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I am submitting herewith a thesis written by Timothy R. Clark entitled “Evaluation of a Two-way Datalink for Airborne Surveillance of and Communication with a Remotely Operated Aircraft Operating in the National Airspace System.” I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

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(Original signatures are on file with official student records.)

EVALUATION OF A TWO-WAY DATALINK FOR AIRBORNE SURVEILLANCE OF AND COMMUNICATION WITH A REMOTELY OPERATED AIRCRAFT OPERATING IN THE NATIONAL AIRSPACE SYSTEM

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Abstract

The purpose of this study is to examine the use of a two-way digital datalink to implement the airborne surveillance and communication functions with a Remotely Operated Aircraft in the National Airspace System. These Air Traffic Control functions are currently implemented using primary and secondary radar systems for airborne surveillance, and radio transmissions for voice communications.

The present Air Traffic Control system was examined, as well as existing datalink technologies and surveillance and communication equipment. Remotely Operated Aircraft are currently employed almost exclusively by the military, and operational experience in the National Airspace System is very limited. Several key military Remotely Operated Aircraft systems were evaluated, including their operations in the National Airspace System. There are numerous potential uses for commercial Remotely Operated Aircraft operations in the National Airspace System to satisfy varied missions and roles, and the issues associated with large numbers of unmanned aircraft operating in the National Airspace System was investigated. The information used in this study was collected from various published sources, as well as from a number of interviews with knowledgeable persons in the Remotely Operated Aircraft industry and the Federal Aviation Administration.

Remotely Operated Aircraft have been established as viable military platforms, and a variety of civilian missions are under consideration to extend their demonstrated usefulness. As civilian Remotely Operated Aircraft system designs and concepts of operation are refined, many cost-effective applications have been identified for using Remotely Operated Aircraft in new roles or in roles currently being performed by manned aircraft. Large numbers of Remotely Operated Aircraft are expected to be operated in the National Airspace System in the future, and the Air Traffic Control system must be able to accommodate their unique needs and facilitate the safe and efficient operation of Remotely Operated Aircraft in the National Airspace System.

Two-way digital datalink technology has significant potential for use in implementing the airborne surveillance and communication functions with Remotely Operated Aircraft in the National Airspace System. A datalink-based Air Traffic Control system provides more accurate and comprehensive time-critical surveillance information to the air traffic controller, and facilitates more efficient communications of large amounts of useful information between the air traffic controller and Remotely Operated Aircraft remote operator. It is recommended that two-way digital datalink technology should be pursued for implementing the airborne surveillance and communication functions with a Remotely Operated Aircraft in the National Airspace System. Although this technology has many key benefits, there are several important operational, safety and security issues that must be addressed before the system can be fully implemented in the National Airspace System.

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List of Acronyms and Abbreviations

ADS-B	Automatic Dependent Surveillance – Broadcast
AGL	Above Ground Level
ARSA	Airport Radar Service Area
ATA	Airport Traffic Area
ATC	Air Traffic Control
BLOS	Beyond Line of Sight
CNS	Communication, Navigation and Surveillance
COA	Certificate of Authorization
FAR	Federal Aviation Regulation
FL	Flight Level
FLIR	Forward-Looking Infrared
ft	Feet
GPS	Global Positioning System
HAE	High Altitude-Endurance
IFR	Instrument Flight Rules
ISR	Intelligence, Surveillance and Reconnaissance
lbs	Pounds
LOS	Line of Sight
LRE	Launch and Recovery Element
MAE	Medium Altitude-Endurance
MCE	Mission Control Element
MSL	Mean Sea Level
NAS	National Airspace System
NM	Nautical Mile
PCA	Positive Control Area
RF	Radio Frequency
ROA	Remotely Operated Aircraft
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communications
TCA	Terminal Control Area
TCAS	Traffic-alert and Collision Avoidance System
TCS	Tactical Control Station
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
VDL	VHF Datalink
VFR	Visual Flight Rules
VHF	Very High Frequency

1.0 NATIONAL AIRSPACE SYSTEM

1.1 AIRBORNE SURVEILLANCE FUNCTIONAL REQUIREMENT

The Air Traffic Control (ATC) system performs a number of different functions to ensure the safe and efficient operation of aircraft in the National Airspace System (NAS). One of these critical functions is the airborne surveillance of manned and unmanned aircraft operating within the NAS. Airborne surveillance involves initially acquiring an aircraft, positively identifying it, and establishing a position track on it. The positive identification and tracking of each aircraft must be maintained continuously from takeoff until landing in controlled airspace. This information is used to ensure all aircraft are safely separated from one another and from airborne hazards such as weather, and to allow each aircraft access to desired routes or airspace to complete their missions as efficiently as possible.

1.2 AIRBORNE COMMUNICATION FUNCTIONAL REQUIREMENT

A second critical function performed by the ATC system to ensure safe and efficient operations in the NAS is maintaining communication with airborne manned and unmanned aircraft. Airborne communication involves establishing an informational link with the aircraft prior to takeoff, and continuously maintaining that link while operating in the NAS until the aircraft lands. The purpose of maintaining communications with aircraft operating in the NAS is to enable two-way exchanges of information between the pilot (or remote operator) and ground-based controller. The information communicated to and from the airborne aircraft may include inquiries, statuses, data or requests and directives. Acceptable forms of communication with the aircraft include verbal and non-verbal exchanges of information with the pilot or remote operator in control of the aircraft.

1.3 CURRENT NAS AIRBORNE SURVEILLANCE SYSTEM

The airborne surveillance function is currently implemented in the ATC system using three methods.[1] The first and most basic method relies on the pilot to report when the aircraft is over a specified ground location when not in radar contact. This allows the air traffic controller to

establish the aircraft's position when not in radar contact. The other two methods involve the use of ground-based radar equipment to acquire and continuously track an aircraft. In the first radar-based method, the radar return from the airborne aircraft is used to establish its position and flight parameters. This method is referred to as primary radar. The effectiveness of primary radar is dependant upon a number of parameters such as the performance characteristics of the radar equipment, transmitted energy levels, distance from ground radar system to the aircraft, proportion of radar energy reflected by the aircraft, and environmental considerations. In general, the accuracy and effectiveness of primary radar in determining the position of an aircraft and maintaining a continuous track diminishes as the distance to the aircraft increases.

The second radar-based method of implementing the airborne surveillance function involves the use of a transponder system installed in the aircraft. This is referred to as secondary radar. In this method, a signal transmitted from the aircraft is received on the ground. This signal may include a variety of aircraft information including the aircraft's identification, position, altitude, airspeed, and flight route information. The secondary radar system that is currently in widespread use is the "Mode-C" transponder. The Mode-C transponder signal includes aircraft identification and altitude information. The transponder normally transmits its signal only when it is interrogated by the ground surveillance radar system. This Mode-C signal is used in conjunction with the primary radar information to implement the airborne surveillance function.

A third method for implementing the airborne surveillance function under development is use of a digital datalink to transmit aircraft information to a ground receiving site for ATC use. The information required by the ATC facility to perform the airborne surveillance function must be generated by the aircraft, encoded into the datalink signal, and transmitted. An example of this technology is Automatic Dependant Surveillance – Broadcast (ADS-B), which was successfully demonstrated on a limited scale during the Safe Flight 21 program[2]. The ADS-B system uses equipment installed in an aircraft to automatically transmit its position and other critical data to receivers located on the ground or in other aircraft. ADS-B transmitted information typically includes the aircraft's identification, position, altitude, airspeed and whether the aircraft is

climbing, descending or turning. In the ADS-B demonstration, aircraft equipped with the equipment were able to be effectively tracked and separated from other traffic without the use of primary or secondary radar airborne surveillance systems. The ADS-B system is discussed in more detail in section 4.2.

1.4 CURRENT NAS AIRBORNE COMMUNICATION SYSTEM

The airborne communication function is currently implemented in the ATC system using two primary methods. The first and most common method is to exchange verbal information using a two-way radio link. This method is referred to as voice radio communications. The second method is to exchange non-verbal information using a one-way or two-way digital datalink. This method is referred to as datalink communications, and is not currently widely used in the NAS for airborne communications. These two methods for airborne communication within the NAS are discussed in the following paragraphs.

1.4.1 Voice Radio Communications

Voice radio communications uses a radio frequency (RF) link between the aircraft and the ground controller to relay voice communications. The verbal information is transmitted between ground-based and aircraft antennas. The RF link is commonly established in the VHF or UHF frequency bands for direct line-of-sight (LOS) applications. The link may also be established via a relaying satellite for beyond line-of-sight (BLOS) over the horizon applications using satellite communication (SATCOM) technology. Voice radio communications links use relatively narrow bandwidth signals to carry analog or digital voice data between the ground controller and the aircraft. The effectiveness of this communication method is dependant upon a number of parameters such as the RF frequency band, performance characteristics of the ground and aircraft equipment (primarily transmitters, receivers, and antennas), transmitted power levels, distance between the transmitting/receiving sites, and environmental conditions. For SATCOM communication links, the effectiveness may also be susceptible to interference and high message

volume. In general, both LOS and BLOS radio communications links are very effective for relaying voice information between an aircraft and a ground controller.

