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Abstract: The objective of this white paper is to help achieve the ACCESS 5 goal by sharing the UNITE members knowledge of current HALE ROA communication systems with other ACCESS 5 participants so that all interested parties start from a common understanding as we begin the clarification of requirements for voice and C2 communication. This white paper is also intended to describe the point of departure for any future developments that need to be realized to achieve the long term ACCESS 5 goal. Although this white paper describes the current systems, the functional and performance requirements that are also being developed under ACCESS 5 may not require the same levels of functionality and performance as currently exist. The paper addresses the following: 1) A description of a typical current HALE ROA communications system, 2) HALE ROA communications systems performance metrics, 3) HALE ROA communications systems performance, and 5) A comparison of current HALE ROA communications systems with current regulations.

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WHITE PAPER

CURRENT HALE ROA
VOICE AND CONTROL
COMMUNICATION
PRACTICES AND PERFORMANCE

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

CURENT HALE ROA VOICE AND CONTROL COMMUNICATION PRACTICES AND PERFORMANCE

1.0. OVERVIEW.

This white paper describes, in generic terms, the voice communication and aircraft command and control (C2) communication systems and practices used by the UAV (Unmanned Air Vehicle) National Industry Team (UNITE) group of companies in the operation of their High Altitude Long Endurance (HALE) Remotely Operated Aircraft (ROA).

UNITE is an alliance of companies formed to pursue the common objective of creating the capability for ROAs to "file and fly" in the National Airspace System (NAS). UNITE represents several U.S. companies with High Altitude Long Endurance UAV experience. The alliance and its member companies are actively participating in the ACCESS 5 program with three federal government agencies to achieve the "file and fly" objective. The UNITE Alliance consists of AeroVironment, Aurora Flight Sciences, The Boeing Company, General Atomics Aeronautical Systems Inc, Lockheed Martin and Northrop Grumman all of whom have contributed technical information in support of this white paper.

1.1. OBJECTIVE.

ACCESS 5 is a collaborative alliance between government and industry whose vision is, to operate HALE ROAs routinely, safely, and reliably in the National Airspace System. This vision is being achieved through the mission of a strategic alliance between government and industry to develop standards, regulations, and procedures, develop and demonstrate technologies and define and implement initial aviation infrastructure that enable routine access to the NAS by HALE ROAs.

The objective of this white paper is to help achieve the ACCESS 5 goal by sharing the UNITE members knowledge of current HALE ROA communication systems with other ACCESS 5 participants so that all interested parties start from a common understanding as we begin the clarification of requirements for voice and C2 communication.

This white paper is also intended to describe the point of departure for any future developments that need to be realized to achieve the long term ACCESS 5 goal. Although this white paper describes the current systems, the functional and performance requirements that are also being developed under ACCESS 5 may not require the same levels of functionality and performance as currently exist.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

1.2. INTRODUCTION.

This white paper is divided into the following four sections.

Section 2.0: A description of a typical current HALE ROA communications system.

Section 3.0: HALE ROA communications systems performance metrics.

Section 4.0: HALE ROA communications systems performance.

Section 5.0: A comparison of current HALE ROA communications systems with current regulations.

HALE ROAs have been in existence for a number of years and have successfully logged many tens of thousands of flight hours; however most of these operations have been for either military or scientific missions. The design and operation of HALE ROAs has therefore been optimized for these types of mission and not optimized for the future civil and commercial roles that the completion of the ACCESS 5 goal will allow. This means that many of the HALE ROA design solutions, including their communications capabilities, have not been aimed at the same requirements as will be needed to operate HALE ROAs routinely, safely, and reliably in the National Airspace System.

A good example of this optimization is the sharing of the wide bandwidth payload (cameras, radars, sensors etc.) data link with aircraft C2 and voice communication. This is an effective approach for the current missions flown by HALE ROAs but the bandwidth required for the payload data back-haul is far in excess of that required to safely and reliably control an ROA. This white paper will not discuss any current payload related data link capabilities but will focus specifically on the voice and C2 communications systems required by the ACCESS 5 initiative.

One of the corner stones of the ACCESS 5 program is to achieve integration of HALE ROAs into the NAS with minimal impact on the current users and regulators by adopting as many current manned aircraft practices and requirements as is practical, safe and realistic. However, HALE ROAs do bring new and unique challenges to this environment two of which are as a direct result of the pilot in command or operator of the aircraft not traveling with the vehicle.

Firstly, compared to a manned aircraft, there must be some additional or different communication mechanism for the pilot in command or operators voice to be carried to Air Traffic Controllers (ATC) or other pilots of manned or unmanned aircraft.

