ORBITER User Manual

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Contents

1. Introduction

ORBITER is a space flight simulator which uses realistic physical models for planetary motion, spacecraft dynamics and atmospheric effects. Use sophisticated instruments and navigation computers to travel between spaceports on planet surfaces and orbital stations throughout the solar system. ORBITER is highly configurable and allows the modification of existing objects as well as the addition of new spacecraft, orbital stations, surface bases or the construction of a new planetary system from scratch.

ORBITER is not an arcade game. To make the most of it, a basic understanding of physics is required.

2. Support

Suggestions, corrections, bug reports (and praise) for the ORBITER software or this documentation 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 discussion list at www.fsdiscuss.com. I will also try to answer mail sent to directly to me, but I haven't really got the time or resources to officially provide support for ORBITER (after all it's free!)
Before posting a bug report make sure you have got the latest ORBITER release from www.medphys.ucl.ac.uk/~martins/orbit/orbit.html, and that your problem is not already documented in the FAQ.

3. Installation

3.1. Hardware Requirements

The standard ORBITER distribution requires the following hardware specs:

- 166MHz PC or better (Pentium, Athlon, etc.)
- 64MB system memory or more
- Windows 95/98/Me/NT/2000
- Direct3D 7.0 or higher, and DirectX compatible 3D graphics accelerator card with at least 4MB of video memory; 16bit z-buffer or higher (24bit or higher recommended)
- 640x480 display resolution (800x600 or higher recommended)
- Approximately 30MB of free disk space (mostly for planetary texture maps)
- DirectX compatible joystick (optional)

If you want to use the high resolution planetary texture packages, some additional requirements apply:

- AGP 3D graphics accelerator card with 32MB of video memory or more
- Hardware support for DXT1 texture compression (important!)
- 233MHz PC or better
- 128MB system memory or more
- Additional 16MB of disk space for each planetary texture.

Please read the section "Notes on high resolution textures" below before downloading the hires packages.

⚠️ Since ORBITER keeps evolving these specs tend to become obsolete over time. If you don't get a reasonable frame rate (say >= 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.

3.2.   Notes on DirectX

ORBITER uses Microsoft's 3D API, DirectX for interfacing with the 3D hardware. DirectX is not included in the ORBITER distribution. On most Windows systems DirectX will already be installed. If not, it can be downloaded from the Microsoft web site. You need version 7 to run ORBITER. Later versions should also work, but I have not tested them.

Please beware that no uninstall option is provided for DirectX. If at some point you need to remove DirectX for any reason you could face a complete re-installation of Windows.

3.3.   Notes on High Resolution Textures

The ORBITER standard texture package contains planetary textures up to resolution level 7 (4096x2048 pixel bitmap size). The hires packages for Earth, the Moon and Mars contain texture maps for these planets up to resolution level 8 (8192x4096).

The hires textures require better than average graphics hardware. See "Hardware requirements" above for minimum specs.

PLEASE DO NOT DOWNLOAD THE HIRES TEXTURES IF YOUR GRAPHICS CARD DOES NOT SUPPORT DXT1 TEXTURE COMPRESSION! If in doubt please consult your card manufacturer's manual.

Without DXT1 support ORBITER must decompress all textures at the program start. This will take a very long time, and in addition it will increase memory requirements 8-fold. The textures up to level 8 for a single planet would in that case require 130MB of video memory!

Even if you think your hardware can handle the hires textures, you should download the standard version (*Base* and *Textures* package) first and make sure ORBITER runs fine, before downloading the hires packages.

If downloading the hires packages takes too long there is an alternative: Download the *Textool* package and "roll your own": get high-resolution planetary maps from the internet and use the pltex tool to convert them into ORBITER textures. See Section 14 for usage of pltex.

3.4.   Download

The ORBITER distribution can be obtained from the Download page of the ORBITER site, http://www.medphys.ucl.ac.uk/~martins/orbit/orbit.html. The *Base* and *Textures* packages are required, other packages are optional. When upgrading you should only download packages with a time stamp more recent than the ones you have got already. In particular, there is no need to download the hires planetary texture packages more than once.

To minimise download times you should use a mirror closest to your location. Make sure to download the packages in binary mode. If you have problems downloading you may want to try at a different time of day.

3.5.   First-time installation

- Create a directory for the ORBITER installation, e.g. \Program Files\Orbiter
- Download the *Base* package and *Textures* package from the ORBITER Download page into this directory and unzip them. Take care to preserve the directory structure of the packages.
- Edit the Orbiter.cfg configuration file as required to fine-tune ORBITER to your system. See Section 13.1 for explanation of the entries.
- Run Orbiter.exe.

3.6.   Upgrading from a previous installation

- It is recommended to back up your existing installation in case the new snapshot causes problems. At least you should back up any customised configuration files, in particular Orbiter.cfg.

- Download the *Base* package into your Orbiter directory and unpack, retaining the package directory structure. Answer "Yes" if prompted about overwriting files.
- Download and unpack the *Textures* package only if there is a newer version available.
- Merge the new Orbiter.cfg with your backup, if applicable.
- Run Orbiter.exe.

3.7.   Uninstall

- Remove the Orbiter directory with all contents and subdirectories. ORBITER does not modify the registry or any system resources.

4. Keyboard Interface

4.1.   General

F	Toggle between frame rate and field-of-view display.
T	Time warp: Speed up simulation by factor 10 (up to a maximum warp factor of 1000).
X	Zoom out (increase field of view).
Z	Zoom in (decrease field of view).
Ctrl + C	Comms: Request takeoff or landing clearance if within radio range of a space traffic control (STC) center.
Ctrl + D	Comms: Request docking or undocking clearance if within radio range of the selected docking target (orbital station).
Ctrl + T	Time warp: Slow down simulation by factor 10 (down to real-time).
F1	Toggle internal/external view of the user-controlled spacecraft.
Ctrl + F1	Display selection list for external view targets.
F2	Toggle tracking mode for external camera views (target-relative / absolute direction / global frame).
Ctrl + F2	Display selection list for camera tracking modes (external views only).
F3	When the user-controlled ship is parked on a launch pad or docked to an orbital station, this allows to switch to any ship currently landed at the same spaceport or docked to the same station.
F9	"Planetarium mode": Toggle display of constellations.

4.2.   Spacecraft Controls

These keys allow manual maneuvering of the user-controlled spacecraft. See also joystick controls.

⚠ Note that manual control of the attitude thrusters (Numpad 1/2/3/4/6/8 and corresponding joystick controls) is disabled in accelerated time mode.

Numpad 4/6	Engage attitude thrusters for rotation around longitudinal axis (bank)
Numpad 2/8	Engage attitude thrusters for rotation around transversal axis (pitch)
Numpad 1/3	Engage attitude thrusters for rotation around vertical axis (yaw)
Numpad 5	Toggle "Kill rotation" navigation computer mode. Stops spacecraft rotation by engaging appropriate attitude thrusters.
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.
`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)
`Numpad 0`	Increase hover thruster setting. (Applies only to spacecraft with vertical thrusters)
`Numpad .`	Decrease hover thruster setting. (Applies only to spacecraft with vertical thrusters)
`Numpad /`	Toggle attitude thruster mode between rotational (engage opposite thruster pairs) and linear (engage parallel thruster pairs)
`Ctrl` + `Numpad 2/8`	Trim control (only vessels with aerodynamic surfaces)

4.3.   External Views

`I`	Toggle display of information about current object.
`PgUp`	Move camera away from target object.
`PgDn`	Move camera towards target object.
`Ctrl` + `Arrows`	Rotate camera around object.

4.4.   Head-up Display and Multifunctional Display Control

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.

`Ctrl` + `H`	Toggle HUD display on/off.
`H`	Switch HUD mode.
`Shift` + `F1`	Opens a menu for left/right MFD mode selection.
`Shift` + `A`	Display *Align orbital plane* mode MFD.
`Shift` + `D`	Display *Docking* mode MFD.
`Shift` + `L`	Display *Launch/landing* mode MFD.
`Shift` + `M`	Display *Map* mode MFD.

Shift + O	Display *Orbit* mode MFD.
Shift + S	Display *Surface* mode MFD.
Shift + Y	Display *Synchronise orbit* mode MFD.
Shift + Q	Turn off MFD.

Align orbital plane Mode MFD

Shift + T	Input new target object.

Orbit Mode MFD

Shift + M	Toggle display mode (list only, graphics only and both)
Shift + N	No target orbit.
Shift + P	Toggle orbit projection mode (ecliptic, ship's and target's orbital plane)
Shift + T	Input new target object.

Map Mode MFD

Shift + B	Select the next surface base on the current planet as landing target.

Synchronise orbit Mode MFD

Shift + T	Input new target object (orbital station or moon)
Shift + R	Change reference axis.
Shift + N	Select number of entries in the reference transit time list.
Shift + <>	Rotate reference axis (in manual mode only).

4.5.   Menu Selections

UpArrow	Move to previous item in the list.
DnArrow	Move to next item in the list.
RightArrow	Display sub-list for selected item, if available.
LeftArrow	Go back to the parent list from a sub-list.
Enter	Select current item and close list.
Esc	Cancel list.

5. 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	Rotate around vessel's vertical axis (yaw)

holding joystick button 2	
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.

If the joystick has a direction controller ("coolie hat") it can be used to rotate the camera around the observed object in external view mode.

6. Camera modes

6.1. Internal view

In internal (cockpit) view the player is placed inside the cockpit of his/her spaceship and looks forward. Head-up display (HUD) and multifunctional displays (MFD) are only displayed in internal view. To return to cockpit view from any external views, press `F1`.

6.2. 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. To bring up a list of objects to look at, press `Ctrl` + `F1`. See Section 4.5 on how to navigate selection lists.

Figure 1: Solar system main selection list.

In external view a display of target parameters can be toggled by pressing `I`.
From cockpit view, an external view of the current spaceship can be selected by pressing `F1`.
In movable external views the camera can be rotated around the target object by pressing `Ctrl` + `Arrow` keys. The `PgUp` and `PgDn` 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 a menu by pressing `Ctrl` + `F2`:

- **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` + `Arrow` 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` + `Arrow` will rotate the camera around the axes of the ecliptic.
- **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` + `Arrow` 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 + Arrow) is deactivated, but radial camera movement with PgUp and PgDn is still available.

