things that many people in the world take for granted (e.g., in North America, Europe, parts of Asia, and a few other areas), and it's only natural that other people should want these things too. But all of this takes more energy – which is one of the reasons we are using up the remaining supplies of oil and other fossil fuels so quickly now. More people on Earth want them. When people look back on today from 100 years in the future, the era of cheap and rapidly expended energy from fossil fuels will probably be seen as a strange, unique, and rather brief time. We will learn to make better use of solar and other alternative energy sources, and we will develop safer and more powerful nuclear power systems based on nuclear fusion in addition to more advanced uses of nuclear fission. These developments will help us in space as well as with the energy needs of Earth. Space will give us more options, and will give us a new frontier that will inspire our future generations.

But Aren't We Already in Space?

It's true that we have been sending men and women into space for over forty years, including the small number of Moon flights in the Apollo program that were the first in which humans visited a world other than Earth (1968-1972). A few countries (mainly the U.S. and Russia) have since continued to send people into low Earth orbit for research and a few other purposes. Space stations have been built and occupied for thousands of days, and the first reusable "space transportation system" (the U.S. Space Shuttle) has been flown with much success since 1981, despite the tragic loss of *Challenger* and *Columbia* and their crews. The experience gained and the technology derived from these flights are certainly valuable, and people from around the world have now experienced space flight. While I wish we had continued our piloted exploration of the Solar System right after Apollo, I'm glad that we have not given up on space completely, and I honor and appreciate the important efforts and sacrifices of all the people who have made space a *place* and not just an abstract idea.

But these pioneering, largely exploratory, research oriented flights are not the real future of space. I believe the future of space will involve people going to and eventually living on other planets and moons in the Solar System and perhaps beyond. The technology to go to Mars already exists. I think we are moving in that direction, and I think this will be one of the most important developments of the next fifty years. As the late Carl Sagan said in his 1980 book *Cosmos* (Chapter VII, final paragraph),

> "Exploration is in our nature. We began as wanderers, and we are wanderers still. We have lingered long enough on the shores of the cosmic ocean. We are ready at last to set sail for the stars."

…or at least to start with Mars!

What about you, the reader?

If you have stuck with me this far in this epilogue, you may be wondering if there's something specifically for *your* future, or just some more discussions about trends and problems in general. I don't know what will really happen in the future or what jobs or careers will be needed most in ten years, let alone twenty or fifty, though I do have a few thoughts about what I would do if I were starting out now.

But first let me quote a passage from a favorite science fiction novel, John Barnes' *The Sky So Big and Black*. The story takes place on Mars in the late twenty-first century when colonies have been established there in the wake of multiple disastrous events that take place on Earth in the early years of the century. The main characters are a father and his teenage daughter Teri who work as an "ecospecting" team, searching for underground deposits of water, methane, and other materials that are needed by the colonists who are terraforming Mars (modifying its climate to eventually be more directly suitable to humans). They are discussing the next step in Teri's education, and how pre-disaster Earth educational systems tended to teach students to be paper-pushers and consumers. Teri had attended a Mars "CSL" school which taught students to be independent, self-sufficient, technically savvy, and resourceful. Teri replies to a comment by her father on the old "high school" system:

> "And *that's* what we're going back to?" For the first time in my life I was glad I to have gone to CSL school.
>
> "Naw, it was just an example of the way every society always makes the kids it needs. Up until about 2000, they just didn't need anybody very smart or capable – what they needed was people to buy stuff and follow rules." [Barnes, *The Sky So Big and Black*, page 121]

Teri's father later adds that after the Earth-wide disasters of the early 2000's,

> "…just to keep the species going, you needed people who would learn anything, and use everything they knew, all the time. You not only couldn't afford to be stupid, you couldn't let your neighbor be stupid." [Ibid, page 122]

Current educational systems in most places are not as bad as Barnes' characters portray here, and teachers certainly work hard to prepare their students for the challenges and changes ahead. But the point is that in a relatively stable and prosperous society that lacks a frontier, the standard educational system does not necessarily prepare you for the future in all the ways you may need if things start to change dramatically or catastrophically. (Video and PC games supplement the educational system for many students, and there are some indications that these actually do a better job at developing certain problem solving skills than mainstream education does.)

I wouldn't presume to tell anyone what to do, but I've thought about what I might do if I were younger and starting out now in my education and career and wanted to be involved in space. I would want to go on space missions myself if I could, but even if I were to have some other role in space flight, I think the preparation would be much the same.

- **Education** – I would pursue a technical education of some sort and make sure it was at a school and in a program that emphasized fundamentals and problem solving, including math, physics, computers, and some aspects of current practical technology, while recognizing that any technology learned today will be mostly obsolete within 10-15 years. Strategies for continued learning and re-learning (as well as acceptance of the need for this) are vital parts of any modern education. I don't know if I would focus on space science and technology or not – a lot depends on the program. People of many specialties will be needed in space related jobs.

- **Other preparation** – I would try to pursue other skills, physical and mental, that might be useful in space exploration. Flying might be one of those skills, even though not every astronaut needs to be a pilot. Flying encourages 3D thinking, a methodical approach to complex tasks, and the ability to quickly evaluate, prioritize, and solve problems (I wish I had learned to fly earlier than I actually did – if you have an interest, I suggest you start saving the money and taking lessons as soon as you can). I would also pursue more varied physical activities – space flight is not all that strenuous, but many tasks require good coordination, strength, and dexterity. Some classes and field experience in geology and biology would also be valuable – learning to observe your surroundings in detail. Experience with caves and rock climbing could be useful too.

- **Versatility** – In *The Case for Mars,* Dr. Zubrin suggests that early piloted Mars exploration missions will likely have a crew of four, and that the needs of a long flight (~6 months each way) and long surface stay on Mars (~500 days) are so diverse, that you could hardly afford to have a dedicated pilot-astronaut in this small group. Of course even with automated systems, you need one or two skilled pilots, if only for backup, but more important skills will be engineering (mechanical, electrical, chemical, aeronautical, maybe others, with hands-on skills for maintaining, repairing, and improvising) and science (geology, biology, material science, etc.). Piloting and even medicine will be "cross trained" (along with horticulture, small group psychology, and a variety of other things) over a good mix of other skills. Versatility will help if you ever go to space, but it will also help if you happen to live 120 years or so and need to have three or four careers!

