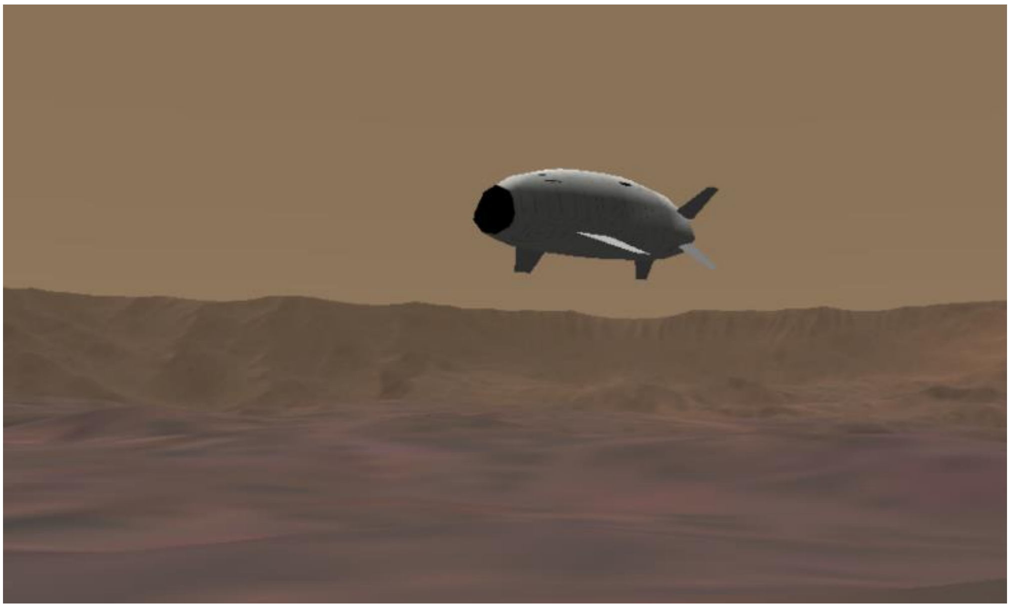
Hybrid Airship for Orbiter

Developed by markp and boogabooga



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Special note: Press 0 on the main keyboard to launch the airship after loading the scenario. This activates the buoyancy force on the airship and sets the airship to the correct mass. To 'secure' the airship to the surface press 3. This removes the buoyancy force and sets the mass to a low amount. In Orbiter 2016 this works quite well but in Orbiter 2024 it doesn't work. It's also possible to secure the airship using the scenario editor.

