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Flat Earth theory: an exercise in critical thinking

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Abstract
In this paper we present a critical analysis of some of the arguments of flat Earth theory, and we also try to show that this analysis and refutation of these false claims can be a useful exercise in critical thinking that is so much needed today. This article can also make it easier for teachers who are exposed to some of the arguments of flat Earth theory by their students. Some arguments of this theory are completely senseless, and some can simply be disproved by trigonometry or basic physical laws.

1. Introduction

The topic of flat Earth theory has recently resonated not only on the Internet, which is the breeding ground for various conspiracy theories, but also in the media. One musician is trying to get the money to launch a satellite to prove that Earth is flat [1], and amateurs build steam-powered rockets to demonstrate the same thing by direct observation [2]. Regarding this article, it is worth noting that Mike Hughes, designer of a steam-powered rocket, declares that he does not have much trust in science. As he previously told the Associated Press, [3] 'I do not believe in science' when discussing his launch plans. 'I know about aerodynamics and fluid dynamics and how things move through the air, about the certain size of rocket nozzles, and thrust. But that's not science, that's just a formula', he said.

That says a lot about how science is perceived by the public. Today, opinions of experts, scientists, and teachers are not more reliable than information found on obscure websites.

Social networks offer people a careful selection of posts, information, and news that peak their interest or make them react. So, people gradually turn to their social bubble (the 'echo chamber' as Polish-British sociologist Zygmunt Bauman calls it), where their view is accepted. Psychologists Everett, Faber, and Crockett summarized a series of experiments in 2015 that showed how people behave differently to individuals in their group and how individuals perceive them as 'the others' [4].

In this article we present a critical analysis of some of the arguments of flat Earth theory, and we also try to show that this analysis and refutation of false claims can be a useful exercise in critical thinking that is essential today.

2. Flat earth theory

The idea of a flat Earth is found in the oldest civilizations, the idea of a globe appears up to Pythagoras, and the radius of the Earth was estimated by Eratosthenes. Aristotle provided physical and observational arguments supporting the idea of a spherical Earth, for example that travellers going south see southern constellations

rise higher above the horizon or that the shadow of Earth on the Moon during a lunar eclipse is round.

The theory of a flat Earth in the modern sense that we will deal with in this article occurs at the turn of the nineteenth and twentieth centuries. English writer Samuel Rowbotham in 1849 argued for a flat Earth and published results of many experiments that tested the curvatures of water over a long drainage ditch and later published studies that purported to show that the effects of ships disappearing below the horizon could be explained by the laws of perspective in relation to the human eye [5]. Figure 1 represents flat Earth map drawn by Orlando Ferguson, 1893. The map contains several references to biblical passages as well as various jabs at the 'Globe Theory'.

3. A hundred proofs the Earth is not a Globe

The following interpretation will be based on the core work [6], where some arguments are based on *A hundred proofs that Earth is not a sphere* [7] that has been translated into many languages. The technique used here is known as Gish Gallop (also 'proof by verbosity'). It focuses on overwhelming one's opponent with as many arguments as possible, without regard for accuracy or strength of the arguments.

This method can be traced back to the book *Hundert Autoren gegen Einstein* (A Hundred Authors Against Einstein, although '100' authors was an overestimate), published in 1931 [8], which is a collection of various criticisms of the theory of relativity, some of them due to the authors' misunderstanding of relativity. And as Albert Einstein declared, commenting on the book, 'If I were wrong, then one would have been enough!'

In the case of *One hundred proofs that Earth is not a sphere*, many arguments for flat Earth are practically the same and can be divided in these categories:

3.1. Arguments 'by geometry'

Proof 83: The Egerö Light in Norway is 154 feet above highwater and visible from 28 statute miles where it should be 230 feet below the horizon.

