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It's Not Rocket Science: Project Management Failures in an Esoteric Field

D'Anthony Brown, Justin McStay, Nathaniel Miseli, and Matt Young

Department of Systems Engineering
United States Military Academy
West Point, NY 10996

Corresponding author's Email: nathaniel.miseli@westpoint.edu

Author Note: The primary authors of this essay are cadets studying at the United States Military Academy in the Department of Systems Engineering and contributing members of the Space Engineering and Applied Research Hypersonic Rocket Team capstone project. Cadet Miseli manages the project broadly as the program manager; Cadet McStay leads the interagency coordinating efforts; Cadet Brown coordinates local testing efforts; and CPT Young is the Department of Systems Engineering capstone advisor for this project. The views expressed herein are those of the authors and do not reflect the position of the United States Military Academy, the Department of the Army, or the Department of Defense.

Abstract: The Space Engineering and Applied Research (SPEAR) club's capstone section strives to send a rapidly deployable sounding rocket to Low Earth Orbit (LEO), becoming the first collegiate group to do so. While the team has flown closer to this goal with each iteration, its members had become overwhelmed with coordination and management work that distracted from the technical work required of them. After establishing the need for project managers, it brought on additional members to oversee tasks and scheduling. These management-focused cadets did not have any technical background in rocketry or aerospace engineering but sought to understand the project through systems thinking. With a systems thinking framework, these managers reconciled subsystems with known tasks and requirements, developing a timeline and work breakdown structures (WBS); however, the project encountered delays due to stakeholder requirements that the managers failed to identify early by neglecting the systems lifecycle process and management practices.

Keywords: SPEAR, LEO, systems thinking, WBS, systems lifecycle process

1. Introduction to the SPEAR-HRT Management Problem

The United States Military Academy's (USMA) Space Engineering and Applied Research (SPEAR) club began as a hobby rocketry club, but in AY18 the Department of Civil and Mechanical Engineering (CME) sponsored a capstone team within SPEAR with the goal of becoming the first undergraduate team to successfully launch into Low Earth Orbit (LEO). In the years since, this capstone team has continually improved their rockets' performances, eventually going hypersonic (Mach 5.2) and earning the title Hypersonic Rocket Team (SPEAR-HRT) and reaching within 9 kilometers of the Kármán Line, the atmospheric threshold for LEO, in AY22. In AY23, the team endeavored to make massive upgrades to the rocket system to finally surpass the Kármán Line by improving launch and testing facilities and trying new rocket configurations. CME decided that additional team members would be necessary to manage timeline and coordination for this project, which previously comprised only technically specialized cadets from within CME. Three cadets and an additional advisor from the Department of Systems Engineering (DSE) were brought onto the team to manage and support the four functional specialist cadets and CME advisor.

The project falls under CME and is sponsored by several external stakeholders. Aviation and Missile Command (AvMC), U.S. Army Combat Capabilities Development Command (DEVCOM) closely monitors the project progress and supports the project members. AvMC's primary interest in this project is the testing value of hypersonic flight. The Office of Naval Research has provided funding for this project since its inception. Lastly, the Department of Defense (DoD) Space Experiments Review Board (SERB) sponsors the project with a particular interest in the rapidly deployable and payload-bearing elements of the project; SERB's interests include the potential for rapid 'CubeSat' deployment into LEO. Many other stakeholders are involved, imposing launch requirements, some of which will be discussed in later sections. At the time of this article's authoring, the project is still underway with the culminating event, three successive launches, scheduled and prepared but not yet executed.

1.1 Background of SPEAR-HRT

SPEAR-HRT's primary goal is the successful launch of a sounding rocket into LEO. As the project has continued, additional goals have been identified by stakeholders and sponsors: the rocket must allow for a small payload section, which may include small satellite systems in the future; the rocket is, and will continue to be, rapidly deployable, allowing for quick reconstitution of 'CubeSat' systems; and, after a launch in AY22 reached a peak velocity of Mach 5.2, stakeholders have identified the value of maintaining hypersonic capabilities, as hypersonic testing is one of DoD's chief research concerns (Cronk, 2021; Vergun, 2021). The CME cadets involved in the AY23 iteration of this capstone project have each taken on a specialty role intended to contribute to these goals by means of improving specific subsystems; DSE cadets managed the implementation of project upgrades, delegating tasks, developing a work breakdown structure (WBS), and creating the timeline of key tasks necessary for a launch meeting stakeholders' requirements. SPEAR-HRT's rocket systems feature two motors each: a booster to lift off and a sustainer to maintain velocity at altitude. The greatest change from AY22 to AY23 was the inclusion of a third rocket configuration; previously, only two configurations were launched: a 98mm booster with a 75mm sustainer and a 127mm booster with a 75mm sustainer. The modification of a 98mm to act as a sustainer to a 127mm booster promises to contribute to the project goals during the AY23 launch; however, this major system improvement did not require much direct attention, as the rocket manufacturer managed the necessary changes for this new configuration, allowing the team to focus on other subsystem upgrades.