So that's what *I* would do if I were starting out today – if any of those ideas work for you, that's great. I think that even without the disasters imagined in *The Sky So Big and Black*, the next century will be a period of rapid and probably surprising changes, and we will need a lot of people (to paraphrase Barnes) "who will learn anything, and use everything they know, all the time."

Mars Direct, Mars for Less, VSE, Other Options?

Although there are other "design reference missions" (DRMs) by NASA, ESA, and others, certain aspects of Robert Zubrin's well-known *Mars Direct* proposal have been adopted in almost every humans-to-Mars study since it was published in the early 1990's, especially the ideas of sending an unmanned Earth return craft to Mars ahead of the astronauts, and of using local resources to make propellants for the return (known in the Mars trade by the acronym ISRU, in situ resource utilization).

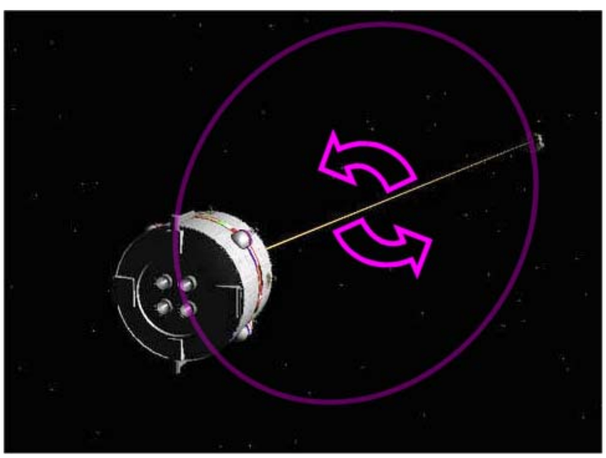
Live Off the Land – *Mars Direct* suggests using extensions and variations of existing launch vehicle and spacecraft technology, along with some clever but relatively simple and even demonstrated innovations. The plan started as a reaction to overly complex and expensive Mars mission plans developed in the 1980's. Perhaps its hallmark is the ISRU idea, using local resources to "live off the land."

What does this mean? In the case of Mars, it mostly means that instead of carrying all the fuel you need with you to Mars (requiring an immense launch vehicle), you make most of it on Mars. Zubrin recognized that the mostly carbon dioxide (CO_2) Mars atmosphere can be used to make rocket fuel right on Mars. With the addition of hydrogen (H_2, possibly available from water on Mars, but light and fairly easy to transport to Mars if necessary), a simple chemical process can turn CO_2 and H_2 into methane (CH_4) for rocket fuel, and oxygen (O_2) for the oxidizer (since there is no oxygen in space, space vehicles must carry their own oxygen or alternate "oxidizer," or the fuel will not burn).

So "live off the land" means "make your return rocket fuel from mostly local materials." A huge proportion of spacecraft mass on any long-range mission is propellant, so the ability to make most of your return-trip propellant on Mars rather than carrying it from Earth saves a lot of weight. It makes it possible to perform the mission with a reasonable payload using current-technology rocket engines. The chemical engineering needed to do this is well known and easily automated. Power to run the chemical plant (and later the Mars base itself) is the big problem, but a small nuclear reactor solves this. A bigger problem will likely be the political and environmental concerns over launching nuclear reactors into space, but the safety issues are manageable, and there is no other practical way to supply the needed power at the distance of Mars (solar panel arrays would have to be huge and would only generate power on the surface of Mars in daylight hours – Mars rotates at about the same rate as Earth and has a similar day/night cycle with a 24.6 hour day).

Shuttle-Derived HLLV Booster could build upon Space Shuttle launch technology to create a powerful new heavy-lift launch vehicle (HLLV), shown here with the *Mars Direct* HAB and upper stage. Note the side-mounted cluster of engines derived from the Shuttle Main Engines, the rust-colored external-tank-like main body (solid rocket boosters and payload faring already jettisoned). Two HLLV launches would be needed for the original heavy-lift *Mars Direct* mission. NASA's ESAS describes plans to eventually develop and deploy a similar CaLV (cargo launch vehicle) as well as a smaller CLV (crew launch vehicle).

The Technology – Another key point of *Mars Direct* and most other recent DRMs is the use of multiple spacecraft and launches, though the number of launches, the payload capability of the launchers, and how and when the craft are deployed vary considerably among the various Mars plan. In *Mars Direct* itself, the first craft to launch direct for Mars would be the ERV (Earth return vehicle), which would land under autopilot/remote control, deploy a small nuclear reactor for power, deploy a small automated chemical plant for methane/oxygen production, and start making propellants for the astronauts' return voyage (hence the name ERV). Robots and computers would operate this setup, and video cameras and other sensors would allow Earth based engineers to control and monitor these processes.



Pseudo Gravity can be generated by rotation. For *Mars Direct* and similar missions, a 330 m long tether (very strong cable) could be used to attach the top of the HAB to the empty final stage of the launch vehicle, which serves as a non-critical counterweight (it isn't needed for anything else). The HAB's thrusters can start the pair spinning to generate 0.38G (Mars normal) of pseudo gravity directed toward the floors of the HAB. This will avoid the harmful long-term effects of zero G during the six month flight to Mars.

Original image courtesy Orbiter Mars Direct Project, from web site Gallery page at http://barnstormer.home.mindspring.com /marsdirectproject/marsdirectproject.htm, used with permission.

With their fully fueled ERV sitting on the surface of Mars, the piloted "habitation vehicle" (HAB) would launch two years later. For safety reasons, the crew would most likely be launched in a separate "CEV" (Crew Exploration Vehicle), a smaller craft that will be developed specifically for transporting astronauts, to dock with the HAB in low Earth orbit (LEO rendezvous and docking is a routine maneuver). A clever but simple "tether" (cable) method could be used to slowly spin the HAB in a circle for most of the six-month flight, using the empty final stage of the rocket booster as a counterweight. The spin would generate Mars-equivalent artificial gravity, protecting the astronauts from the harmful effects of a long time in zero-G. After a six month voyage to Mars, the HAB would be landed very near the ERV, and using several methane/oxygen fueled "rover" vehicles, the astronauts would begin their exploration of Mars. After some 500 days on the surface, the low-energy "launch window" for return to Earth would open up, and the astronauts would launch in the ERV for the long trip home.

