Reflection and Technical Investigation of SpaceX as Proposed By Eric Berger in “Reentry”

Jack Liedel

In *Reentry*, author Eric Berger details the intricate journey of SpaceX, from start-up to the world's leading rocket manufacturer. He accomplishes this mainly through employee interviews, although he does analyze previous SpaceX launches, making sure to comment on their performance and respective implications. Throughout this paper, I will provide a background for Eric Berger, commenting on his previous accomplishments that lend credit towards the technical proficiency of his story. I will then analyze, critique, and synthesize Berger's work into a discussion of SpaceX's implications on the Aerospace industry as well as offering a possible timeline for competition catch-up. Finally, I will analyze a relevant engineering to SpaceX's fundamental company mission as portrayed by Berger. This philosophical reflection and simulation framework will ultimately conclude in the reader's greater understanding of SpaceX and its mission with respect to the information embedded in *Reentry*, as well as narrate the feasibility of Starship in achieving the fundamental extraterrestrial ambitions of SpaceX.

Before recounting the content of the book, it is best to start with a narration of the author. Eric Berger started his professional career as an astronomy major at the University of Texas. After losing interest in pursuing the field long term, he earned his masters in journalism from the University of Missouri. Shortly after graduating, he began work at the *Houston Chronicle* in late 1998. After working as the general assignments reporter, he transitioned to the science desk where his background in astronomy and meteorology ultimately allowed him to earn the 2009 Pulitzer prize for his coverage of Hurricane Ike and its effects over the eastern half of the continental United States. After this, Berger dissociated from the *Houston Chronicle,* later joining *Ars Technica* and simultaneously starting the *Space City Weather* blog in late 2015. At the same time, he picked up covering United States aerospace companies such as SpaceX, Blue Origin and NASA. From these interactions, Berger birthed his first book *Liftoff* and later *Reentry* which acted primarily as a sequel to the former, narrating the rise of SpaceX's influence through the advent of the Dragon and Falcon programs.

Now, it is best to detail the general development of the company as told through the lens of Berger. Chapters 1 through 5 indicate SpaceX's early struggle developing the Falcon 1 and 9. The team started comparatively few engineers and technicians, a majority of which coming from distinct backgrounds which may not have had relevance in aerospace. Most of the company's struggle took place surrounding the rapid development of Falcon 1, which was a partially expendable rocket meant for delivering satellites and other small payloads into orbit.

Comparatively meager to its later counterpart, the Falcon 9, this iteration focused on securing SpaceX's name in rocketry the market for potential investors and customers. Therefore, Berger recalls that the engineers were focused more on building a rocket that *worked* rather than building one that was elegant (such as a self guided booster stage). Expectedly, Falcon 1 failed three out of the five times it was launched; all equally violent and embarrassing. On its first attempt, the Merlin engines failed approximately 30 seconds after launch. This was most likely due to a corroded aluminum component which caused a fuel leak and subsequent fire. The second launch of Falcon 1 featured another failure, this time due to a premature second stage cutoff before reaching orbit. This caused the second stage to violently fall back to Earth, compromising the mission and its desperately desired success. The final failure occurred due to the first stage of the rocket colliding with the second. This was due mainly to the engineers overestimation of exactly how long thrust would remain after the main engine valve shut off. Although this issue was quickly resolved by the engineers, it was not received well publicly, even more so since this failure caused the loss of the Trailblazer satellite, which was used for important military purposes.

During this time, SpaceX was rapidly developing an operations site in McGregor, Texas. This site was formerly owned by a company with a similar mission: Beal Aerospace. Beal was a company started by Andrew Beal to create a low-cost heavy lift rocket (similar to the mission of SpaceX). However, in 2000 it was shut down due to significant competition from Boeing and Lockheed. Yet the operations site once held by Beal maintained significant rocket testing infrastructure. The most relevant for SpaceX was a concrete propulsion testing apparatus aptly named 'the tripod' in lieu of its unique three-legged geometry. This 100-foot tall device was used extensively in development of the Merlin engines that were employed on all Falcon 1 launches.

Around the same time, Musk and other high ranking engineers like Tom Mueller and Ricky Lim rapidly expanded employee workforce, taking the team from just 10 engineers in 2002 to 500 by 2008 exponentially increasing SpaceX's performance. Yet this team's general focus never changed in this period. The development of the Falcon 1 rocket was all that mattered to Elon. For if it proved successful, it would have secured a $1.6 billion NASA contract for ISS resupply missions as part of the Commercial Resupply Services (CRS) program. This came at a troubling time for Musk financially. With both SpaceX and Tesla floundering, along with rumors of SpaceX not being able to make payroll, failure would have all but guaranteed SpaceX and

Musk's financial ruin. However, with the success of the fourth flight of Falcon 1, SpaceX was awarded the CRS contract in December of 2008.

Although the CRS award served as a massive milestone for the early SpaceX, it still did not completely mend the company's troubling financial situation. Mainly, this was because the award used milestone-based payments, which intrinsically prevented Musk from tapping into immediate capital to fund rocket research and development. Thus, this team switched focus to a new, more demanding, project, not having the time or money to continue work on the Falcon 1 that occupied their minds for the past six years.

In addition to ridicule by competitors (like Lockheed Martin and Boeing rocket conglomerate United Launch Alliance), constant engineering setbacks and seemingly nonstop work hours made SpaceX an volatile workplace internally. With desires from Musk to keep accelerating this pace amid these failures to stay on track for contract milestone achievement, resulted in the company's success seeming indeterminate. Additionally, by having the goal to significantly reduce spaceflight cost for ISS travel, having a reusable booster stage was deemed necessary by leadership, necessitating rapid vehicle testing. This daunting string of tasks and project constraints was chalked up as the drawbacks to rapidly creating this new project, which was more powerful and efficient than Falcon 1. This project, later named Falcon 9 and more broadly the Dragon spacecraft, served as the operational method by which Musk intended to reach the ISS. To begin development, the team recycled the Merlin engines powering the Falcon 1 as they did not have the time, nor the money (once again) to develop a 'Merlin 2' engine. The governing philosophy was to make this rocket more powerful, instead of having five engines, like what was initially proposed when SpaceX won its first smaller NASA grant in 2006, the team worked towards a rocket with *nine* engines. This task was incredibly daunting, mainly due to the extreme structural and thermal effects of having such a large number of high-powered components at such a small distance away from each other.

