

Endurance Space Exploration System

Operations Manual



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March 12, 2018

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The Endurance Space Exploration System models the spacecraft conceived by Nathan Crowley for Christopher Nolan's 2014 film Interstellar.

Required Programs

Orbiter 2010 P1
LC39-EAFB 2006.3 Hi-Res
Hi-Res Kennedy Space Center
Interstellar system
Multistage2015
Runway Markers for Orbiter 2010
Orbiter Sound 3.5 or later
Pluto and Moons
UMmu 2.0 or later
UCGO

Installation

Endurance, its associated Cargo Pods, Lander, and Ranger are contained in the Endurance Space Exploration System package. To install, create a clean Orbiter 2010 P1 (100830) and add:

LC39-EAFB 2006.3 Hi-Res (You may delete the associated scenarios)

(High and Low-Res versions available at <http://www.gule.it/Orbiter/>)

Hi-Res Kennedy Space Center (You may delete the associated scenarios)

(Available at <http://www.orbithangar.com/searchid.php?ID=2811>)

Interstellar System (You may delete associated scenarios)

(Available at <https://www.orbithangar.com/searchid.php?ID=6745>) Note: this add-on downloads and is installed via an auto-installer

Multistage2015 (<https://www.orbithangar.com/searchid.php?ID=6838> for Orbiter 100830P1, or <https://www.orbithangar.com/searchid.php?ID=7010> for Orbiter 160828)

Runway Markers for Orbiter 2010 (Available at

<http://simviation.com/1/search?submit=1&keywords=orbiter&categoryId=&page=0&filename=>)

Orbiter Sound 3.5 or later (<http://orbiter.dansteph.com/index.php?disp=d>)

Pluto and Moons (<https://www.orbithangar.com/searchid.php?ID=4595>)

UMmu 2.0 or later (<http://orbiter.dansteph.com/index.php?disp=d>)

UCGO (<http://orbiter.dansteph.com/index.php?disp=d>)

Unzip the Endurance Space Exploration System package to the location of your Orbiter 2010 P1 folder. Be sure to preserve the directory structure of the package (for example, in WinZip this requires activating the "Use Folder Names" option).

Note: We have provided a version of olrik jhor's Gargantua Tex in the Endurance Space Exploration System package (Textures/StarG.dds). **If you chose to use this texture to emulate Gargantua, you must first back up Orbiter's default Star.dds, then rename StarG.dds, Star.dds while leaving it in the Textures folder.**

Replacing the default texture with olrik jhor's Gargantua texture will result in all primary planetary system stars in your Orbiter installation being rendered as Gargantua.

You should start Orbiter and make sure that "Limited Fuel" is selected under the "Parameters" tab. Under the "Modules" tab select "Rcontrol" to activate Orbiter Remote Vessel Control. This utility will be required for docking operations. Under the "Extra" tab select "Debugging options" and select "Orbiter shutdown options". Select the "Respawn Orbiter Process" option then "OK". This will ensure that when closing and restarting simulation you will avoid crash to desktop (CTD) problems.

The following programs are optional, but enhance the functionality and visual presentation of the simulation:

AeroBrake MFD (<http://www.orbithangar.com/searchid.php?ID=2139>)
BaseSync MFD 3.0 (<http://www.orbithangar.com/searchid.php?ID=6881> for Orbiter 100830P1 or BaseSync MFD 3.1 <http://www.orbithangar.com/searchid.php?ID=6965> for Orbiter 160828) **Requires ModuleMesagingExt**, available at (<http://www.orbithangar.com/searchid.php?ID=6889>)
Burn Time Calc MFD 2.9.2 (<http://www.orbithangar.com/searchid.php?ID=6989> for Orbiter 100830P1 or <http://www.orbithangar.com/searchid.php?ID=6413> for Orbiter 160828) **Requires ModuleMesagingExt**
CameraMFD v0.12 (<http://www.orbithangar.com/searchid.php?ID=2645>)
Launch MFD v1.6.4 (<http://www.orbithangar.com/searchid.php?ID=6988> for Orbiter 100830P1 or <http://www.orbithangar.com/searchid.php?ID=2802> for Orbiter 160828) **Requires ModuleMesagingExt and HUDDrawer SDK v.0.4 available for Orbiter 100830P1 at <http://www.orbithangar.com/searchid.php?ID=6990> or Orbiter 160828 at <http://www.orbithangar.com/searchid.php?ID=6023>**)
Realistic Background (<http://www.orbithangar.com/searchid.php?ID=4799>)
TransX 2016.04.04 MMExt (<http://www.orbithangar.com/searchid.php?ID=6987> for Orbiter 100830P1 or <http://www.orbithangar.com/searchid.php?ID=6393> for Orbiter 160828) **Requires ModuleMesagingExt**

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

Note

The following standard Orbiter keystrokes do not perform their usual functions:

1. Shift + "S" no longer calls up Surface MFD. "S" now brings up the vessels' crew manifest
2. Shift + "C"/"C" no longer calls up Comm MFD, this key combination a UCGO command
3. Shift + "J" no longer calls up TransX, this key combination is nonfunctional

These MFD's and utilities can be activated via cursor from the on-screen menu (Shift + "F1").

Change Log

Endurance Space Exploration System 180312

- Initial release

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Introduction

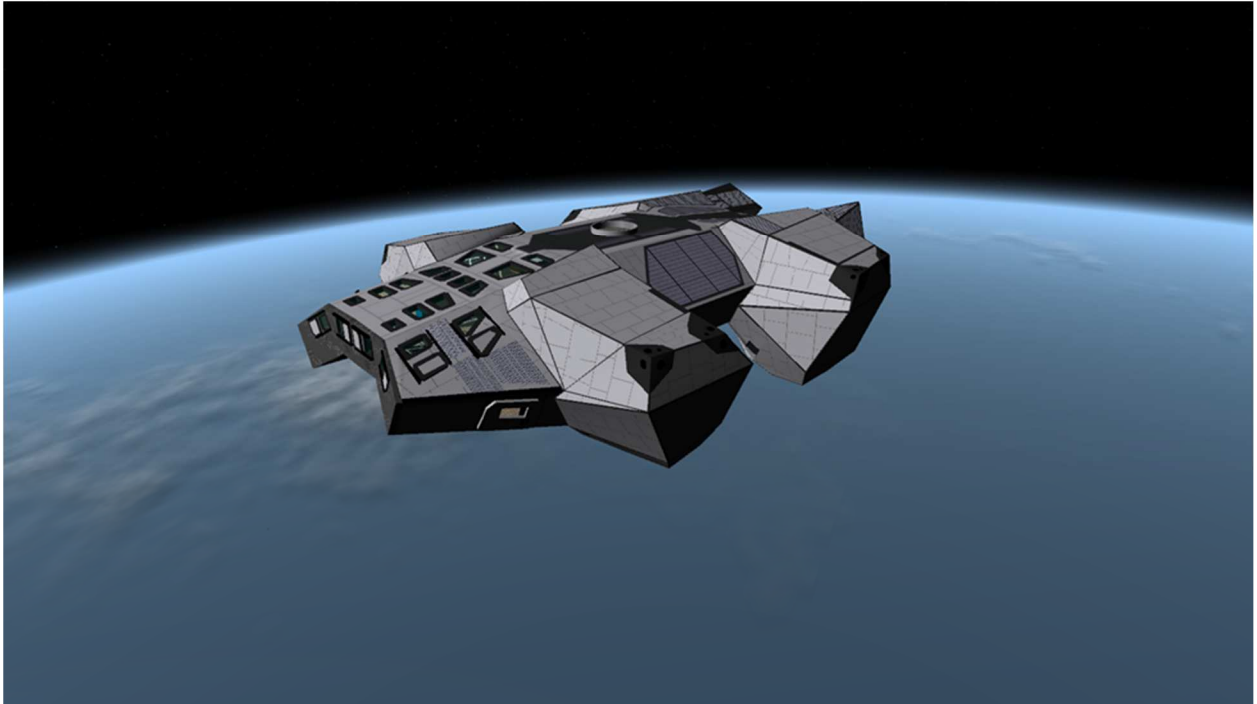
The Endurance Space Exploration System is a modular manned spacecraft. It is the product of a NASA project to produce a self-sufficient, multiply redundant, high-efficiency spacecraft, capable of long term habitation in order to allow exploration of our solar system. This system evolved from nearly a century of NASA's accumulated experience in manned spaceflight. Biomedical research, metallurgic research, as well as breakthroughs in propulsion systems and nuclear fusion influenced the systems final design.²

The Endurance was assembled in low Earth orbit requiring 37 construction launches (20 Falcon 9, 2 Falcon Heavy, 13 Atlas V, 2 Delta V Heavy) over the course of nine and a half years. Construction was managed from Marshall Space Flight Mission Control in Huntsville, AL.

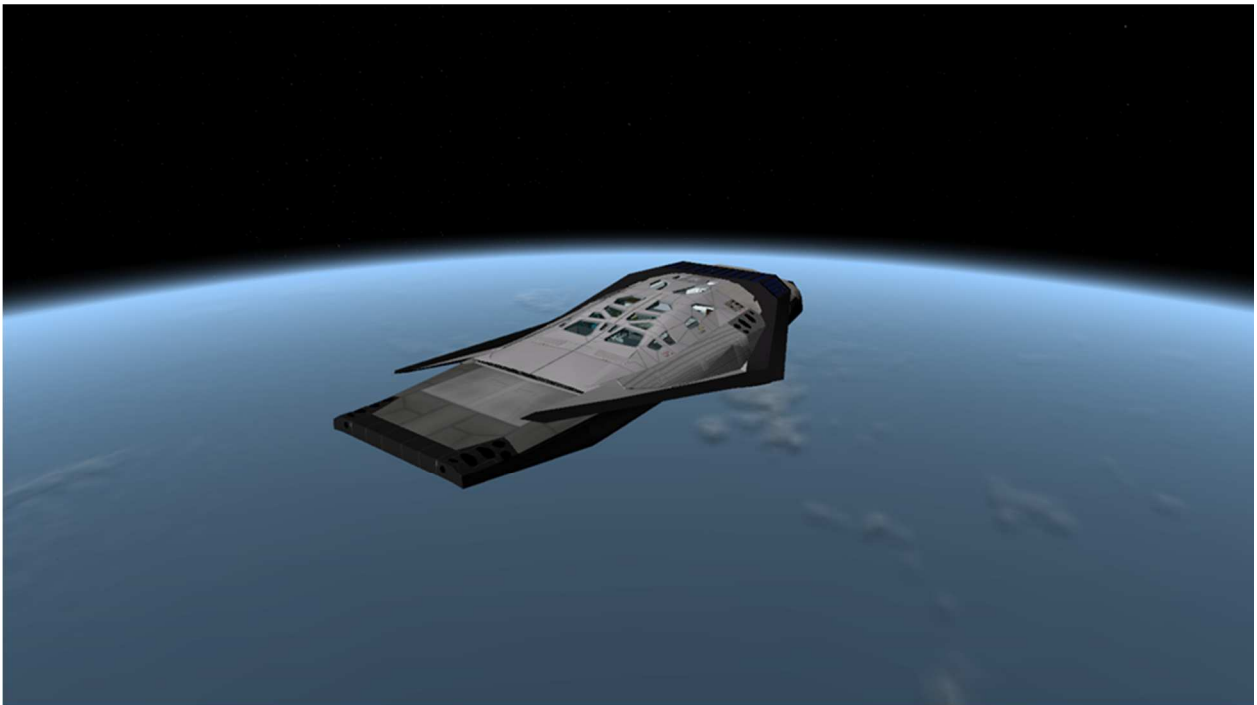
The Endurance is composed of twelve modules arrayed around a pressurized ring; a Command Module, four Main Engine Modules, four Landing Modules, two Habitat Modules, and a Cryo-Lab Module.



The Endurance, two Landers,



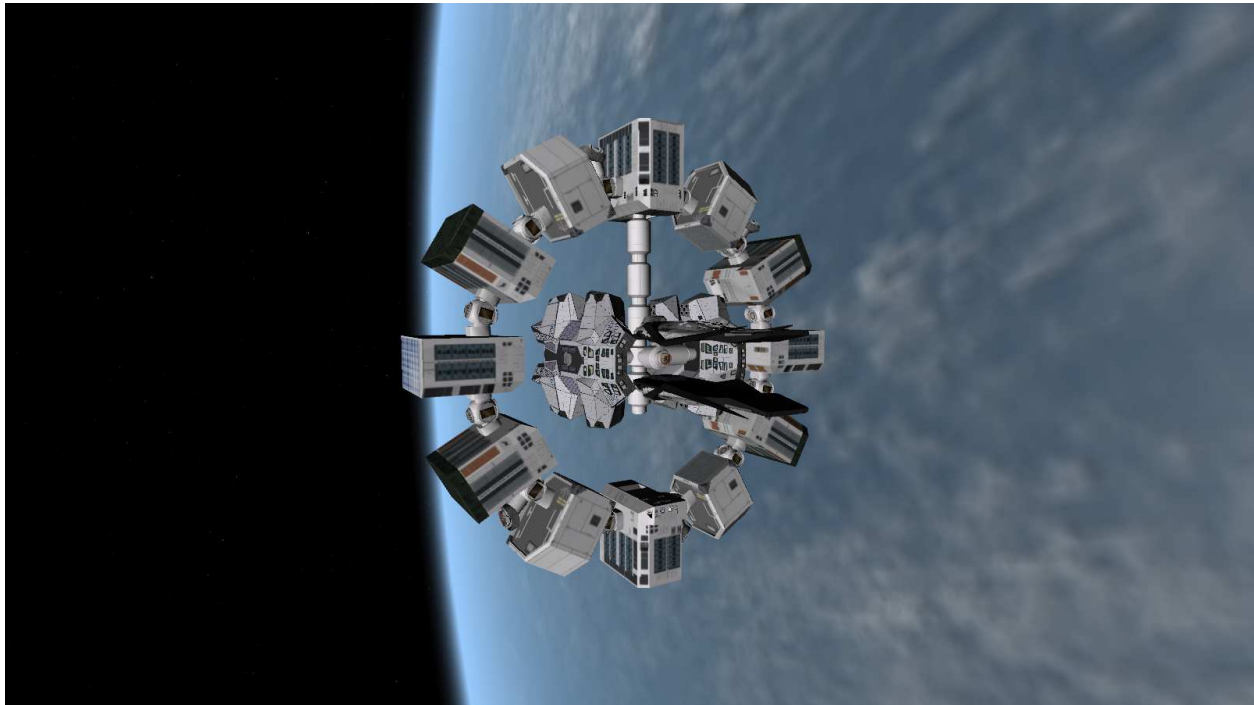
and two Rangers comprise the Endurance Space Exploration System.



The Landers and Rangers are each docked with the Endurance via a central docking hub which connects to the Endurance ring through one of the Habitat Modules.

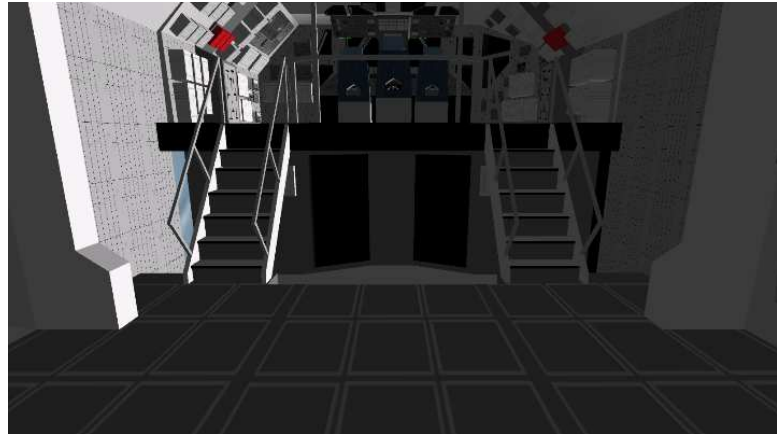


Endurance



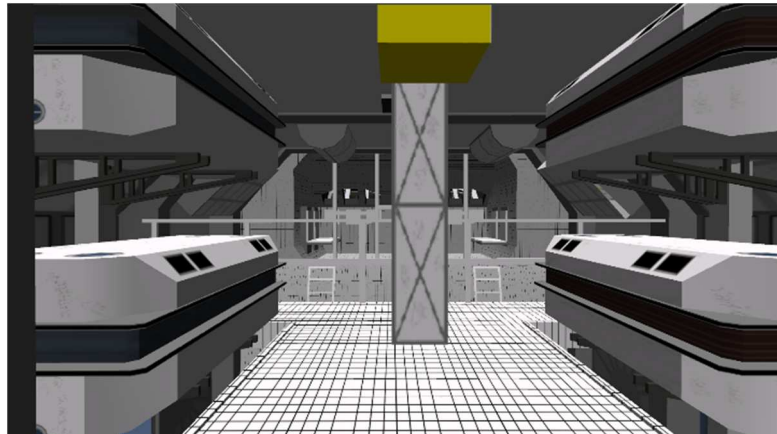
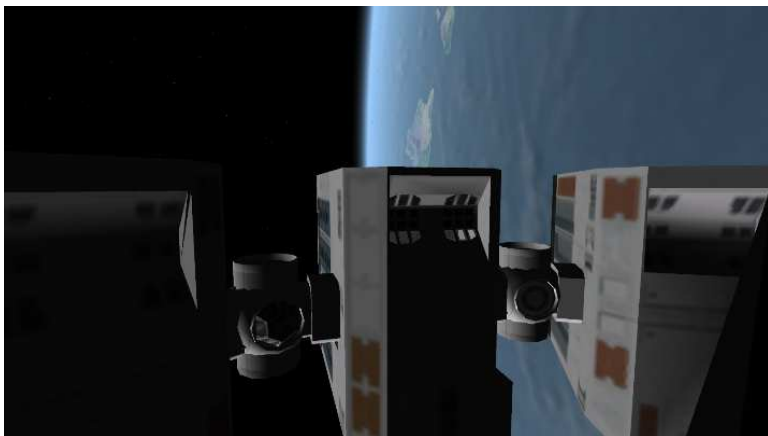
Endurance is the centerpiece of the Space Exploration System. It is a modular manned spacecraft designed as the base station for long duration manned missions capable of exploring our solar system. This spacecraft is designed around a pressurized ring 64.3 meters in diameter with twelve modules arrayed along its circumference. The ring allows passage between the various modules with docking access at four sites along the ring and a central docking hub which connects to the Endurance ring through one of the modules. The modules are specialized to support all aspects of a long duration mission with a Command Module, four Landing Modules, four Main Engine Modules, two Habitat Modules, and a Cryo-Lab Module. Each module can be isolated from the ring and each carries its own power supply through either compact tokamak fusion reactors or photovoltaic arrays.³ Life support for Endurance is redundantly distributed between the two Habitat Modules and the Cryo-Lab Module with back-up systems available in the four Landing Modules. If necessary, each module can handle its individual life support demands. During a long duration mission, the Endurance is spun along its thrust vector at 5.6 revolutions per minute to establish a 1 G environment. The Endurance is UMMu and UCGO compliant.