There is more to *Mars Direct* than this, but that's the gist of it. It doesn't require breakthrough science, Moon bases, or huge space stations, though it does require development of a new heavy-lift launch vehicle (125 metric tonne [mT] class HLLV) in addition to several new spacecraft, a new upper stage, and a number of advanced automated systems. These things involve a lot of careful engineering and modifications of existing technology, but they are generally extensions of things we know how to do. They also involve a lot of money, of course. Although the U.S. has announced plans to return to the Moon and eventually go on to Mars, the timing and long-term funding are uncertain, and there are many difficult milestones to achieve. Mars is an ambitious project for any one nation, even the U.S.

Other Mars Possibilities – The U.S. Vision for Space Exploration (VSE) was announced in 2004, and NASA's ESAS (Exploration Systems Architecture Study, search www.nasa.gov for ESAS) was released in 2005 to describe specific system-level plans for human space exploration over the next twenty years. It starts with the development of new spacecraft (CEV by 2012-2014) and launch vehicles (CLV, CaLV) that will take U.S. astronauts back to the Moon by 2018, and will be the basis of further developments needed for human Mars missions some years later. Although ESA (European Space Agency) has also studied human Mars missions, the U.S. is likely the only nation capable of near future development of a HLLV in the required 125 mT range. Since this sort of launch vehicle is needed for *Mars Direct* and for most other design reference missions (DRMs), its development is a prerequisite for any of these proposed missions. The web site of Dr. Donald Rapp is an extensive, well-researched, and readable source for information on the ideas and tradeoffs for various Mars mission designs (http://www.mars-lunar.net).

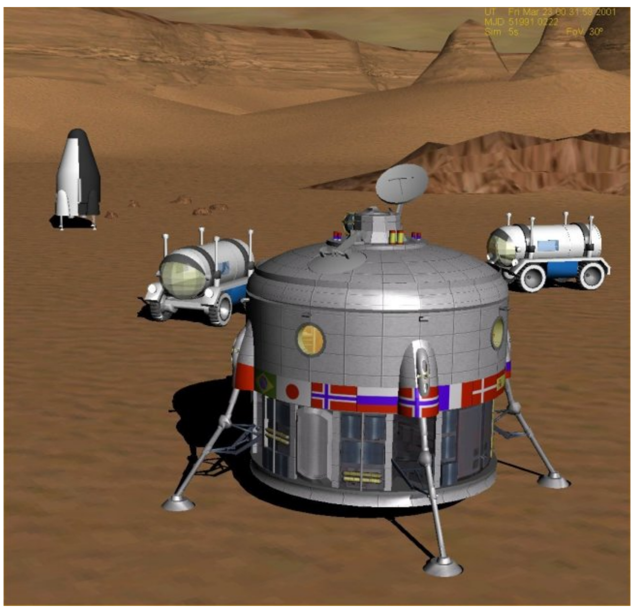
Mars for Less – One bottleneck for both *Mars Direct* and for NASA's various Mars plans is the need for a HLLV with a payload in the 125 mT range. While such a vehicle certainly can be developed, it is an expensive project with no critical application other than human Moon and Mars missions. Its development over a number of years, presidential administrations, and budgets is certainly in question, and if the mission depends on this one vehicle, failure to develop it would be a complete "show stopper." It is also difficult for other nations or private groups to participate in a significant and secure way when the primary launch vehicle is under exclusive U.S. control. The completion of the International Space Station (ISS) is dependent on the still troubled Space Shuttle (and thus is in doubt) because large ISS modules developed by partner nations can only be carried by the Shuttle. A similar "critical path" would be formed for Mars missions based on a U.S.-controlled HLLV.

Grant Bonin of MarsDrive Consortium (MDC) has developed an alternative reference mission that is similar to *Mars Direct*, but designed around modular components that can be launched using medium-lift launch vehicles (MLLV, 20-30 mT class). The modules would be designed for ease of assembly in low Earth orbit. Although there are risks associated with multiple launches (a total of perhaps 12 MLLV launches, vs. 2 or 3 HLLV launches for *Mars Direct* and various NASA DRMs), there is less critical functionality in any one launch, and there are multiple LV types that could handle the required payloads, allowing partner nations to share launch duties. Eight of the nominal twelve MLLV launches would be carrying identical propulsion modules which would be relatively easy to replace if lost (backups could be available). Loss of an unmanned crew module (MTSV: Mars Transfer and Surface Vehicle, ERV: Earth Return Vehicle) or utility modules would be more expensive but might not kill the project. The crew itself would require a later launch in a CEV-type vehicle to board the assembled MTSV for injection for Mars.

Visit www.MarsDrive.com for more on MDC's *Mars for Less* reference mission and other plans.

Mars Missions and Orbiter – As you perhaps have experienced in chapter 6, Orbiter can help you to start thinking about Mars and to start planning how to get there. The Delta Glider won't really be around for a few years, but there are other rides you can take in the meantime. In addition to giving you a basic familiarity with the concepts and tools of space flight, and helping you to know your way around the Solar System, Orbiter familiarizes you with orbital maneuvering, especially rendezvous and docking. This is sure to be an important part of any future human Mars missions, especially a *Mars for Less* mission, which I hope will become an Orbiter add-on in the near future.

There is an Orbiter add-on available with the basic components of *Mars Direct* (by "jgrillo2002" – search for Mars Direct at www.orbithangar.com). As shown in some pictures in this book, there is a also a current multi-person add-on development project which aims to model *Mars Direct* in more detail. Progress has been made (e.g., the HLLV model on E-8 and the beta HAB below), but work remains to be done. See http://barnstormer.home.mindspring.com/marsdirectproject/marsdirectproject.htm.



