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Design of a Drone-Based Regional Scale Agricultural Surveillance (RSAS) System

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Abstract: Agricultural Commodity brokers use satellite images and USDA reports to forecast crop yields. However, these images have limited resolution and are affected by cloud cover, and survey sample sizes are limited. Technological advancements enable Regional Scale Agricultural Surveillance (RSAS) using a fleet of fixed-wing drones operating Beyond Visual Line of Sight (BVLOS) at altitudes between 1000’-4000’ equipped with hyperspectral sensors. RSAS assigns Weekly Surveillance Plans (WSP) to dispatch vehicles and staff around the U.S., and a 4-D Flight Plan (FP) for each drone flight. For economically viability, the WSP and FP must be achieved 95% of the time despite weather, equipment, and staff variability. A Logistics Management Simulation (LMS) and Flight Plan Assurance Simulation (FPAS), using Monte Carlo methods, found that achieving a 500,000-acre surveillance quota in 5 days with a 95% success rate requires one pilot flying five drones at 3000’ with a ≥45° sensor Field of View (FOV).

Keywords: Agricultural Surveillance, Drone Surveillance, Remote Sensing, Logistics Planning, Flight Planning, Monte Carlo Simulation

1. Introduction and Context Analysis

The agricultural commodity market, valued at $276 billion in 2023, is dominated by corn and soybeans, which make up about half of that total. The agricultural commodity market depends on accurate data collection to inform trading decisions, which, in turn, influences prices throughout the entire supply chain (Ram et al., 2024). These trading decisions based on agricultural growth trends rely on detailed reports from data analysts who interpret hyperspectral images of farmlands captured by satellite companies. These images help identify growth patterns that influence trading decisions. Meanwhile, the USDA generates crop forecast reports through farmer field surveys. Drone and sensor technology advancements enable the RSAS to use a fleet of fixed-wing drones operating BVLOS between 1000’ and 4000’ with hyperspectral sensors. The RSAS has the capability to provide high resolution, agricultural surveillance data that is not limited by cloud cover. This paper describes the Concept of Operations, Mission Requirements, and design for the RSAS. The requirements and design parameters are defined by detailed analysis using a LMS and a FPAS which are defined in later sections.

2. Stakeholders and Their Objectives

Commodity brokers make trading decisions based on agricultural growth trends, relying on detailed reports from data analysts who interpret hyperspectral images of farmlands captured by satellite companies. These images help identify growth patterns that influence trading decisions. Meanwhile, the USDA generates crop forecast reports through low sampled farmer field surveys, aiming to provide accurate agricultural data. However, since there is no competition between satellite companies and the USDA, there are low incentives for both entities to improve their data collection methods. Weather analysts assess atmospheric conditions to help farmers mitigate weather-related crop losses, while sensor manufacturers develop electromagnetic spectrum sensors used in hyperspectral imaging. Drone manufacturers equip commercial drones with these sensors, allowing drone operators to conduct daily aerial surveys that capture farmland images, which are then fused with satellite imagery for further analysis. The agricultural supply chain includes various stakeholders such as agricultural suppliers who provide seeds and fertilizers, farmers work to optimize soil conditions and maximize profits, and distributors purchase produce to supply food processing plants that convert raw goods into sellable products. These products are then transported by food distributors to retailers, ensuring consumer availability.

Table 1. Stakeholder Objectives

Stakeholder:	**Objectives**	**Expected Outcome**	**Tensions**
Commodity Brokers (High Influence, High Interest)	- Make trading decisions based of growth trends -Turn a profit from detailed agricultural report obtained from data analysts	-Facilitation of the buying and selling of agricultural commodities -Profits made from trading decisions	-Tensions due to inaccurate forecasts made from both the USDA and satellite imagery
USDA (Low Influence, Low Interest)	-Protect human, animal, and crop and health/stability by minimizing crop stress, presence of pests and disease	-US consumers are free to purchase produce without the worry that it is unsafe for consumption	-Tensions with commodity brokers from supplying inaccurate forecasts
Farmers (High Influence, Low Interest)	-Minimize loss of crops -Gain insight on soil/crop conditions -Sell crops to crop distributors	-Salvage or save failing crops -Maximize operational efficiency of crop growth -Maximize profits from crop sales	Tensions with the USDA due to set regulations -Tensions with commodity brokers from selling price of crops
Satellite Companies (Low Influence, Low Interest)	-Capture and provide data analysts with hyperspectral images of farmlands	-Data analysts purchase hyperspectral images from satellite companies	Tensions due to selling price of satellite data
Data Analysts (High Influence, Low Interest)	-Analyze hyperspectral images provided by satellite companies and identify growth trends	-Commodity brokers make trading decisions based of growth trends identified by data analysts	Tensions due to buying price of satellite data