7. Head-up Display

The Head-up display (HUD) provides information about the current status of your spacecraft when internal (cockpit) view mode is selected. 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. Two multifunctional displays (MFDs) can be displayed independent of the HUD mode (see Section 8).
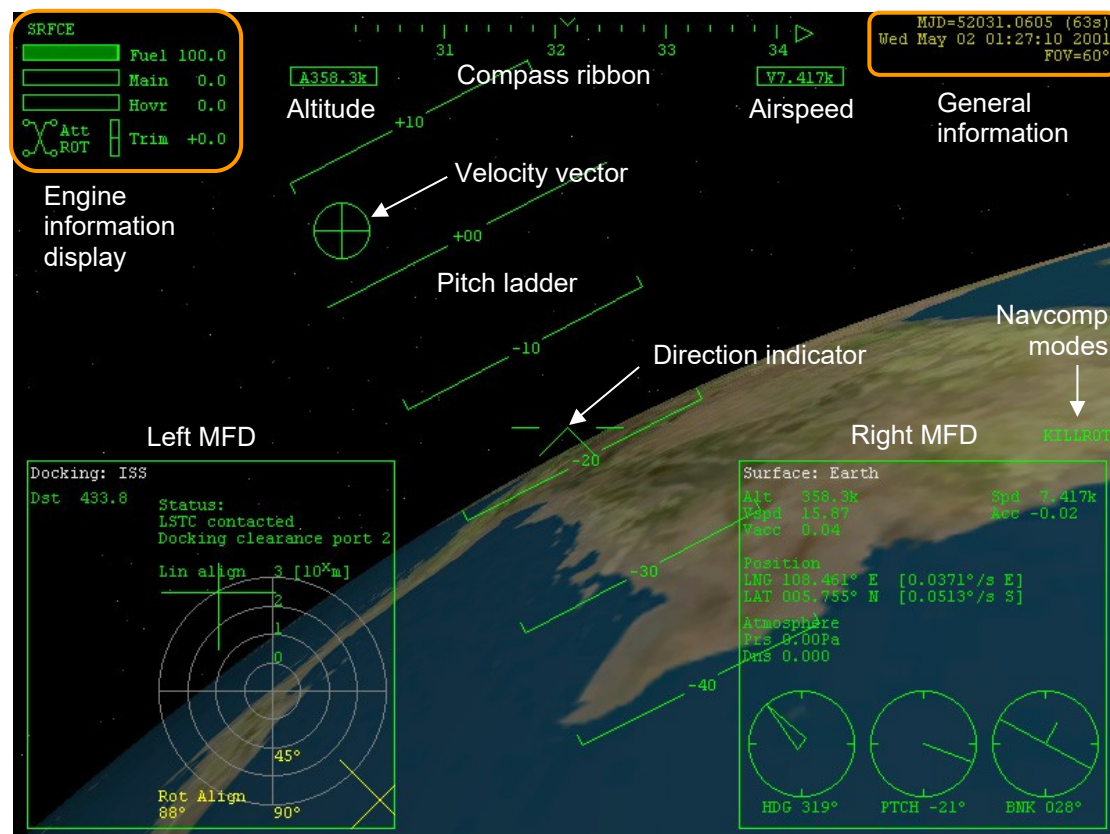
Figure 2: HUD in surface mode, including docking and surface MFDs.

7.1.   General information display
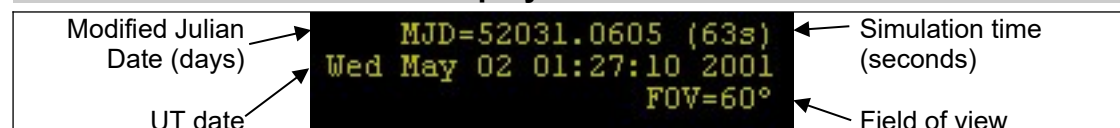
Figure 3: General simulation information

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 00000.5

UT: Universal time counted from 0^h at midnight. Unit is mean solar day.

FOV: (vertical) field of view, i.e. viewport camera aperture.

The display can be toggled between FOV and viewport resolution/frame rate via the F key.

7.2.   Engine information display
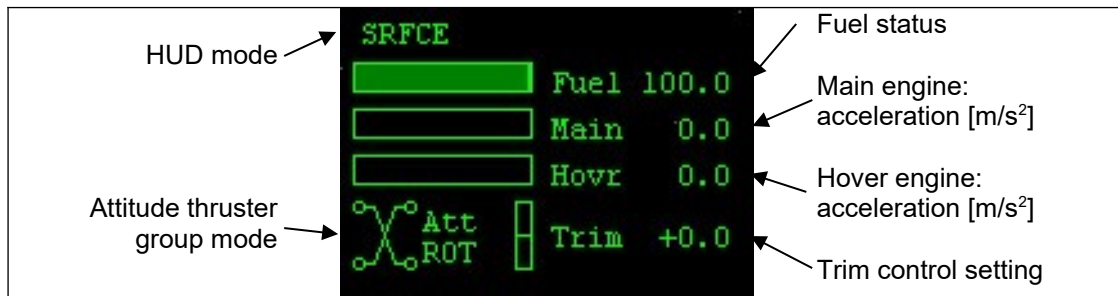
Figure 4: Fuel/engine displays

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.

Attitude thruster mode: Attitude thrusters are small engines used for rotation and fine translational adjustments. The display shows the current mode (rotational/translational).

Trim setting: Displays the current setting of the trim control (if available). Trimming allows to adjust the flight characteristics during surface flight.

For more information about engines and spacecraft control see Section 10.

7.3.   Surface 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 "⊕✕"🖐.

7.4.   Orbit Mode

Indicated by "ORBIT" in the upper left corner.

This mode displays a pitch ladder relative to the current orbital plane. It also marks the direction of the orbital velocity vector (prograde direction) by "⊕ " and retrograde direction by "+".

7.5.   Docking Mode

(Under construction).

This mode marks the current docking target (orbital station) and its distance. It also shows the direction and magnitude of the target-relative velocity vector.

8. Multifunctional Display Modes

Two multifunctional displays (MFD) can be displayed simultaneously on the screen. MFDs provide essential information about all spacecraft flight parameters. A range of different MFD modes is available to assist in various navigational problems such as launch/landing, surface flight, orbit determination etc. MFDs are controlled by Shift key combinations, where the left Shift key controls the left MFD, the right Shift key controls the right MFD.

MFD modes can be selected either directly (see section 4.4 for keyboard commands) or by pressing ⎡Shift⎤+⎡F1⎤ to bring up a menu.

8.1.   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 parameters will then be displayed as well.

Shift + T opens an input box to specify a target object. Only targets which orbit around the same body as the spacecraft will be accepted. The target display can be turned off with Shift + N.

The plane into which the orbits are projected can be selected via Shift + P. The current projection plane is indicated in the top right corner of the instrument. *Ecliptic* projects into the plane of the ecliptic (Earth's orbital plane). *Ship* projects into the vessel's current orbital plane, and *Target* projects into the target's current orbital plane, if a target is specified.

Key options:

Shift + M	Toggle display mode (list only, graphics only and both)
Shift + N	No target orbit.
Shift + P	Toggle orbit projection mode (ecliptic, ship's and target's orbital plane)
Shift + T	Input new target object.

Label	Self	Target
Reference object	Orbit: Earth	
	---SELF---	--TARGET--
Semi-major axis	SMa 10.10M	SMa 6.721M
Semi-minor axis	SMi 9.519M	SMi 6.721M
Periapsis distance	PeD 6.720M	PeD 6.721M
Apoapsis distance	ApD 13.48M	ApD 6.721M
Radial distance	Rad 6.723M	Rad 6.721M
Eccentricity	Ecc 0.3347	Ecc 0.0000
Orbit period	T 10.10K	T 5.484K
Time to periapsis passage	PeT 10.07K	PeT 2.281K
Time to apoapsis passage	ApT 5.014K	ApT 5.023K
Velocity	Vel 8.895K	Vel 7.701K
Inclination	Inc 1.89°	Inc 0.00°
Longitude of asc. node	LAN 207.32°	LAN 0.00°
Longitude of periapsis	LPe 207.92°	LPe 0.00°
Argument of periapsis	AgP 0.60°	AgP 0.00°
True anomaly	TrA 2.91°	TrA 210.25°
True longitude	TrL 210.84°	TrL 210.25°
Mean anomaly	MnA 1.37°	MnA 210.25°
Mean longitude	MnL 209.29°	MnL 210.25°

Spacecraft elements
Target elements

Figure 5: Orbit MFD in parameter list mode.
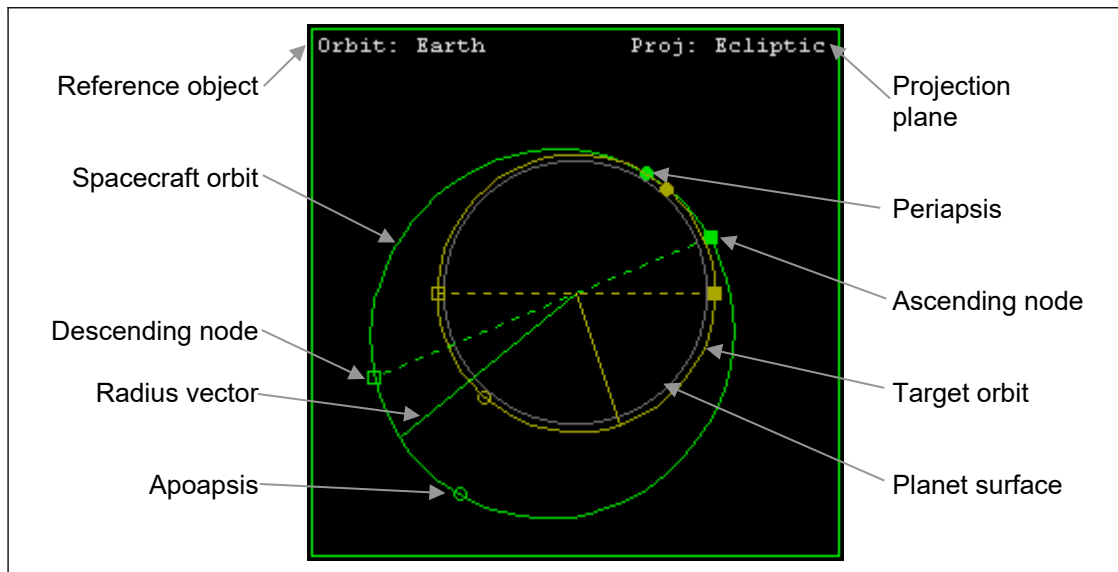
Figure 6: Orbit MFD in graphic mode.

