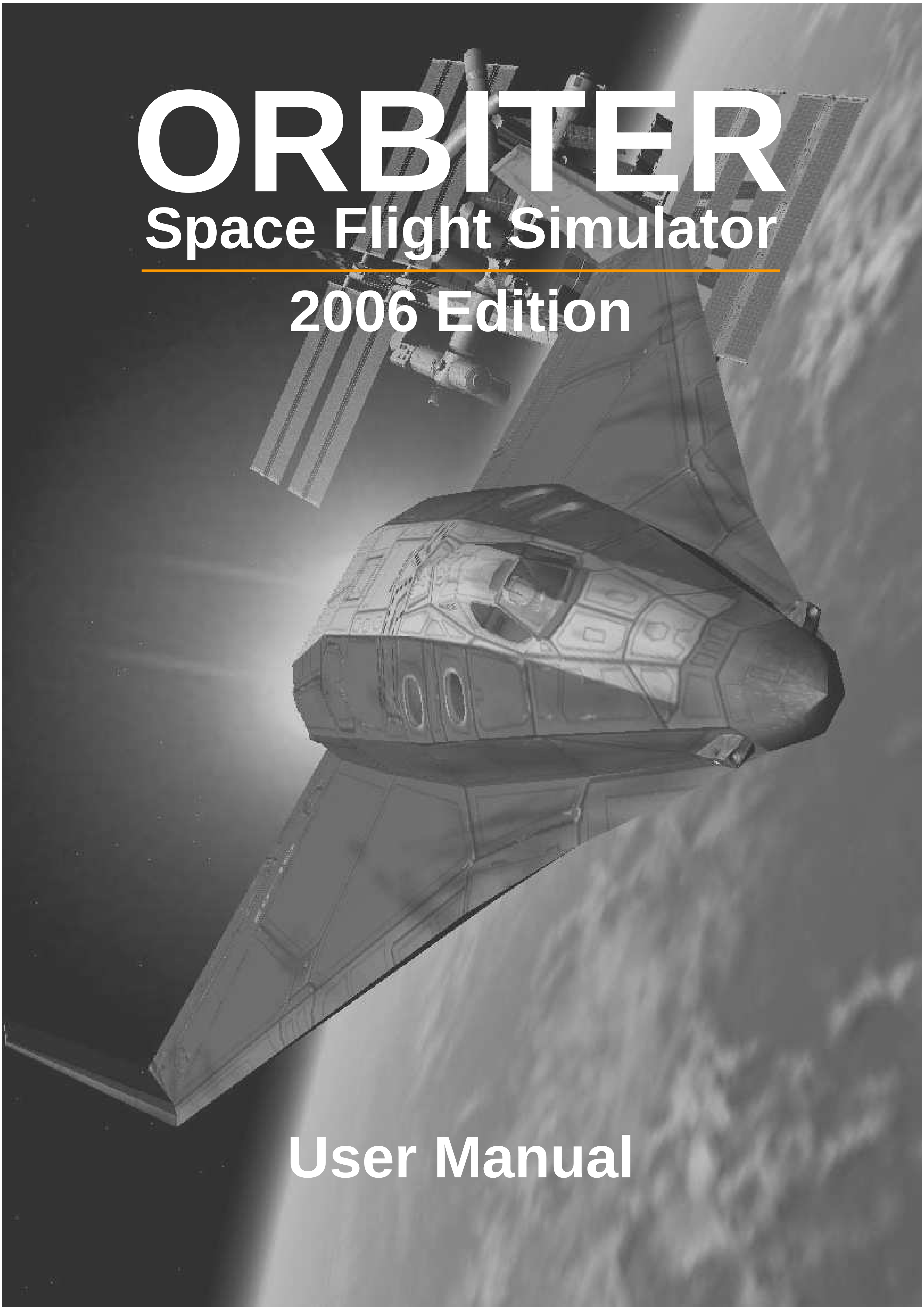
ORBITER

Space Flight Simulator

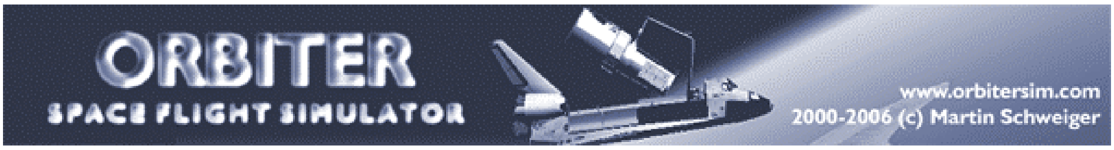
2006 Edition



User Manual

ORBITER User Manual

26 September 2006
Orbiter home: orbit.medphys.ucl.ac.uk/ or www.orbitersim.com



Contents

1 Introduction

Welcome to the ORBITER 2006 Edition!

This release incorporates quite a few exciting new features, both in terms of the physics engine and visual appearance. Planet surfaces can now be rendered at twice the previous resolution, which makes a big difference in low orbit. A flight recording and playback function allows to replay and share flights. Orbiter now comes with a scenario editor module for creating, editing and deleting spacecraft in a running simulation. Additional MFD display windows provide all the flight data you need. Gravity-gradient torque is supported, and makes the alignment during docking maneuvers just a bit more difficult.

ORBITER is a free flight simulator that goes beyond the confines of Earth's atmosphere. Launch the Space Shuttle from Kennedy Space Center to deploy a satellite, rendezvous with the International Space Station or take the futuristic Delta-glider for a tour through the solar system – the choice is yours. Unlike many commercial "space simulator" games Orbiter aims at accurately simulating the physics of space flight. Don't get frustrated if you don't succeed immediately – it's only rocket science. Read the documentation and try some of the numerous Orbiter tutorials available on the internet, and you will soon be orbiting like a pro.

At the very least, you should familiarise yourself with the primary spacecraft controls and instrumentation in this manual to get your ship off the ground. "Advanced" missions like rendezvous maneuvers or interplanetary trips will require a lot more effort!

Suggestions, corrections, bug reports (and praise) for Orbiter are always welcome. The preferred way to post your comments, in particular if they may be of interest to other users, is via the Orbiter mailing list or the web forum, available via links from the official Orbiter site: orbit.medphys.ucl.ac.uk/ (alias www.orbitersim.com).

Unfortunately I can't guarantee to answer all Orbiter-related mail sent directly to me.
Before posting a bug report make sure you have got the latest ORBITER release, and that your problem is not already documented in the FAQ, the bug tracker or the bug forum (all accessible from the ORBITER home page).

ORBITER – the thinking being's simulator.
Enjoy the ride!

Martin Schweiger

1.1 About Orbiter

Orbiter is a space flight simulator based on Newtonian mechanics. Its playground is our solar system with many of its major bodies - the sun, planets and moons. You take control of a spacecraft - either historic, hypothetical, or purely science fiction. Orbiter is unlike most commercial computer games with a space theme - there are no predefined missions to complete, no aliens to destroy and no goods to trade. Instead, you will get an idea about what is involved in *real* space flight - how to plan an ascent into orbit, how to rendezvous with a space station, or how to fly to another planet. It is more difficult, but also more of a challenge. Some people get hooked, others get bored. Finding out for yourself is easy - simply give it a try. Orbiter is free, so you don't need to invest more than a bit of your spare time.

Orbiter is a community project. The Orbiter core is just the skeleton that defines the rules of the simulated world (the *physical model*). A basic solar system and some spacecraft (real and fictional) are included, but you can get a lot more with addon modules developed by other enthusiasts in the Orbiter community. There are addons for nearly every spacecraft that ever flew (and quite a few that never got beyond the drawing board), for many more celestial bodies in the solar system (or entirely new fictional systems), for enhanced instruments, and much more. The Orbiter web site contains links to many Orbiter addon repositories.

1.2 About this manual

This document is the main help file that comes with the basic distribution of Orbiter. It is a User's Guide to the Orbiter software - which is to say that it gives an introduction into *how* most things work, but doesn't tell you much *why* they behave as they do. By following the instructions, you will find out how to operate the engines of your spacecraft, how to use the instruments, and how to perform the most common missions.

But a big part of the appeal of Orbiter is finding out about the *why* - why do spacecraft in orbit behave as they do, what is involved in a gravity-assist flyby, why do rockets have multiple stages, why can it be tricky to line up for docking with a space station, what do the numbers in the instrument displays actually mean ... ?

This is where physics comes into the picture. If you want to become an orbiter pro, you will at some stage need to understand a few of the fundamental physical concepts that form the basis of astrodynamics and space flight. Luckily most of it is not very difficult - if you learn a bit about forces and gravity ("Newtonian mechanics") and how they relate to the motion of planets and spacecraft in orbit ("Kepler's laws"), you will have covered a good deal of it. Of course, there are always opportunities to dig deeper into the details, so your next steps might be finding out about the effects of orbit perturbations, attitude control, trajectory optimisation, mission planning, instrument design - to name just a few.

Eventually you might start to develop your own addon modules to enhance Orbiter's functionality, write tutorials and help files for newcomers - or even take active part in the Orbiter core development by identifying and discussing flaws or omissions in the Orbiter physics model (and there are still many!)

1.3 Getting more help

The help files that come with the main Orbiter package are located in the *Doc* subfolder below your main Orbiter directory. Many addons will place their own help files in the same directory after installation. The *Doc\Technotes* folder contains a few documents with technical details for interested readers. They are not required for using Orbiter.

Many people have written documentation and tutorials covering particular aspects of Orbiter. Some of them can be found via links from the Orbiter web site at orbit.medphys.ucl.ac.uk/ . Other useful online resources are the Orbiter forum, orbit.m6.net/Forum/default.aspx, the Orbiter wikipedia entry, en.wikipedia.org/wiki/Orbiter_(sim) and the Orbiter community wiki site, www.orbiterwiki.org/wiki/Main_Page.

A very good introduction to using and understanding Orbiter for beginners is Bruce Irving's online book *Go Play In Space*, which can be found via a link from the *Manual* page on the Orbiter web site.

The scientific and technical background of space flight is covered in many textbooks and online sites. A good introduction is JPL's *Basics of Space Flight*, at www.jpl.nasa.gov/basics/ . Among the many online resources for the general mathematics and physics relevant for space flight, you might find the Scienceworld site useful, at scienceworld.wolfram.com .

2 Installation

This section lists the computer hardware requirements for running Orbiter, and contains download and installation instructions.

2.1 Hardware requirements

The standard ORBITER distribution requires the following minimum hardware features:

- 600 MHz PC or better (Pentium, Athlon, etc.)
- 256 MB RAM or more
- Windows 95/98/Me/2000/XP
- DirectX 7.0 or higher
- DirectX compatible 3D graphics accelerator card with at least 16MB of video RAM (32MB or more recommended) and DXT texture compression support
- Approximately 100MB of free disk space for the minimum installation (additional high-resolution textures and addons will require more space).
- DirectX compatible joystick (optional)

Installing high-resolution texture packs or addons may have an impact on performance and could require significantly higher computing specs.

> Since ORBITER keeps evolving these specs tend to become obsolete over time. If you don't get a reasonable frame rate (approx. ≥ 20fps) using the default Orbiter.cfg on a machine which meets the specs then please drop me a note and I will correct the requirement list upward.

2.2 Download

The ORBITER distribution can be obtained from one of several Orbiter mirror sites on the internet. You can find links to these mirrors at the Download page of the ORBITER site, http://orbit.medphys.ucl.ac.uk/. Orbiter is distributed in several packages (.zip files). The *Base* package contains the basic Orbiter system and is the only required package. All other packages are optional extensions to the basic system.

All package names contain a 6-digit time stamp (YYMMDD) which allows to identify the modification date of the package. For example, orbiter060504_base.zip contains the base package built on May 4, 2006. Note that not all current packages may have the same time stamp. In particular, high-resolution planetary texture packages are rarely updated and may have an older time stamp. Check the download pages for the latest versions of all packages.

2.3 Installation

- Create a new folder for the ORBITER installation, e.g. \Program Files\Orbiter.
- If a previous version of ORBITER is already installed on your computer, you should *not* install the new version into the same folder, because this could lead to file conflicts. You may want to keep your old installation until you have made sure that the latest version works without problems. Multiple ORBITER installations can exist on the same computer.
- Download the *Base* package from an ORBITER download site into your new ORBITER folder and unzip it with WinZip or an equivalent utility. **Important**: Take care to preserve the directory structure of the package (for example, in WinZip this requires to activate the "Use Folder Names" option).
- After unzipping the package, make sure your ORBITER folder contains the executable (Orbiter.exe) and, among other files, the *Config*, *Meshes*, *Scenarios* and *Textures* subfolders.
- Run Orbiter.exe. This will bring up the ORBITER "Launchpad" dialog, where you can select video options and simulation parameters.
- You are now ready to start ORBITER. Select a scenario from the Launchpad dialog, and click the "ORBITER" button!

If Orbiter does not show any scenarios in the *Scenario* tab, or if planets appear plain white without any textures when running the simulation, the most likely reason is that the packages were not properly unpacked. Make sure your Orbiter folder contains the subfolders as described above. If necessary, you may have to repeat the installation process.

2.4 Uninstall

- ORBITER does not modify the Windows registry or any system resources, so no complicated de-installation process is required. Simply delete the Orbiter folder with all contents and subdirectories. This will uninstall ORBITER completely.

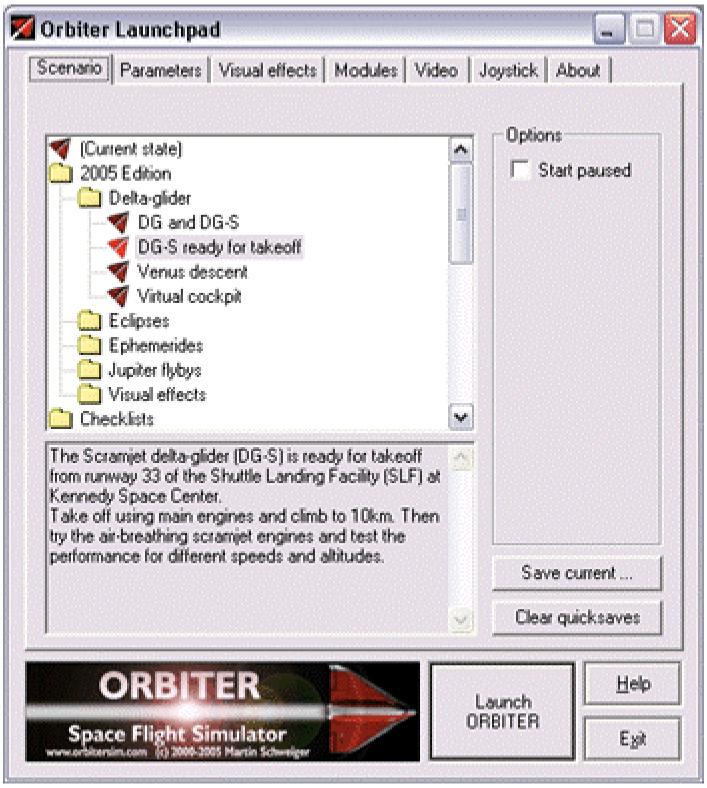
3 The Launchpad

Starting Orbiter.exe brings up the *Orbiter Launchpad* dialog box. From here, you can

- set simulation, video and joystick parameters
- load available plugin modules to extend the basic Orbiter functionality
- select a startup scenario
- open the online help system
- launch the Orbiter simulation window, or
- exit to the desktop.

From the Launchpad dialog, the simulation can be started by pressing the “Launch ORBITER” button, provided a scenario has been selected. If you are running Orbiter for the first time, you should make sure that the simulation parameters (in particular video options) are properly set before starting the simulation.

3.1 Scenario tab



The Scramjet delta-glider (DG-S) is ready for takeoff from runway 33 of the Shuttle Landing Facility (SLF) at Kennedy Space Center.
Take off using main engines and climb to 10km. Then try the air-breathing scramjet engines and test the performance for different speeds and altitudes.

Figure 1: Launchpad dialog, Scenario tab

Scenario:
Contains a hierarchical list of available scenarios. Select one and launch it with the “Launch ORBITER” button. Below the list is a description of the currently selected scenario.

Special scenarios and folders:

- The ***(Current state)*** scenario is automatically generated whenever you exit the simulator. Use this to continue from the latest exit state.
- The ***Tutorials*** folder contains pre-recorded flights with onscreen annotations that explain different aspects and stages of space flight missions.
- The ***Playback*** folder contains the flights you have recorded with Orbiter's built-in flight recorder. Launching one of these will start a replay.
- The ***Quicksave*** folder contains in-game saved scenarios generated by pressing Ctrl S. Multiple quicksaves are possible. Orbiter saves the quicksave states under the original scenario name, followed by a quicksave counter. The counter is reset each time the simulation is launched, so make sure to copy any scenarios you want to keep!

- The ***Demo*** folder can be filled with scenarios that are automatically run in kiosk/demo mode (see Section 20.2). This allows to put together a set of simulations that can be run in unsupervised environments.

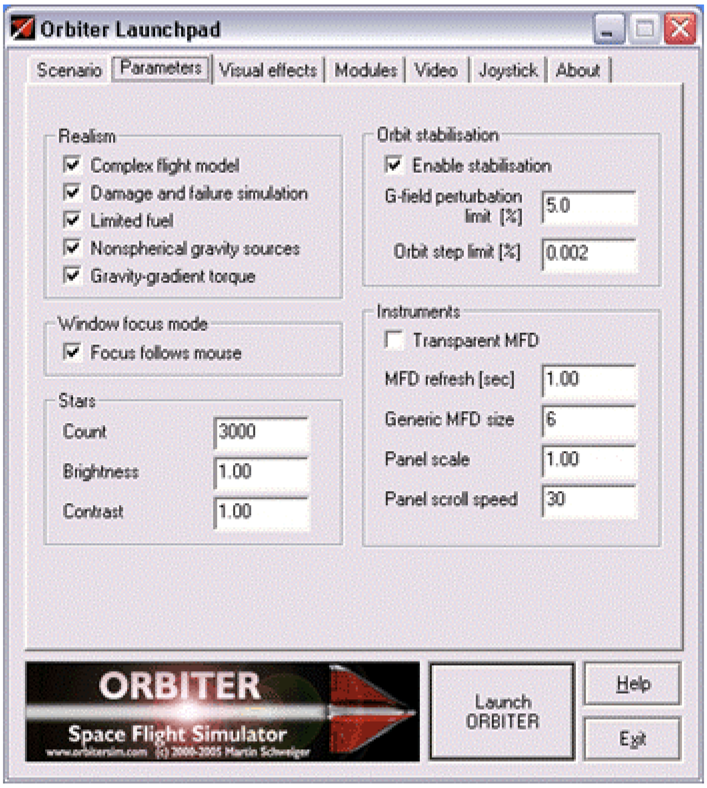
Options:

- **Start paused**: Pause simulation on start. Press Ctrl P to un-pause after launch.

Save current:
Save the current exit state under a new name with a custom description.

Clear quicksaves:
Empty the Quicksave folder.

3.2 Parameters tab



Realism
☑ Complex flight model
☑ Damage and failure simulation
☑ Limited fuel
☑ Nonspherical gravity sources
☑ Gravity-gradient torque

Window focus mode
☑ Focus follows mouse

Stars
Count 3000
Brightness 1.00
Contrast 1.00

Orbit stabilisation
☑ Enable stabilisation
G-field perturbation limit [%] 5.0
Orbit step limit [%] 0.002

Instruments
☐ Transparent MFD
MFD refresh [sec] 1.00
Generic MFD size 6
Panel scale 1.00
Panel scroll speed 30

Figure 2: Launchpad dialog, Parameters tab

Realism

- **Complex flight model**: Select the realism of the flight model for spacecraft. Tick this box to enable the most realistic flight parameters available for all vessel types. Disabling this option may activate simplified flight parameters which make spacecraft easier control for newcomers. Not all vessel types may support this option.

NEW!

- **Damage and failure simulation**: Spacecraft can sustain damage and system failure, for example if operational limits are exceeded. Not all vessel types may support this option.
- **Limited fuel**: Un-tick this box to ignore fuel consumption of your spacecraft.

Some of the more “realistic” spacecraft, such as the Space Shuttle, may *NOT* work properly if “Limited fuel” is not selected, because they rely on the reduction of mass during liftoff as a consequence of fuel consumption.

- **Nonspherical gravity sources**: This option activates a more complex gravity calculation which can take into account perturbations in the gravitational potential due to nonspherical object shapes, thus allowing more accurate orbit predictions. Note that this option can make orbital calculations more difficult, and may reduce the stability of instruments that don’t take this effect into account. For a planet to make use of the perturbation code, its configuration file must contain the `JCoeff` entry.

> ***Technical background**: Orbiter uses the following simple perturbation approach to calculate the gravitational potential U of a celestial body as a function of its radial distance* r *and latitude* ϕ:

$$U(r,\phi)=\frac{GM}{r}\left[1-\sum_{n=2}^{\infty}J_n\left(\frac{R}{r}\right)^2 P_n(\sin\phi)\right]$$

where M and R are the planet's mass and equatorial radius, G is the gravitational constant, P_n is the Legendre polynomial of order n, and J_n is the associated perturbation coefficient.
The gravitational acceleration is given by the gradient of the potential:

$$\vec{a}=\vec{\nabla}U$$

NEW!

- **Gravity-gradient torque**: If this option is enabled, vessels can experience an angular moment in the presence of a gravitational field gradient. This will be noticeable in particular in low orbits and can lead to attitude oscillations around the equilibrium or attitude-locked orbits.

Window focus mode

- **Focus follows mouse**: If this option is ticked, the input focus is switched between the Orbiter simulation window and any open dialog boxes by moving the mouse over the window. If unticked, the focus is switched in normal Windows style by clicking the window.

Orbit stabilisation

- **Enable stabilisation**: If this option is enabled, Orbiter uses an alternative method to update the state vectors of orbiting bodies under certain conditions, where only the perturbations of the osculating 2-body orbital elements with respect to a dominant gravity source are dynamically propagated. This can help to avoid orbit deterioration at high time compressions.
- **G-field perturbation limit**: Defines the upper limit of perturbation [%] of the gravity field of the main gravity source under which stabilisation is enabled. A higher value will switch to stabilisation mode even if the 2-body assumption is not very accurate. Default value is 0.01 (1%).
- **Orbit step limit**: This entry allows to limit the application of orbit stabilisation to time steps which propagate an object by more than a given fraction of its full orbital path. More precisely, orbit stabilisation will only be applied if this condition is satisfied:

  $$v\Delta t > \alpha 2\pi r$$

  where v is the orbital velocity, r is the length of the radius vector, Δt is the time step, and α is the user-specified step limit. Default value is α = 0.0001 (0.01%).
- **Note**: Orbiter uses now an improved stabilisation algorithm. Unlike previous versions, this can now account for perturbations of the gravitational field, aerodynamic and thruster forces.

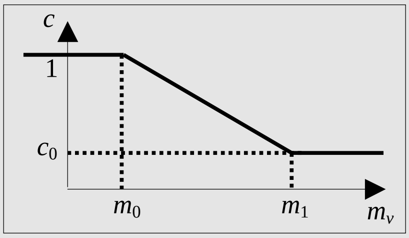
Stars

- **Count**: Number of displayed background stars. Orbiter uses the Hipparcos database of more than 100000 bright stars. Specifying a large number will provide a more impressive night sky, but may degrade performance. Set to zero to suppress background stars.
- **Brightness**: Brightness scaling factor for background stars. Valid range is –4 to 4 (default 1). Note that the dynamic range becomes less realistic for large values.
- **Contrast**: Intensity contrast used for rendering stars. Valid range is 0 to 5 (default 1).

If you use only a small part of the database, you may want to increase the contrast (e.g. to 1.5) and reduce the brightness (e.g. to 0.8). If you use the full database, values of brightness 1.5 and contrast 1.0 give good results.

***Technical background**: The mapping between a star's apparent magnitude m_v and pixel render brightness c is calculated by the clamped linear relationship*

$$c=\min\left[1,\max\left[c_0,\frac{m_1-m_v}{m_1-m_0}(1-c_0)+c_0\right]\right]$$



where

$$m_0=2B-2/C+2,$$
$$m_1=2B+2/C+3,$$
$$c_0=0.3$$

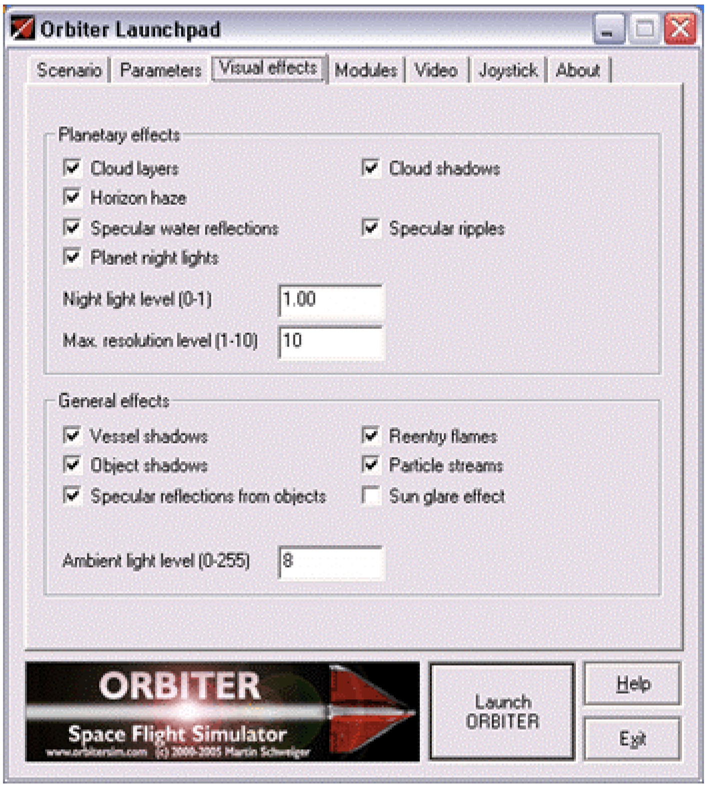
with B and C the user-supplied brightness and contrast values. For default values B=1, C=1, the supported contrast range is thus m_0=2 to m_1=7.

Instruments

- **Transparent MFD**: Make the onscreen multifunctional displays transparent. This provides a better view of the 3D environment, but makes it more difficult to read the instruments.
- **MFD refresh**: Time (in seconds) between MFD updates. Shorter intervals provide smoother updates, but may degrade performance. Some built-in MFD modes, such as the Surface and HSI modes, define a lower limit for the update frequency.
- **Panel scale**: Sizing factor for instrument panels. Scale 1 provides optimal visual quality, but other values may be used to adapt the panel size at low or high screen resolutions.
- **Panel scroll speed**: Determines how fast the panel can be scrolled across the screen [pixels/second]. Negative values invert the panel scroll direction.

3.3 Visual effects tab

This section provides options for tuning the rendering parameters. These options will improve the visual appearance and realism of the simulator, but most of them have an adverse effect on simulation performance (frame rates) when enabled, and may increase video and main memory demands, so they should be used with care. As a first step in troubleshooting Orbiter problems, it is often a good idea to turn off all visual effects.



Planetary effects

☑ Cloud layers
☑ Cloud shadows
☑ Horizon haze
☑ Specular water reflections
☑ Specular ripples
☑ Planet night lights
Night light level (0-1) 1.00
Max. resolution level (1-10) 10

General effects

☑ Vessel shadows
☑ Reentry flames
☑ Object shadows
☑ Particle streams
☑ Specular reflections from objects
☐ Sun glare effect
Ambient light level (0-255) 8

Figure 3: Launchpad dialog, Visual effects tab

Planetary effects

- **Cloud layers**: Render clouds as a separate mesh layer for appropriate planets.
- **Cloud shadows**: Render cloud shadows cast on the planet surface. Only planets whose configuration files contain a *CloudShadowDepth* entry < 1 will actually render cloud shadows.
- **Horizon haze**: Render intensity-graded ("glowing") horizon layer for planets with atmospheres.
- **Specular water reflections**: Render water surfaces on planets with specular reflection effects.

NEW!

- **Specular ripples**: Generate "ripple" effect in specular reflections from oceans for improved appearance of water surfaces.
- **Planet night lights**: Render city lights on the dark side of planet surfaces where available.
- **Night light level**: Defines the brightness of night city lights. Valid range is 0 to 1. (ignored if planet night lights are disabled)

NEW!

- **Max. resolution level**: The maximum resolution at which planetary surfaces can be rendered. Supported values are 1 to 10. Higher values provide better visual appearance of planets that support high texture resolutions, but also significantly increase the demand on computing resources (graphics processor and memory). Simulation loading and closedown times are also affected by this option.

Using a high resolution level can severely increase loading times at the start of a simulation session, in particular if you have installed many high-res addon planet textures.

General effects

- **Vessel shadows**: Enable shadows cast by spacecraft on planet surfaces.
- **Object shadows**: Enable dynamic shadows of ground-based objects such as buildings.
- **Specular reflections from objects**: Render reflective surfaces like solar panels, window panes or metallic surfaces. May degrade performance.
- **Reentry flames**: Render glowing plasma hull during reentry.
- **Particle streams**: Render ionised exhaust gases and vapour trails with particle effects.
- **Ambient light level**: Defines the brightness of the unlit side of planets and moons. Ambient level 0 is the most realistic, but makes it difficult to spot objects in the dark. Level 255 is uniform lighting (no darkness).

3.4 Modules tab

This tab allows to activate and deactivate plugin modules for Orbiter which can extend the functionality of the core simulator. Plugins can contain additional instruments, dialogs, interfaces to external programs, etc. Make sure you only activate modules you actually want to use, because modules can take up some processing time even if they run in the background, and thus affect Orbiter's performance.

To activate a module, select it in the *Inactive modules* list, and click *Activate selected* (or simply double-click it in the list). It will then be moved from the *Inactive* to the *Active* list. In the same way, active modules can be deactivated.

The modules provided with the standard Orbiter distribution are demos from the SDK package, and are available in full source code. A wide variety of additional modules by 3rd party add-on developers can be downloaded from Orbiter repositories on the internet.

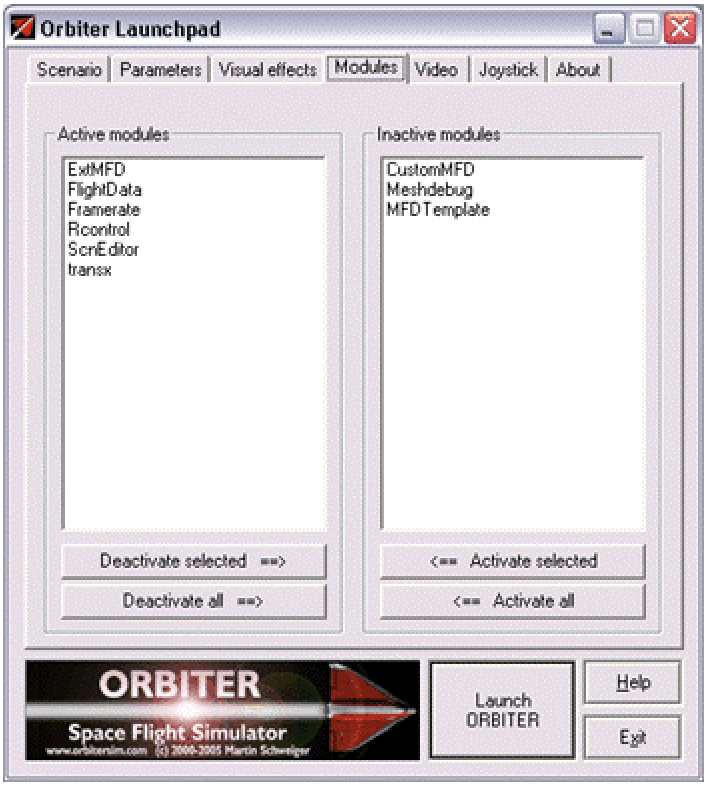


Figure 4: Launchpad dialog, Modules tab

Some of the standard modules distributed with Orbiter are:

ScnEditor: A versatile scenario editor that allows to add, edit and delete spacecraft in a running simulation. See Section 18.1 for more details.

ExtMFD: This module allows to open additional multifunctional displays in external dialog boxes. Useful if you need more information than a vessel's built-in MFD displays provide, or if you want to track flight data in external camera views.

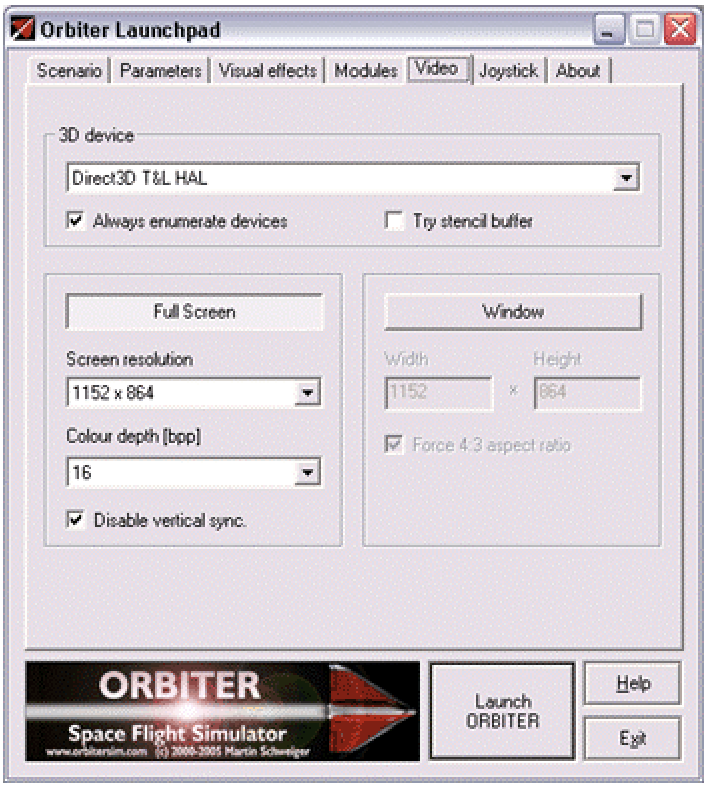
CustomMFD: This module provides an additional "Ascent MFD" mode for the multifunctional displays, which can be selected via Shift P.

Rcontrol: Remote control of ship engines. This allows to manipulate vessels even if they don't have input focus. If this module is active, the remote control window can be selected from the *Custom Functions* list (Ctrl F4).

FlightData: Real-time atmospheric flight data telemetry. If this module is active, the flight data window can be selected from the *Custom Functions* list (Ctrl F4).

Framerate: A graphical simulation frame rate (FPS) display. If this module is active, the frame rate window can be selected from the *Custom Functions* list (Ctrl F4).

3.5 Video tab



3D device: Direct3D T&L HAL
☑ Always enumerate devices
☐ Try stencil buffer
Screen resolution: 1152 x 864
Colour depth [bpp]: 16
☑ Disable vertical sync.
Width: 1152 × Height: 864
☑ Force 4:3 aspect ratio

Figure 5: Launchpad dialog, Video tab

3D Device: Lists the available hardware and software devices for 3D rendering. Select a hardware device when possible, such as Direct3D HAL or Direct3D T&L HAL. Software devices such as RGB Emulation will produce poor performance. Note that some hardware devices do not support window mode.

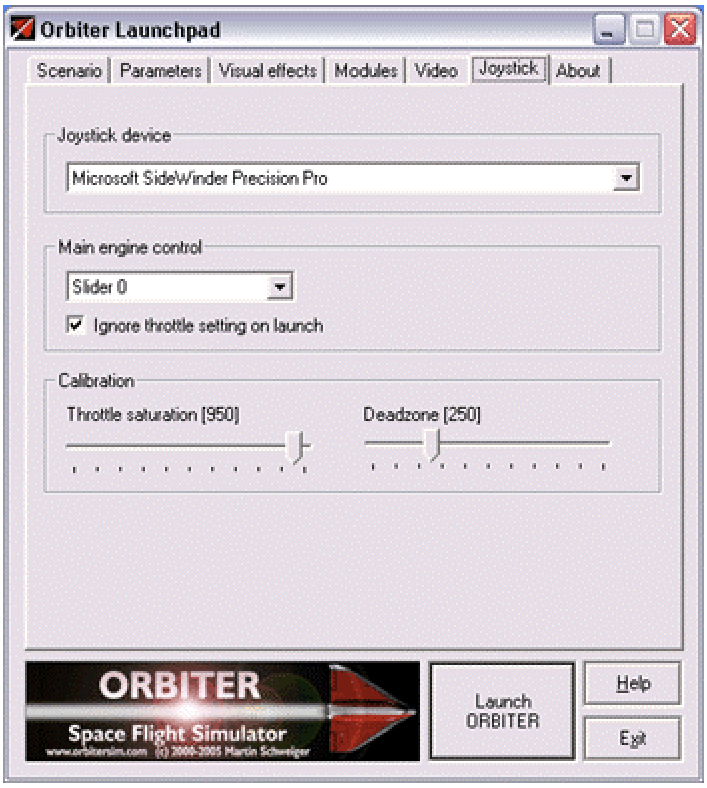
Always enumerate devices: Tick this box if Orbiter does not display 3D devices or screen modes correctly. This option enforces a hardware scan whenever Orbiter is launched and skips the device data stored in device.dat. Make sure to tick this box after upgrading your graphics hardware or DirectX/video drivers to make Orbiter aware of the changes.

Try stencil buffer: Enables stencil buffering, if the video mode supports it. Stencil buffers can improve various visual effects (for example, provide support for alpha-blended shadows), but have a slight impact on frame rates. If the selected video mode doesn't support stencil buffers, this option is ignored.

Full Screen: Select this option to run Orbiter in fullscreen mode. You can choose the screen resolution and colour depth from the lists provided. Only modes supported by the selected device are listed here. Higher resolution and colour depth will improve the visual appearance at the cost of reduced performance.
In addition, you can select the *Disable vertical sync* option. This allows Orbiter to update a frame without waiting for a synchronisation signal from the monitor. This can improve frame rates, but may lead to visual artefacts (tearing).

Window: Select this option to run Orbiter in a window. You can specify the size of the render window here. For best results, use a width:height ratio close to 4:3 (or tick the *Force 4:3 aspect ratio* button to keep the optimal aspect ratio). Large window sizes can reduce simulation performance. Note that some older graphics drivers may not allow 3-D applications to run in window mode.

3.6 Joystick tab



Joystick device: Microsoft SideWinder Precision Pro

Main engine control: Slider 0

☑ Ignore throttle setting on launch

Calibration

Throttle saturation [950]

Deadzone [250]

Figure 6: Launchpad dialog, Joystick tab

Joystick device: Lists all attached joysticks.

Main engine control: Define the joystick axis which controls the main thrusters. Try different options if the throttle control on your joystick doesn't work in Orbiter.

Ignore throttle setting on launch: If ticked, the joystick throttle will be ignored at the launch of a scenario util the user manipulates it. Otherwise, the throttle setting is used immediately.

Deadzone: Use this to define how soon the joystick will respond when moved out of its centre position. Smaller values make it respond sooner. Increase if attitude thrusters do not cut out completely in neutral position.

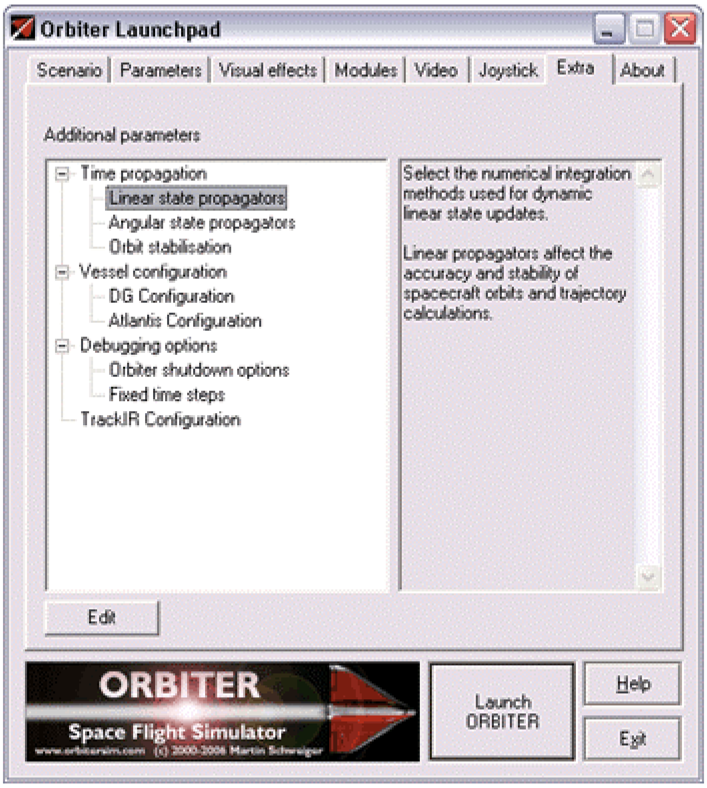
Throttle saturation: Defines the tolerance zone at the minimum and maximum range of the throttle control at which the joystick reports zero and maximum throttle, respectively. Reduce if main engines do not cut out completely at minimum throttle setting. (Applies only to joysticks with throttle control).

If further calibration is required you should use the appropriate tools in the Windows Control Panel.

3.7 Extra tab

NEW!

The *Extra* tab contains a list of more advanced and specialised settings and configuration parameters, including details about Orbiter's dynamic state propagation, vessel configuration and debugging options. Addon plugins may add their own configuration entries to the list when activated.
It is generally safe for new users to leave all settings in this list at their default values. Advanced users can fine-tune the behaviour of the simulator here.



Select the numerical integration methods used for dynamic linear state updates.

Linear propagators affect the accuracy and stability of spacecraft orbits and trajectory calculations.

Figure 7: Launchpad dialog, Extra tab

Click on an item to see a short description of its purpose to the right of the list. Double-clicking, or pressing the *Edit* button opens the associated configuration dialog.

4 Quickstart

This section demonstrates how to take off and land with one of Orbiter's default spacecraft, the Delta-glider. If you are using Orbiter for the first time, this will help to familiarise yourself with some basic concepts of spacecraft and camera control. You should also read the rest of this manual, in particular sections 5 and 7 on keyboard and joystick interface, section 13 on instrumentation, section 14 on spacecraft controls, and section 16 on basic flight maneuvers.

Make sure you have configured Orbiter before launching your first simulation, in particular the video and joystick parameters (see section 3). Once you have started the scenario, you can get the following scenario instructions also on-screen by opening the Help window with Alt F1.

Starting:

- Select the *Checklists|Quickstart* scenario (see Section 3.1 on scenario selection), and press the "Launch ORBITER" button to launch the scenario. Once the mission has been loaded (this can take a few moments), you will see in front of you runway 33 of the SLF (Shuttle Landing Facility) at the Kennedy Space Center, Cape Canaveral, Florida.
- You are in control of a Delta-glider, a powerful futuristic spacecraft, aligned and ready for takeoff.
- You can always exit the simulation by pressing Ctrl Q or Alt F4, or by clicking "Exit" on the main menu (F4). Orbiter saves the current simulation status in the "*(Current status)*" scenario, so you can continue your flight later by selecting this scenario.

Camera modes:

You are in an external camera mode, looking towards your ship.

- You can rotate the camera around your ship by pressing and holding down the Ctrl key and pressing a cursor key (↓↑→←) on the cursor keypad of your keyboard. Alternatively you can press the right button on your mouse and drag the mouse to rotate the camera. Or, if you have a joystick with a direction controller ("coolie hat"), you can use that as well.
- To jump into the cockpit of your glider, press F1. (F1 always toggles between cockpit and external view of the spacecraft you are controlling).
- In the cockpit, you can look around by rotating the camera with Alt ↓↑→←, or with the right mouse button or the joystick coolie hat.
- To look straight ahead, press the Home button.
- To learn more about camera modes and views, have a look at Section 11.

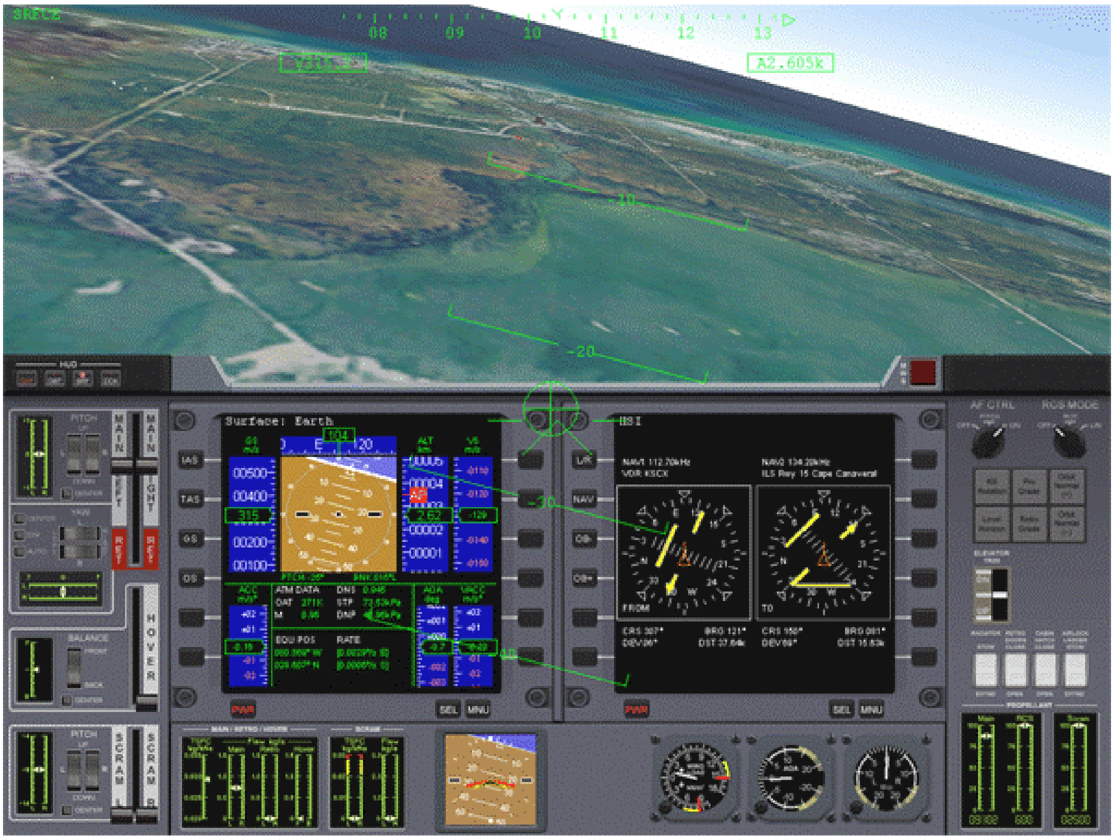
Cockpit modes:

- At the moment, you are in "virtual cockpit" mode - that is, you are inside a three-dimensional representation of the glider cockpit, with the glass pane of the head-up display (HUD) in front of you, and the instruments and controls arranged around you. If you look back, you can even get a glimpse of your passengers in the cabin behind you!
- You can switch to a different cockpit mode by pressing F8. Pressing F8 once will open the "generic" cockpit mode with only the HUD and two onscreen multifunctional displays. Pressing F8 again will open a 2-D panel mode.
- The panel can be scrolled by pressing a cursor key (↓↑→←) on the cursor keypad. To scroll the panel out of the way, press ↑. You should now be able to see the runway stretching in front of you. Scrolling the panel is useful if you want to see more of your surroundings. Also, if the panel is larger than your simulation window, you can scroll different parts of the panel into view.
- Some spacecraft have more than a single panel which can be accessed by pressing Ctrl in combination with a cursor key. If you press Ctrl ↑, you will see the glider's overhead panel with some additional controls. Pressing Ctrl ↓ twice will bring up the lower panel with brake and gear controls. For now, switch back to the main panel with Ctrl ↑.
- Not all spacecraft types support 2-D panels or 3-D virtual cockpits, but the generic cockpit mode is always available.

MFD instruments:

The most important and versatile instruments are the two *multifunctional displays* (MFDs) in the centre of the instrument panel. Each MFD consists of a square LCD screen and buttons along the left, right and bottom edges.

- MFDs can be set to different modes: With the mouse, left-click the “SEL” button at the bottom edge of one of the MFDs. (Alternatively, you can press Shift F1. MFD keyboard interfaces always use Shift key combinations, where the left Shift key controls the left MFD, and the right Shift key controls the right MFD). You will see a list of available modes.
- Click on one of the buttons along the left or right edge to select the corresponding mode. If you click the top-left button, the MFD switches to *Orbit* mode.
- If you want to select a mode via keyboard, press Shift , or Shift . to move the highlight marker (green box) to the desired mode, then press Shift Enter to select the mode.
- Most modes have additional settings and parameters that can be controlled with the buttons as well. The button labels change to indicate the various mode functions. For example, the Orbit mode has a button labeled “TGT”. This can be used to display the orbit of a target object. Click this button – you will see a dialog box to select a target object. Press Enter, type “iss” in the text box, and press Enter again. This will show the orbital parameters of the International Space Station in the MFD display.
- To see a short description of the available mode functions, click the “MNU” button at the bottom of the MFD (Alternatively, use Shift ‘).
- A description of standard MFD modes can be found in Section 13. Orbiter can also be extended with addon MFD modes, so you may see additional modes in the list.
- For now, switch the left MFD to *Surface* mode, and the right MFD to *HSI* mode.

