Bird Flight on MARS

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Abstract

The planet Mars has been terriformed and scientists have managed to make living conditions on the planet every bit as identical as that of the Earth. With exception to the gravitational force of the planet and the atmospheric density, factors such as atmospheric composition, temperature, and vegetation on the planet accurately mimic our planet. Can birds now be introduced on the "new" Mars and proliferate successfully? Since gravity is weaker on the surface of Mars than it is on Earth, flight should be easier on the planet as the force of gravity pulling the bird down towards the planet is much less. However, the density of the planet's atmosphere is only 1/100th the density of that of Earth. Is this density adequate to provide enough lift force in the bird's wings for it to fly properly? It was found that a Canadian goose (out representative bird) would have to fly at a speed of 730.8 km/hr in order to have its wings generate adequate lift to glide over the Martian surface. This is not physiologically possible simply because birds aren't capable of generating enough power for the thrust required to reach such a speed. It was also found that even if the goose flew at an altitude of 0 metres (as compared to 1000m) where the air density was at its greatest, only about 3% of the required lift could be generated.

Introduction

This project addresses the question of whether or not birds are capable of flight on Mars. Mars is a much smaller planet than Earth and has conditions that are most similar to Earth out of any other planet in the Solar System when factors such as gravity, atmosphere, and temperature are taken into consideration. This however does not meet the prerequisites required for animal habitation on this still very environmentally hostile planet. Being a much smaller planet, Mars should have a weaker gravitational field than Earth. This is indeed the case as objects on Mars accelerate towards the planet at 3.71 m/s^2 (about a third of Earth's value of 9.81 m/s^2). Birds on Mars in the air would thus have a smaller downward force acting on it. Lift force is of course another factor that must be taken into consideration when discussing bird flight. Larger air densities can account for greater lift forces assuming the other variables determining this force were held constant. Due to the different history and size of Mars, the Martian atmosphere has an air density that is a mere 1/100th that of Earth's atmosphere. This would undoubtedly thwart the lift force that can be generated by a bird's wings as it flew over the Martian terrain. It can be said that the advantages of a weaker gravitational field on Mars for bird flight are easily overcome by the disadvantage of flying in a medium where the lift force could be reduced by up to 99%. The lift force that can be generated by a bird's wings is governed by the equation $½•C_L•S•\rho•v^2$. The variables v (velocity) and ρ (air density) are both factors that a bird on Mars is capable of manipulating in order to achieve the necessary lift force. For the sake of simplicity, C_L (the coefficient of lift) will be held constant. The C_L value varies between different birds and man-made aircraft. It is a value that is determined by many variables, the most influential of which is α (the angle of attack). V could be increased by the bird simply by flapping its wings more frequently and/or vigorously. A higher ρ could be acquired by the bird by flying at a lower altitude where the pressure of the air is much greater. Could increases in either of these variables by the bird create the lift required for it to fly on Mars?

Calculations and Results

The following calculations utilize values that are approximated for a Canadian goose that weighs about 7kg and fly at ease at an altitude of 1000 metres. The ρ (air density) value for this altitude on Earth is about 0.9002 kg/m^3. An assumption must be made that birds are capable of performing ventilation and gas exchange at such low air pressures.

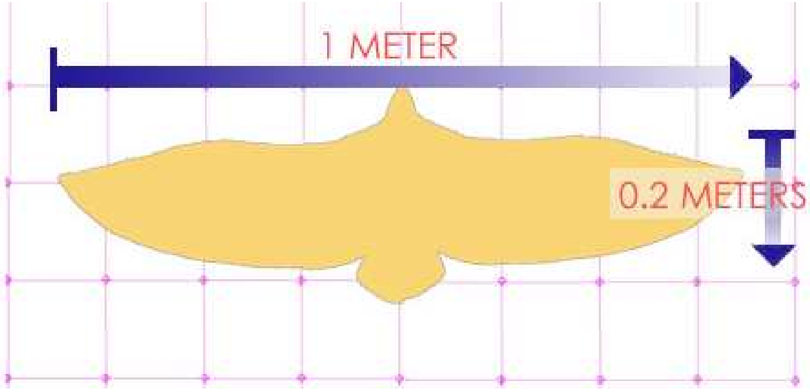


Figure 1
The silhouette of a bird was used to approximate the surface area of its wings.

