HALE Collision Avoidance Functional Requirements Report

# Purpose

The purpose of this functional requirements report is to document the requirements that the HALE (High-Altitude Long-Endurance) collision avoidance system must fulfill to ensure safe and efficient operations within the National Airspace System (NAS). This report serves as a reference for stakeholders, developers, and certification authorities, providing a comprehensive understanding of the necessary capabilities and functionalities of the collision avoidance system.  
  
The collision avoidance system is a critical component of the HALE project, which aims to enable unrestricted access to the NAS for high-altitude, long-endurance unmanned aircraft systems (UAS). The project encompasses various aspects, including technology development, policy and procedure formulation, implementation planning, and simulation and flight testing [1].  
  
Collision avoidance is a fundamental requirement for operating UAS in the NAS, as it ensures the prevention of mid-air collisions with other aircraft. The collision avoidance system must detect and track both cooperative (with transponders) and non-cooperative aircraft within a specified surveillance volume. It must evaluate the collision potential, prioritize threats, determine appropriate avoidance maneuvers, and command their execution while minimizing deviations from the planned flight path [2].  
  
The development of these functional requirements considers the HALE UAS operating in the NAS, adhering to applicable regulations and procedures. The assumptions include the availability of cooperative traffic information, the ability to detect and track non-cooperative targets, and the integration with air traffic control (ATC) systems for coordination and information exchange [3].  
  
The requirements in this report are organized into several categories, including surveillance, collision prediction, avoidance maneuver determination, execution and monitoring, contingency management, and integration with NAS systems. The gathered information, including technical documents, regulations, and industry standards, has been analyzed to derive these requirements [4-7].  
  
The stakeholder requirements presented in Table 1 should be used as a reference throughout the development, testing, and certification processes of the HALE collision avoidance system. They ensure that the system meets the necessary safety, performance, and operational standards for integration into the NAS.  
  
In conclusion, this functional requirements report establishes a comprehensive set of requirements that the HALE collision avoidance system must fulfill to enable safe and efficient operations within the NAS, while complying with applicable regulations and standards.  
  
References:  
[1] ThunderGraph/HALE/Hale Concept of Operations.pdf  
[2] ThunderGraph/HALE/comms.pdf  
[3] ThunderGraph/HALE/Human System Integration Reqs.pdf  
[4] ThunderGraph/HALE/Human factors design guide.pdf  
[5] 14 CFR 91.215 (up to date as of 3-07-2024).pdf  
[6] 14 CFR 91.123 (up to date as of 3-07-2024).pdf  
[7] 14 CFR 91.155 (up to date as of 3-07-2024).pdf

# Background

The NASA HALE (High-Altitude Long-Endurance) project aims to develop technologies, policies, and procedures that enable routine operations of unmanned aircraft systems (UAS) at high altitudes (above 40,000 feet) within the National Airspace System (NAS) [8]. The project encompasses various aspects, including airworthiness certification, flight operations, pilot certification, and the development of appropriate standards.  
  
One of the critical components of the HALE project is the collision avoidance system, which is essential for ensuring the safe integration of HALE UAS into the NAS by preventing mid-air collisions with other aircraft. Collision avoidance involves detecting and tracking both cooperative (with transponders) and non-cooperative aircraft within a specified surveillance volume, evaluating collision potential, determining appropriate avoidance maneuvers, and commanding their execution while minimizing deviations from the planned flight path.  
  
The functional requirements for the HALE collision avoidance system are derived from an analysis of relevant technical documents, regulations, and industry standards [5-7, 9-10]. These requirements encompass various aspects, such as surveillance, collision prediction, avoidance maneuver determination, execution and monitoring, contingency management, and integration with NAS systems.  
  
The development of the functional requirements considers the HALE UAS operating within the NAS, adhering to applicable regulations and procedures. Key assumptions include the availability of cooperative traffic information, the ability to detect and track non-cooperative targets, and the integration with air traffic control (ATC) systems for coordination and information exchange [3, 11].  
  
The stakeholder requirements presented in Table 1 of the functional requirements report establish a comprehensive set of requirements that the HALE collision avoidance system must fulfill to enable safe and efficient operations within the NAS while complying with applicable regulations and standards. These requirements serve as a reference for stakeholders, developers, and certification authorities throughout the development, testing, and certification processes.  
  
References:  
[8] ThunderGraph/HALE/Hale Concept of Operations.pdf  
[9] ThunderGraph/HALE/Mission Planning Req Doc.pdf  
[10] ThunderGraph/HALE/20080017109.pdf  
[11] ThunderGraph/HALE/comms.pdf

Collision avoidance is a critical aspect of ensuring the safe integration of HALE (High-Altitude Long-Endurance) unmanned aircraft systems (UAS) into the National Airspace System (NAS). It involves detecting and tracking both cooperative (with transponders) and non-cooperative aircraft within a specified surveillance volume, evaluating collision potential, determining appropriate avoidance maneuvers, and commanding their execution while minimizing deviations from the planned flight path.  
  