1.4.2 Digital Datalink Communications

Datalink communications use a RF link between the aircraft and ground controller to relay a variety of digital data that may also include voice communications. The digital information is also transmitted between ground-based and aircraft antennas using LOS and BLOS RF links. Datalink communications links typically use larger bandwidth signals to carry encoded digital data between the ground controller and the aircraft. The effectiveness of this communication method is dependant upon the same parameters identified in paragraph 1.4.1 for voice radio communications. In general, both LOS and BLOS digital datalink communications links are effective in relaying very large amounts of information between an aircraft and a ground controller, with minimal demonstrated system errors.

1.5 CURRENT AIRSPACE CLASSIFICATIONS AND REQUIREMENTS

The NAS is divided into six classes of airspace[1]. In each of these classes, specific operating rules have been established for all aircraft flying in them. The airspace categories are Class A, B, C, D, E and G, with the extent of restrictions associated with each class of airspace ranging from Class A being the most restrictive to Class G having the least operating restrictions. Each of these airspace classes is discussed in the following paragraphs. The NAS airspace classifications are depicted in figure 1-1.

1.5.1 Class A Airspace

Class A airspace includes all areas over the 48 contiguous states and Alaska, and extends from 18,000 ft MSL (Flight Level 180) to Flight Level (FL) 600. This airspace is also referred to as the positive control area (PCA). Federal Aviation Regulation (FAR) 91.135 requires that every aircraft operating in Class A airspace must operate under Instrument Flight Rules (IFR) and receive a clearance from ATC. In addition, the pilot must be rated for instrument flight, the aircraft must be operated on a route and at an altitude assigned by ATC, and all aircraft must be

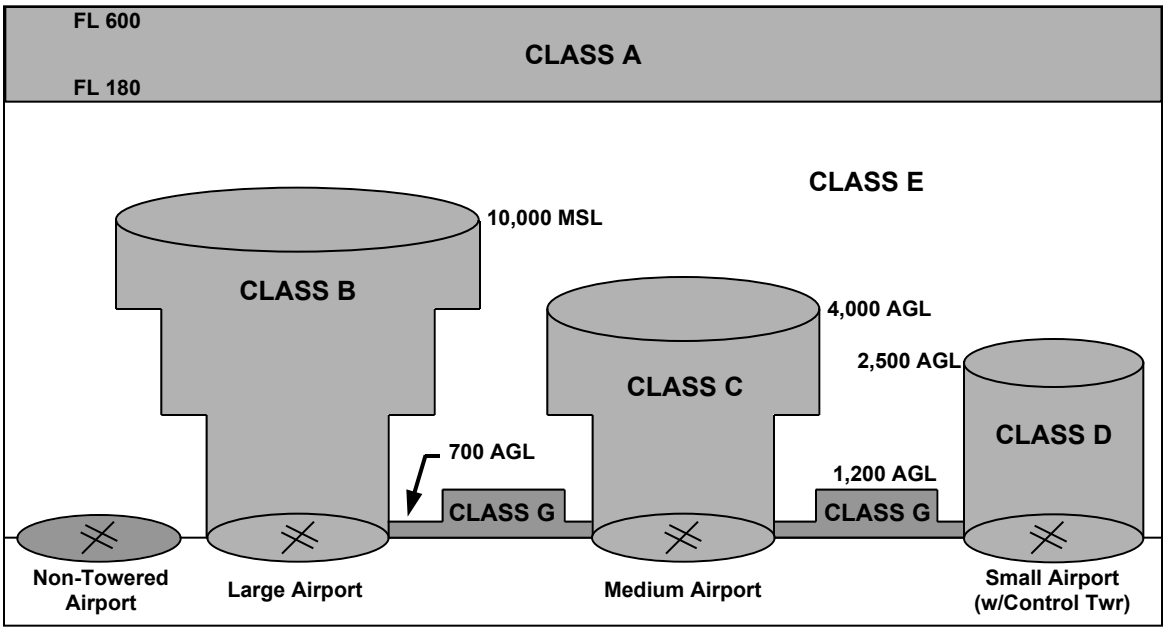


Figure 1-1. NAS Airspace Classifications[1]

equipped as specified in FAR 91.215. In the Class A PCA, air traffic controllers ensure the positive separation of all aircraft.

1.5.2 Class B Airspace

Class B airspace includes areas surrounding large airports, and extends from the surface to 10,00 ft MSL. This airspace is also referred to as a terminal control area (TCA). The configuration of each Class B airspace area is individually tailored and consists of a surface area and two or more layers designed to contain all published instrument procedures associated with the airport. An ATC clearance is required for all aircraft operating in the area, and all aircraft receive separation services from air traffic controllers. Aircraft may operate in Class B airspace under both IFR and Visual Flight Rules (VFR), and aircraft can be operated by non instrument-rated pilots including pilots with a student certificate. Aircraft must be equipped with appropriate communication and navigation equipment including a two-way radio, VOR or TACAN navigation

capability and a Mode-C transponder. Exceptions to these requirements may be granted by ATC on an individual basis.

1.5.3 Class C Airspace

Class C airspace includes areas surrounding medium-sized airports that do not qualify for a TCA. Class C airspace evolved from airport radar service areas (ARSA). Class C airspace areas are individually tailored and extend from the surface or an intermediate altitude up to approximately 4,000 ft AGL. Both IFR and VFR aircraft may operate in Class C airspace, but must establish communications with the specified air traffic control facility prior to entering. Aircraft must also be equipped with an operable Mode-C transponder.

1.5.4 Class D Airspace

Class D airspace includes areas surrounding small airports with an operational control tower, and is also referred to as an airport traffic area (ATA). The areas are individually tailored, and include airspace extending from the surface to 2,500 ft AGL. Both IFR and VFR aircraft may operate in Class D airspace. Pilots are required to establish two-way radio communications with the air traffic control tower prior to entry. At airports where the control tower does not operate 24 hours a day, the airspace reverts to Class E or G rules when the tower is closed.

1.5.5 Class E Airspace

Class E airspace is controlled airspace that has not been otherwise designated. Class E airspace generally has no defined vertical limit, but rather it extends upward to the overlying or adjacent controlled airspace. Both IFR and VFR operations are permitted in the airspace, but only IFR aircraft are required to maintain radio communications with the ATC authority.

1.5.6 Class G Airspace

Class G is uncontrolled airspace within which ATC separation services are not provided to any aircraft. Most Class G airspace is located away from major airports below 1,200 ft AGL, or below 700 ft AGL in the vicinity of certain airports. Both IFR and VFR operations are permitted in the airspace.

1.5.7 Special Use Airspace

Special use airspace is designed to accommodate unique aircraft operations or to restrict or entirely prohibit flight within the specified area. Special use airspace includes prohibited areas, restricted areas, warning areas, military operations areas, alert areas, controlled firing areas, national security areas and temporary flight restriction areas. Some special use airspace areas are in effect 24 hours a day, whereas others operate temporarily or part-time and are available for normal flight operations when they are not active.

2.0 REMOTELY OPERATED AIRCRAFT

2.1 REMOTELY OPERATED AIRCRAFT MISSIONS AND ROLES

Remotely Operated Aircraft (ROA), also referred to as Unmanned Aerial Vehicles, are becoming increasingly common in a variety of roles. Missions that employ ROA include both military and civilian applications. Military and civilian missions and roles for ROA are discussed in the following paragraphs.

2.1.1 Military ROA Operations

ROA have traditionally been utilized almost exclusively by the military in an intelligence, reconnaissance and surveillance (ISR) role. Military ROA have recently expanded their roles to include tactical strike missions. Within the NAS, military ROA are currently operated primarily in a test and demonstration role. These ROA are normally based from military airfields, and operate in special use airspace or within very restricted and defined profiles in Class A and Class E airspace. In addition to ISR and tactical strike, a number of other roles are being explored and developed for military ROA. These roles include battlespace management, real-time targeting and bomb damage assessment, area missile defense, communications relay, suppression of enemy air defenses, mine countermeasures, counter drug operations, search and rescue, nuclear, biological and chemical weapons detection sampling and psychological operations.[3] Military flight operations associated with these expanded roles may extend beyond merely testing and demonstrating the ROA, and have the potential for long-term operational activities within the NAS. In particular, the recent domestic terrorism incidents on 11 September 2001 have raised the possibility of extensive military ROA operations in the NAS to monitor and defend domestic locations. Domestic locations that might require long-term support from military ROA operating in the NAS include major cities or high-value assets such as military or Government installations, power plants, bridges or dams, ports, airports or stadiums.