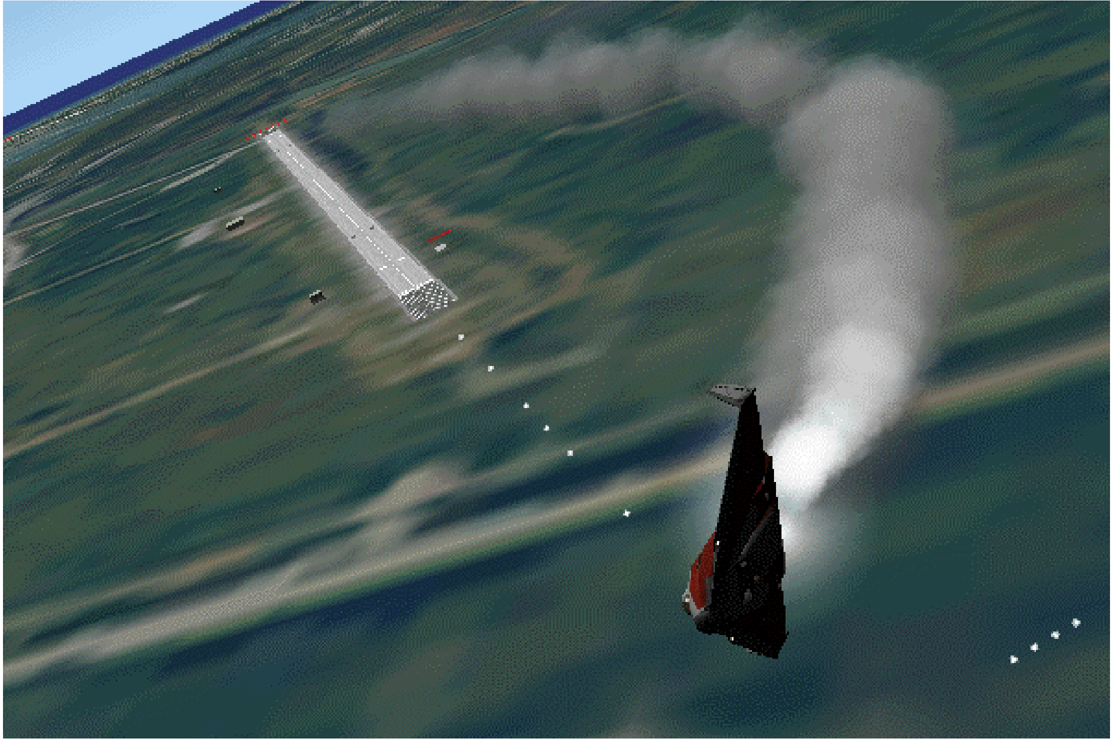


Takeoff:

Your glider is capable of runway takeoffs and landings on Earth (and on any other planet, if the atmospheric density is sufficient to provide aerodynamic lift).

- For takeoff, engage main engines at full thrust. You can do this by pushing the *Main* engine sliders at the left of the panel to the top using the mouse (make sure you push both sliders simultaneously!), or by pressing Ctrl +*Numpad* until engines are at full throttle. If you have a joystick with throttle control, you can use that to engage the main engines.

- Your spacecraft will start to roll. You can check the speed (in meters/second) on the AIRSPD indicator of the Surface MFD, or on the HUD (head-up display) – the value in the green box at the top right of the screen.
- When the airspeed reaches 100 m/s, pull back on the joystick to rotate, or press and hold 2*Numpad*.
- Once clear of the runway, press G to raise the landing gear.



When the atmosphere is too thin to produce enough lift for a runway takeoff (for example when taking off from the Moon) or when no runway is available, you can use the glider's *hover* engines to lift off:

- Move the Hover slider on the instrument panel up by clicking and dragging with the mouse. Alternatively, press the 0*Numpad* key until hover engines are fully engaged.
- Your glider should now lift off vertically. Once clear of the ground, engage main engines. Note that a fully loaded and tanked glider may be too heavy to lift off vertically from Earth when the "realistic" flight model is used.
- As you gain airspeed, you can gradually reduce hover thrust.

Atmospheric flight:

In the lower atmosphere, the glider behaves very much like an aircraft. Try the joystick controls for pitch, roll and yaw to get a feeling for handling at different altitudes. Without a joystick, you can use the numerical keypad (2/8*Numpad* for pitch, 4/6*Numpad* for roll, and 1/3*Numpad* for yaw). The glider has powerful rocket engines, but their performance depends on atmospheric pressure (at very low altitudes, it will not even go supersonic).

This is a good time to try different camera modes. Open the Camera dialog (Ctrl F1), and check the effect of different track modes and field of view (FOV) settings.

Landing:

- Go around and approach runway 33 of the SLF from the south. Line up with the runway. Your HSI instrument helps to maintain the correct approach path and slope. One of its two displays should already be tuned to the runway ILS system. The HSI contains a course pointer, deviation and glideslope indicator. It works like a standard aircraft instrument, so you may already be familiar with its use. If not, check section 13.4 for details.
- As you approach the runway, you will see PAPI and VASI landing aids in front of and beside the runway (see section 16.6). The PAPI is of limited use here, because it is adjusted for the Space Shuttle's steep descent slope of 20°.
- Throttle back and engage airbrakes (Ctrl B) to reduce speed. Lower the landing gear (G).

- After touchdown, engage left and right wheel brakes (, and .) until you come to a full stop.

Space flight:
So far we have treated the glider much like a conventional aircraft. Now it is time to aim a bit higher ...

- Take off as before. Turn east (use the compass ribbon at the top edge of the HUD, or the one in the Surface MFD display), and pitch up to 50°.
- As you gain altitude, you will notice that your craft starts to behave differently, due to the reduction in atmospheric pressure. One of the effects is a loss of lift, which causes the flight path indicator (the ⊕ HUD marker) slowly to drift down. Another effect is the loss of response from your aerodynamic control surfaces.
- At about 30km altitude your glider will start to drop its nose even while you are pulling back on the stick. Now activate the RCS (Reaction Control System) by right-clicking the “RCS Mode” selector (on the right side of the instrument panel) or by pressing Ctrl /*Numpad*. You are now controlling your craft with attitude thrusters.
- Pitch down to about 20°. After leaving the dense part of the atmosphere, you need to gain tangential velocity to achieve orbit. Your flight path indicator should stay above 0°.
- Now is a good time to activate the Orbit mode in one of your MFDs. This shows the shape of your current orbit (the green curve) in relation to the planet surface (the gray circle), together with a list of orbital parameters along the left side of the display. You should switch the display to “current orbital plane” projection mode, by clicking on the “PRJ” button until “Prj: SHP” is shown in the top right corner of the display.
- At the moment, your orbit will be a rather eccentric ellipse, which for the most part is *below* Earth’s surface. This means that you are still on a ballistic trajectory rather than in a stable orbit. As you keep gaining tangential velocity, the orbit will start to expand. Once the green curve is completely above the planet surface (and sufficiently high above the atmosphere) you will have entered orbit.
- At this point, the most important pieces of information from the Orbit display are the orbital velocity (“Vel”) and apoapsis radius (“ApR”). For a low Earth orbit, you need to achieve a velocity of at least 7800 m/s. Once you reach this value, you will see the orbit rising rapidly above Earth’s surface. At the same time, the apoapsis distance (the highest point of the orbit) will start to grow. Keep firing your engines until ApR reaches about 6.670M. This corresponds to an altitude of 300km. Now cut the engines.
- You are now nearly in orbit. All that remains to do is raise the periapsis (the lowest point of the orbit) to a stable altitude. This is done best when you reach apoapsis, which should be half an orbit (or about 45 minutes) from your current position. Time to switch into an external camera mode and enjoy the view!
- It is also a good idea to switch the HUD from surface to orbit mode now. Do this by clicking the “OBT” button in the top left corner of the instrument panel, or by pressing H twice. In this mode, the HUD flight path ladder is aligned with the orbital plane instead of the horizon plane, and there is a ribbon showing your orbital azimuth angle. It also shows indicators for prograde (the direction of your orbital velocity vector) and retrograde (the opposite direction).
- When you approach apoapsis, turn your craft prograde. You can see how close you are to the apoapsis point by checking the ApT (time to apoapsis) value in the Orbit MFD. If it takes too long, press T to engage time acceleration, and R to switch back. To turn prograde, you can activate the RCS manually, but it is easier to leave it to the automatic attitude control, by simply pressing the “Prograde” button on the right of the instrument panel (or [).
- Now fire your main engines for final orbit insertion. The two parameters to watch are the orbit eccentricity (“Ecc”) and periapsis radius (“PeR”). The eccentricity value should get smaller, indicating that the orbit becomes more circular, while the periapsis radius approaches the apoapsis radius (ApR). Once the eccentricity value reaches a minimum, turn the main engines off. You can also deactivate the prograde attitude mode by clicking “Prograde” again.
- Congratulations! You made it into orbit!

Deorbiting:

Should you ever want to come back to Earth, you need to *deorbit*. This means to drop the periapsis point to an altitude where the orbit intersects the dense part of the atmosphere, so that your vessel is slowed down by atmospheric friction.

- Deorbit burns are performed retrograde. Click the “Retrograde” button, wait until the vessel attitude has stabilised, and engage main engines.
- Keep burning until the periapsis point is well below Earth’s surface, then cut the engines. Strictly speaking, the deorbit burn must be timed precisely, because too shallow a reentry angle will cause you to skid off the atmosphere, while too steep an angle will turn you into a shooting star. For now we are not concerned with such fine detail...
- Turn prograde again and wait for your altitude to drop. As you enter the lower part of the atmosphere, friction will cause your velocity to decrease rapidly. Reentries are usually performed with a high angle of attack (AOA) – about 40° for the Space Shuttle.
- Once your aerodynamic control surfaces become responsive again you can turn off the RCS system. Your glider has now turned back into an aircraft.
- You have probably ended up a long way from your launch point at the KSC. Re-entering towards a specified landing point requires some practice in timing the deorbit burn and the reentry flight path. We’ll leave this for a later mission. For now, simply look for a dry patch to land your glider.
- This completes your first orbital excursion!

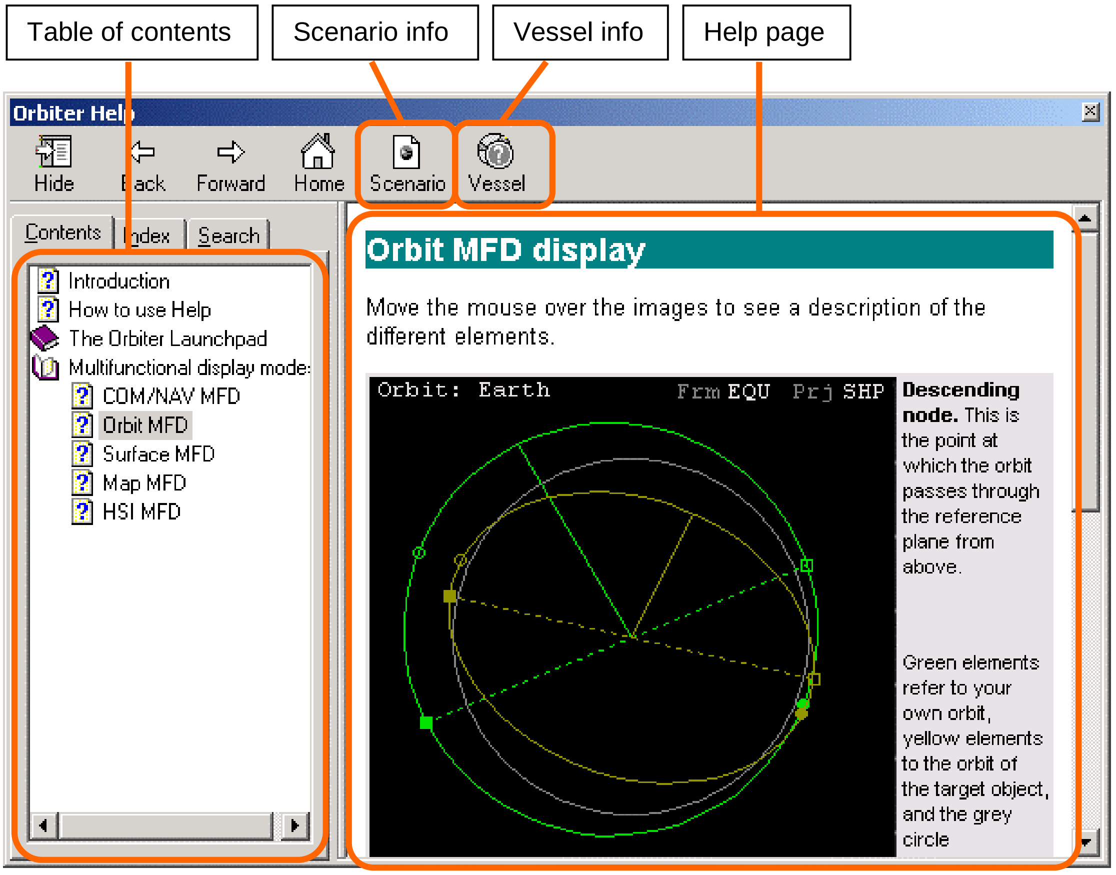
You are now ready to try more advanced missions. Try the “Launch to docking with the ISS” flight described in section 19. First you might want to learn a bit more about orbital maneuvers and docking procedures in section 16.

5 The help system

From the Orbiter launchpad, you can get a description of the different dialog box options by pressing the “Help” button in the bottom right corner.

During the simulation you can open the Orbiter help window by pressing Alt F1, or by selecting “Help” from the main menu (F4).

The help system provides information about MFD modes, and optionally a description of the current scenario or the currently active spacecraft.



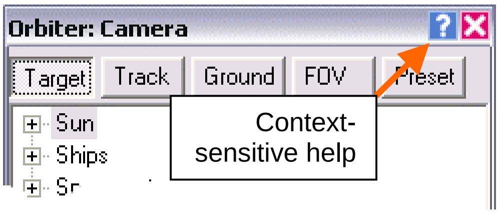
Orbit MFD display

Move the mouse over the images to see a description of the different elements.

Descending node. This is the point at which the orbit passes through the reference plane from above.

Green elements refer to your own orbit, yellow elements to the orbit of the target object, and the grey circle

NEW! Many in-game dialog boxes provide context-sensitive help. To activate the relevant help pages, click the “?” button in the title bar of the dialog box.



The help system is currently still under development. Not all scenarios and vessels currently support context-sensitive help. The system can be extended by adding additional scenario and vessel help pages, and addon developers are encouraged to use the help system to provide user-friendly information about their spacecraft, or to include documented tutorial scenarios that illustrate the features of their plugins.

6 Keyboard interface

This section describes the *default* Orbiter keyboard functions. Please note that the key assignments are customizable by editing the keymap.dat file in the orbiter directory, and that therefore the keyboard controls for your Orbiter installation may be different.

The key assignment reference in this section and the rest of the manual refers to the keyboard layout shown in Figure 8. For other layouts (e.g. language-specific) the key labels may be different. The relevant criterion for key functions in Orbiter is the *position of the key* on the keyboard, not the key label. For example, on the German keyboard, the keys for the "turn orbit-normal" (`;`) and "turn orbit-antinormal" (`'`) will be "Ö" and "Ä".

Keys from the numerical keypad or the cursor keypad will be denoted by subscript, e.g. $+_{Numpad}$ or $\text{Home}_{Cursorpad}$.

Note that certain spacecraft may define additional keyboard functions. Check individual manuals for a detailed description of spacecraft controls and functionality.

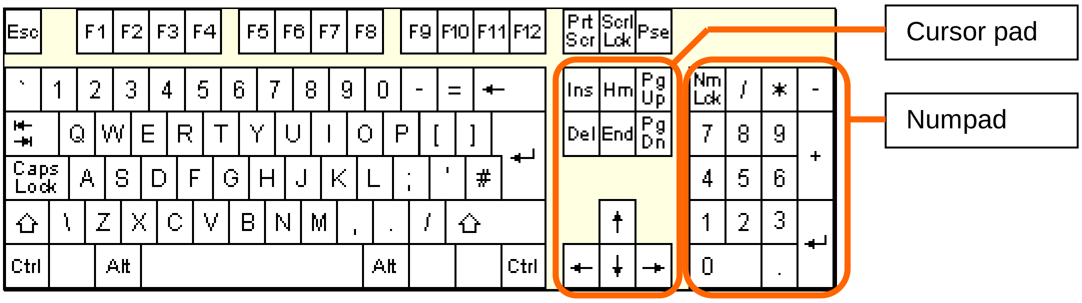


Figure 8: Keyboard layout reference

6.1 General

F	Toggle frame rate info on/off
I	Toggle display of information about current object and camera mode.
R	Time warp shortcut: Slow down simulation by factor 10 (down to real-time). See also Time acceleration dialog (Ctrl F2)
T	Time warp shortcut: Speed up simulation by factor 10 (up to a maximum warp factor of 100000). See also Time acceleration dialog (Ctrl F2)
X	Zoom out (increase field of view). See also Camera dialog (Ctrl F1)
Z	Zoom in (decrease field of view). See also Camera dialog (Ctrl F1)
Ctrl C	Start/stop recording a flight, or stop a flight playback. See also Flight recorder dialog (Ctrl F5)
Ctrl D	Undock from a vessel.
Ctrl P	Pause/resume simulation.
Ctrl Q	Exit to Launchpad dialog.
Ctrl S	Quicksave scenario.
F1	Toggle internal/external view of the user-controlled spacecraft.
Ctrl F1	Open the *Camera* dialog to select camera target, view mode and field of view.
F2	Toggle tracking mode for external camera views (target-relative / absolute direction / global frame).
Ctrl F2	Open the *Time acceleration* dialog. This allows to speed up/slow down the simulation, and to pause/resume.

F3	Open vessel dialog to switch control to a different spacecraft.
Ctrl F3	Switch control back to the previously active vessel. This allows to quickly switch backwards and forwards between two vessels.
F4	Main menu.
Ctrl F4	Open the *Custom functions* dialog. Contains a list of functions defined in plugin modules, if available.
Ctrl F5	Open the *Flight recorder/playback* dialog. Contains recording and playback options.
Ctrl I	Open the *Object Info* dialog for object-specific data such as ILS navaid frequencies etc.
Ctrl M	Open the *Map* dialog (spaceports, navaid locations etc.)
Ctrl N	Open the *Navaid Info* dialog containing a list of navigational radio beacons.
Ctrl F9	Open the *Planetarium options* dialog for controlling the display of grids and markers.
F9	"Planetarium mode": Toggle display of constellations.

6.2 Spacecraft controls

These keys allow manual maneuvering of the user-controlled spacecraft. See also joystick controls. Note some spacecraft may not define all thruster types.

Main/retro thruster controls:

Ctrl + *Numpad*	Accelerate by increasing main thruster setting or by decreasing retro thruster setting.
Ctrl - *Numpad*	Decelerate by decreasing main thruster setting or by increasing retro thruster setting.
* *Numpad*	Kill main and retro thrusters.
+ *Numpad*	Fire main thrusters at 100% while pressed (overrides permanent setting)
- *Numpad*	Fire retro thrusters at 100% while pressed (overrides permanent setting)

Hover thruster controls (where available):

0 *Numpad*	Increase hover thruster setting.
. *Numpad*	Decrease hover thruster setting.

Attitude thruster controls (rotational mode):

4 / 6 *Numpad*	Engage attitude thrusters for rotation around longitudinal axis (bank)
2 / 8 *Numpad*	Engage attitude thrusters for rotation around transversal axis (pitch)
1 / 3 *Numpad*	Rotational mode: Engage attitude thrusters for rotation around vertical axis (yaw)
5 *Numpad*	Toggle "Kill rotation" navigation computer mode. Stops spacecraft rotation by engaging appropriate attitude thrusters

Note: In combination with Ctrl, thrusters are engaged at 10% max. thrust for fine control.

Attitude thruster controls (linear mode):

2 / 8 *Numpad*	Engage attitude thrusters for up/down translation.
1 / 3 *Numpad*	Engage attitude thrusters for left/right translation.

6 / 9 *Numpad*	Engage attitude thrusters for forward/back translation

Note: In combination with Ctrl, thrusters are engaged at 10% max. thrust for fine control.

Other controls:

/ *Numpad*	Toggle reaction control thruster mode between rotational (engage opposite thruster pairs) and linear (engage parallel thruster pairs)
Ctrl / *Numpad*	Enable/disable reaction control system (RCS). The RCS (if available) is a set of small thrusters which allows attitude (rotation) and linear control of the spacecraft.
Alt / *Numpad*	Enable/disable manual user control (via keyboard or joystick) of aerodynamic control surfaces (elevator, rudder, ailerons) if available.
A	Toggle “Hold altitude” navcomp mode. Maintain current altitude above surface by means of hover thrusters only. This will fail if hover thrusters cannot compensate for gravitation, in particular at high bank angles. Combining this mode with the “H-level” mode is therefore useful.
L	Toggle “H-level” navcomp mode. This mode keeps the spacecraft level with the horizon by engaging appropriate attitude thrusters.
[	Toggle “Turn prograde” navcomp mode. This mode turns the spacecraft into its orbital velocity vector.
]	Toggle “Turn retrograde” navcomp mode. This mode turns the spacecraft into its negative orbital velocity vector.
;	Toggle “Turn orbit-normal” navcomp mode. Rotates spacecraft normal to its orbital plane (in the direction of $\vec{R}\times\vec{V}$)
’	Toggle “Turn orbit-antinormal” navcomp mode. Rotates spacecraft antinormal to its orbital plane (in the direction of $-\vec{R}\times\vec{V}$)
Insert / Delete *Cursorpad*	Trim control (only vessels with aerodynamic surfaces)
,	Apply left wheel brake (where applicable)
.	Apply right wheel brake (where applicable)

6.3 External camera views

Page Up	Move camera away from target object.
Page Down	Move camera towards target object.
Ctrl ↑ ↓ → ←	Rotate camera around object.

In ground-based camera views, Ctrl ↑ ↓ → ← will move the observer position, Page Up and Page Down will change the observer altitude, and ↑ ↓ → ← will rotate the observer direction (unless locked to the target).

6.4 Internal (cockpit) view

The two multifunctional displays (MFD) on the left and right side of the screen are controlled via left/right Shift key combinations, where the left Shift key addresses the left MFD, the right shift key addresses the right MFD.
The Head-up display (HUD) and MFDs are visible only in internal cockpit view.

F8	Toggle between generic, 2D panel, and 3D virtual cockpit modes (if supported by the current spacecraft)
Alt ↑ ↓ → ←	Rotate view direction.

	Home	Return to default view direction.
	↑ ↓ → ←	Scroll instrument panel (in 2D panel view).
	Ctrl ↑ ↓ → ←	Switch to neighbour panel, if available (in 2D panel view).
	Ctrl H	Toggle HUD display on/off.
	H	Switch HUD mode.
	Ctrl R	HUD reference selection. Orbit HUD: opens reference selection input box. Docking HUD: steps through available NAV receivers.
	Ctrl Alt R	Docking HUD: Reference selection, bypassing XPDR and IDS transmitters.
NEW!	Shift Esc	Toggle MFD on/off.
	Shift F1	Open a menu for left/right MFD mode selection.
NEW!	Shift , / .	When the MFD mode selection page is open, this moves the selection highlight.
NEW!	Shift Enter	When the MFD mode selection page is open, this selects the highlighted mode.
	Shift ‘	Open/page/close the MFD-specific parameter selection menu.

For control of specific multifunctional display (MFD) modes see Section 13 or the quick reference in Appendix A.

6.5 Menu selections

↑	Move to previous item in the list.
↓	Move to next item in the list.
→	Display sub-list for selected item, if available.
←	Go back to the parent list from a sub-list.
Enter	Select current item and close list.
Esc	Cancel list.

7 Joystick interface

A joystick can be used to operate the attitude and main thrusters of the user-controlled spacecraft manually.

Action	**Effect**
Push stick left or right	Rotate around vessel’s longitudinal axis (bank)
Push stick forward or backward	Rotate around vessel’s transversal axis (pitch)
Operate rudder control *or* Push stick left or right while holding joystick button 2	Rotate around vessel’s vertical axis (yaw)
Operate throttle control	Controls main thruster settings. This is similar to the Ctrl + *Numpad* and Ctrl - *Numpad* keyboard controls, but it affects only the main thrusters, not the retro thrusters.
Direction controller (“coolie hat”)	Cockpit view: rotate view direction
	External view: rotate camera around the observed object
Direction contoller + joystick button 2	Cockpit view: scroll instrument panel (if applicable)
	External view: rotate view direction (ground observer mode only)

8 Mouse interface

Spacecraft instrument panels can be operated by the mouse. Most buttons, switches and dials are activated by pressing the left mouse button. Some elements like multi-way dials may respond to both left and right mouse buttons. In generic cockpit view, the buttons around the two multifunctional displays (MFDs) can be operated with the mouse.

In external camera modes, the *mouse wheel control* (if available) can be used to move the camera towards or away from the view target. The mouse wheel acts like the Page Up and Page Down keys.

The camera direction can be rotated by holding down the right mouse button and dragging the mouse. This works both in external and cockpit views.

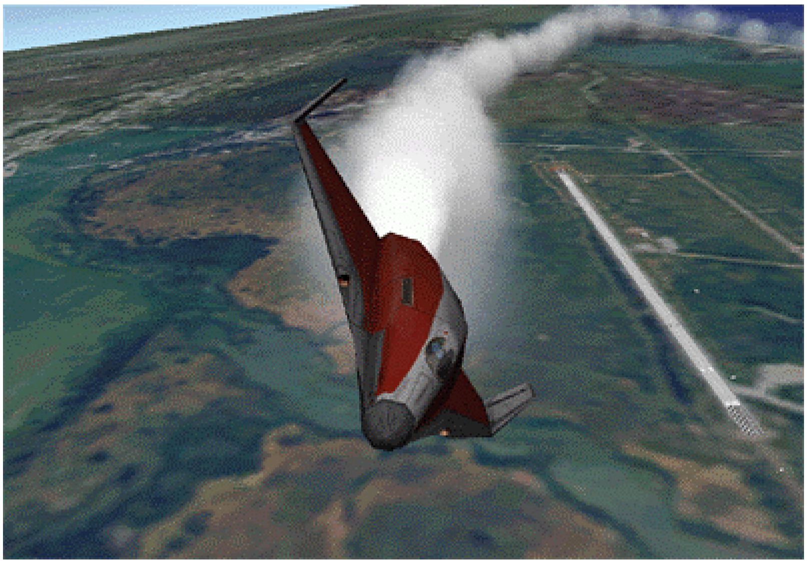
The mouse can of course also be used to select and manipulate dialog controls.

9 Spacecraft classes

The following standard spacecraft types are currently available in the Orbiter standard distribution. Many more can be downloaded as add-ons. See the Orbiter web site for a list of add-on repositories.

9.1 Delta-glider

The Delta-glider is the ideal ship for the novice pilot to get spaceborne. Its futuristic design concept, high thrust and extremely low fuel consumption make it easy to achieve orbit, and it can even be used for interplanetary travel. The winged design provides aircraft-like handling in the lower atmosphere, while the vertically mounted hover-thrusters allow vertical takeoffs and landings independent of atmospheric conditions and runways.



Delta-glider model and textures by Roger "Frying Tiger" Long. Instrument panels by Martin Schweiger.

Two versions are available: The standard DG is equipped with main, retro and hover engines. The scramjet version (DG-S) has in addition two airbreathing scramjet engines fitted, which can be used for supersonic atmospheric flight. The scramjets have an operational airspeed range of Mach 3-8.

The DG supports 2-D instrument panels and a virtual cockpit in addition to the standard "glass cockpit" camera mode.

The glider comes with operating landing gear, nose cone docking port, airlock door, deployable radiator and animated aerodynamic control surfaces. It supports particle exhaust effects.

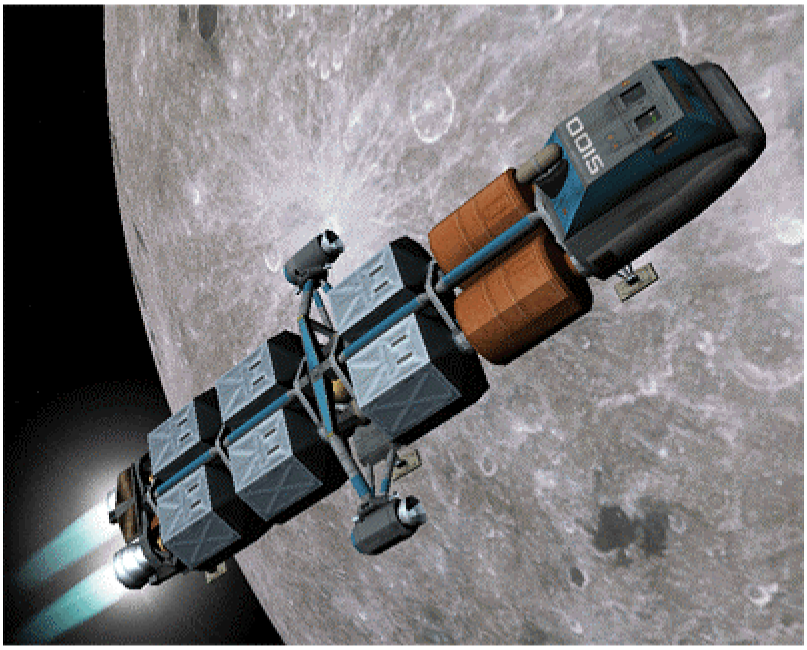
Details on instrumentation, controls, camera modes and technical specifications can be found in the separate document Doc\DeltaGlider.pdf.

→ **see also: Doc\DeltaGlider.pdf**

9.2 Shuttle-A

The all-new Shuttle-A, designed by Roger "Frying Tiger" Long. A medium size freight-vessel, designed preliminary for low gravity/low density environments. The current design allows to achieve LEO from Earth's surface, but you need to plan your ascent carefully not to run out of fuel.

The vessel has a set of two main and two hover thrusters, plus a pair of auxiliary thruster pods which can be rotated 180° for main, hover or retro thrust.

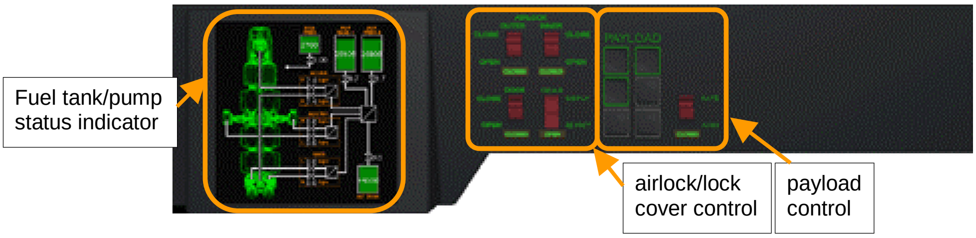


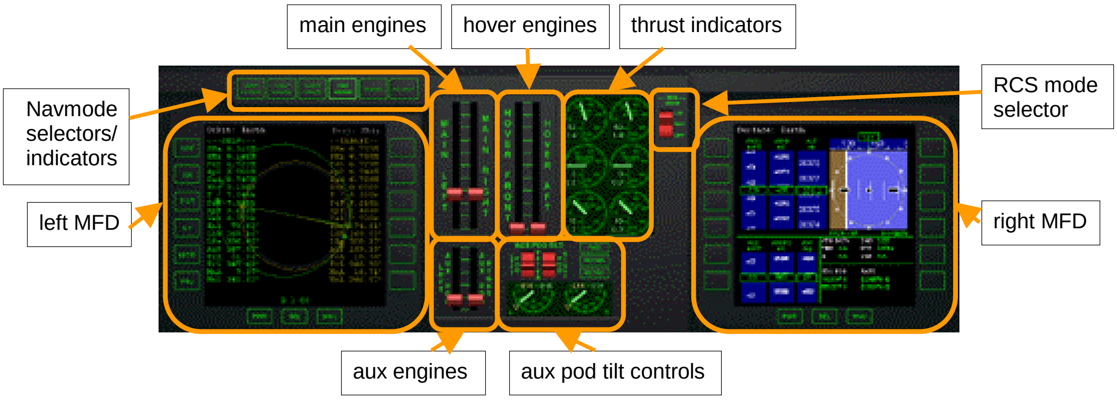
Model design: Roger Long. Instrument panels and module code: Martin Schweiger. Virtual cockpit, payload management extensions: Radu Poenaru.

The Shuttle-A comes with instrument panels. For operational details and technical specifications see the separate Shuttle-A Technical Manual.

The latest version of the Shuttle-A supports a virtual cockpit, detachable cargo pods, and working landing gear, contributed by Radu Poenaru.

Main and overhead instrument panels:
Turn the panels on and off with F8. The Shuttle-A supports two panels which can be selected with Ctrl↓ and Ctrl↑.



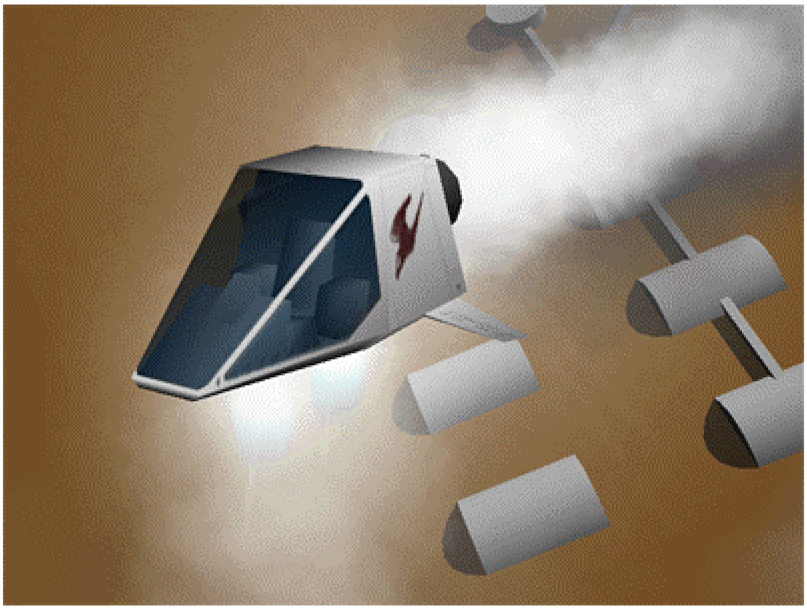


Vessel-specific key controls:

K	Operate docking hatch mechanism
O	Open/close outer airlock door
G	Operate landing gear.

9.3 Shuttle PB (PTV)

The PB is a very agile single-seater. It produces little lift in atmospheric flight, and depends on its hover thrusters for takeoff and landing. Aerodynamic control surfaces are not supported in this version. Attitude control is performed via the RCS (reaction control system).



Overall design and textures: Balázs Patyi. Model improvements: Martin Schweiger

Technical specifications:

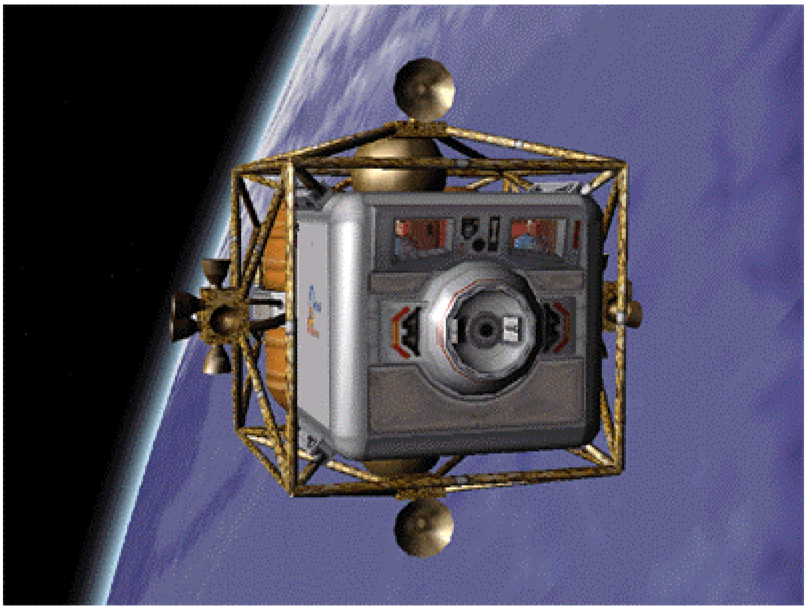
Mass	500 kg	(empty orbiter)
	750 kg	(fuel capacity)
	1250 kg	(total)
Length	7 m	
Thrust	$3.0 \cdot 10^4$ N	(main)
	2 x $0.75 \cdot 10^4$ N	(hover)
Isp	$5.0 \cdot 10^4$ m/s	(fuel-specific impulse in vacuum)

9.4 Dragonfly

The Dragonfly is a space tug designed for moving payload in orbit. It may be used to bring satellites delivered by the Space Shuttle into higher orbits, or to help in the assembly of large orbital structures.

The Dragonfly has no dedicated main thrusters, but a versatile and adjustable reaction control system.

THE DRAGONFLY IS NOT DESIGNED FOR ATMOSPHERIC DESCENT OR SURFACE LANDING!



Dragonfly original design: Martin Schweiger. Model improvements and textures: Roger Long. Systems simulation and instrument panels: Radu Poenaru.

The Dragonfly is the first vessel to be modeled with detailed electrical and environmental systems simulation, contributed by Radu Poenaru. For detailed information see the Dragonfly Operations Handbook.

Technical specifications:

Mass	$7.0\cdot10^3$ kg	(empty)
	$11.0\cdot10^3$ kg	(100% fuel)
Length	14.8 m	
Width	7.2 m	
Height	5.6 m	
Propulsion system		
RCS mounted in 3 pods (left, right, aft) total 16 thrusters		
Thrust rating	1.0 kN	per thruster
Isp	$4.0\cdot10^4$ m/s	(vacuum)

9.5 Space Shuttle Atlantis

Space Shuttle Atlantis represents the only “real” spacecraft in the basic Orbiter distribution (but there are many more available as addons). Its flight characteristics are less forgiving than fictional models like the Delta-glider, and just reaching orbit is a challenge.

The Atlantis orbiter features a working payload bay with remote manipulator system (“Canadarm”), so you can simulate the deployment or even recapture of satellites, or the shipment of resupplies to the International Space Station.

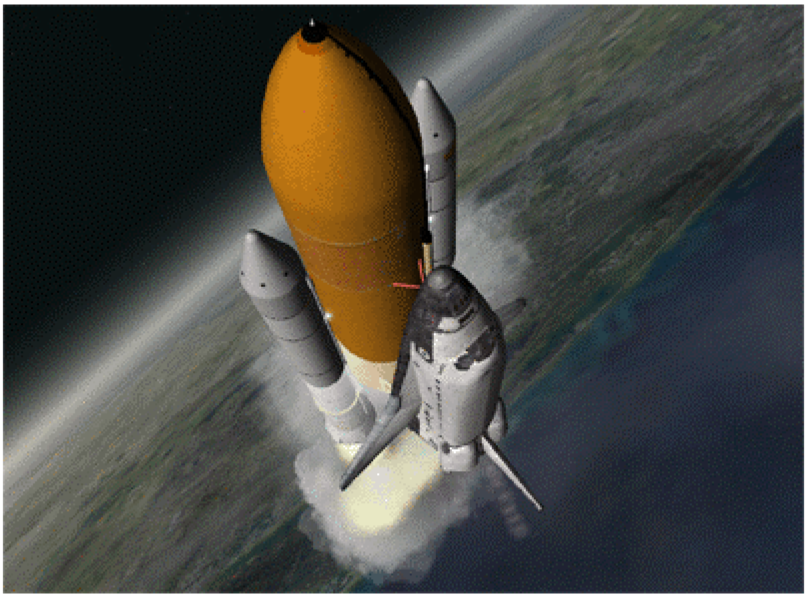
The model now also features a virtual cockpit, with working MFD instruments and head-up display, a working payload bay and remote manipulator arm, as well as MMU support.
Operation procedures and implementation details are provided in separate documents:

→ see also: Doc\Atlantis.pdf
→ see also: Doc\Atlanis_MMU_Sat_30.pdf

Below are a few simplified checklists for launch, docking and payload operation.

Launch:

- Fire main engines at 100%.
- SRBs are ignited automatically when main engines reach 95%. SRBs are not controlled manually. Once ignited, they cannot be shut off.



3D model and textures: Michael Grosberg, Don Gallagher (orbiter) and Damir Gulesich (ET+SRB). Original module code: Martin Schweiger. Original grappling, RMS and MMU extensions: Robert Conley. Module code extensions: David Hopkins and Douglas Beachy.

NEW!

The virtual cockpit from the commander's seat.

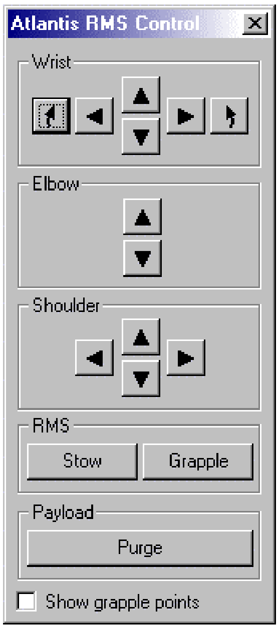
- During launch, attitude is controlled via SRB thrust vectoring. Roll shuttle for required heading, and decrease pitch during ascent for required orbit insertion.
- SRBs separate automatically at T+2:06min. In an emergency, SRBs can be jettisoned manually with J.
- Ascent continues with Orbiter main engines. Throttle down as required for 3g max acceleration.
- Tank separates at T+8:58min (alt 110km) when empty, or manually with J.
- After tank separation, orbiter switches to OMS (orbital maneuvering system) using internal tanks, for final orbit insertion. Attitude thrusters (RCS – reaction control system) are activated.

Docking:

- The orbiter carries a docking attachment in the cargo bay.
- Open cargo bay doors before docking.
- Docking direction is in orbiter's +y direction (up). The Docking MFD must be interpreted accordingly.

RMS manipulation and grappling:

- The shuttle carries a mechanical manipulator arm in the cargo bay which can be used for releasing and recapturing satellites, MMU control, etc.
- The arm can be used in orbit once the cargo doors have been fully opened.



- To bring up the RMS control dialog, press Ctrl+Space.
- The arm has three joints: the shoulder joint can be rotated in yaw and pitch, the elbow joint can be rotated in pitch, and the wrist joint can be rotated in pitch, yaw and roll.
- To grapple a satellite currently stowed in the cargo bay, move the RMS tip onto a grappling point, and press “Grapple”. If grappling was successful, the button label switches to “Release”.
- To make it easier to identify the grappling points of satellites, you can tick the “Show grapple points” box. This marks all grappling points with flashing arrows.
- To release the satellite, press “Release”.
- You can also grapple freely drifting satellites if you move the RMS tip onto a grappling point.
- To return a satellite back to Earth, it must be stowed in the cargo bay. Use the RMS arm to bring the satellite into its correct position in the payload bay. When the Payload “Arrest” button becomes active, the satellite can be fixed in the bay by pressing the button. It is automatically released from the RMS tip.
- The RMS arm can be stowed in its transport position by pressing the RMS “Stow” button. This is only possible as long as no object is attached to the arm.
- Payload can be released directly from the bay by pressing the “Purge” button.

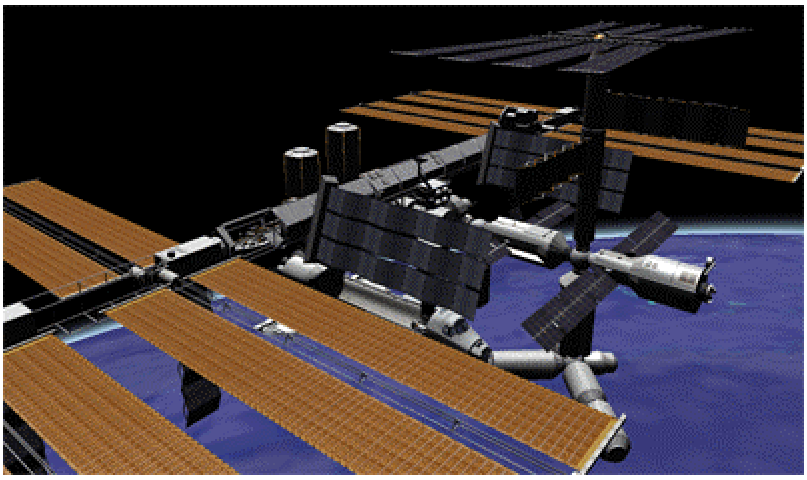
Atlantis-specific key controls:

J	Jettison: separate SRBs or main tank
K	Operate cargo bay doors. The cargo bay doors cannot be closed when the Ku-band antenna is deployed.
G	Operate landing gear (activated only after tank separation)
Ctrl B	Operate split-rudder speed brake.
Ctrl U	Deploy/retract Ku-band antenna. The antenna can only be operated if the cargo bay doors a fully open.
Ctrl+Space	Open RMS control dialog.

Unlike the futuristic spacecraft designs, Atlantis provides only a small margin of error for achieving orbit. Try some of the other ships before attempting to launch the Shuttle. Limited fuel *must* be selected, otherwise Atlantis is too heavy to reach orbit!

9.6 International Space Station (ISS)

The International Space Station is a multinational scientific orbital platform currently under construction (although its fate is now somewhat in doubt after the Columbia disaster).
Orbiter contains the ISS in its completed state. The ISS is a good docking target for Shuttle and other spacecraft missions.



3D model and textures: Project Alpha by Andrew Farnaby

In Orbiter, the ISS can be tracked with its transponder (XPDR) signal, which by default is set to frequency 131.30.

The ISS contains 5 docking ports. In Orbiter, each is equipped with an IDS (Instrument Docking System) transmitter. The default IDS frequencies are:

Port 1	137.40
Port 2	137.30
Port 3	137.20
Port 4	137.10
Port 5	137.00

For docking procedures see Section 16.7.

9.7 Space Station MIR

In Orbiter, the Russian MIR station is still in orbit around Earth and can be used for docking approaches. Furthermore, unlike its real-life counterpart, Orbiter's MIR is orbiting in the plane of the ecliptic, which makes it an ideal platform to launch lunar and interplanetary missions.

MIR model and textures by Jason Benson

MIR sends a transponder (XPDR) signal at default frequency 132.10 which can be used for tracking the station during a rendezvous maneuver.

MIR supports 3 docking ports, with the following IDS transmitter frequencies:

Port 1	135.00
Port 2	135.10
Port 3	135.20

9.8 Lunar Wheel Station

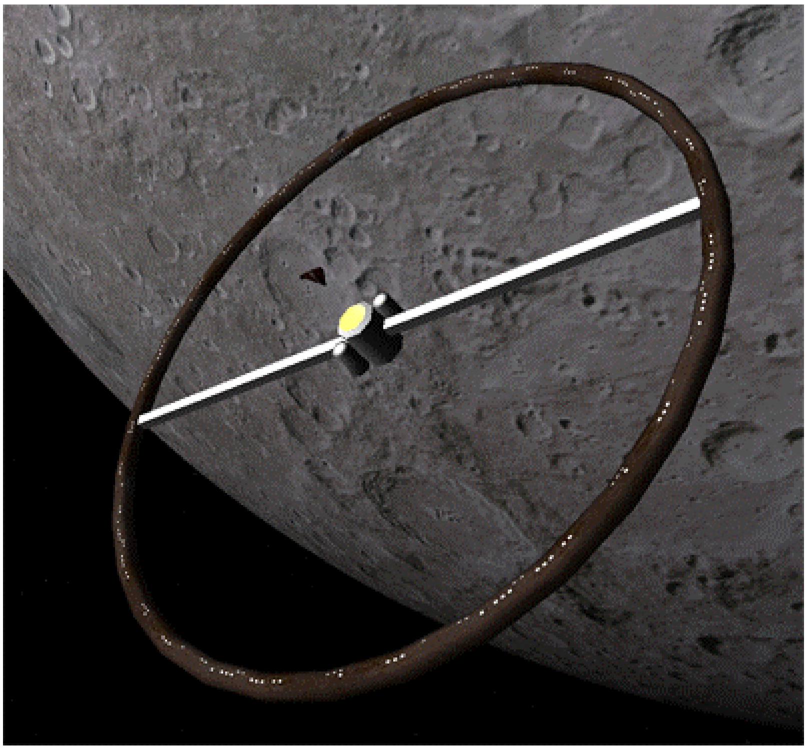
This is a large fictional space station in orbit around the Moon. It consists of a wheel, attached to a central hub with two spokes. The wheel has a diameter of 500 metres and is spinning at a frequency of one cycle per 36 seconds, providing its occupants with a centrifugal acceleration of 7.6 m/s^2, or about 0.8g, to mimic Earth's surface gravitational force.

The main problem the station poses to the spacecraft pilot is in performing a docking maneuver. Docking to a rotating object is only possible along the rotation axis. The wheel has two docking ports in the central hub. The docking approach is performed along the axis of rotation. Before docking, the approaching vessel must synchronise its own longitudinal rotation with that of the station. For docking procedures, see Section 16.7.

