When Rockets Launch, OPSS Sees What Others Miss

1. Executive Summary

The Optical Projectile Sensing System (OPSS), developed by DeepFlight, is an autonomous visual tracking system designed to support high-powered rocket launches with precision flight monitoring and recovery assistance. Most rocketry programs lack affordable solutions that combine real-time visual tracking with predictive trajectory estimation. This gap leads to frequent rocket losses, incomplete data, and increased post-launch recovery time and costs.

OPSS addresses this by integrating a YOLOv8-based computer vision to maintain rocket tracking at frame rates exceeding 140 FPS and servo-driven actuation with sub-0.01-degree precision. These capabilities enable the OPSS to follow rockets throughout launch and ascent.

Unlike conventional systems that rely on either manual visual operation or internal telemetry alone, OPSS captures both positional and visual data, improving recovery outcomes and providing more valuable data for post-flight analysis. All the tracking and control components in OPSS have been implemented in simulation, with an integrated prototype development planned for upcoming field trials

OPSS directly addresses the growing demand for hands-on aerospace instrumentation in collegiate rocketry programs. In 2025, “the American Rocketry Challenge (ARC) saw participation from over 1,000 teams across 46 states, with over 5000 students”. This record level of engagement is just one of many that highlights the increasing national enthusiasm for hands-on aerospace education, underscoring the need for accessible tracking solutions like OPSS [1].

At DeepFlight, future development for OPSS will focus on improving precision through higher-end imaging and actuation hardware, expanding detection capabilities to low-visibility environments, and validating the system through field trials at varied test ranges.

DeepFlight is currently seeking sponsorship to allow OPSS to transform into a fully field-ready system. Funding will support hardware upgrades, software refinement, and formal testing, with the goal of enabling wide adoption among academic institutions and aerospace partners.

2. Background

Project Short Title: OPSS

Project Title: Optical Projectile Sensing System

Project Overview: This project proposes the development of a portable, relatively cost-efficient model rocket tracking camera system. The system aims to use artificial intelligence-based detection methods integrated with mathematical modeling to accurately locate high-powered rockets during and post launch. The innovations brought by this technology have significant implications for the aerospace industry.

Technical Objectives/Deliverables: Accurately track a model rocket using an optical sensing system integrated with sensors and algorithms.

3. Project Rationale

Data collection is necessary when improving design, presenting findings, and recovering a rocket. From organizations at the highest level, to collegiate-level institutions, all levels of rocketry require multi-dimensional data collection, comprised of both visual and positional data, a capability NASA itself emphasizes as "the most valuable asset of the mission" [2]. With the increasing complexity of these projectiles, suitable rocketry data collection methods are now increasing in demand. Existing rocket-tracking solutions fail to meet the basic requirements of data collection, given the increased complexity of high-powered rocketry, generally offering desired features such as precise tracking capabilities or portability, with critical tradeoffs like high costs, inaccurate tracking capabilities, and/or zero visual data. **Table 4-1** further examines the benefits and limitations of current technologies as it aims to weigh the positives and negatives to outline whether OPSS is something that is indispensable.

4. Introduction

As high-powered rocketry becomes more accessible, the demand for reliable rocket tracking systems continues to increase. Existing methods for rocket tracking, while beneficial in certain ways, only collect and provide positional data, neglecting an entire domain of data collection: positional data. This inherently makes nearly all conventional methods of rocket tracking ineffective at maximizing useful data collection.

Table 4-1 - Current Capabilities

Current Technology	Benefits	Consequences
Telemetry Systems	• Allows for positional data	• Provides no visual feedback • Susceptible to signal loss or latency • Often unreliable at high altitude or speeds
Hand-Held Cameras	• Allows for visual data • Simple and accessible	• Inconsistent tracking due to human error & data quality • No positional or predictive data
On-Rocket Cameras	• Captures onboard visuals from launch to descent • Provides immersive first-person footage	• Offers no external or positional perspective • Data may be lost if rocket fails • Visuals are often distorted by smoke, vibration, etc. • Adds payload weight and consumes power

The Optical Projectile Sensing System (OPSS) is a system with the primary objective of autonomously tracking rockets. This system uses artificial intelligence-based detection and mathematical modeling. OPSS provides an ample method for troubleshooting, a feature that is unavailable in conventional technology.

This white paper covers the overall development, architecture, and benefits of OPSS. This document is intended to bridge our conceptual design as detailed in the PDR, with our formal sponsorship proposal, offering sponsors and stakeholders a clear understanding of OPSS's value and unique capabilities within a growing field.

