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A4_8 Whales Can't Fly

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Abstract

In this paper the physics of the descent of the sperm whale from "*A Hitchhiker's Guide to the Galaxy*" falling into the ocean on Earth is investigated. It is found that the terminal velocity of the whale is 460 m s^{-1}, the penetration depth is 76 m and approximately 20 times of the total mass of the whale could be destroyed in the impact.

Introduction

A famously devastating and improbable scene from the book series 'A Hitchhikers Guide to the Galaxy' describes a sperm whale falling to its doom on an alien planet just after coming into existence several miles above the surface [1]. If this ill fated whale were to fall instead above an ocean and on Earth, how far into the ocean would it travel? And how much of the sperm whale would be destroyed?

Assumptions

Before the force of a sperm whale hitting the ocean can be calculated, there are a number of assumptions that must be taken into account. Firstly, the size of the sperm whale. Unfortunately the size, age and gender of the whale are not mentioned in it's last thoughts. So, an average size must be used; sperm whales generally range from 2.1 - 3.4 m in height, 12 - 19 m in length and 35 - 59 metric tonnes in weight [2]. Taking the average value of each of these gets a height, d, of 2.8 m, length, l, of 16 m, a mass, m, of 4.7x10^4 kg and, assuming we can model the whale as a cylinder, a volume, V, of 99 m^3.

The sperm whale falls face down towards the ocean as its mass is being focused towards the front of its body. Assuming this, it can be modelled as a long streamline body due to its affinity for swimming through water. Therefore, its drag coefficient, $C_d = 0.1$ [3]. Furthermore, the frontal area of the body can be assumed to be a circle with diameter 2.8 m (the height of the whale) so $A = 6.2$ m^2.

Approximating "several miles" [1] to 7 miles means that the sperm whale falls a height of 11 km, h - the height of the troposphere.

The Descent

We begin by calculating the impact velocity of our ill-fated sperm whale, v_i, (neglecting air resistance) using Eq. (1) [4],

$$v_i = \sqrt{2gh}, \tag{1}$$

where $g = 9.8$ m s^{-2} and is the acceleration due to gravity, $\rho_{air} = 1.2$ kg m^{-3} and is the density of air at sea level [5]. Inputting these values we get a value of $v_i = 460$ m s^{-1}.

As the whale hits the water it will experience a drag force, F_d, according to Eq. (2),

$$F_d = C_d \frac{1}{2} \rho_w v_i^2 A, \tag{2}$$

where ρ_w is the density of the ocean and is equal to 1000 kg m^{-3} [6]. Therefore, $F_d = 6.6\times10^7$ N. Another force acting on the whale as it falls through the water is the buoyancy force, F_b, which can be found using Eq. (3),

$$F_b = \rho_w g V, \tag{3}$$

to get a value of $F_b = 9.7\times10^5$ N. From adding this (F_b) to the drag force (F_d) we get a total force, $F_t = 6.7\times10^7$ N. From the total force we can calculate the deceleration of the whale as it hits the water, a, using Eq. (4),

$$a = \frac{F_t}{m}, \tag{4}$$

to be $a = 1.4\times10^3$ m s^{-2}. Next, assuming the whale experiences a constant acceleration for simplicity, we must utilise suvat equations to calculate the distance the whale travels through the water. Using Eq. (5),

$$v_i^2 = u^2 + 2as, \tag{5}$$

we can rearrange and substitute for our previously calculated values to arrive at Eq. (6),

$$s = \left(\frac{-v_i^2}{2a}\right), \tag{6}$$

this gives us a value for the distance the whale travels under the water from the surface, $s = 76$ m.

The Fallout

Starting by calculating the kinetic energy just before the impact, KE, using Eq. (7),

$$KE = \frac{1}{2} m v_i^2, \tag{7}$$

we get a value of $KE = 5.0\times10^9$ J. This is equivalent to about 1.0×10^3 kg of TNT and therefore comparable to the energy output of a lightning strike [7]. As 1 kg of TNT is capable of blowing up or destroying a small car (mass of approx. 1 tonne or 1×10^3 kg) we can scale this up to suggest that 1 Mg of TNT could destroy a mass of 1×10^6 kg. As this is approximately 20 times the mass of the sperm whale, the force of the impact would completely destroy the whale and surely kill it.

Conclusion

So, if Douglas Adams's sperm whale instead crashed into the ocean on Earth it would crash through the surface by 76 m and therefore if still intact would be able to swim on as if nothing happened. However, due to the large force and energy of impact the unfortunate sperm whale would be destroyed and it would certainly be killed. This puts into perspective the improbability and accidental cruelty of Arthur Dent and the probability drive.

In a future study the impact on the Earth of the sperm whale's untimely demise could be investigated. For example, the size of wave and destruction caused by it could be calculated.

References

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