Notation:

- Periapsis: The point of the orbital ellipse closest to the central body.
- Apoapsis: The point furthest away from the central body.
- Ascending node: The point at which the orbit passes through the ecliptic (or other reference plane) from below.
- Descending node: The point at which the orbit passes through the ecliptic from above.
- Radius vector: The vector from the central body to the current position of the orbiting body.

For further explanation of orbital elements see Appendix C.

8.2.   Landing

The *Landing* MFD mode contains graphical indicators for horizontal and vertical airspeed components, altitude, landing target direction and distance, and takeoff/landing clearance status.

- The altitude bar has a range from 1 to 10^4m (logarithmic scale).
- The vertical speed bar has a range from ±0.1 to $\pm10^3$m/s (logarithmic scale). Positive vertical speed is indicated by a green bar, negative vertical speed by a yellow or red bar.
- Horizontal speed and target indicator are displayed relative to the ship's orientation, on a logarithmic radial scale. Hspeed range between 0.1 and 10^3m/s, target distance range between 1 and 10^4m.
- The landing cone for the current altitude is shown as a green or red circle. Green indicates that the ship is within the cone. The radius of the circle is a linear function of the ship's altitude.
- The status indicator shows if contact to Local Space Traffic Control is established, and the takeoff/landing clearance status.

Figure 7: Landing MFD.

8.3.   Docking

Figure 8: Docking MFD.

The *Docking* MFD assists during final approach to an orbital station. The layout is similar to the Landing MFD.

- **Docking target**: the currently targeted orbital station.
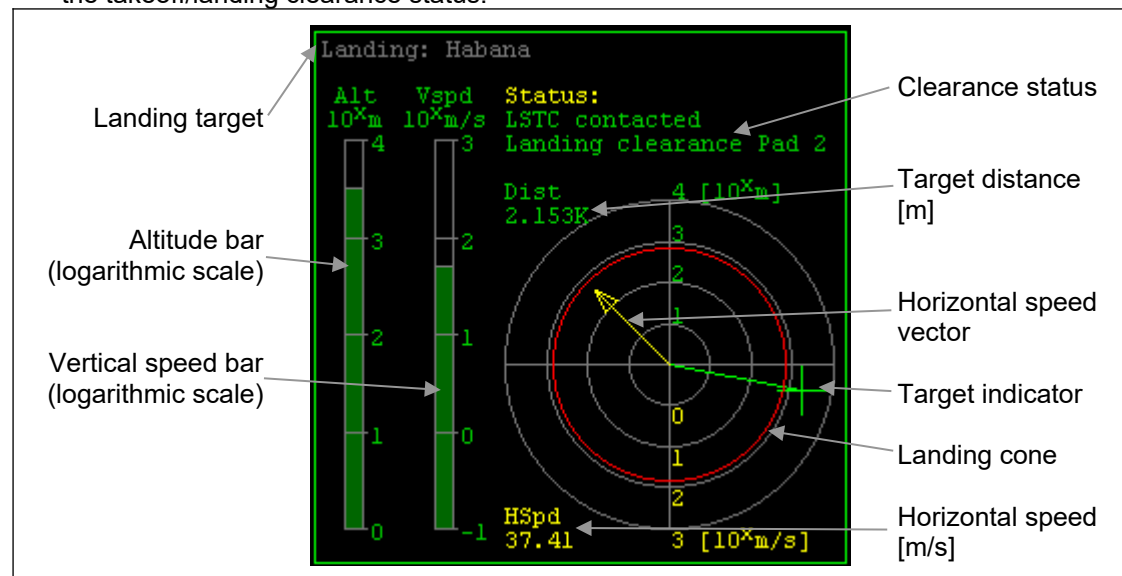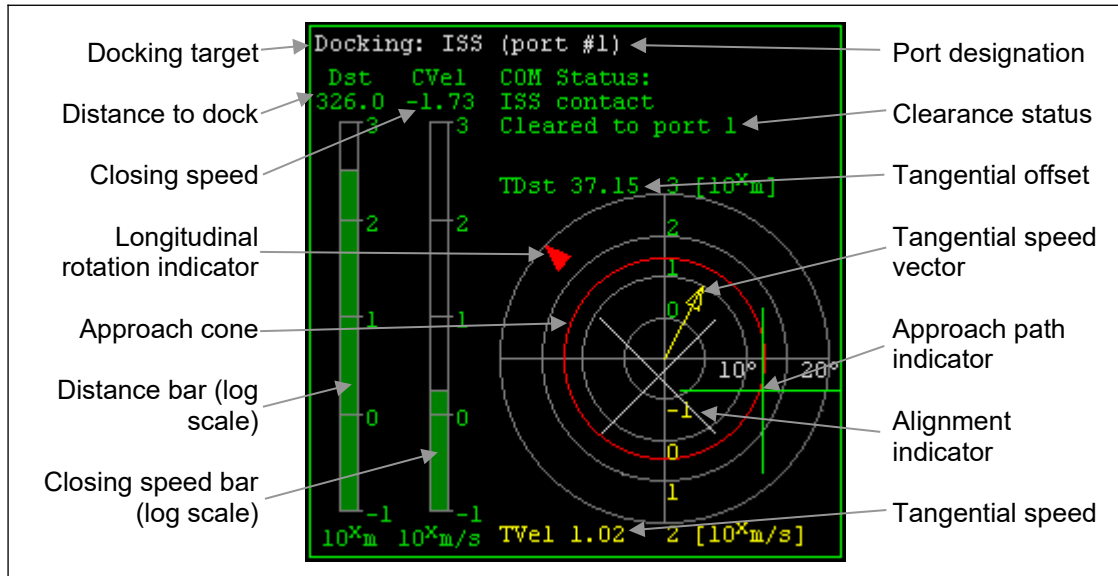- **Port designation**: If a dock has been allocated for your ship, its designation is displayed in the title line.
- **Dst**: Distance to dock [m], or distance to station if no dock is allocated. The bar shows the distance on a logarithmic scale in the range $0.1–10^3$ m.
- **CVel**: Closing speed [m/s]. The bar shows the closing speed on a logarithmic scale in the range $0.1–10^3$ m/s. Yellow indicates positive closing speed.
- **COM status**: indicates whether the target is within radio range, and the current docking/undocking clearance status.

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

- **TDst**: 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. The numerical value is the ship's tangential distance from the approach path [m]. Tangential alignment should be performed with attitude thrusters in *linear* mode (see Section 10.2).
- **TVel**: 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 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 10.2).
- **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 10.2). 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 currect 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.

You can only dock at a port allocated to you by the station's traffic controller. To request docking (and undocking), press Ctrl + D . Clearance status is displayed in the MFD.

Note:
- Engine controls are disabled while docked to an orbital station.
- 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 station.
- After docking successfully your ship will automatically be refuelled.

8.4. Surface

The *Surface* MFD mode assists in flight close to planetary surfaces. It lists altitude, horizontal and vertical speed and acceleration, atmospheric pressure and density (if applicable), vessel position in equatorial coordinates, and indicators for heading, pitch and bank angles.
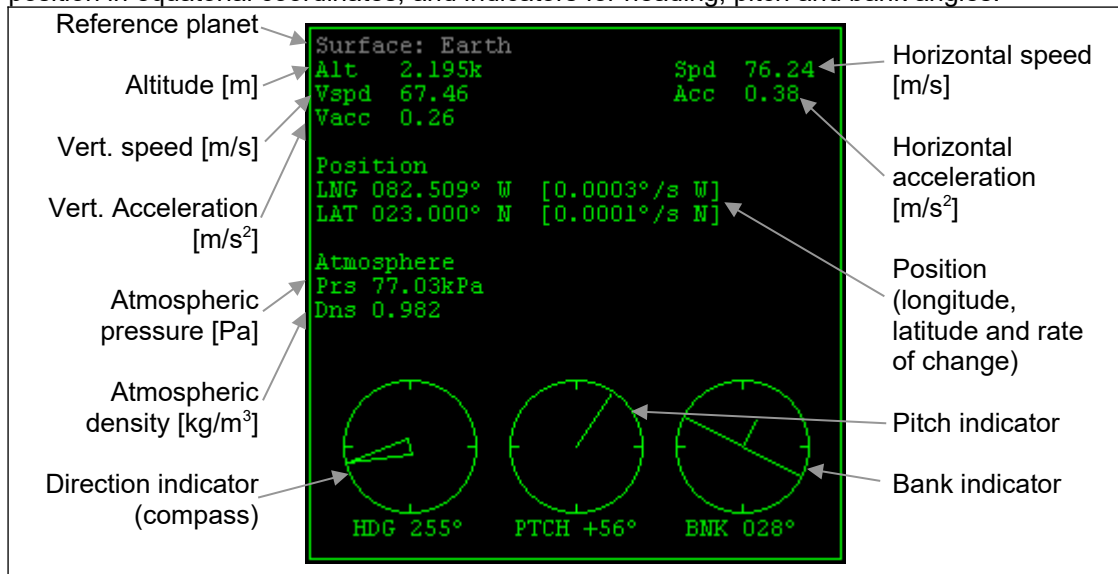
Figure 9: Surface MFD.

8.5. Map

The *Map* MFD mode shows a surface map of the currently orbited planet, including all available surface bases. 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 station onto the planet surface are plotted.