Mars Direct Mashup – Several add-ons were combined to create this Mars scene in Orbiter. The 3D terrain is Vallis Dao by "jtiberius" and the ERV (left background) is from jgrillo2002's *Mars Direct* add-on (both available at www.orbithangar.com). The rovers are actually Andy McSorley's "Jason" Moon rover from his Prometheus CEV add-on (also available at orbithangar.com). The beautifully modeled HAB in the foreground is a beta version from an ambitious Mars Direct Project for Orbiter that is still in development. For more information, check the link below, especially the Mars Direct Forum link found there. March-April 2006 posts indicate some recent progress on this big add-on project.

http://barnstormer.home.mindspring.com/marsdirectproject/marsdirectproject.htm

Conclusions

I hope you have found the main part of this book to be a fun and informative introduction to space flight. I really think Orbiter is the ideal way to get a feel for some of the things that are involved in flying in space, and while it took a lot of words and pictures, if you actually followed chapters 2-6, you got to experience a lot in a pretty short time – and you even flew to the Moon, to the ISS, and to Mars! I also hope that this epilogue has given you a few things to think about regarding the future in general, and yours in particular, and whether you might actually have a future in space. If this book gets even a few people thinking about and working toward this, it will have been well worth the time to write it (not to mention it was actually fun to write, especially with Andy McSorley's help on this second edition).

I have recently gotten involved with educational outreach for the MarsDrive Consortium (MDC, www.marsdrive.com). I believe we humans can and should get to Mars sooner rather than later and I want to help if I can. If you have an interest in this, I hope you will join MDC or another space advocacy group. Thanks again to Dr. Martin Schweiger for creating Orbiter so that you and I and I hope a lot more people can virtually play in space. Maybe some of you reading this will truly go play in space someday.

References for This Chapter

These are just a few of many excellent books that relate to the topics in this epilogue.

Barnes, John, *Orbital Resonance* (novel), Tor Books 1991

Part of a series that also includes *The Kaleidoscope Century*, this book takes place in a space colony built from an asteroid as part of an off-Earth "lifeboat" plan following a series of planet-wide disasters on Earth.

Barnes, John, *The Sky So Big and Black* (novel), Tor Books 2002

Takes place on Mars in the late 21st century some years after *Orbital Resonance*. Interesting ideas about the future and about human life on Mars.

Baxter, Stephen, *Voyage* (novel), Harper Prism 1996

This is a huge, detailed, and fascinating "alternate history" SF novel that assumes that instead of deciding in 1972 to build the Space Shuttle after the Apollo program, that President Nixon decided to pursue a Mars project based on Apollo technology. Excellent in many ways, including the descriptions of what space flight is like. Richard Wall developed an extensive add-on for an earlier version of Orbiter based on Baxter's descriptions in *Voyage,* but I have not tried this add-on and don't know if it will work in Orbiter 2006 (search for **richard wall** on www.avsim.com, at least three files starting with apollo_saturn2mars_v0.98.zip).

Benford, Gregory, ***The Martian Race*** (novel), Warner Books 1999

This book features a privately-funded Mars mission based on the *Mars Direct* approach, but it is also an excellent SF novel in its own right, apart from any connection with *Mars Direct*. Believable characters, credible situations, many surprises. A really good read.

Bonin, Grant, ***Reaching Mars for Less: The Reference Mission Design of the MarsDrive Consortium***
Technical paper presented at International Space Development Conference (ISDC), May 2006

This paper describes the *Mars for Less* reference mission in more detail, including discussions of trajectories; propulsion and propellant storage issues; spacecraft design; orbital assembly issues; lunar mission variations; artificial gravity; multiple launch issues; and the effects of propulsion stage failures and launch delays. Bonin points out that by breaking the mission into approximately 25 metric tonne modules, existing MLLVs (Ariane V, Delta IV-H) and in-development or planned MLLVs (NASA CLV, SpaceX Falcon 9-29, Chinese Long March 5) could be used to launch the mission components for orbital assembly.

Crossman, Frank and Zubrin, Robert (editors), *On To Mars 2*, Apogee Books 2005

A collection of papers from the Mars Society's 2002-2004 annual conferences, this book provides an interesting cross-section of the Mars-exploration-related thinking and research that is going on today. The papers cover plans for proposed Mars missions, research on various aspects of Mars missions (including reports from the Mars Society's arctic and desert Mars analog research sites), propulsion issues, tools, social issues of settling Mars, and much more. The book includes a bonus CD-ROM with a large number of additional papers.

Edwards, Bradley & Westling, Eric, ***The Space Elevator,*** BC Edwards (avail. Amazon.com), 2003

Subtitled "A Revolutionary Earth-to-Space Transportation System" and based on a study done for NIAC (NASA Institute for Advanced Concepts, http://www.niac.usra.edu/), this book describes what is needed to build a space elevator in amazing but readable detail. Carbon nanotubes will make it possible, and it could possibly be built within the next 20 years. A 43 page PDF summary: http://www.spaceelevator.com/docs/521Edwards.pdf.

Kurzweil, Raymond, ***The Age of Spiritual Machines***, Penguin Books, 1999

Subtitled "when computers exceed human intelligence," this book concerns the future and the implications of rapidly growing technology and especially of the arrival of machines (something beyond computers and robots as we know them) with intelligence beyond that of humans. Whether or not this is a good thing, and whether or not you accept Kurzweil's ideas of the possible timing (his premise is that the rate of change will soon move from rapid to explosive), this fascinating book is well reasoned and thought provoking.

Kurzweil, Raymond and Terry Grossman, M.D., ***Fantastic Voyage: Live Long Enough to Live Forever***, Rodale Books 2004

One of Kurzweil's other interests is life extension (he clearly believes the future will be pretty interesting and would like to be around for more of it). The book outlines a detailed (if somewhat controversial) approach to radical life extension.

