Is it possible for Man to move the Earth off its orbit?

by Shanon Seet

I. Motivation

Newton's third law of motion has always intrigued me, that for every action we push off the ground to make, we can simultaneously "move" the ground as well. Knowing that force from a single person makes a negligible difference on the Earth's motion, I would like to analyse extreme scenarios and if they could possibly affect the Earth's orbit.

The Earth orbits the Sun with a period of 365 days due to its gravitational force of attraction to the Sun, given by Newton's gravitational law. If possible, moving Earth off the orbit will have dire consequences. Moving the Earth closer or further from the Sun will alter its rotational period (the length of a year). More importantly, it will affect the temperature of the Earth's surface significantly, especially since energy from the Sun varies inversely with the square of the distance between the Earth and the Sun[1].

If the Earth moved closer to the Sun, glaciers would melt, causing sea levels would rise, flooding most of the planet. The carbon dioxide in the ocean's water would be released into the atmosphere along with more water vapour, raising temperatures further. If the Earth moved further from the Sun, the opposite would happen, and the Earth will be cooled till it is unsuitable to sustain life[2]. If any actions from Earth made it possible to move Earth off its orbit, it would have an extensive impact on all living creatures on Earth.

II. Explanation

First, let us consider if every person on Earth gathered at a spot, and jumped at the same time.

Suppose everyone on Earth (about 7.5 billion people) jumped at the same time. Assume the average mass of every person on Earth is 50kg (total mass of people m_p), assume each person jumps an average of h = 0.5m into the air, and for simplicity, assume everyone is jumping on the same spot. By considering the system of the people and the Earth, using the principle of conservation of energy, taking v_p and v_E as the initial velocity of the people and the Earth respectively when they first start to move apart,

$$\frac{1}{2}m_p v_p^2 + \frac{1}{2}m_E v_E^2 = m_p gh.$$

By the principle of conservation of momentum (initial momentum = 0):

$$0 = m_E v_e + m_P v_P.$$

From these equations, we can calculate that (refer to Appendix A for detailed working[3])

$$v_E = 1.95 \times 10^{-13} ms^{-1},\ s_E = 3.13 \times 10^{-14} m.$$

The distance the Earth would move is 3.13 x 10^{-14}m, which is about 1/100th the diameter of a Hydrogen atom. We can see that the force of every person on Earth jumping will not be anywhere near enough to make a difference to the Earth's orbit.

So, let us consider the force of the world's most powerful explosive ever built, the Tsar Bomba, a thermonuclear bomb used by the Soviet Union in 1961. The detonation of the Tsar Bomba yielded 50Mt, or 50 megatons of TNT[4]. This is equivalent to a yield of $2.09 \times 10^{17} J$ of energy.

Calculating the gravitational potential energy (U) between the Earth and the Sun, given by the expression $U = \frac{GM_{sun}m_E}{distance\ between\ Earth\ and\ Sun}$:

$$U_{between\ Earth\ and\ Sun} = \frac{6.67\times10^{-11}\times2.0\times10^{30}\times6\times10^{24}}{1.496\times10^{8}} = 5.35 \times 10^{36} J.$$

From this calculation alone, we can see that the energy produced by the strongest nuclear bomb denotated in the world is only a tiny fraction – around 10^{-19} – of the gravitational potential energy between the Earth and the Sun. Intuitively, we know that an explosion of even that magnitude will not have much effect on altering the Earth's orbit.

We must also note that any movement of the Earth produced by anything Earth-bound will be only temporary, and that the Earth will move back to its original position, by the principle of conservation of momentum. When people jump, they return to the ground due to gravitational attraction to the Earth. Similarly, the Earth is gravitationally attracted to the people and will return to its original position. When a bomb explodes, bomb fragments are exploded in all directions. However, the fragments will not escape the atmosphere (Earth's escape velocity[5] is $11kms^{-1}$, nearly 33 times the speed of sound) and return to the Earth due to gravitational attraction. The Earth will similarly return to its original position.

Let us therefore consider a rocket that launches out of Earth's atmosphere and out of orbit.

