

SPEAR–THOR AY26: Improving Recovery and Data Collection of Affordable Hypersonic Vehicles

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Author Note: This paper serves as a culmination report of the AY26 SPEAR-THOR capstone project. The team would like to thank both Army Development Command (Army DEVCOM) Aviation and Missile Center as well as Space Launch Tech for their essential funding and support of the team’s effort throughout the year. Their support has fueled the effort of our team as well as previous year’s teams in designing, manufacturing, and launching hypersonic rockets. Lastly, the team would like to clarify that the views included in this report reflect those of the team and do not represent the Department of War, Department of the Army, or the United States Military Academy at West Point.

Abstract: This paper illustrates the development, design, and testing of the SPEAR-THOR capstone’s hypersonic rockets throughout AY26. The primary efforts were to improve recovery reliability and onboard data collection of affordable hypersonic rockets. The team used the Systems Decision Process to design an improved parachute recovery system as well as generated redundancies to prevent the loss of the vehicle due to single-point failures of the original telemetry architecture. Weighted decision matrices and risk analyses guided the selection of additional data collection devices. Although the added instrumentation ultimately malfunctioned, the fit and power capabilities provide a proof of concept and a framework for future instrumentation. The team was also able to accomplish these improvements while keeping each vehicle under the cost of \$100,000 per rocket. These results validate a scalable, low-cost approach to hypersonic research and provide a foundation for future SPEAR-THOR program development.

Keywords: hypersonic rocketry, systems engineering, recovery systems, decision analysis, risk management

1. Introduction

The SPEAR-THOR capstone project at the United States Military Academy is a multi-year effort to field a two-stage hypersonic rocket capable of reaching the Kármán Line (100 kilometers above Earth’s surface) while collecting flight data via onboard instrumentation. In 2026, SPEAR-THOR focused on increasing the rocket’s recoverability while improving onboard instrumentation. The team employed the Systems Decision Process (SDP) to guide trade-offs and support decision-making while operating in an environment plagued by government shutdowns, supply chain issues, and strict cost constraints. Following stakeholder analysis, SPEAR-THOR focused on three main requirements: improving recoverability, improving vehicle instrumentation, and maintaining the low price point of the rocket. SPEAR-THOR launched four rockets during the 2026 campaign, organized launch stand improvements and procedures, improved simulation fidelity, added on-board data collection, and introduced best practices and redundancies into recovery protocol. The central problem this year was recovery failure: two of the first four AY26 launches were unrecovered due to a telemetry single-point-of-failure. Recovery is critical because apogee data, onboard sensor readings, and hardware reuse all depend on retrieving the vehicle. The AY25 team’s academic submissions and design documentation informed this year’s approach, establishing the baseline from which AY26 improvements were derived. This paper presents the systems engineering methodology, design trade-off analysis, and implementation decisions the AY26 team used to address these improvements.

2. Problem Definition and Stakeholder Requirements

SPEAR-THOR’s primary stakeholder is the U.S. Army Combat Capabilities Development Command Aviation Missile Center (AvMC). AvMC’s mission is to “develop, integrate, demonstrate, and sustain aviation and missile systems capabilities to support the future Army and improve readiness.” Through this mission statement, the systems engineers on SPEAR-THOR determined that AvMC was interested in a reliable, cost-effective hypersonic rocket. SPEAR-THOR also acknowledges that theirs is a multi-year endeavor, meaning that the team’s stakeholders include future teams. With these two key groups of

stakeholders in mind, SPEAR-THOR wrote the 2026 mission statement: to provide a reliable, cost-effective, hypersonic rocket capable of delivering a payload and supporting future Army rocketry research. As a result of our stakeholder analysis, we derived three primary requirements listed below:

- **R1:** Improve recoverability of major vehicle components post-flight. Past iterations of SPEAR-THOR have struggled greatly in reliably recovering the rocket components. Because apogee and onboard sensor data is best collected by recovering the rocket, the team determined that a major focus for the 25-26 launch campaign would be to increase the reliability of the recovery system.
- **R2:** Improve instrumentation of the vehicle. After the success of the 25-26 launch campaign in reliably reaching the Karman line, the team determined adding instrumentation would best fulfill stakeholder needs. By adding this capability, SPEAR-THOR's product can now provide meaningful data for current and future stakeholders.
- **R3:** Maintain low price point of rocket. Small sounding rockets cost between \$100,000 and \$1,000,000 to launch, which is prohibitive for programs with smaller budgets to test in hypersonic conditions. SPEAR-THOR's low price point is an asset for stakeholders, which is why the team decided to include it as a key stakeholder requirement.

