PEAK OF FLIGHT NEWSLETTER

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PEAK OF FLIGHT

The Reality of an Amateur Orbital Rocket

By Bobby Potter

Since the dawn of our hobby, many of us have dreamed of becoming the first amateur hobbyist to escape the confines of our planet. The goal is an admirable one, but is it even possible? What would it take?

I want to discuss the limiting factors here: The dominance of the rocket equation, the material strength and weight required, the minimum amount of funding needed, and what a potential success could look like.

What is the problem?

The problem is a complicated one; it is multi-faceted, and of a scope that is hard to get your head around. The first component that is often overlooked is what an orbital velocity actually is. You see, you can't just get to space and stay there. In reality, there is nearly as much gravity pulling on the astronauts on the space station as there is pulling on us here on the ground. The difference is in the horizontal velocity relative to the Earth. To get up and stay up, you need to be traveling around the globe so fast that your outward radial velocity is equal to the rate at which gravity pulls you to the Earth. Essentially, in orbit you are continuously falling toward the planet, just moving so fast that you keep missing it.

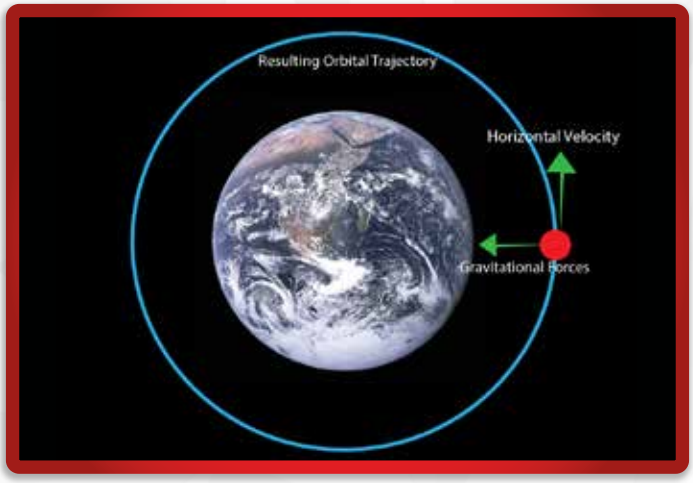

FIGURE 1: THE FORCES ACTING ON AN OBJECT IN ORBIT AND THE RESULTING ORBITAL TRAJECTORY

This requires a tremendous amount of speed. For some perspective, the space station manages to stay in orbit by traveling around the globe at 4.76 miles per second. A bullet from a gun only travels about half a mile per second (or about twice the speed of sound).

Propulsion

The first step to solving this problem is the propulsion systems needed to get to space. Some of us are familiar with the book "What-if?" written by Randall Monroe, where he details the amount of propellant needed for an amateur rocket, powered by commercially available motors, to reach orbit. The result was a structure that weighed more than the great pyramid in Egypt, built from 65,000 model rocket engines. I know of no airframe materials strong enough to carry the great pyramid, and so solid rocket motors are not going to be a viable option.

Konstantin Tsiolkovsky, a Soviet physicist, was the first to mathematically calculate the amount of force required to reach an orbital velocity in what has now been coined "The Rocket Equation". He hypothesized that by using liquid propellant, we could escape the confines of Earth and explore the stars. He was right, and using his equations we have started the journey to do just that.

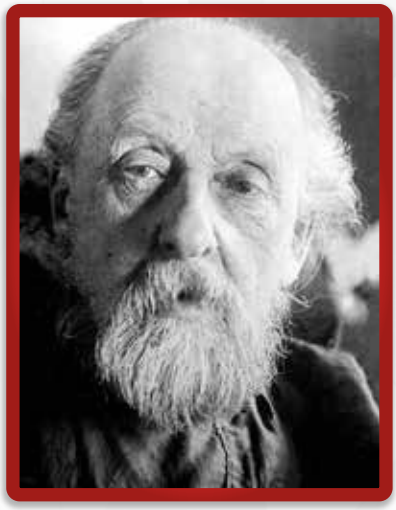

FIGURE 2: KONSTANTIN TSIOLKOVSKY, ONE OF THE FATHERS OF MODERN-DAY ROCKETRY

However these equations are very limiting, and every space organization on the planet has tried to beat them and failed. The rocket equation states that as the mass of your payload increases, so does the mass of the propellant required to reach orbit, and it quantifies the amount of propellant needed.

