Sky Net

Futuristic Innovative Technologies

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Design Dossier

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| 1 | 9/30/2021 | Updated Problem Statement, Mission statement, section 2 Stakeholders, 3.1 Stakeholder Needs, 3.2 Stakeholder Requirements, CONOPS, QFD, and Goals |
| 2 | 11/18/2021 | Updated Stakeholder Requirements Based on Feedback, updated mission statement and stakeholders, Stakeholder Needs, QFD, FMECA, Feasibility Table for System\ Level Requirements, AHP Trade Study, Added Requirements Justifications Appendix |
| 3 | 12/09/2021 | Updated S.R., CONOPS, and select edits |

Student Contribution:

All students contributed equally to the Design Dossier.

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# Purpose of the Project

## Problem Statement

Futuristic Innovative Technologies (FIT) is a high-end producer of specialized UAV systems for extreme applications working to produce a feasibility study for building an Autonomous UAV (AUAV). This new AUAV would integrate state-of-the-art ATC imaging capabilities with GPPP technology in real time, perform “search and find” maneuvers, object of interest tracking, and threat aversion. The AUAV will operate both independently and as an autonomous integrated swarm of AUAVs with adaptive, AI-based decision-making/mission reconfiguration and will be adaptable for future features such as a natural language AI-based Command and Control Interface. This AUAV must also compensate for atmospheric turbulence in the collected imagery, perform digital signal processing, and automatic target recognition. The AUAV must additionally be worldwide deployable and have a neutral profile.

In .

## Mission Statement

The mission of the three-letter agency is to provide multi-purpose surveillance support for worldwide scientific collection activities, support low-profile data and information collection efforts for allies and national partners, conduct rapid worldwide deployments and surveillance activities in support of national treaty monitoring interests, and implement surveillance and reconnaissance missions for national strategic and tactical targets-of-interest (TOIs). The three-letter fosters science, innovative technology, and collaborations with strategic partners.

# Stakeholders

## Point-of-Contact

The Point-of-Contact (POC) is Wilford Erasmus, Chief of Operations from the U.S. Department of Homeland Security and the U.S. Customs and Border Protection. The Chief of Operations is representing a 3-letter agency and is accountable for the project and ~~thus will be the applicable point of contact~~ customer interface.

## The Customer

The Customer is a 3-letter agency represented by the U.S. Department of Homeland Security.

## Other Stakeholders

An investigation of other stakeholders yielded individuals and groups that Futuristic Innovative Technologies (FIT) may need to consult with, have negative interest in the project succeeding, or may benefit from the success of the project. Table 1 summarizes the other stakeholders for this project.

Table 1: Table of Other Stakeholders

|  |  |
| --- | --- |
| Stakeholder Class | Stakeholder Description |
| External Consultant | * Commercial Off the Shelf (COTS) Suppliers * Technical Subject Matter Experts (if necessary) * Federal Aviation Administration (FAA) * Federal Communications Commission (FCC) * General Atomics – original developer of the AUAV * National Weather Service * Embassies * National Society of Professional Surveyors * AFRL and Air Force Life Cycle Management Center (AFLCMC) |
| Negative Stakeholders | * Competitors (Northrup Grumman and other bidders) * Civil Liberty and Citizen Privacy Groups (EPIC, ACLU, HRW, etc.) * Political Parties * Environmental and Ecological Organizations |
| Functional Beneficiaries | Primary Stakeholder   * 3-Letter Agency * International Universities * International Research Organizations * International Air and Space agencies * US Allies and Partners * US Military   Secondary Stakeholders   * Government National Security Agencies (HSBP, FBI, CIA, ATF, DEA, DIA, U.S Marshals Service, Local Law Enforcement, etc.) * First Responders (U.S and International Search and Rescue) * U.S. Coast Guard * National Park Service * Aid Organizations * Interpol |

It is expected that the Federal Aviation Administration (FAA) will need to be consulted to obtain airframe and airworthiness certifications and that the State and Municipal Governments of the US. The Federal Communications Commission (FCC) will be consulted to obtain transmitting licenses. As well, FIT will need to consult with COTS suppliers for system components. Depending on the requirements, FIT may need to contract with, or sub-contract work to, subject matter experts (SMEs) to resolve deficiencies during the project. General Atomics as the designer of the UAV being modified will need to be consulted for drawings, cable routing and other issues that will impact the design. Applicable Embassies will also need to be contacted to ensure proper permissions and certifications for overseas deployment.

Although we believe that all design work can be performed in-house, FIT should be aware that Northrop Grumman and any other bidders are negative stakeholders that FIT may need to contract out for specialized components to adhere to schedule, cost, quality, and risk expectations are met, although direct competitors in the AUAV sector. The other negative stakeholders and functional beneficiaries will not be actively engaged in the project otherwise.

Especially considering the benign appearance of the AUAV and the advanced search and rescue functions, the product may be of interest to agencies and organizations that regularly participate in rescue efforts in extreme environments. The product may be beneficial to these stakeholders with minimal changes or updates.

## The Hands-On Users

The project has identified five (5) entities that are the hands-on users. These are AUAV Flight Officers, AUAV Optical Operator, Intelligence Officers, AUAV Maintenance Technicians, and Unmanned Aerial System (UAS) Maintenance Technicians.

Table 2 shows each of the hands-on users’ current roles and responsibilities.

Table 2: Hands-On Users Current Roles and Responsibilities

|  |  |
| --- | --- |
| Stakeholder | Current Tasks |
| AUAV Flight Officer | * Remotely pilot the AUAV through taxiing, take-off, in-flight operations, and landing when the option for manual control is triggered on. * Direct AUAV to locations as instructed by Superior Officers. * Update mission flight plans as directed by Superior Officers. * Select visibility mode (e.g. Day, Infrared Radiation (IR) at night, or perhaps both during dawn and dusk). |
| AUAV Optical Operator | * Orient electro-optical imaging on AUAV to view necessary locations from AUAV’s position. * Optimize and modify settings of AUAV during direct control operations. * Monitor AUAV data stream and notify the proper channel in case of situational uncertainties. * Pay attention to any warning or level indicators and send AUAV to maintenance as necessary. * Lock on the target (objective) and stay on it or follow it. |
| Intelligence Officer | * Interpret images from AUAV to confirm bipedal movement. * Initiate contact with a land-based mission control center, mobile command centers. * Confirmation of AI Identification/detection of target (objective). * Use obtained intelligence to guide AUAV operations and recommend course of action. * Verify operations are proceeding as planned. |
| AUAV Maintenance Technicians | * Perform pre- and post- flight checks. * Fill fuel tanks and oil reservoirs. * Start and stop the AUAV engine. * Perform preventative maintenance, diagnostics, repairs and servicing. * Troubleshoot any mechanical breakdown while under deployment ~~within a reasonable amount of time.~~ |
| UAS Maintenance Technicians | * Perform preventative maintenance, diagnostics and repairs to AUAV mission control centers, mobile control centers, and communications links. |

# Stakeholder Needs and Requirements

## Stakeholder Needs

The customer has requested a world-wide deployable AUAV to be used for surveillance, scientific data collection, and other monitoring purposes. After discussions with the primary stakeholders, customer and client, the following needs were identified as specific requests and planned use-cases for the AUAV system. The following concepts guided the development of system and subsystem requirements:

Main:

A state-of-the-art Atmospheric Turbulence Compensating (ATC) imaging capability with integrated digital filtering technology. This will provide the fastest (real-time), highest spatial resolution images available on the planet. It will use the General Purpose Parallel Processing (GPPP) technology for rapid filter/transform/inverse-transform applications.

Ability to detect and identify human target of interest.

Capabilities of autonomous flight with Artificial Intelligence (AI) - based decision-making for station-keeping, threat-aversion, “search and find” maneuvers and Object of Interest (OoI) tracking.

Ability to be used individually or as part of an Autonomous Integrated Swarm (AIS) of Autonomous UAVs with adaptive, AI-based decision-making/mission reconfiguration.

Adaptability for other features/capabilities/sensor packages: natural language, AI-based Command and Control Interface.

A component-level detailed bottoms-up analysis for the power/energy support system for the mobile command center.

Additional Needs:

Ability to be remotely controllable, and/or use AI to perform tasks (e.g., collect images) on its own.

The AUAV system has to be world-wide deployable.

Must be capable of protecting itself in harsh and extreme environments.

The AUAV system must look like a benign Search and Rescue AUAV (looks like a generic search and rescue AUAV)

The Mobile Command Center (MCC) must be deployed indefinitely in remote, low access areas. The MCC needs a versatile, quiet energy source to accomplish it. Use of renewable energy, specifically solar energy was suggested. (Feasibility analysis for a quiet, 10kW-Hr to 20kW-Hr generator that uses renewable energy)

Provide an image to command center within 5 seconds.

Provide on-demand video to command center within 5 seconds.

The following preferences were identified:

The use of Agile methods where possible.

The delivery of Model-Based Systems Engineering (MBSE) artifacts if possible.

Operational support phase over 25 years after delivery with pre-planned product improvements.

The use of COTS where possible.

Provide maintenance.

Provide upgrades.

Provide service.

## Stakeholder Requirements

From the identified project needs, and interviews with the primary stakeholders the following stakeholder requirements were identified:

S.R. 01 The AUAV system shall interface with the existing AUAV mission control center to provide the best possible imaging technology and data processing for detection, identification, and tracking capabilities.

S.R. 02 The Sky Net program shall meet or exceed mission detection, identification, and tracking requirements as specified in Table 3 Permutation of Stakeholder Requirements.

Table 3: Permutation of Stakeholder Requirements

|  |  |
| --- | --- |
| **Requirement** | **Permutation for Target of Interest (TOI)** |
| S.R. 02 The Sky Net program shall meet or exceed mission detection, identification, and tracking requirements. | 1. Detect human TOI within a slant range of 9.543 km during daytime.  2. Detect human TOI within a slant range of 1.5 km during nighttime.  3. Identify human TOI within a slant range of 1.5 km during daytime.  4. Identify human TOI within a slant range of 250 m during nighttime (with slipstream sensors).  5. Identify human TOI within a slant range of 1.5 km (with slipstream sensors). |

S.R. 03 The AUAV shall conduct its operations in a safe manner.

S.R. 04 The AUAV shall have a flexible control scheme through either a remote mission control center, local mobile command center, or independent A.I. based decision-making system; with the ability to exchange authority over the AUAV between all control methods.

S.R. 05 The AUAV shall be adaptable for other features/capabilities/sensor packages/upgrades including a natural language, AI-based decision-making/mission reconfiguration.

S.R. 06 The AUAV should utilize commercial off the shelf products (COTS) where possible to reduce risk and cost.

S.R. 07 The AUAV shall be capable of supporting 24/7 operations worldwide.

S.R. 08 The AUAV shall be supported and maintained throughout the program’s lifecycle over 25 years after delivery with pre-planned program improvements.

S.R. 09 The AUAV shall have an operational availability of at least 98%.

S.R. 10 The AUAV shall have an instantaneous reliability of at least 70%.

S.R. 11 The AUAV ~~Optical System~~ shall have a Mean time between failures (MTBF) of 20 years.

S.R. 12 The AUAV shall have a Mean time to repair (MTTR) of less than 8 hours.

S.R. 13 The AUAV shall be capable of performing solo missions with the aid of the onboard AI system.

S.R. 14 The AUAV shall be capable of flying as a part of an integrated swarm of AUAVs with adaptive, AI-based decision-making/mission reconfiguration.

S.R. 15 The integrated swarm of AUAVs shall be able to cooperatively intercept and geolocate Objects of Interest (OoI).

S.R. 16 The AUAV shall be capable of sending critical information to the Mission Command Center in less than 5 seconds.

S.R. 17 The mobile command center shall have a power source that ~~meets the AUAV operators’ needs.~~ is capable of supplying 10kW hr to 20 kW hr per day to the MCC.

S.R. 18 The system shall be able to operate in harsh and extreme environments.

S.R. 19 The AUAV system must look like a benign Search and Rescue AUAV.

## Feasibility Analysis and Risk Identification

The following tables provide the supporting documentation to the requirement feasibility assessment for technical, cost and schedule, organizational, and political and operational. The conclusion is that all requirements have been proven feasible with current technology.

S.R. 01 - The AUAV system shall interface with the existing AUAV mission control center to provide the best possible imaging technology and data processing for detection, identification, and tracking capabilities.

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| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | The system will need to detect, identify, and track human activity both day and night. | | | | |
| Fit Criterion: | This will be done by using at least 10 spatial resolution cells across the observed object of interest under all imaging conditions. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequence | Initial Perceived Risk | Risk Mitigation | Risk after Mitigation |
| Technical Assessment: | ~~This is possible as the other systems connect directly to the master control center.~~  The imaging system won’t be able to identify and detect humans as a function of stand-off distance and entrance pupil diameter. | Failure of project objective. | High | AUAV Optical Operator tasks of orienting the electro-optical imaging on AUAV to view specific locations based on AUAVs position.  AUAV Optical Operator controls are in existence.  Use of slipstream sensors alleviates risk of failing to detect or identify a TOI. | Medium |
| Cost and Schedule Assessment: | Could require new integration technology, as the imaging system is not yet fully defined. | Project cost and schedule delays while being resolved. | Medium | Good engineering practices for image processing and detection/identification/tracking feasibility. | Low |
| Organizational Assessment: | Lack of subject matter expert. | Project cost and schedule delays. | Low | In-house team available.  Will outsource through consultation or send out job requests as needed. Proper documentation of progress and knowledge capture presentation events will be held. | Low |
| Political and Operational Assessment: | AUAV becomes difficult to maintain.  AUAV may require intervention to fly mission. | No cost savings, project failed objective. | Medium | Reliability analysis required.  Component / software code to be modeled the verify operability.  AI software package allows for programmable missions and more autonomy. | Low |

S.R. 02 – The Sky Net program shall meet or exceed mission detection, identification, and tracking requirements as specified in Table 3 Permutation of Stakeholder Requirements.

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| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | A state-of-the-art atmospheric turbulence compensating imaging capability with integrated digital filtering technology, that provides real-time, high spatial resolution images, with General Purpose Parallel Processing (GPPP) technology for rapid filter/transform/inverse-transform applications. | | | | |
| Fit Criterion: | Ensure spatial resolution requirements are met for all imaging scenarios | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequence | Initial Perceived Risk | Risk Mitigation | Perceived Risk |
| Technical Assessment: | There must be enough storage on board for the GPPP device.  The computer turnaround time must be very fast. | Unable to continue storing and processing data resulting in project failure. | Low | Detect human Target of Interest (TOI) within a slant range of 9.543 km during daytime.  Detect human TOI within a slant range of 1.5 km during nighttime.  Identify human TOI within a slant range of 1.5 km during daytime  Identify human TOI within a slant range of 250 m during nighttime (with slipstream sensors)  Identify human TOI within a slant range of 1.5 km (with slipstream sensors) | Low |
| Cost and Schedule Assessment: | High reliability high precision inertial navigation is costly. | No cost savings | Low | Consider utilizing low accuracy inertial navigation supplemented by air data reference units. | Low |
| Organizational Assessment: | Lack of subject matter expert (SME) on Optics unit. | Project delays while being resolved. | Low | In-house team available.  Will outsource through consultation or send out job requests as needed. Proper documentation of progress and knowledge capture presentation events will be held. | Low |
| Political and Operational Assessment: | AUAV becomes difficult to maintain.  AUAV still requires intervention to fly mission. | No cost savings, project failed objective.  Political inquiry  International incident | Medium | Simulate AUAV operation before implementation.  FAA certification of airworthiness.  Good engineering practices. | Low |

S.R. 03 - The AUAV shall conduct its operations in a safe manner.

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| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | This is to ensure that the existing fleet, other flying objects, and unintended civilians/targets around it are safe and no accidents, collisions, failure, and/or death occur. | | | | |
| Fit Criterion: | Simulations will ensure that the AUAV will operate safely. Satisfy FAA flight safety regulations. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequence | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | Design of unsafe aircraft.  Communicating with other aircrafts. | Engineering failure, loss of reputation.  Loss of equipment.  Injury or loss of life | Medium | The use of good engineering practices, codes, standards, and redundancies reduces risk of poor engineering design.  Approval required by FAA prior to flight. | Medium |
| Cost and Schedule Assessment: | Meeting American Institute of Aeronautics and Astronautics (AIAA) standards for flying objects. | Potential lawsuit.  No cost savings. | Medium | The use of strong system engineering practices and planning to prevent issues ahead of time will reduce cost additions or schedule delays.  Consultation with FAA early on in project. | Low |
| Organizational Assessment: | Missions of three-letter agency and its partners conflict on TOI designations. | Schedule Delay. | Low | Clear definitions of scope and mission by all involved parties and use of operation protocols to prevent issues. | Low |
| Political and Operational Assessment: | AUAV must follow all AIAA standards and guidelines  Possible grounding for unsafe operation.  AUAV collides with object.  AUAV crashes in flight.  AUAV fails to report near-miss with objects. | Political inquiry and loss of AUAV.  Potential lawsuit.  Loss of human life, or human injury if AUAV hits someone. | High | Install manual override setting to operate AUAV.  Simulations of operation and AI system reduce risk of errors and failure mechanisms.  Redundant systems.  Interactive diagnostics. | Medium |

S.R. 04- The AUAV shall have a flexible control scheme through either a remote mission control center, mobile command center, or A.I. based decision-making system; with the ability to exchange authority over the AUAV between all control methods.

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| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | Stakeholder requests that operation of AUAV to occur from Mission Control Center in Colorado Springs, Colorado as well as other field control units that can assume control locally from mobile command centers in special trucks or deployed portable command centers. | | | | |
| Fit Criterion: | Simulations will ensure that the AUAV will operate safely. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequence | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | Unexpected engineering work due to lack of vendor documentation.  Unexpected production delays due to lack of vendor materials. | Unable to operate AUAV from multiple locations. | High | Ensuring cross platform compatibility.  Testing of all equipment as it becomes incorporated into the system. | Medium |
| Cost and Schedule Assessment: | Expedited completion could increase shipping costs, overhead, overtime cost, etc. | Project Delays. | Medium | Futuristic Innovative Technologies has suitable project controls in place.  The contract has mechanisms to allow for a shift in the project end date based on any Client or Certifying Agency decision / approval delays.  Use of non-ideal components to get the retrofit completed within timeline. | Low |
| Organizational Assessment: | Lack of manpower / resources.  Unexpected delays due to employee turnover. | Project delays or additional cost of overtime. | Low | Have additional technicians starting with the installation of the other AUAVs, once the first AUAV has been completed and approved. | Low |
| Political and Operational Assessment: | Expedited completion could increase shipping costs, overhead, overtime cost, etc.  As the 3-Letter Agency is funded with public funds, any unexpected delays would involve the Chief of Operations have to explain the delays to higher ranking leadership within the Department of Defense. | The need for the system might increase during the design phases of the system. This could increase the political response needed, possibility of addition of requirements. | High | Use well established Systems Engineering and Program Management techniques to account for the potential change in demand of the stakeholders and ensure the best quality system is delivered within the project parameters.  As the 3-Letter Agency is funded with public funds, any unexpected delays would involve the Chief of Operations have to explain the delays to higher ranking leadership within the Homeland Security. | Medium |

S.R. 05 - The AUAV shall be adaptable for other features/capabilities/sensor packages/upgrades including a natural language, AI-based decision-making/mission reconfiguration.

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| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | The AUAV will have increased operational capacities from these additional features/capabilities/sensor packages. | | | | |
| Fit Criterion: | The fleet should be able to be upgraded for new needs and as technology improves. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequence | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | Technology potentially not available to provide all needed adaptations. | Inability to meet requirements. | Low | Use COTS to help reduce cost and avoid unnecessary product development. | Low |
| Cost and Schedule Assessment: | The updates required would increase overall cost of project and increase the time needed to accomplish it. | Potential to go over budget and miss schedule deadline. | Low | Use COTS to help reduce cost and so the technology doesn’t need to be reinvented. | Low |
| Organizational Assessment: | Potential need for dedicated team just on updating and optimizing project. | Will have to put more man hours on the project and take away from other areas. | Low | Hire more employees. | Low |
| Political and Operational Assessment: | Stakeholder finds upgrades unnecessary | Political inquiry. | High | Make sure there is a valid reason to use the AUAV capabilities.  Clear definitions of scope and mission by all involved parties and use of operation protocols to prevent issues. | Medium |

S.R. 06 - The AUAV should utilize commercial off the shelf products (COTS) where possible to reduce risk and cost.