The total wing surface area is about 0.2, this value will also be used in the calculations.

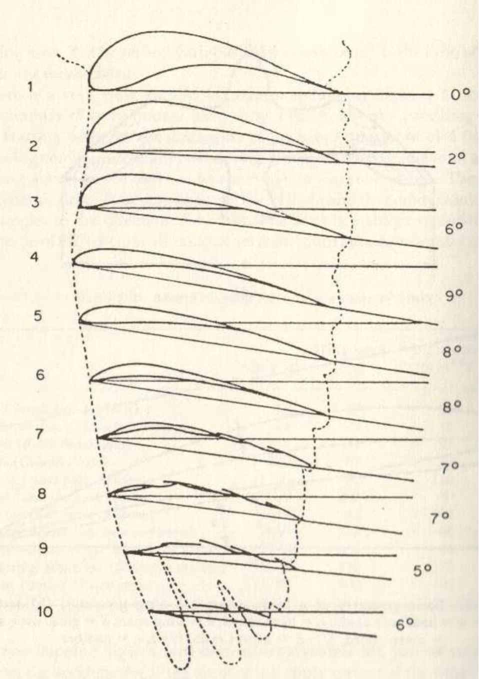


Figure 2
This figure shows α (attack angle) of different regions of a bird's wing (Ward-Smith, 1984).

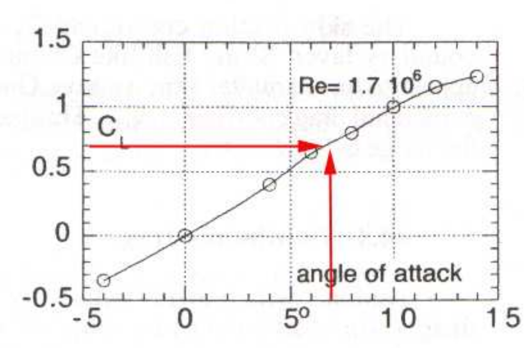


Figure 3
Relationship of C_L to α (Ahlborn, 2002)

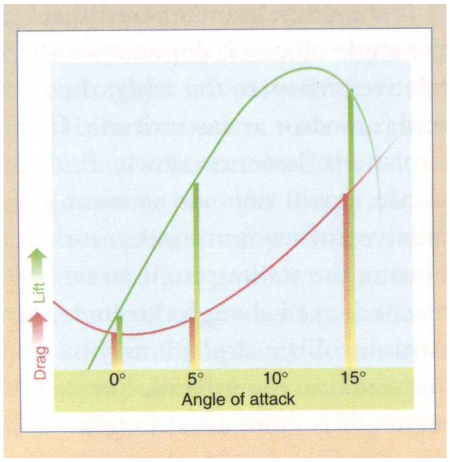


Figure 4
Relationship of the forces of drag and lift at different angles of attack for the wings of a bird of man-made aircraft.

As mentioned earlier, C_L (lift coefficient), is greatly influence by the attack angle of wing of the bird. Since large birds supposedly fly most efficiently with an α of about 6 degrees (Burton, 1990), we selected the C_L value of 0.7 that coincides with this. It is important to note that the angle of attack of a bird's wing is not constant from region to region and varies depending what part of the wing you are looking at. *Figure 2* shows the different attack angles of a pigeon's wing. *Figure 4* shows that the angle of attack generally cannot exceed 10-15 degrees for large birds. At high attack angles, the ratio of lift-to-drag decrease drastically due to turbulent airflow on the upper surface of the wing, this would cause stalling. Nevertheless, we'll use the value 0.7 for C_L.