With substantial development of Falcon 9 SpaceX officially launched its first test flight in the summer of 2010. Although the rocket was planned to be reusable, self guided descent was not yet implemented, thus causing the rocket's first stage to be lost into the ocean upon parachute guided descent. The second stage, Dragon, was successfully placed into orbit, later splashing down into the Pacific Ocean. This mission was mainly about proving the viability of Falcon 9 for future contracts and development and the milestone payment from the Commercial Orbital

Transportation Services grant came as a bonus, taking a substantial amount of stress off of the company. The next few months were dedicated solely to putting the scaled up version of the aforementioned rocket, Cargo Dragon, into orbit and docking with the ISS. Similar to the last flight, the payload Dragon was launched on the Falcon 9 booster. However, this mission focused primarily on demonstrating Dragons capabilities in relation to docking with the ISS. Although a docking maneuver was never actually implemented (instead performing flybys), the tasks performed by the spacecraft demonstrated Dragon's mechanistic sophistication and its ability to eventually deliver cargo to the ISS.

With Musk satisfied with the success of his rocket company, the casual reader might infer that he would lessen the crushing pressure he imposed on the SpaceX engineers. However, because NASA demanded a higher payload capacity than what the aforementioned Falcon 9 could lift, Musk demanded a redesign of their former rocket. This new Falcon 9 iteration (creatively named Falcon 9 v1.1) featured the upgraded Merlin 1D engine which could produce more thrust than the former Merlin engines that flew on all previous launches. Additionally, the booster was upgraded with larger LOX and RP-1 (a refined version of kerosene), for greater efficiency and power components. In October 2011, this design iteration was put through its first test flight, with successful performance. With all NASA testing milestones seemingly achieved, and a relentless Musk leading the helm, SpaceX was on track to perform its first commercial resupply mission to the ISS. Finally, only one year after the first test flight of the Falcon 9 v1.1, Cargo Dragon successfully docked to the ISS.

After celebrating and taking one 'magical' week off from SpaceX, Musk returned to the inboxes of employees demanding a new chapter for the company: reusability. The first prototype to stem from this vision was the Grasshopper, which almost all employees deemed was unnecessary. In general, this pseudo-rocket would launch to about 11500 ft and then activate reverse thrusting, ultimately landing on its four attached lander legs. The Grasshopper was later upgraded to F9R Dev1 which was constructed from a previously flown Falcon 9 stage with the Grasshopper's former legs. Although there was pushback from the employees, the relentless driving force for this program's continuation came from Elon and a few other high ranking SpaceX associates. Berger claims that the leadership's judgement turned out to be beneficial for company progress, as this program gave important insights to self-guided falcon landings, providing a significant leap in rocket reusability. About a year later, using this technology, SpaceX successfully landed the Falcon 9 booster stage in a controlled descent onto a drone ship. Another year after that, in December 2015, Falcon 9 landed on soil after successfully launching Orbcomm OG2 providing an unseen and unexpected success for Musk's reusable rocket. After these two successes, Falcon 9 kept launching and landing successfully, surpassing all expectations of the United Launch Alliance, Northrop Gumman, and NASA. In total, the cost of spaceflight dropped significantly relative to the similarly ambitious Space Shuttle and all other launch vehicles. With these successes under his belt, Berger indicates that Musk turned his attention to a new project: Starship.

Berger points out that although Musk had always said in public that the reason for SpaceX's founding was to populate Mars, no one *actually* took him seriously. That was until Musk sent out an email to all workers demanding all company work to focus on another new project, Starship, whose sole purpose was to achieve this ambition. Initial Starship testing began with its first prototype, Starhopper. Inspired by the Falcon prototype, Grasshopper, Starhopper embodied the same core function; that is low altitude launches with careful self guided control. The company has since moved onto SN (or serial number) prototypes with tests like SN8 reaching altitudes up to 10 km, but ultimately failing on attempting self-guided landing. By mid 2021, however, tests SN15 and SN16 proved successful, with a high altitude flight and complete self-guided landing.

Berger ends this recount of the Falcon and Starship development by highlighting the previously unexpected success of SpaceX today. He claims that despite the hardships faced internal and external (citing Musk specifically), SpaceX continues to sit on the bleeding edge of rocket technology with no signs of being dethroned. The perseverance of the workers in face of these challenges highlights the grit, intelligence, and determination of the company and its willingness to go beyond expectation. Ultimately their work has paid off for our generation and future ones, and hopefully may serve as the method by which the latter steps foot on a new planet: Mars.

Overall, I believe that this work serves as a tremendously precise recounting of SpaceX's company journey. It highlights the individual achievements, ambition, and set-backs, while simultaneously narrating the general goals of the company in a personal and temporal sense. It was truly wonderful seeing where SpaceX came from. Starting with just 10 employees in 2002 to becoming perhaps the most advanced rocket company in the world is truly awe-inspiring and particularly relevant to my work as an engineer. Yet, I think Berger too often simply summarizes SpaceX. Although he does allow a human element to the story, for example focusing on workers such as Mueller and Rose, he ultimately neglects to consider SpaceX's development through a perspective external to the company. Ultimately I maintain that while Berger accurately retells the trajectory of the company, he does not do much beyond this, which, in my opinion, leaves the reader unfulfilled.