Command Module



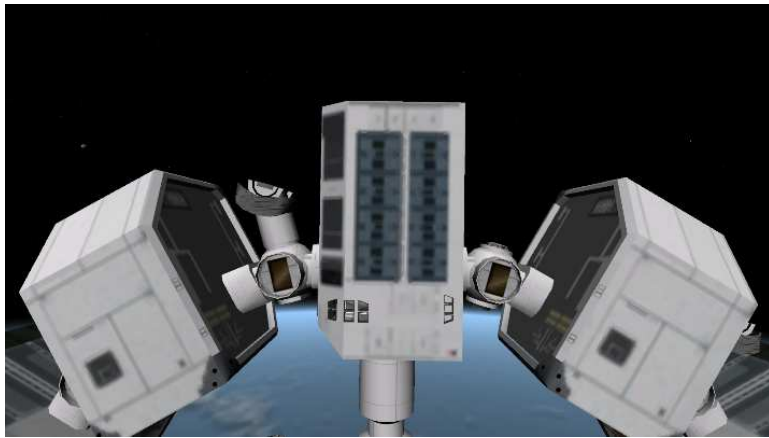
The Endurance is commanded from this module. Its upper level contains the ship's Flight Deck and primary avionics. Operations is housed on the lower level of the Command Module. It contains the resources for mission planning and a station for long range communication. The Command Module has a photovoltaic solar array on its outward-facing surface.³

Cryo-Lab Module



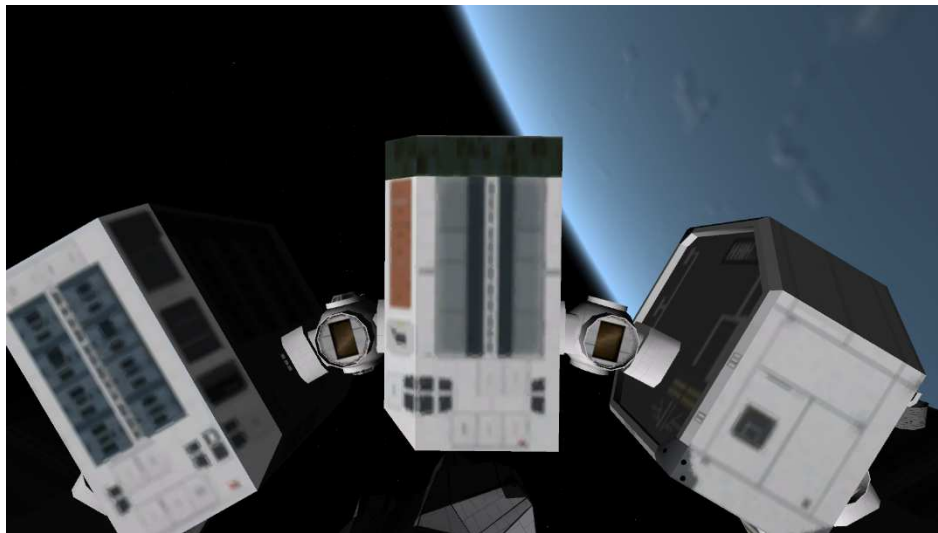
On its main deck, this module houses the cryogenic sleep tanks used by the crew for long duration space travel. The Cryo Lab also serves as the Endurance's sickbay and medical center. The lower deck of the Cryo Lab module houses a life sciences laboratory.³

Habitat Module



The Endurance carries two Habitat Modules. They serve as the crew living areas and include the mess, conference room, and astronaut workstations. The Habitat Modules also contain the stores of consumables required for the ship's mission. Water and air recycling units as well as primary life support are housed in the Habitat Modules below the floor of the crew cabins, providing additional radiation shielding. The Habitat Modules feature photovoltaic solar arrays on their outward-facing surfaces. The electricity produced by the arrays provides a redundant backup to the tokamaks.³

Landing Module



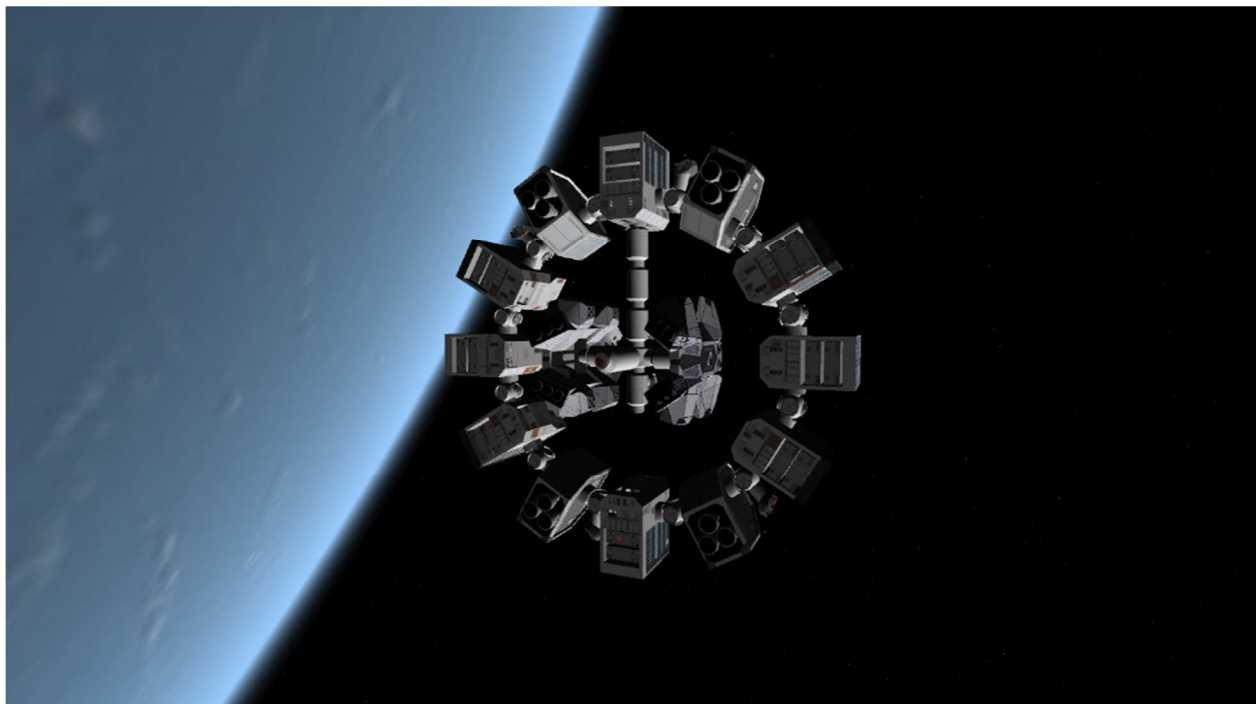
The Endurance's prime mission is exploration of our solar system and its planetary bodies. To accomplish this, the Endurance carries four Landing Modules. Recessed into the aft section of Landing Modules (as well as the Command Module, Habitat Modules, and Cryo-Lab Module) are cargo pods containing surface mission stores. These cargo pods can be detached and ferried down to a planet's surface using the Lander. On the surface the empty module can be used as a shelter to protect the explorers from the planet's environmental conditions. Each Landing Module features a ceramic heat shield on its surface.³

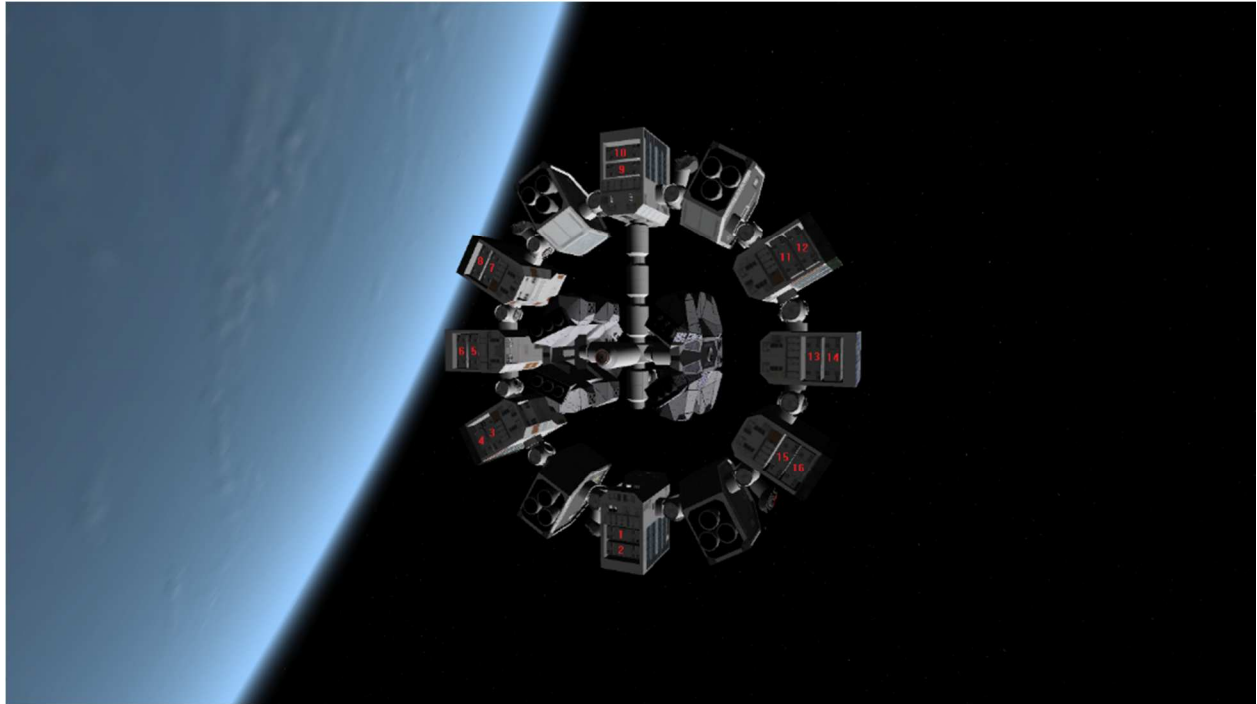
Main Engine Module



The Endurance is equipped with four Main Engine Modules. Each Main Engine Module contains three advanced Hybrid Variable Specific Impulse Magnetoplasma Rocket (H-VASIMR) engines, which produce a distinctive blue exhaust plume of ionized gas when firing. The H-VASIMR engine has the ability to more widely vary its exhaust parameters (thrust and specific impulse) in order to optimize mission requirements resulting in the lowest trip time with the highest delivered payload for a given fuel load. Each module contains a compact tokamak power plant which generates electricity via magnetically-confined fusion. As well as generating electricity for use in the engines, the tokamaks supply power to the rest of the Endurance's systems. Each engine module features smaller reaction control system thrusters on the forward and aft outboard corners. These are standard hydrazine thrusters of the type used in present day space travel.³

Cargo Pods





To support planet surface exploration, sixteen Cargo Pods are carried on racks recessed in cargo bays on the aft surface of the Command Module, Landing Modules, Habitat Modules, and Cryo-Lab Module. Each cargo bay holds two Cargo Pods. The Cargo Pods are numbered 1-16 (moving clockwise) beginning with the inboard pod stored in the Command Module. From the Endurance's focus, Press "" to select the desired Cargo Pod. When selected, a red beacon is illuminated on the Cargo Pod. Press "keypad 3" to extend or retract the cargo rack. Pressing "J" releases the Cargo Pod from the rack, pressing "K" attaches the Cargo Pod to the rack.

Endurance Operations

The Endurance is the foundation of the Space Exploration System. The Endurance's primary flight controls, navigation, and onboard systems are managed from the Flight Deck. There are three Flight Deck stations; Commander (left seat), Pilot (right seat), and Mission Specialist (center seat). The Flight Deck has four active multi-function displays (MFD's) that can be configured as needed to support mission parameters and a Heads-Up-Display (HUD) at the Commander and Pilot stations with annunciators for crew compliment, cargo status,



and airlock state. Cargo and airlock information is also displayed on monitors in the center panel. The operations hub of the Endurance is the Command Module's lower deck. Operations contains the base station's communication center and work station. Here, the ship's daily operations are planned, mission telemetry is reviewed, and archived.

Endurance Key Commands

Ctrl + Arrow	Selects views in modules
V	Selects focused views within each module
`	Selects active Cargo Pod
5	Toggle High Performance Balance Engine
N	Selects airlock hatch
\	Opens/Closes airlock hatch
3	Extends/Retracts cargo rack
J	Detach cargo pod
K	Attach cargo pod

Of the twelve Endurance modules, three (Command Module, Cryo-Lab Module, and Habitat Module) can be accessed from the Endurance's focus by pressing "F1" to select internal view. "F8" selects the Endurance's "virtual cockpit". Ctrl+Arrow (up, down, left, and right) allows you to move between the Command Module, Cryo-Lab Module, and Habitat Module. Pressing "V" while in the selected module selects focused views in each module as shown below:

Station 1: **Command Module, Commander's Station** (there are four sites viewed by cycling through "V")
Commander's Station, Commander's panel, Overhead, Center Overhead
Pressing "Ctrl+Right Arrow" moves you to

Station 2: **Mission Specialist Station** (there are four sites viewed by cycling through "V")
Mission Specialist Station, Mission Specialist Laptop, Center panel, Cargo Monitor
Pressing "Ctrl+Right Arrow" moves you to

Station 3: **Pilot's Station** (there are four sites viewed by cycling through "V")
Pilot's Station, Pilot's panel, Overhead, Center Overhead
Pressing "Ctrl+Down Arrow" moves you to

Station 4: **Command Module Operations** Pressing "Ctrl+Up Arrow" moves you back to the Flight Deck
Pressing "Ctrl+Right Arrow" moves you to

Station 5: **Cryo Module** (there are three sites viewed by cycling through "V")
Ring Viewport, Cryo Lab View, Cryo Tank View
Pressing "Ctrl+Right Arrow" moves you to

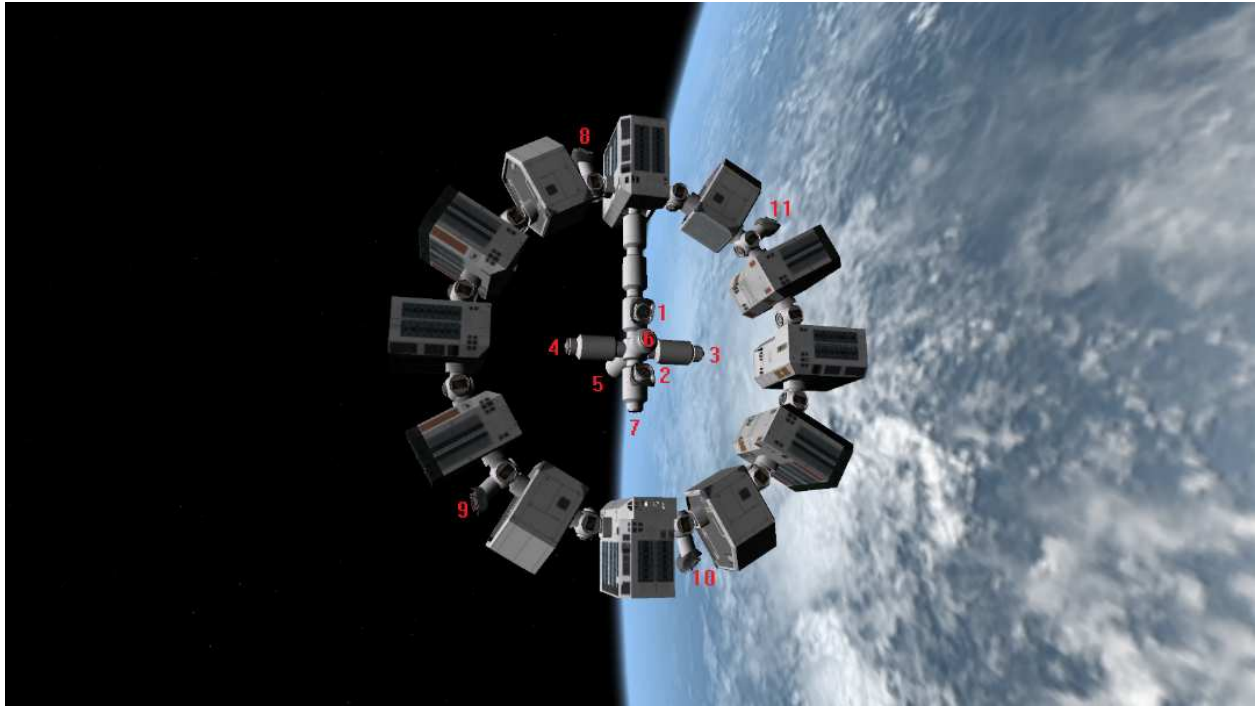
Station 6: **Habitat Module** (there are three sites viewed by cycling through "V")
Common Room, Habitat Laptop, Crew Quarters

Pressing "Ctrl+Right Arrow" moves you back to **Command Module Operations**

The Endurance's ring structure with its distributed Main Engine Modules, RCS system, and the distributed mass of its docked vessels, require a damping autopilot to allow smooth transitions in attitude. The High Performance Balance Engine (HPBE) satisfies this function and is on by default. The HPBE is a mission critical autopilot function and has quintuple redundancy via the networked navigation computers of the Landers, Rangers, and a duplicate system onboard the Endurance. Failure of this system is grounds for a mission abort.

Endurance's distributed thrust sources, and the distributed mass of its docked vessels require pitch, roll, and yaw transitions to be initiated manually to avoid autopilot induced attitude oscillation. Rotations should not exceed 2.0° per second (in pitch or yaw, maximum G-load 25 G along thrust axis, 80 G centrifugal⁴). As the desired attitude is approached, use RCS thrust to null motion prior to engaging the desired autopilot setting. Endurance's main engine and RCS are controlled and monitored from the Flight Deck. Mission-specific transfer orbits are plotted and initiated from the Flight Deck MFD stack. Once the transfer burn is completed, use Endurance's RCS to spin the ship along its thrust vector and establish a 1 G environment.

Endurance Docking Conventions



The Endurance has eleven docking rings. Seven arrayed along the central docking hub (docking rings 1-7) and the remaining four (docking rings 8-11) arrayed around the Endurance's ring.

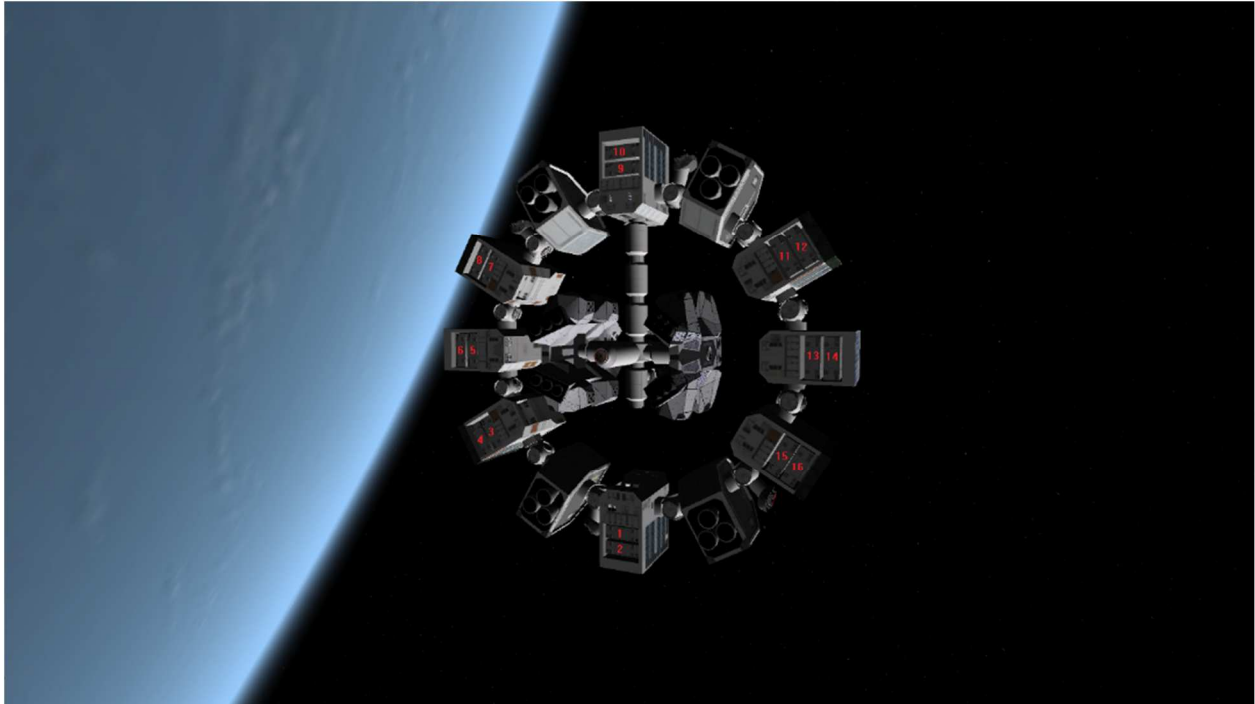
Docking rings 3-5, & 7 can accept Lander docking via either its ventral (Dock 1) or dorsal (Dock 2) docking ring. Due to insufficient clearance between the Lander's undersurface and the docking ring's diaphragm and gimbal structure, Endurance docking ring 6 can only accept Lander docking via its dorsal (Dock 2) docking ring.