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| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | The use of standardized and readily available components will ensure readily available spare parts are available as well as vendor support of the product. | | | | |
| Fit Criterion: | Annual and at end of the project audits will take place to ensure that these components are used where necessary and possible. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequences | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | Could be determining criteria in selecting between two equal components. | Choice of inferior product. | Low | Trade-off studies need to be performed between components prior to procurement to ensure that standard tools are part of the criteria. | Low |
| Cost and Schedule Assessment: | Other parts might be more expensive, or the contractors and vendors could raise costs unexpectedly. | Cost increase. | Medium | Ensure that all costs and vendors agree to maintenance and availability early. | Low |
| Organizational Assessment: | None identified. | None identified. | N/A | None required. | N/A |
| Political and Operational Assessment: | None identified. | None identified. | N/A | None required. | N/A |

S.R. 07 - The AUAV shall be capable of supporting a 24/7 operations worldwide.

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|  | | | | | |
| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | This will ensure top operational time for the system, making sure any field the AUAV is used in will always be accounted for in any field. | | | | |
| Fit Criterion: | The AUAV will provide detection 24 hours per day / 7 days per week. Sustained operations should be up to a month of operations at any hot-spot. Ensure that MCC and AUAV can be deployed to worldwide locations. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequences | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | None Identified. | None identified. | N/A | None required. | N/A |
| Cost and Schedule Assessment: | None identified. | None identified. | N/A | None required. | N/A |
| Organizational Assessment: | None identified. | None identified. | N/A | None required. | N/A |
| Political and Operational Assessment: | No components available.  Systems fail during the time frame.  Inability to deploy AUAV and MCC to target location. | AUAV fleet grounded. | Medium | Use of multiple systems with redundancies to ensure that the time expectancies are met. | Low |

S.R. 08 - The AUAV shall be supported and maintained throughout the program’s lifecycle over 25 years after delivery with pre-planned program improvements.

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|  | | | | | |
| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | This is to ensure that when the AUAVs require maintenance, they are able to be fixed, repaired, maintained, etc. | | | | |
| Fit Criterion: | This will be done by having AUAV Maintenance Technicians on hand. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequences | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | Could be determining criteria in selecting between two equal components. | Choice of inferior product. | Low | Trade-off studies need to be performed between components prior to procurement to ensure that standard tools are part of the criteria. | Low |
| Cost and Schedule Assessment: | None identified. | None identified. | N/A | None required. | N/A |
| Organizational Assessment: | None identified. | None Identified. | N/A | None required. | N/A |
| Political and Operational Assessment: | No tool available at time of need. | AUAV grounded due to lack of maintenance tools. | Medium | The maintenance manuals will be reviewed for all specialty tools and vendor will be requested to supply as part of contract. | Low |

S.R. 09 - The AUAV shall have an operational availability of at least 98%.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | | | | | |
| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | This will ensure that the 3-Letter Agency can rely on this product to successfully and accurately identify and detect a human being within the appropriate system operations and mission. | | | | |
| Fit Criterion: | Trade studies completed to prove that the operational availability shall be 98%. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequences | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | Could be determining criteria in selecting between two equal components. | Choice of inferior product. | Low | Trade-off studies need to be performed between components prior to procurement to ensure that standard tools are part of the criteria. | Low |
| Cost and Schedule Assessment: | None identified. | None identified. | N/A | None required. | N/A |
| Organizational Assessment: | None identified. | None Identified. | N/A | None required. | N/A |
| Political and Operational Assessment: | No tool available at time of need. | AUAV grounded due to lack of maintenance tools. | Medium | The maintenance manuals will be reviewed for all specialty tools and vendor will be requested to supply as part of contract. | Low |

S.R. 10 - The AUAV shall have an Instantaneous reliability of at least 70%.

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|  | | | | | |
| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | This is to ensure that all components are working properly and accurately. | | | | |
| Fit Criterion: | Reliability studies to ensure that the components selected maintain this reliability. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequences | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | Could be determining criteria in selecting between two equal components. | Choice of inferior product. | Medium | Use of only system-specific pieces.  Have all parts in spare storage to decrease repair time and increase reliability when changing out parts quickly.  Trade-off studies required. | Low |
| Cost and Schedule Assessment: | None identified. | None identified. | N/A | None required. | N/A |
| Organizational Assessment: | Tools might not be available when needed. | AUAV grounded due to lack of tools to fix components. | Medium | Ensure that all tools and vendors will be available at time of service. | Low |
| Political and Operational Assessment: | No tool available at time of need. | AUAV grounded due to lack of tools to fix components. | Medium | The maintenance manuals will be reviewed for all specialty tools and vendor will be requested to supply as part of contract. | Low |

S.R. 11 – The AUAV ~~Optical System~~ shall have a Mean time between failures (MTBF) of 20 years.

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|  | | | | | |
| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | This is to ensure that there will always be a working fleet and reducing lifetime cost. | | | | |
| Fit Criterion: | FMECA and failure studies will ensure that all AUAV subsystems will be able to support a 20-year MTBF. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequences | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | Could be determining criteria in selecting between two equal components. | Choice of inferior product. | Medium | Trade-off studies need to be performed between components prior to procurement to ensure that standard tools are part of the criteria. | Low |
| Cost and Schedule Assessment: | None identified. | None identified. | N/A | None required. | N/A |
| Organizational Assessment: | None identified. | None Identified. | N/A | None required. | N/A |
| Political and Operational Assessment: | No tool available at time of need. | AUAV could be grounded longer due to lack of proper components to lend a high operational availability time. | Medium | Ensure all parts and components available before AUAV comes in for repair. | Low |

S.R. 12 – The AUAV shall have a Mean time to Repair (MTTR) of less than 8 hours.

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| --- | --- | --- | --- | --- | --- |
|  | | | | | |
| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | This is to ensure that there will always be a working fleet and reducing maintenance cost. | | | | |
| Fit Criterion: | The designs shall support a modular configuration to make repairs easy on the AUAV Maintenance Technicians. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequences | Initial Perceived Risk | Risk Mitigation | Perceived Risk |
| Technical Assessment: | Possible determining criteria in selecting between two equal components, possible choice of inferior product, decreasing the performance of the system. | Choice of inferior product. | Medium | Trade-off studies need to be performed between components prior to procurement to ensure that standard tools are part of the criteria.  Have one spare AUAV for each active AUAV for quick replacement/repair/downtime. | Low |
| Cost and Schedule Assessment: | None identified. | None identified. | N/A | None required. | N/A |
| Organizational Assessment: | None identified. | None Identified. | N/A | None required. | N/A |
| Political and Operational Assessment: | No tool available at time of need. | AUAV could be grounded longer due to lack of proper components to lend a high operational availability time. | Medium | Ensure all parts and components available before AUAV comes in for repair. | Low |

S.R.13 The AUAV shall be capable of performing solo missions with the aid of the onboard AI system.

|  |  |  |  |  |  |
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|  | | | | | |
| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | The AUAVs shall be able to complete missions without operator input in cases of communication or power failure, and reduce operator active control time to use for other purposes. | | | | |
| Fit Criterion: | The AI system shall be tested through simulation and field operations. The AUAV has a solitary flight mode that can be autonomous, AI-based, or user controlled. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequences | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | AI system temporarily goes down.  On solo mission AUAV encounters unprogrammed scenario requiring decision making and intervention. | Loss of control or equipment.  Failing a mission due to missing the objective. | Medium | Utilize top of the line software/hardware.  Include redundancy in design.  Operators on standby to take control, if necessary, with 24/7 monitoring.  Include flexibility to program new solo mission configurations in real-time. | Low |
| Cost and Schedule Assessment: | More expensive technology might be required. | Project cost and schedule delays. | Medium | Allocate budget for higher costs. | Low |
| Organizational Assessment: | None identified. | None Identified. | N/A | None required. | N/A |
| Political and Operational Assessment: | None identified | None identified. | N/A | None required. | N/A |

S.R. 14 - The AUAV shall be capable of flying as a part of an integrated swarm of AUAVs with adaptive, AI-based decision-making/mission reconfiguration.

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| --- | --- | --- | --- | --- | --- |
|  | | | | | |
| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | The AUAV’s shall be able to complete missions as a group. | | | | |
| Fit Criterion: | THE AUAV communications must include being able to ‘talk’ with multiple systems. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequences | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | In fields of use the AUAVs must be able to work together. | Loss of communication or equipment.  Failing a mission due to missing the objective. | Medium | Utilize top of the line communication software/hardware. | Low |
| Cost and Schedule Assessment: | More expensive technology might be required. | No cost saving.  Schedule might be delayed to accommodate for such high technology | Medium | Use of off the shelf products and in-house development allow for minimized costs | Low |
| Organizational Assessment: | None identified. | None Identified. | N/A | None required. | N/A |
| Political and Operational Assessment: | None identified. | None Identified. | N/A | None required. | N/A |

S.R. 15 - The integrated swarm of AUAVs shall be able to cooperatively intercept and geolocate Objects of Interest (OoI).

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| --- | --- | --- | --- | --- | --- |
|  | | | | | |
| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | Intercepting and locating OoI helps protect national security, failure would lose mission value. | | | | |
| Fit Criterion: | Communication and OoI system testing must be verified in the breadboard and field setups. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequences | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | Failure to find OoI, mission failure. | National security risk. | Medium | Extensive testing protocol with verification testing and repeatability. | Low |
| Cost and Schedule Assessment: | More expensive technology might be required. | No cost saving.  Schedule might be delayed to accommodate for such high technology. | Medium | Allocate budget for higher costs. | Low |
| Organizational Assessment: | None identified. | None Identified. | N/A | None required. | N/A |
| Political and Operational Assessment: | None identified. | None Identified. | N/A | None required. | N/A |

S.R. 16 –The AUAV shall be capable of sending critical information to the Mission Command Center in less than 5 seconds.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | | | | | |
| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | Any critical information should be sent in a timely manner. | | | | |
| Fit Criterion: | All critical information sent in less than 5 seconds. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequences | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | Critical information must be sent in no more time than 5 seconds. | Performance objectives will not be met. | Low | Communication systems must be able to handle that fast of a response time. | Low |
| Cost and Schedule Assessment: | More expensive technology might be required. | No cost saving.  Risk of going over budget. | Low | None required. | Low |
| Organizational Assessment: | None identified. | None Identified. | N/A | None required. | N/A |
| Political and Operational Assessment: | None identified. | None identified. | N/A | None required. | N/A |

S.R. 17 – The mobile command center should have a consistent and reliable power source that is capable of supplying 10kW-hr to 20 kW-hr per day to the MCC.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | | | | | |
| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | Power must be available to control the swarm of AI AUAV’s from the mobile command center and maintain living conditions for operators. | | | | |
| Fit Criterion: | Power source must use a versatile, quiet, 10kW-Hr to 20kW-Hr generator that uses renewable energy sources that can be deployed indefinitely in remote, low access areas. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequences | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | Renewable energy sources must provide 24/7 power. | Performance objectives will not be met. | Medium | Use of COTS products with emphasis on minimizing power losses based on time of day, and meeting required power ratings in poor weather conditions. | Low |
| Cost and Schedule Assessment: | More expensive technology might be required. | No cost saving.  Risk of going over budget. | Low | None required. | Low |
| Organizational Assessment: | None identified. | None Identified. | N/A | None required. | N/A |
| Political and Operational Assessment: | Mobile Command Center is inoperable due to lack of power | AUAV cannot meet mission objectives | Medium | Implement backup power generation and storage systems. | Low |

S.R. 18 - The system shall be able to operate in harsh and extreme environments.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | | | | | |
| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | AUAV operating environment may include but is not limited to deserts, wilderness, and coastlines/waterways with high heat, cold, humidity, dryness, and salinity. | | | | |
| Fit Criterion: | System requires built-in features such as fans, heaters, and proper seals with access to routine maintenance to prevent system failure in extreme environments. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequences | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | Failure to collect data and potential loss of AUAV. | Performance objectives will not be met. | Low | Using built-in features such as fans, heaters, and proper seals with access to routine maintenance. | Low |
| Cost and Schedule Assessment: | May need to replace AUAV unit or repair entire fleet. | No cost saving.  Risk of going over budget. | Low | None required. | Low |
| Organizational Assessment: | None identified. | None Identified. | N/A | None required. | N/A |
| Political and Operational Assessment: | None identified. | None identified. | N/A | None required. | N/A |

S.R. 19 - The AUAV system must look like a benign Search and Rescue AUAV.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | | | | | |
| Stakeholder: | Wilford Erasmus, POC of the three-letter agency | | | | |
| Rationale: | Desire to blend into surrounding and avoid unwanted interest and conflict from allies, collaborative partners, and non-allies. | | | | |
| Fit Criterion: | Appearance must resemble and have markings consistent with a Search and Rescue vehicle. | | | | |
|  | | | | | |
| Risk | Risk Issue | Risk Consequences | Initial Perceived Risk | Risk Mitigation | Risk After Mitigation |
| Technical Assessment: | Critical information can’t take longer to send than 5 seconds. | Performance objectives will not be met. | Low | Communication systems must be able to handle that fast of a response time. | Low |
| Cost and Schedule Assessment: | More expensive technology might be required. | No cost saving.  Risk of going over budget. | Low | None required. | Low |
| Organizational Assessment: | None identified. | None Identified. | N/A | None required. | N/A |
| Political and Operational Assessment: | None identified. | None identified. | N/A | None required. | N/A |

## Quality Functional Deployment

The Stakeholder Requirements were evaluated for the project feasibility and any associated risks. The team developed a Quality Functional Deployment (QFD) to capture the critical aspects of the Stakeholder Requirements and to give a visual representation to the technical responses for these driving requirements. Additionally, we conducted benchmarking studies to determine the feasibility and quantitatively compared our solution to comparative products to ensure we met or exceeded every given requirement and the standards of our competitors.

The team used a modified QFD. This provides a quantitative value to the requirements (functional and stakeholder). Each stakeholder requirement was given an importance value determined by how crucial it was to the projects needs and functions. The values are multiplied to give a functional requirement score which is then multiplied again by a degree of difficulty factor. The final score is the functional requirements importance and ranking.

After inputting all the data and populating the QFD (Figure 1), the team has a good understanding of the most crucial parts of project. The two most important functional requirements, according to this QFD, are the off-board processing capabilities and the Spatial Resolution. These requirements dictate the detail that can be processed by the AUAV’s optical sensors and the speed at which the information can be processed. The system’s reliability and the use of standard equipment also hold quite a bit of importance as well. A more detailed version of the QFD can be found in the Supporting Documentation, [here](https://onedrive.live.com/edit.aspx?cid=99996a2d5edba56b&page=view&resid=99996A2D5EDBA56B!11716&parId=99996A2D5EDBA56B!10689&authkey=!AJB1hp2tCc2mQKg&app=Excel) for readability.



Figure 1: Quality Functional Deployment

# Concept of Operations

Figure 2 shows the concept of operations (CONOPS). The figure depicts the AUAV when operated as part of an autonomous, integrated swarm of AUAVs within the area of operations in the US – Desert, Coastline, and Alaskan wilderness Search and Rescue environment, as well as world-wide terrains and climates. The AUAV has an AI-based decision-making capability with manual override and is capable of advance (Signal/Image Processing) such as Automatic Target Recognition (ATR) and real time Atmospheric Turbulence Compensation (ATC) that will provide the fastest real-time, and highest spatial resolution images available. The AUAV will also be capable of autonomous flight with Search and Find maneuvers, and Object of Interest (OoI) tracking. The AUAV system will also be adaptable for additional capabilities, such as natural language, AI-based Command and Control Interface.

The system will have a Mobile Command Center (MCC) that can be deployed indefinitely in remote, low access areas and it will be powered up by a quiet and renewable energy source.

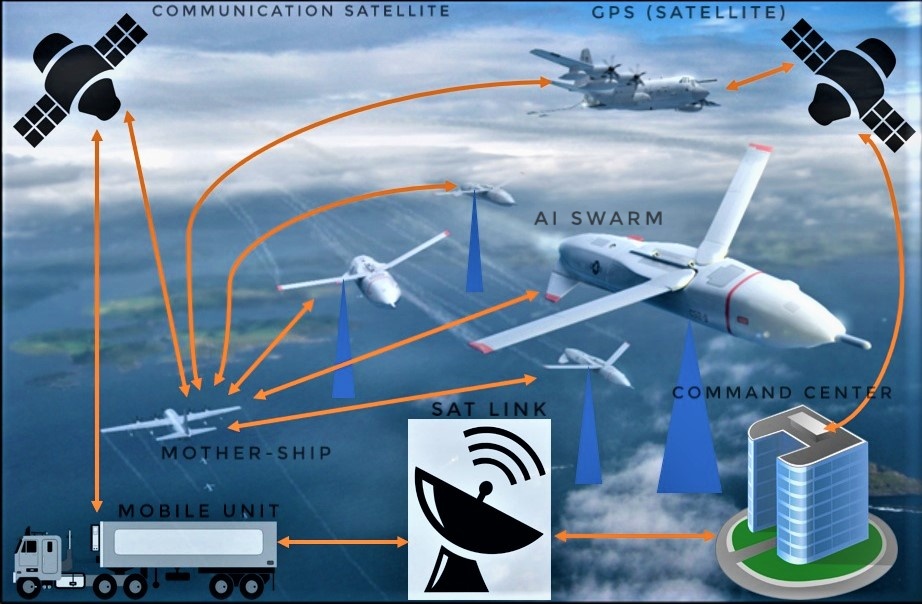
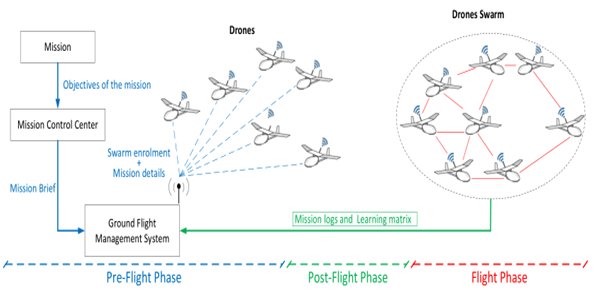


Figure 2: Concept of Operations Diagram

This CONOPS focuses on the AUAV as it monitors a search area associated with a hot spot. The AUAV system will provide 24/7 detection coverage of up to 50 hot spots simultaneously, in a 100 Km2 observation area – with an expanded capability of a 169,737 Km2. This CONOPS also depicts the AUAV as it interacts with its guidance control measures, ground network, and in-flight operations relative to its inherent navigation dependence.

* The CONOPS focuses on the AUAV as it monitors a search area associated with a hot spot, operated as part of an autonomous system, on as part of an autonomous integrated swarm (AIS) of AUAV within designated, world-wide area of operations.
* This intelligent AUAV system is designed to be a search and rescue AUAV.
* This system is capable of interacting with U.S. internal agencies and external allies, strategic partners using a voice-based AI capability.
* The AUAV has an AI-based decision-making capability with manual override and is capable of advance (Signal/Image Processing) such as automatic target recognition and real time atmospheric turbulence compensation.
* The AUAV system can conduct Object of Interest tracking and can be controlled by its internal AI system.
* The system has a Mobile Command Center (MCC) that can be deployed indefinitely in remote, low access areas and it will be powered up by a quiet and renewable energy source.

Figure 3: AUAV SWARM mission coordination



The AUAV SWARM mission coordination figure above, shows how the drones receive their enrollment and mission details. The pre-flight phase informs the mission control center of the mission brief. The mission is then sent to the ground flight management system. The ground flight management system sends the mission out to the AUAVs so they can form a swarm to perform the objectives of the mission.

Figure 4: AUAVs forming a 3D array for interferometry

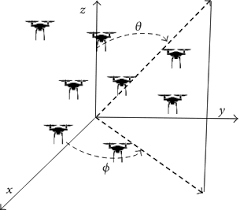


Figure 4 shows the AUAVs forming a 3D array for interferometry. The swarm will position themselves into the correct flight formation and with the proper formula they will use antenna arrays off of each other. This is to improve communication when there may be limited range from the mission control.

