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Safety Case for Small Uncrewed Aircraft Systems (sUAS) Beyond Visual Line of Sight (BVLOS) Operations at NASA Langley Research Center

Matthew W. Coldsnow and Louis J. Glaab
Langley Research Center, Hampton, Virginia

Jacob Revesz and Leslie O. Kagey
National Institute of Aerospace, Hampton, Virginia

Robert G. McSwain and Jacob R. Schaefer
Langley Research Center, Hampton, Virginia

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

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Certificate of Authorization (COA) Safety Case for Small Uncrewed Aircraft Systems (sUAS) Beyond Visual Line of Sight (BVLOS) Operations at NASA Langley Research Center

Version 1.0

November 1, 2022

High Density Vertiplex Beyond Visual Line of Sight Safety Case Version 1.0

Context: This document is prepared to support the expansion of small uncrewed aerial systems (sUAS) operational capabilities at the NASA Langley Research Center (LaRC) City Environment for Range Testing Autonomous Integrated Navigation (CERTAIN) range. This document contains the initial approach and plans for achieving sUAS beyond visual line of sight operations (BVLOS) in support of the Advanced Air Mobility (AAM) High Density Vertiplex (HDV) project. *It is anticipated that as new results are acquired during the review and coordination of this document with the FAA, that additions and changes will be incorporated*. Updates to this document will be coordinated and documented in a change log for subsequent versions. NASA personnel listed below were provided an opportunity to review and comment. Resulting changes were incorporated into this version of the document. Initial BVLOS operations are planned for January of 2023.

Jeff Homola (High Density Vertiplex Sub-Project Manager)

Brian Baxley (Eastern Region Airworthiness Review Board Chairman)

Thomas Jordan (Operational Readiness Review Chairman)

Taylor Thorson (Chief Pilot)

Greg Slover (Aviation Safety Officer)

Mark Frye (Center Range Flight Safety Lead)

Executive Summary

This document summarizes the safety risk management activities undertaken to assure that Beyond Visual Line of Sight (BVLOS) flight operations with Small Uncrewed Aircraft Systems (sUAS) can be conducted at an acceptable level of safety. This Safety Case, and the requested waiver, is limited to NASA Langley BVLOS operations for the purposes of research and development, crew training and autonomous technology assessments.

The Advanced Air Mobility High Density Vertiplex (AAM HDV) project endeavors to perform system integration, simulation, and flight testing in support of Urban Air Mobility (UAM) ecosystem research and development using sUAS as surrogates for larger UAM vehicles. The primary focus of the HDV project is on vertiport automation systems and system integration using a phased approach that includes three spiral wraps. Each spiral wrap involves increased UAM Ecosystem complexity and increased testing capability.

The intended operations, which are provisionally scheduled to commence in January 2023 – subject to approval from the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) – will include a combination of within Visual Line of Sight (WVLOS) and BVLOS flights, comprising of at most five sUAS operating concurrently, with no more than three operating BVLOS. Flights will occur in a subset of the Langley Air Force Base (LAFB) Class D airspace (KLFI) at a maximum altitude of 400 ft AGL. Most operations within this subset will take place in the City Environment Range Testing for Autonomous Integrated Navigation (CERTAIN) Range. The CERTAIN Range includes airspace inside the borders of NASA Langley Research Center (LaRC). Additional airspace over the northern section of CERTAIN will be requested as part of the Certificate of Authorization (COA) similar to 2021-ESA-9599-COA which is already approved for BVLOS operations with Visual Observers (VOs).

NASA LaRC BVLOS operations on the CERTAIN Range can be broken down into five critical components needed to meet the 14 CFR § 91.113 see and avoid requirement: *1)* procedural deconfliction with LAFB for UAS operations at or below 400 ft and manned aircraft at or above 900' AGL; *2)* ground equipment for detection of intruder aircraft and to support communications between crewmembers ; *3)* sUAS vehicles with advanced onboard automation capable of autonomously maintaining safe separation; *4)* BVLOS standardized operating procedures (SOPs); *5)* and personnel to execute the flight operations in accordance with the SOPs and respond to airborne contingencies.

The introduction of new ground equipment includes the use of the Remote Operations for Autonomous Missions (ROAM) UAS Operations Center, development and use of an Integrated Airspace Display (IAD), use of the L-STAR and GA-9120 radars, and the incorporation of standardized Vertiports. The ROAM Operations Center will be the central point for all BVLOS sUAS operations. All command and control (C2), voice communications and airspace awareness displays will reside inside ROAM. The IAD will provide raw data from ADS-B, FLARM, radar tracks and telemetered GPS vehicle positions for interpretation by an Airspace Monitor. Additionally, an Anra fusion algorithm will be evaluated for its ability to merge corollary track data from the different ground sources into a single fused track. Functionality of the Anra fusion is not required for BVLOS operations. The radars will search the class D airspace around the CERTAIN Range with the primary purpose of detecting non-participating aircraft so that the 91.113 see and avoid requirement can be met. Finally, the incorporation of Vertiports will have video and network connectivity that enables large numbers of sUAS launches and recoveries from a single location.

The sUAS vehicle with advanced onboard automation includes Independent Configurable Architecture for Reliable Operations of Uncrewed Systems (ICAROUS) and Safe2Dithch (S2D) NASA technologies designed to aid BVLOS operations by serving as backup safety features for the Pilot-in-Command (PIC). ICAROUS uses vehicle track data to monitor safe separation criteria and if necessary, command the sUAS to maneuver to avoid the traffic and maintain the minimum safe separation distance. S2D searches a landing site for moving traffic and will re-route the vehicle to an alternate landing site should the first site be categorized as unsafe. Both autonomous systems are designed as secondary safety devices for deconfliction actions, should human intervention fail.

The BVLOS SOPs establish procedural processes for crewmembers to follow during BVLOS operations so all crewmembers understand what is expected during the typical phases of flight operations (ground operations, preflight, takeoff, in-flight operations, landing/recovery, post flight and contingency operations). These SOPs also provide guidance on contingency operations and where applicable, include hazard mitigation barriers discussed in this safety case.

The crewmembers executing the BVLOS flight operation include a Range Safety Officer (RSO), a Flight Test Manager (FTM), one Ground Control Station Operator (GCSO) PIC for each sUAS, a Radar Operator (RO), an Airspace Monitor (AM), and a Vehicle Service Crew (VSC) for each Vertiport. The Range Safety Officer is responsible for providing a project-independent safety monitoring function ensuring that the operation is conforming to appropriate NASA and FAA regulations as well as the planned and authorized conditions as defined in the Airworthiness Review Board (ARB) and Operational Readiness Review (ORR) documentation. The FTM executes the flight test plan by working with and managing the flight crew. The GCSO PIC is responsible for programming, running, and managing the autonomous control modes of the vehicle as well as monitoring weather conditions, clearing the airspace, monitoring the vehicle, and maneuvering the aircraft as required to ensure safe flight operations. The RO ensures that the radar system is operational and provides complementary scanning of the airspace with the AM to detect intruder traffic in LAFB Class D airspace. The AM monitors the airspace using the IAD and informs crewmembers of potential traffic conflicts. The VSC typically consists of one or two individuals that are responsible for the maintenance, inspection and visual pre-flight of the vehicle while it is on the ground. The VSC can perform additional duties such as Visual Observer (VO) and/or Safety Pilot (SP) while the UAS in in the air and WVLOS of the VSC location.

This safety case is consistent with the requirements for content and format, in FAA Order 8900.1, 16-4-8, and it shows how the applicable general operational requirements in Order 8900.1, 16-4-5, will be met. To develop the safety case and move through the associated safety risk management process, the guidance from the following documents has been adopted, in part:

- FAA Order 8900.1, Flight Standards Information Management System (FSIMS); Volume 16, UAS
- NASA Procedural Requirements (NPR) 7900.3D, Aircraft Operations Management Manual
- NPR 8715.5B, Range Flight Safety Program
- Langley Procedural Requirements (LPR) 1710.16, Aviation Operations and Safety Manual
- NAII 7900.3, Airworthiness Review Process for the Eastern Region Airworthiness Review Board (ER-ARB)

Based on the safety risk analysis and assessment conducted, the Initial Risk Level assesses BVLOS operations with no mitigations, whereas the Residual Risk Level assess BVLOS operations with proposed mitigations applied. Each hazard was assigned a Risk Assessment Code (RAC) characterizing the severity and probability of their occurrence. The identified hazards along with their initial and mitigated residual risk levels, are as follows:

Hazard ID	Hazard Description	Initial Risk Level	Mitigated Residual Risk Level
Primary Hazards			
PH1	Midair collision with manned aircraft	RAC 1 (I/C)	RAC 3 (I/D)
PH2	Mid-air collision between UA	RAC 2 (II/C)	RAC 3 (II/D)
PH3	UAS flies off the CERTAIN range	RAC 2 (II/C)	RAC 3 (II/D)
PH4	GPS Failure	RAC 2 (III/B)	RAC 3 (III/D)
Secondary Hazards			
SH1	UA impacts people/structures on the ground	RAC 2 (II/C)	RAC 3 (II/D)
Contributory Hazards			
CH1	Degradation of ground surveillance system	RAC 3 (III/C)	RAC 3 (IV/C)
CH2	Loss of all command and control links	RAC 3 (IV/B)	RAC 3 (IV/C)
CH3	Unrecoverable failure of UA or GCS during flight	RAC 2 (II/D)	RAC 3 (II/D)
CH4	Human factors events, including loss of situational awareness, crew miscommunication, and crew fatigue.	RAC 3 (III/C)	RAC 3 (III/D)
CH5	Loss of voice communications	RAC 3 (IV/C)	RAC 4 (V/D)
CH 6	Lithium battery fire	RAC 3 (III/D)	RAC 4 (IV/E)

Overall safety during flight test operations will be achieved by employing defense in depth, i.e. through a combination of layering of several hazard mitigations barriers, including:

- Airspace deconfliction procedures include limiting sUAS BVLOS operations to times when LAFB Tower is open, utilizing ground-based surveillance to provide situational awareness of LAFB

Class D airspace, and adhering to the procedures documented in the Letter of Procedure with LAFB and applicable COAs for ensuring safe separation. Each of these mitigators reduces the risk of a mid-air collision.

- Airworthiness, flight readiness, and crew qualifications are key components to LaRC BVLOS flight operations. NASA Langley certified airworthy vehicles that are flown by crews that are current and qualified in their respective positions adds three defense-in-depth layers to BVLOS operations.
- Onboard and ground safety equipment offers yet another layer of defense-in-depth hazard mitigations. Onboard safety equipment mitigations include the requirement for all multi-rotor sUAS to have eight motors minimum such that the loss of one motor still allows the vehicle to be controllable and the incorporation of an independent system capable of interrupting the commands from the onboard autonomous systems to isolate the primary flight control system from research equipment. Ground safety equipment include the flight mode indicator in front of ROAM UAS Operations Center notifying all crewmembers when flight operations are in progress, ground-based surveillance fed by L-STAR, GA-9120, ADS-B, GCS and FLARM data provides real-time airspace picture of LAFB Class D on the IAD, ClearComm radio belt packs for communication between crewmembers and clearly marked ditch sites for all emergency UAS landing areas.
- Nominal operating procedures from NASA LaRC's 20+ years of experience conducting UAS operations are captured in lessons learned, procedures, hazard mitigations, and limits that are defined in LPR 1710.16 (wind, weather, and temperature limits; currency, training, and qualification requirements; planning, lost link, range containment and mishap procedures). All general operating procedures and limits prescribed in LPR 1710.16 shall be adhered to unless specifically approved by the ARB and ORR.
- HDV's risk reduction actions are implemented to add to the defense in depth hazard mitigation strategy. These items include spectrum management mitigation steps, additional system redundancies (C2 links, voice comms and GPS tracking), and mitigators specific to HDV operations.
- The build-up approach used by HDV is critical to developing BVLOS capability and safely conducting BVLOS operations. The build-up approach includes simulation, flight envelope expansion, abort procedure and emergency procedure verification and ROAM UAS Operations Center checkout.
- Technology risk reductions are utilized to help the machine/human interface by incorporating autonomous backup technologies to limit the impacts of a human or mechanical failure. These backups include both commercial off-the-shelf autonomous capability (geofence, lost link, etc.) and HDV autonomous technologies (S2D, ICAROUS). To help enable HDV autonomous technologies, some ground-based surveillance data will be routed to the vehicle to enable autonomous sense and avoid with HDV autonomous technologies.
- The emergency/contingency procedures represent a suite of procedural risk mitigation actions that the operations crew will take in the unlikely event that the identified hazardous and off-nominal scenarios materialize during sUAS operations (i.e., assuming that other preventative barriers have been unsuccessful).

*For more detailed description on the hazard mitigation barriers, refer to Section 11 of the safety case.

Taken together, the hazard mitigation barriers specified in this safety case are expected to reduce the risk associated with the intended operations to an acceptable level. NASA LaRC will accomplish an Airworthiness Review Board (ARB) and an Operational Readiness Review (ORR) before every phase of testing to, among other things, *a)* validate the assumptions made in this safety case, *b)* verify the safety performance of the identified hazard mitigation barriers, *c)* track/monitor the identified hazards, and *d)* update the safety analysis and assessment to be consistent with the actual system and its operations.

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Abbreviations

#	Abbreviation	Definition
1	AADS	Airspace Awareness and Detection System
2	AAM	Advanced Air Mobility Project
3	ADS-B	Automatic Dependent Surveillance Broadcast
4	AFSRB	Airworthiness Flight Safety Review Board
5	AGL	Above Ground Level
6	AI	Artificial Intelligence
7	AM	Airspace Monitor
8	AOA	Advanced Onboard Automation
9	AMOPS	Airfield Management Operations
10	ARB	Airworthiness Review Board
11	ARC	Ames Research Center
12	ATAC	Airborne Tactical Advantage Company
13	ATC	Air Traffic Control
14	ATM	Air Traffic Management
15	AVAL	Autonomous Vehicle Applications Lab
16	AOL	Airspace Operations Lab
17	ASAA	Autonomous Sense and Avoid
18	ATIS	Automatic Terminal Information Service
19	ATOL	Air Traffic Operations Lab
20	ARB	Airworthiness Review Board
21	AZ	Azimuth
22	BIT	Built In Test
23	BDOC	Base Defense Operations Center
24	BVLOS	Beyond Visual Line of Sight
25	C2	Communication and Control
26	CAN	Controller Area Network
27	CAS	Commercial Air Services
28	CERTAIN	City Environment for Range Testing Autonomous Integrated Navigation
29	cFS	Core Flight Systems
30	COA	Certificate of Authorization
31	COTS	Commercial Off the Shelf
32	CRM	Crew Resource Management
33	DAIDALUS	Detect and Avoid Alerting Logic for Uncrewed Systems
34	DCA	ICAO 3 letter identifier for Washington National airport
35	DOF	Degrees of Freedom
36	ER-ARB	Eastern Region Airworthiness Review Board
37	EMI	Electro Magnetic Interference
38	ESC	Electronic Speed Controller
39	EVLOS	Extended Visual Line of Sight
40	FAA	Federal Aviation Administration
41	FAY	ICAO 3 letter identifier for Fayetteville airport
42	FCC	Federal Communications Commission
43	FLARM	Flight Alarm

44	FLO	ICAO 3 letter identifier for Florence Regional airport
45	FON	Flight Operations Network
46	FSIMS	Flight Standards Information Management System
47	FSN	Flight Safety Network
48	FTM	Flight Test Manager
49	FTP	Flight Termination Point
50	GA	General Aviation
51	GCS	Ground Control Station
52	GCSO	Ground Control Station Operator
53	GCSO-R	Ground Control Station Operation - ROAM
54	GSFC	Goddard Space Flight Center
55	GPS	Global Positioning Systems
56	HDOP	Horizontal Dilution of Precision
57	HDV	High Density Vertiplex subproject
58	HWG	Hazards Working Group
59	HHITL	Human+Hardware In The Loop
60	IAD	Integrated Airspace Display
61	IP	Instructor Pilot
62	ICAROUS	Independent Configurable Architecture for Reliable Operations of Uncrewed Systems
63	IFR	Instrument Flight Rules
64	ILS	Instrument Landing System
65	IMU	Inertial Measurement Unit
66	KLFI	ICAO 4 letter identifier for LAFB
67	LAFB	Langley Air Force Base
68	LaRC	Langley Research Center
69	LaRCNET	LaRC firewall-protected network
70	LLP	Lost Link Point
71	LMV	Langley Monitoring Volume
72	LNAV	Lateral Navigation GPS approach
73	LOA	Letter of Agreement
74	LOC	Localizer type of radio navigation system
75	LOP	Letter of Procedure
76	LPR	Langley Procedural Requirements
77	LPV	Localizer Performance with Vertical Guidance GPS approach
78	LSTAR	Lightweight Surveillance and Target Acquisition Radar
79	4G LTE	4^{th} Generation Long Term Evolution
80	METAR	Meteorological Aerodrome Reports
81	MC	Mission Commander
82	MPATH	Measurement for Performance for Autonomous Teaming with Humans
83	MRR	Mission Readiness Review
84	MSL	Mean Sea Level
85	MTBF	Mean Time Between Failures
86	NASA	National Aeronautics and Space Administration
87	NAS	National Air Space
88	NM	Nautical Miles

89	NPR	NASA Procedural Requirements
90	NTIA	National Telecommunication Information Administration
91	OAS	Onboard Autonomous Systems
92	ORF	ICAO 3 letter identifier for Norfolk airport
93	ORR	Operational Readiness Review
94	PAO	Prototype Assessment Operations
95	PDARS	Performance Data Analysis and Reporting System
96	PHF	ICAO 3 letter identifier for Patrick Henry International Airport
97	PIC	Pilot In Command
98	PMC	Persons Manipulating the Controls
99	PPR	Prior Permission Required
100	PSU	Provider of Services UAM
101	QGC	Q Ground Control system
102	SRM	Safety Risk Management
103	RAC	Risk Assessment Category
104	R/C	Radio Control
105	RDU	ICAO 3 letter identifier for Raleigh/Durham airport
106	RF	Radio Frequency
107	RFA	Radio Frequency Authorization
108	RFMS	Radio Frequency Monitoring Systems
109	RO	Radar Operator
110	ROAM	Remote Operations for Autonomous Missions
111	RSO	Range Safety Officer
112	RTCA	Radio Technical Commission for Aeronautics
113	SAA	Sense and Avoid
114	S2D	Safe2Ditch
115	SIC	Second In Command
116	SID	Standard Instrument Departure
117	Sim2flight	Simulation to flight test methodology
118	SDSP	Supplemental Data Service Provider
119	SMO	Spectrum Management Office
120	SOA	Scalable Autonomous Operations
121	STAR	Standard Terminal Arrival
122	SP	Safety Pilot
123	STEReO	Scalable Traffic-management for Emergency Response Operations
124	SWIM	System Wide Information Management
125	STAR	Standard Terminal Arrival
126	sUAS	Small Uncrewed Aerial Systems
127	TACAN	Tactical Air Navigation System
128	TAF	Terminal Area Forecast
129	TRACON	Terminal Radar Approach Control facilities
130	TIS-B	Traffic Information System - Broadcast
131	UAM	Urban Air Mobility
132	UART	Universal Asynchronous Receiver Transmitter
133	UPS	Uninterruptable Power Supply
134	UAS	Uncrewed Aerial System

135	VAL	Vision Assisted Landing
136	VFR	Visual Flight Rules
137	VOA	Vertiport Operations Area
138	VOs	Visual Observers
139	VO	Vertiport Operations
140	VP	Visual Pilot
141	VPV	Vertiport Protection Volume
142	VM	Vertiport Manager
143	VMC	Visual Meteorological Conditions
144	VSC	Vehicle Service Crew
145	VTOL	Vertical Takeoff and Landing
146	WAHLDO	Wide Area Hazard Locator for Drone Overflight
147	WVLOS	Within Visual Line of Sight
148	xTM	eXtensible Traffic Management system interface

1 Introduction

This introduction includes several subsections. Section 1.1 provides a background of the High Density Vertiplex project and presents the needs for expansion of small uncrewed aerial systems operations at National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC). Section 1.2 provides an overall scope and purpose of this document. Section 1.3 provides an overview of the approach to assure adequate mitigation of risks and introduce the process for specifically meeting the requirements of 14 CFR § 91.113. Section 1.4 provides an overview of the major sections of this document.

1.1 Background

The Advanced Air Mobility High Density Vertiplex (AAM HDV) project endeavors to perform system integration, simulation, and flight testing in support of Urban Air Mobility (UAM) ecosystem research and development using small uncrewed aerial systems (sUAS) as surrogates for larger UAM vehicles. A rapid prototyping and assessment approach for HDV will yield valuable results to help guide future NASA and industry investments. A second thrust of the HDV project is to conduct comprehensive safety risk assessments supported by test results to achieve operational credit (tested under realistic scenarios in a real-world environment) for a series of NASA sUAS technologies. Within this context, operational credit implies that specific elements of the proposed operations are enabled through risk mitigations provided by a NASA technology. Achieving operational credit will enable more liberal transfer of these NASA technologies to sUAS Part-135 operators and envisioned UAM vehicles.

Overall, the HDV project endeavors to prototype the UAM Ecosystem focusing on the following elements: 1) Onboard autonomous systems, 2) Airspace management systems, 3) Ground control and fleet management systems, and 4) Vertiport automation systems. The primary focus of the HDV project is on vertiport automation systems and system integration. The other elements are required to effectively develop and test the vertiport automation systems.

The HDV project is phased into three spiral wraps that involve increasing UAM Ecosystem complexity combined with increasing testing capability. The first spiral wrap is referred to as Advanced Onboard Automation (AOA) and focuses more on the elements of the UAM Ecosystem envisioned to be part of the UAM aircraft. Following AOA, the Scalable Autonomous Operations (SAO) wrap endeavors to include vertiport automation systems and Beyond Visual Line of Sight (BVLOS) sUAS operations. The last spiral wrap is referred to as Vertiport Operations (VO) where more complex and higher-density operations are envisioned.

A requirement of the HDV project is to achieve BVLOS flight at NASA Langley Research Center’s City Environment for Range Testing of Autonomous Integrated Navigation (CERTAIN) Range. This goal is driven by two supporting objectives: 1) Enable sUAS flight operations that support UAM Ecosystem prototype assessments, and 2) Complete the testing and safety risk assessments required to achieve operational credit for NASA sUAS technologies.

As the scale and complexity of sUAS operations in support of prototype assessment increase, the ability to perform them within visual line of sight (WVLOS) becomes increasingly challenging due to several limitations. One limitation involves maintaining line of sight of the vehicle with the sUAS crew due to visual obstructions such as trees and buildings. Expanding sUAS operational capability to include BVLOS segments can greatly expand the usable airspace and better replicate envisioned UAM operations.

A product of the safety risk assessment process required for BVLOS operations is itself extremely valuable to NASA, FAA, and industry. Maturing NASA technologies through comprehensive testing and documenting and fully publishing the safety risk assessment process will greatly facilitate NASA technology transfer as well as benefit the industry at large. Currently, most NASA testing is performed to establish the efficacy of a given technology in a highly controlled environment. While the technologies are offered for subsequent licensing to outside entities, there is little that can be achieved with the NASA technologies until the comprehensive testing and safety risk assessment process is completed. HDV is endeavoring to perform the integration, testing, and safety risk assessment process that will both enable effective technology transfer of HDV technologies and create a blueprint or pathway for other related technologies. Fully documenting and disseminating the approaches and results achieved within HDV will serve to facilitate similar efforts at NASA as well as industry and academia.

1.2 Scope and Purpose

The scope and purpose of this document is to clearly define the intended operations and identify hazards and associated mitigations necessary to achieve relief from 14 CFR § 91.113 (see and avoid). Risks to overflight of people were also considered and addressed through hazard mitigations. In order to understand these risks, Section 2 provides a comprehensive description of the operating environment and local airspace. Section 3 introduces the Flight Review and Approval process at NASA LaRC. Section 4 provides a list of assumptions to help frame the safety risk discussions and support conclusions. A System Description of both the systems on the vehicle and on the ground is provided in Section 5 to fully describe the system employed for flight operations. In Section 6, the proposed operations, including a detailed description of the operational buildup, training, surveillance, testing, and operational procedures, describes the BVLOS Operational Model. Safety Risk Management Planning and Impacted Organizations are described in Section 7. Failure analysis, including Failure Mode Effects and Criticality Analyses are presented in Section 8. Section 9 identifies the Hazards, Section 10 summarizes the risk of each hazard before and after application of risk mitigations and Section 11 provides a discussion regarding the Treatment of Risks and application of Hazard Mitigations. Section 12 presents NASA's safety and mishap management plan to validate the assumptions made in this safety case, verify the safety performance of the identified hazard mitigation barriers and to track/monitor the identified hazard. Finally, Section 13 includes an array of Appendices to support discussions and conclusions provided herein.

1.3 General approach to risk mitigation for proposed operations

The intended operations are organized and phased to build-in extensive application of the crawl, walk, run mantra. Within this construct, the starting point for HDV sUAS operations will closely resemble existing sUAS operations performed at NASA LaRC under existing COAs. A gradual expansion of sUAS operations will be accomplished to transition from WVLOS to BVLOS operations. One example of operational expansion will be to limit the resulting BVLOS operations to those conducted WVLOS but without direct line of sight observations by the persons manipulating the controls (PMCs). This includes previously flown flight paths, locations, vehicle speeds, and altitudes. This acts as a significant risk mitigator since the vehicle responses, command and control links, and flight characteristics can be evaluated WVLOS before transitioning to BVLOS operations.

The approach taken within NASA Langley Research Center (LaRC) sUAS and HDV flight operations is to use highly reliable commercial off the shelf (COTS) sUAS vehicles as the basis for flight testing. Vehicles are selected based on flight test requirements and manufacturer's specifications. A thorough inspection and extensive testing is performed to verify and document vehicle performance. Vehicle make/models are limited to a single primary configuration to minimize challenges created when using different platforms. Routinely scheduled inspections and preventative maintenance actions along with extensive pre-flight checklists are included as examples of mitigations to ensure vehicle reliability and continued airworthiness.

For HDV, a strong simulation to flight (sim2flight) approach is employed to help mitigate risks. The sim2flight methodology employs a high-fidelity 6 degree of freedom (6-DOF) vehicle simulation with human+hardware in the loop (HHITL) capability used to drive the COTS vehicle autopilot system. This enables the vehicle autopilot to respond as though it were in flight so that the performance of the autonomous systems integrated on the companion computer can be tested. The sim2flight approach also includes high-fidelity pilot interfaces to fully replicate the flight environment for the sUAS operator using actual vehicle telemetry links between the ground control station (GCS) and the vehicle simulation. Extensive sim2flight testing is planned in HDV to assess the integrated vehicles systems and capabilities. Current results from the HDV sim2flight testing can be found in Appendix H and Appendix I.

A training syllabus that includes both simulation and live flight operations will be used to train ground control station operator pilots in command (GCSO PIC) to operate the integrated vehicle and systems. The training syllabus will include all aspects of vehicle operation from pre-flight through takeoff, all envisioned contingencies, safe landings, and effective crew resource management. For HDV, knowledge and practical testing will be included in both initial and recurrent training that will be updated for each spiral wrap. A core team of GCSOs will be established and support the HDV project throughout the lifetime of the project.

All onboard NASA autonomous systems will include NASA Class-C software as defined in Reference 1 NPR 7150.2C. NASA software classification is determined through the use of the NASA-wide software classification structure. For aeronautical vehicles, in this case a sUAS, Class-C software is integral to the control of the airborne vehicle. Some examples of Class-C software include algorithms responsible for guidance, navigation, and control as well as software contained on autopilots. For HDV, related Class-C software tasks include, but are not limited to, requirements definition, review, effective project management, and extensive testing of the resulting software system to ensure requirements are achieved. Software system engineering, documentation, and testing employing the sim2flight approach will be leveraged to help support the resulting Class-C software certification. See Appendix N for an example software Critical Design Review that helps ensure HDV software meets the Class-C software classification requirements.

The NASA aviation safety and risk assessment policies and procedures are applied to all NASA aircraft and aircraft systems. This ensures an independent aircraft airworthiness assessment of all aircraft and an operational safety review for all aircraft operations. Additionally, scheduled and periodic maintenance and detailed documentation of all maintenance actions are leveraged to maintain continued airworthiness.

A thorough data-driven build-up approach is employed in several dimensions to progressively expand operational capabilities from current WVLOS operations. Figure 1 illustrates the crew distribution associated with existing WVLOS operations at NASA LaRC. In this configuration the Safety Pilot (SP) is the pilot in command (PIC), the Range Safety Officer (RSO) provides safety oversight and the GCSO provides complementary vehicle monitoring supporting the SP in direct communications.

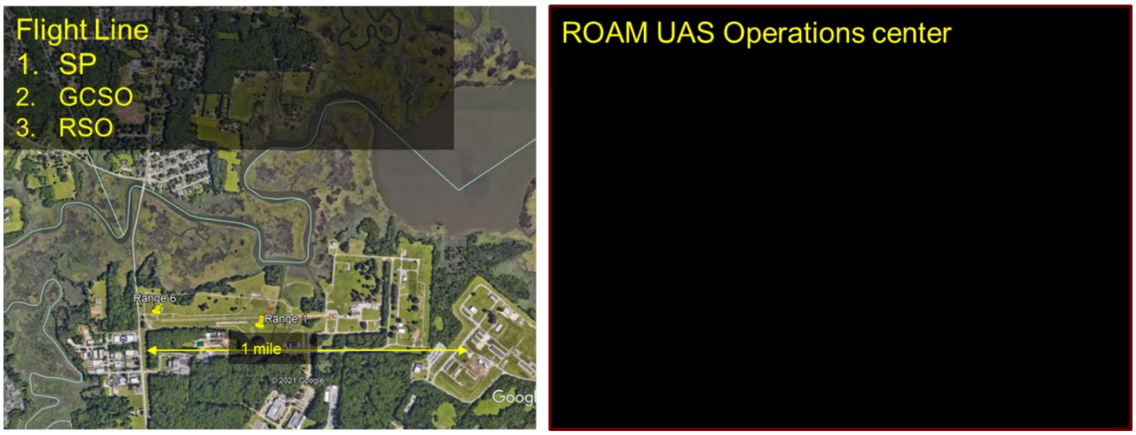

Figure 1 - Initial Condition for Current sUAS Operations.

The first step in the build-up approach to BVLOS operations will be to transition the GCSO from being located on the flight line, in close proximity to the rest of the flight operations team, to being located within the Remote Operations for Autonomous Missions (ROAM) UAS Operations Center as illustrated in Figure 2. The ROAM UAS Operations center is being developed to provide shared situational awareness to the sUAS operations team that will enable comprehensive testing in support of HDV research and test objectives and allow BVLOS flight operations. At this point the ROAM UAS operations center provides a single command and control link with the controls and displays similar to what the GCSO had in the field. Primary and backup voice communications between the field crew and the ROAM are available for crew coordination before, during and after flight operations. Additional displays in ROAM are provided to show advisory traffic data from FlightAware, Airspace Awareness and Detection System (AADS), graphical weather displays, etc. Visual Observers (VOs) are added to ensure the vehicle remains within visual line of sight.

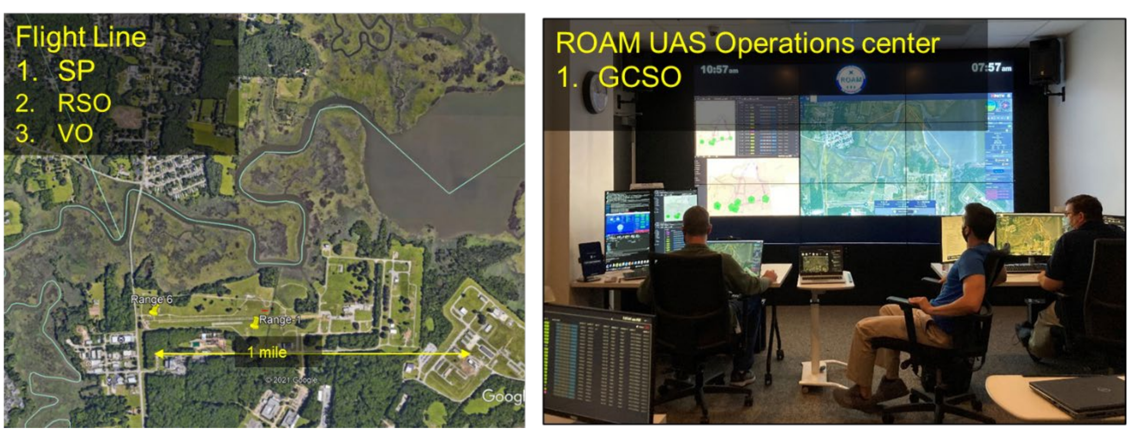

Figure 2 -Move GCSO into ROAM UAS Operations Center.

The next step in the process is to transition the PIC duties from the SP, located in the field, to the GCSO located in the ROAM UAS operations center as illustrated in Figure 3. Transitioning PIC duties to ROAM will be accomplished through focused comprehensive training and the provisioning of displays and dual command and control links inside ROAM. At this point, the role of the SP with remote control (R/C) transmitter can be deleted or transitioned to a Visual Pilot (VP). Visual Pilots serve a similar role as the current Safety Pilots but will only initiate a change of aircraft control when the vehicle is within visual line of sight. If a situation arises that identifies a need for a VP to take control, the VP will first verbally request to take control from the GCSO before taking control. VOs are retained to ensure the vehicle remains within visual line of sight even when the vehicle is not within line of site of the VP. The RSO still provides safety oversight through visual means on the flight line.

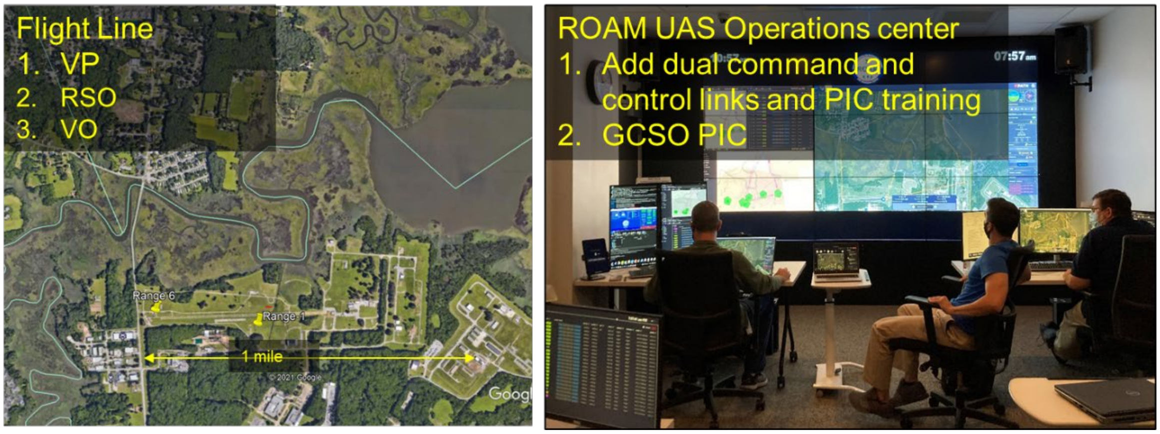

Figure 3 - Transition GCSO to GCSO-PIC.

The next step moves the RSO into the ROAM UAS Ops center leaving the VP/Vehicle Service Crew (VSC) and VOs in the field as illustrated in Figure 4. For this step, the ROAM UAS operations center will provide adequate air traffic awareness information for the RSO to perform their duties from ROAM while the VOs are still on the range. It is expected that the surveillance system will be up and running, displaying the required air traffic data in the ROAM UAS operations center (for more technical details on the ground surveillance system, reference section 6.9). Other required crew for this step include the Airspace Monitor to who monitors the surveillance system inputs and the airspace traffic, a Radar Operator to monitor the status of the radar systems, and the VSC who will ready the vehicle for flight.

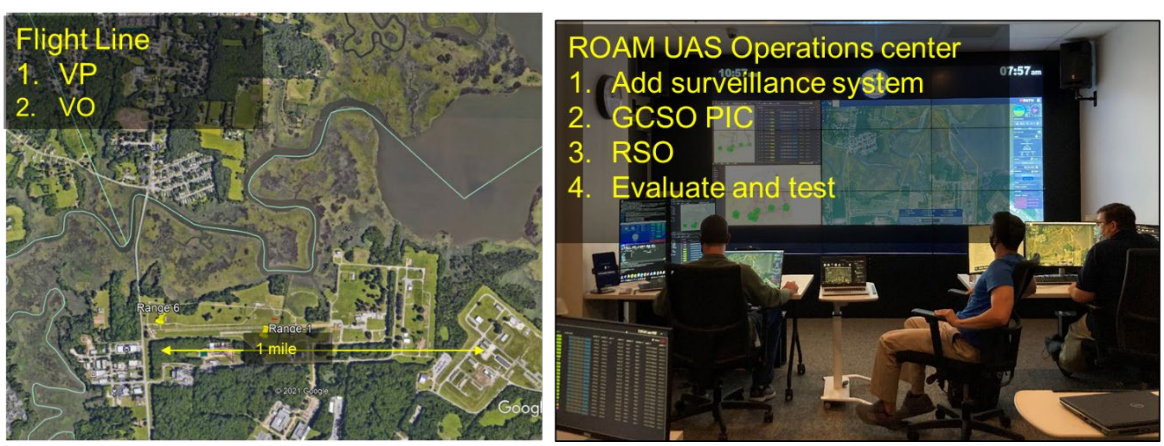

Figure 4 - Transition to RSO in ROAM UAS Operations Center.

At this stage the PMCs and operations team will gain valuable experience operating the vehicle without direct line of sight while VOs continue to maintain sight of the vehicle and airspace. Assessments of the situational awareness provided in the ROAM UAS Operations center can be performed to compare the information coming from the displays in ROAM with the total information needed for safe operations. These operations are already approved under 2021-ESA-9599-COA with a special provision to utilized VOs to meet the 14 CFR § 91.113 see and avoid requirement. NASA Langley is referring to these BVLOS operations with VOs as Extended Visual Line of Sight (EVLOS) operations.

Once all required information is provided by means other than the VO (ie visual displays of fused traffic data from ADS-B, FLARM, radar tracks and telemetered GPS vehicle positions), then the VOs can be removed resulting in true BVLOS operations. The approval to ultimately remove VOs from the flight operation and utilize airspace surveillance and vehicle monitoring data displayed in the ROAM UAS operations center to meet the 91.113 see and avoid requirement is what this safety case is justifying. This configuration is illustrated in Figure 5. At this stage, the ROAM UAS Operations Center is required to provide the necessary air traffic awareness that allows the RSO and GCSO-PIC to maintain well clear separation while operating sUAS BVLOS. As a backup to the RSO and PIC, fully tested and verified onboard autonomous systems, can add an additional layer of mitigation to the risk of BVLOS operations. Autonomous systems like ICAROUS and S2D will undergo simulator and flight test to demonstrate and validate that these research systems are reliable and effective enough to be a consistent mitigation.

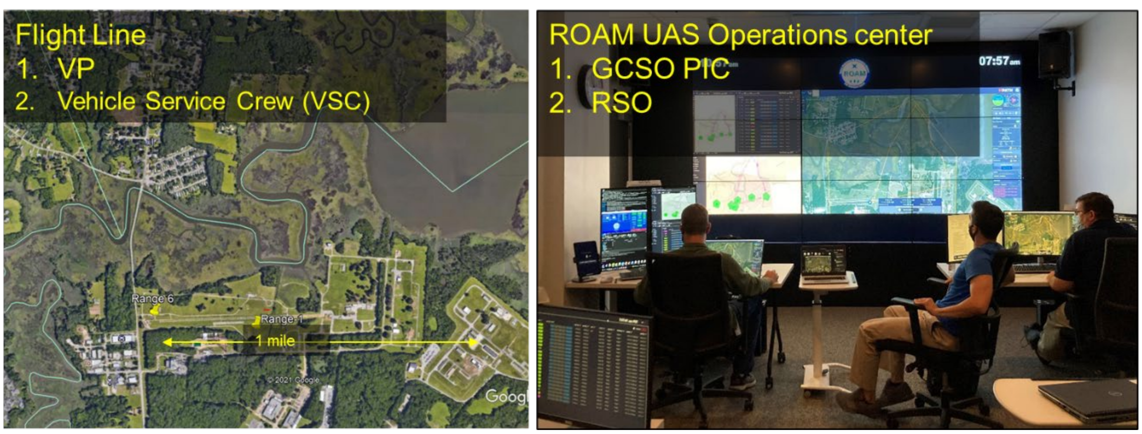

Figure 5 - Remove Dedicated Visual Observer(s).

1.4 Overview Regarding 14 CFR § 91.113 and See and Avoid

The approach to meeting 14 CFR § 91.113 see and avoid requirements will be accomplished through a layered integrated approach. This approach uses comprehensive airspace characterization analysis to determine the overall usage of the airspace and to help understand the overall risk of mid-air collisions. Two key components of this approach are a Letter of Procedure (LOP) with the Langley Air Force Base (LAFB) to prohibit manned aircraft operations below 900 ft AGL over the CERTAIN Range, and incorporation of a comprehensive airspace surveillance system to provide the complete airspace picture on an Integrated Airspace Display (IAD). Within this surveillance system, multiple independent sensors are included such as: 1) ADS-B, 2) Flight Alarm (FLARM), 3) dual radar system inputs from an SRC LSTAR and multiple OWL GA-9120 radars and 4) GPS positional information from all GCS. These independent sensors will be displayed within the ROAM UAS operations center to provide situational awareness of the airspace. The data will also be fused together using the Anra fusion algorithm and displayed on the IAD for evaluation (note: that Anra fusion is not required for BVLOS operations). Radar data from the ground radar systems can also be routed to the sUAS to enable airborne detect and avoid (DAA) functions for non-cooperative aircraft.

Procedures are established to monitor air traffic within the local area and identify nominal and off-nominal traffic that could pose a threat for the proposed sUAS operations. An example of this off-nominal/intruder traffic would be an aircraft within the LAFB Class D airspace at a low altitude (ie well below normal visual pattern altitudes). Criteria are established to both pause or abort operations for certain air traffic scenarios. Abort procedures are defined to maintain the well clear criteria through rapid reductions in sUAS altitudes to take advantage of protection provided by the 250 ft tall NASA LaRC Gantry structure. Abort procedures include standard response times for rapid descents below the Gantry altitude as well as response times for rapid descents and landings. Aborts are also performed for other contingency and emergency situations based on sUAS status. In the event that an identified hazards or an off-nominal scenario materialize during sUAS operations, a predefined suite of procedural risk mitigation actions are available for the crew to use during emergency and contingency situations. A simple example of these types of contingency operations is a loss of a single command and control link. If either communication link is lost or considered degraded, a precautionary abort will be performed.

Crew roles and responsibilities are also defined to manage operations and ensure well clear separations are ensured. Through working with the sUAS operations team and displays and infrastructure provided in the ROAM UAS operations center, the GCSO is assigned the primary task maintaining well clear. In this capacity, GCSOs command vehicle aborts based on air traffic displayed in the ROAM UAS Operations Center. To complement and augment the role of the GCSO, onboard autonomous detect and avoid functions are also provided through the Integrated Configurable Architecture for Remote Operations (ICAROUS) on a companion computer. ICAROUS provides alerting and flight path deviations to ensure well clear. Procedurally, if ICAROUS identifies a potential traffic conflict, the GCSO will observe the alert and react to the avoidance actions provided by ICAROUS. The GCSO will override ICAROUS commands if the situation warrants to ensure well clear is ensured. In the event of total (dual) comm link loss with the sUAS, ICAROUS will maintain well clear through usage of ADS-B and FLARM inputs.

2 Operational Environment

2.1 Prevailing Operational Requirements

Small Uncrewed Aerial Systems operations currently performed in NASA LaRC’c CERTAIN Range are performed within specific certificates of authorization (COAs) such as 2020-ESA-7889-COA. Relevant NASA and LaRC regulations are also applied from NPR 7900.3D [Reference 4], LPR 1710.16 [Reference 5], and NAII 7900.3 [Reference 6]. Comprehensive safety risk assessments are performed to ensure that the planned operations conform to these references and regulations.

NASA LaRC regularly convenes the Eastern Region Airworthiness Review Boards (ER-ARBs) to establish the airworthiness of specific vehicles and vehicle configurations within the range of the planned flight operations. Following successful completion of the ER-ARB or ARB for short, an Operational Readiness Review (ORR) is performed to examine the proposed operation.

In general, current UAS operations are performed WVLOS with a crew that includes the SP, GCSO, RSO and additional VOs as required based on the flight operation.

Flights are conducted within the NASA LaRC CERTAIN Range. The CERTAIN Range is used to conduct testing of an array of advanced NASA sUAS technologies as well as general NASA LaRC support operations. An example of a general support operation is using sUAS to perform building roof inspections. Predominantly, the vehicles used for flight testing on the CERTAIN Range are multi-rotors between 20 and 30 lbs. However, some operations include unique vertical takeoff and landing (VTOL) designs and small fixed wing aircraft. Pilot training and proficiency operations are also included as part of NASA LaRC’s nominal UAS operations.

For typical flights, the SP can see the sUAS and the airspace at all times and issues commands to the vehicle using standard R/C transmitter interface. In addition to the SP, the flight crew includes a RSO who closely monitors and provides safety oversight of the operation. RSOs are also responsible for communicating with Langley Air Force Base (LAFB) tower per the existing Letter of Procedure with LAFB. In addition to the SP and RSO, flight operations typically include a GCSO. GCSOs monitor vehicle health and mission progress, inform the SP of vehicle status and issue commands to the vehicle autopilot. Maintenance personnel perform vehicle battery charging and assist in pre-flighting the vehicle.

While sUAS flights can be performed across the CERTAIN Range, a large majority of these flights are performed in and around the yellow oval in Figure 6. The yellow oval is about 500m long by 300m wide and is the primary low-risk, WVLOS operations area for NASA Langley. The reference point for the CERTAIN Range is Latitude 37.101867 and Longitude -76.384257 which is indicated by the LaRC Ref-2 location marker in Figure 6.

