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A4_5 Harvesting the Gas Giants

David Winkworth, Vlad Tudor, Elliott Shaw

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH.

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Abstract

The four gas giants in the solar system contain more than 80% hydrogen. This report examines the possibility of using this as a fuel source in the future by harvesting it with a spacecraft descending into their atmosphere. It was found that this strategy is feasible for Saturn, Uranus and Neptune, with the possibility of gathering a large amount of hydrogen within minutes.

Introduction

The hydrogen content of the four gas giants in the solar system ranges from 80% for Neptune to 96% for Saturn.[1] This large pool of molecular hydrogen may one day be used for energy production via combustion.

For this to be efficient, the energy spent on harvesting the gas has to be lower than the energy gained from burning it.

The harvesting method proposed is an orbiting streamlined ship which can descend into the upper atmosphere and collect gas through a frontal trapdoor and compress it into tanks for future use.

Discussion:

The chemical formula for hydrogen *H* combusting in oxygen *O* is the following:

$$2H_2 + O_2 \rightarrow 2H_2O + Q, \qquad [1]$$

where *Q* is the released energy and is equal to 286kJ/mol. Therefore, one kilogram of molecular hydrogen can provide up to 143MJ of energy. The following calculations assume that 100% of this can be used by the engines for thrust.

A spaceship descending into the atmosphere of a planet experiences a drag force opposing its movement. The power required to keep it at constant velocity P_{lost} is given by equation 2:

$$P_{lost} = \frac{1}{2}\rho v^3 C_D A, \qquad [2]$$

where ρ is the density of the gas surrounding the spaceship, v is the relative velocity of the spaceship to the gas, C_D is the drag coefficient and A is the reference area of the spaceship.

The potential energy P_{gain} gained from gathering hydrogen is acquired at a rate given by equation 3

$$P_{gain} = \varepsilon \rho v A Q, \qquad [3]$$

where ε is the ratio of hydrogen in the atmosphere. For a net gain in energy, P_{gain} has to be bigger than P_{lost}. Rearranging for v shows

$$v < \sqrt{\frac{2\varepsilon Q}{C_D}}. \qquad [4]$$

The next step is to find an approximate value for C_D. If the trapdoor is considered to be a flat plate that covers all the reference area of the spaceship, then $C_D \approx 1$. Using this value in equation 4 gives a maximum relative velocity of $v_M \approx$ 16,900m/s.

For a spaceship orbiting a planet in the equatorial plane and in the same direction as its axial rotation, the relative velocity is given by equation 5,

$$v_r = v_o - v_{eq} + v_w, \qquad [5]$$

where v_0 is the orbital velocity, v_{eq} is the equatorial rotation velocity of the planet and v_w is the wind speed. A low relative velocity is desirable to reduce energy lost through drag. The wind velocity has a plus sign in consideration of the worst case scenario of wind blowing against the motion of the ship.

In table 1, some properties of the gas giants are displayed, along with the calculated orbital velocity from equation 5, the radius of the orbit of the spaceship corresponding to its orbital velocity and the ratio between the orbital and planetary radii (k).

	Jupiter	Saturn	Uranus	Neptune
v_{eq} km/s	12.6	9.87	2.59	2.68
v_w km/s	0.1	0.5	0.25	0.6
v_o km/s	29.4	26.3	19.2	19
Mass $\times10^{26}$ kg	19.0	5.68	0.87	1.02
Radius $\times10^{6}$ m	71.5	60.3	25.6	24.8
Orbit $\times10^{6}$ m	147	54.8	15.7	18.8
k	2.05	0.91	0.61	0.76
v_{es} km/s	59.5	35.5	21.3	23.5

Table 1. Calculating the minimum k that the ship can achieve with net energy gain considering the planet as a point mass and ε=1 [1],[2],[3],[4].

A value for k around or less than 1 shows that the spaceship can descend into the atmosphere for hydrogen collection. A value higher than 1 as in the case of Jupiter shows that gas can only be harvested from the exosphere. Here, the particle density is very low so it would take a very long time to collect a large amount of fuel. For the other three gas giants it would be best for the spaceship not to descend too low into the atmosphere as its hull might heat up to dangerous levels.

To find the minimum amount of time required to spend in the atmosphere, the energy required to escape the gravitational well of the planet has to be considered. This is expressed in equations 6 and 7,

$$P_{net}t > \Delta E, \qquad [6]$$

$$\Delta E = \frac{1}{2}m(v_e^2 - v_o^2), \qquad [7]$$

where ΔE is the energy required to escape the gravitational well of the planet, m is the mass of the spaceship and v_e is the escape velocity.

As an example, take an orbiter around Uranus at an altitude of 0m, defined as the point where the pressure is 1 bar. Here, the temperature is 75K [1], which gives a gas density of 0.32 kg/m^3 according to the ideal gas law. The relative velocity is calculated to be 12,700m/s using equation 5 and the orbital velocity for this altitude. Using this value in equations 2 and 3 with ε=0.83, the net power gain is found to be equal to 1.5×10^{11} W/m^2, which translates to a gain of hydrogen of 1.05×10^{3}kg s^{-2}m^{-2}. However, equation 7 shows that 1kg of hydrogen needs the energy of 0.3kg of hydrogen to escape the gravitational well of Uranus. Therefore, only 70% of the net gain calculated above can be used for launching the spaceship out of Uranus' well and for storage.

For a spaceship with a mass of 10^8 kg and reference area of 10^3 m^2, the ship would gather enough hydrogen (3×10^7kg) in less than 1 minute at this altitude. Any surplus can be stored for future use.

Conclusion

Harvesting hydrogen from the last three gas giants might prove to be an efficient energy source in the far future. An example spaceship is modelled and found to acquire enough hydrogen within minutes, hence suggesting the technique is viable.

References

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