# Scope

## Scope Statement

The project scope is to integrate state-of-the-art ATC imaging capabilities with GPPP technology in real time into an AUAV. Its functions are to perform “search and find” maneuvers, conduct object of interest tracking, and include programming for threat aversion; operate both independently and as an autonomous integrated swarm of AUAVs with adaptive, AI-based decision-making/mission reconfiguration; and is adaptable for future features such as natural language, AI-based Command and Control Interface. and compensate for atmospheric turbulence imaging atmospheric aberrations and system noise and automatic target recognition. FIT will also create a feasibility study for the development of a Mobile Command Center (MCC), which will have the capability to be deployed indefinitely in remote low access areas. The main elements to be assimilated in this project are:

* A high-speed Atmospheric Turbulence Compensating (ATC) capability and General Purpose Parallel Processing (GPPP) technology.
* Capability to operate autonomously with Artificial Intelligence (AI) - based decision-making technology in “search and find” maneuvers and Object of Interest (OoI) tracking.
* A controller for individual or Autonomous Integrated Swarm (AIS) of autonomous AUAVs.
* The capability to operate an adaptable system to supplement other features or capabilities such as natural language, AI-based Command and Control Interface depending on the type of mission or environment it would operate on.
* A component-level detailed bottoms-up analysis for the power/energy support system for the mobile command center.

Additional integrated features proposed for the AUAV include a need to look like a generic ‘Search and Rescue’ UAV and be world-wide deployable. Specifically, the project is to provide desert, coastline, Alaskan wilderness search and rescue aptitudes; thus, a specific emphasis on adaptability to recognize hardships and defend itself due to very harsh and extreme environments and circumstances. The system should provide capabilities to either be autonomous or controlled remotely (“manual override” capability), and have the ability to conduct maintenance, upgrades, pre-planned product improvement, service, availability, and reliability.

## Scope Boundaries

Table 4 categorizes the project tasks to comply with the four integrated technologies as well as highlights what has been excluded from the current scope. It is broken down by identified systems.

Table 4: Table of Scope Boundaries

|  |  |  |
| --- | --- | --- |
| System | Anticipated Task(s) | Exclusions |
| Atmospheric Turbulence Compensating imaging capability | * State-of-the-art * High Spatial resolution images development * Vibration and shock isolators * Environmental conditioning * Requires light capture at least at two wavelengths simultaneously * Cooling system for detectors to reduce noise | None |
| Autonomous Flight Control System | * Object of Interest (OoI) tracking * “Search and find” maneuvers * Controller for telescope, detector, UAV gimbal pod, on-board signal processing unit, and UAV communications unit * Telescope with Instantaneous Field of View (IFoV) * Anti-reflection coating for optical surfaces | None |
| Individual or Autonomous Integrated Swarm (AIS) | * Detect & identify human Target of Interest (TOI) within a day time or night time slant ranges * Remotely controllable with AI integration. * Controlled by a live operator or have way-points and pre-programmed mission profiles with voice command adaptation. | Night time slant range exclusion of minimum 250 meters |
| Adaptability to future possible functions | * Laser ranging, magnetic sensing, infrasound sensing, polarization imaging * World-wide deployable * Adaptable to harsh and extreme circumstances * Able of protecting itself * Adaptive optics processor | None |

# Goals and Objectives

## Technical Goal and Objective

The goal is to provide a feasibility study of a set of four highly specialized features/capabilities for a potentially new AUAV for a three-letter national agency within a 16-week period. The customer also has asked for a set of baseline documentation and associated artifacts. Finally, the customer has funded FIT for a feasibility study for a Mobile Command Center (MCC) that can be deployed in a remote, low access area. Table 5 lists some tasks needed to be done and approximate time for accomplishments based on the relative number of weeks after the project start date.

Table 5: Technical Goals and Objectives

|  |  |  |
| --- | --- | --- |
| Objectives | Completion Date | Exit Criteria |
| Start Project | Week 0 | Project Award |
| Problem Definition | Week 4  (+4 weeks) | Stakeholder requirements are identified. Feasibility studies are completed. |
| Conceptual Design Phase | Week 13  (+9 weeks) | A-Spec documents are completed |
| Preliminary Design Phase | Week 15  (+ 2 weeks) | Preliminary Design Review completed |
| Final Project | Week 16  (+ 1 weeks) | Proposal to three-letter agency complete |

## Business Goals and Objectives

The business goal is to increase the market share of Futuristic Innovative Technologies by 15% within 5 years by developing and marketing a potentially advanced AUAV (subject to a contract with a three-letter national agency). Table 6 summarizes the business goals and objectives for the project.

Table 6: Business Goals and Objectives

|  |  |  |
| --- | --- | --- |
| Objectives | Completion Date | Exit Criteria |
| Market research. | Month 6  (+ 6 months) | Conceptual design review with management and project sanction. |
| Research and Development.  Develop and implement a set of specialized capabilities for an AUAV. | Month 30  (+ 2 years) | Optimized working prototype. |
| Intellectual property and licensing. | Month 54  (+ 2 years) | Approval granted |
| Marketing campaign and demonstrations for different national and international security agencies. | Ongoing | Ongoing. |

# Conceptual Design Introduction

This section of the design dossier captures the system design associated with the conceptual design. Specifically, it defines the subsystem function block and functional flows that help add details to the System Specification.

Additional project risk analysis is provided in the form of a feasibility analysis on select requirements and the provided Failure Mode, Effect and Criticality Analysis.

# Functional Block Diagram

The focus of this project is to create a fleshed-out concept of an AUAV with a unique set of highly technical capabilities. This section will provide a high-level description of the functional systems within the AUAV. The aim is to show the overall relationships of the system. The high-level functional block diagram, shown in Figure 5, has been included to illustrate the various functions that make up the AUAV. In order to achieve a successful mission, all these functions must cooperate to achieve their objective while interacting with all of the other functions in the AUAV.

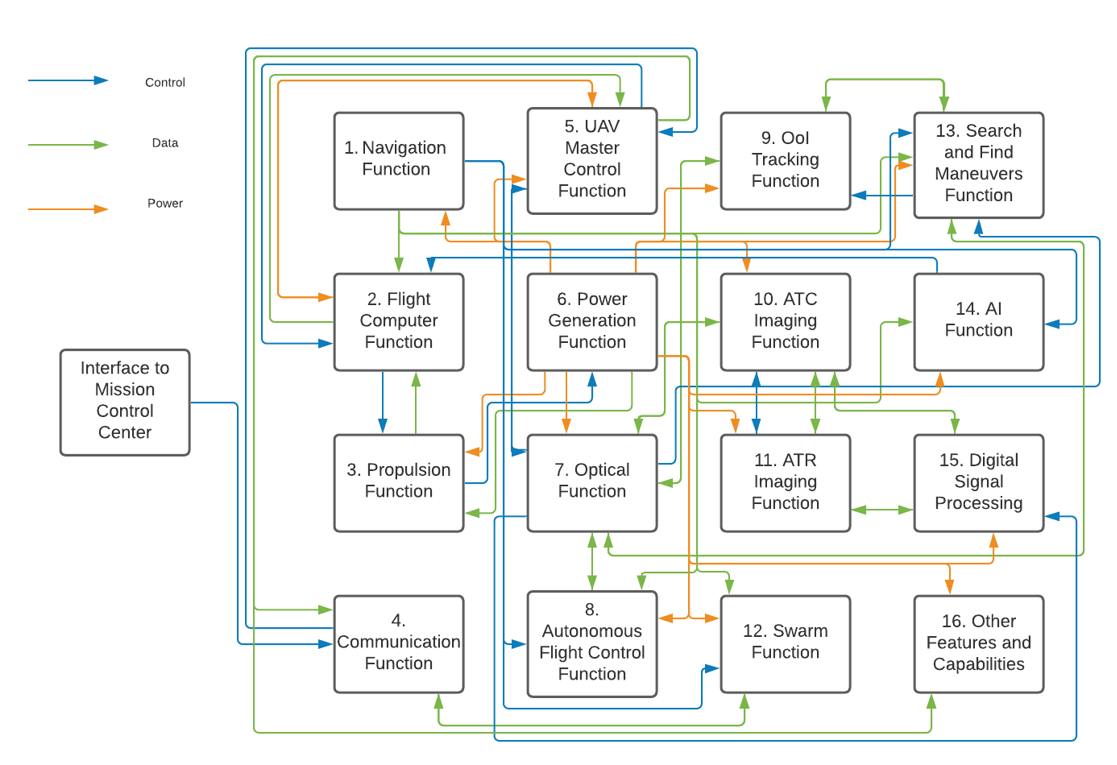


Figure 5: High Level System Functional Diagram

The functional block diagram in Figure 5 shows the overall architecture of the AUAV system. It consists of sixteen functional blocks. These functions are as follows:

1. Navigation Function

2. Flight Computer Function

3. Propulsion Function

4. Communication Function

5. Unmanned Aerial Vehicle (UAV) Master Control Function

6. Power Generation Function

7. Optical Function

8.Autonomous Flight Control Function

9. Object of Interest (OoI) Tracking Function

10. Atmospheric Turbulence Compensation (ATC) Imaging Function

11. Automatic Target Recognition (ATR) Function

12. Swarm Function

13. Search and Find Maneuvers Function

14. AI Function

15. Digital Signal Processing (DSP)

16. Other Features and Capabilities

# Feasibility Analysis

The following Feasibility Analysis was performed to see if the project requirements for Daytime and Nighttime Identification and Detections can be met. The primary stakeholder gave varying distances that the UAV would need to either Identify or Detect a human target during either the day or night. For Detection the UAV will need to be able to spot something the size of a human body. For identification it will need to do the same but with a significantly smaller target, a human eye.

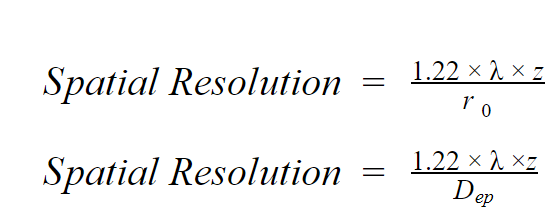


Figure 6: Spatial Resolution for Circular Aperture Imaging System Calculation

Equations: The top equation is calculating the Spatial Resolution for Circular Aperture Imaging Systems in the Atmosphere. The bottom equation is calculating the Spatial Resolution for Atmospheric Turbulence Corrected Imaging Systems.

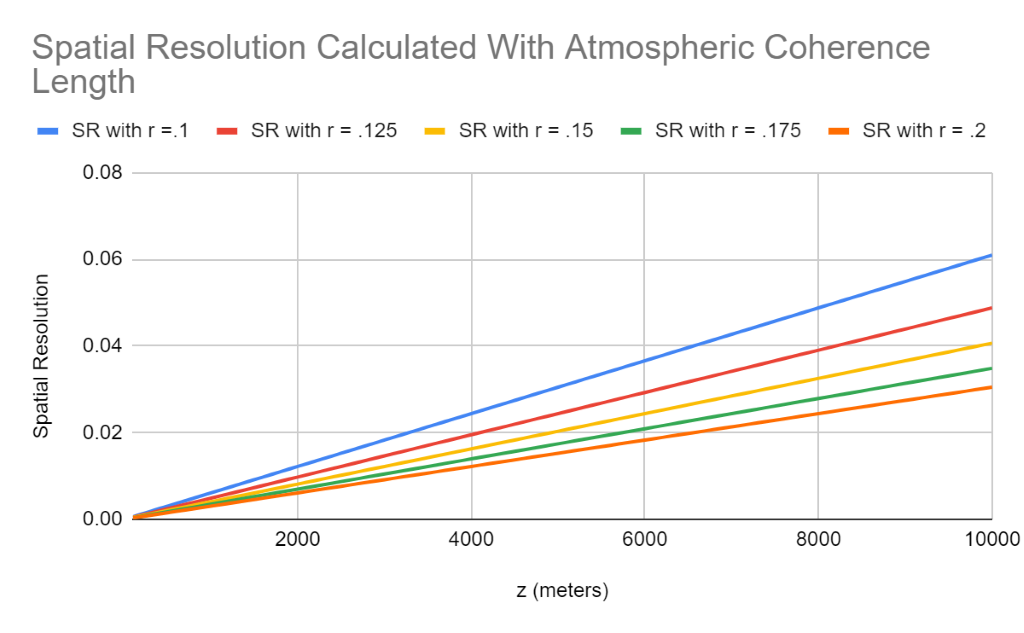


Figure 7: Spatial Resolution of Circular Aperture Imaging System

**Figure 7: Spatial Resolution of Circular Aperture Imaging Systems in Atmosphere with Fried Parameter of .15m (+/-.05m)**

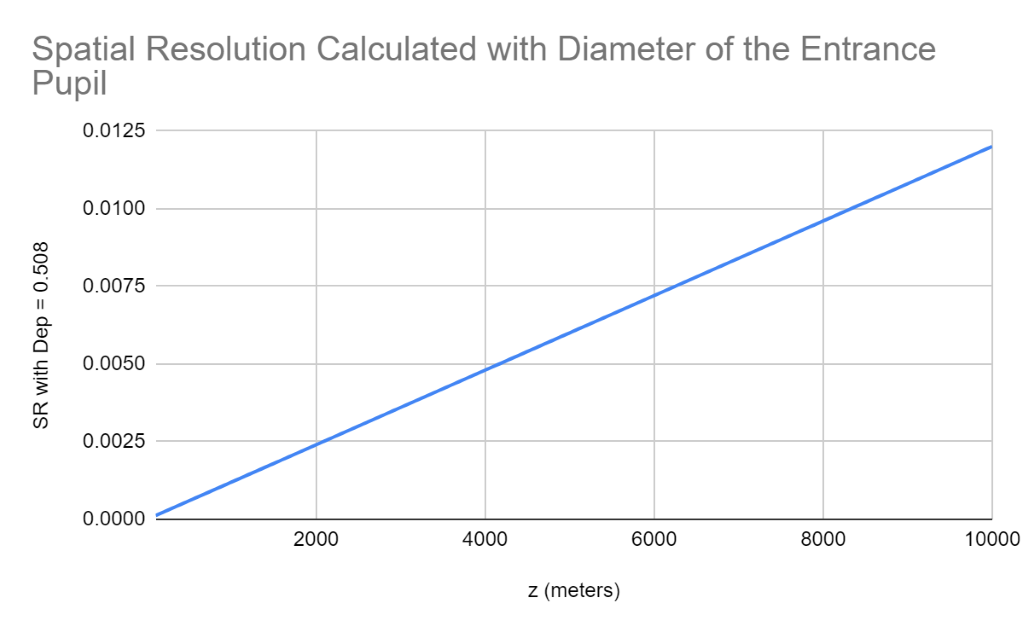


Figure 8: Spatial Resolution for Atmospheric Turbulence Corrected Imaging Systems

**Figure 8: Spatial Resolution for Atmospheric Turbulence Corrected Imaging Systems with Diameter of the Entrance Pupil = 0.508m**

**Testing, Defense, and Feasibility**

The purpose of this feasibility study is to determine if the AUAV can detect and/or identify a human from different ranges during its operation. The team has been given the range of values and constants to use in the equations so they can see if it’s possible to obtain what the customer wants within the project parameters.

The two above equations were used to generate the values in the table and graphs. All applicable units were switched to meters (m). Lambda is the mean wavelength with different values depending on daytime or nighttime. The value for the day is 500 nanometers (0.0000005 m) while the value for night is 0.0000095 m. For the other variables: z is the separation distance from TOI to sensor with values ranging from 1m to 10,000m, r0 is the atmospheric coherence length (Fried Parameter) which is .15m (+/-.05m) so the team used 0.1, 0.125, 0.15, 0.175, and 0.2m to get an accurate range, and Dep was the full diameter of the Entrance Pupil which is 0.508m.

With these values and the graphing function in Excel spreadsheets, the team was able to generate the two-line graphs. As the equation is linear and the changing variable increases, a positively sloped linear graph is what was expected. The first graph is using the Spatial Resolution with the Fried Parameter in the denominator. Each line represents a different value used by the team. The second graph is using the Spatial Resolution with the diameter of the Entrance Pupil, as there is only one diameter, there is only one line on this graph.

Next, the team input the desired customer requirements into the equation to see if what the customer wanted was feasible. The customer wanted to be able to detect and identify humans in the daytime and nighttime. The max distances for each of these parameters were as follows:

* Daytime Detection: 9.543 km (9543m)
* Daytime Identification: 1.5 km (1500m)
* Nighttime Detection: 1.5 km (1500m)
* Nighttime Identification: .25 km (250m)
* Nighttime Identification (when equipped with Slipstream Sensors): 1.5 km (1500m)

Due to there being two parameters for Nighttime Identification, it will have two rows in the table. Each of these values were input into the listed equations as the z variable and their values were recorded in Table 7.

Table 7: Spatial Resolution Values

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | r0 = .1 | r0 = .125 | r0 = .15 | r0 = .175 | r0 = .2 | Dep = .508 |
| Daytime Detection (9543 m) | 0.0582 | 0.0467 | 0.0388 | 0.0333 | 0.0291 | 0.0115 |
| Daytime Identification (1500 m) | 0.0092 | 0.0073 | 0.0061 | 0.0052 | 0.0046 | 0.0018 |
| Nighttime Detection (1500 m) | 0.1739 | 0.1392 | 0.1159 | 0.0993 | 0.0869 | 0.0342 |
| Night Time Identification (250 m) | 0.029 | 0.0232 | 0.0193 | 0.0166 | 0.0145 | 0.0057 |
| Night Time Identification (1500 m) | 0.1739 | 0.1391 | 0.1159 | 0.0993 | 0.0869 | 0.0342 |

**Table: The Spatial Resolution values found with the different values given by the customer. The units for this table are meters.**

Now that the spatial resolution is found for each requirement, the team needed to see if these were good enough to identify and detect humans. To detect a human, the Spatial Resolution needs to be less than or equal to .2m (2m^2 / 10 resolution cells). To identify a human the team needed a Spatial Resolution less than or equal to .001m (.01m^2 / 10 resolution cells). As can be seen from Table 7, all values for the detection of a human in daytime and nighttime fall into the range of less than or equal to 0.2 m. The same cannot be said for The Daytime and Nighttime Identification categories. For these, the corresponding spatial resolutions are not in the acceptable range. Table 8 shows what the z distance (in meters) should be to get a Spatial Resolution of 0.001m

Table 8: Feasible Z distances

|  |  |
| --- | --- |
| Fried Parameter (r0) and Entrance Pupil Diameter (Dep) in meters | z distance (meter) |
| r0 = 0.1 | 163.9344262 |
| r0 = 0.125 | 204.9180328 |
| r0 = 0.15 | 245.9016393 |
| r0 = 0.175 | 286.8852459 |
| r0 = 0.2 | 327.8688525 |
| Dep = 0.508 | 832.7868852 |

Table 8 was generated from rearranging the two Spatial Resolution equations so the value being found was z

|  |  |
| --- | --- |
| Fried Parameter (r0) and Entrance Pupil Diameter (Dep) in meters | z distance (meter) |
| r0 = 0.1 | 8.6281 |
| r0 = 0.125 | 10.7852 |
| r0 = 0.15 | 12.9422 |
| r0 = 0.175 | 15.0992 |
| r0 = 0.2 | 17.2563 |
| Dep = 0.508 | 43.8309 |

Table 9 was generated from rearranging the two Spatial Resolution equations so the value being found was z

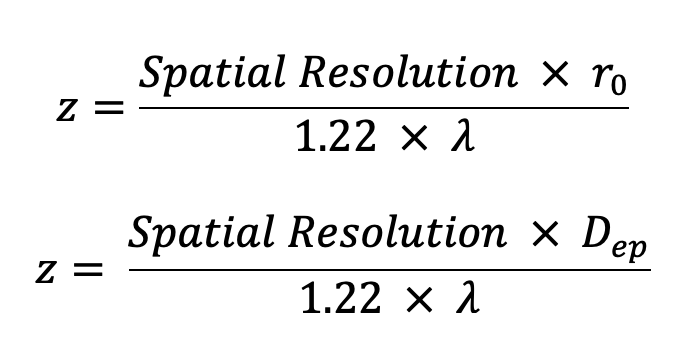


Figure 9: Feasible Z distances

Spatial Resolution is set as 0.001m, and the rest of the variables are the same values as used before.

As can be seen from Table 8, the furthest away the AUAV can identify a human is 832.79 m which is below the 1.5 km want of the customer. In conclusion, it is not feasible in in its current state as it does not meet all the ‘shall’ requirements. However, with addition the slipstream sensor that FIT developed, the project would be able to meet all the stakeholder requirements and be feasible.

## System Requirement Feasibility Analysis

The following pages contain the feasibility analysis performed on the system level requirements. It represents the analysis taken on each requirement with risk to assess if the requirement is feasible based on any combination of cost, performance, technical, security, or operational.