The concept of collision avoidance is based on the fundamental requirement for pilots to "see and avoid" other aircraft, as outlined in Title 14 of the Code of Federal Regulations (14 CFR) Part 91, Section 91.113 [5]. However, without a human pilot onboard, UAS require alternative means to comply with this requirement, necessitating the development of a collision avoidance system.  
  
The collision avoidance system facilitates the "detect, see, and avoid" functions traditionally performed by pilots. It involves scanning the surrounding airspace, tracking detected aircraft, identifying potential collision threats, determining appropriate avoidance maneuvers, initiating those maneuvers, and assessing their effectiveness [10]. This process is crucial for maintaining safe separation and preventing mid-air collisions.  
  
The key assumptions made in developing the functional requirements for the HALE collision avoidance system include:  
  
1. Availability of cooperative traffic information, such as transponder data, from air traffic control (ATC) systems [3, 11].  
2. Ability to detect and track non-cooperative aircraft through onboard sensors, such as radar or electro-optical systems [10].  
3. Integration with ATC systems for coordination, obtaining clearances, and exchanging flight plan information [3, 11].  
4. Adherence to applicable regulations, procedures, and airspace constraints within the NAS [5-7].  
  
The functional requirements for the HALE collision avoidance system are derived from an analysis of relevant technical documents, regulations, and industry standards [5-7, 9-10]. These requirements cover various aspects, including surveillance, collision prediction, avoidance maneuver determination, execution and monitoring, contingency management, and integration with NAS systems. The broad requirement categories and their sources are briefly described, with Table 1 in the functional requirements report presenting the comprehensive set of stakeholder requirements.  
  
The stakeholder requirements established in the functional requirements report serve as a reference for developers, certification authorities, and other stakeholders throughout the development, testing, and certification processes. They ensure that the HALE collision avoidance system meets the necessary safety, performance, and operational standards for integration into the NAS.  
  
References:  
[5] 14 CFR 91.215 (up to date as of 3-07-2024).pdf  
[6] 14 CFR 91.123 (up to date as of 3-07-2024).pdf  
[7] 14 CFR 91.155 (up to date as of 3-07-2024).pdf  
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[11] ThunderGraph/HALE/comms.pdf

In developing the functional requirements for HALE's collision avoidance system, several key assumptions were made regarding the operating environment. These assumptions were crucial in narrowing the scope and defining finite requirements for the system.  
  
First, it was assumed that cooperative traffic information, such as transponder data, would be available from air traffic control (ATC) systems [3, 11]. This information is essential for detecting and tracking aircraft equipped with transponders or other cooperative systems.  
  
Second, the system must be capable of detecting and tracking non-cooperative aircraft through onboard sensors, such as radar or electro-optical systems [10]. This capability is necessary to address aircraft without transponders or other cooperative systems.  
  
Third, the collision avoidance system is expected to integrate with ATC systems for coordination, obtaining clearances, and exchanging flight plan information [3, 11]. This integration ensures safe and efficient operations within the National Airspace System (NAS) and compliance with applicable regulations and procedures.  
  
Finally, the system must adhere to relevant regulations, procedures, and airspace constraints within the NAS [5-7]. Compliance with these requirements is essential for maintaining safety and legal operations.  
  
The functional requirements were developed based on an analysis of technical documents [9-10], regulations [5-7], and industry standards. The broad requirement categories cover various aspects, including surveillance, collision prediction, avoidance maneuver determination, execution and monitoring, contingency management, and integration with NAS systems. Table 1 in the functional requirements report presents the comprehensive set of stakeholder requirements derived from this analysis.  
  
These requirements serve as a reference for developers, certification authorities, and other stakeholders throughout the development, testing, and certification processes. They ensure that the HALE collision avoidance system meets the necessary safety, performance, and operational standards for integration into the NAS.  
  
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[3] ThunderGraph/HALE/comms.pdf  
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# Requirements

The functional requirements for the HALE collision avoidance system are derived from an analysis of various sources, including technical documents, regulations, and industry standards. The broad requirement categories encompass surveillance, collision prediction, avoidance maneuver determination, execution and monitoring, contingency management, and integration with National Airspace System (NAS) systems.  
  
The surveillance requirements address the detection and tracking of both cooperative (with transponders) and non-cooperative aircraft within a specified surveillance volume. This information is essential for evaluating collision potential and determining appropriate avoidance maneuvers.  
  
Collision prediction requirements ensure that the system can accurately identify potential collision threats based on the trajectories, speeds, and closure rates of detected aircraft. The system must prioritize these threats based on factors such as proximity and time to closest approach.  
  
Avoidance maneuver determination requirements focus on the system's ability to calculate and recommend appropriate avoidance maneuvers that maintain safe separation while minimizing deviations from the planned flight path. These maneuvers must consider the ownship's performance characteristics, operational constraints, and established rules and procedures.  
  