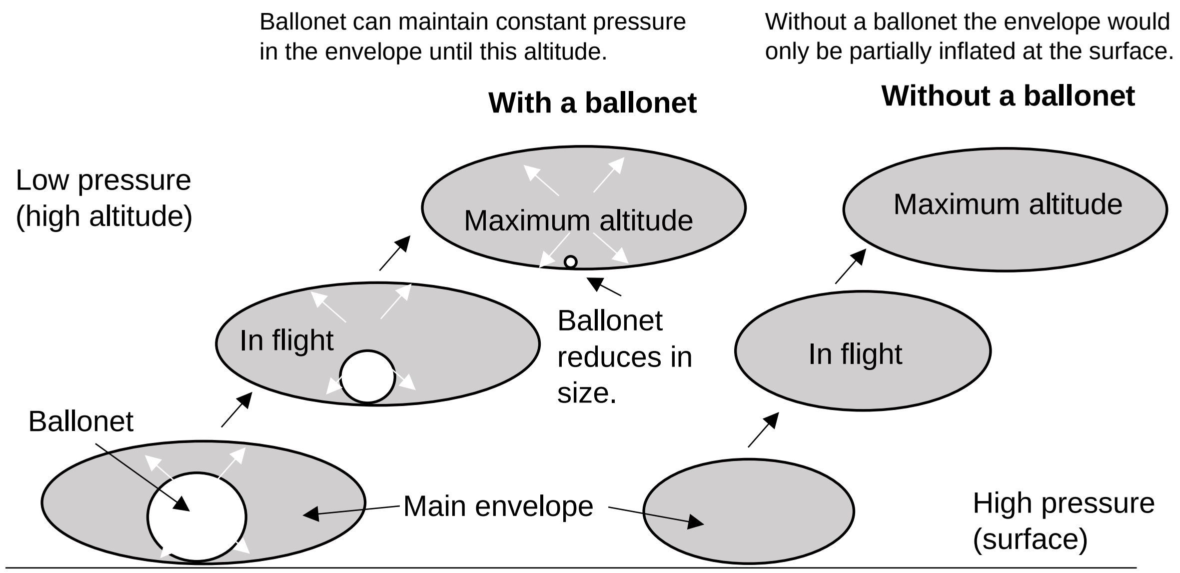
1. Introduction

A hybrid airship is a heavier-than-air aircraft that obtains part of its lift from a lighter than air gas, such as helium in this case, and partly from aerodynamic lift. This hybrid airship addon was partly inspired by a scene in the short film Wanderers, where what appears to be an airship with wings approaches a group of people waiting on the surface of Mars. The addon is also inspired by recent developments of hybrid airships for passenger and cargo transport such as with Airlander 10 and Aeroscraft.

One of the main motivations for the addon, apart from making something that looks cool, was to determine whether large hybrid airships are practical for Mars. The atmosphere on Mars is very thin, requiring a large amount of lifting gas that may be difficult to obtain. In addition, the envelope would have to be very large possibly making it difficult to manage due to winds and risks of damage. Some effort has been made to test the applicability of hybrid airships in extreme environments on Earth such as the Antarctic and to investigate operational procedures such as the transport of cargo. The addon has been tailored for conducting some simple experiments in Orbiter to test different configurations of the airships to gain a first order understanding of the issues for operating a hybrid airship in different atmospheres of the Solar System.

The addon includes a physical model of an airship ballonet system, developed by boogabooga, and adds some realism to the addon. In a real airship the ballonet system helps maintain structural integrity of the envelope by keeping the pressure difference between the lifting gas and the outside air at a constant overpressure, i.e. the lifting gas is pushing outwards keeping the envelope taut. An interesting aspect of the ballonet system, that boogabooga noticed while developing his model, also helps maintain constant buoyancy with altitude. This simplifies the handling of the airship.

The figure below shows the basic principles of the ballonet system for maintaining the shape of the airship as it changes altitude. This is particularly important for a hybrid airship because it obtains lift from the envelope's shape. Above the maximum altitude, or pressure ceiling, the airship is at risk of rupturing because the pressure difference between the inside and outside gases will increase with altitude. In an emergency, to prevent this from occurring the airship can vent some lifting gas to the atmosphere. Of course, this means the airship may lose some buoyancy, lose structural integrity and experience a hard landing.



Basic operation of a ballonet.