Table 10 System Requirement Feasibility Analysis

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **S.R. #** | **Requirement** | **Risk Type** | **Risk Issue** | **Original Cost Impact** | **Risk Mitigation** | **Potential Cost Impact** | **Overall Cost Impact** |
|  | **Performance Characteristics** |  |  |  |  |  |  |
| 3.2.1.1 | The AUAV system shall have a cold start time of a maximum of 30 seconds. | Operational | Software errors | Medium | Achievable with existing technology | AUAV unable to fly mission. | Medium |
| 3.2.1.2 | The AUAV system shall have a hot start time of a maximum of 5 seconds. | Operational | Software errors | Medium | Achievable with existing technology | AUAV unable to fly mission. | Medium |
| 3.2.1.3 | The AUAV system shall have a data transfer rate of a maximum of 150 Mbits/sec. | Technical | Data loss | Medium | Achievable with existing technology | AUAV loses communication | Medium |
| 3.2.1.4 | The AUAV system shall operate at full performance for all temperatures ranging from -70.0 degrees Fahrenheit [-56.67 degrees Celsius] to +120.0 degrees Fahrenheit [+48.9 degrees Celsius], inclusively. | Technical | Freezing of fuel. Optical sub- system fails to collect images. Engine overheats. | Medium | Achievable with existing technology. | AUAV is grounded for ambient temperature issues during 24/7 support. Loss of working time. | Medium |
| 3.2.1.5 | The AUAV system shall operate at full performance for all atmospheric pressures ranging from -9.0 pounds per square inch absolute [-62.1 kilopascals absolute] and 0.0 pounds per square inch absolute [0.0 kilopascals absolute], inclusively. | Technical | System exterior frame is crushed under pressure. System cannot function in severe storms. | Medium | Achievable with existing technology. | AUAV is grounded for ambient pressure issues during 24/7 support. | Medium |
| 3.2.1.6 | The AUAV system shall be able to control the AUAV flight speed from 0.0 miles per hour [0.0 kilometers per hour] to 158.45 miles per hour [255.00 kilometers per hour], inclusively, within a tolerance of +/- 5 miles per hour [8 kilometers per hour]. | Operational | Operators lose speed control of AUAV, potential crash hazard. | Medium | Achievable with existing technology. | Loss of AUAV. | Medium |
| 3.2.1.7 | The AUAV system shall be able to control the AUAV flight altitudes from ground level to a maximum of 15240 meters above mean sea level [15.240 kilometers], inclusively, with a tolerance of +/- 0.914 meters. | Operational | Operators lose speed, gyroscopic, or locational control of AUAV due to weather interference or other flying vehicles/objects, potential crash hazard. | Medium | Achievable with existing technology. | Loss of AUAV | Medium |
| 3.2.1.8 | The AUAV system shall be able to control the AUAV flight spatial position (latitude and longitude) with a tolerance of +/- 0.914 meters. | Operational | Loss of GPS and Navigation. AUAV spinning in circles. | Medium | Achievable with existing technology. | Loss of AUAV. | Medium |
| 3.2.1.9 | The AUAV system shall prevent the AUAV from experiencing g-forces greater than 0.5 in the negative direction. | Performance | Loss of control of AUAV due to extreme forces on the AUAV | Medium | Employ redundant flight control systems to ensure the forces acting on the aircraft are acceptable | Loss of AUAV | Medium |
| 3.2.1.10 | The AUAV system shall prevent the AUAV from experiencing a bank angle greater than 40 degrees. | Performance | Loss of control of AUAV due to extreme forces on the AUAV | Medium | Employ redundant flight control systems to ensure the forces acting on the aircraft are acceptable | Loss of AUAV | Medium |
| 3.2.1.11 | The AUAV system shall position the optical sensors at its target location within a tolerance of +/- 0.610 meters. | Technical | Unable to meet mission parameters | Medium | Develop and utilize the best optical sensors available | Misidentification/Detection of target | Medium |
| 3.2.1.12 | The AUAV system shall be able to control the magnification of the electro-optical sensor from 1 time to 25 times magnification, inclusively, with a tolerance of +/- 0.5 millidegrees. | Technical | Unable to meet mission parameters | Medium | Develop and utilize the best optical sensors available | Misidentification/Detection of target | Medium |
| 3.2.1.13 | The AUAV system shall be able to assess an image for a target / no-target decision within a maximum time of 1 second from receiving the image. | Technical | Unable to meet mission parameters | Medium | Develop and utilize various image processing techniques | Misidentification/ Detection of target | Medium |
| 3.2.1.14 | The AUAV system shall have a 90% positive target detection rate. | Operational | Misidentification/Detection of target | Medium | Develop and utilize various image processing techniques | Misidentification/ Detection of target | Medium |
| 3.2.1.15 | The AUAV system shall determine optimal flight control settings within a maximum time of 200 milliseconds. | Performance | Loss of Control of Aircraft due to the inability to respond to environmental flight factors | Medium | Utilize tested flight control, and communications systems | Loss of AUAV | Medium |
| 3.2.1.16 | The AUAV system shall determine optimal optical control settings within a maximum time of 200 milliseconds. | Performance | Misidentify or unable to detect a target due to system not being able to respond to environmental/mission factors | Medium | Utilize tested communications systems so mission control can respond in a timely manner to environmental conditions | Misidentify/Detect a Target | Medium |
| 3.2.1.17 | The AUAV system shall detect a ground-based obstacle entering its sphere of influence within of 0.5 seconds. | Performance | Misidentify or unable to detect a target due to system not being able to respond to environmental/mission factors | Medium | Utilize tested communications systems so mission control can respond in a timely manner to environmental conditions | Misidentify/Detect a Target | Medium |
| 3.2.1.18 | The AUAVs sphere of influence shall be 3.658 m +/- 0.914 m. while on the ground. | Operational | Inability to communicate with various ground systems | Medium | Uncontrolled or inability to communicate with AUAV | Investigative maintenance costs associated with finding communication error | Medium |
| 3.2.1.19 | The AUAV system shall detect human Target of Interest (TOI) with a slant range of 9.543 km during daytime. | Technical | Operational impact | Medium | Procure / Produce robust and reliable components | Lack of accurate data collection | Medium |
| 3.2.1.20 | The AUAV system shall detect human Target of Interest (TOI) with a slant range of 1.5 km during nighttime. | Technical | Operational impact | Medium | Procure / Produce robust and reliable components | Lack of accurate data collection | Medium |
| 3.2.1.21 | The AUAV system shall identify human Target of Interest (TOI) with a slant of 1.5 km during daytime. | Technical | Operational impact | Medium | Procure / Produce robust and reliable components | Lack of accurate data collection | Medium |
| 3.2.1.22 | The AUAV system shall identify human Target of Interest (TOI) with a slant range of 250 m during nighttime (with slipstream sensors). | Technical | Operational impact | Medium | Procure / Produce robust and reliable components | Lack of accurate data collection | Medium |
| 3.2.1.23 | The AUAV system shall identify human Target of Interest (TOI) within a slant range of 1.5km (with slipstream sensor). | Technical | Operational impact | Medium | Procure / Produce robust and reliable components | Lack of accurate data collection | Medium |
| 3.2.1.24 | The AUAV system shall provide an image/dataset to command center within 5 seconds. | Technical | Data loss | Medium | Split data storage into two standalone units for redundancy | Loss of data | Medium |
| 3.2.1.25 | The AUAV system shall provide on-demand video to command center within 5 seconds. | Technical | Data loss | Medium | Split data storage into two standalone units for redundancy | Loss of data | Medium |
| 3.2.1.26 | The AUAV system shall provide detection 24 hours per day / 7 days per week with a 98% operational availability during on-station time. | Operational. | Operational impact. | High | Enforce maintenance schedules. Use of Simulation and modeling to understand interactions | Schedule impacts due to downtime resulting in lack of operational availability | Medium |
| 3.2.1.27 | The AUAV system shall observe a nominal 10 km by 10 km swatch centered on each hot-spot location. | Operational. | Operational impact. | Medium | Develop and utilize the best optical sensors available | Misidentification/ Detection of target | Medium |
| 3.2.1.28 | The AUAV system shall also be able to search a large grid within a 256 km by 256 km range associated with each hot spot. | Operational. | Operational impact. | Medium | Develop and utilize the best optical sensors available | Misidentification/ Detection of target | Medium |
| 3.2.1.29 | The AUAV system shall have an optical system that can detect human heat in the IR with a peak wavelength of 9.5 micrometers. | Technical | Data loss | Low | Include reliable detection hardware. | Upgrade or change sensor hardware | Low |
| 3.2.1.30 | The AUAV system shall process atmospheric turbulence compensation video data on streaming data at video rate of 30 Hz, or on individually selected images. | Technical | Data loss | Medium | Send an alert if video rate is at its capacity. Procure / Produce robust and reliable components | Upgrade or change sensor hardware/software | Medium |
|  | **Physical Characteristics** |  |  |  |  |  |  |
| 3.2.2.1 | The AUAV system shall not exceed 66 feet wide x 36 feet long x 12.5 feet high [ 20.11m x 10.97 m x 3.81 m]. | Operational | System is excessively large for its intended mission | Low | Refer to systems that are currently in use that are within the required specs | Operational costs lowered due to the system being within the required specs | Low |
| 3.2.2.2 | The AUAV system weight shall not exceed 4,901 pounds [2,223 kilograms]. | Operational | Operational impact | Low | Design AUAV with lighter material. Metrology and weight testing. | Schedule and operational impacts due to shortened mission times. Cost impact due to additional/replacement hardware/battery | Low |
| 3.2.2.3 | The AUAV system shall include an optical system that consists of a telescope, relay optics and detectors. | Operational | Optical system cannot meet the requirements without a system comprised of these components | Low | Refer to optical systems that already utilize these components; Ensure the optical system has these components | Optical system performance will be too low without these components | Low |
| 3.2.2.4 | The AUAV system shall have filter wheels to apply notch filters, high pass, low pass, optical modulators (for background suppression), and specialized filters. | Operational | Optical system cannot meet required specs without including these components | Low | Utilize a compatible COTS product or design one that works with the optical system | Optical system features will be minimal without these components | Low |
| 3.2.2.5 | The AUAV system shall have vibration and shock isolators. | Operational | Data loss | Medium | Design AUAV with vibration and shock isolators | Loss of data and/or impact to quality of collected data | Medium |
| 3.2.2.6 | The AUAV system shall have an optical system with anti-reflection coatings for the optical surfaces. | Operational | Image quality can be reduced without this coating | Medium | Ensure that our lenses have this coating; Ensure our assembly procedure accounts for this coating | Loss of ability to identify objects from collected video | Low |
| 3.2.2.7 | The AUAV system shall have an atmospheric turbulence compensating system with light captured at least at two wavelengths simultaneously. | Technical | Data loss | Medium | Procure / Produce robust and reliable components.  Send an alert identifying when ATC system is failing and images are distorted. | Loss of data and/or impact to quality of collected data | Medium |
| 3.2.2.8 | The AUAV system shall have an image parallel processing interface with fast memory, and long-term storage. | Operational | Loss of contract, as the stakeholder was looking specifically for this technology(GPPP) | High | Use the GPPP technology | Collected imagery will be processed too slowly without this addition | Low |
| 3.2.2.9 | The AUAV system shall look like a benign search and rescue AUAV, in color and geometry. | Operational | Stakeholder requires appearance of system to look this way | Low | Ensure the system appears benign | System may attract unwanted attention if it fails to meet this requirement | Low |
|  | **Effectiveness Requirements** |  |  |  |  |  |  |
| 3.2.3.1 | The AUAV system shall maintain an Operational Availability of at least 98% during on-station time. | Operational | The AUAV will not be operational due to Maintenace or other issues. | Medium | The AUAV will be designed to operate within extreme environments as to limit the need for Maintenace or repair. | The AUAV will not be operational when required for a mission. | Medium |
| 3.2.3.2 | The AUAV system shall be capable of AUAV Operational Availability to increase software robustness and redundancy to maximize operation time. | Operational/Technical | The AUAV control system, and A.I. will become obsolete with time. | Low | The AUAV is designed to be capable of easily integrating new software updates and developments. | The AUAV will not be a viable option when compared to competitors via technical advancement. | Low |
|  | **Reliability** |  |  |  |  |  |  |
| 3.2.4.1 | The AUAV system shall have an Instantaneous Reliability of at least 70%. | Technical | Operational impact | High | Reliability Analysis | Operations task delayed | Medium |
| 3.2.4.2 | The AUAV system shall have a Mean Time Between Failure (MTBF) of 20 years. | Technical | Design issues | High | Reliability Analysis | Faulty equipment | Medium |
| 3.2.4.3 | The AUAV system mean time to repair (MTTR) shall be a maximum of 8 hours. | Technical | Operational impact | High | Reliability Analysis | Operations task delayed | Medium |
|  | **Maintainability** |  |  |  |  |  |  |
| 3.2.5.1 | The AUAV system shall not result in down time of more than 5 hours due to regular system maintenance. | Operational | Hardware related issues | Low | Spare AUAV available | AUAV cannot put in service | Low |
| 3.2.5.2 | The AUAV system shall require complete system inspection after every 1000 hours of flight time. | Operational | Hardware related issues | Low | Spare AUAV available | AUAV cannot put in service | Low |
| 3.2.5.3 | The AUAV system shall self-check and perform software updates when needed 5 hours prior to operation time. | Operational | Hardware related issues | Low | Spare AUAV available | AUAV cannot put in service | Low |
| 3.2.5.4 | The AUAV system shall allow for 30-minute updates by maintenance personnel. | Operational | Hardware related issues | Low | Spare AUAV available | AUAV cannot put in service | Low |
| 3.2.5.5 | The AUAV system shall have a built-in-test (BIT) protocol incorporated into the controller to allow for easier maintenance. | Operational | Hardware related issues | Low | Spare AUAV available | AUAV cannot put in service | Low |
| 3.2.5.6 | The AUAV system BIT function shall store BIT error files onto onboard memory. | Operational | Hardware related issues | Low | Spare AUAV available | AUAV cannot put in service | Low |
| 3.2.5.7 | The AUAV system shall transmit BIT error files to the mission control center within 30 seconds of receipt of error. | Operational | Hardware related issues | Low | Spare AUAV available | AUAV cannot put in service | Low |
| 3.2.5.8 | The company shall maintain the capability of repairing individual modules. That is if a module (Line Replaceable Unit, LRU) fails, it should be replaced with a spare at the customer site and the failed module transported to the factory where it can be repaired by personnel with high skill levels. | Operational | Hardware related issues | Low | Spare AUAV available | AUAV cannot put in service | Low |
| 3.2.5.9 | All documentation for the maintenance schedules and procedures shall be provided for the system as part of the contractual deliverables. | Operational | Hardware related issues | Low | Spare AUAV available | AUAV cannot put in service | Low |
| 3.2.5.10 | The AUAV system shall be maintained with Commercial Off the Shelf (COTS) tools and equipment. | Cost/Schedule | Delay in repair time or budget overruns | Low | Design AUAV with COTS maintainable materials and hardware | Special order/non-COTS parts and tooling required | Low |
|  | **Usability** |  |  |  |  |  |  |
| 3.2.6.1 | The AUAV system shall be designed so that it can be operated by a single operator with intermediate skills. Intermediate skills in this case are defined as High School Graduate with 9th grade reading/writing level with no prior work experience and around 40 hours of training plus some on-the-job training. | Operational | Operational use complexity | Medium | Certify and train operators | Cost of new AUAV | Medium |
| 3.2.6.2 | The AUAV system shall have a user-friendly interface to minimize training and user skill requirements. | Operational | Operational use complexity | Low | Design AUAV with intuitive user interface | Sub-optimal operation of AUAV system | Low |
| 3.2.6.3 | The AUAV system shall include the user authorization procedure where users must identify themselves using log in name and password. Only users that are authorized have access to system data. | Technical | Leak of secured data to unauthorized individuals. | Low | The system will have a system that can track and determine authorized system users. | Leak of secured data/information to an unauthorized source. | Low |
|  | **Supportability** |  |  |  |  |  |  |
| 3.2.7.1 | The AUAV system shall support different data transfer protocols. | Technical | Loss communications | High | Add an alternative way of transmitting data. | More equipment may suffer communication loss | Medium |
| 3.2.7.2 | The data processing, and control processing code from the AUAV shall be written with a programming language which is cross-platform. | Technical | Software compatibility | High | Develop software using cross-platform capable programming language | Code would have to be rewritten or converted to a more compatible language driving cost increase | Medium |
|  | **Transportability/Mobility** |  |  |  |  |  |  |
| 3.2.8.1 | The AUAV system shall accommodate ease of transport during system integration and maintenance | Operational | Damage | Medium | Design the system to take up minimal space during transport. | AUAV may sustain damage and will be unusable for an operational task. | Medium |
| 3.2.8.2 | The AUAV system should not sustain damage while being transported. | Security | Damage | Medium | Provide a more protective storage space while being transported | AUAV may not be used for operational task | Medium |
|  | **Flexibility** |  |  |  |  |  |  |
| 3.2.9.1 | The AUAV system shall be flexible such that changing mission requirements can be adapted into the operation. | Operational | Software issues. | Low | Enhance decision making capacity | Operational task not completed or skipped | Low |
| 3.2.9.2 | The AUAV system shall be designed to be flexible by making use of functional modularity that will allow for cost effective modification. | Operational | Elevated modification cost. | Low | System is designed for modularity and the use of off the shelf parts as to decrease cost for modification. | Operational task cannot be completed due to system inabilities. | Low |
| 3.2.9.3 | The AUAV system shall support multifunctional tasking, including detection, oversight, and tracking. | Operational | Software issues. | Low | System is designed to be able to complete several functions simultaneously using an A.I. based decision-making system. | Operational task cannot be completed due to system inabilities. | Low |
| 3.2.9.4 | The AUAV system shall be reversible when the commander wants to update or cancel tasks. | Operational | Loss control of operations | Medium | Configure two flight modes | AUAV flight control loss | Medium |
|  | **Sustainability** |  |  |  |  |  |  |
| 3.2.10.1 | The AUAV system shall be designed with system recycling in consideration. | Technical | Introduction of unidentified hazardous materials | Medium | Components to be assessed for any hazardous components and identified on hazardous goods register. | Potential to dispose of material inappropriately, facing fines and penalties from authorities. | Medium |
| 3.2.10.2 | The AUAV system shall have the minimal infrared heat signature and acoustic emission to support environmental sustainability. | Operational | Unnecessary environmental damage/effects. | Medium | The system will be designed to emit the lowest possible infrared heat signature and acoustic emissions. | Unnecessary environmental damage/effects. | Medium |
| 3.2.10.3 | The AUAV system shall have an optical system with environmental conditioning protection features (temperature regulators, moisture and humidity control, dust, pressure, and light shields). | Operational | Inhibit operations of AUAV | Medium | Design AUAV to include environmental conditioning protection features | Increased maintenance of AUAV and possible replacement of damaged or worn components. | Medium |
|  | **Safety** |  |  |  |  |  |  |
| 3.2.11.1 | The AUAV system shall not present any safety hazards to maintenance personnel. | Security | Injury to workers | High | Protective labelling and component layout to be optimized. Train operators. | Cost of maintenance personnel off duty. | Medium |
| 3.2.11.2 | The AUAV system shall maintain constant transponder communication visible to all aircraft and Air Traffic Control to maintain air traffic safety. | Security | Injury to workers | High | Protective labelling and component layout to be optimized. Train operators. | Cost of maintenance personnel off duty. | Medium |
| 3.2.11.3 | The AUAV system shall allow the transponder unimpeded communication without interference. | Security | Injury to workers | High | Protective labelling and component layout to be optimized. Train operators. | Cost of maintenance personnel off duty. | Medium |
| 3.2.11.4 | Personal protective equipment (PPE) shall be worn as necessary i.e. repairs, noise levels, low oxygen environments, etc. | Security | Injury to workers | High | Protective labelling and component layout to be optimized. Train operators. Use of PPE and compliance with OSHA or international standards. | Cost of maintenance personnel off duty. | Medium |
|  | **Security** |  |  |  |  |  |  |
| 3.2.12.1 | The AUAV system shall incorporate secure data encryption with the communication between the UAV and the mission control center. | Security | AUAV Mission intent corruption | Medium | Include enough software encryption to prevent malicious intrusion | Loss of operational control and data | Medium |
| 3.2.12.2 | The AUAV system shall incorporate secure data encryption for all stored data (mission planning files, flying logs, maps). | Security | AUAV Mission intent corruption | Medium | Include enough software encryption to prevent malicious intrusion. | Loss of operational control and data storage. | Medium |
| 3.2.12.3 | The AUAV system shall incorporate a special security token to modify or upload new software to the controller modules. | Security | AUAV Mission intent corruption | Medium | Include enough software encryption to prevent malicious intrusion. | Loss of operational control and data. Use of unauthorized parts, modules, software, etc. | Medium |
| 3.2.12.4 | The AUAV system shall notify mission control as it approaches near international borders and airspaces, and other no-fly zones. | Security | Potential political border backlash by allies, non-allies, and partners. Possible targeting by weapons systems. | High | Train operators properly. Regular communications and protocols training. Use displays and maps with reminders and/or warnings when approaching a no-fly zone. | Loss of AUAV. Political Backlash. Loss of trust with allies or partners. | Medium |
| 3.2.12.5 | The AUAV system shall report operational data, including battery information and functional performance in the event of an attack. | Security | Failure of AUAV threat aversion system. Loss of critical data collected. | Medium | Install software to automatically transmit data when threat is detected. Install operator override to transfer critical data if AUAV is unable to transmit on its own. | Loss of AUAV data and AUAV. | Medium |
| 3.2.12.6 | The AUAV system shall be tamper-proof. | Security | AUAV Mission intent corruption | Medium | Include enough software encryption to prevent malicious intrusion | Loss of operational control and data | Medium |
| 3.2.12.7 | The AUAV system shall data clear. | Security | Potential data theft | Medium | Include software scripts to trigger data wiping protocols upon critical system failure. | Data leak | Medium |
| 3.2.12.8 | The AUAV system shall support data security to prevent data theft. | Security | Compromising secure data | Medium | Include capabilities for recurring software security updates | Data leak | Medium |
| 3.2.12.9 | The AUAV system shall prevent GPS jamming. | Security | Loss of AUAV and/or data leak | Medium | Include anti-jamming hardware | Overall AUAV control loss, costs associated with data leak | Medium |
| 3.2.12.10 | The AUAV system shall counter Electronic Warfare | Security | Loss of AUAV and/or data leak | Medium | Use state-of-the art security software and encryption of sensitive or proprietary information | Overall AUAV control loss, costs associated with data leak | Medium |

# Analytic Hierarchy Process (AHP)

The goal of the Analytic Hierarchy Process is to help FIT select the technical feature “optical sensor/detector” for the AUAV from a set of three alternatives, shown in Table 10, based on the importance values of certain criteria. For this purpose, we will use six factors or criteria. The weightings of importance were provided by the stakeholders and FIT specialists, the values were then averaged. Table 11 shows the importance value attributed to each number. Table 12 shows the importance of each criterion.