3. Solution design

SPEAR-THOR worked through the solution design process for three major components of the hypersonic rocket which includes the parachute deployment system (PDS), recovery system (RS), and instrumentation system (IS). For all systems, SPEAR-THOR first conducted a rapid idea generation period, followed by a rigorous engineering analysis of alternatives, and concluded with the selection of an alternative.

3.1 Parachute Deployment System Idea Generation

The parachute deployment system is the sequencing of events that occur within the rocket, while in flight, which results in the deployment of the parachute. Ensuring the successful opening of the parachute directly leads to a higher chance of recovery, as it slows the descent and allows onboard telemetry assets to gain a longer, more stable descent with which to send back location data, directly helping fulfill Requirement 1. After evaluating data from last year's launch campaigns, the SPEAR-THOR team evaluated competing separation alternatives using a weighted decision matrix. The weighted decision matrix uses a 1–4 scoring scale, where lower scores indicate better performance and an ideal score of 1.0 represents full satisfaction of all weighted criteria. Criteria weights were derived from the project's requirements and stakeholder priorities. Criteria derived from the project's requirements, including reliability, complexity, mass, cost, recoverability, and mission effectiveness, were weighed and scored across four recovery system configurations. As Figure 1 shows that the resulting scores enabled the team to compare tradeoffs between recovery system architectures and identify the configurations that best balanced engineering performance, operational safety, and mission requirements.

- **Alt 1:** Separate at apogee; recover sustainer and payload under a single parachute.
- **Alt 2:** Separate at ~20 km AGL; deploy an independent parachute for each body.
- **Alt 3:** Separate at apogee; recover instrumentation body only.
- **Alt 4:** Separate at ~20 km AGL; recover instrumentation body only.

3.2 Parachute Deployment System Analysis and Selection

Although Alternative 3 produced the best numerical score due to minimal hardware and complexity, SPEAR-THOR rejected it because leaving the sustainer unrecovered conflicted with federal land-use requirements, range regulations, and post-flight analysis needs. SPEAR-THOR selected Alternative 2 because it ensured full vehicle recovery and improved reliability despite slightly greater mass and complexity. Alternatives 1 and 4 scored lower due to stability concerns and higher recovery failure risk.

3.3 Recovery System Idea Generation

Design Criterion	Weight Factor	Units	Alternative 1			Alternative 2			Alternative 3			Alternative 4						
			Magnitude	Score	Rating	Magnitude	Score	Rating	Magnitude	Score	Rating	Magnitude	Score	Rating				
Weight	0.050	#	2		0.1	4		0.2	1		0.05	3		0.15				
Cost	0.050	#	1		0.05	3		0.2	2		0.1	4		0.2				
Required Volume	0.100	#	3		0.3	4		0.2	1		0.1	2		0.2				
Tensile Strength	0.200	#	4		0.8	1		0.2	1		0.2	1		0.2				
Stages	0.150	#	1		0.15	1		0.6	1		0.15	4		0.6				
Stability Concerns	0.250	#	4		1	2		0.25	2		0.5	1		0.25				
Parts Lost	0.200	#	1		0.2	1		0.2	3		0.6	3		0.6				
			Total Rating			2.6	Total Rating			1.85	Total Rating			1.7	Total Rating			2.2

Figure 1: Piecewise Comparison of PDS Alternative

SPEAR-THOR’s first launch campaign resulted in two failed attempts at recovering the rocket payload. These first two launches exposed a single-point-of-failure in the telemetry system and limited post-landing signal acquisition. The baseline, unimproved recovery system, shown in Figure 2 below, provided insufficient redundancy, as telemetry is rendered inoperable for any reason the entire recovery system fails.

