Archimedes

Jupiter balloon mission
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For the Orbiter Space Flight Simulator
www.orbitersim.com

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1. Introduction

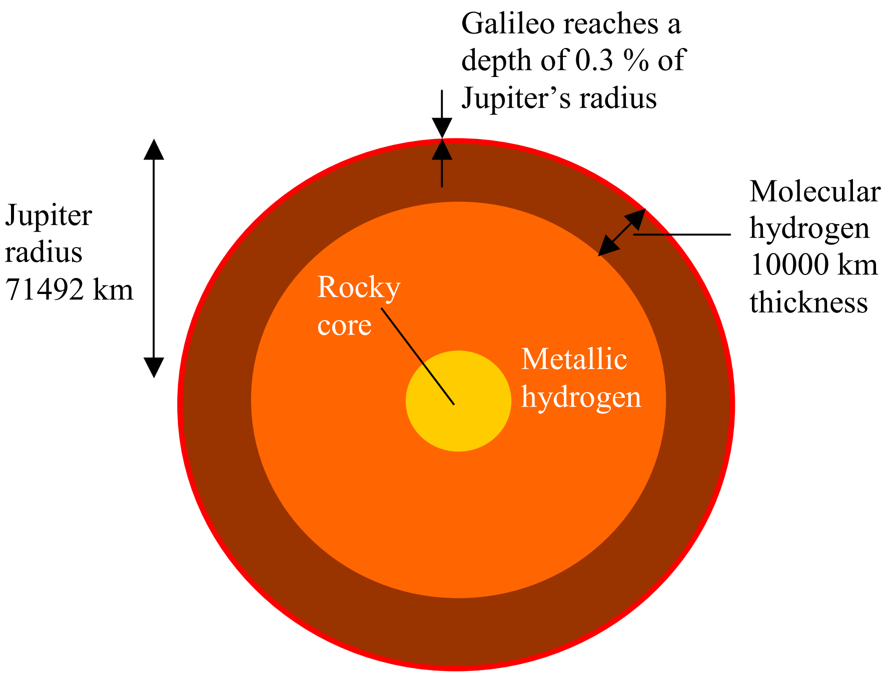
The Archimedes mission is a fictional mission ‘cooked up’ from ideas and comments posted on the Orbiter Web Forum. Present and near-future robotic space exploration capabilities have been used to create the probe and to make the mission as realistic as possible. Scenarios are included that follow the mission from Earth orbit to Jupiter.

2. Background on the robotic exploration of Jupiter's atmosphere

The first and so far only insertion of a spacecraft into Jupiter's atmosphere was that of the Galileo atmospheric probe on 7th December 1995. The Galileo probe descended by parachute to a depth of nearly 160 km (below 1 bar) into Jupiter's atmosphere making a variety of scientific measurements of its environment – but no photographs. Transmission to the Orbiter stopped after pressures of up to 22 bars and a temperature of 388 K (153°C) had been reached. This was not due to an impact with Jupiter's surface but failure due to the extreme environment of Jupiter's lower atmosphere.

As the surface of Jupiter has not been seen and is theoretically thought not to exist a virtual surface can be defined at a point in Jupiter's atmosphere where the pressure is equal to that of the Earth's surface (1 bar). The deeper you go below the higher the pressure due to the mass of atmosphere pressing down from above. At a great enough depth, maybe a few thousand kilometres, the pressure becomes so great that the atmosphere behaves like a liquid.

At a depth of about 10000 km the molecular hydrogen in the atmosphere is compacted so much that bonds between atoms are broken and electrons are freed. The hydrogen then behaves as a liquid metal. At the boundary between molecular hydrogen and metallic hydrogen the temperature is about 6000°C and the pressure is about a million times that on the surface of the Earth.



Jupiter's interior

The Galileo orbiter was in contact with the probe for just over 1 hour. Due to a permanent fault with the high-gain antenna the transmission of the atmospheric probe data had to be transmitted via the low gain antenna that took several months. In 2003 the Galileo orbiter finally followed the atmospheric probe into Jupiter's atmosphere. This was in part to protect any life on Europa from being contaminated by material on Galileo. As the orbiter did not have the probe's 130 kg heat shield it was destroyed by impact with the atmosphere.