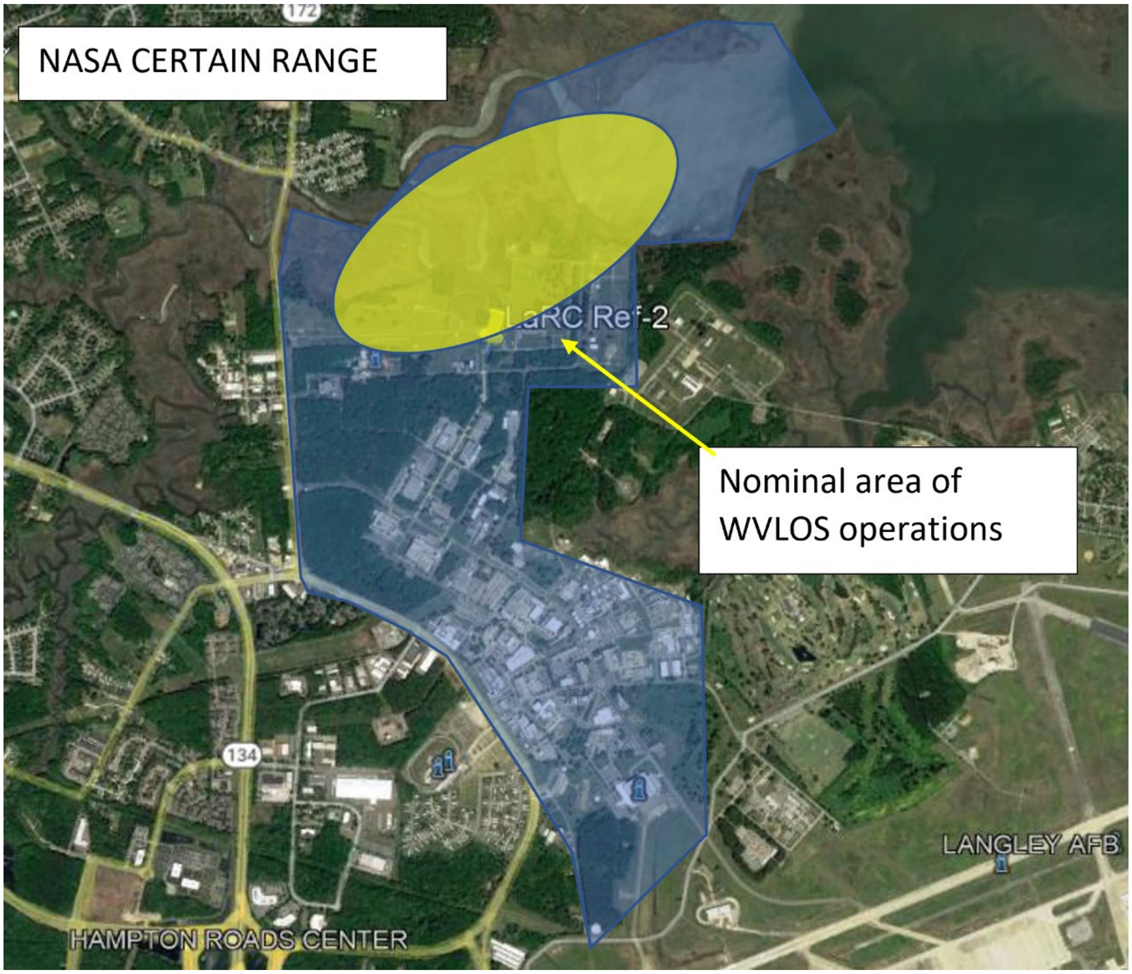

Figure 6 - Overview of CERTAIN Area with COA 2021-ESA-9599-COA Boundary

The High Density Vertiplex project endeavors to perform prototyping and assessment of envisioned UAM Ecosystem including vertiports, on-board autonomous systems, vertiport automation systems, ground control and fleet management systems, and autonomous airspace management systems. Small uncrewed aerial systems are used to perform low-cost prototype assessments of the UAM Ecosystem prototype. The proposed operations include installation of several representative vertiports and performing operations with a mix of real and simulated aircraft to reach various traffic density levels. HDV flight operations can be separated into three types: 1) WVLOS single and multi-vehicle operations, 2) EVLOS single and multi-vehicle operations, and 3) BVLOS single and multi-vehicle operations. Low density operations will likely be achieved for short periods of time through actual sUAS aircraft (see Figure 7 for an example of multi-vehicle WVLOS/EVLOS operations in the low-risk areas of LaRC). Beyond visual line of sight operations will begin with single vehicle operations over low-risk areas of LaRC and build-up to multi-vehicle operations. Expansions to high-risk overflight areas of LaRC are part of future planned efforts but are not included herein.

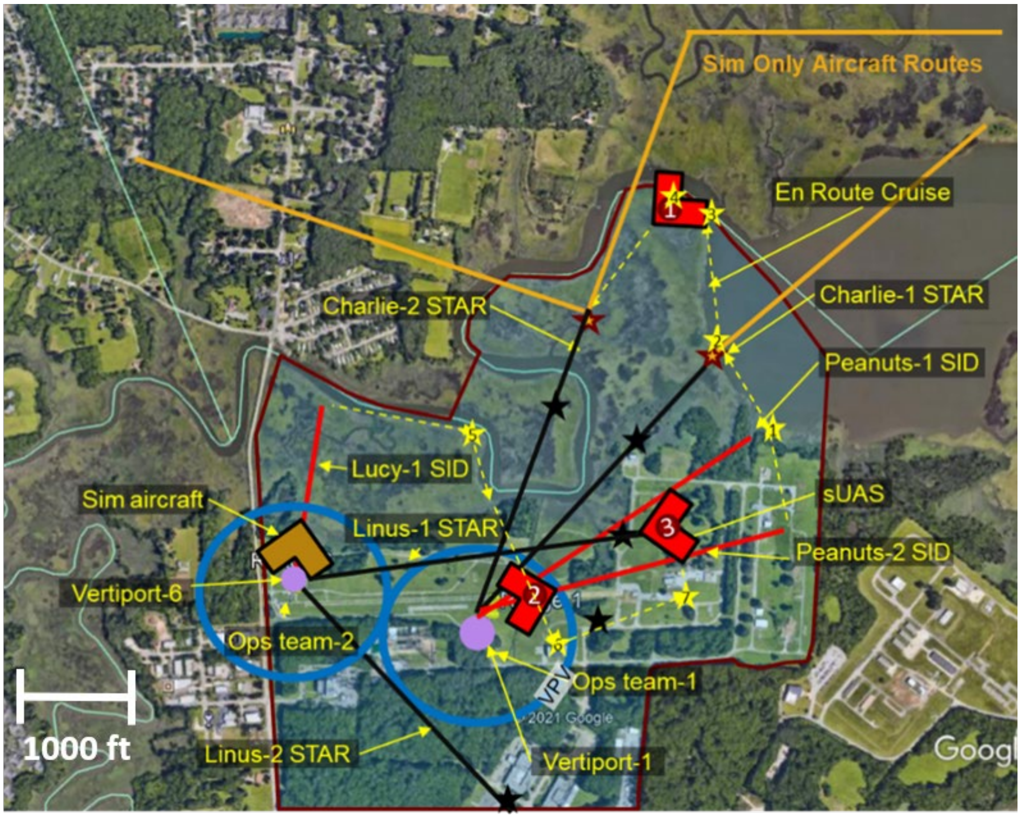

Figure 7 - Example WVLOS Operations.

2.2 Airspace and Area of Operations

Langley Research Center is located at 37 06 09 N / 076 23 12 W within the City Limits of Hampton, Virginia and is at an estimated elevation of 8.5 ft MSL. NASA Langley is adjacent to the Langley Air Force Base (KLFI), within 7.5 NM of Patrick Henry International Airport (KPHF) and 17 NM of Norfolk International Airport (KORF). The airspace within the 5 NM radius around LaRC is Class D.

The Langley Research Center borders Langley Air Force Base to the south and east, the Back River to the east and north and the city of Hampton to the West. The areas within the 5 nm around NASA Langley include the cities of Hampton, Poquoson, Newport News, and York County. Table 1 provides the population density estimates for the surrounding areas as well as NASA LaRC for both high population and low population workdays.

Table 1 - Population Densities of LaRC and Surrounding Localities.

Counties / Cities	Population (2019)	Density persons/sq mi	Land Area sq mi	Water Area sq mi
Hampton	134,510	2,614	51.46	84.81
Poquoson	12,271	780	15.36	63.10
Newport News	179,225	2,597	68.99	50.63
York County	68,280	300	105.4	110.2

LaRC High Population	3,383	2,843	1.19	N/A
LaRC Low Population	200	168	1.19	N/A

York County is a county in the eastern part of the Commonwealth of Virginia. Located on the north side of the Virginia Peninsula, with the York River as its northern border.

Poquoson is an independent city located on the Virginia Peninsula bordered by the Chesapeake Bay, Poquoson River and Back River. A large portion is tidal marsh includes plum Tree Island National Wildlife Refuge includes a 3,501-acre (14.17 km^2) refuge that is managed by the U.S. Fish and Wildlife Service.

Newport News is an independent city at the southeastern end of the Virginia Peninsula, on the northern shore of the James River extending southeast from Skiffe's Creek along the waterfront to the river's mouth at Newport News Point on the harbor of Hampton Roads.

The airspace for HDV operations is located within the LAFB Class D airspace and is referred to as the CERTAIN Range (Figure 8). The lateral confines of the CERTAIN Range are identified by the NASA LaRC property boundaries. The vertical confines of the airspace encompass surface to 400 feet above ground level (AGL).

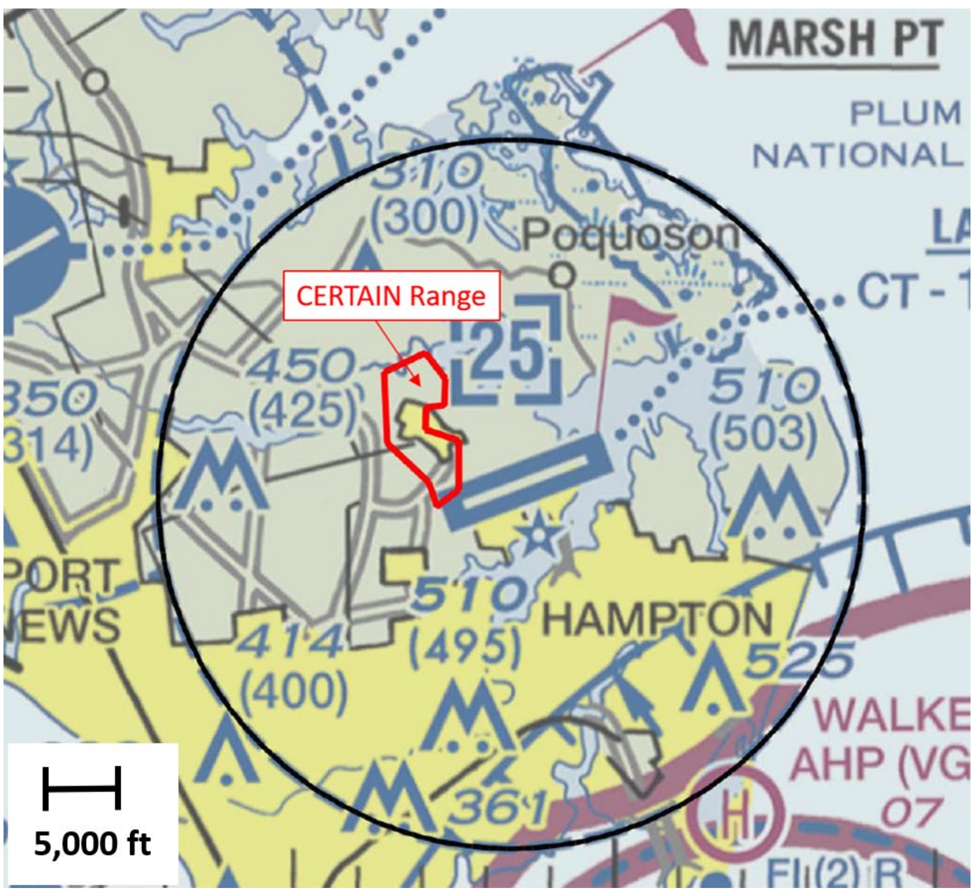

Figure 8 - Sectional Chart of Local Area with CERTAIN Range Boundary.

2.3 Current Letter of Procedure with Langley AFB

NASA LaRC has a letter of procedure (LOP) agreement with LAFB dated 1 May 2021 (Appendix A). The LOP establishes guidelines and identifies responsibilities for the safe, orderly, and expeditious operation of UAS in LAFB's Class D airspace, as well as provides instructions for operations of UAS when LAFB's Air Traffic Control Tower is closed and the airspace reverts to Class G (e.g. holidays, after hours).

The LOP with LAFB also establishes provisions for research missions that require a single pilot to control multiple UAS aircraft (M to N operations), beyond visual line-of-site operations, and flights of UAS aircraft weighing up to 125 pounds. Under the LOP, these types of operations are only authorized if an approved COA specifically authorizes these types of operations.

A summary of the LOP guidelines are as follows: 1) establishes procedures for processing NOTAMS with LAFB base operations which includes adding an advisory on Automatic Terminal Information Service (ATIS) announcing all UAS operations; 2) provides guidelines on communication procedures with security forces, LAFB Tower, and base operations; 3) establishes minimum weather requirements and documents contingency plans that include lost coms, lost link, emergency recoveries, and termination of operations; 4) establishes procedures which keep manned aircraft operations above 900 feet AGL and UAS operations below 400 feet AGL over the CERTAIN Range.

2.3.1 CERTAIN Operating Range

The LOP divides LaRC into four sections labeled CERTAIN I, II, III and IV (Figure 9).

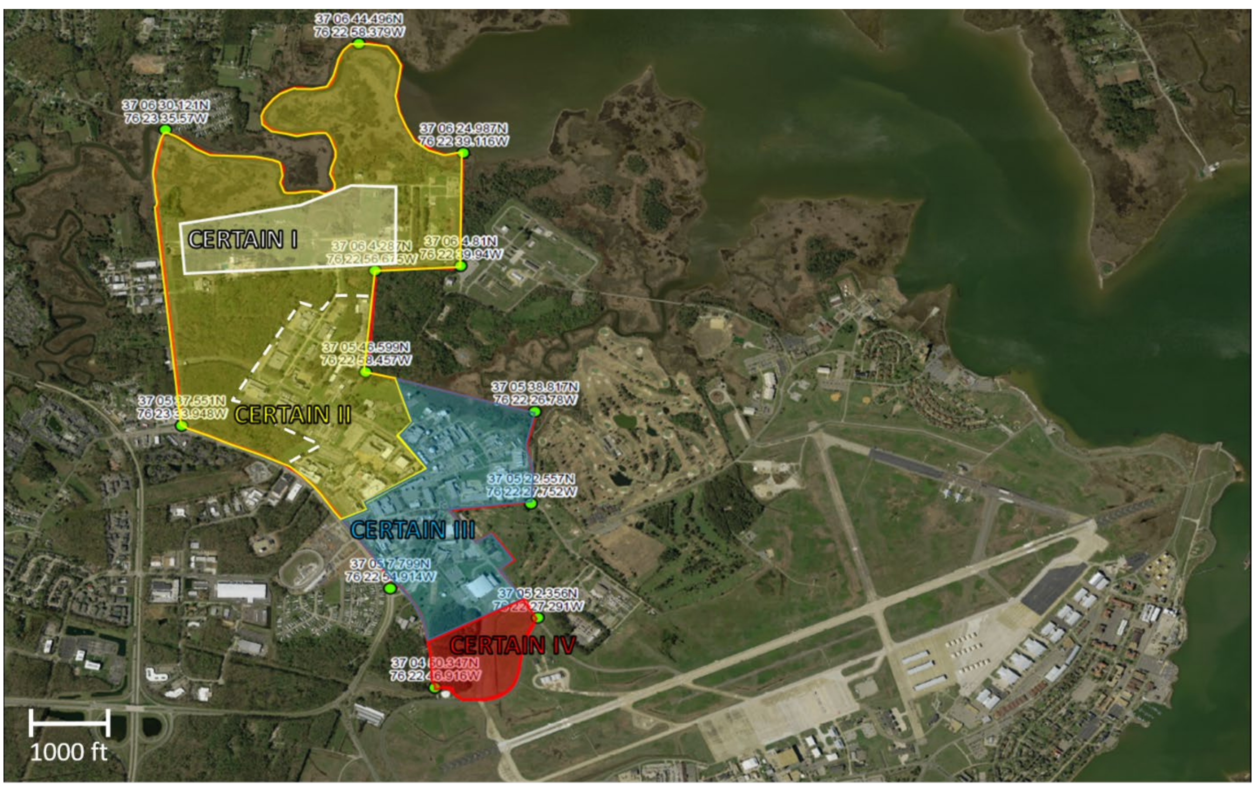

Figure 9 - NASA LaRC CERTAIN Range Definition in the Letter of Procedure with LAFB.

Together, CERTAIN I, II, III, and IV make up the CERTAIN Range. CERTAIN I and portions of CERTAIN II are rural in nature. CERTAIN II-a is to the north of the white dashed line and covers areas of NASA LaRC that are unpopulated or have very low numbers of workforce populating buildings (<10 workers per building). CERTAIN II-b is to the south of the white dashed line and covers areas of NASA LaRC that more closely resemble an industrial park or college campus with more concentrated population, parking lots, walkways, and buildings. Operations in CERTAIN II-a pose a very small risk to people and infrastructure on the ground. The southern half of CERTAIN II (CERTAIN II-b) and CERTAIN III are more urban in nature with two, three, four and five story buildings. Over 96 percent of the NASA LaRC workforce is concentrated in the CERTAIN IIb and III areas. CERTAIN IV includes the NASA LaRC ramp and Taxiway H that leads to Langley AFB runway 8/26. NASA LaRC has the authority to control vehicle and foot traffic in all areas of the CERTAIN Range to control risk during operations over people.

2.4 CERTAIN Range Certificates of Authorization

NASA Langley also has several Certificates of Authorization with the FAA that allow for UAS operations in Langley AFB's class D airspace. COAs include 2020-ESA-7889-COA for operations of vehicles below 55 lbs and 100 mph which is included in Appendix B. Other COAs for operations of vehicles above 55 lbs and 100 mph are covered in 2020-ESA-10788-COA. Recently, NASA LaRC applied for special provisions to start expansion of sUAS operations to include BVLOS testing. In December 2021, COA 2021-ESA-9599-COA was received that removed requirements for PMC's to be able to see the vehicle and airspace at all times and provided an expanded area for operations to the northeast. COA 2021-ESA-9599-COA is also included in Appendix B. Figure 10 illustrates the COA boundaries provided in 2021-ESA-9599-COA and establishes the basis for operations described herein.

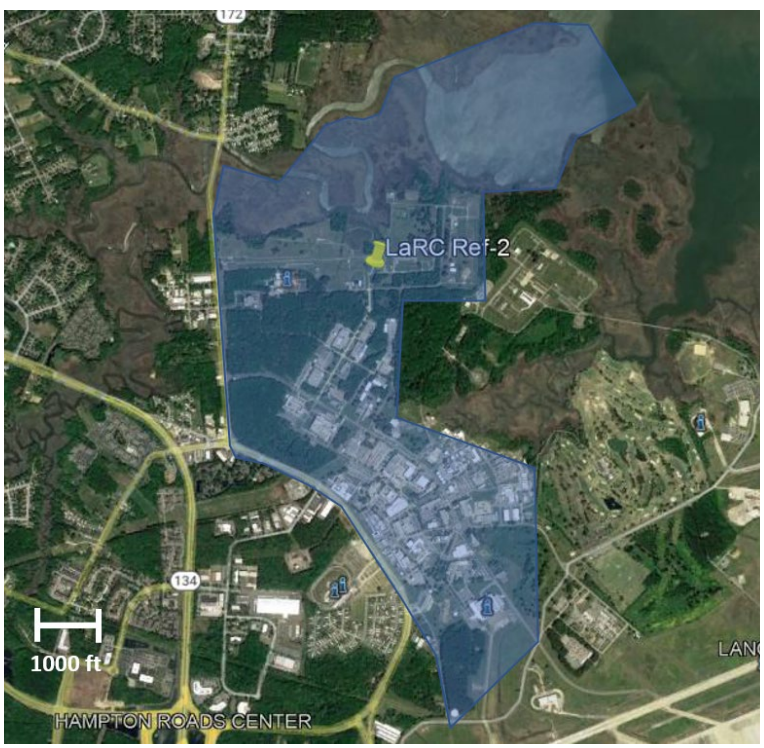

Figure 10 - 2021-ESA-9599-COA Airspace Definition.

The combination of the LOP with LAFB and the approved FAA COAs authorize NASA LaRC to operate fixed wing and vertical take-off and landing multi-rotor UAS platforms weighing less than 125 pounds, at airspeeds no greater than 87 knots (100 mph), at altitudes no greater than 400 feet AGL utilizing personnel (PICs or VOs) in the field to satisfy 91.113 see and avoid requirements.

2.5 Airspace Demographics

Langley AFB (KLFI) Class D airspace is adjacent to Newport News (PHF) class D to the northwest and the Norfolk (KORF) Class C veil to the southeast. Figure 11 illustrates the various airspace categories in use in the general vicinity of NASA LaRC.

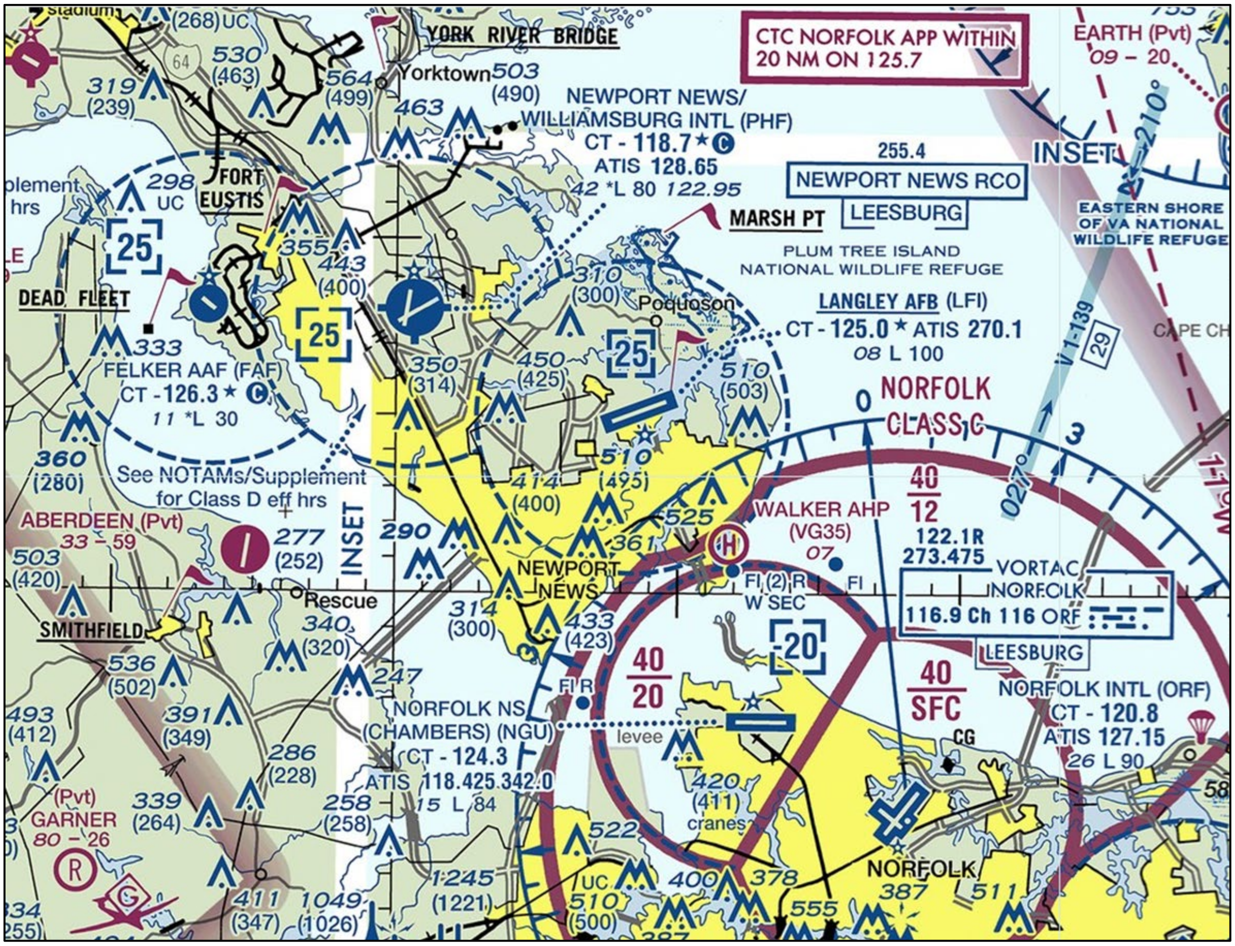

Figure 11 - FAA Sectional Chart of Area.

KLFI has both precision Instrument Landing System (ILS) and Localizer Performance with Vertical guidance (LPV) precision approaches and non-precision Localizer (LOC), Tactical Air Navigation (TACAN) and Lateral Navigation (LNAV) approaches to runway 08/26. Runway 08/26 is 10,000 feet long with a 1,000-foot underrun/overrun at each end. KLFI also has specific Visual Flight Rules (VFR) arrival and departure procedures for their home station aircraft to help expedite fighter aircraft launches and recoveries. KLFI VFR pattern procedures include VFR reporting points, segregated altitudes, right-of-way rules and breakout procedures. Transient aircraft typically arrive and depart under IFR control. VFR traffic patterns for KLFI include right patterns for runway 26 and left patterns for runway 08. As a result, a large majority of the KLFI local traffic overfly NASA LaRC and the CERTAIN Range. All local VFR pattern procedures are procedurally deconflicted (greater than 500’ altitude separation) from the CERTAIN

Range and the LOP specifically prohibits manned aircraft from flying lower than 900 feet above ground level (AGL) during UAS operations in CERTAIN.

2.5.1 Airspace Characterization

2.5.1.1 The Langley Monitoring Volume (Threat Volume)

The Langley Monitoring Volume (LMV) is illustrated in Figure 12 and establishes a traffic monitoring area of 5 NM to support the proposed BVLOS operations. Its purpose is to define a specific area to monitor air traffic and to facilitate sUAS operational aborts and/or precautionary actions enacted by the operations team to ensure well clear distances are maintained (for more detail see Section 6.9).

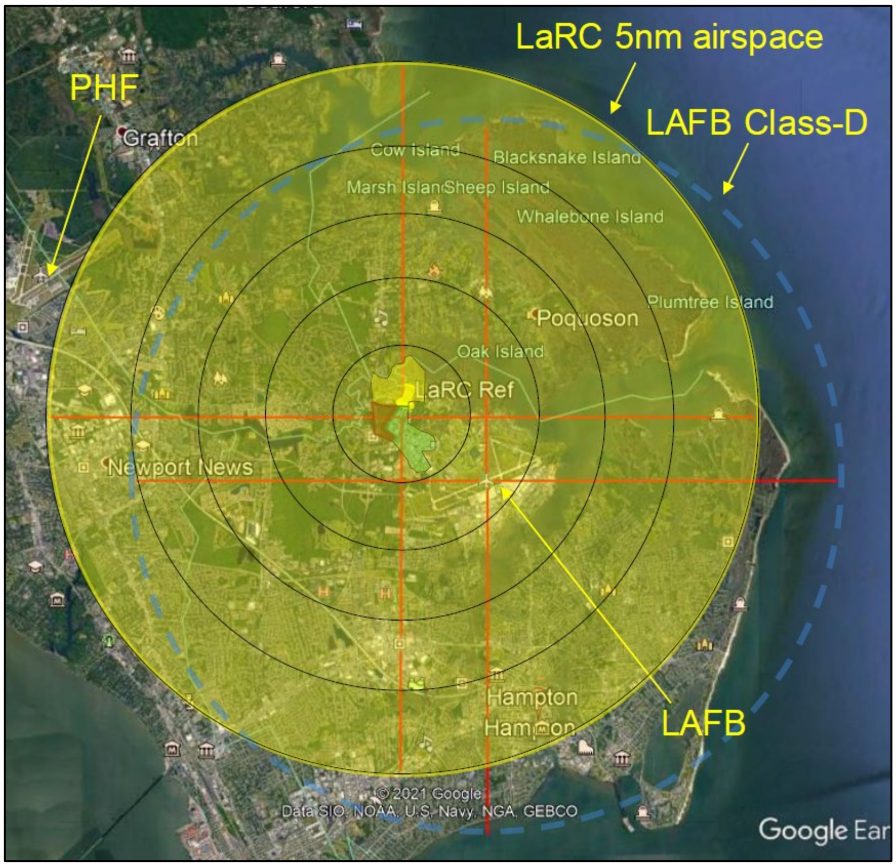

Figure 12 - Langley Monitoring Volume.

It is assumed that the most likely potential intruder aircraft would have a maximum ground speed of 120 knots covering 2 NM/minute. Sizing the LMV to extend 4 NM beyond the core area was intended to provide an approximate 2-minute warning for the sUAS operations team. The LMV was further broken down into sub areas based on radial distance from the LaRC reference point, altitude above ground level, and cardinal heading (ie NW, NE, SE, and SW). Sub areas of the LMV are provided in Figure 13. The primary core area is defined as the airspace within 1 NM of the LaRC reference point up to 400 ft AGL. Additional core areas (ie C2, C3, C4, C5) are defined as concentric rings spaced every 1 NM out to the extent of the LMV (5 NM). Similarly, the primary buffer area is the airspace directly over the core area extending from 400 ft up to 900 ft AGL with additional buffer areas out to the extent of the LMV (ie B2, B3, B4, B5). Lastly, overflight areas are defined from the top of the buffer areas from 900 ft up to

2,500 ft AGL with a similar approach (ie O2, O3, O4, O5). In total the LMV has 60 sub areas (three altitudes, five radial distances, and four cardinal heading sectors).

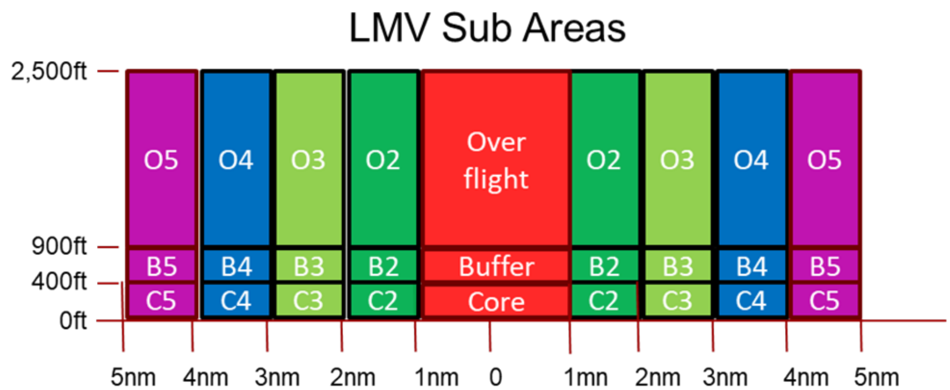

Figure 13 - LMV Subarea Definition.

Lateral separation of 2,000 ft or vertical separation of 250 ft will be maintained from manned aircraft. Traffic will be monitored within the LMV to ensure maintenance of well clear volumes. Nominal traffic is that which is expected to exist within the LMV with the ability to predict future locations of these aircraft and is not expected to penetrate the minimum safe separation criteria. Most of these aircraft are stationed at KLFI and follow the defined KLFI Tower VFR pattern procedures. Off-nominal (or intruder) aircraft are typically transient aircraft who may not follow KLFI Tower VFR pattern procedures and will be more closely tracked.

2.5.1.2 Airspace Characterization Overview and Approach

Langley Air Force Base is 1.8 miles southeast of the LaRC CERTAIN reference point and is home to two squadrons of F-22 fighter aircraft and one squadron of T-38 aircraft. F-22 and T-38 flights launch daily during the week and occasionally on the weekends. There are also five NASA aircraft based at KLFI (G-III, G-IV, B-200, SR-22 and an LC-40). These aircraft fly on an as needed basis to support NASA test missions. Transient aircraft occasionally land and takeoff from KLFI using prior permission required (PPR) authorization. Some common transient aircraft include C-5, C-12, C-17, C-21, LJ-35, C-37, C-130, F-15, F-16, UH-1, MH-53 and UH-60. It is estimated that an average of 512 aircraft operations take place per day according to AirNav.com.

Newport News/Williamsburg airport (KPHF) is 6.4 miles west northwest of the LaRC reference point. KPHF is also Class-D airspace with significant GA activity and some commercial regional airline traffic. KPHF has four runways (02/20 and 07/25). It is estimated that a total of 107 aircraft operations occur per day at KPHF with a total of 127 aircraft based at this location according to AirNav.com.

An airspace characterization analysis was performed to help to establish the risk of mid-air collision with manned aircraft operations. To accomplish this study, the airspace around the CERTAIN Range was broken into concentric rings from 1-5 NM, centered at the CERTAIN reference location (37.1019, -76.3843). For this study, a 6-month window was defined to help shape the analysis. The flight test plans for the HDV project involve three main multi-month flight tests occurring over four years. Each flight test for HDV (ie AOA, SAO, VO) are planned to span approximately 2 months and occur about 13 months apart. The months of the year that these flight tests will occur are expected between February and

August. To acquire the most relevant pre-pandemic data, the timeframe selected for the study was from 2/2019 through 8/2019. Proceeding in this manner provides relevant data for the planned months of BVLOS operations.

Airspace characterization data were acquired from several sources, including Automatic Dependent Surveillance Broadcast (ADS-B) data from FlightAware, System Wide Information Management (SWIM) data from NASA Ames's Sherlock Data Warehouse, and Performance Data Analysis and Reporting System (PDARS) data from Airborne Tactical Advantage Company (ATAC). Initially the FlightAware data was used to assess the analysis approach employing the LMV architecture. The concentric rings of the LMV define a series of threat volumes to assess the risk of planned sUAS operations.

The SWIM and PDARS data together served as the primary sources of flight data that included IFR, VFR, and military flights. For the flights around LaRC, the SWIM and PDARS data systems drew flight data from nearby Terminal Radar Approach Control (TRACON) facilities including Norfolk International Airport (KORF), Raleigh-Durham International Airport (KRDU), Fayette Regional Airport (KFAY), Washington Airport (KDCA), Florence Regional Airport (KFLO), and others that received flight data. All SWIM and PDARS flight data included standard flight data such as aircraft position (lat/lon), altitude, time, ground speed, Beacon code, aircraft ID (if provided), and origin / destination (if provided).

Results from the characterization analysis show the numbers of flights that flew through the various subregions of the LMV and include detailed inspection of flights that flew through the core area. Note the core area is within 1 NM of the LaRC reference location and below 400 ft. All analysis and flight visualization were conducted with MATLAB and Jupyter Notebook (Python).

2.5.1.3 Results from the Airspace Characterization

The results from the airspace characterization are provided in Tables 2 and 3 and Figure 14. Table 2 shows the results for all portions of the LMV whereas Table 3 only presents results for SW, NW, and NE quadrants of the Core area. It should be noted that the proposed BVLOS operations proposed herein would be in the SW, NW, and NE Core quadrants. Figure 9 illustrates the aircraft tracks that penetrated the SW, NW, and NE quadrants for at least 10 seconds with their trajectories highlighted in green for when these aircraft were within these quadrants.

Table 2 - Airspace Characterization Results.

Total: 44654	0-1 (nm)				1-2 (nm)				2-3 (nm)				3-4 (nm)				4-5 (nm)				5+ (nm)			
900-2500 ft	Total (OF)				Total (O2)				Total (03)				Total (O4)				Total (O5)				Total (O5+)			
	1331				2577				3946				5726				12265				35357			
	NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW
	678	758	812	357	1457	1434	1918	576	1457	1383	1918	936	2221	1040	2075	1950	2816	415	2123	8941	9062	14384	####	19392
400 - 900 ft	Total (Buffer)				Total (B2)				Total (B3)				Total (B4)				Total (B5)				Total (B5+)			
	267				1863				2317				2495				9293				33795			
	NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW
	72	212	125	49	159	860	1363	77	249	1234	1088	95	831	1290	457	728	653	750	374	7987	4219	16904	7649	18701
<400 ft	Total (Core)				Total (C2)				Total (C3)				Total (C4)				Total (C5)				Total (C5+)			
	39				1072				567				131				4349				26266			
	NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW
	1	32	6	2	27	914	432	5	24	494	70	3	34	89	18	17	100	29	98	4138	2814	14194	4561	11968

The data presented in the tables do not account for the status of the CERTAIN Range (active or inactive) or whether the tower was open or closed. During this analysis period, a total of 66 sUAS operational days were conducted which results in CERTAIN being active during portions of approximately 31% of the days. One challenge to this airspace characterization effort was that while sUAS operational dates were known, the precise start and end times of sUAS operations were not known. As a result, the data presented below indicate the traffic levels that are more consistent for the LMV for when sUAS operations were not being conducted (ie CERTAIN Range inactive) as well as times when the LAFB tower was open and closed (Class-D or Class-G airspace). For the BVLOS operations proposed herein, operations will be performed with the LAFB tower open and CERTAIN Range active and only in the SW, NW, and NE quadrants.

One significant result of the airspace characterization was that there were a total of 41 flights that entered the core area which is not a surprising result considering the proximity to LAFB. In Table 2 it can be seen that many of these flights passed through the SE quadrant which would be expected due to its proximity to the LAFB runway. Excluding the SE quadrant, Table 2 shows that a total of 8 aircraft penetrated the core area (ie within 1nm of the LaRC reference point and below 400 ft AGL). Table 2 indicates 9 total aircraft penetrations as one aircraft had 2 separate entries. The other 23 other aircraft penetrated the SE core quadrant and were aircraft operating to/from LAFB.

Table 3 - Flights That Penetrated SW, NW, and NE Core Quadrants.

Flight Unique ID	Color	Date	Day of Week	Time	Beacon Code	Aircraft ID (call sign)	Aircraft Type	Core Ground Speed (Knots)
29076		2/15/2019	Friday	3:19 PM	1200	1200	Unknown	88-105
37137		4/7/2019	Sunday	8:46 AM	4344	N54452	C172	54 - 58
27168		2/27/2019	Wednesday	9:42:55	1200	1200	Unknown	41 - 58
28189		4/11/2019	Thursday	8:17:58	1200	1200	Unknown	24 - 54
25819		7/2/2019	Tuesday	9:45:18	1200	1200	Unknown	22 - 55
27324		8/1/2019	Thursday	10:52:39	1200	1200	Unknown	10 - 58
30094		8/1/2019	Thursday	11:46:55	1200	1200	Unknown	17 - 59
18124		8/13/2019	Tuesday	10:43:17	1200	1200	Unknown	74 - 84

Of the 8 aircraft, a total of 6 were determined to likely be helicopters based on their ground speed while maneuvering within the core volume. Two aircraft were likely to be fixed wing aircraft (29076 and 37137). Aircraft 37137 was designated as a C-172 in the PDARS database and entered the Core area on a Sunday, however its' ground speed is very low and just above the stall speed of a C-172. After leaving the LMV area, aircraft 37137 accelerated to speeds more consistent with a C-172. Aircraft ID 29076 was also determined to likely be a NASA LaRC aircraft that potentially descended below 400 ft for a brief period while crossing the CERTAIN Range.

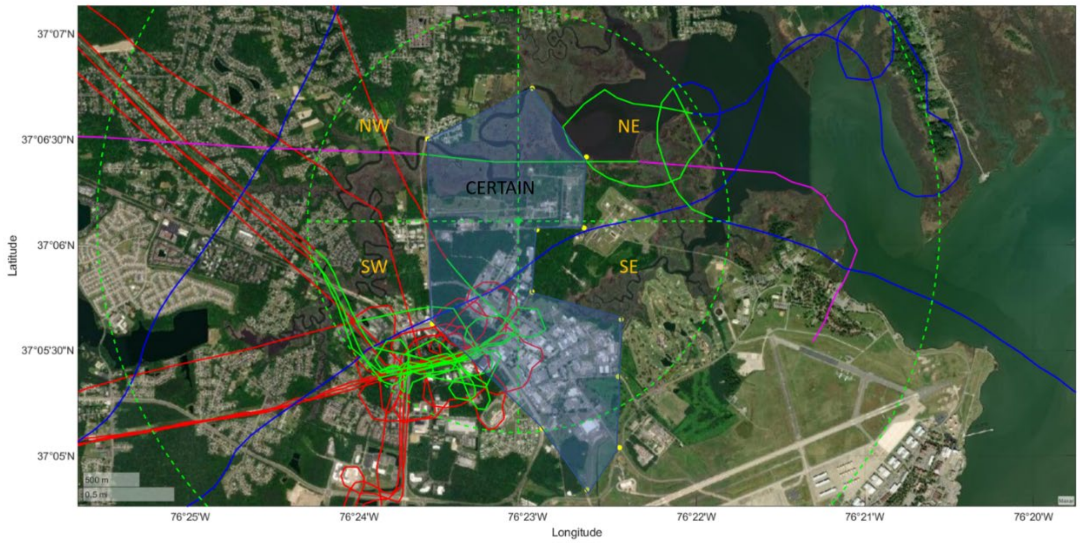

Figure 14 - Flights That Penetrated the SW, NW, and NE Core Area Segments Based on PDARS Data Analysis.

Some limitations of the current airspace characterization effort include accuracy of the reported altitude. Based on analysis of the aircraft altitude vs time revealed that altitudes were reported to the nearest 100 ft increment and update rates were on the order of 30 seconds or more. There are also some other anomalies in the altitude data that degrade the apparent accuracy. For example, some altitude profiles have +/-100 jumps more rapidly than an aircraft could be expected to support and is likely due to sensor and/or system error. It is possible that some errors are resident within the various databases used herein and results should be considered as approximate.

2.6 Atmospheric Environment

The CERTAIN Range, located in Hampton VA, has summers that can be warm and muggy, winters that may be cold and windy, with precipitation and varying cloud cover year-round. Average temperatures vary from 33 degrees F to 87 degrees F. The climate in Hampton VA allows NASA Langley to conduct sUAS operations year-round, provided the maximum/minimum temperature, wind limits, minimum ceiling and minimum visibility requirements specified in the LOP or NPR 1710.16 are not violated. Small UAS operations are not conducted during rain or snow. Figure 15, taken from weatherspark.com, shows average climate conditions in Hampton, Virginia.

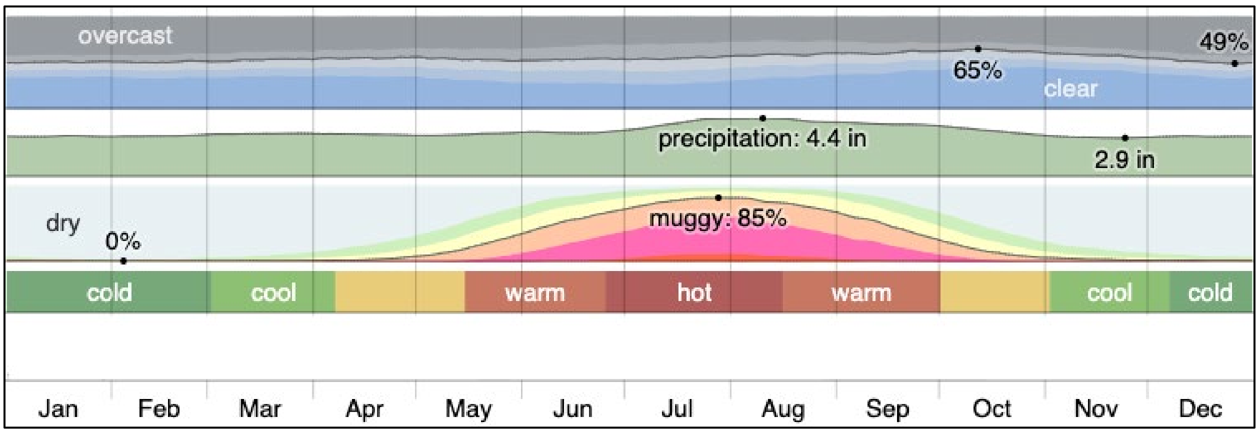

Figure 15 - Hampton, VA, Average Climate Conditions.

2.7 Radio Frequency Environment

All radio frequency (RF) emitting devices on NASA Langley are reviewed by the Spectrum Management Office (SMO) prior to use. The SMO conducts a thorough review of each system, to include transmit power levels, frequencies spectrums and the potential for interference with other devices on center. Each RF device receives a radio frequency authorization (RFA) which specifies the location of use, the operating frequency band, the authorized duration, the maximum power density, the minimum safe range and any other restrictions that may apply.

All sUAS telemetry devices transmitting and receiving command and control messages shall undergo a link analysis to identify vulnerabilities in the command and control links. This link analysis shall be presented to the Airworthiness Review Board as part of NASA Langley's airworthiness certification process.

NASA Langley has also installed four Radio Frequency Monitoring Systems (RFMS) RF detection systems capable of detecting frequencies up to 8 GHz and generating heat maps to identify threats to communication and navigation links. The system will also be used to perform a thorough review of the CERTAIN airspace to identify and characterize the RF environment. The RF characterization is scheduled to take place during calendar year 2022. The RFMS RF monitoring system will be used to look for maximum power levels across a range of frequencies and record the maximum value in 15-minute intervals. Those max RF spectrum summaries will be recorded for 3 months and then summarized to support a risk/threat assessment for the vehicle telemetry links (See Appendix G for complete analysis). An example max RF spectrum plot is included for reference.

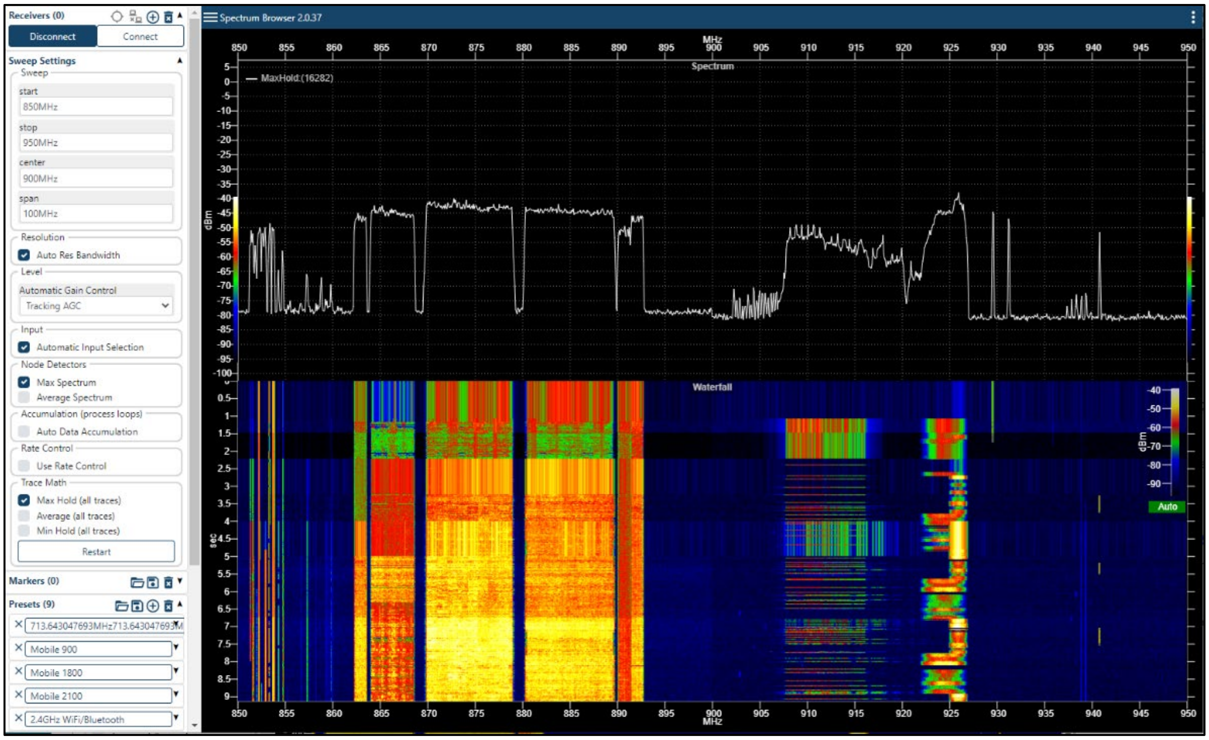

Figure 16 - Example RF Spectrum Analysis.

2.8 Federal Aviation Administration Requirements

A number of general operational requirements exist that must be fulfilled for conducting sUAS operations in the National Air Space (NAS). This section is included to provide a summary of the relevant Federal Aviation Administration (FAA) operational requirements considered applicable to the proposed BVLOS operations.

One reference consulted was FAA 8900.1 Flight Standards Information Management System (FSIMS). Overall, FSIMS includes 16 Volumes ranging from General inspector Guidance and Information (Volume 1) to Continuous Airworthiness Maintenance Program (Volume 20). Selected requirements taken from FAA 8900.1 are listed in this section.

2.8.1 Radar and Other Sensors

Utilizing special types of radar systems or other sensors to mitigate risk requires providing supporting data which demonstrates that the following can be accomplished safely:

- Both cooperative and noncooperative (air) traffic can be detected and tracked to ensure appropriate separation and collision avoidance.
- The proposed system can effectively mitigate a potential collision.
- Operators are suitably trained and equipped to use the system effectively, and
- Procedures are in place for the Pilot in Command (PIC) to effectively use the data.