Lift force is given by the following equation:
$F_L = ½•C_L•S•\rho•v^2$

Force of gravity acting on the bird:
$F_{g\ Earth} = mg = (7kg)(9.81m/s^2) = 68.67N$

Since we know that birds on Earth are capable of gliding, the following equation arises:
$F_{g\ Earth} = F_L = 68.67N = ½•C_L•S•\rho•v^2$

Now we calculate the velocity which the bird must travel at in order to obtain enough lift to glide at an altitude of 1000m on Earth:

$68.67N = ½•C_L•S•\rho•v^2$
$v^2 = (2)(68.67N)/[C_L•S•\rho]$
$v^2 = [137.34\ N]/[(0.7)(0.2m^2)(0.9002kg/m^3)]$
$v^2 = 1089.79\ N•m/kg$
$v = 33.01\ m/s$

The Canadian goose must travel at a velocity of 33.01 m/s in order to maintain enough lift to remain at relatively constant altitude. This is equivalent to 118km/hr, which is practical for large birds.

How much of the lift force requirements would be met if the same goose flying at the same speed, in the same temperature, at the same altitude on Mars?
$g_{Mars} = 3.71\ m/s^2$

$F_{g\ Mars} = mg = (7kg)(3.71m/s^2) = 25.97N$

Since air density on Earth is 100x greater than on Mars, $\rho_{Mars} = 9.002 \times 10^{-3}$ kg/m^3

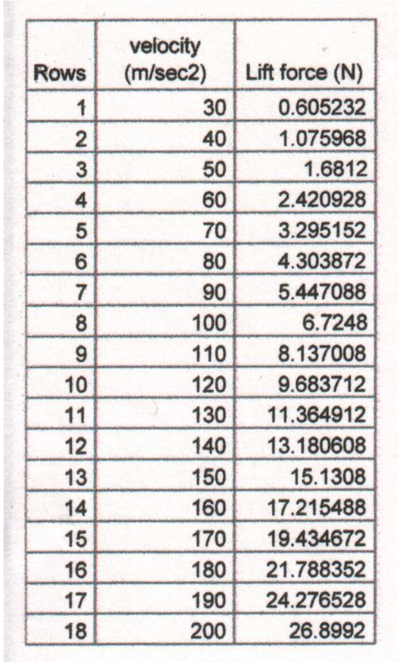
$F_L = ½•C_L•S•\rho•v^2 = (0.5)(0.7)(0.2m^2)(9.002 \times 10^{-3}\ kg/m^3)(33.01\ m/s)^2 = 0.6866\ N$

Only 0.6866N of the required 25.97N of force are met by the Canadian Goose.

Variables that the birds can manipulate to obtain the required lift on Mars
Velocity
$\rho_{Mars} = 9.002 \times 10^{-3}$ kg/m^3

Lift force required = 25.97N
$F_{L\ required} = ½•C_L•S•\rho•v^2 = 25.97N$
$v^2 = [(2)(F_{L\ required})]/[C_L•S•\rho]$
$v^2 = [(2)(25.97N)]/[(0.7)(0.2m^2)(9.002 \times 10^{-3}\ kg/m^3)]$
$v^2 = 51.94N / 0.1260 \times 10^{-3} kg/m$
$v^2 = 41213.06\ Nm/kg$
$v = 203.0\ m/s = 730.8\ km/hr$

The Canadian goose would have to fly at 730 km/hr to attain the required lift force, an impractical value. Even if the physiology of birds allowed for this, birds would not have the capabilities of generation enough power to reach such speeds. *Figure 7* shows the qualitative relationship of power versus velocity for a large bird flying on Earth. At very high speeds, the parasitic drag increases at an increasingly high rate and requires an increasingly large amount of power.



Rows	velocity (m/sec2)	Lift force (N)
1	30	0.605232
2	40	1.075968
3	50	1.6812
4	60	2.420928
5	70	3.295152
6	80	4.303872
7	90	5.447088
8	100	6.7248
9	110	8.137008
10	120	9.683712
11	130	11.364912
12	140	13.180608
13	150	15.1308
14	160	17.215488
15	170	19.434672
16	180	21.788352
17	190	24.276528
18	200	26.8992

Figure 5
Table of lift force that can be attained at various velocities.