The Jupiter Icy Moon Orbiter may follow up the Galileo orbiter mission. There is currently no mission to follow up the Galileo atmospheric probe to study the atmosphere of Jupiter.

3. The Archimedes Balloon probe

The mission uses a 32 metre balloon to prevent the probe falling, like the Galileo probe, into the destructive high pressures and temperatures of Jupiter's interior. The balloon can suspend a payload in Jupiter's atmosphere by making the probe plus balloon less dense than the surrounding atmosphere it has displaced. As the craft is then 'lighter-than-air' a pressure gradient will produce an upward force on the vessel. The balloon uses hydrogen to lighten the probe. Hydrogen is used because Jupiter's atmosphere is 90% hydrogen and 10 % Helium. If Helium was used the probe would sink as it would be heavier than the atmosphere it had displaced.

Archimedes used the displacement of a liquid to find the true composition of a gold crown for his King during the times of the ancient Geeks. Knowing the weight of an equal volume of solid gold Archimedes was able to determine that the crown was not made of solid gold. The weight of the crown should have equalled the weight of an equal volume of solid gold. This is from the well known 'Eureka' event that Archimedes is supposed to of had in his bath The story was recorded by a Roman Architect living 200 years after Archimedes. The concept of buoyancy is encapsulated in the following statement known as Archimedes's principle. It states:

An object partially or wholly immersed in a fluid is acted upon by an upward buoyant force equal to the weight of the fluid it displaces.

When considering the forces acting on an object immersed in a fluid (atmosphere) an equation can be derived that shows the lifting force is dependent on the difference in density, the volume and the acceleration due to gravity.

$$F_{net} = F_{buoyancy} - F_{gravity} = \rho_{fluid} V_{fluid} g - \rho_{object} V_{object} g$$

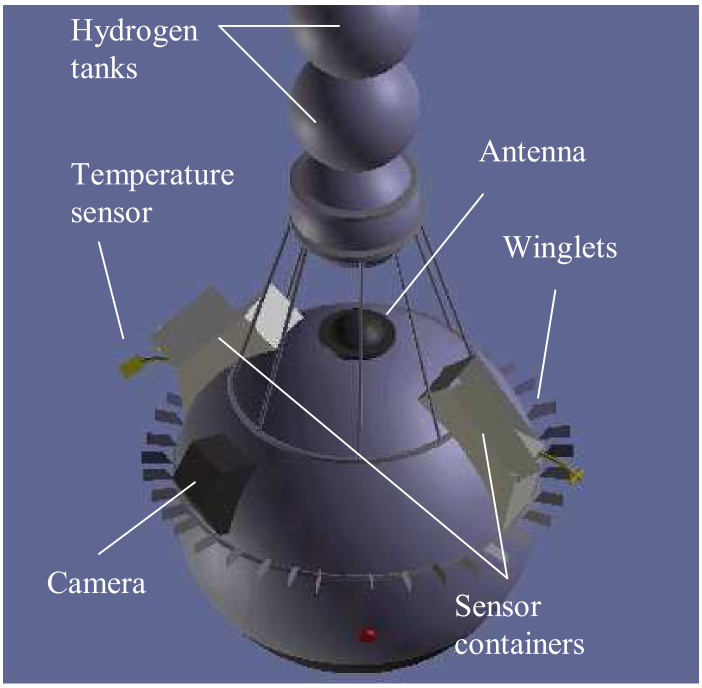
If the object if fully immersed in the fluid then $V_{fluid}=V_{object}$. It is possible that Archimedes detected the composition of the King's crown by using his theory of buoyancy. Two objects of equal masses but of different densities (or composition) will experience different amounts of up thrust when immersed in water. This is because they will have different volumes and so displace different masses of water.

On Earth the atmosphere is composed mostly of molecular Nitrogen that has an atomic mass of 28 amu (atomic mass units). The perfect gas equation says (with some mathematical arrangement) that the density is directly proportional to the pressure and atomic mass and is inversely proportional to the temperature. So a gas at the same pressure and density but at a different atomic mass will have a lower density. This is why hydrogen was the preferred choice for early balloon pioneers. It has an atomic mass of only 2 amu.