If the Earth is assumed to be a featureless sphere, the distance to the horizon can easily be calculated. Since the line of sight is a tangent to the Earth, it is perpendicular to the radius at the horizon. This sets up a right triangle, with the sum of the radius and the height as the hypotenuse.

$$(R+h)^2 = R^2 + d^2,$$

$$R^2 + 2Rh + h^2 = R^2 + d^2,$$

$$d = \sqrt{h\,(2R+h)}. \tag{1}$$

Here d is the distance to the horizon, h height of the observer above sea level and R is radius of the Earth. If the observer is close to the surface of the earth, then it is valid to disregard h in the term $(2R+h)$, and the formula (1) becomes

$$d = \sqrt{2R+h}. \tag{2}$$

For the Eigerøy (sic!) lighthouse we can find that light sits at an elevation of 46.5 meters (153 ft) above sea level. According to equation (2) we calculate

$$D = 24.3\ \text{km} = 15.2\ \text{mi},$$

which is considerably less than in *Proof 83*. But, we have to take into account that we usually do not search for the lighthouse from the sea level. To compute the greatest distance at which an observer can see the top a lighthouse above the horizon, we have to calculate the distance to the horizon for an observer on top of that object, and add it to the observer's distance to the horizon.

This brings up another variable into the problem that is not listed in *Proof 83*. We can take $h_1 = 5$ m for ship deck height above the sea level. The result is

$$D_1 = 32.3\ \text{km} = 20.2\ \text{mi}.$$

It should be noted that due to light refraction in atmosphere, real range of vision is 7 % higher than calculated from trigonometry itself. A detailed derivation of this result can be found in [9], a simpler one in [10]. In that case, we calculated 21.6 miles, which is still a considerably lower value than 28 miles from *Proof 83*. But according to Wikipedia, the light of the Eiger Lighthouse can be seen from all directions for up to 18.8 nautical miles (34.8 km; 21.6 mi), which is an excellent agreement.

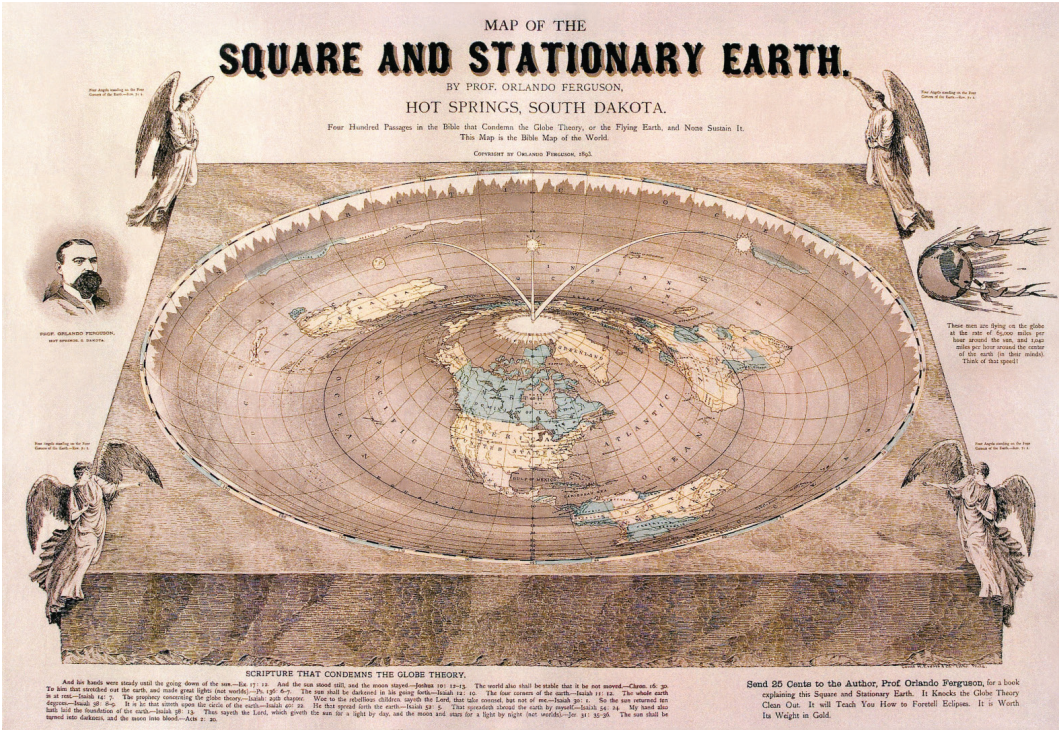

Figure 1. Flat Earth map drawn by Orlando Ferguson, 1893. This Orlando-Ferguson-flat-earth-map edit has been obtained by the author(s) from the Wikimedia website https://en.wikipedia.org/wiki/File:Orlando-Ferguson-flat-earth-map_edit.jpg, where it is stated to have been released into the public domain. It is included within this article on that basis.