2.8.2 Lost Link Points

Failure modes associated with degraded and/or total loss of command and control (C2) links need to be considered such that in the event of credible failure modes the sUAS remains within the authorized operational area. One such element of C2 link loss is to define lost link points that the sUAS will use to either regain C2 link or to manage its trajectory to remain within the authorized operational area. Lost Link Points (LLPs) must be defined in the event of a total loss C2 link. LLPs shall be designed to:

- Hold/loiter for a defined period or until the C2 link is re-established, or
- Proceed to another LLP or
- Autoland, or
- Proceed to a Flight Termination Point (FTP) (which may itself be an LLP) to terminate flight.

Moreover, in concurrent and multiple UAS operations, the relevant sUAS will be segregated, e.g., through a combination of altitude offsets and/or horizontal separation or separated in time if flying the same trajectory and use independent LLPs for deconfliction in the event of simultaneous loss of C2 links which is considered a highly remote possibility at most.

2.8.3 Flight Termination System

When a UAS does not have system redundancies and independent functionality to ensure overall safety and predictability of the system, then a Flight Termination System (FTS) may be required, whose architecture and activation are independent of the UAS and which may be manually or automatically invoked by the aircraft PIC.

2.8.4 Spectrum Authorization

Spectrum authorization must be obtained from the National Telecommunications and Information Administration (NTIA) or the Federal Communications Commission (FCC) to transmit on the radio frequencies used for uplink/downlink of control, telemetry, and payload information.

2.8.5 Observer Requirement

Visual Observers (VO) located on the ground, or in a dedicated chase aircraft may be required to assist the PIC with navigational awareness, and in exercising the see-and-avoid responsibilities required by (and for complying with) 14 CFR Parts 91.111, 91.113 and 91.115, by scanning the area around the aircraft for potentially conflicting traffic. VOs must be able to see the aircraft and the surrounding airspace to determine the proximity of the sUAS to all aviation activities and other hazards (e.g., terrain, weather, and structures). Additionally, VOs must be able to assist the PIC with exercising effective control of UAs, prevent them from creating a collision hazard, and inform the PIC before losing visual contact either with the UA or with a previously sighted collision hazard.

2.8.6 Air Traffic Control Communication Requirements

The UAS pilot must establish and maintain direct two-way radio communication with appropriate Air Traffic Control (ATC) facilities if stipulated under the requirements of the authorization to operate.

2.8.7 Intercommunication Requirements

Unless approved otherwise, only the PIC shall communicate with Air Traffic Control (ATC). Any VO, sensor operator, or person charged with providing see-and-avoid assistance must have immediate communication capabilities with the sUAS PIC. If the sUAS PIC is in communication with ATC, then that frequency is recommended to be monitored by all crewmembers, for shared situational and navigational awareness.

2.8.8 Electronic Devices

Electronic devices including cellular phones should not interfere with the UAS. Electronic devices, including cellular phones cannot be used for primary communication with ATC unless authorized.

2.8.9 Flights Over Congested Areas

UAS operations over nonparticipants may be approved under the terms of a waiver, conditions of exemption, where the level of airworthiness allows, or in emergency or natural disaster relief situations if the proposed mitigation strategies are found to be acceptable. Note: as a public use entity, NASA Langley shall review and, if appropriate, certify UAS vehicles as airworthy for operations over nonparticipants. Also note that operations over people are not included within the current plans.

2.8.10 Day/Night Operations

UAS operations outside of Class A Airspace, active restricted or warning areas designated for aviation use, or approved prohibited areas, will be conducted during daylight hours.

2.8.11 Visibility Requirements

sUAS operations shall be conducted in Visual Meteorological Conditions (VMC) and shall maintain the cloud clearances stipulated by 14 CFR Part 107.51 (i.e., the minimum distance of the sUAS shall be no less than 500 ft below clouds and 2000 ft horizontally from clouds).

2.8.12 Automation in sUAS Operations

Only those UAS, which have the capability of direct pilot intervention will be allowed in the NAS outside of active restricted or warning areas designated for aviation use or approved prohibited areas. Because the pilot may be technically considered out-of-the-loop in a lost link scenario, this restriction does not apply to sUAS operating under lost link.

2.8.13 Airspace Considerations by Airspace Designation for Class-D

Requests for approval will be handled on a case-by-case basis and may be approved if sufficiently mitigated and subject to the terms established herein. UAS operations approved for Class D must comply with 14 CFR 91.129. For public aircraft, a Letter of Agreement (LOA) (or Letter of Procedure) between the operator describing sUAS segregation procedures may be required. Small UAS operations must not impede, delay, or divert other Class D operations.

2.8.14 In-Flight Emergencies

The PIC shall notify ATC of any in-flight emergency, any loss of control links, or accidents as soon as practical.

In addition to these, there are also requirements on Crew Resource Management (CRM) (16-4-5-7 (L)), specifying the training needs for the crew involved in UAS operations, and sterile cockpits (16-4-5-7 (M)).

2.9 Langley Air Force Base Requirements

A LOP establishes guidelines and identifies responsibilities for the safe, orderly, and expeditious operation of sUAS in Langley AFB’s Class D airspace. The LOP specifies the following requirements for NASA Langley:

2.9.1 Conduct all UAS operations in accordance with LaRC Aviation Operations and Safety Manual, LPR 1710.16, Chapter 5, Uncrewed Aircraft Systems.

2.9.2 UAS procurement, modification, and/or experimental build shall be in accordance with the NASA Langley UAS Information Technology System Security Plan.

2.9.3 Provide a Hazard Analysis submitted by the Range Safety Officer (RSO) in accordance with LPR 1710.16, Chapter 5, Section 8, UAS Range Safety.

2.9.4 Maintain trained and qualified personnel for untethered UAS operations.

2.9.5 Maintain NASA Radio Frequency Authorizations for all radio control and data links in accordance withLMS-CP-5511, Requesting or Coordinating Radio Frequency Authorizations.

2.9.6 Ensure that no Air Force assets will be recorded by sensors on board the UAS. The RSO shall monitor and screen all video and photographs to ensure this requirement is met.

2.9.7 Coordinate with Airfield Management Operations (AMOPS) and Security Forces Base Defense Operations Center (BDOC).

2.9.8 Conduct a two-way radio communication check between the operator and the Tower prior to any operations.

2.9.9 Be prepared to expedite recovery and landing of the UAS if directed by the Tower.

2.9.10 Notify tower in the event of extended loss of command link or any other malfunction or occurrence that would suggest termination of UAS operations.

2.9.11 Notify tower, AMOPS and BDOC that UAS operations are complete.

2.10 NASA Requirements

NASA aircraft and flight operations, including those with UAS, are subject to NASA Procedural Requirements (NPR) and Langley Procedural Requirements (LPR) pertaining to the safety policy (NPR 8715.3D), range safety (NPR 8715.5B [Reference 3]), range flight safety requirements (NASA-STD-8719.25 [Reference 2]), aircraft operations management (NPR 7900.3D), aviation operations and safety manual (1710.16), airworthiness review process (NAII 7900.3) and any additional requirements set forth by the NASA center-specific Airworthiness Review Board (ARB) and Operational Readiness Review (ORR). Thus, all UAS will undergo an airworthiness determination at the ARB, while operations will undergo an Operational Readiness Review (ORR). Additionally, when multiple sUASs are flown, as intended for the present CONOPS discussed in Section 6, a Mission Readiness Review (MRR) will also be conducted.

2.10.1 Airworthiness Review Board

All manned and uncrewed aircraft conducting NASA owned, sponsored, contracted, or partnership operations shall be formally evaluated and approved by the Airworthiness Review Board (ARB) prior to commencing flight activities. Per NPR 7900.3, these reviews are to identify system hazards to minimize risks to persons and property and to enhance the likelihood of mission and program success. The product of the ARB is an Airworthiness Statement.

2.10.2 Operational Readiness Review

The ORR process occurs after the aircraft has a valid Airworthiness Statement, and reviews and authorizes the aircraft to conduct the flight activities. The ORR reviews the operational hazards to minimize risk to persons and property, certifies that the UAS test flight operation is ready to deploy and that the vehicle operations and associated risks of the intended mission are accepted at the appropriate level. The product of the ORR is a risk acceptance and a flight authorization or authority to proceed with the mission.

2.10.3 Aircrew Certification and Training

NASA Langley has a training officer who provides oversight for all aspects of UAS flight crew training and certifications. Specific training programs exist for sUAS Pilots, VOs, flight test leads, GCSOs, and RSOs. These programs include both an initial certification training plan and an annual refresher training plan. Components of each training plan vary but they all include emergency procedure training, crew resource management training, review of flight operations manuals, review of 14 CFR 91.111, 91.113, 91.155, review of the national airspace, review of observer requirements, review of approved COAs and a review of all signed LOPs.

NASA Langley also has currency requirements for PICs. All UAS PICs shall have completed three flights within the preceding 90 days. UAS pilots out of flight currency shall accomplish three flights minimum to re-establish fight currency before supporting research operations.

As part of the HDV project, a new training plan is being developed for BVLOS GCSOs. This plan will include all elements identified above with additional topics pertaining to BVLOS operations, BVLOS emergency procedures, event triggers with memorized responses and communications training. Upon successful completion of this new training plan, GCSOs will be designated as GCSO PICs.

2.10.4 NASA Policy Requirements

As defined in NPR 7900.3D, NASA Mission Qualification Standards (MQS) for Level 1 operations (operations below 1,200 feet) are restricted to WVLOS/daisy chain operations. An MQS waiver is required for BVLOS operations. NASA LPR 1710.16 requires the PICs to complete a NASA LaRC developed BVLOS training plan and requires the GCSO to be a PIC for BVLOS operations. Additionally, when transferring control modes (ex. Radio Control from field to GCSO control from ROAM) during BVLOS operations, a new PIC shall be declared, and the PIC responsibilities shall be transferred.

2.10.5 Contingency Management System

As defined in NASA-STD—8719.25, a contingency management system (CMS) is designed to provide a controlled response. A CMS may provide for deliberate termination for an errant/erratic vehicle's flight but is not considered a flight termination system (FTS) unless the system meets the FTS tracking, telemetry, and command requirements of NASA-STD-8719.25. A CMS that does not meet FTS requirements may be considered as risk mitigation and factor into the range safety risk assessment. Activation of a CMS shall not increase the risk to people or property. If the CMS is to be used for risk mitigation, verification of system functions shall be demonstrated prior to flight.

3 Flight Review Approval

3.1 Flight Test Approval Process

The NASA Langley Flight Test Approval Process involves many NASA organizations working together to ensure a flight campaign/mission is executed at the appropriate risk level. The two main components of this process include an Airworthiness Review Board (ARB) and an Operational Readiness Review (ORR). Figure 17 documents all the steps needed to execute the ARB and the ORR. Completing those two reviews satisfies all review requirements and authorizes a specific flight campaign/mission toto Proceed with the planned flight missions.

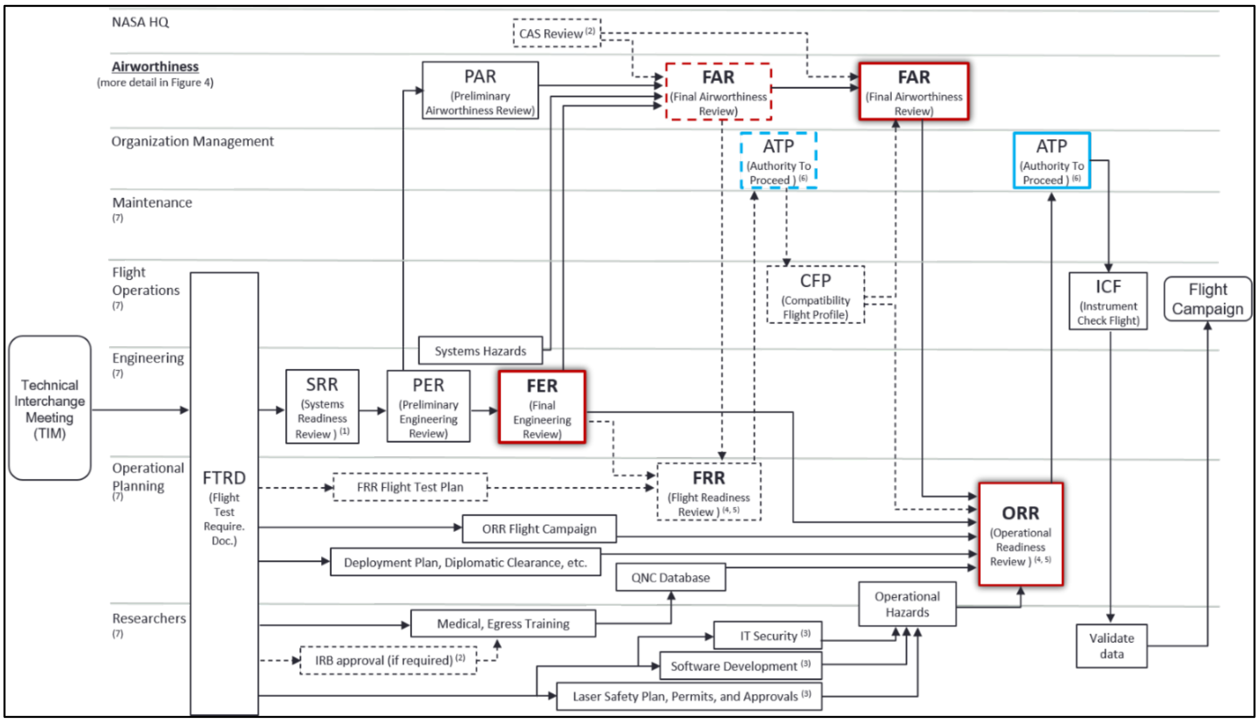

Figure 17 -Reviews Associated with Flight Testing at NASA LaRC.

3.2 Airworthiness Review Board

All manned and uncrewed aircraft conducting NASA owned, sponsored, contracted, or partnership operations shall be formally evaluated and approved by the Airworthiness Review Board (ARB) prior to commencing flight activities. Per NPR 7900.3, these reviews are to identify system hazards to minimize risks to persons and property and to enhance the likelihood of mission and program success.

The airworthiness review process is an engineering and system safety analyses process to determine that an aviation system or its component parts meets minimum design criteria, standards, and configuration for the conduct of safe flight operations, and that the system hazards are understood, risks mitigated to the maximum extent possible, and that residual system hazards are accepted by the project and NASA.

The NASA Eastern Region Airworthiness Review Board (ER-ARB) shall evaluate and approve modifications to NASA LaRC manned and uncrewed aircraft, research equipment, software, flight envelopes and operations for flights in the national airspace. The airworthiness review can approve a type design or modification to a NASA owned aircraft or an aircraft conducting Commercial Aviation Services (CAS) operations funded by NASA. The ARB can also evaluate and approve the airworthiness of an aircraft for nonstandard operations for that aircraft type, or for operations that subject the aircraft to a more hazardous environment than normal.

The review process shall include the engineering rationale, substantiation documentation, and risk mitigations in an airworthiness review board package. This process approves appropriate engineering and systems safety risk mitigation procedures/techniques and provides airworthiness oversight for all activities.

Upon completion of the ARB Review, the ARB shall issue a NASA Airworthiness Statement prior to first flight for that vehicle. UAS airworthiness statements expire on the day the FAA registration expires. This airworthiness process shall be continual throughout the course of a project or aircraft life cycle per NPR 7900.3, whether it is a baseline aircraft change or a temporary research modification.

3.3 Operational Readiness Review

The ORR process occurs after the aircraft has a valid Airworthiness Statement. The ORR reviews the concept of operations, the system and operational hazards, and assesses the need for additional risk mitigations to minimize risk to persons and property. Missions that cannot attain a normal risk of flight status (as determined by the ARB/ORR) shall accomplish additional hazard analyses and supporting mitigations to adequately identify and mitigate hazards associated with the planned flight activities.

The ORR also verifies that the logistics, scheduling, and resources for its intended mission are properly allocated and scheduled. Representatives of all organizations involved with the development, design, fabrication, maintenance, inspection, operations of the vehicle and test plan development attend the review.

If the mission and risk mitigations adequately mitigate hazards to an acceptable risk level, the ORR certifies that the UAS test flight operation is ready to deploy and that the vehicle operations are safe to fly the intended mission. The certification of the ORR is the authority to proceed (ATP) for that particular mission/campaign.

4 Assumptions

Section 4 includes a series of assumptions regarding the proposed BVLOS operations. They are included here to help to organize and communicate the planned operation to team participants, stakeholders, and those performing review functions.

4.1 Airspace and Operational Environment

All BVLOS operations shall be confined to the lateral and vertical limits of CERTAIN I, IIa airspace and the expanded overwater airspace to the N/NE of CERTAIN. WVLOS flights may be performed in other areas of CERTAIN (ie CERTAIN IIb, III, and IV).

The maximum range of wind speeds under which operations will be conducted is 20 knots maximum (including gust). Wind directions would also limit operations depending upon route of flight and amount of time it would take a sUAS to execute a controlled descent or commanded termination.

The minimum weather for BVLOS flight operations shall be 2000 feet ceiling and 3 NM visibility or what is specified in the ORR, whichever is higher.

4.2 UAS Platform

The ALTA 8 aircrafts' airworthiness (as well as flight readiness) have been assessed against NASA Procedural Requirements 7900.3D, NAII 7900.3, and Langley Procedural Requirements 1710.16.

The Airworthiness assessment of the ALTA 8 includes an analysis of their capability to perform the intended mission, including flight aborts and vehicle termination, with verification through ground and WVLOS testing. Analysis and testing of command and control links are included in the airworthiness process.

4.3 Flight Crew

The primary flight crew for WVLOS operations shall consist of a Flight Test Manager (FTM), the Vehicle Service Crew (VSC), Safety Pilot (SP), Pilot in Command (PIC), the Ground Control Station Operator (GCSO), the Range Safety Officer (RSO) and Visual Observers (as necessary). Through the progress of the proposed operations herein, the roles of the SP and GCSOs will evolve. Currently the SP provides a PIC function through direct line of sight with the UAS. An alternative definition of the SP will be to that of a Visual Pilot (VP) who is serving the role of PIC or SIC. A build-up approach that transitions PIC roles form the SP to the GCSO will be accomplished.

- The SP PICs and the GCSO PICs are trained and designated as NASA UAS pilot/GCSOs respectively in accordance with NASA Procedural Requirements 7900.3D and Langley Procedural Requirements 1710.16.
- The RSO is trained and designated as a NASA RSO in accordance with NASA Procedural Requirements 7900.3D and Langley Procedural Requirements 1710.16.
- The FTM shall act as the Mission Commander for multi-UAS operations in accordance NASA Procedural Requirements 7900.3D.

For BVLOS operations, the primary flight crew shall also include personnel supporting ground surveillance operations. The Radar Operator (RO) and the Airspace Monitor (AM) shall work to monitor and verify the reliability of the ground surveillance data and identify intruder traffic.

- The RO shall monitor the radar systems for proper operation and provide complementary scanning of the airspace with the AM to detect intruder traffic in LAFB Class D airspace.
- The AM shall clear the airspace from inside the ROAM UAS Operations Center by monitoring the ground surveillance feeds to look for potential traffic conflicts. The AM will also assess the functionality of the ANRA fusion algorithm but this algorithm is not required for BVLOS operations.
- Both the RO and AM are responsible for alerting the RSO/GCSO PIC of intruder traffic as defined in Section 6.9.5.

4.4 Ground-Based Surveillance

Ground-based surveillance includes radar feeds from the Lightweight Surveillance and Target Acquisition Radar (L-STAR) and GA-9120 radars, ground-based ADS-B receivers, and ground-based Flight Alarm (FLARM) feeds. The monitoring of this information shall be accomplished by the Airspace Monitor and the fusion of this information will be accomplished using an ANRA fusion algorithm (Anra Smart Skies CTR).

Ground-based surveillance methods will focus on detecting crewed aircraft using radars. Participating UAS aircraft will be monitored via FLARM. The GA-9120 radars may provide some capability to detect non-participating UAS but it should be assumed that ground-based surveillance radars will not be able to regularly detect non-participation UAS.

4.5 Separation Requirements

4.5.1 UAS and Crewed Aircraft

The minimum safe separation (i.e., well clear) between crewed aircraft and UAS shall be defined as 2000 feet horizontal or 250 feet vertical. All avoidance maneuvers between manned and UAS aircraft shall be predicated on maintaining these minimum safe separation distances.

4.5.2 UAS and UAS

The minimum safe separation between participating UAS aircraft shall be 500 feet horizonal or 100 feet vertical. All avoidance maneuvers between UAS aircraft shall be predicated on maintaining these minimum safe separation distances.

5 System Description

The objective of this section is to provide an understanding of the system in use to a level that supports an informed risk decision. Section 6 will provide a description of the usage of the systems described herein. As part of the system description in this section the systems and sub-systems intended function and composition will be provided. Connections with other subsystems will also be presented with functional description of the interfaces. Supporting figures and systems diagrams will be provided to describe the system in test and support the informed risk decision process.

In this section, an emphasis is also provided for the systems that are directly involved with the BVLOS operational aspects. This results in a focus on the airframe, telemetry links, control systems, propulsion systems, and Safe2Ditch and ICAROUS autonomous systems. Other systems and subsystems related to testing in support of the Prototype Assessment Operations (PAO), such as the xTM Client, Provider of Services (PSU), and Vertiport Automation Systems, which are more associated with research and evaluation of a UAM Ecosystem prototype, are not considered critical for BVLOS operations and are not included in this document. The PAO-required systems do not directly control the vehicle and their usage is pre-coordinated prior to flight. PAO will be performed in single and multi-vehicle operations in WVLOS, EVLOS, and BVLOS modes of operation. PAO operations will be described in terms of numbers of aircraft and modes of operation.

5.1 System Overview

The overall system architecture can be decomposed into 2 main components: 1) The sUAS vehicle and 2) BVLOS required ground systems. Depending on the intended type of operation the ground control system used will change.

A basic description of the vehicle system includes: 1) COTS sUAS (Alta-8), 2) Extended COTS sUAS equipment to provide required vehicle functionality (e.g., 4G Botlink and uAvionix Micro Link Radio) telemetry links, Flight Alarm (FLARM) 900 MHz vehicle-to-vehicle ADS-B-like system, Ping 2020 ADS-B in receiver, VN-200 auxiliary IMU with GPS antenna, Safe2Ditch camera, and 3) Companion computer (Xavier) with flight software systems (S2D+ICAROUS).

A basic description of the BVLOS ground systems includes: 1) MPATH Ground Control Station (GCS) with uAvionix TM link, 2) MPATH GCS with Botlink TM link, 3) Radar systems (LSTAR and GA-9120), 4) Ground ADS-B system, 5) Ground FLARM system, 6) Remote Operations for Autonomous Missions (ROAM) UAS Operations center, and 7) Anra Smart Skies CTR integrated airspace display and data fusion system.

5.2 sUAS Vehicle and airborne systems

5.2.1 Alta-8 vehicle

The vehicle selected for this project for BVLOS flight operations is the Free Fly Alta-8 vehicle shown in Figure 18. This photo is of N559NU during recent flight test operations for the Advanced Onboard Automation (AOA) flight test that was performed in the spring of 2022. The HDV project will retain this vehicle and configuration for subsequent operations in Scalable Autonomous Operations (SAO) flight test. The Alta-8 was selected for several reasons such as being a nominal octocopter configuration along with strong supporting performance and design material provided by Free Fly. Octocopters provide significant value compared to other multi-rotor configurations through their ability to sustain engine-out conditions better than hexacopters. Nominal 8-armed octocopters also provide superior vibration environments compared to 4-armed configurations with motors located on top and bottom of the arms. Another major strength of this design is the extensive use of vibration isolation systems throughout the vehicle. The Alta-8 features a design approach where all 8 motor arms are joined to a thrust ring that is suspended from the rest of the vehicle by a series of vibration isolators designed to protect the payload. As a result, the payload trays are particularly free of vibrations from the motors. However, the Pixhawk autopilot is mounted in the thrust ring. The primary customer for these aircraft is the movie industry.

NASA LaRC received the first two Alta-8s in the fall of 2020. A comprehensive test series was performed for all Alta-8s that featured a 15-flight test series for all vehicles in their as-delivered configuration. As of 9 September 2022, NASA LaRC has completed 512 flights on six Alta-8s. To date, the Alta-8 has been a very reliable vehicle that has provided robust operational performance with very little issues. The only noted anomaly to date was an arming issue likely associated with very high temps during peak summer operations.

Figure 18 - Alta-8 sUAS as Configured for the HDV AOA Flight Test Project.

Figure 19 provides a photograph of the internal components of the Alta-8 vehicle. One element that makes this vehicle unique is the use of CAN-bus communication control architecture to route control signals from the Pixahwk autopilot to the motor electronic speed controls (ESCs). Free Fly designed and manufactured the interface board which also routes power to the motors as well as connections with the R/C equipment. Free Fly also designed and manufactures the Pixhawk carrier board shown directly beneath the Pixhawk autopilot. This carrier board provides the interface between the autopilot and the vehicle sub-systems such as GPS and telemetry units. This approach greatly decreases the amount of wire and connectors in the vehicle and helps mitigate electromagnetic interference (EMI). It also mitigates the risk of wires and connectors failing through reduction of the numbers of connectors overall. Lastly, all of the COTS vehicle wires are contained inside the vehicle structure which helps mitigate EMI from external sources and protects the remaining wires and connectors from the wear caused by transporting the vehicle to the field and flight induced loads. It is recognized that component overheating can be a challenge with the internal design approach.

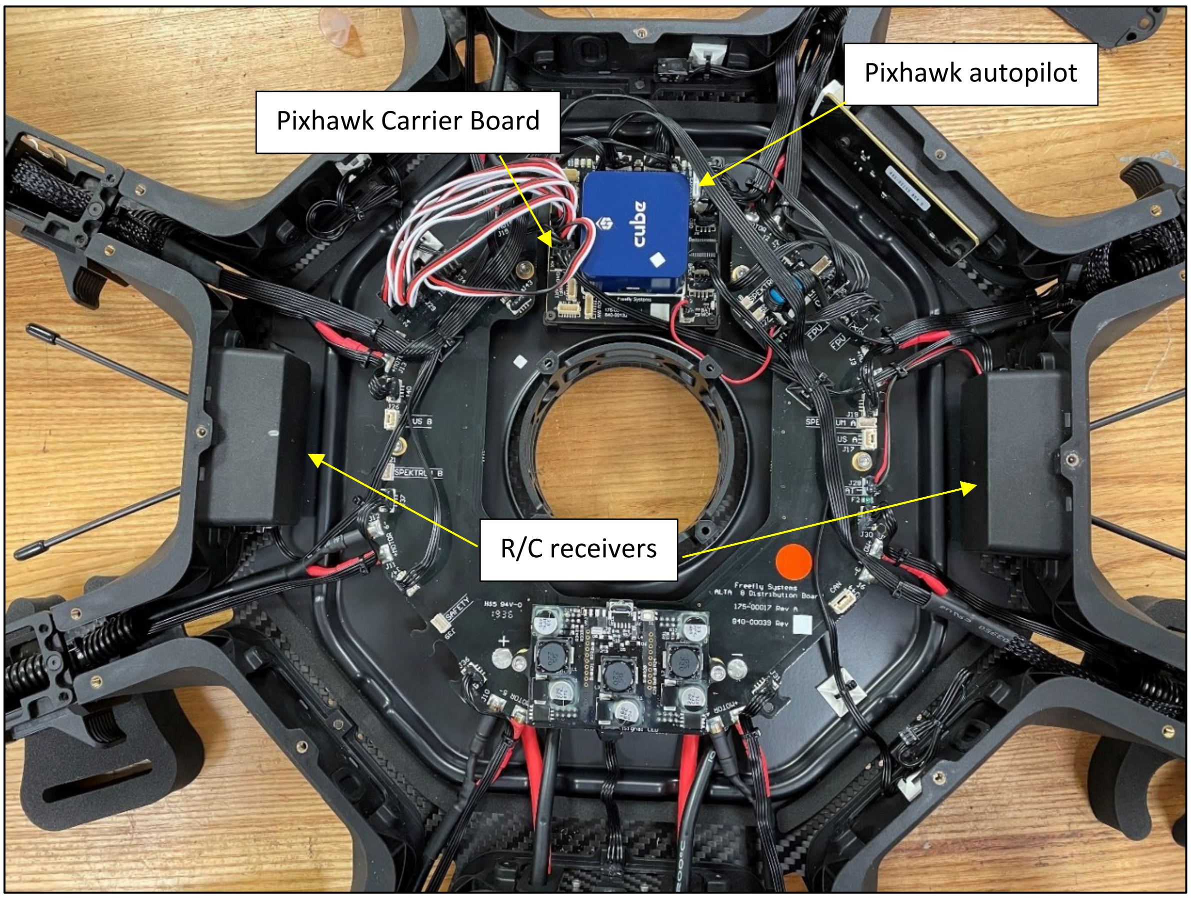

Figure 19 - Photo of Alta-8 Internal Components.

The Pixhawk Blue autopilot is configured to be running PX-4 1.12.3. This version of firmware is the same as the firmware version that will be used in the HITL SAO Simulation, currently planned for the winter of 2022. Firmware updates to the Alta-8 requires support from the FreeFly company since their CAN bus control system is integrated with the autopilot firmware.

Other COTS equipment includes RFD-900 MHz telemetry links to connect the autopilot with the GCS, HERE-2 GPS system, and Futaba 14MZ Radio Control link to connect the SP (or VP) with the autopilot which utilizes dual receivers.

5.2.2 Extended COTS equipment

Several COTS components are subsequently integrated into the Alta-8 vehicle to enable the required system performance. All of these components are commercially available for sUAS applications and include the XRD 4G telemetry link from the Botlink company shown in Figure 20, a 900 MHz mesh radio from uAvionix, Flight Alarm (FLARM) 900 MHz vehicle-to-vehicle ADS-B-like system, VN-200 auxiliary IMU with GPS antenna, and Safe2Ditch camera. See Figure 21 for a photograph of the uAvionix Microlink radio. See Figure 22 for a photograph of the PowerMouse FLARM unit.

Figure 20 – Botlink XRD

The Botlink XRD is a 4G telemetry link used to connect a GCS with the Pixhawk autopilot. It is included in the sUAS to provide a redundant communication link between the ROAM UAS operations center and the vehicle for all phases of flight, including surface operations. The Botlink uses licensed frequency spectrum for 4G telecommunications which allows for communication anywhere there is 4G coverage. A Botlink application is installed on the GCS computer and used to interface with Q Ground Control (QGC). This link offers all the GCS controls that are provided by nominal 900 MHz telemetry links. The Botlink system requires the GCS to be connected to the internet and the sUAS to be connected through 4G LTE to the internet. The Botlink system also requires the Botlink server to also be operational. Initial testing shows very similar response times for both Botlink and RFD-900 telemetry links with non-objectionable delays that are less than 0.5 seconds.

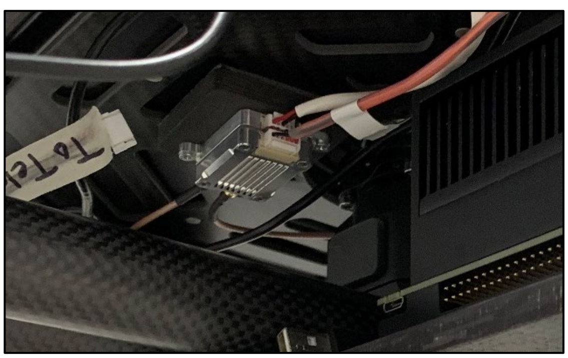

Figure 21 – uAvionix Microlink

The uAvionix Microlink is also used to connect a GCS with the Pixhawk autopilot and will be installed in place of the Alta-8 stock RFD-900. It is included in the sUAS to provide a redundant communication link between the ROAM UAS operations center and the vehicle for all phases of flight, including surface operations. Assuming good line-of-sight for a link analysis, the expected communication range of the 900 MHz C2 links with a 25 dB link margin exceeds 53 kilometers. The maximum expected BVLOS distance on CERTAIN is less than 3 kilometers. One challenge with having GCSOs located inside a building approximately 1 mile away from the takeoff and landing locations is that direct 900 MHz link to the vehicle while the vehicle is on the ground may not be possible. The uAvionix Microlink provides the ability to communicate to the vehicle through the internet. HDV flight testing includes installation of an uAvionix Microlink unit at the sUAS takeoff and landing location directly connected to LaRCNET (LaRC firewall-protected Network). Taken together, the Botlink and uAvionix Microlink provide dual fully independent communication links to the sUAS with similar response times (< 0.5 seconds) and coverage that far exceeds the planned BVLOS flight paths.

Flight alarm (or FLARM) is an ADS-B like technology originally developed for manned sailplanes. Its usage has expanded worldwide and is required equipment in some large sailplane competitions to mitigate the risk of mid-air collisions. FLARM is also available commercially for sUAS applications.

Figure 22 – PowerMouse FLARM

FLARM offers a potential alternative to using ADS-B for sUAS to sUAS deconfliction as well as limited deconfliction with FLARM equipped manned aircraft (limited due to the low number of equipped manned aircraft). FLARM operates in the open 900 MHz ISM band unlike ADS-B with its' associated licensed spectrum. Extensive sUAS FLARM flight testing has been performed to evaluate how well this technology can work to enable autonomous sUAS deconfliction. For the HDV flight testing, the PowerMouse unit has been selected which is manufactured to manned aircraft standards and intended for use in manned sailplanes. Output from the PowerMouse unit is routed to the Xavier companion computer and used by ICAROUS. FLARM transmissions from the sUAS will also be received by a ground-based FLARM unit in the ROAM UAS Ops center and used as a secondary UA position source.

A Vector Nav VN-200 inertial measurement and navigation system is included as part of the extended COTS equipment (Figure 23). The inertial measurement unit (IMU) is mounted to the S2D camera to assist with the geolocation performance of that system. By mounting the VN-200 directly to the camera assembly, the actual camera orientation can be more readily determined. The VN-200 also includes GPS inputs to provide navigation data. In order to acquire usable video from the S2D camera, a vibration isolation systems is employed which can induce some movements of the camera with respect to the sUAS. Including the VN-200 on the camera assembly helps to mitigate the effect of the vibration isolation system upon S2D's capability to geolocate detected targets. Output from the VN-200 is routed to the Xavier companion computer for processing. The VN-200 is also equipped with a dedicated GPS antenna.

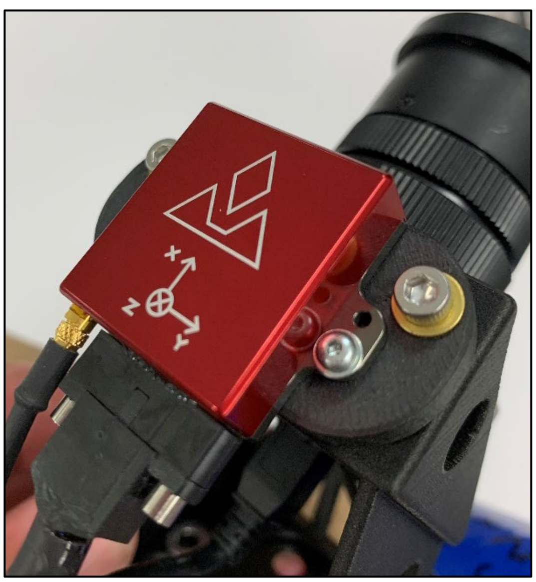

Figure 23 – Vector Nav VN 200

Figure 24 illustrates the IDS UI 1250 ML camera. The UI 1250 ML camera can operate up to 1600x1200 pixels however is configured to operate at a lower resolution to maintain a desired frame rate of ~30 Hz. It connects to the Xavier companion computer through a USB cable. The UI 1250 ML features a

Figure 24 - UI 1250ML Progressive Scan Camera Used for Safe2Ditch Vision Assisted Landing

progressive scanning approach that is beneficial to minimizing vehicle vibration on the resulting imagery. The camera is fixed-mounted to a 45-degree look down angle aligned with the plane of symmetry of the vehicle. This provides scanning coverage for 45-deg glideslope approaches employed for Safe2Ditch. Imagery from this camera is processed to detect moving targets within the intended landing area. If motion is detected in the primary landing area, then Safe2Ditch commands the vehicle to re-route to the next available alternate landing area.

5.2.3 Companion Computer (Xavier)

An Nvidia Xavier computer is used as the companion computer for the flight testing herein and shown in Figure 25. The Xavier computer is designed for robotic and artificial intelligence (AI) type of applications and is an upgrade to the Jetson TX-2 micro-computer in use at NASA LaRC for the last several years. The Xavier offers a 20 times improvement in computing power combined with a decrease in required power. Its size is 105 mm x 105 mm x 65 mm and draws 30 w of power and weighs approximately 140 g. The companion computer provides computational resources to complement what is already provided within the Pixhawk autopilot. The additional computing resources are used to run onboard autonomous systems such as Safe2Ditch and ICAROUS. The companion computer interfaces with the Pixhawk autopilot through a Universal Asynchronous Receiver Transmitter (UART) connection. The Xavier also connects to the VN-200 auxiliary inertial measurement and navigation unit.

Figure 25 – Nvidia Xavier Companion Computer

5.2.3.1 Safe2Ditch

Safe2Ditch (or S2D) provides the capability to perform safe autonomous remote landings that are needed in off-nominal situations without requiring direct human intervention. Having this system onboard the vehicle should provide many advantages such as rapid response times, enable emergency landings without streaming video to GCSOs, and in a lost link scenario, enable the vehicle to perform the desired responses without direct communication link with the sUAS operator. It is composed of several sub-elements that include: 1) Ditch site database, 2) Vision Assisted Landing (VAL), and 3) Health Monitor. The vision assisted landing system is an application of machine vision technology that uses video from the S2D camera to detect moving objects and combines that with vehicle position and orientation information obtained from the autopilot to use for geolocating moving objects.

Safe2Ditch's ditch site data base includes the lat/lons of the ditch site locations, the approximate radius of the ditch site, and the likelihood of the location being safe to use. In this context "safe to use" means likely to be free of people. For example, a parking lot would be listed as a higher-risk ditch site than a remote open area due to the potential for people to be moving around in a parking lot. As employed herein, all ditch sites will be unlikely or highly unlikely to have people in them. Safe2Ditch selects the best location within a limited range of the vehicle. For the current application, the available range of the vehicle will be limited by time and be adjustable by the sUAS operator before flight. Typical range times will be 1 or 2 minutes requiring Safe2Ditch to select ditch sites within ~2,000 ft (~600 m) assuming a 1-minute cruise followed by a 1-minute descent and landing.

The vision assisted landing (VAL) then scans the intended ditch site looking for moving targets. If something is detected in the ditch site, the ditch site is considered unsafe to use and the vehicle re-routes to the next ditch site. The health monitor provides an alert that the vehicle is entering into an off-nominal condition as well as provides an estimated time to live. The time to live will be sUAS operator set parameter for the current operations. For HDV, low battery voltage or direct GCSO control will be used to trigger the Safe2Ditch system. Safe2Ditch has been tested extensively since 2016 with several flight tests campaigns completed.

Previous flight testing of S2D was performed in References 8 through 11. References 8 and 9 document the basic systems ability to detect and geolocate a person-sized moving object within the designated ditch site and to re-route the sUAS to an available alternate landing location. Reference 9 also examined the potential of using S2D to complete emergency landings in partially occupied ditch sites. In this context it is assumed that the sUAS has no place else to re-route to and needs to take the best path to avoid moving objects. As applied herein, S2D will always have a viable ditch site and alternate ditch site.

Testing performed in Reference 8 revealed the efficacy of S2D to both detect moving objects located within the primary ditch site and to safely re-route to an alternate. A simple camera was fix-mounted to the vehicle and aligned along a 45-deg look-down angle. The approach used a 45-deg descent to point the camera approximately onto the ditch site. For these tests a total 13 runs were performed for two different cruising altitudes: 1) 60m/197 ft, and 2) 120m (394 ft). Moving targets representing people in the ditch site were replicated through the use of an R/C car driven at approximate human walking speeds. Both occupied and unoccupied test conditions were performed.

Results from Reference 8 are presented in Figure 26 that shows the altitude the sUAS started the re-route maneuver to the alternate ditch site vs the cruising altitude which is also the altitude at the top of descent. For all the test cases with motion in the ditch site, the sUAS performed an adequate re-route. Analysis of the results revealed that the VAL was able to detect and track the target in the ditch site within ~2 seconds of the vehicle being within the field of view for all tests performed. However, the S2D system was not able to geolocate a target to be within the ditch site until the vehicle was at 32 m (105 ft) for one run. Further analysis is currently underway and subsequent testing is planned. Results of S2D testing accomplished during AOA Test flight are discussed in appendix H. Until the system achieves adequate performance, all ditch sites will be marked and under visual observation by VOs.

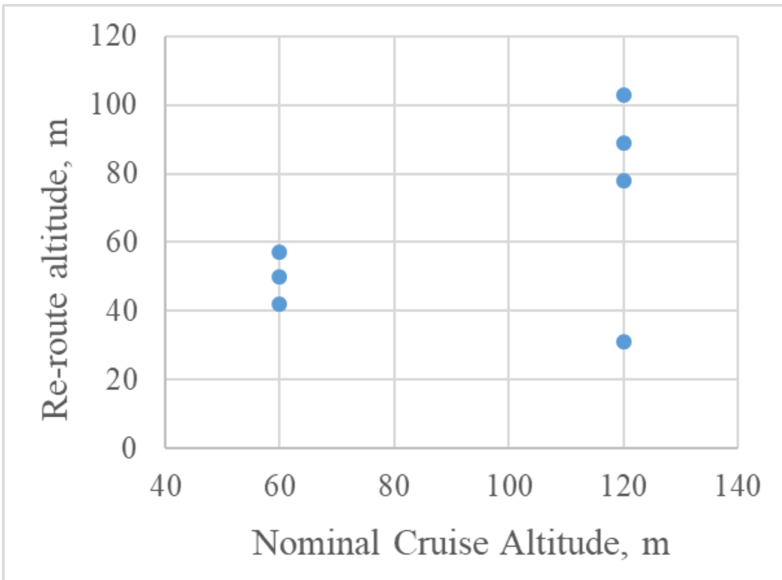

Figure 26 - Example S2D Data from Reference 8.

5.2.3.2 ICAROUS

ICAROUS is an onboard software capability for sUAS developed at NASA LaRC. It is intended to enable autonomous decision making and to provide functionalities needed for beyond visual line of sight sUAS operations [References 12 and 13]. ICAROUS consists of several applications communicating over a software bus provided by the core Flight Systems (cFS, [Reference 14]) middleware. Each application provides a key capability, such as geofence avoidance or sense and avoid (SAA).

The sense and avoid capability within ICAROUS is provided by the Detect and Avoid Alerting Logic for Uncrewed Systems (DAIDALUS) software library [Reference 15]. This library serves as the reference implementation of the DAA Minimum Operational Performance Standards defined in RTCA DO-365 [Reference 16]. The library provides formally verified algorithms that compute maneuver guidance in the form of bands, i.e., ranges of heading, speed, and altitude .maneuvers that avoid conflict with traffic aircraft. While DAIDALUS was developed as an advisory system for a pilot in command, ICAROUS selects the preferred resolution provided by DAIDALUS and commands the autopilot to execute the maneuver.

ICAROUS also runs on the Xavier onboard companion computer, receiving data from various sensors and sending commands to an autopilot to maneuver around obstacles, to enforce adherence to a predetermined flight path, or to avoid intruders in the airspace. The core Flight System is a platform and project independent reusable software framework that also include reusable software applications.

There are three key aspects to cFS architecture: 1) a dynamic run-time environment, 2) layered software, and 3) a component-based design. It is the combination of these aspects that makes it suitable for reuse on a number of NASA flight projects and/or embedded software systems.

Recent testing of ICAROUS occurred in 2018 [Reference 12] and in 2019 [Reference 13] that involved both sUAS and manned aircraft intruders. Both ADS-B in (GA) and FLARM (sUAS) were used to provide intruder location information to ICAROUS. For Reference 13, FLARM data was used for the sUAS intruder position information for ICAROUS. Reference 13 simulated the condition where a sUAS was in an emergency off-nominal situation as utilized in S2D and needed to take a direct route to the ditch site causing a potential loss of well clear separation. Reference 8 also evaluated the usage of a geofence to keep the off-nominal S2D aircraft within its defined airspace and prevent loss of well clear separation. Results from both References 12 and 13 indicate that ICAROUS SAA using DAIDALUS performed safe avoidance maneuvers based on ADS-B and FLARM traffic surveillance. These maneuvers maintained well clear separation in scenarios where a manual operator would have had very limited time to respond.

Results from Reference 13 are included here to provide a relevant summary of recently completed ICAROUS testing. Within Reference 10, a representative sUAS (DJI S-1000) was equipped with ICAROUS with traffic awareness provided by ADS-B in. A series of encounters were performed using both sUAS and GA aircraft equipped with ADS-B out to comprehensively test ICAROUS for both head-on and crossing scenarios. A 500 ft vertical off-set was used for testing with ICAROUS constrained to perform lateral evasive maneuvers only.

A series of configuration parameters were evaluated during the test that was completed in 2018. Overall there were 42 runs, 16 UAS-UAS and 26 UAS-GA encounters. The sUAS-sUAS encounters experienced no losses of separation regardless of horizontal separation or combination of alerting and threshold time parameters used. This indicates that for low closing speeds (< 30 m/s) the configurations chosen are safe and possibly overly conservative. In addition, the testing setup for sUAS-sUAS provided acceptable test conditions while keeping maintaining both vehicles within visual line of sight.

Of the 26 sUAS-GA encounters there were 16 losses of lateral separation, with intrusion distances ranging from 14 feet to 1000 feet. Test limitations resulting from visual line of sight requirements at the selected test site contributed to some of the loss of lateral separation. In those cases, the sUAS was initialized (ICAROUS made active) with the GA intruder aircraft too close to the well clear boundary or in some cases, already in a loss of separation. The most successful set of runs corresponds to 2000 feet of horizontal separation and 20 seconds of alerting time as indicated in Figure 27.

One other testing artifact revealed during Reference 13 was the evidence of Traffic Information Services Broadcast (TIS-B) traffic data duplicated for the SR-22 intruder aircraft. This had the effect of ICAROUS attempting to avoid two closely-spaced aircraft. Modifications enacted to ICAROUS enables the creation of aircraft tracks from multiple input streams of data. It is anticipated that the TIS-B data will be merged with the directly received ADS-B data to form a more accurate track but subsequent testing will be performed. Removal of the TIS-B data from the ICAROUS traffic input data is another option being considered. Overall, ICAROUS alerted adequately to all incursions tested.