5. Solution Overview

The OPSS is a portable, low-latency, servo-mounted tracking system designed to visually follow the motion of high-speed model rockets during launch and ascent. The system combines computer-vision detection, Kalman filtering for predictive modeling, and servo actuation to maintain a visual lock on the rocket throughout flight. The OPSS system was developed with the primary goal of turning gaps within current rocket tracking systems into primary capabilities.

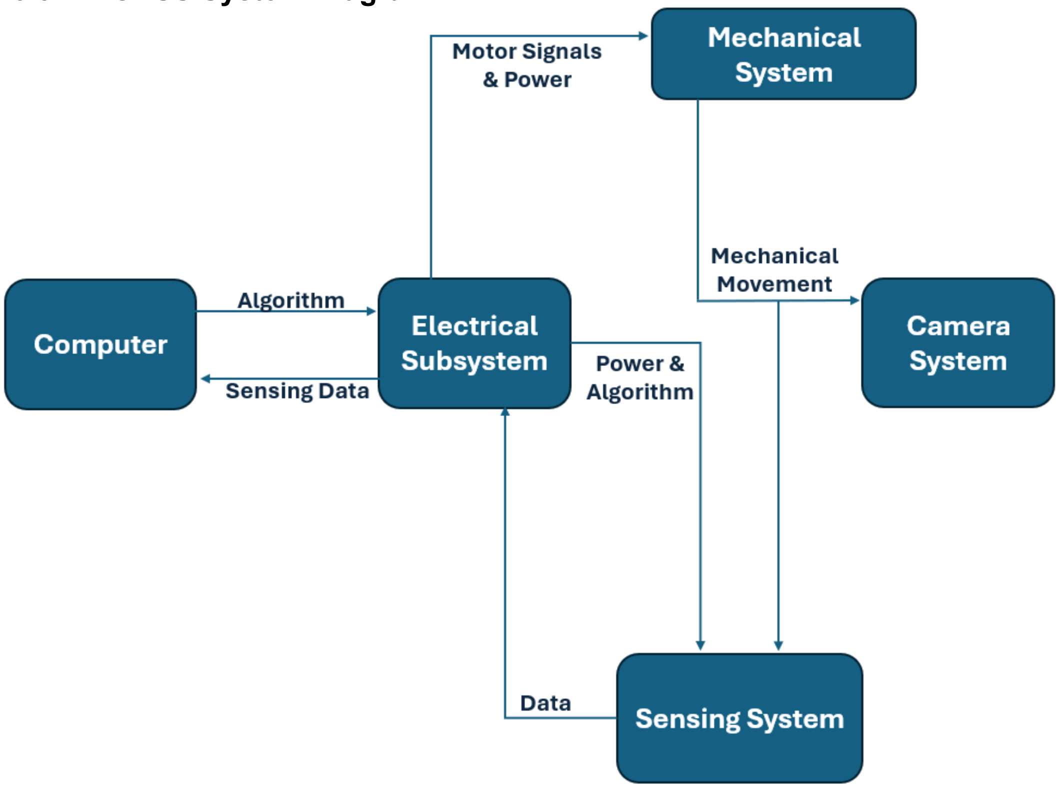
Table 2-1 – OPSS Primary Capabilities

Capability	Significance	Result
Launch Analysis	• Launch data plays a key role in understanding thrust performance, trajectory accuracy, and directional stability.	• Offers a reusable method for providing thrust analysis, trigonometry-based analysis, and directional analysis.
Troubleshooting	• Many rockets suffer from malfunctions of some type. This includes occurrences such as rocket engine failure, unstable flight, etc.	• Offers a visual method for identifying and troubleshooting various malfunctions during high-powered rocket flight.
Recovery	• Accurate tracking footage helps visually locate the landing zone of the rocket, especially if telemetry is lost or system malfunctions occur.	• Provides visual tracking throughout flight to assist in locating the rocket and verifying deployment in instances where telemetry fails.

The tracking system pipeline consists of four tightly integrated components:

- **Computer Vision Module:** Using a YOLOv8 based object detection model, the system identifies and isolates the rocket in real time from a video feed.
- **Kalman Filtering:** A constant acceleration Kalman Filter predicts the rocket's future position between detection frames, allowing for smooth tracking despite latency caused by mechanical actuation, frame drops, or other potential externalities.
- **Servo Control Architecture:** Servo motors receive predictive tracking data to adjust camera orientation, with motion profiles dynamically smoothened to prevent jitter or overshooting.
- **Hardware Setup:** A jetson Orin nano, wide angle Pi camera module, and metal geared servos are mounted on a 3D printed frame, allowing for a modular and field deployable system.