Robinson, Kim Stanley, *Mars Trilogy: Red Mars, Green Mars, Blue Mars,* Spectra, 1993-1997

The most comprehensive and realistic treatment of the human settlement of Mars, this trilogy is a modern SF classic. There are many impressive things about these books, from the detailed geology and other science descriptions, to the amazing yet believable technology that develops over 100+ years. But perhaps most impressive are the characters, who seem like they could be real people, with all the diversity and conflicts this entails. The Martian society that evolves is also believable – not that it will happen just this way, but when Mars is eventually settled, it will be like this in many ways – messy, confusing, conflicted, non-linear, and surprising, just like any truly human endeavor. Someday there will be Martians, and they will be different for sure, but definitely human. These books also explore the benefits and problems of extreme life extension.

Sagan, Carl, ***Cosmos***, Random House, 1980.

Carl Sagan was a planetary scientist and one of the most successful and influential populizers of science. Several of his books were best sellers, and the Public Television series *Cosmos* remains one of the most successful science series ever broadcast. Although it dates from 1980 (when outer planet data from the Voyagers had just become available), it remains worth reading for the quality of its insights and writing. His 1994 book *Pale Blue Dot* is also highly recommended for anyone with an interest in space.

Stiennon, Patrick and Hoerr, David, ***The Rocket Company,*** AIAA (avail. Amazon.com), 2005

This book is the subject of a cool Orbiter add-on and is briefly discussed on page 8-12 of this book. Although it is fiction, the book is a detailed and highly readable portrayal of the creation and growth of a private space venture, and the "history" of its development of an innovative, fully reusable, two-stage launch vehicle. This book demonstrates that while "rocket science" may get the glory in the well-worn cliché for something that is intellectually difficult, it is rocket *engineering* that's really tough to get right. Illustrated by Doug Birkholz.

Zubrin, Robert, ***The Case for Mars,*** Touchstone Books, 1996

Subtitled "The Plan to Settle the Red Planet and Why We Must," I've talked a bit about the subject of this book in the section above on *Mars Direct*, which Zubrin defines in detailed but very readable form here. Highly recommended.

Zubrin, Robert, ***Entering Space: Creating a Spacefaring Civilization***, Tarcher/Putnam Books, 1999

Zubrin's follow-up to *The Case for Mars* extends the discussion of the various reasons why and of the practicality of becoming a "spacefaring civilization." Very good.

Web References for This Chapter

This is certainly not a complete list of web sites related to the subjects discussed in this epilogue, but it's a start. Note that the various space interest groups (Mars Society, Planetary Society, National Space Society, MarsDrive Consortium, and others) welcome people with interests in space issues, so please consider joining one or more. The web sites below are listed in no particular order.

The Mars Society – Founded by Dr. Robert Zubrin.
http://www.marssociety.org/

MarsDrive Consortium – An organization dedicated to sending humans to Mars and establishing permanent bases there in the next two decades – working to unite individuals and other organizations who support these basic goals. Information on *Mars for Less* can be found here.
http://www.marsdrive.com/

The Planetary Society – Co-founded by the late Dr. Carl Sagan.
http://www.planetary.org/

National Space Society – Since 1974, "dedicated to the creation of a spacefaring civilization."
http://www.nss.org/

NASA's Vision for Space Exploration and ESAS Final Report
http://www.nasa.gov/missions/solarsystem/explore_main.html
http://www.nasa.gov/mission_pages/exploration/news/ESAS_report.html

Mars Direct Project for Orbiter
http://barnstormer.home.mindspring.com/marsdirectproject/marsdirectproject.htm

Red Colony – Red Colony is "…devoted to developing methods for colonizing and terraforming Mars."
http://www.redcolony.com/

SpaceNow.ca – An excellent space information, discussion, and educational site.
http://www.spacenow.ca

KurzweilAI.net – An eclectic future-oriented site from Dr. Raymond Kurzweil.
http://www.kurzweilai.net/

SENS – Strategies for Engineered Negligible Senescence, life extension web site of Aubrey de Grey.
http://www.gen.cam.ac.uk/sens/

4 Frontiers Corporation – Space commerce company formed in 2005 to pursue mining of space resources and Mars settlements by 2025. The four frontiers are Earth, Moon, Mars, and the asteroids.
http://www.4frontiers.com

Mars Foundation – "Working toward the first permanent settlement on Mars."
http://www.marshome.org

SpaceX – Another private space venture, this company is developing a family of launch vehicles "intended to reduce the cost and increase the reliability of access to space ultimately by a factor of ten."
http://www.spacex.com/

LiftPort Group – "The space elevator companies," working to make it happen by 2018.
http://www.liftport.com

Appendix A:
Joystick Notes

I'm a great believer in the value of realistic controls for flight simulators, and I have spent some money and time over the years acquiring and configuring programmable joysticks, flight yokes, throttles, rudder pedals, and even a few game pads. These things can really make a difference in the realism of a flight sim (especially the rudder pedals). With extensive configurable features, whether defined within the sim's own interface, or set up with a customizing utility provided with the joystick, you really can improve your effectiveness and "immersion" in the flight simulator world.

Orbiter provides some support for joysticks, but not nearly to this extent, and for the most part, it's not nearly as important. There are a few basic configuration features on the Joystick tab of the Launchpad. Joystick use is briefly described in the Orbiter manual (chapter 7). It is most helpful and natural in atmospheric flight of airplane-like spacecraft like the Delta Glider (launch and landing) and the Space Shuttle (dead stick landing). But it is by no means essential – you can learn to control your spacecraft in the atmosphere or in space quite well using just the keyboard/keypad.

Rotational/Atmospheric Flight Controls

- **Pitch** – Stick forward (nose down), stick back (nose up)
- **Roll or bank** – Stick left (roll left), stick right (roll right)
- **Yaw (thrusters) or rudder (aerodynamic)** – With a twist-grip, twist left/right for yaw left/right OR push stick left/right while holding joystick button 2
- **Throttle** – Throttle control (axis or slider as configured in Launchpad) can control main engines only (not retro engines, not hover engines)

View Control

Direction controller ("coolie hat") rotates view or camera (like the right mouse button)

Programmable Features

Orbiter itself has no joystick button programming or mapping features, but most higher-end joysticks include configuration utilities that allow you to assign keyboard sequences to joystick buttons and even in some cases to sliders and joystick control axes. Once programmed and activated, when you press a button on the stick, the stick software sends its programmed key sequence to Orbiter just as if you had typed it.