But I want to focus the rest of my comments on how this book makes me feel in relation to important political contexts. I mention these two modes because I think it is important for viewing SpaceX, and more specifically its leader, holistically. It is obvious that Elon has taken a *somewhat* controversial position on the political front. Therefore, when viewing his highly opinionated politics it is intrinsic that one forms some sort of intuition on his personal values. But after analyzing how he runs his companies, it makes sense that he would act the way he does politically. For one, he is unbelievably harsh and demanding on his employees. As Berger points out, although he compensates highly and provides generous stock options, he requires an extreme amount of accomplishment and does not hesitate to fire one at any time, as seen by his treatment of Carlson and Thompson (Berger 63). Although I have heard this from friends who work at SpaceX, it is more substantial to *quantify* the amount of work and hear *exactly* what employees had to endure. It is no secret that Musk is mean, but hearing the stories of his reactions to company failures as well as successes is troublesome. This confirms some of the assumptions that I have had from my encounters with him on the political front. I do maintain though that his company's mission is virtuous, and further his commitment to it. Although the prospect of inhabiting Mars seems like a scheme to collect more investor revenue and publicity, it seems that Elon is taking active steps to achieve this. In general, because I believe taking steps to ensure human survival is fundamentally good, I maintain that Musk is virtuous in this context.

Overall, Eric Berger's *Reentry* provides a thorough and insightful summary of SpaceX's journey, carefully highlighting its triumphs and set-backs. Through individual employee interviews and external technical analysis, he successfully displays the ambition and perseverance that have defined the company's rise in the rocketry industry. Yet, while the book recounts SpaceX's internal development, I believe that it would have benefited from an analysis of the broader social implications of the company, especially in lieu of the current political landscape. Nevertheless, Berger's work underscores the feasibility of Falcon and Starship and what this means for the future of space exploration. It is clear after reading this book, that as the company pushes the boundaries of technology, it will intrinsically shape the future of the rocket industry at large, and more broadly humanity's potential for extraterrestrial development.

Problem Definition and Abstract

In order to understand SpaceX's product trajectory dynamics, it is necessary to perform a numerical 2 dimensional simulation on a chosen, relevant, aeronautical situation. In this case, a two dimensional simulation that describes Starship's trajectory to Mars is investigated. This involves a starting altitude of 10000 km from Earth's center when radial thrusting occurs. The precise initial position value serves as the desired starting altitude, as it will allow Starship to get close to the surface of Earth, entering into the lowest stages of LEO at ~6570 km during imposed elliptical orbit. This results in a comparatively higher tangential velocity to significantly decrease total energy required for exiting Earth's orbit. After the maximum tangential velocity is reached, both radial and tangential thrusting occurs. The magnitude of radial thrusting is imposed as exactly equal to the magnitude of gravitational force that occurs on Starship. The remaining thrust is applied directly to the tangential direction to speed up starship as it leaves LEO. No more thrust is applied during transit as all remaining fuel is used during this second stage. In the final stage of analysis, Starship approaches Mars, travelling radially at ~9300 m/s. This speed ensures a relatively short travel time to Mars at the expense of a high entrance velocity.

Assumptions and Possible Limitations

The power of the Super Heavy Booster must be such to allow Starship to arrive at the starting altitude of 10000 km above sea level. If it cannot, then this proposed mission operation is deemed irrelevant mainly because the velocity gains associated with tangential thrusting at lower stages of elliptical orbits cannot be achieved without getting this far from Earth's surface. Additionally, 'multidirectional' thrusting is computed in this simulation. In practice, this would be done by rotating Starship at an angle such that the radial component of its thrust is exactly equal to the radially acting force of gravity from earth. This requires a rotation of Starship about its center of gravity which intrinsically demands either vector thrusting or more complicated rotational dynamics imposed by the booster stage or six raptor engines during ascent or tangential thrusting, respectively. Either method is beyond the scope of this simulation. Finally, this study does not analyze the landing methodology of Starship. This is of particular concern because the low Mars orbit entrance velocity is very high. There are methods to slow the ship down for arrival. However, this would increase total travel time and those more complicated methods would justify significant analysis that is beyond this simulation's scope.

Governing Equations:

Stage 1:

Integrated in ODE45

$$\frac{dv}{dt} = \frac{h^2}{r(t)^3} - \frac{GM_e}{r(t)^2} + \frac{T}{m_{Structure} + m_{fuel}(t)}$$

$$m_{fuel}(t) = \frac{dm_{fuel}}{dt} t$$

$$\frac{dm_{fuel}}{dt} = -\frac{T}{I_{sp} g_{0,e}}$$

$$h = r_0 \times V_{Leo,i}$$

$$V_{Leo,i} = 9.81\sqrt{\frac{(6600\times10^3)^2}{r_0^2}}$$

$$\omega = h/r(t)^2$$

Time domain: [0 s, 20755 s] | M.E.C.O at t = 200 s so enough fuel remains for stage 2

Plotting,

$$x(t) = r(t) \times cos(\omega)$$

$$y(t) = r(t) \times sin(\omega)$$

Stage 2: Completes computation when fuel mass ($m_{fuel}(t)$) is zero.

Integrated in ODE45

$$\frac{dv_{tan}}{dt} = \frac{T}{m_{Structure} + m_{fuel}(t)}(1 - \gamma)$$

$$\frac{dv_{rad}}{dt} = \frac{T}{m_{Structure} + m_{fuel}(t)}(\gamma) - \frac{GM_e}{r(t)^2} \approx 0 \text{ , } \forall t\text{: } m_{fuel}(t) > 0\ [kg]$$

$$m_{fuel}(t) = \frac{dm_{fuel}}{dt} t$$

$$\frac{dm_{fuel}}{dt} = -\frac{T}{I_{sp}\, g_{0,e}}$$

$$\gamma = \frac{\frac{GM_e}{r(t)^2}}{\frac{T}{m_{Structure} + m_{fuel}(t)}}$$

Plotting,

$$\theta_{motion} = arctan\left(\frac{y(end)-y(end-1)}{x(end)-x(end-1)}\right)$$

$$x = r(t) \times cos(\theta_{motion})$$

$$y = r(t) \times sin(\theta_{motion})$$

Note: γ computes ratio of Earth gravitational acceleration, to thruster magnitude. This allows quantification of radially and tangentially acting thrust values while simultaneously bypassing explicit theta calculation, and allowing mass equation to compute with the correct *total* magnitude of thrust, as opposed to mistakenly using any individual directional component.