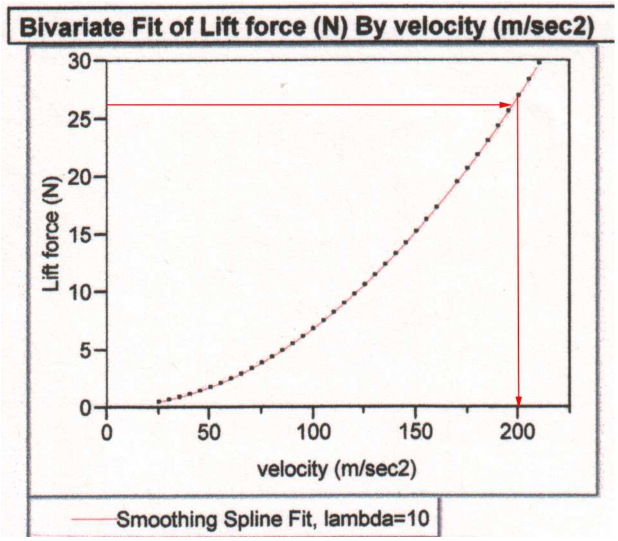


Figure 6
Graph of lift force versus velocity the bird travels at.

Since lift force is related to the square of velocity, an exponential graph can be generated when plotting out F_L against v as shown in *figure* 6.

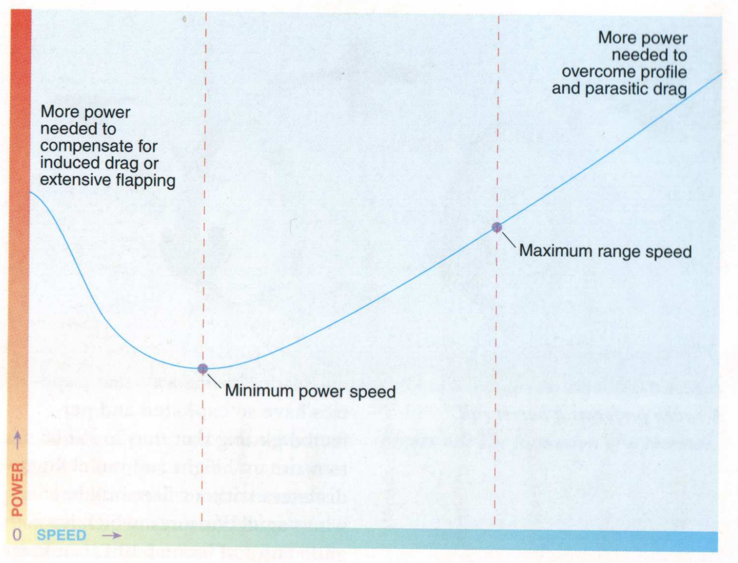


Figure 7
Relationship between energy expenditure and speed of a large bird (Dalton, 1999)

Air Density

Can a bird fly at a low enough altitude to be in a medium with a ρ(density) large enough to support the lift force requirements?

Air density in the atmosphere of a planet is determined by the following equation:

$$\rho = \frac{1000P}{T_{Kv}R} = 3.486\frac{P}{T_{Kv}}$$ = air density [kg/m^3]

Air density is shown to be dependent on two other variables, temperature [K] and pressure [kg/m^3]

The following equation can be used to determine the air pressure at various altitudes on Earth:

$$P = 101.3\left(\frac{293 - 0.0065z}{293}\right)^{5.26}$$ = pressure [kPa]

z = height [m]

convert the P on Earth at a given height to what P would be on Mars at the same height and we get the following plot:

