Journal of Physics Special Topics

P3_2 Power Boating on Jupiter

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October 09, 2013

Abstract

Hydrofoils can be used to provide lift to a boat-like craft and reduce drag. Jupiter has a fluid composition and a large gravitational field; this paper investigates the possibility of using hydrofoils as a source of lift for a craft within its atmosphere. We concluded that the minimum speed required for a successful hydrofoil in this scenario would be 12.2ms^{-1}, provided that the craft was relatively small. This velocity is comparable to similar Earthly vehicles.

Introduction

Aerofoils and hydrofoils are used to provide lift to a vehicle moving through a fluid medium. A hydrofoil on a boat raises the said boat out of the water, drastically reducing its drag. This allows for easier and more efficient travel, a practice often used in power boat racing. Jupiter has a fluid composition and a strong gravitational field; making in situ measurements of its outer layers difficult. This paper investigates whether a craft could use hydrofoils to aid movement around the inside of Jupiter's outer layers, assuming it successfully 'landed'.

Theory

The lift on any aerofoil or hydrofoil is a consequence of a pressure differential on either side of a foil (or wing in aerospace). To calculate this pressure difference we will use the incompressible Bernoulli's equation,

$$\frac{P}{\rho} + gz + \frac{v^2}{2} = const, \qquad (1)$$

where P is pressure, ρ is fluid density, g is the acceleration due to gravity, z is the vertical height and v is the relative fluid velocity. Figure 1 depicts the fluid flow around a typical aerofoil/hydrofoil. The top surface of the aerofoil/hydrofoil is longer than the bottom surface. The ratio of these two lengths is *m:1*.

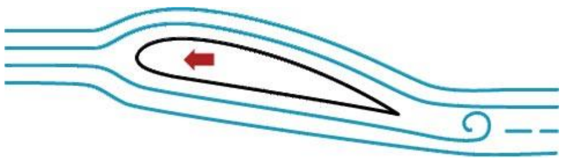

Figure 1 – Fluid flow around a moving aerofoil/hydrofoil. [1]

By considering Bernoulli's equation for the top and bottom of the hydrofoil, and assuming that the height difference is negligible, the following relationship can be established;

$$\frac{P_1}{\rho} + \frac{v^2}{2} = \frac{P_2}{\rho} + \frac{m^2 v^2}{2}, \quad (2)$$

where subscript *1* refers to bottom surface and subscript *2* refers to the top surface. As the top surface is a factor of m longer than the bottom surface, the airflow moves at a rate m faster than the bottom surface to maintain airflow. Solving for $P_1 - P_2$ then yields the pressure difference,

$$\Delta P = P_1 - P_2 = \frac{\rho v^2}{2}(m^2 - 1). \quad (3)$$

The force generated by this pressure difference is

$$F = \Delta P A = \frac{\rho v^2 A}{2}(m^2 - 1), \qquad (4)$$

where F is the force in the upward direction and A is the area of the hydrofoil.

In order to be an effective hydrofoil, F must be greater than the weight of the craft, Mg, where M is the mass of the craft and g is the acceleration due to gravity. Equation 4 shows that the uplifting force is proportional to the density of the fluid that it is travelling in. Hence, a hydrofoil (in water) is far more effective than an aerofoil (in air) as water has a density three orders of magnitude greater than that of air.

Discussion

The interior profile of Jupiter is predominately fluid hydrogen. Beyond its small solid core is ~60,000km of fluid hydrogen; in a metallic form near the core and transitioning to molecular hydrogen near its surface. A thin layer of aerosols, ammonia and ice provides the exterior layer [2]. An intricate atmospheric density profile of Jupiter is yet to be characterised; however there are data that gives approximate values for each layer. We shall assume that our considered hydrofoil is racing around on top of the liquid molecular hydrogen which has density of $500kgm^{-3}$[3], and also assume that this fluid is incompressible. The acceleration due to gravity on Jupiter, g_J, is different to that on Earth, where g_J is equal to $25.95ms^{-2}$ on the surface of Jupiter [4]. Finally, we shall assume that the m value of the hydrofoil is 1.1.

We will consider two sizes of hydrofoil craft: a small 'personal' craft (1500kg) [5] and a larger ferry-like craft (10^7kg) [6]. The size of the hydrofoil makes a significant difference to the force generated. As a reasonable restriction, we limited the size of the hydrofoil to be a third of the area of its respective craft.

For the smaller craft (6m by 2.5m) [5], equation 4, when solved for v, requires a minimum velocity of $12.2ms^{-1}$. The larger craft (112m by 30m) [6] would require a minimum velocity of $66.4ms^{-1}$, far greater than the smaller craft.

Conclusion

The velocities quoted are both fairly high when compared to typical hydrofoil speeds. The smaller craft's required velocity is comparable to typical boat cruising speeds and could be appropriate if large distances across Jupiter is required. However, the atmosphere would provide further problems. Even if the pressure, temperature and wind speeds are overlooked, the density of the atmosphere would create significant drag. This would make the required velocities harder to accomplish.

Further study into this means of Jovian transportation could look into the drag created from the atmosphere and the necessary propulsion to overcome it, possibly a form of rocket. Alternatively, further study could investigate whether the ammonia rich atmosphere could provide the source of fuel.

References

[1] *http://firstflight.open.ac.uk/pages/aerodynamics/how_planes_fly/vortex.php* last accessed on 09-10-2013

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[3] *http://lasp.colorado.edu/education/outerplanets/images_giants/thumbs/pie.jpg* last accessed on 09-10-2013 last accessed on 09-10-2013

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