2.1.2 Civilian ROA Operations

In addition to military considerations, civilian ROA supporting both research and commercial activities have been proposed for a wide variety of future support roles. These roles include communications relay, environmental surveillance and monitoring (of weather, traffic, wildlife, plants, natural resources or natural disasters), law enforcement, firefighting, and other mapping and sensing functions.[4] Civilian ROA will likely be based from non-military airfields, and may require the ability to operate in all airspace categories.

The varied missions and roles of future military and civilian ROA will require many different types of ROA. These ROA will operate over a wide range of mission parameters, including altitudes, airspeed, time on station, and range. ROA will become much more commonplace in the NAS, and be required to operate efficiently and safely among manned aircraft with a minimum of restrictions.

2.2 ROA OPERATIONAL ELEMENTS

The use of military or civilian ROA in the NAS has several unique operating elements that must be considered when compared to typical general aviation, corporate or commercial passenger and cargo aircraft. A number of issues are related to the fact that no human operator is onboard the aircraft. The human operator that is responsible for monitoring and actively controlling the ROA is located at a remote ground location. The characteristic flight profiles that ROA need to fly due to their unique mission requirements also presents a number of operational issues. Potential safety issues with unmanned aircraft operating in proximity to manned and other unmanned aircraft must also be considered. Relevant operational elements that must be taken into account to conduct safe and efficient large-scale ROA operations within the NAS are discussed in the following paragraphs.

2.2.1 See And Avoid

The first ROA operating element that must be considered is the inability of the remote operator of an ROA to effectively “see and avoid” potentially conflicting aircraft or other hazards

while operating within the NAS. The ability to detect and avoid other traffic is a fundamental requirement for any aircraft operating under VFR. ROA are more likely to operate under IFR. While operating IFR in Class E airspace, the ROA must be able to detect and avoid VFR aircraft. Under current FAR rules, the ability to see and avoid is not specifically required while operating in a Class A airspace PCA. In a PCA, all aircraft must operate under IFR and are separated from one another by ATC. Even when not required for a particular airspace and operating categories, the ability to effectively see and avoid airborne traffic or other hazards provides an additional measure of safety.

The ROA operator has no direct way to visually detect hazards and subsequently implement appropriate actions to correct an undesirable situation such as a midair collision or flight through severe weather. A coalition of government, university and industry researchers recently demonstrated the ability to effectively detect and avoid other traffic on a Scaled Composites Proteus ROA[5]. The demonstration used technology similar to Traffic-alert Collision Avoidance System (TCAS) as well as passive sensors on the host vehicle to detect the approaching traffic so that the remote operator was able to maneuver the ROA away from a collision course. The primary sensor used in the Proteus flight test was the Goodrich Skywatch HP traffic advisory system. This system is also being integrated onto the General Atomics Predator-B ROA for a future capability demonstration[6].

In general, ROA need to be able to employ both “cooperative” and “non-cooperative” means to detect and image other aircraft to operate effectively in the NAS. Cooperative means requires the use of active systems on both the ROA and the other aircraft. Examples of cooperative technologies are TCAS and Automatic Dependent Surveillance- Broadcast (ADS-B). Non-cooperative means requires the ROA to be equipped with sensors capable of detecting and determining the location of the other aircraft, with no dedicated equipment required on the other aircraft. Examples of sensors providing a non-cooperative means of detection include radar or infrared systems to image aircraft not equipped with a transponder or ADS-B system. One issue

with using the vehicles onboard sensors is ensuring the systems have sufficient scan volume to detect traffic that may be approaching the ROA from above, below, either side or from behind.

2.2.2 Mission Profiles

A second ROA operating element to consider is the mission profiles typically flown by an ROA and the airspace required for that profile. Depending on their mission requirements and specific operational roles, ROA will employ a variety of flight profiles and mission "on-station" times with a wide range of corresponding airspace usage. Mission profiles include "racetrack" or "point-to-point" type routes that may cover small or very large geographic areas. Missions may be constrained to a single or very narrow span of altitudes, or may cover a wide range of altitudes throughout the mission. Certain ROA missions may have corresponding flight profiles that would require IFR operations in Class E airspace where VFR traffic is congested. Other missions may involve flight through Class B, C or D airspace around airports. Most ROA mission profiles will be able to operate IFR in a Class A PCA above FL 180.

ROA currently operate in the NAS either in restricted areas, or must use an exclusive "block" of airspace assigned by the air traffic controller. This block includes a specific altitude or range of altitudes and designated geographic operating boundaries. No other aircraft are allowed to enter this assigned block of airspace. ROA operating in Class E and in some cases Class A airspace are frequently accompanied by a manned safety chase aircraft to provide direct communications with ATC and to maintain a visual traffic lookout. As military and especially civilian ROA proliferate within the NAS, this inefficient exclusive use of airspace and restrictive procedural requirements will not be practicable. In addition, many of the missions and roles being considered for ROA in the NAS will involve long-duration flights, and will require flexible airspace assignments to accommodate real-time changes in flight profiles and operating parameters.

2.2.3 Remote Operator

Another unique operating element is that an ROA has no onboard pilot in control of the aircraft. The remote operator is not in "direct" control of the aircraft, and may not be able to

quickly and effectively modify the vehicles flight parameters or communicate with an air traffic controller or other aircraft. In addition, the remote operator must be sufficiently qualified and trained to fly the vehicle and to interface with the ATC system. These elements are critical to maintaining the safety and efficiency of ROA in the NAS, and are discussed in the following paragraphs.

2.2.3.1 Vehicle Command and Control

The operating procedures and protocols for aircraft flying in the NAS presume that the pilot in control of the aircraft can take rapid and decisive action either independently, or as directed by the controller to maintain the safety of that aircraft within the system. In an ROA, the pilot in control is remotely located, and is only able to receive vehicle status and ATC information via the system's command and control datalink. The time it takes the remote operator to receive vehicle status and ATC information delays the initiation of an appropriate vehicle response. In the Global Hawk ROA described in section 2.3.2, the one-way delay in the LOS datalink is approximately one to three seconds, while the one-way delay for the UHF SATCOM datalink ranges from two to four seconds[7].

Once the remote operator receives the vehicle status or ATC information, the vehicle response must be initiated. In most ROA systems including Global Hawk, the remote operator does not directly manipulate the vehicle's flight controls, but rather interfaces with the vehicle's autopilot. The vehicle's onboard computer guidance systems calculate appropriate flight control inputs. If the remote operator receives an ATC request to modify a particular flight parameter, the operator must indirectly complete the action by re-programming the autopilot or modifying the current mission data rather than simply moving a flight control. In the Global Hawk system, the operator must take "override" control of the vehicle and reprogram the desired parameter.[7] For simple modifications such as altitude changes, it requires 3-5 seconds to reprogram the parameter. For a more complicated modification such as heading or ground track changes, it may require 10 seconds or more to updated the autopilot or mission data. The one-way datalink delay is then encountered again as the commands are uplinked to the ROA. The operational and

flight safety impacts resulting from the total delay in ROA vehicle response must be considered during situations involving vehicle system failures or airborne traffic conflicts.

2.2.3.2 Vehicle Communications

The operating procedures and protocols for aircraft flying in the NAS also presume that the pilot in control of the aircraft can readily communicate with the air traffic controller and other aircraft. For an ROA, the remote operator is "indirectly" linked to the aircraft and to communications with the air traffic controller or other aircraft. If it becomes necessary for the air traffic controller to confirm or modify the ROA flight parameters, or if the remote operator desires to change the ROA's current flight parameters (due to mission considerations or vehicle problems), the air traffic controller and ROA remote operator must communicate via an indirect method. Any delay in communications between the air traffic controller and the ROA remote operator will result in increased response times.

2.2.3.3 Operator Qualification and Training

To operate an ROA in the NAS, the FAA requires a Certificate of Authorization (COA). The COA specifies required operating procedures and conditions, including pilot qualifications. Current COAs being issued by the FAA require an instrument-rated pilot to be in control of an ROA while operating in the NAS.[8] There are no additional ROA-specific training, currency or experience requirements for the remote operator. An instrument-rated pilot will have completed substantial training and certification activities, and will have a general knowledge and understanding of ATC procedures and protocols. This general background of knowledge is necessary to safely and efficiently operate in the NAS without adversely impacting the ATC system or other aircraft.

2.2.4 System Design and Installed Equipment

A final ROA operating element that must be considered is the ROA overall system design features and installed equipment. To function effectively in the NAS, FAA functional and

regulatory requirements must be incorporated into the ROA system. These considerations are discussed in the following paragraphs.