It is unclear why the lighthouse should be 230 feet (70.1 m) below the horizon. It can be calculated that sea level is 94.9 m below the line of sight at 34.8 km and 157 m at 44.8 km (28 miles).

3.2. Ignoration of the Newton's laws

Proof 29: If the Earth and its atmosphere were constantly spinning Eastwards over 1000 mph, this should somewhere somehow be seen, heard, felt or measured by someone, yet no one in history has ever experienced this alleged Eastward motion; meanwhile, however, we can hear, feel and experimentally measure even the slightest Westward breeze.

This is is a basic misunderstanding of the first Newtonian law and the fact that the atmosphere (or cannon) rotates with the earth, an argument that can be provided by an elementary school pupil. If the advocates of the flat Earth theory are not capable of such simple reasoning, there is little point in exploring the Coriollis force and the influence of Earth's rotation on the direction of rotation of the tornadoes.

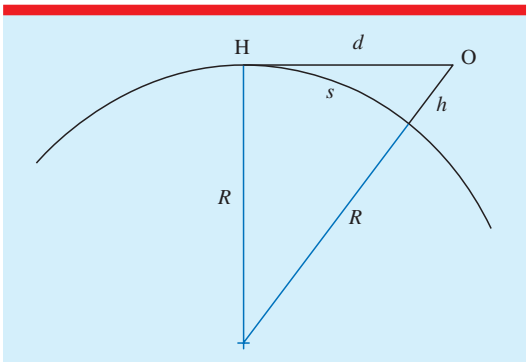

Figure 2. Geometrical distance to horizon by Pythagorean theorem.

Proof 33: If 'gravity' is credited with being a force strong enough to curve the massive expanse of oceans around a globular Earth, it would be impossible for fish and other creatures to swim through such forcefully held water.

This is a misunderstanding of Newton law of gravity. Gravitational force is proportional to the product of the masses. A force acting on the large

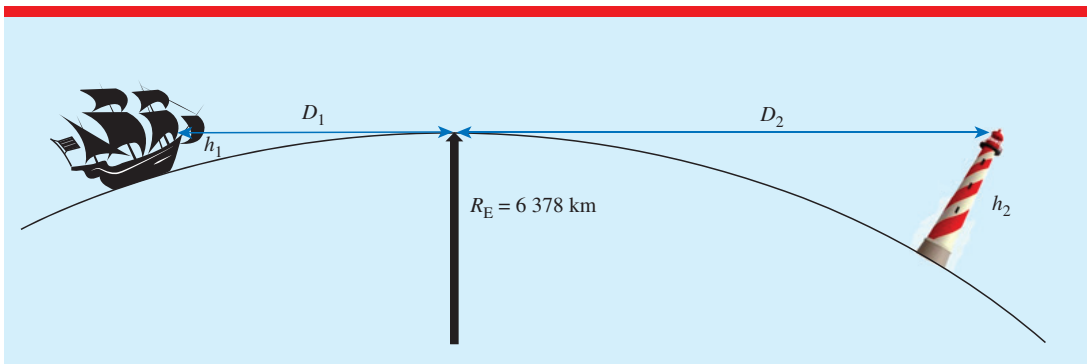

Figure 3. Visibility of the lighthouse.

mass of water in the ocean is of course higher in magnitude than that acting on the 'fish and other creatures'. Force acting on the mass is

$$F = mg,$$

where

$$g = \frac{GM_E}{R^2}.$$

Force is proportional to mass, so it is possible that the water in the oceans is also affected by the weak gravitational force of the Moon and causing tidal phenomena.

3.3. Flight routes and times

Proof 43) If Earth was a ball there are several flights in the Southern hemisphere which would have their quickest, straightest path over the Antarctic continent such as Santiago, Chile to Sydney, Australia. Instead of taking the shortest, quickest route in a straight line over Antarctica, all such flights detour all manner of directions away from Antarctica instead claiming the temperatures too cold for airplane travel!

In a fact, there are many flights taking advantage of shortest path. For example, Sydney to Santiago de Chile is 7000 miles long flight and takes about 12 h. This flight would be impossible on the flat Earth model. The straight route (red line in figure 4) would be over 17 000 miles. Covering that distance in 14 h would require a plane to go nearly twice the speed of sound. On the globe model, the great circle distance is only 6300 miles, comfortably reached with speeds of about 500 mph. This flight is extensively documented (including photographs compared to satellite images) by the aircraft crew member in [11].