Currently, Orbiter's docking instrumentation works on rotating docking targets *only* if the vessel's docking port is aligned with its longitudinal axis of rotation. This is the case for Shuttle-A and Dragonfly, but *not* for the Delta-glider or Space Shuttle.

The wheel station sends a transponder signal at frequency 132.70. The default IDS transmitter frequencies for the two docking ports are

Port 1	136.00
Port 2	136.20



Wheel model and textures: Martin Schweiger

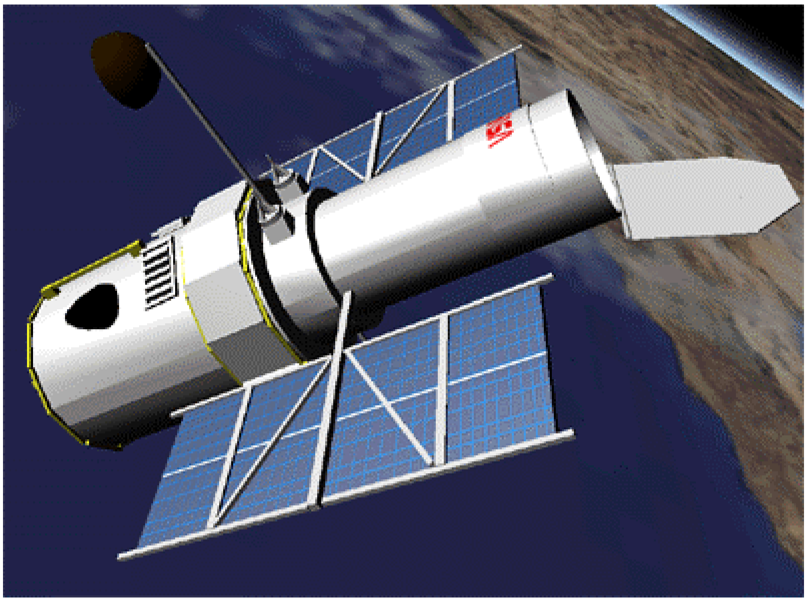
9.9 Hubble Space Telescope

The Hubble Space Telescope is the visible/ultraviolet/near-infrared element of the Great Observatories astronomical program. The spacecraft provides an order of magnitude better resolution than is capable from ground-based telescopes. The objectives of the HST are to: (1) investigate the composition, physical characteristics, and dynamics of celestial bodies; (2) examine the formation, structure, and evolution of stars and galaxies; (3) study the history and evolution of the universe; and (4) provide a long-term space-based research facility for optical astronomy. During initial on-orbit checkout of the Hubble's systems, a flaw in the telescope's main reflective mirror was found that prevented perfect focus of the incoming light. This flaw was caused by the incorrect adjustment of a testing device used in building the mirror. Fortunately, however, Hubble was designed for regular on-orbit maintenance by Shuttle missions. The first servicing mission, STS-61 in December 1993, fully corrected the problem by installing a corrective optics package and upgraded instruments (as well as replacing other satellite components). A second servicing mission, scheduled for March 1997, installed two new instruments in the observatory.

Orbiter provides several Space Shuttle/HST missions for both deployment and recapture operations. For Shuttle payload manipulation, see Section 9.5 above.

HST-specific key controls:

Ctrl 1	Deploy/retract high-gain antennae
Ctrl 2	Open/close telescope tube hatch
Ctrl 3	Deploy/fold solar arrays

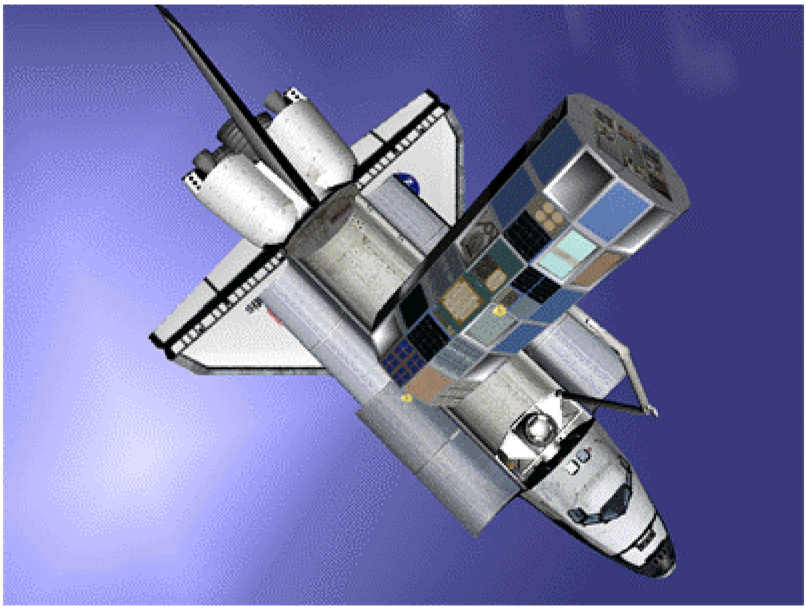


HST model and textures by David Sundstrom

9.10 LDEF Satellite

Long Duration Exposure Facility (LDEF)
Deployed in orbit on April 7, 1984 by Shuttle Challenger and intended for retrieval after one year, the LDEF satellite was stranded in orbit for six years after the Challenger accident. The crew of STS-32 recovered the LDEF from its decaying orbit on January 11, 1990, two months before it would have re-entered the Earth's atmosphere and would have been destroyed.

The LDEF makes a good object for deployment and retrieval missions in Orbiter.



LDEF mesh by Don Gallagher.

10 Object information

Use the object information window to retrieve data and current parameters about

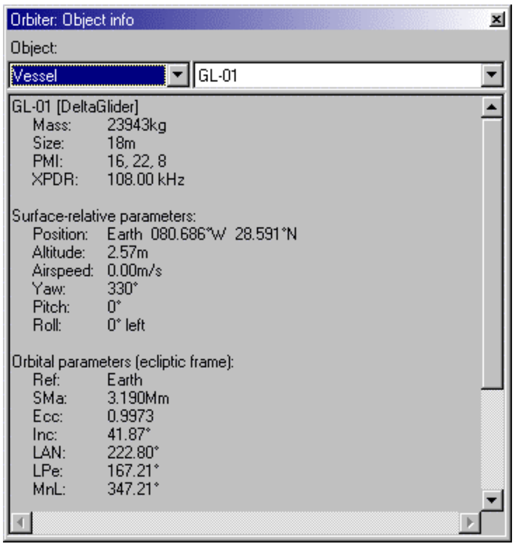
- the current camera target object
- spacecraft
- spaceports
- celestial objects (sun, planets, moons)

The object information window can be opened during the simulation by selecting *Object info* from the main menu, or by pressing Ctrl I.

10.1 Vessel information

Select object type *Vessel*, and pick one of the spacecraft in the current simulation from the list. The information sheet for spacecraft and orbital stations contains:

- current mass
- size
- mass-normalised principal moments of inertia (PMI)
- transponder frequency
- equatorial position (longitude and latitude) above currently orbited planet
- altitude
- ground speed
- attitude relative to local horizon (yaw, pitch, roll angles)
- orbital elements in the ecliptic frame of reference, relative to currently orbited planet (semi-major axis, eccentricity, inclination, longitude of ascending node, longitude of periapsis, mean longitude at epoch)
- docking port status, if applicable (free/docked vessel, instrument docking system [IDS] transmitter frequency)
- time propagation mode (free-flight/landed, dynamic or stabilised time step updates)

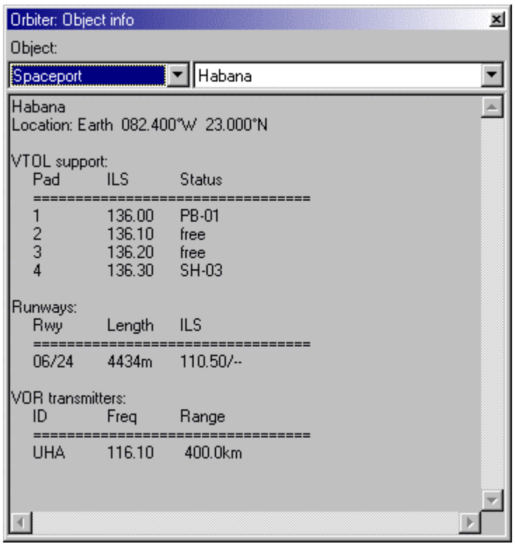


```
GL-01 [DeltaGlider]
   Mass:      23943kg
   Size:      18m
   PMI:       16, 22, 8
   XPDR:      108.00 kHz

Surface-relative parameters:
   Position:  Earth  080.686°W  28.591°N
   Altitude:  2.57m
   Airspeed:  0.00m/s
   Yaw:       330°
   Pitch:     0°
   Roll:      0° left

Orbital parameters (ecliptic frame):
   Ref:       Earth
   SMa:       3.190Mm
   Ecc:       0.9973
   Inc:       41.87°
   LAN:       222.80°
   LPe:       167.21°
   MnL:       347.21°
```

10.2 Spaceport information

Select object type *Spaceport* and pick one of the available surface bases from the list. Spaceport information sheets contain:

- planet/moon and equatorial position
- landing pad status (free/landed vessel, and instrument landing system [ILS] transmitter frequency)
- runway information (runway alignment direction, length, and ILS transmitter frequency)
- frequencies for any VOR (very high frequency omnidirectional radio) transmitters associated with the spaceport.

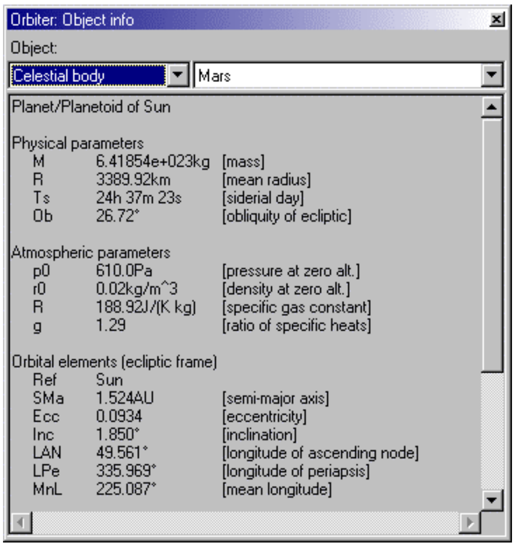


```
Habana
Location: Earth  082.400°W  23.000°N

VTOL support:
   Pad        ILS        Status
   ===================================
   1          136.00     PB-01
   2          136.10     free
   3          136.20     free
   4          136.30     SH-03

Runways:
   Rwy        Length     ILS
   ===================================
   06/24      4434m      110.50/--

VOR transmitters:
   ID         Freq       Range
   ===================================
   UHA        116.10      400.0km
```

10.3 Celestial body information

Select object type *Celestial body* and pick one of the bodies listed. Information sheets for celestial bodies (such as sun, planets and moons) contain:

- physical parameters:
  - mass (M)
  - mean radius (R)
  - length of siderial (“star”) day (Ts)
  - obliquity of ecliptic (Ob) – tilt of axis of rotation against plane of ecliptic
- atmospheric parameters (if applicable):
  - atmospheric pressure at zero altitude (p0)
  - atmospheric density at zero altitude (r0)
  - specific gas constant (R)
  - ratio of specific heats c_p/c_v (g)
- orbital elements in the ecliptic frame of reference, relative to currently orbited body (semi-major axis, eccentricity, inclination, longitude of ascending node, longitude of periapsis, mean longitude at epoch)
- current ecliptic position in polar coordinates (longitude, latitude and radius) relative to currently orbited body.
- geocentric celestial position (right ascension and declination)



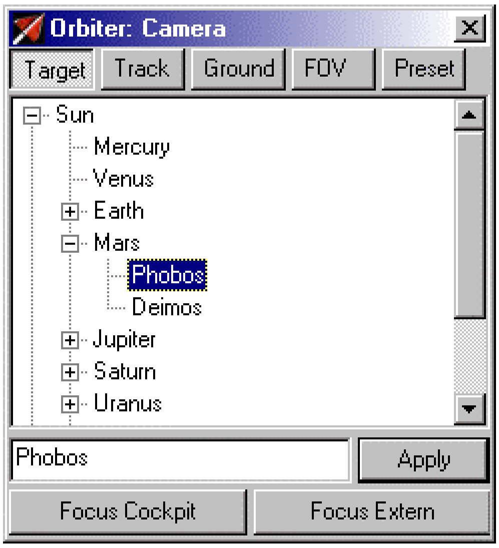
Object: Celestial body | Mars

```
Planet/Planetoid of Sun

Physical parameters
   M        6.41854e+023kg  [mass]
   R        3389.92km       [mean radius]
   Ts       24h 37m 23s     [siderial day]
   Ob       26.72°          [obliquity of ecliptic]

Atmospheric parameters
   p0       610.0Pa         [pressure at zero alt.]
   r0       0.02kg/m^3      [density at zero alt.]
   R        188.92J/(K kg)  [specific gas constant]
   g        1.29            [ratio of specific heats]

Orbital elements (ecliptic frame)
   Ref      Sun
   SMa      1.524AU         [semi-major axis]
   Ecc      0.0934          [eccentricity]
   Inc      1.850°          [inclination]
   LAN      49.561°         [longitude of ascending node]
   LPe      335.969°        [longitude of periapsis]
   MnL      225.087°        [mean longitude]
```

11 Camera modes

Orbiter's solar system contains a variety of objects, including planets, moons, spacecraft and launch sites. You can have a look at any of these by adjusting the camera mode. To open the camera configuration dialog, press Ctrl F1. You can now

- Point the camera to a new target.
- Jump back to the current focus object in external or cockpit view. (Shortcut: F1)
- Select the external camera tracking or ground-based mode. (Shortcut: F2)
- Change the camera field of view (FOV). (Shortcut: Z and X)
- Store and recall camera modes via the preset list.



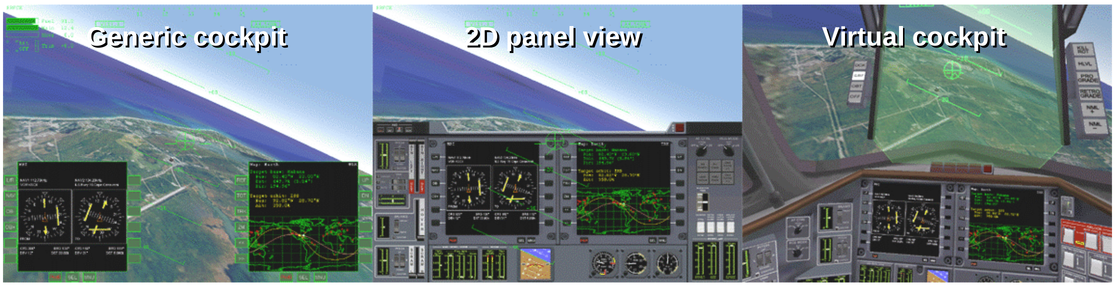
Phobos

Figure 9: Camera dialog – target selection list.

11.1 Internal view

In internal (cockpit) view the player is placed inside the cockpit of his/her spaceship and looks forward. Instrument panels, head-up display (HUD) and multifunctional displays (MFD) are only shown in internal view. To return to cockpit view from any external views, press F1, or select *Focus Cockpit* from the camera dialog.

Some spacecraft types support scrollable 2D instrument panels and/or a 3-dimensional "virtual cockpit", in addition to the generic view. Press F8 to switch between the available cockpit modes.
You can rotate the view direction by pressing the Alt key in combination with a cursor key (↓↑→←) on the cursor keypad. To return to the default view direction, press Home on the cursor keypad.



2D panels can be scrolled with ↓↑→←. This is useful if the panel is larger than the simulation window, or to scroll the panel out of the way.

If a ship supports multiple panels, you can switch between them with Ctrl ↓↑→←.

For details on HUD and MFD modes, see sections 12 and 13.

11.2 External views

External views allow to have a look at any objects currently populating the simulated solar system, including the Sun, planets and moons, spacecraft, orbital stations and surface bases. From cockpit view, an external view of the current spaceship can be selected by pressing F1. Other objects can be selected from the target list in the *Camera* dialog (Ctrl F1).

Two types of external camera modes are available:

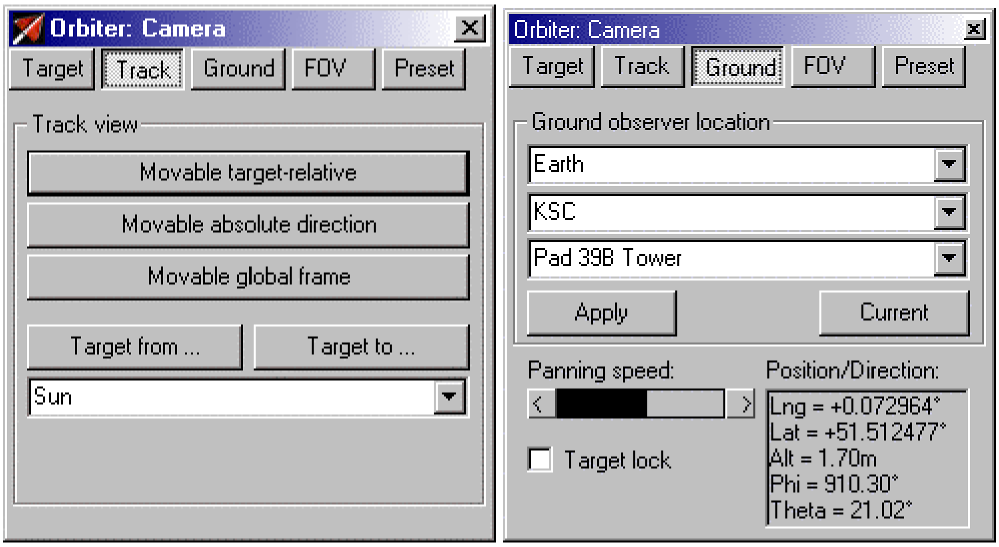
Track views follow the object. The camera can be rotated around the target object by pressing Ctrl ↓ ↑ → ← keys. The Page Up and Page Down keys move the camera towards or away from the target. Different camera panning modes for external views can be selected by pressing F2 or via the *Track* tab in the Camera dialog:

- **Target-relative**: The camera is fixed in the target's local frame of rotation. Looking at a planet in this mode for example will rotate the camera together with the planet around its axis. Ctrl ↓ ↑ → ← will rotate the camera around the target's local axes.
- **Global frame**: The camera is fixed in a non-rotating reference frame. Looking at a planet in this mode will show the planet rotating underneath the camera. Ctrl ↓ ↑ → ← will rotate the camera around the axes of the ecliptic frame of reference.
- **Absolute direction**: This can be regarded as a mixture of the two modes above: The direction into which the camera points is fixed in an absolute frame, but it is tilted with respect to the target's local frame. Ctrl ↓ ↑ → ← will rotate the camera around the target's local axes.
- **Target to** …: Positions camera so that the specified object is behind the target.
- **Target from** …: Positions camera so the specified object is behind the camera.

In *Target to …* and *Target from …* modes camera rotation (Ctrl ↓ ↑ → ←) is deactivated, but radial camera movement with Page Up and Page Down is still available.

Ground-based views place the camera at a fixed point on the surface of a planet. This is a good way to follow the launch of a rocket from a spectator's perspective, or view the final approach of a Shuttle from the control tower. To select a ground-based view, select the *Ground* tab in the Camera dialog. You can now select one of the predefined observer locations from the lists, e.g. "Earth" + "KSC" + "Pad 39 Tower". Alternatively, you can just specify the planet and enter the location by hand, providing longitude (in degrees, positive towards east), latitude (in degrees, positive towards north), and altitude (in metres), e.g. "Earth" + "-80.62 +28.62 15". Click *Apply* to jump to the selected location.
You can also directly use the current camera location in ground observer mode, by clicking "Current". The longitude, latitude and altitude are then entered automatically.
You can move the observer location by pressing Ctrl ↓ ↑ → ←, and the observer altitude by pressing Page Up and Page Down.The speed at which the observer moves can be adjusted with the *Panning speed* slider in the dialog box, in the range from 0.1 to 10^4 m/s.
There are two ways to select the camera orientation: If the *Target lock* box in the dialog is ticked, the camera is always automatically pointing towards the current camera target. If the box is not ticked, the camera direction can be modified manually by pressing ↓ ↑ → ←.

See also Section 22.3 on how to add new observer sites to a planet definition file.



Sun

Earth
KSC
Pad 39B Tower

Lng = +0.072964°
Lat = +51.512477°
Alt = 1.70m
Phi = 910.30°
Theta = 21.02°

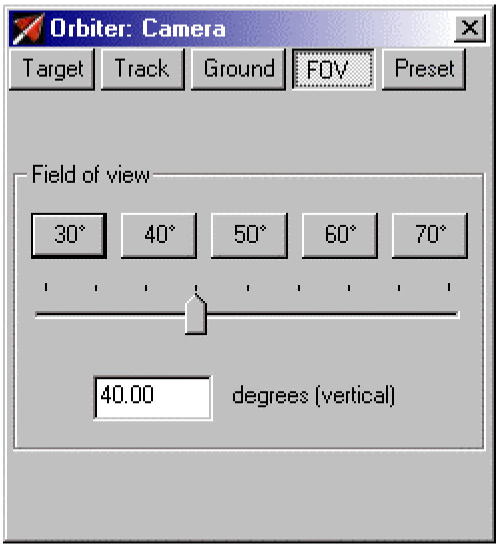
Figure 10: Selecting a track camera mode (left) or a ground-based view (right).

In external views a display of target parameters can be toggled by pressing I.

11.3 Selecting the field of view

The camera aperture can be adjusted under the *FOV* tab in the Camera dialog. The supported range is between 10° and 90° (Orbiter defines the field of view as the vertical aperture, between the top and bottom edge of the simulation window). The most natural aperture depends on the size of the simulation window on your screen, and the distance between your eyes and the screen. Typical values are between 40° and 60°.

You can adjust the field of view by clicking one of the aperture buttons, moving the slider, or entering a numerical value in the edit box.



40.00 degrees (vertical)

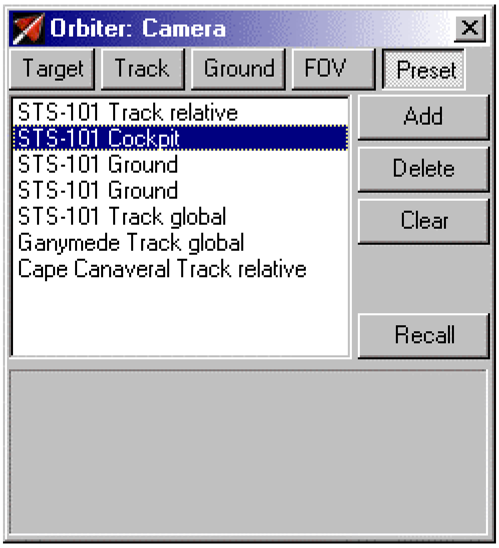
Figure 11: Camera field of view selection.

The keyboard shortcuts are Z to decrease the FOV, and X to increase the FOV. The current field of view is displayed in the status section in the top left corner of the simulation window.

11.4 Storing and recalling camera modes

Orbiter provides an easy method to store and recall camera modes in a preset list. Click on the *Preset* tab in the Camera dialog. Any available modes are listed here. To activate a mode, double-click it in the list, or select the mode and click *Recall*.

To store the current camera mode as a new preset in the list, simply click *Add*. This will produce a new entry with a short description. To delete a mode, click *Delete*, or *Clear* to clear the whole list.



STS-101 Track relative
STS-101 Cockpit
STS-101 Ground
STS-101 Ground
STS-101 Track global
Ganymede Track global
Cape Canaveral Track relative

Figure 12: The camera mode preset list.

Each entry remembers its track mode, position, target and aperture. The preset list is a good way to prepare a set of camera angles beforehand (for example to follow a launch) and then activate them quickly without having to adjust the positions manually. The preset list is stored together with the simulation state, so it can be shared via a scenario file.

12 Generic cockpit view

Generic cockpit mode displays flight information in a standard format and is available for all vessels. Some vessel types may additionally provide customised instrumentation in the form of 2-D panels or 3-D virtual cockpits. In that case, F8 switches between the available modes.

The generic view mode represents a head-up display (HUD) that projects various avionics data displays directly onto the pilot's forward view.

The HUD is switched on/off with Ctrl H. HUD modes can be selected with H. The following modes are available:

- **Surface**: Displays horizon pitch ladder, compass ribbon, altitude and "airspeed".
- **Orbit**: Displays orbital plane pitch ladder, prograde and retrograde velocity markers
- **Docking**: Displays target distance and relative velocity markers.

All HUD modes show engine and fuel status in the top left corner, and general information (time and camera aperture) in the top right corner.

NEW!

Two multifunctional displays (MFDs) can be displayed independent of the HUD mode (see Section 13). Each MFD has up to 12 mode-dependent function buttons along the left and right edges of the display, and 3 standard buttons below the display. The standard buttons are:

- **PWR**: Turns the MFD display on or off. This button is available even if the MFD is deactivated, provided that the HUD is activated.
- **SEL**: Displays the MFD mode selection screen. This allows to activate a different MFD mode. If more than 12 modes are available, use SEL repeatedly to show more modes.
- **MNU**: Displays an onscreen menu for the available function buttons of the current MFD mode, including the associated keyboard shortcuts.

The MFD buttons can be operated either with the mouse, or with keyboard shortcuts.

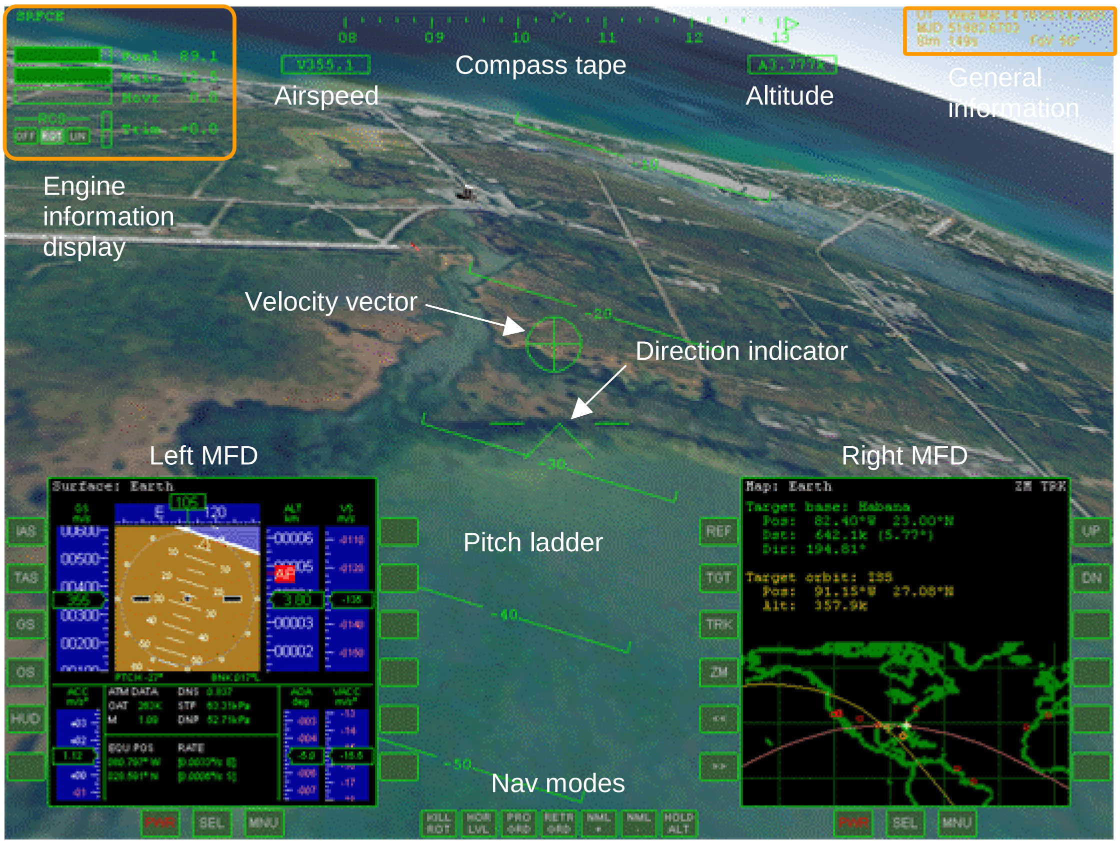
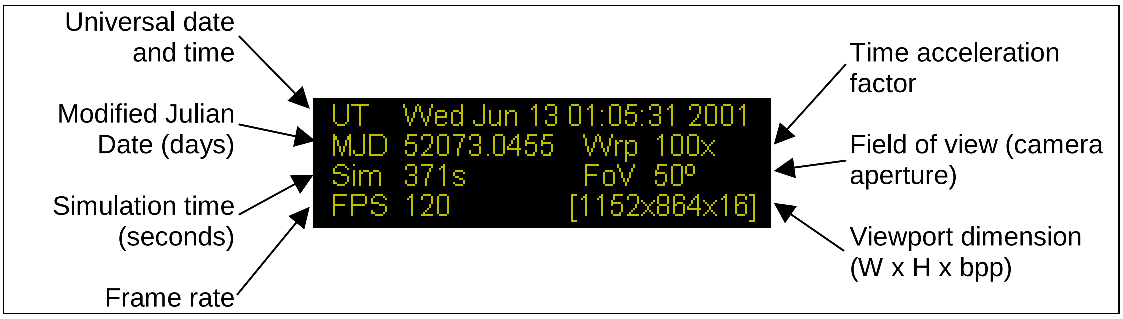


Figure 13: Generic cockpit view with two onscreen MFD displays and HUD in surface mode.

12.1 General information display

A block of data with information about simulation time and speed, frame rate and camera aperture, displayed in the top right corner of the simulation window. This display can be turned on and off with I.


Universal date and time
Modified Julian Date (days)
Simulation time (seconds)
Frame rate
Time acceleration factor
Field of view (camera aperture)
Viewport dimension (W x H x bpp)

```
UT   Wed Jun 13 01:05:31 2001
MJD  52073.0455   Wrp  100x
Sim  371s         FoV  50º
FPS  120        [1152x864x16]
```

Figure 14: General simulation information

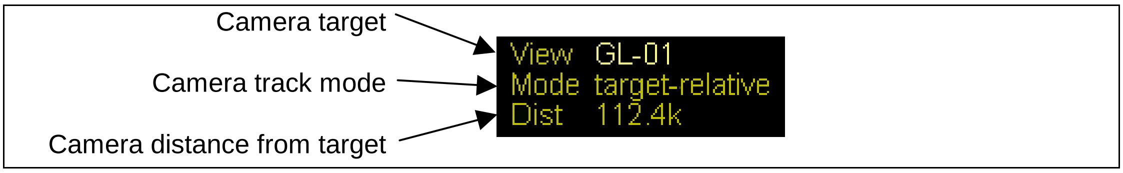
UT: Universal time counted from 0^h at midnight. Unit is mean solar day.
MJD: The *Julian Date* (JD) is the interval of time in mean solar days elapsed since 4713 BC January 1 at Greenwich mean noon. The *Modified Julian Date* (MJD) is the Julian Date minus 240 0000.5
Sim: Simulated time (in seconds) elapsed since the start of the simulation.
Wrp: Time acceleration factor. This field is not displayed for acceleration factor 1 (real time).
FoV: (vertical) field of view, i.e. viewport camera aperture.
FPS: current frame rate (frames per second)
Dim: viewport dimension (width and height in pixels, colour depth in bits per pixel)

The display of frame rate and viewport dimension can be turned on and off with the F key.

NEW! Orbiter provides a date conversion utility (*date.exe*) in the *Utils* subdirectory. The *Scenario Editor* (see Section 18.1) allows to manipulate the date of a running simulation.

12.2 Camera target/mode display

This data block is displayed in external camera modes only, in the top left corner of the simulation window. It contains information about the camera target and track mode. This display can be turned on and off with I.



```
View  GL-01
Mode  target-relative
Dist  112.4k
```

Figure 15: External camera information

View: Name of the current camera target.
Mode: The camera mode used for tracking the target.
Dist: Distance between camera and target.

12.3 Engine information display

The engine information display is only shown in non-panel cockpit views.

Fuel status: Remaining fuel is displayed as percentage of full tanks.
Main engine: The horizontal bar shows current main/retro engine thrust as fraction of max. engine thrust. Green indicates main thrusters, orange indicates retro thrusters. The numerical value shows acceleration in units of m/s^2 (positive for main, negative for retro thrust). Note that the acceleration may change even if the thrust setting doesn't, because the ship's mass changes as fuel is consumed.
Hover engine: If available, hover engines are mounted underneath the ship's fuselage to assist in surface flight, in particular during takeoff/landing. Display analogous to main engine.

NEW!

RCS indicators/controls: The Reaction Control System (RCS) is an assembly of small thrusters arranged on the spacecraft so that they can be used for rotation and fine translational adjustments. The display shows the current mode (off/rotational/translational). The indicator buttons can be clicked with the mouse to change the RCS mode.
Trim setting: Displays the current setting of the trim control (if available). Trimming allows to adjust the flight characteristics during atmospheric flight.

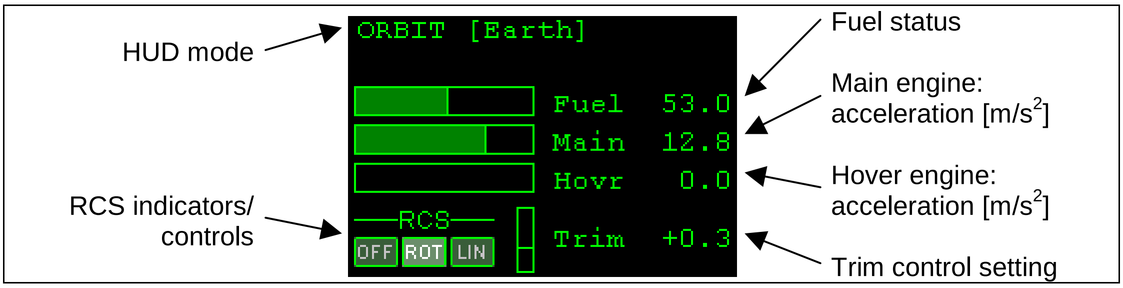


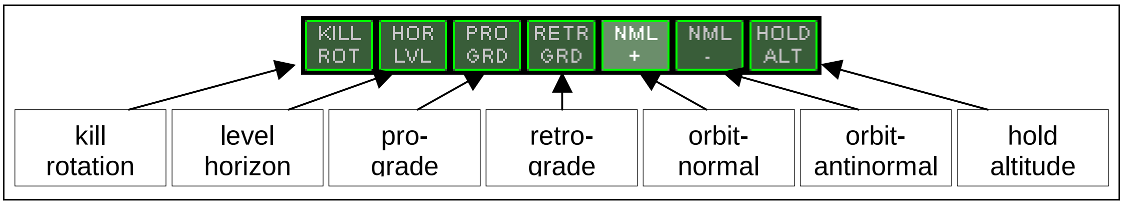
Figure 16: Fuel/engine displays and controls.

For more information about engines and spacecraft control see Section 14.

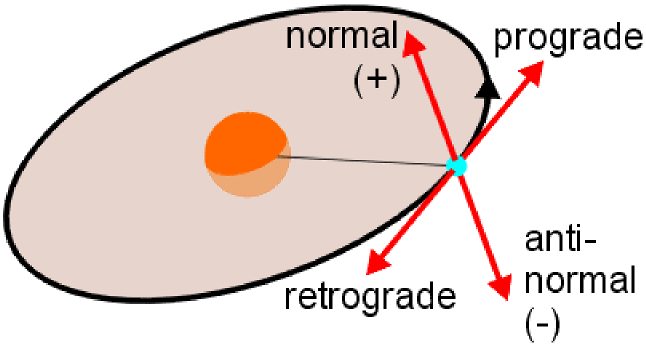
NEW!

12.4 Navigation mode indicators/controls

The navigation mode indicators are shown as a row of buttons at the bottom edge of the generic cockpit view window. They display any active *navigation sequences* such as “prograde orientation” or “kill rotation”. The buttons can be clicked with the mouse to select or deselect modes. Note that some spacecraft types may not support all or any navigation modes.
The navigation mode indicators are not shown if the HUD is deactivated.



mode	**shortcut**	**action**
KILLROT	5 *numpad*	kill any vessel rotation (auto-terminates)
HORLVL	L	keep vessel level with local horizon
PROGRD	[	align vessel with orbital velocity vector
RETRGRD	]	align vessel with negative orbital velocity vector
NML+	;	align vessel with normal of orbital plane
NML-	'	align vessel with negative normal of orbital plane
HOLDALT	A	hold altitude (hover function)



All navigation mode except HOLDALT make use of the RCS. PROGRD, RETRGRD, NML+ and NML- align the vessel into a specific attitude with respect to the orbital velocity vector and orbital plane, while HORLVL aligns with respect to the local horizon.
HOLDALT is only available for vessels that provide hover thrusters.
The KILLROT mode terminates automatically at zero angular velocity. All other modes are persistent and terminate only when deselected or when a conflicting mode is selected.

12.5 Surface HUD mode

Indicated by “SRFCE” in the upper left corner.

This mode displays a pitch ladder which indicates the ship’s orientation w.r.t. the current plane of the horizon. The plane of the horizon is defined by its normal vector, from the planet centre to the spacecraft.
The compass ribbon at the top of the screen indicates the ship’s forward direction w.r.t. geometric north. A marker shows the direction of the current target (spaceport).
The box left below the compass ribbon shows the current altitude [m]. The box right below the compass ribbon shows the current “airspeed” [m/s] (even if there is no atmosphere).
The surface-relative velocity vector direction is marked by “⊕”.

12.6 Orbit HUD mode

Indicated by “ORBIT *Ref*” in the upper left corner, where *Ref* is the name of the reference object.
This mode displays a pitch ladder relative to the current orbital plane, where the “0” line indicates the orbital plane. It also marks the direction of the orbital velocity vector (prograde direction) by “⊕ “ and retrograde direction by “+”. If neither the prograde nor retrograde direction is visible, then the direction of the ⊕ marker is indicated by a pointer labeled “PG” (prograde).
The reference object for the HUD can be manually selected by pressing Ctrl R.

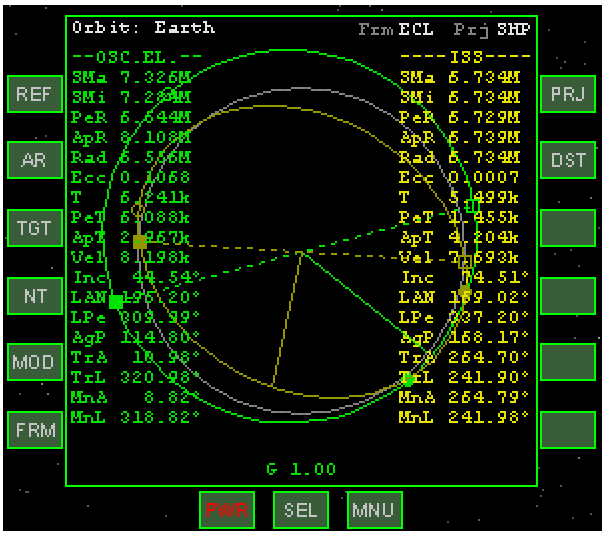
12.7 Docking HUD mode

Indicated by “DOCK *Tgt*” in the upper left corner, where *Tgt* is the name of the target station.
This mode marks the current docking target (orbital station) with a square marker, and displays its name and distance. It also shows the direction and magnitude of the target-relative velocity vector. The velocity of the target relative to the ship is indicated by “⊕ “. This is the direction in which you need to accelerate to synchronise your speed with the target. The opposite direction (the velocity of the ship relative to the target) is indicated by “+”. If neither ⊕ nor + are visible, then the direction of the ⊕ marker is indicated by a pointer. Similarly, if the target marker is offscreen, its direction is indicated by a pointer.
The target station for the HUD can be manually selected by pressing Ctrl R.

13 Multifunctional display modes

NEW!

Multifunctional displays (or MFDs) are used in the cockpits of most military aircraft and modern airliners. They combine the function of a variety of traditional instruments in a compact format, and in combination with computerised avionics data processing present the pilot with situation-dependent relevant data.
In space flight, providing the pilot with information appropriate to the current flight regime is even more critical, and the Space Shuttle makes extensive use of MFD displays. Orbiter uses the MFD paradigm in a general and extendable way to provide flight data independent of vessel type.



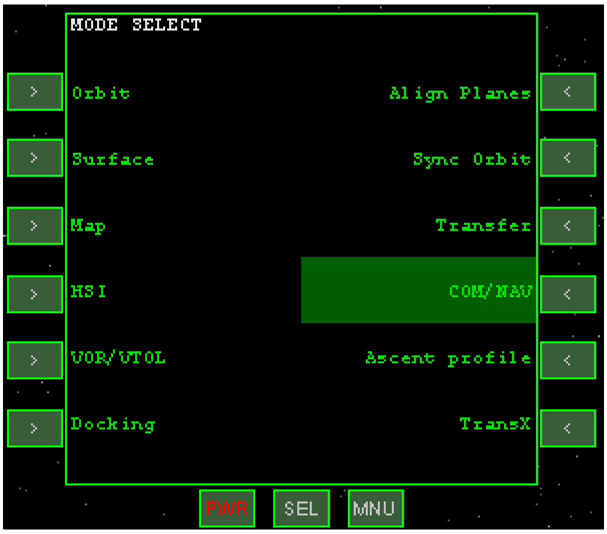
```
Orbit: Earth                  Frm ECL  Prj SHP
--OSC.EL.--                   ----ISS----
SMa 7.326M                    SMa 6.734M
SMi 7.284M                    SMi 6.734M
PeR 6.544M                    PeR 6.729M
ApR 8.108M                    ApR 6.739M
Rad 6.556M                    Rad 6.734M
Ecc 0.1068                    Ecc 0.0007
T   6.241k                    T   5.499k
PeT 6.088k                    PeT 1.455k
ApT 2.967k                    ApT 4.204k
Vel 8.198k                    Vel 7.693k
Inc  44.54°                   Inc  74.51°
LAN 195.20°                   LAN 169.02°
LPe 309.99°                   LPe 337.20°
AgP 114.80°                   AgP 168.17°
TrA  10.98°                   TrA 264.70°
TrL 320.98°                   TrL 241.90°
MnA   8.82°                   MnA 264.79°
MnL 318.82°                   MnL 241.98°
               G 1.00
```

An MFD is essentially a square computer display (e.g an LCD screen) and a set of input controls (usually push buttons arranged around the screen). The specific layout can vary, but the functionality is the same. The picture shows the MFD representation for the generic cockpit view mode which is available for all vessel types. Up to two MFDs can be displayed in this mode. Vessels which support customised 2-D instrument panels or 3-D virtual cockpits may use a different number of MFD screens. In generic mode, the displays are superimposed directly onto the 3-D scenery, representing for example a projection onto the pane of a HUD display in front of the pilot.

In the centre of the MFD is the data display. The 12 buttons along the left and right edge are mode-dependent function buttons. Their labels may change according to the current operation modus of the instrument. The three buttons along the bottom edge are static and mode-independent.

The MFDs can be operated either by left-clicking with the mouse on the buttons, or via the keyboard. All MFD keyboard functions are Shift-key combinations, where the left and right Shift keys operate the left and right MFD, respectively. For instrument panels with more than two MFD displays, only two can be operated with the keyboard; the others are limited to mouse control.

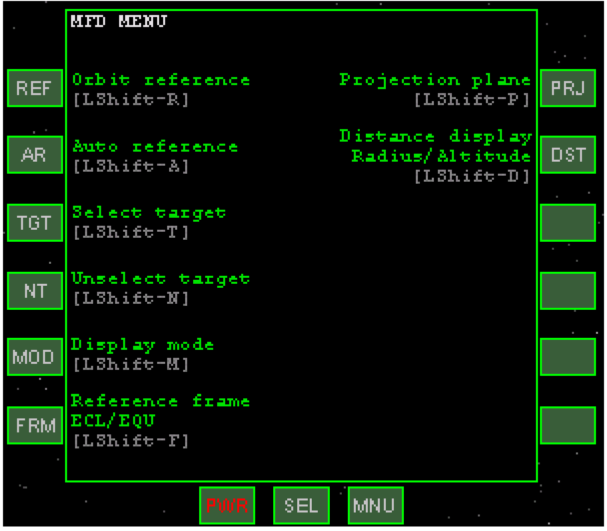
Turning the MFD on and off
The *PWR* button activates and deactivates the MFD display. Keyboard shortcut is Shift Esc. In generic view mode, turning off the MFD also hides the buttons (except the power button, so it can be turned on again).



Mode selection
The *SEL* button activates the mode selection screen. Keyboard shortcut is Shift F1. Each MFD mode provides information for a different navigation or avionics problem (orbital parameters, surface parameters, docking and landing aids, etc.) For a full list of default modes see the following sections in this chapter. Many additional modes are available via3rdparty addons.
The display shows the available modes in the display area, one mode next to

each function button. To select a mode, simply click the corresponding button. For selection with the keyboard, press the Shift key together with the mode selection key displayed in grey with each of the listed modes (for example, Shift O for Orbit mode).
If there are more modes than can be displayed in a single page, pressing *SEL* (or Shift F1) repeatedly will page through all mode screens. Pressing *SEL* on the last mode screen will return to the previously selected MFD mode. Note that the mode selection with keyboard shortcuts works from any of the mode selection pages, even if the desired mode is not displayed on the current page.

Function buttons
The function of the buttons to the left and right of the display depends on the current MFD mode, and their labels will change accordingly. Check the descriptions of the individual MFD modes in the following sections for the button functions of standard MFD modes. For addon modes, consult the accompanying documentation. In some cases the buttons may act as switches, where each press executes a specific function. In other cases it may be necessary to press down a key continuously to adjust a parameter.
Function buttons can also be activated with Shift-key combinations. Pressing the *MNU* button on the bottom edge of the screen will switch into menu mode (keyboard shortcut is Shift ‘), where a short description of each function button is displayed, together with the associated keyboard key. Pressing *MNU* again (or pressing a function button) will restore the display.
In generic view mode, and in most instrument panels in Orbiter the MFDs have 12 function buttons, but in principle this could vary. If an MFD mode has defines more functions than can be assigned to the buttons, then pressing *MNU* repeatedly will page through the available sets of functions.


MFD MENU

Orbit reference
[LShift-R]

Auto reference
[LShift-A]

Select target
[LShift-T]

Unselect target
[LShift-N]

Display mode
[LShift-M]

Reference frame
ECL/EQU
[LShift-F]

Projection plane
[LShift-P]

Distance display
Radius/Altitude
[LShift-D]

Below is a description of the standard MFD modes provided by Orbiter. See also the Quick MFD reference in Appendix A.

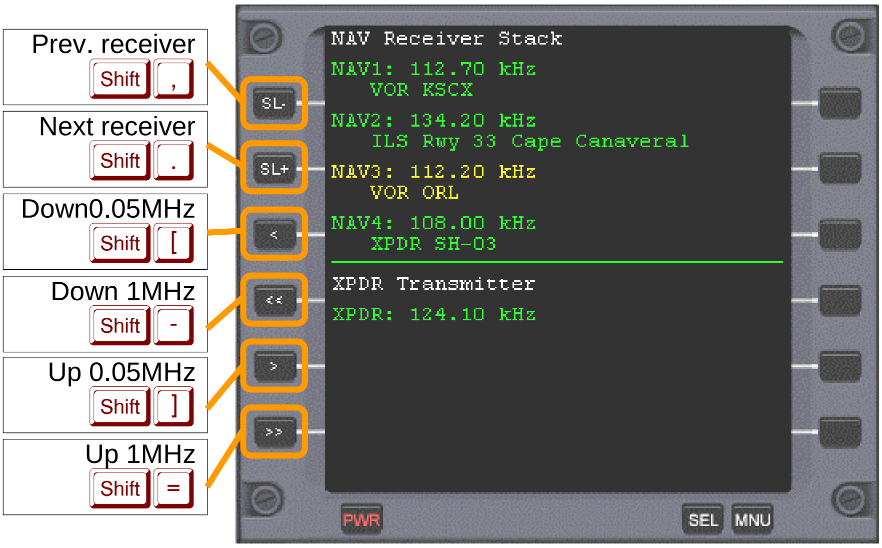
13.1 COM/NAV receiver setup

The *COM/NAV setup* MFD mode provides an interface to the ship’s navigation radio receivers which feed data to the navigation instruments. It also allows to select the frequency of the ship’s transponder which sends a signal to identify the vessel. The mode is activated via the *COM/NAV* entry from the MFD mode selection page (Shift F1).
The MFD lists frequency and signal source information for all NAV radios (NAV1 to NAV*n*). The number of receivers (*n*) depends on the vessel class. A NAV receiver can be selected from the list by Shift , and Shift . . The selected receiver is highlighted in yellow (see below).