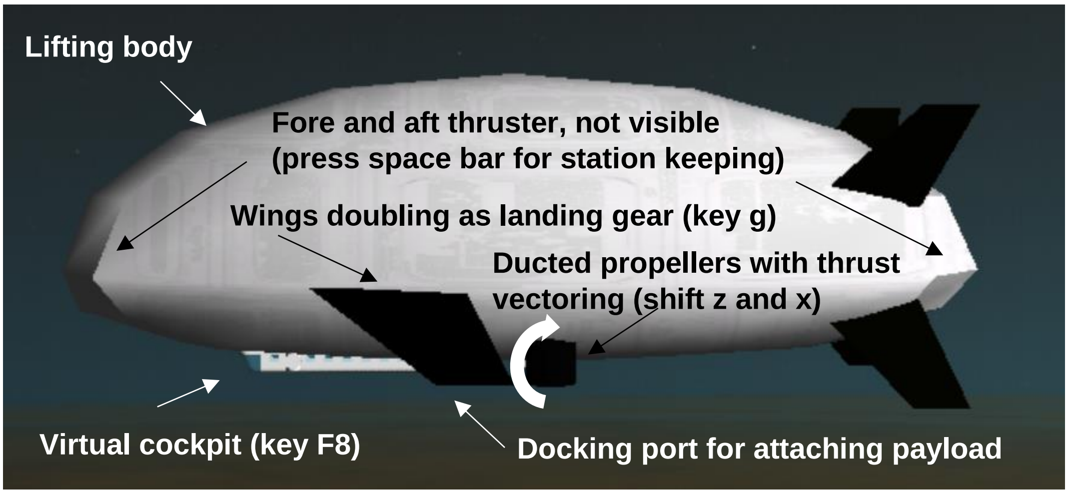
2. Features

The airship features a lifting body formed by its envelope that acts like a giant wing. The side wings add some more lift. The wings on this airship can rotate and act as landing gear. Located at the front and rear of the airship there are small thrusters that help maintain attitude and position. In the middle of the airship are ducted propellers that can be rotated to vector the thrust. The airship also features a virtual cockpit.

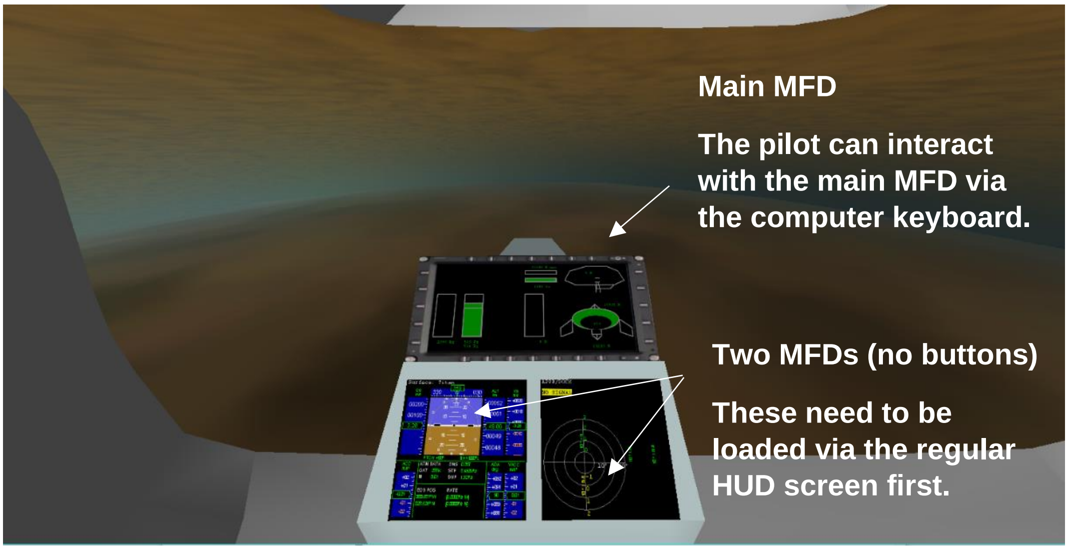
A list of some of the airship’s features.

- Ability to lift and move cargo using Orbiter’s docking port feature
- Configurable, i.e. thrust, ballast, ceiling altitude
- Sideways thrusters available for docking
- Rotating hover engines
- Local wind gusts can be added in the scenario file
- Autopilot for horizontal station keeping
- Engine thrust decreases with decreasing atmospheric density
- Realistic buoyancy system using a ballonet
- Virtual cockpit
- Automated airship sizing