Key options:

Shift + B	Select the next surface base on the current planet as landing target.
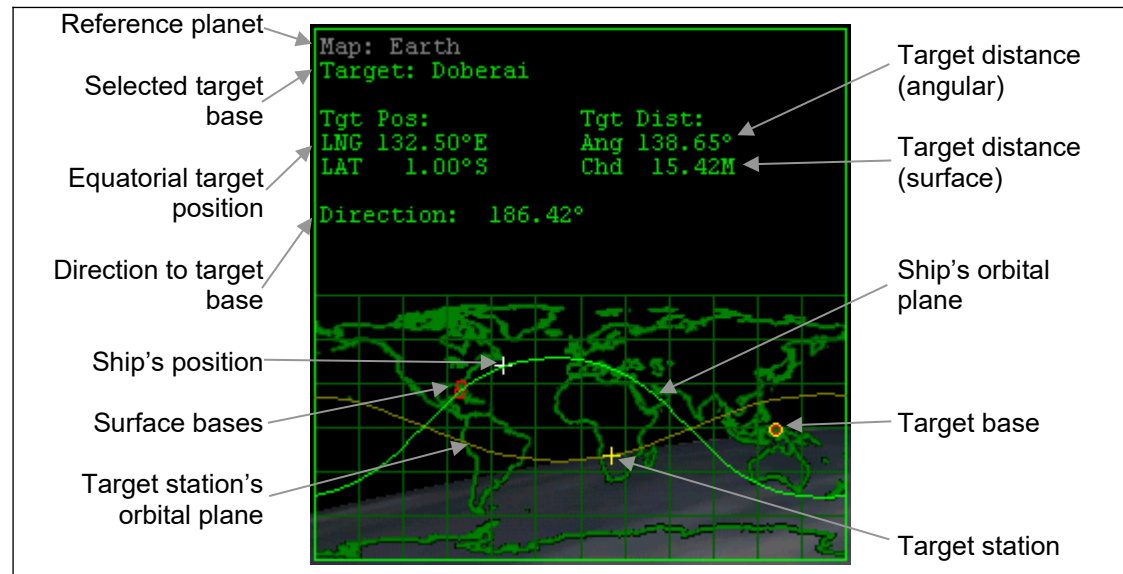
Figure 10: Map MFD.

8.6.   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 11.3 on how to use this MFD mode.

Key options:

Shift + T	Input a new target object or target orbital parameters.
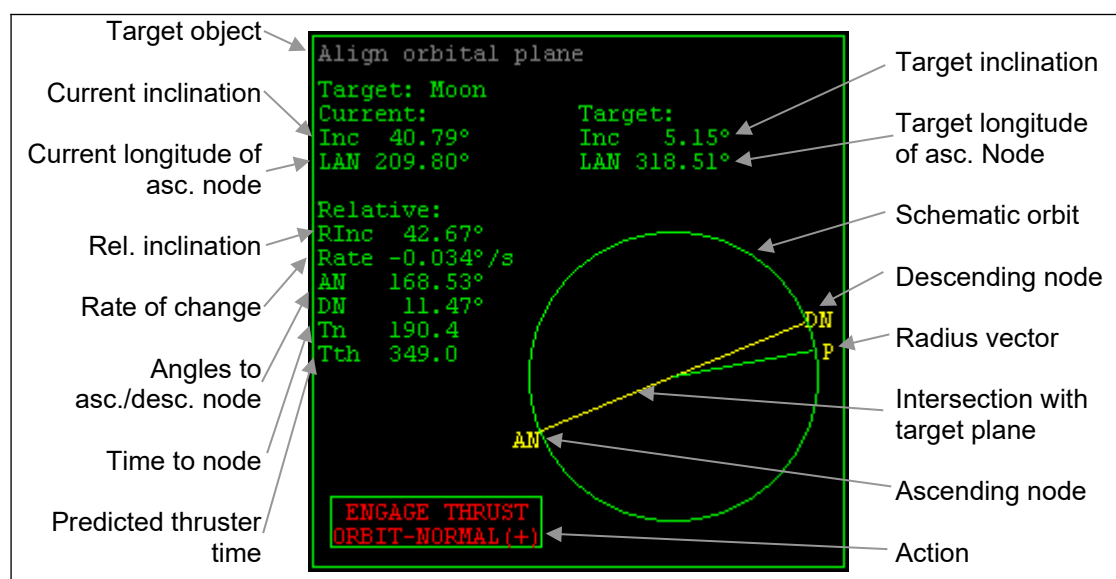
Figure 11: Align Orbital Plane MFD mode.

8.7.   Synchronise Orbit
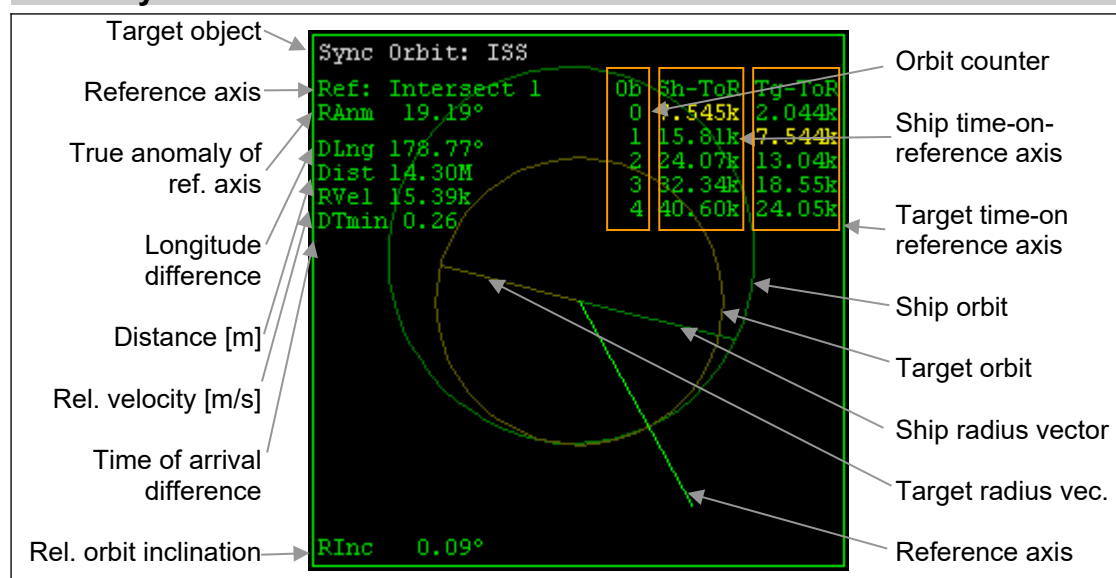
Figure 12: Synchronise Orbit MFD mode.

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 manoeuvres should be performed in this plane.

- **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 with `Shift` + `R` 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.

Key options:

`Shift` + `T`	Select target object. Only objects orbiting the same body as the ship will be accepted.
`Shift` + `R`	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.

For usage of this MFD mode in orbit synchronisation, see Section 11.5.

9. Quickstart

At the start of the program you are inside a spacecraft located on a launch pad at Habana International Spaceport.

Have a look at your ship:
- Press F1 to switch to an external camera. Use Ctrl+Arrow keys to move the camera around your craft.
- Pressing F1 again from any external camera mode gets you back inside the cockpit.

What else is there?
- Press Ctrl+F1 to bring up a list of objects in the solar system. Use the up and down arrow keys to highlight an object, and Enter to select it.
- Objects with an '>' indicator have associated objects which can be selected with the right arrow key. To return from a sub-menu press the left arrow key.
- Use Ctrl+Arrow keys to move the camera around the selected object. PgUp and PgDown moves the camera in or out. The 'z' and 'x' keys zoom in and out.

Head up display

- Press F1 to get back into the cockpit.
- Press Ctrl+H to activate the HUD.
- Press H until Surface mode is selected ('SRFCE' in the upper left corner of the screen)
- Press LeftShift+S to bring up the left MFD in Surface mode.
- Press RightShift+L to bring up the right MFD in Landing mode.

Launch

- Press Ctrl+C to request launch clearance from Space Traffic Control.
- When clearance is given, press 'Ins' on the numerical keypad to engage launch thrusters. Press until your acceleration is 10m/s^2.
- Once you have reached about 100m altitude, point the nose upward about 30 degrees (by pulling on your joystick or pressing the Down arrow on the num-keypad) and fire your main engines (using the joystick throttle control or pressing Ctrl+'+' on the num-keypad).
- If your craft has airfoils (like the glider) which produce a lift vector during atmospheric flight, the hover thrusters can slowly be reduced ('Del' on the numeric keypad) as airspeed is picking up.

Free flight

- Practise handling your spacecraft, but keep an eye on the altitude indicator!
- Ctrl+'Keypad+' increases main thrusters/reduces retro thrusters.
- Ctrl+'Keypad-' reduces main thrusters/increases retro thrusters.
- Ctrl+'Keypad*' resets main/retro thrusters to zero.
- Ins increases hover thrusters.
- Del reduces hover thrusters.
- '8' and '2' on the num-keypad engage the pitch attitude thrusters.
- '4' and '6' on the num-keypad engage the roll attitude thrusters.
- '1' and '3' on the num-keypad engage the yaw attitude thrusters.
- '5' on the num-keypad engages the 'kill rotation' sequence.
- When you get to high altitudes you will notice how the handling of the ship changes as atmospheric pressure drops.
- The "Hold altitude" (keyboard 'A') and "Keep level with horizon" (keyboard 'L') functions may help stabilise the ship at low altitudes.

Landing

- Press RightShift+M to bring up the Map display.
- Press RightShift+B until Cape Canaveral is selected.
- Press RightShift+L to bring up the Landing display for your landing target.
- Fly towards Cape Canaveral (should roughly be north of your position). Use the indicator on the compass ribbon at the top of the HUD and the target indicator (green cross) on the Landing display for directions.
- Once within 100km of the base press Ctrl+C to request landing clearance.
- Move towards your assigned pad (flashing green). Use the Landing display to align your vessel above the target at altitude ~1km (that's the tricky bit). You can make position adjustments by tilting the ship to get a horizontal acceleration component from the hover thrusters (similar to a helicopter).
- Reduce the hover thruster settings so that you start sinking. Reduce your vertical velocity as you approach the ground (the vertical velocity indicator should not turn red until about 10m above ground).
- You should now be sitting in the middle of the launch pad.

What next?

- Check out Section 11 (Basic Flight Maneuvers) for more information on surface and orbital flights.
- You could try to rendezvous with the ISS (International Space Station) orbiting the Earth. This requires several orbit synchronisation and intercept manoeuvres. Use the *Orbit*,

Align Orbital Plane, *Synchronise Orbit* and *Docking* MFD modes to assist in the necessary steps.