Key options:

Shift ,	Select previous NAV receiver
Shift .	Select next NAV receiver
Shift -	Step down frequency 1 MHz.
Shift =	Step up frequency 1 MHz
Shift [	Step down frequency 0.05 MHz
Shift]	Step up frequency 0.05 MHz

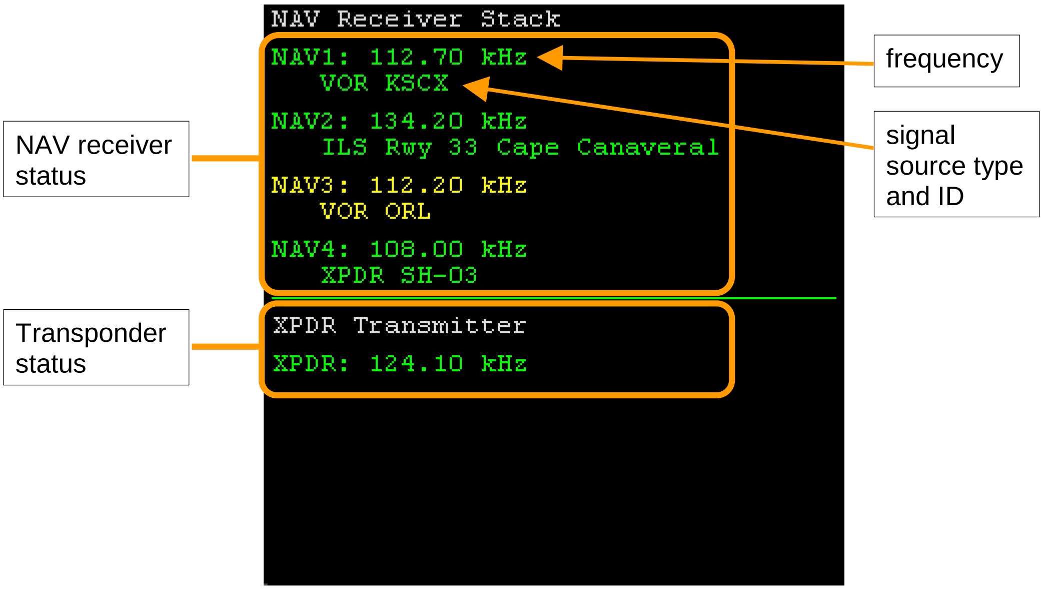
MFD control layout:



```
NAV Receiver Stack
NAV1: 112.70 kHz
   VOR KSCX
NAV2: 134.20 kHz
   ILS Rwy 33 Cape Canaveral
NAV3: 112.20 kHz
   VOR ORL
NAV4: 108.00 kHz
   XPDR SH-03
XPDR Transmitter
XPDR: 124.10 kHz
```

MFD display components:

The display is divided into two sections: The NAV receiver stack, listing the frequency and signal status of the ship's navigation radio receivers, and the Transponder status, showing the frequency of the ship's transponder.

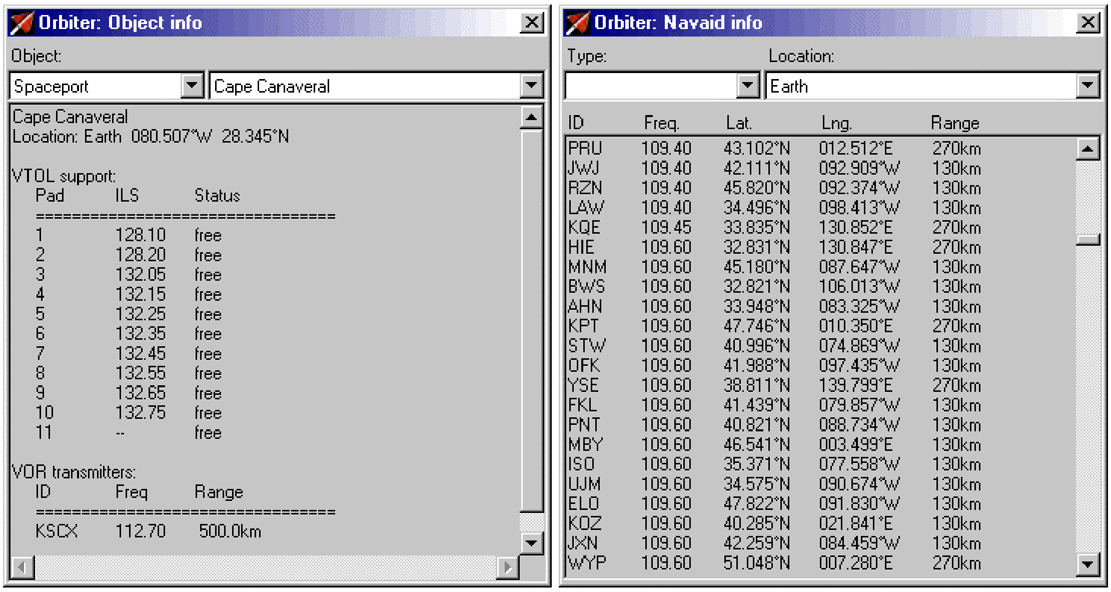


```
NAV Receiver Stack
NAV1: 112.70 kHz
   VOR KSCX
NAV2: 134.20 kHz
   ILS Rwy 33 Cape Canaveral
NAV3: 112.20 kHz
   VOR ORL
NAV4: 108.00 kHz
   XPDR SH-03
XPDR Transmitter
XPDR: 124.10 kHz
```

The frequency of the selected receiver/transmitter can be tuned in steps of 1MHz with Shift - and Shift =, and in steps of 0.05MHz with Shift [and Shift], in the range from 85.00MHz to 140.00MHz. If a compatible NAV transmitter is within range, the instrument displays information about the signal source.

Notes:

- Certain instruments such as the Launch/Land MFD mode are slaved to a NAV receiver, and will only work if a suitable signal is available. This behaviour differs from earlier Orbiter versions, where the data reference was obtained automatically.
- The *Object Info* (Ctrl I) and *Navaid Info* dialogs (Ctrl N) are a useful tools to obtain frequencies for navaid transmitters such as VOR and ILS beacons or vessel transponders.
- The positions and frequencies of VOR stations in your vicinity can also be displayed directly in the simulation window via the *VOR Markers* option of the *Visual helpers* dialog box (Ctrl F9).



Object: Spaceport | Cape Canaveral

```
Cape Canaveral
Location: Earth  080.507°W  28.345°N

VTOL support:
   Pad       ILS       Status
   ==================================
   1         128.10    free
   2         128.20    free
   3         132.05    free
   4         132.15    free
   5         132.25    free
   6         132.35    free
   7         132.45    free
   8         132.55    free
   9         132.65    free
   10        132.75    free
   11        --        free

VOR transmitters:
   ID        Freq      Range
   ==================================
   KSCX      112.70     500.0km
```

Type: | Location: Earth

ID	Freq.	Lat.	Lng.	Range
PRU	109.40	43.102°N	012.512°E	270km
JWJ	109.40	42.111°N	092.909°W	130km
RZN	109.40	45.820°N	092.374°W	130km
LAW	109.40	34.496°N	098.413°W	130km
KQE	109.45	33.835°N	130.852°E	270km
HIE	109.60	32.831°N	130.847°E	270km
MNM	109.60	45.180°N	087.647°W	130km
BWS	109.60	32.821°N	106.013°W	130km
AHN	109.60	33.948°N	083.325°W	130km
KPT	109.60	47.746°N	010.350°E	270km
STW	109.60	40.996°N	074.869°W	130km
OFK	109.60	41.988°N	097.435°W	130km
YSE	109.60	38.811°N	139.799°E	270km
FKL	109.60	41.439°N	079.857°W	130km
PNT	109.60	40.821°N	088.734°W	130km
MBY	109.60	46.541°N	003.499°E	130km
ISO	109.60	35.371°N	077.558°W	130km
UJM	109.60	34.575°N	090.674°W	130km
ELO	109.60	47.822°N	091.830°W	130km
KOZ	109.60	40.285°N	021.841°E	130km
JXN	109.60	42.259°N	084.459°W	130km
WYP	109.60	51.048°N	007.280°E	270km

Figure 17: Info and Navaid dialogs with VOR and ILS frequencies.

13.2 Orbit

The *Orbit* MFD mode displays a list of elements and parameters which characterise the ship's orbit around a central body, as well as a graphical representation. In addition, a target object (ship, orbital station or moon) orbiting the same central body can be selected, whose orbital track and parameters will then be displayed as well. The mode is activated via the *Orbit* entry from the MFD mode selection page (Shift F1).

The display shows the *osculating orbits* at the current epoch, i.e. the 2-body orbit corresponding to the vessel's current state vectors, with respect to a given celestial body. The orbital parameters may change with time due to the influence of perturbing effects (additional gravity sources, distortions of the gravitational field due to nonspherical planet shape, atmospheric drag, thruster action, etc.)

The orbital elements can be displayed with respect to one of two frames of reference: *ecliptic* or *equatorial*. The plane of the ecliptic is defined by the Earth's orbital plane, and is useful for interplanetary flights, because most planets orbit close to the ecliptic. The equatorial plane is defined by the equator of the current reference object, and is useful for low orbital and surface-to-orbit operations. Use Shift F to switch between the two frames of reference. The current mode is displayed in the top line of the display (Frm).

The plane into which the graphical orbit displays are projected can be selected via Shift P. The current projection plane is indicated in the top right corner of the instrument (Prj). *ECL* or *EQU* project into the plane of the ecliptic or equator, respectively. *SHP* projects into the vessel's current orbital plane, and *TGT* projects into the target's current orbital plane, if a target is specified.

The length of the current radius vector, and the apoapsis and periapsis distances can be displayed in two modes:

- planetocentric distance (distance from orbit focus), indicated by Rad, ApR, PeR, respectively
- altitude above planet mean radius, indicated by Alt, ApA, PeA, respectively.

Use Shift D to switch between the two modes.

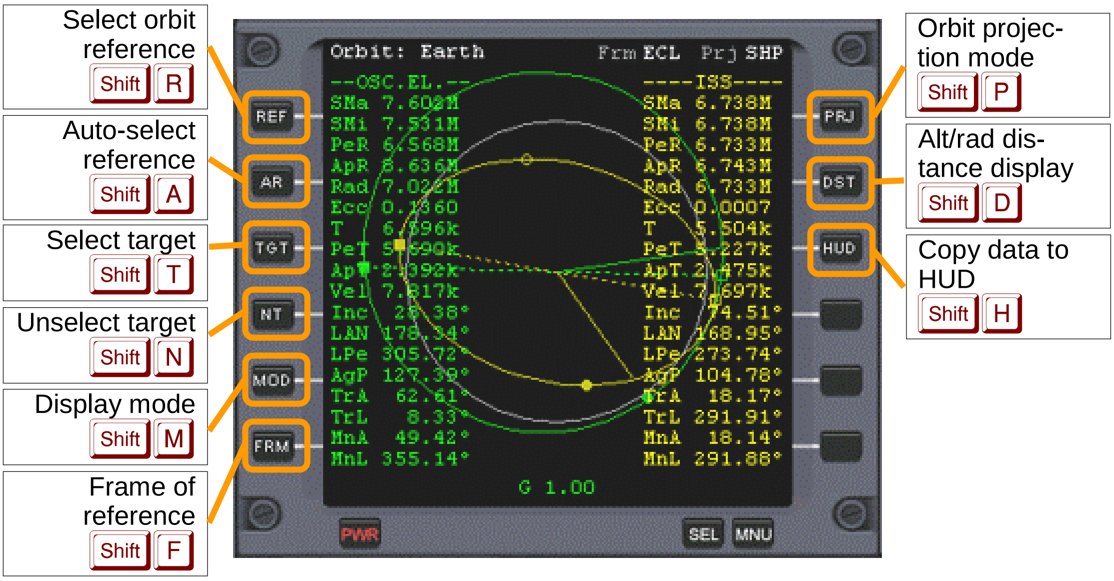
Shift T opens a menu to specify a target object. Only targets which orbit around the current reference object will be accepted. The target display can be turned off with Shift N.

NEW! Pressing Shift H will switch the vessel's head-up display to *Orbit* mode and copy the orbit reference object from the MFD to the HUD. This is often more convenient than selecting the HUD reference directly with Ctrl R.

Key options:

Shift A	AR	Auto-select reference object.
Shift D	DST	Toggle radius, apoapsis and periapsis data display between planetocentric distance and altitude above mean planet radius.
Shift F	FRM	Toggle frame of reference (ecliptic, equator of reference object)
Shift H	HUD	Set HUD to Orbit mode and copy the current MFD orbit reference object.
Shift M	MOD	Toggle display mode (list only, graphics only and both)
Shift N	NT	No target orbit.
Shift P	PRJ	Toggle orbit projection mode (reference frame, ship's and target's orbital plane)
Shift R	REF	Select new reference object (planet or moon) for orbit calculation.
Shift T	TGT	Open menu for target selection.

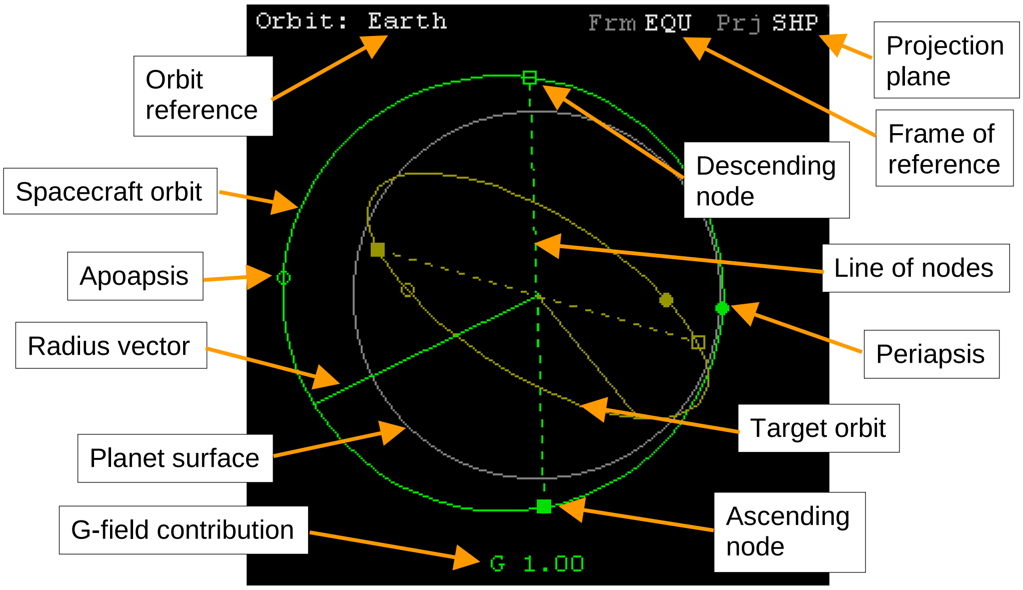
MFD control layout:



```
Orbit: Earth              Frm ECL  Prj SHP
--OSC.EL.--               ----ISS----
SMa 7.602M                SMa 6.738M
SMi 7.531M                SMi 6.738M
PeR 6.568M                PeR 6.733M
ApR 8.636M                ApR 6.743M
Rad 7.022M                Rad 6.733M
Ecc 0.1360                Ecc 0.0007
T   6.596k                T   5.504k
PeT 5.690k                PeT 5.227k
ApT 2.392k                ApT 2.475k
Vel 7.817k                Vel 7.697k
Inc  28.38°               Inc  74.51°
LAN 178.34°               LAN 168.95°
LPe 305.72°               LPe 273.74°
AgP 127.39°               AgP 104.78°
TrA  62.61°               TrA  18.17°
TrL   8.33°               TrL 291.91°
MnA  49.42°               MnA  18.14°
MnL 355.14°               MnL 291.88°
              G 1.00
```

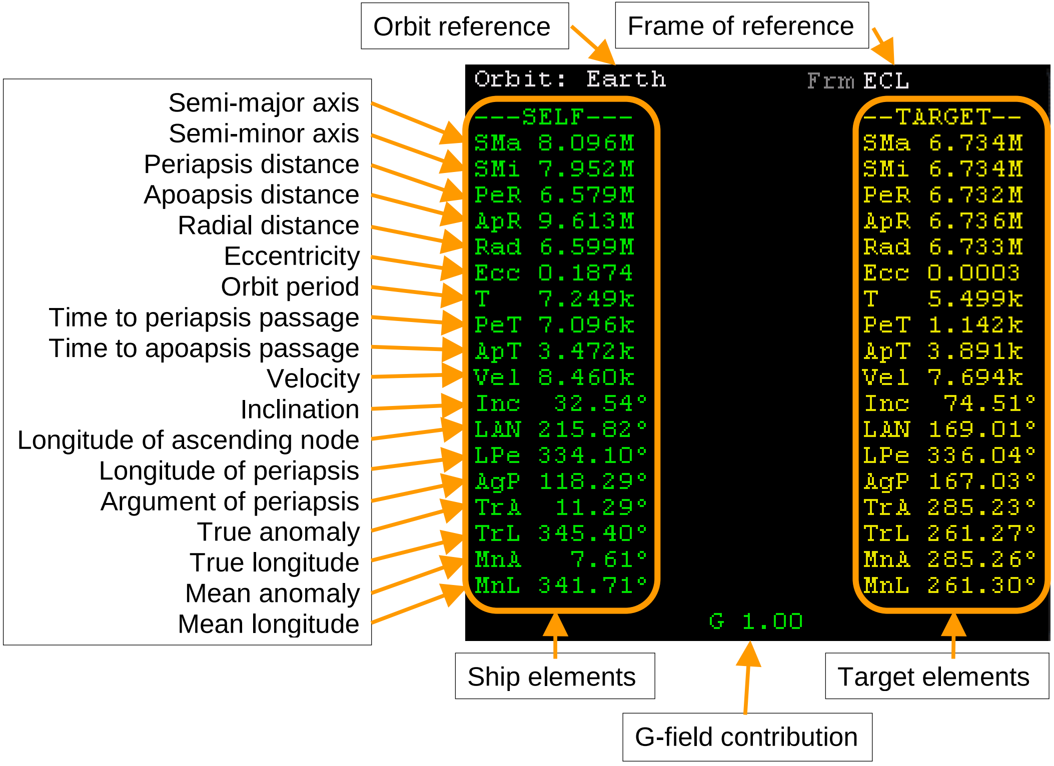
MFD display components:

1. Graphic display mode
In graphical mode, the Orbit MFD shows the ship's orbit (green) and optionally the orbit of a target object (yellow) around the reference body (surface represented in gray). The display also shows the ship's current position (radius vector), the periapsis (lowest point of the orbit) and apoapsis (highest point), and the ascending and descending nodes w.r.t. the reference plane.
The user can select the plane into which the orbit representations are projected (orbital plane of the ship or target, ecliptic or equatorial plane).



2. Orbital element list mode

In list mode, the ship's orbital elements and other orbital parameters are listed in a column on the left of the MFD display (green). If a target is selected, its elements are listed in a column on the right of the MFD (yellow). The elements refer to the selected frame of reference, so they will change when switching between ecliptic (ECL) and equatorial (EQU) frame.



```
Orbit: Earth                 Frm ECL
---SELF---              --TARGET--
SMa 8.096M              SMa 6.734M
SMi 7.952M              SMi 6.734M
PeR 6.579M              PeR 6.732M
ApR 9.613M              ApR 6.736M
Rad 6.599M              Rad 6.733M
Ecc 0.1874              Ecc 0.0003
T   7.249k              T   5.499k
PeT 7.096k              PeT 1.142k
ApT 3.472k              ApT 3.891k
Vel 8.460k              Vel 7.694k
Inc  32.54°             Inc  74.51°
LAN 215.82°             LAN 169.01°
LPe 334.10°             LPe 336.04°
AgP 118.29°             AgP 167.03°
TrA  11.29°             TrA 285.23°
TrL 345.40°             TrL 261.27°
MnA   7.61°             MnA 285.26°
MnL 341.71°             MnL 261.30°
             G 1.00
```

Notation:

- Semi-major axis: the longest semi-diameter of the orbit ellipse.
- Semi-minor axis: the shortest semi-diameter of the orbit ellipse.
- Periapsis: The lowest point of the orbit (For Earth orbits, this is also called perigee. For solar orbits, it is also called perihelion).
- Apoapsis: The highest point of the orbit (for Earth orbits, this is also called apogee. For solar orbits, it is also called aphelion).
- Ascending node: The point at which the orbit passes through the reference plane (plane of the ecliptic, or equator plane) from below.

- Descending node: The point at which the orbit passes through the reference plane from above.
- Radius vector: The vector from the orbit's focal point to the current position of the orbiting body.

For further explanation of orbital elements see Appendix C.

For hyperbolic (non-periodic) orbits, the following parameters are interpreted specially:
SMa: real semi-axis *a*: distance from coordinate origin (defined by intersection of hyperbola asymptotes) to periapsis. The semi-major axis is displayed negative in this case.
SMi: imaginary semi-axis $b = a\ sqrt(e^2-1)$
ApD: apoapsis distance: not applicable
T: orbital period: not applicable
PeT: time to periapsis passage; negative after periapsis passage
ApT: time to apoapsis passage: not applicable
MnA: mean anomaly, defined as $e \sinh E - E$, with *E* hyperbolic eccentric anomaly

G-field contribution

The "G" value at the bottom of the display shows the relative contribution of the current reference body to the total gravity field at the ship's position. This can be used to estimate the reliability of the Keplerian (2-body) orbit calculation. For values close to 1 a 2-body approximation is accurate. For low values the true orbit will deviate from the analytic calculation, resulting in a change of the orbital elements over time.
As a warning indicator, the G display will turn yellow for contributions < 0.8, and red if the selected reference object is not the dominant contributor to the gravity field. In that case, Shift A will select the dominant object.

13.3 VOR/VTOL

The *VOR/VTOL* MFD mode is a navigational instrument used for surface flight and vertical takeoff and landing. In addition to altitude and airspeed readouts it can display a graphical indicator of the relative position of a VOR (very high frequency omnidirectional range) navigation radio transmitter.

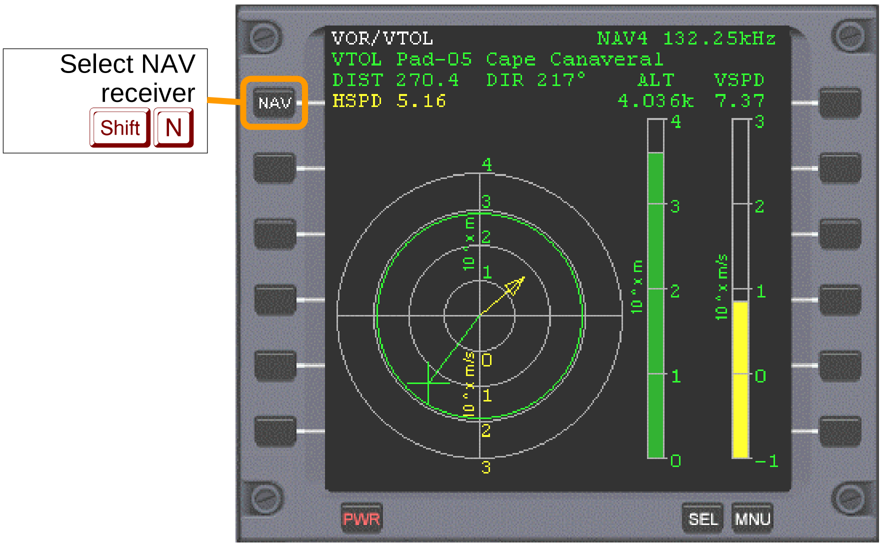
This MFD mode can be slaved to one of the ship's NAV receivers. The current receiver and frequency is shown in the upper right corner of the display. If a signal is received, the transmitter ID is displayed in the second line. If the ship supports more than a single NAV receiver, a different receiver can be selected with Shift N. To set the receiver frequency, use the COM/NAV MFD mode (see section 13.1).

The instrument can also be used for vertical instrument landing (VTOL). When slaved to a VTOL transmitter, the target indicator shows the relative position of the corresponding launch pad.

Key options:

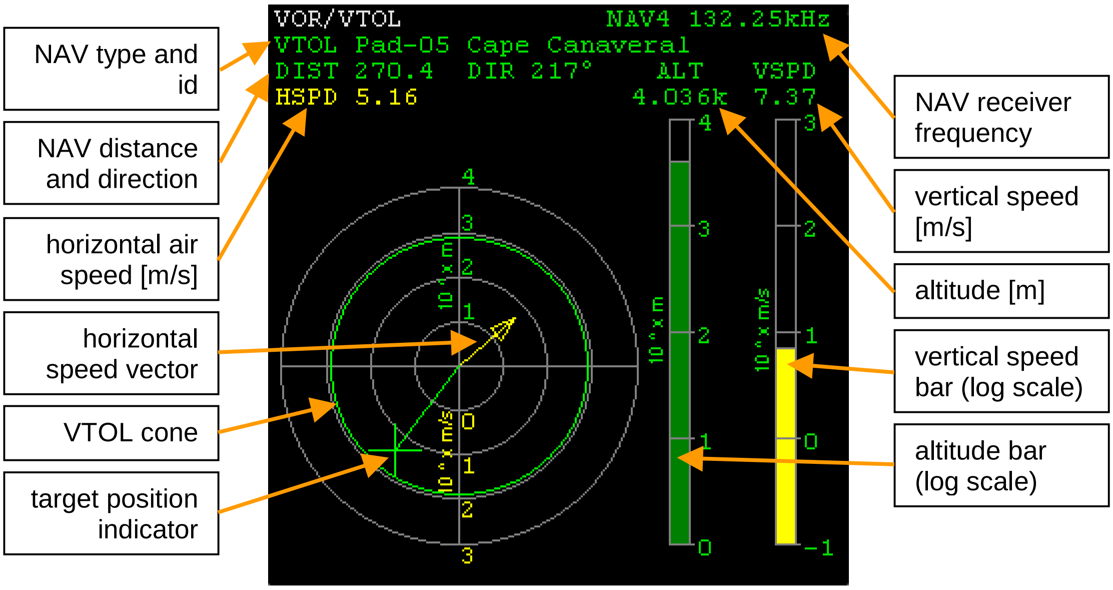
Shift N	Select navigation radio (NAV) receiver for VOR or VTOL information input.

MFD control layout:



```
VOR/VTOL          NAV4 132.25kHz
VTOL Pad-05 Cape Canaveral
DIST 270.4  DIR 217°    ALT   VSPD
HSPD 5.16            4.036k  7.37
```

MFD display components:



- **DIST**: distance to NAV transmitter [m]
- **DIR**: direction of NAV transmitter (ship-relative)
- **HSPD**: horizontal airspeed component [m/s]
- **ALT**: altitude [m]. The altitude bar has a range from 1 to 10^4m (logarithmic scale).
- **VSPD**: vertical airspeed component [m/s]. The vertical speed bar has a range from ±0.1 to $\pm 10^3$m/s (logarithmic scale). Positive vertical speed is indicated by a green bar, negative vertical speed by a yellow or red bar. *Red* is a surface impact warning.
- **Target indicator**: Shows the horizontal location of the slaved NAV transmitter (ship-relative) on a logarithmic scale. Range: 1 to 10^4m.
- **Hspeed vector**: Shows the horizontal component of the airspeed vector (ship-relative) on a logarithmic scale. Range: 0.1 to 10^3m/s.
- **VTOL cone**: This circle indicates the admissible deviation from the vertical touchdown vector as a function of altitude. During VTOL landing, the target indicator must remain inside the VTOL cone. A *red* circle indicates that the ship is outside the cone. The VTOL cone is displayed only when the MFD is slaved to a VTOL transmitter.

13.4 Horizontal Situation Indicator

The Horizontal Situation Indicator (HSI) consists of two independent displays. Each display can be slaved to a NAV receiver and show directional and relative bearing information. The instruments accept data from surface-based transmitters such as VOR and ILS. The function is similar to instrument navigation systems found in aircraft.

The display consists of a gyro-compass indicating the current heading at the 12 o'clock position. The yellow arrow in the centre of the instrument is the *course arrow* or *Omni Bearing Selector* (OBS). When the slaved NAV radio is tuned to a VOR transmitter, the OBS can be adjusted with the OB- (Shift [) and OB+ (Shift]) keys. For ILS transmitters, the OBS is automatically fixed to the approach direction.
The middle section of the course arrow is the *Course Deviation Indicator* (CDI). It can deflect to the left and right, to show the deviation of the OBS setting from the current bearing to the NAV sender. If the CDI is deflected to the left, then the selected radial is to the left of the current position.
In the lower left corner of the instrument is the TO/FROM indicator. "TO" means that you are working with a bearing from you *to* the ground station; "FROM" indicates a radial *from* the ground station to you.

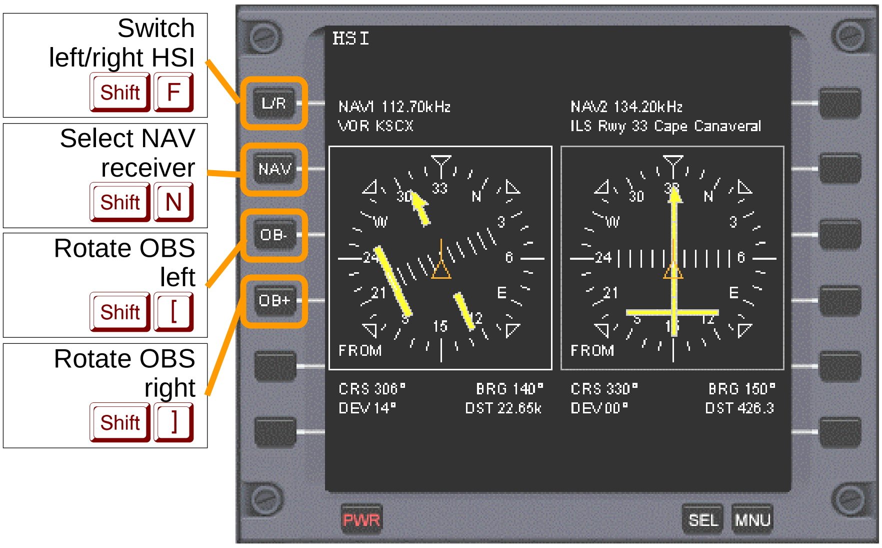
When tuned to an ILS (localiser) transmitter, the instrument shows an additional horizontal glideslope bar for vertical guidance to the runway. If the bar is centered in the instrument, you are on the correct glide slope. If it is in the upper half, the glide slope is *above* you, i.e. you are too low. If it is in the lower half, the glide slope is *below* you and you are approaching too high.

The refresh rate for the HSI MFD is 4Hz or the user selection in the Launchpad dialog, whichever is higher.

Key options:

Shift N	Select NAV receiver
Shift F	Switch focus to left/right HSI instrument
Shift [	Rotate OBS left
Shift]	Rotate OBS right

MFD control layout:



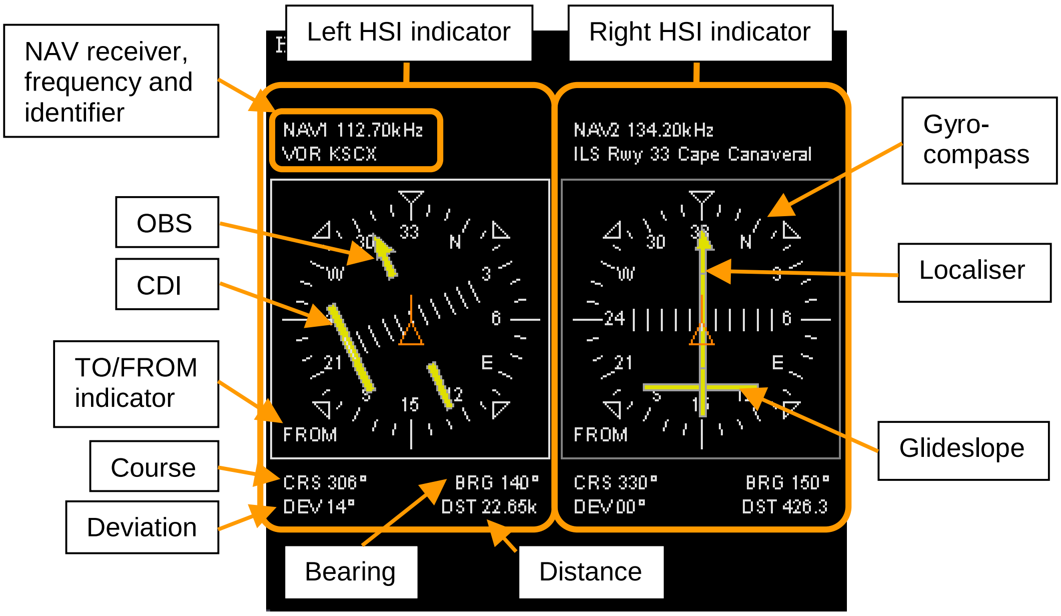
NAV1 112.70kHz
VOR KSCX

NAV2 134.20kHz
ILS Rwy 33 Cape Canaveral

CRS 306° BRG 140°
DEV 14° DST 22.65k

CRS 330° BRG 150°
DEV 00° DST 426.3

MFD display components:



To use the HSI for surface navigation:

- Determine the frequency of the VOR station you want to use (e.g. from the Map Ctrl M or spaceport info dialog Ctrl I) and tune one of your NAV receivers to that frequency (on the COM/NAV MFD)
- Slave one of the HSI displays to that receiver with Shift N.
- To fly directly towards the station, turn the OBS indicator until the CDI aligns with the arrow, and the TO/FROM indicator shows “TO”.
- Turn the spacecraft until the OBS indicator points to the 12 o’clock position.
- If the CDI wanders off to the left or right, turn the spacecraft in that direction until the arrow is aligned again.
- To fly away from the station, use the same procedure, but make sure that the TO/FROM indicator shows “FROM”.

To use the HSI for instrument landing:

- Make sure the runway is equipped with ILS (use the spaceport info dialog, Ctrl I), and tune one of your NAV receivers to the appropriate frequency.
- Slave one of the HSI displays to that receiver.
- As soon as the ILS transmitter is in range, the OBS indicator will turn into the approach direction and can be used as a localiser indicator. At the same time, the glideslope indicator will become active. When both indicators are centered to form a crosshair, you are on course and on glideslope to the runway.

13.5 Docking

The *Docking* MFD assists during final approach to dock with another vessel or orbital station. It provides indicators for translational and rotational alignment with the approach path, as well as distance and closing speed readouts.
This instrument relies on docking approach data received by your spacecraft. Approach data can be acquired in three different modes:

- IDS mode: data are acquired from a radio signal sent by the docking target. The IDS (Instrument Docking System) signal is obtained by tuning a NAV receiver to the appropriate frequency and slaving the Docking MFD to that receiver. The typical range for IDS is ~100km. To select a NAV receiver, press Shift N. The selected frequency is displayed in the upper right corner of the MFD.
- Visual mode: Docking parameters are acquired from onboard visual systems (typically video cameras mounted in the docking port. The visual system aids in docking to targets

which don't provide IDS. The typical range for visual mode is ~100m. To switch to visual mode, press Shift V.

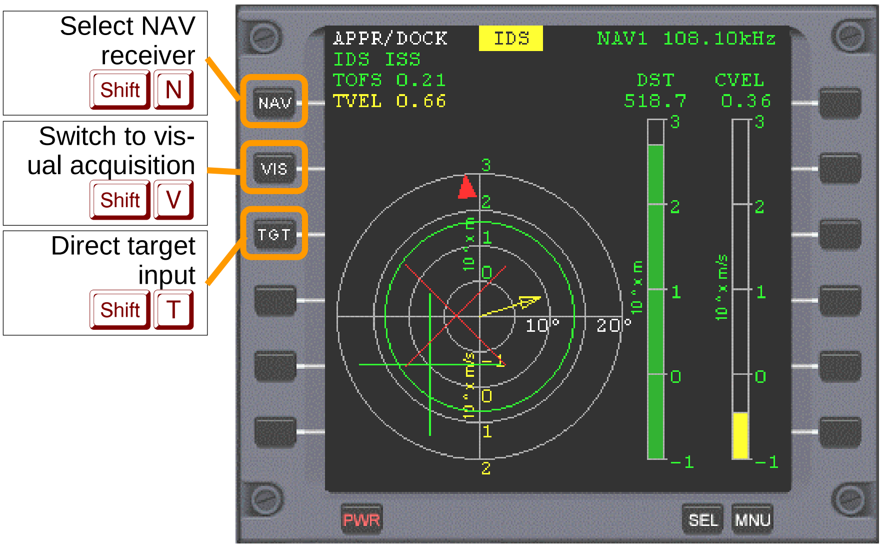
- Direct target selection: If you want to avoid the need to tune into a navigation transmitter signal, you can open target dialog (Shift T) and enter target name (and optional docking port index ≥ 1) directly. (This shortcut method may be dropped in a future version).

Apart from their different operational range, the three modes provide are identical in terms of the produced MFD display.

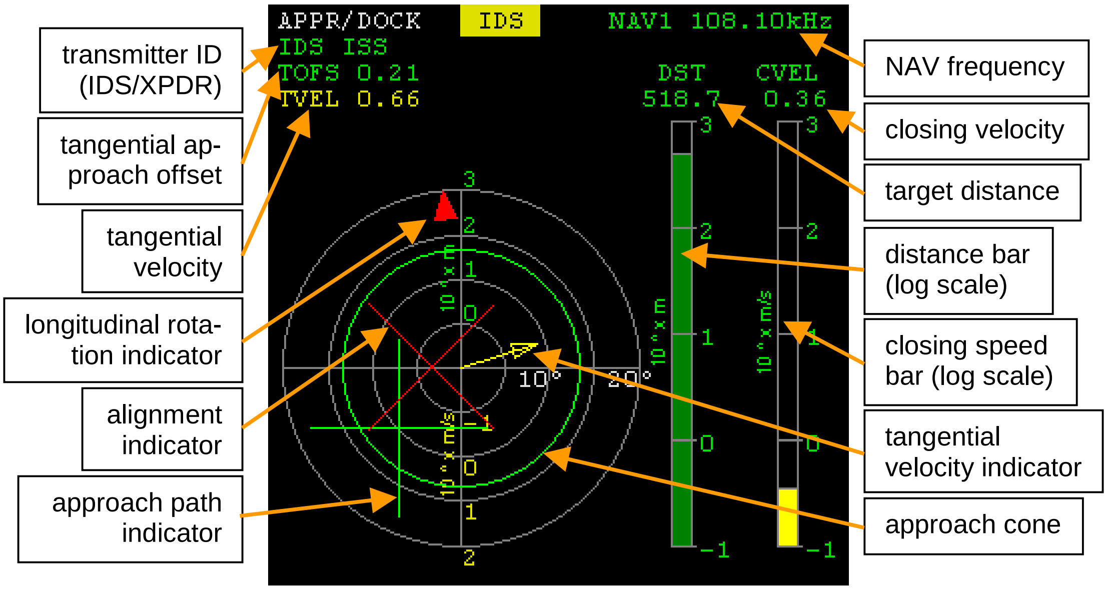
Key options:

Shift N	Select NAV receiver for IDS information input.
Shift V	Switch to visual docking data acquisition mode.
Shift T	Direct target and docking port selection

MFD control layout:



MFD display components:



- **IDS source**: identifies the source of the currently received IDS signal.
- **TOFS**: tangential offset from approach path. This value is given in units of the approach cone radius at the current target distance. TOFS < 1 indicates a position inside the approach cone.

- **TVEL**: Tangential velocity (velocity relative to target, projected into plane normal to approach path) [m/s]
- **DST**: Dock-to-dock distance [m]. The bar shows the distance on a logarithmic scale in the range 0.1–10^3 m.
- **CVEL**: Closing speed [m/s]. The bar shows the closing speed on a logarithmic scale in the range 0.1–10^3 m/s. Yellow indicates positive closing speed.

The circular instrument shows the ship's alignment with respect to the approach path towards the allocated dock.

- **Approach path indicator**: The *green cross* indicates the position of the approach path relative to the ship. When centered, the ship is aligned on the approach path. The radial scale is logarithmic in the range 0.1–10^3 m. Tangential alignment should be performed with attitude thrusters in *linear* mode (see Section 14.2).
- **Tangential velocity indicator**: The *yellow arrow* indicates the relative tangential velocity of your vessel with respect to the target. The radial scale is logarithmic in the range 0.01–10^2 m/s. The numerical value is the tangential velocity [m/s]. *To align your ship with the approach path, engage linear attitude thrusters so that the arrow points towards the approach path indicator.*
- **Alignment indicator**: The *white/red cross* indicates the alignment of the ship's forward direction with the approach path direction. When centered, the ship's forward direction is parallel to the approach path. The cross turns red if misalignment is > 2.5°. The radial scale is linear in the range 0–20°. Rotational alignment should be performed with attitude thrusters in *rotational* mode (see Section 14.2).
- **Longitudinal rotation indicator**: This arrow indicates the ship's longitudinal alignment with the docking port. To align, the indicator must be moved into 12 o'clock position by rotating the ship around its longitudinal axis, by engaging bank attitude thrusters in rotational mode (see Section 14.2). When alignment is achieved, the indicator turns white (misalignment < 2.5°). Note that this indicator is only displayed when directional alignment (see above) is within 5°.
- **Approach cone**: The concentric red or green circle indicates the size of the approach cone at the current dock distance. The ship should approach the dock so that the approach path indicator is always inside the approach cone (indicated by a green circle). The approach cone becomes smaller as the ship approaches the dock.

Closing speed should be reduced as the ship approaches the dock (using retro thrusters). The final speed should be < 0.1 m/s.

Notes:
- To dock successfully, you must approach the dock to within 0.3 m. Additional restrictions may be implemented in the future (speed, alignment, etc.)
- No collision checks are currently performed. If you fail to dock and keep closing in, you may fly your ship through the target vessel.

13.6 Surface

The *Surface* MFD mode assists in flight close to planetary surfaces. It contains the following elements:

- **Artificial horizon** with pitch and bank readouts.
- **Heading indicator tape**
- **Altitude tape** with markers for pherihel and aphel altitude
- **Vertical speed tape**
- **Vertical acceleration tape**
- **Speed tape** (IAS/TAS/GS/OS)
- **Acceleration tape**
- **Angle of attack tape**
- **Atmospheric data**
- **Equatorial position** (longitude and latitude, and rate of change)

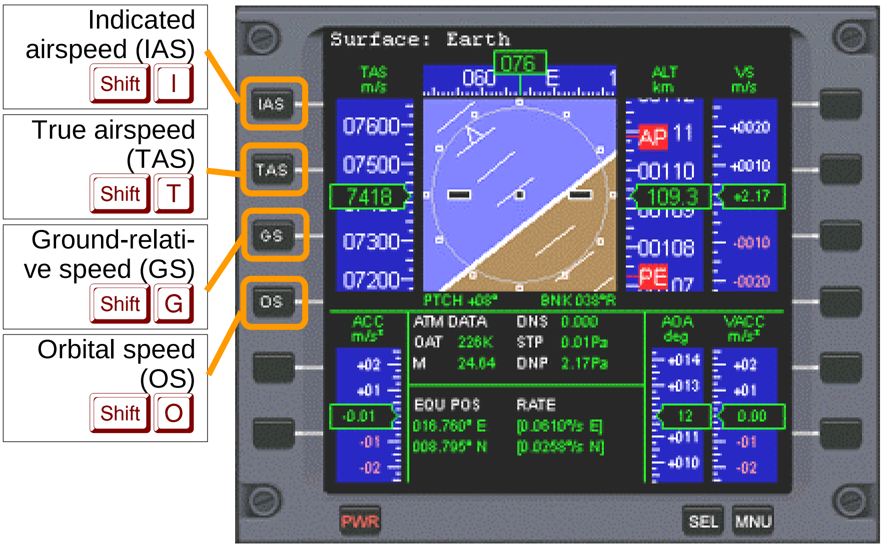
The following atmospheric data are displayed (if applicable):

- **OAT**: Outside Air Temperature: Absolute atmospheric freestream temperature [K].
- **M**: Mach number $M=v/a$, with airspeed v and speed of sound a.
- **DNS**: Atmospheric density ρ [kg m^{-3}]
- **STP**: Static pressure [Pa]
- **DNP**: Dynamic pressure $q = ½ \rho v^2$ [Pa].

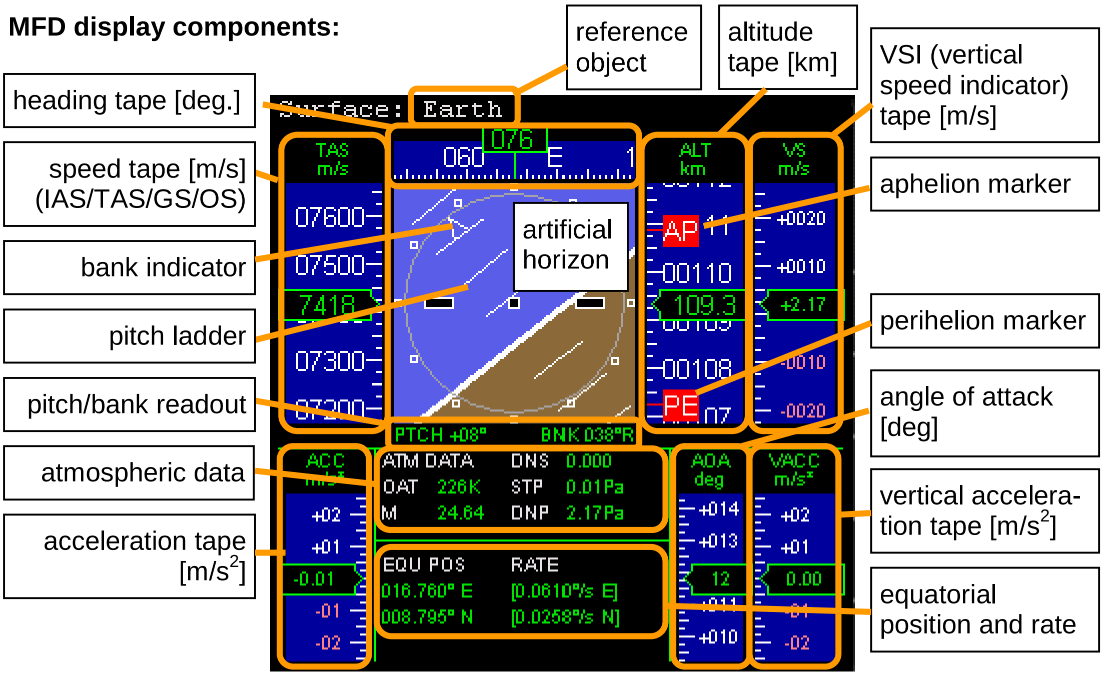
Key options:

Shift I	Select *Indicated Airspeed* display.
Shift T	Select *True Airspeed* display.
Shift G	Select *Ground-relative Speed* display.
Shift O	Select *Orbital Speed* display.

MFD control layout:



MFD display components:



Speed display modes:
The user can choose between four different speed indicator modes:

- **TAS (true airspeed)**: The speed of the spacecraft relative to the surrounding atmosphere. Airspeed is usually measured with a pitot tube in the airstream recording the difference between freestream and stagnation point pressure. The TAS mode is only available if the freestream pressure $p_1 > 10^{-4}$Pa (on Earth, this corresponds to approx. 140 km altitude). If TAS cannot be measured, the speed tape is reset to 0 and the readout shows “----“.
- **IAS (indicated airspeed)**: Commonly used in conventional aircraft. IAS is calibrated to atmospheric density and speed of sound at sea level. IAS and TAS are similar at low altitude, but start to diverge at higher altitudes, with IAS < TAS. The limit $p_1 > 10^{-4}$Pa also applies for IAS availability.
- **GS (ground-relative speed)**: The magnitude of the vessel’s velocity vector transformed into the rotating planet reference frame. This is similar to TAS at lower altitudes, but diverges at higher altitudes. Usually, TAS is no longer available at altitudes where the differences would become significant. *Note*: For an object in geostationary orbit, GS is zero since it is stationary relative to the rotating planet frame.
- **OS (orbital speed)**: The vessel’s velocity relative to the planet’s centre in a non-rotating frame. This is identical to the “Vel” readout in the Orbit MFD. *Note*: OS is usually nonzero for a vessel at rest on the planet surface, since the planet itself rotates.

The speed tape left of the artificial horizon displays the vessel speed in the selected mode. The acceleration tape below shows the speed rate of change in the same mode. The vertical speed and vertical acceleration tapes are not affected by the speed display mode.

The refresh rate for the Surface MFD is 4Hz or the user selection in the Launchpad dialog, whichever is higher.

***Technical background**: Orbiter uses a compressible flow model to calculate indicated airspeed:*

$$v_{\mathrm{IAS}} = a_s \sqrt{\frac{2}{\gamma - 1}\left[\left(\frac{p_0 - p_1}{p_s} + 1\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

where p_0 and p_1 are the stagnation and freestream pressures, respectively, p_s and a_s are the standard sea level values for static pressure and speed of sound, and γ is the ratio of specific heats.
The stagnation point pressure p_0 is obtained from the true airspeed by

$$v_{\mathrm{TAS}} = a_1 \sqrt{\frac{2}{\gamma - 1}\left[\left(\frac{p_0}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

where a_1 is the freestream speed of sound.

13.7 Map

The *Map* MFD mode shows a surface map of a planet or moon in an equatorial projection. Planets for which a map is not available only show the longitude and latitude grid.