Execution and monitoring requirements cover the system's capability to command and execute the determined avoidance maneuvers with sufficient lead time, as well as continuously monitor their effectiveness and initiate corrective actions if necessary.  
  
Contingency management requirements address situations where the initial avoidance maneuver is inadequate or cannot be executed, necessitating contingency plans, autonomous responses, and the ability to recover aircraft control in the event of system failures or lost communication links.  
  
Integration with NAS systems requirements ensure that the collision avoidance system can coordinate with Air Traffic Control (ATC) systems, obtain and share flight plan information, comply with airspace constraints, and adhere to applicable airworthiness and flight operations standards.  
  
The stakeholder requirements presented in Table 1 of the functional requirements report provide a comprehensive set of requirements derived from the analysis of these sources. These requirements serve as a reference for developers, certification authorities, and other stakeholders throughout the development, testing, and certification processes, ensuring that the HALE collision avoidance system meets the necessary safety, performance, and operational standards for integration into the NAS.  
  
References:  
[12] ThunderGraph/HALE/comms.pdf  
[13] ThunderGraph/HALE/Human System Integration Reqs.pdf  
[14] ThunderGraph/HALE/Human factors design guide.pdf  
[15] 14 CFR 91.215 (up to date as of 3-07-2024).pdf  
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Table 1. Stakeholder Requirements