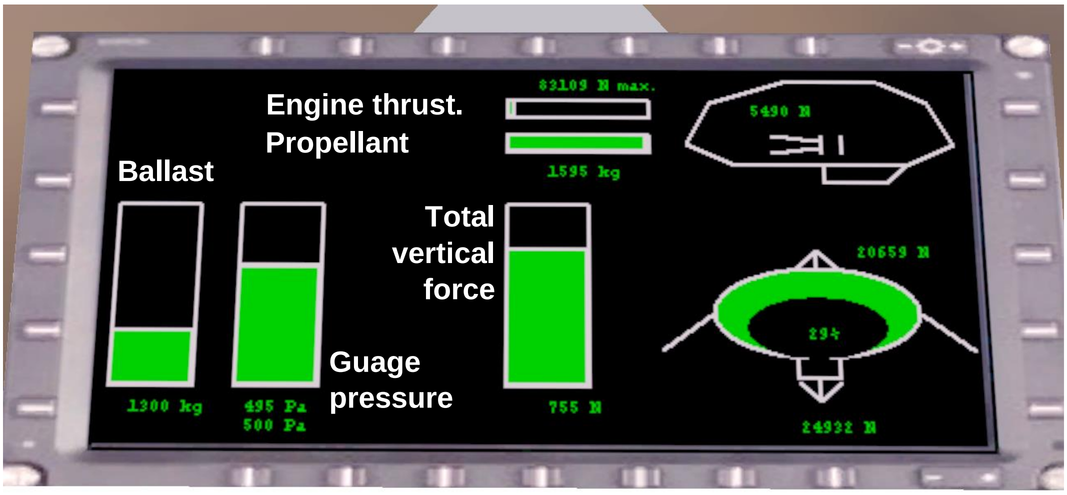
View of the airship in flight on Titan



View from inside the airship



Main MFD (F8 for VC and then SHIFT-a for airship MFD page)



3. Controls

The airship is neutrally buoyant without any modifications, i.e. without ballast or payload added. This means that without any propulsion it will remain floating in the air, neither sinking nor rising. Although there may be slow changes in altitude because the forces are not perfectly balanced.

Normally, a hybrid airship, like Airlander 10, is heavier than air because it uses an aerodynamic lift to stay airborne. Being heavier than air also allows the airship to land like an airplane, i.e. without using a mooring mast. In Orbiter the airship can be made heavier-than-air by adding ballast (key 1 then SHIFT-1 or SHIFT-2), carrying a payload or configuring the static lift in the scenario file. . The airship can be made heavier than air in the scenario file by using the keyword HEAVY followed by a mass value.

For propulsion, the airship is fitted with two ducted propellors, one on each side of the airship. These can be rotated in any direction within a vertical place. This means the thrust of the engines can be directed to propel the airship upwards (key q), downwards, forwards (CTRL-o), backwards and any direction in between (SHIFT-z and SHIFT-x). In addition, the airship includes sets of small thrusters at the front and rear (not visible in the model) for fine tuning of maneuvers. These are operated in the same manner as linear thrusters are normally used in Orbiter.

The altitude can be varied, while hovering over a specific location, by applying thrust (numpad '0' or '.') when the engines are orientated vertically. To move forward the engines need to be orientated horizontally (key q) and then thrust applied. Once in motion the altitude can be varied by either raising or lowering the nose like with a regular airplane. This is possible because aerodynamic lift is generated by the airship's shape. The altitude can also be controlled by changing the weight of the airship, i.e. by adding or dropping ballast, or in an extreme situation, venting the lifting gas.

