Spinlaunch with Basic Physics

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1 Introduction

Today I was on the internet and I came across this company called Spinlaunch[1]. Watch this video. I immediately got excited, because when I was a kid I played Kerbal Space Program[2] and picked up the tiniest imaginable speck of rocket dynamics knowledge. I also remember high school physics pretty well because I had great teachers. So, I immediately realized 2 things:

- I could probably do really good back-of-the-envelope math for how much fuel mass Spinlaunch could save shooting things to orbit.
- It was gonna be a *lot* of mass saved. (or so I thought)

Go look at the spinlauncher in Figure 1. Pretty simple, right? Turns out we can work out how it ought to perform with one fact about rockets and Newton's laws of motion.

The Tsiolkovsky rocket equation Alright, time to learn some rocket science, again starting from basic physics. A rocket is a propulsion system that basically explodes some fuel and shoots it out in one direction. Then by the conservation of momentum the rocket gets pushed in the other direction. Consider what that looks like for a short period of time Δ_t. The rocket (with original mass m_0) releases Δ_m fuel traveling v_e m/s down. Since momentum is conserved,

$$\Delta_m v_e = (m_0 - \Delta_m) v_r,$$

where v_r is the rocket velocity.

Turns out, this is a differential equation when you include time:

$$m \frac{dv_r}{dt} = -v_e \frac{dm}{dt}. \tag{1}$$

Assuming v_e is constant, we can integrate it to get the Tsiolkovsky rocket equation:

$$\Delta V = v_e \log \frac{m_0}{m_f}, \tag{2}$$

[1] spinlaunch.com/
[2] kerbalspaceprogram.com/

Figure 1: A spinlauncher. Source here.

where ΔV is the total change in rocket velocity, m_0 is the initial rocket mass, and m_f is the final rocket mass. The fuel and oxidizer must make up $m_0 - m_f$ of the mass.

Spinlaunchers, Human Biology, and Free-Body Diagrams The natural question that came into my head when I saw this was, could I go to space in one of these things? It would be a pretty wild way to get up there. If not me then maybe cargo?

Check out the diagram in Figure 2. It's a spinlauncher in the language of high school physics. We know that if you're going around a loop you're gonna have some gravitational force mg and some normal force F_N acting on you. The sum of those two forces needs to equal your acceleration. If we assume no friction in the spinlauncher (apparently they have a vacuum tube) and no further forward acceleration by the time you hit the bottom the last loop, the diagram describes the full picture, where v_b is the velocity on the bottom. In particular Newton's second law gives you that

$$F_N - mg = m\frac{v_b^2}{r}$$

$$F_N = gm\left(1 + \frac{v_b^2}{gr}\right).$$

It turns out that under the common usage of the term 'pulling gees', the gees are equivalent to $\frac{F_N}{mg}$. So, gees $= 1 + \frac{v_b^2}{gr}$. We can rewrite this as

$$v_b = \sqrt{(\text{gees} - 1)gr}.$$

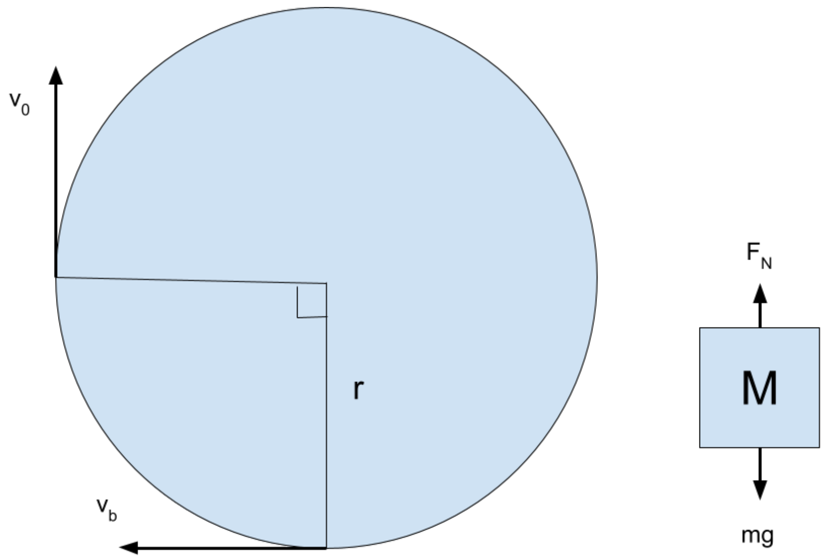

Figure 2: Rough diagram of spinlauncher physics

Finally, we can work out the relation between v_0 and v_b via conservation of energy:

$$mgr = \frac{1}{2}m(v_b - v_0)^2$$
$$v_b - v_0 = \sqrt{2gr}.$$

So, for a given spinlauncher radius and a given max gee load, the exit velocity v_0 is given by

$$v_0 = \sqrt{(gees - 1)gr} - \sqrt{2gr}. \tag{3}$$

Bringing the rockets back Say you had a rocket you were flinging around in a spinlauncher. How much fuel would it need to bring?