At its first stage of launch, the rocket Saturn V produced a thrust force of 7.5 million pounds[6], or 33.4 million Newtons of thrust. By the formula $F = ma$, this force would have accelerated the Earth by $a = \frac{F}{m_E} = 5.57 \times 10^{-18} ms^{-2}$. Assuming a constant rate of acceleration, the time needed to move the Earth by one percent of its current distance from the Sun (1% x 1.496 x 10^8m) can be calculated using the formula $s = ut + \frac{1}{2}at^2$:

$$t = \sqrt{\frac{2s}{a}} = 7.33 \times 10^{11} s = 23241 \text{ years.}$$

As can be observed, it would take thousands of years for rockets launching off Earth to move the Earth by any significant amount. Of course, more rockets can be launched to increase the force on the Earth, but it will be costly and limited by resources (such as depletion of fuel).

III. Validation and Conclusion

The Earth is undeniably massive and requires a huge amount of force to be moved. Trying to move the Earth from within its atmosphere will have no effect, as gravitational attraction always remains present within the Earth's atmosphere. Launching rockets or spaceships to outside the Earth's orbit will affect the Earth's orbit, although the effect is very small and will take thousands of years to observe. Launching multiple rockets is limited by cost and natural resources – Saturn V required 770,000 litres of kerosene fuel alone.

A possible way to change the orbit of the Earth would be by making use of passing asteroids, a theory that scientists are currently looking into[7]. Making use of an asteroid's gravitational field to move our planet could alter Earth's orbit, but there are many considerations and very careful calibration would have to be done to make sure the asteroid is close enough to move the planet, but far enough to not be caught in Earth's gravitational field.

The near-impossibility of moving Earth out of its orbit is ultimately beneficial for our planet, as it stays in its delicate position at a temperature just right to support life. Although it may seem like a possible solution to global warming, any significant movement of the Earth from its orbit will take thousands of years to implement and is a solution that a pressing and imminent problem such as global warming cannot wait for.

References

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Appendix A

Assumptions/values used:

- Total mass of people, $m_p = 7.5 \times 10^9 \times 50 = 3.75 \times 10^{11} kg$
- Mass of Earth, $m_E = 6 \times 10^{24} kg$
- Average height the people jump, $h = 0.5m$
- Gravitational acceleration, $g = 9.8\, ms^{-2}$
- Every person is jumping on the same spot (impossible, but this will calculate maximum force generated on the Earth and therefore maximum displacement of the Earth)

By conservation of energy:

$$\frac{1}{2} m_p v_p^2 + \frac{1}{2} m_E v_E^2 = m_p g h$$

$$v_p^2 = \frac{2m_p gh - m_E v_E^2}{m_P} \tag{1}$$

By conservation of momentum:

$$0 = m_E v_e + m_P v_P$$

$$v_E = -\frac{m_p v_p}{m_E}$$

Squaring the equation, substituting (1),

$$v_E^2 = \frac{m_p^2 v_P^2}{m_E} = \frac{m_p^2 (\frac{2m_p gh - m_E v_E^2}{m_P})}{m_E} = \frac{2ghm_p^2}{m_E^2} - \frac{m_E v_E^2 m_P}{m_E^2}$$

Rearranging,

$$v_E^2 \left(1 + \frac{m_E m_P}{m_E^2}\right) = \frac{2ghm_p^2}{m_E^2}$$

$$v_E^2 = \frac{2ghm_p^2}{\left(1 + \frac{m_P}{m_E}\right) m_E^2}$$

Hence,

$$v_E = \sqrt{\frac{2ghm_p^2}{m_E^2 + m_p m_E}} = 1.96 \times 10^{-13}\, ms^{-1}$$

$$v_P = 3.13\, ms^{-1}$$

Assuming a constant deceleration of the Earth, we can use one of the four kinematic equations to calculate displacement, $s = \frac{1}{2}(u + v)t$ (2).

We know that the time that the Earth and the people move in opposite directions is the same. Since $s_p \gg s_E$, we can assume $s_p = h$. Using equation (2),

$t = \frac{2h}{v_p}$

$s_E = \frac{1}{2}(v_E)(\frac{2h}{v_P})$.

Substituting calculated values into the equation,

$s_E = 3.13 \times 10^{-14} m$.