3. AS-IS Process

Satellite images from multi-spectral sensors are captured at 10m resolution, with a turnaround of up to 2 weeks. While multi-spectral sensors typically offer 3-15 spectral bands, hyperspectral sensors provide hundreds, greatly enhancing feature extraction and crop analysis. However, satellite image resolution may be too coarse to detect small-scale variations in crop health, soil conditions, and localized weather impacts, which can spread quickly and affect yields. The 1–2-week turnaround time is also problematic, as farming changes rapidly over days or weeks, and delays lead to outdated reports and slow trading decisions. Cloud cover and atmospheric interference can obscure up to 55% of satellite data (King et al., 2013), while limited satellite overpasses reduce real-time monitoring, as some satellites capture images of an area only every few days or weeks. Additionally, USDA surveys and manual inspections rely on qualitative methods, including farmer surveys, which are prone to uncertainty, bias, and error, limiting the accuracy of crop reports. These issues contribute to poor crop forecasts, commodity trading losses, and market instability, affecting food prices and security.

4. Problem/Need Statement

Advances in drone and sensor technologies enable at-scale collection of accurate, rapid, and gapless crop data for forecasting crop yields and prices. These technologies can provide better accuracy (hyperspectral sensors, quantitative, <10m spatial resolution) data, and gapless data collection system that is unaffected by cloud coverage (<55% cloud obstruction).

5. RSAS Con-Ops

The proposed solution to meet stakeholder needs is Drone-Based RSAS (Figure 2). This system uses high-altitude (1000ft to 4000ft) fixed-wing drones with vertical take-off and landing (VTOL) capability, equipped with hyperspectral sensors with on-board edge processing and memory capable of storing up to 512 GB of data for crop surveillance. Drones will fly BVLOS in class-G airspace. To fly at altitudes higher than the 400' limit set by the FAA a Part 107 waiver must be applied for and approved. RSAS Logistics Managers will create a weekly surveillance plan (WSP) detailing field locations, sizes, deadlines, and crew requirements, while considering factors like weather, system costs, and surveillance goals. Based on the WSP, logistics managers will deploy drone crews. Upon arrival, pilots will prepare a flight plan (FP), defining the drone's path to cover the entire field, factoring in battery use, weather conditions, and environmental hazards (e.g., wind turbines, power

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lines). After completing the flight, the data collected will be processed into high-resolution, gapless hyperspectral images, which will be sold to data analysts and commodity brokers for crop forecasting and trading decisions.