The intersection of the plane of your current orbit with the surface of the planet is shown in a green and or red curve. Your own position on the trajectory is shown with a white cross. The green section of the curve is the part of the orbit above the planet surface. The red part, if shown, indicates the section of the orbit below the planet surface.
The presence of a red section therefore indicates a ballistic trajectory which will result in a surface impact unless the periapsis is raised by an engine burn.
The intersection points of the trajectory with the surface are indicated with red and green boxes, where the red box is the impact point.
The impact point display can be used as an approximate aid for timing reentry burns.

Note that even orbits which do not intersect the surface may not be stable if they pass through planetary atmospheres and cause significant drag.

In addition to your own orbit, the orbital plane of a target object (e.g. a spacecraft or moon) orbiting the same central body can be displayed. This trajectory will be shown in yellow, and the target position is indicated by a yellow cross. Sub-surface parts of the target trajectory are not specially marked.

Note that the trajectory curves show the intersection of the orbital plane at the current time, and *not* the projected ground tracks of the orbiting bodies. This means that the curves will shift horizontally over the planet surface with time, due to the rotation of the planet underneath.

Surface bases are indicated by red squares. The position of the currently selected base and the distance to it are displayed. In addition, the projections of the orbital planes of the ship and the selected orbital target onto the planet surface are plotted.

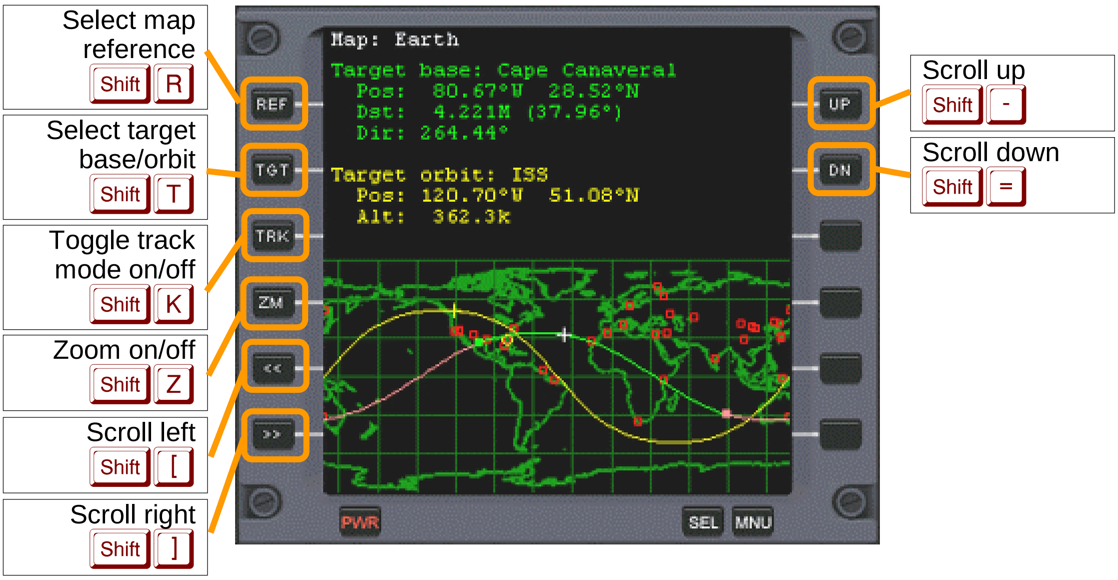
The map display can show either the full planet surface in global view (360º x 180º) or a smaller (180º x 90º) area in 2x zoom mode. Scrolling buttons allow to pan the visible part of the map display.

Alternatively, by switching to Track mode, the vessel's current position is kept centered in the display. In this case, the scrolling function is disabled.

Key options:

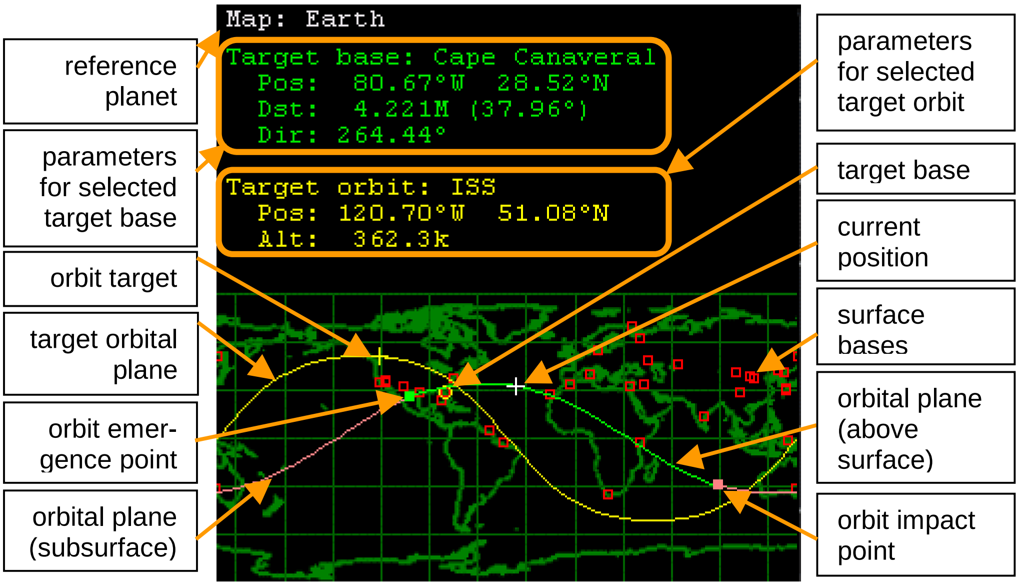
Shift R	REF	Open input box for reference planet/moon selection.
Shift T	TGT	Open a menu for target selection.
Shift K	TRK	Switch automatic vessel track mode on or off.
Shift Z	ZM	Toggle between global map view and 2x zoom.
Shift [	<<	Scroll map display left (not in track mode).
Shift]	>>	Scroll map display right (not in track mode).
Shift -	UP	Scroll map display up (not in track mode or global view).
Shift =	DN	Scroll map display down (not in track mode or global view).

MFD control layout:



```
Map: Earth

Target base: Cape Canaveral
  Pos:  80.67°W  28.52°N
  Dst:  4.221M (37.96°)
  Dir: 264.44°

Target orbit: ISS
  Pos: 120.70°W  51.08°N
  Alt:  362.3k
```

MFD display components:



```
Map: Earth
Target base: Cape Canaveral
  Pos:  80.67°W  28.52°N
  Dst:  4.221M (37.96°)
  Dir: 264.44°
Target orbit: ISS
  Pos: 120.70°W  51.08°N
  Alt:  362.3k
```

Target base:

- **Pos**: Equatorial coordinates (longitude, latitude) of selected spaceport.
- **Dst**: Surface distance of ship's projected position to the target base.
- **Dir**: Direction of the target base as seen from the ship.

Target orbit:

- **Pos**: Equatorial coordinates (longitude, latitude) of the projected target position.
- **Alt**: Target altitude.

Notes:

- Only objects (ships, stations or moons) orbiting the current reference planet will be accepted as orbit targets.
- Only bases located on the current reference planet will be accepted as target bases.
- Your ship's orbital plane will only be plotted if you are orbiting the current reference planet.

13.8 Align orbital plane

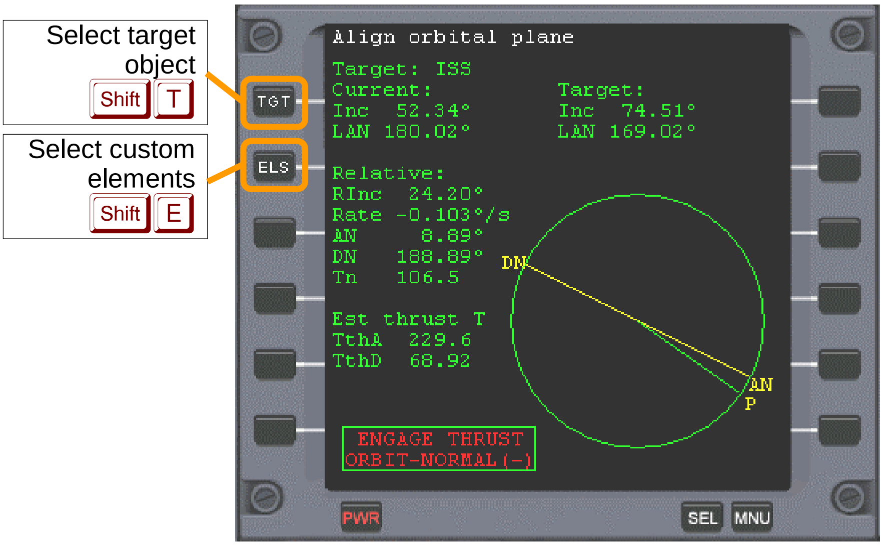
This MFD mode aids in rotating the orbital plane in space so that it corresponds with some target plane, e.g. the orbital plane of another object. The instrument contains the relevant orbital elements (inclination and longitude of the ascending node) of the current and target orbits. It also shows the relative inclination (angle between the two planes), the angles of the current radius vector towards ascending and descending nodes, the time to intercept the next node, and the predicted required thruster burn time. See section 16.4 on how to use this MFD mode.

The target plane can be either defined in terms of the orbital plane of another orbiting object, or by specifying the parameters that define the orientation of an orbital plane: the inclination and longitude of ascending node with respect to the ecliptic frame of reference.

Key options:

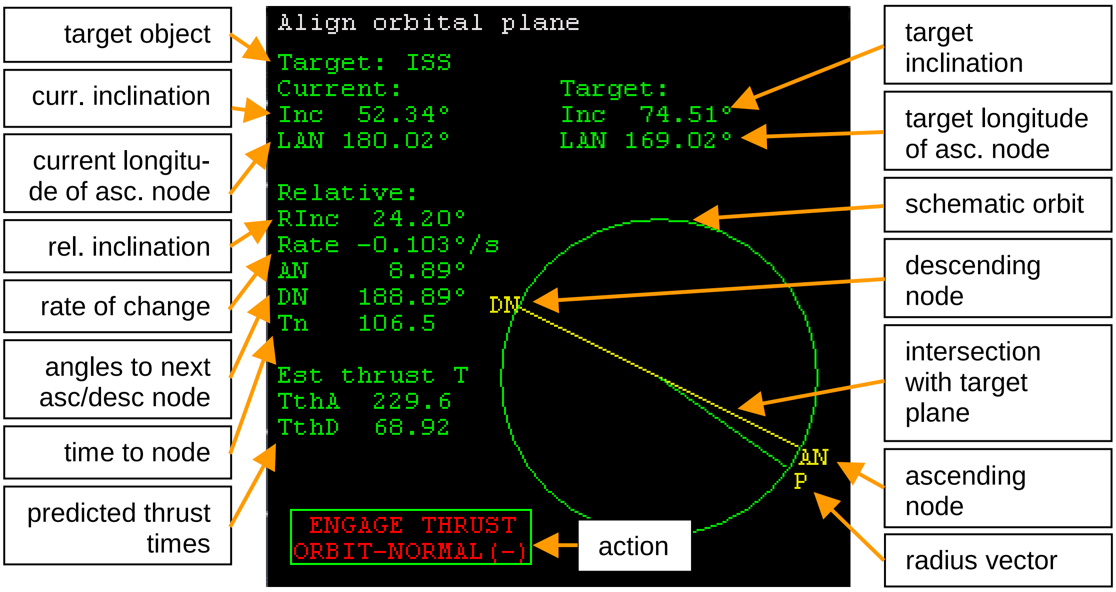
Shift T	Input a new target object or target orbital parameters.
Shift E	Input target plane as ecliptic inclination and longitude of ascending node.

MFD control layout:



```
Align orbital plane
Target: ISS
Current:            Target:
Inc  52.34°         Inc  74.51°
LAN 180.02°         LAN 169.02°

Relative:
RInc  24.20°
Rate -0.103°/s
AN      8.89°
DN    188.89°
Tn    106.5

Est thrust T
TthA  229.6
TthD  68.92

ENGAGE THRUST
ORBIT-NORMAL(-)
```

MFD display components:



```
Align orbital plane
Target: ISS
Current:            Target:
Inc  52.34°         Inc  74.51°
LAN 180.02°         LAN 169.02°

Relative:
RInc  24.20°
Rate -0.103°/s
AN      8.89°
DN    188.89°
Tn    106.5

Est thrust T
TthA  229.6
TthD  68.92

ENGAGE THRUST
ORBIT-NORMAL(-)
```

The MFD display shows a schematic orbit, indicating the directions of the ascending (*AN*) and descending (*DN*) nodes of the intersection of the current orbit with the target orbit, as well as our current position (*P*) along the orbit. The angular distances from the current position to the next AN and DN passages are shown on the left (range 0-360°). Also shown is the time to the next node passage (*Tn*).

Readouts for the relative inclination between the current and target orbits (*RInc*) and the rate of change of the relative inclination, d*RInc*/dt (*Rate*) help with timing the alignment burn.

Finally, the estimated burn times required to align the orbit with the target plane are listed, assuming a main engine burn at full thrust, perpendicular to the orbital plane.

NEW!

Note that the required velocity change (Delta-V), and thus the burn time, depends on the orbital velocity, and may therefore be different at the ascending and descending nodes, if the orbit is not circular. The MFD shows the burn times both for the ascending (*TthA*) and descending nodes (*ThtD*).

Tip: It is often more fuel-efficient to make the orbit more eccentric before applying the plane change, so that the radius distance of one of the nodes is increased and the corresponding Delta-V decreased. In particular if the plane change is to be combined with other changes to the orbit, a careful planning of the sequence of burns can help to minimise the fuel expenditure.

13.9 Synchronise orbit

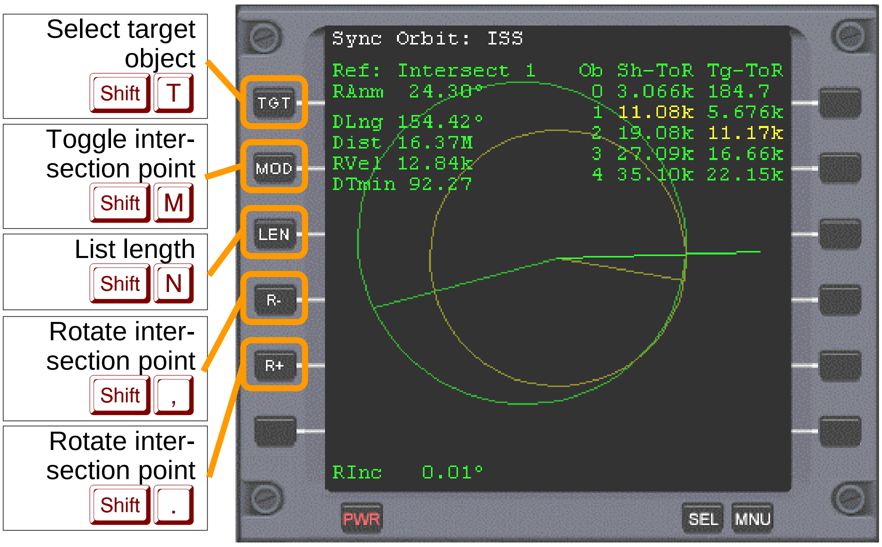
The Synchronise Orbit MFD assists in catching up with an orbiting body once the orbital planes have been aligned (see previous section).
The instrument displays the ship's and target body's orbits, together with a reference axis and lists the times it will take both objects to reach this axis for a series of orbits.

> ⚠ For this instrument to work properly the orbital planes of both objects must coincide. The relative inclination of the orbital planes is shown in the lower left corner ("RInc"). If this becomes greater than 1°, realign the planes using the *Align Orbital Planes* MFD. Once the planes are aligned, all subsequent maneuvers should be performed in this plane.

Key options:

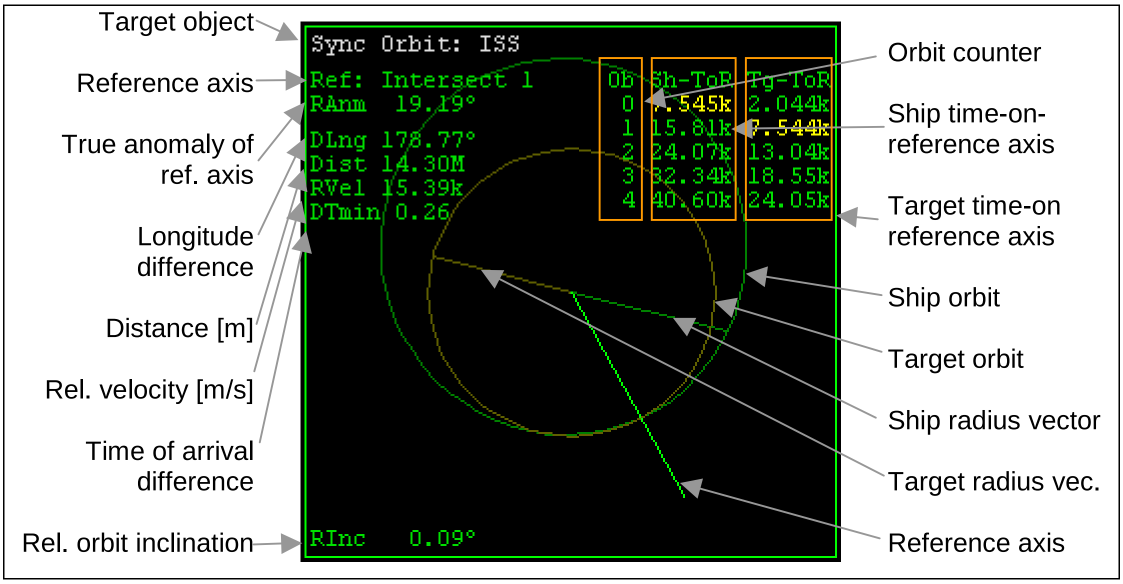
Shift T	Select target object. Only objects orbiting the same body as the ship will be accepted.
Shift M	Select reference axis mode. Intersection 1 and 2 are only available if the orbits intersect.
Shift , / .	Rotate reference axis (manual axis mode only).
Shift N	Select number of orbit timings in the list.

MFD control layout:



```
Sync Orbit: ISS
Ref: Intersect 1     Ob Sh-ToR Tg-ToR
RAnm  24.30°          0 3.066k 184.7
                      1 11.08k 5.676k
DLng 154.42°          2 19.08k 11.17k
Dist 16.37M           3 27.09k 16.66k
RVel 12.84k           4 35.10k 22.15k
DTmin 92.27

RInc   0.01°
```

MFD display components:



```
Sync Orbit: ISS
Ref: Intersect 1            Ob Sh-ToR Tg-ToR
RAnm  19.19°                 0 7.545k 2.044k
                             1 15.81k 7.544k
DLng 178.77°                 2 24.07k 13.04k
Dist 14.30M                  3 32.34k 18.55k
RVel 15.39k                  4 40.60k 24.05k
DTmin 0.26

RInc   0.09°
```

Figure 18: Synchronise Orbit MFD mode.

- **Target object**: The synchronisation target is displayed in the title line. It can be selected with Shift T.
- **Reference axis**: A selectable axis for which timings are computed. Can be selected with Shift M from one of the following: orbit intersection 1 and 2 (if applicable), ship and target apoapsis and periapsis, and manual. The manual axis can be rotated with Shift , and Shift ..
- **True anomaly of ref. axis (RAnm)**: The direction of the reference axis w.r.t. the ship's periapsis direction.
- **Longitude difference (DLng)**: The angle between ship and target as seen from the central body.
- **Distance (Dist)**: Distance between ship and target [m].
- **Rel. velocity (RVel)**: Relative velocity between ship and target [m/s].
- **Time-of-arrival difference (DTmin)**: This is the minimum time difference [s] between the ship's and target's arrival at the reference point for any of the listed orbits (see below).
- **Rel. orbit inclination (RInc)**: Inclination between ship's and target's orbital planes.
- **Time-on-reference lists (Sh-ToR and Tg-ToR)**: A list of time intervals for the ship and target to reach the selected reference point. The number of orbits can be selected with Shift N. The closest matched pair of timings is indicated in yellow. The DTmin value refers to this pair.

For usage of this MFD mode in orbit synchronisation, see Section 16.5.

13.10 Transfer

The Transfer MFD mode is used for calculating transfer orbits between planets or moons (or more generally, between any objects with significantly different orbits, for which the Sync orbit MFD is not sufficient).

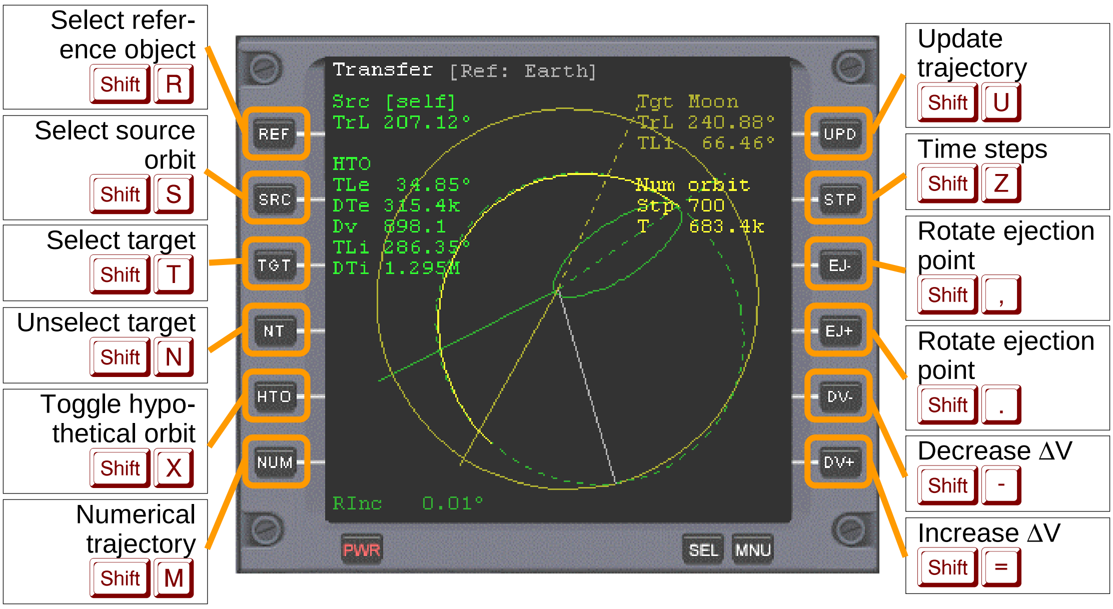
Note that Orbiter now contains Duncan Sharpe's *TransX* MFD mode as a plugin module, which supersedes and extends most of the Transfer MFD mode. TransX is described in a separate document (TransXmanualv3).

Key options:

Shift R	Open input box for selection of reference celestial body.
Shift S	Open a menu for source orbit object selection.
Shift T	Open a menu for target selection.

Shift N	Unselect target.
Shift X	Toggle HTO (hypothetical transfer orbit) display on/off.
Shift M	Toggle numerical multi-body trajectory calculation.
Shift U	Refresh numerical trajectory, if displayed.
Shift Z	Open input box for time step definition.
Shift , / .	Rotate transfer orbit ejection longitude.
Shift - / =	Decrease/increase ejection velocity difference.

MFD control layout:



MFD display components:

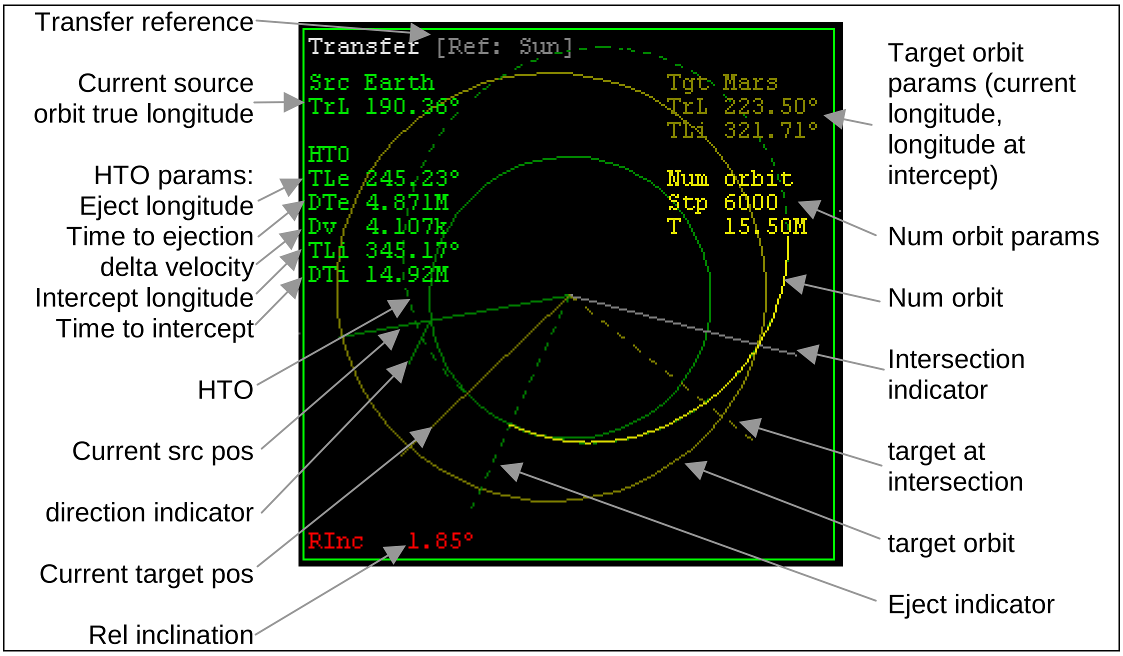


Figure 19: Transfer MFD mode.

The Transfer MFD looks similar to the Orbit MFD: it displays a *source* and a *target* orbit, relative to a selectable orbit *reference*. The source orbit is usually your ship’s current orbit, although sometimes a different source is more appropriate (see below). The MFD again assumes matching orbital planes of source and target, although this condition usually can not be precisely satisfied for interplanetary orbits.

Source orbit selection

The source orbit is the orbit from with to eject into the transfer orbit. Usually the source orbit will be the ship's current orbit. In certain situations however it is better to use a different source. Consider for example an interplanetary transfer from Earth to Mars, using the Sun as reference. Since the ship's primary gravitational source will be Earth rather than the Sun, its orbit w.r.t. the Sun will be strongly distorted by the Earth's field. In this case it is better to directly use Earth as the source orbit.

Whenever the source is not identical to the ship, a small direction indicator will be displayed at the current source position which shows the ship's direction w.r.t. the source. This helps with timing the ejection burn (e.g. direction indicator pointing away from the Sun.

Hypothetical transfer orbit

Unlike in Orbit mode, this MFD allows you to plot a hypothetical transfer orbit (HTO), which allows to set up "what if" scenarios, without having to change the actual orbit. The HTO display is toggled on/off via Shift X. It is calculated assuming that somewhere along the current source orbit a prograde or retrograde orbit ejection burn occurs. The HTO has two parameters: the *longitude* at which the ejection burn occurs (adjusted with Shift ,/.) and the *velocity change* during the burn (adjusted with Shift -/=). The HTO is displayed as a dashed green curve in the MFD. The position of the ejection burn is indicated by a dashed green radius vector.

A number of parameters is shown when the HTO is turned on:

TLe: True longitude of orbit ejection point
DTe: Time to ejection point [s]
Dv: Velocity difference resulting from ejection burn [m/s]
TLi: True longitude of interception with target orbit (if applicable)
DTi: Time to interception with target orbit [s] (if applicable)

Intercept indicator

If the source orbit (or, if shown, the HTO) intersects the target orbit, the intersection point is marked by a gray line, and the intersection longitude is displayed (TLi). The position of the target at the time when the ship reaches the intersection point is marked by a dashed yellow line. *The objective is to adjust the HTO so that the gray and dashed yellow lines coincide, so that ship and target arrive at the intersection point simultaneously.*

Hohmann transfer orbit

A transfer orbit which just touches the target orbit (i.e. where ejection and intersection longitude are 180° apart) is called a Hohmann minimum energy transfer orbit, because it minimises the amount of fuel used during the orbit ejection and injection points. Transfer orbits with larger major axis require more fuel, but are faster than Hohmann orbits.

Ejection burn

Once the HTO has been set up, the ejection burn takes place when the ejection point is reached (when the solid and dashed green lines coincide). The ejection burn is prograde (or retrograde) given the orbit w.r.t. the current orbit reference. As the burn takes place, the current orbit (solid green line) will approach the HTO. The burn is terminated when the orbit coincides with the HTO, and Dv has reached zero. After ejection the HTO should be turned off so that intercept parameters are displayed for the actual transfer orbit.

Numerical multi-body trajectory calculation

The source, target and transfer orbits discussed above are analytic 2-body solutions. The Transfer MFD however also supports a numerical trajectory calculation, to account for the effect of multiple gravitational sources. The display of the numerical trajectory is toggled with Shift M. The trajectory is displayed as a solid bright yellow line. The calculation is performed in discrete time steps, starting from the current source position, or (if displayed) from the HTO ejection point. Since the calculation of the trajectory can be time-consuming, it is not automatically updated, but can be refreshed with Shift U. The interval between time steps is automatically adjusted to provide consistent accuracy. The number of time steps, and thus the length of the trajectory, can be selected via Shift Z. The number of time steps, and the total time interval covered by the trajectory, are displayed under “Num orbit” in the MFD.

Interplanetary transfers

Using the Transfer MFD for Earth to Moon orbits should be straightforward. For interplanetary transfers (e.g. Earth to Mars) a few caveats apply:

- For interplanetary transfers, the reference should be the Sun, and the source orbit should be the *planet currently being orbited*. This is because the ship’s orbit w.r.t. the Sun will be severely distorted by the planet.
- The ship should be in an orbit with zero inclination against the ecliptic before ejection. The relative inclination between source and target orbits cannot be adjusted, it is simply given by the relative inclination between the planets’ orbits.
- The ejection burn should take place with the Sun in opposition (on the planet’s “dark” side) so that the ship’s orbital velocity is added to the planetary velocity. This is the case when the source→ship direction indicator is pointing away from the Sun.
- Immediately before the ejection burn, switch the source orbit to your ship, so that Dv can be estimated.

13.11 Ascent profile (custom MFD mode)

This MFD mode is only available if the “Custom MFD” plugin is activated in the *Modules* section of the Launchpad dialog.

The ascent profile records a number of spacecraft parameters and displays them in graphs on the MFD. The following are recorded:

- Altitude as a function of time.
- Pitch angle as a function of altitude.
- Radial velocity as a function of altitude.
- Tangential velocity as a function of altitude.

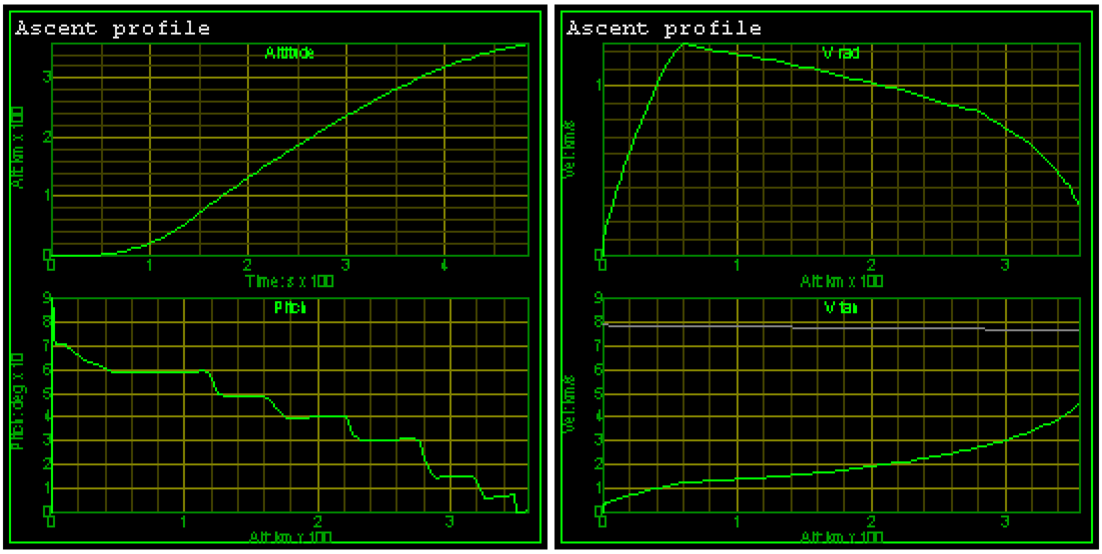


Figure 20: Ascent profile MFD mode, pages 1 and 2

Key options:

Shift P	Switch display page.
Shift A	Set altitude range.
Shift R	Set radial velocity range.
Shift T	Set tangential velocity range.

Parameters are sampled at 5-second intervals. A total of 200 samples are stored and cycled. By default, axis ranges are adjusted automatically, but manual range setting is possible.

Circular orbit insertion

In the tangential velocity graph (Vtan), a gray line indicates the orbital velocity for a circular orbit as a function of altitude. If the vessel's tangential velocity crosses this line for a given altitude, while simultaneously the radial velocity crosses zero, circular orbit is achieved.

14 Spacecraft controls

This chapter contains guidelines on how to control your spacecraft in free space (outside the influence of aerodynamic forces due to an atmosphere). We are considering a “generic” vessel. Note that the handling of different spacecraft types may vary considerably. Always read the operating instructions of individual vessels, if available.

14.1 Main, retro and hover engines

Main thrusters accelerate the ship forward, *retro thrusters* accelerate it backward. Main and retro engines can be adjusted with Ctrl + *Numpad* (to increase main thrust or decrease retro thrust) and Ctrl - *Numpad* (to decrease main thrust or increase retro thrust). Main and retro thrusters can be killed with Ctrl * *Numpad*. The permanent setting can be temporarily overridden with + *Numpad* (set main thrusters to 100%) and - *Numpad* (set retro thrusters to 100%). If available, a joystick throttle control can be used to set main thrusters.

The ship’s acceleration $\mathbf{a}$ resulting from engaging main or retro thrusters depends on the force $\mathbf{F}$ produced by the engine and the ship’s mass m:

$$\mathbf{F} = m\mathbf{a}$$

Note that both $\mathbf{a}$ and $\mathbf{F}$ are vectors, that is, they have a direction as well as a magnitude. In the absence of additional forces (such as gravitation or atmospheric drag) the spacecraft will move with constant velocity $\mathbf{v}$ as long as no engines are engaged. When engines are engaged, the ship’s velocity will change according to

$$\frac{d\mathbf{v}(t)}{dt} = \mathbf{a}(t) \quad \text{or} \quad \mathbf{v}(t) = \mathbf{v}(t_0) + \int_{t_0}^{t} \mathbf{a}(t')dt'$$

Note that for a fixed thruster setting $\mathbf{F}$ the acceleration will slowly increase as fuel is consumed, resulting in a reduction of the ship’s mass m.

Hover engines, if available, are mounted underneath the ship’s fuselage to provide upward thrust. Hover thrust is increased with 0 *Numpad* and decreased with . *Numpad*. Hover thrusters are useful to compensate for gravitational forces without the need to tilt the ship upward to obtain an upward acceleration component from the main thrusters.

The current main/retro thruster setting and corresponding acceleration is displayed in the upper left corner of the generic HUD (“Main”). The indicator bar is green for positive (main) thrust, and yellow for negative (retro) thrust. The hover thrust setting is also displayed if applicable (“Hovr”). The numerical acceleration value is in units of m/s^2. Spacecraft with customised instrument panels usually have their own indicators for thrust levels.

Spacecraft equipped with airfoils moving within a planetary atmosphere usually do not require hover thrusters except for launch and landing, because they produce an upward force (lift) when moving with sufficient airspeed, like a normal aircraft. Lift is speed-dependent and will collapse below a threshold speed (stall speed).

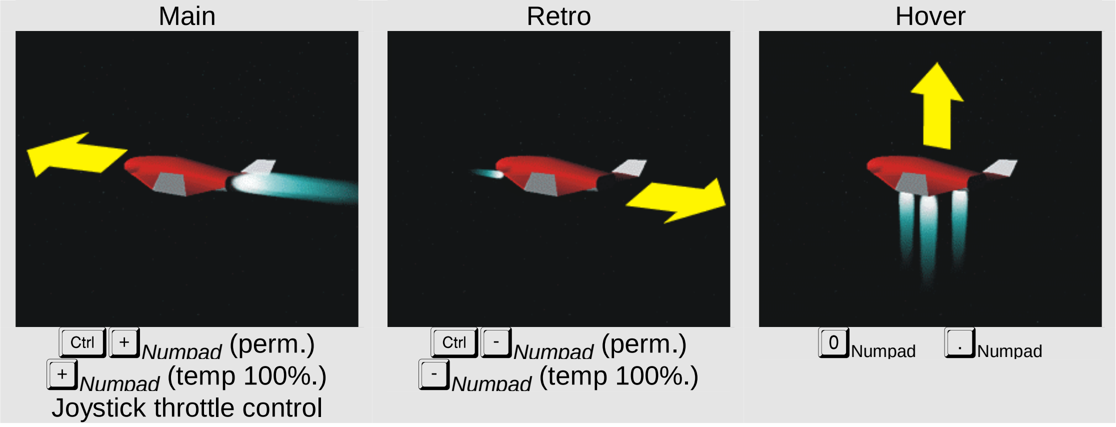


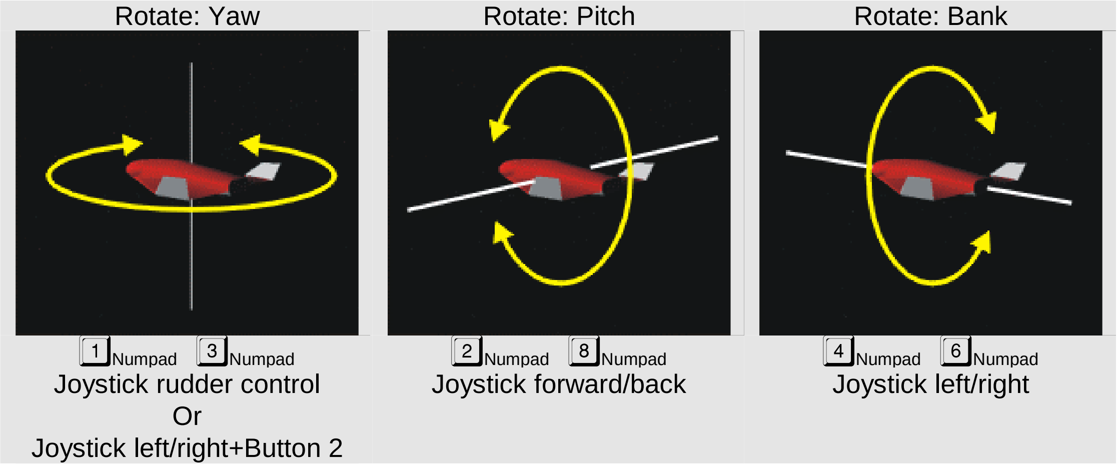
Figure 21: Acceleration from main, retro and hover thrusters.

The maximum vacuum thrust ratings for main, retro and hover thrusters as well as the current spacecraft mass are displayed in the vessel's info sheet (Ctrl I). Values are in Newton (1N = 1kg m s^{-2}). Note that the actual ratings may be lower in the presence of ambient atmospheric pressure.

14.2 Attitude thrusters

Attitude thrusters are small engines which are engaged in pairs to enable rotation or translation of the spacecraft. In rotation mode, attitude thrusters are fired in cross-linked pairs to produce a rotational moment (e.g. front right and back left to rotate left). In translation mode, thrusters are fired in parallel pairs to produce a linear moment (e.g. front right and back right to accelerate left). The current attitude mode is indicated in the top left corner of the HUD (*Att ROT* and *Att LIN*) and can be toggled with / *Numpad*.

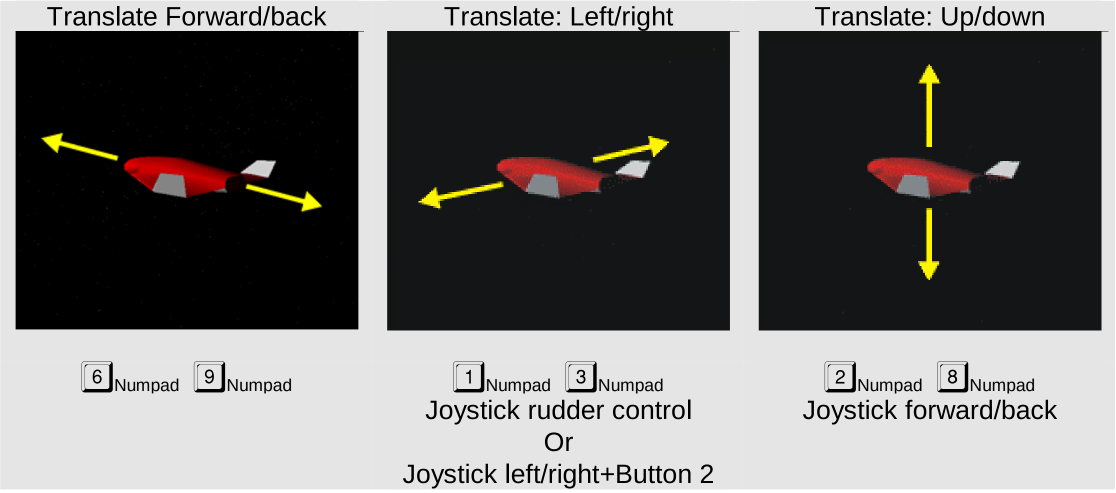
Attitude thrusters are controlled with the joystick or keyboard. In rotation mode:



Rotate: Yaw	Rotate: Pitch	Rotate: Bank
1 Numpad 3 Numpad Joystick rudder control Or Joystick left/right+Button 2	2 Numpad 8 Numpad Joystick forward/back	4 Numpad 6 Numpad Joystick left/right

Figure 22: Attitude thrusters in rotational mode.

In translation mode the spacecraft can be linearly accelerated forward/back, left/right and up/down.



Translate Forward/back	Translate: Left/right	Translate: Up/down
6 Numpad 9 Numpad	1 Numpad 3 Numpad Joystick rudder control Or Joystick left/right+Button 2	2 Numpad 8 Numpad Joystick forward/back

Figure 23: Attitude thrusters in translational (linear) mode.

For fine control of attitude thrusters with the keyboard use Ctrl-Numpad key combinations. This engages the engines at 10% thrust.
An important control function is the *Kill rotation* sequence (5 *Numpad*). This will automatically engage appropriate attitude thrusters to stop the ship's rotation.

15 Radio navigation aids

Orbiter uses various types of radio transmitters and receivers to provide information for spacecraft instrument navigation systems. Most vessels are equipped with one or more NAV radio receivers which can be tuned to the frequency of a navigation radio transmitter, and feed the data to the vessel's navigation subsystems.

To tune a NAV receiver, open the Comm Control MFD mode, select a receiver (Shift , and Shift .), and tune through the frequency band (Shift [, Shift], Shift -, Shift =).

The following types of navaid radio transmitters are currently supported in Orbiter:

- **VOR**: surface-based omnidirectional radio beacons, typically with a range of several hundred kilometres. VOR signals can be fed into the HSI (horizontal situation indicator) MFD or the VTOL/VOR MFD to obtain direction and distance information. A map with VOR locations is available with Ctrl M. Frequencies of VOR transmitters located at a surface base are also available from the base's information sheet (Ctrl I).
- **VTOL**: Surface landing pads for vertical take-off and landing (VTOL) may be equipped with short-range landing aid transmitters. This signal can be fed to the VTOL/VOR MFD to obtain landing alignment information. A list of available VTOL transmitters can be obtained from the information sheet of a surface base (Ctrl I).
- **ILS**: Many runways are equipped with Instrument Landing Systems (ILS) to provide heading and glideslope information. ILS information is used by the HSI MFD mode. ILS frequencies are available from the runway listing in the information sheets of surface bases.
- **XPDR**: Some spacecraft and orbital stations are equipped with transponders for identification and long-range homing purposes. An XPDR signal can be fed to the Docking MFD to obtain distance and closing speed information. It is also recognised by the Docking HUD mode, which will display a target rectangle, velocity marker and distance information. The Docking HUD can be slaved to a NAV receiver with Ctrl R. XPDR frequencies can be obtained from a vessel's information sheet (Ctrl I).
- **IDS**: Instrument docking system. Most space stations and some spacecraft provide short-range approach signals for their docking ports (typical range 10 km). This signal can be fed to the Docking MFD to obtain dock alignment information. It can also be fed to the Docking HUD to display the approach path as a series of rectangles. IDS frequencies are available from a vessel's information sheet (Ctrl I).

To find out how to set up XPDR and IDS transmitters via a cfg script see the 3DModel document.

16 Basic flight manoeuvres

The following flight techniques are mostly my own invention. They seem plausible, but since I am not a space flight expert (although an enthusiastic amateur) they may be inefficient or plainly wrong. Corrections and suggestions are always welcome.

16.1 Surface flight

By *surface flight* I mean flight paths close to a planetary surface which are not actually orbits, i.e. where the gravitational field of the planet must be countered by applying an acceleration vector, rather than the free fall situation of an orbit. Surface-to-surface transfers (from one surface base to another) typically involve surface flight.

If the planet has no atmosphere

In this case the only forces acting on your ship are the planet's gravitational field and whatever thrust vectors you apply. Most notably, there is no atmospheric friction to reduce the ship's "airspeed". This causes a flight model rather different from a normal airplane. The simplest, but probably not the most efficient strategy for surface flight is:

- Use hover thrusters to balance gravitational acceleration (can be done automatically with "Hold altitude" nav mode). This also means the ship should be kept level with the horizon.
- Navigate with short main thruster bursts.
- At high horizontal velocities the flight path may approach an orbital trajectory. In that case hover thrusters must be reduced to maintain altitude. In the extreme case of horizontal velocity exceeding the orbital velocity of a circular orbit at zero altitude, the ship will gain altitude even for disengaged hover thrusters. That means you have entered into an elliptic orbit at periapsis.

If the planet has an atmosphere

When flying through an atmosphere, the flight model will be similar to an airplane's, in particular if your ship essentially *is* an airplane, i.e. has airfoils that produce a lift vector as a function of airspeed. As with an airplane, you need to apply continuous thrust to counter atmospheric friction and maintain a constant airspeed. If your ship produces lift, hover thrusters are not necessary unless airspeed falls below stall speed (e.g. during vertical lift-off and landing). If your ship does not generate a lift vector, hover thrusters must be substituted, or the ship must be tilted such that the main thrusters provide a vertical component to counter the gravitational field. Note that "lift" produced by thrusters is independent of airspeed.

16.2 Launching into orbit

Launching from a planetary surface and entering into a low orbit is one of the most basic problems of space flight. During the early part of the launch the ship needs to apply vertical thrust to overcome the gravitational field and acquire altitude. As the ship approaches the desired altitude, the pitch is reduced to increase the horizontal acceleration component, in order to reach orbital velocity. A stable orbit is achieved as soon as the periapsis distance is sufficiently high above the planetary surface so that atmospheric friction can be neglected.

Orbits should usually be prograde i.e. rotate in the same direction as the planet surface, to exploit the initial velocity vector provided by the planet. (That is, on Earth ships should be launched eastwards). This also means that launch sites near the equator are most efficient since they provide the largest initial velocity.

In Practice:

(This assumes the ship is initially placed on the Earth's surface).

- Set HUD to surface mode. Bring up Surface and Orbit MFD modes.
- Engage hover thrusters to at least $10 m/s^2$.
- Once free of the surface, turn towards east (90° on HUD compass ribbon).
- Raise nose to 70° pitch, while at the same time engaging full main thrusters.
- As air speed increases, bring hover thrusters slowly back to zero.
- As you gain altitude, slowly reduce pitch (e.g. 60° at 20km, 50° at 50km, 40° at 80km, etc.
- As the desired altitude is reached (e.g. 200km) the vertical velocity and acceleration should fall to zero. (by reducing pitch, not by killing the thrusters). Pitch may still be > 0

because part of the thrust vector is required to counter gravitation until full orbital velocity is reached.

- As the tangential velocity increases, pitch should be reduced to maintain constant altitude.
- As soon as the tangential velocity for a circular orbit is reached (eccentricity = 0) thrusters should be killed.

16.3 Changing the orbit

To change the shape of the orbit without changing the orbital plane, the thrust vector must be applied in the orbital plane. The simplest maneuvers involve modifying the apoapsis or periapsis distances.

- Increase apoapsis distance: Wait until the ship reaches periapsis. Apply thrust vector prograde (ship orientated along velocity vector, engage main thrusters).
- Decrease apoapsis distance: Wait until the ship reaches periapsis. Apply thrust vector retrograde (ship orientated against velocity vector, engage main thrusters).
- Increase periapsis distance: Wait until the ship reaches apoapsis. Apply thrust vector prograde.
- Decrease periapsis distance: Wait until the ship reaches apoapsis. Apply thrust vector retrograde.

In Practice:

Case 1: Assume you want to change from a low circular orbit (200km) into a higher circular orbit (1000km).