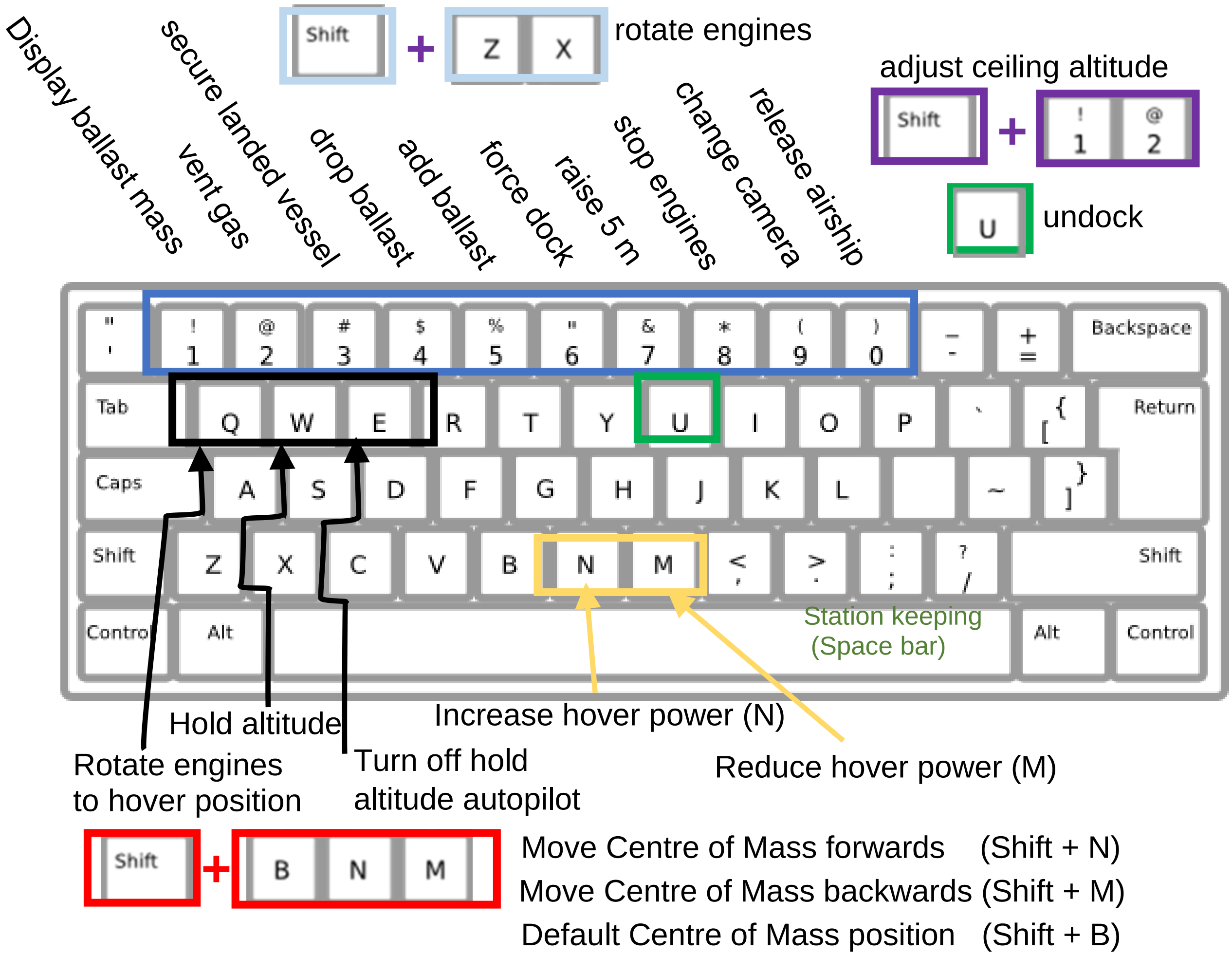
For landing the airship uses its wings, rotated vertically, together with its back fins as a landing gear. When the wings are rotated vertically (key g), they provide a large drag area which slows down the airship significantly. This is useful for preparing the airship for landing but can cause significant control problems if activated in mid-flight.

Orbiter's hover engine keys (numpad '0' and '.') control the airship's main engine thrust. This allows the use of Orbiter's hold altitude autopilot (key a) when the engine thrust is in the vertical position (key q). To move forward the engines need to be level (CTRL-o . However, the airship may start to sink if it is carrying a payload. To counter this the engines can be orientated diagonally so a component of the thrust is downwards and backwards (key o), i.e. force is in the upwards and forwards direction. If Orbiter's hold altitude autopilot is still active it will adjust the thrust, so the airship maintains its altitude.

Before taking off press '0' for flight mode. When on the surface press '3' to secure the airship to the surface.

3.1 Keyboard

The hybrid airship requires many controls to manage the multitude of systems that include rotating engines, buoyancy management and aerodynamic control surfaces. In addition, there are station keeping thrusters and payload systems to manage. The controls for these systems are spread over the computer keyboard in a somewhat haphazard manner, systems being assigned to keys in sequence of their development. Once familiar with the keys only a handful of frequently used keys are likely needed for regular flying around.