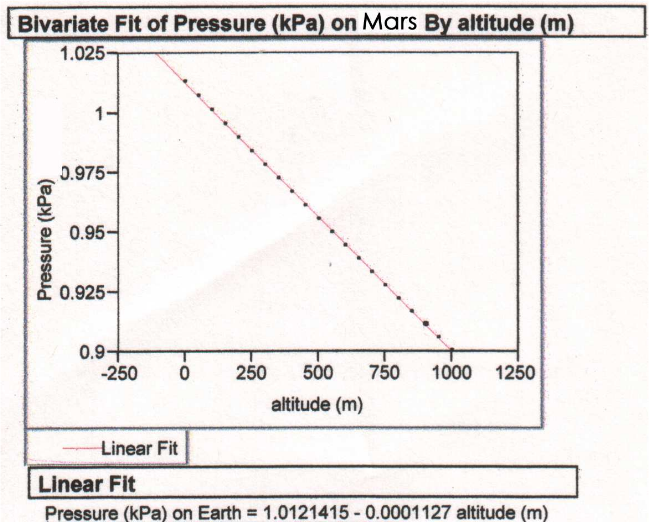


Figure 8
Plot of Pressure (kPa) versus altitude in the Martian atmosphere

$$T_{Kv} = T_K\left(1 - 0.378\frac{e_a}{P}\right)^{-1} \quad = \text{virtual temperature}$$

e_a = vapour pressure [kPa] = assume constant to simplify)
T_{Kv} = virtual temperature [K]
T_K absolute temperature [K]

We can see in *figure 8* that temperature in the Martian atmosphere would vary largely for slight changes in altitude.

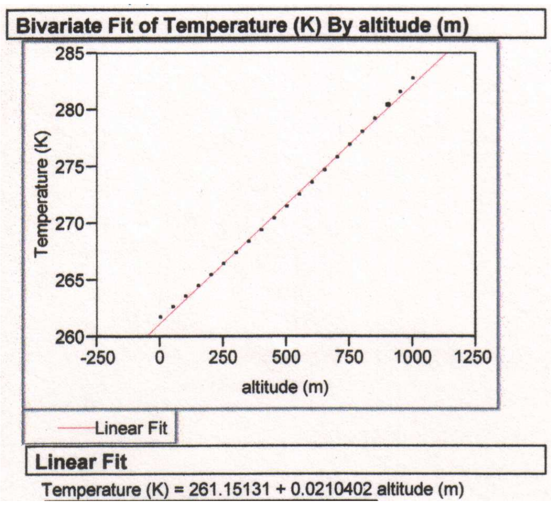


Figure 9
Plot of Temperature versus altitude in the Martian atmosphere

Finally, the air density in Mar’s atmosphere can be calculated for various altitudes:

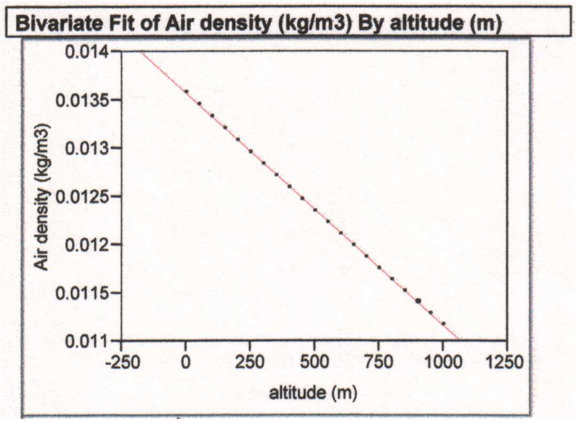
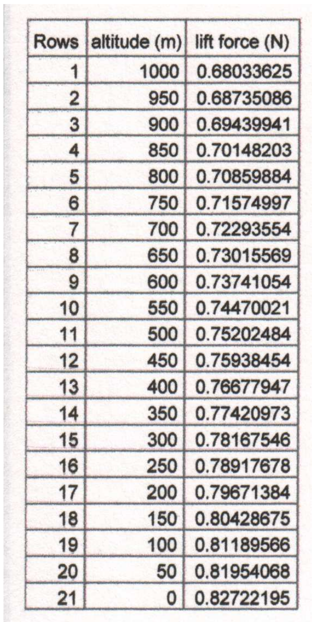


Figure 10
Air density (kg/m^3) versus altitude (m) on Mars.