Note: '*end*' is a placeholder for the final value for that variable, computed in the previous stage. Therefore, notations like $r(end)$, would correspond to y(end,1) for attached MATLAB code.

Stage 3: Completes computation when Starship is 200 km from Mars' surface.

Integrated in ODE45

$$\frac{dv}{dt} = -g_{0,E}\left(\frac{R_{0,E}^2}{r(t)^2}\right) + g_{0,m}\left(\frac{R_{0,m}^2}{(d-r(t))^2}\right)$$

Plotting,

$$\theta_{motion} = arctan\left(\frac{y(end)-y(end-1)}{x(end)-x(end-1)}\right)$$

$$x = r(t) \times cos(\theta_{motion})$$

$$y = r(t) \times sin(\theta_{motion})$$

[1] In stages 1 and 2, gravitational pull from Mars is neglected as it is very small as Starship is close to Earth.

Initial Conditions:

Constant Definitions

Table 0. Initial conditions used in MATLAB simulation. All SpaceX related numerical values have been highlighted and were discovered through tabulated data via SpaceX. Note, the variable T is 90% of the total thrust for the 6 Raptor engines on Starship operating each at 2980 kN.

r_0	v_{rad}	$R_{0,E}$	$g_{0,E}$	T	I_{sp}	M_{Fuel}	$M_{Structure}$	$R_{0,M}$	$g_{0,m}$	d	G	M_E
10000 [km]	0 [m/s]	6400 [km]	9.81 [m/s^2]	16.092 [MN]	380 [s]	1360777.11 [kg]	90718.47 [kg]	3400 [km]	3.71 [m/s^2]	74.796 [Gm]	6.6743e-11 [$m^3 s^2 kg^{-1}$]	5.972e24 [kg]

Boundary Conditions

Table 1. Boundary conditions used in each stage for ODE 45 computing.

Stage:	Boundary Conditions for respective ODE computation
Stage 1	$[r_0; 0; 0; M_{Fuel}]$
Stage 2	$[r(end); v_{tan}(end); M_{Fuel}(end)]$
Stage 3	$[r(end); v_{tan}(end)]$

Table 2. Time-related boundary conditions used in each stage for ODE 45 computing. ‘MaxStep’ values were chosen by keeping in mind travel velocity and time scale. Relative tolerance values are determined through convergence analysis shown subsequently.

Stage:	Boundary Conditions for respective ODE computation: [‘RelTol’, ‘AbsTol’, ‘MaxStep’]
Stage 1	$[1\times 10^{-16}, 1\times 10^{-16}, 10]$
Stage 2	$[1\times 10^{-16}, 1\times 10^{-16}, 10]$
Stage 3	$[1\times 10^{-14}, 1\times 10^{-16}, 1000]$

Convergence

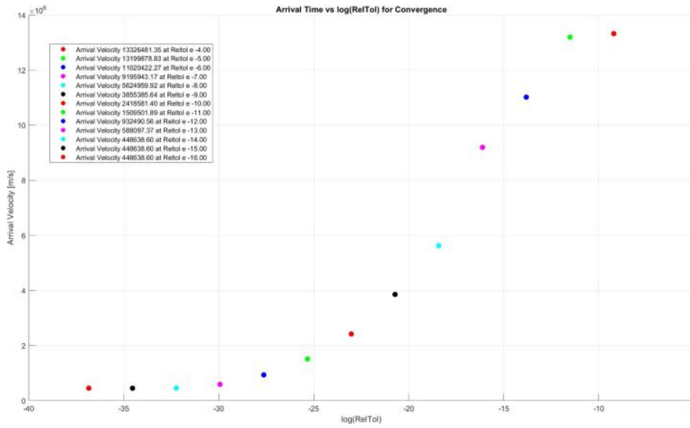

Figure 0. Convergence plot showing arrival velocity (velocity when Starship reaches LMO) vs RelTol. Here convergence is reached at Reltol = 10^{-14}.

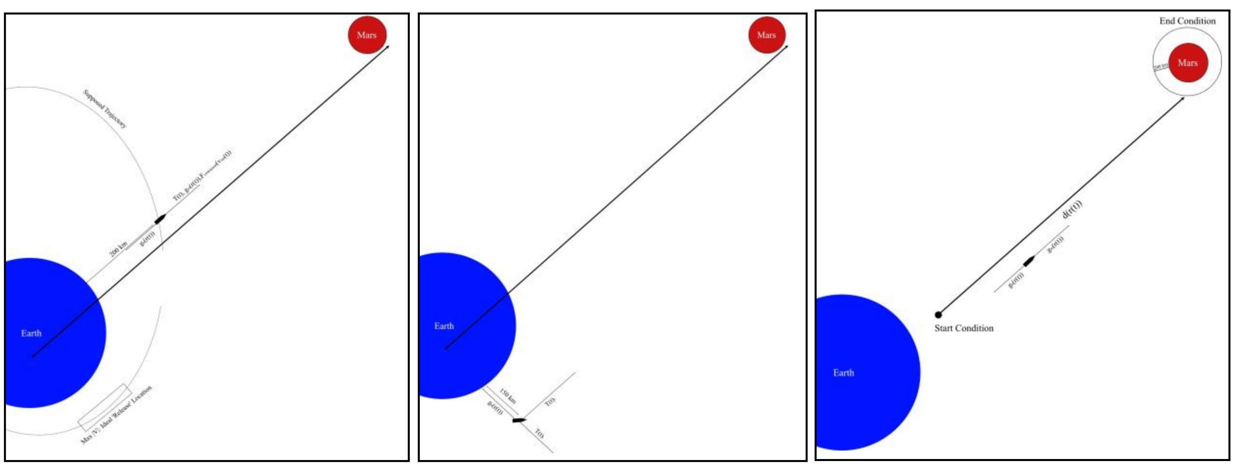

Figure 1. Free body diagrams of Starship CONOPS ordered Stage 1, Stage 2, and Stage 3 from left to right. Each stage indicates the initial force conditions as well as a trajectory imposed by radial and/or tangential trusting. The line connecting Earth to Mars in Stage 1 and 2 is longer than that in Stage 3 and is of magnitude 74.8 million km.