Docking rings 1, 2, 8-11 accept Ranger docking via its aft docking ring. Docking rings 3-7 accept docking via Ranger's ventral docking ring with its docking tube extended.

Prior to initiating docking operations with the Endurance, the HPBE should be engaged, all rotational motion should be nulled, and all autopilot settings disengaged to place the Endurance in free flight mode. Docking by the Lander to Endurance (docking rings 3-7) or Ranger (to Endurance docking rings 1-11) may be initiated and monitored through Docking MFD and Camera MFD.

Cargo Operations

Sixteen Cargo Pods are rack-mounted and carried in the cargo bays on the aft surface of the Command Module, Landing Modules, Habitat Modules, and Cryo-Lab Module. Each pod is identified as shown below.



Landers are designed to transport up to two Cargo Pods from orbit to a planetary surface in support of planet exploration. A Rack-Mounted Cargo Deployment System allows transfer of the Cargo Pods from a module's



cargo bay to a Lander's cargo bay without requiring extravehicular activity (EVA) except in the case of a cargo extension, release, or attachment failure.

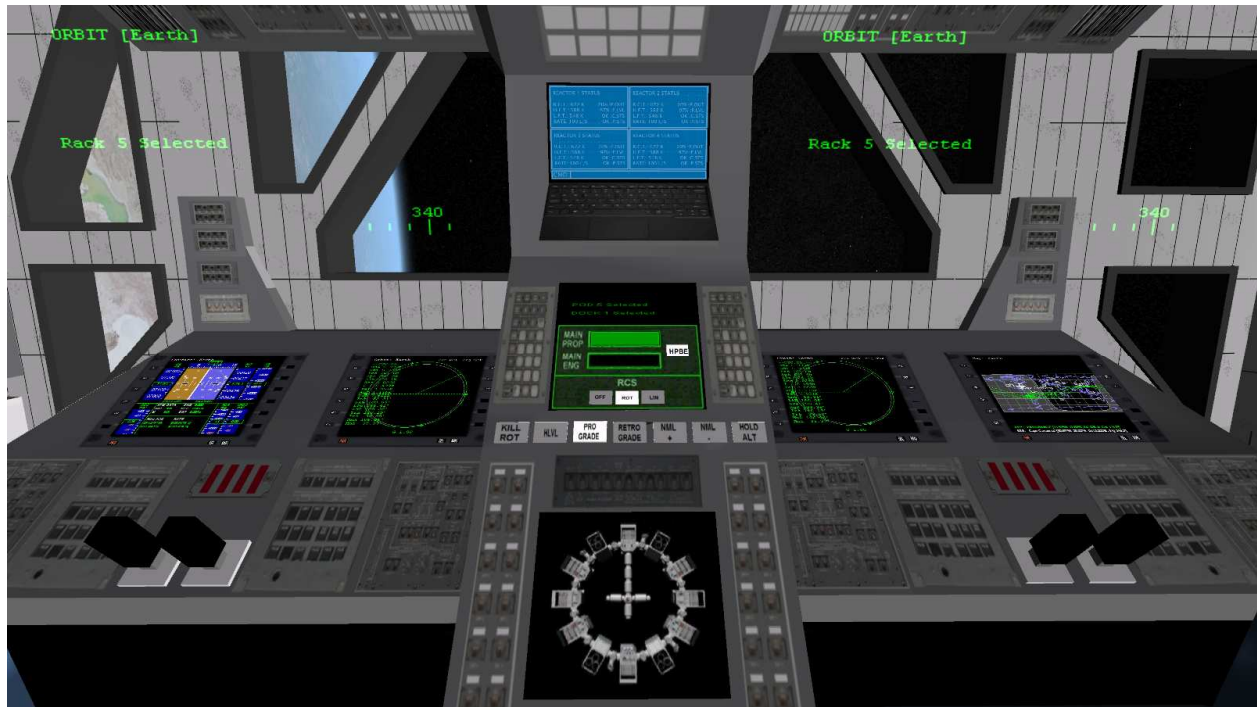
The Cargo Pods are displayed in the Flight Deck center pedestal monitor. Pressing “” selects the desired cargo rack for deployment. The selected Cargo Pod is highlighted by a red annunciator at its location on the center pedestal monitor and is identified on the center annunciator panel.

The selected rack is identified in the Commander and Pilot station HUD displays. A red beacon is also illuminated on the selected Cargo Pod's outer surface.

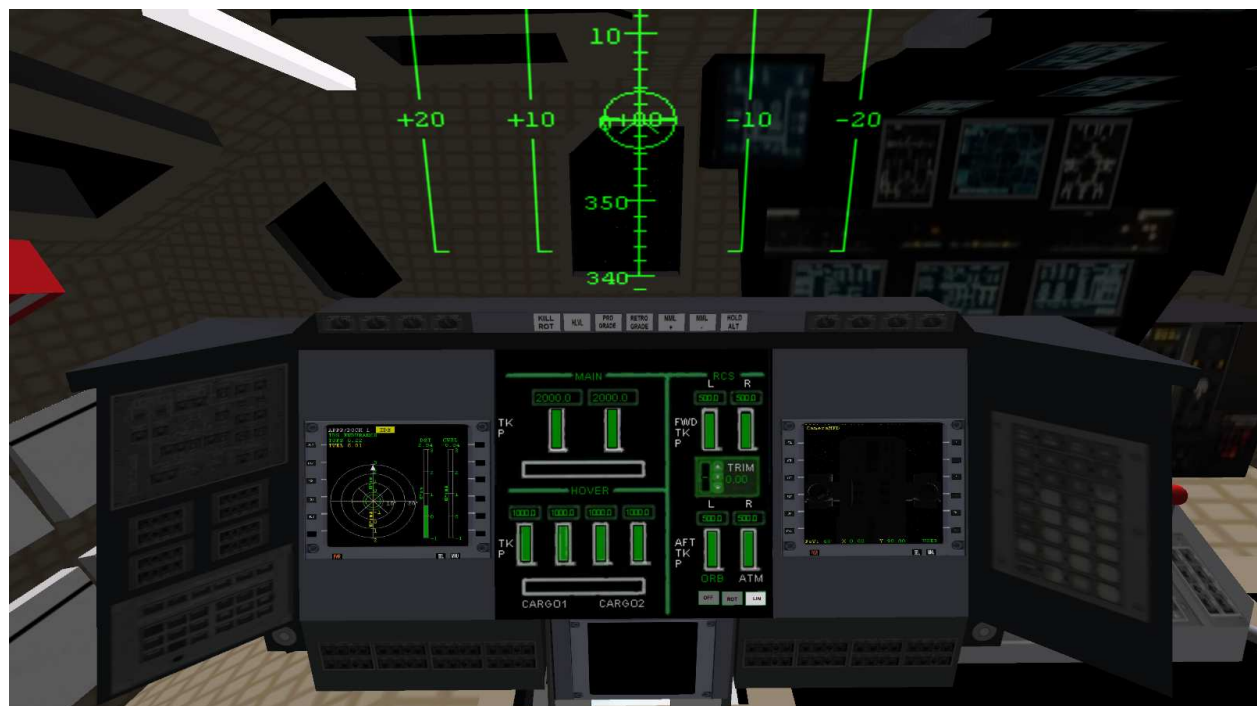


Cargo transfer operations are controlled from the Command Module flight deck. **Mission safety protocol requires either Commander and Pilot or Pilot and spaceflight rated robot be present on station in the Endurance Flight deck and Lander cockpit during Cargo Pod transfer operations.** Cargo transfer operations may be performed in either free flight or autopilot controlled attitudes. **The pilot in command is responsible for maintaining vessel separation at all times.**

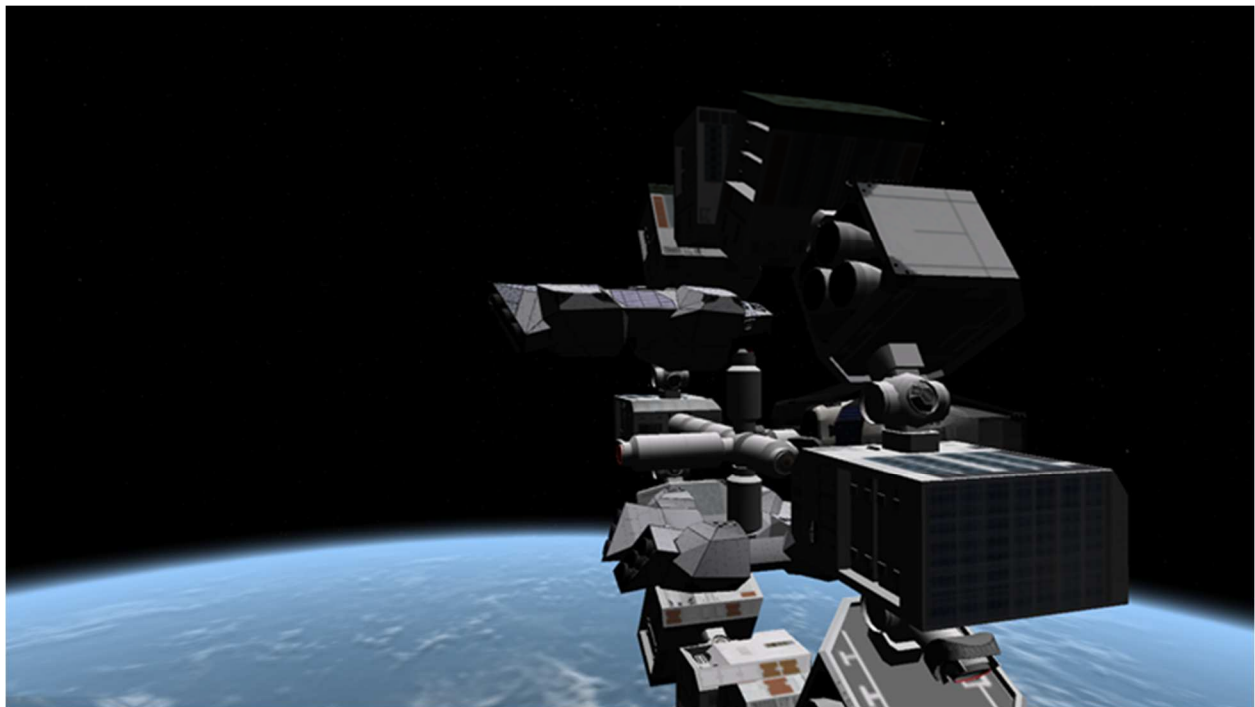
Once a mission plan has been determined and flight plan logged, a flight crew consisting of Commander and Pilot or Pilot and spaceflight rated robot, is dispatched to the Lander logged for cargo transport. The desired Cargo Pod(s) is selected from the Flight Deck.



Prior to Lander launch, activate Docking MFD targeting Endurance Dock 3 (Lander 1) or Dock 4 (Lander 2) for undocking guidance. Activate Camera MFD (camera point of view up) to monitor undocking. When cleared, undock with a separation rate < 0.2 meters per second. Use Docking MFD to monitor separation rate and distance. **Note: There is limited clearance within the Endurance ring. Maximum vertical separation from the Endurance must not exceed 3.5 meters.**



With approximately 3.5 meters vertical separation from the Endurance docking ring, translate aft to a minimum separation of 45 meters.



Once 45 meters aft of the Endurance docking, ring use Docking MFD (targeting Endurance Dock 5) to guide nose up pitch for alignment with the plane of the cargo bays. Verify with Mission Control the selected Cargo Pod. Rotate as necessary to acquire the cargo bay of the selected Cargo Pod.



Using Docking MFD (targeting Endurance Dock 5) and Camera MFD, translate and rotate as necessary to align with the selected cargo bay. Hold position approximately 20 meters over the cargo bay. From Endurance's focus press "keypad 3" to extend the selected cargo rack. Endurance's center pedestal monitor



beacon highlighting the selected Cargo Pod will turn yellow while the cargo rack is in transit and green when it is fully extended. The HUD will also indicate when rack extension is complete. When the cargo rack is fully extended press “J” to release the Cargo Pod. Cargo release is indicated in the HUD. Switch focus to the Lander and press “K” to grapple the Cargo Pod. The cargo annunciator in the Lander’s lower center panel will turn green to indicate a successful grapple.



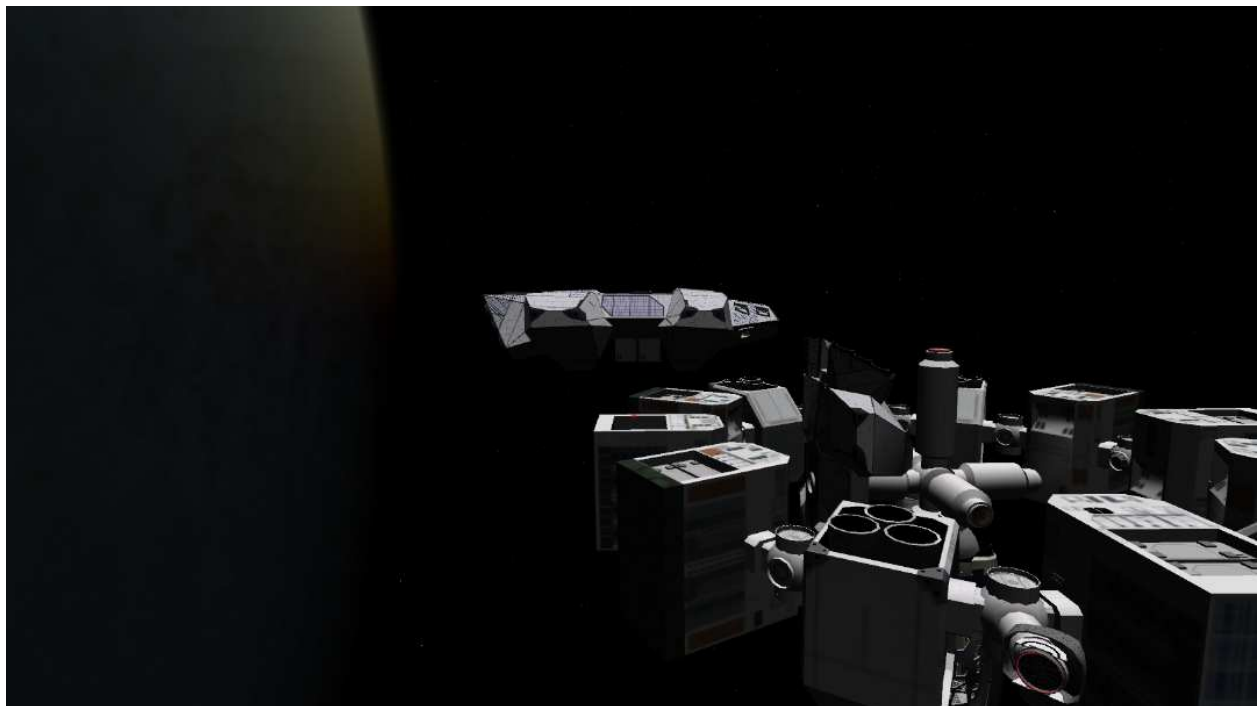
Quickly switch focus to Endurance and press “keypad 3” to retract the selected cargo rack. Return focus to the Lander to maintain stationkeeping. To transfer a second Cargo Pod, repeat the steps outlined above to extend the desired Cargo Pod from Endurance’s focus. Maintain the Lander’s position over the selected cargo bay.



From the Endurance's focus, release the selected Cargo Pod then, from the Lander's focus, Press "B" to grapple the second Cargo Pod. The second cargo annunciator will turn green to indicate a successful grapple.



From the Endurance's focus, press "keypad 3" to retract the cargo rack. Return to the Lander's focus to separate from the Endurance and establish orbital alignment to prepare for deorbit burn.



Lander



The Lander is a heavy lift transport. Its function is to ferry crew, shelter, and provisions from orbit to a planetary surface with single stage to orbit (SSTO) capability. It has a crew capacity of four with a dedicated station for a spaceflight-rated robot. It is self-sufficient and has an extended planetary dwell time. The Lander's design is optimized for reliable atmospheric deceleration while carrying a heavy payload to a planetary surface. To meet these mission parameters, the Lander's payload is carried on the undersurface of the ship while its upper surface serves as its heat shield. The ship performs atmospheric entry inverted thus protecting the belly-mounted payload.⁵

The Lander's propulsion system consists of two banks of three advanced Hybrid Variable Specific Impulse Magnetoplasma Rocket (H-VASIMR) engines mounted in two nacelles at the aft of the ship. Flanking the fuselage are four faceted pods, with the reaction control system (RCS) thrusters (eight clusters of four motors) recessed into the upper outer corners of each pod. These thrusters are fueled by hydrazine and nitrogen tetroxide.³ The Lander has no moveable control surfaces, thus the RCS also generates the forces necessary for pitch, roll, and yaw. The RCS thrust can be augmented from their orbital settings to higher settings by increasing reactant flow rate to allow maneuvering during atmospheric flight. Each pod also contains five magnetoplasmadynamic (MPD) thrusters to generate lift for atmospheric flight and hovering, as the ship has no aerodynamic lift generating surfaces. The Lander is UMMu and UCGO compliant.

Lander Key Commands

Ctrl + Arrow	Selects cabin views
V	Selects focused views within cabin stations
Keypad 9/0	Selects Left Hatch/Right Hatch/Upper Airlock Hatch/Lower Airlock Hatch
5	Toggle Console/Seat rotation
6/7	Toggle CASE/TARS animation
G	Toggle Reentry Shields open/close
`	Toggle ORB/ATM RCS settings
\	Open/Close Selected Hatch
N/B	Select Cargo1/Cargo2
J	Detach cargo pod
K	Attach cargo pod
Ctrl+1/Shift+1	Front light on/off
Ctrl+2/Shift+2	Top light on/off
Ctrl+3/Shift+3	Bottom light on/off

The Lander's cabin has five stations that can be viewed by pressing "Ctrl+Arrow" (up, down, left, right). Focused views within each station are displayed by pressing "V". The views by station are shown below:

Station 1: **Left Console** (there are two sites viewed by cycling through "V")

Console, Front window (HUD)

Pressing "Ctrl+Right Arrow" moves you to

Station 2: **Aft Airlock chamber** (there are two sites viewed by cycling through "V")

Ventral hatch, Dorsal hatch

Pressing "Ctrl+Right Arrow" moves you to

Station 3: **Right Console** (there are two sites viewed by cycling through "V")

Console, Front window (HUD)

Pressing "Ctrl+Down Arrow" moves you to

Station 4: **Right Aft**

Pressing "Ctrl+Left Arrow" moves you to

Station 5: **Left Aft**

Pressing "Ctrl+Up Arrow" moves you to the default position **Left Console**

Endurance Docking Conventions



The Endurance has eleven docking rings. Seven arrayed along the central docking hub (docking rings 1-7) and the remaining four (docking rings 8-11) arrayed around the Endurance's ring.