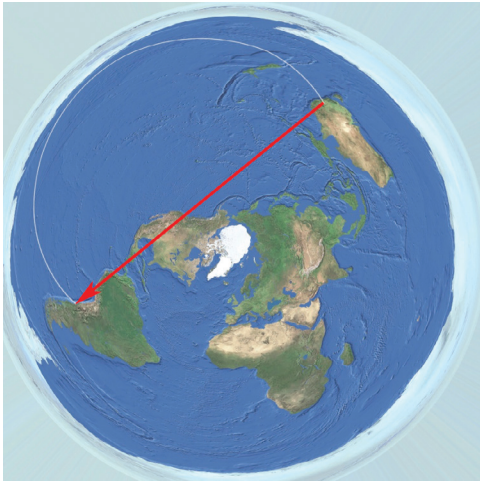

Figure 4. Flights on flat Earth.

A very nice treatment of flight times on the flat Earth and globe can be found in [12]. On a globe, flight times are proportional to great circle paths measured on the large globe (with correlation coefficient $R^2 = 0.98$), but not to distances measured on flat Earth ($R^2 = 0.34$). If a large globe is available, this simple measurement can be done during a lesson.

3.4. Angle of incidence

Proof 49: If Earth were a spinning ball heated by a Sun 93 million miles away, it would be impossible to have simultaneously sweltering summers in Africa while just a few thousand miles away bone-chilling frozen Arctic/Antarctic winters experiencing little to no heat from the Sun whatsoever. If the

Figure 5. Solar ray absorption during winter and summer.

heat from the Sun traveled 93 000 000 miles to the Sahara desert, it is absurd to assert that another 4000 miles (0.00004 %) further to Antarctica would completely negate such sweltering heat resulting in such drastic differences.

Proponents of flat Earth theory correctly point out that the difference in distance is not critical here, but they are forgetting that absorbed energy is affected by the angle of incidence. The energy from direct radiation collected by the Earth's surface decrease with increasing angle of incidence, as indicated by the width of the shaded areas. A panel tilted 90 degrees from the direction of the sunlight cannot collect any of the direct radiation.

These simple images (even though figure 5 is not to scale) provide a clear insight into the geometry of the problem. One can clearly see that on the left there is summer on the northern hemisphere and polar day behind the northern arctic circle, while on the right polar night is evident. To explain these phenomena on a flat Earth, it is necessary to devise very complex thought constructs which usually do not survive the encounter with Occam's razor.

4. Conclusion

Although it may seem unnecessary, we can mention here some convincing evidence that the earth is round and that it rotates: aristotle noticed that during lunar eclipses, the shadow on the Moon's surface is round. This shadow is the Earth's, and it is a great clue on the spherical shape of the Earth. Since the earth is rotating, the consistent oval-shadow it produces in each and every lunar eclipse proves that the earth is not only round but spherical. After returning from a trip to Egypt, Aristotle noted that 'there are stars seen in Egypt which are not seen in the northerly regions'. This phenomenon is only possible on the round Earth, and Aristotle claimed that the sphere of the Earth is 'of no great size, for otherwise the effect of so slight a change of place would not be quickly apparent' [13].

The curvature of Earth can be calculated with the simple setup described in [14, 15] or [16]. Definite proof of the Earth's rotation is the foucault pendulum. If it is not necessary that the pendulum to work 24 h a day (as in museum), a simple demonstration can be constructed very easily using, for example, a bowling ball hanging on piano wire (a similar construction is described in [17]).

Nowadays more than ever it is important to encourage students to learn critical and sceptical thinking and to adopt methods to help distinguish between ideas that are considered valid science and those that can be considered pseudoscience. Alongside almost classic publications [18] or [19] activities such as rigorous deconstruction of specific arguments of presented pseudoscientific theory, can be beneficial for students.

Also, students' participation in this refutation of individual 'proofs' is important not only for the consolidation of individual physical knowledge, but also for students to see the benefits of physics. By introducing these exercises into the teaching of physics and mathematics, we have succeeded in motivating students not only to do so, but also to make greater use of critical thinking when assessing information from the Internet.

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