- Turn ship prograde and engage main thrusters.
- Kill thrusters as soon as apoapsis distance reaches 1000km+planet radius (e.g. 7370km for Earth). Use *Orbit* MFD mode to monitor this.
- Wait until you reach apoapsis.
- Turn ship prograde and engage main thrusters.
- Kill thrusters as soon as periapsis equals apoapsis and eccentricity is back to 0.

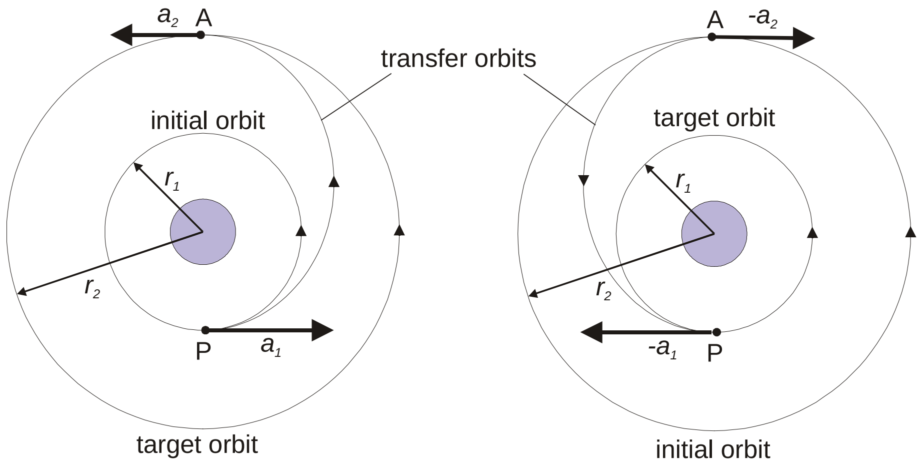


Figure 24: Moving into a higher orbit involves prograde acceleration at P and A (periapsis and apoapsis of the transfer orbit). Conversely, moving from the higher to the lower orbit requires retrograde acceleration at A and P.

Case 2: Rotate the argument of periapsis of an elliptic orbit (i.e. rotate the orbital ellipse in its plane).

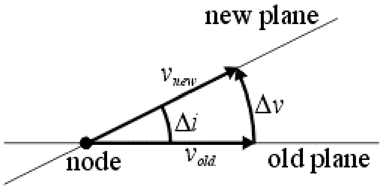
- Wait until you reach periapsis.
- Turn ship retrograde and engage main thrusters until orbit is circular (eccentricity = 0).
- Wait until you reach the desired new periapsis position.
- Turn ship prograde and engage main thrusters until original eccentricity and apoapsis distances are re-established.

16.4 Rotating the orbital plane

When trying to rendezvous with another object in orbit, the required orbit changes can often be simplified by splitting them into two separate phases: a plane change that rotates the plane of the current orbit into that of the target, and further in-plane operations that only require the application of thrust in the plane of the orbit. Once you are in the same plane as your target, most of the following navigational problems become essentially two-dimensional, which makes them more robust and a lot easier to compute.

In terms of the orbital elements, aligning the plane of the orbit with a target plane means to match the two elements which define the orientation of the orbit in space: inclination (i) and longitude of the ascending node (Ω).

The rotation of the orbital plane requires the application of out-of-plane thrust. To match the plane with a target plane, thrust should be applied normal to the current plane, in one of the nodes (the points where the orbit crosses the intersection of the current and target planes). This will rotate the orbital plane around an axis defined by your current radius vector.



The amount of normal Δv required to rotate by a given angle Δi is proportional to the orbital velocity v. It is therefore more fuel-efficient to perform the plane change where v is small, i.e. close to aphelion. For a given line of nodes, it is more efficient to perform the plane change at the node closer to aphelion. Sometimes it may even be useful to make the orbit more eccentric prior to the plane change maneuver, so that the radius distance of one of the nodes is increased.

Note:

- If the angle between the initial and target OP is large it may be necessary to adjust the orientation of the spacecraft during the maneuver to keep it normal to the OP.
- It may not be possible to align the plane in a single node crossing. If the angle towards the target plane cannot be reduced further by accelerating normal to the current orbit, cut the engines and wait for the next node crossing.
- Since the maneuver will take a finite amount of time ΔT, thrusters should be engaged approximately ½ ΔT before intercepting the node.

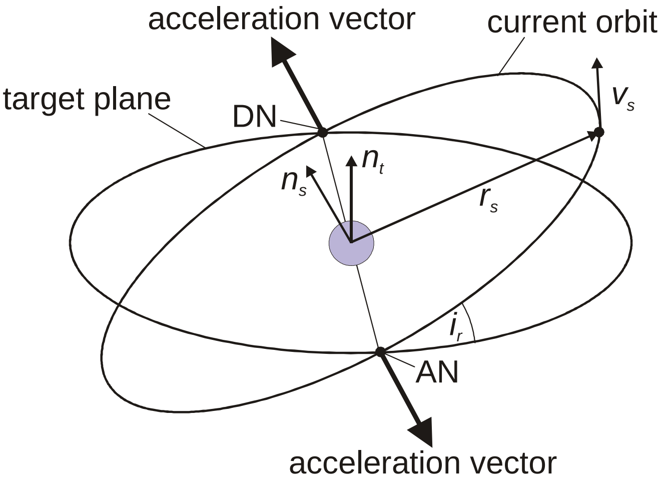


Figure 25: Alignment of the orbital plane. r_s*: radius vector.* v_s*: velocity vector. AN: ascending node. DN: Descending node.* n_s*: normal of the current plane.* n_t*: normal of the target plane.*

The direction of the normal vector n_s is defined by the direction of the cross product $r_s \times v_s$. Acceleration should be applied in direction $-n_s$ in the ascending node (AN), and in direction $+n_s$ in the descending node(DN). (see Figure 25).

In Practice:

- The *Align orbital plane* MFD mode (see Section 13.8) is designed to aid in plane alignment. Select the target object (Shift T).
- The HUD should be in Orbit mode. As your ship approaches the intersection with the target plane, rotate it to a normal (if at DN) or anti-normal (if at AN) orientation to the current orbital plane. There are automated RCS sequences (; and ') available to perform the required alignment. Use the HUD Orbit inclination ladder to monitor progress.

- As soon as the time to node (*Tn*) reaches half the estimated burn time (*TthA* or *TthD* for AN and DN, respectively) the “Engage thruster” indicator will start flashing. Engage full main thrusters. Make sure the relative inclination (*RInc*) decreases, i.e. the rate of change (*Rate*) is negative, otherwise you may be pointing in the wrong direction.
- Adjust the ship’s orientation as required to keep normal to orbital plane (the automated RCS sequences will do this for you).
- Disengage thrusters as soon as the action indicator turns back to “Kill thruster”.
- If the relative inclination was not sufficiently reduced repeat the procedure at the next node passage.
- During the maneuver make sure your orbit does not become unstable. Watch in particular for the eccentricity (use the Orbit MFD to monitor this).

16.5 Synchronising orbits

This section assumes that the orbital planes of ship and target have been aligned (see previous section).

The next step in a rendezvous maneuver after aligning the orbital planes is to modify the orbit in the plane such that it intercepts the target’s orbit and both ship and target arrive simultaneously at the interception point. Use the *Synchronise Orbit* MFD to calculate the appropriate orbit.

For simplicity we first assume that the ship and target are in a circular orbit with the same orbital radius (for synchronising the orbital radius see Section 16.3), i.e. both objects have the same orbital elements except for the mean anomaly. The method for intercepting the target is then as follows:

- Switch the reference mode of the *Synchronise Orbit* MFD to “Manual” and rotate the axis to your current position.
- Turn your ship prograde (using Orbit HUD mode) and fire main thrusters.
- The orbit will become elliptic, with increasing apoapsis distance. Periapsis is your current position. Simultaneously the orbit period and the times to reference axis will increase.
- Kill thrusters as soon as one of the Sh-ToR times coincides with one of the Tg-ToR times.
- Then you just have to wait until you intercept the target at the reference axis.
- At interception, fire thrusters retrograde to get back to the circular orbit and match velocity with the target.

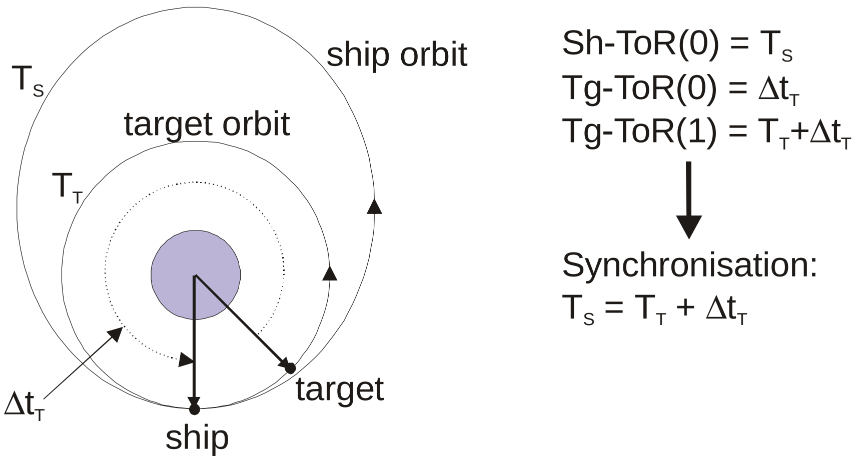


Figure 26: A transition orbit to intercept the target at the next periapsis passage.

Notes:

- Instead of increasing the apoapsis distance one could fire retrograde and reduce the periapsis distance in this maneuver. This may be more efficient if the target is ahead of the ship. But make sure that periapsis does not become dangerously low!
- It should always be possible to match your next ToR (orbit 0) with the target’s ToR at orbit 1. If you are low on fuel it may however be better to match later orbits if this can be achieved with less distortion to the original orbit. For example, if the target is marginally ahead, then to intercept it in the next orbit you need to nearly double your orbital period.

- It is not essential that the orbits are identical or circular at the start of the maneuver. It is sufficient for them to intersect. In that case it is best to use Intersection 1 or 2 reference mode in the *Synchronise* MFD.
- You don't necessarily need to wait until you reach the reference point before firing thrusters, but it simplifies matters because otherwise the intersection point itself will move, making the alignment of orbit timings more difficult.

16.6 Landing (runway approach)

Some of Orbiter's spacecraft support powered or unpowered runway approaches, similar to normal aircraft. Examples are the delta glider and the Space Shuttle. The Shuttle Landing Facility (SLF) at the Kennedy Space Center provides an good opportunity for exercising landing approaches.

Visual approach indicators

The visual approach aids at the SLF are designed for Shuttle landings. They include a Precision Approach Path Indicator (PAPI) for long-range glide slope alignment, and a Visual Approach Slope Indicator (VASI) for short-range alignment. The PAPI is set up for a glide slope of 20° (about 6 times as steep as standard aircraft approach slopes!). The VASI is set up for a 1.5° slope during the final flare up prior to touchdown.

Precision Approach Path Indicator

The PAPI consists of an array of 4 lights, which appear white or red to the pilot depending on his position above or below the glide slope. At the correct slope there will be 2 white and 2 red lights (see figure). In Orbiter there are 2 PAPI units per approach direction at the SLF, located about 2000 meters in front of the runway threshold.

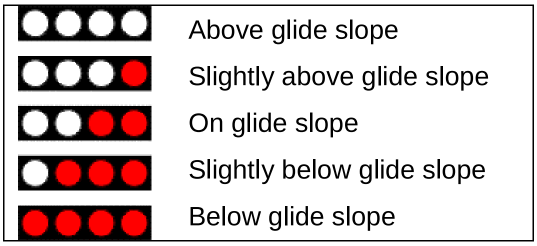


Figure 27: PAPI indicator signals

Visual Approach Slope Indicator

The VASI consists of a red bar of lights, and a set of white lights in front of them. At the correct slope, the white lights are aligned with the red bar. (see figure). At the SLF, the VASI is located about 670 meters behind the runway threshold.

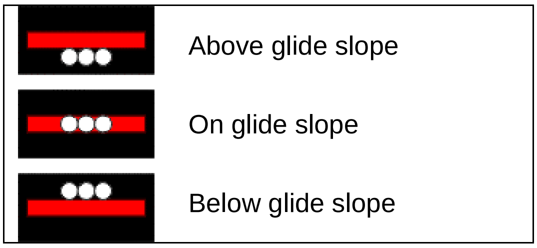


Figure 28: VASI indicator signals

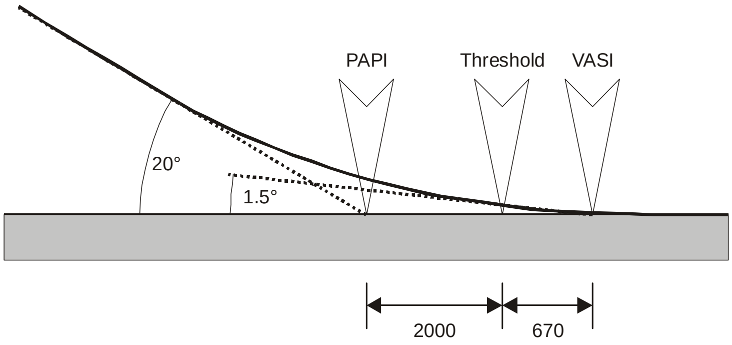


Figure 29: SLF Shuttle approach path

16.7 Docking

Docking to an orbital station is the last step in the rendezvous maneuvered. Assuming you have intercepted the target station following the preceding steps, here we discuss the final docking approach.

- Select *Docking mode* in one of your MFD displays, and the *Docking* HUD by pressing H until docking mode is selected.
- Tune one of your NAV receivers to the station's XPDR frequency, if available. The frequency is listed in the station's information sheet (Ctrl I).
- Slave the Docking MFD and Docking HUD to that NAV receiver (Shift N and Ctrl R, respectively)
- If not done already, synchronise relative velocity by turning the ship until it is aligned with the relative velocity marker (⊕) and fire main thrusters until velocity value (V) approaches zero.
- Rotate the ship to face the station (□ marker).
- At a range of approx. 10 km, tune a NAV receiver to the IDS (Instrument Docking System) frequency of the designated docking port, if available. Slave Docking MFD and Docking HUD to that receiver, if applicable. This will display orientation and direction information in the MFD, and a visual representation of the approach path in the HUD (rectangles).
- Move towards the approach path rectangle furthest away from the station and hold.
- Align the ship's heading with the flight path direction using the 'X' indicator in the MFD.
- Align the ship's position on the approach path using the '+' indicator in the MFD. Switch attitude thrusters to linear mode for this.
- Align the ship's rotation along its longitudinal axis using the arrow indicator in the MFD.
- Approach the station by engaging main thrusters briefly. During approach correct your position continuously using linear attitude thrusters.
- Slow down approach speed to less than 0.1m/s before intercepting the dock.
- You need to approach the dock to less than 0.3 m for a successful docking maneuver.
- To disengage from the docking port, press Ctrl D.

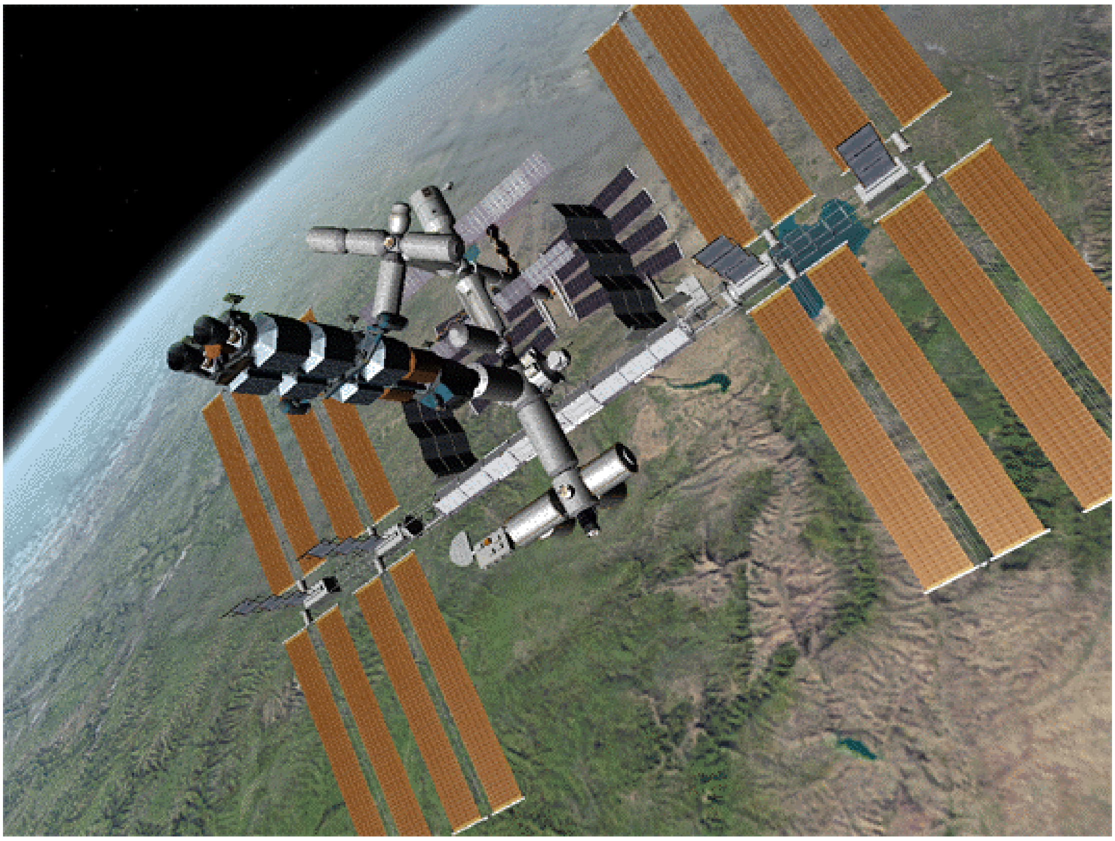


Figure 30: A Shuttle-A class cargo ship after successfully completed docking approach to the ISS.

Notes:

- For precise attitude control with the keyboard use the attitude thrusters in “low power” mode (Ctrl + Numpad key).
- Rotational alignment is not currently enforced, but may be in future versions.
- Currently no collision tests are performed, so you might fly straight through the station if you miss the docking approach.

Docking at rotating stations

Stations like Luna-OB1 rotate to use centrifugal forces for emulating gravity – which is nice for their inhabitants but makes docking a bit more complicated. Docking is only possible along the rotation axis, so at most 2 docking ports can be provided. The docking procedure is similar to the standard one, but once aligned with the approach path, the rotation around the ship’s longitudinal axis must be aligned with that of the station.

Important:

- Initiate your ship’s longitudinal rotation only immediately before docking (when past the last approach marker). Once you are rotating, linear adjustments become very difficult.
- Once the rotation is matched with the station, don’t hit Numpad5 (Kill rotation) by accident, or you will have to start the rotation alignment again.

Cheat:

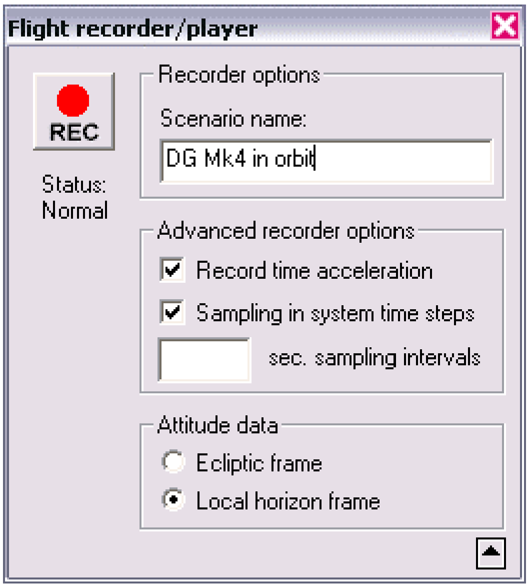
Since rotational alignment is not enforced at present, you can simply ignore the rotation of the station and fly straight in.

NEW!

17 Flight recorder

You can record and play back your Orbiter simulation sessions with the built-in flight recorder feature. To access the recorder during a simulation, open the *Flight recorder/player* dialog with Ctrl F5. You can now select a name for the recorded scenario. By default, the recording will be stored under the current scenario name. Then press the *REC* button to begin recording the flight to disc. Press the *STOP* button to turn the recorder off again. You can also start and stop the recorder directly from the simulation with the keyboard shortcut Ctrl C. An active recorder is indicated by a "Record" box in the simulation window.

Some additional recorder options can be accessed by pressing the ∇ button. These include:



Scenario name: DG Mk4 in orbit

☑ Record time acceleration

☑ Sampling in system time steps

sec. sampling intervals

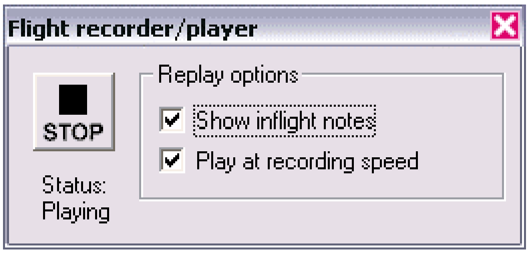
○ Ecliptic frame

● Local horizon frame

- **Record time acceleration**: this option records any changes in time compression during the recording. During playback, the user has then the option to set time compression automatically from the recorded data.
- **Sampling in system time steps**: If ticked, the intervals between recorded data samples are determined in system time, otherwise in simulation time. In system time, sampling is less dense during time compression. This allows to reduce the size of the data files when recording over long periods of time, by fast-forwarding through less critical parts of a mission.
- **Sampling intervals**: Currently not used.
- **Attitude data**: Can be recorded either with respect to the global ecliptic frame of reference, or with respect to the local horizon of the current reference celestial body.

To play back a previously recorded session, launch the scenario under the *Playback* scenario folder. During playback, all vessels will follow their pre-recorded trajectories and will not respond to manual user control. At the end of the playback, the simulation will automatically switch back to manual mode, and the user can take over control. You can terminate the playback before the end of the recorded data is reached by pressing Ctrl C, or by pressing the *STOP* button in the Recorder dialog. In that case, control returns immediately to the user.

During playback, the user has still various options to interact with the simulation. For example, it is possible to move the camera, change between internal and external views, and even manipulate the MFD instruments to access more flight data. Manual control of time compression is only possible if the *Play at recording speed* option is deactivated in the Player dialog (Ctrl F5). Otherwise, Orbiter sets the time compression directly from the recorded data.



☑ Show inflight notes

☑ Play at recording speed

Recorded flights can be annotated with onscreen notes which appear on the simulation window at predefined times. This opens an exciting new way to write tutorials and space flight demonstrations. (The annotations can be turned off from the recorder dialog during a playback by deactivating the *Show inflight notes* option).

The data for recorded simulation sessions are stored under the *Flights* subdirectory. Orbiter creates a new folder for each recording, using the same name as the recorded scenario. Each vessel in the scenario writes three data streams to this folder, including:

- **position and velocity** (*.pos). At the moment, these data are recorded relative to the reference planet, either in a non-rotating reference system (ecliptic and equinox of J2000), or a rotating equatorial reference system. As a result, trajectories are recorded in an absolute time frame. Samples are written in regular intervals (currently 4 seconds) or if the velocity vector rotates by more than 5 degrees.
- **attitude** (*.att). Attitude data are saved in terms of the Euler angles of the spacecraft with respect to the ecliptic reference frame or local horizon frame. Samples are written whenever one of the angles has changed by more than a predefined threshold limit.
- **articulation events** (*.atc). This stream contains changes in thrust levels of spacecraft engines, and other types of events (e.g. change of RCS mode, activation/deactivation of navigation modes, etc). It can also be used by individual vessel modules to record custom events such as animations. Further, time compression events can be recorded here. This data stream can also contain timed annotations that are displayed on top of the simulation window during replay. Annotations must be added manually to the atc file after the recording is completed.

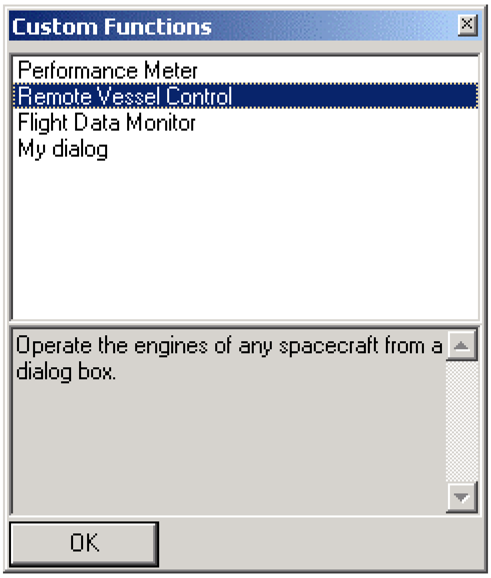
A complete recording session consists of the playback scenario in the Scenarios\playback folder, and the corresponding flight data folder under the Flights directory. To share a playback with other Orbiter users, these files must be copied. Note that the scenario file can be moved to a different Scenario folder, but no two playback scenarios can have the same name.

Be aware that long simulation sessions (in particular during time acceleration) may lead to very large data files if the *Sampling in system time steps* option is not used.

Note that the recorder feature is still under development. Future versions may introduce changes to the recording mechanism and file formats. Certain features, such as the recording of animations, require modifications to the vessel plugin modules and may not be available for all vessel types.

For more implementation details see the *RecorderRef* document in the Doc/Technotes folder.

18 Extra functionality



Operate the engines of any spacecraft from a dialog box.

Orbiter comes with a default set of plugin modules to enhance the core functionality of the simulator. To access these additional functions, the appropriate modules must be loaded in the Modules tab of the Orbiter Launchpad dialog (see Section 3.4 on how to activate plugin modules).

Many more plugins are available from 3rd party addon developers. Check out the Orbiter repositories on the web to find more.

You should only activate modules you want to use, because many plugins may access the CPU even if they are running in the background. Too many active modules can degrade simulation performance.

When activated, some plugins, such as custom MFD modes, take effect automatically whenever the simulation runs. Others are accessible via the Custom functions dialog. Press Ctrl F4 to get a list of the available functions.

NEW!

18.1 Scenario editor

→ see also: Doc\ScenarioEditor.pdf

Orbiter has an editor that allows to create, configure and delete vessels within a running simulation, and to change the simulation time. The editor is provided as a plugin module. To use it, make sure that the *ScnEditor* module is activated in the *Modules* tab of the Orbiter Launchpad dialog.

During the simulation, you can access the editor by opening the *Custom Functions* dialog with Ctrl F4, and double-clicking the *Scenario Editor* entry in the list. This will bring up the editor's main page. From here, you can either configure any vessels currently present in the simulation, or create new vessels in any location.

The operation of the scenario editor is described in a separate document: *ScenarioEditor.pdf*. This also contains a section for vessel addon developers who want to integrate the scenario editor with their vessel code.

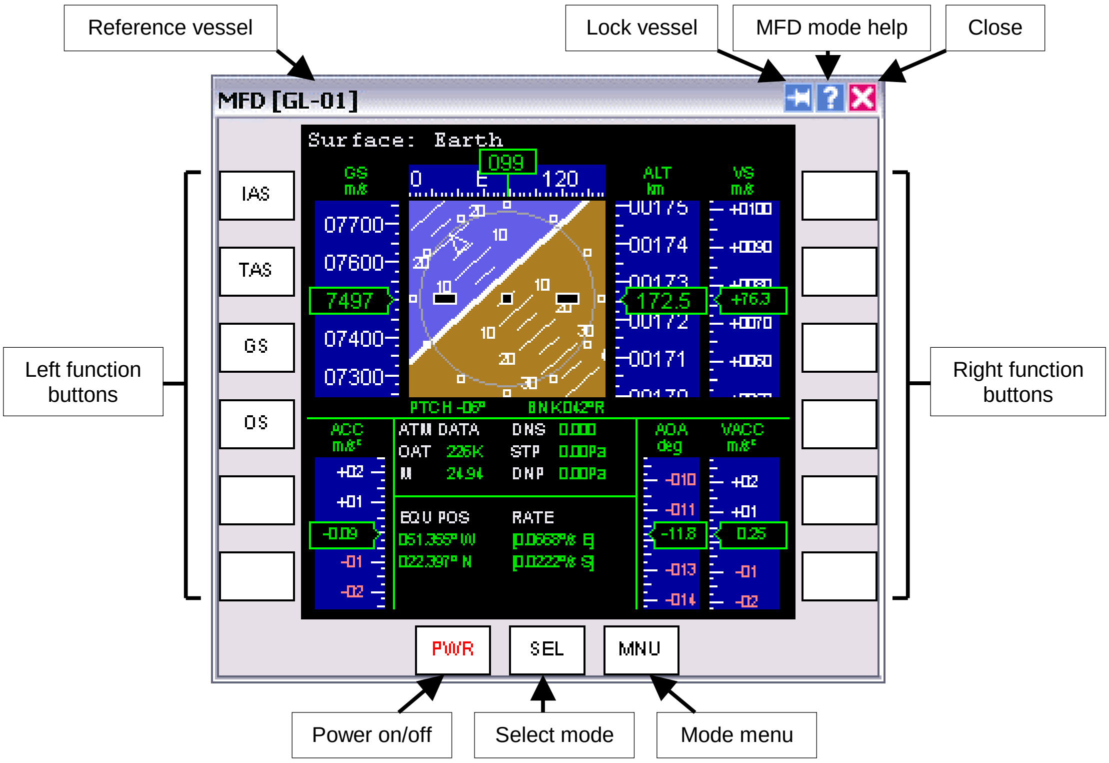
NEW!

18.2 External MFDs

If the multifunctional displays (MFD) integrated in the vessel instrument panels don't provide enough information, you can open additional MFD displays in external windows. This is particularly useful in multi-monitor setups where you can display the Orbiter simulation window on one monitor, and a set of MFDs on the other.

To open external MFDs, the *ExtMFD* module must be activated in the Orbiter Launchpad dialog. You can then open any number of MFD windows by clicking *External MFD* from the Custom Functions dialog (Ctrl F4).

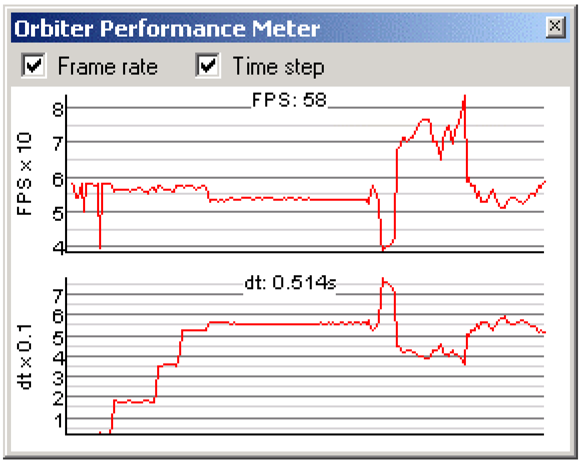
External MFDs behave in the same way as built-in MFDs. They can be controlled by pressing the buttons on the left, right and bottom edges. See Section 13 for a description of the available MFD modes and controls.



Unlike built-in MFD displays, the window MFDs can be resized. They are available in external view as well as cockpit view, and they can be configured to either automatically follow the focus vessel, or remain attached to a specific vessel, even if the focus is switched to a different vessel.

18.3 Performance monitor

This is a little dialog box to keep track of Orbiter's frame rate performance and simulation time step intervals. It shows the frames per second (FPS) and/or the step length interval (in seconds) between consecutive frames in a graphical display over the last 200 seconds. This is a useful tool to estimate the impact of complex scenery and visual effects on the simulation performance. The time step graph also incorporates the effect of time acceleration, and thus reflects the fidelity of the physical model (accuracy of trajectory calculation, etc.)

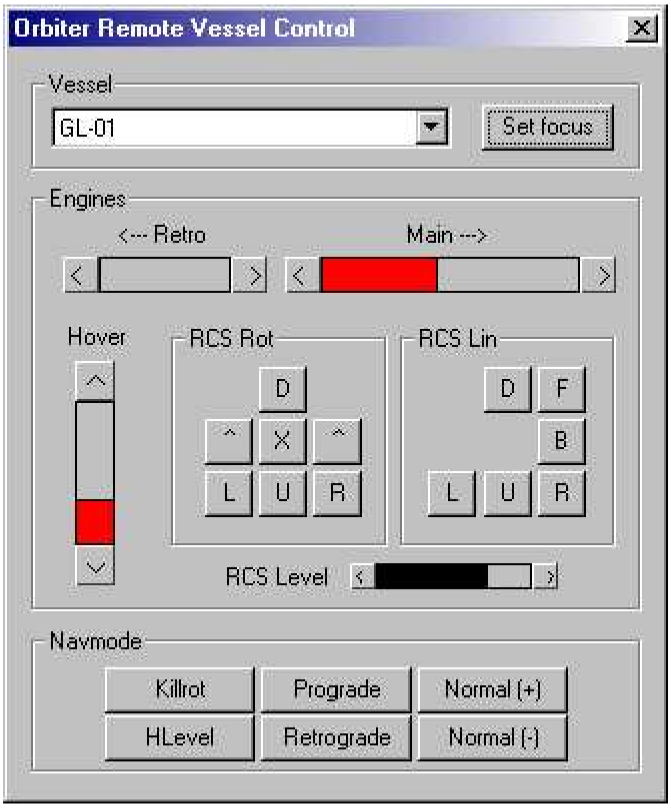


This function is only available if the *Framerate* module is active and is accessible via the *Frame Rate* entry in the *Custom functions* panel (Ctrl F4).

18.4 Remote vessel control

The *Remote Vessel Control* plugin allows to remotely control the engines of all spacecraft. The dialog contains the a vessel selection list, gauges for main, retro and hover engines, controls for RCS thrusters in rotational and linear mode, and access to the standard navmode functions. This interface can also be useful if simultaneous access to linear and rotational RCS modes is required.

This tool is available only if the *Rcontrol* module is active, and can be accessed via the *Remote Vessel Control* entry in the *Custom functions* panel (Ctrl F4).



Vessel: GL-01

Figure 31: Remote vessel control dialog.

18.5 Flight data monitor

The flight data monitor graphically displays a number of flight parameters as a function of time. This tool is available only if the FlightData module is active. The dialog box is accessible via the *Custom functions* panel (Ctrl F4).

The control area of the dialog box allows to select the vessel for which the flight data are displayed, the sampling rate, and the flight parameters to show.

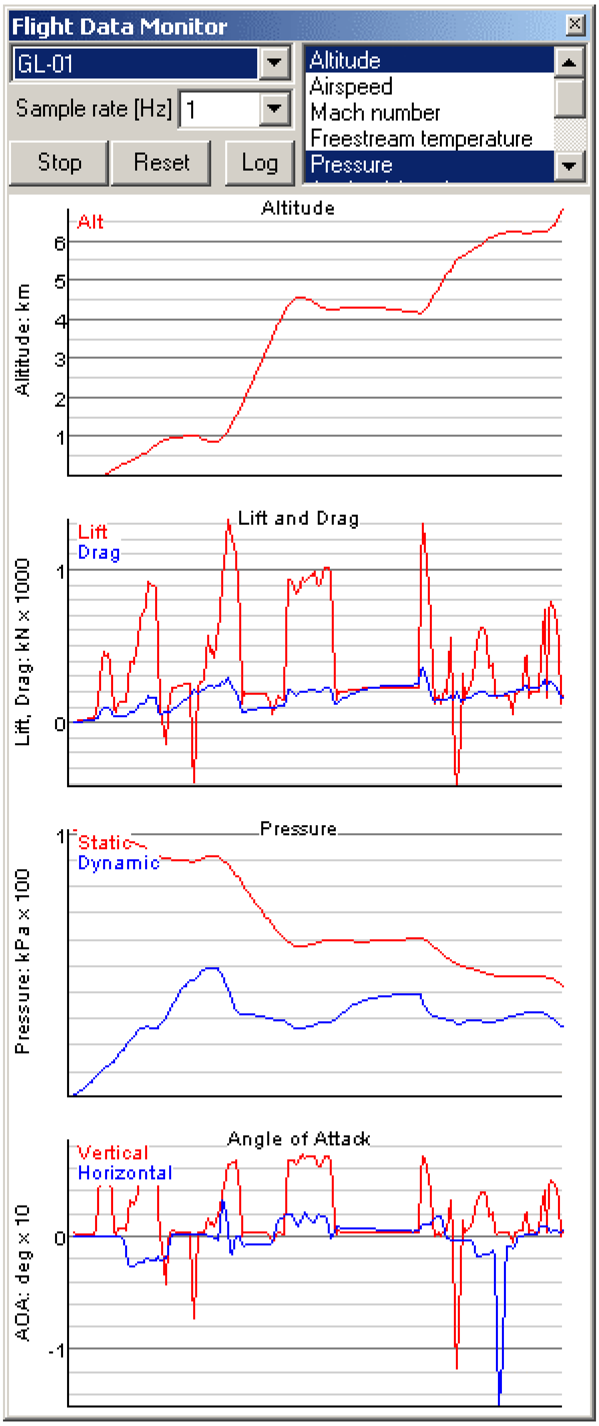
The following parameter displays are currently supported:

- Altitude
- Airspeed
- Mach number
- Free stream temperature
- Static and dynamic pressure
- Angle of attack
- Lift and drag force
- Lift over drag ratio (L/D)
- Vessel mass

For each parameter category selected in the list, a graph display is opened below the control area to track that parameter as a function of time.

- The Start/Stop button starts or stops the update of the data graphs.
- The Reset button clears the data graphs.

- The Log button starts or stops the output of flight data to a log file. When the Log button is ticked, Orbiter will write out data into text file *FlightData.log* in the main Orbiter directory. This file can later be used to analyse or visualise the data with external tools. FlightData.log is overwritten whenever Orbiter is restarted.



GL-01

Sample rate [Hz] 1

19 Flight checklists

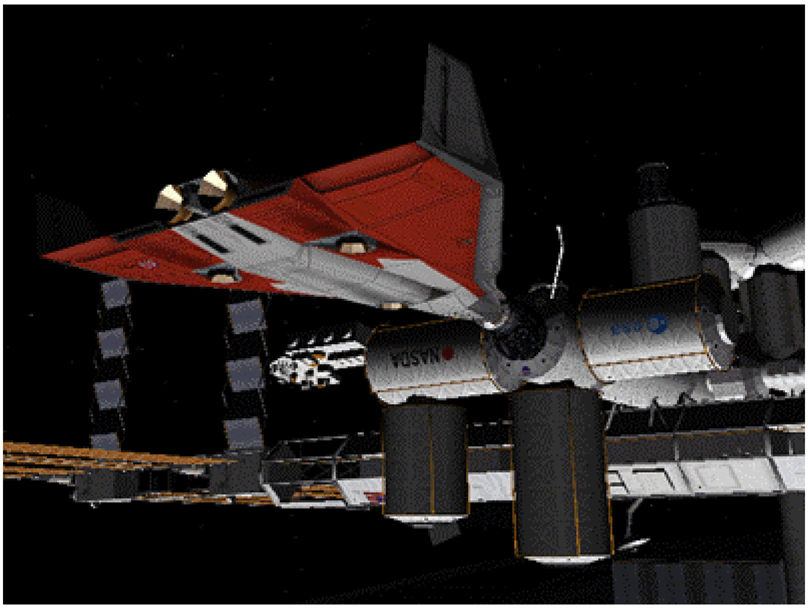
This section contains point-by-point checklists for some complete flights. While flying these checklists, you may want to save regularly (Ctrl S), so you can pick up from a previous state if necessary.
The checklists can also be accessed during the simulation when running a checklist scenario by calling up help (Alt F1) and clicking the *Scenario* button in the help window. Other scenarios may also provide online help.

19.1 Mission 1: Delta-glider to ISS

In this mission we launch the Delta-glider into orbit from runway 33 of the Shuttle Landing Facility (SLF) at the Kennedy Space Center, and perform a rendezvous and docking maneuver with the International Space Station.

- Start Orbiter with the *Checklists|DG to ISS* scenario. Your glider is ready for takeoff from SLF runway 33 at the KSC.
- You may need to scroll the instrument panel down a bit (↑$_{Cursorpad}$) to see the runway in front of you. Make sure you can still see the top half of the panel with the MFD screens.
- Your launch is scheduled at MJD=51983.6308 (the *Modified Julian Date*, or MJD, is Orbiter's universal time reference, and is shown in the top right corner of the screen). This leaves plenty of time to get used to the instrumentation. If you are not yet familiar with the glider's panel layout, check section 9.1. For details on MFD modes, see section 13.
- The left MFD screen is in *Surface* mode and shows velocity and altitude data.
- The right MFD screen is in *Map* mode and shows your current location (KSC) as a white cross. The orbital plane of the ISS is shown as a yellow curve. As time progresses, the curve will shift across the map, as the Earth rotates under the station's orbital plane.
- To fast-forward to your launch window, press T. (Each time you press T, time accelerates by a factor of 10). As you approach launch time, switch back to real-time by pressing R until the "Wrp" indicator in the top right corner of the screen disappears.
- Engage main engines (Ctrl +$_{Numpad}$) to 100% thrust. You may also use the sliders on the instrument panels or the throttle control on your joystick to operate the main engines.
- At ground speed 100 m/s (surface MFD or HUD readout), pull the stick (or press 2$_{Numpad}$) to rotate.
- Climb at 10° and retract the landing gear (G).
- Turn right towards heading 140°.
- Pitch up steeply to 70°.
- At about 30km altitude your glider will start to drop its nose due to decreasing atmospheric pressure, even while you are pulling back on the stick. Now activate the RCS (Reaction Control System) by right-clicking the "RCS Mode" selector (on the right side of the instrument panel) or by pressing Ctrl /$_{Numpad}$. You are now controlling your craft with attitude thrusters.
- Pitch down to about 20°. After leaving the dense part of the atmosphere, you need to gain tangential velocity to achieve orbit. Your flight path indicator (the "⊕" symbol on the HUD) should stay above 0°.
- Switch the right MFD to Orbit mode (*SEL*, *Orbit*). Select the ship's orbit as reference plane (Shift P) and select ISS as target (Shift T, 'ISS').
- Continue at 100% thrust. Maintain your heading, and adjust pitch angle so that the flight path vector remains slightly above 0°. You will see how your orbit trajectory (green curve in the Orbit MFD) grows.
- Cut thrusters when your apogee radius (highest point of the orbit) reaches 6.731M (the "ApR" entry in the left column of the Orbit MFD). This corresponds to an altitude of 360 km.
- Switch to Orbit HUD mode (H,H)
- So far we are on a ballistic flight path that would eventually bring us back to the surface. To enter orbit, we need to perform a further burn ("orbit insertion burn") at the apex of the trajectory. Wait until you reach apogee (the remaining time is shown in the "ApT" entry of the Orbit MFD). This could take a while, so you may want to time-accelerate.

- At apogee, press the “Prograde” button to turn prograde. Once the velocity marker (“⊕”) is centered on the screen, engage main thrusters until orbit eccentricity (“Ecc”) reaches a minimum, and perigee radius (“PeR”) equals ApR. (this will require only a short burn!)
- Switch the left MFD to Align Orbital Plane (*SEL*, *Align planes*). Select ISS (Shift T, ‘ISS’).
- Ideally the orbital planes should already be roughly aligned (RInc within 5°). You now need to fine-adjust the plane.
- As your ship (P) approaches an intersection point with the target plane (AN or DN): Rotate the ship perpendicular to your current orbital plane (90° on the Orbit HUD inclination ladder). If you are approaching the ascending node (AN), turn *orbit-antinormal*. If you are approaching the descending node (DN), turn *orbit-normal*. You can use the Auto-navigation modes (; for orbit-normal and ' for orbit-antinormal) to obtain the correct orientation.
- As soon as the “Engage engines” indicator starts flashing, engage full main engines. The relative inclination between the orbital planes should now decrease.
- Kill thrusters as soon as the “Kill thrust” indicator appears. If you could not reduce the orbit inclination sufficiently (within 0.5°) repeat the process at the next nodal point.
- Once the planes are aligned, the next step is intercepting the ISS. Switch to Sync Orbit MFD (*SEL*, *Sync orbit*). Switch the reference point to “Intersect 1” or “Intersect 2” “ (Shift M). If the orbits don’t intersect, select “Sh periapsis” instead.
- The two columns on the right of the MFD screen show the times it will take you (Sh-ToR) and your target (Tg-ToR) to pass the reference position at your current orbit (Ob 0) and the 4 subsequent orbits (Ob 1-4).
- Turn the ship prograde (align with “⊕” velocity marker of the orbit HUD). This can be done by engaging the Prograde auto-navigation mode ([).
- Fire main engines until Sh-ToR(0) matches Tg-ToR(1). You will now intercept the ISS at your next passage of the reference point. You may want to engage time acceleration until the time-on-target counters are close to zero, indicating that you are approaching the encounter point.
- On approach, tune your NAV receivers to the station’s navaid radio transmitters: Select Comm MFD mode (*SEL*, *COM/NAV*), and tune NAV1 to 131.30 MHz (ISS XPDR frequency) and NAV2 to 137.40 MHz (Dock 1 IDS frequency).
- Switch to Docking HUD mode (H,H) and to Docking MFD (*SEL*, *Docking*).
- Make sure both HUD and Docking MFD are slaved to NAV1 (use Ctrl R to cycle through the NAV receivers for the HUD, and Shift N for the MFD).
- Rotate the ship to align with the HUD relative velocity marker (“⊕”) and fire main engines until relative velocity is close to zero.
- Rotate the ship towards the ISS (□ target designator box) and move to within 5km of the station. You may want to use attitude thrusters in linear (translatorial) mode for this. Switch between linear and rotational mode with the /*Numpad* key.
- Slave HUD and Docking MFD to NAV2. If you are within 10 km of the ISS you will receive the signal of the IDS system for dock 1, providing alignment information in the MFD and a visual representation (series of rectangles) of the approach path on the HUD.
- Move towards the rectangle furthest away from the station and hold.
- Align your ship’s longitudinal axis with the approach path direction (align “X” indicator in the MFD) using attitude thrusters in rotational mode.
- Align your ship’s rotation around its longitudinal axis (align “^” indicator at 12 o’clock position in the MFD).
- Center your ship on the approach path (align “+” indicator in the MFD) using linear attitude thrusters.
- Expose the docking mechanism under the nose cone by pressing K.
- Start moving towards the dock with a short burst of the main engines. Closing speed (CVel) should be gradually reduced as you approach the dock. Final speed should be < 0.1 m/s. Re-align ship on the approach path with linear attitude thrusters as required.
- The docking mechanism should engage once you are within 0.3 m of the designated dock. A “Dock” indicator will appear in the MFD once your ship has successfully docked.
- Finished!



Mission 1 completed successfully.

19.2 Mission 2: ISS to Mir transfer

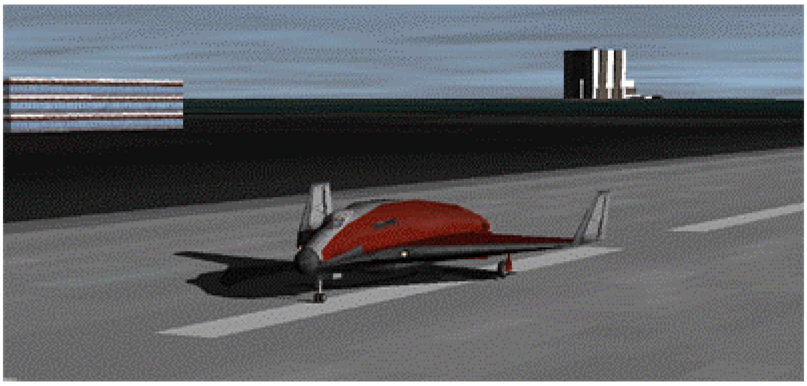
This mission performs an orbital transfer from the International Space Station to the Russian Mir station (which in Orbiter's virtual reality is still happily in Earth orbit). Note that in Orbiter, Mir is placed in an ecliptic orbit to make it a platform for interplanetary missions. This means that ISS and Mir have a very high relative inclination which makes the transfer very expensive in terms of fuel expenditure.

- Start Orbiter with the *Checklists|ISS to Mir* scenario. Your glider is docked to the ISS.
- Press F1 to jump into the glider's cockpit.
- Select target Mir in Orbit MFD: Press Right-Shift T, Enter, "Mir".
- ISS and Mir orbits have a high relative inclination. To prepare for orbit change, select the Align plane mode in the left MFD (*SEL*, *Align planes*, and Left-Shift T, "Mir").
- Undock from the ISS (Ctrl D). Once you are clear of the dock, close the nose cone (K).
- Switch to Orbit HUD mode (H).
- The first burn will take place at the DN (descending node) point. Use time compression to fast-forward there, but switch back to real-time when the "time-to-node" (Tn) value in the Align plane MFD is down to 500.
- Prepare attitude for the burn: click the "Orbit normal (+)" button. Your glider will now orient itself perpendicular to the orbital plane.
- When the "Engage engines" indicator in the Align MFD begins to flash, engage full main engines. The relative orbit inclination (RInc) should start to drop. Terminate the burn when the "Kill thrust" indicator appears and the inclination reaches its minimum.
- This is a very long burn (about 900 seconds), so you may want to fast-forward, but do not miss the end of the burn!
- You probably won't be able to sufficiently reduce the inclination (less than 0.5°) in a single burn. Repeat the process at the AN (ascending node) point. Remember that the glider must be oriented in the opposite direction for this burn, by clicking the "Orbit Normal (-)" button.
- Once the orbital planes are aligned, you need to plot a rendezvous trajectory using the Sync Orbit MFD. The procedure is the same as in the previous mission.
- Tune your NAV1 receiver to MIR's transponder frequency at 132.10, and NAV2 to the IDS frequency of Dock 1 at 135.00.
- Once the sync maneuver is complete, switch the HUD to Docking mode (H,H), and switch one of the MFD displays to Docking (*SEL*, *Docking*). Slave both HUD and MFD to NAV1.
- Proceed with the docking maneuver to Mir in the same way as you did for docking at the ISS in the previous mission. Don't forget to open the nose cone before making contact.