- You could try to land at the Moon. The transit will take several hours but you can engage time warp mode ('T' to increase, Ctrl+T to reduce). Try to get into a stable orbit around the Moon. There is also a space station you can try to find.

10.   Spacecraft Controls

10.1.   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:

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

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

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

The current main/retro thruster setting and corresponding acceleration is displayed in the upper left corner of the HUD ("Main"). The indicator bar is green for positive (main) thrust, and yellow for negative (retro) thrust. The numerical acceleration value is in units of m/s^2. 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 Numpad 0 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.

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).

Main	Retro	Hover
Ctrl + Numpad + (perm.) Numpad + (temp 100%.) Joystick throttle control	Ctrl + Numpad − (perm.) Numpad − (temp 100%.)	Numpad 0 Numpad .
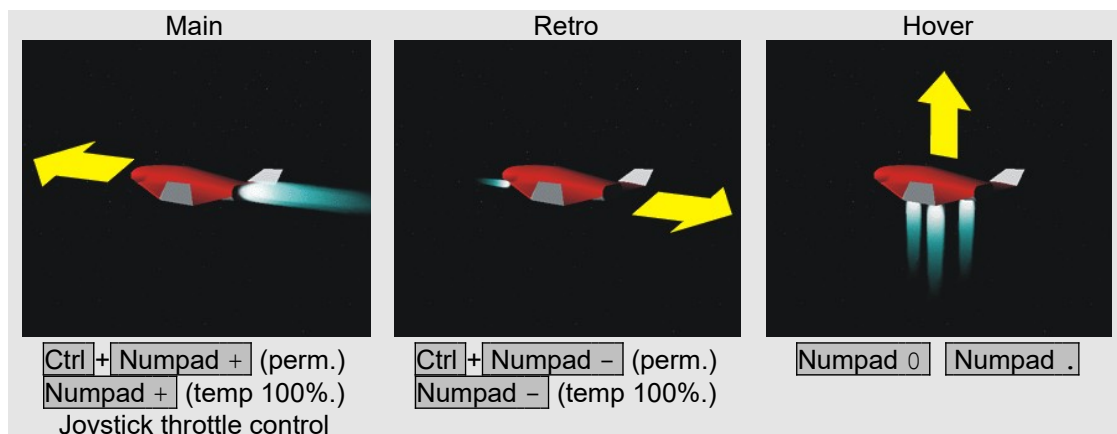
Figure 13: Acceleration from main, retro and hover thrusters.

The maximum thrust ratings for main, retro and hover thrusters as well as the current spacecraft mass are displayed in external spacecraft views. Values are in Newton (1N = 1kg m s^{-2}).

10.2. 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
Numpad 1 Numpad 3	Numpad 2 Numpad 8	Numpad 4 Numpad 6
Joystick rudder control Or Joystick left/right+Button 2	Joystick forward/back	Joystick left/right
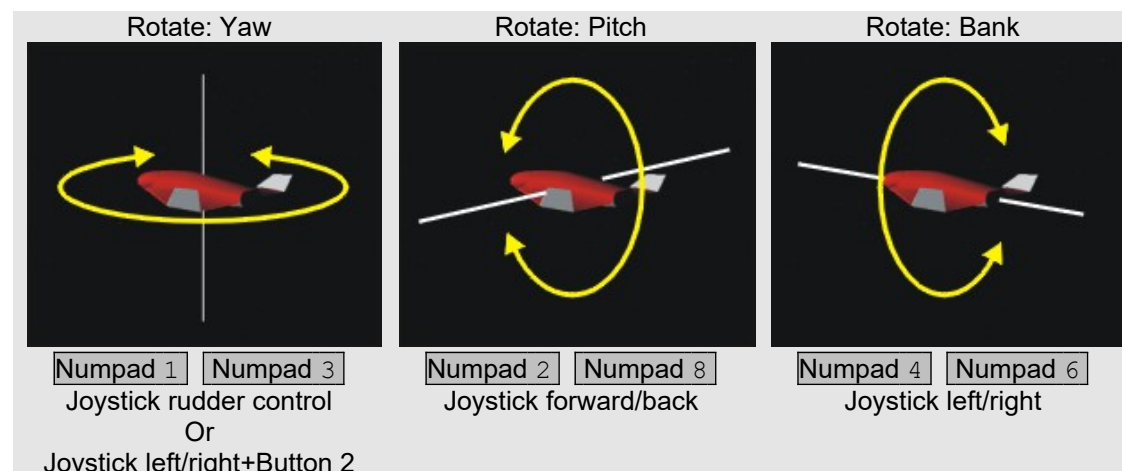
Figure 14: Attitude thrusters in rotational mode.

In translation mode the spacecraft can be linearly accelerated left/right and up/down. For forward/backward acceleration main and retro thrusters must be used.

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

Figure 15: Attitude thrusters in translational (linear) mode.

An important control function is the *Kill rotation* sequence (Numpad 5). This will automatically engage appropriate attitude thrusters to stop the ship's rotation.

11.　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 plain wrong. Corrections and suggestions are always welcome.

11.1.　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 involves 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.
- As very 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 orbital velocity for 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 t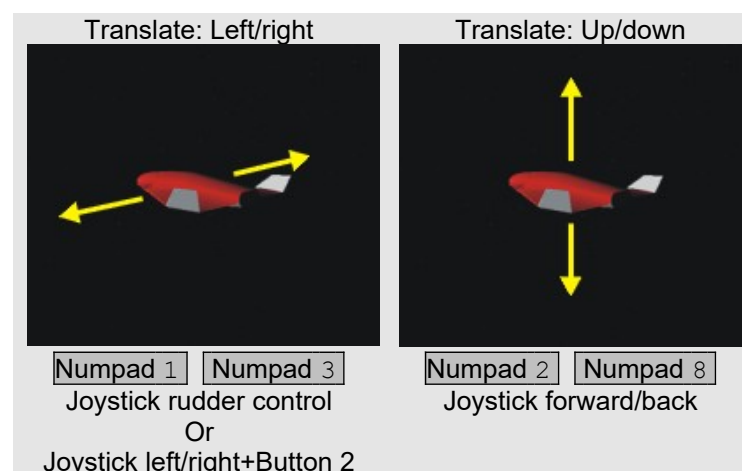o counter atmospheric friction and maintain a constant airspeed. If your ship produces lift, hover thrusters are not necessary unless airspeed falls below stall speed (e.g. during vertical lift-off and landing). If your ship does not generate a lift vector, hover thrusters must be substituted, or the 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.

11.2.　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 (Shift-S) and Orbit (Shift-O) MFD modes.
- Engage hover thrusters to at least 10m/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.

11.3.   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.
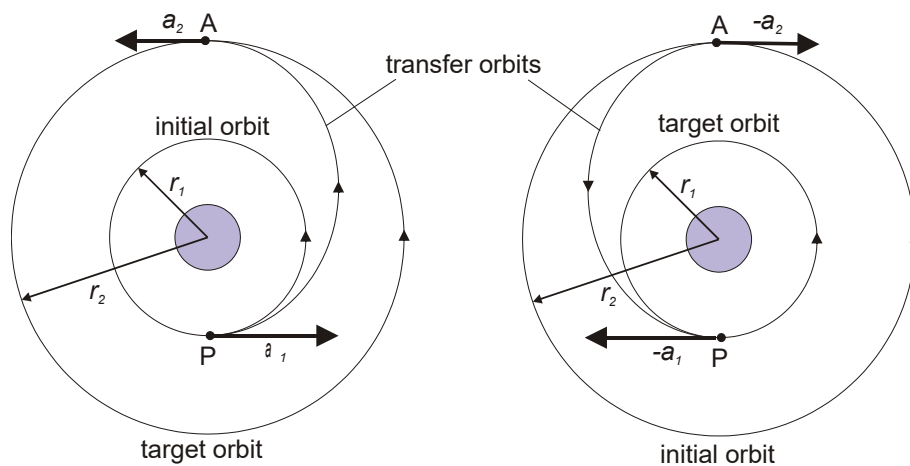
Figure 16: Moving into a higher orbit involves prograde acceleration at P and A (periapsis and apoapsis of the transfer orbit). Conversely, moving from the higher to the lower orbit requires retrograde acceleration at A and P.

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 periapsis distances are re-established.

11.4.   Rotating the Orbital Plane

In order to rendezvous with another orbiting body (e.g. a space station) or to prepare for transit to a moon or planet, the first step is to align the orbital plane (OP) of your ship with that of the target. Once you are in the same OP 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 principal technique to rotate the OP is to point the spacecraft normal (perpendicular) to the current orbital plane, and to fire the engines. This will start to rotate the OP around an axis defined by your current radius vector. Therefore in order to align the orbit with a given target plane:

- Wait until you reach the intersection (node) of your orbit with the target plane
- Rotate the ship to point normal to the current orbit
- Fire the engines until the OP aligns with the target plane.

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.
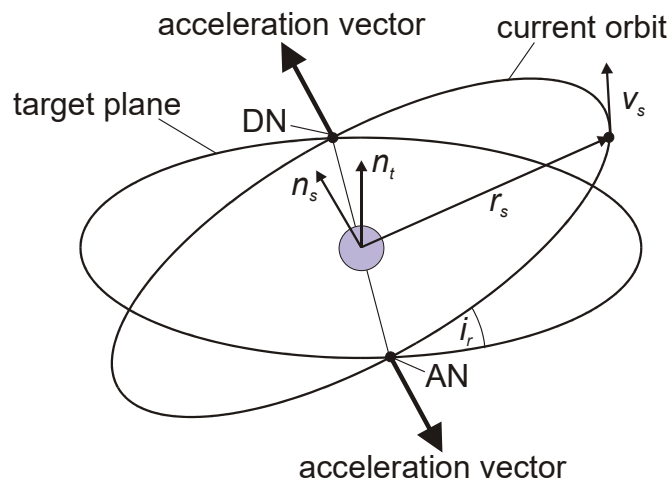
Figure 17: Alignment of the orbital plane. r_s: radius vector. v_s: velocity vector. AN: ascending node. DN: Descending node. n_s: normal of the current plane. n_t: normal of the target plane.

The direction of the normal vector n_s is defined by the direction of the cross product r_s x 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 17).