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| --- | --- | --- | --- | --- |
| Name | Description | Basis | Acceptance Criteria | Status |
| DETECT\_COOPERATIVE\_AIRCRAFT | The collision avoidance system shall detect all cooperative aircraft within the surveillance volume. | Detecting cooperative aircraft is a key requirement for maintaining situational awareness and avoiding collisions in the National Airspace System. | Perform simulations or flight tests with cooperative aircraft targets at varying distances, altitudes, and trajectories within the defined surveillance volume. The system shall consistently detect and track all cooperative targets. | preliminary |
| DETECT\_NON\_COOPERATIVE\_AIRCRAFT | The collision avoidance system shall detect all non-cooperative aircraft within the surveillance volume. | Detecting non-cooperative aircraft is crucial for avoiding collisions with aircraft that do not have transponders or other cooperative systems. | Perform simulations or flight tests with non-cooperative aircraft targets at varying distances, altitudes, and trajectories within the defined surveillance volume. The system shall consistently detect and track all non-cooperative targets. | preliminary |
| SURVEILLANCE\_VOLUME\_COVERAGE | The collision avoidance system shall provide a surveillance volume that covers a minimum horizontal range of 5 nautical miles and a vertical range of +/- 3,000 feet from the ownship's altitude. | The specified surveillance volume is necessary to provide sufficient time and distance for detecting and avoiding potential collisions. | Conduct simulations or flight tests to verify that the system can consistently detect and track targets within the specified horizontal and vertical ranges. | preliminary |
| TRACK\_DETECTED\_AIRCRAFT | The collision avoidance system shall continuously track and update the position, altitude, and trajectory of all detected aircraft within the surveillance volume. | Accurate tracking of detected aircraft is essential for evaluating collision potential and determining appropriate avoidance maneuvers. | Perform simulations or flight tests with multiple aircraft targets moving at varying speeds and trajectories within the surveillance volume. The system shall accurately track and update the position, altitude, and trajectory of all targets. | preliminary |
| EVALUATE\_COLLISION\_POTENTIAL | The collision avoidance system shall evaluate the collision potential for all detected and tracked aircraft within the surveillance volume. | Evaluating collision potential is necessary to identify potential threats and initiate appropriate avoidance actions. | Conduct simulations or flight tests with various collision scenarios involving cooperative and non-cooperative aircraft targets. The system shall accurately identify and prioritize collision threats based on the calculated collision potential. | preliminary |
| PRIORITIZE\_COLLISION\_THREATS | The collision avoidance system shall prioritize collision threats based on the evaluated collision potential, proximity, and time to closest approach. | Prioritizing collision threats is necessary to determine the most critical threats and allocate resources for avoidance maneuvers. | Simulate scenarios with multiple potential collision threats at varying distances, trajectories, and closure rates. The system shall consistently prioritize threats based on collision potential, proximity, and time to closest approach. | preliminary |
| DETERMINE\_AVOIDANCE\_MANEUVER | The collision avoidance system shall determine appropriate avoidance maneuvers for prioritized collision threats to maintain a safe separation distance. | Determining suitable avoidance maneuvers is crucial to avoid collisions while minimizing deviations from the planned flight path. | Simulate various collision scenarios with prioritized threats. The system shall calculate and recommend avoidance maneuvers that maintain a safe separation distance while adhering to operational constraints and minimizing deviations. | preliminary |
| COMMAND\_AVOIDANCE\_MANEUVER | The collision avoidance system shall command the determined avoidance maneuver to the aircraft flight control system with sufficient lead time for execution. | Commanding the avoidance maneuver to the flight control system is necessary for executing the maneuver and avoiding collisions. | Simulate collision scenarios and verify that the system commands the appropriate avoidance maneuver to the flight control system with adequate lead time for execution based on the aircraft's performance characteristics. | preliminary |
| EXECUTE\_AVOIDANCE\_MANEUVER | The aircraft flight control system shall execute the commanded avoidance maneuver within the specified time and performance constraints. | Executing the avoidance maneuver as commanded is crucial for maintaining safe separation and avoiding collisions. | Conduct simulations or flight tests with commanded avoidance maneuvers. The aircraft flight control system shall execute the maneuvers within the specified time and performance constraints, maintaining a safe separation distance from the collision threat. | preliminary |
| ASSESS\_MANEUVER\_ADEQUACY | The collision avoidance system shall assess the adequacy of the executed avoidance maneuver and determine if further actions are required to maintain safe separation. | Assessing the adequacy of the executed maneuver is necessary to ensure that safe separation is maintained and to initiate additional actions if required. | After executing avoidance maneuvers in simulated collision scenarios, the system shall assess the resulting separation distance and trajectory. If safe separation is not maintained, the system shall initiate additional actions or maneuvers as required. | preliminary |
| IDENTIFY\_COLLISION\_POTENTIAL | The collision avoidance system shall identify the collision potential for each detected and tracked aircraft within the surveillance volume based on their trajectories, speeds, and closure rates. | Identifying the collision potential is a crucial step in determining which aircraft pose a threat and require avoidance maneuvers. | Conduct simulations with various aircraft trajectories, speeds, and closure rates within the surveillance volume. The system shall accurately identify the collision potential for each aircraft based on their relative motion and proximity. | preliminary |
| COORDINATE\_WITH\_ATC | The collision avoidance system shall coordinate with Air Traffic Control (ATC) to obtain and share flight plan information, clearances, and any deviations from planned trajectories. | Coordination with ATC is necessary to ensure safe and efficient operations within the National Airspace System, and to comply with applicable regulations and procedures. | Perform simulations or flight tests involving ATC coordination for various scenarios, including flight plan sharing, obtaining clearances, and communicating deviations from planned trajectories. Verify that the system correctly exchanges information with ATC and adheres to the provided instructions and clearances. | preliminary |
| MAINTAIN\_SAFE\_SEPARATION | The collision avoidance system shall maintain a minimum safe separation distance from all aircraft within the surveillance volume, in accordance with established separation standards and procedures. | Maintaining safe separation is the primary objective of the collision avoidance system to prevent mid-air collisions and ensure the safety of flight operations. | Simulate various scenarios with multiple aircraft within the surveillance volume, approaching or crossing at various angles, speeds, and altitudes. The system shall consistently execute avoidance maneuvers that maintain the minimum safe separation distance from all aircraft, as specified by established standards and procedures. | preliminary |
| PREDICT\_COLLISION\_TRAJECTORY | The collision avoidance system shall predict the future trajectory of detected aircraft to evaluate potential collisions. | Predicting the future trajectory of aircraft is necessary to anticipate potential conflicts and initiate avoidance maneuvers in a timely manner. | Conduct simulations with various aircraft trajectories, speeds, and maneuvers. The system shall accurately predict the future trajectory of each aircraft within the surveillance volume, accounting for their current position, velocity, and acceleration. | preliminary |
| CONSIDER\_OWNSHIP\_DYNAMICS | The collision avoidance system shall consider the ownship's performance characteristics, dynamics, and operational constraints when determining avoidance maneuvers. | Accounting for the ownship's limitations and constraints is crucial for ensuring that the recommended avoidance maneuvers are feasible and safe for execution. | Simulate collision scenarios with various ownship configurations and operational constraints. The system shall recommend avoidance maneuvers that are within the ownship's performance limits and comply with specified operational constraints. | preliminary |