Secondly, compared to manned aircraft, there must be some additional communications mechanism to allow the pilot in command or operator to control the HALE ROA and receive status from the HALE ROA.

Regulations already exist that define the performance for the overall voice communication system so the additional or different mechanisms outlined above must fall under these requirements. However, no regulations currently exist that cover the additional mechanism for the pilot or operator to control and receive status from the HALE ROA.

2.0. A DESCRIPTION OF A TYPICAL CURRENT HALE ROA COMMUNCIATIONS SYSTEM.

This description will be divided into the following four sections.

Section 2.1: Line Of Sight HALE ROA command and control.

Section 2.2: Beyond Line Of Sight HALE ROA command and control.

Section 2.3: Voice Communication.

Section 2.4. Lost Links.

2.1. LINE OF SIGHT HALE ROA COMMAND AND CONTROL.

For Line Of Sight (LOS) communication the maximum distance between the take off and landing location, which is usually where the pilot or operator and communications equipment are located, and the aircraft is approximately one to two hundred miles. This distance is somewhat arbitrary but is used to differentiate between LOS communication and Beyond Line Of Sight (BLOS) communication where additional or more complex communication mechanisms are required to allow the aircraft to be flown many hundreds if not thousands of miles away from the location of the pilot or operator.

All current HALE ROAs are equipped with LOS C2 data links. HALE ROAs with more autonomy (e.g. automatic take off and landing) rely less on the LOS system for take off and landing since the pilot or operator is not “in-the-loop” (actively flying the aircraft) but “on-the-loop” (monitoring the flight of the aircraft with the capability to override maneuvers if needed) in these systems.

This level of reliance on the LOS system is also reflected in the level of redundancy adopted by different HALE ROA systems as well as the importance of low C2 data link latency. All pilot or operator in-the-loop take off and landing HALE ROA systems use dual redundant data links and have low pilot control input to pilot observable response latencies. Conversely pilot or operator on-the-loop systems often only have single-thread LOS data links and higher latencies.

Dual redundant LOS C2 data links offer two advantages. Firstly having two sets of data link equipment significantly improves the overall reliability (see section 3 for a definition of reliability) of the data link system since compounded reliabilities are squared. Secondly the two links can also offer improved data link availability (see section 3 for a definition of availability). For example if one of the links is temporarily suffering degradation (due to interference or propagation related effects) the other link will often be able to take over the delivery of control and status data.

2.2. BEYOND LINE OF SIGHT HALE ROA COMMAND AND CONTROL.

Some current HALE ROAs are equipped with Beyond Line Of Sight systems. These BLOS systems are all currently satellite based.

Satellites offer very wide geographical coverage areas and allow the aircraft to be controlled many thousands of miles away from its take off and landing location.

Currently all take off and landing activity is controlled using the LOS systems described in the previous section. However at a manufacturer specific altitude or range the ROA is switched from LOS to BLOS control and is usually flown this way for the bulk of the distant flight activity. The pilot or operator using the LOS system to control the aircraft does not necessarily have to be the same pilot or operator controlling the aircraft using the BLOS system. A LOS system will again be used for landing but not necessarily the same one that was used for take off allowing the ROA to make landings at distant locations.

Two types of satellite communication system are currently used. The first type offers truly global coverage (e.g. UHF SATCOM, Inmarsat and Iridium). Although these systems operate at low data rates (100bps to 100kbps) they are still adequate to safely control the aircraft. The second type of satellite system uses geostationary satellites that offer higher data rates (1Mbps to 30Mbps) but have restricted footprints of coverage on the earth's surface. This restricted footprint may not be a significant limitation. For example many of the satellites used are designed to provide nation-wide telecommunication capabilities (e.g. PanAmSat Galaxy 10R has a footprint that covers all of the Continental United States, Alaska and Hawaii). As a result a HALE ROA can be flown anywhere in the NAS from a ground station that can also be located anywhere within the NAS.

Satellite BLOS systems by their very nature have levels of both equipment reliability and data link availability that are less than one hundred percent. To compensate for this lack of perfect data link integrity, current HALE ROAs that fly BLOS missions utilize multiple (two or three) and different (e.g. global and geostationary) satellite communications systems all operating in parallel. Typically the flight computer on the aircraft and the computer in the ground control station simultaneously monitor all links and choose, on a real-time basis, the best link as appropriate. This link choice can also be manually controlled by the pilot or operator.

2.3. VOICE COMMUNICATION.

Not all current HALE ROA aircraft carry voice communication equipment. However all HALE ROA systems have the ability for their pilot or operator to have voice communication with Air Traffic Controllers and pilots of other aircraft.