In Practice:

- The *Align orbital plane* MFD mode (Shift-A, see Section 8.6) 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 normal (if at DN) or anti-normal (if at AN) to the current orbital plane. Use the HUD Orbit inclination ladder for this.
- As soon as the time to node (Tn) reaches half the estimated burn time (Tth) 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.
- 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).

11.5. 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 manoeuvre 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* (Shift-Y) 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 11.3), 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.

$$\text{Sh-ToR}(0) = T_S$$
$$\text{Tg-ToR}(0) = \Delta t_T$$
$$\text{Tg-ToR}(1) = T_T + \Delta t_T$$

$$\downarrow$$

Synchronisation:
$$T_S = T_T + \Delta t_T$$
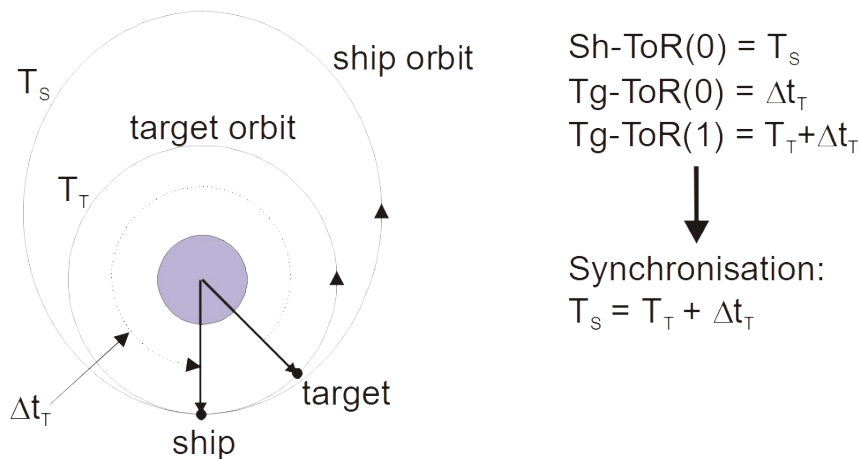
Figure 18: A transition orbit to intercept the target at the next periapsis passage.

Notes:
- Instead of increasing the apoapsis distance one could fire retrograde and reduce the periapsis distance in this manoeuvre. 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 manoeuvre. 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 alingment of orbit timings more difficult.

11.6.   Docking

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

- Turn on the *Docking* MFD (Shift-D) and the *Docking* HUD by pressing 'H' until docking mode is selected.
- 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).
- Request docking clearance (Ctrl-D). Once clearance is given, the HUD will display rectangular approach path indicators, and the alignment indicators in the Docking MFD will be activated.
- Move towards the approach path indicator 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 manoeuvre.
- Once docked, your ship will automatically be refuelled. As with spaceports, you can jump into any other ship currently docked to the station by pressing F3.
- To undock, request clearance again with Shift-D.

Figure 19: A successfully completed docking approach to the ISS.

Notes:

- You can only dock to a port you have been cleared.
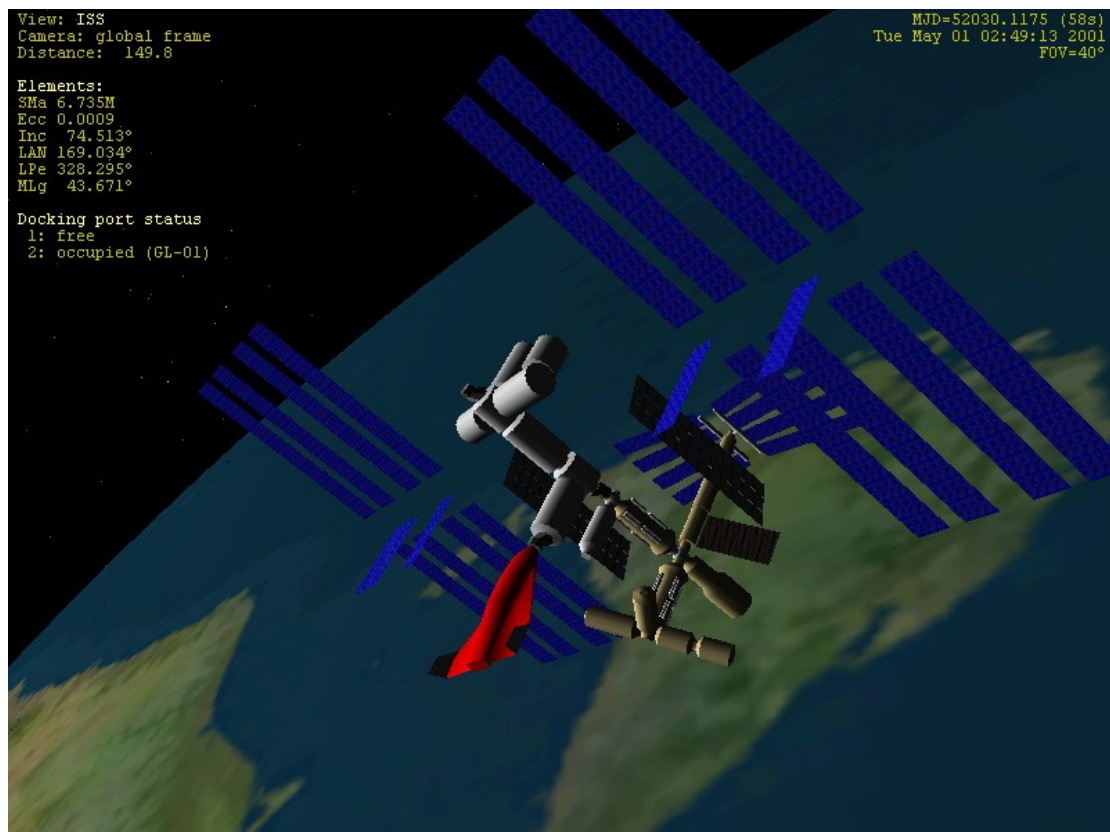- Rotational alignment is not currently enforced, but may be in future versions.
- Currently no collision tests are performed, so you might fly straight through the station if you miss the docking approach.

12. Flight Checklists

This section contains point-by-point checklists for some complete flights.

12.1. Launch from Habana for the International Space Station

This checklist assumes you are currently parked on a Habana Spaceport launch pad. Modify configuration files if necessary.

For this flight, avoid 1000x time acceleration because it will degrade the accuracy of orbit calculation. Remember that spacecraft controls are disabled at time acceleration > 1x.

- Press LShift-M to bring up the Map MFD. The yellow sinosidal curve is the orbital plane of the ISS, projected on the Earth map. The white cross is your current position.
- Wait for your launch window. You should launch as soon the yellow curve intercepts your position. This could take several hours, so you may need to engage time acceleration (T). Switch back to realtime (Ctrl-T) as soon as the ISS orbit intersects your position.
- Press RShift-L to bring up the Launch/Land MFD.
- Press Ctrl-H, H to bring up the HUD in Surface mode.
- Press Ctrl-C to request launch clearance. Wait until you get clearance (shown in the Launch MFD).
- Engage Hover thrusters by pressing Numpad-Ins until you get acceleration >= 10 m/s^2 ('Hovr' indicator in upper left corner).
- After takeoff turn towards heading 45° or 135° using attitude thrusters Numpad-1 and Numpad-3. Turn to 45° if you are intercepting the rising part of the ISS orbit, and to 135° if you are intercepting the falling part of the orbit. (The point is to approximately align your orbital plane with the ISS so that only small corrections are required later).
- At altitude > 100 m engage main thrusters fully (Ctrl-Numpad+) and lift the nose to 70° pitch, using Numpad-2 and Numpad-8.
- Kill hover thrusters (Numpad-Del).
- Switch to Surface MFD (LShift-S).
- Switch to Orbit MFD (RShift-O). Select the ship's orbit as reference plane (RShift-P) and select ISS as target (RShift-T, 'ISS').
- Reduce pitch gradually as you gain altitude: 60° at 20km, 50° at 60km, 40° at 100km, 30° at 150km, 20° at 200km, 10° at 270km, 0° at 340°. Maintain heading during climb. The objective is to reach tangential orbital velocity at ~360km (the altitude of the ISS). During the final stage of the orbit injection you will need to adjust the pitch to drop to zero vertical speed ('VSpd' in surface MFD) when reaching altitude 360km. The exact altitude is not critical at this stage.
- Kill thrusters (Numpad*) when the eccentricity of the orbit is close to zero ('Ecc' in orbit MFD). You have now entered a circular orbit.
- Switch to Orbit HUD mode (H, H)
- Switch to Align Orbital Plane MFD (LShift-A). Select ISS (LShift-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 *south*. If you are approaching the descending node (DN), turn *north* (as explained in Section 11.4).
- 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 Synchronise Orbit MFD (LShift-Y). Select "Manual" reference mode (LShift-R) and rotate the reference axis until it points just behind your current position. The time-on-reference indicator for orbit 0 (Sh-ToR(0)) should now approximately equal the orbital period.
- Turn the ship prograde (align with "⊕" velocity marker). 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 now until you reach the reference point.
- Switch to Docking HUD mode (H, H) and to Docking MFD (LShift-D).
- Rotate the ship to align with the 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.
- Request docking clearance (Ctrl-D).
- When cleared for docking, the approach path indicator in the Docking MFD will become active, and the approach path will be shown as a series of rectangles 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.
- 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!

13. 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".

13.1. 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.