| MINIMIZE\_FLIGHT\_PATH\_DEVIATIONS | The collision avoidance system shall minimize deviations from the planned flight path when determining avoidance maneuvers, while maintaining safe separation. | Minimizing deviations from the planned flight path is important for maintaining efficient operations, reducing fuel consumption, and minimizing disruptions to the overall air traffic management system. | Conduct simulations with various collision scenarios and planned flight paths. The system shall recommend avoidance maneuvers that maintain safe separation while minimizing deviations from the planned flight path. | preliminary |
| COMPLY\_WITH\_OPERATIONAL\_RULES | The collision avoidance system shall comply with applicable operational rules, regulations, and procedures when determining and executing avoidance maneuvers. | Compliance with operational rules and regulations is necessary to ensure safe and legal operations within the National Airspace System. | Simulate various collision scenarios in different airspace classes and operational environments. The system shall recommend and execute avoidance maneuvers that adhere to the applicable rules, regulations, and procedures for the given operational context. | preliminary |
| AUTONOMOUS\_OPERATION | The collision avoidance system shall operate autonomously without requiring manual intervention for detecting potential collisions, evaluating threats, and determining avoidance maneuvers. | Autonomous operation is necessary to ensure timely and consistent collision avoidance responses, especially in time-critical situations where human intervention may be inadequate or delayed. | Conduct simulations and flight tests with various collision scenarios involving cooperative and non-cooperative aircraft targets. The system shall autonomously detect, evaluate, and determine appropriate avoidance maneuvers without requiring any manual intervention. | preliminary |
| MANEUVER\_EXECUTION\_TIMEFRAME | The collision avoidance system shall command and execute avoidance maneuvers with sufficient lead time to ensure safe separation, taking into account the ownship's performance characteristics and the closure rates of potential collision threats. | Executing avoidance maneuvers within an appropriate timeframe is crucial to ensure that safe separation is achieved before a potential collision occurs. | Simulate collision scenarios with varying closure rates and ownship performance characteristics. Verify that the system commands and executes avoidance maneuvers with sufficient lead time to maintain a safe separation distance, based on the ownship's dynamics and the relative motion of the collision threat. | preliminary |
| CONTINUOUS\_MONITORING | The collision avoidance system shall continuously monitor the airspace within the surveillance volume and update the collision potential evaluation and avoidance maneuver determination as necessary, based on changes in traffic conditions or aircraft trajectories. | Continuous monitoring and updating of collision avoidance actions are necessary to adapt to dynamic situations and ensure that safe separation is maintained throughout the flight. | Conduct simulations with dynamic traffic scenarios, where aircraft trajectories and positions change over time. The system shall continuously monitor the airspace, update collision potential evaluations, and adjust avoidance maneuvers as needed to maintain safe separation from all traffic. | preliminary |
| MULTIPLE\_THREAT\_HANDLING | The collision avoidance system shall be capable of handling multiple simultaneous collision threats and prioritize avoidance maneuvers based on the level of risk and proximity of each threat. | In high-density traffic environments, it is possible to encounter multiple potential collision threats simultaneously. The system must be able to handle these situations and prioritize avoidance actions accordingly. | Simulate scenarios with multiple aircraft within the surveillance volume, presenting varying levels of collision risk and proximity. The system shall identify and prioritize all potential threats, and determine avoidance maneuvers that maintain safe separation from the highest priority threats. | preliminary |
| INITIATE\_AVOIDANCE\_MANEUVER | The collision avoidance system shall initiate the determined avoidance maneuver with sufficient lead time for execution, considering the ownship's performance characteristics and the closure rate of the collision threat. | Initiating the avoidance maneuver with adequate lead time is crucial for ensuring that safe separation is achieved before a potential collision occurs. | Simulate collision scenarios with varying closure rates and ownship performance characteristics. Verify that the system initiates the avoidance maneuver early enough to maintain a safe separation distance, based on the ownship's dynamics and the relative motion of the collision threat. | preliminary |
| MONITOR\_AVOIDANCE\_EFFECTIVENESS | The collision avoidance system shall continuously monitor the effectiveness of the executed avoidance maneuver and initiate corrective actions if necessary to maintain safe separation. | Monitoring the effectiveness of the avoidance maneuver is necessary to ensure that safe separation is maintained, and corrective actions can be taken if the initial maneuver is insufficient. | After executing avoidance maneuvers in simulated collision scenarios, monitor the resulting separation distance and trajectory. If safe separation is not maintained or the collision threat persists, verify that the system initiates corrective actions or additional maneuvers as required. | preliminary |
| AVOIDANCE\_RULES\_AND\_PROCEDURES | The collision avoidance system shall adhere to established rules and procedures for collision avoidance, such as right-of-way regulations and traffic prioritization, when determining and executing avoidance maneuvers. | Adhering to established rules and procedures for collision avoidance is necessary to ensure safe and predictable operations within the National Airspace System. | Simulate various collision scenarios involving multiple aircraft with different priorities and right-of-way rules. Verify that the system determines and executes avoidance maneuvers in accordance with the applicable rules and procedures, giving proper priority and right-of-way to the appropriate aircraft. | preliminary |
| ASSESS\_MANEUVER\_COMPLETION | The collision avoidance system shall assess when the executed avoidance maneuver has been completed and safe separation from the collision threat has been achieved. | Assessing the completion of the avoidance maneuver is necessary to determine when normal flight operations can resume and to ensure that safe separation has been maintained throughout the encounter. | After executing avoidance maneuvers in simulated collision scenarios, verify that the system accurately assesses when the maneuver is complete and safe separation has been achieved based on the relative motion and trajectory of the ownship and the collision threat. | preliminary |
| INTEGRATE\_ATC\_COORDINATION | The collision avoidance system shall integrate with Air Traffic Control (ATC) systems to coordinate avoidance maneuvers, obtain clearances, and communicate deviations from planned trajectories. | Integration with ATC systems is crucial for ensuring safe and efficient operations within the National Airspace System, and for complying with applicable regulations and procedures regarding collision avoidance maneuvers. | Perform simulations or flight tests involving ATC coordination for various collision avoidance scenarios. Verify that the system correctly exchanges information with ATC systems, obtains necessary clearances, and communicates deviations from planned trajectories in accordance with established protocols. | preliminary |
| CONTINGENCY\_MANEUVER\_PLANNING | The collision avoidance system shall have contingency maneuver plans in place for situations where the initial avoidance maneuver is deemed inadequate or cannot be executed. | Having contingency maneuver plans is necessary to ensure that safe separation can be maintained even in cases where the initial avoidance maneuver is not successful or cannot be executed due to unforeseen circumstances. | Simulate scenarios where the initial avoidance maneuver is deemed inadequate or cannot be executed due to various reasons (e.g., ownship performance limitations, dynamic changes in traffic conditions). Verify that the system has contingency maneuver plans in place and can execute alternative avoidance actions to maintain safe separation. | preliminary |
| ALERT\_VIOLATION\_OF\_SEPARATION | The collision avoidance system shall alert the operator or initiate automated actions if the executed avoidance maneuver does not maintain the required separation standards. | Alerting the operator or initiating automated actions when separation standards are violated is necessary to ensure that corrective measures can be taken to prevent potential collisions. | Simulate scenarios where the executed avoidance maneuver does not maintain the required separation standards. Verify that the system generates appropriate alerts or initiates automated corrective actions to mitigate the violation and maintain safe separation. | preliminary |