Current HALE ROAs that are only equipped for LOS flights often have their voice communication VHF transceiver located in the ground control station. This is adequate when the aircraft cannot fly outside of the coverage area of the ground control station based VHF transceiver; however for BLOS operation this is unacceptable. For BLOS missions the VHF voice communication equipment must be carried on the aircraft so the pilot or operator can communicate with various ATC centers or pilots as the aircraft transits different regions. In current BLOS HALE ROA systems the voice traffic is carried as part of the overall C2 data link between the ground control station and the aircraft.

Back up systems for voice communication on current HALE ROAs rely on telephone connections for LOS only systems and multiple parallel C2 data links and often multiple VHF transceivers on BLOS equipped HALE ROAs.

All of the VHF voice equipment currently used for both LOS and BLOS systems is standard equipment covered by current TSOs. However, the method for getting the voice traffic between the pilot or operator and the VHF equipment, when it is carried by the aircraft flying a BLOS mission, is not specifically covered by current regulations. The methods are only indirectly covered by the fact of them being an integral part of the voice communications system so some specific performance parameters may need to be developed as part of the ACCESS 5 program.

2.4. LOST LINKS.

Mobile radio communication systems operate under many demanding conditions, which lead them to not always be available for their intended purpose. All mobile radio communication systems, including those used on HALE ROAs, are designed to achieve a specific level of performance but under certain conditions even the best systems can become temporarily unavailable. These lapses, called drop-out periods, which can be caused by multipath fading, airframe blockage of the signal, bad weather etc. range in duration from a few milliseconds to many minutes. The amount of time a particular HALE ROA can operate without its data links is dependent on its design and level of autonomy. If a drop-out lasts longer than is acceptable to the particular system experiencing the loss of communication then a “lost link” situation will be declared.

All HALE ROAs have built in procedures to accommodate Lost Link situations. Again the level of autonomy plays a major part in what the ROA does after loosing its link, but in most cases the aircraft will fly a pre-planned maneuver trying to reestablish any data link that might be available while making its way to a pre-coordinated location where it can be picked up again by the LOS system located at that facility.

3.0. HALE ROA FUNCTION AND PERFORMANC METRICS.

The following is a list of the key performance metrics for HALE ROA voice and C2 data links as well as a description of some of the key factors that affect these metrics.

3.1. AFFORDABILITY.

Although not a classic metric the cost of acquisition and the cost of operation are of significant concern in the choice of a data link system. HALE ROAs are not inexpensive. However, it is certainly true today that the payloads carried by HALE ROAs can often cost more than the aircraft themselves. For example the cost of a multiple data link suite, which may be required to meet the high levels of availability and reliability needed to fly safely in the NAS, can very quickly add to many hundreds of thousands of dollars.

Operational costs are also important. Geostationary satellite monthly costs as well as global satellite costs per minute are high costs that will always be significant in any business plan or federally funded operation.

3.2. AVAILABILITY.

Mobile radio communications systems face a significant challenge when compared to their wired communication counterparts, that of link availability. Availability in this context is defined as the percentage of time information can flow through working equipment. It is distinctly different from reliability that defines the percentage of time information cannot flow because the equipment is broken. Achieving 100% availability is a major challenge with many factors impacting the actual performance.

In principal if more availability is required then more signal power needs to be either sent from the transmitter or collected at the receiver so that the factors affecting the link availability are less able to degrade the link to the point where information cannot be transferred.

Of the many factors affecting data link availability the mobile nature of the aircraft and the environmental conditions in which it is flying predominate. Pointing antennas at satellites and ground stations from the mobile aircraft platform is not very difficult but minimizing the blockage of the signal by the airframe is often very difficult. For example, since geostationary satellites are located above the equator, flying directly north or south often means that the aircraft's satellite dish is pointing through the fuselage and tail of the aircraft. Although missions can be planned around these limitations including these aspects in a "file and fly" environment is not practical.

All current HALE ROAs have been developed around these limitations. Therefore the aircraft does not rely on 100% link availability and only executes a "lost link" procedure after a time, which is much longer than the worst case link drop-out time. All current HALE ROA aircraft that fly BLOS use some form of autopilot to fly through these link availability drop-outs and have messaging protocols that ensure all messages eventually get through even under the most arduous of data link conditions.

It should be noted that in some HALE ROA systems that carry the voice communication to the aircraft from the ground control station on the C2 data link then the data links availability will also affect the availability of the voice communication.

3.3. CAPACITY.

A significant consideration in the design of any data link system is the capacity it has to carry multiple links in the same geographic area or more specifically the area over which the transmitted signal would stop another link reusing the same frequency.

Current HALE ROA communication systems do not consider capacity as a key factor. But with the growth in HALE ROA flights that will be the result of the ACCESS 5 initiative capacity needs to be given a high priority in the definition of future data link requirements.