2.2.4.1 ROA Design Requirements

The key requirement is high reliability, which requires double or triple redundancy on critical vehicle systems and no single-point failure modes. These features are not typically found to a large extent on a military ROA due to the increased cost and complexity. An ROA that is intended to operate in the NAS substantially outside of restricted airspace must be specifically designed with a very high level of reliability to be able to meet FAA design and certification requirements. The FAA's final certification requirements for ROA may in fact exceed the reliability and redundancy requirements currently specified for manned aircraft due to uncertainties and conservatism with this new class of aircraft. The ROA will also have to be designed to respond to system degradations and failures with an acceptable, non-catastrophic response. For example, the loss of the datalink to the ground controller must result in a controlled and safe autonomous recovery at an acceptable location.

2.2.4.2 ROA Equipment Requirements

ROA are also relatively sensitive to avionics weight, volume, thermal (cooling) and electrical requirements. ROA typically do not have a large margin to accommodate additional communication, navigation and surveillance (CNS) equipment that may be required to operate within the NAS. Any additional equipment the ROA is required to carry must be interoperable with all of the types and classes of unmanned aircraft. These types and classes range from small, tactical or regional systems with short endurances and a limited ability to accommodate CNS avionics to large, strategic or broad-area systems with long endurances and extensive avionics support capability.

2.3 REMOTELY OPERATED AIRCRAFT SYSTEMS

Two ROA systems that are currently operated by the military are discussed in the following paragraphs. These include the RQ-1 Predator, which is representative of current

medium altitude-endurance (MAE) vehicles, and the RQ-4A Global Hawk, which is representative of current high altitude-endurance (HAE) vehicles.

2.3.1 RQ-1 Predator ROA

The General Atomics Predator-A is a propeller-driven medium-altitude, medium endurance vehicle with a published range of 400 NM and endurance of 24 hours, and operating altitude of 25,000 ft. The RQ-1A Predator aircraft is shown in figure 2-1. The vehicle is 27 ft long, has a wingspan of 49 ft and can carry up to 450 lbs of payload. Payloads include synthetic aperture radar (SAR), electro-optical sensors and a forward-looking infrared (FLIR) sensor. It is equipped with both a LOS datalink and a BLOS SATCOM datalink.

The Predator-A was designed for military use only, and has a number of single-point failures and inadequate reliability that precludes its effective transition to a commercial platform with extensive operations in the NAS.[6] A follow-on Predator-B version is under development in response to increased military mission requirements and potential civil missions. The RQ-1B Predator-B aircraft, shown in figure 2-2, is prop-jet powered and has 50% more payload capacity, higher operating speeds, and an operating ceiling of 45,000 ft. The B-model has been designed with no single-point failures and with a much higher reliability rating and is intended to meet FAA certification requirements.

2.3.1.1 Predator Command and Control System

The Predator uses a multi-ROA, multi-payload control common ground station manufactured by General Atomics[9]. It uses a C-band LOS datalink for direct control of the aircraft and passing of real-time payload data at ranges up to 150 NM. In addition, a Ku-band satellite datalink allows for over-the-horizon operations. The ground control station can be configured as a vehicle-mounted or mobile system for tactical use on the battlefield or at sea, respectively. The Predator ground station operators console is shown in figure 2-3.



Figure 2-1. RQ-1A Predator Aircraft



Figure 2-2. RQ-1B Predator-B Aircraft



Figure 2-3. Predator Ground Control Station

The ground station embeds the vehicle's UHF/VHF radio communications into both the LOS and BLOS datalinks, enabling the remote operator to effectively maintain radio communications with the other aircraft or ground stations in the vicinity of the aircraft.

2.3.2 RQ-4A Global Hawk ROA

The Northrop-Grumman Global Hawk is a jet-powered high-altitude, long-endurance vehicle with a published range of 13,500 NM, endurance of 36 hours and operating altitude of 65,000 ft. The vehicle is 44 ft long, has a wingspan of 116 ft and a gross takeoff weight of 25,600 lbs. The RQ-4A Global Hawk aircraft is shown in figure 2-4. It can carry up to 2,000 lbs of payload, including high-resolution SAR with a moving target indicator mode, electro-optical sensors and infrared sensors. Global Hawk is equipped with both a wide bandwidth LOS datalink and two BLOS SATCOM datalinks. The BLOS datalinks include a Ku-band wide-bandwidth system and a UHF-band narrow bandwidth Common Data Link System. All three datalinks are used for command and control of the vehicle. In addition, the wide bandwidth LOS and Ku-band BLOS datalinks embed voice radio communications into the link, enabling the local air traffic controller to maintain LOS communications with the vehicle that are then linked back to the remote ground controller via the datalink.



Figure 2-4. RQ-4A Global Hawk Aircraft

The Global Hawk ground control segment consist of two elements, the launch and recovery element (LRE) and the mission control element (MCE).[10] The LRE uses the LOS datalink, and must be co-located with the aircraft at its operating base. The MCE communicates with the aircraft and LRE through the SATCOM datalinks, and can be located anywhere in the world.

2.3.2.1 Global Hawk Launch Recovery Element

The LRE is used to launch and recover the Global Hawk. It verifies the health and status of the various subsystems aboard the vehicle, receives the mission plan from the MCE and loads it into the aircraft. During launch and recover, the LRE is responsible for air vehicle management, coordination with local and en route traffic control facilities, and hand-off of the aircraft to the MCE

once airborne. The takeoff and landing sequence is automatically executed with assistance from differential Global Positioning System (GPS) inputs.

2.3.2.2 Global Hawk Mission Control Element

The MCE provides for management of the aircraft and its sensors. The MCE is operated by four persons, responsible for the command and control, mission planning, imagery quality control, and communications functions of the system. The MCE has the ability to control up to three Global Hawks simultaneously and disseminate near real-time information anywhere in the world. The operator of the MCE does not directly interface with the vehicle's flight controls. If changes are required to the preplanned mission data currently being executed, the updates are uplinked to the vehicle, and the vehicle determines the appropriate flight control commands to execute the updated mission route.

2.4 ROA GROUND STATION SYSTEMS

There are several different types of ROA ground stations either in use or in development. All are from military or Government research ROA systems, as the civilian ROA currently under discussion have not evolved beyond their military roots. For this discussion, ROA ground station types are divided into two categories: tactical systems for short-range ROA, and strategic systems for long-range ROA. These two general types are discussed below, followed by a specific discussion of the joint military Tactical Control Station (TCS), which is currently in development to support a broad range of current and future Army, Air Force and Navy/Marine Corps ROA.

2.4.1 Tactical Ground Control Stations

Tactical ground control stations support short-to-medium range ROA in a confined tactical environment. They generally rely primarily on LOS datalinks to the ROA, although some may also feature a BLOS SATCOM datalink for limited over-the-horizon operations. Tactical ground control stations tend to provide the operator with a higher degree of real-time authority over the ROA including the ability to manually "fly" the vehicle. Although many tasks and the

even the mission route may be automated, this type of ground control station typically requires the operator to exercise more manual oversight and control of the ROA.

2.4.2 Strategic Ground Control Stations

Strategic ground control stations support medium-to-long endurance ROA in a regional or trans-regional environment. They generally rely primarily on BLOS SATCOM datalinks to the ROA for extensive over-the-horizon operations, although most also feature a LOS datalink for the limited local operations such as takeoffs and recoveries. Strategic ground control stations tend to automate most vehicle activities, and provide the operator with limited real-time authority over the ROA. The mission route and most flight/payload activities are pre-planned and executed autonomously during the mission. The operator will typically have the ability to make real-time modifications to the pre-planned route and mission tasks, but has no capability to manipulate the flight controls and manually “fly” the vehicle.

2.4.3 Tactical Control System

The TCS is an ROA ground control station under development by Raytheon and the Joint Forces Command. It is designed to provide the military services with a single ground station for the command and control of a range of present and future tactical and medium range ROA and their payloads. In addition, TCS can also be used for data processing, export and dissemination to designated command, control, communication, computers and intelligence systems. TCS provides for five levels of interaction with a particular ROA. Level 1 is the indirect receipt and direct retransmission of imagery or data. Level 2 is the receipt of imagery or data directly from the ROA plus the functionality of Level 1. Level 3 is the control of the ROA payload plus the functionality of the previous levels. Level 4 is the control of the ROA, less takeoff and landing, plus the functionality of the previous levels. Level 5 is the full functionality and control of the ROA from takeoff to landing.

The TCS contains four high-resolution computer screens that show terrain data in the vicinity of the operating vehicle, a forward view of the vehicle’s flight, and what the sensors are

viewing. The remote operator pilot occupies the left seat, and can switch between several vehicles under the station's control. The payload operator occupies the right seat and controls the sensors installed in the vehicles. The TCS operators console is shown in figure 2-5.