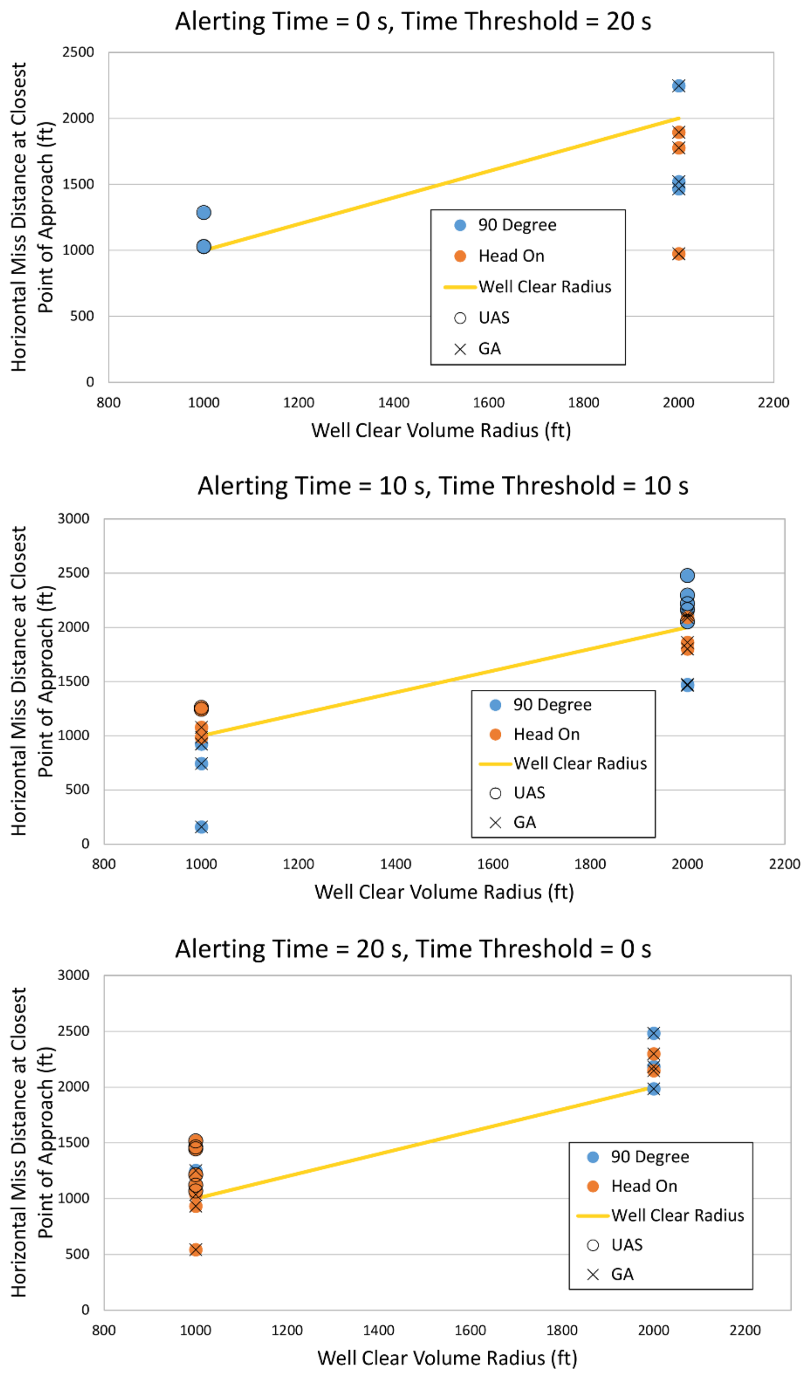

Figure 27 - Results from Reference 13.

Additional ICAROUS testing was accomplished during the AOA flight test spiral (Spring 2022). The AOA flight test results, including those testing ICAROUS functionality, can be found in Appendix H.

5.2.4 Resulting Integrated Vehicle

In Figure 28, a composite system diagram illustrates how all major components come together to describe the integrated system (ALTA 8, C2 links, autonomous systems and ground control stations). This is the configuration used for the AOA Flight test series performed from February to May, 2022 and is the configuration that will be used for BVLOS flights described herein. As indicated in Figure 28, there are two controllable power relays included wihtin the system design to enable control of reversionary modes. One relay is used to control power to the Xavier computer. Opening that relay will shut-down or isolate the Xavier in order to provide protection against undersired autonomous system action. While both extensive ground testing and flight testing will be performed to ensure adequate autonomous system performance and provide a NASA Class-C software certifcaiton, the ability to remove those systems for reversionary mode operation has some risk mitigation value, especially during build-up testing. Similarly, the second power relay to the Botlink affords contingency management for the Botlink communications link. This is valuable for build-up operations durign the transition into the ROAM UAS operations center in that the GCSO in the field could remove the remote GCSO from controlling the vehicle. Controlling power to the Botlink also enforces the primary control link to be the uAvionix Microlink. Once the GCSO in ROAM becomes PIC, the Botlink power relay may be removed.

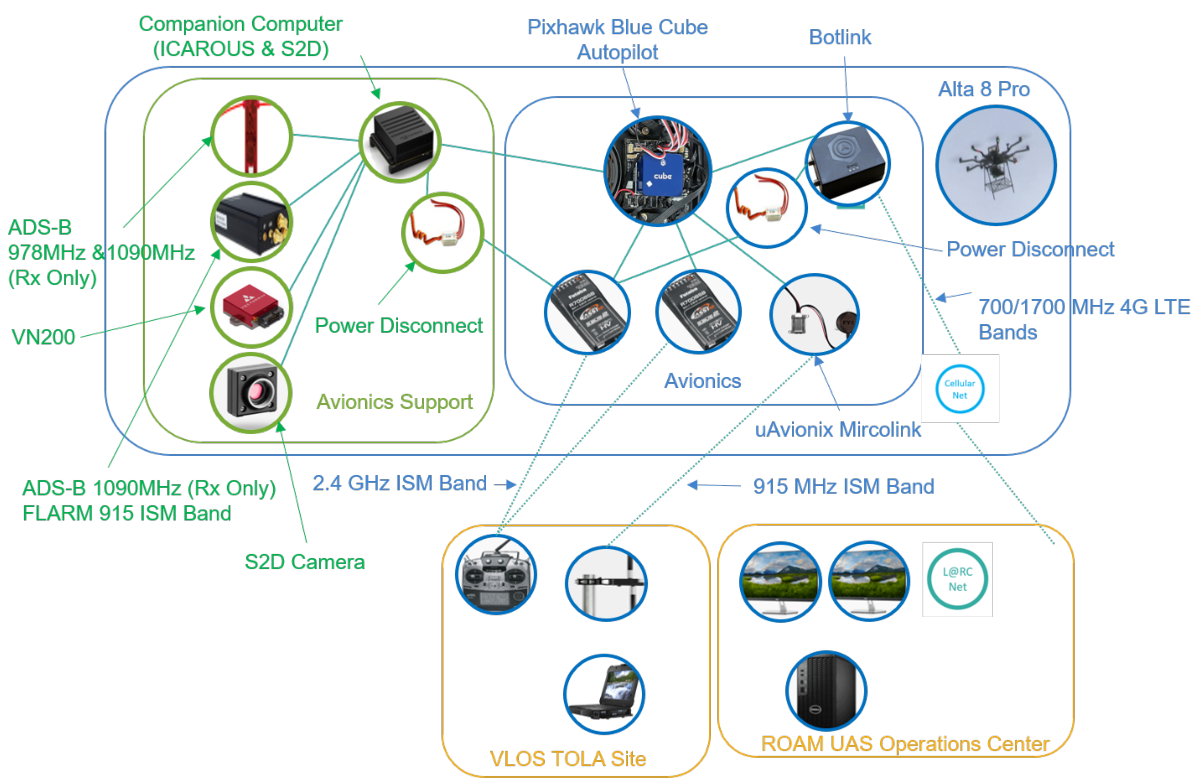

Figure 28 - Photograph of Alta-8 Vehicle with Extended COTS Components Installed.

Figure 29 shows the fully integrated ALTA 8 vehicle with each component labeled. Element #1 is the mounting for the Taoglass MAXIMUM antenna that provides signal reception for the Botlink XRD with antenna installed. The MAXIMUS antenna provides a very compact and flexible antenna that provides effective performance over a range of frequencies from ~800 MHz up to 6 GHz. It has been used in several previous NASA flight tests combined with Botlink XRDs. Element #2 is a battery mounting tray for the companion computer and FLARM system power supply. Element #3 is the RCATS R/C controlled relay that isolates the Companion Computer from the primary flight control system. This relay can be controlled directly from the R/C receiver or from the Pixhawk autopilot. This relay can be used to potentially isolate parts of the system to manage off-nominal conditions. For example, if Safe2Ditch or ICAROUS were determined to be in an off-nominal condition, the companion computer could be isolated to eliminate those systems allowing the vehicle to revert back to a near COTS configuration. Element #4 is the Botlink XRD. Element #5 is the Lume Cube strobe light. Element #6 is the antenna for the uAvionix Microlink radio. Element #7 is the uAvionix Microlink radio GPS. Element #8 is the uAvionix Ping unit. The Xavier companion computer will be located on a tray below the vehicle. Element #9 is the Pixhawk GPS unit. Element #10 is the VN-200 GPS unit. Element #11 is the FLARM GPS unit.

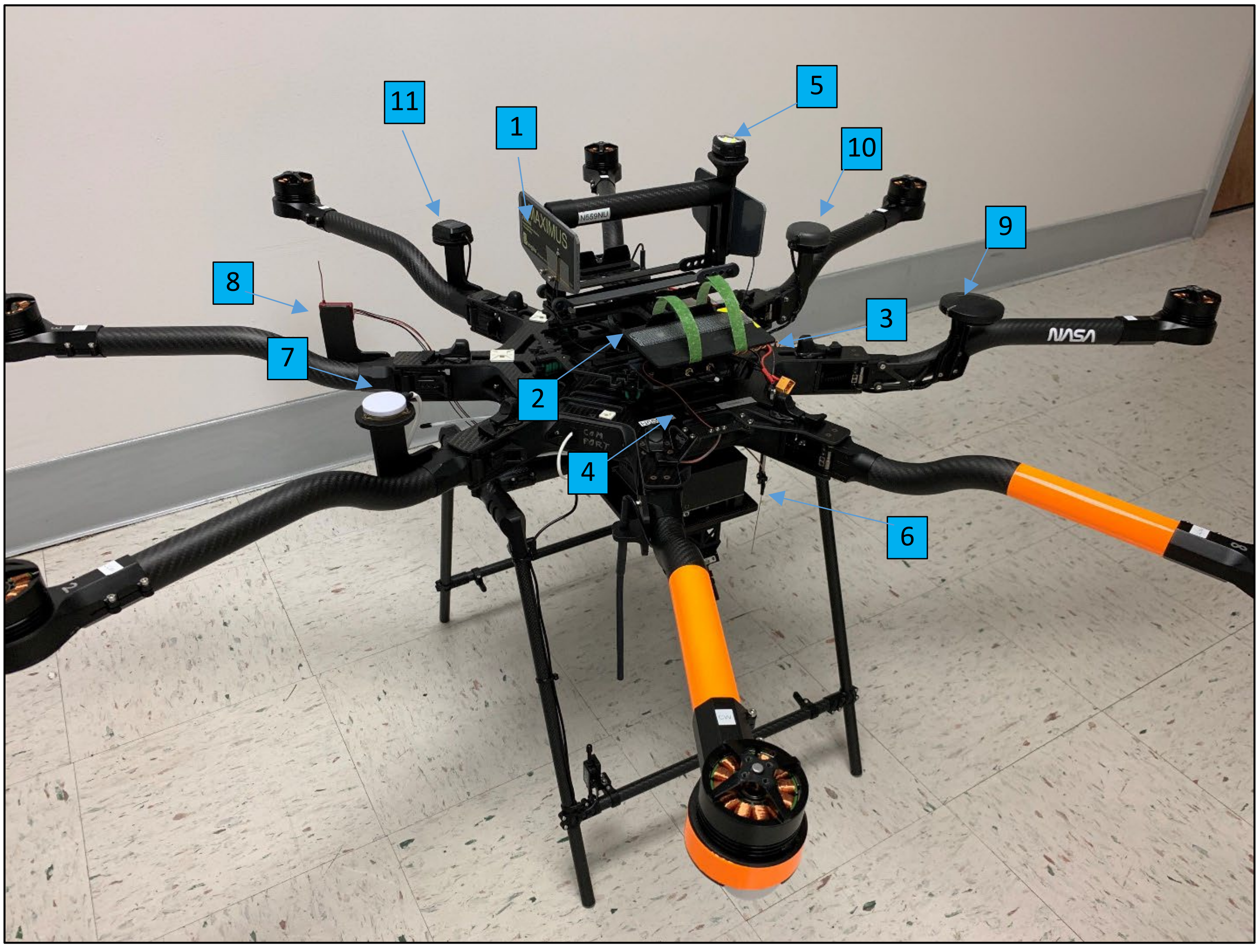

Figure 29 - Photograph of Alta-8 Vehicle with Extended COTS Components Installed.

5.3 Beyond Visual Line of Sight required ground systems

The Beyond Visual Line of Sight (BVLOS) ground system is designed to provide functionality and performance to achieve BVLOS operations. Overall, the inherent difference between basic WVLOS and BVLOS flight is the method to provide the awareness of the airspace and the capability to manage off-nominal vehicle conditions while mitigating risk to both manned aviation and risk to people and property on the ground. A basic description of the BVLOS ground systems includes: 1) Remote Operations for Autonomous Missions (ROAM) UAS Operations center, 2) Primary COTS GCS hardware with uAvnionix Microlink, 3) Secondary COTS GCS hardware with Botlink TM link, 4) Measuring Performance for Autonomous Teaming with Humans (MPATH) ground control station software, 5)

Auxiliary weather information displays, 6) Radar systems (LSTAR and GA-9120), 7) Ground ADS-B system, 8) Ground FLARM system, and 9) Anra Smart Skies CTR airspace display and data fusion system.

5.3.1 Remote Operations for Autonomous Missions UAS Operations Center

The Remote Operations for Autonomous Missions (ROAM) UAS Operations Center (referred to as ROAM) is a dedicated UAS control room at NASA LaRC. It is designed to provide the shared situational awareness required to support BVLOS sUAS operations as well as enable high-fidelity simulation and HHITL system testing.

The overarching design considerations for ROAM were to relocate existing field operators to the remote vehicle operation center, produce a shared situational awareness environment for participating personnel, and provide the ability to pursue advanced vehicle C2 operations supporting Advanced Air Mobility and other various research activities. The remote operations center is envisioned to provide a user training environment, flight operations planning and briefing environment, and a research facility for simulated and live UAS operations. The ROAM UAS Operations Center is designed to facilitate three major components of BVLOS flight: 1) the safe conduct of BVLOS operations; 2) the integration of BVLOS operations in the local airspace; and 3) the collection of data pertaining to human-autonomy teaming.

5.3.1.1 ROAM UAS Operations Center configurations

See Figure 30 for a top view of the ROAM layout showing the locations of the various sUAS operations personnel. ROAM will provide configurable crew stations for up to 6 personnel with an overflow room capable of adding an additional 9 crew stations. Various configurations can be accommodated through its flexible display architecture approach. For initial BVLOS operations, the ROAM UAS Ops center will include 1 GCSO (for 1 sUAS), a Range Safety Officer (RSO), a Flight Test Manager (FTM), a Radar Operator (RO) and an Airspace Monitor (AM). See Table 4 for some other ROAM configurations to support various types of proposed operations. On the left side of Figure 21 is a large video wall, referred to as the forward video wall, that can accommodate up to 128 different displays. It is envisioned that the forward video wall will be used to present information from up to 10 different displays.

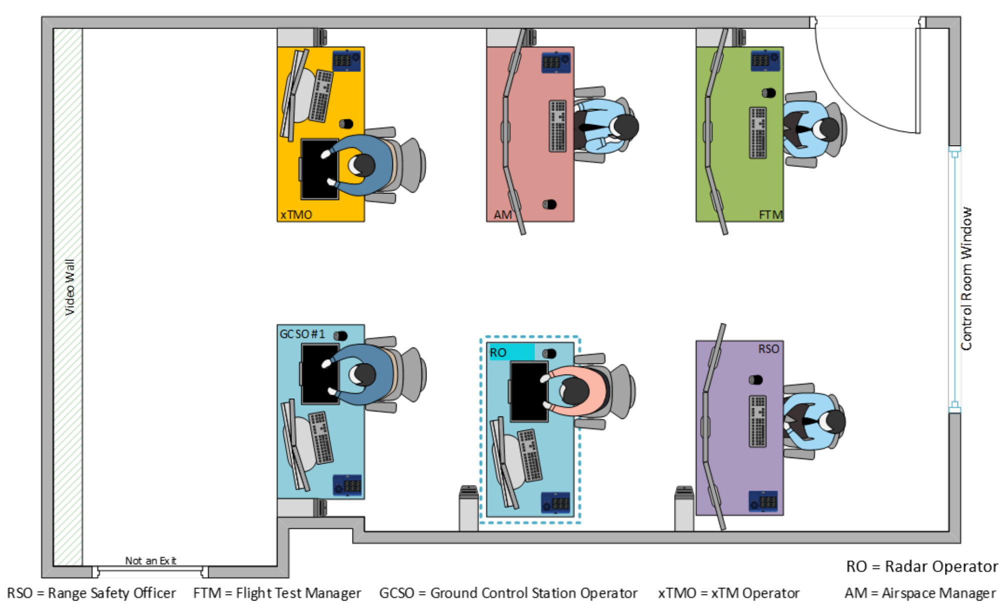

Figure 30 - Top view of ROAM UAS Operations Center for Two Vehicle BVLOS Configuration.

Table 4 - Potential ROAM Configurations.

ROAM Conf	Operation	Control Station Allocation
1	BVLOS Build-up, single-vehicle	GCSO-1, RSO, FTM, AM, RO (AM and RO not required if utilizing VOs)
2	BVLOS, single-vehicle	GCSO-1, RSO, FTM, AM, RO
3	BVLOS, two-vehicle	GCSO-1, GCSO-2, RSO, FTM/MC, AM, RO
4	BVLOS, three-vehicle	GCSO-1, GCSO-2, GCSO-3, RSO, FTM/MC, AM, RO

Each GCSO will have a separate GCS. The RSO will have a control station equipped with a series of configurable displays to enable oversight of the operation. The RSO provides authorization to start the flight operations and can direct aborts or suspend operations should safety concerns arise. The FTM controls the sequence of events for a given flight operation in terms of which test conditions are to be performed and general flow and control of the operations. The FTM will typically provide the operational brief for each session. The RO will ensure that the radar system is operational and will provide complementary scanning of the airspace with the AM to detect intruder traffic in LAFB Class D airspace. The AM will monitor the airspace using the IAD and informs crewmembers of potential traffic conflicts.

5.3.1.2 ROAM UAS Operations Center Forward Video Wall

The video wall is included to provide shared information that is needed for the sUAS operations team and complements and extends information displayed on each of the sUAS workstations. The design of the video wall allows it to be segmented into a series of smaller displays and arranged as needed. Build-up operations conducted under WVLOS and EVLOS will enable assessments of content displayed on the video wall and allow operators to assess the ability to adjust display locations should a change be required. Initial configuration of the video wall includes the following: 1) Integrated Airspace Display, 2) Operations Status Message board, 3) Repeat displays of each sUAS, 4) Planned flight schedule, and 5) Vertiport video.

The Integrated Airspace Display (IAD) is provided from the Anra Smart Skies CTR system. The Anra Smart Skies CTR (SS CTR) system includes a data fusion sub-system designed to integrate multi-sensor information and provide a comprehensive display of the operational environment. The fusion sub-system takes inputs from multiple sources, fuses corollary tracks and displays them as a single vehicle track. HDV is using inputs from radar systems, ground-based ADS-B, vehicle telemetry, and ground-based FLARM to feed the fusion algorithm. The Anra SS CTR system also displays the raw track files, airspace boundaries, and the Langley Monitoring Volume rings for assessing airborne traffic. The functionality of the fusion algorithm will be evaluated during HDV operations but is not required for BVLOS operations.

5.3.2 Ground Control Operator's Station in ROAM UAS Operations Center

The Ground Control Station includes several sub-elements. See Figure 31 for a photograph of a representative GCS being developed within the ROAM UAS Operations center. All GCS will include QGroundControl (QGC) with touch-screen and keyboard/mouse interfaces (#1). In addition, the GCS can be configured to include: Auxiliary weather information displays (#2 and #3), Real-time airspace monitor display (not shown), and xTM traffic monitor interface (#4), and a ClearComm voice control unit (#5).

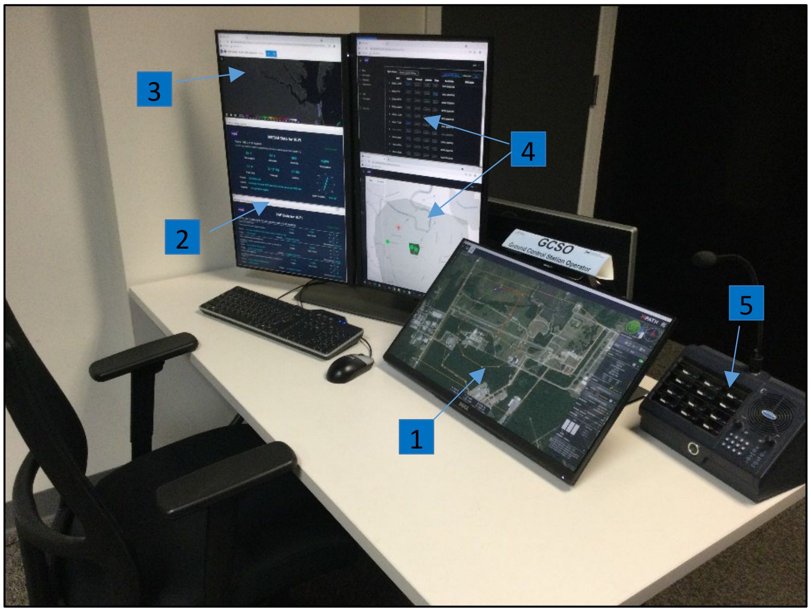

Figure 31 - Ground Control Station in ROAM UAS Operations Center.

QGC is a software system designed to provide a control interface for the GCSO to control the vehicle through standard computer-style interfaces (ie keyboard, mouse, computer display). It enables the GCSO to perform a series of functions such as vehicle pre-flight, mission waypoint creation, mission start, vehicle health monitoring, provisions to control the vehicle using a series of control modes (ie Hold, Mission, Return, Position, etc), and modify and upload the flight plan in flight. To provide the required level of control of the Safe2Ditch and ICAROUS autonomous systems, QGC was modified as part of the Measurement for Performance for Autonomous Teaming with Humans (MPATH) project. Modifications performed to QGC include: 1) Improved multi-vehicle control user interface, 2) Automation transparency for ICAROUS and Safe2Ditch (an example of this includes the display of traffic avoidance alerting bands that are generated by ICAROUS and displayed on the GCS display), 3) More functional integration and control capability of Safe2Ditch including the ability to view ditch site locations on the map display and the ability to modify their locations and update the Safe2Ditch ditch site database, and 4) the ability to see designated airspace volumes that are provided from air traffic management systems. Note that the multi-vehicle control from a single GCS (ie m:n>1) are not part of the current BVLOS operations.

Weather displays, shown in Figure 31, are used to provide Meteorological Aerodrome Reports (METAR), Terminal Area Forecasts (TAF), and localized real-time weather station information to the sUAS team during sUAS operations. A series of weather stations will be used for HDV flight operations with sensors located at the sUAS takeoff and landing locations.

The xTM Client is part of the UAM Ecosystem Prototype Assessment Operations but not a critical part of the BVLOS operations. The xTM Client provides an interface to the NASA's ATM-X project Provider of Services UAM (PSU) traffic management system as well as other advanced air traffic management functions. One example of a function performed under XTM Client is trial planning where a GCSO could request a re-route in-flight from the PSU to an alternate location.

The GCSO will be provided with two separate and independent vehicle control interfaces. Both will use the same GCS (MPATH). However, one will be linked to the vehicle through the uAvionix Microlink 900 MHz radio and the other will be linked to the vehicle using the 4G Botlink system. This dual control system provides two fully independent means of controlling the vehicle. It is expected that the backup GCS will be located in the element 4 area in Figure 31. This location will provide easy monitoring of both vehicle links by the GCSO.

5.3.3 Range Safety Officer's station

The Range Safety Officer's (RSO) control station will be similar in design to the GCS control station. However, several other informational displays will be included to help the RSO monitor and ensure safe operations. For example, the Integrated Airspace Display (IAD) will provide most of the information an RSO needs to perform duties, with the integrated depiction of the airspace, and the location of all sUAS and non-participating traffic.

The RSOs console will also be able to display any of the other displays available in the ROAM UAS Operations Center similar to the other control consoles. For example, RSOs could chose to display real-time video from cameras located at each of the takeoff and landing locations.

Finally, the RSO will have a highly configurable desktop ClearComm system that enables pushbutton communications with all members of the test team and ATC agencies.

5.3.4 Flight Test Manager station/Mission Commander

The Flight Test Manager/Misssion Commander (FTM/MC) control station will be configured to provide awareness of the quality of the flight test maneuvers and manage general sequencing of events for a given operational day. The FTM/MC will manage the sequence of test cards and order of events in order to accomplish test objectives.

5.3.5 Airspace Monitor station

The Airspace Monitor (AM) station will support the monitoring of all the surveillance sub-systems required to support the IAD. This includes constituent data sources from the LSTAR and GA-9120 radars, ADS-B, FLARM and telemetered GPS vehicle positions. The AM shall also have direct lines of communication with the Radar Operator (RO) to receive radar status updates. Additionally, the IAD shall allow the AM to assess the Anra SS CTR system to ensure the fusion algorithm is functioning nominally (functionality of the fusion algorithm is not required for BVLOS operations).

5.3.6 Ground Based Surveillance Infrastructure

The Ground Based Surveillance infrastructure consists of several independent systems all feeding information into the Anra Smart Skies CTR system and displayed in ROAM. This surveillance infrastructure will be used to detect and track air traffic that could pose a threat to BVLOS sUAS flight operations on the CERTAIN Range. Cooperative aircraft are assumed to be equipped with ADS-B out and providing position updates. Non-cooperative aircraft are assumed to be not-equipped with ADS-B. The surveillance infrastructure includes the use of an SRC LSTAR Q49 V2 target acquisition radar, two Dynetics GA9120 digital multibeam forming radars, Automatic Dependent Surveillance – Broadcast (ADS-B) and Flight Alarm (FLARM) ground receivers.

5.3.6.1 LSTAR Radar

See Figure 32 for a photograph of the LSTAR radar located on top of B1230 at NASA LaRC. This location was used to perform initial LSTAR characterization testing conducted within the Radar-1 test. The LSTAR has since been moved to the top of the Hangar building (B1244) at NASA LaRC which is shown in the background. The height of the hanger is approximately 100 ft high and will provide an excellent field of view for the LSTAR. The LSTAR operates on the L-Band frequency between 1215 and 1300 MHz and is adjustable. With an RF transmitted power of 720 W it can provide an instrumented range of 40 km (25 miles). The radar has a self-test capability, and the status of the radar is continually reported on the display so that the operator can be alerted if a radar degradation occurs. Further details regarding the LSTAR radar system can be found in Section 6.9 and Appendix J.

Figure 32 - Photograph of LSTAR Radar at Temporary Testing Location on B1230, NASA LaRC.

5.3.6.2 GA-9120 Radar

The GA-9120 radar operates in the S-Band frequency range between 3150 and 3250 MHz and is tunable. Ultimately the plan is to have 4 or more of these units in service as resources permit. The GA-9120s can detect manned aircraft up to 15km (9 miles) away and can also detect and sUAS, like a DJI Phantom IV, out to 5km (3 miles) based on manufacturer's specification (additional information on the GA-9120 can be found in Section 6.9 and Appendix K). For the current planned operations, only two GA-9120s will be available due to resource limitations, but that could change. See Figure 33 for a photograph of the GA-9120 during indoor lab assembly. The GA-9120s will be installed on NASA LaRC Gantry structure at an elevation of approximately 200 ft. See Figure 34 for an illustration of the installation location for the LSTAR and GA-9120s.

Figure 33 - Photograph of GA 9120 Radar in The Lab.

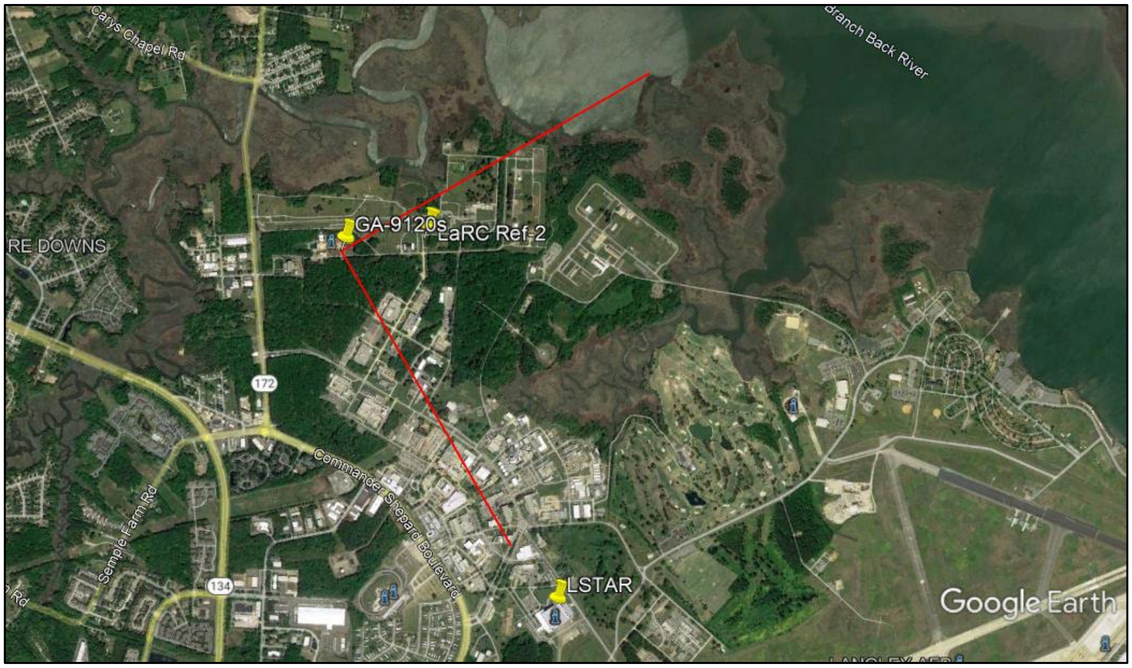

Figure 34 - Location of GA-9120(s) and LSTAR Radar with GA-9120 Boresight Indicated by Red Lines.

It is fully expected that the LSTAR and GA-9120 radar systems will complement each other's performance. One benefit will be at least partial coverage of the LSTAR's cone of silence by the south facing GA-9120.

Figure 35 shows the vertical radar cross-section coverage for the LSTAR and GA-9120 Radars across LAFB Class D and the LMV. The LSTAR cone of silence is partially covered by the G.A-9120. The installation altitude of the GA-9120 is 250 feet and the LSTAR altitude is 100 feet AGL. Aircraft in the "uncovered airspace" area could vertically descend into the LMV undetected until approximately 1,270 feet, but

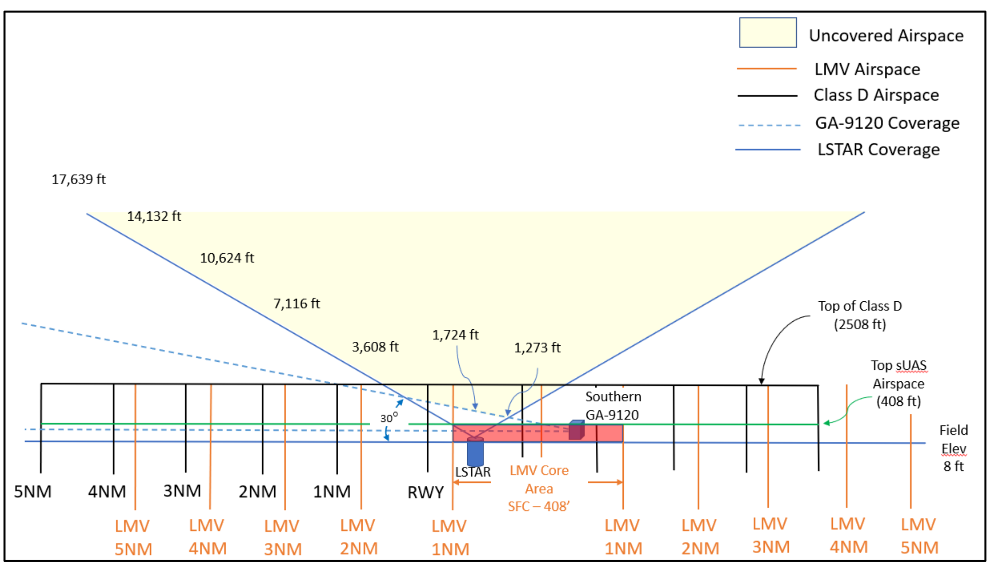

Figure 35 – Cross-section View of Airspace Coverage Provided by LSTAR and GA-9210 Radars Along with LMV and Core Areas. View Looking E or W

they would either need to be a helicopter or a fixed wing aircraft executing an excessively steep descent (>30 degrees). The mitigations for this gap in radar coverage take advantage of the procedural deconfliction in the LOP (manned aircraft at or above 900' AGL during UAS operations), conducting operations while LAFB Tower is open and the realization that such a steep descent is highly improbable from a fixed wing aircraft. Each radar system will have individual displays to monitor the sensor system health and operational status and will be monitored during flight operations.

5.3.6.3 ADS-B ground station

The ADS-B sensor system will be a uAvionix Ping Station-2 system. This system features a weatherproof antenna enclosure with power over ethernet to provide a reliable and easy to install system. The Ping Station-2 will be mounted to a structure at NASA LaRC with the output routed to the ROAM UAS ops center and into the Anra SS CTR system via LaRCNet. The range of reception will vary based on aircraft altitude and transmitter power but likely exceed the LMV dimensions multiple times and will be evaluated during HDV radar evaluation testing.

5.3.6.4 Flight Alarm ground station

The Flight Alarm (FLARM) ground station will be composed of a PowerFlarm unit mounted within a weatherproof enclosure. It will be connected to a computer that will route output information to the ROAM UAS ops center via LaRCNet. FLARM is designed for usage in manned sailplanes providing valuable situational awareness regarding the locations of other sailplanes. It is used extensively in Europe as well as in the U.S. There is a soaring operation approximately 23 miles southwest of LaRC that operates primarily on weekends. We are not expecting to see any manned aircraft equipped with FLARM in the LMV.

FLARM data will serve as the sUAS vehicle to sUAS vehicle communication for ICAROUS engagements and also provide a fully-independent vehicle position source (backup to the GCS) for personnel to monitor inside ROAM.

5.3.7 Air Traffic Surveillance Data Integration System (Data Fusion)

The data from the multiple ground surveillance sources shall be integrated and displayed using two software applications provided by ANRA Technologies, Inc. SmartSkies fusion shall read the multiple data streams from the ground-based FLARM unit, ADS-B Ping 2020 receiver, vehicle GPS telemetry, GA 9120 Radar, and the LSTAR Radar. This data will be fused together to produce a more accurate and consistent single track than can be provided by any individual surveillance data source alone. SmartSkies VISUALIZER shall provide a visual depiction of the integrated surveillance data and include UAS telemetry, weather, terrain, AIM, obstacles, NOTAMs, etc. The application will process and provide a selectable collection of data sources to support flight safety decisions and improve operating intelligence. Note: The data fusion algorithm will be evaluated during BVLOS operations but is not required to conduct them.

The user interface for displaying the fused tracks shall have the following capabilities:

- Record and playback capabilities
- Live map display of the vehicle data, identifying and displaying multiple vehicle targets
- Integration of target position from asynchronous input data sources
- Weighted average single point view that is based on type of aircraft position source (ie: ADS-B, radar, FLARM, sUAS vehicle telemetry).

5.3.8 Integrated Airspace Display

HDV will use the IAD, along with other displays, in the ROAM UAS Operations Center to help meet the FAA 14 CFR § 91.113 see and avoid requirements for BVLOS operations in the National Air Space (NAS). The IAD will display both the raw data from each of the ground surveillance systems and a consolidated air traffic picture of real-time surveillance data fused by the ANRA Technologies SmartSkies system. The IAD will be displayed on the forward wall of the ROAM UAS operations center and can also be displayed on the various control consoles within ROAM.

The ground-based surveillance infrastructure which includes the IAD, shall enable the detection of airborne threats in a timely manner and provide sufficient information to allow for the execution of an appropriate avoidance maneuver. In addition to providing real-time surveillance during flights, the ground-based systems will be used to gather historical data to characterize the airspace in and around the CERTAIN Range.

In summary, the IAD and ground surveillance systems shall:

- Provide real-time awareness of the Langley Monitoring Volume that will enable Beyond Visual Line of Sight (BVLOS) UAS operations in the CERTAIN Range
- Detect and track aircraft (out to 5NM, up to 2,500' AGL)
- Provide warning time for all detected aircraft as defined by the Langley Monitoring Volume (LMV) parameters
- Augment an existing historical airspace assessment
- Provide backup position information for sUAS
- Demonstrate that the following can be accomplished safely:
    - Both cooperative and noncooperative (air) traffic can be detected and tracked to facilitate appropriate separation and collision avoidance
    - Ground-based surveillance data displayed on IAD can be effectively used by the RSO, AM, and PIC to make decisions on flight path routes
    - IAD data routed to ICAROUS for interpretation and use in autonomous avoidance maneuvers

5.3.9 Voice Communications Equipment

A voice communications system consisting of ClearComm devices complemented by VHF handheld radios, Microsoft Teams, and backup cell phones will be used to provide required voice communications for the sUAS operations team. Essential crew members in the field will be equipped with single-ear headsets with ClearComm belt packs to enable hot-mic communications with the entire UAS operations team. Crew members in the ROAM UAS Operations Center will also be equipped with ClearComm devices that are routed through a primary voice comm control interface. It is anticipated that multiple communication loops will be established to enable more effective communications across the team. All Flight Crew members must have a primary and backup method of voice communication when not co-located. RSOs will be in direct contact with Langley tower via VHF radio and will utilize a cell phone or landline as a backup.

6 BVLOS Operational Model

Section 6 provides a description of the proposed operations and serves as a concept of operations (CONOPS). Together, the System Description described in Section 5 and the BVLOS operational description below provide a complete picture of the equipment capabilities and how they will be used to conduct BVLOS operations.

6.1 Concept of Operations Overview

NASA Langley currently operates underneath two COAs in Langley AFB Class D airspace (2020-ESA-7889 and 2020-ESA-10788 – Appendix B) for conducting WVLOS UAS operations. In preparation for the High Density Vertiplex (HDV) beyond visual line-of-site (BVLOS) operations in late 2022, NASA Langley recently obtained a waiver and approved COA (2021-ESA-9599-COA) with the FAA that allows for the use of visual observers (VOs) to meet the 14 CFR § 91.113 see and avoid requirement. NASA LaRC is referring to these VO operations as extended visual line-of-site (EVLOS) operations. These EVLOS operations were part of the Advanced Onboard Automation (AOA) phase of HDV where only the VO(s) maintain visual awareness of the entire airspace in which the operation occurred. Detecting non-participating crewed traffic and taking the appropriate action to resolve airborne conflicts using a VO is a bridge between WVLOS and full BVLOS operations. The second spiral wrap of HDV, Scalable Autonomous Operations (SAO), requires a full transition to BVLOS operations to meet HDV Project objectives. SAO operations will use procedural deconfliction, ground surveillance feeds, predetermined pilot-initiated avoidance maneuvers, and NASA autonomous technologies to satisfy 14 CFR § 91.113 see and avoid requirement.

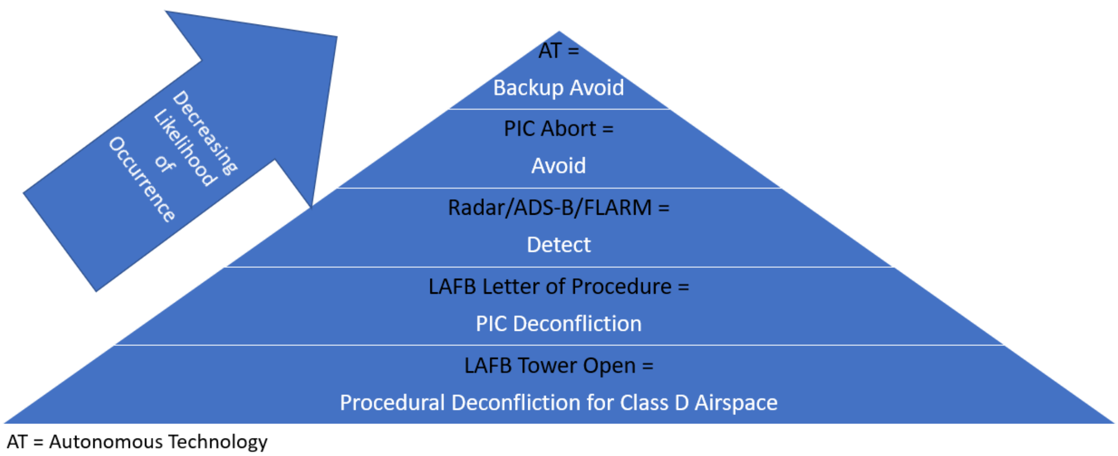

Figure 36 – HDV SAO 14 CFR § 91.113 See and Avoid Mitigations

Inside the Remote Operations for Autonomous Missions (ROAM) UAS Operations Center, airspace monitoring and conflict resolution will be accomplished using the display of ground surveillance data. The Airspace Monitor (AM) and Radar Operator (RO) will utilize the ground surveillance data to maintain awareness of the entire airspace and make recommendations to the Range Safety Officer (RSO) and Ground Control Station Operator Pilot in Command (GCSO PIC) to resolve airborne traffic conflicts.

BVLOS operations will integrate sUAS GCSO, RSO, AM and (RO operations into the ROAM UAS Operations Center. A vehicle service crew (VSC) shall prep the vehicle for takeoff and perform servicing activities after landing. The primary takeoff and landing sites for HDV are referred to as vertiports. There will be five vertiports designated across the CERTAIN Range, capable of supporting UAS BVLOS launches and recoveries. A wide array of operational scenarios shall be tested to meet the SAO test objectives. Flight paths will include sufficient predetermined and clearly marked ditch sites for contingency operations should a 'land as soon as possible' situation arise.

6.2 Crew Deployment and Transitions for BVLOS Operations

For the proposed operations a logical progression of crew roles and responsibilities will be accomplished. The starting condition is identical to the current sUAS operations at NASA LaRC where there are two people manipulating the controls (PMCs). One PMC uses a handheld R/C transmitter and observes the vehicle flight path and status through direct visual observations of the vehicle and airspace. This individual is referred to as the Safety Pilot (SP). The other PMC uses a GCS and may or may not be able to directly see the vehicle and the airspace. This individual is referred to as the Ground Control Station Operator (GCSO). In addition to the dual PMCs, a RSO is used to help ensure safe operations through direct visual observation of the vehicle, airspace, and monitoring of both the SP and the GCSO.

Through a series of progressive steps, the proposed operations will transition into one PMC, supported by a team of personnel, located in the ROAM UAS operations center where airspace awareness will be provided via an integrated airspace awareness system that includes radars, ADS-B, FLARM, GPS vehicle telemetry and real-time video inputs. Personnel still located on the flight line will perform vehicle servicing, direct visual preflight inspections of the sUAS, and visual observer roles for segments of the proposed flight operations that are WVLOS. These progressions are broken up into phases (0-5) described below. Each phase will have its own Operational Readiness Review to ensure that the HDV project is ready to next phase of operation.

6.2.1 Phase-0

Phase-0 of the transition will provide dual GCSOs each with fully separate and independent control links to the vehicle. One will use a 900 MHz link and the other a 4G cell link using MPATH or basic QGC. This team of GCSOs will work with and follow the directions of the SP, who is still the designated PIC. In this phase, all 3 PMCs are co-located, within visual line of sight of the vehicle, and have the ability to send commands to the vehicle. Flights in this phase will be WVLOS of the entire flight crew. These flights are authorized under 2020-ESA-7889-COA and were flown during the HDV Flight Path Assessment test flights (Fall 2021).

6.2.2 Phase-1

Phase-1 of the transition will relocate the GCSO role to the ROAM UAS operations center. Initially, one of the GCSOs will be relocated to the ROAM UAS operations center. The GCSO in ROAM will be initially just monitoring the vehicle (Phase-1a) and be in voice communications with the team in the field. After sufficient monitoring has been accomplished, the GCSO in the field will be removed and the GCSO in ROAM (GCSO-R) will become the primary GCSO. In this situation, the GCSO-R is still second in command (SIC) with the SP retaining PIC roles (Phase-1b) and still WVLOS of the vehicle. Flights covering Phase-1a, -1b are authorized under 2021-ESA-9599-COA and were flown during the HDV AOA flight test (Spring 2022). The results to AOA flight test are being compiled and will be located in Appendix H.

6.2.3 Phase-2

Phase-2 will continue the transition into ROAM by moving the RSO role into ROAM with augmentation from one or more visual observers in the field. The visual observer(s) will be in a position where the sUAS and the entire airspace is visible while being in direct voice communication with the sUAS operations team in ROAM. The RSO will be able to observe airspace information from available advisory level systems in ROAM such as ADS-B, FLARM, GPS vehicle telemetry and Radar. The phase-2 transition will also transfer the PIC duties from the SP to the GCSO in ROAM. At that point, the SP will transition to a VP who will monitor the vehicle only when the vehicle is WVLOS. Initial flights (Phase-2a) will be performed WVLOS of the VP and VOs in the field (2a). In Phase-2b, segments of the flights will be performed beyond the visual line of the sight of the VP over very sparsely populated areas of LaRC. In Phase-2b, the sUAS failsafe RTL characteristics will no longer execute an RTL when R/C link (controlled by the VP) is lost. Phases-2a and -2b will utilize the Extended Visual Line of Sight (EVLOS) flight operations approved in 2021-ESA-9599-COA. These flights will be flown during the HDV SOA flight test preparation spiral wrap (Winter 2023).

6.2.4 Phase-3

Phase-3 will continue to utilize VOs and add an Airspace Monitor (AM) and Radar Operator (RO) in ROAM. In Phase-3, a significant number of flights will be performed with periodic operational reviews to evaluate the information provided in the ROAM UAS operations center. Elements included in the reviews will evaluate overall system performance and situational awareness of the UAS operations team. One objective is to perform testing to transition the ground-based surveillance system from an advisory role to a role that provides an alternate means of meeting the 91.113 see and avoid requirement. Verification of this capability is critical to mitigating the risks of a mid-air collision and proceeding onto full BVLOS operations. These flights are authorized under 2021-ESA-9599-COA and will be flown during the SAO build-up flight test.

Note, phases 1-3 will be conducted with under single and multi-vehicle operations to mitigate risks to Phase-5 (multi-vehicle BVLOS operations).

6.2.5 Phase-4

Phase-4 will remove VOs from the flight operation and the VP will no longer be required for flight operations. In Phase-4, personnel in the field will still include the vehicle service crew who will be responsible for performing pre-flight inspections of the vehicle, positioning the vehicle for takeoff, removing the vehicle after landing, and conducting post flight inspections. This phase and all subsequent phases described below will require a BVLOS waiver to 14 CFR § 91.113 and is the premise for this safety case.

6.2.6 Phase-5

Phase-5 will add additional vehicle(s) (up to 5 total). Initially, in Phase-5a, vehicles will fly pre-deconflicted routes. All routes and alternate contingencies plans will be fully deconflicted before flight. In Phase-5b, vehicles will be separated pre-flight however will fly the same/similar routes separated only in time with the flight crew and autonomous systems managing off-nominal route deconflictions.

6.2.7 Vertiport Operations Area

Figure 37 shows a representative scenario utilizing Vertiport-1 and Vertiport-6 in the Vertiport Operational Area for flights that are WVLOS. These flight paths would be expanded to BVLOS operations using Phases 2- 4 and Phase 5 would introduce multi-vehicle BVLOS operations. The blue lines enclosing each vertiport are Vertiport Protection Volumes (VPVs). Within this application, it is assumed that only vehicles going to or from a vertiport would be able to enter a VPV. The red circle portrays a Vertiport Operational Area (VOA). Aircraft are required to be appropriately equipped and qualified to enter a VOA. Each vertiport is configured with representative standard instrument departures (SIDs) as well as Standard Terminal Arrivals (STARs). Vertiport-1 is shown with two SIDs to the Northeast along with two Southwest bound STARs. The red chevrons indicate actual sUAS aircraft. For this scenario, sUAS will takeoff and follow a SID, then proceed along the yellow waypoints and then enter a STAR. Small UAS will essentially be flying a "traffic pattern" to each vertiport, replicating UAM operations at a vertiport during the outbound (SID) and inbound (STAR) segments. The brown chevron located near Vertiport-6 represents a simulated aircraft.