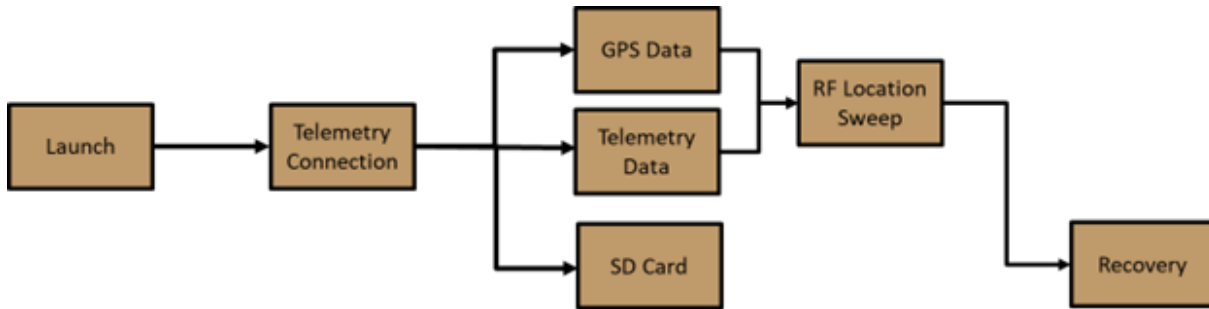


Figure 2: Unimproved Recovery System

Improvements in the redundancy of the recovery system directly seeks to fulfill Requirement 1 and is constrained by Requirement 3. Following this campaign SPEAR-THOR rapidly generated different alternatives to improve the chances of vehicle recovery. These alternatives, as well as a brief overview of what they entail, are captured in Table 1.

Table 1: Recovery Tracking Alternatives

Alternative	Description
Spot Trace GPS	A small, rugged COTS device capable of transmitting GPS data to a mobile cellphone application; typically used for backpacking and other outdoor activities.
Thermal Imaging Drone	A thermal imaging drone flown over the expected rocket landing area; thermal sensors used to detect the heat signature of the still-hot motor.
Satellite Messaging	A device capable of sending GPS information via satellite connection to an online application.
RF Triangulation	Multiple directional antennas detect a small RF “chirp” from the rocket in flight; bearings from multiple observation posts used to generate an approximate search grid.
LoRa Broadcast	Long-range, low-power radio transmitting GPS data from the flight computer up to 20 miles to a mobile LoRa receiver.

3.4 Recovery System Analysis and Selection

SPEAR-THOR then conducted a qualitative analysis of these concepts and eventually selected just the LoRa module as the redundant telemetry system. The team elected to use the LoRa due to its low power requirements, long range, small form factor, and high chance of viability. The other alternatives were discarded for the reasons listed below in Table 2.

Table 2: Eliminated Recovery Concepts and Rationale

Concept	Rationale
Spot Trace GPS	RF attenuation in aluminum payload bay; orientation reliability ~44%; size/power constraints.
Thermal-imaging drone	Insufficient discrimination at range; deployment timeline incompatible with rapid post-landing search.
Satellite messaging	Integration with flight computer untested; RF-opaque bay; hardware lead-times.
RF triangulation	Requires multiple fixed stations; range/resources not available for campaign operations.

3.5 Instrumentation System Idea Generation

Following the first launch campaign, SPEAR-THOR also elected to explore different instrumentation alternatives for the newly created payload bay. SPEAR-THOR elected to add an accelerometer to the payload bay to fulfill the instrumentation requirement assigned in Requirement 2. Proper accelerometer instrumentation required three separate components: a power source, an accelerometer, and an onboard computer capable of both running the accelerometer and storing the resulting data. Several alternatives for each of these components were generated by the team. These alternatives are listed below in Table 3.

Table 3: Instrumentation Hardware Alternatives Comparison

Component	Alternative 1	Alternative 2	Alternative 3
Battery	CR123	18650	AAA
Accelerometer	Adafruit H3LIS331	ADXL375	Eagle Flight Computer
On-Board Computer	Raspberry Pi	PicoZED	MicroZED

3.6 Instrumentation Analysis and Selection

Once generated, the options for power sources, accelerometers, and on-board computers were subjected to a rigorous pairwise comparison, similar to the method used to evaluate the PDS shown in Figure 1. This was intended to determine the instrumentation hardware with the best compatibility with the project requirements and the highest overall likelihood of success. The selected combination was 18650 for the battery, ADXL375 for the accelerometer, and the Raspberry Pi for the computer.