3.2 List of keys

// 0 Release airship from surface
// 1 Displays ballast mass
// 2 Vent lifting gas
// 3 Secure the airship on the surface
// 4 Replace vented lifting gas
// 5 Set ballast mass to default as set in the scenario file
// 6 Grab and dock with closest payload
// 7 Raise and lower airship mesh
// 8 Switch off all main engines
// 9 Change camera view
// q Rotate thrust direction up
// m Reduce engine thrust level
// n Increase engine thrust level
// u Undock
// o Rotate thrust direction to up and backwards

// SPACE activate or deactivate targeting autopilot

// SHIFT 1 Decrease ballast by 10 kg
// SHIFT 2 Increase ballast by 10 kg
// SHIFT c Press multiple times to change ballast increase of decrease
// SHIFT 3 Decrease thrust direction by five degrees
// SHIFT 4 Increase thrust direction by five degrees
// SHIFT 5 Toggles gusts on and off (if set in the scenario file)
// SHIFT 6 Thrust northwards
// SHIFT 7 Thrust westwards
// SHIFT 8 Thrust southwards
// SHIFT 9 Thrust eastwards
// SHIFT n Move back buoyancy force
// SHIFT m Move forward buoyancy force
// SHIFT b Move buoyancy force to centre of mass
// SHIFT o Thrust vector up and forward
// SHIFT z Reduce thrust angle by one degree
// SHIFT x Increase thrust angle by one degree
// SHIFT c Set the ballast amount to add or remove
// SHIFT k Display airship properties
// SHIFT a Display graphical representation of airship status

// CTRL k Display predicted pressure ceiling altitude
// CTRL k Display envelope length (same key as above)
// CTRL a Display system information on big MFD in the VC
// CTRL 1 Move camera left
// CTRL 2 Move camera right
// CTRL 3 Move camera down
// CTRL 4 Move camera up
// CTRL 5 Move camera back
// CTRL 6 Move camera forward
// CTRL 7 Camera grid size
// CTRL 8 Search down list of targets
// CTRL 9 Search up list of targets
// CTRL 0 Chose either vessel or base
// CTRL o Full forward thrust
// CTRL SPACE brake and hold airship in position (horizontal plane only)

4. Setting up scenarios

4.1 Scenario file

The scenario files can be found in the “Hybrid airship” folder in the “Scenarios” folder. They can be opened with a text editor, e.g. notepad.

```
BEGIN_SHIPS
docking_practice:airship_mars
  STATUS Orbiting Earth
  RPOS -5211454.694 3205003.006 1779731.300
  RVEL -26.1027 151.2420 -348.8021
  AROT 39.018 -33.105 -77.588
  RCSMODE 2
  AFCMODE 7
  PRPLEVEL 0:0.994425
  THLEVEL 5:1.000000 6:1.000000 10:0.169103
  IDS 0:10 100
  NAVFREQ 491 11 0 0
  XPDR 479
  INFLIGHT
  SURFACEREF
  BALLAST 1000
  DROPPED 0
  CEILING 3000.000000
  AIRSHIP MARS
  PAYLOAD 0
  HORSEPOWER 2000
  VERTICAL
  HOLDALT
  STOP
END
```

INFLIGHT	Indicates the airship starts in flight. This keyword is not required if landed.
SURFACEREF	Reference altitude keyword for calculating airship properties.
BALLAST 1000	Default ballast mass in kg. Useful for heavy cargo transport operations.
DROPPED 0	Amount of ballast jettisoned.
CEILING 3000.000000	Pressure ceiling altitude in metres related to airship design.
AIRSHIP MARS	Indicates which airship mesh to use,
PAYLOAD 0	Can be used to account for payload mass if attached.
HORSEPOWER 2000	Power of the main engines in horsepower. Thrust (N) = 40 x hp.
VERTICAL	Direction preset for the main engine.
HOLDALT	Activate Orbiter's hold altitude autopilot.
STOP	Activate airship's horizontal station keeping autopilot.