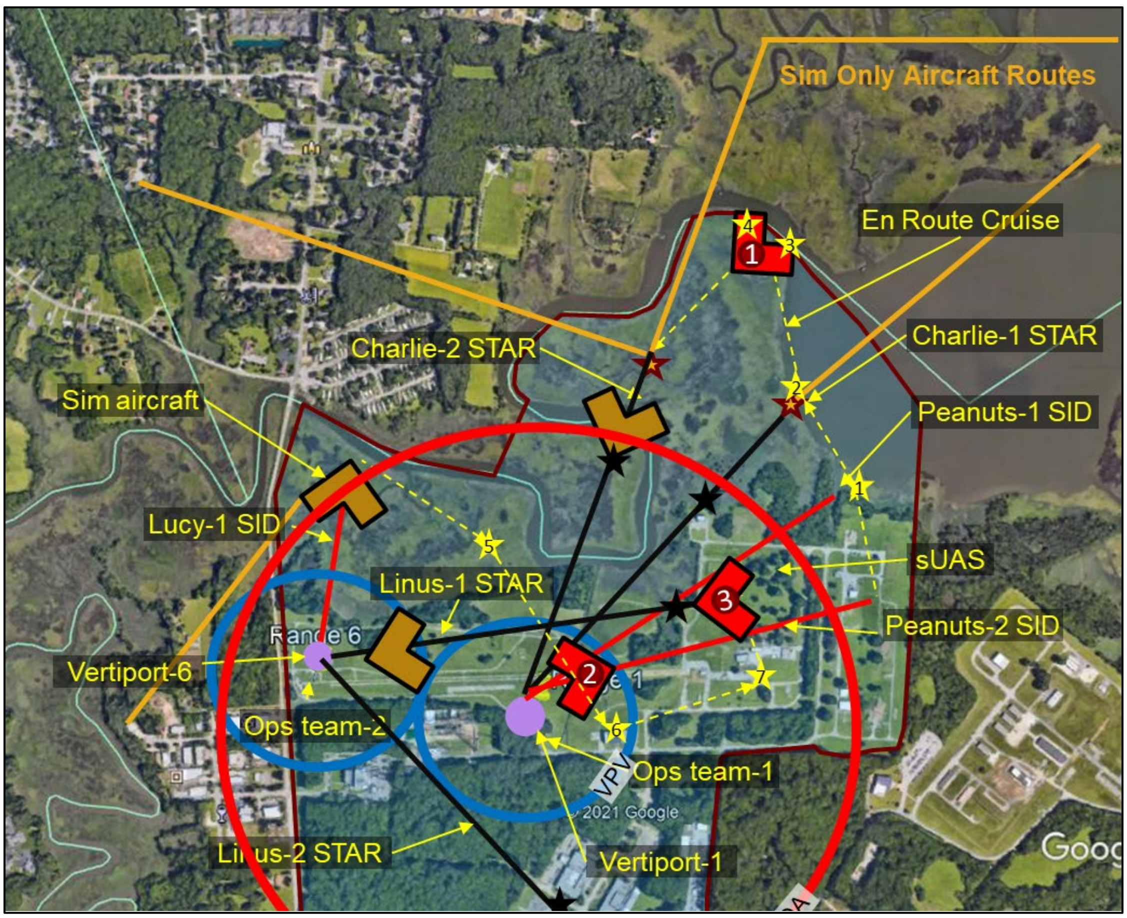

Figure 37 - Nominal Scenario for Prototype Assessment Operations.

For operations within the VOA, simulated vehicles will be used to alter traffic density within the VOA. However, the testing of autonomous responses using ICAROUS will only occur with live sUAS vehicle interactions. Other test operations within the VOA will include the testing of vehicle responses to off-nominal conditions as would be encountered with vehicles in emergency states needing to perform emergency landings and vehicle re-routing due to conditions at a vertiport

Operations within the VOA environment were performed using the Human and Hardware in the Loop (HHITL) Advanced Onboard Automation (AOA) simulation (fall of 2021), and the AOA Flight Test (spring of 2022). AOA Flight Test completed Phases 0 and 1 defined previously. A follow-on spiral wrap of the HDV project, referred to as Scalable Autonomous Operations (SAO) will include both a HHITL simulation (SAO Sim) and SAO Flight Test. SAO Sim (Fall/Winter 2022), will serve to expand operations within the VOA environment as well as fully test systems required for SAO Flight. SAO Flight will continue with the BVLOS buildup and achieve Phases 3, 4, and 5.

6.3 Flight Crew

Table 5 identifies the crew required to conduct BVLOS operations (Phases 4, 5) and their specified locations for the HDV project. Locations are identified as either Field (launch and recovery area, divert area or rooftop) or Remote (ROAM UAS Operations Center) located inside building 1268 on NASA LaRC. Optional members are not required but can be used as part of the build-up approach to full BVLOS operations at NASA LaRC.

Table 5 - Flight Crew Designation, Roles, Required/Optional need, and Location for Phase-4, -5, and -6 Operations.

Abbreviation	Role	Required/Optional	Location
FTM/MC	Flight Test Manager/Mission Commander	Required	Remote or Field
GCSO (SIC)	Ground Control Station Operator (SIC)	Optional	Field
GCSO (PIC)	Ground Control Station Operator (PIC)	Required	Remote or Field
VSC	Vehicle Service Crew	Required	Field
RO	Radar Operator	Required	Remote
AM	Airspace Monitor	Required	Remote
RSO (Field)	Range Safety	Optional	Field
RSO (ROAM)	Range Safety Officer	Required	Remote
VP	Visual Pilot	Optional	Field
VO	Visual Observer	Optional	Field
KLFI Tower	Class D Airspace Control KLFI	Required	External

The primary Flight Crew for BVLOS operations includes a Flight Test Manager/Mission Commander (FTM/MC), Ground Control Station Operator (GCSO), Range Safety Officer (RSO), Airspace Monitor (AM), Radar Operator (RO) and the Vehicle Service Crew (VSC). The Flight Crew is responsible for executing BVLOS test flights in a safe and efficient manner. Visual Pilots (VPs) and Visual Observers (VOs) may be utilized to augment the primary Flight Crew during the build-up to BVLOS flight operations. KLFI Tower is the Class D controlling agency external to NASA LaRC that authorizes the activation/deactivation of the CERTAIN Range.

6.3.1 Flight Test Manager and Mission Commander

The Flight Test Manger/Mission Commander (FTM/MC) executes the flight test plan by working with and managing the flight crew. The FTM/MC is responsible for defining test objectives for all phases of flight activity by clearly defining the test set-up, reviewing the required test conditions/parameters for mission assurance and ensuring the flight activity is flown in accordance with the approved test plan. The FTM/MC primary location for BVLOS operation will be in the ROAM UAS Operations Center but during build-up flight test execution, the FTM/MC may manage test operations from the field.

6.3.2 Ground Control Station Operator

For the testing defined herein, the Ground Control Station Operator (GCSO) will serve as second in command (SIC) to the SP/VP as well as pilot in command (PIC) depending on the phase of operation.

6.3.2.1 GCSO Second In Command

The GCSO Second In Command (SIC) is typically used during WVLOS operations. The GCSO SIC is responsible for programming, running, and managing the autonomous control modes of the vehicle using the Q-Ground Control software and the PX4 autopilot. This typically includes vehicle initialization, autopilot programming, monitoring vehicle states and trajectories and issuing commands to the UAS autopilot. The GCSO SIC typically acts at the direction of the SP/VP PIC, who is responsible for clearing the airspace and monitoring the vehicle. The GCSO SIC is not required to be a qualified PIC but will act as a second in command during flight operations. NASA Langley WVLOS operations frequently co-locate the GCSO with the SP PIC so the GCSO can provide the PIC with vehicle status/parameters, but it is acceptable for the PIC and GCSO SIC to be in different locations provided there are communication links that allow for real-time communications.

6.3.2.2 GCSO Pilot In Command

The GCSO PIC has all the responsibilities of a GCSO SIC but also is responsible for monitoring weather conditions, clearing the airspace, monitoring the vehicle, and maneuvering the aircraft as required to ensure safe flight operations. The GCSO PIC primary location for BVLOS operation will be in the ROAM UAS Operations Center. The GCSO PIC must have primary and secondary lines of communication to all Flight Crew members. For multi-vehicle, BVLOS operations, there shall be one GCSO PIC for each vehicle flown.

During the HDV Project, the GCSO PIC will also be the main point of interest for the human factors subject research. Within this capacity, associated run data logs will be retrieved from the workstation and saved locally until the end of the day. GCSO will be responsible for answering questionnaires after each scenario run to capture human factors data.

6.3.3 Range Safety Officer

The Range Safety Officer (RSO) is responsible for providing a project-independent safety monitoring function ensuring that the operation is conforming to appropriate NASA and FAA regulations as well as the planned and authorized conditions as defined in the ARB and ORR documentation.

The RSO provides oversight for UAS vehicle operations by monitoring range airspace, sUAS vehicle state information (health, trajectory, and flight parameters), and local weather conditions. The RSO also files NOTAMS, maintains communications with KLFI Tower, performs pre-operational safety briefings, reviews safety procedures, and confirms roles and responsibilities for each flight. The RSO makes real-time operational decisions when required for flight safety and ensures compliance with hazard mitigations documented in the hazard analysis. The RSO must give the final approval prior to each flight operation in the NAS and may direct avoidance maneuvers to be utilized by the affected PIC based upon airspace traffic and information received from the RO, AM, and/or VOs. In the event of a mishap, the

RSO takes control of the situation to ensure safety, preserve evidence, collect preliminary details, and notify required personnel.

The RSO maintains situational awareness of all sUAS and is empowered to make any decision necessary to maintain range safety, including grounding all aircraft and directing the termination of a flight vehicle.

6.3.4 Airspace Monitor

The airspace monitor (AM) serves the role of monitoring the airspace surveillance and display systems from ROAM to ensure that they are operating according to expectations. In this role, the AM will monitor the constituent surveillance systems to ensure they are operating as well as assess the the Anra SS fusion system for adequate performance. The AM will interface with surveillance system operators (e.g., radar, ADS-B, FLARM) as needed to monitor the LSTAR, GA-9120, ADS-B and FLARM ground based systems. The AM also scans the surveillance information to look for traffic in the LMV and characterize it as intruder or nominal traffic (7.9.5).

The AM shall inform the RSO/GCSO PIC of intruder traffic and support GCSO-monitored sUAS deviations from the planned route. The AM is also responsible for monitoring the status and performance of the surveillance system including the ANRA Fusion algorithm to verify raw data (radar, ADS-B, FLARM) is being represented accurately on the airspace situational awareness display. The AM shall notify the RSO of any failures/malfunctions of the surveillance system including the radar units, FLARM and ADS-B receivers. If an intruder appears within the LMV, the AM will help determine if it poses a credible threat based upon its geometry (heading, altitude and airspeed), location with respect to KLFI and KPFH and its predicted flight path. Once the intruder is assessed as a threat, the RSO and GCSO will be notified of the impending threat, its location, altitude, and direction of travel. The RSO will verify the appropriate avoidance maneuver is being executed by the GCSO and, if required, direct vehicle termination or other actions to ensure well clear distances are maintained.

During BVLOS operations, the AM will be co-located with the RSO within earshot of each other inside the ROAM UAS Operations Center. For general situational awareness, the AM shall have the ability to monitor local frequencies used by civilian air traffic but have no ability to broadcast/communicate with air traffic. Once the performance of the ANRA Fusion algorithm is verified, the duties of the AM may be transferred to the RSO.

6.3.5 Radar Operator

The Radar Operator (RO) shall be familiar with radar surveillance procedures, have a basic understanding of Air Traffic Management (ATM) with regards to airspace coordination of crewed and uncrewed flight operations, and receive sufficient training on operating the radar system. The core responsibility of the RO will be to ensure that the radar system is operational and provide complementary scanning of the airspace with the AM to detect intruder traffic in the Langley Monitoring Volume (LMV). This assessment shall be based upon the intruder geometry (heading, altitude and airspeed), location with respect to KLFI and KPFH and the predicted flight path of the intruder. The RO shall monitor both the L-STAR and the GA-9120 radars for proper operation. If a malfunction occurs with either the L-STAR or the southern facing GA-9120, the RO shall inform the RSO and AM.

The RO will maintain a direct line of communication with the RSO and AM (and, indirectly, with the PICs via the RSO) over a dedicated range safety channel. This is communication link is required when sUAS will be operating BVLOS of the VSC located at the launch/recovery area. The RO will track aircraft within the LMV and support the traffic scanning process. If an intruder appears within the LMV, the RO will communicate that to the AM and RSO who will determine if it poses a credible threat. Once the intruder is assessed as a threat, the RSO will notify the operations team on the rage safety channel and verify the appropriate avoidance maneuver is being executed by the GCSO. If required, the RSO will direct vehicle termination or other actions to ensure well clear distances are maintained. The RO can also augment intruder information by notifying the AM and RSO, of specific boundaries the intruder reaches as it passes through the LMV.

6.3.6 Vehicle Service Crew

The Vehicle Service Crew (VSC) typically consists of one or two individuals that are responsible for the maintenance, inspection and visual pre-flight of the vehicle while it is on the ground. The VSC is stationed at the Vertiport takeoff and landing sites and are responsible for prepping and position the vehicle for takeoff. After landing, they are responsible for removing the vehicle from the Vertiport to perform servicing activities. The VSC shall have primary and secondary communication links with the GCSO PIC and the RSO. The VSC can perform additional duties such as VO and/or VP/SP while the UAS is in the air and WVLOS of the VSC location.

6.3.7 Visual/Safety Pilot

The Visual/Safety Pilot (VP/SP) can take control of the sUAS while it is WVLOS by using a manually operated radio-controlled (R/C) control transmitter. The Visual/Safety Pilot may perform crewmember duties acting as a fail-safe to an uncrewed aircraft system that is normally controlled by a GCSO PIC or GCSO SIC when the vehicle is WVLOS. The VP/SP will typically be located with and help perform the pre/post flight duties handled by the VSC. The VP/SP shall have primary and backup communications with the RSO and GCSO PIC. One delineation of roles between VP and SP is that SPs are associated with being the pilot in command. A VP is associated with a second in command role working with the GCSO PIC.

6.3.8 Visual Observers

Visual Observers (VOs) are used as part of the build-up approach and can be used as a backup for ground surveillance systems or for operations in the takeoff and landing areas. Their primary responsibility will be to scan their viewable airspace for potential traffic conflicts and notify the operations team when such threats are detected. The VOs can also supplement the radar systems by providing visual coverage of the airspace during buildup operations. Note that the design of the radar surveillance system is complementary and includes provisions to use the GA-9120 to provide at least partial coverage for the LSTAR's cone of silence that exists approximately 30 degrees above the horizon. Additionally, VOs may be asked to visually acquire and confirm any intruder traffic detected on the radar that is WVLOS. As stipulated in 8900.1, 16-4-4, the VOs will communicate any information to Flight Crew that is required to remain clear of any detected conflicting traffic, terrain, and obstructions. Additionally, the VOs will notify the Flight Crew of any major observed deviations from the planned flight path and provide navigational awareness, as able, when the sUAS are within visual line of sight. For full BVLOS under phases 4 and 5, flight segments will be performed in areas with no VO coverage.

6.3.9 Langley Air Force Base Tower

Langley Air Force Base (KLFI) Tower approves request for the opening of airspace at NASA Langley CERTAIN Flight Range and confirms the request for the closure of the same airspace. KLFI tower also issues NOTAMs and broadcasts alerts on Automated Terminal Information System (ATIS) identifying UAS operations are in progress. KLFI Tower also limits manned traffic to be at or above 900 feet AGL during sUAS operations. The RSO monitors KLFI VHF Tower frequency at all times and is able to respond to all KLFI Tower communications instantaneously.

6.4 Operational Scenarios

HDV SAO BVLOS operations will begin with single vehicle BVLOS operations and progress to multi-vehicle operations as outlined. Specific flight routes will cover a wide variety of options and are still in development. There are several guidelines/risk mitigation procedures that help bound all the operational scenarios. See Appendix D for the detailed hazard analysis and associated mitigations.

6.4.1 Single Vehicle BVLOS Operations

In a traditional build-up approach, BVLOS profiles shall be flown using a combination of VOs and ground surveillance data monitored by the AM, RO, and RSO in ROAM. Successful completion of these combination build-up flights is required before HDV will transition to only using the ground surveillance information to clear the airspace for BVLOS flights.

Two single vehicle BVLOS operation scenarios are depicted in Figure 38 below. The first depicts a vehicle departing on a closed predefined route, climbing to a safe transit altitude, flying the route, and recovering back at the same vertiport it departed. The areas in yellow are visible by the crew located in and around Vertiport-1. Areas in green are beyond visual line of sight from Vertiport-1. As a build-up and initial risk mitigation, this flight operation shall be accomplished using VOs monitoring the entire flight path to verify proper ground surveillance data in ROAM. These EVLOS flights also allow for the checkout of vehicle/voice communication links from the ROAM UAS Operations Center before transitioning to BVLOS operations.

The second scenario depicts a vehicle departing on a predefined route, climbing to a safe transit altitude, flying the route, and recovering at a different vertiport. As a build-up and initial risk mitigation, this flight operation can also be accomplished using EVLOS operations to ensure satisfactory performance before transitioning to BVLOS operations. It should be noted that Scenario 2 can only be performed when NASA LaRC is closed to mitigate the risk of overflight of people since it proceeds beyond CERTAIN-I and CERTAIN-IIa.

For both Scenarios 1 and 2, no flight will be completely BVLOS as the VSC will have direct line of sight with the vehicle for a period time. However, once the vehicle proceeds on course, they will lose sight of the vehicle due to trees and buildings occluding direct view of the vehicle and it will enter into BVLOS flight segments.

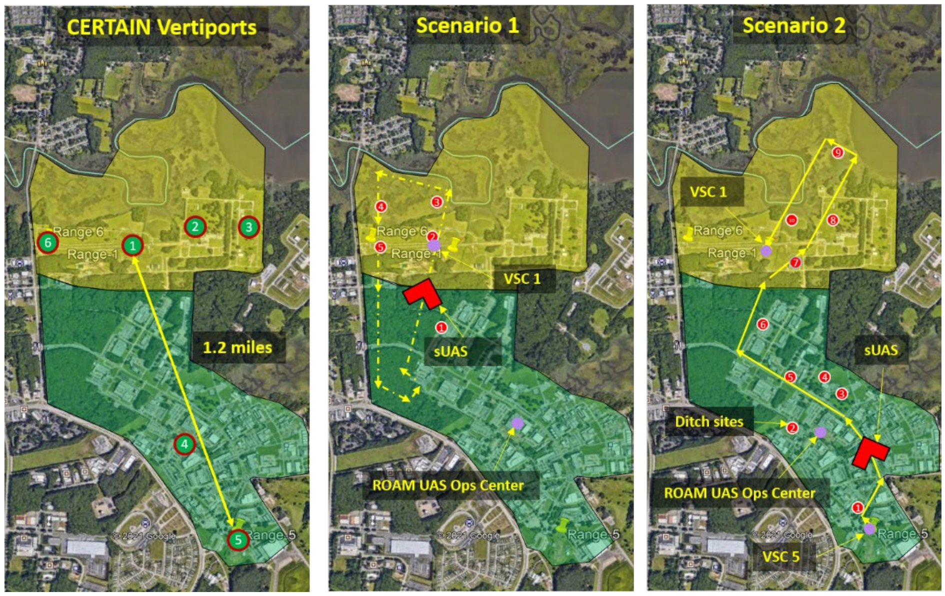

Figure 38 - Example BVLOS Flight Paths.

6.4.2 Multi-vehicle BVLOS Operations

BVLOS operations for SAO CONOPS will progressively build from single vehicle operations to multi-vehicle operations. In Figure 39, a scenario depicting two BVLOS flights and one WVLOS flight occurring simultaneously. As with single vehicle BVLOS operations, multi-vehicle operations shall also be conducted under EVLOS conditions to ensure adequate system performance before transitioning to full BVLOS operations.

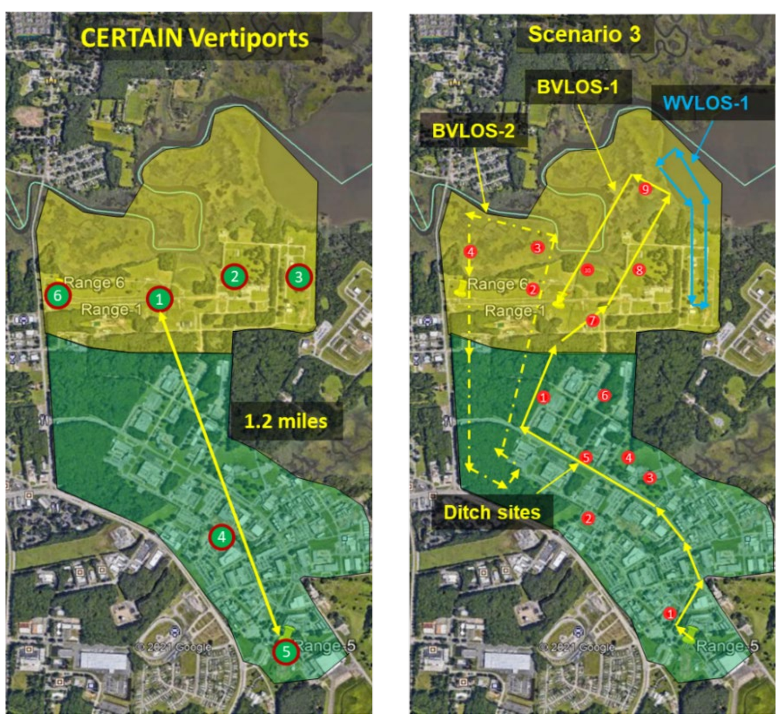

Figure 39 - Example of Multiple BVLOS Flight Paths.

Table 6 defines the participants, their priority, and location for a potential three sUAS vehicle operation. Primary and Secondary help to identify lead vs subordinate roles and help delineate between required vs not required. A secondary role may be used as part of the build-up approach to provide another layer of safety/risk mitigation, but that individual is not required to conduct the BVLOS operation. It will be noted that for the Location columns of the table, FIELD refers to the CERTAIN Flight Range at NASA Langley Research Center, including Vertiports; REMOTE is the ROAM UAS Operations Center or some other location at NASA LaRC that is not in the field; and EXTERNAL is any Actor's role that is outside of NASA Langley Research Center that includes participants at Langley Air Force Base (KLFI) airspace tower control.

Table 6 - Identification of Roles Supporting HDV Project (Up to 3 BVLOS Vehicles)

Abbreviation	Role	Priority	Location
RSO	Range Safety Officer	Primary	Remote
		Secondary	Field
VP/SP	Visual/Safety Pilot #1	Secondary	Field
	Visual/Safety Pilot #2	Secondary	Field
	Visual/Safety Pilot #3	Secondary	Field
GCSO PIC	Ground Control Station Operator PIC #1	Primary	Remote
		Secondary	Field
	Ground Control Station Operator PIC #2	Primary	Remote
		Secondary	Field
	Ground Control Station Operator PIC #3	Primary	Remote
		Secondary	Field
VO	Visual Observer #1	Secondary	Field
	Visual Observer #2	Secondary	Field
	Visual Observer #3	Secondary	Field
FTM/MC	Flight Test Manager/Mission Commander	Primary	Remote
		Secondary	Field
VSC	Vehicle Service Crew	Primary	Field
RO	Radar Operator	Primary	Remote
AM	Airspace Monitor	Primary	Remote
KLFI Tower	Airspace Control, KLFI	Primary	External

6.5 Communication Plan

In general, several forms of communication will be employed to support HDV operations with applicability towards different segments of the operations and team composition. For example, before pre-flight and during team ramp-up, a mix of asynchronous and real-time voice and visual communications may be employed. Examples include text messaging and/or chat functions to convey non-critical information. Once the crew crosses into deliberate and focused preparations for flight (e.g., start of pre-flight) then a sterile cockpit approach will be applied to the distributed crew. Extraneous communications will be prohibited and all required information will be communicated using bi-directional communication links with required responses. Non-critical crewmembers may still employ various forms of communication to monitor the progress of events, but critical crewmembers will adhere to the sterile cockpit approach. Critical crewmember communications will have both primary and backup systems with all required communications systems tested before the first flight of the day.

6.5.1 Voice Communication

Communication links are vital to the success of HDV BVLOS operations on NASA Langley. Voice communications with KLFI Tower shall be handled through the RSO on VHF 125.0. Typically, KLFI Tower provides an authorization to begin operations and is notified when operations are complete. If at any point, KLFI Tower needed to issue instructions to the sUAS operators, that communication would be handled by the RSO. Voice communications between crewmembers in the field and crewmembers in the ROAM shall be handled by VHF radios using discrete network channels. At a minimum, there will be a Flight Safety Network (FSN) and a Flight Operations Network (FON). When a vehicle is ready for takeoff or expected to land in the next 30 seconds, an announcement shall be made on the FON making all participants aware of impending takeoff/landing. Should individuals be co-located and within earshot of each other then only one member of the group needs to have VHF transmit and receive capability for both the FSN and the FON. The RSO shall always have transmit and receive capability with KLFI Tower, the FSN and FON. Radio checks on FSN and FON are required prior to each mission. See tables 7 and 8 for more information on the voice communication plans.

Table 7 - Communication Plan Summary for BVLOS Operations

	Radio Communication Plan and Preflight Radio Checks (Build-up BVLOS Crew)							
	FTM/ MC	**GCSO PIC**	**GCSO SIC**	**RSO Field**	**RSO ROAM**	**RO**	**AM**	**VSC/VP/VO**
KLFI Tower (VHF 125.0)	O	O	O	TXR	TXR	O	O	O
Flight Safety Net (Channel 4)	R	R	R	TXR	TXR	TXR	TXR	TXR
Flight Operations Net (Channel 1)	TXR	TXR	TXR	TXR	TXR	R	R	TXR
TXR = Transmit/Receive R = Receive O=Optional **All required communications require a backup communication device								

Table 8 - Communication Plan for Minimum-Crew BVLOS Operations

	Radio Communication Plan and Preflight Radio Checks (Min BVLOS Crew)					
	FTM/MC	**GCSO PIC**	**RSO**	**RO**	**AM**	**VSC**
KLFI Tower (VHF 125.0)	O	O	TXR	O	O	O
Flight Safety Net (Channel 4)	R	R	TXR	TXR	TXR	TXR
Flight Operations Net (Channel 1)	TXR	TXR	TXR	R	R	TXR
TXR = Transmit/Receive R = Receive O=Optional **All required communications require a backup communication device						

6.5.2 Data/Command and Control Communication Links

Flight vehicles used during BVLOS operations will have at least two independent digital communications links. These digital radio communication links will be used during operations to support connectivity in low altitude (less than 400’ AGL) urban and vertiport operations. The links will be used by the GCSO PIC to monitor/observe real-time vehicle data and control the flight vehicle with issued commands during all phases of flight.

The digital data links will include frequencies in separate disparate bandwidths to minimize the chances of EMI in one band affecting the connectivity in the other band. HDV plans to use one digital communication link in the 4G/LTE band and another link in the 900 MHz unlicensed band. The cellular network frequencies band is expected to provide the capability to maintain connectivity during low altitude urban navigation much like cell phone users. The other data and command link will utilize industrial, scientific, and medical (ISM) frequencies in the unlicensed band and is expected to provide the capability to maintain connectivity when the flight vehicle is within line of sight of the ground link transceiver. To support low altitude urban operations a network of ground link transceivers will be used to ensure the flight vehicle will always have line of sight with at least one ground link transceiver at any time during flight.

Command links utilized by the GCSO PIC will use encryption standards set by the data/command link equipment manufacturer. The equipment used for BVLOS operations will be tested during build-up WVLOS/EVLOS flight testing in the planned operational areas to provide performance expectations for BVLOS flight.

6.6 Buildup and Risk Reduction Activities

The HDV Project is implementing multiple buildup and risk reduction activities to minimize the chances of an off nominal/unexpected event from occurring. These activities include ground/bench testing to assess component level performance, hardware-in-the-loop simulator testing and training to assess autonomous software performance and train crewmembers in their roles, and flight testing to assess vehicle system performance.

Buildup in flight test execution is also a key component of the HDV BVLOS flight operations. As part of the crawl, walk, run approach, each BVLOS scenario shall be flown under EVLOS operations first before transitioning to BVLOS operations (See Appendix B for EVLOS COA). Additionally, mission profiles with single vehicle operations shall be flown before adding a second vehicle and two vehicle operations shall be executed before progressing to three vehicle operations.

Finally, HDV is utilizing a layered risk reduction approach to BVLOS operations. The first layer establishes procedural rules in Langley’s Class D airspace that prevent manned aircraft from flying below 900 feet during UAS operations. The second layer is the introduction of ground surveillance data (radar, ADS-B, FLARM) and the AM to clear the LMV and identify traffic that may pose risks for mid-air collisions and allow the GCSO PIC to execute the appropriate abort response. The final layer is the incorporation of autonomous technologies (e.g., ICAROUS) that enable the sUAS to autonomously detect, alert, and initiate an avoidance maneuver when a traffic conflict will result in loss of well clear separation. ICAROUS provides a backup to PIC intervention should a traffic conflict go undetected by the GCSO, AM, RO, and RSO. In the unlikely event of a complete loss of vehicle communication links, ICAROUS also provides the means to perform detect and avoid functions for cooperative traffic.

6.6.1 Risk Reduction Test Methodology

All equipment used for HDV flight operations is tested with a focus on functional checks and performance evaluation. Although various equipment is tested differently, the generic approach includes indoor ground/bench testing, simulation testing, constrained outdoor testing and flight testing. Similarly, sUAS equipment used in previous flight test campaigns that provided reliable and predictable performance conveys into the current effort. Examples here are the Alta-8 vehicles themselves and Botlink XRDs.

6.6.1.1 Ground Testing

Individual equipment testing is conducted to provide a baseline of performance and function/behavior assessment prior to system integration. Examples of individual equipment functional testing include flight vehicle motor arm safety switch, ground control station communication telemetry links, and flight vehicle global positioning system.

After system integration, a complete system test is conducted on all end-to-end functions that can be tested on the ground. Vehicle assembly labs include GPS repeaters so vehicle navigation system connectivity can be evaluated. Examples of complete system testing include power relay and/or C2isolation testing, command link connectivity testing, data link testing, and integrated software functional testing.

The results of the ground and bench level testing both at the component and system level provide an understanding of the component and system functionality and aid in the formalization of a complete vehicle system checklist.

6.6.1.2 Simulation Testing

One goal of the simulation testing is to verify HDV procedures and capabilities for flight tests in both AOA and SAO spiral wraps. Another goal is to provide the means to fully test autonomous systems prior to flight testing and support the issuance of NASA Class-C software certification. Evaluations focus on onboard aircraft automation, GCSO operation of the sUAS as well as the tools, displays, and roles for various users and the operations/setup within the ROAM UAS Operations Center. The testing will verify system-in-test software and hardware, connectivity, and human performance using a simulated environment. See Figure 40 for a photograph of the ROAM UAS Operations center as employed for the AOA Sim test.

The AOA Simulation apparatus featured a 6-DOF model of a sUAS that was adapted (size/weight) to replicate the Alta-8 sUAS vehicle performance data captured during previous flight tests. Vehicle linear and angular accelerations, position, attitudes, and GPS status were injected into the Pixhawk autopilot. This resulted in the Pixhawk achieving a “flight like” condition that enabled high-fidelity testing of the autonomous systems residing in the Xavier companion computer. This simulation was then used to integrate with the ROAM UAS Operations center providing a high-fidelity environment to perform route evaluation, GCSO training, and Human Factors data acquisition (e.g., HF questionnaires and eye tracking data).

Figure 40 - Photograph of ROAM UAS Operations Center as Used for the AOA HHITL Simulation Test.

The following are a list of software and hardware components included in the HDV simulation:

a) Software systems included in the simulation: integrated onboard vehicle automation (ICAROUS, Safe2Ditch, PX4) and associated simulated sensors (GPS, VN-200, FLARM, and ADS-B), ground control MPATH, and MavProxy for routing data to multiple stations.

b) Hardware systems included in the simulation: Ground control station operator workstation, Botlink radios, Pixhawk Blue Cube autopilot, NVIDIA Jetson Xavier and all associated connectors and interfaces.

The data from the simulation will inform, but is not sufficient to fully support, the safety risk assessment used to justify a request for BVLOS operations on the CERTAIN Range. Flight test results from AOA Flight Test operations shall also be used to support the final HDV Safety Case BVLOS submission (see Appendix H for AOA Flight Test Results).

Human factors analysis from Human+Hardware In The Loop (HHITL) AOA Sim provided an evaluation of the operators' ability to perform nominal operations and flight path deviations and landings with the assistance of automation. Additionally, AOA Sim provided a diagnostic of the predictability of trust in the automation through potential indicators, such as subjective workload, situation awareness, and visual attention allocation while interacting with a highly automated system. Results from the AOA Simulation, completed in October 2021, will be complemented by the SAO Simulation planned for Fall/Winter 2022.

A total of six GCSOs participated in the AOA Sim Test. The same personnel participated in the AOA Flight Test. Subsequent simulations (SAO Sim, VO Sim) and flight tests (SAO Flight, VO Flight) will likely include additional personnel from NASA LaRC to serve as GCSO PICs.

For the AOA Sim, each test scenario provided a representative portion of the HDV AOA Flight test. Test scenarios were designed to establish specific boundaries of the capabilities within the system architecture that were available in the simulation described above.

For the AOA Sim, the following scenarios were tested:

1) Nominal vehicle operation: GCSOs flew a simulated ownship vehicle from takeoff to landing in the presence of other simulated aircraft.
2) Off-nominal low-conflict traffic incursion: GCSOs flew a simulated ownship vehicle that performed an autonomous diversion to avoid another sUAS in an emergency landing operation. The vehicle in the emergency condition landed at a location near the approach path of ownship.
3) Off-nominal high-conflict: This scenario was same as #2 except the vehicle in the emergency condition landed at the same location as intended for ownship.
4) Off-nominal ownship in emergency condition: This scenario required the GCSO to engage S2D and perform an autonomous emergency landing.
5) Geofence test: This scenario required the GCSO to command ownship along a route that would encounter a geofence breach.
6) In-flight reroute: This scenario required the GCSO to execute a coordinated in-flight re-route simulating a situation where the destination vertiport is unexpectedly closed requiring the vehicle to be re-routed to the nearest available vertiport.

6.6.1.3 Outdoor Net Testing

Prior to conducting flights in the NAS, most sUAS with major configuration changes undergo first flight checkouts in the outdoor netted areas. NASA LaRC currently has two netted areas that are approximately 100 ft long with 50 ft high ceilings. Net testing provides a very limited step from lab testing but does provide the ability to apply actual flight EMI environments to the vehicle subsystems. Examples of net testing objectives include EMI testing, limited control input testing, hover endurance testing, and command and data link connectivity testing.

6.6.1.4 Buildup Flight Testing

Flight testing is the final step in the risk reduction test methodology process. Flight test is necessary because some BVLOS functions or performance evaluations for UA systems cannot be adequately tested on the ground, in the simulator, or in a limited netted area. These tests are designed to focus on end-to-end system testing during flight using the planned BVLOS operational area. Although various tests are conducted depending on the tests being hardware or software related, the following categories are considered for flight testing: flight path testing; equipment testing; roles, responsibilities, and communications testing; system integration testing; and automation testing.

Flight path testing provides the planned operational area environment for testing planned flight profiles. The main focus for these tests is to establish and verify visual/digital references for the ground crew during flight. An example of this type of test would verify that FLARM position reports of the flight vehicle can be viewed by ground crew during all phases of flight on the planned flight profile.

Equipment testing provides the planned operational area environment for testing planned flight profiles. The focus for these tests is to establish equipment performance for planned flight profiles. Depending on the equipment, data is also collected for future review/analysis needs. An example of this type of testing would be to evaluate data and command link robustness used for future flight operations.

Roles, responsibilities, and communications testing evaluates the crew roles, responsibilities, and communications used by the flight crew. The main focus for these tests is to establish a step-wise approach to transition standard crew roles and responsibilities to newly defined ones needed for BVLOS flight operations. This includes assessing the operations conducted in a remote facility and comparing those operations to operations in the field WVLOS of the flight vehicle. An example of this type of testing would be to verify that a newly proposed communications plan works before relying on it for future BVLOS flight operations.

System integration testing provides the end-to-end analysis for functions that require exposure to environmental or external sources. The focus for these tests is to introduce those systems needing exposure to the flight environment or needed data, and verify they function as designed. An example of this type of test would be to verify there is no degraded transceiver performance due to electromagnetic interference between all transceivers used in the system.

Automation testing, much like systems integration testing, provides the end-to-end analysis for autonomous functions that require exposure to environmental and/or external data sources. The main focus for these tests is to introduce those systems that need exposure with the needed data to verify they function as designed. An example of this type of testing would be to evaluate the trajectory of autonomous navigation software that relies on real-time traffic data to function.

In order to support BVLOS operations, the flight testing referenced will implement stepwise changes to flight vehicle configurations and flight operations personnel. Due to the system of systems integration between various equipment and personnel, a simple to complex process will be applied. The first equipment to be integrated and tested includes data and command links between the GCSO PIC and the flight vehicle focusing on the COTS Alta-8 and extended COTS equipment. The second equipment to be integrated and tested includes autonomous systems (e.g., S2D, ICAROUS) needed to support hazard mitigations. When equipment has been tested and is capable of enabling expanded flight operations, new personnel roles and responsibilities will be tested and evaluated in a stepwise progression.

6.7 General Approach to Safe Separation Operations

To help ensure safe separation from participating and non-participating aircraft there are several mission rules that will be adhered to for the HDV project BVLOS operations.

6.7.1 Limitation in Areas of Operation:

The first rule restricts BVLOS operations to CERTAIN I, IIa. Eliminating CERTAIN-IIb, -III and -IV greatly mitigates the risk of sUAS overflight of people and eliminating BVLOS operations in CERTAIN-III -IV increases the standoff distance from KLFI 08/26 runway.

6.7.2 Minimum Ceiling and Visibility:

The second rule establishes a minimum ceiling and visibility (2,000 ft AGL and 3 Miles) requirement for sUAS BVLOS operations to help prevent a potential conflict with IFR traffic that could be executing a low altitude circling approach to Langley AFB.

6.7.3 Coordinated KLFI Operations:

The third rule, as coordinated with KLFI Tower, requires all manned aircraft to remain at or above 900 feet AGL during UAS operations on the CERTAIN Range, while all UAS shall remain below 400 feet AGL. Additionally, NOTAMs shall be published, and announcements placed on ATIS to alert manned aircraft of sUAS operations on the CERTAIN Range.

6.7.4 Airworthiness and Testing:

The fourth rule requires the airworthiness review to verify that all BVLOS vehicles are airworthy and can perform all specified avoidance maneuvers, aborts, and terminations. This rule will be supported from both HHITL simulation and flight test results.

6.7.5 Avoidance Maneuver Criteria:

The fifth rule establishes avoidance maneuver criteria that allows GCSO PICs to take the appropriate action should a traffic conflict arise that requires the execution of an avoidance maneuver. Under normal conditions a descent to loiter altitude should be used to avoid intruder traffic. The loiter altitude can vary depending upon the flight profile but needs to be defined such that there is a high confidence that traffic incursions can be resolved. As an example, the tallest structure on NASA Langley is the Gantry. The Gantry stands about 250 feet high, so setting a loiter altitude below 250’ would be a reasonable technique to avoid non-cooperative traffic but may also require the creation of a geofence to keep the sUAS from running into the Gantry when executing a vertical descent avoidance maneuver. Other avoidance maneuvers include flight path vector changes to ensure lateral separation or as a last resort, a vehicle flight termination executed by removing power to the motors. HDV plans to use the GCSO PIC as the primary means of maintaining minimum safe separation, but the vehicles are also equipped with ICAROUS detect and avoid technology to complement the GCSO-PIC.

6.7.6 Crew Resource Management:

While the AM, RO, and RSO have the primary responsibility of monitoring the indicated airspace display for non-participating and intruder traffic, the entire operations team provides support. Based off information from VOs, SP/VP, the IAD and the AM, the RSO will recommend an abort of operations if off-nominal traffic in the vicinity pose a threat to the minimum safe separation criteria. The RSO will recommend a specific abort maneuver on the Flight Safety Net, which the GCSO PIC will consider when taking action. Additionally, crewmembers are trained and experienced with the universal knock-it-off criteria that encourages all personnel to call “knock-it-off” (KIO) if an unsafe situation arises. The first step after a KIO is to clear all flight paths to ensure deconfliction and then assess the situation.

6.7.7 UAS-Crewed Aircraft Separation

The minimum safe separation between participating/non-participating crewed aircraft and sUAS shall be 2000 feet horizontal or 250 feet vertical. All avoidance maneuvers between manned and uncrewed aircraft shall be predicated on maintaining these minimum safe separation distances. Section 6.9.5 (Crewed Traffic Classification) identifies criteria and procedures for dealing with potential traffic conflicts and identifies when actions should be taken to help ensure minimum safe separation is maintained.

6.7.8 UAS-UAS Separation

The minimum safe separation between UAS aircraft shall be 500 feet horizonal or 100 feet vertical. All avoidance maneuvers between sUAS aircraft shall be predicated on maintaining these minimum safe separation distances.

6.7.9 Managing Access

NASA Langley controls access to Langley Research Center and can block off roads, sidewalks and parking lots to control foot traffic on Langley Research Center. Flight paths requiring the use of restricted access (ie Scenario 2 – Figure 37) will be flown during restricted access times.

6.8 Maintenance and Inspection Process

The process used for maintaining sUAS at NASA Langley Research Center is described within Section 5.0 of NASA Langley's Management System Technical Directive (LMS-TD-0903 – Reference 7). This document describes the practice of maintaining continued sUAS airworthiness through annual progressive, preflight and post flight aircraft inspections. Records for routine maintenance, modifications, annual and regular progressive inspections for sUAS are maintained in the aircraft flight/maintenance logbook. Additionally, preflight and postflight inspections are accomplished for each vehicle to help minimize the risk of an in-flight failure. The purposes of these maintenance practices are to help ensure the safety of sUAS flight operations and support mission assurance.

6.8.1 Progressive Inspections

Upon initial receipt of a new sUAS, and as part of determining and maintaining airworthiness, the sUAS undergoes a thorough inspection process to baseline the aircraft's readiness for flight. This inspection is known as a progressive inspection and is derived from the integration of the sUAS manufacturer's maintenance recommendations, NASA's internal engineering recommendations, and the appropriate baseline inspection appendix within LMS-TD-0903. During the initial inspection, the vehicle is thoroughly inspected and photographed with all access panels and service areas opened up. Additionally, independent vehicle inspections are performed by the Research Services Directorate in combination with project personnel. Before sUAS are used for flight test activities, a 15-flight evaluation is typically performed with the vehicle maintained in the manufacturer's configuration. On rare occasions, the vehicles configuration may require modification prior to the 15-flight evaluation if the manufacturer's configuration is determined to be unacceptable.

Progressive inspections are tailored to each sUAS type and configuration and are conducted prior to each sUAS's initial airworthiness certification and annually (or every 25 consecutive flights - or approximately every 8 hours of flight) thereafter. In general, this inspection is designed to identify, correct, and document any component wear (or damage) as it relates to the overall operational integrity of the sUAS. The following categories are evaluated as part of this inspection.

6.8.1.1 Structural or Vibration Dampening Components

Structural or vibration damping components (such as fuselage, wings, wing joiners, tail, main body of multi-rotor and motor mounts) are inspected for cracks or signs of abrasions indicating wear that may lead to a failure of the component or the system. All fasteners are torqued to sUAS manufacturer's specifications and marked with a torque stripe to easily identify fasteners that have moved during routine preflight inspections. Any rubber/silicone components designed to reduce vibration or shock absorption are inspected for damage. These items are replaced if damaged or at the end of their recommended life expectancy. Any component damage found is noted in the progressive inspection report along with the recommended corrective action. If the issue is safety critical, the correction must be made and inspected prior to the next flight.

6.8.1.2 Propulsion Systems

Motors, propellers, propeller adaptors and associated hardware are inspected for damage and checked for secure attachment by applying the specified torque to mounting fasteners and applying torque stripe to all fastener installations. Propeller vibration dampeners (rubber bumpers) are inspected for signs of cracking, chipping, or deformation and replaced if any damage is found. Motors should spin freely with no grinding noise or free play of motor shafts that would indicate excessive bearing wear or possible failure.

6.8.2 Operations Check(s)

In addition to progressive inspections, sUAS also undergo comprehensive integration testing and checkout within the sUAS integration labs. All vehicular modifications and test results are documented in the vehicle logbook and communicated with the sUAS team.

6.8.2.1 Command and Control Links

The team performs ground tests to verify the operation of the command and control links such as verifying that pilot commanded flight mode changes sent to the to the autopilot are being reported by the ground control station. Small UAS onboard sensor data and flight plan information are sent through both primary and secondary command and control links between the ground control station(s) and the sUAS verifying the independent operation of these links. Additionally, ground-based radio frequency range tests are performed per radio manufacturer's specifications/guidelines to evaluate link performance.

6.8.2.2 Sensor Verification

The polarity of the aircraft's accelerometers and rate gyros, used to indicate the aircraft's attitude, are verified against the ground station's artificial horizon display for proper pitch and roll polarity. Global Positioning System (GPS) operation is verified by its ability to receive and report satellites. The aircraft's reported heading is obtained from the onboard magnetometer and is verified by comparing it to an independent off board compass.

6.8.2.3 Loss Link/Failsafe

Ground testing is performed to ensure proper/expected system performance based upon various lost link scenarios (e.g., sUAS Reroute/Ditch/RTL, etc.) when various command and control links are lost or removed. These ground-based tests are performed by removing all motor propellers to ensuring both personnel and vehicle safety. The vehicle systems are then powered and armed followed by a take-off command from the safety pilot or the ground control station operator. At this point the loss of the various command and control links are evaluated to ensure the vehicle is performing as expected through ground control station's reported warnings. The ground control station's loss link is tested by first establishing connection with the vehicle, then disconnecting it for specified period of time, and then reestablishing link with the vehicle to ensure expected mode changes or warning are reported.

6.8.2.4 General sUAS vehicle tests

Other testing performed includes verification that all motors spin in the correct direction to ensure that subsequent flight operations are controllable. If provided, sUAS weight and balance information is also reviewed and verified for each sUAS.

6.8.2.5 Inspection Documentation

A verification is performed to ensure that the sUAS has a current registration number and that the aircraft maintenance logbook reflects up to date modifications, repairs, testing and inspections.

6.8.3 Preflight and Post Flight Inspection(s)

These inspections are performed before and after every flight and are specifically designed to check for component defects or general problems within the subsystems of the aircraft. Communications checks are performed on various command and control links to ensure proper operation prior to flight. During these inspections the pilot and/or ground maintenance crew personnel verify the following: correct assembly of the aircraft to include research payload (if applicable), correct use and installation of the flight batteries, and that aircraft components are securely attached and free of damage.

6.8.3.1 Aircraft Assembly

Aircraft assembly is checked to ensure that the aircraft is assembled per the aircraft manufacturer's instructions. Part of this inspection is to verify that all fastener's torque strip marks are still aligned, indicating the fastener has not rotated (or slipped) from original installation position. Aircraft components are inspected to ensure they are secure and free of play. Motor propeller and frame vibration dampers are visually inspected to ensure they are in place and without damage. Electrical leads are checked for damage, verified clear of moving parts, and properly secured to the aircraft.

6.8.3.2 Flight Battery Checks

All flight batteries go through a qualification process and are labeled with unique tracking identifiers. If batteries do not provide at least 90% of their rated capacity or are older than two years, they are removed from flight service. Batteries having passed this qualification process are used for flight operations. This qualification process verifies that the battery is being used within the manufacturer's recommended life cycle and that the battery's measured capacity is within an acceptable percentage of the manufacturer's stated capacity. Prior to installing and securing the battery in the aircraft, battery voltage is measured to verify full state of charge. Battery re-charge data is monitored and flight durations are established to ensure that at least 30% of the battery capacity remains at vehicle touch-down.

