Journal of Physics Special Topics

P5_9 The Daredevil on Mars

H.Lerman, B.Irwin, P.Hicks

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

November 11, 2013

Abstract

This paper analyses the dynamics of the Daredevil, Felix Baumgartner's Red Bull Stratos freefall if he were to perform the event in Mars' atmosphere. We used an iterative simulation to calculate the trajectory taken under the effects of balancing drag and acceleration. We found that Felix would reach terminal velocity only a few hundred metres above the surface of Mars.

Introduction

On October 14th 2012 Felix Baumgartner, nicknamed the Daredevil, broke the speed of sound in freefall claiming the current highest freefall record of 19.5miles. A capsule took him 39,045m (24.26miles) above Earth and he fell in freefall for 4m 22s [1]. This paper explores the dynamics of his fall if he were to perform it on Mars from the same height.

Theory

To calculate the dynamics of Felix's freefall we used a customly coded C program to iteratively calculate his trajectory under the changing acceleration, height, speed and forces he felt through his fall.

When Felix made the initial step out of his capsule his initial speed was 0m/s (assuming the balloon he jumped from was stationary). He immediately felt an acceleration due to gravity calculated using the equation

$$g(t) = \frac{GM}{r^2(t)}, \quad (1)$$

where G is the gravitational constant $G = 6.67 \times 10^{-11}\text{m}^3\text{kg}^{-1}\text{s}^{-2}$, M is Mars' mass given as 639×10^{21}kg [2] and r is the radius of Mars, 3,390km [2], plus Felix's current altitude. Felix jumped from 39,045m above the surface of Earth. Assuming he jumps from the same altitude, we calculate $r = 3{,}429$km. Substituting the values into equation (1) we calculated that the initial acceleration he feels $g = 3.62\text{ms}^{-2}$. This value is much less than the acceleration he felt when he first stepped from his balloon on Earth, which was 9.69m/s^2 [3].

As Felix began his freefall he would encounter two forces: a force due to gravity, F_G, and aerodynamic drag, F_D, such that the total force he felt is

$$F(t) = F_G(t) - F_D(t). \quad (2)$$

Due to these two forces, his total acceleration would change with time. Using Newton's second law we were able to calculate the new acceleration at time t using

$$a_t = \frac{F(t)}{m}. \quad (3)$$

The gravitational force he would feel is

$$F_G(t) = mg(t), \quad (4)$$

where m is Felix's mass, which includes his gear, recorded at the time of fall on Earth as $m = 118$kg [1]. The equation used to calculate F_D is

$$F_D(t) = \frac{1}{2} C_D \rho(t) {v_t}^2 A, \quad (5)$$

where C_D is the drag coefficient, ρ is the density of the air, v_t is his speed at time t and A is the area which is facing the direction of motion. The average skydiver's surface area is taken to be $A = 0.75\text{m}^2$ [4]. We also assumed that $C_D = 0.41$ [5] and remains constant throughout the fall.

At 39km above the Martian surface, Felix would begin his jump in the troposphere [6]. We used an atmospheric model designed by NASA to calculate the local temperature, pressure and density during the fall on Mars [7]. To calculate ρ in equation (5) we used

$$\rho(t) = \frac{P(t)}{0.1921 T(t)}, \quad (6)$$

where $P(t)$ is the atmospheric pressure defined as

$$P(t) = 0.699 \times e^{-0.00009h_t}, \quad (7)$$

where h_t is the height above Mars' surface at time t. $T(t)$ is the atmospheric temperature. In NASA's model there are two temperature equations which depend on the height above the Martian surface [7]. To calculate the temperature for $h_t > 7000$m we used

$$T(t) = -23.4 - 0.00222h_t + 273.15, \quad (8)$$

and for $h_t \leq 7000$m

$$T(t) = -31 - 0.000998h_t + 273.15. \quad (9)$$

All of these parameters were recalculated at every second of the fall using the iterative code. The height at each point in the fall was calculated using

$$h_t \rightarrow h_{t-1} - v_t t_{step}\,, \quad (10)$$

and the velocity at time t was calculated using

$$v_t \rightarrow v_{t-1} + a_t t_{step}\,, \quad (11)$$

Equations (10) and (11) are iterative processes, in which $t_{step} = 1$s, the time resolution of the program.

Discussion

In this section we show how Felix's velocity and total force vary with height, shown in Figures 1 and 2.

When $F_G(t) = F_D(t)$ Felix would reach terminal velocity. In Figure 2, Felix's point of terminal velocity is seen at $F(t) = 0$. According to the program he would reach terminal velocity at $h_t \approx 700$m with $v_t = 456$ms^{-1}. The terminal velocity is seen in Figure 1 as the curve tends to a straight line at $h_t \approx 1000$m. In Figure 2, it is seen that the total force goes negative just before Felix reaches the Martian surface. This is because $F_D(t) > F_G(t)$. However, because the time resolution is coarse, that is $t_{step} = 1$s, the program oscillates around the terminal velocity while converging to it.

We do not take into consideration when Felix would finish his freefall and aim to land safely, such as using a parachute. However, given a parachute landing, it can be seen that Felix would not have enough time to reach terminal velocity.

Conclusion

The Daredevil would begin his freefall at an acceleration of 3.62ms^{-2}. As he fell he would encounter two forces: a force due to gravity and a drag force. These forces would cause the acceleration and hence velocity to vary throughout his fall. We found that Felix would reach terminal velocity only a few hundred metres above the surface of Mars.

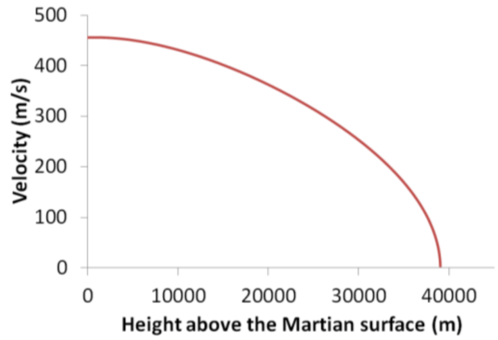

Figure 1 – A graph showing how the velocity varies with height.

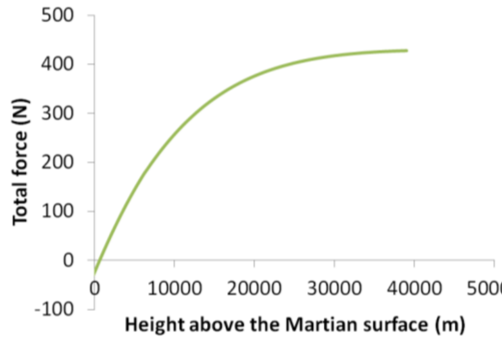

Figure 2 – A graph showing how the total force varies with height.

References

[1]http://www.redbullstratos.com/the-mission/world-record-jump/ accessed on 17/10/2013.

[2]http://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html accessed on 17/10/2013.

[3] http://www.jimmo.org/the-physics-of-the-felix-baumgartner-jump/ accessed on 17/10/2013.

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[5]http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/7070/1/03-0652.pdf accessed on 17/10/2013.

[6] Gonzelez-Galindo,F. et al, *The Martian Upper Atmosphere*, National Accelerator Laboratory, 2009.

[7]http://www.grc.nasa.gov/WWW/K-12/airplane/atmosmrm.html accessed on 17/10/2013.