This can be useful for things like Kill Rotation (keypad **5**), Toggle translation/rotation thruster mode (keypad **/**), and toggle internal/external view (**F1**). You can program all sorts of features if you have enough buttons and can remember what they do! People who have highly configurable sticks such as Saitek have reported that they can do almost all Orbiter operations (except perhaps MFD interactions) without touching the keypad once they have properly programmed their joystick.

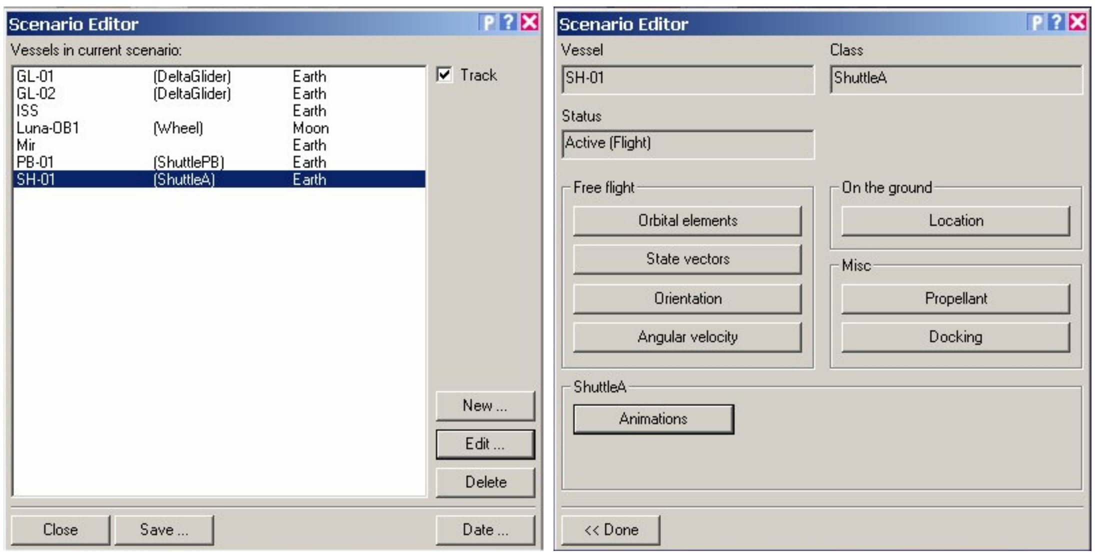
Appendix B:

Using the Orbiter Scenario Editor

Orbiter 2006 includes a fantastic tool called the Scenario Editor. It runs as a module within Orbiter, allowing you to modify a scenario as it is running. Note that you must start with a scenario that contains at least one spacecraft, but since you can easily add, modify, and delete spacecraft, it doesn't really matter much which scenario you start with.

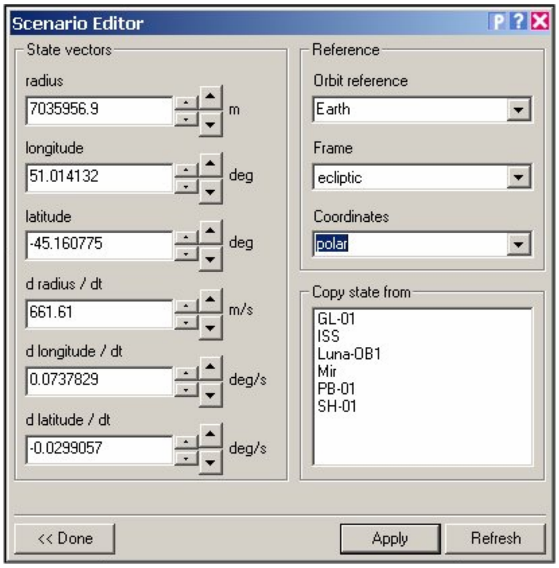
Orbiter comes with a clear and complete PDF manual for the Scenario Editor, located in the \Docs folder of the Orbiter installation. The manual is only about 15 pages, of which the last three are for add-on developers, so it's a quick and highly recommended read. We won't duplicate that information here, but will instead start with some tips for use, followed by a quick example.

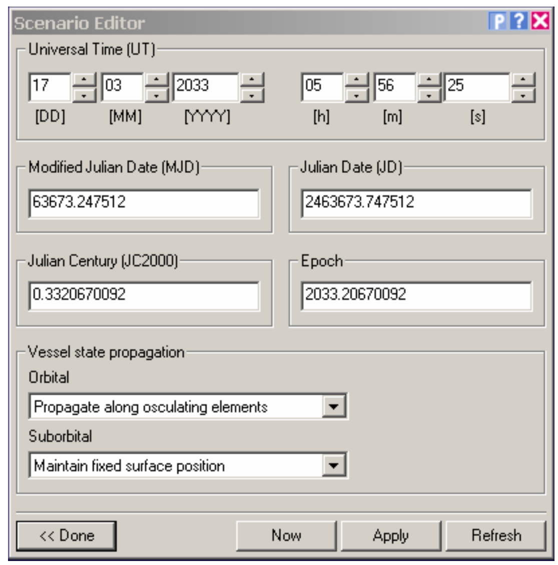
Although the Scenario Editor is an easier and more intuitive option for most people, the .scn files are plain text and are structured pretty logically, so they are not that hard to modify with a text editor. But you can't change a running scenario this way (text edit changes will apply the next time you launch the edited scenario).



- **Activate** – To use the Scenario Editor, you must first activate it in the Modules tab of the Orbiter Launchpad (it's called ScnEditor).
- **Launch & Pause** – Launch Orbiter with the scenario you wish to modify, then pause the simulation (Control-**P**). This isn't strictly required, but things move fast in space, and if you edit "on the fly," your spacecraft may not end up where you expect.
- **Launch the Editor** – Press Control-**F4** to see installed modules, and launch ScnEditor.
- **Only for Spacecraft** (picture above left) – The Editor first displays a list of "vessels" in the current scenario. It can do just about anything with spacecraft and space stations, but it does not affect the properties of planets or surface bases. You must still edit .cfg files and the like to make changes to planets and bases.
- **Select Then Edit** – Unless you are adding a new ship, you first need to select the ship you wish to edit from the main "Vessels in current scenario" page. After you click Edit, you will have several editing options (above right). You also select first to delete (there's no undo, be careful).