6.8.3.3 Command and Control Link Checks

Flight mode changes are initiated by the PIC to verify that these commands are recognized by the autopilot and reported to the ground control displays. Autopilot failsafe and lost link settings are verified for correctness based upon flight range guidelines and/or range safety officer's recommendations. Independent primary and secondary command and control loss link checks are performed to verify the proper link status is reported on the GCS and verify that the GCSO still has positive control of the aircraft with the other link.

Note: During initial flights of an aircraft, or after hardware modifications that may affect the command and control link(s) performance, in-flight assessments are performed on the command and control links using a flight build-up approach. This build-up approach consists of shortrange flight profiles to establish link performance followed by several additional flights, each with increased range not to exceed the Radio Frequency (RF) link budget calculations of reliable range as determined by hardware specifications.

6.8.3.4 Sensor(s) Verification Checks

Aircraft attitude polarity tests are performed to verify proper pitch, roll and yaw attitudes on the aircraft's artificial horizon indicator. Global Positioning System's (GPS) operation is verified by its ability to report satellites along with additional indicator of Horizontal Dilution of Precision (HDOP). Aircraft heading and yaw polarity is verified against the ground station reported heading display.

All required UAS maintenance or modifications are performed by experienced personnel that are familiar with the UAS manufacturer's recommended maintenance guidelines and NASA policy guidelines for maintaining airworthiness. All work performed is inspected by a secondary ground crew member and/or Range Safety Officer. Over the life of an aircraft, problems are noted and documented appropriately. Persistent or reoccurring problems are documented and actions are taken to either resolve issues, shorten the inspection interval, or modify maintenance practices.

6.9 Ground-based Surveillance Operations

Ground-based surveillance operations include radar characterization, operation and monitoring of the L-STAR radar, operation and monitoring of the GA-9120 radars, monitoring of the ADS-B and FLARM and the monitoring and interpretation of the ANRA fusion algorithm on the integrated airspace display (IAD). Ground-based surveillance operations also include how traffic will be identified, classified, labeled and responded to. All of these tasks are required to ensure HDV BVLOS operations are able to meet the 91.113 see and avoid requirement.

6.9.1 Radar Characterization

With the LSTAR radar temporarily located on the top of building 1230 (B1230), a radar characterization test flight was performed using the LaRC SR-22 GA aircraft to conduct a preliminary assessment of LSTAR radar performance. The flight path and ground track of the SR-22 was chosen to cover the LMV and also to focus on predicted blockage areas provided by the manufacturer for the B1230 rooftop location. The SR-22 was flown at 1,000 (+/- 100) feet AGL. Figure 41 shows the ground track of the SR-22 (red lines) and the raw LSTAR data (black dots).

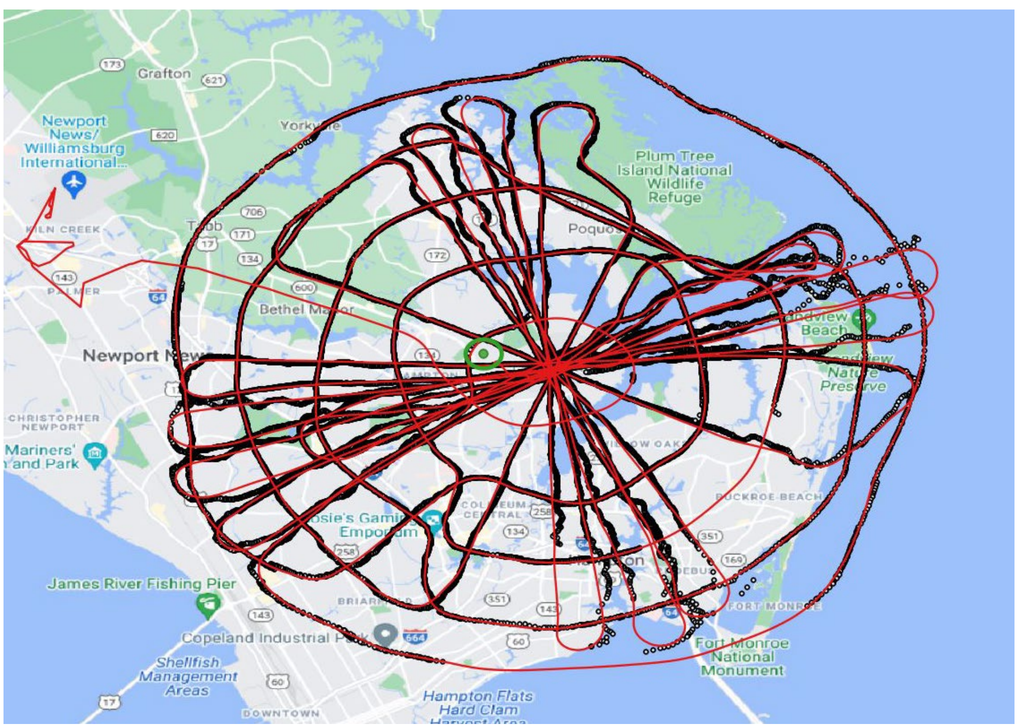

Figure 41 - Initial Comparison of LSTAR Tracking Results of the NASA LaRC SR-22 Aircraft with ADS-B

Preliminary results indicate good LSTAR radar coverage across the LMV at 1,000 feet AGL. Southern tracks appear to be partially blocked by the NASA Langley Hangar (B1244). The LSTAR radar was moved to the top of the Hangar in June 2022 and additional radar evaluation flights are underway to assess

LSTAR performance. The move is expected to improve the ability of the LSTAR to track GA aircraft in the southern sector.

Follow-on radar characterization test flights will include incorporation of GA-9120 with the LSTAR on the Hangar. The first of these will be the GA-9120 and LSTAR assessment flights during the fall 2022 to assess performance of the LSTAR and GA-9120 radars operating simultaneously. The HDV project is attempting to utilize the LSTAR and GA-9120 radars to track general aviation aircraft within 5 NM better than 95% of the time. The radar characterization test flights will help verify this this goal. When complete, the additional radar characterization flights, data collection, and analysis will be appended to this document in Appendix L.

6.9.2 LSTAR and GA-9120 Radar Operations

The LSTAR radar's main function is to provide 360 coverage of the airspace surrounding the CERTAIN Range and to detect and track GA aircraft out to at least five miles (capable of tracking out to 21.5 miles) at altitudes ranging from 400-2500 feet. For GA and helicopter traffic traveling at 120 knots, this will provide a two-minute warning before intruder traffic enter the Core area of the LMV. The LSTAR radar can detect and track general aviation aircraft and ultra-light aircraft, using a combination of short-range and long-range waveforms. Its operational modes are operator selectable depending on the targets of interest, desired update rates, and/or required detection range.

The GA-9120 radars will complement the LSTAR and may also add some enhanced capability to detect and track sUAS aircraft due to its' higher operational frequency. The GA-9120 is a 3D digital multi-beamforming radar system that provides both short-range drone and long-range GA aircraft detection (drones out to 3 miles, GA aircraft out to 9 miles). Initial BVLOS operations will be conducted with two GA-9120 radars that will provide coverage over most of the CERTAIN Range. The southern facing GA-9120 will also be used to partially cover the 30-degree cone of silence directly above the LSTAR.

Ground-based surveillance methods for detecting non-participating aircraft will focus on detecting crewed aircraft using the LSTAR and GA-9120 radars. Participating UAS aircraft will be monitored via FLARM. The GA-9120 radars may provide some capability to detect non-participating UAS but it should be assumed that ground-based surveillance radars will not be able to regularly detect non-participation UAS.

Radar operations and monitoring of both the LSTAR and the GA-9120 radars shall be performed by the radar operator (RO). The LSTAR radar has a self-test capability and the status of the radar is continually reported on the display, so that the operator can be alerted if the radar becomes non-functional. Similar self-test functionality of the GA-9120 will be confirmed once testing of the GA-9120 is complete. The LSTAR and GA-9120s will only be operating when supporting system checkouts, airspace characterizations or actual sUAS flight operations.

For HDV BVLOS flight operations, the RO shall provide a Go/No-Go to the AM, FTM/MC, and RSO prior to the commencement of BVLOS operations. This Go/No-Go decision will be based off successful built-in test (BIT) and status indicators for each radar. The LSTAR radar and the southern facing GA-9120 are required to be operational for all BVLOS operations. During operations, the RO will monitor all radars for nominal performance, communicate any non-participating traffic meeting the intruder criteria and report any anomalies with radar operations to the AM, FTM and RSO.

6.9.3 ADS-B, FLARM and Radar Data Monitoring

Along with the LSTAR and GA-9120 radar systems, the ground-based surveillance infrastructure will also include ADS-B and FLARM ground receivers capable of receiving broadcasts from ADS-B/FLARM equipped aircraft. The ADS-B and FLARM data will also be available in ROAM to allow the AM to interpret multi-sensor air traffic data in and around the LMV. Ideally, the AM will have the responsibility of monitoring the radar, ADS-B and FLARM data on an IAD but this task my occur on several different displays, provided that an accurate assessment and characterization of traffic can be made. The RO will also be monitoring the LSTAR and GA-9120 radars for functionality and providing complementary assessments and characterization of traffic inside the LMV. Should a data dropout occur, the RSO and FTM shall be informed immediately so that an assessment can be made on the impacts to continued BVLOS operations.

6.9.4 ANRA Fusion and Integrated Airspace Display Monitoring

The ANRA SmartSkies Fusion algorithm will have inputs from the LSTAR and GA-9120 radars, the ADS-B and FLARM receivers, and all sUAS GPS positions as reported through their telemetry streams (for more information on the fusion system see Appendix M). The inputs will be assimilated into a single display called the integrated airspace display (IAD). The IAD will have the ability to display raw data from each of the data sources and/or provide a fused picture by merging all available data from a single vehicle into a track that represents the current location of that vehicle. The IAD will also display the LMV threat volume overlays to aid in the classification of non-participating traffic.

The AM will utilize the IAD to assess if the ANRA fusion is properly displaying coalesced data correctly. Should an error in ANRA fusion occur, the RSO and FTM shall be notified immediately so that an assessment can be made on the impacts to continued BVLOS operations (note: ANRA fusion is not required for BVLOS operations).

6.9.5 Crewed Traffic Classification

Traffic will be monitored within the LMV to ensure maintenance of well clear volumes. Nominal traffic is that which is expected to exist within the LMV with the ability to predict future locations of these aircraft and is not expected to penetrate the minimum safe separation criteria. Most of these aircraft are stationed at KLFI and follow the defined KLFI Tower VFR pattern procedures. Off-nominal (or intruder) aircraft are typically transient aircraft who may not follow KLFI Tower VFR pattern procedures and will be more closely tracked.

Vehicle altitude will be used primarily to establish the presence of off-nominal traffic (ie <900 ft AGL) in areas sufficiently far away from KLFI and PHF runway environments (>2 nm). Off-nominal traffic in proximity to the Core area will be the primary consideration for aborting BVLOS flights or delaying flights from starting. Any off-nominal traffic in the B3, B2, C3, C2, Buffer and Core areas will trigger an abort. Off-nominal traffic in the C4, C5, B4, B5 areas heading towards the Core and Buffer area will trigger an abort. Off-nominal traffic in the C4, C5, B4, B5 areas not heading towards the core area will trigger a caution and/or pause in starting operations, however will not trigger an abort. All traffic in the Buffer zone (directly above the Core) will be considered off-nominal traffic and will trigger an abort. All traffic entering the Core area will trigger an abort. Precautionary actions from the GCSO PIC, and potentially autonomous systems, may be necessary to maintain minimum safe separation (ie descent or abort). Nominal traffic in the overflight sub areas shall be monitored but no action is needed from the GCSO

PIC. See Figure 42 for a breakdown of the LMV Sub Areas. Note: The LMV rules may need to be adjusted based upon the results of the Radar Characterization flights (Appendix L).

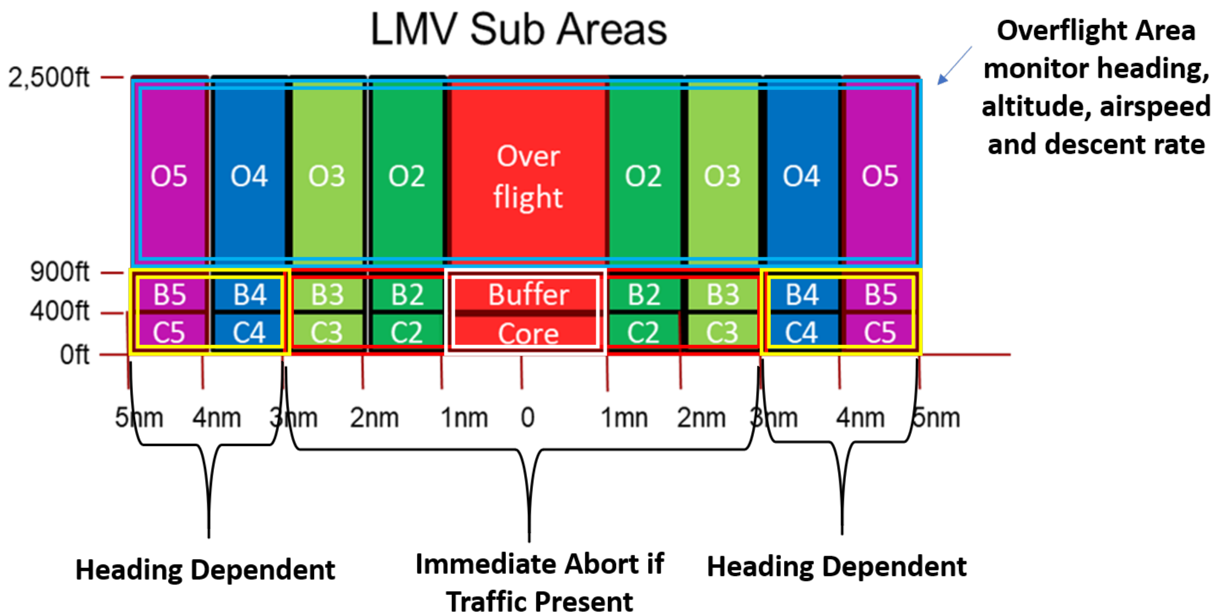

Figure 42 - LMV Subarea Definition.

BVLOS UAS aborts will be performed using rapid descents to get below 250 ft within 30 seconds of abort initiation. This will get the aircraft to be below the altitude of the NASA LaRC Gantry structure but keep the aircraft within 4,000 ft laterally of the Gantry. Then, vehicles will cruise to the nearest ditch site location and execute an autonomous landing. Overall, the time required to safely recover the vehicle on the ground will be no more than 2 minutes (20 seconds to get below the Gantry altitude, then 1:40 to get on the ground).

In Figure 43, the 1 nm core area is shown along with the 4,000 ft BVLOS UAS operations area. As long as manned aircraft don't laterally enter the core area while a sUAS is airborne, then lateral separation of 2,000 ft will be achieved between UAS and manned aircraft. Planned BVLOS flight operations will be performed in the SW, NW, and NE quadrants primarily. WVLOS flights and flight segments will be conducted in areas outside of the BVLOS operations area within the CERTAIN Range.

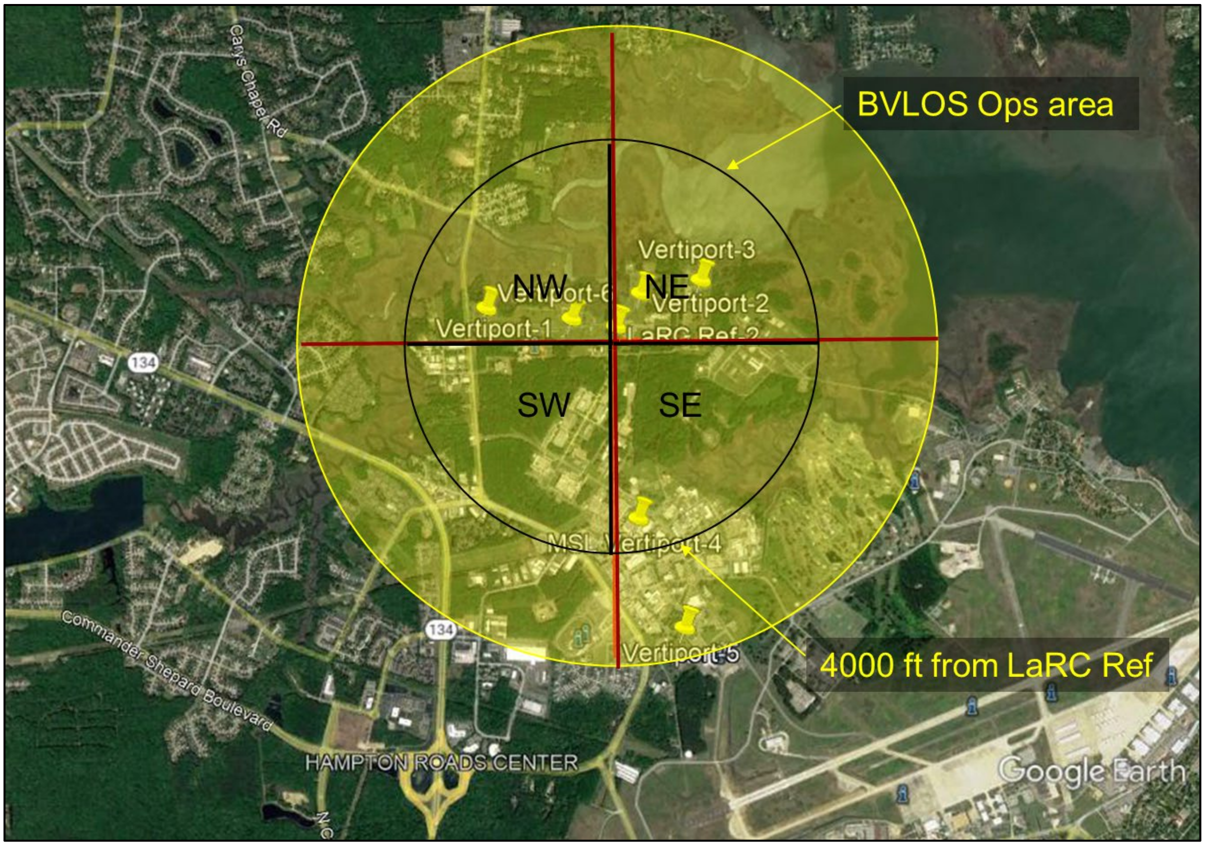

Figure 43 - Core Area (up to 400 ft AGL) Also Indicating BVLOS Operations Area Along with Core Area Quadrants.

6.10 Ground Control Station Operator PIC Training

With the integration of the ROAM UAS Operation Center and the requirement for HDV to conduct BVLOS operations, a new training program was developed to certify our GCSO PICs (Table 9 lists maneuver tasks and evaluation criteria). The GCSO PIC training program focuses on remote operations and communications, system performance monitoring and recognition of off-nominal conditions, issuance of vehicle commands, recognition of and properly responding to abort scenarios, and monitoring surrounding airspace for potential traffic conflicts. The majority of these skills shall be developed and evaluated during HDV simulation and during EVLOS operations. Full certification of a GCSO PIC for BVLOS operations will be issued once all training criteria are met.

An upgrading GCSO PIC must first be trained and certified as GCSO. To become a GCSO, a person must complete the LaRC UAS Crew Continuous Training Plan, receive NASA LaRC General GCSO academics, receive system specific training on a GCS operating system and execute GCSO duties during WVLOS operations. Note: a GCSO does not need to be a PIC during WVLOS operations. The GCSO typically acts at the direction of the SP/VP and is not required to be a qualified PIC but will act as a second-in-command (SIC) during WVLOS flight operations.

Once a GCSO is fully trained, they may proceed with GCSO PIC training. GCSO PIC training begins in the ROAM UAS Operations center with 10 simulation runs (minimum). These runs exercise the following maneuver tasks and test the upgrading GCSO PIC on a set of evaluation criteria.

Table 9 – GCSO PIC Training Scenarios and Syllabus

Maneuver Tasks	Evaluation Criteria	Rating (Inadequate/Adequate)
Vehicle Pre-Flight	Effective usage of vehicle checklists with operations team (ie VSC) Zero missed checklist steps	
Flight Path Planning	Flight path programmed with all appropriate waypoints and aircraft parameters All applicable ditch sites are reviewed for possible contingency responses	
Contingency Parameter Programming	Contingency parameters (RTL/GeoFence/Lost Link) programmed correctly with zero errors	
Preflight Planning/Coordination	Weather minimums verified Communication checks with FON and FSN accomplished Review GPS NOTAMS Verify vehicle preflight check by VSC is complete Verify correct flight plan uploaded Vehicle confirmed in takeoff position and takeoff area is clear Verify all C2 links are operational Verify GPS accuracy and signal strength Approval for flight received from RSO Verify vehicle is properly armed Be knowledgeable of all vehicle flight paths during multi-vehicle operations	
Takeoff	Takeoff announcement made on FON and FSN within 30 seconds of first takeoff Traffic check accomplished prior to takeoff Takeoff command sent to vehicle	
Flight Path Monitoring	Flight path deviations are recognized and assessed in a timely manner (eg ~<5 sec) Unexpected vehicle responses are handled IAW specified abort criteria	

	Required flight path changes are made prior to hazardous situation develops	
Issuance of Vehicle Commands	Vehicle commands are safe and appropriate for the situation Command errors are recognized in corrected in a timely manner	
Vehicle Status Situational Awareness	Perform frequent Ops check to verify GPS, battery and vehicle health Vehicle anomalies are recognized and diagnosed in a timely manner (<30 sec) Proper abort criteria are applied in response to detected anomalies	
Airspace Situational Awareness	In collaboration with AM/RSO, intruder traffic are identified in a timely manner Demonstrate proper communication with AM/RSO for non-participating traffic	
Traffic Conflict Response	Execute traffic conflict response to abort criteria Take appropriate action to ensure minimum safe separation is maintained Terminate vehicle if needed to ensure well clear	
Landing	Verify weather conditions within limits Verify landing zone is clear with VSC and/or real-time ground-based video of landing zones Execute proper procedure for an occupied landing zone (ie hold and/or proceed to alternate)	
Post Flight Coordination	Verify vehicle is properly disarmed Landing announcement made on FON and FSN within 30 seconds of last landing	
Emergency Procedures	Correctly assess the situation and handle the emergency and approved emergency procedures (<30 sec) Declare an emergency by notifying all players of intentions FON and FSN (where and when you intend to land)	

	Provide status of S2D engagement and system progress	
Crew Coordination	Demonstrate effective communication between all members of the Flight Safety and Flight Operations Team Execute three-way handoff when transferring from one control mode to another during BVLOS operations (SP to GCSO PIC)	

Upon successful completion of the simulator training, the GCSO PIC in training will conduct a minimum of 5 BVLOS flights under the supervision of an IP. Upon the satisfactory completion of these BVLOS flights, the GCSO PIC may be certified as a GCSO PIC.

Annual recurring training requires the accomplishment of all Emergency and Abort Procedures at least once annually. These maneuvers may be flown in the sim or during flight operations. GCSO PICs shall have a requirement to conduct three flights (minimum) in a 90-day period to maintain currency.

6.11 Operational Procedures

This section is included to provide an expectation of the nominal progression of events during a given flight day. A Remote C2 Standard Operating Procedure (SOP) was developed to standardize operations from inside the ROAM UAS Operations Center and establish minimum requirements for remote C2 operations (the SOP is attached in Appendix E).

6.11.1 Prior to Flight

In general flight days will begin early in the day to support optimal usage of daylight VMC conditions. It is expected that some crewmembers may need to arrive T-3 hours prior to first flight to start bringing up systems and perform basic system checks. Prior to flight, the entire BVLOS system will be checked to ensure that all systems are ready for operation. This includes sUAS preflights, ground system checkouts, team communication checks, etc. In general, the entire BVLOS system will be pre-flighted as if to support an actual vehicle launch. At that point, the team will stand-down to complete the team preflight briefing

6.11.1.1 Range Safety Commit Criteria

The range safety commit criteria will be assessed to ensure that prevailing weather conditions are within prescribed limits. Crew duty limits will be evaluated to support the given operational day.

6.11.1.2 Test Card Review

The FTM will provide a briefing of the flight test objectives for the current mission and conduct a test card review. Estimated start and end times for the mission will be provided. All test conditions, scenarios, and expected responses for the mission will be reviewed. Key mission rules and standard contingency plans will be discussed, and all responses to abort scenarios will be reviewed.

6.11.1.3 Operational Safety Review

During the daily team briefing, a review of the operational safety aspects and critical risk mitigations will be briefed by the FTM. A call for operational comments and concerns will be held to allow all team members to provide comments on the planned days operations. Once elements 7.11.1.1 through 7.11.1.3 are completed, the crew will move into sUAS operational mode.

6.11.2 Takeoff

The GCSO will request the vehicle to be taken to the launch location for takeoff. The VSC will place the sUAS at the designated motor arming/takeoff/RTL location and, at the direction of the GCSO, arm the vehicle for takeoff. Immediately prior to takeoff, an announcement will be made on the FON notifying everyone that the mission will begin momentarily. Once final takeoff clearance is received from RSO, then the GCSO will commence an auto takeoff and execute the mission.

6.11.3 In-Flight / Test Operations

During flight, the GCSO, supported by the FTM, RSO, RO and AM, will monitor flight progress, assess vehicle health parameter status, and maintain situational awareness of the airspace. The FTM will manage the flight test, the RSO will provide an independent safety monitoring perspective and the AM/RO will monitor the airspace for intruder traffic. Other members of the sUAS operations team are encouraged to also monitor as able while still maintaining situational awareness of their required systems.

6.11.4 Landing / Recovery

Prior to landing, an announcement will be made on the FON notifying all crewmembers that a landing is about to occur. During vehicle recovery and landing the GCSO will monitor the sUAS and confirm landing and shutdown with the VSC. Once the vehicle is declared safe (ie disarmed) the VSC can then move the sUAS from the takeoff/landing/RTL location to the vehicle preparation area.

6.11.5 Post Flight

A short team debrief will be performed over the FSN to gather team inputs to fully discharge crew resource management aspects and look for areas of potential concern and confirm the existence of nominal operational conditions.

6.11.6 Contingency and Abort Conditions

During flight, the GCSO will monitor vehicle progress and health. The FTM and RSO will also provide supporting monitoring functions but it is the primary role of the GCSO to monitor and assess vehicle health. In the event of off-nominal vehicle conditions, the GCSO will declare an emergency situation and select the appropriate abort strategy (ie either nominal RTL or S2D landing).

6.12 Avoidance and Abort Maneuvers

The PIC has the responsibility to initiate all avoidance and abort maneuvers to maintain safe separation from other sUAS and/or manned aircraft and handle off nominal situations. The HDV project combines avoidance and abort maneuvers into a single category called aborts. Aborts can be performed for a wide variety of scenarios ranging from loss of an individual communication link to traffic conflicts. Responses to these scenarios are binned into five types of vehicle responses: 1) Return to Launch/Rally Point (RTL); 2) Rapid descent to safe altitude (200 ft); 3) Rapid safe landing; 4) Slow descent with the wind; and 5) Vehicle termination.

A RTL or return to rally point will be limited to be no more than 2 minutes for the vehicle to arrive at these locations and then an additional 30 seconds to proceed down to loiter safe altitude (~200ft). The total time allocated for an RTL is 2.5 minutes from initiation to vehicle touchdown at its takeoff location. This would be used for precautionary measures, like loss of an individual telemetry link.

Rapid descent to a safe altitude is used to avoid incoming traffic. The safe altitude is defined as being at or below the height of the LaRC Gantry (ie 250 FT AGL). Using the Gantry as a safe altitude reference, a descent from 375 feet to 200 feet at 10 feet/sec results in a ~20 second response to a traffic conflict. Once below the safe altitude, either a nominal RTL or a S2D landing at the nearest designated ditch location will be performed. If a nominal RTL is selected from below safe altitude, then the total time to vehicle touchdown will be approximately 2 minutes from maneuver initiation.

Rapid safe landings (S2D) are driven by more time critical scenarios where there is a strong reason to suspect that the UAS vehicle is in distress or longer duration flight induces significant risk. This scenario will take advantage of the S2D autonomous technology to safely execute an emergency landing. Within this abort scenario, the vehicle will touchdown in less than 2 minutes from maneuver initiation.

Slow descent with the wind is an abort mode that shall be exercised if the vehicle experiences a total GPS failure and manual control is not possible. The intent is to bring the vehicle down to the ground in a controlled and stabilized manner prior to the vehicle exiting the CERTAIN airspace. This will likely result in the vehicle landing in an undesignated area on the CERTAIN Range.

A vehicle termination is a last resort vehicle response to either keep the UAS on the CERTAIN Range or prevent a midair collision. Vehicle termination requires an active C2 link to remove power to the motors.

All these abort maneuvers are tied to a list of triggers (table 10) and are documented in an abort checklist as predetermined responses to specific scenarios. All abort procedures will be performed by the PIC. For traffic conflict scenarios, PIC action is also backed up by ICAROUS DAA technology. Should the PIC be unable to take the proper action or fail to initiate the abort in a timely manner, ICAROUS will respond and by sending maneuver commands to the vehicle autopilot to maintain the minimum safe separation criteria defined in Section 6.7.7 and 6.7.8. During build-up simulation and flight testing, the abort procedures will be evaluated to verify proper vehicle response and assessed for ease of execution. Additionally, as part of the GCSO training, abort maneuvers execution shall be tested both in simulation and flight test.

Table 10 - Abort Triggers and Subsequent Abort.

Trigger	**Abort**
-Loss of vehicle communication link -Loss of radar (LSTAR and southern facing GA-9120) -Loss of voice communication (primary and backup) -Unexpected autonomous system response -Geofence breach	Return to launch or return to rally point

-Degraded GPS -Low battery -Failed/Failing ground control station that doesn't lead to a lost link RTL -Critical system warnings	1) Rapid safe landing (S2D); or 2) Vehicle termination
-Loss of GPS	Slow descent with the wind
-Non-participating traffic enters operations area (intruder traffic)	1) Rapid descent to safe altitude followed by RTL; or 2) Rapid descent to safe altitude followed by- S2D landing; or 3) Vehicle termination

7 Safety Risk Management Planning and Impacted Organizations

Individuals from the following organizations have been involved in the planning, definition, and execution of the Safety Risk Management (SRM) activities associated with this safety case:

- NASA Langley Research Center (LaRC)
  - LaRC Uncrewed Aircraft Systems Operations Office (UASOO)
  - LaRC Aeronautics Research Directorate (ARD)
  - LaRC Research Services Directorate (RSD)
  - LaRC Air Traffic Operations Lab (ATOL)
- Langley Air Force Base (LAFB)
- NASA Ames Research Center (ARC)

The following organizations/activities are the primary collaborators for the BVLOS activities described herein:

- KLFI: Langley Air Force Base
- LaRC: Langley Research Center

8 Failure Analysis

A preliminary failure modes analysis was performed on the Alta 8 Pro in the HDV Configuration and the primary flight equipment contained in the ROAM UAS Operations Center. The first level of analysis was a functional analysis. This approach postulates the functions and functional failure modes associated with overall system performance. The primary objective of this analysis was to identify failure modes for all flight essential equipment. Tables 11 through 16 identify an individual system, potential failure modes, pre-failure mitigations, and ways to mitigate the effects of each failure after it occurs. The systems analyzed include the propulsion system, the Alta 8 flight control system (autopilot), voice communications, onboard autonomous systems (S2D and ICAROUS), the command and control system, the aircraft structure, and the ground-based surveillance systems.

Table 11 - Failure Modes Analysis for Pixhawk Autopilot

System	Failure mode	Pre-failure Mitigation	Mitigating Effects Post Failure
ALTA 8 Flight Control System (PX4)	Power Failure	- Positive locking connectors - Power wiring internally routed and protected by enclosure	
	GPS Failure	- EMI/EMC ground testing - Preflight inspection of wire routing and GPS antenna mount - All connectors to carrier board are secured with RTV - GPS and space weather NOTAMs checked before flight	- Redundant independent methods to accurately track UAS position (FLARM) - Vehicle termination - Wind adjusted flight routes
	IMU Failure	- Triple redundant IMU - Pre-Arm self-checks - EKF monitoring IMU performance	- Flight routes selected over very low populated areas - Supports anytime flight termination
	Compass Failure	- Redundant compass - Pre-Arm self-checks - EKF monitoring compass performance	- Flight routes selected over very low populated areas - Supports anytime flight termination

Table 12 - Failure Mode Analysis for Team Voice Communications.

System	Failure mode	Pre-failure Mitigation	Mitigating Effects Post Failure
Voice Communications	Internal (Flight Crew) VHF Communication Failure	- Multiple VHF handheld radio channels - Amplified VHF radio Base station radio - All crewmembers required to have a primary and backup method of voice communication - Digital asynchronous systems will be used to convey non-safety critical information and alleviate voice comm traffic.	- Cellular phone communication - LaRC VoIP phones - Loss of communications between any required crew member shall drive an RTL response
	External (ATC) VHF Communication Failure	- Multiple VHF radios - Alternate pre-programed frequencies for Langley Tower (ex TWR and GND) - RSO has a primary and backup method of voice communication with Langley Tower	- Call Langley tower landline - Call Langley tower on alternate frequency

Table 13 - Failure Mode Analysis of Onboard Autonomous Systems.

System	Failure mode	Pre-failure Mitigation	Mitigating Effects Post Failure
Onboard Autonomous Systems (OAS)	Battery Failure	- Battery management program - Preflight battery checks - Battery voltage checked on battery before installed on vehicle - OAS battery life exceeds total mission flight time - Fuses used to prevent overcurrent - Separate batteries used for aircraft systems (flight systems battery and autonomous systems battery) - System architecture designed to fail to COTS+extended COTS vehicle for aborts	- PIC can maneuver aircraft from ground station manually - Alta 8 autopilot geofence powered by flight battery - Return-to-launch failsafe
	Primary Flight Control Isolation	- Operational check preformed during preflight	- PIC directed Return-to-launch - PIC directed de-energization of motors
	Regulator failure	- Redundant Regulators	- PIC directed Return-to-launch - PIC directed de-energization of motors
	NVIDIA Xavier failure	- Primary Flight Control Isolation - NASA Class-C software requirements are being used - Hardware in the loop simulations - WVLOS flight testing conducted	- PIC can maneuver aircraft from ground station manually - Alta 8 autopilot geofence - Return-to-launch failsafe
	Autonomous Emergency Landing System Failure	- Primary Flight Control Isolation - NASA Class-C software requirements are being used - Simulations have been conducted - WVLOS flight testing conducted	- Return-to-launch failsafe - Alta 8 autopilot auto land failsafe

	Autonomous Traffic Avoidance System Failure	- Primary Flight Control Isolation - NASA Class-C software requirements are being used - Hardware in the loop simulations - WVLOS flight testing conducted - Langley Airforce base tower required for BVLOS operations - Procedural deconfliction methods - Predefined abort criteria (avoidance maneuvers)	- PIC can maneuver aircraft from ground station manually (execute avoidance maneuvers) - PIC directed de-energization of motors for rapid decent
	Autonomous Airspace Containment Failure	- Primary Flight Control Isolation - NASA Class-C software requirements are being used - Hardware in the loop simulations - WVLOS flight testing conducted	- Return-to-launch failsafe - PIC can maneuver aircraft from ground station manually - Alta 8 autopilot geofence - PIC directed de-energization of motors for rapid decent

Table 14 - Failure Mode Analysis of Command and Control System.

System	Failure mode	Pre-failure Mitigation	Mitigating Effects Post Failure
Command & Control System	Data Link/Connectivity Failure	- Redundant C&C links operate on separate frequency bands - Spectrum analysis - Link analysis - Flight path assessment testing	- Return-to-launch failsafe - Independent methods to accurately track UAS position (FLARM)
	Antenna Failure	- Redundant C&C links	- Return-to-launch failsafe - Independent methods to accurately track UAS position (FLARM)
	GCS Power Failure	- Uninterrupted power supply (backup power) - Shore power (Reliable)	- Dual independent GCS available for use - Return-to-launch failsafe - Independent methods to accurately track UAS position (FLARM) - Integrated Airspace Display can isolate and display independent sources to help identify actual vehicle position
	Network Failure	- Ethernet connection to network	- Return-to-launch failsafe - Independent methods to accurately track UAS position (FLARM) - Partial ICAROUS DAA functionality retained (ie ADS-B and FLARM in)
	Software Crash	- NASA class-C software standards - Hardware in the loop simulations - Flight testing conducted	- Back up GCS available for use - Return-to-launch failsafe - Independent methods to accurately track UAS position (FLARM)

Table 15 – Failure Mode Analysis of the Alta-8 Structure.

System	Failure mode	Pre-failure Mitigation	Mitigating Effects Post Failure
Aircraft Structure (Alta 8 Pro)	Airframe, Component, or Subcomponent Failure	- Preflight checks to verify that components are secure and airworthy - Flight critical fasteners secured using Loctite - Manufactures 15-flight & 15-hour inspections are complied with - NASA Langley UAS annual/progressive (≥50 flights) inspection checklist - OEM life limited parts changed at manufactures recommended intervals - Route of flight selected to avoid overflying non-participants	- PIC directed auto land failsafe - Flight routes selected over very low population areas
	Payload Failure	- Vibration isolation mounts - Redundant mechanisms for securing payload items to aircraft (I.E tie wraps or Velcro) - Route of flight selected to avoid overflying non-participants	- PIC directed auto land failsafe

Table 16 – Failure Mode Analysis of the Ground Based Surveillance Systems.

System	Failure mode	Pre-failure Mitigation	Mitigating Effects Post Failure
Ground Based Surveillance Systems	GA-9120 Radar Failure or LSTAR Radar Failure	- Shore power (reliable) - Will not commence flight operations without system fully functional - Predefined abort criteria for degraded surveillance data - Langley Airforce base tower is required for BVLOS operations - Procedural deconfliction methods are in place - Historical usage of radar system will inform future reliability - Consult with Center Operations Directorate re: power availability metrics - Connected to LaRC network via ethernet - Multiple location input data streams - Predefined abort criteria for degraded surveillance data	- Backup workstations - Pilot directed abort procedure - Autonomous avoidance algorithm (ICAROUS) - Independent methods of tracking UAS (GCS & FLARM) - Langley tower is available for airspace deconfliction

9 Identified Hazards

For the purposes of this safety case, the definition of *hazard* has been adapted from the FAA ATO Safety Management System (SMS) manual and is given as "any real or potential condition that can cause injury, illness, or death to people; damage to property; or damage to the environment." More specifically, loss of the system equipment (with the exception of the radar surveillance infrastructure), including the sUAS, is considered as an acceptable risk so far as that loss does not lead to any of the losses considered above.

Hazards have been formulated as a combination of system states (that may or may not be a deviation from the required operational state) and one or more credible worst-case environmental conditions, such that there is a potential for harm. The *system* comprises the elements discussed in Section 5. Everything that is not part of the system is considered as part of the *environment*, i.e., the weather conditions, operating location, and air traffic in the operational airspace.

Tables 17, 18, and 19 summarize the identified hazards along with their worst-case credible outcomes/effects, as determined by the hazard working group (HWG). Hazards have been classified as *primary*, if the source of the threat lies in the environment (i.e., other aircraft, terrain, weather, GPS constellation); *secondary* if the threats are induced by the primary hazards; and *contributory* when the threats arise from the system.

9.1 Primary Hazards

Table 17 - Listing of Primary Hazards.

Hazard ID	Hazard Description	Credible Worst-case Outcomes
Primary Hazards		
PH1	Midair collision with manned aircraft	• Midair collision, resuling in loss of non-participating manned aircraft and possible injury/loss of life • Debris ejected over people/infrastructure on ground and causes injury/death to people and damage to infrastructure
PH2	Mid-air collision between UA	• UA damage from impact • Severe injury or death to non-participants on ground and/or; • Property damage caused by falling debris
PH3	UAS flies off the CERTAIN Range	• Flight into airspace outside the CERTAIN Range and/or Class D airspace that results in a loss of

		safe separation with non-participating manned aircraft; • Midair collision with manned aircraft resulting in severe injury or death to airborne non-participants; and/or significant property damage • Flight over populated areas outside the CERTAIN Range, resulting in severe injury or death to non-participants on ground
PH4	GPS Failure	• Loss of UA navigation capabilities, potentially followed by deviation from approved flight path and/or breach of the CERTAIN Range boundaries • Impairment of surveillance systems capability to resolve UA position due to dependence on GPS

9.2 Secondary Hazards

Table 18 – Listing of Secondary Hazards

Hazard ID	**Hazard Summary**	**Credible Worst-case Outcomes**
Secondary Hazards		
SH1	UA impacts people/structures on the ground	• Severe injury or death to ground personnel and/or; • Significant property damage

9.3 Contributory Hazards

Table 19 - Listing of Contributory Hazards

Hazard ID	Hazard Summary	Credible Worst-case Outcomes
Contributory Hazards		
CH1	Degradation of ground surveillance system	• Flight that results in a loss of safe separation with participating sUAS or non-participating manned aircraft; • Midair collision with non-participating manned aircraft resulting in severe injury or death to airborne non-participants and/or injury or death to non-participants on the ground caused by falling debris; and/or significant property damage caused by falling debris • Midair collision with participating sUAS that results in severe injury or death to non-participants on ground and/or property damage caused by falling debris
CH2	Loss of all command and control links	• Loss of capability to positively control sUAS, and/or command avoidance maneuvers if and when required. • Loss of position information on GCS and loss of GCS input to IAD
CH3	Unrecoverable failure of sUAS or GCS during flight	• Loss of capability to positively control sUAS • Potential loss of lift and/or deviation from the approved flight path • Autopilot unable to maintain stabilized flight

		• Controlled or uncontrolled descent into terrain/terrestrial entities, resulting in a loss of the aircraft • Injury or death to non-participants on the ground caused by falling debris; and/or significant property damage caused by falling debris
CH4	Human factors events, including loss of situational awareness, crew miscommunication, and crew fatigue.	• Inability to execute timely avoidance manuevers • Non-timely reporting of detected threats and/or sUAS flight path deviation not recognized immediatly • Improper entry of waypoints, UA commands, and/or improper UA autopilot programming
CH5	Loss of voice communications	• Inability to inform airspace users and ATC service providers in the event of emergencies • Inability to convey aircraft intentions to Vehicle Service Crew (VSC) • Inability of Radar Operator (RO) to relay critical information
CH6	Lithium battery fire	• Severe injury or death to non-participants and/or; • Significant property damage and/or; • Damage / loss of UA

10 Risk Analysis

A Safety risk analysis was performed by using the NASA LaRC Hazard Analysis process and a Hazard Working Group (composed of both project and UAS Operation Office personnel), to systematically identify the primary, secondary, and contributory hazards of the planned HDV BVLOS operations. Similar to the risk level associated with the FAA's ATO SMS Hazard Analysis Worksheets, the NASA LaRC process utilizes a hazard analysis form that identifies the undesired event or risk associated with the hazard, the causes for the undesired event, the consequences or effects of the undesired event, and mitigations to reduce the likelihood of the undesired event occurring. This risk assessment looked at the proposed operations without any mitigations put in place (Initial Risk) and then again with the proposed mitigations (Mitigated Residual Risk). Each hazard was assigned a Risk Assessment Code (RAC) characterizing the severity and probability of their occurrence. The net result is the assignment of a Risk Assessment Code (RAC) ranging from 1 to 4, with 1 being the highest risk and 4 the lowest. RAC level 2 requires Center Director approval to be an "Accepted Risk" and Level 1 requires an additional approval by NASA HQ. The NASA Hazard Analysis Forms and the Risk Assessment Matrix are included in Appendix C. Below is the list of hazards, and a quick look comparison of the initial before mitigation and residual risks after mitigation (Table 20).

Table 20 - Summary of Hazards with Predicted Initial and Residual Risk Levels.

Hazard ID	Hazard Description	Initial Risk Level	Mitigated Residual Risk Level
Primary Hazards			
PH1	Midair collision with manned aircraft	RAC 1 (I/C)	RAC 3 (I/D)
PH2	Mid-air collision between UA	RAC 2 (II/C)	RAC 3 (II/D)
PH3	UAS flies off the CERTAIN Range	RAC 2 (II/C)	RAC 3 (II/D)
PH4	GPS Failure	RAC 2 (III/B)	RAC 3 (III/D)
Secondary Hazards			
SH1	UA impacts people/structures on the ground	RAC 2 (II/C)	RAC 3 (II/D)
Contributory Hazards			
CH1	Degradation of ground surveillance system	RAC 3 (III/C)	RAC 3 (IV/C)
CH2	Loss of all command and control links	RAC 3 (IV/B)	RAC 3 (IV/C)
CH3	Unrecoverable failure of UA or GCS during flight	RAC 2 (II/D)	RAC 3 (II/D)

CH4	Human factors events, including loss of situational awareness, crew miscommunication, and crew fatigue.	RAC 3 (III/C)	RAC 3 (III/D)
CH5	Loss of voice communications	RAC 3 (IV/C)	RAC 4 (V/D)
CH 6	Lithium battery fire	RAC 3 (III/D)	RAC 4 (IV/E)

11 Treatment of Risks/Mitigation of Hazards

Hazard mitigation will be accomplished by employing the principle of defense in depth, using a combination of hazard mitigations, each comprising various measures for hazard control. Below is a list of the major mitigation categories.

M1) Airspace deconfliction procedures

M2) Airworthiness, flight readiness and crew qualifications

M3) Onboard and ground safety equipment

M4) Nominal operating procedures

M5) Risk reduction actions

M6) Build-up approach

M7) Technology risk reductions

M8) Emergency/contingency procedures

Each of these mitigating categories have multiple mitigators that help reduce the risk of the primary, secondary, and contributory hazards to an acceptable risk level. These categories and their mitigations will be summarized the sections below.

11.1 Airspace Deconfliction Procedures

Airspace deconfliction procedures include limiting sUAS BVLOS operations to times when LAFB Tower is open, utilizing ground-based surveillance to provide situational awareness of the LMV airspace and adhering to the predetermined measures/procedures for ensuring safe separation. Each of these mitigators helps to reduce the risk of a mid-air collision.

11.1.1 BVLOS Operations Only with Tower Open

LAFB Tower is critical to HDV's defense in depth hazard mitigation concept. LAFB Tower must be open to conduct BVLOS operations. This allows the enforcement of procedural rules designed to keep manned aircraft at or above 900 feet (500 ft separation between manned and uncrewed). LAFB also updates the Automatic Terminal Information Services (ATIS) advisory alerting manned aircraft that UAS operations are in progress on the CERTAIN Range. With tower open, UAS operating NOTAMS are also issued through LAFB Base Operations which help to inform all local and transient crews of the sUAS operations on CERTAIN. Additionally, the RSO manages all communications with LAFB Tower through a primary push-to-talk and backup (cell/land line) method. This helps to keep extraneous sUAS communications to a minimum (sUAS crewmember communications operate on a separate frequency) and gives LAFB Tower the ability to issue instructions pertinent to sUAS operations when necessary. Finally, the minimum weather for BVLOS operations is set at 2000 ft ceiling and 3 NM visibility. This ensures LAFB visual pattern rules will be in effect which eliminates the need for manned aircraft to potentially fly below 900 feet AGL.

11.1.2 Ground-based Surveillance

The Ground Based Surveillance infrastructure consists of several independent systems all feeding information into the IAD in ROAM. This surveillance infrastructure will be used to detect and track air traffic that could pose a threat to BVLOS sUAS flight operations on the CERTAIN Range.

To ensure complete coverage of the LMV airspace, the L-STAR, southern facing GA-9120, ADS-B feed, FLARM, GCS GPS telemetry and an operational IAD are all required for BVLOS flight operations. The L-STAR and GA-9120 are monitored by a trained radar operator during all BVLOS operations. The RO is responsible for monitoring the radars for acceptable performance, advising AM/RSO of radar degradations and providing complementary scanning of the LMV airspace to intruder traffic. The ground-based surveillance feeds from the L-STAR, GA-9120, ADS-B, GCS GPS telemetry, and FLARM data provides real-time airspace picture of the LMV on the IAD. Additionally, an ANRA fusion algorithm will be evaluated for its ability to merge corollary track data from the different ground sources into a single fused track. Functionality of the Anra fusion is not required for BVLOS operations. The IAD will also show airspace boundaries, live aircraft positions and can isolate and display independent surveillance sources to help identify actual vehicle position. The AM has the responsibility to monitor the LMV for traffic, identify sUAS deviations from planned flight route and monitor the performance of the ANRA Fusion algorithm to ensure accurate representation. For multi-UAS operations, FLARM provides an additional source of vehicle to vehicle and vehicle to ground sUAS position monitoring. It is the responsibility the AM, RSO and RO to identify potential traffic conflicts and characterize them as either intruder or nominal traffic. Finally, the VSC will call out perceived traffic conflicts within their field of view.

