False KSP Lessons

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Moving from Kerbin to Earth

Growing up on Kerbin, we often learn facts about the universe that just don't apply when we move to Earth.

1. **Myth: MOAR BOOSTERS is a pilot's best friend.**

   Fact: In fact, there are two major downsides to a high TWR: the chance of ripping apart your vessel (or it being uncontrollable) due to aerodynamic forces, and the massive mass penalty you suffer for having such a high TWR. A third major downside (you're stuck with the high thrust, can't throttle down) is covered in Myth 2. In real life, launch vehicles often have very low thrust / long burn-time upper stages. The current EELVs, for example, have upper stages with burn times of 10-20 minutes and ignition TWRs of less than 0.2! A few "puny" (by KSP lights) engines in a cluster should be enough for most upper stages--even one might be enough! Remember, the lighter your engine, the lighter your stage, and the higher mass ratio you can achieve, and delta V is a function of mass ratio. Where TWR does matter is in the first 30 seconds or so of flight, maybe up to the first minute or two; there, it's nice to have a high TWR for the same reason TWR later doesn't matter: TWR lowers gravity losses, but most gravity losses occur in the first minute, especially the first seconds, of flight. A near-optimal configuration for LEO is some small (30s burntime) strapon solids, a 3 minute core, and a 6 minute upper stage. If you find yourself adding MOAR BOOSTERS, it's time for a redesign.

2. **Myth: Rocket engines all throttle down to 0.1%.**

   Fact: In fact, very few rocket engines throttle. Engines designed for landing (like the LMDE) do, that's called deep throttling, and the LMDE got down to about 10% max thrust. Some modern first-stage engines do, to decrease G loads on the crew (called shallow throttling, i.e. down to 70% or so). The RS-25 Space Shuttle Main Engine (SSME) is an example of the latter. Other than that, engines do not throttle, and g-loads are managed by shutting down some engines early.

3. **Myth: Rocket engines are infinitely restartable.**

   Fact: In fact, restarting an engine is a tricky prospect, requires just the right conditions, and even then most engines only have a limited number of restarts. Issues such as freefall causing propellants to float away from their feed lines complicate the matter. To solve this, LVs use small motors called "ullage motors" to settle the propellants before igniting their main engines. Spacecraft often use RCS for this purpose. Assuming propellants are settled, the engine must be able to ignite; most first stage engines have only one ignition (often provided externally), though some upper stage engines have multiple ignitions. Because of their simplicity--needing neither to ignite their propellants nor spin up a turbopump--pressure-fed hypergolic engines have effectively infinite ignitions. Indeed, that's all RCS is: sets of small hypergolic (or catalyzed monopropellant or cold-gas) pressure-fed engines.

4. **Myth: You burn up to get an apoapsis, then burn right to circularize.**

   Fact: In fact, many LVs perform their ascent to parking orbit in a single burn, interrupted only by staging. While the "burn up, then burn right" thing is no longer as common in KSP as it used to be, thanks to the new aerodynamics model, the size of the planet alone (compared to its atmosphere height) means that most ascents will be two-burn affairs: perform a gravity turn to establish an apoapsis, then perform a multi-hundred-m/s circularization burn at apoapsis to establish orbit. In real life, not only do most LVs not burn for apogee and then coast (only the early things like Juno I / Juno II did that, due to their fast-burn solid kick motors), they keep burning **well after** apogee. Indeed, the most efficient ascent may involve boosting higher than one's desired orbital altitude and falling back down, burning all the while, canceling vertical velocity at the instant one reaches orbital velocity (and at the desired altitude). Many modern LVs with their long-burning hydrolox upper stages use this method, as did Saturn V. This is because the steering losses encountered are very minor compared to the delta V gained by having such long-burn-time (and consequently high-mass-ratio) stages. Even if you don't circularize after apogee, however, you still likely won't have time (or a restartable engine) to allow for a coast and a long circularization burn; the "gravity turn" portion of most ascents takes up only the first three minutes or so of a 7 to 12+ minute ascent. The remaining time involves pitching to manage apogee (and time to apogee), or if circularizing after apogee, pitching to manage sink rate and establish desired final perigee. Oh, one more note: the "apogee" you ascend towards and insert at becomes the *perigee* of your parking orbit; a mere RCS burn alone should be enough to circularize the parking orbit to the desired orbit once you reach apogee.

5. **Myth: All propellants are created equal.**

   Fact: In fact, rocket propellants are the subjects of books and hundreds of thousands of hours of research. Each propellant mixture is carefully selected for its strengths and compatibility with the mission profile. Kerosene-liquid oxygen (Kerolox), liquid hydrogen-liquid oxygen (Hydrolox), and storables are the three most common propellant mixtures for chemical rocket engines, and each have their advantages and disadvantages. Nuclear-Thermal Rockets (NTR) in most reference designs use liquid hydrogen as propellant, though are capable of using other propellants such as ammonia, methane, and water. *Ignition!* by John D. Clark is an entertaining informal history of the subject of rocket fuels.
   Just to put it in perspective, a modern kerolox mixture is about 1kg/liter and yields around 350s specific impulse in vacuum, whereas LH2 (as used by a NTR) is 1/14th as dense (0.07085kg/l) and may yield up to 1000s in a NTR. Hydrolox is only 1/2.84 as dense as kerolox, and provides up to around 460s specific impulse in vacuum. The advantage of hypergolic storables is that they do not 'boil off' since they are liquids at room temperature (storable) and ignite on contact with each other (hypergolic), as well as often being more dense (up to well over 2kg/l) but have much, much lower performance.