3.4. COVERAGE.

Closely aligned with capacity is the coverage of the data link system. NAS-wide coverage can be achieved with one geostationary satellite footprint but then if one frequency is being used in one part of the NAS it cannot be reused anywhere else. NAS-wide coverage can also be accomplished by having many smaller footprints (or cells) that allow frequency reuse but this requires that each cell be somehow linked to all of its neighbors so as to allow seamless hand-off of the aircraft as it transits from one cell to the next. The bottom line is that capacity and coverage require a heavy investment in infrastructure (leading back to the affordability metric described earlier).

An important consideration in respect of coverage is whether the data link system must work over the adjoining regions on the boundaries of the NAS or even allow HALE ROAs flying from other regions of the world to transit into US airspace.

3.5. GRADE OF SERVICE.

Grade of Service covers such metrics as latency, voice and data throughput as well as voice and data collisions or blockage. Quality of Service will be defined and discussed latter.

For HALE ROAs the most important Grade of Service metric is latency. There are many latencies associated with the control and status as well as voice communication system employed by current HALE ROAs.

For a pilot or operator in the loop the latency between them making a control input in the ground station and that input being observable as a response by the aircraft on their monitor back in the ground station is a key latency. This is a latency that is currently not considered when the pilot in command is traveling with the aircraft.

The most important latency from an Air Traffic Controllers perspective is the time it takes for the pilot or operator to provide verbal feedback to their verbal request to perform a maneuver or supply status or intention.

Both of these latencies can be considered important if the Air Traffic Controller is advising the pilot or operator to make a time sensitive safety related maneuver.

Another aspect of the Grade of Service provided by the data link is its ability to ensure that no message is blocked by another message. In the manned flight arena this is managed by protocols and procedures observed by the users of the service but this is not necessarily possible or so easily achievable with remotely piloted or operated ROAs.

3.6. MAINTAINABILITY.

In its simplest form maintainability, without a flight engineer/pilot on the ROA repairing or working around equipment problems is not as easy. However other aspects of data link maintainability are important. The majority of HALE ROAs do not have environmentally controlled equipment bays so the equipment must survive wider extremes of temperature pressure and other environmental parameters than would be experienced by equipment used on a manned aircraft.

This will inevitably lead to the need for more frequent inspection and preventive maintenance unless, because of the lower likelihood of equipment malfunction causing loss of life, a reduction in the reliability of HALE ROA data link equipment may be acceptable. Again affordability becomes a key factor in this equation.

3.7. OPERABILITY.

This metric covers a wide range of parameters. Two key areas are described in the following sub-sections.

3.7.1. Size, weight and power consumption.

Key to all aircraft designs are the SWAP parameters of the payloads. But with HALE ROAs often targeted for long endurance missions the size, weight and power of any data link solution are critically important. While multiple data links have a distinct appeal for improving availability and reliability they are certainly not attractive from a SWAP perspective.

3.7.2. Human Systems Interface.

The more complex multiple data link systems used on HALE ROAs demand a much higher level of data link knowledge, training and operational interaction than is currently expected of a pilot flying a manned aircraft. Maintaining a geostationary satellite link often requires the full-time attention of both pilot or operator and a specialized SATCOM technician.

3.8. QUALITY OF SERVICE.

Quality of Service (QoS) metrics include voice readability for the analog voice communications system as well as its digital link equivalent Bit Error Rate (BER).

Both metrics define the utility of the received information. In the digital domain there are many precise ways of determining the acceptable BER for a particular data link. However the QoS of analog voice systems has not traditionally been so precisely defined.

In HALE ROA systems the voice signals may travel over many more links between pilot or operator and ATC personnel or other pilots and under some circumstances may even be converted to digital signals and back to analog. So defining a metric such as Mean Opinion Score (as used in the wired telephone industry) may be required.

3.9. RELIABILITY.

As indicated in the section on Maintainability HALE ROA payload equipment often operates in much harsher environments than equipment in manned aircraft. For example at typical HALE operating altitudes of 40 to 60 thousand feet outside air temperatures can drop to as low as -60C to -80C. Equipment in manned aircraft that fly at altitudes of 25 to 40 thousand feet is only required to operate at temperatures, as specified by RTCA /DO-160, in the range -20C to -55C.

Current HALE ROA data link equipment is also often much more complex than the VHF voice equipment or even Inmarsat systems carried by manned aircraft.

Both the harsher operating environment and the higher complexity of equipment will make achieving the required levels of reliability harder for the unmanned system. As has been described before current HALE ROAs have often not been asked to achieve the levels of equipment reliability required to fly in the NAS so some improvements may well be required.