4. Risk analysis

Building on the AY25 team’s safety framework, the AY26 SPEAR-THOR team refined and implemented risk assessment and hazard mitigation processes across all project phases. A dedicated Safety and Launch Control Officer was established to ensure FAA and DoW compliance, manage documentation, and oversee launch operations. The team used DD Form 2977 to identify and mitigate hazards across subsystems, with each subsystem lead conducting area-specific risk analyses that fed into the overall safety plan. This covered both technical risks (motor ignition failure, stage separation, parachute deployment) and operational risks (range setup, transportation). Mitigation measures included controlled access zones, standardized communication protocols between the Launch Control Officer and Range Safety personnel, and pre-event risk briefings for all team members. A key improvement this year was refining the recovery system risk profile based on 2025 lessons learned. Parachute

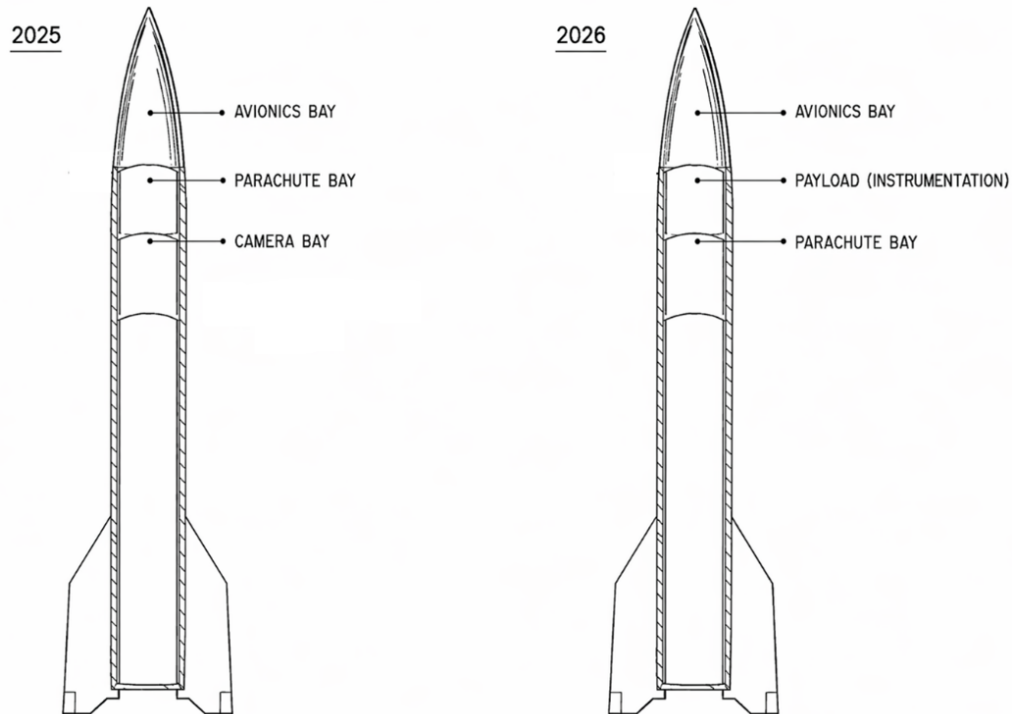


Figure 3: Changes in Rocket Configuration. *Designs Not to Scale

deployment timing and separation dynamics had previously posed hardware and personnel risks. The AY26 team addressed this by relocating the separation point, adding a dedicated payload bay, and lowering the deployment altitude, reducing structural stress during recovery and improving instrumentation retrieval success.

5. Implementation

5.1 Parachute Deployment System Implementation

Following the selection of separating at 20 km Above Ground Level (AGL) and deploying an independent parachute for the payload and the sustainer, several structural refinements were implemented: a dedicated parachute bay was added to reduce deployment interference, the GPS module was relocated for better signal continuity, and legacy components (AY25 camera and Spot Trace modules) were removed to reduce mass, streamline avionics, and allow space for onboard instrumentation. These changes are captured in Figure 2.