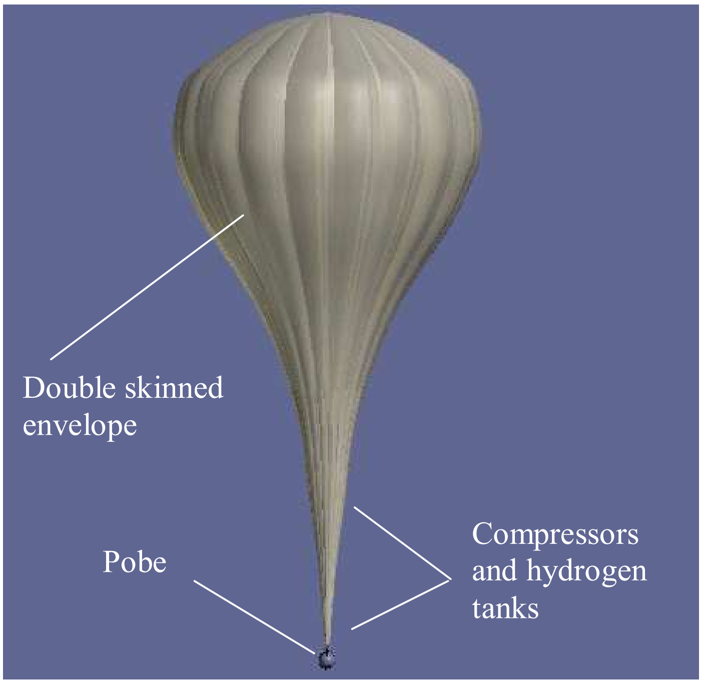
On Jupiter the atmosphere is mostly made of Hydrogen so it may appear that a hydrogen balloon would require, according to the equation for buoyancy, a large volume. A balloon on Jupiter has the advantage of a large gravitational acceleration that is 2.5 times of Earth's. This will reduce the required volume of the balloon by 2.5 times of a balloon floating in a Hydrogen atmosphere on Earth.

The probe can perform controlled descent and ascents by varying the amount of Hydrogen gas in its balloon. Compression pumps transfer the Hydrogen gas into high-pressure tanks located in the neck of the balloon. As the hydrogen gas is compressed its density increases so eventually the probe will become heavier than air and sink. To rise again the hydrogen is released from the tanks to make the balloon buoyant. During descent the balloon envelope's shape is maintained by filling a second cavity with the native atmosphere of Jupiter. When the hydrogen is released then Jupiter air is squeezed out.

The ability of the probe to move up and down vertically allows the probe to catch winds that may take it to different latitudes on the planet. This method is used by balloon navigators on Earth to add some degree of control over their flight path. In 1999 the Breitling Orbiter 3 balloon was successfully piloted around the Earth, taking about 20 days. Use was made of high velocity winds, blowing from west to east that exists at high altitudes. Jupiter has winds of 180 m/s as measured by tracking the Galileo atmospheric probe. On Earth the jet streams can reach in excess of 100 m/s.



The atmospheric probe



The balloon

Statistics

Balloon

Radius at 1 bar 15.9 m
Envelope mass 54 kg
Hydrogen mass 2441 kg
Displaced atmosphere mass at 1 bar 2694 kg

PSA Hydrogen extraction plant

Mass 100 kg (ejected before balloon inflation)