Figure 2-5. Tactical Control Station Operators Station

3.0 CURRENT ROA-NAS INTEGRATION

3.1 CURRENT ROA AIRBORNE SURVEILLANCE IMPLEMENTATIONS

To operate in the NAS, ROA are required to be equipped for airborne surveillance the same as manned aircraft. The equipment required depends on the airspace category and flight rules under which the ROA will be operating. The following paragraphs describe the current ROA airborne surveillance implementations in the applicable airspace categories and flight rules. The descriptions are for military ROA that are currently in operational use and have significant flight experience in the NAS.

3.1.1 Restricted Airspace

While operating in restricted special-use airspace, ROA are subject to the military authorities and Using Agencies responsible for the area. ROA operating from military facilities within restricted airspace normally are equipped with transponder equipment to facilitate secondary radar ground surveillance tracking. The Using Agency controls and deconflicts all aircraft operating in the restricted airspace.

One procedure widely used by military ROA staging from military facilities inside of restricted airspace is to take off from the military field, climb above FL 180 in the restricted area, then depart the restricted area and enter the Class A PCA[8]. In the example of Global Hawk, the aircraft normally climbs to above FL 450 before departing to minimize the potential for conflicts with other IFR traffic. Global Hawk is then tracked using its transponder and separated from other traffic using normal ATC procedures. In the example of Predator, the aircraft takes off and climbs in the restricted airspace, then is joined by a chase aircraft before leaving the restricted area and entering the Class A or E controlled airspace.

3.1.2 Class E Airspace / Visual Flight Rules

Class E airspace extends from 1,200 ft AGL to FL 180, and includes both IFR and VFR traffic. To operate in Class E airspace under VFR, aircraft are not required to be equipped with any transponder equipment, but must be able to “see and avoid” any other traffic. No ROA are

currently operated under VFR in Class E airspace. ROA operating under IFR in Class E airspace are equipped with a transponder, and are normally escorted by manned aircraft to maintain a "see and avoid" capability. The manned aircraft is able to detect and identify any conflicting traffic, and is in communication with both the air traffic controller and the remote operator of the ROA.

3.1.3 Positive Controlled Airspace / Instrument Flight Rules

The Class A PCA extends from FL 180 to FL 600, and includes only IFR operations. In the PCA, all aircraft must be equipped with an altitude-encoded Mode-C transponder, and are positively tracked and separated by ATC. Depending upon the requirements of the ROA's COA, it may operate like any other manned traffic, or it may require a chase aircraft. Aircraft in the PCA are not required to detect other traffic, although that is generally regarded as an effective and assumed safety backup to positive ATC control.

3.2 CURRENT ROA AIRBORNE COMMUNICATION IMPLEMENTATIONS

To operate in the NAS, ROA are required to be in constant communication with the cognizant ATC authority. This includes the Controlling Agency (en route center or approach control) and Using Agency for restricted areas if applicable. For the military ROA currently in use, this is primarily accomplished via a UHF and/or VHF radio for voice communications. The radio communications between the vehicle and remote operator are "embedded" into the ROA's command and control datalink. This allows the air traffic controller to establish radio communications directly with the unmanned vehicle in the local airspace, and the radio communications are then relayed to the remote operator via the ROA's LOS or BLOS datalink. This arrangement precludes any changes in local ATC equipment or procedures to communicate with ROA in the local airspace. For BLOS SATCOM datalinks, this technique may result in a noticeable lag in the communications cycle. For the Global Hawk ROA discussed in section 2.3.2, the two-way delay in the LOS datalink is approximately 3-5 seconds, while the two-way delay for the UHF SATCOM command and control datalink is 5-7 seconds.[7] The voice

transmissions themselves are similar in quality to a standard radio. ATC communications with an ROA that has their radio communications embedded in the datalink are functionally similar to communications with a manned vehicle, and have comparable sound quality.[8]

In addition to voice radio, a telephone land-line is typically pre-arranged for direct communications between the ROA remote operator and the Controlling Agency.[7, 8] Telephone communications are also used for critical situations such as the loss of the embedded radio link or entire command and control datalink. Setup and implementation of this telephone backup capability requires substantial preflight coordination, and would not be practicable for extensive ROA operations in the NAS.

4.0 AIRBORNE DATALINK SYSTEMS

4.1 AIRBORNE DATALINK SYSTEMS OPERATION

There are a number of different types of digital datalinks that may be employed in an ROA to implement the airborne surveillance and communication functions. Datalinks are generally divided into either terrestrial-based or satellite-based systems. For each of these, their potential for use in supporting the airborne surveillance and communication functions with an ROA in the NAS is discussed in the following sections. For the airborne surveillance function, the digital datalink is only used to downlink aircraft information to the ATC receiving site. For the airborne communication function, a two-way datalink would be used to carry information between the ATC ground site and the ROA. This information would in turn be relayed to the remote operator via the ROA two-way ground station datalink.

4.1.1 Terrestrial-Based Datalink Systems

Terrestrial-based systems use ground stations to transmit/receive the datalink signals and relay them to ATC facilities. Terrestrial-based datalink systems can only be used for airborne surveillance where there is line-of-sight from the aircraft to the ground receiving station. They include the Mode Select (Mode S) Extended Squitter, the Universal Access Transceiver and the VHF Data Link (VDL) Mode 3 and Mode 4.[11]

4.1.2 Satellite-Based Datalink Systems

Satellite-based systems relay the datalink signals directly to ATC facilities via a communications satellite. SATCOM datalink systems can be used for airborne surveillance anywhere satellite coverage exists, since there is no line-of-sight requirement to an established ground receiving station. This is particularly applicable to airborne surveillance over oceanic or most isolated regions. Some areas such as the polar regions may have limited SATCOM coverage, although the NAS over the 48 contiguous states has excellent coverage.

4.2 AUTOMATIC DEPENDENT SURVEILLANCE - BROADCAST

The ADS-B system is one datalink technology under development that may be used by an ROA to implement the airborne surveillance function in the NAS. ADS-B uses equipment installed in an aircraft to automatically transmit its position and other critical data to receivers located on the ground or in other aircraft. ADS-B technology allows the position of an aircraft to be determined much more precisely, and is effective in remote or mountainous areas where current primary or secondary radar-based surveillance systems are ineffective. ADS-B transmitted information typically includes the aircraft's identification, position, altitude, airspeed and whether the aircraft is climbing, descending or turning. This information is broadcast to receivers located at ATC ground stations (air-ground) or onboard other ADS-B equipped aircraft (air-air) via a digital datalink. For the air-ground application of ADS-B, the datalink information may be used by an ATC facility to execute the airborne surveillance function.

ADS-B uses the satellite-based GPS to determine the aircraft's precise three-dimensional position. This position information is then combined with the other aircraft information, encoded into a digital format, and transmitted from the aircraft on a discrete frequency. The information is typically updated several times per second to provide an accurate, real-time depiction of the aircraft's status. When all aircraft operating in the area are equipped with ADS-B, the system provides the same real-time information to the air traffic controller and all other aircraft within the area, enabling a comprehensive and integrated method for implementing the airborne surveillance function.

ATC ground sites and other aircraft are able to receive the ADS-B signal transmitted from an aircraft at ranges in excess of 100 miles. This range allows conflict detection and resolution with a much greater margin than is currently available with a radar-based surveillance system. ADS-B is also not subject to the "dynamic lag" found in radar systems. As the aircraft changes airspeed, altitude or heading, the ADS-B system is immediately updated, and current and accurate parameters are transmitted real-time. In a radar system, aircraft parameter changes

can only be detected after several radar data samples are collected; the radar-derived parameters always lag behind the aircraft's current state.

To implement the airborne surveillance function using ADS-B, only a one-way datalink is required which transmits the information from the aircraft to a ground station. To include the airborne communication function, a two-way datalink will be required. The digital information transmitted from the aircraft will consist of the ADS-B signal and also include voice or text communications. The signal transmitted from the ground ATC facility to the aircraft will include voice or text information only. In this system, no voice radio communications or radar will be required to execute the primary airborne communications and surveillance functions, respectively. Voice radio and primary/secondary radar systems may still be used as a backup to the datalink-based implementation.

5.0 ROA DATALINK SYSTEM IMPLEMENTATION IN THE NAS

5.1 AIRBORNE SURVEILLANCE FUNCTIONAL IMPLEMENTATION

The airborne surveillance function for an ROA operating in the NAS can most effectively be executed via a digital datalink. The implementation of this proposed system is discussed in the following sections.

5.1.1 System Operation

An airborne surveillance system for an ROA using a digital datalink will require dedicated equipment on both the ROA and the ground-based ATC facility. The system can most effectively be executed via a LOS terrestrial-based datalink, although LOS to the ATC facility where the air traffic controller is located is not required if a SATCOM datalink is utilized. The system will require a network of ground receiving sites that are linked back to the ATC facility. The ROA will require dedicated datalink equipment to generate and transmit the datalink messages. The GPS-INS navigation system typically used in an ROA will provide the necessary position information and accuracy required by the controller. Messages should include the vehicle's identification, position, altitude, airspeed and whether the aircraft is climbing, descending or turning. Additional communication information that may be included in the downlinked message is discussed in section 5.1.2.

