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A6_4 Take Us Up

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Abstract

The Federation Starfleet Starship *U.S.S. Voyager*, the titular vessel in the 1995-2001 TV Show Star Trek: Voyager, was the first televised vessel in the Star Trek universe to feature landing gear. In this paper, we will analyse the required thrust to launch *U.S.S. Voyager* into an orbit of 250 km above Earth, the same orbit of the International Space Station. We further find that the required thrust in this scenario is comparable to that of $\sim$ 2640 Saturn V Rockets. This means the cost of launching *Voyager* today is $\sim$ \$1.4 Trillion.

Introduction

In the TV Show Star Trek: Voyager, it is shown that the titular vessel, *U.S.S. Voyager*, is capable of landing on the surface of planets, a first for the franchise. In this paper, we estimate the current day cost of launching this fictional ship into a Close Earth Orbit (CEO) of 250 km.

We do this by comparing the thrust required to accelerate *Voyager* to the parking orbit velocity at an altitude of 250 km to the thrust of a Saturn V rocket. By calculating the effective number of Saturn V rockets needed, we estimate the total cost of launching *Voyager*.

Thrust Derivation

First we must apply some restraints on the system due to the scope of this paper. For this calculation, we will ignore the effects of drag on *Voyager*, we will assume *Voyager* has a constant acceleration, and we will assume that *Voyager's* mass is constant. From [1] we know that *Voyager* has a mass m of $700,000$ metric tonnes. We also set the orbital altitude at $r = 250$ km.

First we determine the parking orbital velocity, v_p, at an altitude of 250 km. This is the velocity required for the spacecraft to stay at this altitude, and is given by Eq. (1):

$$v_p = \sqrt{\frac{GM_E}{R}} \tag{1}$$

Where $G = 6.67\text{x}10^{-11}$ $m^3kg^{-1}s^{-2}$ is the gravitational constant, $M_E = 5.972\text{x}10^{24}$ kg is the mass of the Earth, and R is the orbital radius, which includes the radius of the Earth.

By substituting in the values for the constants G and M_E, with an orbital radius of $R = 6371$ $km + 250$ km, we get a value for the parking velocity of $v_p = 7755$ ms^{-1}. By utilising a simple SUVAT equation, Eq. (2), and rearranging for a in Eq. (3):

$$v^2 = u^2 + 2as \tag{2}$$

$$a = \frac{v^2 - u^2}{2s}, \tag{3}$$

we find that the required acceleration for *Voyager* to experience in order to reach v_p at 250 km is $a = 120$ ms^{-1} from a stationary starting position. We can use SUVAT here as we have assumed a constant acceleration.

Now using Newton's second law, and by factoring in the gravitational force experienced by *Voyager*, $F_g = mg$, where $g = 9.81\ ms^{-1}$, we find that the required thrust to maintain this acceleration is $T_{voy} \approx 91\text{x}10^9 N$.

Cost Analysis

In order to obtain an estimate for the cost of launching *Voyager* today, we need to find a space vessel to use as a baseline. For this paper we decided to go with the famous Saturn V rocket, used for the Apollo Missions in the late 1960s and early 1970s. In 1970, the cost of making 5 Rocketdyne F-1 engines (the engines in a Saturn V first stage) was $\sim$ \$75 million [2]. Today this is $\sim$ \$525 million, due to inflation [3].

For simplicity, we only consider the peak thrust provided by the 1st stage of the Saturn V rocket. This is given as $T_{SV} = 34.5\text{x}10^6 N$ [4]. Therefore, in order to produce enough thrust to launch *Voyager*, we would require the equivalent of 2640 Saturn V rockets. By using our approximation of only the engine cost from above, this gives a cost estimate for the launch of $\sim$ \$1.4 trillion.

Conclusion

By equating the required thrust for *Voyager* to launch from the surface of the Earth to an equivalent number of Rocketdyne F-1 engines, the engines used in a Saturn V rocket, we determine an estimated cost of the launch to be $\sim$ \$1.4 trillion.

Although this seems like a potentially reasonable price for launching such a large object into space, there are certain factors to be considered which do have significant effects on this estimate.

Firstly, this cost is based upon the relative cost of building a space faring vessel with 1970s manufacturing techniques. As shown by SpaceX, the cost of sending 1kg of mass to space is much lower than it was 50 years ago [5]. This would definitely reduce the estimate in this paper.

This analysis also ignores the effect of drag on *Voyager*, which would have a minor effect on the thrust requirement. We omitted it as drag losses are usually minimal during a launch, but *Voyager* has a very different drag profile to a rocket.

We do not use the so-called rocket equation to simulate *Voyager's* motion, but rather a SUVAT equation. As vessels in the Star Trek universe do not use a fuel expulsion based propulsion system, attempting to apply current rocket theory would not be accurate to the problem. The approximation of constant acceleration is taken from observing the ship's motion on screen, as seen in the episode Basics, Part 1 [6]

To summarise, although this data is interesting, it is unlikely that a launch of a vessel this size will ever happen during the current era of space travel. A $700,000$ metric tonne vessel is incredibly large, and we as a civilisation don't currently have the ability to make a spaceship this large.

References

[1] Star Trek: Voyager: Season 5 Episode 23 - Relativity.

[2] `https://www.thespacereview.com/article/3724/1` [Accessed 02/11/2021].

[3] "How much is a dollar from the past worth today?" MeasuringWorth, 2021. `https://www.measuringworth.com/dollarvaluetoday/?amount=185000000&from=1970` [Accessed 02/11/2021].

[4] `https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-was-the-saturn-v-58.html` [Accessed 02/11/2021].

[5] The Recent Large Reduction in Space Launch Cost; Jones, H; ICES; 2018; `http://hdl.handle.net/2346/74082`

[6] Star Trek: Voyager: Season 2 Episode 26 - Basics, Part 1