Resulting Plots and Analysis:

Stage 1 Analysis

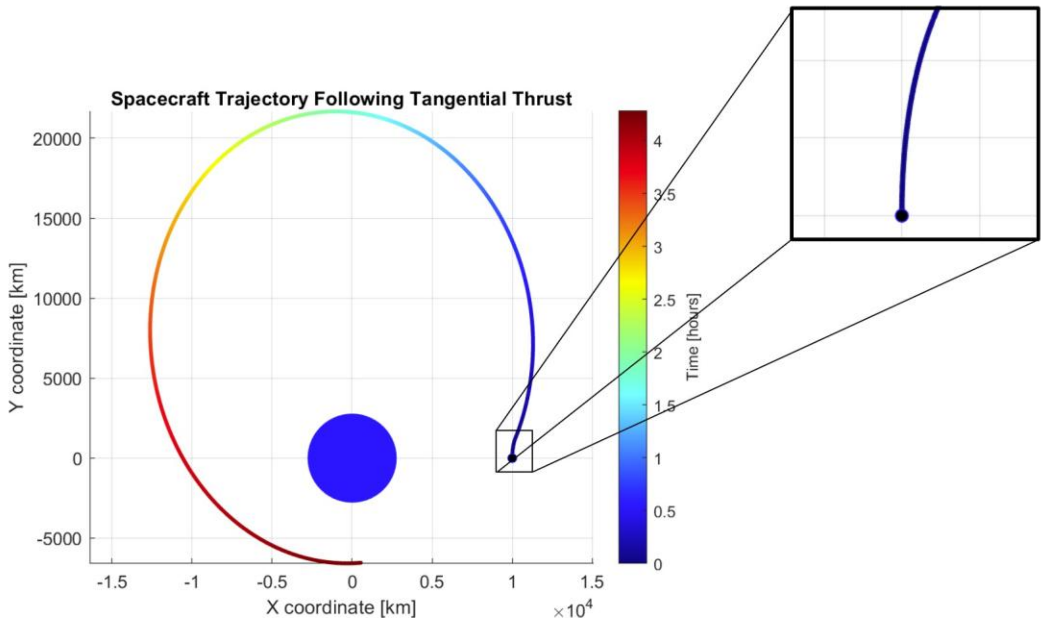

Figure 2. XY plot of Starship trajectory following Tangential Thrust. Thrusting occurs for 200 seconds during which 63.45% of initial fuel storage is used. Projected view reveals the domain such that t: [0, 200], which is the region tangential thrusting is activated.

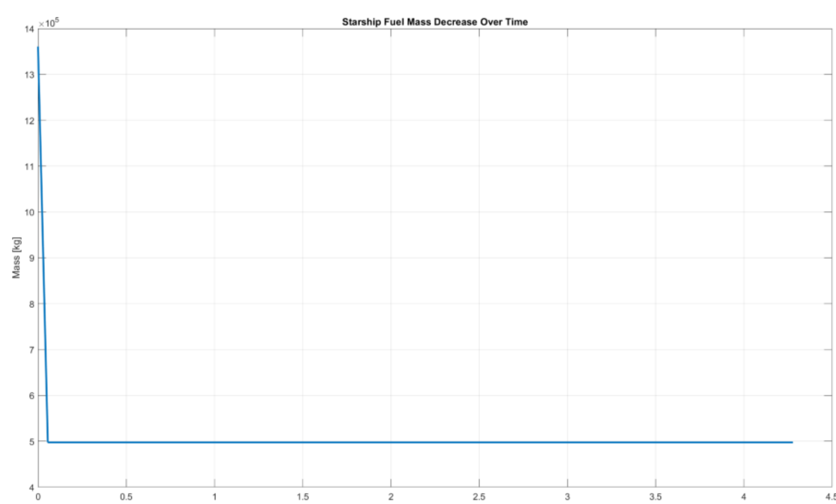

Figure 3. Starship fuel mass over a total period of 4 hours. Fuel utilization stops at $t = 200s$ with $m = 497426\ [kg]$ in lieu of stage 2 radial and tangential thrusting for orbital escape.

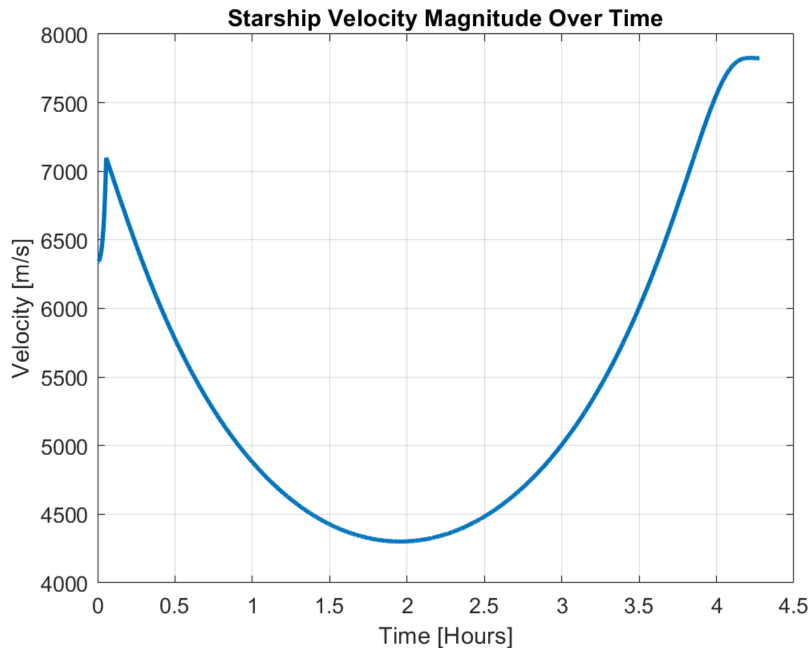

Figure 4. Velocity magnitude over time (magnitude of tangential and radial velocity components). In the period of thrusting, velocity sharply increases. As the spacecraft gets farther from the center from Earth, velocity drops following a sinusoidal path. This is to be expected, as the tangential velocity is a function of Starship radius which varies in a sinusoidal pattern. Maximum velocity is reached causing the stage to terminate and radial/tangential thrusting to begin subsequently.