Even if the voice and C2 data links fail all HALE ROA aircraft will perform a pre-programmed Lost Link procedure to safely as possible bring the aircraft back to a know location where it will either land or be landed depending on its level of autonomy.

3.10. SECURITY.

With the inevitable growth of ROA flights in general and more specifically with the impending significant increase in NAS wide activity as a result of the ACCESS 5 program hi-jacking of ROAs must be considered a potential threat.

Whilst hi-jacking an ROA by overpowering its data link is a distinct possibility other threats such as gaining physical access to an ROA control center and hi-jacking the ROA using its normal C2 facilities or stealing ROA data link equipment and using it illegally need to be considered.

There are a number of factors involved in hi-jacking an ROA via its data link. These factors are very similar to the factors involved in any military (aircraft, missile or communication) jamming scenario or even the threat of jamming or hi-jacking of commercial or military satellites etc. Consequently there is a wealth of knowledge, both commercial and military, for evaluating and designing data links to achieve a specified level of security.

Before hi-jacking can take place the data link itself must be intercepted. Hi-jacking can then take the form of either jamming of any future commands to the ROA or misdirection of the ROA by sending it false commands.

There are then two further factors that must be considered. Firstly, the inherent security features of the data link system itself and secondly, any additional security features that can be added to the data link to make it more robust.

3.10.1. Interception.

With the types of ROA data link currently deployed there is some inherent protection against finding or intercepting the data link. Information on the data link frequencies being used, the location of the ROA and control station and the time when the ROA is airborne are all that will be required to intercept a data link. This information can be protected but with the growth of HALE ROA activity this information will inevitably become public. However HALE ROA data links do have some resistance to specific interception inherent in their design.

ROA data links use directional antennas to beam the RF power directly at the ROA from ground control station and vice versa. This means that any interceptor is disadvantaged because to receive enough signal power the interceptor must be very close to the direct path between the two ends of the data link, which is a difficult task to physically accomplish.

There are a number of “add-on” techniques that can reduce the likelihood of interception. These techniques also improve the data links resistance to jamming and misdirection of the ROA so they will be discussed latter.

3.10.2. Jamming.

Once intercepted jamming of the commands to the ROA is the simpler of the two hi-jacking techniques. However because of the design of all ROA data links it will not result in a serious situation. All ROA data links have to be designed to accommodate the “unreliable” nature of the RF communications link. The percentage of time that the data link is good is dependent on a number of factors but it is always less than 100%. Because of this the ROA is designed to perform a pre-programmed schedule under these lost link conditions.

With the increased level of autonomy and sophistication required by HALE ROAs to fly in the NAS (Detect See and Avoid, auto land etc.) lost link situations will be easier to work around. In fact once hundreds of ROAs are flying in the NAS it is unlikely that they will all be in continuous communication with their ground controllers since there is not enough radio spectrum available for this to occur.

3.10.3. Misdirection.

Clearly misdirection of an ROA has the most serious consequences. However, misdirection is also the most difficult to achieve. Not only must the specific ROA data link be intercepted it must also be overridden by the interceptor and then false commands must be sent to the ROA. These manufacturer proprietary and unique ROA commands are not public knowledge but with effort could be interpreted and used to misdirect an ROA. What is simpler is just to record and then replay a command sequence that would not be appropriate in a different situation. For example bank left instead of bank right or dive instead of climb.

Again the higher levels of sophistication required by HALE ROAs to fly in the NAS will to some extent counteract the use of malevolent commands. For example, for general safety reasons, the ROA flight computer will be designed to not allow the aircraft to fly close to the ground in places other than at a, GPS accurate, approved location such as the runway of an ROA certified airport or fly close to another aircraft whilst en-route. These safety related design aspect will clearly reduce the likelihood of malevolent commands causing misdirection.

3.10.4. Additional Techniques.

There are a wide range of add-on techniques that can significantly improve the inherent ability of an ROA data link to withstand deliberate misuse. These techniques either make the RF signal harder to detect or to overpower or if the former occurs then make the data itself more robust against interpretation and reuse. As described earlier these techniques are well established and their effectiveness can be calculated.

Reducing the power spectral density of the data link RF signal (spread spectrum and frequency hopping) will combat RF interception and overpowering of the true commands by false commands. Adding data encryption techniques will protect the commands themselves from being interpreted or inappropriately reused.

4.0. CURRENT HALE ROA COMMUNICATIONS SYSTEMS PERFORMANCE.

This section discusses current HALE ROA communications systems performance based on the typical systems described in Section 2 and the metrics defined in Section 3.