Table 11: Alternatives for the optical sensor/detector

|  |  |  |
| --- | --- | --- |
| **Alternative 1 (“A”)** | **Alternative 2 (“B”)** | **Alternative 3 (“C”)** |
| High Spatial Resolution Sensor | Multispectral Camera | Polarimetric Camera |

Table 12: Definition of Importance

|  |  |
| --- | --- |
| **Importance Scale** | **Definition of Importance of Scale** |
| 1 | Equally Important |
| 2 | Equally to Moderate Important |
| 3 | Moderately Important |
| 4 | Moderately to Strongly Important |
| 5 | Strongly Important |
| 6 | Strongly to Very Strongly Important |
| 7 | Very Strongly Important |
| 8 | Very Strongly to Extremely Important |
| 9 | Extremely Important |

Table 13: Scores for the Importance of factors

|  |  |
| --- | --- |
| **Criteria** | **Importance Scale** |
| Maintenance/Support | 7 |
| Reliability | 8 |
| Material Discrimination | 4 |
| Cost | 6 |
| Spatial Resolution | 5 |
| Weight | 3 |

Table 14 shows the criteria matrix (preference matrix), where each criterion is compared in importance with the other criteria, which will help us select the best choice for the optic sensor/detector.

Table 14: Estimated parameter comparison values (preference matrix)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Maintenance/ Support | Reliability | Material Discrimination | Cost | Spatial Resolution | Weight |
| Maintenance/ Support | 1 | 1/4 | 2 | 1/2 | 1/3 | 2 |
| Reliability | 4 | 1 | 8 | 6 | 4 | 7 |
| Material Discrimination | 1/2 | 1/8 | 1 | 1/4 | 1/3 | 1/2 |
| Cost | 2 | 1/6 | 4 | 1 | 1/3 | 4 |
| Spatial Resolution | 3 | 1/4 | 3 | 3 | 1 | 2 |
| Weight | 1/2 | 1/7 | 2 | 1/4 | 1/2 | 1 |

From Table 14 we will deduct the Row Mean (Eigen Vector), which we will use to calculate the Consistency Ratio (CI) and Consistency Index (CI).

Table 15: Row Mean (Eigen Vector)

|  |
| --- |
| Row Mean |
| 0.0897 |
| 0.4776 |
| 0.0441 |
| 0.1421 |
| 0.1833 |
| 0.0633 |

Table 15 to Table 20 show the comparisons between each alternative for every criterion. In this case we have six criteria.

Table 16: Alternative matrix values for Maintenance/Support

|  |  |  |  |
| --- | --- | --- | --- |
| Maintenance/  Support | A | B | C |
| A | 1 | 2 | 3 |
| B | 1/2 | 1 | 1/2 |
| C | 1/3 | 2 | 1 |

Table 17: Alternative matrix values for Reliability

|  |  |  |  |
| --- | --- | --- | --- |
| Reliability | A | B | C |
| A | 1 | 3 | 4 |
| B | 1/3 | 1 | 1/2 |
| C | 1/4 | 2 | 1 |

Table 18: Alternative matrix values for Integration

|  |  |  |  |
| --- | --- | --- | --- |
| Material Discrimination | A | B | C |
| A | 1 | 1/2 | 1/2 |
| B | 2 | 1 | 1/2 |
| C | 2 | 2 | 1 |

Table 19: Alternative matrix values for Cost

|  |  |  |  |
| --- | --- | --- | --- |
| Cost | A | B | C |
| A | 1 | 3 | 5 |
| B | 1/3 | 1 | 3 |
| C | 1/5 | 1/3 | 1 |

Table 20: Alternative matrix values for Spatial Resolution

|  |  |  |  |
| --- | --- | --- | --- |
| Spatial Resolution | **A** | **B** | **C** |
| A | 1 | 2 | 1/2 |
| B | 1/2 | 1 | 1/4 |
| C | 2 | 4 | 1 |

Table 21: Alternative matrix values for Weight

|  |  |  |  |
| --- | --- | --- | --- |
| Weight | A | B | C |
| A | 1 | 2 | 1/2 |
| B | 1/2 | 1 | 1/3 |
| C | 2 | 3 | 1 |

Table 22 shows each row mean from each criterion grouped together to form a matrix.

Table 22: Row means of each alternative matrix consolidated into one matrix

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Maintenance/ Support | Reliability | Material Discrimination | Cost | Spatial Resolution | Weight |
| A | 0.5374 | 0.6196 | 0.1976 | 0.6333 | 0.2857 | 0.2973 |
| B | 0.1946 | 0.1560 | 0.3119 | 0.2605 | 0.1429 | 0.1638 |
| C | 0.2680 | 0.2243 | 0.4905 | 0.1062 | 0.5714 | 0.5390 |

Using Table 22 and Table 15, we get the best option for the optical sensor/detector for our project. Table 23 ranks the alternatives, being alternative A the best choice, High Spatial Resolution Camera.

Table 23: Results from the AHP, showing Rank and Value

|  |  |  |
| --- | --- | --- |
| Alternatives | Value | Rank |
| A | 0.514 | 1 |
| B | 0.179 | 3 |
| C | 0.307 | 2 |

To obtain the Consistency Index and the Consistency Ratio we use the Eigen method. From Table 14 (preference matrix A) and Table 15 (Eigen vector, matrix P) we obtain the Eigen Value matrix (A\*P = λ\*P). Table 24 shows different values for the Eigen Value (λ), this tells us that there is an inconsistency in our survey results for the three alternatives and their criteria.

Table 24: Multiple values for the Eigen Value (λ)

|  |  |  |
| --- | --- | --- |
| A\*P | Row Mean | Eigen Value (λ) |
| 0.5558 | 0.0897 | 6.198 |
| 3.2175 | 0.4776 | 6.736 |
| 0.2768 | 0.0441 | 6.282 |
| 0.8915 | 0.1421 | 6.273 |
| 1.2567 | 0.1833 | 6.856 |
| 0.3917 | 0.0633 | 6.191 |

Consistency Index:

Given the formula CI = (λmax-n)/n-1

Where: n = number of criteria

λmax = average value from the Eigenvalue matrix = 6.4231

CI = 0.08462

Consistency Ratio:

Given the formula CR = CI/ACI

Where: ACI is the average consistency index

For n = 6, the ACI = 1.2358

CR = 0.0684

It should be noted that a consistency ratio lower than 0.10 verifies that the results of comparison are acceptable.

# Functional Flow Diagrams

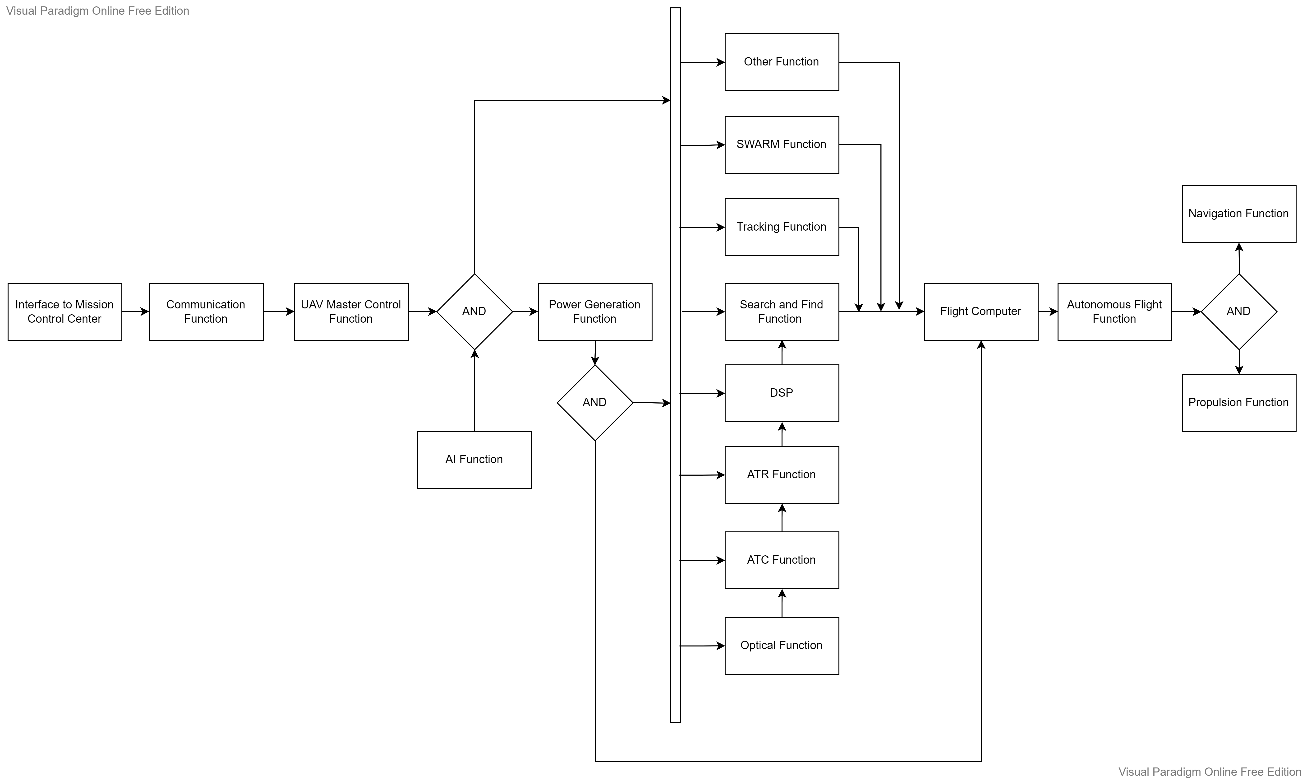
Figure 10 displays the functional flow diagram using Visual Paradigm Process Flow Diagram software in which the AUAV’s functions interact at a high level. The Interface to the Mission Control Center will send commands to the AUAV which will be received by the Communication Function. Depending on the command received, the Communication Function will feed all commands to the UAV Master Control Function. The UAV Master Control Function will signal the Power Generation function to power to all functions nascency for the command to be initialized/completed. The UAV Master Control Function also sends the MCC’s command to all functions that are required for the task to be initialized/completed. The SWARM Function will take in data received from the Communication Function and the UAV’s Master Control function. The Optical Function will feed imagery data to the ATC to clean up the image. Once processed, the data will be passed to the ATR and then the Search & Find Function. The data will then be sent to the Tracking Function. The Flight Computer will take in data from the Tracking Function, SWARM Function, and any other functions in order to send necessary input to the Autonomous flight function which will send signals to the Navigation Function and Propulsion Function for the AUAV to perform the appropriate flight maneuvers (search & find and SWARM flight). 

Figure 10: Functional Flow Diagram

# Reliability Model and Analysis

This reliability model addresses the maintenance support for the components in the navigation subsystem.

The System Level Requirements (SLRs), developed in the Conceptual Design phase, yielded two requirements that the sub-systems need to satisfy. Firstly, the Mean Time Between Failure (MTBF) of the system shall be at least 10 years and the instantaneous reliability at least 70%.

The reliability model block diagram is shown in Figure 11. Mean Time Between Failure data was found for representative components of the Inertial Measurement Unit, GPS, and Processors. The MTBF for the Power Distribution Unit (PDU) was not found but an estimated value of 128,000 hours was used. The software was intentionally left out of the model as it is expected that after operational acceptance the source code will not be subject to development. The software is specific to this autonomous UAV and once proven successful and complete will not be modified.



Figure 11: Reliability Model Block Diagram

As the AUAV’s navigation system needs to be inspected every 1,000 hours, the preventative replacement policy will assign part replacements at one of the 1,000-hour intervals to not add to the downtime with additional outages. The reliability analysis requires the Power Distribution assembly to be replaced every 6,000 hours of operation, the GPS to be replaced every 42,000 hours and the Inertial Measurement Unit (IMU) to be replaced every 42,000 hours. The two processors have redundant components given the severity of the consequences of failure in operation. Together this provides 70% instantaneous reliability across the system lifecycle.

Figure 12 shows the system reliability over a 10-year period as a function of time. The sawtooth nature of the overall system reliability is due to the adoption of the preventative replacement policy for the components. Should future work locate more reliable systems, they should be assessed for suitability.

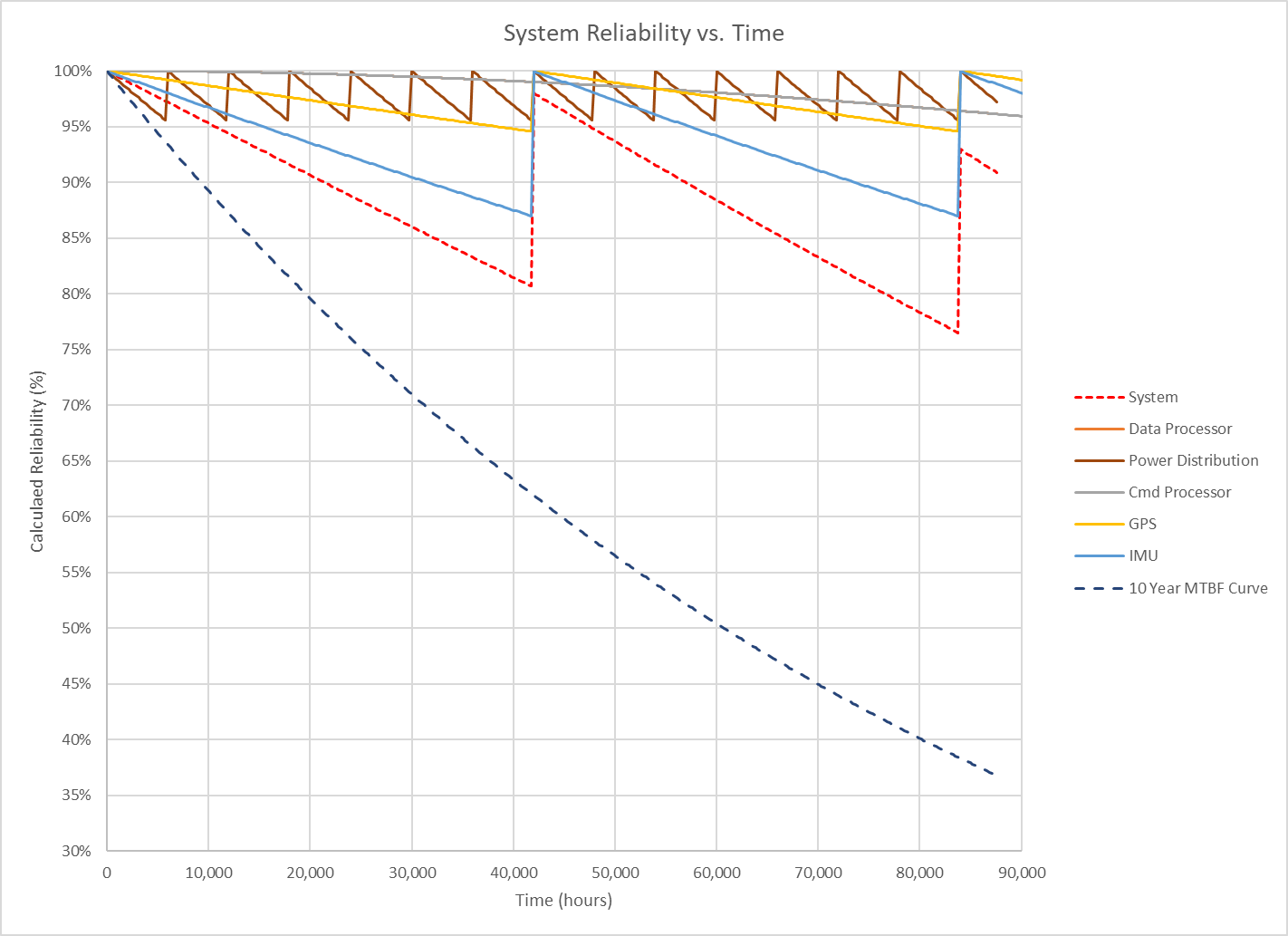


Figure 12: System Reliability Analysis

This reliability analysis covers only the Navigation Subsystem.

The AI is a software-based system and so can be assumed to have a software-based reliability model. With periodic debugging efforts and use of a reliable system like Linux that is also compatible with Windows 10 as per a System Requirement, we can assume that the reliability is 0.97 as per the feasibility study.

Overall UAV reliability cannot be performed at this time due to insufficient data. A full system and component reliability model will be performed with the full development of the AUAV, but given these preliminary calculations, we believe the system will fulfill all reliability requirements.

# Commercial Off the Shelf (COTS) Products

Given the design, all components are available as COTS Products, the detailed design captures the software development as defined in the preliminary design phase as well as specifying the COTS products.

A table of COTS products within the OSS can be found below.

Table 25: COTS Products

|  |  |
| --- | --- |
| **Component** | **Model** |
| Terminal Strip | Molex 9.53 [0.375] Double Row Low Profile Bit Test & Set (BTS) Assembly (or Equal) |
| Voltage Regulator | PST-DCZ0305-W 3.3 Volt Output Voltage Regulator (or Equal) |
| Voltage Regulator | PST-DCZ0505-W 5.0 Volt Output Voltage Regulator (or Equal) |
| Inertial Measurement Unit | MTi-G-710 GNSS (or Equal) |
| GPS Receiver | i-Lotus M12M (or Equal) |
| Programmable Logic Controller | Allen Bradley CompactLogix 5380 (or Equal) |
| ATR | Raytheon VADER |
| Data Storage | Seagate Expansion 4 TB STEA4000400 |

Additional items are not defined at this point in the project.