4.2 Scenario key words

A description of keywords used to specify the properties of the airship. A ‘n’ after the keyword means a number is required. In all cases here an integer is used.

CEILING n

As the airship ascends higher into the atmosphere the pressure from the air outside, pressing down on the ship’s envelope decreases. The pressure from the gas inside the envelope pushes with greater force on the envelope as there is less outside air to push back. This causes tension in the envelope’s skin. At a certain altitude the envelope will rupture causing the lifting gas to escape and cause the airship to return to the surface. The ceiling, or pressure ceiling as it is commonly known, is the altitude where this rupture would happen. To be on the safe side this pressure ceiling is normally specified at a lower altitude than the actual rupture point to allow for an error in knowing the envelope strength or uncertainties in navigation when flying. Typically, the pressure ceiling is around 3000 m for airships. See, eaglepubs.erau.edu/introductiontoaerospaceflightvehicles/chapter/lth/

BALLAST n

This is the airship’s default ballast capacity or the maximum ballast the airship can carry. An airship might be limited due to space to hold sand or water as ballast.

Normally the airship has neutral buoyancy. This means that the buoyancy force balances its weight, so it floats in the air. Ballast is mass that can be added to the airship to make it heavier than air. This might be if you want to be sure the airships stay on the surface, or you want a backup in case you accidentally fly above the pressure ceiling and vent some lifting gas. In that second case the ballast can be dropped to maintain neutral buoyancy.

Another purpose for ballast is to help manage the transport of heavy cargo. If your airship is lighter than air and has significant static lift, to help if carry cargo, then you might want some ballast to prevent the airship shooting up into the air if the airship is released without any cargo. Once the cargo is attached to the airship the ballast can be dropped allowing the airship to use its static lift to carry the cargo. Once the airship arrives at its destination ballast can be reloaded to rebalance the airship in preparation for releasing the cargo. Ballast might be sand of water but in Orbiter the ballast can be controlled in game from the cockpit.

DROPPED n

This is the amount of ballast that has been discarded. The remaining ballast is then the default ballast specified using the BALLAST keyword above minus the dropped ballast specified here.

INFLIGHT

A keyword to indicate that the airship is in the air. If the keyword is present, then the airship properties are set for flight. If the keyword is absent, then this means the airship is landed and its properties are set so it remains on the surface. This is a workaround to try and address a bug in Orbiter where landed vehicles sometimes do not remain stable on the surface. The workaround works by deactivating the buoyancy force and reducing the mass of the airship to a very low level. This then allows the airship to attach to the surface and not move around.

SURFACEREF

If this keyword is present, then the ceiling altitude is relative to the surface altitude.

SEALEVELREF

If this keyword is present, then the ceiling altitude is relative to sea level.

HORSEPOWER

The maximum engine thrust in Newtons is calculated based on the power of the engine in horsepower, $T=40*hp*\rho_z/\rho_0$, where hp is the power. A unit of horsepower is equivalent to about 740 watts (735 for imperial and 745 for metric). The thrust also depends on the air density, ρ_z, and decreases with decreasing air density as ρ_z/ρ_0, where ρ_0 is the air density of air at sea level on Earth. The factor of '40' was derived from flight tests with the airship to obtain a sensible horizontal speed for a given horsepower. The formula is based on one found in Introduction to Aeronautics: A Design Perspective, by Brandt, Stiles, Bertin and Whitford.

AIRSHIP name

Sets the appearance of an airship. There are currently three options, MARS, EARTH1 and EARTH2. The MARS variant is a sand-coloured airship to fit in with the Martian scenery. EARTH1, EARTH2 are airships are light couloured envelopes to fit in with the brighter conditions that may occur on Earth. It works by loading a mesh and texture depending on the specified type.

GUSTS n

Add this to liven things up a bit. There are 4 levels of gust strength from 1 (low) to 4 (high). The wind speed of the gusts, using the highest setting, is about 90 km/h.