4.1. AFFORDABILITY.

Current HALE ROAs utilize a wide range of voice and C2 communications equipment. As has been discussed earlier HALE ROA voice equipment is frequently identical with equipment used in manned aircraft so from a cost perspective is no different.

The bandwidth required in either LOS or BLOS systems for just HALE ROA control (and not payload back-haul) is modest and so the equipment required for this should also not be prohibitively expensive. However current implementations are expensive because of the sharing of the wide band payload back-haul discussed previously.

Any satellite based system is going to be expensive from an operational perspective. Geostationary satellite time costs in the order of $5,000 per Megahertz per month and global satellite (Inmarsat or Iridium) service costs approximately $1.0 per minute. Both of these costs can be reduced with special contracts but these items will always be significant in any operational cost model.

4.2. AVAILABILITY.

As was discussed earlier multiple parallel links of different types are used in all BLOS based systems primarily to improve availability. Typically commercial satellite data link availabilities (geostationary or global) are in the order of 99.50% for a satellite to fixed earth station data link. Two (identical) links in parallel would then yield 99.997500% (“four nines”) availability and three links 99.999987% (“six nines”). In operation this level of availability is not achieved due to the vagaries of the mobile nature of the aircraft. Little data exists to support operational availabilities in an aeronautical environment.

Information on LOS data links is also not readily available but from the experience of the UNITE HALE ROA operators it is reasonable to project similar best case availabilities to the BLOS calculation performed above.

A key factor in understanding the effect of availability is the amount of time the link is unavailable during a link drop-out. These drop-out times can range from a few milliseconds to many seconds depending on the type of link being used and the exact nature of the cause of the link drop-out. Longer drop-outs occur less frequently. Any drop-out longer than 20 to 30 seconds is almost certainly the beginning of a lost link condition or possible equipment malfunction.

If these temporary drop-out conditions are not going to cause a major problem to the operators of the system then it may be reasonable to assume that the static link availabilities cited above are achieved even in the mobile HALE ROA environment. It is certainly true that the much more frequent drop-outs of less than 200 to 300 milliseconds may not even be noticed.

File and fly access to the NAS will require the C2 communications system to support various aspects of ROA situational awareness (Conflict Avoidance etc.) Current characterization of the link availability and drop-out statistics is not adequate to precisely predict the performance of the C2 link in this respect. Funding of the capture of availability and drop-out data should be considered as part of the future ACCEES 5 program.

4.3. CAPACITY.

As described previously capacity is driven by frequency availability and frequency reuse distance.

Current HALE ROA LOS and BLOS systems operate mainly in the microwave bands at either L Band (circa 1,600MHz), S Band (circa 2,300MHz), C Band (circa 5GHz) or Ku Band (circa 14GHz). The total amount of bandwidth available in any of these bands is in the order of 200 - 500MHz but it must be shared with many other users.

Currently there is no dedicated HALE ROA C2 data link frequency band.

As a first approximation and again based on the UNITE members operational experience the C2 and voice communication needs of a HALE ROA can be satisfactorily supported with a data link transmission bandwidth of well below 100kbps. If this is taken as an upper bound then ten ROAs could be controlled in every megahertz of available spectrum, including some allowance for guard bands between each channel to avoid interference.

If we project into the future when perhaps 1,000 ROAs could be simultaneously transiting the NAS then 100MHz of bandwidth would need to be available to control them. It would certainly appear reasonable to assume a more sophisticated cellurarized network (similar to other NAS communications networks) could be developed so that frequency reuse distances of 300 - 500 miles were achieved leading to a total bandwidth requirement to simultaneously fly 1,000 HALE ROAs in the NAS of only 10 - 20MHz.

Of course there may not be enough frequency to support a thousand HALE ROAs each transmitting many Megahertz of payload data but it is unlikely that all

HALE ROA activity in the future is going to focus on this type of mission. Many other types of mission that require no real-time high data rate back-haul such as cargo transport and agricultural will be possible once file and fly access to the NAS is achieved.

4.4. COVERAGE.

Current HALE ROA BLOS systems certainly have the ability to cover the entire Continental United States with their voice and C2 communication links. However the current systems would certainly be challenged if they were required to fly to Alaska or Hawaii. Again this is partly due to the current systems supporting the voice and C2 data links on the much wider bandwidth payload back-haul data links. These wide band links can only be supported on geostationary satellites that do not have oceanic or sometimes even littoral coverage.

If a dedicated low data rate voice and C2 data link is considered then more mechanisms exist to support this type of system many of which can give truly global coverage.

4.5. GRADE OF SERVICE.

As was discussed previously latency is probably the most important aspect of this group of metrics.

