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A4_2 Plausibility of Planes on Other Planets

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Abstract

In this paper we explore the possibility of a typical passenger aeroplane taking-off from the surface of each of the terrestrial planets using aerodynamic lift from its wings. This should be possible on Venus, with the minimum take-off speed found to be $v \approx 10\ m\ s^{-1}$, compared to $v \approx 81\ m\ s^{-1}$ on Earth. However, this would be unlikely on Mars, as this would require $v \approx 340\ m\ s^{-1}$, and impossible on Mercury, where the lack of atmosphere prevents the wings from generating lift.

Introduction

In a previous study, [1], it is discussed whether a typical aeroplane, namely the Cessna 172 Skyhawk, could maintain a stable flight on each of the largest 32 astronomical objects within the solar system. To do this, it was calculated whether the lift generated by the wings of the aircraft was sufficient to counteract the force of gravity at 1 km above the surface, and prevent the aircraft from plummeting into the terrain below. In this paper, we focus on the terrestrial planets, and determine the minimum speed a typical passenger aeroplane, the Boeing 747-400, would require to take-off from the surface of each planet, and discuss the plausibility of this.

Theory

To generate lift, the wings of an aeroplane are angled slightly upwards with respect to the ground [2]. As the aeroplane accelerates, the angle of the wings causes air to be deflected downwards by the underside of the wing which applies a net downwards force. In accordance with Newton's third law, the deflected air applies a reaction force of equal magnitude and opposite direction on the wing, forcing the wings and hence the entire plane upwards [2]. The magnitude of the lift force this generates can be calculated using equation (1) [3].

$$F_L = \frac{1}{2} C_L \rho A v^2 \tag{1}$$

In equation (1): A is the surface area of the wings, for the Boeing 747-400 this is given as $A = 525\ m^2$ [4], v is the speed at which the air flows over the wings, which we assume to be equal to the speed of the aircraft and C_L is the "Lift Coefficient" for the Boeing 747-400, which is given as $C_L = 1.85$ [5]. ρ is the density of the air, which is calculated using a rearranged form of the ideal gas law, as shown in equation (2).

$$\rho = \frac{P M_M}{kT} \tag{2}$$

In equation (2): P is the surface pressure on the planet, M_M is the mean molecular mass of the air, k is Boltzmann's constant (which is given as $1.38 \times 10^{-23}\ m^2\ kg\ s^{-2}\ K^{-1}$) and T is the surface air temperature. To take-off, the lift force must overcome the opposing force due to the weight of the aircraft (F_W), which is given by equation (3).

$$F_W = Mg \tag{3}$$

In equation (3): M is the mass of the aircraft, given as $M = 395\times10^3\ kg$ [4] and g is the acceleration due to gravity at the surface of the planet. The minimum speed required for take-off is then the speed at which these two forces balance. By equating F_L and F_W, then rearranging for v, we find that the minimum speed required for take-off is given as in equation (4).

$$v = \sqrt{\frac{2MkTg}{APM_MC_L}} \tag{4}$$

	$T\ (K)$	$g\ (m\ s^{-2})$	$P\ (Pa)$	$M_M\ (u)$
Mars	208	3.7	1.0E+3	44.0
Earth	288	9.8	1.0E+5	28.8
Venus	737	8.9	9.2E+6	44.0
Mercury	440	3.7	0.0E+0	0.0

Table 1: Relevant properties of terrestrial planets for equation (4) [6][7]

Results

Applying the relevant values from table 1 to Earth gives $v \approx 81\ m\ s^{-1}$. This speed is approximately equal to the actual takeoff speed of this aircraft, $82.3\ m\ s^{-1}$ [8], and so this shows the accuracy of this method.

As the surface pressure on Mercury is $0\ Pa$, the take-off speed would be infinite ($v = \infty\ m\ s^{-1}$). The lack of atmosphere on Mercury means that there is no air for the wings to deflect, and hence they are unable to generate lift.

For Venus, $v \approx 10\ m\ s^{-1}$, this is far smaller than on Earth, due to the high surface pressure from its thick atmosphere. Whilst it is possible that the drag from the atmosphere could limit the top speed of the aeroplane, we do not know the scale of the impact this would have and so further studies should be carried out to verify this. Venus's dense, acidic atmosphere and high surface temperature [1] could also pose significant problems for take-off on this planet, but this is beyond the scope of this paper.

For Mars $v \approx 340\ m\ s^{-1}$, whilst this is well above the usual take-off speed of this aircraft on Earth, [8], it is possible that the different conditions on Mars may allow for this speed to be reached on the surface. This could be verified by finding the maximum force of the engines and comparing this to the horizontal resistive forces acting on the aircraft during take-off.

Conclusion

In this paper we have calculated the minimum speed required for a Boeing 747-400 to take-off from the surface of each of the terrestrial planets via aerodynamic lift. On Mercury, the aircraft cannot generate lift and so would be unable to take-off. On Mars, the take-off speed is far higher than on Earth, though may still be possible by considering the balance of horizontal accelerating and resistive forces during take-off. On Venus, the required speed is far lower than on Earth, suggesting take-off should be possible. However, further studies should be done to determine if drag from the Venus' atmosphere could prevent the aeroplane reaching this minimum speed.

References

[1] `https://what-if.xkcd.com/30/` [Accessed 3 October 2019]

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[4] `https://web.archive.org/web/20121230173833/http://konzern.lufthansa.com/en/themen/boeing-747-8-roll-out.html` [Accessed 5 October 2019]

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[6] `https://nssdc.gsfc.nasa.gov/planetary/factsheet/` [Accessed 2 October 2019]

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[8] `https://www.flightdeckfriend.com/ask-a-captain/what-speed-does-a-747-take-off-and-land/` [Accessed 22 October 2019]