Ground-based surveillance defense in depth is obtained by utilizing multiple vehicle detection methods, dedicated personnel to monitor, classify, and detect traffic conflicts, and an IAD designed to present ground surveillance tracks of the entire LMV airspace on a single display.

11.1.3 Measures for Safe Separation

The measures for safe separation include a minimum safe separation for manned-UAS and UAS-UAS conflicts as well as clearly defined airspace boundaries, avoidance areas, arrival/departure corridors and procedures for responding to traffic that penetrates the minimum safe separation distances. Additionally, during HDV sUAS operations, other sUAS operations shall only be permitted on a case-by-case basis with proper coordination with the HDV operation. These measures all add to HDV’s defense in depth hazard mitigation strategy.

The minimum safe separation between sUAS and manned aircraft is 250 ft vertical or 2,000 ft horizontal. The minimum safe separation between sUAS aircraft is 100 ft vertical or 500 ft horizontal. Arrival and departure procedures are established for sUAS operations in and out of vertiport locations with a minimum temporal separation of 30 seconds in the arrival/departure corridors. For added clarity, the IAD shows the LMV rings as well as CERTAIN Range lateral boundaries. To further simplify the operations, a GCSO PIC shall:

1) command one sUAS at a time;
2) utilize predetermined abort/contingency procedures for traffic conflicts to ensure minimum safe separation is maintained;
3) have the ability to follow ATC instructions; and

4) if required, land all airborne UAS within 120 seconds.

Finally, the GCSO PIC, AM or FTM shall announce any sUAS deviations from flight planned route to inform all GCSO PICs that a deviation is occurring.

11.2 Airworthiness, Flight Readiness and Crew Qualifications

Airworthiness, flight readiness and crew qualifications are key components to the HDV operation. Airworthy vehicles flown by crews that are current and qualified in their respective positions adds three defense-in-depth layers to LaRC BVLOS flight operations.

All LaRC UAS operated in an environment that is not physically contained or tethered shall possess and maintain a Statement of Airworthiness issued by the Airworthiness Review Board (ARB). Continuous airworthiness and configuration control of all NASA LaRC sUAS is key to ensuring that the sUAS is functional, operating normally, and in an airworthy state. As part of that continued airworthiness process, VSCs shall check all connections, mounts, GPS antennas, vehicle components and subsystems to ensure they are secure and airworthy prior to every flight. Regularly scheduled maintenance and inspection plans are utilized to ensure sUAS are fully functional and continued airworthiness is maintained. This includes inspecting batteries for punctures, abnormal expansion, or frayed wires prior to each use. A battery management plan is key to maintaining continued airworthiness. All batteries are qualified upon acquisition and must be labeled with date acquired, tested capacity, voltage, charging and discharging rates. Additionally, batteries undergo periodic and 6-month capacity checks to verify functionality and all batteries more than 2 years old will be removed from service. Finally, due to the sUAS high dependency on GPS and C2 links, the GPS components and constellation must be fully functional and all comm links must be operational prior to takeoff. Should the GPS figure of merit (Horizontal Dilution of Precision, HDOP) rise above 2 meters or the minimum number of satellites drop below 6, BVLOS flight operations will be halted.

Flight Readiness is a key component to HDV BVLOS operations that ensures crewmembers know their responsibilities, are proficient in their tasks and are in the proper mental state to conduct flight operations. As an independent safety observer, the RSO is responsible for monitoring the entirety of the flight test operation to include flight operations and personnel. FTMs are used for all BVLOS operations and will brief all crew members (GCSO PICs, RSO, AM and VSC) on mission details and expected outcomes of all test events. All UAS pilots are required to accomplish at least three flights in a 90-day period to maintain a minimum standard of currency. Finally, crews shall be well rested and afforded the opportunity to take breaks during the flight test operation. At a minimum, GCSO PICs shall take 15-minute breaks every two hours with at least a 30-minute meal break between hours 4-7 of the duty day. Additionally, crew duty cycles will be limited to a maximum of 12 hours per day, 60 hours per week, with the ability to get 8 hours of uninterrupted sleep and at least one day off in a 7-day period.

Crew Qualifications are essential to safe flight operations. All UAS crew members shall have annual sUAS Operations refresher training and be current in Crew Resource Management (CRM). Additionally, all sUAS crewmembers shall be trained on the usage and limitations of the communication system and to utilize clear, correct, concise communication while maintaining strict adherence to radio discipline during flight operations (essential communications only). All sUAS pilots shall be trained and certified by aircraft type under NASA LaRC Crew Initial/Refresher Training program. Pilots are ultimately responsible for the safe execution of the test objectives and be ready to intervene in all abort/contingency/emergency situations. GCSO PIC training will include simulation training that focuses on communications, GCS parameter crosscheck, emergency procedure responses and crew coordination/CRM as well as execution of all abort/contingency maneuvers (special emphasis on traffic avoidance). Critical failures will also be simulated during GCSO PIC simulator qualification training (GPS failures, lost com). Full-scale mission simulations using all required members (FTM/MC, AM, RSO, and GCSO PICs) shall be accomplished before conducting actual BVLOS flight operations. Finally, ROs shall be trained to operate, monitor, and assess functionality of L-STAR/GA-9120 radars.

11.3 Onboard and Ground Safety Equipment

Onboard and ground safety equipment offers yet another layer of defense in depth hazard mitigations. For starters, the onboard safety equipment mitigations include the requirement for all multi-rotor sUAS to have 8 motors minimum such that the loss of one motor/ESC still allows the vehicle to be controllable. Finally, a primary flight control isolation system is utilized as a failsafe to isolate the primary flight control system from the advanced onboard autonomous system commands.

The ground safety equipment includes the flight mode indicator in front of ROAM UAS Operations Center that will illuminate when flight operations are in progress, effectively notifying all personnel that aircraft are airborne. All GCSO workstations shall have standardized configurations so that GCSOs can see all participating sUAS positions on each of their GCS. Additionally, the ground-based surveillance feeds from the L-STAR, GA-9120, ADS-B, GCS and FLARM data provides real-time airspace picture of the LMV on the IAD. Finally, all Clearcomm radio belt packs will provide audible warnings for range exceedance and low battery situations, all ditch sites will be clearly marked to identify the potential for UAS takeoff/landings and Class D fire extinguishers shall be available for controlling lithium battery fires.

11.4 Nominal Operating Procedures

NASA LaRC has over 20 years of experience conducting UAS operations. These experiences are captured in lessons learned, procedures, hazard mitigations and limits that are defined in LPR 1710.16 and characterized as normal operating procedures. Therefore, all general operating procedures and limits prescribed in 1710.16 shall be adhered to unless specifically approved by the ARB and/or ORR (wind, weather, and temperature limits; currency, training, and qualification requirements; planning, lost link, range containment and mishap procedures). Additionally, the following best practices will be implemented for HDV BVLOS operations:

1) Visual observers utilized for WVLOS or EVLOS operations;

2) Mobile handheld and Clearcomm (VHF) radios shall be fully charged at the beginning of the day;

3) Voice communications shall be tested daily to verify reliability;

4) All failsafe autonomous programming (RTL, Geofence, ICAROUS, S2D) shall be verified by two people before first flight of the day or after a change to the autonomous failsafe programming;

5) Flight plan in the autopilot shall be verified for proper upload;

6) Pre-flight checks shall verify GPS satellite signals can be acquired and maintained by checking GPS NOTAMS and space weather forecasts that could lead to rare GPS errors;

7) GCSO PICs shall monitor GPS signal strength and number of satellites during flight operations;

8) Battery charging limits appropriate for battery type, number of cells and overall capacity, shall not exceed 1C rate (60 minutes to full charge) and closely monitored with periodic checks during charging cycle;

9) Battery bags are utilized to mitigate the effects of thermal runaway;

10) Batteries shall be fully charged and voltage shall be monitored throughout flight – sUAS shall plan to land with 30% battery reserve.

11.5 Risk Reduction Actions

HDV's risk reduction actions are implemented to add to the defense in depth hazard mitigation strategy. These items include spectrum management mitigation steps, additional system redundancies and mitigators to specific to HDV operations. The following mitigation items are specific to HDV BVLOS flight operations:

1) Flight routes and altitudes shall account for wind direction/magnitude to ensure range containment for total GPS failure;

2) Vehicle flight paths will be constrained to very low populated areas of NASA LaRC consisting of open fields, woods, and sparsely located small buildings;

3) Digital asynchronous systems will be used to convey non-safety critical information and reduce voice communication traffic;

4) Crew communication plan will define which communication channels/methods are available for all crewmembers;

5) COTS vehicles undergo 15-flight checkout series prior to system integration;

6) RTL and geofence procedures tested to verify functionality if any software or hardware changes are made to the baseline sUAS configuration;

11.5.1 Spectrum Management

The LaRC Spectrum Management Office approves the use of all RF frequencies and assures that the various electromagnetic signals emitted by the system or existing in the environment do not interfere with each other (e.g., electromagnetic radiation from high-tension wires/towers, or ground based radars also operating in the L-band). Additionally, a spectrum analyzer is being deployed on the CERTAIN Range to aid in the troubleshooting and documentation of any potential radio interference issues. In addition to these steps, HDV is accomplishing the following actions to mitigate the chances of EMI:

1) Historical spectrum analysis of critical communication frequencies (900 MHz, 2.4 GHz, 4G/LTE) performed (Appendix G);

2) Primary and secondary communication links shall be tested for functionality and verified free of EMI with all crewmembers before the first flight of the day;

3) CERTAIN Range vertiports and ditch sites chosen to be free of natural obstacles that could impede receiving GPS signals during takeoff, departures, arrivals and landings;

4) Radar flight evaluations accomplished to verify L-STAR/GA-9120 radar detection performance and verify known blind zones;

5) Ground and flight expansion testing shall be performed during WVLOS and EVLOS conditions to ensure GCS 900 MHz C2 links allow multiple 900 MHz links to operate simultaneously prior to executing multi-vehicle BVLOS operations;

Finally, assuming good line-of-sight for a link analysis, the expected communication range of the 900 MHz C2 links with a 25 dB link margin exceeds 53 kilometers. The maximum expected BVLOS distance on CERTAIN is less than 3 kilometers.

11.5.2 Added Redundancy

With defense in depth in mind, HDV has added redundancy in voice communications, C2, GPS tracking, range containment and ROAM power supplies to decrease the likelihood of a hazard occurring during BVLOS flight operations. Both primary and backup communications are required for all sUAS crewmembers during BVLOS operations (VHF, cell phone/land line, TEAMS, chat) to mitigate the chances of loss of voice communications. Redundant methods of command and control using separate telemetry links (900 MHz and 4G/LTE) are utilized to help minimize the chances of a lost link. Redundant independent methods of tracking sUAS position (GCS and FLARM) are utilized to help maintain positional awareness of the sUAS and redundant geofences (COTS autopilot and ICAROUS) are utilized to ensure range containment. Finally, in the event of a power loss to building 1268, uninterruptible power supplies (UPS) are utilized in ROAM to help facilitate graceful shutdown and ensure that at least one C2 link is maintained for any BVLOS flight.

11.6 Build-up Approach to Hazard Mitigations

The build-up approach used by HDV is critical to developing BVLOS capability and safely conducting BVLOS operations. The build-up approach includes simulation, flight envelope expansion, abort procedure and emergency procedure verification, and ROAM UAS Operations Center/IAD checkout. The following is a list of build-up risk reduction activities HDV is using to help with their defense in depth mitigation process:

1) Simulation to flight system testing used to verify HHITL interface, autonomous software integration (ICAROUS and S2D) and integrated system checkout (ROAM/IAD);

2) High fidelity hardware-in-the-loop simulation utilized to validate ICAROUS and S2D functionality in simulated multi-sUAS environments;

3) Warnings and callouts on QGC and MPATH shall be reviewed and assessed during high fidelity simulation;

4) Simulation will also test emergency procedures such as loss of C2 links, GCS failure and loss of GPS;

5) Envelope expansion flights performed under WVLOS and EVLOS conditions for initial checkout and after major configuration changes before conducting BVLOS operations;

6) Vehicle flight times progressively expanded;

7) Flight paths shall be flown under WVLOS (as able) and EVLOS conditions before flying them under BVLOS conditions;

8) RTL and geofence functionality tested under WVLOS and EVLOS conditions before flying BVLOS;

9) Voice communications tested during WVLOS, EVLOS and simulated BVLOS operations before being used for BVLOS operations;

10) IAD tested during simulation to ensure proper display of radar, ADS-B, FLARM, and GCS position data.

11.7 Technology Risk Reductions

Technology risk reductions are utilized to help the machine/human interface by incorporating autonomous backup technologies to limit the impacts of a human or mechanical failure. These backups include both COTS autonomous redundancy and HDV autonomous technologies (S2D, ICAROUS).

COTS autonomous technologies inhibit the sUAS autopilot from arming if GPS not acquired, allow for the establishment of a geofence for range containment and execute RTL procedures for lost communications.

HDV technologies like the autonomous avoidance algorithm (ICAROUS) are utilized to help maintain minimum safe separation between sUAS and manned aircraft. When ICAROUS perceives a penetration of the minimum safe separation criteria, the ICAROUS bands will show up on the GCS and inform the GCSO PIC that ICAROUS is executing an avoidance maneuver by recalculating a secondary route to maintain safe separation. No fly and avoidance areas within CERTAIN, such as over critical infrastructure or populated areas, are also incorporated into ICAROUS to aide in range containment and keep the sUAS out of prohibited areas. Safe to Ditch is also utilized to help ensure a clear landing area during a rapid autonomous landing. Both HDV onboard autonomous software technologies (S2D and ICAROUS) help direct malfunctioning sUAS away from ground movement and steer clear of congested landing sites.

11.8 Emergency/Contingency Procedures

The emergency/contingency procedures represent a suite of procedural risk mitigation actions that the crew involved in the operations will undertake in the unlikely event that the identified hazardous, and off-nominal scenarios materialize during sUAS operations (i.e., assuming that other preventative barriers have been unsuccessful).

The HDV project combines avoidance and contingency procedures into a single category called aborts. Contingency procedures can be performed for a wide variety of scenarios (triggers) ranging from loss of C2 link to traffic conflicts.

11.8.1 Abort Procedures

Contingency procedures are a subset of the abort procedures introduced in table 10. These procedures were not identified as emergency procedures but were important enough to develop standardized responses for should they occur.

Table 21 - Contingency Procedures

Trigger	Abort
-Loss of single vehicle communication link -Unexpected autonomous system response -Geofence breach	Return to launch or return to rally point
-Degraded GPS -Low battery -Failed/Failing ground control station that doesn't lead to a lost link RTL -Critical system warning(s)	1) Rapid safe landing (S2D); or 2) vehicle termination
-Non-participating traffic enters operations area (intruder traffic)	1) Rapid descent to safe altitude followed by RTL; or 2) Rapid descent to safe altitude followed by S2D; or 3)Execution or vehicle termination

11.8.2 Emergency Procedures

The following list of emergency procedures identify the corrective actions in the unlikely event that the hazard occurs even with the mitigations in place.

Midair collision with manned aircraft

1) Initiate knockoff and clear all flight paths
2) Identify approximate location of impact over the ground
3) Recover all airborne sUAS
4) Notify LAFB Tower of the midair and inform them of approximate location
5) Notify NASA Langley Fire Department and inform them of approximate location
6) Follow NASA LaRC Mishap Preparedness and Contingency Plan (LMS-CP-8621 and LMS-OP-0939)

Midair collision between sUAS

1) Initiate knockoff and clear all flight paths
2) Identify approximate location of impact over the ground
3) Recover all airborne UAS
4) Notify NASA Langley Fire Department and inform them of approximate location
5) Follow NASA LaRC Mishap Preparedness and Contingency Plan (LMS-CP-8621 and LMS-OP-0939)

sUAS flies off the CERTAIN Range without returning

1) Recover all other airborne sUAS
2) Notify LAFB Tower of the departure from the CERTAIN Range and inform them of approximate location and time of last known position, speed, heading, altitude, remaining time of flight and pilot intentions.
3) Follow NASA LaRC Mishap Preparedness and Contingency Plan (LMS-CP-8621 and LMS-OP-0939)

Pixhawk Global Positioning System Failure

1) Ensure slow descent with the wind to land is automatically initiated; if not, GCSO PIC must initiate.
2) Monitor vehicle position with secondary GPS source (FLARM)
3) If range containment is in jeopardy, GCSO PIC must assess the impact of removing all power to vehicle
4) Notify VSC of landing location so the vehicle can be safely disarmed and recovered
5) In necessary, notify NASA Langley Fire Department and inform them of approximate location
6) If necessary, follow sUAS flies off CERTAIN Range corrective actions

Degradation of Ground Surveillance System

1) Knock off all operations and assess source of failure
2) Initiate recovery IAW prescribed procedures (RTL or Rapid Descent)
3) Notify LAFB Tower of loss of Ground Surveillance Data
4) GCSO PIC shall notify VSC of inbound aircraft using GCS position
5) If applicable, refer to appropriate Midair hazard for additional corrective actions

Loss of All Command and Control Links

1) Knock off all operations
2) Monitor sUAS position with FLARM on IAD
3) RSO notify LAFB and PHF (as appropriate) Towers of loss link with sUAS and unexpected autonomous vehicle response GCSO PIC notify VSC of inbound aircraft
4) Recover all other airborne sUAS

Human Factors Events, Including Loss of SA, Fatigue and Miscommunication

1) Announce loss of SA or unexpected result
2) Knock off flight operations (transition all vehicles to hover)

Unrecoverable Failure of sUAS or GCS During Flight

1) Knock it off, clear all flight paths and recover all airborne sUAS
2) If possible, monitor vehicle position with remaining GPS source (FLARM or GCS Position)
3) If range containment is in jeopardy, GCSO PIC/RSO must assess the impact of removing all power to motors
4) Notify VSC of landing location so the vehicle can be safely disarmed and recovered
5) In necessary, notify NASA Langley Fire Department and inform them of approximate location
6) If necessary, follow UAS flies off CERTAIN Range corrective actions
7) If necessary, follow NASA LaRC Mishap Preparedness and Contingency Plan (LMS-CP-8621 and LMS-OP-0939)

Loss of Voice Communication

1) Attempt contact using backup communication method(s); if unable
2) Knock off all flight test
3) GCSO PIC initiate RTL

Lithium Battery Fire

1) Knock off flight operations
2) Notify NASA Langley Fire Department and inform them of fire location
3) If able, without putting someone at risk, fight fire with a dry powder fire extinguisher

sUAS Impacts People/Structures on the Ground

1) Initiate knockoff and clear all flight paths
2) Identify sUAS location on the ground
3) Recover all airborne sUAS
4) Notify VSC of landing location so the vehicle can be safely disarmed and recovered
5) Follow NASA LaRC Mishap Preparedness and Contingency Plan (LMS-OP-0939)
6) If necessary, notify NASA Langley Fire Department and inform them of approximate location
7) If necessary, notify LAFB Tower of the incident and inform them of approximate location

12 Tracking and Monitoring of Hazards

NASA Langley will use phased Airworthiness and Operational Readiness Reviews to validate the assumptions made in this safety case, verify the safety performance of the identified hazard mitigation barriers, and update the safety case as appropriate, so that it is consistent with the actual system and its operations.

M1) Airspace deconfliction procedures will be evaluated during high fidelity simulation and during WVLOS and EVLOS operations. These build-up operations will thoroughly test deconfliction procedures and, if required, enable NASA LaRC to make necessary modifications prior to transitioning to full BVLOS operations. Flight/ground testing, as appropriate, will also be used to verify C2 link performance, crew performance, as well as the effectiveness of the avoidance maneuvers and the ability for them to be performed in the specified time, by simulating scenarios that trigger contingency operations. In turn, these will be used to validate the avoidance maneuvers, contingency procedures, and redundancy as hazard mitigation barriers.

Additionally, the assumptions made for airspace characterization, in particular the worst-case ground speeds and descent rates for characteristic intruder aircraft, as well as traffic density and occupancy information, will be validated against acquired data.

M2) Airworthiness, flight readiness and crew qualifications will be monitored and updated as required to maintain continued airworthiness, flight readiness and crew qualifications. The level of airworthiness for the UA involved as well as their capabilities to maintain the safe separation specifications will be assessed during build-up testing. That assessment, in turn, will be used to update the safe separation specifications (if required) as well as to verify the adequacy of the abort procedures.

Flight readiness and crew qualifications will be monitored IAW NPR 7900.3D and LPR 1710.16J.

M3) Onboard and ground safety equipment will be evaluated during build-up WVLOS and EVLOS operations and If required, adjustments can be made prior to executing BVLOS operations.

M4) Nominal operating procedures will be evaluated for impacts on BVLOS operations. If changes are required, new procedures will be presented to the ARB and/or the ORR for consideration and approval.

M5) Risk reduction actions will be evaluated continuously throughout the build-up and BVLOS flight testing. Proposed adjustments will be reviewed by the ARB and/or ORR for approval and incorporation.

M6) Build-up flight test approach, including simulation, flight envelope expansion, abort procedure and emergency procedure verification, and ROAM UAS Operations Center/IAD checkout will be continuously assessed for additional opportunities to reduce risks to BVLOS operations. Additions/changes to the build-up approach will be included in revisions to the HDV flight test plan.

M7) Technology risk reductions for both COTS and HDV autonomous technologies focused on limiting the impacts of a human or mechanical failure will be tested during high fidelity simulation, WVLOS, and EVLOS flight test operations. Performance assessments from these build-up test will verify proper functionality and reliability of autonomous systems. That assessment, in turn, will be used to update the safe separation specifications (if required) as well as to verify the adequacy of the autonomous abort procedures.

Finally, during build-up simulator and flight testing, radar testing, as well as during the actual mission operations, data will be collected on the frequency and nature of the identified hazards, reviewed to determine if the hazard analysis should be updated and/or assess whether any new or missed hazards unique to the intended CONOPS should be created.

13 Appendices

Appendix A: Langley AFB Letter of Procedure

LETTER OF PROCEDURE

Effective: 1 May 2021

SUBJECT: Unmanned Aircraft Systems (UAS) Operations and Testing within Langley Air Force Base's (LAFB) Class D Airspace.

1. **PURPOSE:** This Letter of Procedure (LOP) establishes guidelines and identifies responsibilities for the safe, orderly, and expeditious operation of UAS in LAFB's Class D airspace, as well as provides instructions for operations of UAS when LAFB's Air Traffic Control Tower is closed (e.g. holidays, after hours).

2. **CANCELLATION:** This LOP may be cancelled upon written notification by the 1st Fighter Wing Commander at LAFB.

3. **SCOPE:** This LOP is binding on any UAS operations by NASA Langley Research Center (LaRC) within LAFB's Class D airspace. NASA LaRC shall maintain a copy of this LOP and be cognizant of the responsibilities as outlined below. Failure of NASA LaRC to comply with the following requirements may result in denial of permission to operate UAS inside of LAFB's Class D airspace. NASA UAS operators and the LAFB Air Traffic Control Tower (Tower) must comply with all appropriate FAA regulations; FAA Certificate of Authorization (COA) or 14 CFR Part 107; Air Force Instruction 13-204v3, *Airfield Operations Procedures and Programs*; this LOP; and Langley Air Force Base Instruction 11-250, *Airfield Operations and Base Flying Procedures*. Additionally, NASA LaRC will comply with Langley Research Center Aviation Operations and Safety Manual, Langley Procedural Requirements (LPR) 1710.16.

4. **RESPONSIBILITIES:**

A. NASA LaRC shall:

(1) Conduct all UAS Operations in accordance with the Langley Research Center Aviation Operations & Safety Manual, LPR 1710.16, Chapter 5, Unmanned Aircraft Systems.

(2) UAS procurement, modification and/or experimental build shall be in accordance with the NASA Langley UAS Information Technology System Security Plan.

(3) Provide a Hazard Analysis submitted by the Range Safety Officer (RSO) in accordance with LPR 1710.16, Chapter 5, Section 8, UAS Range Safety.

Appendix B: FAA Certificates of Authorization

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

CERTIFICATE OF WAIVER OR AUTHORIZATION

ISSUED TO
Public Agency – National Aeronautics and Space Administration (NASA) Part 91

ADDRESS
National Aeronautics and Space Administration (NASA)
4 Langley Blvd
Hampton, VA 23681-2199

This certificate is issued for the operations specifically described hereinafter. No person shall conduct any operation pursuant to the authority of this certificate except in accordance with the standard and special provisions contained in this certificate, and such other requirements of the Federal Aviation Regulations not specifically waived by this certificate.

OPERATIONS AUTHORIZED
Operation of small Unmanned Aircraft System(s) weighing less than 55 pounds and operating at speeds of less than 87 kts. (100 mph) in Class D airspace at or below 400 feet Above Ground Level (AGL) in the vicinity of Hampton, VA under the jurisdiction of Langley Air Force Base Air Traffic Control Tower (LFI AFB ATCT). See Special Provisions and Attachments.

LIST OF WAIVED REGULATIONS BY SECTION AND TITLE
N/A

STANDARD PROVISIONS

1. A copy of the application made for this certificate shall be attached and become a part hereof.
2. This certificate shall be presented for inspection upon the request of any authorized representative of the Federal Aviation Administration, or of any State or municipal official charged with the duty of enforcing local laws or regulations.
3. The holder of this certificate shall be responsible for the strict observance of the terms and provisions contained herein
4. This certificate is nontransferable.

Note-This certificate constitutes a waiver of those Federal rules or regulations specifically referred to above. It does not constitute a waiver of any State law or local ordinance.

SPECIAL PROVISIONS

Special Provisions Nos. A thru G, inclusive, and Air Traffic Control Special Provisions are set forth on the reverse side hereof.

The certificate is effective from February 21, 2021 to February 20 2023, and is subject to cancellation at any time upon notice by the Administrator or his/her authorized representative.

BY DIRECTION OF THE ADMINISTRATOR

FAA Eastern Service Center
(Region)

For Ryan Almasy
(Signature)

Manager, Operations Support Group
(Title)

FAA Form 7711-1 (7-74)

Version Date: May 2019

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

CERTIFICATE OF WAIVER OR AUTHORIZATION

ISSUED TO

Public Agency – National Aeronautics and Space Administration (NASA) Part 91

National Aeronautics and Space Administration (NASA)
4 Langley Blvd
Hampton, VA 23681

This certificate is issued for the operations specifically described hereinafter. No person shall conduct any operation pursuant to the authority of this certificate except in accordance with the standard and special provisions contained in this certificate, and such other requirements of the Federal Aviation Regulations not specifically waived by this certificate.

OPERATIONS AUTHORIZED

Operation of small Unmanned Aircraft System(s) weighing less than 55 pounds and operating at speeds of less than 87 kts. (100 mph) in Class D airspace at or below 400 feet Above Ground Level (AGL) in the vicinity of Hampton, VA under the jurisdiction of Langley Air Force Base Airport Traffic Control Tower (LFI AFB ATCT). See Special Provisions and Attachments.

LIST OF WAIVED REGULATIONS BY SECTION AND TITLE

14 CFR §91.113(b) (BVLOS)

STANDARD PROVISIONS

1. A copy of the application made for this certificate shall be attached and become a part hereof.
2. This certificate shall be presented for inspection upon the request of any authorized representative of the Federal Aviation Administration, or of any State or municipal official charged with the duty of enforcing local laws or regulations.
3. The holder of this certificate shall be responsible for the strict observance of the terms and provisions contained herein
4. This certificate is nontransferable.

Note-This certificate constitutes a waiver of those Federal rules or regulations specifically referred to above. It does not constitute a waiver of any State law or local ordinance.

SPECIAL PROVISIONS

Special Provisions Nos. A thru H, inclusive, and Air Traffic Control Special Provisions are set forth on the reverse side hereof.

The certificate is effective from December 10, 2021 to December 9, 2023, inclusive, and is subject to cancellation at any time upon notice by the Administrator or his/her authorized representative.

BY DIRECTION OF THE ADMINISTRATOR

FAA Eastern Service Center
(Region)

For Matthew Cathcart
(Signature)

Acting Manager, Operations Support Group
(Title)

FAA Form 7711-1 (7-74)

Version Date: May 2019

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

CERTIFICATE OF WAIVER OR AUTHORIZATION

ISSUED TO
Public Agency – National Aeronautics and Space Administration (NASA) Part 91

ADDRESS
National Aeronautics and Space Administration (NASA)
4 Langley Blvd
Hampton, VA 23681-2199

This certificate is issued for the operations specifically described hereinafter. No person shall conduct any operation pursuant to the authority of this certificate except in accordance with the standard and special provisions contained in this certificate, and such other requirements of the Federal Aviation Regulations not specifically waived by this certificate.

OPERATIONS AUTHORIZED
Operation of the LA-8 Tiltrotor and Alta X Unmanned Aircraft Systems (UAS) in Class D airspace at or below 400 feet AGL in the vicinity of Hampton, VA under the jurisdiction of Langley Air Force Base Airport Traffic Control Tower (LFI ATCT). See Special Provisions and Attachments.

LIST OF WAIVED REGULATIONS BY SECTION AND TITLE
N/A

STANDARD PROVISIONS

1. A copy of the application made for this certificate shall be attached and become a part hereof.
2. This certificate shall be presented for inspection upon the request of any authorized representative of the Federal Aviation Administration, or of any State or municipal official charged with the duty of enforcing local laws or regulations.
3. The holder of this certificate shall be responsible for the strict observance of the terms and provisions contained herein.
4. This certificate is nontransferable.

Note-This certificate constitutes a waiver of those Federal rules or regulations specifically referred to above. It does not constitute a waiver of any State law or local ordinance.

SPECIAL PROVISIONS

Special Provisions Nos. A thru F, inclusive, and Air Traffic Special Provisions are set forth on the reverse side hereof.

The certificate is effective from June 25, 2022 to June 24, 2024, inclusive, and is subject to cancellation at any time upon notice by the Administrator or his/her authorized representative.

BY DIRECTION OF THE ADMINISTRATOR

FAA Eastern Service Center
(Region)

For Greg Garmon
(Signature)

Tactical Operations Team Manager, AVJ-E23
(Title)

FAA Form 7711-1 (7-74)

<table>
<tr><th colspan="8">Risk Assessment Matrix</th></tr>
<tr><th rowspan="2">Severity</th><th colspan="7">Probability</th></tr>
<tr><th>A (Expected)</th><th>B (Probable)</th><th colspan="2">C (Likely)</th><th colspan="2">D (Unlikely)</th><th>E (Improbable)</th></tr>
<tr><td>I(Catastrophic)</td><td>1</td><td>1</td><td colspan="2">1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td>II(Critical)</td><td>1</td><td>1</td><td colspan="2">2</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td>III(Major)</td><td>2</td><td>2</td><td colspan="2">3</td><td colspan="2">3</td><td>4</td></tr>
<tr><td>IV(Minor)</td><td>2</td><td>3</td><td colspan="2">3</td><td colspan="2">3</td><td>4</td></tr>
<tr><td>V(Negligible)</td><td>3</td><td>3</td><td>3</td><td>4</td><td colspan="2">4</td><td>4</td></tr>
</table>

Hazard Severity Definition		*Probability of Occurrence Definition*	
I	Catastrophic • Human: may cause death, permanent total disability, • Asset: system or equipment damage in excess of $2m, crewed aircraft hull loss, unexpected departure from controlled flight	A	Expected • Qualitative: Expected to occur repeatedly during the life cycle of the test activity, even after all mitigations applied • Quantitative: (Pr > 10-1)
II	Critical • Human: may cause permanent partial disability, in patient hospitalization of 3 or more people, or severe lost-time injury or illness • Asset: system or equipment damage between $500k and $2m	B	Probable • Qualitative: Expected to occur at least once during the life cycle of the test activity, even after all mitigations applied • Quantitative: (10-1 ≥ Pr > 10-2)
III	Major • Human: may cause OSHA recordable lost-time injury/illness, in patient hospitalization of 2 or less people or restricted duty • Asset: system or equipment damage between $50k and $500k	C	Likely • Qualitative: Confidence that the procedures or features used in the mitigations will prevent occurrence, but still likely to occur sometime during the life cycle of the test activity • Quantitative: (10-2 ≥ Pr > 10-3)
IV	Minor • Human: may cause non-lost time OSHA-recordable injury not meeting the above • Asset: system or equipment damage between $20k and $50k	D	Unlikely • Qualitative: High confidence that the procedures or features used in the mitigations will prevent occurrence. Not likely to occur during the life cycle of the test activity • Quantitative: (10-3 ≥ Pr > 10-8)
V	Negligible • Human: may cause minor injury requiring first aid • Asset: system or equipment damage less than $20k	E	Improbable • Qualitative: Normal flight procedures mitigate operational risk. High confidence that the engineering and installation procedures specified in the STC, FAR, or equivalent shall mitigate systems safety risk. Low risk make it highly unlikely to occur during the life cycle of the test activity • Quantitative: (10-8 ≥ Pr)

RAC 1	Requires Center Director approval and HQ level approval; “Accepted Risk” only by exception
RAC 2	Risk revalidated by research organization manager; requires Center Director approval to become “Accepted Risk”
RAC 3	Risk acceptance requires Project manager acceptance and ASRB Chair approval
RAC 4	Risk assessed as normal with standard mitigations sufficient; additional mitigations not required

Note: the safety working group makes the final RAC determination. For example, a hazard in cell V-C could be assigned a RAC 3 rating, and hazard in cell V-C could be assigned a RAC 3 or RAC 4 rating.

<table>
<tr><td>HAZARD number, name, and Post-Mitigation RAC

1: Midair collision with manned aircraft [I-D, RAC 3]</td><td>☒ Initial
☐ Revision</td><td>☐ Systems
☒ Operational</td><td>Exposure:
☐ High</td></tr>
<tr><td colspan="4">UNDESIRED EVENT (RISK):
UAS collides with manned aircraft</td></tr>
<tr><td colspan="4">CAUSE OF UNDESIRED EVENT:
Undetected non-participating aircraft enters the CERTAIN Range on a collision course with UAS
Non-participating aircraft takes-off from an airport within the LMV and is not detected early enough to execute avoidance maneuver
Failure of autonomous traffic avoidance software
UA operators are unaware of airspace situation</td></tr>
<tr><td colspan="4">EFFECT OF UNDESIRED EVENT:
Midair collision, resuling in loss of non-participating manned aircraft and possible injury/loss of life
Debris ejected over people/infrastructure on ground and causes injury/death to people and damage to infrastructure</td></tr>
<tr><td colspan="4">CONTROLS/MITIGATIONS

<u>Engineering Design and Reviews</u>

1) Airspace review accomplished to characterize traffic within the Langley Monitoring Volume (LMV)

<u>Validation Testing</u>

1) Simulation to flight system testing used to verify human + hardware in the loop (HHITL) interface, autonomous software integration and integrated system checkout.
2) Radar flight eval accomplished to verify L-STAR radar detection performance and verify known blind zones/limitations of L-STAR radar.
3) HDV’s Advanced Onboard Automation (AOA) simulation and flight tests and Scalable Autonomous Operations (SAO) simulation and flight tests will validate Safe to Ditch (S2D) and ICAROUS functionality in simulated BVLOS operations.

<u>Safety Interlocks and Protective Devices</u>

1) Ground based surveillance on the Integrated Airspace Display (IAD) fed by L-STAR, GA-9120, ADS-B, GCS and FLARM data provides real-time airspace picture of LMV
2) Procedural rules established with Langley AFB (LAFB) Tower to keep manned at or above 900 feet during UAS operations (500 feet separation between UAS and manned aircraft)</td></tr>
</table>

3) Autonomous avoidance algorithm (ICAROUS) utilized to maintain minimum safe separation between UA and manned aircraft
4) Redundant independent methods to accurately track UAS position (GCS and FLARM)
5) Redundant methods of command and control using separate telemetry links (900 MHz and LTE)
6) Safe to ditch (S2D) utilized to help clear a landing area during a rapid landing
7) Airspace monitor (AM) is responsible for monitoring the LMV for traffic, identifying UAS deviations from flight planned route and monitoring the performance of the ANRA Fusion algorithm to ensure raw data (radar, ADS-B, FLARM) are being represented accurately on the Integrated Airspace Display. **Note:** *This duty may be handed off to the Range Safety Officer (RSO) once full verification of the ANRA fusion algorithm is complete.*

Software Assurance

1) ANRA Smart Skies CTR (ANRA Fusion) will be evaluated during HDV's SAO Sim and SAO flight test to verify system performance requirements are achieved.
2) ICAROUS and S2D are NASA certified to a level C class of software (extensive testing of software system to ensure performance requirements are achieved).

Caution/Warning Placards

1) NOTAM generated for all UAS operations
2) Automatic Terminal Information Service (ATIS) advisory alerting manned aircraft that UAS operations are in progress

Procedures

1) RSO shall handle all communications with LAFB Tower during flight operations
2) Predetermined abort procedures for conflicts with intruder aircraft shall be identified
   - -Return to land (RTL) or rally point within 120 seconds
   - -Rapid descent to safe altitude (below gantry height in less than 30 sec)
   - -Rapid safe landing (S2D)
   - -Vehicle termination
3) The AM, RO and RSO shall identify traffic using the LMV Sub Areas to characterize the traffic as either intruder or nominal traffic.
4) GCSO PIC shall initiate the proper abort procedure based on the traffic conflict scenario and/or the recommendation from the RSO.

Training

1) All UAS pilots shall be trained and certified by aircraft type under NASA LaRC UAS Crew Initial/Refresher Training program.

2) Ground Control Station Operator (GCSO) Pilot in Command (PIC) training will include system proficiency checks using simulation (proficiency checks shall include execution/discusion of all abort/emergency procedures).

Operating Limits

1) GCSO PICs shall have the ability to follow ATC instructions and if required, land all airborne UAS within 120 seconds.
2) Minimum safe separation between UA and manned aircraft shall be 250’ vertical or 2,000’ horizontal.
3) The minimum weather for BVLOS flight operations shall be 2000’ ceiling and 3 NM visibility

Mission Rules

1) L-STAR, Southern facing GA-9120, ADS-B feed, ICAROUS, S2D, FLARM, and Integrated Airspace Display required for BVLOS flight operations.
2) Integrated Airspace Display shall show CERTAIN Range boundaries and LMV range rings.
3) LAFB Tower must be open to conduct BVLOS operations.
4) Visual Observers shall be utilized for WVLOS or EVLOS operations.
5) GCSO PIC shall only command one UA at a time.

CORRECTIVE ACTIONS IF UNDESIRED EVENT OCCURS

1) Initiate knockoff and clear all flight paths
2) Identify approximate location of impact over the ground
3) Recover all airborne UAS
4) Notify LAFB Tower of the midair and inform them of approximate location
5) Notify NASA Langley Fire Department and inform them of approximate location
6) Follow NASA LaRC Mishap Preparedness and Contingency Plan (LMS-OP-0939)

REMARKS/ADDITIONAL INFORMATION

1) Periodic meetings with LAFB Tower personnel to ensure complaince with procedural rules.
2) Standard Specifications for Detect and Avoid System Performance Requirements (F3442/F3442M – 20) utilized for minimum safe separation criteria.

<table>
<tr><td>HAZARD number, name, and Post-Mitigation RAC

2: Midair collision between sUAS [II-D, RAC 3]</td><td>☒ Initial
☐ Revision</td><td>☐ Systems
☒ Operational</td><td>Exposure:
☐ High</td></tr>
<tr><td colspan="4">UNDESIRED EVENT (RISK):

• Two uncrewed aircraft (UA) collide while airborne</td></tr>
<tr><td colspan="4">CAUSE OF UNDESIRED EVENT:

• Failure of UAS GCSO PICs to maintain minimum safe separation
• Loss of UA positional awareness
• Failure of autonomous traffic avoidance software
• Autopilot failure to respond to command and control inputs</td></tr>
<tr><td colspan="4">EFFECT OF UNDESIRED EVENT:

• UA damage from impact
• Severe injury or death to non-participants on ground and/or;
• Property damage caused by falling debris</td></tr>
<tr><td colspan="4">CONTROLS/MITIGATIONS

<u>Engineering Design and Reviews</u>

1) Operational readiness review to assess arrival, departure and holding procedures and verify planned vehicle separations

<u>Validation Testing</u>

1) Simulation to flight system testing used to verify human + hardware in the loop (HHITL) interface, autonomous software integration and integrated system checkout.
2) HDV's Advanced Onboard Automation (AOA) simulation and flight tests and Scalable Autonomous Operations (SAO) simulation and flight tests will validate ICAROUS functionality in multi-UAS environments.
3) FLARM functionality shall be verified during HDV AOA flight test.

<u>Safety Interlocks and Protective Devices</u>

1) Ground based surveillance on the Integrated Airspace Display (IAD) fed by L-STAR, GA-9120, ADS-B, GCS and FLARM data provides real-time airspace picture of LMV
2) Arrival, departure and holding procedures established for UAS operations in the vertiport environment
3) Autonomous avoidance algorithm (ICAROUS) utilized to maintain minimum safe separation between UA aircraft (backup to GCSO C2 inputs)
4) Redundant independent methods to accurately track UAS position (GCS and FLARM)
5) Redundant methods of command and control using separate telemetry links (900 MHz and LTE)</td></tr>
</table>

6) Airspace monitor (AM) is responsible for monitoring the LMV, identifying UAS deviations from flight planned route and monitoring the performance of the ANRA Fusion algorithm to ensure raw data (radar, ADS-B, FLARM) are being represented accurately on the airspace Integrated Airspace Display. **Note:** *This duty may be handed off to the Range Safety Officer (RSO) once full verification of the ANRA fusion algorithm is complete.*

Software Assurance

1) ANRA Smart Skies CTR (ANRA Fusion) will be evaluated during HDV's SAO Sim and flight test to verify system performance requirements are achieved.
2) ICAROUS is NASA certified to a level C class of software (extensive testing of software system to ensure performance requirements are achieved).
3) Commercial off the shelf (COTS) system (FLARM) utilized for UAS tracking

Caution/Warning Placards

1) When ICAROUS perceives a penetration of the minimum safe separation criteria, the ICAROUS bands will display on the GCS

Procedures

1) Flight Test Manager/Mission Commander (FTM/MC) shall brief all GCSO PICs, RSO and AM on mission details and expected outcome of all test required/planned traffic conflicts
2) The AM, FTM/MC, RSO or GCSO PIC shall identify and announce any UAS deviations from flight planned route
3) GCSO PIC shall initiate the proper abort procedure based on the UAS traffic conflict and/or the recommendation from the RSO to ensure minimum safe separation criteria is maintained (unless conducting scripted test of ICAROUS).

Training

1) All UAS pilots shall be trained and certified by aircraft type under NASA LaRC UAS Crew Initial/Refresher Training program.
2) Ground Control Station Operator (GCSO) Pilot in Command (PIC) training will include system proficiency checks using simulation (proficiency checks shall include execution/discussion of abort procedures for UA to UA conflicts).
3) Missions shall be simulated using all required members (FTM/MC, AM, RSO and GCSO PICs) before conducting actual BVLOS flight operations.

Operating Limits

1) Minimum safe separation between UA aircraft shall be 100' vertical or 500' horizontal.
2) Minimum separation on arrival/departure corridors is 30 seconds

Mission Rules

1) L-STAR, Southern facing GA-9120, ADS-B feed, ICAROUS, S2D, FLARM, and Integrated Airspace Display required for BVLOS flight operations.
2) Visual Observers shall be utilized for WVLOS or EVLOS operations.
3) GCSO PIC shall only command one UA at a time.

CORRECTIVE ACTIONS IF UNDESIRED EVENT OCCURS

1) Initiate knockoff and clear all flight paths
2) Identify approximate location of impact over the ground
3) Recover all airborne UAS
4) Notify NASA Langley Fire Department and inform them of approximate location
5) Follow NASA LaRC Mishap Preparedness and Contingency Plan (LMS-OP-0939)

REMARKS/ADDITIONAL INFORMATION

1) Previous NASA testing of ICAROUS in 2017, 2018, 2019 and 2021included integration with ADS-B, FLARM and airborne radar sensors to test and evaluate autonomous 3D traffic avoidance maneuvers.
2) Standard Specificaitons for Detect and Avoid System Performance Requirements (F3442/F3442M – 20) utilized for minimum safe separation criteria.

HAZARD number, name, and Post-Mitigation RAC **3: sUAS flies off the CERTAIN Range [II-D, RAC 3]**	☒ Initial ☐ Revision	☐ Systems ☒ Operational	Exposure: ☐ High

UNDESIRED EVENT (RISK):

- Uncrewed Aircraft flies off the CERTAIN Range and continues in controlled flight until batteries or fuel are depleted, possibly exiting class D airspace controlled by Langley Air Force Base (KLFI) tower

CAUSE OF UNDESIRED EVENT:

- Loss of flight termination capability
- Unrecoverable onboard, inflight UA malfunction
- UAS autopilot and ICAROUS geofence improperly configured
- UAS autopilot programmed response to loss of C2 links, GCS, or GPS improperly configured
- Loss of crew situational awareness

EFFECT OF UNDESIRED EVENT:

- Flight into airspace outside the CERTAIN Range and/or Class D airspace that results in a loss of safe separation with non-participating manned aircraft;
- Midair collision with manned aircraft resulting in severe injury or death to airborne non-participants; and/or significant property damage
- Flight over populated areas outside the CERTAIN Range, resulting in severe injury or death to non-participants on ground

CONTROLS/MITIGATIONS

<u>Engineering Design and Reviews</u>

1) Airworthiness Review Board and Operational Readiness Review approve responses to lost command and control links, loss of GPS and flight termination capability
2) Multilayered failsafe design for command and control redundancy and reliability

<u>Validation Testing</u>

1) Simulation to flight system testing used to verify human + hardware in the loop (HHITL) interface, autonomous software integration and integrated system checkout.
2) HDV's Advanced Onboard Automation (AOA) simulation and flight tests will validate UAS autopilot and ICAROUS geofence functionality in simulated BVLOS operations.
   The Integrated Airspace Display (IAD) shall be tested during SAO sim and SAO flight to ensure proper fusion of Radar, ADS-B, FLARM and GCS position data.

<u>Safety Interlocks and Protective Devices</u>

1) UAS autopilot geofence and autonomous avoidance algorithm (ICAROUS) geofence

2) Loss of GCS shall result in autonomous RTL
3) UAS autopilot response to lost GPS is an autonomous slow descent with the wind to land
4) Flight termination capability (command all motors off via 2-step process utilizing GCS)
5) Redundant independent methods to accurately track UAS position (GCS and FLARM)
6) Redundant methods of command and control using separate telemetry links (900 MHz and LTE)

Software Assurance

1) UAS autopilot firmware version maintained under configuration control
2) ICAROUS is NASA certified to a level C class of software (extensive testing of software system to ensure performance requirements are achieved).
3) ANRA Smart Skies CTR (ANRA Fusion) will be evaluated during HDV's Scalable Autonomous Operations (SAO) Sim and flight test to verify system performance requirements are achieved.