- **Copying a State** (picture below left) – The manual has detailed notes on all the editing modes and when they are best used, but note that an especially convenient mode for ships in flight is to edit the state vectors (best to be paused), then to do "Copy state from" the list of other ships on that page and click Apply. The modified ship may start out hiding inside a bigger ship like the ISS, but you can tweak the state vector values to move the new ship nearby to fly in formation (changing to a convenient reference frame will help you to better see what to tweak, polar coordinates are especially handy in orbit). The docking page is also handy for getting a ship (very) near another one, as long as it is in flight and has a docking port. Don't dock with a landed ship.





- **Master of Time** (picture above right) – The main page has a Date… button in the lower right which allows you to set the date and time of your scenario in a number of ways. Pay attention to the "Vessel state propagation" controls at the bottom to be sure your spacecraft will do what you want them to do when you start time traveling. Note also that the "Epoch" control on the Orbital Elements page has a selector for MJD (date), but this is a reference date for the orbital elements, it does not change the date of the scenario.

- **Add-on Ships** – The Editor can place and modify add-on spacecraft as well as built-in ones, but there are a couple of limitations. The Editor will only see vessels which have configuration files (ship_name.cfg) located in the installation folder Config\Vessels, so the add-on developer (or possibly you) must makes sure that the spacecraft's .cfg file ends up there, or it will not be listed as an available ship. The other limitation is that unless the developer has written vessel-specific editor extensions (special code), there will be no controls for special features of the ship such as animations or payloads. If there are such extensions, buttons for them will show up at the bottom of the main editing page. For example, when a Delta Glider is selected for editing, this page will have buttons for animations and passengers.

- **Save Your Work** – Each page has one or more page navigation buttons at the bottom and when you return to the main page, you will see buttons for Save… and Close, which are pretty self-explanatory. Since the changes are generally applied to Orbiter as you work in the editor, closing without saving is not fatal, but this save is very handy in that it allows you to immediately supply the name, folder, and comments to be saved with the scenario.

Scenario Editor Example – Smack Traffic Jam

This is a pretty crazy application of the Scenario Editor, designed mainly to require use of most of its features. The view from the Dragonfly of the altered "Smack!" docking scenario is pretty cool, though. Up close and personal.

1. Start Orbiter, make sure ScnEditor is activated on the Modules tab, check the "Start paused" box on the Scenario page (important), and launch the "Smack!" scenario found in the Delta-glider folder.

2. Stay in pause, but press Control-**F4** and launch the ScnEditor.

3. On the main page, select GL-02, click Edit…, click Orientation, and carefully write down the Euler angle values (they should be **-117.1**, **0.99**, **-86.2111** if you started and stay in pause mode). Then click << Done.

4. Click Angular Velocity and write down the bank value (should be **-13.1**, and other two rotation values should be zero). Click << Done twice to get back to the main vessel selection page.

5. Select SH-01 (ShuttleA which is currently parked on the Moon, as you will see), click Edit, then click State vector to go to that page.

6. On the State vector page, click **GL-02** in the "Copy state from" list, then click the Apply button and then << Done. Note that you are still editing the SH-01— you have only copied its position and velocity from the GL-02 so it is now apparently merged with it and at a crazy angle.

7. Back on the edit button page, click Orientation and carefully type in the alpha, beta, gamma, values you copied from the GL-02, then click Apply and << Done. The SH-01 should now be lined up within the GL-02 with its nose sticking out, and I think you can see where this is going.

8. On the edit page, click Angular velocity, enter the bank value saved before (should be -13.1), then click Apply and << Done.

9. On the edit page, click the Animations button, and on the next page, click the Open button for the SH-02 docking port. Then click << Done until you are back at the main vessels page.

10. No need for GL-02 any more, so select it in the list and click Delete .

11. Time to add the voyeur. Click the New… button on the main vessels page, and in the page that follows, click on the **Dragonfly** in the list, and enter a name for it at the top (I called it DragonWatch). Then click Create >>.

12. We'll abbreviate somewhat from here on since the remaining steps are similar to positioning the SH-01 on top of the now departed GL-02. Click the State vector button, choose **GL-01** from the list, and apply. The Dragon moves to GL-01.

13. Staying on the State vector page, select **Polar** from the Coordinates list, and **Ref equator (fixed)** from the Frame list. Then click the small arrows next to radius, longitude, and latitude to shift the Dragonfly a short distance away (my values were radius 7035973.9, long. 60.528884 degrees, lat. -25.620672 degrees, but it's really not critical in this case). Note that as you click the arrows, you can actually see the selected object move or rotate in the Orbiter 3D view.

14. Go back to the edit buttons page, click Orientation, and use the Yaw, Pitch, and Bank (Rotate) spinner controls to aim the Dragonfly at the unlikely pair that is soon to be spinning and docking. Notice that if you need to enter the Orbiter window to rotate the view with the mouse to see better, you can just do it. The Apply button is not needed if you use the "instant" spinner controls but it doesn't hurt anything as long as you are in pause (so things don't change between clicks).

15. Optional mayhem: If you would like to make something like the picture shown above, repeat the above procedures and add more Dragonfly spacecraft (be sure to give each a unique name), astronauts (nasa_mmu), and what-have-you and position them as desired. For more dynamic action, use the Angular velocity page and apply a bank rotation value to any of the added ships so they will rotate like the original pair.

16. Back to the main page, click the Save… button, fill in the name and description, and save this vitally important (not!) scenario.

Close the scenario editor, and turn off the pause (Control-P). You may want to slow time to 0.1x with R so there is time to use **F3** and **F1** to get inside your new Dragonfly, go back to normal time T, and watch the brief spinning/docking show.

Appendix C:

Glossary and Acronyms

Acceleration – Change in velocity (change in speed or direction)

AgP (Orbit MFD) - Argument of periapsis

Alt (Orbit MFD) - Altitude (above surface)

AOA (Surface MFD) - Angle of Attack

Ap- or Apo - Prefix used for apoapsis from a particular object (apogee=Earth, aphelion=Sun, apolune=Moon, etc.)