Figure 5-1 – OPSS System Diagram



OPSS Integration Strategy & Risks/Mitigations:

Each subsystem was intentionally designed to offset the limitations of its counterparts. For instance, although the YOLOv8 model provides fast object detection, it occasionally misses frames. The Kalman Filter bridges this gap by predicting the rocket path, ensuring the servos continue to track smoothly even without constant visual input. Finally, all subsystems are tightly coupled through scripts and data flow between components, allowing for adaptability and potential future iterations. This integration strategy was chosen specifically to overcome the latency, reliability, and modularity challenges typical of existing rocket tracking methods.

Table 5-1 – OPSS Risks & Mitigation

Risk	Impact	Mitigation
Launch Dropped frames during rocket tracking	Potential Loss of lock during rapid ascent	A Kalman filter mathematical model to predict trajectory during frame loss
Servo Overshoot	Reduced tracking precision	Motion profile, smoothing, and dynamic feedback tuning.
YOLO model makes a false positive	False locks into clouds, birds, etc.	Training dataset to diverse negatives using post-detection thresholding

6. Future Direction

Although the current developments of OPSS successfully demonstrate the feasibility of a computer-vision based rocket tracking system, the ease of replicability, which was integrated into this project’s infrastructure since day one, allows for upgrades to nearly every subsystem with proper funding.

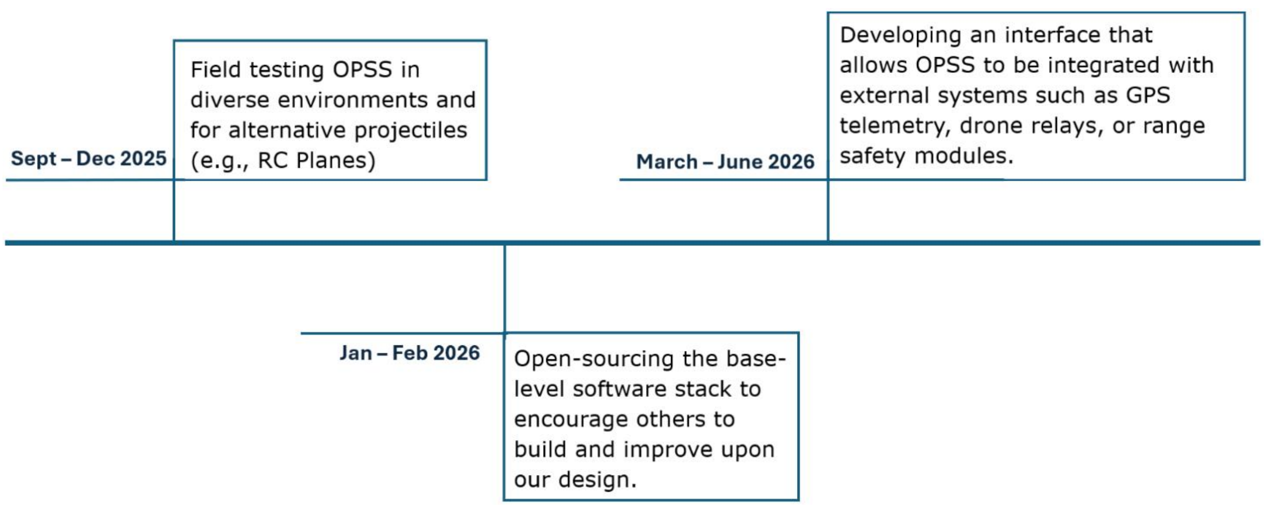
With an estimated budget of $7,500, we can implement the following upgrades to improve the performance and adaptability of OPSS under real-world launch conditions:

Replacing current **camera/servos** with higher-performance alternatives **to improve frame rate, resolution,** and **actuation precision.**

Upgrading the **object detection model with more data and fine tuning for better accuracy** and **fewer false positives** at high speeds.

Implementing thermal imaging support features **allowing** for rocket **tracking under low-visibility conditions** such as dusk, smoke, or cloud cover.

Strategic goals over the next 12–18 months (about 1 and a half years) include:



Although OPSS is a stand-alone project with a unique scope, objectives, and deliverables, the computer-vision predictive-filtering pipeline is a technology that we plan to integrate into a separate project, acting as the vision system within an autonomous UAV capable of learning to stabilize and maneuver without conventional PID control.

7. References:

- Caldwell, S. (2021, October 16). *11.0 Ground Data Systems and Mission Operations*. NASA. https://www.nasa.gov/smallsat-institute/sst-soa/ground-data-systems-and-mission-operations/
- *The American Rocketry Challenge | World's Largest Student Rocket Contest*. (n.d.) The American Rocketry Challenge. https://rocketcontest.org/