1.1.1 Early Requirements

The four subsystems identified for significant improvement upon the previous year's project were the second-stage rockets (sustainers), static fire test stand (to include stability, data readability, and rocket movability), launch stand stability, and payload. While the whole static fire test stand subsystem was identified for overhaul, the other three subsystems would only feature specific elemental upgrades: new nozzles for the sustainers, grounding elements for the launch stand, and new transponders (in addition to the antennas already included) with protective layering in the payload sections. The early focus on the project was to conduct analysis in these areas and design upgrades to the previous configurations. The team would manufacture a new nozzle in-house for testing after extensive research and simulation to attempt to optimize sustainer thrust; the launch stand would include tighter guide wires for a more stable launch; and the team would attempt to fit a transponder in the payload section of each rocket to allow better telemetry data collection, though only the 98mm sustainer ultimately accommodated a transponder. Because the early project requirements largely comprised technical research and manufacturing, the project managers enabled technical efforts by managing materials orders for these upgrades and outlining a tentative schedule for the major events. The planning and ordering phase of this project took all of first semester, AY23, though event schedules continued to change in later phases and materials orders would not be complete until mid-second semester. The timeline developed at this stage outlined physical requirements and ordering deadlines but was not all-inclusive.

Managers also began interagency coordination in this first phase. Stakeholders identified for launch coordination included the launch site (Spaceport America), range support with DoD assets through the nearby White Sands Missile Range (WSMR), and regulatory government agencies whose domains the project would enter (FAA, FCC, Civil Air Patrol, etc.). This coordination would carry over into the second semester of AY23 due to the unclear and often multifaceted requirements from these stakeholders. Failure to identify and outline these stakeholders' requirements and incorporate them into the project schedule early contributed to project delays, as discussed in later sections.

1.1.2 Static Fire Testing

The culmination of the static fire test stand improvements and nozzle modifications were two static fire tests. These tests were necessary to test the efficiency of the upgraded sustainer nozzles. The tests were initially scheduled for early second semester, AY23, but encountered delays due to delays in materials orders for static fire test stand parts. These delays would not only affect the static fire testing but shift the entire launch timeline back, as the rockets could not be built or shipped until determining the efficiency of the new sustainer nozzles and deciding whether to use them. The upgraded nozzles ultimately did not meet project needs and the team proceeded with stock nozzles. This initial delay shifted the project timeline back by about two weeks.

During this phase, a major issue with interagency coordination became known. A synchronization meeting between the project managers, Spaceport America, and WSMR foregrounded a key requirement by WSMR's range support: a 30-day notice before range support may be scheduled, requiring all other government agency requirements to already be met and approval documentation to be shared with WSMR range control. While this requirement was identified outside the 30-day window before the scheduled launch, most paperwork had not yet been submitted, which itself would take some time to process. Furthermore, many agencies' paperwork requirements, now identified for fast-tracking, would demand the attention of the CME cadets and their technical expertise, who at this time were focused on enabling a static fire test and preparation for launch. The deconfliction of these cadets' time to meet both physical requirements and agency requirements proved difficult;

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ultimately, all required paperwork was submitted only slightly behind schedule, shortly after the second static fire test, but these efforts distracted from the launch stand upgrade and would raise concerns for further delays.

1.1.3 Launch Campaign

The culminating event of this project, the launch campaign, required the most involvement from the project managers and the fewest technical requirements of the CME cadets. While upgrades were designed properly and on time, the fast-tracking of agency coordination efforts meant that orders for launch stand parts were put in later than scheduled. While these orders were anticipated to arrive within a safe margin, issues with order processing and supply chain resulted in massive delays that would push the deadlines, raising concerns about shipping within the launch timeline. The orders were received with enough time to redress the timeline and ship everything on time; however, other issues came to light that caused worry over the timeline.