We can combine Equations 2 and 3 to give a clear answer. As our total achievable velocity in a vacuum for the rocket will be the rocket ΔV as well as the spinlauncher velocity, we can write

$$\Delta V_S = v_e \log \frac{m_0}{m_f} + \sqrt{(gees - 1)gr} - \sqrt{2gr}. \tag{4}$$

Getting to Orbit Turns out you can compute the requirements to getting to different kinds of orbit in terms of total ΔV required, when you do the appropriate integrals involving air resistance and especially gravity. Those are outside the scope of this document, but the numbers to note are that getting to the Xprize altitude of 100km requires 1.4 $\mathrm{km\,s^{-1}}$ in ΔV and getting to the kind of Low Earth Orbit (LEO) that, say the International Space Station lives at takes $9.4\text{km}\,\text{s}^{-1}$ in ΔV. So we can see how much fuel mass is required given different constraints and spinlauncher configurations.

Here we can plug in know values and see what things look like. If you're on a roller coaster, you can experience up to 6 gees. If you're a trained fighter pilot wearing a suit, this goes up to 9[3]. Apparently this is because we're made of water mostly and it gets kinda centrifuged out of the places where water needs to be in our body and that's not good for staying alive.

Not sure how big we'd build these things, but the Freedom Tower in NYC is roughly 1 km tall, that seems pretty big but maybe doable for r. A typical rocket engine has v_e of $2 - 4\text{km}\,\text{s}^{-1}$, gravity is 9.8m/s^2. Say we need to just get you to space for a quick trip, and it's a tiny, 100kg package doing it. You and a glider plus some oxygen or something.

If you look at Figure 3, it turns out that this is simply not useful in the human case. Even with more generous settings for cargo (see the notebook), this simply doesn't affect things much.

Perhaps under other assumptions the spinlauncher could be useful, so you should try them for yourself at this notebook.

[3] source

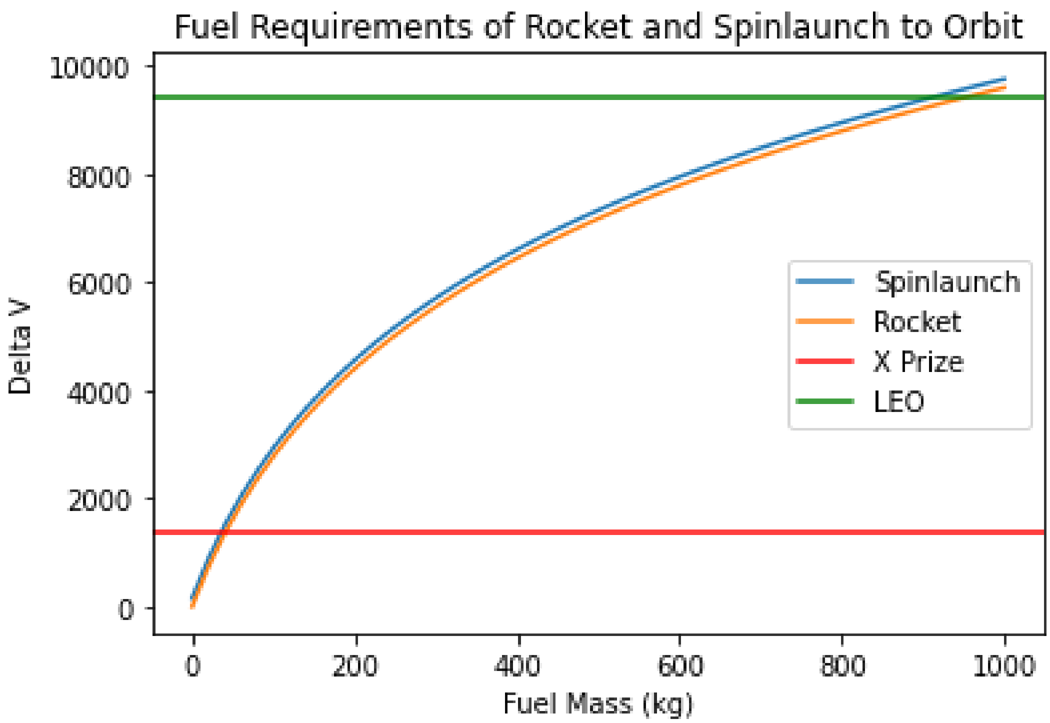

Figure 3: It seems like the spinlauncher is not actually affecting the fuel required to launch under these assumptions.