Stage 2 Analysis

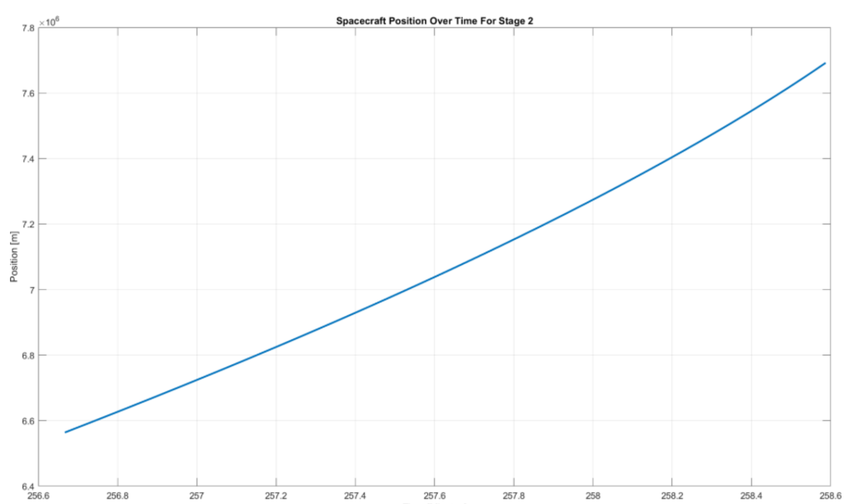

Figure 5. Starship position vs time for stage 2. Position is computed as magnitude between Starship current coordinates and center of Earth coordinates.

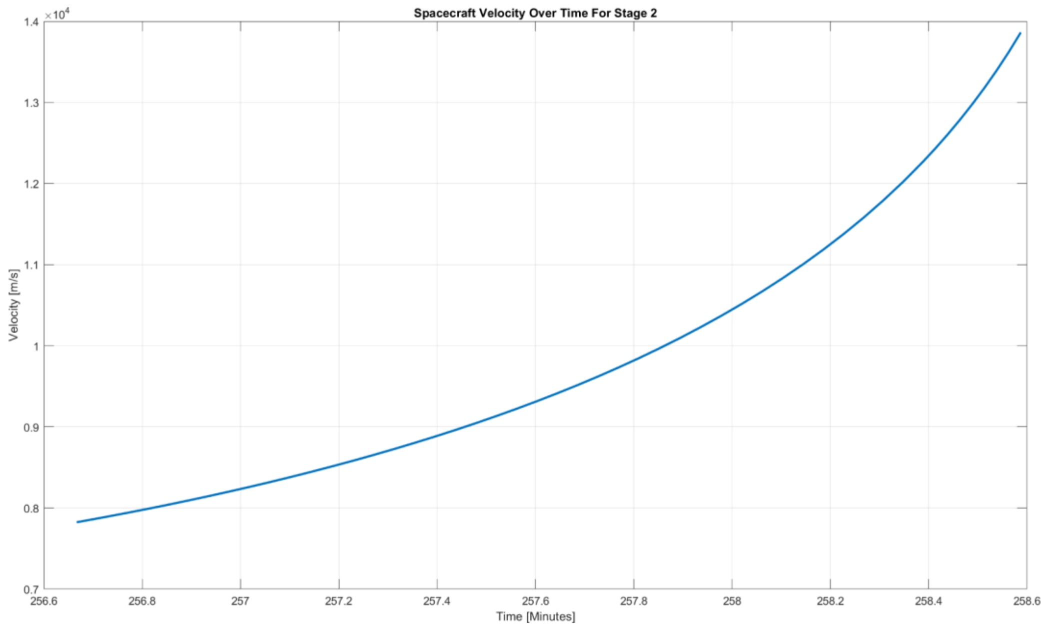

Figure 6. Starship velocity vs time for stage 2. Here, an exponential increase in velocity magnitude is observed, agreeing with intuition as Earth's gravitational acceleration component becomes exponentially smaller as Starship varies its radial position.

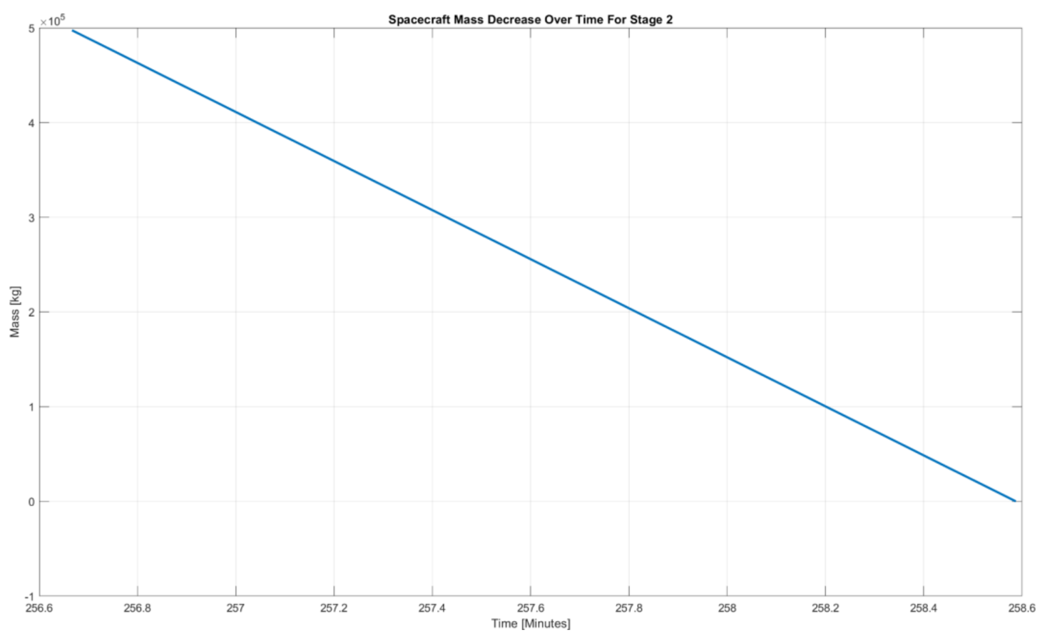

Figure 7. Starship fuel mass vs time for stage 2. All fuel is expended at $t \approx 258.6$ minutes, causing stage 2 to end and stage 3 to begin computation.