As the managers submitted the required paperwork shortly after the 30-day mark, expecting just a slight delay, correspondence with WSMR indicated that they could not schedule range support yet and anticipated further delays due to the payment processing time. The team's primary sponsor, AvMC, had submitted paperwork to transfer payments to WSMR along with our deadline, not expecting that the 30-day window included processing times for this paperwork. WSMR indicated that the payment would take weeks and the other documentation could not be assessed for scheduling until payment had processed. Though AvMC followed the timeline the team provided, the managers failed to elaborate on WSMR's requirements and identify the earlier deadline for the payment. This negligence led to delays that prevented launches from being scheduled until three weeks after the desired dates. As discussed below, the team should have followed the systems lifecycle processes and common management practices, which would have led to the early detection of these administrative requirements and likely prevented these delays.

2. Rockets as Systems

SPEAR-HRT was a well-established project before cadets were brough in from DSE as managers, with already-functioning systems and clearly defined physical system requirements. While DSE's cadets did not have the technical background in aerospace engineering that CME's cadets did, framing the project and its elements with systems thinking made the known requirements and elements comprising the rocket systems comprehensible from a systems perspective. Systems thinking focuses on outcome, first determining the required system outputs, then current outputs or capabilities, and finally defining the steps to produce desired outputs (Parnell, Driscoll, & Henderson 2011, p. 28). Using this framework, DSE cadets first identified the required outputs: the systems are rockets, which should fly at hypersonic speeds and reach LEO while carrying a protected payload. Undergoing the next step in systems thinking – identifying what the system currently outputs – found that the project goals were nearly realized already: the system already flies at hypersonic speeds, features a payload, and nearly reached LEO with its last configuration. The final step in systems thinking shed light on only one missing requirement: the system needs to reach slightly greater altitudes to enter LEO and fulfill requirements. The CME cadets had already identified their four areas for subsystem improvement as well as the new motor configuration, and without additional personnel to which to assign tasks, the DSE cadets saw this as a project already on-track to satisfying its final requirement. This assumption proved detrimental, as the DSE cadets chose to focus on management of known requirements, rather than investigate for further requirements. The managers should have treated this systems problem as any other: conducting stakeholder interviews with all parties at the beginning of the project to identify abstract requirements and adjusting the WBS and timeline to reflect them.

A systems framework also allowed the managers to partially understand the subsystems contributing to the whole rocket system; DSE cadets applied this framework to understand the processes of the physical subsystems but disregarded additional subsystems, which contributed to the failure to identify key requirements (Parnell et al., 2011, p. 34). The project's subsystems, as understood by the managers now, can be listed as: the payload subsystem, the booster subsystem, the sustainer subsystem, the static fire testing subsystem, and the launch subsystem. As discussed in paragraph 1.1.1, specific elements were identified for improvement from AY22 before DSE cadets were even introduced to the project. The managers, viewing the project as a functioning system comprising working subsystems, further neglected the proper engineering management practices by focusing on developing a timeline and working on the logistics behind the physical upgrades. Had the managers viewed the project through a proper systems lens, they would have identified the abstract subsystems within the launch subsystem, including the range support from WSMR and the process of paying for and scheduling such support. Recognizing such abstract subsystems early would have forced the managers to investigate their requirements earlier in the project, shedding light on hidden requirements and likely preventing delays by confronting time-bound requirements early.

3. Delays and Challenges in Coordination

Being as this project was ostensibly a continuation of an existing project, the managers failed to identify it as a systems engineering problem, instead treating it as a strictly management-focused problem. Had the managers applied the systems lifecycle process to this project, the team might not have encountered the coordination issues it did and may have prevented the delays in launch campaign. The AY22 project team left a 'continuity book' for the AY23 team, including references for some major stakeholders and the areas identified for improvement, which inspired the AY23 CME cadets' upgrade focuses. The AY23 managers used this 'continuity book' as their absolute guide in the first semester of AY23, as it explained key requirements for system performance. This 'continuity book,' however helpful, was unexhaustive; it did not outline requirements for abstract subsystems, list all known stakeholders, or leave a roadmap of previously implemented steps in the project lifecycle. Despite the limitations of the 'continuity book,' the managers proceeded to treat it as a baseline from which the next iteration of the project would expand, when they should have treated the new iteration as a new problem to address.