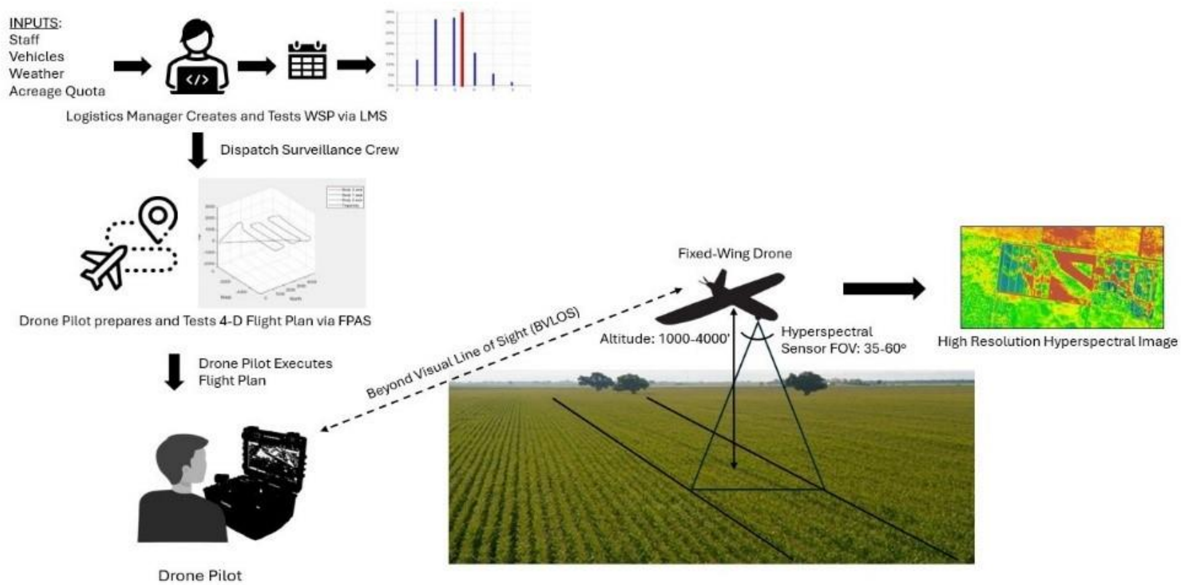

Figure 1. OV1 Diagram

6. RSAS Mission Requirements

To fulfill the Con-Ops of the system, the following mission requirements are required. The thresholds and quantitative metrics cited in the mission requirements were identified through analysis using LMS and FPAS.

Table 2. Mission Requirements

Requirement ID	Description ("The system shall")	Rationale
MR.1	collect ≤1m spatial resolution hyperspectral images of farmland	Ensures improved spatial resolution over existing systems
MR.2	produce hyperspectral image data with 0% cloud obstruction	Ensures images produce less inaccuracies in crop forecasts over existing systems
MR.3	be capable of covering at least 100,000 acres a day	Ensure at scale collection of agricultural data within a feasible timeframe
MR.4	have ≥95% Weekly Surveillance Plan success	Ensures the mitigation of wasted resources (time, parts, and money)
MR.5	have ≥95% drone flight success	Ensures safety and mitigation of property damage

7. Logistics Management Simulation

To conduct requirements analysis for the RSAS system, two simulations have been developed: LMS and FPAS.The LMS receives a WSP as input and tests its feasibility. The WSP defines the location of the fields to be surveyed in the U.S. during the week, the size of the fields, the maximum number of days allowed to complete the field scans, and the crew size, which includes the number of pilots, staff, and drones. The simulation parameters include costs (staff wages, per diem travel costs), drone reliability, and weather forecasts. Utilizing the Monte Carlo method, the WSP is simulated over multiple iterations to calculate the final output which is the probability of successfully completing the WSP.

Analysis of the LMS results reveal non-linear relationships between crew size, mission success probability, and the probability of inclement weather. Specifically, the probability of success increases significantly as the chance of inclement weather decreases or as crew size increases. Experiments were also conducted with the minimum required crew size 1 pilot, 1

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assistant, and 5 drones. This crew size was used to test the success rate at varying drone flight altitudes (1000' to 4000'), sensor FOVs (35° to 60°), and varying days allotted (4 to 5 days) to complete the WSP.

The simulation shows that probability of success increases with higher altitudes and larger sensor FOVs. The optimal ranges for sensor FOV and altitude are 45°-60° and 3000'-4000', respectively. Additionally, extending the days allotted to complete the acreage quota leads to a significant increase in probability of success. Adding one extra day to the mission can enhance the probability of success by 15% to 35%. However, if the plan is already close to feasibility or already feasible within 4 days, the increase is only between 1% and 5%. Figure 7 shows how the probability of success changes for each FOV at different altitudes and with the goal time extended by one day.

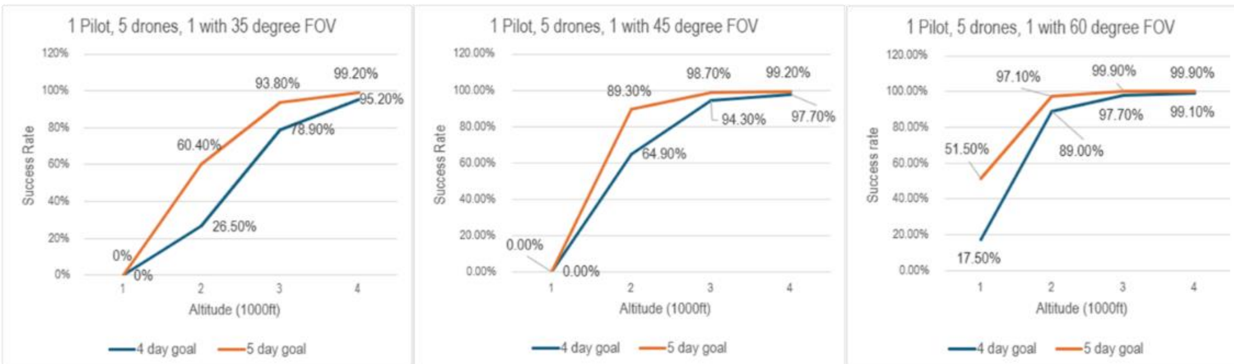
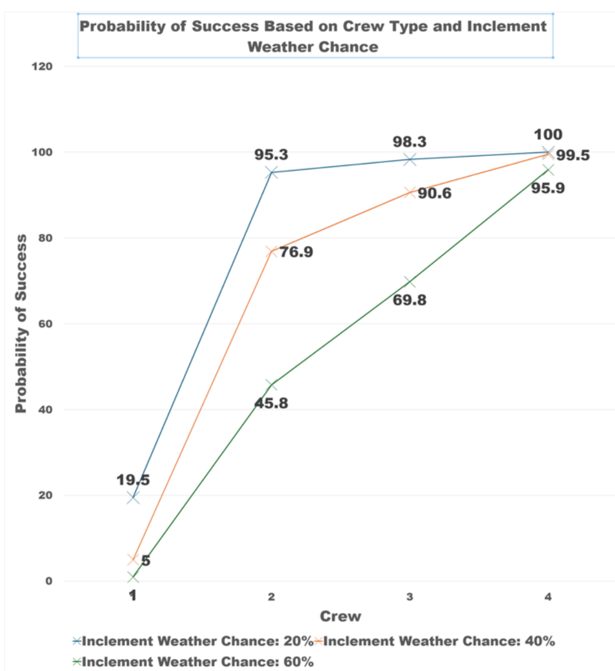


