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P4_3 Spaceball

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Abstract

In this paper, we investigated the amount of energy and force an oncoming piece of debris the size and mass of a baseball would have on an International Space Station (ISS) window, and the effects of a collision between the two. It was found that the energy of the 'baseball' is 4.4x10^6 J, meaning the pressure it exerts as it hits the window is 3.11x$10^9 Pa$, 64 times greater than the tensile strength of that window. The force of the collision is also shown to be 1719 times bigger than the force exerted between two cars during a car crash. We concluded that the ISS collision would cause serious damage to its shielding and modules and would be the largest collision to date.

Introduction

There are over half a million pieces of space debris in low Earth orbit. With speeds of approximately 7800 ms^{-1}, these pieces of meteoroid, metal and other man-made objects can easily penetrate and damage a satellite or station [1]. This debris is becoming an increasing problem, and as stated by the European Space Agency 'an object up to 1 cm in size could disable an instrument, above 1 cm could penetrate the shields of the crew modules, and anything larger than 10 cm could shatter a spacecraft into pieces' [2]. How powerful would a baseball-sized piece of space debris be if it struck the ISS?

Theory

The ISS has small rocket thrusters providing propulsive support to guide it out of the way of oncoming debris and keep it above Earth's thin outer atmosphere as it's orbit slowly decays. However, these precautionary thrusters would not be able to stop hull destruction if an oncoming, sizeable meteoroid was not avoided in time and struck the outer layers of the ISS. These layers consist of a protective layer called the *Whipple Shield*, consisting of a thin outer bumper designed to disintegrate incoming debris [3].

We shall imagine a scenario in which a piece of space debris the size of a baseball, with a diameter of 75 mm, is travelling at 7800 ms^{-1} towards one of the windows in the ISS. We will assume that we are in the frame of the ISS, therefore the ISS is stationary when the debris hits it. Though this particular collision is extremely unlikely given the station is an enormous 109 m long [4], there are still precautions in place to prevent this situation. A window on the ISS, for example the Cupola, typically contains 4 panes of glass [5] made of fused-silica and borosilicate-glass [6]. There is an inner layer which the astronauts maintain, and a thinner outer debris panel each 15 mm thick, with two thicker 25 mm glass panels in between. Assuming therefore that the window totals 80 mm thick, the distance which the baseball has to penetrate is very small. The kinetic energy of the baseball is calculated using:

$$E = \frac{1}{2}mv^2, \quad (1)$$

where m is the mass of the 'baseball' at 145 g and v is the speed of the debris at 7800 ms^{-1}. The kinetic energy, E, is therefore 4.4x10^6 J. For comparison, an explosion of 1 kg of TNT produces 4.2x10^6 J [7].

Equation (2) gives the amount of force the window exerts on the debris to bring it to rest:

$$W = Fd, \quad (2)$$

where F is the force of the baseball, d is the distance traversed (0.08 m), and W is the work done (or energy, E, in equation (1)). Equation (2) gives a force equal to 5.5x10^7 N. The surface area of the baseball is 0.018 m^2, therefore the pressure exerted by the ball on the window is:

$$P = \frac{F}{A}, \quad (3)$$

where P is calculated to be 3.11x10$^9 Pa$. If we assume that the Cupola is completely made of fused-silica glass, which has a tensile strength of 48.3MPa [8], then we have shown that the baseball does indeed break the window.

We shall now compare the 'baseball' scenario to a collision between a travelling car with a speed of 70 mph (31.3 ms^{-1}) and a stationary car (representing the ISS window) on Earth. We will assume both cars are Ford Focuses, each with a mass of 1300 kg. The travelling car therefore has an energy, calculated using equation (1), of 6.37x10^5 J. Substituting this for W in equation (2), and assuming d is small (20 m) to keep the calculation equivalent to the one for the ISS collision over a small distance, the force of the car crash is 3.2x10^4 N. By comparing this to the force involved in the debris collision, we find that the 'baseball' collision has a force which is 1719 times as powerful as the car crash.

Discussion

The energy and force comparison between the debris and car scenarios shows that the impact of the 'baseball' on the ISS window would be a catastrophic event, causing irreversible damage. We calculated that energy of the baseball is 7 times higher than the Ford Focus, and the force of the ISS impact is 1719 times as powerful as the force exerted during a car crash. This shows that the forces involved with debris impacts on the ISS are much higher compared to anything we would experience, for example during a car crash. In this paper, we assumed the two collisions act in the same way. The baseball is obviously a lot smaller than the car, however it does much more damage because its smaller surface area and mass means it travels quicker. The car has a larger impact surface area and impacts an object of the same size.

Conclusion

A collision between a baseball-sized piece of debris and a window on the ISS would create huge amounts of damage equal to a force of 5.5x10^7 N. Overall the impact would resemble a car crash as the two objects collide (like the scenario described on Earth) resulting in damage to the space station as the baseball passed through. The baseball would then slow down as it enters the pressurised ISS module, which has a pressure equal to that at sea-level. Thankfully though, this whole event is extremely unlikely.

References

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