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: none)
DD_Driver	Enum	DirectDraw driver to use. Possible options: • PRIMARYHAL – hardware driver for primary device • SECONDARYHAL – hardware driver for secondary device (e.g. add-on 3D card) • RGBEMULATION – software driver • REFERENCERAST – reference rasterizer (slow!)
Fullscreen	Bool	TRUE for fullscreen mode, FALSE for windowed mode
Software	Bool	TRUE allows software drivers, FALSE skips them
ScreenWidth	Int	Horizontal screen resolution for fullscreen mode. Value

		must be supported by hardware (640, 800, 1024, 1152 …)
ScreenHeight	Int	Vertical screen resolution for fullscreen mode. Value must be supported by hardware (480, 600, 768, 864 …)
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	RGB colour bit-depth. Should be 16, 24 or 32. The chosen bit depth must be supported at the selected resolution. This option is only used in fullscreen mode. Default: 16.
MinZBufferDepth	Int	Requested bit-depth for z-buffer. If a z-buffer mode of at least this depth is not found then the highest available depth is used. Set this to 32 to get the highest buffer depth available on your system. Z-buffers of less than 24 bits will cause visual artefacts.
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
MFDTransparent	Bool	Make onscreen multifunctional displays transparent. Default: TRUE
EnableShadows	Bool	Enable/disable object shadows on planet surfaces.
InstrumentUpdateInterval	Float	Interval between MFD display updates (seconds)
PlanetPatchRes	Float	Resolution factor for planet surfaces. Valid range is 0.1 to 10. Higher values produce higher resolution planetary surfaces, but require a fast machine.
DialogFont_Scale	Float	Scaling factor for dialog font size. Default: 1.0
DialogFont1_Face	String	Standard dialog font face. Default: Arial
Date		Simulation start date. Default is current system time. Options: • JD <float> – Julian Date, e.g. JD 2451545.0 for January 2, 2000 at 12:00 UT • MJD <float> – Modified Julian Date, e.g. MJD 51544.5 • JE <float> – Julian Epoch, e.g. JE 2000.0

13.2. Planetary Systems

Planetary systems contain stars, planets and moons. Each planetary system requires at least one star.

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*

13.3. Planets

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. The format for planet (and moon) configuration files is as follows:

Name = <Planetname>
EllipticOrbit = TRUE | FALSE
HasElements = TRUE | FALSE

Epoch = <epoch>
ElReference = <RefFrame>
SemiMajorAxis = <a>
Eccentricity = <e>
Inclination = <i>
LongAscNode = <Ω>
LongPerihelion = <ϖ>
MeanLongitude = <L>

Mass = <M>
Size = <r>
SidRotPeriod = <T>
SidRotOffset = <rot>
Obliquity = <ε>

AtmPressure0 = <p>
AtmDensity0 = <ρ>
AtmAltLimit = <a_{limit}>
AtmColor0 = <R> <G> <B>

MaxPatchResolution = <npatch>
MaxDynamicResolution = <ndyn>

NumBases = <n>
Base1 = <Name> <long> <lat>
...

where
- *EllipticOrbit* – if TRUE then an elliptic orbit is assumed for the planet, and calculated from its elements. This avoids numerical instabilities which may arise in dynamic orbit calculations, but does not take into account perturbations by other celestial objects.
- *HasElements* – if TRUE then the configuration file must contain the definition of the planet's orbital elements to calculate its initial position and velocity. If FALSE, then the planet's initial position and velocity must be supplied directly.

Orbital element definition:
- *Epoch* - reference epoch (e.g. 2000.0)
- *ElReference* – *Ecliptic* (elements refer to ecliptic as frame of reference) or *ParentEquator* (elements refer to equator of parent body as frame of reference – only valid for secondary bodies (moons and orbital stations))
- *SemiMajorAxis* – semi-major axis in meters
- *Eccentricity* – eccentricity (0 = circular orbit)
- *Inclination* – inclination against plane of ecliptic (rad)
- *LongAscNode* – longitude of the ascending node (rad)
- *LongPerihelion* – longitude of the perihelion (rad)
- *MeanLongitude* – mean longitude (rad)

Physical parameters:
- *Mass* – planet mass (kg)
- *Size* – mean planet radius (m)
- *SidRotPeriod* – siderial period (s)
- *SidRotOffset* – planet rotation at reference epoch (rad)
- *Obliquity* – angle between rotation axis and normal of the orbital plane (rad)

Atmospheric data (where applicable):

- *AtmPressure0* – atmospheric pressure at ground level (planet radius) in Pa
- *AtmDensity0* – atmospheric density at ground level (kg/m^3)
- *AtmAltLimit* – altitude limit beyond which atmospheric effects can be ignored
- *AtmColor0* – RGB values (0-1) defining the "colour" of the atmosphere (observer at sea level, looking upward, at noon)

Visual parameters
- *MaxPatchResolution* – resolution level for surface texture maps (1-10)
- *MaxDynamicResolution* – resolution level for generic surface patches at low altitudes

Surface bases
- *NumBases* – number of surface bases
- *Base<X>* - surface base entries (see following section).

3. Create the required surface texture maps up to the specified resolution (see Section 14).
4. Create a monochrome (green on black) outline bitmap (256x128, BMP) to be used in the Planet Map MFD mode. The file name should be *<Planetname>M.bmp*.

13.4. Orbital stations

Configuration files for orbital stations. For an example see Config\ISS.cfg.

Item	Type	Description
Name	String	Name of the station
Mass	Float	Station mass [kg]
Size	Float	Mean station radius [m]
HasElements	Bool	If true, initial position is calculated from supplied orbital elements (for format of element list see planet configuration files) If false, initial position and velocity vector is directly read from config file
CBody	String	Reference body (planet or moon) for orbit
XOrientation	Float	Rotation around local x-axis [deg]
ZOrientation	Float	Rotation around local z-axis [deg]
Docklist	List	List of positions and approach directions for docking ports (see below).

This is the syntax for *Docklist*:

```
BEGIN_DOCKLIST
<Dock-spec 0>
<Dock-spec 1>
<Dock-spec n-1>
END_DOCKLIST
```

where *<Dock-spec i>*:

```
<xi> <yi> <zi> <dxi> <dyi> <dzi> <rxi> <ryi> <rzi>
```

$<x_i>$ $<y_i>$ $<z_i>$ is the reference position of the docking port in the station's local coordinates.
$<dx_i>$ $<dy_i>$ $<dz_i>$ is the direction in which a ship approaches the docking port in the station's local reference frame.
$<rx_i>$ $<ry_i>$ $<rz_i>$ is a reference direction perpendicular to the approach direction used for aligning an approaching ship's rotation along its longitudinal axis.

13.5. Vessel Classes

A vessel class configuration file contains the specifications of a vessel type. Each individual vessel inherits the specifications of its class. An example for a class configuration file is Config\DeltaGlider.cfg.

Item	Type	Description
ClassName	String	Name of the vessel class

MeshName	String	Name of the mesh used for visualisation
Mass	Float	Vessel mass (empty) [kg]
FuelMass	Float	Max. fuel mass [kg]
Isp	Float	Fuel-specific impulse [m/s]: Amount of thrust [N] obtained by burning 1kg of fuel per second.
Size	Float	(Mean) vessel radius [m]
MaxMainThrust	Float	Main thruster rating [N]
MaxRetroTrust	Float	Retro thruster rating [N]
MaxHoverThrust	Float	Hover thruster rating [N]
MaxAttitudeRotAccel	Float	Attitude thruster rating for rotation [rad/s^2]
COG_OverGround	Float	Elevation of centre of gravity over ground when landed [m]
CameraOffset	Vec$_3$	Camera position inside the vessel for cockpit view
CW	Vec$_3$	Airflow resistance coefficients in the three axis directions (transversal, vertical, longitudinal)
LiftFactor	Float	Lift factor for aerodynamic surfaces in atmosphere ($l = \frac{1}{2} c_A A$, with c_A=lift coefficient, A=wing area [m^2])
CrossSections	Vec$_3$	Cross sections in axis directions (z=longitudinal) [m^2]
RotResistance	Vec$_3$	Resistance against rotation around axes in atmosphere, where angular deceleration due to atmospheric friction is $a^{(\omega)}_{x,y,z} = -v^{(\omega)}_{x,y,z} \rho\ r_{x,y,z}$ with angular velocity $v^{(\omega)}$ and atmospheric density ρ.
DockRef	Vec$_3$	Docking reference point
DockDir	Vec$_3$	Docking approach direction
DockRot	Vec$_3$	Longitudinal alignment direction (normal to DockDir)
MEngineRef*i*	Vec$_3$	Reference position for main thruster *i* (*i*=1…)
REngineRef*i*	Vec$_3$	Reference position for retro thruster *i* (*i*=1…)
HEngineRef*i*	Vec$_3$	Reference position for hover thruster *i* (*i*=1…)
AttRef*dij*	Vec$_3$	Reference position for attitude thruster (for rotation around axis *d* (*d*=X,Y,Z), rotation direction *i* (*i*=1,2) and thruster index *j* (*j*=1,2)) for a total of 12 attitude thrusters

13.6. Vessels

Each vessel must be listed in the planetary system configuration file, with a name corresponding to the vessel's own configuration file. The table lists the format for vessel configuration files.

Item	Type	Description
Name	String	Vessel name
Class	String	Vessel class
CBody	String	Name of reference planet/moon (e.g. planet around which the vessel is orbiting or on which it is landed)
Status		Initial vessel status. Must be one of the following: • "Landed Pos *long lat*" – located on the surface of CBody at longitude *long* and latitude *lat*. • "Landed Base *name*" – located on launch pad of base *name*. • "Docked Station *name*" – docked to station *name*. • "Orbiting" – vessel is in orbit around CBody. This requires a set of orbital elements (format as for planets)
XOrientation	Float	Initial rotation around x-axis
ZOrientation	Float	Initial rotation around z-axis

An individual vessel can override any of the physical parameters of its class (but currently not the mesh or engine reference positions).

13.7. Surface Bases

To create a new spaceport on the surface of a planet the following steps are required:
1. In the planet's configuration file
   - Increase the entry for *NumBases* by 1, or add the line
     NumBases = 1
     if no bases are defined for the planet yet.
   - Add a line
     Base<X> = <Name> <Long> <Lat>
     where *<X>* is the base's numeric ID (should be set to the new value of *NumBases*), *<Name>* is the base's name (which identifies its configuration file), and *<Long>* and *<Lat>* define the base's position on the planet surface in equatorial coordinates (degrees). Eastern Longitudes and northern Latitudes are counted positive, western longitudes and southern latitudes are negative.

     Example:
     > *NumBases = 1*
     > *Base1 = Habana -82.5 +23.0*

2. Create a configuration file for the base, *<Name>*.cfg, where *<Name>* corresponds to the base's name in the planet configuration file. The format of the base definition file is as follows:

   ```
   NAME = <Base name>
   SIZE = <size>

   BEGIN_OBJECTLIST
   <Object list>
   END_OBJECTLIST
   ```

   where *<Base name>* is the base's (logical) name which need not correspond to the entry in the planet configuration file. *<Size>* is the base's overall radius in meters.