Stage 3 Analysis

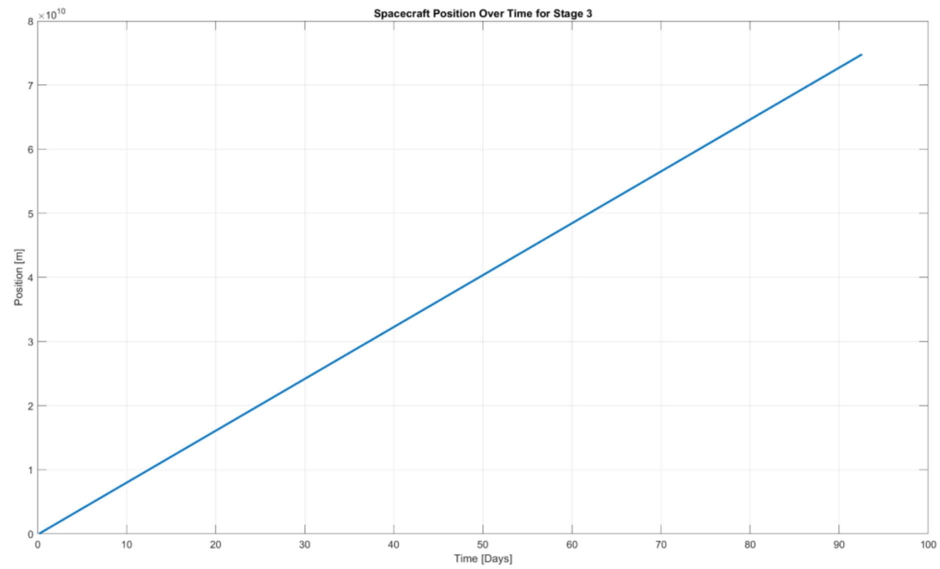

Figure 8. Position vs time for stage 3. Starship is in transit from Earth to Mars with two non-linear forces acting upon its center of gravity (location of Newtonian pointmass) described analytically in the 'Governing Equations' section. A constant velocity is expected for the vast majority of flight until Starship nears low mars orbit (LMO).

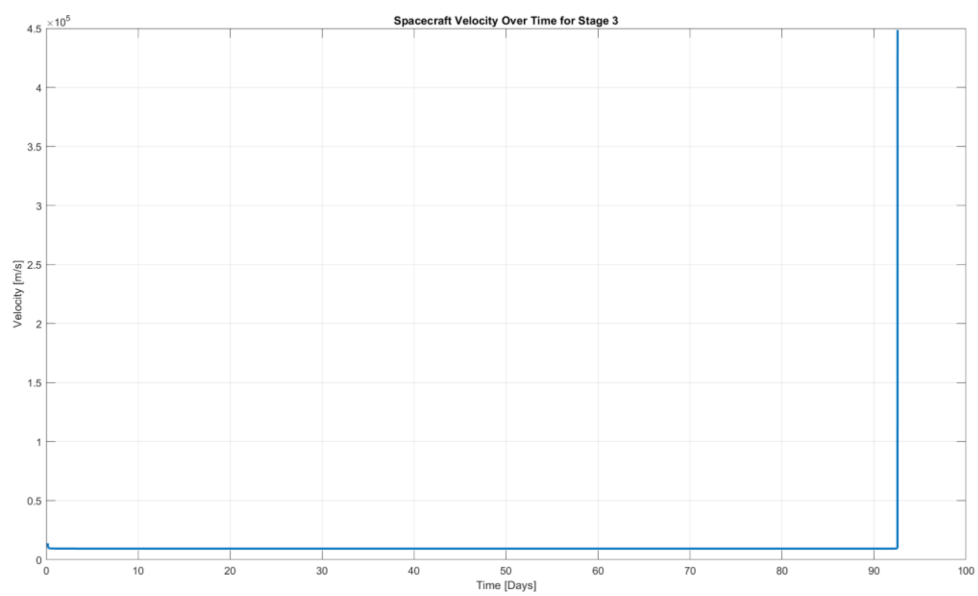

Figure 9. Velocity vs time plot for stage 3. As expected, velocity is nearly constant during the interplanetary travel. However, velocity sharply increases as Starship nears LMO. A more detailed overview of the velocity variation in the latter stage will be put forth in the subsequent section.

Stage Synthesis

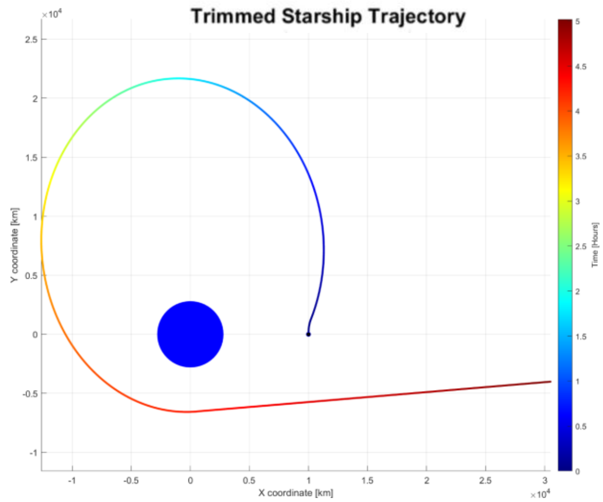

Figure 10. Two dimensional view of three stage synthesis for Earth exit. As in figure 2, the colored line represents the two dimensional trajectory of Starship, where the specific color corresponds to a time denoted by legend on the right hand side. Also, the blue dot poses as Earth with a proportionally large radius.