Caution/Warning Placards

1) ICAROUS displays recalculating secondary route information on GCS
2) GCS puts up yellow box and says geofence breach and displays autonomous RTL indication

Procedures

1) GCSO PIC shall program UA to automatically RTL if C2 links are lost for more than 5 seconds
2) All failsafe autonomous programing shall be verified by two people before first flight of the day or after a change to the autonomous failsafe programming
3) The flight plan in the autopilot shall be verified for proper upload
4) If UA observed to be outside the geofence, GCSO PIC shall command RTL or utilize Guided mode to bring UA back
5) Lost GPS for more than 1 second shall result in the autopilot executing a slow descent but the PIC can execute a rapid descent or throttle idle command such that the vehicle can be on the ground/in the trees in less than 30 seconds.
6) With no other control method available to recover the vehicle, GCSO PIC and the RSO shall assess when to remove power to the vehicle to prevent a significant airspace deviation. **Note:** *pilot/RSO judgment should be used to determine the best time to remove power and bring the vehicle down to minimize injury to personnel and avoid damage to property.*
7) Inadvertent geofence breach will result in abort and geofence breach review

Training

1) All UAS pilots shall be trained and certified by aircraft type under NASA LaRC UAS Crew Initial/Refresher Training program.
2) Ground Control Station Operator (GCSO) Pilot in Command (PIC) training will include system proficiency checks using simulation (Proficiency checks shall include execution/discussion of all abort/emergency procedures).

Operating Limits

1) Minimum safe separation between UA and CERTAIN Range boundary is a function of the wind velocity; UA with GPS failure must have the ability to be on the ground/in the trees in 30 seconds or less

Mission Rules

1) L-STAR, Southern facing GA-9120, ADS-B feed, ICAROUS, S2D, FLARM, GPS position and Integrated Airspace Display required for BVLOS flight operations.
2) Integrated Airspace Display shall show CERTAIN Range boundaries.
3) LAFB Tower must be open to conduct BVLOS operations.
4) Visual Observers shall be utilized for WVLOS or EVLOS operations.
5) GCSO PIC shall only command one UA at a time.
6) RTL and Geofence procedures shall be tested to verify functionality if any software or hardware changes are made to the baseline UA configuration.
7) Flight routes and altitudes shall account for wind direction/mag to ensure range containment for total GPS failure.

CORRECTIVE ACTIONS IF UNDESIRED EVENT OCCURS

1) Recover all other airborne UAS
2) Notify LAFB Tower of the departure from the CERTAIN Range and inform them of approximate location and time of last known position, speed, heading, altitude, remaining time of flight and pilot intentions.
3) Follow NASA LaRC Mishap Preparedness and Contingency Plan (LMS-OP-0939)

REMARKS/ADDITIONAL INFORMATION

1) None

HAZARD number, name, and Post-Mitigation RAC **4: Global Position System Failure [III-D, RAC 3]**	☒ Initial ☐ Revision	☒ Systems ☐ Operational	Exposure: ☐ High

UNDESIRED EVENT (RISK):

- GPS failure resulting in loss of accurate position information for UAS

CAUSE OF UNDESIRED EVENT:

- GPS constellation outage (ionospheric/space weather events or system failure)
- Interference with GPS signal from external source (GPS jammer)
- GPS satellite signal blockage due to obstructions
- Unrecoverable onboard GPS failure (antenna, EKF, autopilot)

EFFECT OF UNDESIRED EVENT:

- Loss of UA navigation capabilities, potentially followed by deviation from approved flight path and/or breach of the CERTAIN Range boundaries

- Impairment of surveillance systems capability to resolve UA position due to dependence on GPS

CONTROLS/MITIGATIONS

Engineering Design and Reviews

1) Airworthiness and Operational Readiness review approves UA response to loss of GPS

Validation Testing

1) Simulation to flight system testing used to verify human + hardware in the loop (HHITL) interface, autonomous software integration and integrated system checkout.
2) HDV's Advanced Onboard Automation (AOA) and/or Scalable Autonomous Operations (SAO) simulation and flight tests shall test UAS autopilot and GCSO responses to loss of GPS
3) Flights shall be flown under WVLOS and EVOS conditions before flying under BVLOS conditions
4) Warnings and callouts are a combination of Qground and MPATH callouts and shall be assessed during SAO Sim

Safety Interlocks and Protective Devices

1) UAS autopilot inhibited from arming if GPS not acquired
2) UAS autopilot response to lost GPS is an autonomous slow descent with the wind to land
3) Flight termination capability (command all motors off via 2-step process utilizing GCS)
4) Redundant methods to track UAS position (GCS GPS and FLARM)
5) CERTAIN Range vertiports and ditch sites chosen to be free of natural obstacles that could impede receiving GPS signals during takeoff, departures, arrivals and landings
6) Integrated Airspace Display can isolate and display independent sources to help identify actual vehicle position

Software Assurance

1) UAS autopilot firmware version maintained under configuration control

Caution/Warning Placards

1) Orange textbox in MPath displays “No GPS Position”, audible alert issued, number of satellites goes to zero and HDOP goes to 100.
2) Integrated Airspace Display shows airspace boundaries and aircraft positions (FLARM and GCS)

Procedures

1) Pre-flight checks shall verify GPS satellite signal can be acquired and maintained by checking GPS NOTAMs (Federal Aviation Administration: NOTAM Search (faa.gov)).
2) Receiver Autonomous Integrity Monitoring (RAIM) checks shall be accomplished before every mission integrity of GPS system throughout the flight time (Automatic Dependent Surveillance – Broadcast (ADS-B) Service Availability Prediction Tool (SAPT) (faa.gov))
3) Additionally, space weather forecasts shall be monitored to provide an early warning about atmospheric events that could lead to rare normal GPS errors (Alerts, Watches and Warnings | NOAA / NWS Space Weather Prediction Center).
4) Vehicle Service Crew (VSC) shall check security of GPS antenna before every launch.
5) GCSOs shall monitor GPS signal strength and number of satellites during flight operations

Training

1) All UAS pilots shall be trained and certified by aircraft type under NASA LaRC UAS Crew Initial/Refresher Training program.
2) Ground Control Station Operator (GCSO) Pilot in Command (PIC) training will include system proficiency checks using simulation (proficiency checks shall include execution/discussion of all abort/emergency procedures).
3) All crews shall see and respond to a minimum of two GPS failures in SAO Sim (one with FLARM providing accurate GPS and one with FLARM providing inaccurate GPS).

Operating Limits

1) Minimum GPS figure of merit such as PDOP must be less than 2 for all UAS GPS systems and the minimum number of satellites must be greater than or equal to 6.
2) Minimum safe separation between UA and CERTAIN Range boundary is a function of the wind velocity; UA with GPS failure must have the ability to be on the ground/in the trees in 30 seconds or less

Mission Rules

1) All UA and ground GPS systems must be fully function before any flight commences
2) Integrated Airspace Display shall show CERTAIN Range boundaries.
3) Integrated Airspace Display shall only display live aircraft (no simulated tracks will be displayed on the IAD).

CORRECTIVE ACTIONS IF UNDESIRED EVENT OCCURS

1) Ensure slow descent with the wind to land is automatically initiated; if not, GCSO PIC must initiate.
2) If possible, monitor vehicle position with accurate GPS source (FLARM or GCS Position)
3) If range containment is in jeopardy, GCSO PIC must assess the impact of removing all power to vehicle
4) Notify VSC of landing location so the vehicle can be safely disarmed and recovered
5) In necessary, notify NASA Langley Fire Department and inform them of approximate location
6) If necessary, follow UAS flies off CERTAIN Range corrective actions

REMARKS/ADDITIONAL INFORMATION

<table>
<tr><td>HAZARD number, name, and Post-Mitigation RAC

5: Degradation of Ground Surveillance System [IV-C, RAC 3]</td><td>☒ Initial
☐ Revision</td><td>☐ Systems
☒ Operational</td><td>Exposure:
☐ High</td></tr>
<tr><td colspan="4">UNDESIRED EVENT (RISK):

• Degradation of airspace situational awareness (participating and/or non-participation aircraft)</td></tr>
<tr><td colspan="4">CAUSE OF UNDESIRED EVENT:

• Failure of the L-STAR radar or L-STAR radar traffic data transfer
• Failure of southern facing GA-9120 radar or GA-9120 traffic data transfer
• Failure of ADS-B antenna or ADS-B traffic data transfer
• Failure of FLARM antenna or FLARM traffic data transfer
• Failure of GCS UAS position or GCS position data transfer
• Failure of the ANRA Fusion Algorithm to accurately display participating and non-participating traffic
• Failure of the Integrated Airspace Display
• Failure of LaRCNet</td></tr>
<tr><td colspan="4">EFFECT OF UNDESIRED EVENT:

• Flight that results in a loss of safe separation with participating UA or non-participating manned aircraft;

• Midair collision with non-participating manned aircraft resulting in severe injury or death to airborne non-participants and/or injury or death to non-participants on the ground caused by falling debris; and/or significant property damage caused by falling debris

• Midair collision with participating UA that results in severe injury or death to non-participants on ground and/or property damage caused by falling debris</td></tr>
<tr><td colspan="4">CONTROLS/MITIGATIONS

<u>Engineering Design and Reviews</u>

1) Airspace review accomplished to characterize traffic within the Langley Monitoring Volume (LMV)

<u>Validation Testing</u>

1) Simulation to flight system testing used to verify human + hardware in the loop (HHITL) interface, autonomous software integration and integrated system checkout.
2) Radar flight evaluations accomplished to verify L-STAR radar detection performance and verify known blind zones.
3) The Integrated Airspace Display (IAD) shall be tested during Scalable Autonomous Operations (SAO) sim and SAO flight to ensure live feeds from Radar, ADS-B, FLARM and GCS position are available.
4) ANRA Smart Skies CTR (ANRA Fusion) will be evaluated during HDV’s SAO Sim and SAO flight test to verify system performance requirements are achieved.</td></tr>
</table>

Safety Interlocks and Protective Devices

1) Airspace monitor (AM) is responsible for monitoring the LMV for traffic, identifying UAS deviations from flight planned route and monitoring the performance of the ANRA Fusion algorithm to ensure raw data (radar, ADS-B, FLARM) are being represented accurately on the Integrated Airspace Display. **Note:** *This duty may be handed off to the Range Safety Officer (RSO) once full verification of the ANRA fusion algorithm is complete.*
2) GCS displays all participating UAS positions on each GCS
3) Multi-UAS operations require operational FLARM to provide vehicle to vehicle and/or vehicle to ground sUAS position monitoring
4) Radar Operator is responsible for monitoring radar status and advising AM and RSO of radar degradations.

Software Assurance

1) All firmware versions for radar, FLARM, GCS, ANRA fusion and IAD shall be verified under configuration control procedures before the first flight of the day.

Caution/Warning Placards

1) LSTAR Radar BIT status indicator monitored for acceptable performance.
2) GA-9120 warning status monitored for radar faults

Procedures

1) Degradation of the ground surveillance system with UA in flight shall result in an immediate abort
   -Return to land (RTL) or rally point (L-STAR data available)

   -Rapid descent to safe altitude (below gantry height in less than 30 sec for L-STAR failure)
2) The AM, FTM/MC, RSO or GCSO PIC shall identify and announce any UAS deviations from flight planned route.
3) Ownship position shall be communicated over voice communications and the VSC shall call out any traffic conflicts
4) All position sources feeding ANRA fusion shall be verified for accuracy

Training

1) Ground Control Station Operator (GCSO) Pilot in Command (PIC) training will include system proficiency checks using simulation (proficiency checks shall include execution/discussion of abort/emergency procedures).
2) Radar operators shall be trained to operate, monitor, and assess functionality of the LSTAR/GA-9120 radars

Operating Limits

1) N/A

Mission Rules

1) L-STAR, Southern facing GA-9120, ADS-B feed, ICAROUS, S2D, FLARM, GCS position and Integrated Airspace Display are required for BVLOS flight operations.
2) LAFB Tower must be open to conduct BVLOS operations.
3) LSTAR and GA-9120 radar monitored by a trained radar operator during all BVLOS flights
4) LSTAR Radar BIT status indicator shall be green for BVLOS flights.
5) GA-9120 shall be monitored for radar faults

CORRECTIVE ACTIONS IF UNDESIRED EVENT OCCURS

1) Knock off all operations and assess source of failure
2) Initiate recovery IAW prescribed procedures
3) Notify LAFB Tower of loss of Ground Surveillance Data
4) GCSO PIC shall notify VSC of inbound aircraft using GCS position
5) If applicable, refer to appropriate Midair hazard for additional corrective actions

REMARKS/ADDITIONAL INFORMATION

HAZARD number, name, and Post-Mitigation RAC **6: Loss of All Command and Control Links [IV-C, RAC 3]**	☒ Initial ☐ Revision	☒ Systems ☐ Operational	Exposure: ☐ High

UNDESIRED EVENT (RISK):

- All communication links with UA fail for a sustained interval (> 5 sec)

CAUSE OF UNDESIRED EVENT:

- Loss/malfunction of ground/airborne transceiver equipment
- External (electromagnetic) interference inhibiting the C2 signals
- Obstruction blocking transmitter and/or receiver antenna, e.g., banking
- Aircraft obstructing airborne transceiver antenna
- Loss of the GCS

EFFECT OF UNDESIRED EVENT:

- Loss of capability to positively control UA, and/or command avoidance maneuvers if and when required.
- Loss of position information on GCS and loss of GCS input to IAD

CONTROLS/MITIGATIONS

Engineering Design and Reviews

1) Airworthiness Review Board and Operational Readiness Review approves responses to lost command and control links
2) Multilayered failsafe design for command and control redundancy and reliability
3) Link analysis/verification of manufacture specifications performed on all C2 links to ensure adequate link margin
4) Power outage analysis performed for ROAM identified need to utilize autonomous programming and autonomous technologies to facilitate aircraft recoveries during complete power loss

Validation Testing

1) Simulation to flight system testing used to verify human + hardware in the loop (HHITL) interface, autonomous software integration and integrated system checkout.
2) HDV's Advanced Onboard Automation (AOA) and/or Scalable Autonomous Operations (SAO) simulation and flight tests shall test UAS autopilot and GCSO responses to loss of all C2 links
3) Flights paths shall be flown under WVLOS or EVLOS conditions before flying them under BVLOS conditions
4) RTL functionality shall be tested under WVLOS conditions before flying BVLOS
5) Historical spectrum analysis of critical communication frequencies (900 MHz, 2.4 GHz, 4G/LTE) performed

Safety Interlocks and Protective Devices

1) Redundant methods of command and control using separate telemetry links (900 MHz and LTE)
2) Loss of all GCS C2 links or GCS will result in automatic RTL after 5 second timeout

Software Assurance

1) UAS autopilot, Botlink, and 900 MHz radio firmware version maintained under configuration control and a change to firmware may require validation testing before continuing with BVLOS operations

Caution/Warning Placards

1) Callout warnings visible on GCSO PIC Display

Procedures

1) GCSO PIC shall program UA to automatically RTL if all GCS C2 links are lost for more than 5 seconds
2) RTL programming shall be verified by two people before first flight of the day or after a change to the RTL programing
3) The AM, FTM/MC, RSO or GCSO PIC shall identify and announce any UAS deviations from flight planned route
4) RTL will be performed if either link is lost for more than 15 seconds

Training

1) All UAS pilots shall be trained and certified by aircraft type under NASA LaRC UAS Crew Initial/Refresher Training program.
2) Ground Control Station Operator (GCSO) Pilot in Command (PIC) training will include system proficiency checks using simulation (proficiency checks shall include execution/discussion of all abort/emergency procedures).

Mission Rules

1) All comm links must be fully functional before any BVLOS flight commences
2) All UA and ground GPS systems must be fully function before any flight commences
3) Ground and flight expansion testing shall be performed during WVLOS/EVLOS operations to ensure GCS 900 MHz C2 links allow multiple 900 MHz links to operate simultaneously prior to executing multi-vehicle BVLOS operations.

CORRECTIVE ACTIONS IF UNDESIRED EVENT OCCURS 1) Knock off all operations 2) Monitor UA position with FLARM on IAD 3) RSO notify LAFB and PHF (as appropriate) Towers of loss link with UA and unexpected autonomous vehicle response 4) GCSO PIC notify VSC of inbound aircraft 5) Recover all other airborne UAS
REMARKS/ADDITIONAL INFORMATION

HAZARD number, name, and Post-Mitigation RAC **7: Unrecoverable Failure of UA or GCS during flight [II-D, RAC 3]**	☒ Initial ☐ Revision	☒ Systems ☐ Operational	Exposure: ☐ High

UNDESIRED EVENT (RISK):

- Unrecoverable failures or malfunctions on the airborne UA or on the Ground Control Station

CAUSE OF UNDESIRED EVENT:

- Loss/malfunction of the system onboard the UA, i.e., electrical, propulsion, flight control, ESCs, airframe, onboard control and communications including avionics, navigation, and autopilot

EFFECT OF UNDESIRED EVENT:

- Loss of capability to positively control UA
- Potential loss of lift and/or deviation from the approved flight path
- Autopilot unable to maintain stabilized flight
- Controlled or uncontrolled descent into terrain/terrestrial entities, resulting in a loss of the aircraft
- Injury or death to non-participants on the ground caused by falling debris; and/or significant property damage caused by falling debris

CONTROLS/MITIGATIONS

Engineering Design and Reviews

1) Design review of QGround Control MPath GCS accomplished
2) NASA Langley shall accomplish engineering design reviews and airworthiness reviews to certify vehicle configurations as airworthy
3) Independent UA inspections performed prior to initial AWS and on recurring intervals

Validation Testing

1) Simulation to flight system testing used to verify human + hardware in the loop (HHITL) interface, autonomous software integration and integrated system checkout.
2) Flights shall be flown under WVLOS and EVOS conditions before flying under BVLOS conditions
3) HDV's Advanced Onboard Automation (AOA) and/or Scalable Autonomous Operations (SAO) simulation and flight tests shall test UAS autopilot ability to handle GCS failure
4) Comprehensive flight envelope expansion performed under WVLOS/EVLOS operations prior to BVLOS operations

Safety Interlocks and Protective Devices

1) Multi-rotor UA shall have 8 motors
2) Redundant methods of command and control using separate telemetry links (900 MHz and LTE)
3) Onboard autonomous software (Safe2Ditch and ICAROUS) available to help direct malfunctioning UA away from ground movement
4) The PIC shall be provided a method to isolate the primary flight control from the advanced onboard autonomous systems

Software Assurance

1) UAS autopilot, Botlink, and 900 MHz radio firmware version maintained under configuration control and a change to firmware may require validation testing before continuing with BVLOS operations

Caution/Warning Placards

1) All ditch sites will be clearly marked to identify the potential for UAS takeoffs/landings

Procedures

1) Flight operations shall not commence until the UA has been verified to be functional, operating normally, and in an airworthy state
2) Preflight checks shall verify all connections, mounts and propellers are secure
3) Batteries shall be fully charged and voltage shall be monitored throughout flight; UA shall plan to land with 30% fuel reserve
4) GCSO PIC shall program UA to automatically RTL if GCS failure occurs
5) RTL programming shall be verified by two people before first flight of the day or after a change to the RTL programing
6) The AM, FTM/MC, RSO or GCSO PIC shall identify and announce any UAS deviations from flight planned route.
7) The flight plan in the autopilot shall be verified for proper upload
8) Manual RTL will be performed if either link is lost for more than 15 seconds
9) With no other control method available to recover the vehicle, GCSO PIC and the RSO shall assess when to remove power to the vehicle to prevent a significant airspace deviation. **Note:** *pilot/RSO judgment should be used to determine the best time to remove power and bring the vehicle down to minimize injury to personnel and avoid damage to property.*

Training

1) All UAS pilots shall be trained and certified by aircraft type under NASA LaRC UAS Crew Initial/Refresher Training program.
2) Ground Control Station Operator (GCSO) Pilot in Command (PIC) training will include system proficiency checks using simulation (proficiency checks shall include execution/discussion of all abort/emergency procedures).

Operating Limits

1) All general operating limits prescribed in 1710.16 shall be adhered to unless specifically approved by the ARB and ORR

Mission Rules

1) All comm links must be fully functional before any flight commences
2) Unexpected/unanticpated vehicle responses shall be treated as system failures leading to an abort
3) All UA and ground GPS systems must be fully function before any flight commences
4) GCSO PIC shall only command one UA at a time.

CORRECTIVE ACTIONS IF UNDESIRED EVENT OCCURS

1) Knock it off, clear all flight paths and recover all airborne UA
2) If possible, monitor vehicle position with accurate GPS source (FLARM or GCS Position)
3) If range containment is in jeopardy, GCSO PIC/RSO must assess the impact of removing all power to motors
4) Notify VSC of landing location so the vehicle can be safely disarmed and recovered
5) In necessary, notify NASA Langley Fire Department and inform them of approximate location
6) If necessary, follow UAS flies off CERTAIN Range corrective actions
7) If necessary, follow NASA LaRC Mishap Preparedness and Contingency Plan (LMS-OP-0939)

REMARKS/ADDITIONAL INFORMATION

1) Optional provisions for Visual Pilot control available when vehicle WVLOS of VSC (2.4 GHz)

<table>
<tr><td>HAZARD number, name, and Post-Mitigation RAC

8: Human factors events, including loss of situational awareness, fatigue, and miscommunication [III-D, RAC 3]</td><td>☒ Initial
☐ Revision</td><td>☐ Systems
☒ Operational</td><td>Exposure:
☐ High</td></tr>
<tr><td colspan="4">UNDESIRED EVENT (RISK):

• Human factors events including
    o Loss of situational awareness
    o Crew miscommunication
    o Crew fatigue</td></tr>
<tr><td colspan="4">CAUSE OF UNDESIRED EVENT:

• Insufficient crew training
• Crew overworked in non-nominal duty cycle
• Complacency due to reliance automation
• Ambiguous statements or unclear voice communication
• Task saturation or fixation
• Improper display orientation or mislabeling</td></tr>
<tr><td colspan="4">EFFECT OF UNDESIRED EVENT:

• Inability to execute timely avoidance manuevers
• Non-timely reporting of detected threats and/or UA flight path deviation not recognized immediatly
• Improper entry of waypoints, UA commands, and/or improper UA autopilot programming</td></tr>
<tr><td colspan="4">CONTROLS/MITIGATIONS

<u>Engineering Design and Reviews</u>

1) Human factors interface displays review shall be accomplished before BVLOS operations

<u>Validation Testing</u>

1) Voice communications (primary and backup) shall be tested during AOA and SAO EVLOS operations to verify reliable operations at all crew locations
2) Human Factors testing accomplished during AOA and SAO sim

<u>Safety Interlocks and Protective Devices</u>

1) Range Safety Officers monitor the entirety of the flight test operation and act as an independent safety observer for all UA flight operations
2) Airspace monitor (AM) is responsible for monitoring the LMV, identifying UAS deviations from flight planned route and monitoring the performance of the ANRA Fusion algorithm to ensure raw data (radar, ADS-B, FLARM) are being represented accurately on the airspace Integrated Airspace Display.</td></tr>
</table>

Note: This duty may be handed off to the Range Safety Officer (RSO) once full verification of the ANRA fusion algorithm is complete.

3) COTS and autonomous systems (ICAROUS and S2D) can mitigate some impacts to loss of situational awareness
4) Standardized configurations shall be used for all GCSO workstations

Software Assurance

1) Autonomous systems are certified to a NASA class-C software certification.

Caution/Warning Placards

1) Flight Mode Indicator in front of the ROAM UAS Operations Center shall illuminate when flight operations are in progress (sterile communications required).

Procedures

1) Flight Test Manager/Mission Commander (FTM/MC) shall brief all GCSO PICs, RSO and AM on mission details and expected outcome of all test required/planned traffic conflicts
2) The AM, FTM/MC, RSO or GCSO PIC shall identify and announce any UAS deviations from flight planned route.
3) All failsafe autonomous programing shall be verified by two people before first flight of the day or after a change to the autonomous failsafe programming
4) Essential communications only during flight operations
5) Use standardized phraseology for multi-UAS operations

Training

1) GCSO PIC training will include simulation training that focuses on communication, GCS parameter crosscheck, emergency procedure responses and crew resource management training
2) All UAS crew members shall have annual UAS Operations refresher training and be current in crew resource management
3) All UAS pilots shall be trained and certified by aircraft type under NASA LaRC UAS Crew Initial/Refresher Training program.
4) Ground Control Station Operator (GCSO) Pilot in Command (PIC) training shall include system proficiency checks using simulation
5) UAS Aircrew are trained on the use of clear, correct, concise communication and radio discipline during flight operations

Operating Limits

1) N/A

Mission Rules

1) Crew duty cycles will be a maximum of 12 hours per day with the ability to get 8 hours of uninterrupted sleep. Maximum of 60 hours in a week with at least one day off.
2) GCSOs shall take a 15-minute break every two hours with at least one 30-minute meal break between hours 4-7 of the duty day
3) Flight test managers or Mission Commanders shall be used for all BVLOS operations
4) GCSO PICs will operate only one UA

CORRECTIVE ACTIONS IF UNDESIRED EVENT OCCURS

1) Announce loss of SA or unexpected result
2) Knock off flight operations (transition all vehicles to hover)

REMARKS/ADDITIONAL INFORMATION

HAZARD number, name, and Post-Mitigation RAC **9: Loss of voice communication [V-D, RAC 4]**	☒ Initial ☐ Revision	☐ Systems ☒ Operational	Exposure: ☐ High

UNDESIRED EVENT (RISK):

- Failure of equipment for voice communications

CAUSE OF UNDESIRED EVENT:

- Communication equipment failures and/or malfunction
- Interference inhibiting communication transmission and/or reception
- Loss of power to communication equipment

EFFECT OF UNDESIRED EVENT:

- Inability to inform airspace users and ATC service providers in the event of emergencies
- Inability to convey aircraft intentions to Vehicle Service Crew (VSC)
- Inability of Radar Operator (RO) to relay critical information

CONTROLS/MITIGATIONS

Engineering Design and Reviews

1) Detailed communication plan designed with separate operations and safety networks for redundancy and eliminate extraneous voice communications.

Validation Testing

1) Voice communications (primary and backup) shall be tested during WVLOS, EVLOS and simulated BVLOS operations before being used for BVLOS operations.

Safety Interlocks and Protective Devices

1) Crewmembers have a primary and a backup method of communicating (VHF, cell phone, land line Teams, chat).
2) Digital asynchronous systems will be used to convey non-safety critical information and alleviate voice comm traffic.
3) Crew communication plan will define which communication channels/methods are available for all team members.

Software Assurance

1) Significant changes (eg software updates, additional team members or hardware) to the communication system will require checkout testing to confirm adequate system performance.

Caution/Warning Placards

1) Clearcomm belt pack system provides audible warnings for range exceedance and low battery.

Procedures

1) Primary and secondary communication links shall be tested for functionality and verified free of EMI with all crewmembers before the first flight of the day
2) All crewmember (GCSO, FTM, RSO, AM) primary communication will be on a Clearcomm channel separate form what is being used to talk to LAFB tower
3) In the event of a failure, cell phone/ land line will be secondary backup with TEAMS as a tertiary backup

Training

1) All team members will receive training on the usage and limitations of the communication system.

Operating Limits

1) N/A

Mission Rules

1) Primary and backup communications are required for all UAS crewmembers during BVLOS operations
2) Mobile handheld and VHF radios shall be fully charged at the beginning of the day
3) BVLOS operations will not be performed unless voice communication systems demonstrate reliable operations
4) Clearly identified loss of communications between any crew member shall drive a GCSO PIC to initiate an RTL response
5) RSO shall have direct push to talk VHF comm with LAFB tower as primary and cell phone or land line as secondary

CORRECTIVE ACTIONS IF UNDESIRED EVENT OCCURS

1) Attempt contact using backup communication method(s); if unable
2) Knock off all flight test
3) GCSO PIC initiate RTL

REMARKS/ADDITIONAL INFORMATION

HAZARD number, name, and Post-Mitigation RAC **10: Lithium battery fire [IV-E, RAC]**	☒ Initial ☐ Revision	☒ Systems ☐ Operational	Exposure: ☐ High

UNDESIRED EVENT (RISK):

- Fire caused by lithium battery

CAUSE OF UNDESIRED EVENT:

- UA collision ruptures Lithium Polymer (LiPo) battery, leading to exothermic thermal runaway
- Overcharging LiPo battery
- Improper storage and/or utilization beyond operating temperatures
- Striking/puncturing the LiPo battery
- LiPo battery manufacturing defects
- Battery system short circuits

EFFECT OF UNDESIRED EVENT:

- Severe injury or death to non-participants and/or;
- Significant property damage and/or;
- Damage / loss of UA

CONTROLS/MITIGATIONS

Engineering Design and Reviews

1) Battery managements plans shall be briefed at the airworthiness review board

Validation Testing

1) All batteries must pass 6-month battery capacity test

Safety Interlocks and Protective Devices

1) Vehicle batteries are removed from service if more than 2 years old
2) Battery bags are utilized to mitigate the effects of thermal runaway
3) Battery charger limits will be set to time and/or total charge limits for specific batteries
4) Battery chargers with built in protective systems are used

Software Assurance

1) N/A

Caution/Warning Placards

1) Batteries labeled with tested capacity, voltage and charging and test discharge rate

Procedures

1) All vehicle batteries labeled to indicate date acquired and undergo initial and periodic capacity checks
2) Battery charging start is closely monitored with periodic checks during the charging cycle
3) Inspect batteries for punctures, abnormal expansion or frayed wires prior to use
4) Limit battery charging to 1C rate (60 min to full charge)

Training

1) Flight crew are trained regarding the use of fire extinguishers with respect to the types of fires associated with UAS flight operations
2) Flight crew is trained and familiar with the use, and maintenance of various battery types and various other batteries in use for UAS operations

Operating Limits

1) Ensure battery charger limits appropriate for battery type, number of cell and overall capacity

Mission Rules

1) Dry powder fire extinguisher shall be used for a lithium battery fire
2) All VSC service crews shall have access to dry powder extinguisher

CORRECTIVE ACTIONS IF UNDESIRED EVENT OCCURS

1) Knock off flight operations
2) Notify NASA Langley Fire Department and inform them of fire location
3) If able, without putting someone at risk, fight fire with a dry powder fire extinguisher

REMARKS/ADDITIONAL INFORMATION

1) For additional information on D201 battery management plan (Appendix F)

HAZARD number, name, and Post-Mitigation RAC **11: UA impacts people / structures on the ground, [II-D, RAC 3]**	☒ Initial ☐ Revision	☐ Systems ☒ Operational	Exposure: ☐ High

UNDESIRED EVENT (RISK):

- UAS crashes on or near non-participants / structures on the ground

CAUSE OF UNDESIRED EVENT:

- UAS component(s) failure resulting in uncontrolled descent
- Abort maneuver (Rapid descent/Rapid S2D landing) causes UA to hit people and/ or ground structures
- Complete depletion of battery reserves

EFFECT OF UNDESIRED EVENT:

- Severe injury or death to non-participants and/or;
- Significant property damage

CONTROLS/MITIGATIONS

Engineering Design and Reviews

1) Multilayered failsafe design for command and control redundancy and reliability
2) NASA Langley shall accomplish engineering design reviews and airworthiness reviews to certify vehicle configurations as airworthy

Validation Testing

1) Flights shall be flown under WVLOS and EVLOS conditions before flying under BVLOS conditions
2) COTS vehicles undergo 15-flight checkout series prior to system integration

Safety Interlocks and Protective Devices

1) The PIC shall be provided a method to isolate the primary flight control from the advanced onboard autonomous systems
2) Flights are over low population areas of CERTAIN
3) No Fly or avoidance areas within CERTAIN identified in operational diagram and implemented in ICAROUS

Software Assurance

1) UAS autopilot, Botlink, and 900 MHz radio firmware version maintained under configuration control and a change to firmware may require validation testing before continuing with BVLOS operations

Caution/Warning Placards

Procedures

1) Flight operations shall not commence until the UA has been verified to be functional, operating normally, and in an airworthy state
2) Preflight checks shall verify all connections, mounts and propellers are secure
3) All vehicle batteries are qualified upon acquisition to ensure rated capacity
4) Batteries are requalified every 6 months
5) Vehicle flight times are progressively expanded
6) Recharge data is monitored with maximum margined endurance established (30% battery reserve maintained)

7) Vehicle components and subsystems are thoroughly inspected
8) Envelop expansion flights are performed and rechecked after major configuration testing
9) Maintenance plan – regularly scheduled maintenance and inspection (annual /periodic – 25 flights)
11) The AM, FTM/MC, RSO or GCSO PIC shall identify and announce any UAS deviations from flight planned route.

Training

1) All UAS pilots shall be trained and certified by aircraft type under NASA LaRC UAS Crew Initial/Refresher Training program.
2) Ground Control Station Operator (GCSO) Pilot in Command (PIC) training will include system proficiency checks using simulation (proficiency checks shall include execution/discussion of all abort/emergency procedures).

Operating Limits

1) All general operating limits perscribed in 1710.16 shall be adheared to unless speciffficaly approved by the ARB and ORR

Mission Rules

1) Maximum margined endurance (MME) established for all vehicles to retain 30% battery reserves
2) All vehicle flight paths will be constrained to very low populated areas of NASA LaRC consisting of open fields, woods, and sparsely located small buildings
3) Unexpected/unanticpated vehicle responses shall be treated as system failures leading to an abort

CORRECTIVE ACTIONS IF UNDESIRED EVENT OCCURS

1) Initiate knockoff and clear all flight paths
2) Identify UA location on the ground
3) Recover all airborne UAS

4) Notify VSC of landing location so the vehicle can be safely disarmed and recovered 5) Follow NASA LaRC Mishap Preparedness and Contingency Plan (LMS-OP-0939) 6) If necessary, notify NASA Langley Fire Department and inform them of approximate location 7) If necessary, notify LAFB Tower of the incident and inform them of approximate location
REMARKS/ADDITIONAL INFORMATION

Remote Command and Control Standard Operating Procedure

28 January 2022

Version 1.0

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Head, UAS Operations Office

Appendix F: Battery Management Plan

ASEB UAS LiPO Battery Management Policy

- **All LiPO batteries shall be kept in a LiPO sack and/or Fire Safe when not in use**
  - Do not store LiPO batteries in aircraft
- **LiPO charging**
  - Shall be monitored, especially at start to check settings
  - Periodically monitor charge process
  - Don't deactivate charger safety features
- **LiPO qualification testing**
  - Cycle test every new battery to verify rated capacity
  - Label battery with received date and initial capacity test and a unique identifier
  - Indicate which aircraft the battery is used for
  - Check capacity and label every 6 months
- **Operations**
  - Log recharge numbers in the aircrafts' logbook
  - Store charge batteries if not used for more than a ~week
- **LiPO battery disposal**
  - Expensive aircraft (i.e. Tempest, GL-10): remove from flight after 2 years, not to exceed manufacturers' recommendation
  - Inexpensive aircraft (i.e. Bixler, Y-6): remove from flight after 3 years, not to exceed manufacturers' recommendation
  - Or if battery capacity checks less than 90% rated capacity
  - Or if battery has more than ~200 cycles
  - Only retain very limited number of ground support batteries
  - Electrical tape battery ends for disposal
  - Call NASA battery management to disposal
- **LiPO battery acquisition**
  - Need to carefully plan battery purchasing
  - Avoid bulk battery purchases
  - May not get used before expiration date

1

Appendix G: Historical Spectrum Analysis (Placeholder)

Data analysis ongoing.

NASA/TM–000000

High Density Vertiplex Flight Test Report
Advanced Onboard Automation

Robert, G, Mcswain
Langley Research Center, Hampton, Virginia

September 2022

Appendix I: Scalable Autonomous Operations Simulation Results (Placeholder)

SAO Sim scheduled for Fall/Winter 2022

Appendix J: LSTAR radar detailed specifications

The primary radar system to provide airspace situational awareness to the sUAS team to support BVLOS is the Lightweight Surveillance and Target Acquisition Radar (LSTAR) Q49 V2 developed by SRC, Inc will be one of two radars used for surveillance of the CERTAIN Range and the Langley Monitoring Volume. Its main function is to detect and track GA aircraft to at least five miles at elevations from ~200-2500 feet. For GA traffic traveling at 120 knots, this will provide a two-minute warning before non-participating traffic enter the Core area of the LMV.

The LSTAR V2 radar can detect and track general aviation aircraft and ultra-light aircraft, using a combination of short-range and long-range waveforms. See Figure I-1 for a photograph of the LSTAR radar assembled in a lab. Its operational modes are operator selectable depending on the targets of interest, desired update rates, and/or required detection range.

Table I-1 summarizes the performance specifications for the radar system. In brief, the radar provides continuous, 360 azimuth coverage using a non-rotating, electronically scanned cylindrical phased array antenna, which can also be configured for focused, less than 360 sector coverage. This provides the ability to update designated tracks at increased rates to improve tracking accuracy.

Operating in the L band (1215–1390 MHz), the radar antenna column scans electronically in azimuth using a pair of fixed elevation beams. Both azimuth and elevation mono-pulse angle measurements are used to provide three-dimensional (3D) target coordinates (range, azimuth, and elevation) over an elevation coverage from the Horizon to 30°. The instrumented range of the radar is approximately 21.5NM, and it can be operated using power produced from the traditional AC grid, a generator, or using DC current (24V) drawn from a vehicle.

The radar has a self-test capability and the status of the radar is continually reported on the display, so that the operator can be alerted if the radar becomes non-functional.

During the intended operations at Langley, the LSTAR radar system will be located at an elevation of 95 ft AGL within a protective radome on a platform at the apex of the hangar roof. This will provide an advantageous field of view and minimize obstructions to the radar beam. The radar will be powered by 120VAC facility power and communicate to ground systems through the secure Langley network using ethernet connections through a Windows 10 computer.

A series of field tests of these radars were conducted at Wallops and included a range of vehicles and flight patterns to corroborate the instrumented specification of the radar by ascertaining actual performance (including the detection range, coverage, and minimal detectable velocity). In addition, operational data was gathered on Mean Time Between Failures (MTBF), false alarm rate, dropouts, and track accuracy.

The Spectrum Management Office at NASA Langley has received approval for the use of the LSTAR at the L-band frequency of 1249MHz and a bandwidth of 2.4 MHZ to 2.7 MHz and ensures no interference with FAA and Military ATC surveillance radars. Additionally, further field testing will be conducted to verify that there is no interference between the radar, its display system, the data link from the radar to its display system, and voice/radio communication equipment.

Table 22 - LSTAR Performance Characteristics.

Performance Parameter	**Specification**
Frequency range	1215 – 1390 MHz
Prime power	90 – 260 VAC, 24 VDC, 40 – 400 Hz
Azimuth coverage	0 – 360°
Elevation coverage	Horizon – 30°
Airspeed	7 – 335 Knots
Azimuth detection/Track accuracy	1.25° / 0.8°
Elevation detection/Track accuracy	2° / 1.5°
Range detection/Track accuracy	30m / 25m
Probability of detection (1m^2 target)	85%
Probability of track	94%
Probability of classification	85%
Track false alarm rate	1.0E-05
Track capacity	300
Instrumented range	~41km

Figure 44 - Photograph of LSTAR Radar Assembled in a Lab at NASA LaRC.

Appendix K: GA-9120 radar detailed specifications

In conjunction with the LSTAR, the GA-9120 radar system will be a critical part of the ground surveillance system. The GA-9120 radar panels were acquired during HDV project formulation. Since that time, the LSTAR radar was provided on loan from NASA ARC. At this time the GA-9120s provide complementary radar coverage to the LSTAR. With more project and/or NASA LaRC resources, additional GA-9120s will be procured forming a constellation capable of 360 horizontal field of view coverage. At this time, however, two GA-9120 panels are available at NASA LaRC for testing and evaluation. Both of these units will be mounted on top of the NASA LaRC Gantry at approximately 250 ft AGL. One panel will be aligned in such a way as to partially cover the blind spot of the LSTAR radar that exists for angles greater than 30 degrees above the horizon. Due to the higher operational frequencies, it is anticipated that the GA-9120s can provide redundant sUAS vehicle position information. Both the outputs from the LSTAR and both GA-9120s will be routed to the ROAM UAS Operations center and integrated with the Anra SS CTR Integrated Airspace Display.

The GA-9120 by OWL GroundAware. Inc. is a 3D digital multi-beamforming radar system that will provide both short and long-range drone and GA aircraft detection. The GA9120 combines digital beamforming radar along with a classification intelligence capability situational awareness. Table J-1 shows the GA9120 performance specifications.

The GA9120 radar enables detection and tracking within 15 km and has a 120˚ field of view per panel. At Langley there are two GA-9120 radar panels mounted at an elevation of 250 ft AGL. The radar panels are mounted 90° apart to provide a FOV = 180° AZ @ 0° EL relative to the horizon. This provides a largely unobstructed field of view of the CERTAIN Range and an excellent vantage point for proposed flights. Figure J-2 shows the Radar coverage in relation to their location on the Gantry.

Table 23- GA-9120 Performance Characteristics

Performance Parameter	**Specification**
Frequency range	S-Band 3150-3250MHz (Tunable) BW: 15.6MHz (optimal)
Power	RF Transmitted: 1Kw (60 dbm) Peak AC power required: 200W 110VAC 60Hz
Azimuth coverage (FOV)	120°
Elevation coverage (FOV)	12.5°
Minimum Detectible Velocity	0.25 – 1 mph
Detection Ranges (GA Aircraft)	15 km

Detection Ranges (Drone – DJI Phantom IV)	5 km

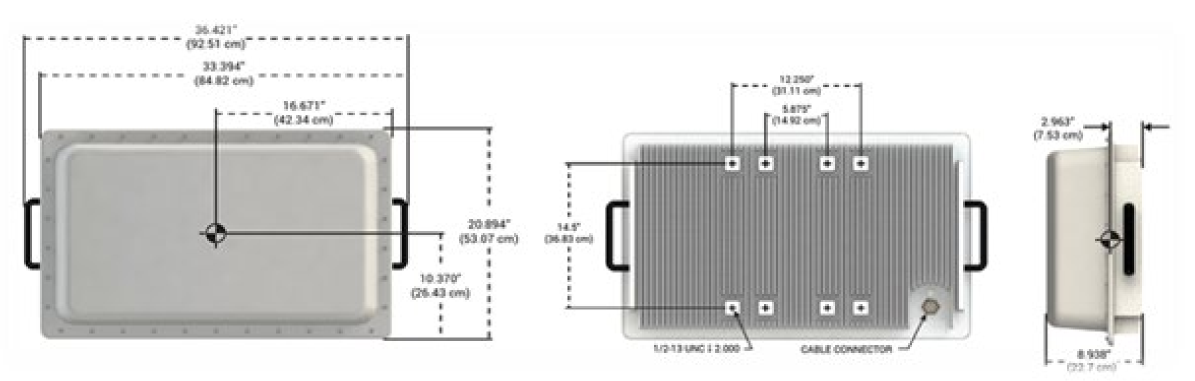

Figure 45 - GA-9120 Panel 3-view with Dimensions.

Figure 46 - Illustration of the GA-9120 Installation Locations with Boresights for Each Panel.

Appendix L: Radar Evaluation Data

Radar performance evaluations are currently underway with the LSTAR radar mounted on top of building 1244 and two GA-9120s mounted on top of the Gantry. A series of flight tests using an LC-40 or an SR-22 are being flown at varying altitudes to evaluate both the GA-9120 and LSTAR radars. The flight tests are also identifying any blind zones, helping to fine-tune radar settings and helping assess the LMV traffic classification criteria that was established to ensure minimum safe separation is maintained. Preliminary results from the second radar evaluation flight flown at 1000' MSL are shown in the figures below. A final radar analysis will be accomplished once all radar performance evaluations are complete.

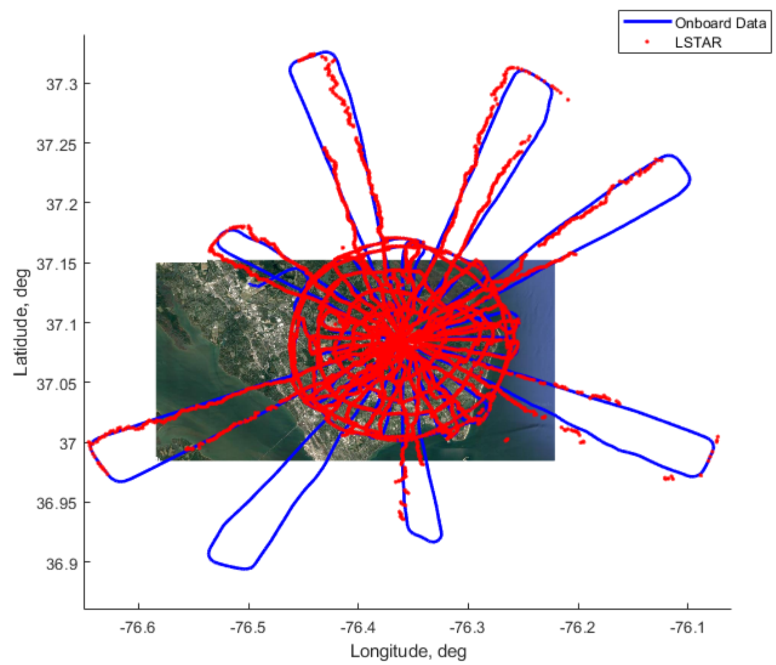

Figure 47 – Lat/Lon Overview of Radar 2 Flight Test and LSTAR Results

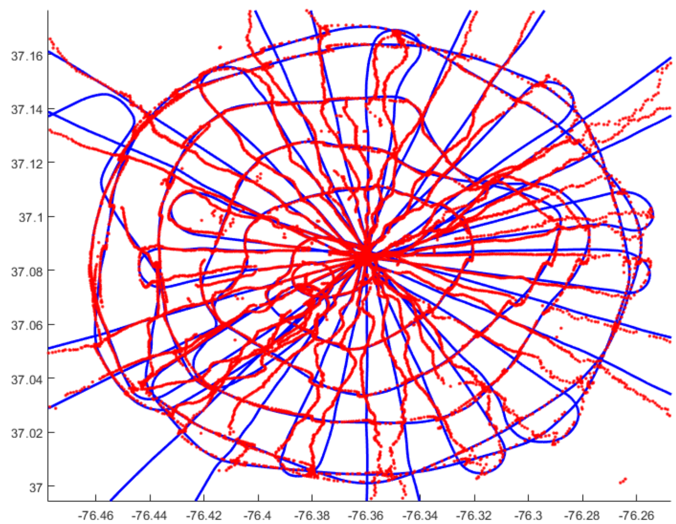

Figure 48 – Zoomed in Lat/Lon Overview of Radar 2 Flight Test and LSTAR Results

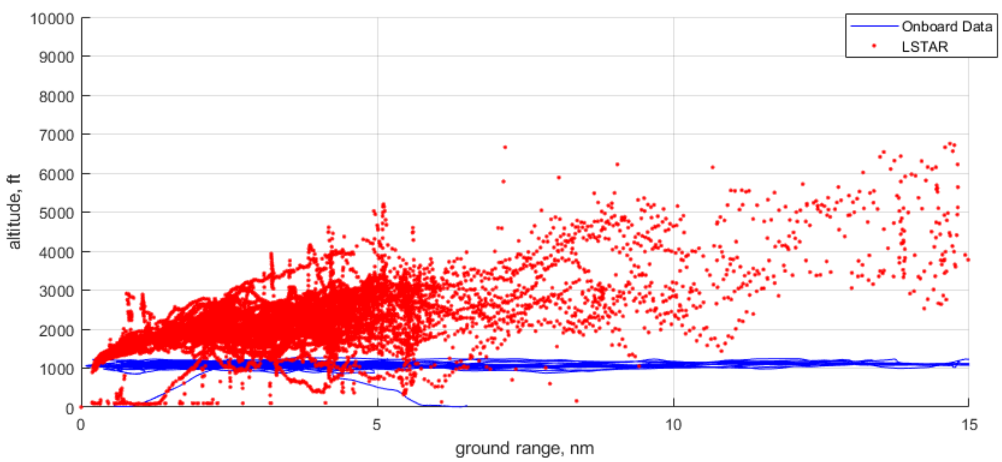

Figure 49 – Vertical Overview of Radar 2 Flight Test and LSTAR Results

Appendix M: ANRA SmartSkies Fusion System

System is still under development. Additional data will be provided when the system is tested and stable.

High Density Vertiplex
Advanced Onboard Automation
Critical Design Review

Advanced Air Mobility Sub-project

January 19, 2022

10/22/2022 Final 1

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