19.3 Mission 3: De-orbit from Mir

This mission completes your orbital roundtrip with a re-entry to return to Kennedy Space Center.

- Start Orbiter with the *Checklists/Deorbit* scenario. This picks up where the previous mission ended, with the glider docked to the Mir station. You are currently over the Pacific ocean, already it the correct location for the deorbit burn.
- Undock (Ctrl D), and engage retros for a few seconds (- *Numpad*) to get clear of the station.
- Close the nose cone (K).
- Turn retrograde (]).
- When the glider's attitude has stabilised and the retrograde direction is no longer obstructed by the station, engage main engines at 100%.
- Kill engines when the perigee radius (PeR in Orbit MFD) has decreased to 5.600M.
- Turn prograde ([).
- When attitude has stabilised, roll the glider level with the horizon (L).
- Switch to Surface HUD mode (H).
- Turn left MFD into Surface mode (*SEL*, *Surface*).
- You should reach 100 km altitude about 4000 km from the target (Dst: 4.000M in Map MFD). At this point, aerodynamic forces will become noticeable.
- At 50 km altitude, turn off attitude stabilisation (L), disable the RCS (Ctrl / *Numpad*), and make sure that "AF CTRL" is set to "ON".
- Lift forces will cause the glider to pitch up. To bleed off energy you should perform left and right banks. Due to the relatively high lift/drag ratio of the glider you need very steep bank angles (90°).
- Your current flight path passes south of the KSC, so you should initially bank left to correct your approach path (check Map MFD).
- The bank angle will determine your rate of descent and airspeed. If you come up short to the KSC, reduce the bank angles to slow your descent and reduce atmospheric deceleration. If you come in too fast or too high, increase the bank angles to increase the descent slope and atmospheric friction.
- Timing of the reentry path is not quite as critical as for the Space Shuttle, because the glider can use its engines for a powered approach.
- When the distance to target drops below 500 km, tune your NAV1 receiver to frequency 112.70 (KSCX VOR), and NAV2 to frequency 134.20 (Rwy 33 ILS) using the COMMS mode (*SEL*, *COM/NAV*) in the right MFD.
- Turn the right MFD to Horizontal Situation Indicator (HSI) mode (*SEL*, *HSI*). Leave the left display slaved to NAV1, and flip the right display to NAV2 (Right-Shift F, Right-Shift N).
- Use the course deviation and glide slope indicators of the HSI displays for adjusting the approach path. They work like standard aircraft instruments.
- Lower landing gear (G). Deploy airbrakes (Ctrl B) as required. Touchdown speed is 150 m/s.
- Use wheel brakes (. and .) on rollout until you come to a halt.



Rollout at the KSC SLF.

20 Visual helpers

Orbiter has the ability to display a number of visual cues to provide additional data to the user. These include

- a “Planetarium”mode that projects different coordinate grids onto the celestial sphere and provides markers and labels for various simulation objects, and celestial and planetary surface features.
- the display of force vectors on spacecraft
- the display of coordinate axes on different objects

The visual helper options can be configured via a dialog (Ctrl F9).

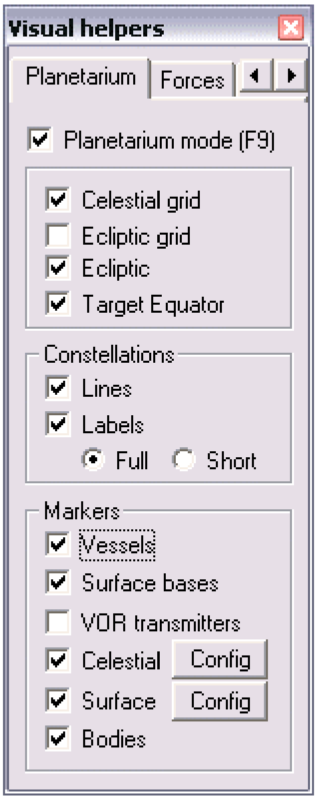
20.1 Planetarium mode

Lost in space? If you lose your bearings in the middle of an interplanetary flight, Orbiter offers guidance in the form of an inflight “planetarium” with grids and object markers. To configure the planetarium options, open the *Visual helper* dialog (Ctrl F9) and select the *Planetarium* tab. A shortcut for turning the planetarium on and off is F9. The following items are available:

- Celestial grid lines (Earth equatorial reference frame)
- Ecliptic grid lines
- Ecliptic great circle
- Equator great circle of the target body (if applicable)
- Constellation lines and labels (full and abbreviated)
- Markers for celestial bodies
- Vessel markers
- Surface base markers
- Markers for navigation radio transmitter locations
- Markers for user-defined objects on the celestial sphere
- Markers for user-defined planetary surface labels

Some marker types will not be visible if the object is out of range, or from a planet surface during daylight.

Figure 33 shows some of the grids and markers available in the simulation.



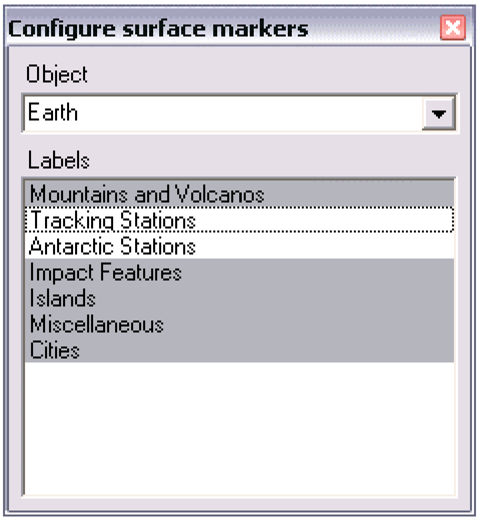
☑ Planetarium mode (F9)

☑ Celestial grid
☐ Ecliptic grid
☑ Ecliptic
☑ Target Equator

Constellations
☑ Lines
☑ Labels
● Full ○ Short

Markers
☑ Vessels
☑ Surface bases
☐ VOR transmitters
☑ Celestial
☑ Surface
☑ Bodies

Planets may define their own sets of surface markers, to locate items such as natural landmarks, points of interest, historic landing sites, navigational aids, etc. Likewise, the planetary system may define sets of markers to identify bright stars, navigation stars, nebulae, etc. You can select marker sets by clicking the "Config" button. This opens a further dialog box, where you can highlight the appropriate sets from a list box. Additional lists may be available as addons from Orbiter internet repositories. If you want to modify the provided marker sets or create your own, see Section 22.6.



Object: Earth

Labels:
Mountains and Volcanos
Tracking Stations
Antarctic Stations
Impact Features
Islands
Miscellaneous
Cities

Orbiter now stores the current planetarium settings in its configuration file, and remembers them in the next simulation run.

Hardcore space simmers may spurn the planetarium as a cheat mode, but for the rest of us it can be a handy tool, and also helps in visualising the dynamics of planetary systems.

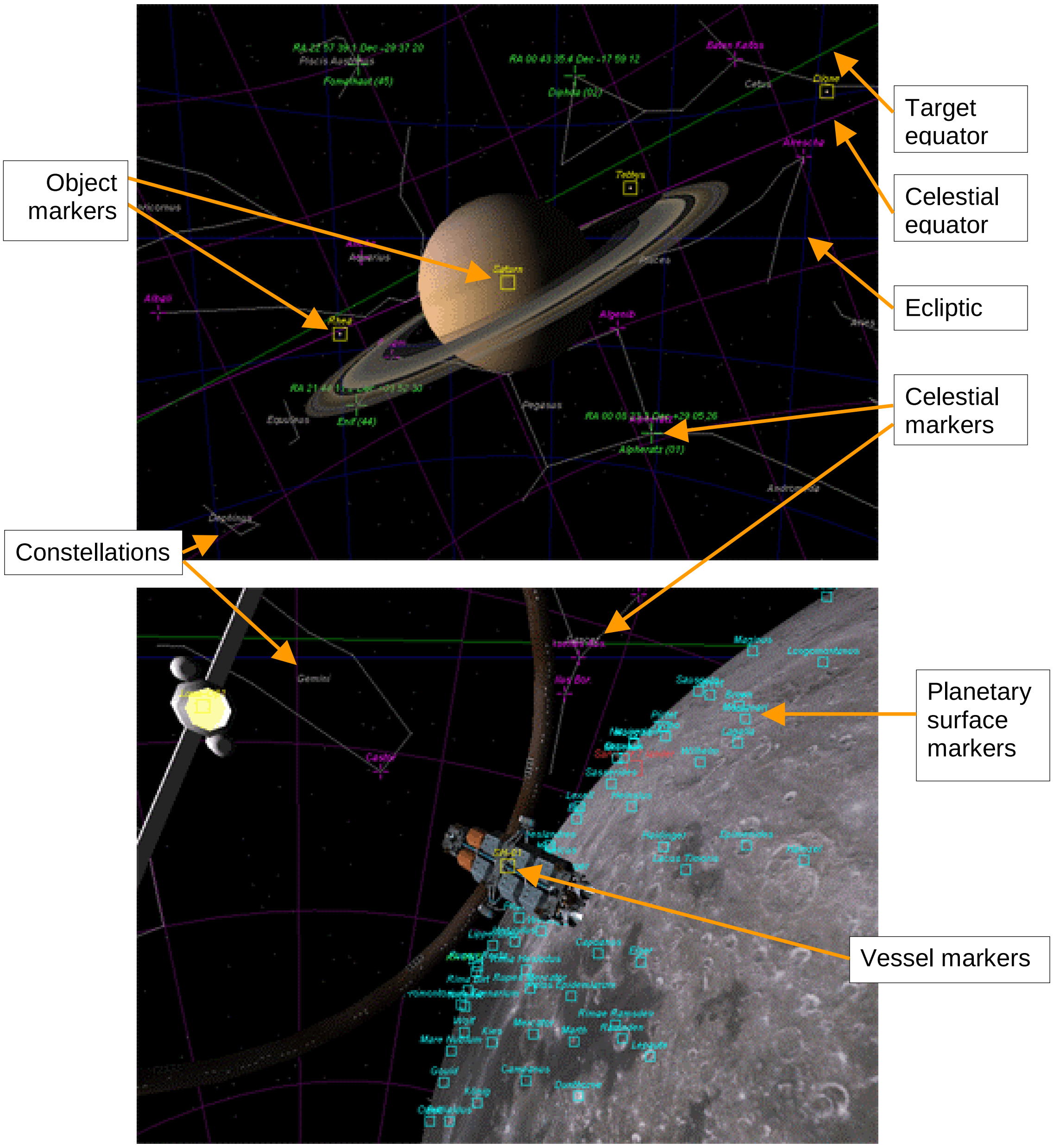


Figure 33: Grid lines, celestial, vessel and surface markers.

NEW!

20.2 Force vectors

Orbiter can provide a graphical display of the force vectors currently acting on a spacecraft. This option is particularly useful for educational applications, to provide a direct feedback of the effects of environmental parameters (gravity, atmosphere) and user input (e.g. change of lift as a function of changing angle of attack).

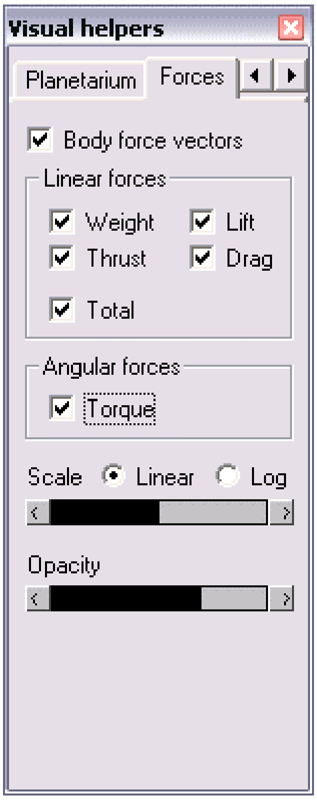
The display of force vectors can be activated and configured via the *Force* tab in the Visual helpers dialog (Ctrl F9).

Tick *Body force vectors* to enable the vector display.

Orbiter allows to show a number of separate linear force components as well as the resulting total force:

Weight	G (yellow)	force due to gravitational field
Thrust	T (blue)	force generated by the vessel's propulsion system
Lift	L (green)	lift force generated by lifting airfoils in airflow
Drag	D (red)	drag force generated by motion through atmosphere

Total	F (white)	total force acting on the vessel



Visual helpers

☑ Body force vectors

Linear forces

☑ Weight ☑ Lift
☑ Thrust ☑ Drag
☑ Total

Angular forces

☑ Torque

Scale ● Linear ○ Log

Opacity

Note that the total force shown may not be equal to the sum of the four component forces, because additional forces may be acting on the vessel (e.g. user-defined forces).

Linear forces are shown graphically as vector arrows originating at the vessel's centre of gravity. The vector lengths are proportional to the force magnitudes, or logarithm of the magnitudes, depending on the *Scale* setting. The lengths can be adjusted with the provided slider. In addition, the magnitudes are also shown numerically in units of Newton [N].

In addition to the linear forces, Orbiter can also display the acting total torque,

$$\mathbf{M} = \sum_i \mathbf{M}_i = \sum_i \mathbf{F}_i \times \mathbf{r}_i \ .$$

The torque vector is shown w.r.t. the centre of gravity of the vessel. The numerical value is shown in units of Newton × metre [Nm].

Note that for forces that are not generated at the vessel's centre of gravity (e.g. the lift vector), the total force displayed is broken up into a linear component originating at the centre of gravity, and a corresponding torque.

The opacity of the displayed force vectors can be adjusted with the *Opacity* slider, from completely transparent to completely opaque.

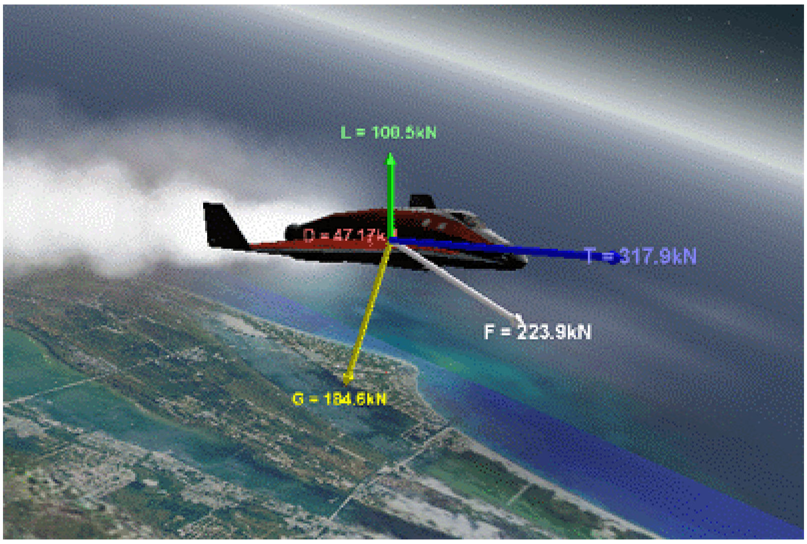


Figure 34: Dynamics in action: A Delta-glider displaying the forces acting on its airframe.

NEW! 20.3 Coordinate axes

The orientation of the coordinate axes for the local frames of vessels, celestial bodies and spaceports can be displayed with the *Axes* tab of the Visual helpers dialog (Ctrl F9). Coordinate frames can be useful in particular for addon designers who want to make sure that the orientation of their spacecraft design within the simulator is correct.

The display of coordinate axes is enabled by ticking the *Coordinate axes* box.

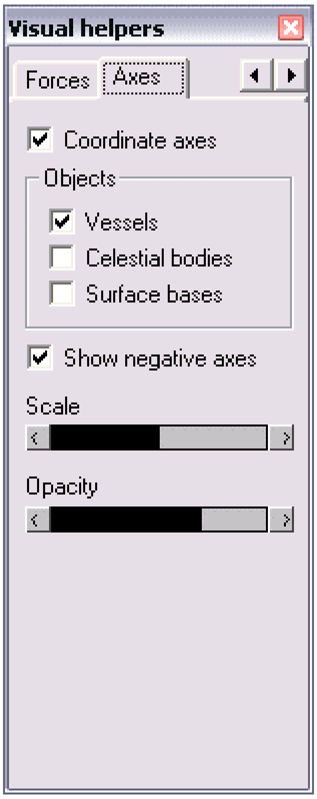
Axes can be displayed for

- vessels (spacecraft)
- celestial bodies (planets and moons)
- surface bases

Unless the *Show negative axes* box is ticked, only the positive x, y and z axes are displayed.

The length of the axis vectors can be adjusted with the *Scale* slider.

The opacity of the displayed vectors can be adjusted with the *Opacity* slider.



☑ Coordinate axes

☑ Vessels
☐ Celestial bodies
☐ Surface bases

☑ Show negative axes

21 Demo mode

Orbiter can be run in "demo" or "kiosk" mode to facilitate its use in public environments such as exhibitions and museums.

Demo mode can be configured by manually editing the Orbiter.cfg configuration file in the main Orbiter directory. The following options are available:

Item	Type	Description
DemoMode	Bool	Set to TRUE to enable demo mode (default: FALSE)
BackgroundImage	Bool	Set to TRUE to cover the desktop with a static image. (default: FALSE)
BlockExit	Bool	Set to TRUE to disable the Exit function in Orbiter's launchpad dialog. If this option is enabled, Orbiter can only be exited via the task manager. (default: FALSE)
MaxDemoTime	Float	Defines the maximum runtime for a simulation (seconds). Orbiter automatically returns to the launchpad when the runtime has expired.
MaxLaunchpadIdleTime	Float	Maximum time spent in the launchpad without user input before Orbiter auto-launches a demo scenario (seconds)

In demo mode, only the Scenario tab is accessible in the launchpad dialog, to prevent users from modifying simulation configuration features such as screen resolution or plugin modules. Orbiter should therefore be configured as required before launching into demo mode.

To use the auto-launch feature in demo mode, a folder "Demo" must be created in the main scenario folder (usually "Scenarios"). Orbiter will randomly pick a scenario from the Demo folder to launch.

Note: When using Orbiter in kiosk mode, it is recommended to run the simulation in a window, or to use a fullscreen mode which matches the native PC screen resolution, to avoid excessive switching between video display modes.

22 ORBITER configuration

Configuration files allow the customisation of various aspects of ORBITER. Configuration files have file extension .cfg. The format is

item = value

A semicolon starts a comment, continuing to the end of line.
All configuration files except for the master file (see below) are located in a subdirectory defined by the ConfigDir entry in the master file, usually ".\Config".

To find out how to set up the configuration file of a *spacecraft class*, see the separate *3DModel* documentation, contained in the Orbitersdk\doc folder (you need to install the SDK package to get this document). This document also contains information on the mesh file format for the vessel's 3D model, and other hints on how to create your own spacecraft.

Scenarios (simulation startup definitions) are located in a subdirectory defined by the ScenarioDir entry in the master file, usually ".\Scenarios". They have file extension .scn.

22.1 Master configuration file

The master configuration file *Orbiter.cfg* is located in the Orbiter main directory. It contains general settings for graphics modes, subdirectory locations, simulation parameters, etc. Note that manual editing of Orbiter.cfg should no longer be necessary, because most parameters can be accessed from the Launchpad dialog.

Item	**Type**	**Description**
ConfigDir	String	Subdirectory for configuration files (default .\Config\)
MeshDir	String	Subdirectory for mesh files (default .\Meshes\)
TextureDir	String	Subdirectory for textures (default .\Textures\)
HightexDir	String	Subdirectory for alternative high-resolution planetary textures (default: .\Textures2\)
ScenarioDir	String	Subdirectory for scenarios (default: .\Scenarios\)
DeviceIndex	Int	Enumeration index for current 3D device *(do not edit manually)*
DeviceForceEnum	Bool	If TRUE, enumerate 3D devices at each start
ModeIndex	Int	Screen mode index *(do not edit manually)*
Fullscreen	Bool	TRUE for fullscreen mode, FALSE for windowed mode
Stereo	Bool	*Currently not used.*
WindowWidth	Int	Horizontal window size for windowed modes.
WindowHeight	Int	Vertical window size for windowed modes. The ratio WindowWidth/WindowHeight should be approximately 4/3.
RGBDepth	Int	Screen colour depth (BPP) for fullscreen modes.
JoystickIndex	Int	Enumeration index for current joystick (0=none; *do not edit manually)*
JoystickThrottle Saturation	Int	Saturation zone for joystick throttle control (0–10000). A setting of 9000 means that the throttle will saturate over the last 10% of its range at either end. Default: 9500
JoystickDeadzone		Deadzone at joystick axis centres (0-10000). A setting of 2000 means the joystick is considered neutral within 20% from the central position. Default: 2500
AmbientLevel	Int	Ambient light level (brightness of not directly lit surfaces). Valid range is 0-15.
NumStar	Int	Number of background stars (<= 15984). Default: 3000
StarBrightness	Float	Brightness scaling factor for background stars (0.2–2). Default: 1.0
ConstellationCol	RGB	Colour for constellation lines. Default: 0.3 0.3 0.3
UnlimitedFuel	Bool	Ignore spacecraft fuel consumption. Default: FALSE
FlightModel	Int	Flight model realism level (currently supported: 0 and 1)
MFDTransparent	Bool	Make onscreen multifunctional displays transparent. Default: TRUE

EnableShadows	Bool	Enable/disable object shadows on planet surfaces.
EnableSunGlare	Bool	Enable sun glare effects.
EnableClouds	Bool	Enable rendering of planetary cloud layers.
EnableCloud Shadows	Bool	Enable rendering of cloud shadows on the ground (also requires CloudShadowDepth < 1 in individual planet config files)
EnableNightlights	Bool	Enable rendering of night lighting effects of planetary surfaces.
NightlightBrightness	Int	Brightness level of night lighting effects (0–255)
EnableWater Reflection	Bool	Enable rendering of specular reflections from oceanic surfaces.
EnableHorizonHaze	Bool	Enable rendering of atmospheric effects at the horizon.
EnableSpecular Reflection	Bool	Enable specular reflection effects from polished surfaces.
InstrumentUpdate Interval	Float	Interval between MFD display updates (seconds)
PanelScale	Float	Scaling factor for instrument panel display.
PanelScrollSpeed	Float	Speed factor for panel scrolling (pixels per second)
PlanetPatchRes	Float	Resolution factor for planet surfaces. Valid range is 0.1 to 10. Higher values produce higher resolution planetary surfaces at a given apparent radius, but reduce performance.
NEW! PlanetHipatch Aperture	Float	Scaling factor for application distance of high-resolution planet patches (-0.5–1; default: 0.1). A higher value will increase the area rendered at high resolution.
DialogFont_Scale	Float	Scaling factor for dialog font size. Default: 1.0
DialogFont1_Face	String	Standard dialog font face. Default: Arial
ActiveModules	List	List of active plugin modules

22.2 Planetary systems

Planetary systems contain stars, planets and moons. Each planetary system requires at least one star. Stars, planets and moons are defined in the planetary system's configuration file.

General parameters

Item	Type	Description
Name	String	A name for the planetary system
MarkerPath	String	Directory path containing surface marker lists for the planet. Default: `.\Config\`<name>`\Marker\`

See also Section 22.6 on how to add celestial markers to a planetary system.

Object list

The object list defines the celestial bodies populating the planetary system, and their hierarchy.

Star entries:

Star<i> = Name

where <i> is an index running from 1 upward. *(note: planetary systems with more than one central star are not currently supported).*

Planet entries:

Planet<i> = Name

where <i> is an index running from 1 upward.

Moon entries:

<Planet>:Moon<i> = Name

where <Planet> is the name of a planet defined before, and <i> is an index enumerating the moons of this planet, running from 1 upward.

Example:

Star1 = Sun
Planet1 = Mercury
Planet2 = Venus
Planet3 = Earth
Earth:Moon1 = Moon
Planet4 = Mars
Mars:Moon1 = Phobos
Mars:Moon2 = Deimos

22.3 Planets

Planet configuration files define the planet's orbital, physical and visual parameters. For an example see Config\Earth.cfg.

General parameters

Item	Type	Description
Name	String	Planet name
Module	String	Name of dynamic link library performing calculations for the planet (default: none)
ErrorLimit	Float	Max. rel. error for position/velocity calculations (only used if the module supports precision adjustment)
EllipticOrbit	Bool	If TRUE, use analytic 2-body solution for planet position/velocity calculation, otherwise update dynamically (ignored if module supports position/velocity calculation)
HasElements	Bool	If TRUE, the initial position/velocity is calculated from the provided set of orbital elements, otherwise from an explicit position/velocity pair (ignored if module supports position/velocity calculation)

Notes:

- If the module calculates the planet position and velocity from perturbation terms, then the value of ErrorLimit will affect the number of terms used for the calculation. A lower value will increase the number of required terms, and thus the calculation time. The valid range for ErrorLimit depends on the module, but is typically 1e-3 ≤ ErrorLimit ≤ 1e-8.

Orbital parameters (Ignored if module supports position/velocity calculation or HasElements = FALSE)

Item	Type	Description
Epoch	Float	Orbital element reference epoch (e.g. 2000)
ElReference	Flag	`ParentEquator` or `Ecliptic`: orbit reference frame (default: Ecliptic)
SemiMajorAxis	Float	Orbit semi-major axis [m]
Eccentricity	Float	Orbit eccentricity
Inclination	Float	Orbit inclination against reference plane [rad]
LongAscNode	Float	Longitude of ascending node [rad]
LongPerihelion	Float	Longitude of periapsis [rad]
MeanLongitude	Float	Mean longitude at epoch [rad]

Physical parameters

Item	Type	Description
Mass	Float	Planet mass [kg]
Size	Float	Mean planet radius [m]

Rotation elements

Item	Type	Description
SidRotPeriod	Float	Siderial rotation period [s]
SidRotOffset	Float	Rotation at epoch [rad]
Obliquity	Float	Obliquity: angle between rotation axis and normal of reference plane at epoch [rad]
LAN	Float	Longitude of projection of rotation axis onto reference

		plane [rad]

Atmospheric parameters (only required if planet has atmosphere)

Item	Type	Description
AtmPressure0	Float	(Mean) atmospheric pressure at zero altitude [Pa]
AtmDensity0	Float	(Mean) atmospheric density at zero altitude [kg/m^3]
AtmGasConstant	Float	specific gas constant [J K^{-1} kg^{-1}]. Default: 286.91 (Earth value)
AtmGamma	Float	ratio of specific heats c_p/c_v. Default: 1.4 (Earth value)
AtmColor0	Vec$_3$	RGB triplet for atmospheric colour at ground level (0-1 each)
AtmAltLimit	Float	altitude limit beyond which atmospheric effects can be ignored [m]
AtmHazeExtent	Float	Width parameter for extent of horizon haze rendering. Range: 0 (thinnest) to 1 (widest). Default: 0.1
AtmHazeShift	Float	Shifts the reference altitude of the haze base line. Can be used to adjust haze altitude to a cloud layer. (in units of planet radius). Default: 0 (align with surface horizon). Shift is not applied if camera is below cloud layer.
AtmHazeDensity	Float	Modifies the density at which the horizon density is rendered (basic density is calculated from atmospheric density) Default: 1.0
AtmHazeColor	Vec$_3$	RGB triplet for horizon haze colour (0-1 each). Default: use AtmColor0 values.
AtmHorizonAlt	Float	altitude scale for horizon haze rendering [m]. Default: 0.01 of planet radius.
NEW! ShadowDepth	Float	Depth (“blackness”) of object shadows (0 ... 1, where 0=black, 1=no shadows). Default: exp(-ρ_0/2), where ρ_0 is the atmospheric density at the surface. This option is only used when stencil buffering is enabled. Otherwise shadows are always black.

Cloud parameters (only required if planet contains a cloud layer)

Item	Type	Description
CloudAlt	Float	Altitude of cloud layer [m]
CloudShadowDepth	Float	Depth (“blackness”) of cloud shadows on the ground (0 ... 1) where 0 = black, 1 = don’t render shadows. Default: 1
CloudRotPeriod	Float	Rotation period of cloud layer against surface [s] (default: 0 – static cloud layer)
CloudMicrotextureAlt	Float+ Float	Altitude range [m] for cloud microtexturing. First value is altitude at which full microtexture is applied. Second value is altitude at which microtexture starts to kick in. First value ≥ 0 and second value > first value is required. Default: no microtexture.

Visualisation parameters

Item	Type	Description
MaxPatchResolution	Int	Max. resolution level for surface texture maps (1 ... 10)
MinCloudResolution	Int	Min. resolution at which clouds are rendered as separate layer (1 ... 8)
MaxCloudResolution	Int	Max. cloud resolution level (MinCloudResolution ... 8)
NEW! SpecularRipple	Bool	If TRUE, and if “Specular ripples” option is enabled in the Launchpad dialog, specularly reflecting surfaces use a “water ripple” microtexture. Default: FALSE.

Surface marker parameters (optional)

Item	Type	Description
MarkerPath	String	Directory path containing surface marker lists for the planet. Default: `.\Config\`<planet name>`\Marker\`

See also Section 22.6 on how to add surface markers to a planet.

Surface bases (optional)
This list contains the names and locations of surface landing sites (“spaceports”). Each entry in this list must be accompanied by a configuration file for the corresponding surface base.

```
BEGIN_SURFBASE
   <base list>
END_SURFBASE
```

Base list entries have the following format:

```
   <name>: <lng> <lat>
```

where

<*name*>	Name which identifies the base config file (<*name*>.cfg). The actual name of the base as it appears in Orbiter is given by the NAME tag in the base config file.
<*lng*> <*lat*>	Base position (equatorial coordinates) [deg]

Note that there is an alternative format for this list, using a NumBases entry and BaseXX tags. This format is obsolete and should no longer be used.

Ground-based observer sites (optional)
This list contains the pre-defined locations for ground-based observers (launch cameras, spectators, etc.) which can be selected in the Camera dialog. The format of the list is

```
BEGIN_OBSERVER
   <observer list>
END_OBSERVER
```

List entries have the following format:

```
   <site>:<spot>:  <lng> <lat> <alt>
```

where

<*site*>	a name which identifies the site (e.g. KSC)
<*spot*>	the particular location at the site (e.g. Launch pad 39)
<*lng*> <*lat*>	observer position (equatorial coordinates) [deg]
<*alt*>	observer altitude [m] (>0)

The easiest way to find the coordinates for a new observer spot is to open the *Camera* dialog (Ctrl F1), and select a nearby location under the *Ground* tab. Then move the camera to the new spot using Ctrl ↓↑→← and Page Up Page Down. The coordinates are displayed in the dialog and can be directly copied into the configuration file.

Navbeacon transmitter list (optional)
This list contains all navigation radio transmitter specs except those directly associated with a spaceport (see section 22.4). The list format is as follows:

```
BEGIN_NAVBEACON
   <NAV list>
END_NAVBEACON
```

List entries have the following format:

```
   <type> <id> <lng> <lat> <freq> [<range>]
```

where

<*type*>	transmitter type. currently supported: VOR
<*id*>	identifer code (up to 4 letters)
<*lng*> <*lat*>	transmitter position (equatorial coordinates) [deg]
<*freq*>	transmitter frequency [MHz]
<*range*>	transmitter range [m] (default: 500 km)

To implement a custom DLL module for planet position/velocity calculations, see SDK documentation.

To add a new planet to a planetary system the following steps are required:

1. Add an entry for the planet in the planetary system configuration file (see previous section):
   Planet<X> = <Planetname>

2. Create a configuration file *<Planetname>.cfg* for the new planet in the "Config" subdirectory, with entries as listed above.

3. Create the required surface texture maps up to the specified resolution.

4. Optionally, create a monochrome (green on black) surface outline bitmap (256x128, BMP) to be used by the Map MFD. The file name should be *<Planetname>M.bmp*.

22.4 Surface bases

Surface bases (or "spaceports") are launch and landing sites on the surface of planets or moons, usually equipped with launchpads or runways, for vertical and horizontal liftoff and/or landing. Each surface base is defined via its own configuration file. When Orbiter loads a planet configuration, it scans all surface base definitions for the planet and creates the corresponding bases.

The base definition file

To create a new surface base, you need to write a definition file for it. The file name should be of the form <*base-name*>.cfg, and it must be placed in an appropriate folder. (see *Linking surface bases to planets* below).
The format of the surface base definition file is as follows:

```
BASE-V2.0
NAME = <Base name>
LOCATION = <lng> <lat>
SIZE = <size>
OBJECTSIZE = <osize>
MAPOBJECTSTOSPHERE = [TRUE|FALSE]

BEGIN_NAVBEACON
   <NAV list>
END_NAVBEACON

BEGIN_OBJECTLIST
   <Object list>
END_OBJECTLIST

BEGIN_SURFTILELIST
   <Surface tile list>
END_SURFTILELIST
```

`BASE-V2.0`
Format identifer that must be placed in the first line of the file. This item is optional if the base is referenced directly in the planet's base list.

`NAME =` *<Base name>*
Defines the base's (logical) name which need not correspond to the file name.

`LOCATION =` *<lng> <lat>*
Defines the position of the base on the planet surface, where <*lng*> is longitude (deg, West < 0, East > 0), and <*lat*> is latitude (deg, South < 0, North > 0). This item is optional if the base is referenced directly in the planet's base list.

`Size =` *<size>*
Defines the base's overall radius in meters.

`OBJECTSIZE =` *<osize>*
Defines the size of a “typical” object (building, etc.) This value is used by Orbiter to determine up to what camera distance base objects will be rendered. Objects will not be rendered if the apparent size of an object of size *<osize>*, located at the centre of the base, would be smaller than 1 pixel. The default value for *<osize>* is 100.0.

`MAPOBJECTSTOSPHERE` (boolean)
If *true*, the objects in the object list will be automatically adjusted in elevation to correct for the planets curvature. This means that objects with elevation 0 will be mapped onto altitude 0 of the planet surface. If *false*, elevation 0 maps onto the flat horizon plane of the base reference point. Default: *false*.
Note: Currently this function is only implemented for a limited number of base object types.

<NAV list>
Contains a list navigation radio transmitters associated with the base. The format is identical to that of the Planet config file (see section 22.3).

<Object list>
Contains a list of objects which make up the visual elements of the base. See next section for details.

<Surface tile list>
An optional list of high-resolution surface tiles covering the base area. Each tile is represented by a line in the list, with the format

<res> <lng-idx> <lat-idx> <flag>

where *<res>* is the tile resolution (integer ≥ 1), and *<lng-idx>* and *<lat-idx>* are the position indices. The position indices define the location of the tile on the global planet map at the given resolution. *<flag>* is a bitflag (bit 0 = 1: render tile; bit 1 = 1: tile contains transparency in the alpha channel).
For each tile entry, a corresponding texture file in DDS format (DXT1 or DXT5) must exist in the *Textures* subdirectory, with naming convention

*<planet>*_*<res>*_[W|E]*<lng-idx>*_[N|S]*<lat-idx>*.dds

where *<planet>* is the planet name, *<res>* is the tile resolution as defined in the list, and *<lng-idx>* and *<lat-idx>* are the position indices as defined in the list (zero-padded to 4 digits).
Note: Future versions of Orbiter may incorporate local high-resolution planetary surface areas directly in the planet’s texture file. The mechanism of associating surface tiles with base definitions via the surface tile list will then be removed. Using surface tile lists is therefore not recommended.

NEW!

Linking surface bases to planets

After creating the base configuration file, it must be referenced by a planet to instantiate the base. There are several ways to make Orbiter read a surface base definition:

- Place the base configuration file in the default base configuration folder for the planet. By default, Orbiter will scan the folder *Config\<pname>\Base* for base definitions, where *<pname>* is the planet name. For example, the default folder for Earth bases is *Config\Earth\Base*. The default folder is only scanned if the planet doesn’t explicitly define a base list (see below).

- To make Orbiter scan different folders, create a surface base list in the planet’s configuration file, starting with the line *BEGIN_SURFBASE* and ending with the line *END_SURFBASE*. In this list, specify the new surface base directory with the line ‘*DIR <folder>*’, where *<folder>* is the path to the folder containing the base configurations (relative to the *Config* folder). Multiple folders can be specified. If the same base is defined in more than one of the scanned folders, only the first is used. This allows to replace base definitions without having to delete the original configuration file.

  Example:
  ```
  BEGIN_SURFBASE
    DIR Earth\MyBase
  ```

```
  DIR Earth\MoreBases
END_SURFBASE
```

If the surface base list exists in a planet’s configuration file, the default base configuration folder will *not* be scanned, unless it is explicitly listed.

- Base references can be placed directly into the base list, using the following format:

  ```
  <fname>:<lng> <lat>
  ```

  where *<fname>* is the name of the surface base configuration file: Config*<fname>*.cfg, and *<lng>* and *<lat>* are the equatorial coordinates of the base (longitude and latitude) in degrees. When using this format, the base configuration file must be located in the *Config* subdirectory.

NEW!

Selective loading of bases

To provide more control over the loading of surface bases in for a given simulation scenario, two conditional flags can be set with a DIR entry in the base list:

- Specify a time interval with the PERIOD parameter. The corresponding directory will only be scanned if the scenario start date is inside this interval. This allows to replace surface bases only at specific time periods, for example to set up the Kennedy Space Center for the Apollo lunar missions.

  Syntax:

  ```
  DIR <folder> PERIOD <mjd0> <mjd1>
  ```

  where *<mjd0>* and *<mjd1>* are the start and end dates of the period over which the base folder will be scanned, in MJD (Modified Julian Date) format. Either can be set to ‘`-`‘ to disable the limit at one end.

- Specify a scenario context with the CONTEXT parameters. The corresponding directory will only be scanned if the scenario specifies the same context string in its environment context entry (see Section 22.7). This allows to add or replace surface bases only within a defined set of scenarios.

  Syntax:

  ```
  DIR <folder> CONTEXT <string>
  ```

  where <string> is the context string to be matched against the scenario context.
  The PERIOD and CONTEXT parameters can be used simultaneously. In that case the directory will only be scanned if both conditions are satisfied.

  Examples:

  ```
  BEGIN_SURFBASE
    DIR Earth\1969Base PERIOD 40222 42048
    DIR Earth\TempBases CONTEXT RichScenery
    DIR Earth\OtherBases PERIOD – 40000 CONTEXT EarlyBases
    DIR Earth\Base
  END_SURFBASE
  ```

  Note that the list order is important to allow the custom base definitions to replace standard bases.

22.5 Adding objects to surface bases

Surface bases are composed of objects (buildings, train lines, hangars, launch pads, etc.) The configuration file for each surface base contains a list of its objects:

```
BEGIN_OBJECTLIST
   <Object 0>
```

```
    <Object 1>
    …
    <Object n-1>
END_OBJECTLIST
```

Each object entry in the list defines a particular object and its properties (type, position, size, textures, etc.). An object can either be a pre-defined type or a generic mesh. Each object entry has the following format:

```
<Type>
    <Parameters>
END
```

Note that textures used by base objects must be listed in the texture list of the *Base.cfg* configuration file.

The following pre-defined object types are currently supported:

BLOCK

A 5-sided “brick” (without a floor) which can be used as a simple generic building, or as part of a more complex structure. The following parameters are supported:

Parameter	Type	Description
POS	V	Centre of the block’s base rectangle (in local coordinates of the surface base). Note that the y-coordinate is the elevation above ground. Default: 0 0 0
SCALE	V	Object size in the three coordinate axes. Default: 1 1 1
ROT	F	Rotation around vertical axis (degrees). Default: 0
TEX1	S F F	Texture name and u,v scaling factors for walls along the x-axis. Default: none
TEX2	S F F	Texture name and u,v scaling factors for walls along the z-axis. Default: none
TEX3	S F F	Texture name and u,v scaling factors for roof. Default: none

(V=Vector, F=Float, S=String)

HANGAR

A hangar-type building with a barrel-shaped roof. The following parameters are supported:

Parameter	Type	Description
POS	V	Centre of the object’s base rectangle (in local coordinates of the surface base). Note that the y-coordinate is the elevation above ground. Default: 0 0 0
SCALE	V	Object size in the three coordinate axes. Default: 1 1 1
ROT	F	Rotation around vertical axis (degrees). Default: 0
TEX1	S F F	Texture name and u,v scaling factors for walls. Default: none
TEX2	S F F	Texture name and u,v scaling factors for front gate. Default: none
TEX3	S F F	Texture name and u,v scaling factors for roof. Default: none

(V=Vector, F=Float, S=String)

HANGAR2

A hangar-type building with a tent-shaped roof. The following parameters are supported:

Parameter	Type	Description
POS	V	Centre of the object’s base rectangle (in local coordinates of the surface base). Note that the y-coordinate is the elevation above ground. Default: 0 0 0
SCALE	V	Object size in the three coordinate axes. Default: 1 1 1
ROT	F	Rotation around vertical axis (degrees). Default: 0
TEX1	S F F	Texture name and u,v scaling factors for front and back walls. Default: none

TEX2	S F F	Texture name and u,v scaling factors for side walls. Default: none
TEX3	S F F	Texture name and u,v scaling factors for roof. Default: none
ROOFH	F	Roof height from base to ridge. Default: ½ building height.

(V=Vector, F=Float, S=String)

HANGAR3

A hangar-type building with a barrel-shaped roof reaching to the ground. The following parameters are supported:

Parameter	Type	Description
POS	V	Centre of the object's base rectangle (in local coordinates of the surface base). Note that the y-coordinate is the elevation above ground. Default: 0 0 0
SCALE	V	Object size in the three coordinate axes. Default: 1 1 1
ROT	F	Rotation around vertical axis (degrees). Default: 0
TEX1	S F F	Texture name and u,v scaling factors for front and back walls. Default: none [*not supported yet!*]
TEX2	S F F	Texture name and u,v scaling factors for front gate. Default: none [*not supported yet!*]
TEX3	S F F	Texture name and u,v scaling factors for roof. Default: none

(V=Vector, F=Float, S=String)

TANK

A fuel tank-like upright cylinder with flat top. The following parameters are supported:

Parameter	Type	Description
POS	V	Centre of the object's base circle (in local coordinates of the surface base). Note that the y-coordinate is the elevation above ground. Default: 0 0 0
SCALE	V	Cylinder radii in x and z, and height in y. Default: 1 1 1
ROT	F	Rotation around vertical axis (degrees). Default: 0
NSTEP	I	Number of segments to approximate circle. Default: 12
TEX1	S F F	Texture name and u,v scaling factors for mantle. Default: none
TEX2	S F F	Texture name and u,v scaling factors for top.

(V=Vector, F=Float, I=Integer, S=String)

RUNWAY

Texturing for a runway. The texture mapping can be split into segments, to allow inclusion of markings, overruns, etc. This does not include any lighting (see RUNWAYLIGHTS).

Parameter	Type	Description
END1	V	First end point of runway (center line), including any overruns to be textured.
END2	V	Second end point of runway (center line).
WIDTH	F	Runway width [m]
ILS1	F	Localiser frequency for approach towards END1 (108.00 to 139.95). Default: No ILS support
ILS2	F	Localiser frequency for approach towards END2 (108.00 to 139.95). This can be the same frequency as ILS1. Default: No ILS support.
NRWSEG	I	Number of texture segments
RWSEGx	I F F F F F	Definition of segment x (x = 1...NRWSEG). Parameters: 1. Number of mesh sub-segments (≥1) 2. Fractional length of segment (sum of all segments must be 1) 3. texture coordinate u_0 of segment 4. texture coordinate u_1 5. texture coordinate v_0 6. texture coordinate v_1
RWTEX	S	Texture name for all segments

(V=Vector, F=Float, I=Integer, S=String)

RUNWAYLIGHTS

Complete lighting for a single runway, including optional Precision Approach Path Indicator (PAPI) and Visual Approach Slope Indicator (VASI) – see section 16.6. Runway markers are turned off during daytime, but PAPI and VASI indicators are always active.

Parameter	Type	Description
END1	V	First end point of runway (center line).
END2	V	Second end point of runway (center line).
WIDTH	F	Runway width [m]
COUNT1	I	Number of lights along the runway center line (≥2). Default: 40
PAPI	F F F	Precision Approach Path Indicator (PAPI). Default: no PAPI. Parameters: 1. Designated approach angle [deg] 2. Approach cone aperture [deg] 3. Offset of PAPI location from runway endpoints. [m]
VASI	F F F	Visual Approach Slope Indicator (VASI). Default: no VASI Parameters: 1. Designated approach angle [deg] 2. Distance between white and red indicator lights [m] 3. Offset of VASI (red bar) location from runway endpoints [m]

(V=Vector, F=Float, I=Integer)

BEACONARRAY

A linear array of illuminated beacons, usable e.g. for taxiway night lighting.

Parameter	Type	Description
END1	V	First end point of beacon array (in local coordinates of the surface base). Note that the y-coordinate is the elevation above ground.
END2	V	Second end point of beacon array
COUNT	I	Number of beacons in the array (≥2). Default: 10
SIZE	F	Size (radius) of each beacon light. Default: 1.0
COL	F F F	Beacon colour (RGB) Valid range: 0..1 for each value. Default: 1 1 1 (white)

(V=Vector, F=Float, I=Integer)

SOLARPLANT

A grid of ground-mounted solar panels, smart enough to align themselves with the Sun. The following parameters are supported:

Parameter	Type	Description
POS	V	Centre position of the panel grid. Default: 0 0 0
SCALE	F	Scaling factor for each panel. Default: 1
SPACING	F F	Distance between panels in x and z direction. Default: 40 40
GRID	I I	Grid dimensions in x and z direction. Default: 2 2
ROT	F	Rotation of plant around vertical axis (degrees). Default: 0
TEX	S [F F]	Texture name and u,v scaling factors for panels. Default: none

(V=Vector, F=Float, I=Integer, S=String)

TRAIN1

A monorail-type train on a straight track. The following parameters are supported:

Parameter	Type	Description
END1	V	First end point of track
END2	V	Second end point of track
MAXSPEED	F	Maximum speed of train [m/s] Default: 30
SLOWZONE	F	Distance over which train slows down at end of track [m] Default: 100
TEX	S	Texture name

(V=Vector, F=Float, S=String)

TRAIN2

Suspension train on a straight track. The following parameters are supported:

Parameter	Type	Description
END1	V	First end point of track
END2	V	Second end point of track
HEIGHT	F	Height of suspension track over ground [m] Default: 11
MAXSPEED	F	Maximum speed of train [m/s] Default: 30
SLOWZONE	F	Distance over which train slows down at end of track [m] Default: 100
TEX	S	Texture name

(V=Vector, F=Float, S=String)

LPAD1

An octagonal bordered landing pad. Default diameter 80m (at scale 1). Landing pads are numbered in the order they appear in the list. Can be assigned numbers 1-9. For expected layout of texture map see e.g. Textures\Lpad01.dds.

Parameter	Type	Description
POS	V	Pad centre coordinates (in local coordinates of the surface base).
SCALE	F	Scaling factor. Default: 1
ROT	F	Rotation around vertical axis (degrees). Default: 0
TEX	S	Texture name. Default: none
NAV	F	frequency [MHz] of VTOL nav transmitter (valid range: 85.0-140.0, default: none)

(V=Vector, F=Float, S=String)

LPAD2

A square landing pad. Default size 80m (at scale 1). Landing pads are numbered in the order they appear in the list. Can be assigned numbers 1-99. For expected layout of texture map see e.g. Textures\Lpad02.dds.

Parameter	Type	Description
POS	V	Pad centre coordinates (in local coordinates of the surface base).
SCALE	F	Scaling factor. Default: 1
ROT	F	Rotation around vertical axis (degrees). Default: 0
TEX	S	Texture name. Default: none
NAV	F	frequency [MHz] of VTOL nav transmitter (valid range: 85.0-140.0, default: none)

(V=Vector, F=Float, S=String)

NEW!

LPAD2A

Similar to LPAD2, but uses a different layout for the texture map, providing a higher resolution at the same texture size. For expected layout of texture map see e.g. Textures\Lpad02a.dds. The supported parameters are the same as for LPAD2.

MESH

Generic mesh for custom object types. Mesh files must be in ORBITER mesh file format (see *3DModel.pdf* in the Orbiter SDK package).

Parameter	Type	Description
FILE	S	Mesh file name (without path and extension). Mesh files must be located in the mesh subdirectory (see master config file).
POS	V	Position of mesh origin (in local coordinates of the surface base).
SCALE	V	Scaling factors in x and z, and height in y. Default: 1 1 1
ROT	F	Rotation around vertical axis (degrees). Default: 0
TEX	S	Texture name. Default: none
SHADOW		Render the shadow cast on the ground by the object.