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So long as the best method we have for reaching space is liquid-propellant motors, this equation dominates what is possible. So much so that nearly every spacecraft ever made has had roughly the same payload mass to total mass ratio, regardless of design - maxing out at about 4%. Roughly 75% of the total weight of every orbital rocket is from the propellant alone.

Minimum Mass and Burn Duration

It isn't enough to make a rocket that is 75% propellant by mass, and a payload only around 4%. It must also be able to reach that orbital velocity. If you had a model rocket, say the size of the Zephyr, and it was powered by liquid-propellants, you would not have enough fuel to reach the speed required. The smallest rocket to ever reach orbit was a Japanese rocket called "SS-520-5". This rocket measured 9.5 meters tall and 0.5 meters in diameter, or roughly 32 ft tall and 1.5 ft in diameter, and weighed about 5,700 pounds. With a rocket this small, the vast majority of the weight is in the airframe, motor and fuel, leaving only the ability to carry a payload of about 9 lbs with it to low-Earth orbit. The SS-520-5 is incapable of reaching a higher orbit.

FIGURE 3: THE SS-520-5, PHOTO BY THE JAPAN AEROSPACE EXPLORATION AGENCY

But still, low-Earth orbit, that's a win. If we assume 75% of this rocket's mass was fuel, that would mean 4,275lbs of fuel. At wholesale rates for rocket grade kerosene and liquid oxygen, this would be around 25 cents per pound, or $1,068.75. Now that is actually extremely reasonable, and

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does lend some hope to the endeavour, at least as far as fuel costs are concerned.

The SS-520-5 also had an incredibly short burn duration for an orbital rocket. The motor burned for 4 minutes and 23 seconds. A commercially available model rocket motor will burn for less than 10 seconds (usually way less), and lose a great deal of thrust as the burn continues to deplete the fuel. Commonly for orbital rockets the motor will burn for 10 minutes or more, and liquid engines do not lose power as fuel is depleted.

Max Q and the Airframe

During the trip to Space, a rocket undergoes extreme temperatures and pressures created from traveling at such a high velocity through Earth's dense atmosphere. As the rocket picks up speed, these forces get larger and larger until the atmosphere starts to thin and the rocket can pass through it more easily. The moment of peak stress on the rocket is called the moment of "maximum dynamic pressure" or Max Q.

We've all seen fins stripped from a model rocket at launch, or airframes bent under the force exerted by a high-power motor, but we are talking about forces many orders of magnitude greater. Plywood components aren't going to get it done. Even if they survived the heat and pressure from the atmosphere, plywood does not have a strength-to-weight ratio capable of carrying several thousand pounds to orbit, or at least not while still being light enough to make it a viable for the rocket equation.

This means you need metal components, and not just metal, but metal with an incredibly high strength-to-weight ratio. The only real downside to metal, say stainless steel, is that it is incredibly heavy. The more your airframe weighs, the more fuel you need to get it to orbit, and the more fuel you have, the more fuel you need to get that fuel to altitude. It's a vicious cycle.

Active Guidance and Staging

In the world of amateur hobbyists, we use fins to keep our rocket stable. In the world of orbital rockets, this is not possible. Fins use airflow passing over the wings to guide a rocket's trajectory, but once you reach a certain altitude, there is not enough air to provide stability, regardless of velocity. That means you either have to use a cold-gas reaction control system or a thrust vectoring rocket engine. Not just with simple code either, but advanced systems for dynamic controls. It isn't enough to go up and move fast enough, you also have to be pointing in the right direction.