Docking rings 3-5, & 7 can accept Lander docking via either its ventral (Dock 1) or dorsal (Dock 2) docking ring. Due to insufficient clearance between the Lander's undersurface and the docking ring's diaphragm and gimbal structure, Endurance docking ring 6 can only accept Lander docking via its dorsal (Dock 2) docking ring.

Docking rings 1, 2, 8-11 accept Ranger docking via its aft docking ring. Docking rings 3-7 accept docking via Ranger's ventral docking ring with its docking tube extended.

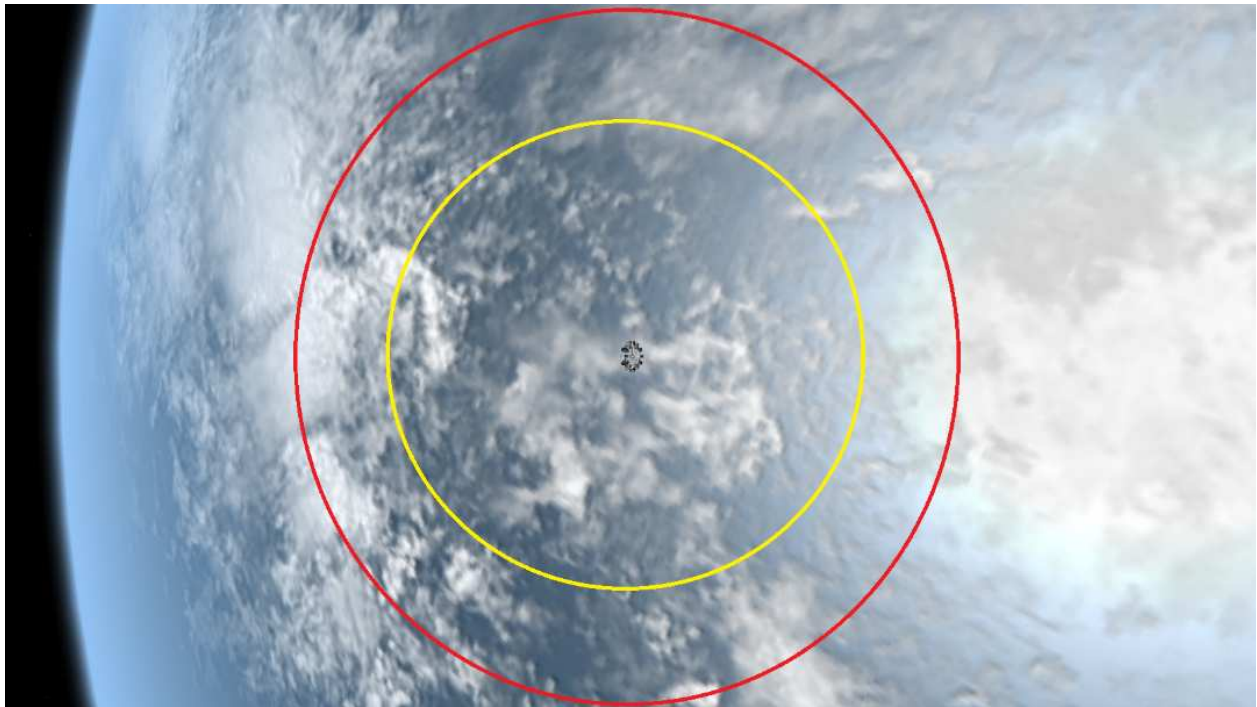
Prior to initiating docking operations with the Endurance, the HPBE should be engaged, all rotational motion should be nulled, and all autopilot settings disengaged to place the Endurance in free flight mode. Docking by the Lander to Endurance (docking rings 3-7) or Ranger (to Endurance docking rings 1-11) may be initiated and monitored through Docking MFD and Camera MFD.

Docking Operations

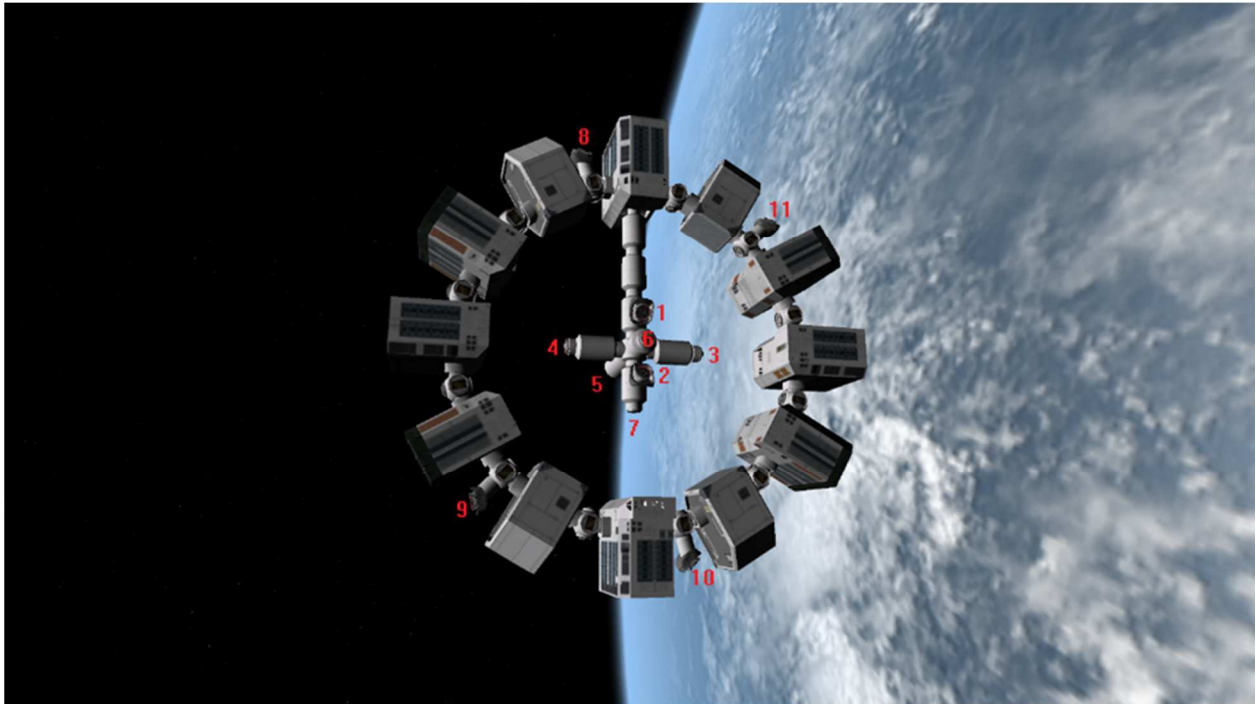
The Lander docks via its ventral (Dock 1) docking ring with Endurance at Docks 3, 4, 5, or 7 or its dorsal docking ring (Dock 2) with Endurance Dock 6. Docking is monitored through Docking MFD and Camera MFD. **Verify the following flight conditions with Endurance Flight Deck prior to initiating docking operations:**

- Endurance High Performance Balance Engine (HPBE) engaged
- All Endurance rotational motion is nulled
- All Endurance autopilot settings are disengaged
- The Endurance is in free flight mode

Approach Endurance from a “High-Key” (red) rendezvous position 1 kilometer from the ship. Align your approach for either anterior or posterior rendezvous by the 500 meter “Low-Key” (yellow) position. Approach velocities within this area should be ≤ 1.0 meter/second.



Approach to Docks 3, 4, 5, and 7 begin from an initial stationkeeping position 150 meters aft of the ship. To approach Endurance's Dock 6, the stationkeeping position is approximately 150 meters forward of the ship. **The pilot in command is responsible for maintaining vessel separation at all times.** Using Docking MFD,



select approach Dock 1 for ventral docking and Dock 2 for dorsal docking. Select as target docks 3, 4, 5, or 7 (may be used with either approach Dock 1 or Dock 2). **Endurance dock 6 can only be accessed via Lander Dock 2. Both Endurance Docks 1 and 2 must be free to assure adequate vessel clearance.** Use Camera



MFD to guide approach, maintain approach velocity 0.5-1.0 meters/second from 150 to 100 meters from docking point. At ≤ 50 meters maintain velocity ≤ 0.25 meters/second. When ≤ 50 meters from selected dock use Camera MFD (view forward) to align the selected dock with the mid-position (red line) of the MFD to assure adequate clearance from the Endurance ring. **There is limited clearance within the Endurance ring.** The pilot in command is responsible for maintaining vessel separation at all times.



At ≤ 25 meters maintain velocity ≤ 0.2 meters/second. When ≤ 15 meters maintain velocity ≤ 0.1 meters/second



When < 5.0 meters from selected dock, orient Camera MFD view down (for Dock 1 operations) up (for Dock 2 operations) to monitor final docking approach.



With docking clamps secured and hard dock verified, press “Keypad 9/0” to select the desired docking ring, then press “\” to open the hatch.

Lander - Ranger Docking



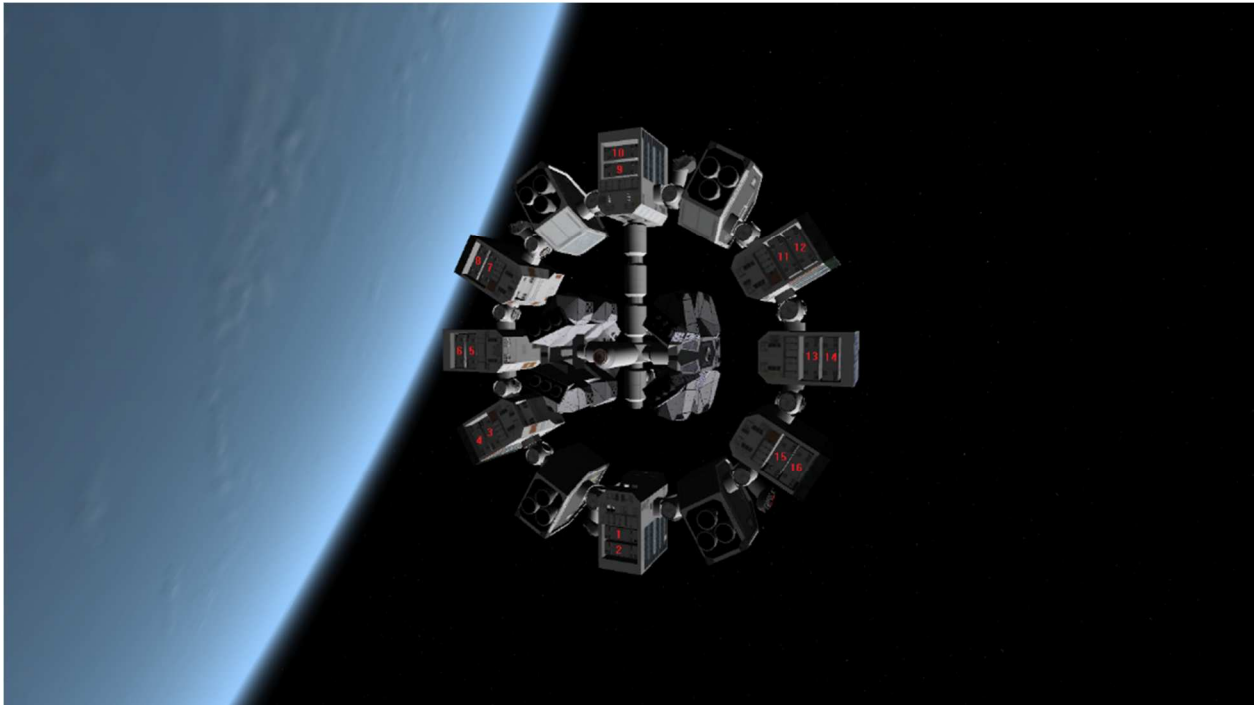
Though the ventral extension of the pods containing the magnetoplasmadynamic (MPD) thrusters limits access to the docking ring on its ventral surface, the Lander can dock with a Ranger via its dorsal docking ring (Dock 2) and the Ranger's ventral dock (Dock 2) with its extended docking tube. This expands the spacecraft's capabilities and serves as a redundancy should the Endurance sustain critical damage. Docking between the Lander dorsal docking ring and Ranger (Dock 2) may be monitored through Docking MFD and Camera MFD and initiated from either vessel. With the Lander as the active vessel, select approach Dock 2 and target Ranger Dock 2. **Verify the following flight conditions with target vessel prior to initiating docking operations:**

- All target vessel rotational motion is nulled
- All autopilot settings are disengaged
- The target vessel is in free flight mode

The pilot in command is responsible for maintaining vessel separation at all times. Maintain approach velocity 0.5-1.0 meters/second from 150 to 100 meters from docking point. At ≤ 50 meters maintain velocity ≤ 0.25 meters/second. At ≤ 25 meters maintain velocity ≤ 0.2 meters/second. When ≤ 15 meters maintain velocity ≤ 0.1 meters/second. With docking clamps secured and hard dock verified, press "Keypad 9/0" to select the desired docking ring, then press "\" to open the hatch.

Cargo Operations

Sixteen Cargo Pods are rack-mounted and carried in the cargo bays on the aft surface of the Command Module, Landing Modules, Habitat Modules, and Cryo-Lab Module. Each pod is identified as shown below.



Landers are designed to transport up to two Cargo Pods from orbit to a planetary surface in support of planet exploration. A Rack-Mounted Cargo Deployment System allows transfer of the Cargo Pods from a module's cargo bay



to a Lander's cargo bay without requiring extravehicular activity (EVA) except in the case of a cargo extension, release, or attachment failure.

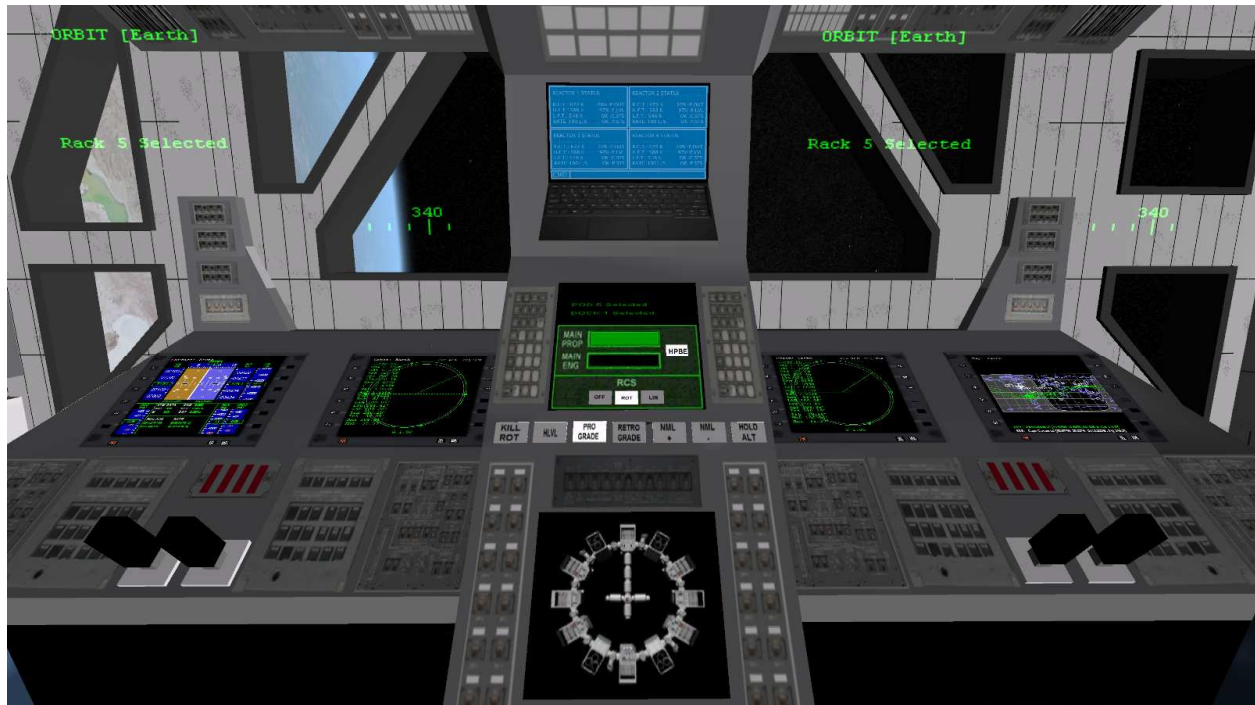
The Cargo Pods are displayed in the Flight Deck center pedestal monitor. Pressing “” selects the desired cargo rack for deployment. The selected Cargo Pod is highlighted by a red annunciator at its location on the center pedestal monitor and is identified on the center annunciator panel.

The selected rack is identified in the Command and Pilot station HUD displays. A red beacon is also illuminated on the selected Cargo Pod's outer surface.