Atmospheric probe

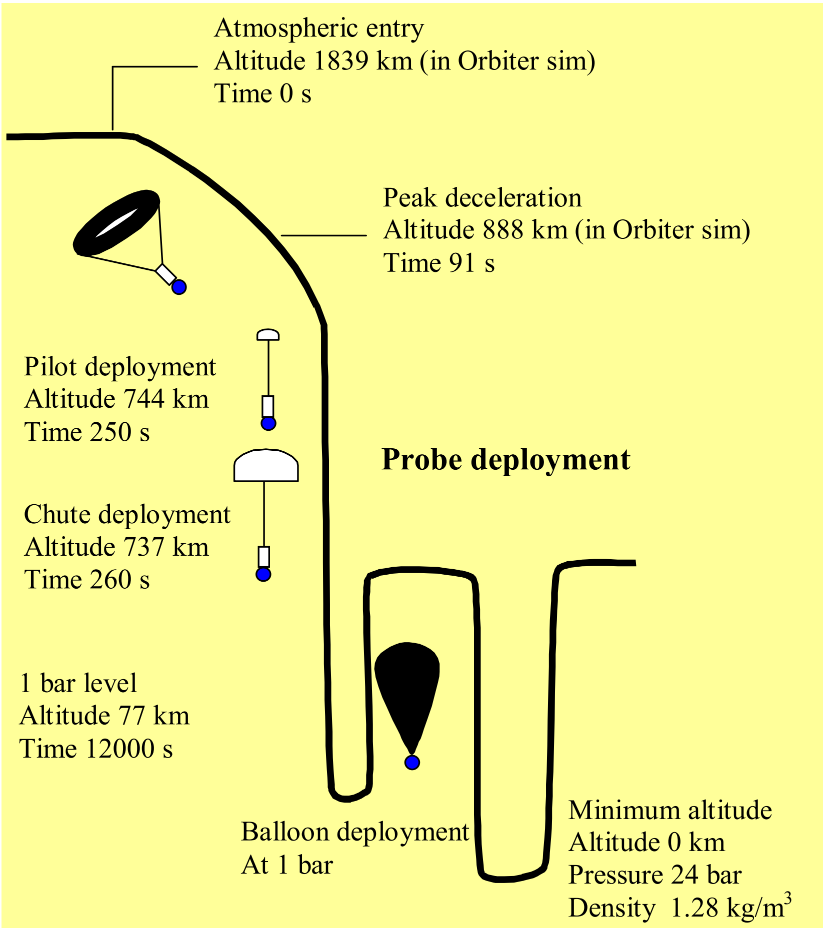
Radius 0.75 m
Mass 200 kg

Ballute

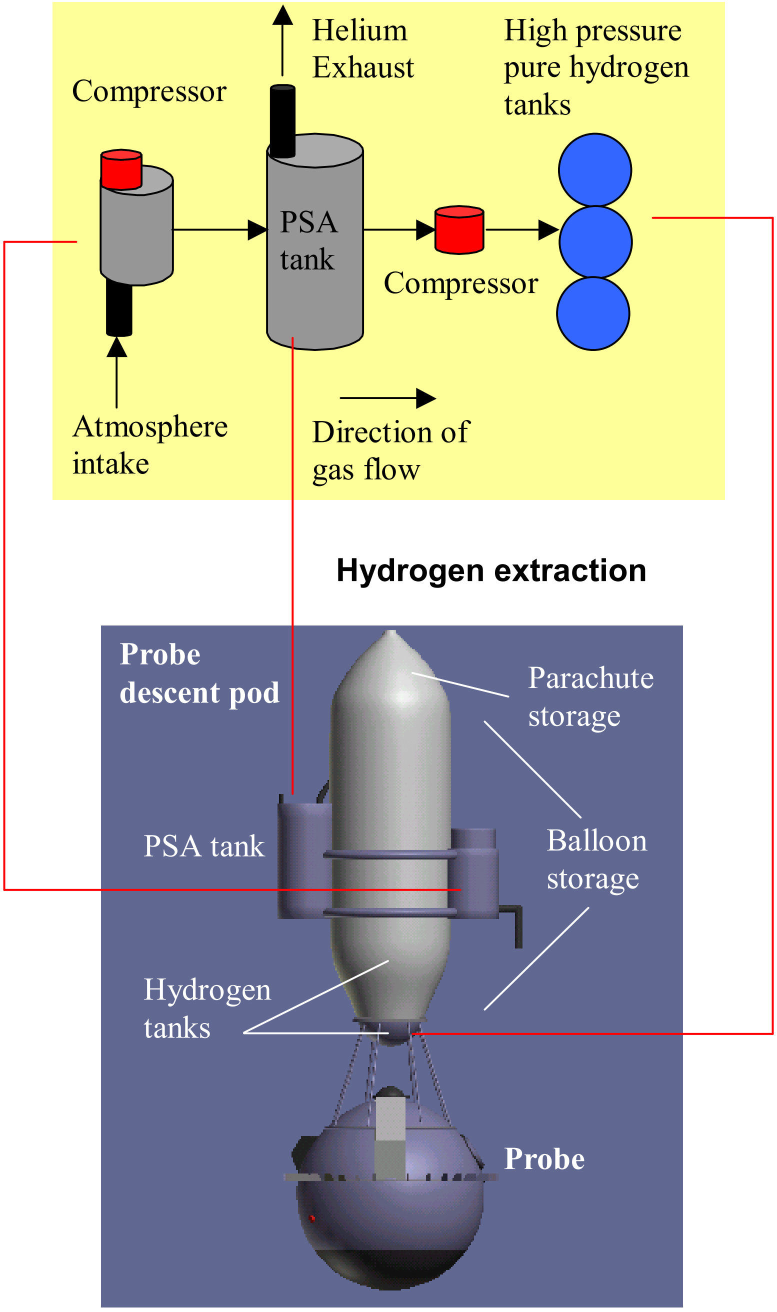
Radius 36 m
Envelope mass 240 kg
Ballute hydrogen 130 kg