PAYLOAD n

If you want your airship to have neutral buoyancy with a payload, of a known mass, attached then the mass of the payload can be included here. The airship addon will calculate the airship properties, taking this mass into account, i.e. the airship will not sink or rise when the payload is attached. It also means that the airship might have a significant static lift, i.e. it might easily shoot upwards when the payload is detached. So, it might be prudent to use some ballast, in conjunction with the payload, to manage the release of any payload. See the description for the BALLAST keyword for more information.

VERTICAL

The default direction of the engine thrust is horizontal. To position the engine ready for a hover takeoff then use this keyword in the scenario.

HOLDALT

Adding this keyword switches on Orbiter's hold altitude autopilot. This might be useful if a scenario includes the airship in some station keeping role, such as preparing to collect a payload.

STOP

Adding this keyword switches on the airship's station keeping autopilot. This keeps the airship from moving horizontally while in the air. It is useful for keeping the airship stationary if other operations need to be completed before taking manual control of the airship, e.g. prepare for payload collection, setting up other vehicles, setting up a camera etc.

DUST

When the airship's engines are close to surface it's possible, they may generate dust clouds. Include this keyword to generate the dust clouds.

STATICLIFT n

The static lift can be set as a percentage of the force acting on the airship due to its weight. Say the airship has a mass of 30000 kg. On Earth the downward force on the airship is 294300 N. Setting the static lift to 50% results in an upward force, due to buoyancy, of 147150 N. This makes the airship heavier than air because the force due to gravity on the airship is higher than the buoyancy force.

HEAVY n

Use this to make the airship heavier than air. For example, setting it to HEAVY 2000 will give the airship an effective weight of 2000 kg.

5. Airship mass and size

The airship mass and size are calculated in Orbiter airship model at the start of a scenario. The calculation is based on the pressure ceiling specified in the scenario file. To find a solution for the mass and size the radius of the envelope is incremented by 1 mm until the mass displaced by the airship at the pressure ceiling equals the total mass of the airship. In the calculation the envelope is assumed to be a sphere.

The masses for different components of the airship are as follows. The gondola, engines and aerodynamic surface of masses of 2000, 4000 and 2000 kg respectively. The total mass of the airship solid structures is then 8000 kg. The fuel mass is set to 1600 kg.

The lifting gas mass is the volume of the envelope multiplied by the gas (helium) density. The mass of the envelope is the surface area of the envelope multiplied by the areal density. The areal density is set to 0.2 kg/m3 which might be a little higher than for a typical blimp. The mass of a spherical envelope with a radius of 30 m would be about 2300 kg.

At the pressure ceiling the ballonet is assumed to be completely deflated. Hower the mass of the ballonet can be included in the calculations by calculating the mass for the expanded ballonet when on the surface. The maximum volume fraction of the ballonet is assumed to be some percentage (was 30% recently increased to 60% to reproduced Airlander 10 performance) volume of the main envelope. If we assume the same areal density as the envelope for the ballonet then the mass of the ballonet turns out to be about 1000 kg (for 30% ballonet). To find a solution for the mass and size the radius of the envelope is incremented by 1 mm until the mass displaced by the airship at the pressure ceiling equals the total mass of the airship. Typical masses for airships used on Earth, including lifting gas (about 2000 kg), might range between 15000 and 20000 kg.

The maximum size of the mesh size in Orbiter is limited to about 500 m due to problems keeping the meshes of the gondola and aerodynamic surface lined up with the envelope mesh.

Press SHIFT-k to see the masses of the different airship components. Press CTRL-k to see the length of the airship. The length is calculated by assuming the airship is an ellipsoid with dimensions like Airlander 10.

On Earth an airship will be around 75-85 m in length. On Mars an airship might be 300 m in length.

Acknowledgements

The addon was partly inspired by the airship depicted in the short film Wanderers.
https://www.youtube.com/watch?v=YH3c1QZzRK4

The addon was also inspired by the Airlander 10 project.
https://www.hybridairvehicles.com/airlander/airlander-10/

Meshes, textures and code by markp, physically based model of the airship by boogabooga with the development helped along by advice from Urwumpe.
https://www.orbiter-forum.com/showthread.php?t=39520