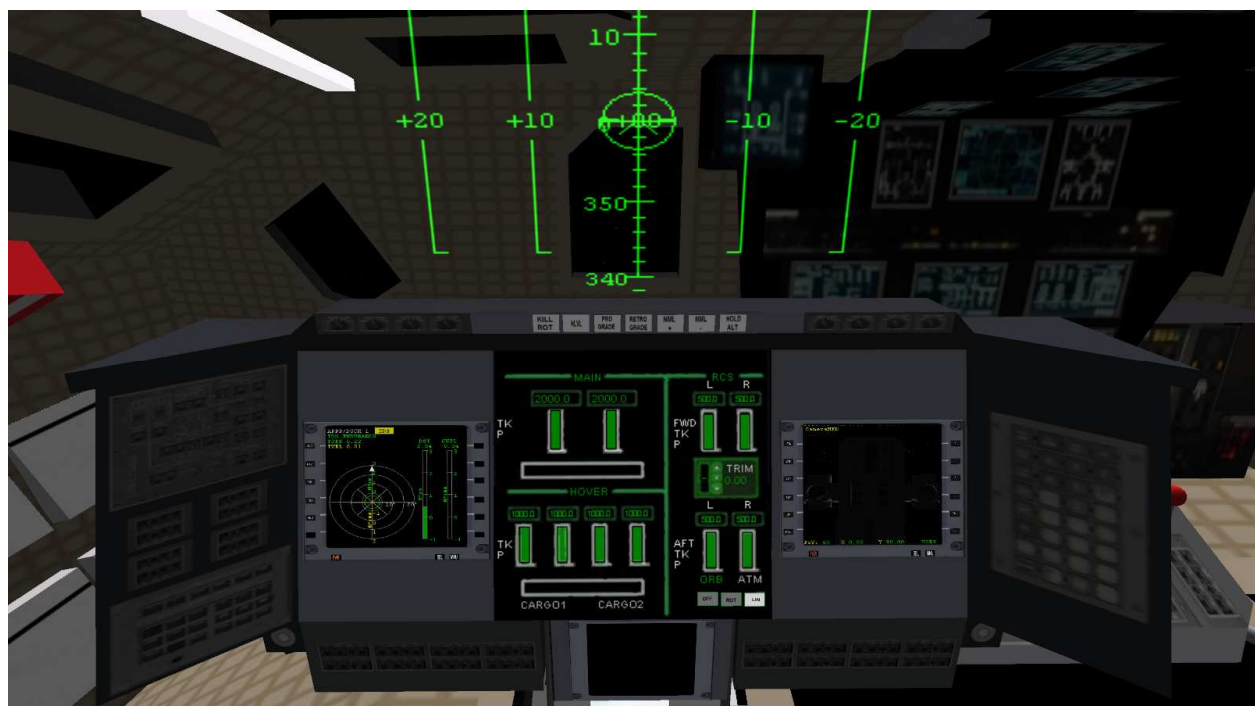


Cargo transfer operations are controlled from the Command Module flight deck. **Mission safety protocol requires either Commander and Pilot or Pilot and spaceflight rated robot be present on station in the Endurance Flight deck and Lander cockpit during Cargo Pod transfer operations.** Cargo transfer operations may be performed in either free flight or autopilot controlled attitudes. **The pilot in command is responsible for maintaining vessel separation at all times.**

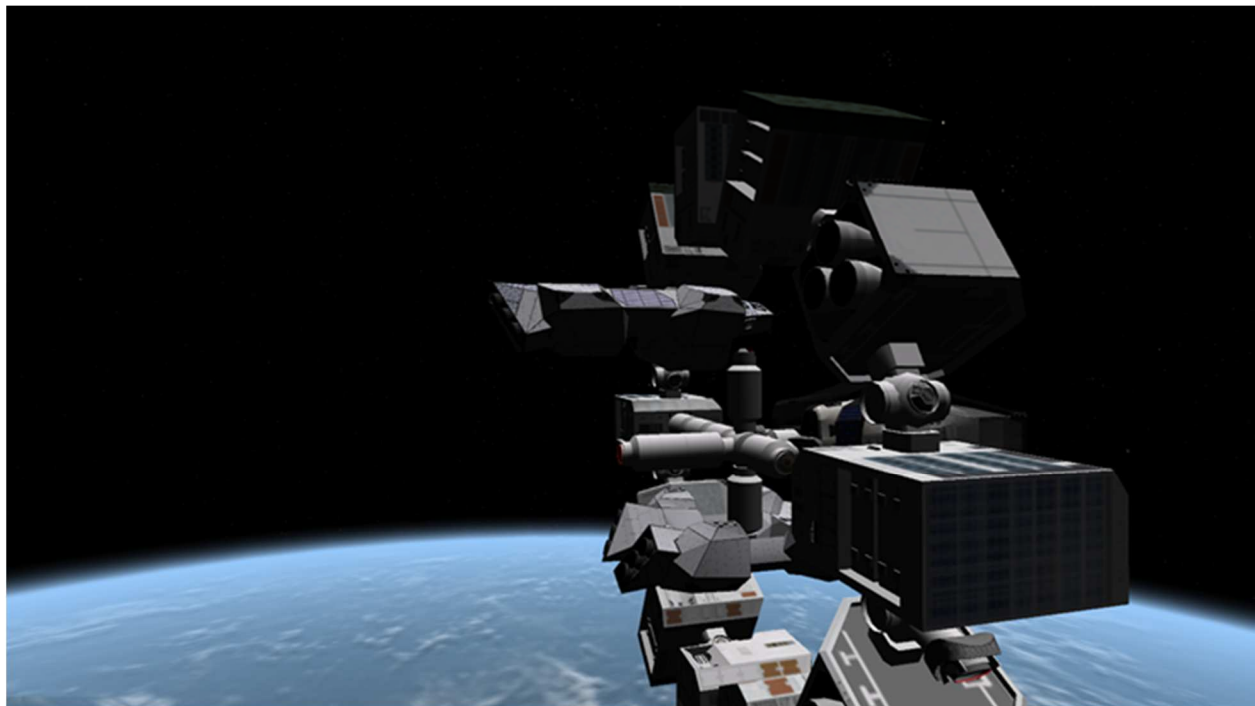
Once a mission plan has been determined and flight plan logged, a flight crew consisting of Commander and Pilot or Pilot and spaceflight rated robot, is dispatched to the Lander logged for cargo transport. The desired Cargo Pod(s) is selected from the Flight Deck.



Prior to Lander launch, activate Docking MFD targeting Endurance Dock 3 (Lander 1) or Dock 4 (Lander 2) for undocking guidance. Activate Camera MFD (camera point of view up) to monitor undocking. When cleared, undock with a separation rate < 0.2 meters per second. Use Docking MFD to monitor separation rate and distance. **Note: There is limited clearance within the Endurance ring. Maximum vertical separation from the Endurance must not exceed 3.5 meters.**



With approximately 3.5 meters vertical separation from the Endurance docking ring, translate aft to a minimum separation of 45 meters.



Once 45 meters aft of the Endurance docking, ring use Docking MFD (targeting Endurance Dock 5) to guide nose up pitch for alignment with the plane of the cargo bays. Verify with Mission Control the selected Cargo Pod. Rotate as necessary to acquire the cargo bay of the selected Cargo Pod.



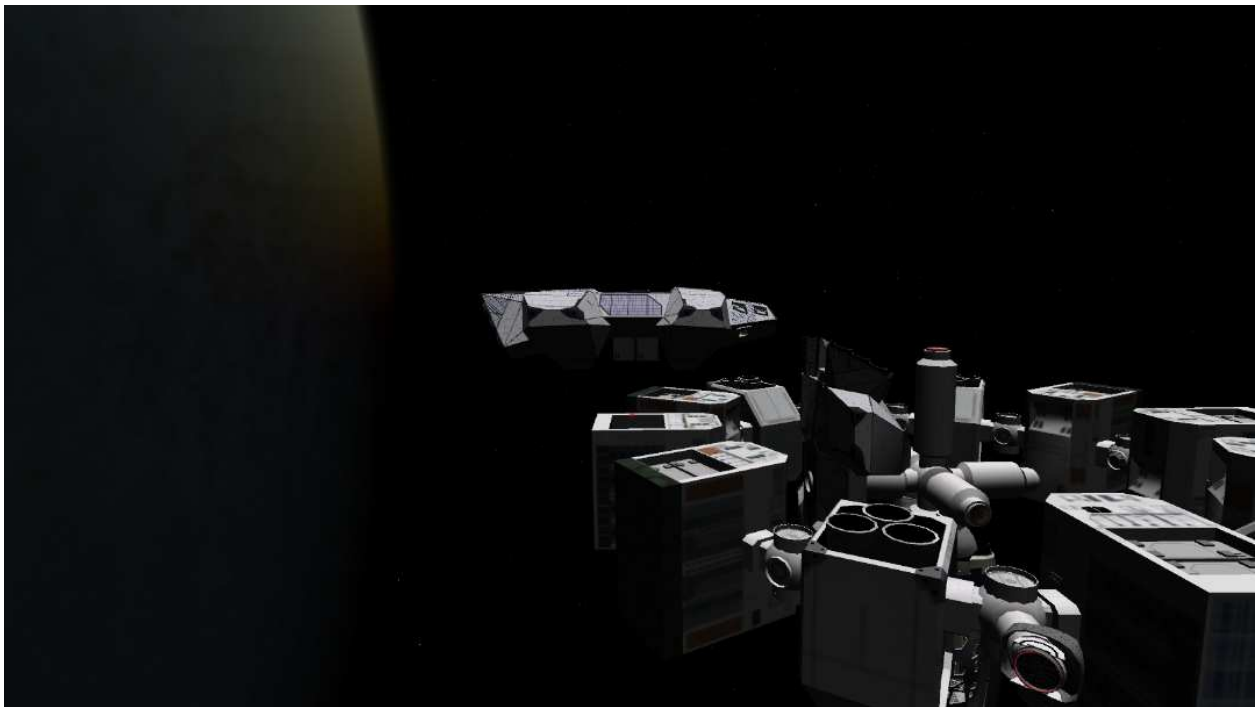
Using Docking MFD (targeting Endurance Dock 5) and Camera MFD, translate and rotate as necessary to align with the selected cargo bay. Hold position approximately 20 meters over the cargo bay. From Endurance's focus press "keypad 3" to extend the selected cargo rack. Endurance's center pedestal monitor



From the Endurance's focus, release the selected Cargo Pod then, from the Lander's focus, Press "B" to grapple the second Cargo Pod. The second cargo annunciator will turn green to indicate a successful grapple.



From the Endurance's focus, press "keypad 3" to retract the cargo rack. Return to the Lander's focus to separate from the Endurance and establish orbital alignment to prepare for deorbit burn.



Reentry

To ferry crew, shelter, and provisions from orbit to a planetary surface, the Lander's payload is carried on the undersurface of the ship while its upper surface serves as its heat shield. The ship performs atmospheric entry inverted thus protecting the belly-mounted payload. Point specific reentries can be plotted and flown using BaseSync MFD and AeroBrake MFD.



Use BaseSync MFD to align orbital plane with the desired landing site. Use Map MFD, Orbit MFD, and BaseSync MFD to plot and initiate deorbit burn.



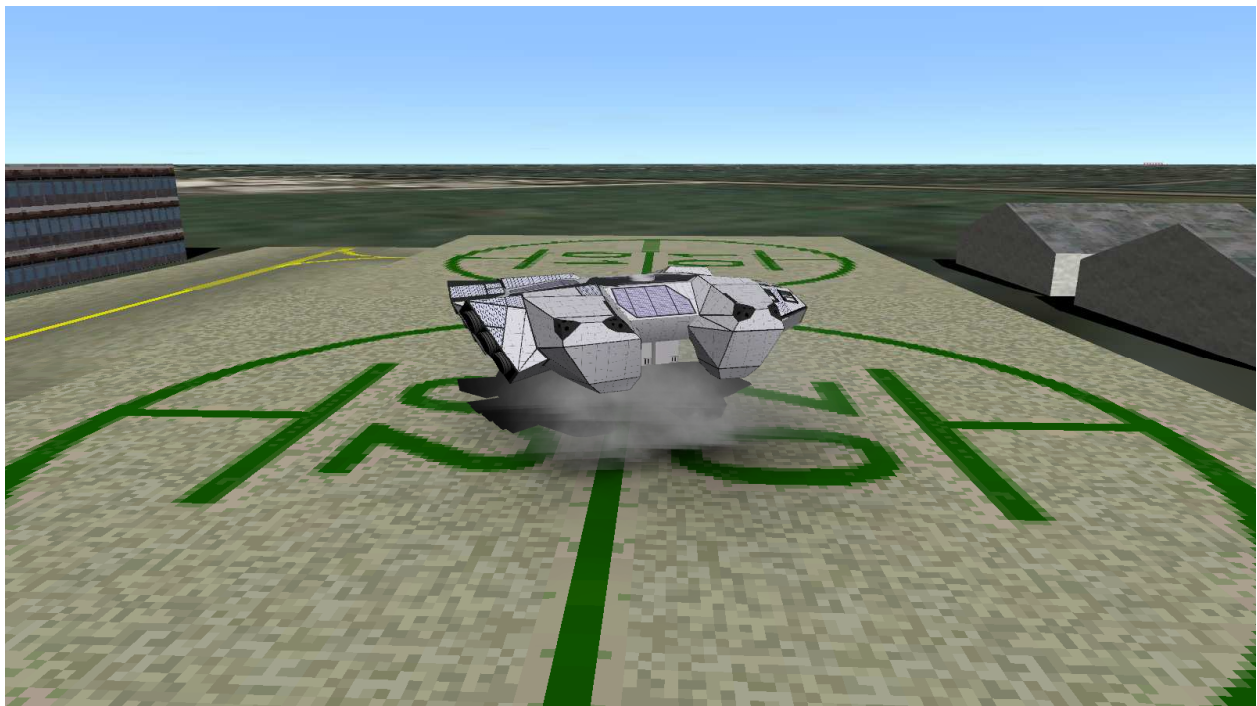
With the deorbit burn completed, roll inverted in prograde attitude. Press “G” to close the reentry shields prior to entry interface.



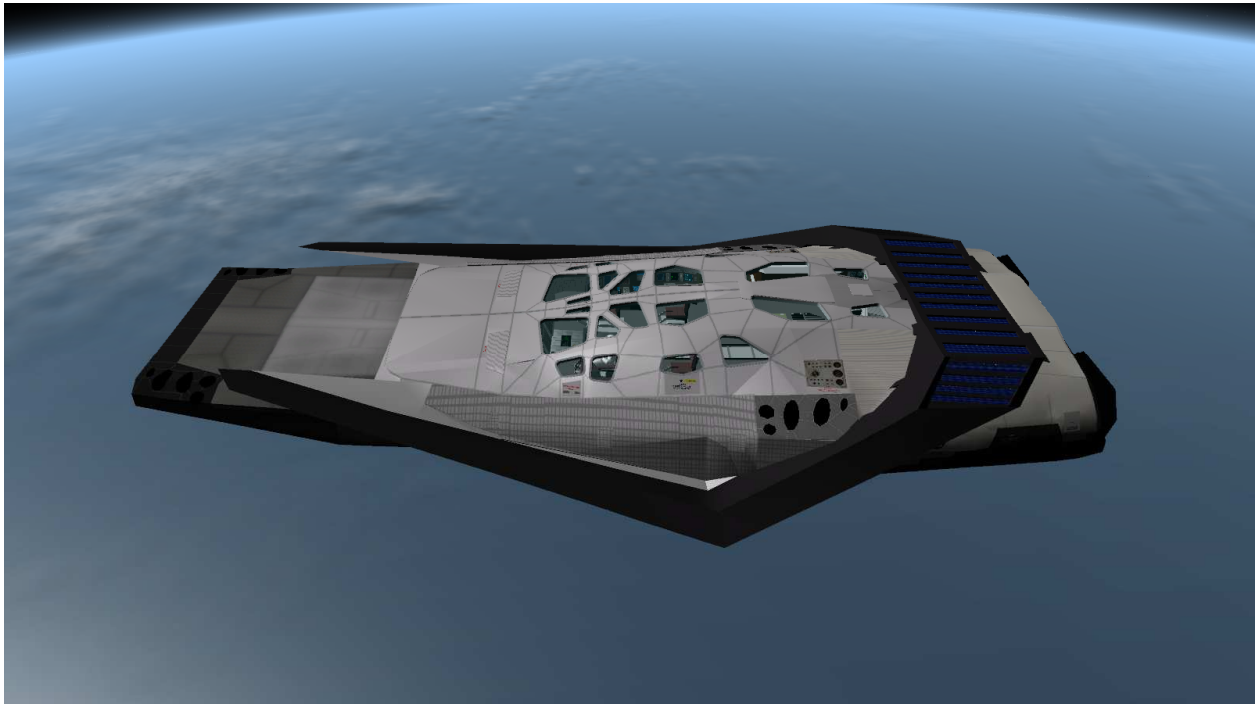
Using AeroBrake MFD, select landing site, establish reentry pitch profile, and determine reentry ground track. Adjust pitch (by RCS or trim) and roll as necessary to maintain desired ground track (Note: pitch trim is generated by auxiliary constant thrust magnetoplasmadynamic thrusters. This system does not null to neutral pitch and must be actively controlled to achieve fine pitch control).



Once below 40 Km altitude, press “” to select atmospheric (ATM) RCS settings. Below Mach 5, press “G” to open the reentry shields. At Mach 3.5, begin a maximum rate roll upright while adjusting trim as needed to achieve the range necessary to acquire the landing site.



Ranger



The Ranger is the product of a NASA program tasked with creating a reusable, maneuverable, high-efficiency SSTO craft that could climb out of the Earth's gravity well, achieve orbit, de-orbit, and land on the planet's surface. The Ranger's fuselage is characteristic of a lifting-body, equipped with winglets that augment lift and stability.⁶ The combination of lifting-body aerodynamics (which minimizes the need for thrust in atmospheric flight), with maneuverability, and SSTO capability, make it possible for the ship to undock from the Endurance, reenter, land on a planetary body, and lift off to rejoin Endurance on orbit. The Ranger's crew compartment is composed of three areas, flight deck, cabin, and airlock. The flight deck includes four 0-0 ejection rated crew seats and two folding benches for four additional passengers with a maximum crew complement of eight. Aft of the flight deck, is the cabin. It contains four hibernation tanks and contingency supplies for long duration missions.⁶ In addition, there is a dedicated station for a spaceflight-rated robot. The airlock is at the aft end of the cabin. The airlock has two docking rings which allow two docking configurations; one aft, which serves as the primary Ranger-Endurance docking ring and a ventral docking ring with a short extendable docking tube that permits ship-to-ship docking. There is also an aft docking hatch which extends down to open and serve as a gangplank to the surface when landed. To conserve fuel achieving Earth orbit, the Ranger can be launched on a multistage rocket. The ship is self-sufficient and is capable of an extended planet-side dwell time.

The Ranger's propulsion system consists of two Hybrid Variable Specific Impulse Magnetoplasma Rocket (H-VASIMR) aerospike engines. The RCS is based on magnetoplasmadynamic (MPD) thrusters that are designed to ionize the gases of a planet's atmosphere as propellant. With the exception of a moveable nose flap for pitch trim, the Ranger relies on its magnetoplasmadynamic RCS thrusters to provide pitch, yaw, and roll eliminating the need for any other control surfaces.⁶ The Ranger is UMMu and UCGO compliant.