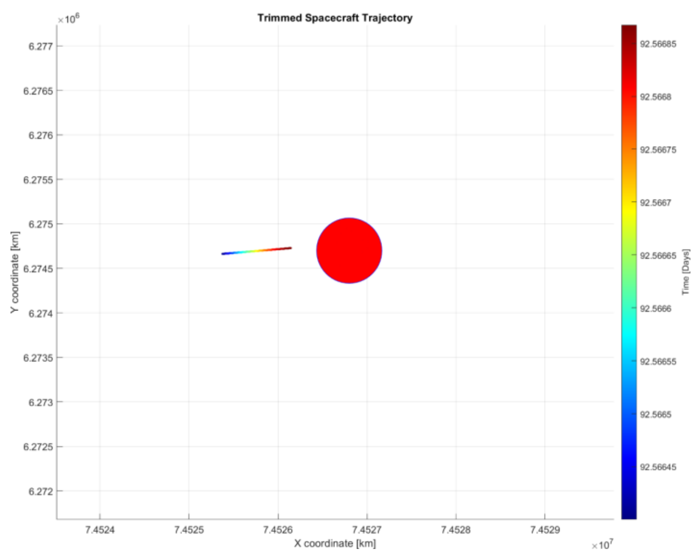

Figure 11. Two dimensional view of three stage synthesis for LMO arrival. As in figure 2, the colored line represents the two dimensional trajectory of Starship, where the specific color corresponds to a time denoted by legend on the right hand side. Also, the red dot poses as Mars with a proportionally large radius. The relatively short time scale indicates the large magnitude of velocity which causes concern for controlled landing methodologies.

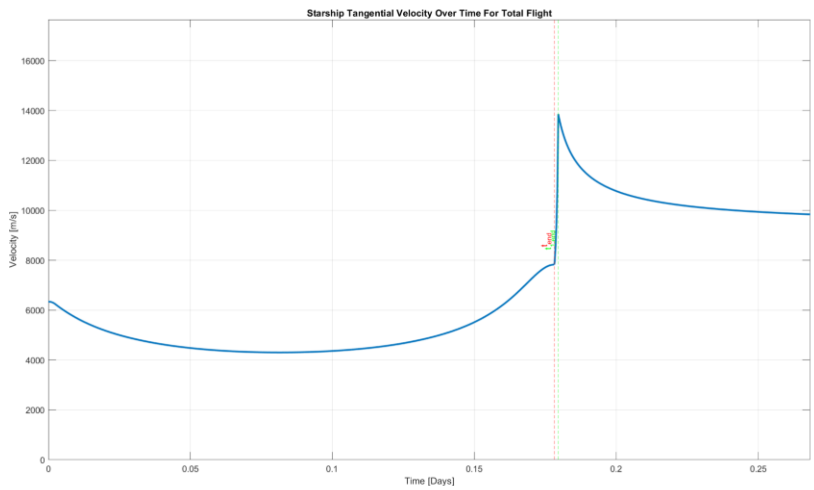

Figure 12. Spacecraft *tangential* velocity over time for stages 1, 2 and 3. The markers t_{end} and $t_{1,end}$ indicate the time domains for stages 1 and 2 are defined. That is stage 1 exits for [0,t_{end}], stage 2 exists for [t_{end},$t_{1,end}$], stage 3 exists for [$t_{1,end}$,$t_{2,end}$]. It is important to observe two things. First, the magnitude of velocity at the end of stage 1 is significantly higher than the initial velocity (7824 m/s vs 6339 m/s). Second, the discontinuity seen connecting stages 1 and 2 can be explained by the assumed instantaneous thrust activation. A more accurate system may describe a first order response. A decayed response then describes the stage 2 to 3 interaction with the velocity of stage 3 settling at a constant ~9360 m/s, as thrust instantaneously goes to 0.

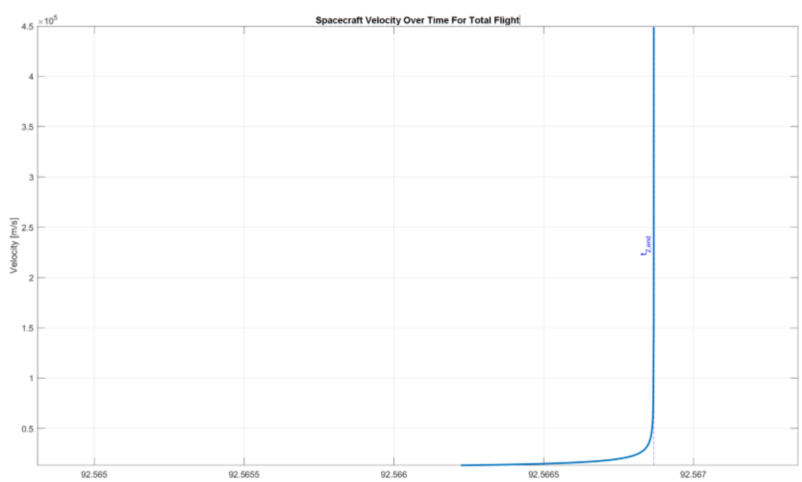

Figure 13. Final total magnitude velocity as Starship approaches LMO. A sudden velocity increase can be seen in this time domain, which is suggested by analyzing the stage 3 gravitational decay seen in figure 12.

Conclusion

The simulation of Starship interplanetary trajectory has been performed above. Additionally, related governing equations, initial conditions, variable values, time step information and force geometric interpretation (FBDs) have been discussed. The limitations discussed in the 'Assumptions and Possible Limitations' section serve to underscore the authors concerns with the simulation results, possibly hinting at a more detailed flight analysis methodology that is beyond the scope of this paper, due primarily to the constraints posed by this project's timeline. In general the author believes this work to be conclusive in determining an approximate flight plan and analysis for the proposed mission which has been both informed and inspired by the book *Reentry* by Eric Berger discussed above.

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