| RECOVER\_AIRCRAFT\_CONTROL | The collision avoidance system shall have the capability to recover control of the aircraft in the event of a lost communication link or other contingency situation that prevents normal avoidance maneuver execution. | In contingency situations where normal avoidance maneuver execution is not possible, the ability to recover control of the aircraft is crucial to ensure safe separation and prevent potential collisions. | Simulate various contingency scenarios, such as lost communication links or system failures, where normal avoidance maneuver execution is not possible. The system shall demonstrate the ability to recover control of the aircraft and execute alternative contingency maneuvers to maintain safe separation. | preliminary |
| PROVIDE\_CONTINGENCY\_GUIDANCE | The collision avoidance system shall provide guidance and recommendations to the operator or other relevant personnel for contingency procedures in the event of system failures or anomalies during collision avoidance operations. | Providing contingency guidance is necessary to ensure that appropriate actions can be taken to maintain safety and prevent collisions in the event of system failures or anomalies. | Simulate scenarios involving various system failures or anomalies during collision avoidance operations. The system shall provide clear and actionable guidance to the operator or relevant personnel regarding contingency procedures to be followed. | preliminary |
| REDUNDANT\_COMPONENTS | The collision avoidance system shall incorporate redundant components or subsystems to ensure continued operation in the event of individual component failures. | Incorporating redundancy in critical components and subsystems is essential for maintaining system availability and reliability, ensuring that collision avoidance functions can continue even in the event of individual component failures. | Conduct simulations or tests where individual components or subsystems of the collision avoidance system are intentionally failed. The system shall demonstrate the ability to continue operations and maintain collision avoidance capabilities through the use of redundant components or subsystems. | preliminary |
| AUTONOMOUS\_CONTINGENCY\_RESPONSE | The collision avoidance system shall have the capability to autonomously respond to contingency situations and execute predefined contingency maneuvers without requiring operator intervention. | Autonomous contingency response is necessary to ensure timely and consistent actions in situations where operator intervention may be delayed or unavailable, mitigating the risk of collisions. | Simulate various contingency scenarios, such as system failures or anomalies, where operator intervention may be delayed or unavailable. The system shall autonomously execute predefined contingency maneuvers to maintain safe separation without requiring operator input. | preliminary |
| OBTAIN\_FLIGHT\_PLAN\_INFORMATION | The collision avoidance system shall obtain flight plan information from the National Airspace System (NAS) information system for traffic conflict prediction and metering/scheduling purposes. | Obtaining flight plan information is necessary for predicting potential conflicts with other aircraft and coordinating with air traffic control for efficient and safe operations within the NAS. | Integrate the collision avoidance system with the NAS information system. Simulate various flight scenarios and verify that the system can reliably obtain and process flight plan information for all relevant aircraft within the surveillance volume. | preliminary |
| PROVIDE\_CONTINGENCY\_FLIGHT\_PLANS | The collision avoidance system shall provide contingency flight plan modifications to the NAS information system to be implemented in case of an emergency or collision avoidance scenario. | Providing contingency flight plan modifications is necessary to ensure that air traffic control and other relevant systems are aware of deviations from the planned flight path due to emergencies or collision avoidance maneuvers. | Simulate emergency and collision avoidance scenarios that require deviations from the planned flight path. Verify that the system generates and communicates appropriate contingency flight plan modifications to the NAS information system. | preliminary |
| COMPLY\_WITH\_AIRWORTHINESS\_STANDARDS | The collision avoidance system shall comply with applicable airworthiness certification standards and procedures to ensure safe operations within the NAS. | Compliance with airworthiness standards is required to demonstrate that the collision avoidance system meets the necessary safety and performance requirements for operation in the NAS. | Conduct testing and certification processes as required by the relevant aviation authorities. Verify that the collision avoidance system meets all applicable airworthiness standards and obtains the necessary certifications. | preliminary |
| COMPLY\_WITH\_FLIGHT\_OPERATIONS\_STANDARDS | The collision avoidance system shall comply with applicable standards and regulations for flight operations within the NAS, including obtaining necessary operating certificates and following established procedures. | Compliance with flight operations standards and regulations is necessary to ensure safe and legal operations within the NAS and to maintain compatibility with existing air traffic management systems and procedures. | Obtain the required operating certificates and demonstrate compliance with applicable flight operations regulations and procedures through simulations and flight tests in various operational scenarios. | preliminary |
| INTEGRATION\_WITH\_NAS\_FLIGHT\_PLANNING | The collision avoidance system shall integrate with the National Airspace System (NAS) flight planning systems to provide and receive updated flight plan information for effective collision avoidance operations. | Integration with NAS flight planning systems is necessary for coordinating collision avoidance maneuvers, obtaining clearances, and communicating deviations from planned trajectories to ensure safe and efficient operations within the NAS. | Perform simulations or flight tests involving the exchange of flight plan information between the collision avoidance system and NAS flight planning systems. Verify that the system can provide updated flight plan details, including contingency plans, and correctly process received flight plan information from the NAS systems. | preliminary |
| CONTINGENCY\_FLIGHT\_PLAN\_UPDATES | The collision avoidance system shall provide updated contingency flight plans to the NAS flight planning systems in the event of an executed avoidance maneuver or other deviations from the originally planned flight path. | Providing updated contingency flight plans to NAS systems is necessary to ensure that air traffic control and other relevant entities are aware of the aircraft's revised trajectory after executing collision avoidance maneuvers or deviating from the planned flight path. | Simulate scenarios where avoidance maneuvers or other deviations from the planned flight path are executed. The system shall generate and communicate updated contingency flight plans to the NAS flight planning systems, reflecting the new trajectory and any subsequent changes. | preliminary |
| NAS\_INFORMATION\_INTEGRATION | The collision avoidance system shall integrate with NAS information systems to obtain relevant data, such as weather information, airspace restrictions, and notices to airmen (NOTAMs), to inform collision avoidance decision-making and trajectory planning. | Integrating with NAS information systems is necessary to ensure that the collision avoidance system has access to up-to-date and accurate information about weather conditions, airspace restrictions, and other relevant data that may impact safe and efficient operations. | Integrate the collision avoidance system with NAS information systems and simulate various operational scenarios. Verify that the system can retrieve and process relevant data, such as weather information, airspace restrictions, and NOTAMs, and incorporate this information into collision avoidance decision-making and trajectory planning. | preliminary |
| AIRSPACE\_CONSTRAINT\_COMPLIANCE | The collision avoidance system shall ensure that any proposed avoidance maneuvers or contingency flight plans comply with applicable airspace constraints, such as restricted areas or temporary flight restrictions (TFRs), obtained from NAS information systems. | Complying with airspace constraints is essential for maintaining safe and legal operations within the NAS, and for preventing violations of restricted areas or other regulated airspace. | Simulate scenarios involving various airspace constraints, such as restricted areas or TFRs. Verify that the collision avoidance system does not propose or execute avoidance maneuvers or contingency flight plans that violate these constraints based on the information obtained from NAS information systems. | preliminary |