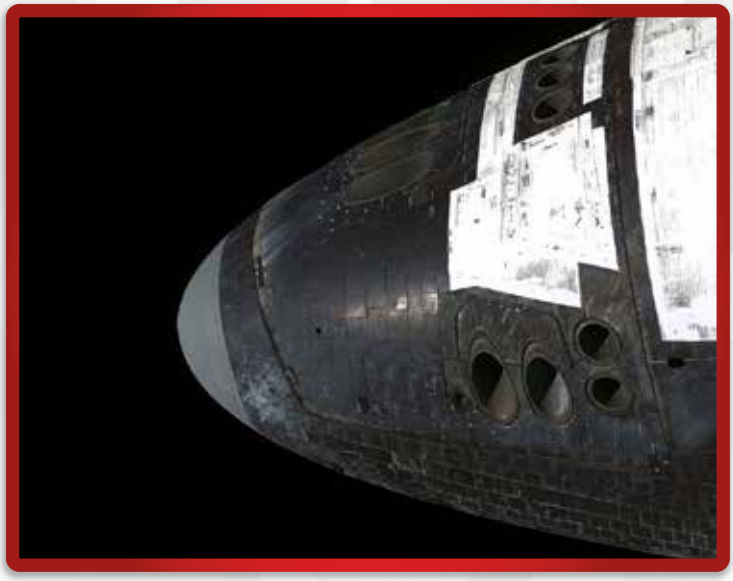

FIGURE 4: A COLD-GAS REACTION CONTROL SYSTEM FOR GUIDANCE ON THE NOSE OF DISCOVERY

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Cost

As we discussed, a minimum sized rocket, with rocket grade kerosene and liquid oxygen, would only cost a bit more than $1,000 for the fuel, but if that was the only cost barrier, people would have done it by now.

The larger costs come in the form of engineering prowess. How much does it cost to design, build and test a rocket engine? A lot. So much so that NASA is willing to pay $145,000,000 for EACH engine on the SLS (Space Launch System) Rocket.

That's a high price point though, even for the space industry, but regardless you are still looking at millions of dollars. Somewhere between $10-30 million for the low-end, at least as far as some of the publicly available pricing is concerned. This does not include the costs for the propellant tanks, turbo pumps, electronics to make it function, or the necessary active guidance systems. This is also assuming the engine you purchase is compatible with the rocket design you have. For instance, a single SpaceX Raptor engine is 3,300 pounds, more than half the weight of the SS-520-5, and therefore not an option. Remember, this does not include the weight of the fuel tanks, fuel, turbo pumps or airframe.

FIGURE 5: AN RS-25 ENGINE TO BE USED ON THE SLS. THE SLS WILL HAVE 4 OF THESE, GENERATING OVER A MILLION POUNDS OF THRUST DURING ITS FLIGHT.

Assuming you could design, test and build one of these yourself, and already had the tools and skills required for the task, you might be able to get the costs down near the raw materials themselves. Niobium alloy, a metal used in the construction of the Merlin engines, costs around $21.50 per pound at large scale pricing. That adds up quickly, coming to $21,500 for a 1k pound engine. This does not include the much more costly materials found in other parts of the engine, nor does it consider the cost of turning these raw materials into the components they make up. For reference, the Merlin 1D engine is the cheapest orbital rocket engine ever made, and it still costs nearly a million dollars each (for SpaceX to make, but they don't sell it). This does not include any of the original development costs.

So? I'm Rich and Brilliant, Ring It Up

Unfortunately, these are just looking at raw material costs, and an actual calculation would be impossible. Some rockets have upwards of 100,000 individual components, and there is just no way you could manufacture them all yourself. The tooling alone would be in the millions of dollars.

But, we can take a look at some of the cheapest attempts to reach orbit, as I imagine the costs could be similar.

The Electron Rocket from Rocket Lab is one of the smallest orbital rockets in use today, and one of the cheap-

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est. Although this rocket can only deliver about 500lbs to orbit, back in 2018 they only charged $5 million per launch. At the time, they were far from reuse, so it can be assumed the cost for the raw materials was substantially less. This is hopeful, as it means it is possible to build an orbital rocket in the low millions.

FIGURE 6: THE ELECTRON ROCKET TAKING FLIGHT

Japan's SS-520-5 would likely be even cheaper, as it originally was a sounding rocket that was modified to orbital capabilities, and a sounding rocket can be as cheap as a million dollars. That being said, it took 5 iterations of design (including 3 attempts) to finally get one into orbit, so development costs were likely far higher than the price tag would indicate. As it stands, Japan does not sell use of this rocket, so we have no way to guess at what the cost of the rocket actually is.

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Conclusion

It seems possible, but in reality it is quite far-fetched. We didn't even consider all the legal barriers here, which would be considerable challenges. If you did all the design and engineering yourself, it would likely take several lifetimes. SpaceX was founded in 2002, and they didn't put a rocket into orbit until 2008. At the time, they had 500 employees. If you got those engineers for the low-low price of $60,000 a year each, that same time frame would add an additional $180,000,000 to your costs. Your only hope would be to get aerospace companies to donate these technologies to your cause, but then, is it even a hobbyist rocket anymore?

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