ApA (Orbit MFD) - Apoapsis altitude

Apoapsis – The farthest point in an orbit from the body being orbited

Apollo – American space program which put men on the Moon in 1968-1972

ApR (Orbit MFD) - Apoapsis radius (was ApD for Distance in older Orbiter versions)

ApT (Orbit MFD) - Time to apoapsis passage

Ascending node - The point at which an orbit crosses the reference plane (equator, ecliptic, target orbital plane) going north

ATM – Atmosphere

CNES – Centre National d'Études Spatiales, the French space agency

COM – Communications

CSM (Apollo) – Command Service Module

Delta-V – change of velocity; a measure of the energy required to perform an orbital maneuver or transfer

Descending node – The point at which an orbit crosses the reference plane (equator, ecliptic, target orbital plane) plane going south

Ecc (Orbit MFD) – Eccentricity

Eccentricity – Often symbolized by **e**, a value that expresses to what extent an elliptical path is elongated from a circle (e=0). At e=1, the path transitions to a parabola (open path), and for e values greater than one (e > 1), the path becomes a hyperbola (also an open path, not a closed orbit).

Ecliptic – The plane in which Earth orbits the Sun

Ellipse – A closed plane curve generated in such a way that the sums of its distances from the two fixed points (the foci) is constant.

EMU – Extravehicular Mobility Unit

Equator – An imaginary circle around a body which defines the boundary between the northern and southern hemispheres.

ESA – European Space Agency

ET (Space Shuttle) – External Tank

FOV – Field of View

Galilean satellites – The four large satellites of Jupiter first observed by Galileo (Io, Europa, Ganymede, and Callisto)

Geostationary – A geosynchronous orbit in which the spacecraft is constrained to a constant latitude.

Geosynchronous – A direct, circular, low inclination orbit about the Earth having a period of 23 hours 56 minutes 4 seconds.

Gravity assist – Technique whereby a spacecraft takes angular momentum from a planet's solar orbit to accelerate the spacecraft

Hohmann Transfer Orbit – Interplanetary trajectory requiring the least amount of propulsive energy (delta-V)

HTO – Hypothetical Transfer Orbit

HUD – Head-up Display (see chapters 3 and 7)

IDSn (Orbiter) – Instrument Docking System

ILS – Instrument Landing System (radio beacon for alignment with runway)

Inc (Orbit MFD) – Inclination

Inclination – The angular distance of the orbital plane from the plane of the planet's equator (in degrees)

ISS – International Space Station

JPL – Jet Propulsion Laboratory (NASA)

KSC – Kennedy Space Center (NASA)

LAN (Orbit MFD) – Longitude of ascending node

LEO - Low Earth Orbit

LM (Apollo) – Lunar Module

LOX – Liquid oxygen

Lpe (Orbit MFD) – Longitude of periapsis

ME – Main Engines

MECO– Main Engine Cut Off

MFD – Multifunction (or Multifunctional) Display

MJD – Modified Julian Date

MMU – Manned Maneuvering Unit (astronaut "thruster pack")

MnA (Orbit MFD?) – Mean anomaly

MnL (Orbit MFD) – Mean longitude

NASA – National Aeronautics and Space Administration

NDB – Receiver (Non-Directional Beacon, a.k.a radio compass)

Node – a point in an orbit at which it intersects a reference plane such as the equatorial plane, the ecliptic plane, or the orbital plane of another object

OMS (Space Shuttle) – Orbiter Maneuvering System

Orbit – the path of a body acted upon by the force of gravity; orbits can be closed or open – closed orbits are generally ellipses

Orbital mechanics – a branch of applied physics concerned with determining the paths of natural and man-made objects under the influence of gravitational and other forces (rocket thrust, atmospheric drag, etc.)

PAPI – Precision Approach Path Indicator (visual landing aid for aircraft and for the Space Shuttle)

PeA (Orbit MFD) – Periapsis altitude

PeR (Orbit MFD) – Periapsis radius (was PeD for Distance in older Orbiter versions)

Per- or peri- (prefix) – closest approach of an orbit, a prefix applied to specify the periapsis of an orbit around a specific planet or moon (perigee - Earth; periline or periselene - Earth's Moon; perihelion - Sun, i.e., solar orbit; perijove - Jupiter)

Periapsis – The point in an orbit closest to the body being orbited

PeT (Orbit MFD) – Time to periapsis passage

Prograde – Orbit in which the spacecraft moves in the same direction as the planet rotates (see retrograde). Also refers to spacecraft orientation in the direction of orbital motion for orbital maneuvering purposes.

Rad (Orbit MFD) – Radial distance from the center of the planet

RCS – Reaction Control System (thrusters)

Retrograde – Orbit in which the spacecraft moves in the opposite direction from the planet's rotation (see prograde). Also refers to spacecraft orientation opposite the direction of orbital motion for orbital maneuvering purposes.

Satellite – A body which orbits another, typically larger one (star, planet, moon). Can be natural (e.g., moon) or artificial (man made).

Sma (Orbit MFD) – Semi-major axis

Smi (Orbit MFD) – Semi-minor axis

SRB – Solid Rocket Booster

SSME – Space Shuttle Main Engines

T – orbital period (time to complete one orbit)

TLI (Apollo)– Trans lunar injection (eject burn for the Moon)

TrA (Orbit MFD) – True anomaly

TrL (Orbit MFD) – True longitude

UT – Universal Time, also called Zulu (Z) time, previously Greenwich Mean Time (GMT).

VASI – Visual Approach Slope Indicator (visual landing aid for aircraft and for the Space Shuttle)

Vel (Orbit MFD) – Velocity

Velocity – Rate of change of position, a vector quantity with both magnitude (speed) and direction

VOR – Very High Frequency Omnidirectional Range (aircraft radio navigation aid)

VTOL – Vertical Take-Off & Landing

XPDR – transponder (radio beacon transmitter/receiver on aircraft or spacecraft)

Zenith – The point on the celestial sphere directly above the observer. Opposite the nadir.