The functional requirements report serves as a comprehensive reference document for stakeholders, developers, and certification authorities involved in the HALE collision avoidance system project. It outlines the necessary capabilities and functionalities the system must possess to ensure safe and efficient operations within the National Airspace System (NAS).  
  
The requirements should be used as a guiding framework throughout the system's development lifecycle, from initial design and implementation to testing and certification processes. They establish the essential criteria for evaluating the system's compliance with safety, performance, and operational standards.  
  
Developers can leverage the requirements as a blueprint for architecting the system's components, ensuring that each component addresses the specified functionalities and meets the prescribed criteria. The requirements provide a roadmap for integrating various subsystems, such as surveillance, collision prediction, avoidance maneuver determination, and contingency management, into a cohesive and reliable collision avoidance solution.  
  
During testing phases, the requirements serve as a basis for developing comprehensive test cases and scenarios. By verifying the system's adherence to these requirements through simulations and flight tests, stakeholders can gain confidence in the system's ability to operate safely and effectively within the NAS.  
  
Certification authorities, responsible for evaluating the system's airworthiness and operational readiness, can utilize the requirements as a reference for assessing the system's compliance with applicable regulations, standards, and best practices. The requirements provide a structured framework for evaluating the system's capabilities, ensuring that it meets the necessary criteria for certification and approval for operational use.  
  