Ranger Key Commands

Ctrl + Arrow	Selects cabin views
V	Selects focused views within cabin stations
3/4	Rotate seats
6/7	Toggle CASE/TARS animation
V	Switch view
`	Toggle ORB/ATM RCS settings
G	Extend/Retract landing gear
N	Select Docking Ring/Hatch
\	Open/Close Docking Ring/Hatch
Keypad 9	Open/Close Docking Ring Door
Keypad 0	Extend/Retract Docking Tube

The Ranger's cockpit/cabin has six stations that can be viewed by pressing “Ctrl+Arrow” (up, down, left, right). Focused views within each station are displayed by pressing “V”. The views by station are shown below:

Station 1: **Left Console** (There are three sites viewed by cycling through “V”)

Console, Center Screen, HUD

Pressing “Ctrl+Right Arrow” moves you to

Station 2: **CASE/TARS** (There are four sites viewed by cycling through “V”)

Aft View, Forward View, Airlock, Center Screen

Pressing “Ctrl+Right Arrow” moves you to

Station 3: **Right Console** (There are three sites viewed by cycling through “V”)

Console, Center Screen, HUD

Pressing “Ctrl+Down Arrow” moves you to

Station 4: **Right Aft** (There are two sites viewed by cycling through “V”)

Right Panel, Left Cabin

Pressing “Ctrl +Down Arrow” moves you to

Station 5: **Docking Panel** (There are three sites viewed by cycling through “V”)

Docking MFD's, Airlock, Forward View

Pressing “Ctrl+Left Arrow” moves you to the default position Left Console or

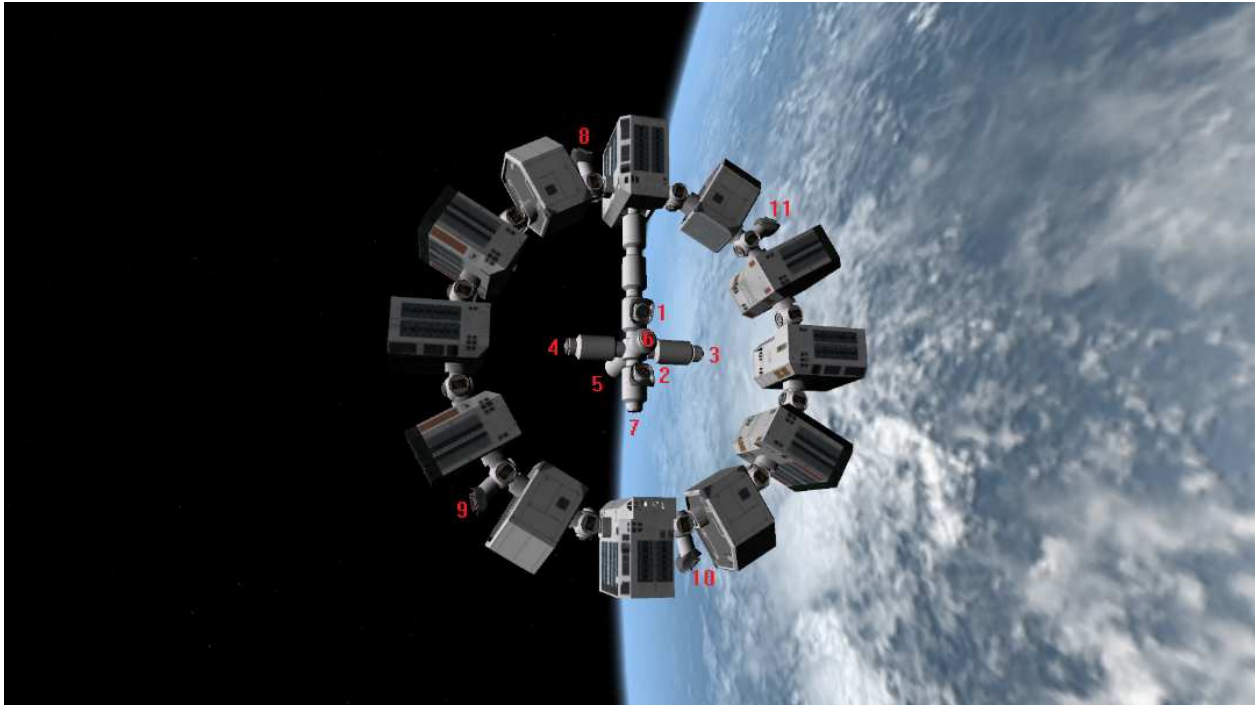
Pressing “Ctrl+Up Arrow” moves you to

Station 6: **Left Aft** (There are two sites viewed by cycling through “V”)

Left Panel, Right Cabin

Pressing “Ctrl+Up Arrow” moves you to the default position **Left Console**

Endurance Docking Conventions



The Endurance has eleven docking rings. Seven arrayed along the central docking hub (docking rings 1-7) and the remaining four (docking rings 8-11) arrayed around the Endurance's ring.

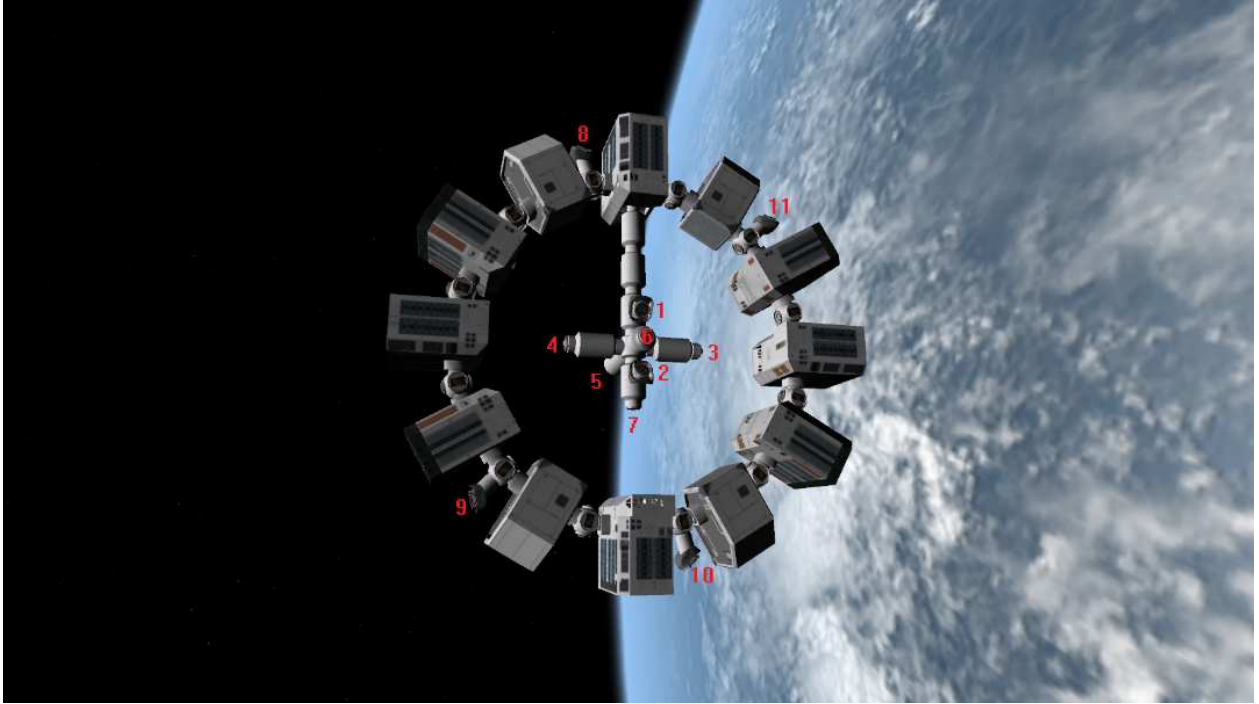
Docking rings 3-5, & 7 can accept Lander docking via either its ventral (Dock 1) or dorsal (Dock 2) docking ring. Due to insufficient clearance between the Lander's undersurface and the docking ring's diaphragm and gimbal structure, Endurance docking ring 6 can only accept Lander docking via its dorsal (Dock 2) docking ring.

Docking rings 1, 2, 8-11 accept Ranger docking via its aft docking ring. Docking rings 3-7 accept docking via Ranger's ventral docking ring with its docking tube extended.

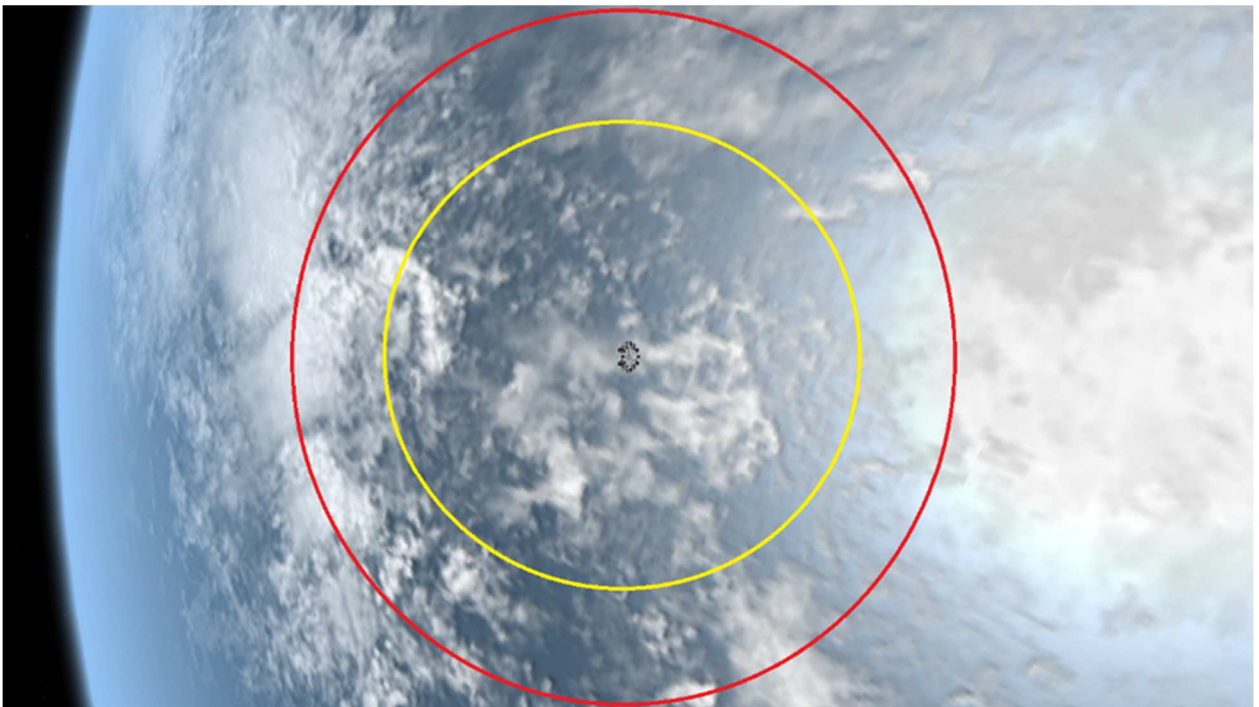
Prior to initiating docking operations with the Endurance, the HPBE should be engaged, all rotational motion should be nulled, and all autopilot settings disengaged to place the Endurance in free flight mode. Docking by the Lander (to Endurance (docking rings 3-7) or Ranger (to Endurance docking rings 1-11) may be initiated and monitored through Docking MFD and Camera MFD.

Docking Operations

The Ranger docks via its primary aft docking ring (Dock 1) with Endurance at Docks 1, 2, 8-11, and its ventral docking ring (Dock 2) with docking tube extended at Endurance Docks 3-7 to allow adequate vessel clearance.



Approach Endurance from a “High-Key” (red) rendezvous position 1 kilometer from the ship. Align your approach for either anterior or posterior rendezvous by the 500 meter “Low-Key” (yellow) position. Approach velocities within this area should be ≤ 1.0 meter/second.



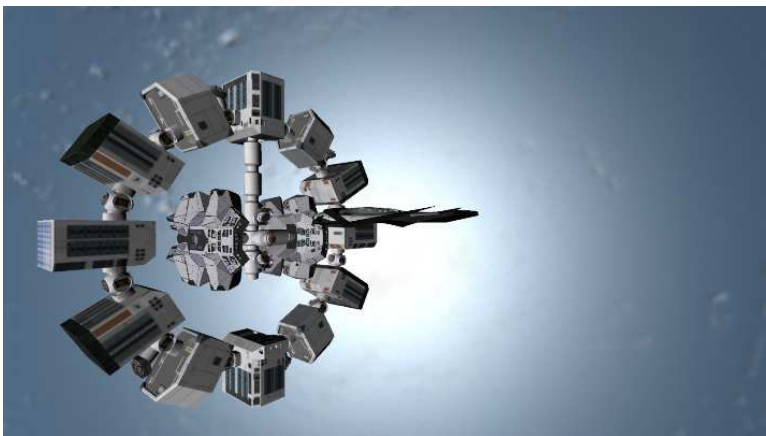
Docking is monitored through Docking MFD and Camera MFD. **Verify the following flight conditions with Endurance Flight Deck prior to initiating docking operations:**

- Endurance High Performance Balance Engine (HPBE) engaged
- All Endurance rotational motion is nulled
- All Endurance autopilot settings are disengaged
- The Endurance is in free flight mode

Approach to Docks 3-7 begin from an initial stationkeeping position 150 meters aft of the ship. To approach Docks 1 & 2, the stationkeeping position is approximately 150 meters forward of the ship. Approach to Docks 8-11 can be initiated from the 150 meter stationkeeping position forward or aft of the ship. **The pilot in command is responsible for maintaining vessel separation at all times.** Press “N” to select the desired docking ring. The selected docking ring is indicated in the HUD and the center console. For aft docking, use Docking MFD choosing approach Dock 1. Select as target, Endurance docks 1, 2, 8-11. Maintain an approach



velocity < 0.5 meters/second less than 100 meters from docking point. When < 5.0 meters from selected dock, use Docking MFD and Camera MFD to monitor final docking approach. The selected docking ring's state is highlighted in the HUD. With docking clamps secured and hard dock verified, press “\” to open the hatch.



The annunciator will show yellow in the center console while the hatch is in motion, and red when the hatch is fully open.



For ventral docking via the docking tube choose Dock 2. **Dock 2 cannot be accessed, nor can the docking tube be extended without opening the Docking Ring Door.** Press “keypad 9” to open the Docking Ring Door. The Docking Ring Door state is highlighted in the HUD. Select as target, Endurance docks 3-7. Monitor approach with Docking MFD and Camera MFD. Use RCS to align and close on the selected docking ring. If



approaching Endurance docks 3-7 Maintain approach velocity 1.0-0.5 meters/second from 150 to 100 meters from docking point. **To allow adequate vessel clearance when docking at docks 3-7, the docking tube must be extended.**

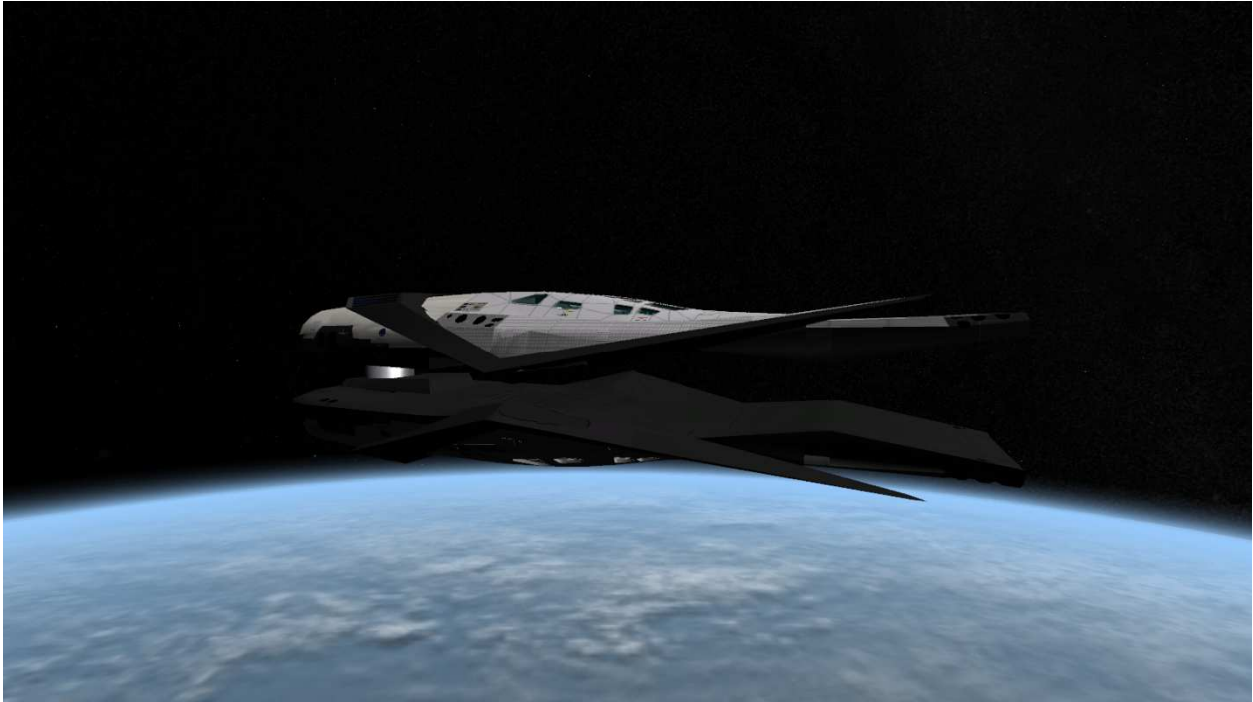
Press “keypad 0” to extend the docking tube. The docking tube state is highlighted in the HUD. Align and close on the selected docking ring. Maintain an approach velocity < 0.5 meters/second less than 100 meters



from docking point. With docking clamps secured and hard dock verified, press “\” to open the hatch. When Dock 2 is selected and the hatch is opened, the center console annunciator and HUD will indicate the hatch state.



Ranger – Ranger Docking



Two Rangers are capable of docking via the ventral docking ring (Dock 2) by utilizing the Ranger's docking tube. This expands the spacecraft's capabilities allowing a Ranger to serve as a lifeboat should its sister ship sustain critical damage. Docking between the Rangers' ventral docking ring and docking tube (Dock 2) may be monitored through Docking MFD and Camera MFD and initiated from either Ranger. With one ship as the active vessel, select approach Dock 2 and target Ranger Dock 2. **Verify the following flight conditions with target vessel prior to initiating docking operations:**

- All target vessel rotational motion is nulled
- All autopilot settings are disengaged
- The target vessel is in free flight mode

The pilot in command is responsible for maintaining vessel separation at all times. Maintain approach velocity 0.5-1.0 meters/second from 150 to 100 meters from docking point. At ≤ 50 meters maintain velocity ≤ 0.25 meters/second. At ≤ 25 meters maintain velocity ≤ 0.2 meters/second. When ≤ 15 meters maintain velocity ≤ 0.1 meters/second. With docking clamps secured and hard dock verified, press "Keypad 9/0" to select the desired docking ring, then press "\" to open the hatch.

Reentry

To ferry crew from orbit to a planetary surface, the Ranger is capable of flying point specific reentries using BaseSync MFD and AeroBrake MFD.



Use BaseSync MFD to align orbital plane with the desired landing site. Use Map MFD, Orbit MFD, and BaseSync MFD to plot and initiate deorbit burn.

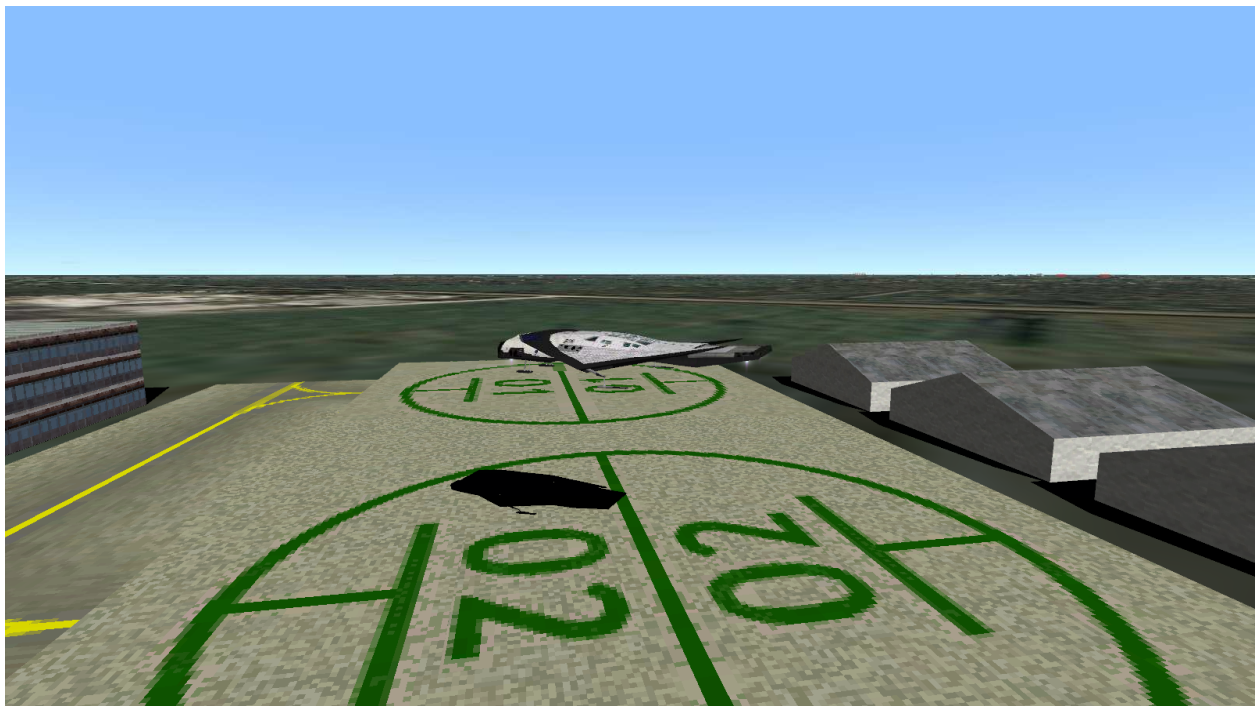




Once below 40 Km altitude, press “” to select atmospheric (ATM) RCS settings. Below Mach 5 adjust pitch trim and roll to maintain heading, altitude, and airspeed necessary to acquire the landing site. Below 500 meters/second adjust pitch trim and hover thrust as necessary, to maintain a sink rate that does not exceed 120 meters/second. Select the desired navigational aids to guide approach to landing.