6. **Myth: Rocket engines and fuel tanks are heavy.**

   Fact: In fact, rocket engines have very, very high thrust to weight ratios (maxing out over 150:1). As for fuel tanks, perhaps the rocket stage with the highest fuel fraction was the Atlas D sustainer: loaded mass 113 tonnes, dry mass 2.347 tons. That includes not just the tanks' dry masses, but the engine, guidance, pressurant, and everything else a rocket stage needs. This only applies to liquid engines and tanks in KSP, however: KSP's solid rockets have more or less reasonable dry masses (a bit high, but well within the range) and its nuclear engine has a spot-on TWR; it's really only the conventional liquid engines and their tanks that underperform so horribly (too heavy by a factor of 3 to 8).

7. **Myth: Reaction wheels are magical all-powerful devices, you can turn a spacecraft on a dime with them.**

Fact: In fact, attitude on spacecraft is often handled through the use of gimbaled thrust and reaction control thrusters. Reaction wheels have limited ability to modify the attitude of a spacecraft, especially under thrust, and can only apply torque for so long since doing so spins them up. Eventually they have to be "spun down" with RCS. They are used for very fine, low-torque applications, like keeping ISS oriented correctly with respect to Earth or keeping a telescope oriented just so.

8. **Myth: Orbital rendezvous is easy and can be done from almost any starting orbit.**

   Fact: In fact, orbital rendezvous is quite difficult to get correct, especially when starting from a non-equatorial launch site. While a rocket can indeed carry enough propellant to make KSP-style rendezvous from wildly different (more than 1*!) orbital inclinations and planes, this requires not putting as much mass to orbit as possible with the given launch vehicle. This is not done because each launch costs many millions of Dollars/Rubles /Euros, so launch providers and their clients want to use payload mass as efficiently as possible.
   To do so, you must first wait until the target orbit is over the launch site and launch into the same plane as the target. In reality, a small amount of reserve delta-vee (dV) can be used near the beginning of launch to turn a 'dogleg' to move the ascent path into the correct plane. The Space Shuttle had enough excess capacity to launch in a ten-minute window and still ascend to the target orbit. This is done early in the ascent when steering losses are low due to the low downrange velocity.
   Secondly, the ascending payload is usually launched into a slightly lower orbit slightly behind the target spacecraft. This is called a 'chaser orbit.' This is again, done for efficiency reasons, as it takes less dV than ascending to a higher 'leader orbit.' The chaser vehicle then takes a number of orbits to catch up to the target, slowly adjusting its orbit to get a low-velocity approach, again for efficiency reasons. Low velocity approaches are also safer for both vehicles in the event of an abort. This is both easier and safer than a direct 'launch to rendezvous.'

9. **Myth: A heatshield is a heatshield, and it's enough for any reentry/aerocapture. And shallower is better.**

   Fact: In fact, reentry is incredibly dangerous, and the heat load difference and peak flux difference between a low orbit reentry and a translunar / interplanetary reentry can be orders of magnitude. A heat shield rated for low orbit reentries probably won't survive reentry from high orbit or translunar reentry, and to due to the unpredictable nature of other atmospheres, craft have either propulsively captured or gone from space to reentry in one go, rather than aerocapturing (as was common in KSP). Many of the early capsules (and other reentry vehicles) were only rated for LEO reentries and won't survive faster ones. If your shield does not say it is lunar rated (or, if part of a capsule, if the capsule was not designed for lunar reentry) you will not survive reentry. Further, while shallower reentries keep peak heat flux low, they do not minimize total heat load. In fact, assuming your heat shield can survive a higher heat flux, a steeper reentry may well be safer (assuming your crew, if any, can withstand the G load). Early RVs were designed as 'heat-sink' RVs: they had fairly steep reentries with high peak heating but low total heat loads; they just had to survive until the heating stopped, at which point the sinked heat could be radiated / convected away. Mercury, though it added an ablative shield to the mix, shared this basic pattern: A negative perigee reentry that gave 9G peak deceleration even from only LEO meant fairly low heat loads in total. Lifting reentries go to the other extreme: the total heat load for a lifting reentry is much, much higher than a ballistic reentry, but the peak heat flux is much lower; that allows the heat shielding to radiate away the heat over time (though, in cases other than STS, with the aid of ablation). The kind of reentry you need to fly (and indeed the kinds of reentry you can't even attempt) depend on your RV design.