# Failure Mode, Effect, and Criticality Analysis (FMECA)

Table 26 is an overview of the failure modes and their criticality (FMECA) analysis performed on the system requirements. We listed requirement with risk within the AUAV System as well as any critical components. For each functional component, we analyzed potential failure modes and the potential causes behind those failures. Understanding the root cause of each failure allows us to assess the probability of each failure. For each component, a possible effect was determined after analyzing the impacts of a failure of that component. Some of these failures create ripple effects that affect other functions of the AUAV as well as the AUAV as a whole. Understanding the impacts of each failure allows us to assess the severity of each failure. The probability of occurrence P(f) and severity of consequences C(f) were determined from charts from the Hughes Missile System company.

A risk priority number (RPN) was then calculated for each failure mode by multiplying each P(f) and C(f) for that failure mode and a subsequent color code was assigned. The thresholds for the color codes are green (RPN < 0.25), yellow (0.25 ≤ RPN < 0.5) and red (0.5 ≤ RPN <1).

A risk mitigation plan was developed for each failure mode. These plans are processes that can be developed and implemented during the development and design phase to reduce the risks of the navigation subsystem. Some of these plans are focused on lowering the probability of the failure cause, and some are focused on reducing the severity of a stated failure. The color coded RPN’s can help make risk management decisions in determining how resources are allocated for each risk mitigation plan. The P(f) and S(f) can be re-analyzed and the RPN recalculated after implementation of the risk mitigation plans to show successful risk reduction.

Table 26: FMECA

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Failure Mode, Effect and Criticality Analysis (FMECA)** | | |  |  |  |  | RPN Threshold Values | |  |  |  |
| System: | Search and Find Maneuvers Function | | |  |  |  |  | RPN < 0.25 |  |  |  |
| Function Block: | 14.0 |  |  |  |  |  |  | 0.25 ≤ RPN < 0.5 |  |  |  |
|  |  |  |  |  |  |  |  | 0.5 ≤ RPN < 1 |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| Requirement | Reference Number | Potential Failure Mode | Potential Cause of Failure | Potential Effects of Failure | Before Mitigation | | | Mitigation | After Mitigation | | |
| Likelihood | Criticality | RPN | Likelihood | Criticality | RPN |
| 3.2.1.24 The system shall provide an image/dataset to command center within 5 seconds. | 3.2.1.24.a | A. Loss of communication B. Corrupt image data C. Loss of Data | Hardware Related issues | Image Corruption, Image lost in transfer and mission failure can occur. | 0.6 | 0.8 | 0.48 | Split data storage into two standalone 4 TB units for redundancy. | 0.4 | 0.8 | 0.32 |
| Cost and Schedule: Potential damage to equipment and design-rework necessary > 2 weeks. | 0.5 | 0.6 | 0.3 | Install and inspect required equipment.  Simulation and modeling needed to understand interactions. | 0.2 | 0.6 | 0.12 |
| Operational: AUAV storage equipment over heads, ventilation and cooling are inadequate causing damage to storage. | 0.3 | 0.7 | 0.21 | Enforce maintenance schedules. | 0.1 | 0.7 | 0.07 |
| 3.2.1.24.b | A. Configuration of software is incorrect. | Software Coding Errors | Image Corruption, Image lost in transfer and mission failure can occur. | 0.6 | 0.8 | 0.48 | Incorporate backup storage of data equipment | 0.4 | 0.8 | 0.32 |
| Cost and Schedule: Rework of software and testing. | 0.3 | 0.7 | 0.21 | Good Engineering Practices Good Software Engineer Practices and Code.  Robust Testing of Code | 0.2 | 0.7 | 0.14 |
| Operational failure due to image loss and corruption. | 0.5 | 0.6 | 0.3 | Development of Software Test Plan | 0.4 | 0.6 | 0.24 |
| 3.2.12.6 The system shall be capable of tamper-proofing. | 3.2.12.6.a | A. Mission intent Corruption B. Encryption errors C. Unauthorized Users controlling the system and accessing data. D. Loss of Operations | Software coding errors | Security issues and corruption of AUAV, images / videos, data leak, and mission disruption. | 0.3 | 0.8 | 0.24 | Incorporate tamper-proof mechanism to protect the AUAV and all data / video. | 0.2 | 0.8 | 0.16 |
| Cost and Schedule: Potential damage to equipment and software and design re-work necessary > 2 weeks. | 0.2 | 0.3 | 0.06 | Security testing and robust software and application installations. | 0.1 | 0.3 | 0.03 |
| Operational: AUAV loses flight control mid-air. Data is unsecure, Data is unrealizable, corruption of data. | 0.3 | 0.9 | 0.27 | Transmit alerts when unauthorized use is detected, encryption errors, and loss of operations. | 0.2 | 0.9 | 0.18 |
| 3.2.12.7 The system shall be capable of data clearing. | 3.2.12.7.a | A. Data leak B. Data corruption C. Security issues | Software coding errors | Security and data leak to unauthorized users. | 0.3 | 0.8 | 0.24 | Incorporate data clearing mechanism to protect the AUAV and all data / video. Upgrade and support software and code. | 0.2 | 0.8 | 0.16 |
| Cost and Schedule: Potential damage to equipment and software and design re-work necessary > 2 weeks. | 0.3 | 0.3 | 0.09 | Security testing and robust software and application installations. | 0.1 | 0.3 | 0.03 |
| Security issues with data access, GPS locations are vulnerable, data leak. | 0.3 | 0.9 | 0.27 | Transmit alerts when unauthorized use is detected, encryption errors, and loss of operations. | 0.2 | 0.9 | 0.18 |
| 3.2.12.9 The system shall have capabilities to prevent GPS anti-jamming. | 3.2.12.9.a | A. GPS System Override B. Loss of control | Software coding errors | Security: GPS system override and loss of control of AUAV. Navigation Disruption. | 0.3 | 0.8 | 0.24 | Incorporate tamper-proof mechanism to protect the AUAV and all data / video. Incorporate anti jamming mechanism to protect the GPS system. | 0.2 | 0.8 | 0.16 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 2 weeks. | 0.2 | 0.3 | 0.06 | Security testing and robust software and application installations.  Installation inspection required prior to initial energization. Procure / Produce robust and reliable components. | 0.1 | 0.3 | 0.03 |
| Operational: AUAV loses flight control mid-air. Data is unsecure, Data is unrealizable, corruption of data. Frequency: Occasional. | 0.3 | 0.9 | 0.27 | Transmit alerts when unauthorized use is detected, encryption errors, and loss of operations. AUAV Master Control System shall transmit an alert and engage safe mode. | 0.2 | 0.9 | 0.18 |
|  |  |  |  |  |  |  |  |  |  |  |  |
| **Failure Mode, Effect and Criticality Analysis (FMECA)** | | |  |  |  |  | RPN Threshold Values | |  |  |  |
| System: | SWARM Functions | |  |  |  |  |  | RPN < 0.25 |  |  |  |
| Function Block: | 13.0 |  |  |  |  |  |  | 0.25 ≤ RPN < 0.5 |  |  |  |
|  |  |  |  |  |  |  |  | 0.5 ≤ RPN < 1 |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| Requirement | Reference Number | Potential Failure Mode | Potential Cause of Failure | Potential Effects of Failure | Before Mitigation | | | Mitigation | After Mitigation | | |
| Likelihood | Criticality | RPN | Likelihood | Criticality | RPN |
| 3.1.4.25 The system shall be capable of flying independently or as part of a SWARM of multiple AUAVs with adaptive, AI-based decision-making/mission reconfiguration. | 3.1.4.25.a | A. AUAV inability to communicate with other AUAV | Hardware Related issues | Requirement not met. | 0.6 | 0.7 | 0.42 | Install compatible SWARM hardware. | 0.3 | 0.7 | 0.21 |
| Cost and Schedule: Potential increase of cost and schedule due to mission failure of a SWARM integration. | 0.5 | 0.6 | 0.3 | Install and inspect required equipment.  Simulation and modeling needed to understand interactions. | 0.2 | 0.6 | 0.12 |
| Operational: AUAV inability to communicate with a SWARM of AUAVs. | 0.3 | 0.7 | 0.21 | Enforce maintenance schedules. | 0.1 | 0.7 | 0.07 |
| 3.1.4.25.b | A. AUAV inability to communicate with other AUAV | Software Coding Errors | Image Corruption, Image lost in transfer and mission failure can occur. | 0.4 | 0.6 | 0.24 | Incorporate SWARM software and applications | 0.2 | 0.6 | 0.12 |
| Cost and Schedule: Rework of software and testing. | 0.3 | 0.7 | 0.21 | Good Engineering Practices Good Software Engineer Practices and Code.  Robust Testing of Code | 0.2 | 0.7 | 0.14 |
| Operational failure due to image loss and corruption. | 0.4 | 0.6 | 0.24 | Development of Software Test Plan | 0.2 | 0.6 | 0.12 |
| 3.1.4.28 The AUAV shall be able to coordinate with other AUAVs in order to position themselves appropriately in the air to form a synthetic antenna array using Global Positioning System (GPS) and the data link. | 3.1.4.28 .a | A. Inability to coordinate with other AUAVs.  B. Positioning of AUAV can cause failure and collapse with other AUAVs if communication is a problem.  C. Equipment Error | Hardware Related issues | Requirement not met. | 0.6 | 0.8 | 0.48 | Install compatible SWARM hardware. | 0.3 | 0.8 | 0.24 |
| Cost and Schedule: Potential increase of cost and schedule due to mission failure of a SWARM integration. | 0.5 | 0.6 | 0.3 | Install and inspect required equipment.  Simulation and modeling needed to understand interactions. | 0.2 | 0.6 | 0.12 |
| Operational: AUAV inability to communicate with a SWARM of AUAVs. | 0.5 | 0.9 | 0.45 | Enforce maintenance schedules. | 0.2 | 0.9 | 0.18 |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| **Failure Mode, Effect and Criticality Analysis (FMECA)** | | |  |  |  |  | RPN Threshold Values | |  |  |  |
| System: | Object of Interest Function | |  |  |  |  |  | RPN < 0.25 |  |  |  |
| Function Block: | 11.0 |  |  |  |  |  |  | 0.25 ≤ RPN < 0.5 |  |  |  |
|  |  |  |  |  |  |  |  | 0.5 ≤ RPN < 1 |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| Requirement | Reference Number | Potential Failure Mode | Potential Cause of Failure | Potential Effects of Failure | Before Mitigation | | | Mitigation | After Mitigation | | |
| Likelihood | Criticality | RPN | Likelihood | Criticality | RPN |
| 3.2.1.19: The system shall detect human Target of Interest (TOI) with a slant range of 9.543km during daytime. | 3.2.1.19.a | A. Incorrect Installation B. Defective Components | Hardware Related issues | Requirement: Slight chance of minor requirement deficiencies | 0.3 | 0.7 | 0.21 | Installation inspection required prior to initial energization. Good Engineering Practices | 0.2 | 0.7 | 0.14 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 2 weeks. | 0.3 | 0.3 | 0.09 | Installation inspection required prior to initial energization. Procure / Produce robust and reliable components | 0.1 | 0.3 | 0.03 |
| 3.2.1.20: The system shall detect human Target of Interest (TOI) with a slant range of 1.5 km during nighttime. | 3.2.1.20.a | A. Loss of communication | Hardware Related issues | Requirement: Slight chance of minor requirement deficiencies | 0.3 | 0.7 | 0.21 | Installation inspection required prior to initial energization. Good Engineering Practices | 0.2 | 0.7 | 0.14 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 2 weeks. | 0.3 | 0.3 | 0.09 | Installation inspection required prior to initial energization. Procure / Produce robust and reliable components | 0.1 | 0.3 | 0.03 |
| 3.2.1.21: The system shall identify human Target of Interest (TOI) with a slant of 1.5 km during daytime. | 3.2.1.21.a | A. Corrupt image data B. Camera out of focus C. Failure to detect target in image D. Insufficient image database to test against. | Hardware Related issues | Requirement: Slight chance of minor requirement deficiencies | 0.3 | 0.7 | 0.21 | Installation inspection required prior to initial energization. Good Engineering Practices | 0.2 | 0.7 | 0.14 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 2 weeks. | 0.3 | 0.3 | 0.09 | Installation inspection required prior to initial energization. Procure / Produce robust and reliable components | 0.1 | 0.3 | 0.03 |
| 3.2.1.22: The system shall identify human Target of Interest (TOI) with a slant range of 250 m during nighttime (with slipstream sensors). | 3.2.1.22.a | A. Incorrect data mapping.  B. Insufficient programming time C. Development before design. | Hardware Related issues | Requirement: Slight chance of minor requirement deficiencies | 0.3 | 0.7 | 0.21 | Installation inspection required prior to initial energization. Good Engineering Practices | 0.2 | 0.7 | 0.14 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 2 weeks. | 0.3 | 0.3 | 0.09 | Installation inspection required prior to initial energization. Procure / Produce robust and reliable components | 0.1 | 0.3 | 0.03 |
| 3.2.1.23: The system shall identify human Target of Interest (TOI) within a slant range of 1.5km (with slipstream sensor). | 3.2.1.23.a | A. Inability to initialize software. | Hardware Related issues | Requirement: Slight chance of minor requirement deficiencies | 0.3 | 0.7 | 0.21 | Installation inspection required prior to initial energization. Good Engineering Practices | 0.2 | 0.7 | 0.14 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 2 weeks. | 0.3 | 0.3 | 0.09 | Installation inspection required prior to initial energization. Procure / Produce robust and reliable components | 0.1 | 0.3 | 0.03 |
| 3.2.1.26 The system shall provide detection 24 hours per day / 7 days per week with a 98% operational availability during on-station time. | 3.2.1.26.a | A. Incorrect Installation B. Defective Components | Hardware Related issues | Technical: Detection failure of Object. | 0.4 | 0.7 | 0.28 | Incorporate reliable detection equipment | 0.4 | 0.7 | 0.28 |
| Cost and Schedule: Potential damage to equipment and design-rework necessary > 2 weeks. | 0.3 | 0.3 | 0.09 | Install and inspect required equipment.  Simulation and modeling needed to understand interactions. | 0.1 | 0.3 | 0.03 |
| Operational: System failure of detection of target objects. | 0.5 | 0.9 | 0.45 | Enforce maintenance schedules. | 0.3 | 0.9 | 0.27 |
| 3.2.1.26.b | A. Incorrect data mapping.  B. Insufficient programming time C. Development before design. | Software Coding Errors | Requirement: Slight change of minor requirement deficiencies | 0.4 | 0.7 | 0.28 | Incorporate detection applications that are reliable. | 0.3 | 0.7 | 0.21 |
| Cost and Schedule: Design rework - necessary > 2 weeks | 0.3 | 0.7 | 0.21 | Good Engineering Practices Good Software Engineer Practices and Code.  Robust Testing of Code | 0.1 | 0.7 | 0.07 |
| Operational: Mission failure | 0.4 | 0.7 | 0.28 | Development of Software Test Plan | 0.2 | 0.7 | 0.14 |
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| **Failure Mode, Effect and Criticality Analysis (FMECA)** | | |  |  |  |  | RPN Threshold Values | |  |  |  |
| System: | ATC/ATR Functions | | |  |  |  |  | RPN < 0.25 |  |  |  |
| Function Block: | 9.0, 10.0 | |  |  |  |  |  | 0.25 ≤ RPN < 0.5 |  |  |  |
|  |  |  |  |  |  |  |  | 0.5 ≤ RPN < 1 |  |  |  |
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| Requirement | Reference Number | Potential Failure Mode | Potential Cause of Failure | Potential Effects of Failure | Before Mitigation | | | Mitigation | After Mitigation | | |
| Likelihood | Criticality | RPN | Likelihood | Criticality | RPN |
| 3.2.1.30 The system shall process atmospheric turbulence compensation video data on streaming data at video rate of 30 Hz, or on individually selected images. | 3.2.1.30.a | A. Incorrect Installation B. Defective Components | Hardware Related issues | Requirement: Slight chance of minor requirement deficiencies | 0.4 | 0.7 | 0.28 | Installation inspection required prior to initial energization. Good Engineering Practices | 0.2 | 0.7 | 0.14 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 2 weeks. | 0.3 | 0.3 | 0.09 | Installation inspection required prior to initial energization. Procure / Produce robust and reliable components | 0.1 | 0.3 | 0.03 |
| Operational: AUAV unable to provide turbulence compensation videos and streaming is lost due to video rate to large. | 0.6 | 0.9 | 0.54 | AUAV ATC System shall transmit an alert if video rate is at its capacity. | 0.4 | 0.9 | 0.36 |
| 3.2.1.30.b | A. Loss of Video Data B. Insufficient Storage space for video C. Streaming Data Communication Loss | Software coding errors | Requirement: Slight chance of minor requirement deficiencies | 0.4 | 0.7 | 0.28 | Testing of video rates, streaming of video data, and communication. | 0.3 | 0.7 | 0.21 |
| Cost and Schedule: Design re-work necessary > 2 weeks | 0.3 | 0.3 | 0.09 | Include in Software Test Plan. | 0.1 | 0.3 | 0.03 |
| Operational: AUAV loses video streaming due to software code error or configuration incorrect. | 0.4 | 0.9 | 0.36 | AUAV ATC System shall transmit an alert if video rate is at its capacity. | 0.3 | 0.9 | 0.27 |
| 3.2.1.25 The system shall provide on-demand video to command center within 5 seconds. | 3.2.1.25.a | A. Loss of communication B. Corrupt image data C. Loss of Data | Hardware Related issues | Image Corruption, Image lost in transfer and mission failure can occur. | 0.6 | 0.7 | 0.42 | Split data storage into two standalone 4 TB units for redundancy. | 0.3 | 0.7 | 0.21 |
| Cost and Schedule: Potential damage to equipment and design-rework necessary > 2 weeks. | 0.5 | 0.6 | 0.3 | Install and inspect required equipment.  Simulation and modeling needed to understand interactions. | 0.2 | 0.6 | 0.12 |
| Operational: AUAV storage equipment over heads, ventilation and cooling are inadequate causing damage to storage. | 0.4 | 0.7 | 0.28 | Enforce maintenance schedules. | 0.3 | 0.7 | 0.21 |
| 3.2.1.25.b | A. Configuration of software is incorrect. | Software Coding Errors | Technical: Image Corruption, Image lost in transfer and mission failure can occur. | 0.4 | 0.6 | 0.24 | Incorporate backup storage of data equipment | 0.2 | 0.6 | 0.12 |
| Cost and Schedule: Rework of software and testing. | 0.2 | 0.7 | 0.14 | Good Engineering Practices Good Software Engineer Practices and Code.  Robust Testing of Code | 0.2 | 0.7 | 0.14 |
| Operational: AUAV failure due to image loss and corruption. | 0.4 | 0.6 | 0.24 | Development of Software Test Plan | 0.2 | 0.6 | 0.12 |
| 3.2.2.7 The system shall have an atmospheric turbulence compensating system with light captured at least at two wavelengths simultaneously. | 3.2.2.7.a | A. Incorrect Installation B. Defective Components | Hardware Related issues | Requirement: Slight chance of minor requirement deficiencies | 0.4 | 0.7 | 0.28 | Installation inspection required prior to initial energization. Good Engineering Practices | 0.2 | 0.7 | 0.14 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 2 weeks. | 0.3 | 0.3 | 0.09 | Installation inspection required prior to initial energization. Procure / Produce robust and reliable components Testing of multiple environmental situations. | 0.1 | 0.3 | 0.03 |
| Operational: AUAV unable to provide turbulence compensation videos and streaming is lost due to video rate to large. | 0.4 | 0.9 | 0.36 | AUAV ATC System shall transmit an alert identifying when ATC system is failing and images are distorted. | 0.2 | 0.9 | 0.18 |
| 3.2.2.7.b | A. Loss of Image B. Distortion of Image C. Image processing errors | Software coding errors | Requirement: Slight chance of minor requirement deficiencies | 0.4 | 0.7 | 0.28 | Provide robust software and upgrades for multiple turbulence modes. | 0.1 | 0.7 | 0.07 |
| Cost and Schedule: Design re-work necessary > 2 weeks | 0.3 | 0.3 | 0.09 | Include in Software Test Plan. | 0.1 | 0.3 | 0.03 |
| Operational: AUAV inability to provide clear images and process images correctly. | 0.4 | 0.9 | 0.36 | AUAV ATC System shall transmit an alert if turbulence mode is not working and image distortion is in effect. | 0.2 | 0.9 | 0.18 |
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| **Failure Mode, Effect and Criticality Analysis (FMECA)** | | |  |  |  |  | RPN Threshold Values | |  |  |  |
| System: | Other Features/Capabilities/Sensor Function | | |  |  |  |  | RPN < 0.25 |  |  |  |
| Function Block: | 12.0 |  |  |  |  |  |  | 0.25 ≤ RPN < 0.5 |  |  |  |
|  |  |  |  |  |  |  |  | 0.5 ≤ RPN < 1 |  |  |  |
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| Requirement | Reference Number | Potential Failure Mode | Potential Cause of Failure | Potential Effects of Failure | Before Mitigation | | | Mitigation | After Mitigation | | |
| Likelihood | Criticality | RPN | Likelihood | Criticality | RPN |
| 3.2.7.1 The system shall support different data transfer protocols. | 3.2.7.1.a | A. Compatibility Issues | Software Related issues | Requirement: Slight chance of minor requirement deficiencies | 0.3 | 0.7 | 0.21 | System shall support different data transfer protocols and upgrade software to be compatible with all transfer protocols. | 0.1 | 0.7 | 0.07 |
| Transfer of data mission failure. | 0.4 | 0.6 | 0.24 | Add failure alert and backup all data if transfer fails. | 0.2 | 0.6 | 0.12 |
| 3.2.7.2 The data processing, and control processing code from the AUAV shall be written with a programming language which is cross-platform. | 3.2.7.2.a | A. Compatibility Issues | Software Related issues | Requirement: Slight chance of minor requirement deficiencies | 0.4 | 0.7 | 0.28 | Provide compatible code as well as language of code. | 0.2 | 0.7 | 0.14 |
| Inability to process data incorrectly, compatible issues. | 0.5 | 0.7 | 0.35 | Add failure alert and backup all data if processing fails. | 0.4 | 0.7 | 0.28 |
| 3.2.5.10 The system shall be maintained with Commercial Off the Shelf (COTS) tools and equipment. | 3.2.5.10.a | A. COTS tools Delay B. Equipment Delay | Equipment / Tools Issue | Requirement: Slight chance of minor requirement deficiencies | 0.3 | 0.7 | 0.21 | Install, maintain, and support compatible equipment and upgrades. | 0.1 | 0.7 | 0.07 |
| Incompatible Equipment and tools can cause mission errors, data transfer, image capture, etc. | 0.4 | 0.6 | 0.24 | Add failure mode and alert on all equipment and software. | 0.2 | 0.6 | 0.12 |
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| **Failure Mode, Effect and Criticality Analysis (FMECA)** | | |  |  |  |  | RPN Threshold Values | |  |  |  |
| System: | Optical Function | |  |  |  |  |  | RPN < 0.25 |  |  |  |
| Function Block: | 7.0 |  |  |  |  |  |  | 0.25 ≤ RPN < 0.5 |  |  |  |
|  |  |  |  |  |  |  |  | 0.5 ≤ RPN < 1 |  |  |  |
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| Requirement | Reference Number | Potential Failure Mode | Potential Cause of Failure | Potential Effects of Failure | Before Mitigation | | | Mitigation | After Mitigation | | |
| Likelihood | Criticality | RPN | Likelihood | Criticality | RPN |
| 3.2.1.29 The system shall have an optical system that can detect human heat in the IR with a peak wavelength of 9.5 micrometers. | 3.2.1.29. a | a. Defective Components b. Loss of Data c. Loss of human tracking | Hardware Related issues | Requirement not met to detect human heat. | 0.4 | 0.7 | 0.28 | System shall have reliable detection hardware. | 0.3 | 0.7 | 0.21 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 8 weeks. | 0.3 | 0.5 | 0.15 | Equipment Maintenance and Support. Increase Inspection and installation. | 0.2 | 0.5 | 0.1 |
| Operational: System may fail in service resulting in ability to detect human heat. | 0.4 | 0.6 | 0.24 | AUAV Optical System shall transmit an alert and engage safe mode. | 0.3 | 0.6 | 0.18 |
| 3.2.1.29. b | A. Inability to detect human heat using IR sensor application  B. Loss of human/object tracking C. IR Software errors | Software Related Issues | Requirement not me to detect human heat. | 0.1 | 0.7 | 0.07 | Increase in testing and verification of software | 0.1 | 0.7 | 0.07 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 8 weeks. | 0.4 | 0.5 | 0.2 | Development of Software Test Plan | 0.2 | 0.5 | 0.1 |
| Operational: System may fail in service resulting inability to detect human heat. | 0.6 | 0.6 | 0.36 | Review procedures to incorporate software application failure alert and mode warnings. | 0.2 | 0.6 | 0.12 |
| 3.2.2.2 The system weight shall not exceed 4,901 pounds [2,223 kilograms]. | 3.2.2.2. a | A. Inability to flight at its capacity.  B. Inability to shift and move during tracking of objects.  C. Inability to maneuver through objects. | Hardware Related issues | Technical: AUAV weight will cause technical problems with flying, maneuvering, and track objects / humans. | 0.2 | 0.7 | 0.14 | Hardware Upgrades, weight testing, and additional operational testing of all equipment and missions. | 0.1 | 0.7 | 0.07 |
| Cost and Schedule: Potential damage to other equipment and design re-work necessary > 8 weeks. | 0.3 | 0.5 | 0.15 | Equipment Maintenance and Support. Increase Inspection and installation. | 0.2 | 0.5 | 0.1 |
| Operational: System may fail in service resulting inability to fly at its potential height and maneuver around objects/humans. | 0.3 | 0.6 | 0.18 | Testing of all equipment and mission capacity. | 0.2 | 0.6 | 0.12 |
| 3.2.2.5 The system shall have vibration and shock isolators. | 3.2.2.5.a | A. Inability to provide clear images and videos due to equipment failure. | Hardware Related issues | Technical: Spring soften vibrations causing images and videos from capturing objects/human correctly. | 0.4 | 0.5 | 0.2 | Installation inspection required prior to initial energization. Good Engineering Practices | 0.2 | 0.5 | 0.1 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 2 weeks. | 0.3 | 0.3 | 0.09 | Installation inspection required prior to initial energization. Procure / Produce robust and reliable components | 0.1 | 0.3 | 0.03 |
| Operational: AUAV unable to provide vibration and shock isolators. | 0.4 | 0.7 | 0.28 | AUAV Optical System shall transmit an alert if vibration and shock isolators are failing. | 0.2 | 0.7 | 0.14 |
| 3.2.10.3 The system shall have an optical system with environmental conditioning protection features (temperature regulators, moisture and humidity control, dust, pressure, and light shields). | 3.2.10.3. a | A. Failure of equipment B. Failure of sensors C. Failure of lighting shields | Hardware Related issues | Technical: Environmental Issues can cause equipment failure, mission to fail, and AUAV to crash. | 0.2 | 0.7 | 0.14 | Hardware Upgrades, weight testing, and additional operational testing of all equipment and missions during multiple environmental occasions. | 0.1 | 0.7 | 0.07 |
| Cost and Schedule: Potential damage to other equipment and design re-work necessary > 8 weeks. | 0.3 | 0.5 | 0.15 | Equipment Maintenance and Support. Increase Inspection and installation. | 0.2 | 0.5 | 0.1 |
| Operational: Environmental issues can cause mission failure. | 0.3 | 0.6 | 0.18 | Testing of all equipment and mission capacity. | 0.2 | 0.6 | 0.12 |