The requirements facilitate effective communication and collaboration among stakeholders by establishing a common understanding of the system's expected functionalities and performance metrics. This shared understanding can streamline decision-making processes and foster seamless integration with existing NAS systems and procedures.  
  
By adhering to the functional requirements outlined in the report, stakeholders can ensure that the HALE collision avoidance system meets the rigorous standards required for reliable and safe operations within the NAS, ultimately enabling the successful integration of high-altitude, long-endurance unmanned aircraft systems into the airspace.  
  
References:  
[18] ThunderGraph/HALE/Hale Concept of Operations.pdf  
[19] ThunderGraph/HALE/comms.pdf  
[20] ThunderGraph/HALE/Human System Integration Reqs.pdf  
[21] ThunderGraph/HALE/Human factors design guide.pdf  
[22] 14 CFR 91.215 (up to date as of 3-07-2024).pdf  
[23] 14 CFR 91.123 (up to date as of 3-07-2024).pdf  
[24] 14 CFR 91.155 (up to date as of 3-07-2024).pdf

# Conclusion

The collision avoidance system is a critical component of the HALE project, aimed at ensuring the safe integration of high-altitude, long-endurance unmanned aircraft systems (UAS) into the National Airspace System (NAS). The system must detect and track both cooperative and non-cooperative aircraft within a specified surveillance volume, evaluate collision potential, determine appropriate avoidance maneuvers, and command their execution while minimizing deviations from the planned flight path. [19, 20]  
  
The functional requirements outlined in this report are derived from an analysis of relevant technical documents, regulations, and industry standards. These requirements cover various aspects of collision avoidance, including surveillance, collision prediction, avoidance maneuver determination, execution and monitoring, contingency management, and integration with NAS systems. [19, 20, 21, 22, 23, 24]  
  
The report serves as a comprehensive reference for stakeholders, developers, and certification authorities throughout the development, testing, and certification processes. It ensures that the collision avoidance system meets the necessary safety, performance, and operational standards for integration into the NAS, enabling safe and efficient operations of HALE UAS within the airspace. [18, 19, 20, 21, 22, 23, 24]  
  
References:  
  
18. ThunderGraph/HALE/Hale Concept of Operations.pdf  
19. ThunderGraph/HALE/comms.pdf  
20. ThunderGraph/HALE/Human System Integration Reqs.pdf  
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22. 14 CFR 91.215 (up to date as of 3-07-2024).pdf  
23. 14 CFR 91.123 (up to date as of 3-07-2024).pdf  
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# References

1. ThunderGraph/HALE/Hale Concept of Operations.pdf  
2. ThunderGraph/HALE/comms.pdf  
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5. 14 CFR 91.215 (up to date as of 3-07-2024).pdf  
6. 14 CFR 91.123 (up to date as of 3-07-2024).pdf  
7. 14 CFR 91.155 (up to date as of 3-07-2024).pdf  
8. ThunderGraph/HALE/Mission Planning Req Doc.pdf  
9. ThunderGraph/HALE/20080017109.pdf  
  
The functional requirements report draws upon a range of sources to establish the necessary capabilities for the collision avoidance system. Technical documents, regulations, and industry standards were analyzed to derive requirements across various aspects, including surveillance, collision prediction, avoidance maneuver determination, execution and monitoring, contingency management, and integration with National Airspace System (NAS) systems.  
  
The surveillance requirements aim to ensure the system can detect and track both cooperative and non-cooperative aircraft within a specified volume [2, 3]. Collision prediction requirements focus on identifying potential threats based on trajectories, speeds, and closure rates, and prioritizing them accordingly [9].  
  
Avoidance maneuver determination requirements address the calculation and recommendation of appropriate maneuvers that maintain safe separation while minimizing deviations from the planned flight path. These maneuvers must consider the ownship's performance characteristics, operational constraints, and established rules and procedures [2, 3, 4, 5, 6, 7].  
  
Execution and monitoring requirements cover commanding and executing avoidance maneuvers with sufficient lead time, continuously monitoring their effectiveness, and initiating corrective actions if necessary [2, 3, 4].  
  
Contingency management requirements address situations where the initial maneuver is inadequate or cannot be executed, necessitating contingency plans, autonomous responses, and the ability to recover aircraft control in case of failures or lost communication links [2, 3, 4, 9].  
  
Integration with NAS systems requirements ensure coordination with Air Traffic Control (ATC), obtaining and sharing flight plan information, complying with airspace constraints, and adhering to airworthiness and flight operations standards [2, 3, 5, 6, 7].  
  
The comprehensive set of stakeholder requirements presented in the report serves as a reference for developers, certification authorities, and other stakeholders throughout the development, testing, and certification processes, ensuring the collision avoidance system meets the necessary standards for safe and efficient operations within the NAS [1, 2, 3, 4, 5, 6, 7].