Current pilot or operator control and one way ATC voice communication HALE ROA Line Of Sight (as would be typically used in the take off and landing phases of a flight) latencies are in the range of 50 to 100 milliseconds. These latencies can be longer, by approximately another 100 to 200 milliseconds, if the voice or video is digitized during transmission.

Current pilot or operator control input to observable response latencies for HALE ROA Beyond Line Of Sight operation can vary from 0.7 to 1.3 seconds.

Current one way ATC voice communication to pilot or operator HALE ROA Beyond Line Of Sight latencies can vary from 300 to 600 milliseconds.

Voice and data throughput and blockage are currently not factored into ROA communication systems design but once more ROAs start using the NAS then these parameters will drive the capacity and bandwidth requirements of the C2 system as well as begin to impact the capacity of the ATC system.

4.6. MAINTAINABILITY.

Current HALE ROAs do not take special steps to deal with maintainability. The majority of the systems are either supported by military logistics organizations or are experimental in nature. In both cases maintenance is carried out either by specialized personnel or by swapping equipment with known working equipment and returning any faulty equipment to a specialized technical center. This technical center is very likely to be the location where the equipment was initially designed and manufactured.

Certainly in the future equipment will be required with higher levels of Built in Test that would allow the pilot or operator on the ground to make a detailed assessment of the status of the system during flight and act accordingly. Maintenance schedules and diagnostic routines will also need to be developed to allow regular ground crew to support the ROA with ease of equipment replacement and short repair times being key criteria.

4.7. OPERABILITY.

4.7.1. Size, weight and power consumption.

Current HALE ROAs have overall payload capacities of between 20 and 50cuft in volume can carry between 100 and 500lbs of payload and have between 500 and 5,000Watts of power available for payloads.

Current HALE ROA LOS data link aircraft systems including antennas are typically 1 to 3cuft in volume, weigh 20 to 40lbs and require 100 to 350Watts of power. All well within the capabilities of the HALE ROA.

Current HALE ROA BLOS data link aircraft systems including antennas are 3-5cuft in volume, weigh approximately 100 to 150lbs and consume approximately 300 to 1,000Watts of power. Again all well within the capabilities of the HALE ROA.

Although HALE ROAs can accommodate the current data link equipment the equipment does use approximately 20 to 40% of the payload capacity of the aircraft, which may not be acceptable for all future HALE ROA applications and certainly reduces the endurance of the aircraft since less fuel can be carried.

The size, weight and power requirements of a voice and C2 only data link will be less than the figures quoted above that are for data link systems that also support payload data back-haul. A reasonable projection for a voice and C2 only data link would be 1 to 2cuft in volume, 20 to 30 lbs in weight and requiring 100 to 200 Watts of power.

4.7.2. Human Systems Interface.

Current HALE ROA voice and C2 communications systems are not highly automated and can occasionally add significantly to the pilot or operators workload. Because ROA systems have amassed less operational experience than their manned counterparts a human operator is still needed to manage unexpected circumstances or anomalous behaviors when they occur. For similar reasons even highly autonomous ROA systems still require the full time support of an operator. Many current ROA data links also require the full time attendance of a data link technician.

The majority of the Human Systems Interfaces are via computer consoles where the pilot or operator has control over frequency selection and other data link parameters and can monitor data link performance and act accordingly. The screens associated with the Data Link are part of the overall HSI for managing the ROA and provide warnings to the pilot or operator if parameters are out of range.

4.8. QUALITY OF SERVICE.

All HALE ROA voice communication systems utilize standard VHF transceivers that provide identical performance to their manned counterparts. Because of the relaxed requirements for voice distortion and Signal to Noise defined in TSO-169 and RTCA/Do-186A it is unlikely that any current HALE ROA voice system will fail to comply with these performance requirements even with the addition of the extra communication links required to connect the pilot or operator to the ROA in BLOS situations.

Typical Bit Error rates range from one error every one thousand bits ($1x10^{-3}$) to one error every one million bits ($1x10^{-6}$). At these error rates the information delivered will be adequate for its intended purpose. Most current HALE ROA data links employ error correction or detection as well as the ability to resend information if it was corrupted during its initial transmission. This additional processing increases the message error rate to easily better than one error every billion ($1 x10^{-9}$).

4.9. RELIABILITY.

The majority of current HALE ROA C2 data links support much more bandwidth and are therefore frequently more complex than would be required to safely control a HALE ROA.

Mean Time Between Failures (MTBF) for Line Of Sight data links, which as described previously are all dual redundant, are typically in excess of 100,000 hours.

This translates to the LOS equipment completely failing approximately once every 10,000 ten hour missions.