UNDERSHADOWS	Object can be covered by shadows cast on the ground by other objects (e.g. roads, landing pads, etc.). Default: object not covered by ground shadows
OWNMATERIAL	Use materials and textures defined in the mesh file. This overrides the TEX entry.
LPAD	Object is a landing pad.
PRELOAD	Mesh should be loaded at program start. This can reduce disk activity during the simulation but increases main memory usage. Default: Load only when used.

(V=Vector, F=Float, S=String)

Notes:

- If the mesh only uses a single texture it is more efficient to specify it via the TEX entry than via the mesh using OWNMATERIAL, because Orbiter can merge objects with the same TEX entries for improved performance.

22.6 Adding custom markers

You can define lists of labels to mark objects on the celestial sphere (e.g. bright stars, navigation stars, nebulae, etc.), or planetary surface markers to locate natural landmarks, points of interest, historic landing sites, navigational aids, etc.
The user can display these markers during the simulation using F9 and Ctrl F9.
All celestial and planetary surface markers are placed in their own subdirectories, which default to `.\Config\`<*name*>`\Marker\`, where <*name*> is the name of the planetary system (for celestial markers) or planet (for surface markers) they are referring to. You can specify a different location with the *MarkerPath* option in the planet's or planetary system's configuration file (see Section 22.3). Marker files must have extension `.mkr`. Multiple files can be defined for a single planet or planetary system, which the user can turn on or off individually. Marker files are in ASCII (text) format:

```
BEGIN_HEADER
  InitialState [on/off]
  ShapeIdx [0 .. 6]
  ColourIdx [0 .. 5]
  Size [0.1 .. 2]
  DistanceFactor [1e-5 .. 1e3]
  Frame [celestial/ecliptic]
END_HEADER
BEGIN_DATA
  <lng> <lat> : <label> [: <label>]
  <lng> <lat> : <label> [: <label>]
  ...
```

The header section contains some configuration options:

- InitialState defines if the labels are initially visible when the user activates surface markers under Ctrl F9. The user can turn lists on and off individually during the simulation. The default is "off".
- ShapeIdx: an integer between 0 and 6 defining the shape of the labels.

0	box (default)
1	circle
2	diamond
3	delta
4	nabla
5	cross
6	X

- ColourIdx: an integer between 0 and 5 defining the colour of the labels. Default is 1.
- Size: A size factor for the markers. Default is 1.0.
- DistanceFactor: Defines up to what distance the markers are displayed. Default is 1.0.
- Frame (used for celestial markers only): defines the reference frame to which the coordinates in the list refer.
    ecliptic: data are ecliptic longitude and latitude

celestial: data are right ascension and declination of J2000 equator and equinox. (default)

Each item in the header section is optional. If missing, the default value is substituted. The header can also be omitted altogether, in which case the "BEGIN_DATA" flag is also not required.

In the data section, each line defines a label. It consists of equatorial position: longitude (in degrees, with eastern longitudes positive, and western longitudes negative), latitude (in degrees with northern latitudes positive, and southern latitudes negative), and one or two label strings to be displayed above and below the marker.

22.7 Scenario files

Scenarios contain all parameters required to set up the simulation at a particular time. They are used for loading and saving simulation states. Scenario files are usually generated automatically when saving a simulation. The format description below is primarily intended for developers of scenario editor add-ons.

Format:

<Description block>
<Environment block>
<Focus block>
<Camera block>
<Panel block>
<VC block>
<HUD block>
<Left MFD block>
<Right MFD block>
<Ship list>

Description block (optional):

Contains a short description of the scenario.

```
BEGIN_DESC
    <Description>
END_DESC
```

<Description>: ASCII text describing the scenario. CR is converted to space. Empty lines are converted to CR. This text is displayed in the description box of the Orbiter launchpad dialog when the user selects the scenario from the list.

Environment block (optional):

Contains the simulation environment.

```
BEGIN_ENVIRONMENT
    <Environment parameters>
END_ENVIRONMENT
```

<Environment parameters>:

Parameter	Type	Description
SYSTEM	S	Name of the planetary system. A configuration file for this system must exist. Default: “Sol”
DATE		Contains simulation start time. Allowed formats are: `MJD` *<mjd>* (*<mjd>*: Modified Julian Date) `JD` *<jd>* (*<jd>*: Julian Date) `JE` *<je>* (*<je>*: Julian Epoch) Default is current simulation time, but this should be avoided if the scenario contains objects defined by position/velocity vectors, which cannot easily be propagated in time.
NEW! CONTEXT	S	Optional context string. This can be used to fine-tune the setup of the planetary system, e.g. by selective loading of surface bases.

Focus block (mandatory):

Contains parameters for the user-controlled spacecraft.

```
BEGIN_FOCUS
   <Focus parameters>
END_FOCUS
```

<Focus parameters>:

Parameter	Type	Description
SHIP	S	Name of the user-controlled ship. The ship must be listed in the ship list (see below).

Camera block (optional):

Camera mode and parameters. If the camera block is missing, the camera is set to cockpit view in the current focus object.

```
BEGIN_CAMERA
   <Camera parameters>
END_CAMERA
```

<Camera parameters>:

Parameter	Type	Description
MODE	Flag	`Extern` or `Cockpit`
TARGET	S	Camera view target. (external modes only; cockpit mode always refers to current focus object)
POS	V	Camera position relative to target (external modes only)
TRACKMODE	Flag [+String]	`TargetRelative` | `AbsoluteDirection` | `GlobalFrame` | `TargetTo` *<ref>* | `TargetFrom` *<ref>* | `Ground` *<ref>* (external modes only)
GROUNDLOCATION	F F F	longitude (deg), latitude (deg) and altitude (m) of ground observer (*Ground* trackmode only)
GROUNDDIRECTION	F F	polar coordinates of ground observer orientation (*free Ground* trackmode only)
FOV	F	Field of view (degrees)

Panel block (optional):

2D instrument panel parameters. If neither this nor the VC (virtual cockpit) block is present, Orbiter initially displays generic cockpit views.

```
BEGIN_PANEL
   <Panel parameters>
END_PANEL
```

Currently no panel parameters are supported.

VC block (optional):

Virtual cockpit parameters. If neither this nor the panel block is present, Orbiter initially displays generic cockpit views.

```
BEGIN_VC
   <VC parameters>
END_VC
```

Currently no VC parameters are supported.

HUD block (optional):

HUD mode and parameters. If the HUD block is missing, no HUD is displayed at startup.

```
BEGIN_HUD
   <HUD parameters>
END_HUD
```

<HUD parameters>:

Parameter	Type	Description
TYPE	Flag	`Orbit` | `Surface` | `Docking`

Left/Right MFD blocks (optional):

Left/right MFD type and parameters. If the block is missing, the corresponding MFD is not displayed. Note that custom MFD modes may have their own set of parameters.

```
BEGIN_MFD Left/Right
   <MFD parameters>
END_MFD
```

<MFD parameters>:

Parameter	Type	Description
TYPE	Flag	MFD type: `Orbit|Surface|Map|Launch|Docking|OAlign|OSync|Transfer`
REF	S	Reference object (Orbit and Map MFD only)
TARGET	S	Target object (for Orbit, OAlign and OSync MFD only)
BTARGET	S	Base target (for Map MFD only)
OTARGET	S	Orbit target (for Map MFD only)
PROJ	Flag	`Ecliptic|Ship|Target` (for Orbit MFD only)
MODE	Flag	`Intersect 1|Intersect 2|Sh periapsis|Sh apoapsis|Tg periapsis|Tg apoapsis|Manual axis` (for OSync MFD only)
MANUALREF	F	Reference axis position [deg] (for OSync MFD in manual mode only)
LISTLEN	I	Number or orbit time listings (for OSync MFD only)

Ship list:

List of spacecraft. The list must at least contain the vessel referred to by the `Focus` entry.

```
BEGIN_SHIPS
   <Ship 0>
   <Ship 1>
   . . .
   <Ship n-1>
END_SHIPS
```

Ship entries <*Ship i*>:

```
<Vessel name>[:<Class name>]
   <Vessel parameters>
END
```

<*Vessel name*>: ship identifier string

<*Class name*>: vessel class (if applicable). If no class is specified, a .cfg file for the vessel, <*vessel name*>.cfg is required.

<*Vessel parameters*>:

Parameter	Type	Description
STATUS	Flag	`Landed` <*planet*> | `Orbiting` <*planet*>
BASE		<*base*>`:`<*lpad*> (only for STATUS Landed)
HEADING	F	Orientation (only for STATUS Landed)
RPOS	V	Position rel. to reference (only for STATUS Orbiting)
RVEL	V	Velocity rel. to reference (only for STATUS Orbiting)
ELEMENTS	List	Orbital elements. This is an alternative to RPOS and RVEL for vessels with STATUS Orbiting. The list contains 7 entries: semi-major axis a [m], eccentricity e, inclination i [°], longitude of ascending node Ω [°], longitude of periapsis ϖ [°], mean longitude at reference date [°], and reference date in MJD format.
AROT	V	Orientation: rotation angles of object frame (only for STATUS Orbiting)
VROT	V	angular velocity [°/s] (only for STATUS Orbiting)
FUEL	F	Fuel level (0 to 1). This entry sets the level of all propellant resources to the same level. For individual settings, use PRPLEVEL option instead.
PRPLEVEL	List	List of propellant resource levels. Each entry is of the form <*id*>`:`<*level*>, where <*id*> is the resource identifier, and

		<*level*> is the propellant resource level (0..1).
THLEVEL	List	List of thruster settings. Each entry is of the form <*id*>:<*level*>, where <*id*> is the thruster identifier (in the order of thruster creation), and <*level*> is the thruster level (0..1). Thrusters with level 0 can be omitted.
DOCKINFO	List	Docking status list. This contains information about all docked vessels. Each entry is of the form <*id*>:<*rid*>,<*rvessel*> where <*id*> is the docking port identifier, <*rid*> is the docking port identifier of the docked vessel, and <*rvessel*> is the name of the docked vessel. Only occupied docking ports are listed. See notes below.

Note that individual vessel types may define additional parameter entries.

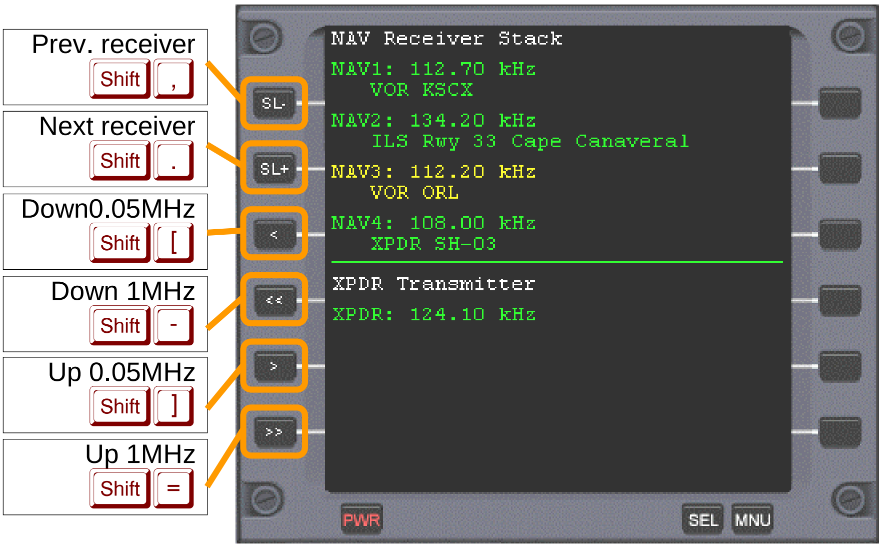
Docking vessels

There are two ways to define vessels as being assembled into a superstructure by docking them together:

- Place the vessels so that their docking ports coincide (by using appropriate RPOS, RVEL, AROT and VROT parameters for both). Orbiter will dock two vessels automatically if their docking ports are close enough.
- Define the DOCKINFO lists for both vessels so that they reference each other. Orbiter will then attach the vessels accordingly. **Important:** The RPOS, RVEL, AROT and VROT parameters of the first vessel in the list which belongs to the superstructure are used to initalise the state vectors of the superstructure. All subsequent vessels docked to the same superstructure do not need to define these parameters.

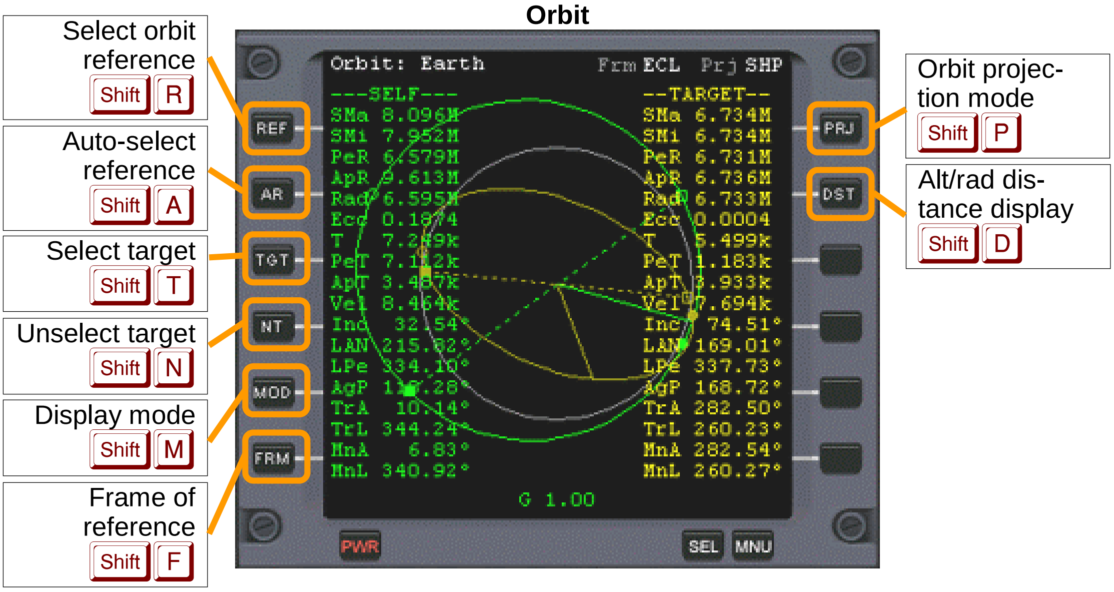
Appendix A MFD quick reference

NAV/COM



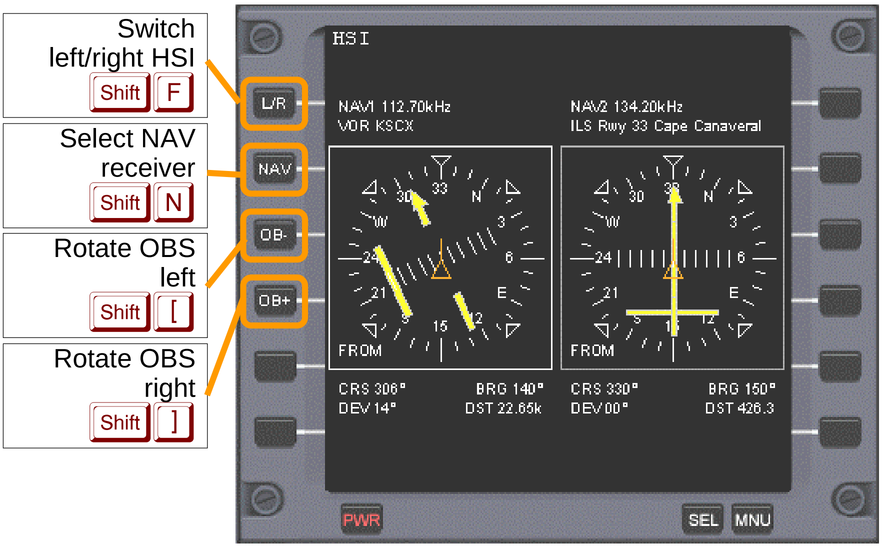
```
NAV Receiver Stack
NAV1: 112.70 kHz
   VOR KSCX
NAV2: 134.20 kHz
   ILS Rwy 33 Cape Canaveral
NAV3: 112.20 kHz
   VOR ORL
NAV4: 108.00 kHz
   XPDR SH-03

XPDR Transmitter
XPDR: 124.10 kHz
```

Orbit



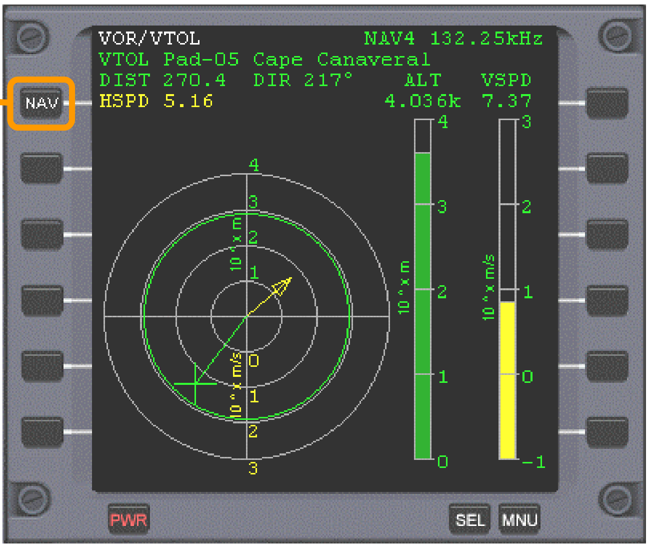
```
Orbit: Earth                Frm ECL  Prj SHP
---SELF---                  --TARGET--
SMa 8.096M                  SMa 6.734M
SMi 7.952M                  SMi 6.734M
PeR 6.579M                  PeR 6.731M
ApR 9.613M                  ApR 6.736M
Rad 6.595M                  Rad 6.733M
Ecc 0.1874                  Ecc 0.0004
T   7.249k                  T   5.499k
PeT 7.112k                  PeT 1.183k
ApT 3.487k                  ApT 3.933k
Vel 8.464k                  Vel 7.694k
Inc  32.54°                 Inc  74.51°
LAN 215.82°                 LAN 169.01°
LPe 334.10°                 LPe 337.73°
AgP 1[illegible].28°                 AgP 168.72°
TrA  10.14°                 TrA 282.50°
TrL 344.24°                 TrL 260.23°
MnA   6.83°                 MnA 282.54°
MnL 340.92°                 MnL 260.27°
              G 1.00
```

HSI



```
HSI

NAV1 112.70kHz              NAV2 134.20kHz
VOR KSCX                    ILS Rwy 33 Cape Canaveral

CRS 306°      BRG 140°      CRS 330°      BRG 150°
DEV 14°       DST 22.65k    DEV 00°       DST 426.3
```

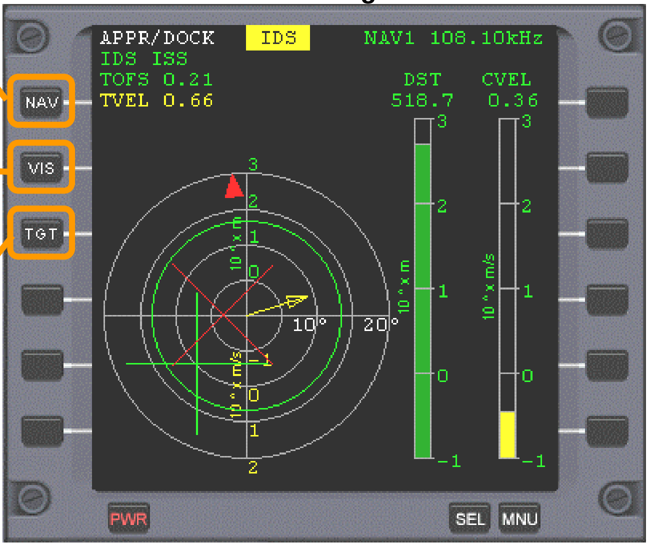
VOR/VTOL



Select NAV receiver Shift N

```
VOR/VTOL                    NAV4 132.25kHz
VTOL Pad-05 Cape Canaveral
DIST 270.4  DIR 217°      ALT    VSPD
HSPD 5.16               4.036k  7.37
```

Docking



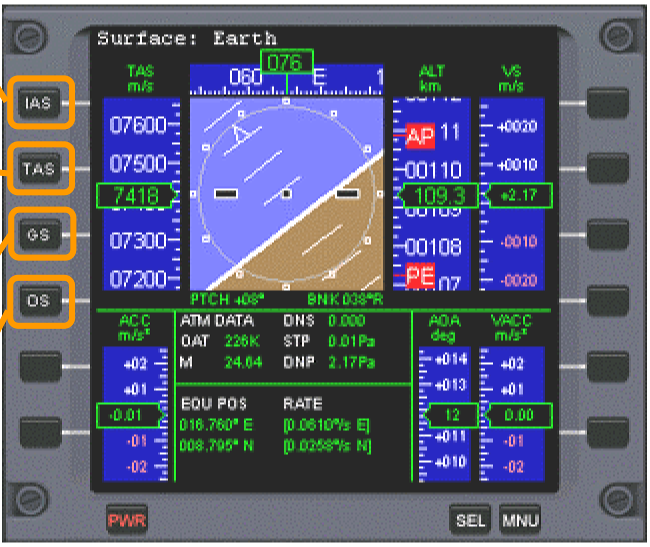
Select NAV receiver Shift N

Switch to visual acquisition Shift V

Direct target input Shift T

```
APPR/DOCK  IDS              NAV1 108.10kHz
IDS ISS
TOFS 0.21                 DST    CVEL
TVEL 0.66                518.7   0.36
```

Surface



Indicated airspeed (IAS) Shift I

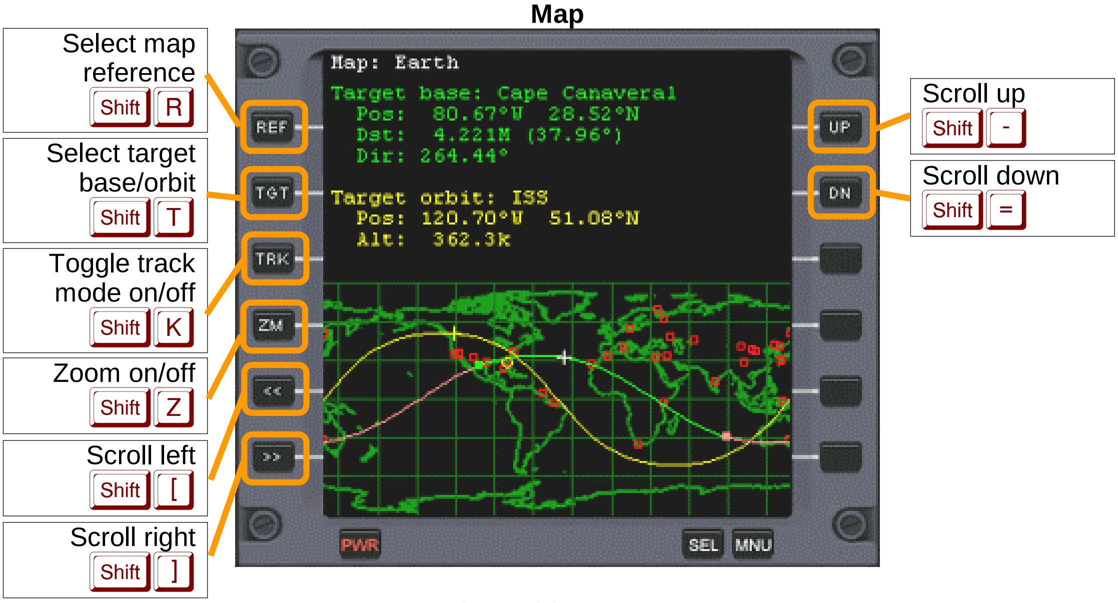
True airspeed (TAS) Shift T

Ground-relative speed (GS) Shift G

Orbital speed (OS) Shift O

```
Surface: Earth
TAS m/s   076 060 E   ALT km   VS m/s
07418     AP  109.3   +2.17
PTCH +08°   BNK 038°R
ACC m/s²  ATM DATA  DNS 0.000      AOA deg  VACC m/s²
-0.01     OAT 226K  STP 0.01Pa     12       0.00
          M   24.04 DNP 2.17Pa
          EQU POS        RATE
          016.760° E     [0.0610°/s E]
          008.795° N     [0.0258°/s N]
```

Map



```
Map: Earth
Target base: Cape Canaveral
  Pos:  80.67°W  28.52°N
  Dst:  4.221M (37.96°)
  Dir: 264.44°

Target orbit: ISS
  Pos: 120.70°W  51.08°N
  Alt:  362.3k
```

Select map reference Shift R

Select target base/orbit Shift T

Toggle track mode on/off Shift K

Zoom on/off Shift Z

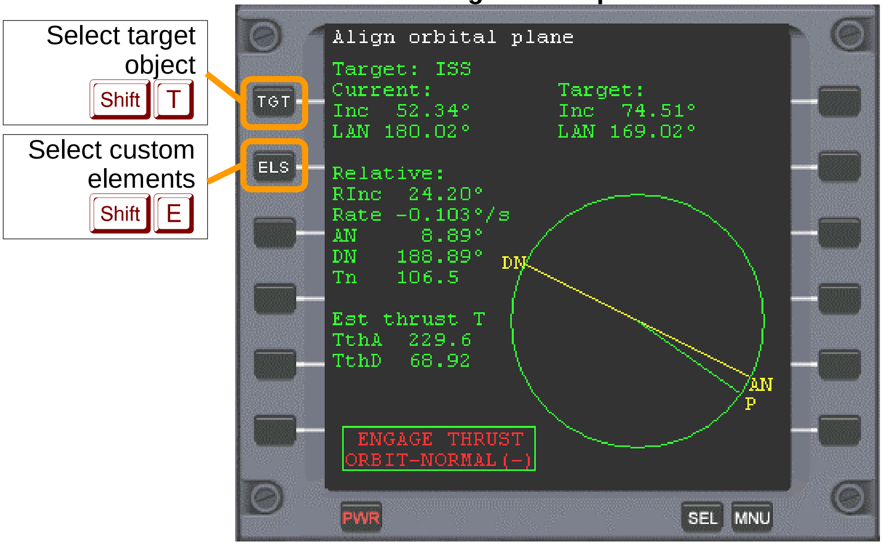
Scroll left Shift [

Scroll right Shift]

Scroll up Shift -

Scroll down Shift =

Align orbital planes

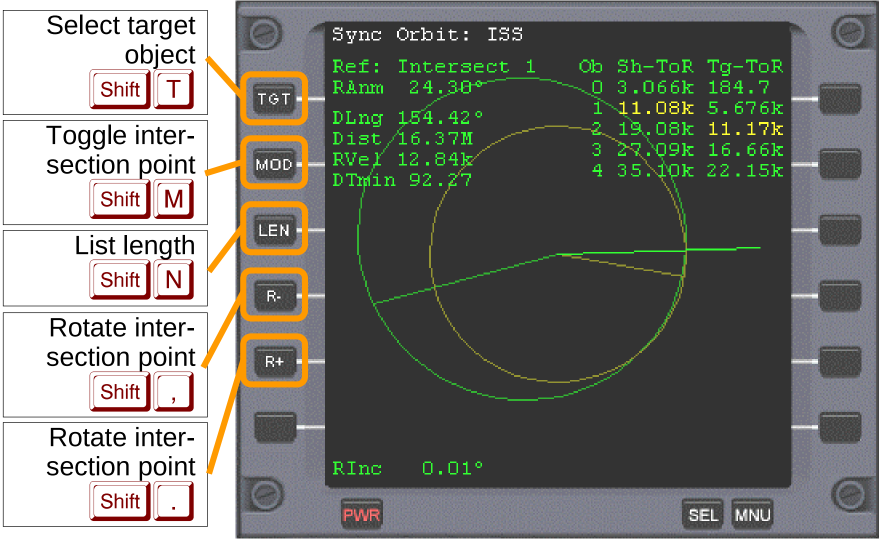


```
Align orbital plane
Target: ISS
Current:          Target:
Inc  52.34°       Inc  74.51°
LAN 180.02°       LAN 169.02°

Relative:
RInc  24.20°
Rate -0.103°/s
AN      8.89°
DN    188.89°
Tn    106.5

Est thrust T
TthA  229.6
TthD  68.92

ENGAGE THRUST
ORBIT-NORMAL(-)
```

Select target object Shift T

Select custom elements Shift E

Synchronise orbits



```
Sync Orbit: ISS
Ref: Intersect 1   Ob Sh-ToR Tg-ToR
RAnm  24.30°        0 3.066k 184.7
                    1 11.08k 5.676k
DLng 154.42°        2 19.08k 11.17k
Dist 16.37M         3 27.09k 16.66k
RVel 12.84k         4 35.10k 22.15k
DTmin 92.27

RInc   0.01°
```

Select target object Shift T

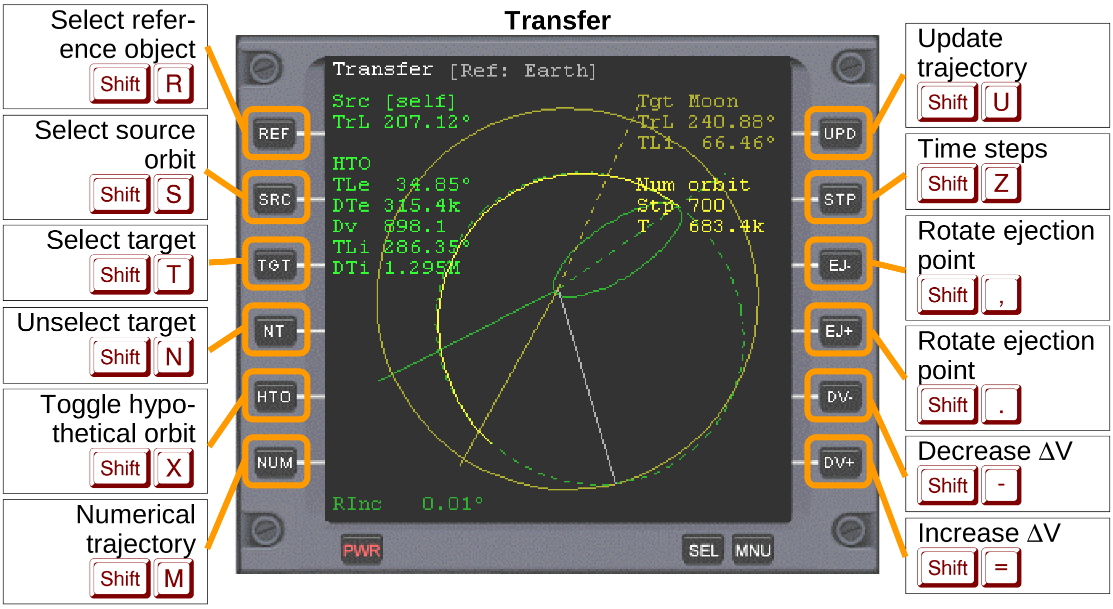
Toggle intersection point Shift M

List length Shift N

Rotate intersection point Shift ,

Rotate intersection point Shift .

Transfer



Select reference object Shift R

Select source orbit Shift S

Select target Shift T

Unselect target Shift N

Toggle hypothetical orbit Shift X

Numerical trajectory Shift M

Update trajectory Shift U

Time steps Shift Z

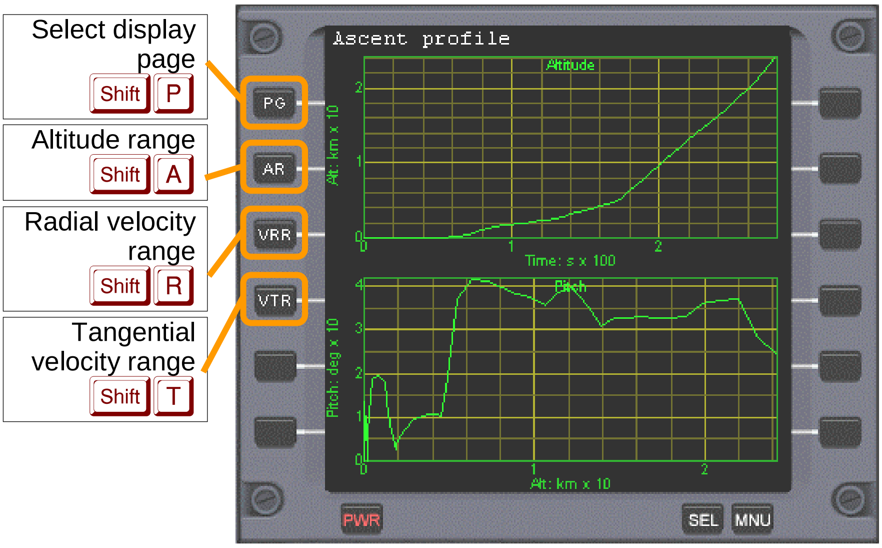
Rotate ejection point Shift ,

Rotate ejection point Shift .

Decrease ΔV Shift -

Increase ΔV Shift =

Ascent



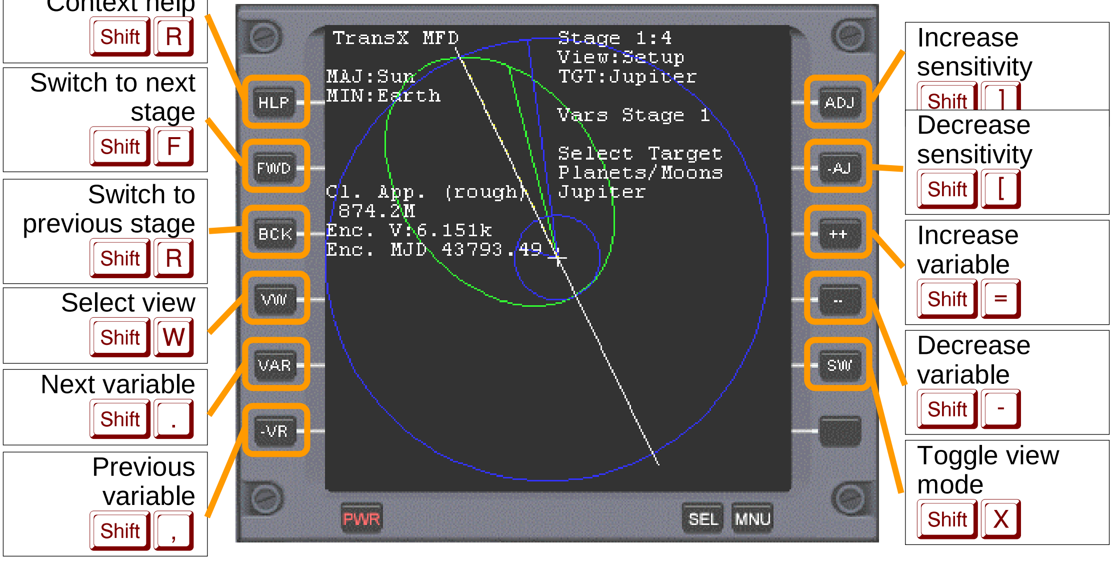
Select display page Shift P

Altitude range Shift A

Radial velocity range Shift R

Tangential velocity range Shift T

TransX



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Appendix B Solar System: Constants and parameters

This section contains a list of physical and orbital planetary parameters used by Orbiter to build its solar system.

B.1 Astrodynamic constants and parameters

Constant	Symbol	Value
Julian day	d	86400 s
Julian year	yr	365.25 d
Julian century	Cy	36525 d
Speed of light	c	299792458 m/s
Gaussian gravitational constant	k	0.01720209895 $(AU^3/d^2)^{1/2}$

Table 1: Defining constants

Constant	Symbol	Value
Mean siderial day		86164.09054 s = 23:56:04.09054
Sidereal year (quasar ref. frame)		365.25636 d
Light time for 1 AU	τ_A	499.004783806 (± 0.00000001) s
Gravitational constant	G	6.67259 (± 0.00030) × 10^{-11} kg^{-1} m^3 s^{-2}
General precession in longitude		5028.83 (± 0.04) arcsec/Cy
Obliquity of ecliptic (J2000)	ε	84381.412 (± 0.005) arcsec
Mass: Sun / Mercury		6023600. (± 250.)
Mass: Sun / Venus		408523.71 (± 0.06)
Mass: Sun / (Earth+Moon)		328900.56 (± 0.02)
Mass: Sun / (Mars system)		3098708. (± 9.)
Mass: Sun / (Jupiter system)		1047.3486 (± 0.0008)
Mass: Sun / (Saturn system)		3497.898 (± 0.018)
Mass: Sun / (Uranus system)		22902.98 (± 0.03)
Mass: Sun / (Neptune system)		19412.24 (± 0.04)
Mass: Sun / (Pluto system)		1.35 (± 0.07) × 10^8
Mass: Moon / Earth		0.012300034 (± 3 × 10^{-9})

Table 2: Primary constants

Constant	Symbol	Value
Astronomical unit distance	$c \times \tau_A = AU$	1.49597870691 × 10^{11} (± 3) m
Heliocentric gravitational constant	$k^2\ AU^3\ d^{-2} = GM_{sun}$	1.32712440018 × 10^{20} (± 8 × 10^9) m^3 s^{-2}
Mass: Earth / Moon		81.30059 (± 0.00001)

Table 3: Derived constants

Notes:

Data are from the 1994 IAU file of current best estimates. Planetary ranging determines the Earth/Moon mass ratio. The value for 1 AU is taken from JPL's current planetary ephemeris DE-405.

Reference:

Standish, E.M. (1995) ``Report of the IAU WGAS Sub-Group on Numerical Standards'', in Highlights of Astronomy (I. Appenzeller, ed.), Table 1, Kluwer Academic Publishers, Dordrecht.

B.2 Planetary mean orbits (J2000)

(Epoch = J2000 = 2000 January 1.5)

Planet (mean)	a [AU]	e	i [deg]	Ω [deg]	ϖ [deg]	L [deg]
Mercury	0.38709893	0.20563069	7.00487	48.33167	77.45645	252.25084
Venus	0.72333199	0.00677323	3.39471	76.68069	131.53298	181.97973
Earth	1.00000011	0.01671022	0.00005	-11.26064	102.94719	100.46435
Mars	1.52366231	0.09341233	1.85061	49.57854	336.04084	355.45332
Jupiter	5.20336301	0.04839266	1.30530	100.55615	14.75385	34.40438

Saturn	9.53707032	0.05415060	2.48446	113.71504	92.43194	49.94432
Uranus	19.19126393	0.04716771	0.76986	74.22988	170.96424	313.23218
Neptune	30.06896348	0.00858587	1.76917	131.72169	44.97135	304.88003
Pluto	39.48168677	0.24880766	17.14175	110.30347	224.06676	238.92881

Table 4: Planetary mean orbits

B.3 Planetary orbital element centennial rates

(for the mean elements given above)

Planet (rate)	a [AU/Cy]	e [1/Cy]	i [“/Cy]	Ω [“/Cy]	ϖ [“/Cy]	L [“/Cy]
Mercury	0.00000066	0.00002527	-23.51	-446.30	573.57	538101628.29
Venus	0.00000092	-0.00004938	-2.86	-996.89	-108.80	210664136.06
Earth	-0.00000005	-0.00003804	-46.94	-18228.25	1198.28	129597740.63
Mars	-0.00007221	0.00011902	-25.47	-1020.19	1560.78	68905103.78
Jupiter	0.00060737	-0.00012880	-4.15	1217.17	839.93	10925078.35
Saturn	-0.00301530	-0.00036762	6.11	-1591.05	-1948.89	4401052.95
Uranus	0.00152025	-0.00019150	-2.09	-1681.40	1312.56	1542547.79
Neptune	-0.00125196	0.0000251	-3.64	-151.25	-844.43	786449.21
Pluto	-0.00076912	0.00006465	11.07	-37.33	-132.25	522747.90

“	arcsecs
Cy	Julian century
a	Semi-major axis
e	eccentricity
i	inclination
Ω	longitude of the ascending node
ϖ	longitude of perihelion
L	mean longitude

Notes:

This table contains mean orbit solutions from a 250 yr. least squares fit of the DE 200 planetary ephemeris to a Keplerian orbit where each element is allowed to vary linearly with time. This solution fits the terrestrial planet orbits to ~25" or better, but achieves only ~600" for Saturn. Elements are referenced to mean ecliptic and equinox of J2000 at the J2000 epoch (2451545.0 JD).

Reference:

Explanatory Supplement to the Astronomical Almanac. 1992. K. P. Seidelmann, Ed., p.316 (Table 5.8.1), University Science Books, Mill Valley, California.

B.4 Planets: Selected physical parameters

Planet	Mean radius [km]	Mass [10^{23}kg]	Density [g/cm^3]	Siderial rotation period [h]	Siderial orbit period [yr]
Mercury	2440. ±1.	3.301880	5.427	1407.509	0.2408445
Venus	6051.84 ±0.01	48.6855374	5.204	-5832.444	0.6151826
Earth	6371.01 ±0.02	59.73698968	5.515	23.93419**	0.9999786
Mars	3389.92 ±0.04	6.418542	3.9335±0.0004	24.622962	1.88071105
Jupiter	69911. ±6.	18986.111	1.326	9.92425	11.856523
Saturn	58232. ±6.	5684.6272	0.6873	10.65622	29.423519
Uranus	25362. ±12.	868.32054	1.318	17.24 ±0.01	83.747407
Neptune	24624. ±21.	1024.569	1.638	16.11 ±0.01	163.72321
Pluto*	1151	0.15	1.1	153.28	248.0208

Planet	V(1,0) [mag.]	Geometric albedo	Equatorial gravity [m/s^2]	Escape velocity [km/s]
Mercury	-0.42	0.106	3.701	4.435
Venus	-4.4	0.65	8.87	10.361
Earth	-3.86	0.367	9.780327	11.186
Mars	-1.52	0.15	3.69	5.027
Jupiter	-9.4	0.52	23.12 ± 0.01	59.5
Saturn	-8.88	0.47	8.96 ± 0.01	35.5
Uranus	-7.19	0.51	8.69 ± 0.01	21.3
Neptune	-6.87	0.41	11.00 ± 0.05	23.5
Pluto	-1.0*	0.3*	0.655	1.3

All values from reference [1] except Pluto data from [2]. Mercury to Neptune masses derived from GM data in [1] (thanks to Duncan Sharpe for pointing this out).

** Orbiter now uses 23.93447h (= 23h 56m 4.09s) which appears to give better long term stability.

References
[1] Yoder, C.F. 1995. ``Astrometric and Geodetic Properties of Earth and the Solar System'' in Global Earth Physics, A Handbook of Physical Constants, AGU Reference Shelf 1, American Geophysical Union.

[2] Explanatory Supplement to the Astronomical Almanac. 1992. K. P. Seidelmann, Ed., p.706 (Table 15.8), University Science Books, Mill Valley, California.

B.5 Rotation elements

Planet	North pole		Obliquity of ecliptic* [°]	Longitude of Sun's transit* [°]
	Right ascension α_1 [°]	Declination δ_1 [°]		
Mercury	280.99	61.44	7.01	228.31
Venus	272.78	67.21	1.27	302.07
Earth	-	90	23.44	0
Mars	317.61	52.85	26.72	262.78
Jupiter	268.04	64.49	2.22	157.68
Saturn	40.14	83.50	28.05	349.39
Uranus	257.29	-15.09	82.19	167.62
Neptune	295.25	40.63	29.48	221.13
Pluto	311.50	4.14	68.69	225.19

Reference:
The Astronomical Almanac 1990 (North pole coordinates)

(*) Derived from north pole coordinates (MS)

B.6 Atmospheric parameters

Planet	Surface pressure [kPa]	Surface density [kg/m^3]	Scale height [km]	Avg. temp [K]	Wind speeds [m/s]
Mercury					
Venus	9200	~65	15.9	737	0.3-1 (surface)
Earth	101.4	1.217	8.5	288	0-100
Mars	0.61 (variable)	~0.020	11.1	~210	0-30
Jupiter	>> 10^4	~0.16 at 1 bar	27	~129 ~165 at 1 bar	up to 150 at < 30° latitude up to 40 else
Saturn	>> 10^4	~0.19 at 1 bar	59.5	~97 ~134 at 1 bar	up to 400 at < 30° latitude up to 150 else
Uranus	>> 10^4	~0.42 at 1 bar	27.7	~58 ~76 at 1 bar	0-200
Neptune	>> 10^4	~0.45 at 1 bar	19.1-20.3	~58 ~72 at 1 bar	0-200
Pluto					

Appendix C Calculation of orbital elements

Six scalar parameters (“elements”) are required to define the shape of an elliptic orbit, its orientation in space and a location along its trajectory.

a	Semi-major axis
e	Eccentricity
i	Inclination
Ω	Longitude of ascending node
ω	argument of periapsis
υ	true anomaly

C.1 Calculating elements from state vectors

Let $\mathbf{r}$ and $\mathbf{v}$ be the cartesian position and velocity vectors of an orbiting object in coordinates of a reference frame with respect to which the elements of the orbit are to be calculated (e.g. geocentric equatorial for an orbit around Earth, or heliocentric ecliptic for an orbit around the Sun). We assume a right-handed system with the x-axis pointing towards the vernal equinox (or other reference direction) and the z-axis pointing upwards.
Compute the following auxiliary vectors:

$$\mathbf{h} = \mathbf{r} \times \mathbf{v} = (r_y v_z - r_z v_y, -r_x v_z + r_z v_x, r_x v_y - r_y v_x)$$

$$\mathbf{n} = \mathbf{z} \times \mathbf{h} = (-h_y, h_x, 0)$$

$$\mathbf{e} = \frac{1}{\mu}\left[\left(v^2 - \frac{\mu}{|\mathbf{r}|}\right)\mathbf{r} - (\mathbf{r}\cdot\mathbf{v})\mathbf{v}\right]$$

where $\mathbf{h}$ is a vector perpendicular to the orbital plane, $\mathbf{n}$ points towards the ascending node (the z-component of $\mathbf{n}$ is zero), and $\mathbf{e}$ is the eccentricity vector (pointing towards the periapsis) with $\mu = GM$, G is the gravitational constant and M is the mass of the central body (neglecting the mass of the orbiter).

Semi-major axis:

$$a = \frac{-\mu}{2E} \quad \text{with} \quad E = \frac{v^2}{2} - \frac{\mu}{|\mathbf{r}|}$$

Eccentricity:

$$e = |\mathbf{e}| \quad \text{or} \quad e = \sqrt{1 + \frac{2Eh^2}{\mu^2}}$$

Inclination:

$$i = \arccos\frac{h_z}{|\mathbf{h}|}$$

Longitude of ascending node:

$$\Omega = \arccos\frac{n_x}{|\mathbf{n}|} \quad (\text{if } n_y < 0 \text{ then } \Omega = 2\pi - \Omega)$$

Ω is the angle between reference direction (1,0,0) (e.g. vernal equinox) and the ascending node.
Ω is undefined for equatorial orbits (*i* = 0), in which case ORBITER by convention sets Ω = 0, i.e. it places the ascending node in the reference direction, which is equivalent to setting $\mathbf{n}/|\mathbf{n}| = (1,0,0)$.

Argument of periapsis:

$$\omega = \arccos\frac{\mathbf{n}\cdot\mathbf{e}}{|\mathbf{n}||\mathbf{e}|} \quad (\text{if } e_z < 0 \text{ then } \omega = 2\pi - \omega)$$

ω is the angle between the ascending node and the periapsis. ω is undefined for equatorial orbits in which case according to above convention we get

$$\omega = \arccos\frac{e_x}{|\mathbf{e}|} \quad \text{(if } e_z < 0 \text{ then } \omega = 2\pi - \omega\text{)}$$

ω is also undefined for circular orbits in which case ORBITER by convention places the periapsis at the ascending node, i.e. $\omega = 0$.

True anomaly:

$$\upsilon = \arccos\frac{\mathbf{e}\cdot\mathbf{r}}{|\mathbf{e}||\mathbf{r}|} \quad \text{(if } \mathbf{r}\cdot\mathbf{v} < 0 \text{ then } \upsilon = 2\pi - \upsilon\text{)}$$

υ is the angle between the periapsis and object position. Note that this expression is undefined for circular orbits, in which case the periapsis coincides with the ascending node according to the convention above, i.e.

$$\upsilon = \arccos\frac{\mathbf{n}\cdot\mathbf{r}}{|\mathbf{n}||\mathbf{r}|} \quad \text{(if } \mathbf{n}\cdot\mathbf{v} > 0 \text{ then } \upsilon = 2\pi - \upsilon\text{)}$$

If in addition the inclination is zero then the true anomaly further simplifies to

$$\upsilon = \arccos\frac{r_x}{|\mathbf{r}|} \quad \text{(if } v_x > 0 \text{ then } \upsilon = 2\pi - \upsilon\text{)}$$

Some dependent parameters can be derived from the above elements:

Linear eccentricity:

$\varepsilon = a\, e$

Semi-minor axis:

$b^2 = a^2(1-e^2)$

Periapsis and apoapsis distances:

$d_p = a(1-e)$

$d_a = a(1+e)$

Longitude of the periapsis:

$\varpi = \Omega + \omega$

Eccentric anomaly:

$$E = \arccos\frac{1-|\mathbf{r}|/a}{e}$$

Mean anomaly:

$M = E - e\sin E$

Mean longitude:

$L = M + \varpi$

True longitude:

$l = \varpi + \upsilon$

Orbit period:

$T = 2\pi\sqrt{a^3/\mu}$

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