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

13.8. Adding objects to surface bases

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

```
BEGIN_OBJECTLIST
<Object 1>
<Object 2>
…
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)

TANK
A 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)

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

(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

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

MESH

Generic mesh for custom object types. Mesh files must be in ORBITER mesh file format (see Appendix A). The group texture and material properties defined in the mesh file are ignored.

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
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
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)

Current restrictions:
- Generic meshes cannot cast shadows. This will be fixed in the future, but shadows will be required to have a convex hull.
- Only one texture is allowed for an object. In the future individual mesh groups will be able to override the global setting.

14.   Planet Surface Textures

14.1.   Texture Format

Each planet has an associated texture file *<pname>*.tex, where *<pname>* is the planet's name. The texture file contains a series of texture maps, stored as DirectDraw surfaces (dds) in DXT1 compression format.

ORBITER uses a variable resolution approach for both meshes and texture maps to render planetary surfaces. The rendering resolution level is determined by the apparent radius of the planet. At low resolutions ORBITER uses a single spherical mesh covered by a single texture. At higher resolutions the spherical surface is constructed from a series of sphere patches, each containing its own texture patch. This method allows efficient rendering by removing hidden patches before invoking the rendering pipeline.

ORBITER currently supports 8 resolution levels for planetary surfaces, as listed in Table 1. At the highest resolution the sphere is constructed from 364 patches with an effective texture resolution of 8192x4096. Figure 20 shows a detail of the Martian surface rendered at different resolution levels.

Level	Resolution*	Mesh patches	Triangles (total)**	Texture memory***	
				with DXT1	w/o DXT1
1	64 x 64	1	144	2K	16K

2	128 x 128	1	256	10K	80K
3	256 x 256	1	576	42K	336K
4	512 x 256	2	1024	106K	848K
5	1024 x 512	8	2592	362K	2.9M
6	2048 x 1024	24	4672	1.1M	9.0M
7	4096 x 2048	100	25440	4.3M	34.6M
8	8192 x 4096	364	116448	16.0M	127.8M

Table 1: Supported resolution levels for planetary surfaces.

*Resolution: Effective texture map resolution at the equator.
**Triangles: This is the total number of triangles for all patches. In practice fewer triangles will be rendered because hidden patches are removed before entering the rendering pipeline.
***Texture memory: Video/AGP memory required to hold texture maps up to this resolution level for a single planet. With DXT1: video hardware supports DXT1 texture compression. W/o DXT1: video hardware doesn't support DXT1 texture compression.

High resolution levels require significant amounts of video/AGP memory and should only be used on systems with adequate 3D graphics subsystems. On older graphics cards which do not natively support DXT1 texture compression ORBITER needs to convert textures into RGBA format which increases memory requirements 8-fold. Conversion to RGBA will also dramatically increase the loading time when starting ORBITER.

Important: Do not try to use resolution level 8 if your video card does not support DXT1 texture compression or has less than 32MB of texture memory!

Figure 20: Mars texture detail at resolution levels 5, 6, 7 and 8 (from left).

14.2. Where ORBITER looks for textures

ORBITER first searches for the texture file in the location specified by the `HightexDir` entry in the *Orbiter.cfg* file (see section 13.1). If the texture file is not found or if `HightexDir` is not defined then ORBITER searches in the directory specified by the `TextureDir` entry. This allows switching between high and low resolution texture maps conveniently by inserting or removing the `HightexDir` entry.
If no texture file is found then the planet is rendered without a surface texture.
Each planet's configuration file <*pname*>.cfg contains an entry `MaxPatchResolution` which defines the maximum texture resolution level to use with this planet (valid range 1 to 8). If the texture file contains higher resolution levels than defined by `MaxPatchResolution` then the additional resolutions are skipped. This allows reducing texture memory requirements without modifying the texture file. If the texture file contains fewer resolution levels than defined by `MaxPatchResolution` then the maximum resolution is reduced accordingly.

14.3. Using *pltex* to Generate Custom Planet Textures

If you prefer, you can use your own planet maps instead of those provided by ORBITER. The ORBITER download page contains a planet texture conversion tool (*pltex*) which allows to convert planet maps from BMP bitmap format to ORBITER's texture format. It resamples the map to the requested resolutions, splits it into surface patches and converts them to DXT1 compressed texture format.

The source map should contain the complete surface in spherical projection, where the left edge corresponds to longitude 180°W, the right edge to longitude 180°E, the bottom edge to latitude 90°S, and the top edge to latitude 90°N. The width/height ratio of the bitmap should be close to 2/1.

Pltex requires the source map in 24bit or 8bit Windows BMP format. If your map is in any other format (e.g. JPEG or GIF) you need to convert it into BMP (using your favourite graphics conversion tool) before invoking pltex.

Synopsis:
`pltex [-i <mapname>] [-l <minres> -h <maxres>]`

<mapname>: source texture file name
<minres>: minimum resolution level (1..8)
<maxres>: maximum resolution level *(<minres>..8)*

- If command line options are omitted then pltex requests values interactively.
- If a higher maximum resolution is requested than can be obtained from the source map, pltex adjusts the maximum resolution accordingly. See Table 1 for map resolutions at the various resolution levels.
- The only justification for *<minres>* ≠ 1 is if you want to compose certain resolution levels from a different source map, e.g. generate Earth resolution levels 1 to 7 from a map that includes clouds, and level 8 from a map without clouds. In that case pltex must be run twice, and the output texture files concatenated.

Pltex will generate a texture file *<mapname>*.tex. If necessary, rename to *<pname>*.tex where *<pname>* is the planet's name, and copy to the `TextureDir` or `HightexDir` directory (see section 13.1).

Note:
To generate resolution level 8 from a 8192x4096 planet map you need at least 128MB of system memory.

PS: If you find a good quality high-resolution public domain planet map on the web, let me know, and I'll put it into the ORBITER distribution.

Appendix A. Mesh file format

ORBITER mesh files are ASCII text files. (A binary format may be introduced in the future). Mesh files are located in the subdirectory defined by the MeshDir entry in the master configuration file.

Mesh file format:

`MESHX1`	header
`GROUPS` *<n>*	*<n>:* number of groups
<group 0>	group spec 0
<group 1>	group spec 1
…	
<group n-1>	group spec *n*-1
`MATERIALS` *<m>*	*<m>:* number of materials
<mtrl-name 0>	material name 0
<mtrl-name 1>	material name 1
…	
<mtrl-name m-1>	material name *m*-1
<material 0>	material spec 0
<material 1>	material spec 1
…	
<material m-1>	materialspec *m*-1
`TEXTURES` *<t>*	*<t>:* number of textures
<tex-name 0>	texture name 0
<tex-name 1>	texture name 1

…	
<tex-name t-1>	texture name *t*-1

Group specs:

[MATERIAL *<i>*]	material index; optional
[TEXTURE *<j>*]	texture index; optional
[TEXWRAP *<wrap>*]	texture wrap mode: *<wrap>* = U or V or UV; optional
GEOM *<nv> <nt>*	*<nv>:* vertex count, *<nt>:* triangle count
<vtx 0>	vertex spec 0
<vtx 1>	vertex spec 1
…	
<vtx nv-1>	vertex spec *nv*-1
<tri 0>	triangle spec 0
<tri 1>	triangle spec 1
…	
<tri nt-1>	triangle spec *nt*-1

Vertex specs:

<x> <y> <z> [<nx> <ny> <nz> [<tu> <tv>]]	
	<x> <y> <z>: vertex position
	<nx> <ny> <nz>: vertex normal (optional)
	<tu> <tv>: texture coordinates (optional)

Missing normals are automatically calculated as the mean of the normals of adjacent faces. Texture coordinates are only required if the group uses a texture.

Triangle specs:

<i> <j> <k>	vertex indices (zero-based). Left-hand face is rendered.

Material specs:

MATERIAL *<mtrl-name>*	material header
<dr> <dg> <db> <da>	Diffuse colour (RGBA)
<ar> <ag> <ab> <aa>	Ambient colour (RGBA)
<sr> <sg> <sb> <sa>	Specular colour (RGBA)
<er> <eg> <eb> <ea>	Emissive colour (RGBA)

All listed textures must correspond to texture files in the texture subdirectory (.dds format – DirectDraw Surface). Texture name "0" means "no texture". At least one material definition must be present.

Appendix B. Solar System: Constants and Parameters

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 2: 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 3: Primary constants

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

Table 4: 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.

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 5: Planetary mean orbits

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.

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.	3.302	5.427	1407.509	0.2408445
Venus	6051.84 ±0.01	48.685	5.204	−5832.444	0.6151826
Earth	6371.01 ±0.02	59.736	5.515	23.93419	0.9999786
Mars	3389.92 ±0.04	6.4185	3.9335±0.0004	24.622962	1.88071105
Jupiter	69911. ±6.	18986.	1.326	9.92425	11.856523
Saturn	58232. ±6.	5684.6	0.6873	10.65622	29.423519
Uranus	25362. ±12.	868.32	1.318	17.24 ±0.01	83.747407
Neptune	24624. ±21.	1024.3	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

References
(all values from reference 1. except (*) from reference 2)
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, Tables 6,7,10.

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

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

Planet				
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

<u>Reference:</u>
The Astronomical Almanac 1990 (North pole coordinates)

(*) Derived from north pole coordinates (MS)

Atmospheric Parameters

Planet	Surface pressure [kPa]	Surface density [kg/m³]	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 location 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

Calculating Elements from Position and Velocity Vectors

Let **r** and **v** be the cartesian position and velocity vectors of an orbiting object in coordinates 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 **h** is a vector perpendicular to the orbital plane, **n** points towards the ascending node (the z-component of **n** is zero), and **e** is the eccentricity vector with $\mu = GM$ (pointing towards the periapsis), G is gravitational constant and M is the mass of the central body (neglecting the mass of the orbiter).

Semi-major axis:

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

Eccentricity:

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

Inclination:

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

Longitude of ascending node:

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

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 $\Omega = 0$, 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:

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

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 perihelion:

$$\varpi = \Omega + \omega$$

True longitude:

$$l = \varpi + \upsilon$$

Eccentric anomaly:

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

Mean anomaly:

$$M = E - e \sin E$$

Orbit period:

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