4. Probe deployment

The probe uses a ballute to decelerate in Jupiter's atmosphere. A ballute is an inflatable device that provides a large drag area. A ballute can be deployed in the vacuum of space unlike a parachute that requires dynamic pressure for inflation. Therefore it is able to use its large surface area high up in the atmosphere where the drag forces will be lower. A small surface area decelerator such as a conventional heat shield has to wait until the atmosphere is thick enough to slow it down. Due to the small size of the heat shield the kinetic energy that goes into compression of the atmosphere during entry has to be dissipated over a smaller surface area leading to higher localised heating. A heat shield prevents its payload from heating up by carrying the heat away by radiation, like the space shuttle, or ablation, like the Galileo atmospheric probe. For a ballute the payload requires no heat shield, as the temperature rise will be small.



A ballute only retains its shape high up in the atmosphere because of its low internal pressure. Deep in Jupiter's atmosphere the high external pressures will deform the ballute making it aerodynamically unstable. After the peak deceleration the ballute has to be discarded. A large descent parachute is deployed to take its place. The parachute has to be deployed while the trajectory contains some horizontal component so the ballute does not fall onto the probe's parachute later on in the descent. After separation of the ballute a pilot chute is used to stabilise the probe. The pilot chute then pulls out the large main descent parachute ten seconds later. The main descent parachute is 16 metres in diameter and slows the descent so the probe has time to extract the balloon hydrogen gas from Jupiter's atmosphere. The probe uses a form of pressure swing absorption (PSA) to extract hydrogen from the atmosphere. PSA extraction uses the capacity of certain materials to absorb and release gases. The probe has a compressor that can alternately subject its PSA material too high and low pressures. The PSA material absorbs Helium under high pressure then releases it under low pressure. During the high-pressure phase of the PSA cycle the pure hydrogen is pumped into high-pressure storage tanks situated inside the balloon envelope by another compressor. Modern PSA techniques can perform up to one cycle every 2 minutes. The PSA production unit on the balloon has a capacity to produce 15 kg of hydrogen every cycle. To produce 2000 kg of hydrogen for the balloon takes about 2 hours.



Hydrogen extraction

Once the hydrogen has been safely stored in the tanks, the mini-hydrogen production plant can be dropped from the probe. The balloon can then be deployed from the descent pod. The hydrogen storage tanks are placed inside the neck of the balloon so the hydrogen can be removed directly from the balloon during a controlled descent.

5. Scenarios

1. Earth orbit

The Jupiter Balloon Probe Archimedes has been delivered into orbit by a delta 4 rocket from Canaveral. The probe is attached to an interplanetary booster that can send the probe on a trajectory directly to Jupiter from Earth orbit. Press j to eject the probe from the booster.

2. Jupiter Arrival

The orbiter and atmospheric probe arrive separately at Jupiter. The probe is on a collision course with Jupiter's atmosphere. To safely decelerate the probe deploys a ballute by pressing j at an altitude of about 2000 km. Once the ballute has slowed the probe down to about 600 m/s then release the ballute and deploy a small pilot chute by pressing j. After 10 seconds deploy the main parachute by pressing j. This will slow the probe down while hydrogen is being extracted from Jupiter's atmosphere. After 4 hours deploy the balloon. To descend again pump the hydrogen into tanks by pressing j. Ascend again by pressing j.