In SPEAR-THOR's first launch campaign of this year, the parachute bay failed to deploy at 20 km AGL, which resulted in the hypersonic reentry of the vehicle. This error resulted from the parachute bay being coded to deploy at a set time in flight, and the flight itself being much shorter than expected. As a result, SPEAR-THOR adapted the original PDS plan to retain separate parachutes, but to deploy those parachutes at apogee, since that deployment mechanism could be triggered without being tied to a timer. In SPEAR-THOR's second launch campaign of this year, the modified PDS was utilized, and resulted in the successful deployment of the parachute for both the first and second launch of that campaign. While the second rocket's payload and sustainer were both recovered with the parachutes intact and still attached to their respective bodies, the first rocket's sustainer was not recovered, and the payload was recovered without the parachute. After examining the descent data, SPEAR-THOR believes that the first launch of the second campaign deployed the parachute at apogee, but that it was violently torn off its attachment during deployment. This indicates success of the deployment but a need for improvement in the method of attachment.

5.2 Recovery and Instrumentation Implementation

After selecting the LoRa module to aid in recovery following the first launch campaign of this year's team, SPEAR-THOR ordered the necessary modules to begin integrating the LoRa module with the rest of the rocket. Due to government shutdowns and shipping delays, SPEAR-THOR integrated the system during the launch campaign. The finalized LoRa Module utilized a Dragino LoRa Bee v1.1 in conjunction with a Raspberry Pi Zero (RASPI0) and 18650 battery power system to receive GPS data from the onboard primary and secondary GPS to send data at a frequency of 433 MHz to a separate LoRa receiver. The rapid integration of this system prohibited extended testing, but initial field tests confirmed communication between the two modules, and the integration of onboard GPSs with the LoRa system. Additionally, the ADXL375 Accelerometer was integrated with the RASPI0 to collect accelerometer data while the vehicle was in flight. While integrating the LoRa system into the payload bay, a hole was drilled into one of the dedicated attachment points of the RASPI0. This hole destroyed the device and resulted in a package that was no longer capable of sending, collecting, or receiving data. However, the instrumentation package was successfully installed into the payload bay and received power throughout flight.

6. Results and Conclusions

The team was limited by several factors. Firstly, government shutdowns, increased shipping times, and delayed launch campaigns all had a negative effect on overall time with which to plan, adapt, and integrate disparate systems. Additionally, SPEAR-THOR experienced near-complete telemetry failure during the first launch campaign, meaning many key decisions were made from suspected results rather than confirmed results. Lastly, the team found significant issues integrating a new payload system into the three-inch diameter of the current sustainer. Several key findings resulted from the efforts of this year's SPEAR-THOR team. First, the team greatly improved recoverability following the first launch campaign. Both payloads of the second launch campaign were recovered, indicating a promising Parachute Deployment System protocol adoption. Second, this year's team successfully proved that an onboard payload bay is technically possible. Additionally, the team proved that a Raspberry Pi Zero can be successfully integrated with a LoRa module and an accelerometer, providing both redundant telemetry assets and improved onboard instrumentation for future sounding rocket missions. Finally, the team was able to keep the total cost of the rocket under \$100,000, successfully proving that these advancements could occur without sacrificing the low-cost nature of the hypersonic rocket.

7. Recommendations and Future Work

SPEAR-THOR recommends that future efforts be devoted to increasing the diameter of the sustainer rocket to four inches. This one-inch increase in diameter nearly doubles the cross-sectional area of the payload bay. This increase would allow for future, more advanced instrumentation, which is vital for the program to continually progress and improve systems and capabilities of the rocket. Additionally, SPEAR-THOR recommends that redundant telemetry systems continue to be explored, so as to avoid a single point of failure in the system.

References and acknowledgments

- Pai, A., et al. (2025). *SPEAR-THOR AY24-25: Reaching the Kármán line—Design, launch, and results of a two-stage hypersonic rocket*. Department of Systems Engineering Capstone Proceedings, United States Military Academy, West Point, NY.
- U.S. Army Combat Capabilities Development Command Aviation & Missile Center. (2026). *AvMC mission statement*. <https://www.avmc.army.mil/>
- U.S. Department of the Army. (2014). *ATP 5-19: Risk management*. Headquarters, Department of the Army.
- U.S. Department of the Army. (n.d.). *DD Form 2977: Deliberate risk assessment worksheet*. Headquarters, Department of the Army.

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