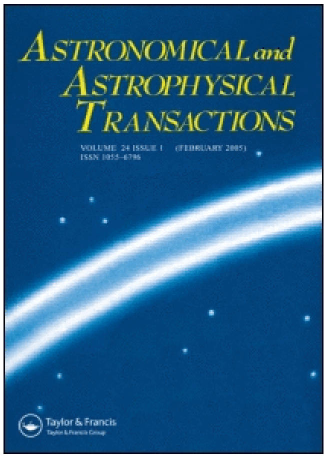

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L. V. Ksanfomality [a]
[a] Space Research Institute, Moscow

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IS IT FEASIBLE TO COMPLETE AN INTERSTELLAR EXPEDITION WITHIN SINGLE HUMAN LIFETIME?

L. V. KSANFOMALITY

Space Research Institute, 84/32 Profsoyuznaya str., 117810 Moscow

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We consider a possible future energy source: deuterium–helium thermonuclear reactions. When this source is used even with no losses the closest star (4.4 l.y.) cannot be reached during a human lifetime. Calculations prove that the average speed of such an interstellar probe consisting only of deuterium fuel (with no mass for any construction!) and the module for the astronauts with a mass of about 0.01 of the total mass of the mission, cannot exceed 17 600 km s^{-1}, and the two-way flight duration is 150 years. Even with a totally unrealistic mass of the module of 0.0001 of the total mass, it is still 105 years. Unless some as yet undiscovered physics leads to new sources of energy or means of travel, interstellar flights piloted by humans will remain a dream forever.

KEY WORDS Piloted interstellar flight energy

1 INTRODUCTION

The late Dr. Oliver, being not only the "Cyclops" project author (and of many other SETI problem publications) but also the inventor of the first pocker calculator, wrote many times that the whole Earth's economy is powerless to provide the tremendous amount of energy required for a piloted interstellar flight (Oliver, 1994). In fact "a piloted" here just means a fast flight (that could be an automatic mission too, intended for returning its material results during the lifetime of the mission authors). The duration of the two-way expedition to the nearest star (Alfa Centauri, 4.4 l.y.) should not exeed 40–50 years, which requires an average speed $V_{\rm av} = 0.2c$. The interstellar probe mass, according to some estimations, could not be less than 2000 tonnes (but could be much more as shown below). It is mainly fuel mass. For the 2000 tonnes mass to of reach the 0.2c speed, an energy of 10^{15} kW-h is required, which would equal 10 years of the entire Earth's production of energy. Taking into account the braking at the goal and energy expenses when returning, for the $V_{\rm av}$ shown above, the energy required would be much higher. That is why Oliver wrote about that as a ruinous enterprise. There is however, an another approach. The probe could be provided with an autonomous effective energy source, e.g. thermonuclear reactions.

2 AN IDEALIZED INTERSTELLAR PROBE

It is possible that motors using thermonuclear reactions are on the technological horizon. One could imagine that this kind of motor will permit interstellar manned flight. In this paper an estimation of the feasibility of such a flight is analysed. The following is an example of the absolutely ideal experiment, *with 100% efficiency* of the nuclear fuel use. The deuterium–helium thermonuclear reaction is the most powerful source of energy existing on Earth: 1.4×10^9 kW-h kg^{-1}. The interstellar probe is intended to reach the closest star (4.4 l.y.). Let us calculate the possible duration of the interstellar probe driven with this possible future energy source (deuterium–helium thermonuclear reactions).

We consider an idealized case and assume that the fuel is used without any loss and the entire energy is provided for acceleration or braking of the probe. The probe has no mass for an engine or for enything else except fuel and a small module for astronauts. The calculations have been made for three different masses m_m of the module for astronauts consisting of only 0.01, 0.001, or 0.0001 of the total mass M (no matter what the absolute mass is, say $M = 1$ kg). As it is only a fuel mass, it is absolutely useless to divide the probe into 1st, 2nd, and so on, stages: it is a single unit. This hypothesis that the probe has no mass for an engine has nothing in common with existing rocket techniques, nevertheless it shows the natural limits. There are four steps of the flight: acceleration up to speed $V_{\max}$ at the end of the first half of the flight; braking down up to full stop at the goal, and repetition of the sequence when returning. (There are other flight schemes, too – see Levantovskii, 1980). The relative part z of fuel spent at each step is the same:

$$z = (1 - m_m^{1/4}); \tag{1}$$

for $m_m = 0.01$, 0.001, or 0.0001, the spent part z is 0.684; 0.822, and 0.900. (For existing techniques it may consist of 0.4 and less, which means that it is not perfect). The well-known formula

$$V_{\max} = w \ln(M/(1 - z)) \tag{2}$$

is useless for the calculation of $V_{\max}$, as the speed of a thrusted propellant body w for this case is unknown (some authors supposed w could reach 100 km s^{-1}, – see Levantovskii, 1980. For our case it should be few ten times more).

3 A POSSIBLE DURATION AND THE SPEED LIMIT OF THE EXPEDITION

As metioned above, we consider an idealized case and assume that the entire energy production Q is transformed into kinetic energy of the probe, as the following equation shows:

$$2Q\,\mathrm{d}m = (m - \mathrm{d}m)(V + \mathrm{d}V)^2 - (m - \mathrm{d}m)V^2. \tag{3}$$

($\mathrm{d}m$ in the first member is the mass spent for acceleration; in the second it is the mass lost before the next step. In fact, it is the same). The energy produced by the deuterium–helium thermonuclear reaction is known; $6 \times 10^{-3}\ mc^2$, or $Q = 5.4 \times 10^{14}$ J kg^{-1} (Orir, 1979). When integrated, the three m_m produce $V_{\max}$ 35.3×10^3; 43.2×10^3, and 49.9×10^3 km s^{-1}. (This is not very high: crossing the Earth's globe in 1/3 s). The average speed V_{av} is two times less. The duration of the two-way flight T is:

$$T = 2(4.4\,\mathrm{l.y})c/V_{\mathrm{av}}, \tag{4}$$

that is 150; 122, and 105 year. This exceed a human lifetime even in this idealized experiment. (The speed of a thrusted propellant body w for this case is 7600; 6200, and 5400 km s^{-1}, much exceeding the estimation shown above).

4 CONCLUSION

The small difference in the expedition duration, despite quite different m_m, means just that $V_{\max}$ is close to the natural limit of this power source. Even for a quite unreal case, $m_m = 10^{-8}$, the $V_{\max}$ is 70×10^3 km s^{-1}.

One may compare the probe mass estimated above (2000 tonnes) with the results for three different masses m_m (0.01, 0.001, or 0.0001) and the module for the astronauts consisting of 50 tonnes. The calculated mass for the idealized probe is 5 000; 50 000 or 500 000 tonnes.

It is evident that the mass m_m must be much higher then our estimation, probably it would be close to 0.1. However it means that $V_{\max}$ is considerably lower, too. Which other kind of fuel besides deuterium–helium thermonuclear reactions may be considered? Antimatter does not exist naturally on Earth, and is very expensive to produce as mentioned by B. M. Oliver. Nevertheless, just for an estimation, let us consider the result of calculations for the annihilation reaction. The Q_a value for the annihilation is mc^2. For $m_m = 0.1$ the speed V_{av} of such an interstellar probe is close to 110×10^3 km s^{-1}. This means that a resonable duration of the expedition may be provided only by the annihilation reaction.

It seems that unless some as yet undiscovered physics leads to new sources of energy or means of travel, the human lifetime of a single generation is not enough for an interstellar piloted flight or for returning an automated probe.

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