3. Atmospheric entry

Atmospheric probe enters the atmosphere of Jupiter. At an altitude of about 2000 km deploy a ballute by pressing j. At an altitude of 744 km deploy pilot chute. Ten seconds later deploy the main parachute by pressing j. At an altitude of 77 km deploy the balloon by pressing j. To descend by pressing j again. To ascend press j again.

4. One bar level

The altitude has been reached where the balloon can be deployed. Press j to deploy the balloon. Press j to descend. Press j again to ascend.

6. Installation

Unzip the files into you orbiter file. You need to edit your Jupiter.cfg file and to include the following lines. These lines go under the heading of ‘Atmospheric Parameters’. Jupiter.cfg is situated in the ‘Config’ folder and can be edited using notepad.

AtmPressure0 = 2400000
AtmDensity0 = 1.28

If you don't have any atmospheric parameters then you can enter the following lines at the end of your Jupiter.cfg file

; === Atmospheric Parameters ===
AtmPressure0 = 2400000
AtmDensity0 = 1.28
AtmGasConstant = 194.92
AtmGamma = 1.3333
AtmAltLimit = 4200e3
;AtmHorizonAlt = 200000

I strongly recommend getting Rolf's outer planets add-on if you haven't got it yet. You get some great clouds and surface textures to make flying around in Orbiter more realistic.
http://www.geocities.com/fastheinz39/Saturns_Moons.html

IMPORTANT

To activate the buoyancy module you need to go to the Module tab on the Orbiter Launch Pad. Then select 'buoyancy' and press the 'Activate selected' button.

Files required to run this add-on :

Config\Spacecraft\Rukh_1.ini
Config\Spacecraft\Arch_boost.ini
Config\Spacecraft\Arch_descent.ini
Config\Spacecraft\Arch_ascent.ini
Config\Spacecraft\Arch_balloon.ini
Config\Spacecraft\Arch_chute.ini
Config\Spacecraft\Arch_ballute.ini
Config\Spacecraft\Arch_cruise.ini
Config\Spacecraft\Arch_probe.ini
Config\Spacecraft\Arch_pilot.ini
Config\Arch_boost.cfg

Meshes\Archimedes_C.msh
Meshes\Archimedes_B.msh
Meshes\Archimedes_0.msh
Meshes\Archimedes_1.msh
Meshes\Archimedes_2.msh
Meshes\Archimedes_3.msh
Meshes\Archimedes_4.msh
Meshes\Archimedes_5.msh
Meshes\Rukh.msh

Modules\Plugin\Buoyancy.dll
Modules\Spacecraft.dll

Scenarios\Archimedes\Arrival at Jupiter.scn

Scenarios\Archimedes\Atmospheric entry.scn
Scenarios\Archimedes\Canaveral.scn
Scenarios\Archimedes\In Earth Orbit.scn
Scenarios\Archimedes\Jupiter Rukh.scn
Scenarios\Archimedes\One bar level.scn

Textures\Rukh_skin.dll

7. Credits

1. The Archimedes mission is based on the 'Zepplins on Jupiter?' message posted by Insane Alien and a selection of subsequent responses. See the post for details.
orbit.m6.net/v2/read.asp?id=21631

2. The buoyancy module is by Cairan. See below for details.

    BUOYANCY DEVELLOPMENT MODULE
    =============================
    Version 0.2a   2005-03-05

    By Remy Villeneuve
    remyv@globetrotter.net

    Blimp mesh freely downloaded
    at http://www.turbosquid.com

    BUOYANCY.DLL compiled with
    Orbiter-SDK 050216
    ----

3. The spacecraft.dll module is by Vinka
    http://users.swing.be/vinka/

4. The meshes were created by myself using anim8or by R. Steven Glanville
    http://www.anim8or.com/
    Meshes were converted using Vinka's 3ds2msh tool
    http://users.swing.be/vinka

8. References

1. The Cambridge Encyclopaedia of Space, 1990, Cambridge University Press
2. Teach yourself the planets, Rothery, D. A, 2000, Hodder Headline Plc
3. The Golden Crown
http://www.mcs.drexel.edu/~crorres/Archimedes/Crown/CrownIntro.html
4. Re-entry heating
http://www.mcrosolv.demon.co.uk/getwrong.html
5. What is PSA?

http://www.questairinc.com/technology/conventional_psa.htm