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| **Failure Mode, Effect and Criticality Analysis (FMECA)** |  |  |  |  |  | | RPN Threshold Values | |  | |  |
| System: | Autonomous Flight Control | |  |  |  | |  | RPN < 0.25 |  | |  |
| Function Block: | 8.0 |  |  |  |  | |  | 0.25 = RPN < 0.5 |  | |  |
|  |  |  |  |  |  | |  | 0.5 = RPN < 1 |  | |  |
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| Requirement | Reference Number | Potential Failure Mode | Potential Cause of Failure | Potential Effects of Failure | Before Mitigation | | | Mitigation | After Mitigation | | |
| Likelihood | Criticality | RPN | Likelihood | Criticality | RPN |
| 3.1.6.1: The system shall interface with the AUAV Master Control System that runs on the AUAV. | 3.1.6.1.a | A. Incorrect Installation  B. Defective Components | Hardware Related issues | Requirement: Slight chance of minor requirement deficiencies | 0.4 | 0.7 | 0.28 | Installation inspection required prior to initial energization.  Good Engineering Practices | 0.2 | 0.5 | 0.1 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 2 weeks. | 0.3 | 0.3 | 0.09 | Installation inspection required prior to initial energization.  Procure / Produce robust and reliable components | 0.1 | 0.3 | 0.03 |
| Operational: AUAV loses flight control mid-air. Frequency: Occasional | 0.4 | 0.9 | 0.36 | AUAV Master Control System shall transmit an alert and engage safe mode. | 0.2 | 0.6 | 0.12 |
| 3.1.6.1.b | A. Incorrect data mapping.  B. Insufficient programming time  C. Development before design. | Software coding errors | Requirement: Slight chance of minor requirement deficiencies | 0.4 | 0.7 | 0.28 | Simulation and modeling needed to understand interactions. | 0.1 | 0.5 | 0.05 |
| Cost and Schedule: Design re-work necessary > 2 weeks | 0.3 | 0.3 | 0.09 | Include in Software Test Plan. | 0.1 | 0.3 | 0.03 |
| Operational: AUAV loses flight control mid-air. Frequency: Occasionally | 0.4 | 0.9 | 0.36 | AUAV Master Control System shall transmit an alert and engage safe mode. | 0.2 | 0.6 | 0.12 |
| 3.1.6.14 The system shall receive Global Positioning System (GPS) data. | 3.1.6.14.a | A. Loss of communication | Hardware Related issues | Requirement: Should meet all requirements with little margin | 0.3 | 0.7 | 0.21 | System shall have independent air data computer for redundant position detection. | 0.1 | 0.7 | 0.07 |
| Operational: System loses heading and speed and flies across Mexico border  Frequency: Occasionally | 0.4 | 0.6 | 0.24 | AUAV Master Control System shall transmit an alert and engage safe mode. | 0.2 | 0.6 | 0.12 |
| 3.1.6.18: The system shall receive processed images for automatic target recognition. | 3.1.6.18.a | A. Corrupt image data  B. Camera out of focus  C. Failure to detect target in image  D. Insufficient image database to test against. | Software coding errors | Requirement: Slight chance of minor requirement deficiencies | 0.4 | 0.7 | 0.28 | Optical System stores images and video, Automatic Target recognition to poll for latest image.  Consider adding an image rejection counter as input to decision making processor.  Add positively detected images to training database. | 0.2 | 0.7 | 0.14 |
| Cost and Schedule: Design re-work necessary > 6 weeks | 0.5 | 0.6 | 0.3 | Software to be inspected and tested for erroneous coding. | 0.1 | 0.6 | 0.06 |
| Operational: Inability to use autonomous optical control mode  Frequency: Occasional | 0.5 | 0.7 | 0.35 | AUAV can still be flown in remote operator mode. | 0.4 | 0.7 | 0.28 |
| 3.1.6.23: The system shall provide optical sensor magnification control signaling. | 3.1.6.23.a | A. Incorrect data mapping.  B. Insufficient programming time  C. Development before design. | Software coding errors | Requirement: Should meet all requirements with little margin | 0.3 | 0.7 | 0.21 | Simulation and modelling needed to understand interactions. | 0.2 | 0.7 | 0.14 |
| Cost and Schedule: Design re-work necessary > 2 weeks | 0.6 | 0.3 | 0.18 | Development of Software Test Plan. | 0.1 | 0.3 | 0.03 |
| Operational: AUAV loses optical system control mid-air  Frequency: Occasional | 0.5 | 0.7 | 0.35 | AUAV can still be flown in remote operator mode. | 0.4 | 0.7 | 0.28 |
| 3.2.1.1: The system shall have a cold start time of a maximum of 30 seconds. | 3.2.1.1.a | A. Inability to initialize software. | Software coding errors | Requirement: Slight chance of minor requirement deficiencies | 0.4 | 0.7 | 0.28 | As-Installed software to be provided as stand alone back-up for re-installation. | 0.3 | 0.7 | 0.21 |
| Cost and Schedule: Design re-work necessary > 2 weeks | 0.3 | 0.3 | 0.09 | Software to be inspected and tested for erroneous coding. | 0.1 | 0.3 | 0.03 |
| Operational: Inability to use autonomous flight control mode  Frequency: Occasional | 0.4 | 0.9 | 0.36 | AUAV can still be flown in remote pilot mode. | 0.3 | 0.9 | 0.27 |
| 3.2.1.3: The system shall have a data transfer rate of a maximum of 150 Mbits/s. | 3.2.1.3.a | A. Incorrect Installation  B. Defective Components  C. Corrosion  D. Vibration induced failure | Hardware Related issues | Requirement: Should meet all requirements with little margin | 0.3 | 0.7 | 0.21 | Installation inspection required prior to initial energization.  Mounting to be vibration dampening. | 0.1 | 0.7 | 0.07 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary . 6 weeks. | 0.5 | 0.5 | 0.25 | Installation inspection required prior to initial energization.  Procure / Produce robust and reliable components | 0.1 | 0.7 | 0.07 |
| Operational: AUAV loses flight control mid-air.  Frequency: Remote | 0.2 | 0.7 | 0.14 | AUAV Master Control System shall transmit an alert and engage fail safe flight. | 0.1 | 0.7 | 0.07 |
| 3.2.1.3.b | A. Missed scenario  B. Insufficient programming time  C. Development before design. | Software coding errors | Requirement: Should meet all requirements with little margin | 0.3 | 0.7 | 0.21 | Simulation and modelling needed to understand interactions. | 0.1 | 0.7 | 0.07 |
| Cost and Schedule: Design re-work necessary > 4 weeks. | 0.4 | 0.5 | 0.2 | Development of Software Test Plan.  External review by Subject Matter Expert. | 0.1 | 0.5 | 0.05 |
| Operational: AUAV loses flight control mid-air.  Frequency: Remote | 0.2 | 0.7 | 0.14 | AUAV Master Control System shall transmit an alert and engage safe mode. | 0.1 | 0.7 | 0.07 |
| 3.2.1.8: The system shall be able to control the AUAV flight spatial position (latitude and longitude) with a tolerance of +/- 0.914 meters | 3.2.1.8.a | A. Incorrect Installation  B. Defective Components  C. Corrosion  D. Vibration induced failure  E. Loss of GPS signal | Hardware Related issues | Requirement: Should meet all requirements with little margin | 0.3 | 0.7 | 0.21 | Installation inspection required prior to initial energization.  Mounting to be vibration dampening.  Spatial awareness subsystem to contain control redundancy. | 0.1 | 0.5 | 0.05 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 6 weeks. | 0.5 | 0.6 | 0.3 | Installation inspection required prior to initial energization.  Procure / Produce robust and reliable components | 0.1 | 0.5 | 0.05 |
| Operational: AUAV loses flight control mid-air.  Political: AUAV crosses border into Mexico | 0.4 | 0.7 | 0.28 | AUAV Master Control System shall transmit an alert and engage safe mode. | 0.4 | 0.5 | 0.2 |
| 3.2.1.8.b | A. Missed flight scenario  B. Insufficient programming time  C. Development before design. | Software coding errors | Requirement: Should meet all requirements with little margin | 0.3 | 0.8 | 0.24 | Simulation and modelling needed to understand interactions. | 0.2 | 0.6 | 0.12 |
| Cost and Schedule: Design re-work necessary > 4 weeks. | 0.4 | 0.5 | 0.2 | Development of Software Test Plan. | 0.1 | 0.5 | 0.05 |
| Operational: AUAV loses flight control mid-air.  Political: AUAV crosses border into Mexico  Frequency: Remote | 0.2 | 0.7 | 0.14 | AUAV Master Control System shall transmit an alert and engage safe mode. | 0.2 | 0.5 | 0.1 |
| 3.2.1.9 The system shall prevent the AUAV from experiencing g-forces greater than 0.5 in the negative direction. | 3.2.1.9.a | A. Failure in spatial awareness system  B. Loss of communication  C. Failure in actuators. | Hardware Related issues | Technical: Engine damage due to loss of oil lubrication. | 0.5 | 0.7 | 0.35 | Installation inspection required prior to initial energization.  Spatial awareness subsystem to contain control redundancy. | 0.4 | 0.6 | 0.24 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 6 weeks. | 0.6 | 0.6 | 0.36 | Installation inspection required prior to initial energization.  Procure / Produce robust and reliable components | 0.3 | 0.7 | 0.21 |
| Operational: AUAV loses propulsion and crashes.  Frequency: Remote | 0.2 | 0.8 | 0.16 | AUAV Master Control System shall transmit an alert and engage safe mode. | 0.2 | 0.5 | 0.1 |
| 3.2.1.9.b | A. Missed flight scenario  B. Poor control loop tuning. | Software coding errors | Technical: Engine damage due to loss of oil lubrication. | 0.5 | 0.7 | 0.35 | Simulation and modelling needed to understand interactions. | 0.3 | 0.7 | 0.21 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 6 weeks. | 0.6 | 0.7 | 0.42 | Development of Software Test Plan. | 0.1 | 0.7 | 0.07 |
| Operational: AUAV loses propulsion and crashes.  Frequency: Remote | 0.2 | 0.8 | 0.16 | AUAV Master Control System shall transmit an alert and engage safe mode. | 0.2 | 0.6 | 0.12 |
| 3.2.2.1 The system shall contain a minimum of four (4) Terabyte of data storage. | 3.2.2.1.a | A. Electro-mechanical failures | Hardware Related issues | Technical: Requirement not met due to inability to upload mission data or download flight logs. | 0.4 | 0.8 | 0.32 | Installation inspection required prior to initial energization.  Split data storage into two standalone 2 TB units for redundancy. | 0.2 | 0.8 | 0.16 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 8 weeks. | 0.6 | 0.6 | 0.36 | Installation inspection required prior to initial energization.  Procure / Produce robust and reliable components  Avoid contamination | 0.3 | 0.8 | 0.24 |
| Operational: AUAV loses flight control mid-air.  Frequency: Occasional | 0.4 | 0.8 | 0.32 | AUAV Master Control System shall transmit an alert and engage safe mode. | 0.1 | 0.8 | 0.08 |
| 3.2.2.1.b | A. Logical data loss | Software coding errors | Requirement not met due to data corruption | 0.5 | 0.8 | 0.4 | Data upload and download training to be provided to personnel | 0.2 | 0.8 | 0.16 |
| Cost and Schedule: Design re-work necessary > 8 weeks. | 0.6 | 0.6 | 0.36 | Development of Software Quality Plan | 0 | 0 | 0 |
| Operational: AUAV loses flight control mid-air.  Frequency: Occasional | 0.4 | 0.8 | 0.32 | AUAV Master Control System shall transmit an alert and engage safe mode. | 0.4 | 0.6 | 0.24 |
| 3.2.5.1 The system shall not result in down time of more than 5 hours due to regular system maintenance. | 3.2.5.1.a | A. Data storage system failure | Hardware Related issues | Requirement not met.  Mission cannot be executed with current AUAV. | 0.4 | 0.7 | 0.28 | Split data storage into two standalone 2 TB units for redundancy. | 0.2 | 0.7 | 0.14 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary < 8 weeks. | 0.5 | 0.5 | 0.25 | Installation inspection required prior to initial energization.  Procure / Produce robust and reliable components | 0.4 | 0.5 | 0.2 |
| Operational: AUAV cannot be put in service when scheduled.  Frequency: Occasion | 0.4 | 0.8 | 0.32 | Spare AUAVs available. | 0.4 | 0.6 | 0.24 |
| 3.2.5.2 The system shall require complete system inspection after every 1000 hours of flight time. | 3.2.5.2.a | A. Unidentified component damage | Behavioral - failure to maintain inspection plan | Requirement not met. Significant safety issue. | 0.5 | 0.7 | 0.35 | Consider adding service clock to system interlocked to autonomous flight control permission. | 0.2 | 0.7 | 0.14 |
| Cost and Schedule: Potential damage to equipment. | 0.4 | 0.7 | 0.28 | Procure / Produce robust and reliable components | 0.1 | 0.7 | 0.07 |
| Operational: System may fail in service resulting in crash.  Frequency: Occasional | 0.4 | 0.7 | 0.28 | Enforce maintenance schedules. | 0.2 | 0.7 | 0.14 |
| 3.2.5.3 The system shall have the ability to self check and perform software updates 5 hour prior to operation time. | 3.2.5.3.a | A. Data storage system failure  B. Built-in-Test function failure | Hardware Related issues | Requirement not met due to inability to get latest software. | 0.4 | 0.8 | 0.32 | Split data storage into two standalone 2 TB units for redundancy. | 0.2 | 0.8 | 0.16 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 8 weeks. | 0.6 | 0.6 | 0.36 | Procure / Produce robust and reliable components | 0.3 | 0.6 | 0.18 |
| Operational: System may fail in service resulting in crash.  Frequency: Occasional | 0.4 | 0.7 | 0.28 | Enforce maintenance schedules. | 0.1 | 0.7 | 0.07 |
| 3.2.11.1 The system shall not present any safety hazards to maintenance personnel. | 3.2.11.1.a | A. Stored energy (shocks)  B. Pinch points (scraps) | Hardware Related issues | Requirement not met due to design failures in layout. | 0.5 | 0.6 | 0.3 | System needs to a electrically grounded.  Safety labels are needed to be affixed to enclosures | 0.2 | 0.6 | 0.12 |
| Cost and Schedule: Potential design re-work necessary > 2 weeks. | 0.3 | 0.3 | 0.09 | Good Engineering Practices | 0.2 | 0.3 | 0.06 |
| Operational: Potential injury to AUAV Maintenance Technician  Frequency: Probable | 0.6 | 0.7 | 0.42 | Maintenance procedures to be developed. | 0.3 | 0.7 | 0.21 |
| 3.2.11.2 The system shall not present safety hazards to the user during operation under either autonomous and non-autonomous flight modes. | 3.2.11.2.a | A. Collision avoidance system failure | Hardware Related issues | Requirement not met due to damage to equipment. | 0.7 | 0.8 | 0.56 | Installation inspection required prior to initial energization.  Consider collision avoidance system redundancy. | 0.4 | 0.8 | 0.32 |
| Cost and Schedule: Potential damage to equipment and design re-work necessary > 6 weeks. | 0.7 | 0.5 | 0.35 | Installation inspection required prior to initial energization.  Procure / Produce robust and reliable components | 0.4 | 0.5 | 0.2 |
| Operational and Political: AUAV collides with object  Frequency: Occasional | 0.4 | 0.8 | 0.32 | AUAV Master Control System shall transmit an alert and engage safe mode. | 0.3 | 0.8 | 0.24 |
| 3.2.11.2.b | A. AUAV movement when switching between modes. | Software coding errors | Requirement not met due to injury of worker | 0.7 | 0.8 | 0.56 | Consider interlocking GPS signal with Speed control signal to ensure propulsion is not available prior to AUAV receiving mission green light. | 0.3 | 0.8 | 0.24 |
| Cost and Schedule: Design re-work necessary > 8 weeks. | 0.6 | 0.6 | 0.36 | Development of Software Test Plan | 0.1 | 0.6 | 0.06 |
| Operational: AUAV injures AUAV Maintenance Technician  Frequency: Occasional | 0.4 | 0.8 | 0.32 | Review start-up and shutdown procedures to incorporate added features. | 0.2 | 0.8 | 0.16 |
| 3.2.11.3 The system shall maintain constant transponder communication visible to all aircraft and Air Traffic Control to maintain air traffic safety. | 3.2.11.3.a | A. Electromagnetic radiation | Hardware Related issues | Requirement: Should meet all requirements with little margin | 0.3 | 0.9 | 0.27 | Good Engineering Practices on electrical shielding | 0.2 | 0.9 | 0.18 |
| Cost and Schedule: Potential need for new equipment and design re-work necessary > 8 weeks. | 0.6 | 0.9 | 0.54 | Procure / Produce components with low EM radiation levels. | 0.4 | 0.9 | 0.36 |
| Operational and Political: AUAV falls out of regulatory compliance  Frequency: Remote | 0.3 | 0.9 | 0.27 | Pre-light checks should confirm transponder operation. | 0.2 | 0.9 | 0.18 |
| 3.2.11.3.b | A. Transponder signal not activated | Software coding errors | Requirement: Should meet all requirements with little margin | 0.3 | 0.9 | 0.27 | Consider interlocking the transponder signal with Speed control signal to ensure propulsion is not available if transponder is not active. | 0.1 | 0.9 | 0.09 |
| Cost and Schedule: Design re-work necessary > 2 weeks. | 0.3 | 0.3 | 0.09 | Development of Software Test Plan | 0.1 | 0.3 | 0.03 |
| Operational and Political: AUAV falls out of regulatory compliance  Frequency: Remote | 0.3 | 0.9 | 0.27 | Pre-light checks should confirm transponder operation. | 0.2 | 0.9 | 0.18 |
| 3.2.4.1 The system shall have an Instantaneous Reliability of at least 70%. | 3.2.4.1.a | A. Design Issue of Hardware | Hardware Related issues | Technical issues of hardware. | 0.7 | 0.8 | 0.56 | Reliability Analysis of Hardware | 0.4 | 0.8 | 0.32 |
| Cost and Schedule: Potential damaged equipment and design re-work necessary > 6 weeks. | 0.7 | 0.5 | 0.35 | Installation inspection required prior to initial energization.  Procure / Produce robust and reliable components | 0.4 | 0.5 | 0.2 |
| Operational impact of the mission. | 0.4 | 0.8 | 0.32 | AUAV Master Control System shall transmit an alert and engage safe mode. | 0.3 | 0.8 | 0.24 |
| 3.2.4.1.b | A. Software Deign Issues  B. Software installation Issues  C. Software code Issues | Software coding errors | Requirement not met due to reliability issues and errors. | 0.7 | 0.8 | 0.56 | Consider Reliability Analysis on software and mission expectation. | 0.3 | 0.8 | 0.24 |
| Cost and Schedule: Design re-work necessary > 8 weeks. | 0.6 | 0.6 | 0.36 | Development of Software Test Plan | 0.1 | 0.6 | 0.06 |
| Operational: Mission failure and unreliable data / videos. | 0.4 | 0.8 | 0.32 | Review start-up and shutdown, other mission procedures to incorporate added features. | 0.2 | 0.8 | 0.16 |