Figure 2. 35°,45°, and 60° Sensor FOV tested at each altitude

Furthermore, if the probability of Inclement weather exceeds 25-30%, it becomes necessary to increase the number of pilots and drones to compensate for the flying time lost due to weather. This is due to the fact that inclement weather will cause the amount of time available to fly per day to be reduced to half or zero. Figure 8 shows how much the crew size needs to increase for a plan to be feasible if the face of inclement weather increases.



	# pilots	# drones	# assistants
Crew 1	1	3	1
Crew 2	1	5	1
Crew 3	2	3	1
Crew 4	2	5	1

Figure 3. Probability of Mission Success based on Crew Size and Chance of Inclement Weather

The analysis also indicates that drone failure and pilot unavailability have minimal impact on the overall success rate of a WSP. Validation testing was conducted using a design of experiment (DOE) table to illustrate how different inputs and parameters influence the outcomes. While the full DOE table is extensive, only selected key results are presented here to highlight the insights discussed in the analysis. The simulation has been validated through these tests and successfully models the expected performance of a real-world system. The findings from this simulation have been applied to the requirements analysis for the broader RSAS system. It was determined that the RSAS system can cover 100,000 acres per day, provided that the WSP achieves a minimum success rate of 95%. To meet this probability of WSP success the following operational configurations are recommended: Drone flight Altitude of 3000'-4000', Sensor FOV of 45° -60°, and a minimum crew size ratio of 1 pilot 1 assistant and 5 drones. This crew size ratio should be scaled up as the acreage quota or inclement weather chance increases.

8. Flight Plan Assurance Simulation

The FPAS is physics-based simulation that was developed to allow drone operators to ensure that flights can be completed with sufficient battery power and in a sufficient amount of time. The FPAS intakes the drone FP, wind speed, and wind direction as inputs, then simulates the drone flight using the input conditions to calculate flight time, battery usage, and mission success. The mission success is calculated the percentage of runs that complete the FP. The drone pilot can use this information to adjust their FP to meet the enterprise's tolerance for flight failures.

Through results analysis for the FPAS, non-linear relationships between sensor FOV and field coverage, post-flight drone battery capacity remaining, and flight time were observed. Experiments have been run to test 1000'-4000' altitude flight with varying sensor FOV from 15-60 degrees over 4000-acre field to determine the effects of altitude and sensor FOV on flight time and battery usage. 1000' 15-degree FOV is infeasible because the drone runs out of battery before it completes its flight. The remaining battery can be negative because the simulation always simulates the full flight regardless of battery usage. There are diminishing returns at sensor FOV's higher than 30-45 degrees. Similarly, the model identified non-linear relationships between flight altitude and field coverage, post-flight drone battery capacity remaining, and flight time where there are diminishing returns at altitudes higher than 2000'-3000'. These results highlight an optimal range of Altitude and sensor FOV, suggesting that drones should be flown between 2000'-3000' with a sensor FOV between 30 and 45 degrees.