The message broadcast rate and the latency of the information included in the message must be considered. The minimum message broadcast rate and maximum data latencies should be specified in the FAR requirements for the system, and may depend on the particular airspace area. Broadcast rate and data latency, as well as the minimum accuracy of the position information transmitted by the ROA are critical characteristics that impact the minimum spacing requirements for traffic deconfliction.

The datalink messages from all manned and unmanned aircraft operating in an area will be received by the ATC ground equipment. The information will be processed, and the position and status of each aircraft will be displayed on the air traffic controller's equipment. The data will

enable the controller to verify aircraft are deconflicted, and if necessary establish positive separation between each aircraft in the area.

5.1.2 System Feasibility

Datalink technologies to enable the airborne surveillance function are available and proven. Equipment that would be installed in the ROA and the ground ATC equipment are under development. ADS-B proof-of-concept technologies have been successfully demonstrated on a limited scale in manned aircraft as discussed in section 1.3. For wide-scale use of a system such as ADS-B for all aircraft operating in controlled airspace, the aircraft and ground-based systems will have to be further developed and refined. In particular, ROA-specific datalink and processing systems will need to be developed that are compatible with ROA environments and other installed systems. For an ADS-B type of datalink-based airborne surveillance system to be widely used in the NAS, its reliability and consistent performance will have to be extensively tested and demonstrated.

5.1.3 Human Factors Considerations

To transition to a datalink-based system for airborne surveillance, human factors issues for the ATC controller and ROA remote operator must be considered. From the ground ATC perspective, the initial transition from the current reliance on a radar-based system will be subtle. In general, the types of information provided to the controller will be the same as is currently available, although the system may include additional useful data such as real-time maneuvering information (i.e., whether the aircraft is in a climb, descent or turn). The position and velocity data provided to the controller will also be more accurate and timely than what would be provided by primary or secondary radar, allowing reduced separation minimums to be applied.

The more significant change for the air traffic controller will be the subsequent transition to a Free Flight environment that is enabled in part by a datalink-based system such as ADS-B. In this ATC environment, the controller must become more of an air traffic manager, and is primarily responsible for verifying the safe separation of aircraft rather than actively applying

positive separation protocols. The manned and unmanned aircraft assume the primary responsibility for their own flight routes and maintaining safe separation from nearby aircraft.

From the ROA remote operator perspective, the initial transition from a radar-based to a datalink-based airborne surveillance system will also be subtle. The protocols for operating in a particular class of airspace will likely change little, and any changes made will probably not effect the remote operator significantly. Flights will be planned and executed procedurally very similar to the current system. As the full benefits of a datalink-based system such as ADS-B are exercised in the transition to a Free Flight environment, the human factors considerations for the ROA remote operator will be profound.

In a Free Flight environment, the ROA remote operator assumes primary responsibility for monitoring nearby traffic and ensuring safe separation between the ROA being controlled and other aircraft. The operator must constantly monitor the ground station displays for traffic and ROA vehicle status, just as the pilot of a manned aircraft would. The operator must be prepared to intervene if necessary to deconflict with other traffic. The Free Flight environment also gives the remote operator significant flexibility in controlling the ROA route of flight, including making real-time modifications to the preplanned route. The operator is not constrained by the established airway system that is currently in use, and can execute the flight as desired to satisfy the specific mission objectives. The remote operators ground station must be designed to optimize the operators situational awareness of the vehicles health and status, the current mission parameters, and the current position and relevant status of other airborne traffic or weather hazards.

5.2 AIRBORNE COMMUNICATION FUNCTIONAL IMPLEMENTATION

The airborne communication function for an ROA operating in the NAS can most effectively be executed via a digital datalink. This ATC datalink between the ground-based ATC facility and the airborne ROA may be implemented via a terrestrial-based or satellite-based system. The features of this proposed system are discussed in the following sections.

5.2.1 System Operation

Implementation of the airborne communication function will be accomplished using the ROA's command and control and ATC datalinks. Information passed between the remote operator and the air traffic controller will include verbal and textual information. Significant amounts of data may be efficiently and accurately transferred in a textual format. For time-critical communications, the datalinks should continue to permit verbal information to be transferred between the remote operator and the controller. Two-way communications between the remote operator and ROA will be embedded into the existing LOS and BLOS SATCOM command and control datalinks. Two-way communications between the ROA and the ATC ground site will be embedded into the ATC datalink.

5.2.2 System Feasibility

The technology required to incorporate verbal and textual communications into a two-way datalink is available and proven. Military ROA systems currently feature verbal communications between the ROA vehicle and the remote operators ground station via LOS and SATCOM datalinks. The addition of non-verbal textual messages to the communications datalink is relatively simple and has been successfully demonstrated. The significant change from the current airborne communications implementation is the equipment required and a shift towards more non-verbal communications to effectively transfer greater amounts of information.

5.2.3 Human Factors Considerations

Executing the airborne communication function for an ROA via a digital datalink has several human factor issues that must be considered. First, the use of a datalink will enable textual as well as verbal information to be communicated between the air traffic controller and the ROA remote operator. Both the controller and the remote operator will have to be trained in the effective use of textual communications, and will have to develop the skills required to generate and interpret these non-verbal messages. Non-verbal communications can also transfer larger quantities of data at a much higher rate than verbal communications, resulting in an increased

amount of time to process and act upon the information received. The datalink system, including controller and remote operator work stations, must be designed to enable efficient creation, transmission and assimilation of the textual information, and ensure the maximum quantities and rates of data communicated do not overload the human involved.

In addition, the use of a datalink will increase the overall transmission delays and signal latencies in the communications process. As was discussed in section 3.2, this will more likely be evident in a BLOS SATCOM datalink. Appropriate procedures, training and experience will be required for both the ROA remote operator and ATC to accommodate this phenomenon and achieve safe and efficient communications. The datalink technologies and controller and remote operator workstations must be designed to facilitate efficient communications, and minimize the systemic latencies in the communications process.

5.3 DATALINK / ROA SYSTEM INTEGRATION

There are several areas that must be considered to integrate an ATC datalink system similar to ADS-B into an ROA to implement the airborne surveillance and communication functions. These areas are discussed in the following sections.

5.3.1 Datalink Technology and Equipment

The type of datalink technology and equipment selected to implement the ATC functions will depend in part on the ROA mission requirements. For an ROA operating within LOS to the ground ATC facilities, a terrestrial datalink will be acceptable. For an ROA operating in remote areas, a SATCOM datalink may be required. In most situations, the ROA will remain within LOS range to the ATC's ground datalink receiving sites and can use a simpler terrestrial-based datalink. This will normally be the case even if the ROA is operating at long distances from the remote operator and being controlled via a BLOS SATCOM datalink.

The ROA command and control datalink to the remote ground operator and the ATC datalink for airborne surveillance and communication will have to operate simultaneously without mutual interference. The two-way datalinks will either have to be deconflicted (by using different

frequencies or multiplexing), or may be fully integrated into a single multi-use datalink. An integrated multi-use datalink may alleviate some of the concern with the limited ability of an ROA to accommodate additional equipment, as was discussed in section 2.2.4.2.

Hardware comprising the ADS-B-like surveillance and communication system will be installed in both the vehicle and the remote operator ground station. This equipment includes an operators display, control panel/data entry unit, processing units, and a datalink transponder and antenna. The operators display and control panel/data entry unit may be fully integrated with the displays and interface controls already incorporated into the ground station. In addition, significant processing capability is already available on the ground station. The datalink transponder and antenna, and an onboard processing unit will be installed on the ROA. The onboard processing unit will control the overall system transmit and receive functions, and process the information and messages to be transmitted. Received messages will be downlinked to the ground station, with very little onboard pre-processing required.

5.3.2 System Implementation

The ROA surveillance and communication system will include an air-ground capability similar to ADS-B to implement the airborne surveillance and communication functions. The ATC datalink will be capable of carrying voice and text messages between the air traffic controller and the ROA, and will broadcast position and status information messages to ATC ground receiving sites. The ROA's information will be included on the ATC display along with other aircraft in the sector. The air traffic controller can then monitor and positively deconflict the traffic. If the ROA is required by the controller to change its flight parameters, a verbal or non-verbal communication will be included in the ATC uplink to the ROA. The communication will then be then relayed to the remote operator via the command and control datalink. If the remote operator desires to change the ROA's flight parameters or report a change in vehicle or mission status, this verbal or textual message can be generated at the ground station, then transmitted to the ATC receiving site via the ROA's command and control and ATC datalinks.