At 25 Km from touchdown maintain a velocity < 50 meters/second. Use hover thrust to achieve a touchdown vertical velocity that does not exceed 3 meters/second.



Ranger-Saturn Launch Vehicle



Though both Landers and Rangers are SSTO capable, the Rangers are launched to low Earth orbit aboard the remaining Saturn V launch vehicles. Using the Saturn launch vehicle allows the Rangers to be launched with minimal fuel onboard. Once docked with Endurance, both Rangers are fully refueled, thus allowing a full fuel compliment to maximize mission flexibility. The Saturn's avionics package has been upgraded to current standards and its propulsion systems inspected and refurbished as necessary to maintain man-rated classification and mission readiness.

The Ranger-Saturn payload consists of four components; two Rangers with their associated fairings, a support truss, and launch carrier. The Rangers are attached by their ventral surfaces to a support truss (Rangertruss). In addition to distributing the launch loads placed on the Rangers, the truss maintains the alignment and separation of the Rangers docking ports. The truss contains an independent RCS system that can be controlled from either Ranger. When separated from the launch carrier, the truss then serves as a tug making simultaneous docking with Endurance possible. The Ranger-truss assembly is attached to the launch carrier (Rangerlaunch). The carrier contains onboard power, consumables, and the hardware necessary to support the Rangers from launch to rendezvous and docking. The carrier is mated to the Saturn V's third stage (S-IVB). The Ranger-Saturn launch vehicle is based at NASA's Cheyenne Mountain Research Facility located in the former NORAD facility outside Colorado Springs, CO.

Rangerlaunch Key Commands

- | | |
|---|--------------------|
| J | Jettison fairings |
| K | Detach Rangertruss |

Rangertruss Key Commands

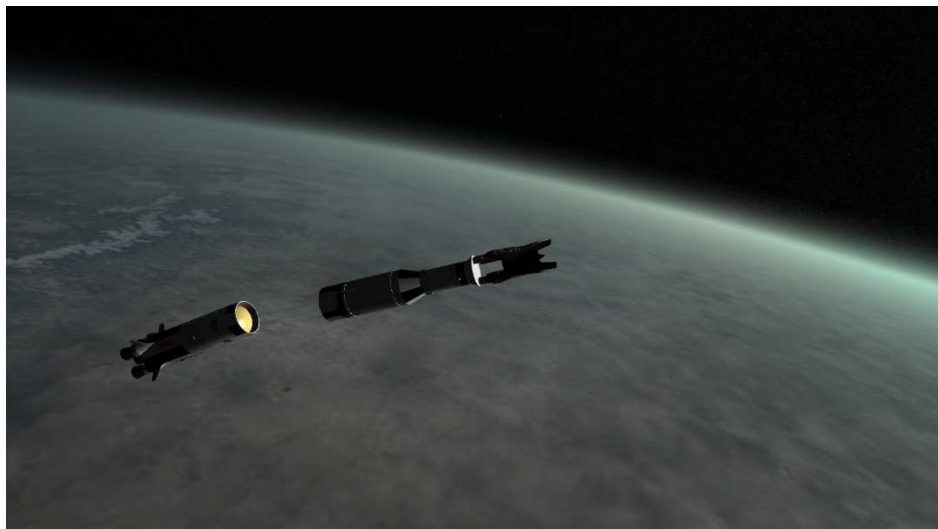
K Detach Rangers/Retract attachment pylons

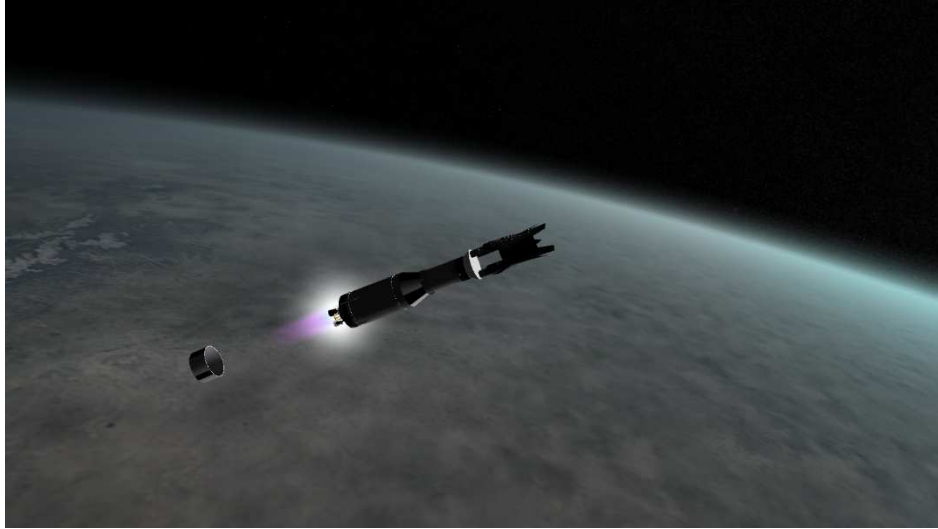
Ranger-Saturn Launch

The Ranger-Saturn launch should be timed to occur at Endurance's closest passage over the launch site. From the focus of the Saturn V, press "P" to initiate the launch sequence and activate the Saturn's launch autopilot (Please review Multistage 2015 documentation for information on Saturn V key commands). With Endurance as target, use Surface MFD, Orbit MFD, and Map MFD to follow the launch to orbital insertion. At 40 Km altitude, the Ranger's fairings are jettisoned.

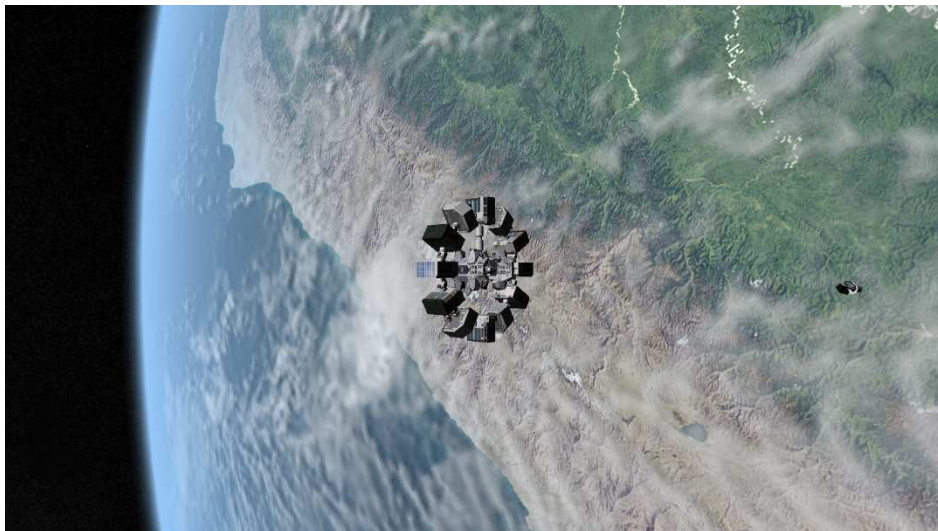


Staging occurs at approximately T+2:20. There is a 10 second delay (during which the 1-2 interstage separates and the ullage motors fire) followed by stage 2 ignition. In the event of a launch abort prior to fairing jettison; (from Rangerlaunch focus) press "J" to jettison the fairings, (from Rangertruss focus) press "K" to detach the Rangers, then switch focus to Ranger 1 to execute a main engine burn as necessary to achieve orbit.





Stage 2-3 staging occurs at T+ 8:35 with S-IVB main engine cutoff (MECO) at T+11:16. From the S-IVB focus, use Align MFD to align orbital planes and Sync MFD to guide rendezvous with Endurance. Using main engine and RCS burns, bring the S-IVB/RANGERLAUNCH stack to a hold position approximately 500 meters from Endurance.



Note, Docking MFD is not available in any of the Saturn V stages. Velocity vector, rate of closure, and range information can be viewed in the S-IVB Docking HUD by selecting Docking MFD, with Endurance as the target and selecting HUD to display the data.

Rangertruss-Endurance Rendezvous and Docking



Verify the following Endurance flight conditions prior to initiating docking operations:

- Endurance High Performance Balance Engine (HPBE) engaged
- All Endurance rotational motion is nulled
- All Endurance autopilot settings are disengaged
- The Endurance is in free flight mode

Move the S-IVB/RANGERLAUNCH stack to a hold position approximately 200-300 meters from Endurance and prepare for approach to docking by switching focus to Ranger 1. Open the Remote Vessel Control window (In Orbiter 100830 P1, press “F4”, select Custom, then select Remote Vessel Control, in Orbiter 160828, press



“F4”, select Function, then select Remote Vessel Control) and choose Rangertruss. Do not select this as focus vessel as you wish to remotely control Rangertruss from the focus of the Ranger. Set the RCS Level slider bar to its minimum setting. Use Docking MFD with Endurance Dock 1 as target, and Camera MFD with its view directed aft, to monitor the approach and docking.



From Rangerlaunch focus, press “K” to release Rangertruss then return focus to Ranger 1. Monitoring the approach closely, use the Remote Vessel Control window to align Rangertruss with Endurance and close on Dock 1. In so doing, Ranger 1 will be aligned with Endurance Dock 1, Ranger 2 will be aligned with Endurance Dock 2, and Rangertruss will be aligned with Endurance Dock 6.





Once below 10 meters separation, decrease closure rate to 0.3 meters/second. Below 5 meters close at 0.01-0.02 m/s. Once docking is indicated, change focus as necessary using Docking MFD to assure all elements of the stack are aligned and docked.

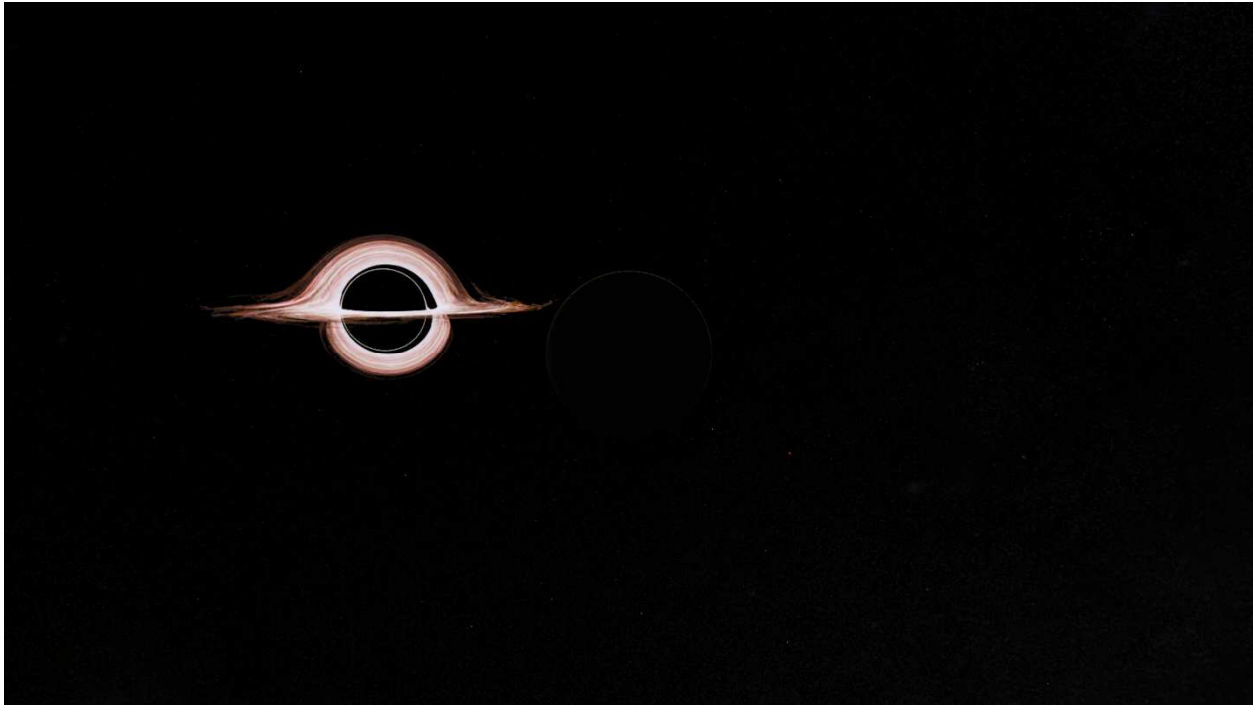


With docking confirmed, switch focus to Rangertruss, press “K” to release the Rangers and retract the attachment pylons.



Press “Ctrl+D” to undock Rangertruss, then translate Rangertruss clear from Endurance. When adequate separation from Endurance has been achieved, use translation thrust to establish a controlled deorbit.

Gargantua-Pantagruel System



In 2019, the Laser Interferometer Gravitational Wave Observatory (LIGO) detected a short burst of gravitational waves stronger than any previously discovered. Further analysis of the data found the source of these gravitational waves to be a neutron star orbiting a black hole. Initial interpretations suggested the location of this unique binary system was orbiting Saturn. This obvious discrepancy prompted closer inspection of the data which revealed the gravitational waves were propagated to our system through a stable wormhole orbiting Saturn⁷.

Over the next 38 years, interferometry, and unmanned probes were used to define the nature of this unusual planetary system. The system was found to consist of a slowly spinning black hole (Gargantua), a neutron star (Pantagruel), twelve planets and the distal mouth of the wormhole.

Remote evaluation of the twelve planets in the system found that there were potentially habitable planets in the system. The potential habitability of these worlds was the impetus for inaugurating the Lazarus Program⁸.

In 2057, twelve astronauts equipped with long-duration habitation (Lazarus) pods were launched through the mouth of the wormhole to explore these twelve planets. Telemetry was received from three of the explorers Dr. Wolf Edmunds, Dr. Hugh Mann, and Dr. Laura Miller suggesting habitability of the planets they had reached.

The orbit of Miler's planet places it closest to Gargantua. While separated from Gargantua's event horizon, it is close enough to the black hole to demonstrate significant time dilation. Mann's planet has an elliptical orbit outside that of the wormhole. Both Mann's and Edmund's planets have orbits that extend out of the system's orbital plane as a result of Gargantua's spin and the gravitational pull of Pantagruel. All three planets are within days to weeks travel from the distal mouth of the wormhole.

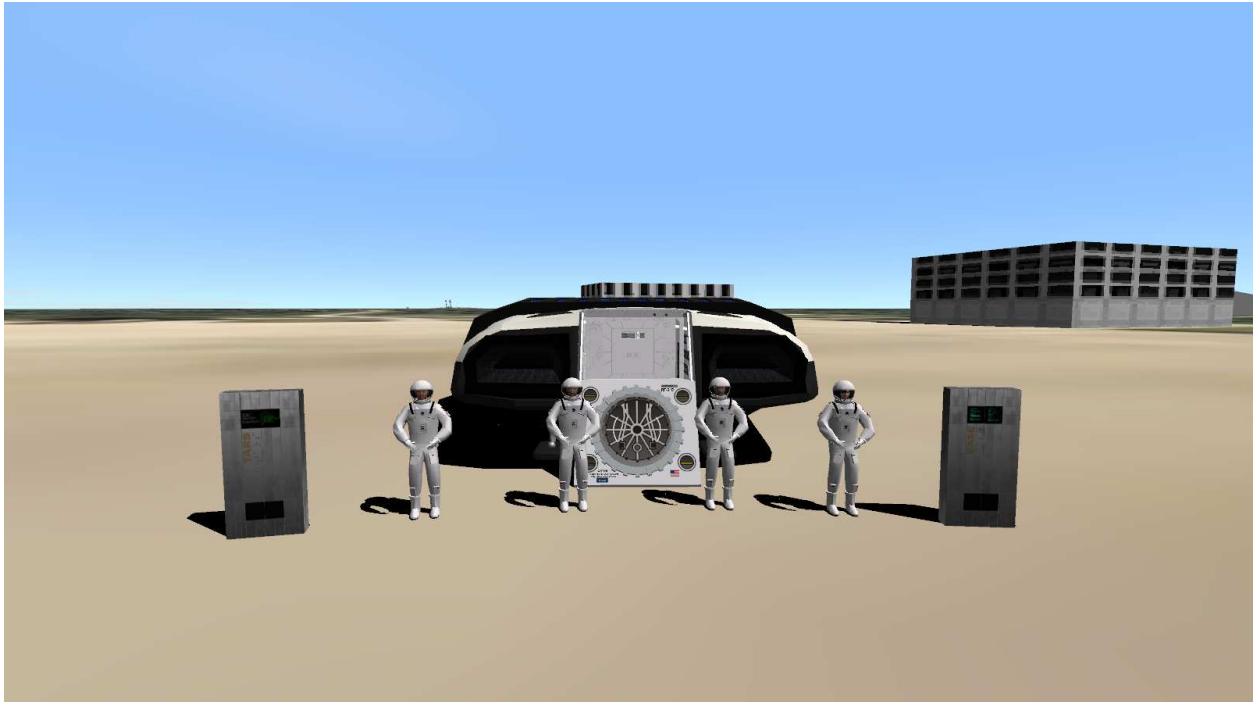
Note

Orbiter does not accommodate faster than light travel, as a result, wormhole travel is not supported. In order to simulate Endurance's transit from the Sol system to the Gargantua-Pantagruel system, use TransX or IMFD to navigate from Earth orbit to Saturn. Identify and rendezvous with the wormhole orbiting Saturn. Close to an altitude of less than 500 Km and end the simulation. Open the Endurance at Gargantua scenario to continue simulation in the Gargantua-Pantagruel system.

Kip Thorne's text, *The Science of Interstellar*, (W. W, Norton & Co, Inc. 2014) defines the Gargantua-Pantagruel system as an atypical binary system where a neutron star orbits a spinning black hole⁹. Miller's planet is in an elliptical orbit of low eccentricity outside Gargantua's accretion ring. Gargantua's spin and Miller's planet's rapid orbital transit (at a velocity of nearly half the speed of light) results in significant time dilation. Mann's highly elliptical orbit demonstrates exaggerated precession due to Gargantua's spin. Edmund's planet also demonstrates an elliptical, out-of-plane orbit as a result of Pantagruel's gravitational pull. Constraints in Orbiter's modeling conventions preclude simulating the orbital mechanics and relativistic effects of the Gargantua-Pantagruel system. As a result, we rely on a simplified Gargantua-Pantagruel system adapted from Anroalh12's (Interstellar System <https://www.orbithangar.com/searchid.php?ID=6745>).^{*} In addition, Orbiter's planetary system modeling algorithms do not allow substituting unique textures for a planetary system's primary star. We have used a version of olrik jhor's Gargantua Tex (<https://www.orbithangar.com/searchid.php?ID=6886>) to emulate the look of Gargantua. As noted on pages 2 - 3, **if you chose to use this texture to emulate Gargantua, you must back up Orbiter's default Star.dds. Substituting olrik jhor's Gargantua Tex Star.dds for the default texture will result in all primary planetary system stars in your Orbiter installation being rendered as Gargantua.**

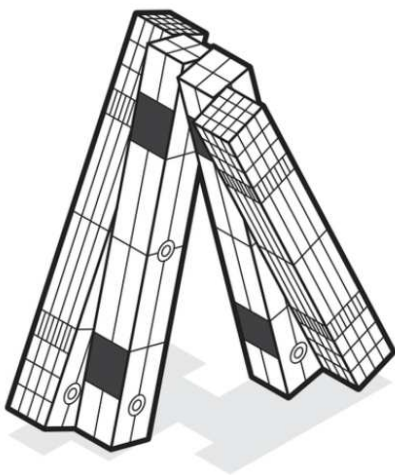
^{*}Within Orbiter's modeling constraints, Anroalh12's Interstellar System attempts to approximate the dynamics of the Gargantua-Pantagruel system. He has modeled a stable and navigable system however, it is not entirely consistent with the system seen in the film or described in the related texts. We have modified Edmunds', Mann's, and Miller's planetary mass as well as Edmunds' semi-major axis in order to give the planets 0.95-1.00 G at their surface.