# NOTES

## Acronyms and Abbreviations

Table 27 lists the acronyms and abbreviations used in this document and their definitions.

Table 27: Acronyms and Abbreviations

|  |  |
| --- | --- |
| **Acronym/Abbreviation** | **Definition** |
| ADRU | Air Defense Radar Unit |
| AHP | Analytical Hierarchy Process |
| AI | Artificial Intelligence |
| AIAA | American Institute of Aeronautics and Astronautics |
| AIS | Automatic Integrated Swarm |
| AoA | Angle of Attack |
| ATC | Atmospheric Turbulence Compensating |
| ATF | Bureau of Alcohol, Tobacco, Firearms |
| ATR | Automatic Target Recognition |
| AUAV | Autonomous Unmanned Aerial Vehicle |
| BTS | Bit Test & Set |
| CIA | Central Intelligence Agency |
| CONOPS | Concept of Operations |
| COTS | Commercial Off the Shelf |
| DEA | Drug Enforcement Administration |
| DIA | Defense Intelligence Agency |
| ESS | Environmental Screening |
| EW | Electronic Warfare |
| FAA | Federal Aviation Administration |
| FBI | Federal Bureau of Investigation |
| FCC | Federal Communications Commission |
| FIT | Futuristic Innovative Technologies |
| FMECA | Failure Mode, Effect, and Critically Analysis |
| FWRM | Factor Weighted Row Mean |
| GPS | Global Positioning System |
| GPPP | General Purpose Parallel Processing |
| IMU | Inertial Measurement Unit |
| IFoV | Instantaneous Field of View |
| IR | Infrared Radiation |
| MATLAB | Matrix Laboratory |
| MCC | Mobile Command Center |
| MTBF | Mean Time Between Failure |
| MTTR | Mean Time to Repair |
| OoI | Object of Interest |
| OSS | Office of Strategic Services |
| PDR | Preliminary Design Review |
| PDU | Power Distribution Unit |
| QFD | Quality Functional Deployment |
| RPN | Risk Priority Number |
| SLR | System Level Requirement |
| SME | Subject Matter Expert |
| SOI | Signal of Interest |
| TOI | Target of Interest |
| UAS | Unmanned Aerial System |
| UAV | Unmanned Aerial Vehicle |

## Project Terminologies

Table 27 lists the project terminologies used in this document and their definitions.

Table 27: Project Terminologies

|  |  |
| --- | --- |
| **Project Terminology** | **Definition** |
| AIAA Standards | Engineering and technical requirements and the inclusion of provisions necessary to verify compliance |
| Airworthiness | Measure of aircraft’s suitability for safe flight |
| Atmosphere Turbulence | Small-scale, irregular air motions characterized by winds that vary in speed and direction |
| Automatic | A system will do exactly as programmed; it has no choice |
| Autonomous | A system has a choice to make free of outside influence |
| Commercial Off The Shelf | Software and hardware that already exist and is available from commercial sources |
| dB | Decibel; measure unit of Sound |
| Electromagnetic Interference | Interference caused by one electrical or electric device to another by electromagnetic fields set up by its operation |
| Electromagnetic Radiation | Electric and magnetic disturbance traveling through space at the speed of light |
| Inertial Measurement Unit | A self-contained system that measure linear and angular motion usually with a triad of gyroscope and triad of accelerometers |
| MATLAB | An interactive programming environment for scientific computing |
| Mean Time Between Failure | Prediction of the time between the inmate failures of a piece of machinery during normal operating hours |
| Mean Time in Between Repair | The average time it takes to repair a system. It includes any repair and testing time |
| Net Asset Value | Value of an entity’s assets minus the value of its liabilities, often in relation to open-end fund |
| Operational Availability | Measurement of the average availability over a period of time includes all experienced sources of downtime |
| Risk Priority Number | Measurement used when assessing risk to help, identify critical failure modes associated with design or process |
| Spatial Resolution | Measurement of the smallest object that can resolved by the sensor, or on the ground area image for the instantaneous field of view or the sensor |
| Subject Matter Expert | Individual or company has a deep understanding of a particular topic and can help improve products, solve problem, or meet technical challenges |
| Unmanned Aerial System | System whose components include the necessary equipment, networks, and personnel to control an unmanned aircraft |
| Unmanned Aerial Vehicle | Vehicle that does not carry a human operator and is capable of flight under remote control or autonomous programming |
| (W/sr) | Watt per Steradian, SI unit of radiant intensity |
| (W/m2) | Watt per Square Meter, SI unit of irradiant intensity |

### 15.3 Requirements Justifications

The purpose of this appendix is to provide further information about some of the requirements to provide the designer the proper background and perspective to understand the respective requirement. This includes reasoning and thought-process used while considering certain requirements. Additionally, any sources consulted will be provided here for additional insight.

S.R. 01 The AUAV system shall interface with the existing AUAV mission control center to provide the best possible imaging technology and data processing for detection, identification, and tracking capabilities.

Justification: Current imaging technology likely has insufficient capability (e.g., data processing, image quality, etc.).

S.R. 02 The Sky Net program shall meet or exceed mission detection, identification, and tracking requirements as specified in Table 3 Permutation of Stakeholder Requirements.

Justification: To meet the mission requirements on worldwide scientific data collection and data collection, the AUAV must be able to collect images and video and other critical data from these distances away.

S.R. 03 The AUAV shall conduct its operations in a safe manner.

Justification: The AUAV must include safety features to avoid damage and harm to allies, US (and world) civilians, and operators, and prevent infrastructure damage, damage to AUAVs, aircraft and collateral damage. It is important to note that these events result in monetary cost, political backlash, and potential acts of war.

S.R. 04 The AUAV shall have a flexible control scheme through either a remote mission control center, mobile command center, or A.I. based decision-making system; with the ability to exchange authority over the AUAV between all control methods.

Justification: The AI system adds a new element that many operators are likely not familiar with. The AUAV will be able to operate independently, as a SWARM with sensors to avoid crashing into other AUAVS and communicating role and targeted data collection, as well as remote operation by a biped operator in a local mobile control center and central mission control center.

S.R. 05 The AUAV shall be adaptable for other features/capabilities/sensor package/upgrade including a natural language, AI-based decision-making/mission reconfiguration.

Justification: Three-letter agency anticipates the future need of these systems and AUAV must be modular to support upgrades. The AI is a critical new feature that must be compatible with existing infrastructures and systems.

S.R. 06 The AUAV should utilize commercial off the shelf products (COTS) where possible to reduce risk and cost.

Justification: In general, it makes sense to not waste allocated funding on development projects that already exist and meet the needs of the mission and scope. These have their own parameters for interfaces and mounting equipment.

S.R. 07 The AUAV shall be capable of supporting 24/7 operations worldwide.

Justification: Some scientific data needs to be collected at night when streets are emptier, there is less visible light, for when observations of nature with minimal biped presence are required, and some processes take more or less time of one parameter at day versus night.

S.R. 08 The AUAV should be supported and maintained throughout the program’s lifecycle over 25 years after delivery with pre-planned program improvements.

Justification: The AUAV will be planned to be in use for a long time due to the scale and cost of development. System retirement and disposal must be accounted for, as well as maintaining an inventory of spare sparts for as long as possible until storage is no longer a viable option to keep the AUAVs running as long as possible.

S.R. 09 The AUAV shall have an operational availability of at least 98%.

Justification: To make the most use of the AUAV’s features, the AUAV should be able to run and operate at any time except during times of maintenance and service to escape threats, collect data when an unexplained or unexpected situation occurs, and potentially protect human lives or the supply of AUAVs.

S.R. 10 The AUAV shall have an instantaneous reliability of at least 70%.

Justification: To make the most use of the AUAV’s features based on the invested cost and meet the requirements of allies, partners, and other collaborative obligations, the AUAV should be able to run and operate at any time.

S.R. 11 The AUAV Optical System shall have a Mean time between failures (MTBF) of 20 years.

Justification: A lesser MTBF will increase frustrations and influence public and general opinion against the AUAV design. As a result, allies and partners etc. May turn to another party to meet their needs and requirements.

S.R. 12 The AUAV shall have a Mean time to repair (MTTR) of less than 8 hours.

Justification: This encourages efficient and speedy repair time for maintenance technicians, as well as improves the likelihood that only one full shift of workers will be able to finish repairs while avoiding issues of errors from improper documentation or interruption in work flow.

S.R. 13 The AUAV shall be capable of performing solo missions with the aid of the onboard AI system.

Justification: The AI reduces required time that operators must spend each time to prioritize other activities.

S.R. 14 The AUAV shall be capable of flying as a part of an integrated swarm of AUAVs with adaptive, AI-based decision-making/mission reconfiguration.

Justification: The SWARM feature helps make sure that the AUAVs to avoid crashing into each other and all taking on the same mission or decision.

S.R. 15 The integrated swarm of AUAVs shall be able to cooperatively intercept and geolocate Objects of Interest (OoI).

Justification: When provided a target, error in approach and cooperation results in the failure of target tracking and potentially results in political backlash from allies and partners etc., if the collaborative needs and requirements by treaties or otherwise cannot be met.

S.R. 16 The AUAV shall be capable of sending critical information to the Mission Command Center in less than 5 seconds.

Justification: In critical or unstable situations, critical data can prevent a conflict or provide additional information that influences decision making in real-time events.

S.R. 17 The mobile command center should have a consistent and reliable power source that meets the AUAV operator’s needs.

Justification: The power source must be consistent and provide proper facilities for the personnel that work there. This includes proper connectivity to the AUAV for nearly instantaneous data monitoring and ability to take over if the drone perceives an unknown threat or the AI system glitches out.

S.R. 18 The system shall be able to operate in harsh and extreme environments.

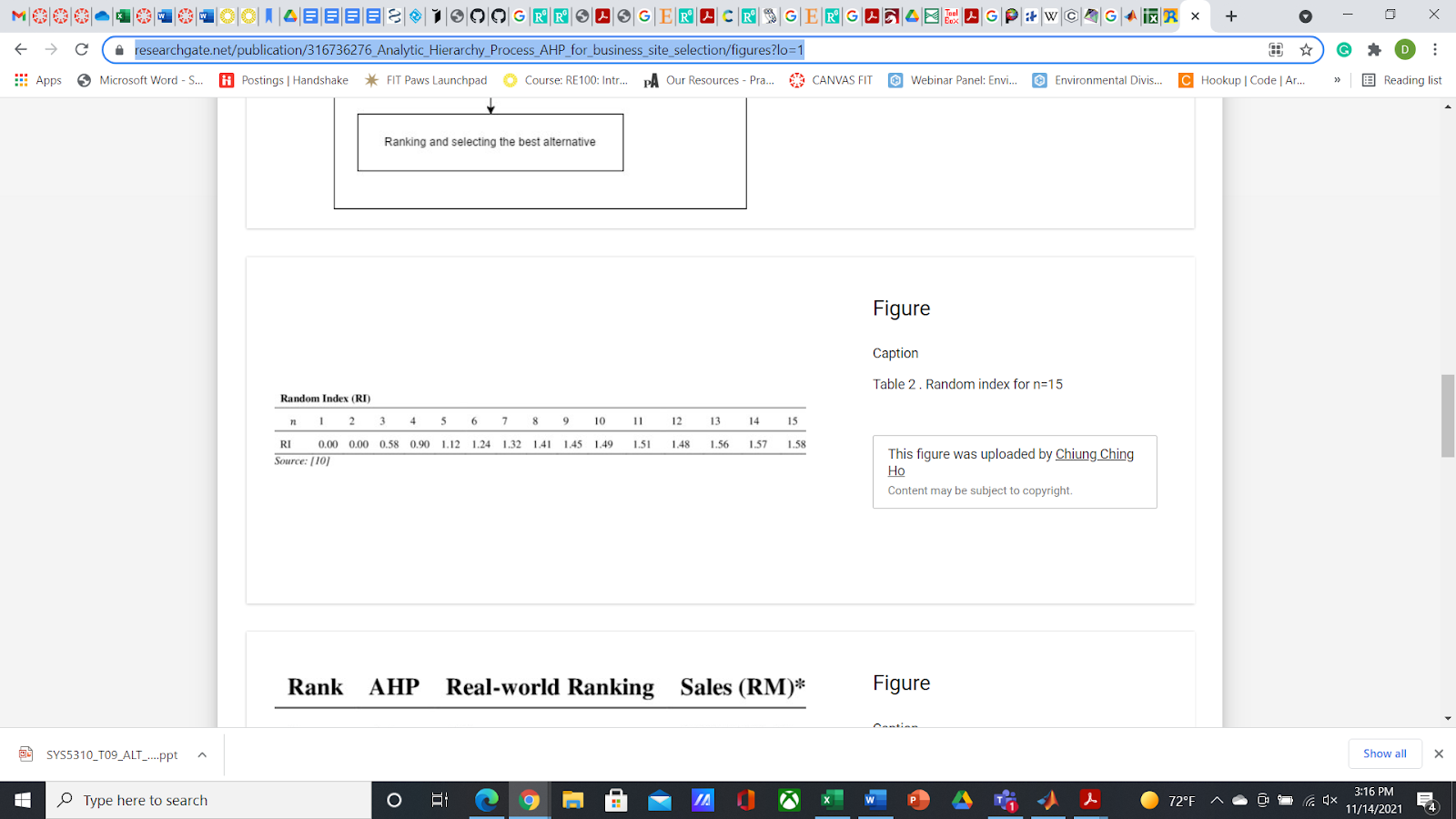
Justification: The AUAV is intended to be US and worldwide deployable in remote areas, which climates could range from deserts to blizzards and wetlands and waterways. This requires environmental controls such as onboard heaters and coolers and pressure regulators. Unforeseen weather events and other natural causes including wildlife may pose a risk to the AUAV mission and 24/7 operational requirement with limited downtime.

S.R. 19 The AUAV system must look like a benign Search and Rescue AUAV.

Justification: This was specified as a want by the Stakeholder and is critical for blending in to the background for scientific and tactical data collection and reducing the impact on wildlife and the environment. This can be achieved by paint color and markings, for instance a gray color. This is especially important as there are international partners and allies that require recognizing the AUAV and marking its radar signature as “friendly” and due to political reasons avoiding unwanted attention from non-allies through neutrality is critical.

AHP Additional Information

The ACI ranges provided were only for number of criteria ranging from 1 to 4. A source was found to get the ACI number for 6 criteria as used in the trade study. Source citation and index is presented before.



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| Yap, Jeremy, et al. *Analytic Hierarchy Process (AHP) for Business Site Selection*. *AIP Conference Proceedings*, vol. 2016, 5 May 2017. |