In addition, the surveillance and communication system should include an air-air capability similar to ADS-B. This will enable an effective detect and avoid capability with other properly configured aircraft. The system will receive other aircraft's position information broadcasts. These received messages will be downlinked to the ground control station, processed, and displayed on the ground station's traffic information display. The remote operator will be able to identify potential traffic conflicts, determine an appropriate avoidance response, and send the necessary control commands to the ROA.

5.4 NAS INTEGRATION OF DATALINK-BASED SURVEILLANCE/COMMUNICATION SYSTEM

5.4.1 Transition From Current System

In the current airborne surveillance and communication systems, a combination of primary and secondary radar is used to positively identify an aircraft and establish its position and altitude, while communications are conducted using a voice radio link. Introduction of a datalink-based system for these functions will require a phased approach as ground and aircraft equipment is installed, effective procedures and protocols are developed, and the reliability and performance of the system is proven.

During the transition period to datalink-based surveillance and communication functions, updated ATC procedures must be in place to address the mixed equipage and associated differences in capabilities. ROA that are configured with an ADS-B-like datalink system with embedded communications capability will be operating together with manned and unmanned aircraft equipped with a transponder and voice radio. The transitional ATC system should be configured to exploit the advantages and additional capabilities of datalink-equipped aircraft to the greatest extent practicable.

The transition to a datalink-based system for airborne surveillance such as ADS-B will provide an immediate alternative for the basic functions of aircraft identification and position and altitude verification. During the introduction of the new technology, primary and secondary radar

systems may continue to be used, and the higher level capabilities provided by the ATC datalink implemented in stages. In this transition period, modifications to ATC equipment will allow datalinked and radar contacts to be displayed together for the controller, permitting aircraft with mixed equipage to be accommodated in the same airspace.

The transition to a datalink-based system for airborne communication will provide a "form and function" replacement for voice radio in its basic operating mode. In this mode, verbal communications carried between the controller and operator via the datalink will operate similar to a radio. During this initial period, there will likely be aircraft using both types of communication equipment. The ATC equipment must accommodate both systems, and both must have similar implementations from the air traffic controllers perspective to avoid confusion.

A critical element of this integration is that all aircraft operating in controlled airspace must transition to datalink-based surveillance and communication systems, including commercial, general aviation and remotely operated aircraft. The full benefits of a surveillance system like ADS-B (including air-air capability) and non-verbal (text message) communications cannot be realized unless all NAS users are equipped with the datalink systems. Effectively transitioning to a datalink-based airborne surveillance and communication capability will require that the FAA mandate its use, and establish a fixed timetable for implementation of compatible systems for any aircraft operating in the NAS. As the ATC datalink system becomes established and proven, the current radar and voice radio systems may eventually be phased out.

5.4.2 System Selection, Regulation and Certification

The datalink-based system that is selected by the FAA, and in particular the datalink technology chosen, must be compatible with all types and classes of NAS users. In addition, the system should be interoperable with international operations. This is particularly critical for an ROA that will be operated both in the NAS and in international airspace. It may not be practicable to equip the vehicle with more than one ATC datalink option, either a terrestrial or satellite-based system depending on the ROA mission and operating environment. To adequately serve all

airspace users, both a LOS terrestrial and a BLOS SATCOM datalink option must be accommodated in the NAS.

Introduction and transition to a datalink-based airborne surveillance and communication system will require numerous changes to the en route procedures and FAR requirements that have evolved for the current radar and radio based system. Updated or new FARs must specifically address datalink-based systems, including data formats and protocols, operating procedures and minimum equipage for IFR and VFR operations in each applicable airspace category.

The proposed datalink-based system for airborne surveillance uses information from the aircraft's primary onboard systems, rather than from secondary systems and external FAA-operated equipment as with a radar-based system. This primary (datalink) system is also the central element for the airborne communication function. Therefore the FAA will have to establish certification procedures and minimum performance standards for all ATC-related equipment including navigation systems and ATC and command and control datalinks. The standards must address the robustness of the equipment including system reliability and redundancy, and also specify a minimum accuracy for the aircraft parameters that are transmitted (position, altitude, and airspeed).

5.5 SAFETY CONSIDERATIONS

Using a digital datalink to implement the airborne surveillance and communication ATC functions with an ROA has several safety advantages and issues that must be considered. These are discussed in the following paragraphs.

5.5.1 Datalink Safety Advantages

Using a datalink to implement the airborne surveillance and communication function in an ROA has several safety advantages over the current radar and voice radio based systems. First, BLOS datalink systems may be used at longer ranges, and can cover areas where current systems are not effective (such as remote regions, mountainous terrain, at very low altitude or

over the open ocean). In these areas, LOS radar and voice radio systems are not able to provide satisfactory coverage of the airborne ROA.

Second, the datalink allows additional airborne surveillance data and text messages to be passed between the ROA and the air traffic controller. This data may include the ROA's velocity , maneuvering state, and future intentions in addition to the basic aircraft identification and position information. This additional data gives the air traffic controller and the ROA remote operator more useful information with which to safely conduct operations.

Finally, datalink technology such as ADS-B is also able to provide more accurate airborne surveillance data and at a much higher update rate, giving the air traffic controller a near real-time indication of the airborne situation. This improved performance will give the air traffic controller an expanded capability to determine the precise location of all airborne traffic and effectively ensure positive deconfliction.

5.5.2 Datalink Safety Issues

Using a datalink to implement the airborne surveillance and communication function in an ROA also has a number of safety issues that must be addressed. In general, as commercial ROA are introduced into the NAS in significant numbers, they will have to demonstrate that they are capable of operating alongside manned aircraft with no undue impacts to safety. ROA will have to meet all current and any future regulatory requirements that may arise. In addition, the public perception regarding the safety of unmanned vehicles operating in the NAS will have to be addressed. This may require additional safety measures to be undertaken above and beyond the FAR minimums, at least until the ROA systems have proven themselves and become accepted by the general public.

In addition to the general safety issues discussed in the preceding paragraph, there are several specific issues. First, the datalink may be the sole system enabling both of the critical airborne functions of surveillance and communication. It must have sufficient reliability and redundancy to ensure these functions are not interrupted or degraded beyond an acceptable level. In the ADS-B technology, the same ROA subsystems that are used for aircraft navigation

are also used for ATC surveillance information. A failure of the vehicle's GPS-based navigation system may provide the same erroneous position data to both the ROA remote operator and the air traffic controller, with limited ability to cross-check the information. Establishing end-to-end redundancy in the entire system is essential, and no single-point failure modes will be permissible. This redundancy must include the aircraft navigation system that provides ADS-B inputs, the ROA's ATC and command and control datalink systems, the ground transceiver and relay systems, and the ATC facility systems. Reliability and redundancy are integral features of the ROA and ATC systems, and must be included in the design and development of the systems from the outset.

Second, the system must degrade gracefully in response to discrete or systemic failures. Graceful degradation of a system requires that one failed component or subsystem not incapacitate the entire system, and that the system provide a positive indication in the event that a component fails or degrades. Any degradations or component failures must be recognizable, and an acceptable backup system or procedural response that maintains the overall ROA system safety must be available. As with reliability and redundancy, these issues (graceful degradation and system backups) are integral to the design of the ROA and ATC systems.

In addition, the integrity of the datalink itself must be considered. The link must be available at all times, with no appreciable dropouts or degradations that effect the ability to send and receive messages. The datalink must not be overly sensitive to environmental factors and meet DO-160 requirements, and be able to carry high message traffic volume during peak airborne traffic periods.

The inherent lags and delays in datalink communications technologies are the final safety issue that will be discussed. Datalinks operate by compiling data over a discrete time period, then transmitting the encoded message in a burst. The incoming message must be received in its entirety, then decoded and presented to the user of the information. This complicated process takes a finite amount of time. For a BLOS SATCOM datalink, an additional delay is normally encountered due to the accommodation of multiple users on a single satellite channel. Although

there are many processing schemes used for SATCOM, they generally add a time delay to each message that passes through the relaying satellite. For a two-way communication, this BLOS SATCOM delay can be up to approximately 7 seconds as was discussed in section 3.2 for the Global Hawk ROA system. With appropriate training and operating protocols, the ROA remote operator and air traffic controller will become accustomed to this delay, and may be able to function effectively with the datalink-based systems. This inherent lag in the transfer of airborne surveillance and communication messages will have to be accommodated in the effected regulatory procedures such as the separation requirements for datalink-equipped aircraft.

5.6 EFFICIENCY CONSIDERATIONS

5.6.1 Airborne Surveillance

Implementation of the air-ground capabilities inherent in an ADS-B-like digital datalink system for airborne surveillance will result in an increase in efficiency in several areas. The near real-time update rates and much greater accuracy over radar in airspeed, altitude and especially position will allow the air traffic controller to establish the location of datalink-equipped aircraft much more precisely. This will allow the controller to decrease the lateral and vertical separation requirements and utilize existing airspace more densely. The same separation requirement may be applied to datalink-equipped aircraft regardless of where they are in a control sector; with radar-based surveillance, position uncertainty increases with range, necessitating increased separation minimums at greater distances from the radar site.