Rows	altitude (m)	lift force (N)
1	1000	0.68033625
2	950	0.68735086
3	900	0.69439941
4	850	0.70148203
5	800	0.70859884
6	750	0.71574997
7	700	0.72293554
8	650	0.73015569
9	600	0.73741054
10	550	0.74470021
11	500	0.75202484
12	450	0.75938454
13	400	0.76677947
14	350	0.77420973
15	300	0.78167546
16	250	0.78917678
17	200	0.79671384
18	150	0.80428675
19	100	0.81189566
20	50	0.81954068
21	0	0.82722195

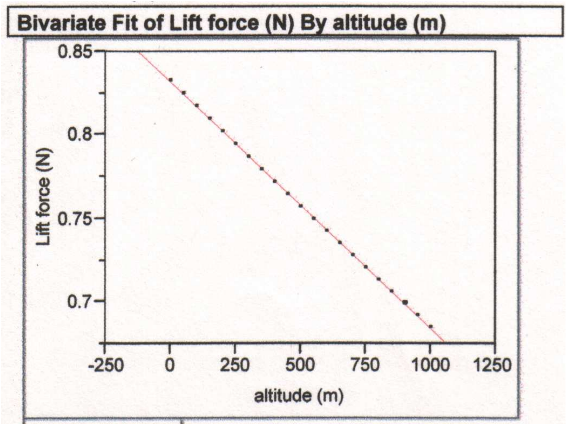


Figure 11
Table of lift force that
can be attained at
various altitudes on Mars.

Figure 12
Graph of lift force versus
velocity of the bird when gliding
at various altitudes.

As shown in *figure 11*, the force of lift can only be increased up to 0.82272N from 0.6803N when flying at the lowest altitude possible. This is still not near the 25.97N required for it to glide at a relatively constant altitude.

Conclusion

Even though the gravitation force acting on a bird was only a third of what it would be on Earth, it was found that the bird would have to fly at a velocity of

203.0m/s in order to generate the adequate lift required to remain at a constant altitude. This is a value that isn't practical for birds to travel at due to physiological and energetic limitations. Muscles wouldn't have the capabilities of delivering the thrust required, and it would be prohibitively difficult for a bird to attain enough energy to power muscles that are so active. Calculations were done to calculate the theoretical air density at 0 metres altitude on Mars to see if flying at a lower altitude, and thus a greater air density, would allow a bird to generate enough lift to glide. As compared to flying at altitude of 1000m, the lift force that could be generated would only increase by 20.46% up to 0.82272. This value would still be much less than the 25.97N of force acting on a bird of this mass (7kg) and would not be adequate to keep the bird at a constant altitude. In this project, I have assumed that the C_L remained constant when it is in fact a value that continually changes during the flight of the bird. However, If a larger C_L value was used (if the bird's wings had a larger attack angle) for the calculations, the velocity required to be reached by the bird to attain the lift required would reduced significantly. However, this reduction would still require that birds fly at speeds that they are not physiologically capable of. In the calculation of the temperature variation at different altitudes on Mars, the E_a (vapour pressure), was held constant. Although this value varies depending on the altitude in the Earth's atmosphere, no information could obtained on what the vapour pressure was on Mars. A reasonable value was assumed and the calculations should not be affected significantly by this assumption. Birds have been on Earth for a considerably long period of time and have had much time to evolve and adapt to flight under conditions only experienced on this planet. This report illustrates that even if fantastical modifications were made to alter conditions on Mars so as to resemble that of Earth's, birds would still be restricted to being merely a terrestrial animal that wouldn't be able to glide very far to stay off the Martian surface. Although it may be impossible to glide in Mar's atmosphere with a relatively small glide angle. Would it be possible for birds to glide an appreciable distance if it took-off at an initial high altitude (such as a cliff)? Although the glide angle may be much larger for any given bird on

Mars than it would be here on Earth, it is likely a possibility that they could glide a noticeable distance. How far would different birds be able to glide for before they made it back onto the surface of Mars at various initial altitudes? These are all questions that can be answered by an individual who takes an interest in how birds would function in Mars

References

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Ward-Smith, A.J. 1984. Biophysical Aerodynamics and the Natural Environment. New York: John Wiley & Sons. pp 74.

Ahlborn, Boye K. 2002. How Animals Make Use of Physics. pp 3-22.