The systems lifecycle process may be implemented according to several different models, the simplest and most common of which is the "V-model." The V-model features many steps, each of which may be broadly organized into three phases: project definition, which includes stakeholder interviews allowing for requirement definitions; system implementation; and system integration (Liu, 2016). The SPEAR-HRT managers' assumption that this project would be a straightforward continuation of the previous iterations following the continuity book led to the dangerous decision to skip the project definition phase and primarily operate within the system implementation phase. Had the managers followed the systems lifecycle process from the beginning, intensive stakeholder interviews would have been conducted. These stakeholder interviews, conducted up-front at the beginning of the project timeline, would have helped the team to identify the unseen requirements within the launch subsystem and address these requirements on time.

4. Modeling Manager Functions

The team's three managers outlined management functions and divided them by domain near the beginning of the project timeline, employing a WBS. These tasks were then organized into Activity Diagrams, further broken down into specialized roles – CME cadets and DSE cadets – using Innoslate to illustrate the expected flow of functions, as featured in Figure 1. Though the managers recognized the need to be flexible and add or remove functions as needed, the division of tasks did not account for who would manage additional and unspecified tasks. Notably, the team did not include stakeholder interviews in its set of defined tasks. While the program manager orchestrated and led periodic meetings with stakeholders, proper investigative interviews with the intention of identifying requirements were not conducted, contributing to the late emergence of requirements that led to delays. The proper breakdown of tasks should have included stakeholder interviews and noted which stakeholders to consult – at least as understood initially.

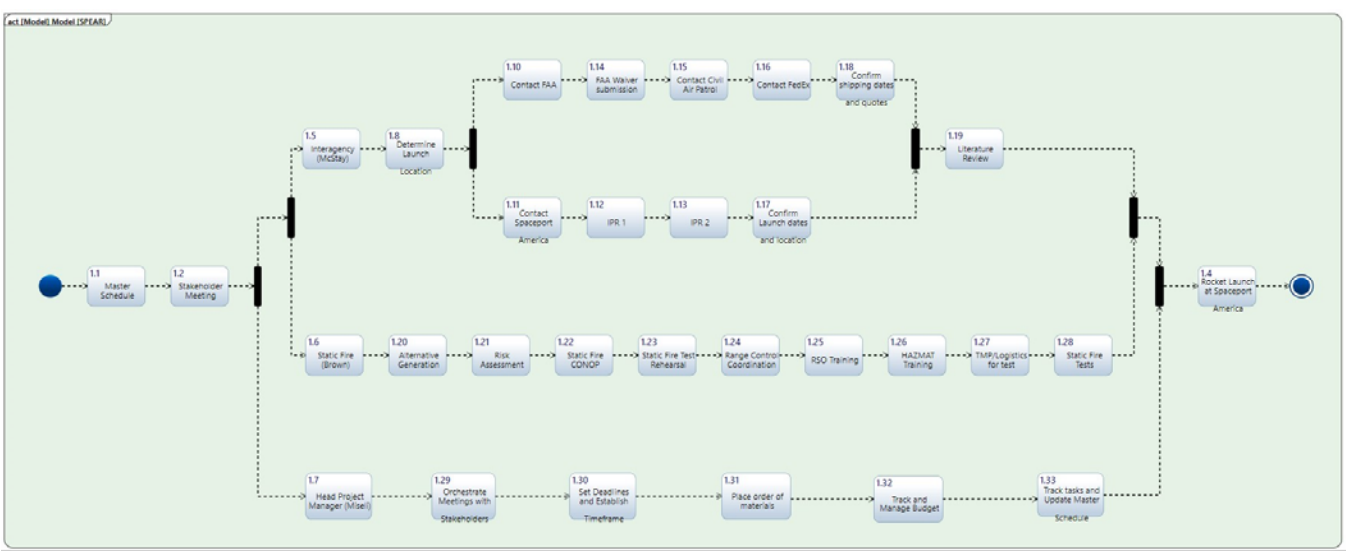

Figure 1. SPEAR-HRT DSE Cadet Activity Diagram

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5. Conclusion

The DSE cadets, consisting of engineering managers and a systems engineer, supposed their roles in this project to be simple managers, failing to identify the systems engineering problem at hand and neglecting proper engineering management practices regarding stakeholder interviews and requirements engineering. These malpractices drastically affected the project timeline. Minor delays early on due to poorly managed timelines for materials orders first shed light on the poor approach taken by the project managers; soon, bigger issues were identified with this approach as the project encountered bigger and less manageable delays due to undefined requirements. While the project met all administrative requirements eventually, bad practices led to entirely preventable delays and uncertainty for a long portion of the project. Should the managers have applied the proper approaches, either through a systems engineering framework or an appropriate engineering management framework, these issues may have been avoided

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