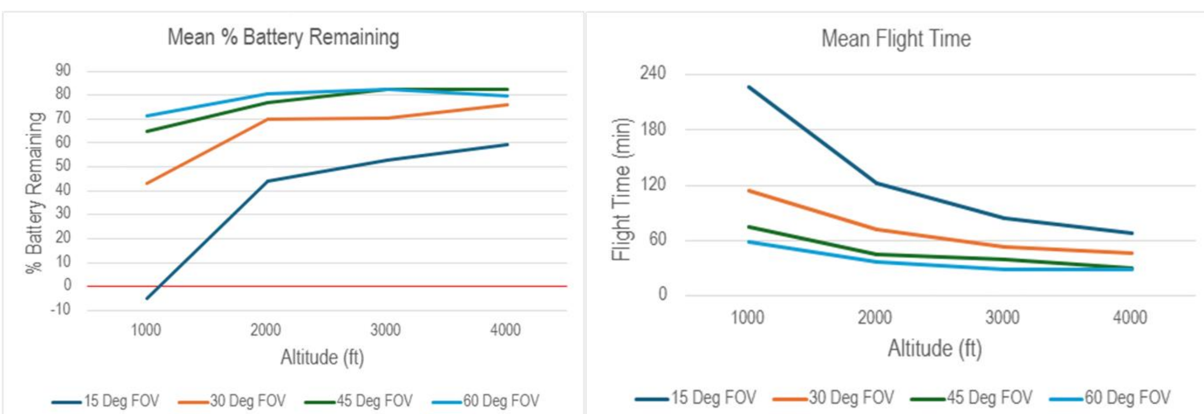


Figure 4. 15°, 30°, 45°, and 60° Sensor FOV Tested at each Altitude

A second set of tests was run for the FPAS using a 3000' altitude and 45-degree sensor FOV to determine how much land could be covered with one of the optimal flight configurations from the first set of tests. A non-linear relationship was found between the field size and flight time, however, the mean % battery remaining still decreases linearly, this suggests that longer flights are more efficient in both battery usage and amount of land covered.

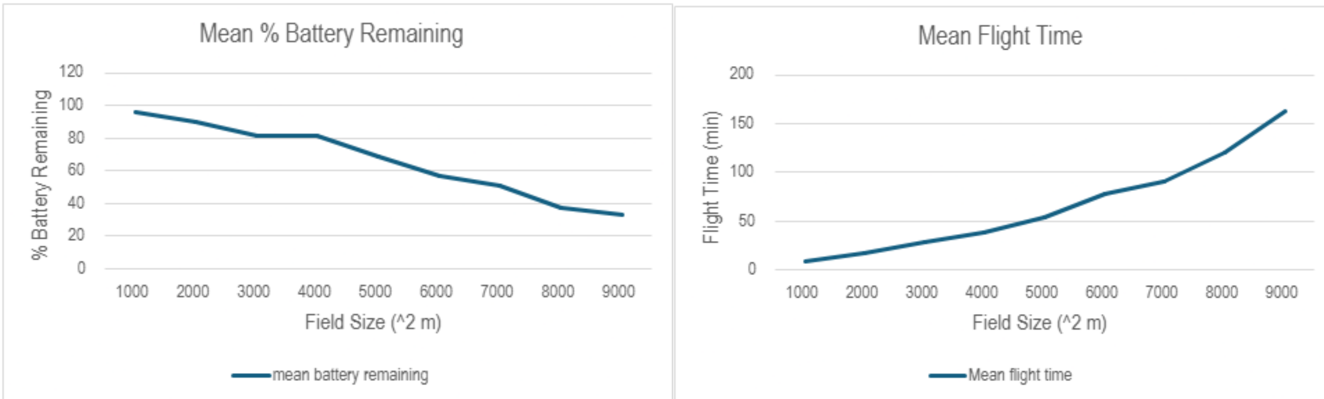


Figure 5. Different Field Sizes for 3000’ Altitude 30° Sensor FOV

9. Conclusion

The RSAS system was developed to enhance the efficiency and accuracy of crop data collection. Analysis identified that current data collection methods like satellite imaging and USDA manual surveys face significant limitations which cause gaps in crop forecasting, leading to trading losses, commodity market instability, and inefficient agricultural planning. Through the developed LMS and FPAS, an extensive requirements analysis was conducted to determine the optimal operational parameters for RSAS system configuration. It was found that to achieve a 500,000-acre surveillance quota in 5 days with a 95% success rate, one pilot flying five drones at 3000’ with a ≥45° sensor FOV is required. These simulations defined the key required performance for drone flights and logistics plans, ensuring that the system meets its performance, accuracy, and scalability needs. The implementation of LMS and FPAS within RSAS ensures that both logistics plans, and flight plans are verified before being put into motion, addressing challenges in crew allocation, flight feasibility, and mission success rates.

10. References

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