The increased effective surveillance range of the digital datalink will allow conflict detection and resolution to be implemented at increased distances between aircraft. This will increase mission flexibility and allow aircraft to operate with a minimum of constraints. This is especially important for an ROA that needs to fly a precise flight profile to conduct its specific mission role. By identifying a potential conflict earlier, any required maneuvering or route adjustments and resulting disruptions in the ROAs mission may be minimized.

The digital datalink will allow precision tracking services to be expanded to areas not presently covered by the radar-based airborne surveillance system. These areas are currently required to use inefficient non-radar separation procedures. Non-radar procedures require large vertical, lateral or longitudinal separation margins that limit the number of users in a given sector and also constrain their operating flexibility. A precision tracking capability in these areas will increase airspace usage efficiency, and benefit manned and unmanned aircraft.

The air-air capabilities inherent in an ADS-B-like digital datalink system for airborne surveillance are a key enabling technology for the transition to a Free Flight environment. Free Flight will revolutionize the airborne surveillance function, and greatly increase the efficiency of the NAS utilization. This ATC environment will allow ROAs in particular to fly the varied and flexible profiles required for their unique missions and roles.

5.6.2 Airborne Communication

The digital datalink will allow increased quantities and rates of information to be passed between the air traffic controller and the ROA remote operator. The datalink system will also permit non-verbal text messages to be communicated. This increased effective flow of information will allow the controller and remote operator to work together to execute the desired flight profiles with a minimum of constraints and delays. The textual messages in particular will permit useful data such as aircraft intentions, flight requests, and weather or traffic status to be exchanged and exploited.

The increased effective range of the digital datalink will expand communications coverage beyond the current capabilities of the LOS radio. As with airborne surveillance, this greater range will increase ROA mission flexibility and allow aircraft to operate safely at further distances from ground ATC sites.

5.7 SECURITY CONSIDERATIONS

Use of a digital datalink to implement the airborne surveillance and communication ATC functions for an ROA has several security considerations that must be considered. The first

security issue is authentication of the digital data messages between the air traffic controller, ROA and remote operator[12]. Technologies and protocols will be required to permit the source and content of messages to be verified. This will prevent an unauthorized party from emulating one of the communication nodes and transmitting bogus or corrupted messages. The second security issue is intentional interruption of the datalink communications. The ATC and the command and control datalinks should be designed to preclude jamming from external sources. The end-to-end datalink system must be robust and secure to prevent an interruption of the ability to maintain surveillance and communications with airborne manned and unmanned aircraft.

To rely on digital datalink as the sole or primary source for the airborne surveillance and communication functions, effective and comprehensive security measures must be developed to protect the integrity of the system. This must be accomplished before widespread implementation of the technology becomes practicable in the NAS.

6.0 CONCLUSIONS

ROA have been established as highly useful systems for a number of military applications. A variety of ROA are currently in use by the military, and many more are under development. During extensive military testing and operational use, ROA non-military applications have become apparent. Civilian ROA have the potential for effective employment for a wide range of missions and roles. As civilian ROA system designs and concepts of operation are refined, there will be many cost-effective applications for using ROA in roles currently performed by manned aircraft or other systems. In addition, new or expanded roles will be identified that are enabled by the unique operating capabilities of ROA. The economic viability of ROA in performing these missions and roles will be the primary factor pushing the integration of this technology and acceptance of widespread ROA operations in the NAS.

The current implementation of the airborne surveillance and communication functions in the NAS will support limited ROA activities in the near-term. This system of using primary and secondary radar and LOS voice radio has limitations in terms of the total numbers of manned and unmanned aircraft it can effectively support, and in the efficiency of services that may be safely provided to a variety of ROA operating in the NAS. The current ATC system has evolved in support of the passenger transportation mission. The airborne surveillance and communication functions are optimized to service manned aircraft flying from one terminal area to another terminal area via a designated route structure. This “point-to-point” concept enables large numbers of aircraft to move with relative efficiency and safety between their departure and destination locations. ROA flight profiles are dictated by their highly specialized missions, and typically do not involve direct point-to-point navigation between two locations. ROA missions and roles will require flight profiles that loiter for extended periods over designated areas, follow along a particular geographic feature such as a river or oil pipeline, or track a dynamic event such as weather phenomena. In addition, ROA are more likely depart and return to the same location.

To effectively conduct varied missions, ROA must be able to fly a planned mission on desired route profiles with a minimum of restrictions and limitations. These routes may

encompass all classes of controlled airspace, and operating procedures must accommodate both IFR and VFR traffic. ROA must also have some reasonable level of flexibility en route to modify their flight profile in response to changes in external or internal conditions. External conditions that might change include weather or the particular feature that is being monitored (fire, freeway traffic, weather disturbance, etc.) Internal conditions would include mechanical failures or multiple sensor modes.

Two-way digital datalink technology has significant potential for use in implementing the airborne surveillance and communication functions. This technology provides more accurate and comprehensive time-critical surveillance information to the air traffic controller, and facilitates more efficient communications of large amounts of useful information between the air traffic controller and the ROA remote operator. One airborne surveillance datalink technology that has been successfully demonstrated is ADS-B, which is one of the Free Flight operational enhancements that are being proposed for the ATC system[13]. ADS-B has the potential to facilitate the en route flexibility that ROA require to safely and efficiently conduct their unique missions. In addition, the air-air feature inherent in ADS-B systems will enable an effective "detect and avoid" capability for ROA without requiring additional dedicated sensor systems.

Current state of the art ROA lack effective technologies to accomplish the "detect and avoid" criteria for VFR operations or for detecting VFR traffic while operating IFR in Class E airspace. This is a critical safety capability for detecting airborne traffic or other hazards such as weather. A cooperative means of accomplishing this function has been demonstrated using a combination of transponder-based systems and onboard sensors. In addition, the air-air capabilities of ADS-B has the potential for satisfying the detect and avoid criteria for ROA. An effective means for implementing the airborne detect and avoid capability is essential for large-scale safe operations of ROA in the NAS. This capability must be enabled without requiring additional dedicated sensor systems on the vehicle.

Finally, the operation of large numbers of ROA in the NAS using a two-way digital datalink for the airborne surveillance and communication functions has a number of operational,

safety and security issues. The datalink systems must be compatible with a variety of types and classes of ROA vehicles. The ATC system must accommodate aircraft with mixed equipage during the transition from radar and radio based systems to datalink based systems. The end-to-end datalink system must be robust and reliable, and preclude any unauthorized use or intentional interruption.

7.0 RECOMMENDATIONS

Two-way digital datalink technology should be pursued for implementing the airborne surveillance and communication functions with an ROA in the NAS. A datalink-based ATC system has numerous benefits for ROA, and is a key enabling technology for expanding the operations of ROA in the NAS.

Need further development of datalink technologies, including a full assessment of the safety and security impacts of a datalink-based ATC system. Critical issues are the reliability of the datalink, susceptibility to corruption or interruption (intentional and non-intentional), and the effects of the communication time delays.

To enable the integration of large numbers of ROA into the NAS using datalink technology for airborne surveillance and communication, the FAA and the ROA industry must take a number of positive steps.

1) *The FAA must begin to consider ROA as an important user of the NAS.* The ROA industry including commercial, military and research organizations must be included in the FAA's planning for future ATC system improvements. This combined FAA/industry consortium should define an appropriate course for integrating ROA into the ATC system and expanding their presence in the NAS.

2) *The FAA must embark on the Free Flight operational enhancements that have been developed in conjunction with the NAS user community.* ADS-B in particular will provide extensive efficiency and safety benefits for both manned and unmanned aircraft in the NAS and should be pursued aggressively. The full air-ground and air-air benefits of ADS-B can only be realized when all aircraft operating in controlled airspace are equipped with an ADS-B transmitter. This will not occur in a timely manner unless the FAA embraces the technology and its implementation.

3) *FAA certification standards and operating regulations must be updated to address the unique needs and issues of ROA operating in the NAS.* The FAA must review the current FAR

requirements and ensure that they are reasonable, correct and applicable to unmanned as well as manned aircraft. New FARs and subsequent updates must include all users of the NAS.

4) *The ROA industry and user community must incorporate current FAA certification requirements and operating standards to begin integrating into the NAS.* ROA should not expect special consideration, tailored regulations or relaxed requirements from the FAA. As ROA become established and proven in the NAS, certification standards and operating regulations will evolve to more effectively accommodate the unique requirements of unmanned vehicles. In the interim, first-generation ROA may require special design features and additional installed equipment to interface with the ATC system that has evolved to support manned aircraft, and prove their viability and safety in the NAS. Lessons learned from these early ROA systems can be applied as the ATC system evolves to fully include ROA-peculiar issues and needs.

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Vita

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