Endurance Crew

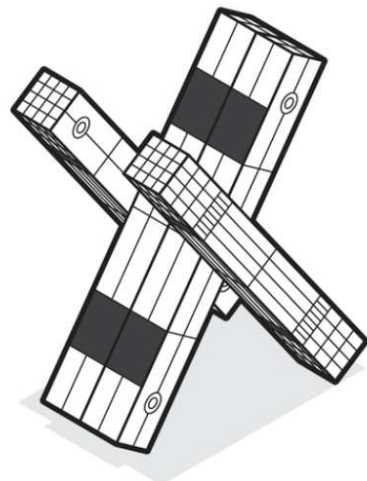


The Endurance Space Exploration System was conceived to host a crew complement of both human and robotic members, each selected for the skills required to meet mission requirements. The robotic crew associated with the Endurance Space Exploration System are re-purposed ex-military automated machines programmed with artificial intelligence. The robots are rectangular prisms composed of four primary segments with the geometrical proportions of a parallelepiped in "static" configuration of 1:4:8 (depth, width and height)¹⁰. Each of the robot's primary segments contain multiple folding components. By splitting these folding components along different axes of rotation, the robots are capable manipulating objects. By the same technique, they are also capable of independent movement;

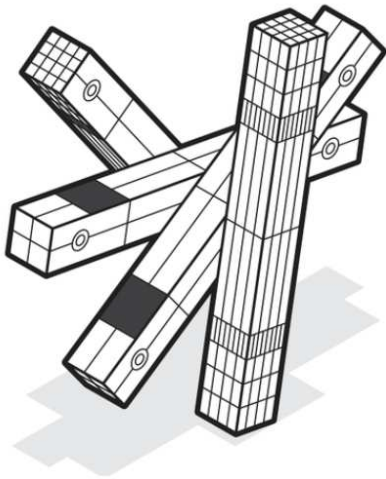
A two legged human-like locomotion



A slow "crutch walk", or faster gallop



A high-speed, four legged “wheel-like” mobility



The robot’s prime function is to assist human crewmembers and act as companions during long duration missions. These machines are designed to emulate humans in humor and attitude. NASA long duration psychological studies demonstrated that personality traits programmed into the robotic crewmembers make them better suited for human companionship. Their personality traits (such as humor, honesty, and discretion) can be altered in their settings.

The Endurance has two spaceflight rated robotic crew:

- CASE; A re-purposed U.S. Marine Corps tactical robot capable of crew support, data collection, and mission logistics
- TARS; A re-purposed U.S. Marine Corps tactical robot capable of data collection, perimeter security, piloting, and crew support

The UMMU ID associated with the following crew are noted below:

Endurance crew female	ECF
Endurance crew male	ECM
Endurance crew female other	EFO
Endurance crew male other	EMO
CASE	CASE
TARS	TARS

Crew Activities

UMmu compliance allows the ship's crew to perform extra vehicular activities (EVA's) or transfers between the Endurance, Lander, and Ranger. To initiate an EVA, from the focus of the ship, select the airlock for egress and open its hatch. In the Endurance, press "N" to select the airlock (indicated in the center panel annunciator and in the HUD), in the Lander, press "keypad 9/0" to select the airlock (indicated in the HUD), in the Ranger, press "N" to select the airlock (indicated in the HUD). Press "keypad 1" or "keypad 2" to scroll through and select the desired crewmember for egress. With the airlock selected, press "\" to open the airlock. Once the hatch is open, press "E" to egress the selected crewmember then close the airlock. At the conclusion of the EVA, move the crewmember back to the egress point, open the ingress airlock and press "E" to return to the ship.

To transfer UMmu between docked vessels, use the transfer vessel's key commands to select and open its airlock. Switch focus to the target vessel to select and open the appropriate airlock. Return to the transfer vessel and select the desired crewmember for transfer. Press "E" to transfer the selected crewmember then close the airlocks of the transfer and target vessels.

Please review UMmu documentation for information on UMmu control, EVA, and motion commands. **Note: UMmu is currently not supported in Orbiter 160828.**

Errata

Known Issues

- Endurance Space Exploration System is UMmu compliant and will run in Orbiter 100830 P1 and Orbiter 160828. However, until oMMU is released for Orbiter 160828, all scenarios will display the following error message: ERROR UMmu 2.0 not properly initialized in your code
- Scenarios containing UMmu on extravehicular activities or those landed and not associated with a vessel will cause a CTD in Orbiter 160828. To avoid CTD when running Endurance Space Exploration System in Orbiter 160828, delete any UMmu from scenarios that is not placed as crew aboard a vessel
- The UMmu based scenario Endurance Crew, is provided in this package. **Do not open this scenario in Orbiter 160828 as it will result in a CTD**
- In Orbiter 160828, a revised touchdown point paradigm causes the Lander and Ranger to sink into the surface when landed or slide across the surface on touchdown

Appendix

Lander Approach Cues

After the deorbit burn, rotate the Lander inverted in prograde orientation. With landing pad selected in AeroBrake MFD and the necessary navigation aids programed into COMM MFD and Land MFD, fly approach guided by AeroBrake MFD monitoring velocity and sink rate. Use trim to adjust pitch and control both sink rate and velocity. Note that in an inverted orientation; nose down trim increases AoA and sink rate to decrease range, while nose up trim decreases AoA and sink rate to increase range. Below 40 Km altitude, select ATM RCS settings. At Mach 3.5, begin a maximum rate roll upright while quickly adjusting trim to 0. Monitor the G loading as you roll through 90° to upright. Smoothly adjust trim 35 - 45 nose up once G loading has passed its peak value (7.0 – 7.5 G). Complete the roll as you decelerate below Mach 1 and select Land MFD to guide approach. Adjust pitch using trim to maintain an altitude of 2.0 – 5.0 Km and smoothly decelerate. Maintain < 300 m/s 100 Km from landing site while minimizing sink rate. Use hover thrust as necessary. Within 50 Km of landing site, decelerate to < 100 m/s. Select HorzLvl, Altitude hold, and translation RCS while employing hover, and translational thrust on final approach to achieve a controlled landing.

Ranger Approach Cues

With landing site selected in AeroBrake MFD and navigation aids programed into COMM MFD and Land MFD, fly approach guided by AeroBrake MFD monitoring velocity. During descent, do not exceed a sink rate of 120 meters/second. Below 40 Km altitude, select ATM RCS settings. Adjust pitch using trim to smoothly decelerate below 500 meters/second. Monitor vertical acceleration. When below 35 Km use pitch to continue to decelerate with a maximum sink rate of < 200 meters/second. Less than 50 Km from landing site, note the rate of deceleration and the rate of descent. Transition from AeroBrake MFD to Land MFD for approach guidance. Below a velocity of 200 meters/second, use hover thrust or HoldAlt as necessary to control altitude and sink rate. Select HorzLvl autopilot and translation RCS to use hover, and translational thrust on final approach to achieve a controlled landing.

Interplanetary Missions

The major planetary bodies of our solar system consist of the Sun; the eight official planets, and at least three "dwarf planets. There are more than 130 satellites of the planets, a large number of small bodies (comets and asteroids), and the interplanetary medium. The inner planets include; Mercury, Venus, Earth, and Mars. Jupiter, Saturn, Uranus, and Neptune (Pluto is now classified as a dwarf planet) compose the outer planets. A general concept of interplanetary flight within our solar system is that flight to the those planets outside Earth's orbit; Mars, Jupiter, Saturn, Uranus, Neptune and the dwarf planet Pluto, require positive delta-V added at the transfer orbit insertion burn. Flight to the planets within Earth's orbit requires delta-V be subtracted (negative prograde velocity) at the transfer orbit insertion burn.

Endurance TransX Flight Cues

Interplanetary Flight

The mission parameters of the Endurance's Earth-Saturn/Wormhole flight are derived from movie, *Interstellar* and Kip Thorne's *The Science of Interstellar*, (W. W, Norton & Co, Inc. 2014). According to these sources, the Earth-Saturn transit began in the spring of 2067^{11, 12} and took 24 months. Our rendering of a wormhole bearing, Sol system dictates a fall 2067 Trans-Saturn-Ejection burn with a transit time of 16 months. The salient parameters summarized below:

Endurance's Earth-Saturn/Wormhole Mission Parameters

- Ejection on or about MJD 76326.8376
- Arrival on or about MJD 76883.1849
- Wormhole Inclination 62.43°, AeS 82,020 Km

Endurance's Earth-Saturn/Wormhole Flight plan

Open left and right TransX windows. The stage sequence is critical in creating the flight plan (Asterisks denote transition points between right and left MFD's Parenthesis denote TransX key commands).

Left Window

- View to Setup (W) [Stage 1]
- Graph to Plan (+/-)
- View to Escape Plan
- Adjust PeDistance (+/-)
- Adjust Ej Orientation (+/-)

With initial draft stage established*

- Forward (F) [Stage 2]
- Select Eject Plan (W)
- Refine variables monitoring
Wormhole

Second stage established**

With plan Established***

- Back to Stage 1 (R)
- View to Maneuver (W)
- Create Maneuver

Right Window

- View to Setup [Stage 1]
- Graph to Plan (+/-)
- Select Escape (+/-)
- Forward (F) [Stage 2]
- Select Saturn (+/-)
- View to Eject Plan (W)
- Adjust variables as required
- Forward (F) [Stage 3]
- View to Encounter (W) (+/-) to toggle
Saturn/Wormhole

Initial draft stage established *

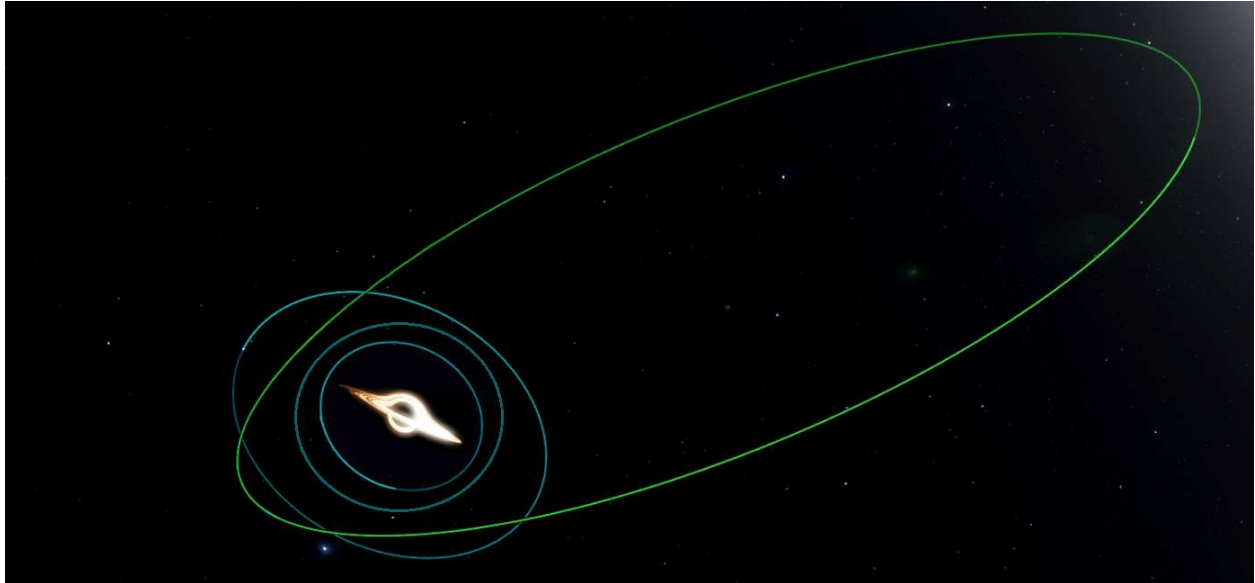
With second stage established**

- Back to Stage 2 (R)
- View to Encounter (W)

Plan Established***

Once in Saturn's sphere of influence, select the Wormhole as target. Use TransX stage to achieve closest possible approach and orbital alignment. Use Synchronize Orbit MFD to guide the final approach. Orbiter does not accommodate faster than light travel, as a result, wormhole travel is not supported. In order to simulate Endurance's transit from the Sol system to the Gargantua-Pantagruel system, once you have rendezvoused with the Wormhole, close to an altitude of less than 500 Km and end the simulation. Open the Endurance at Gargantua scenario to continue simulation in the Gargantua-Pantagruel system.

Navigating the Gargantua-Pantagruel System



The Endurance at Gargantua scenario opens in May 2069 as the Endurance has transited the wormhole. Gargantua is orbited by Miller, the distal mouth of the Wormhole, Mann, Edmunds and its binary partner, the neutron star Pantagruel. Use the MFD's to determine your location in the Gargantua-Pantagruel system. Flight to Mann and Edmunds (the planets outside the wormhole's orbit) requires positive delta-V added at the transfer orbit insertion burn. Flight to Miller which is within the wormhole's orbit, requires delta-V be subtracted (negative prograde velocity) at the transfer orbit insertion burn. Use Orbit MFD and TransX to determine a fuel efficient flight plan for exploring the system. Options to consider include; leaving Endurance in a stable parking orbit employing it as a base station to support long distance ferry missions by the Lander and Ranger versus using the Endurance as the sole exploration vehicle reserving the Lander and Ranger for orbital ferry missions.

Wormhole/Miller Flight plan

Open left and right TransX windows. Initiate this flight plan from Gargantua orbit.

Left Window

- View to Setup (W) [Stage 1]
- Graph to Focus (+/-)

With initial draft stage established*

- View to Maneuver (W)
- Refine variables monitoring Miller

Maneuver created

- View to Target (W)

Right Window

- View to Setup [Stage 1]
- Select Miller (+/-)
- Graph to Focus (+/-)
- Orbit to Icept 1.0 (+/-)
- View to Maneuver (W)
- Adjust variables as required
- Forward (F) [Stage 2]
- View to Encounter (W)

Initial draft stage established *

Wormhole/Mann Flight Plan

Open left and right TransX windows. Initiate this flight plan from Gargantua orbit.

Left Window

- View to Setup (W) [Stage 1]
- Graph to Focus (+/-)

With initial draft stage established*

- View to Maneuver (W)
- Refine variables monitoring Mann

Maneuver created

- View to Target (W)

Right Window

- View to Setup [Stage 1]
- Select Mann (+/-)
- Graph to Focus (+/-)
- Orbit to Icept 1.0 (+/-)
- View to Maneuver (W)
- Adjust variables as required
- Forward (F) [Stage 2]
- View to Encounter (W)

Initial draft stage established *

Wormhole/Mann Flight Plan

Open left and right TransX windows. Initiate this flight plan from Miller orbit.

Left Window

- View to Setup (W) [Stage 1]
- Autoplan off (+/-)
- Graph to Focus (+/-)

With initial draft stage established*

- Forward (F) [Stage 2]
- Select Eject Plan (W)
- Refine variables monitoring Mann

Second stage established**

With plan Established***

- Back to Stage 1 (R)
- View to Maneuver (W)
- Create Maneuver

Right Window

- View to Setup [Stage 1]
- Autoplan off (+/-)
- Graph to Focus (+/-)
- Plan to Eject (+/-)
- Orbit to Icept 1.0 (+/-)
- Select Escape (+/-)
- Forward (F) [Stage 2]
- Autoplan off (+/-)
- Graph to Focus (+/-)
- Orbit to Icept 1.0 (+/-)
- Select Mann (+/-)
- View to Eject Plan (W)
- Adjust variables as required
- Forward (F) [Stage 3]
- View to Encounter (W)

Initial draft stage established *

With second stage established**

- Back to Stage 2 (R)
- View to Encounter (W)

Plan Established***

Edmunds Flight Plan

Open left and right TransX windows. Initiate this flight plan from Gargantua orbit.

Left Window

- View to Setup (W) [Stage 1]
- Graph to Focus (+/-)

With initial draft stage established*

- View to Maneuver (W)
- Refine variables monitoring Edmunds

Maneuver created

- View to Target (W)

Right Window

- View to Setup [Stage 1]
- Select Edmunds (+/-)
- Graph to Focus (+/-)
- View to Maneuver (W)
- Adjust variables as required
- Forward (F) [Stage 2]
- View to Encounter (W)

Initial draft stage established *

Mann/Edmunds Flight Plan

Open left and right TransX windows. Initiate this flight plan from Mann orbit.

Left Window

- View to Setup [Stage 1]
- Graph to Plan (+/-)
- View to Escape Plan
- Adjust PeDistance (+/-)

With initial draft stage established*

- Forward (F) [Stage 2]
- Select Eject Plan (W)
- Refine variables monitoring Edmunds

Second stage established**

With plan Established***

- Back to Stage 1 (R)
- View to Maneuver (W)
- Create Maneuver

Right Window

- View to Setup [Stage 1]
- Graph to Focus (+/-)
- Orbit to Icept 0.5 (+/-)
- Select Escape (+/-)
- Forward (F) [Stage 2]
- View to Setup (W)
- Orbit to Icept 0.5 (+/-)
- Graph to Focus (+/-)
- Select Edmunds (+/-)
- View to Eject Plan (W)
- Adjust variables as required
- Forward (F) [Stage 3]
- View to Encounter (W)

Initial draft stage established *

With second stage established**

- Back to Stage 2 (R)
- View to Encounter (W)

Plan Established*

Acknowledgements

The Endurance Space Exploration System was inspired by Christopher Nolan's 2014 film, *Interstellar*. Like our other endeavors, this project could not have succeeded without the generous help of others in our Orbiter community. We acknowledge; Anroalh12, for allowing us to use his model of the Gargantua-Pantagruel system (contained in his *Interstellar System* add-on), Face, for his troubleshooting and coding support, GLS, for his coding help and assistance in solving Endurances' cargo pod rendering issues, grid4dante, for his help troubleshooting and for helping us try to create a functional transport (wormhole) that accepts attached vessels (alas to no avail), Lisias, for his work modeling the Endurance, Lander, and Ranger cockpits and interior points of view, Marcogavazzeni, for his help simplifying our ship's meshes, olrik jhor, for his texture of Gargantua, and Urwumpe, for his assistance as an overall troubleshooter. Gattispilot started this project over two and a half years ago. We've reached this point through an international collaboration and extend our thanks to all who contributed to bringing these ships and these worlds to the Orbiter community.

Orbiter is the platform that has allowed us to visualize these vessels and glimpse a unique star system in a galaxy far, far, away. For this, we thank Dr. Martin Schweiger.

Gattispilot

BenSisko

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