Mean Time Between Failures for global satellite data link equipment are typically in the 3,000 to 6,000 hour range. Mean Time Between Failures for the more complex geostationary satellite data links can be as low as 1,000 hours.

Current HALE ROAs typically use multiple Beyond Line Of Sight data links to compensate for these low MTBFs. Combining two satellite based BLOS systems with for example 1,000 and 3,000 hour MTBFs will result in an overall MTBF of 3,000,000 hours.

This translates to the BLOS equipment completely failing approximately once every 300,000 ten hour missions.

In practice there are many unpredictable reasons why the data links may fail that are not specifically equipment related. Under these circumstances other mechanisms such as the lost link procedure will take over.

4.10. SECURITY.

The consequences of hi-jacking of HALE ROAs are too serious to ignore. In the Reliability Work Package under ACCESS 5 the HALE ROAs operational reliability is being defined so as to provide less than a certain probability of loss of life per flight hour. Any hi-jacking threat should be considered in a similar manner.

There are many well established techniques to calculate and improve the security of the data links. What needs to be performed is a more detailed threat analysis and decision made on the acceptable risk so that an appropriate level of security can be included in the requirements.

5.0. A COMPARISON OF CURRENT HALE ROA COMMUNICATIONS SYSTEMS WITH CURRENT REGULATIONS.

The following documents have been reviewed in an attempt to find current regulations that could be applicable to defining the operation of HALE ROA voice and C2 communications systems.

NAS Concept of Operations and Vision for the Future of Aviation.

FAA NAS-SR-1000. NAS System Requirements Specification by the year 2000.

FAA NAS-SS-1000 Volume I. NAS System Specification by the year 2000.

ICAO Annex 2 (Rules of the Air, Annex 2 to the Convention on International Civil Aviation).

ICAO Annex 10 (Aeronautical Telecommunications, Annex 10 to the Convention on International Civil Aviation).

AIM (Aeronautical Information Manual).

Federal Aviation Regulations (FAR).

RTCA/DO-I86A, Minimum Operational Performance Standards For Airborne Radio Communications Equipment Operating Within The Radio Frequency Range 117.975 - 137.000 MHz.

RTCA/DO-264, Guidelines for Approval of the Provision and Use of Air Traffic Services Supported by Data Communications.

RTCA/DO-258, Interoperability Requirements for ATS Applications Using ARINC 622 Data Communications.

DOT/FAA/CT-TN03/04. The Effect of Voice Communications Latency in High Density, Communications-Intensive Airspace.

In the Far Term vision (2010 and beyond) described in section 4.2.3 of the NAS Concept of Operations ROAs performance is described by "To the extent practicable, the ROA operates in the same manner as other aircraft during respective phases of flight". This clearly reinforces the ACCESS 5 goal of seamless integration of ROAs. From this perspective voice and C2 communications must comply to the extent practicable with current and future manned regulations.

Of all of the metrics discussed in the previous two sections Availability and Latency are currently of the most interest so these will be the focus of the remainder of this section.

5.1. AVAILABILITY.

NAS-SR-1000 defines three service levels categorized according to the severity of the impact of loss of that service on safe separation and control of aircraft.

Critical Services are functions or services which, if lost, would prevent the NAS from exercising safe separation and control over aircraft.

Essential Services are functions or services which, if lost, would reduce the capability of the NAS to exercise safe separation and control over aircraft.

Routine Services are functions or services which, if lost, would not significantly degrade the capability of the NAS to exercise safe separation and control over aircraft.

Table 3-6 of NAS-SR-1000 defines Air to Ground Communications (voice and data) functions as Critical Services.

Although HALE ROA C2 communication is not covered by NAS-SR-1000 it is certainly an Essential if not a Critical Service according to the above definitions. The level of autonomy of the HALE ROA will clearly have a significant impact on the ability of the HALE ROA to continue to operate safely without an operational C2 data link. With voice recognition and a full non-cooperative collision avoidance capability a HALE ROA may be able to continue to respond to Air Traffic Controllers and maintain safe separation with minimal risk. Conversely with a man-in-the-loop only HALE ROA loss of the C2 data link is clearly much more critical to its continued safe operation. If the "Critical Service" of voice communication is carried on the C2 data link, as is often the practice with current HALE ROAs operating Beyond Line of Sight, then this will clearly have an impact on the classification of the C2 link as well.

Section 3.8.1 B of NAS-SR-1000 continues to define the requirements of the three levels of service in terms of availability, redundancy, period of loss of service and frequency of loss of service.

Availability	Critical Services	0.99999
	Essential Services	0.999
	Routine Services	0.99

Redundancy. No single failure of equipment, system, installation or facility shall cause loss of service to the user/specialist.

Single Loss of Service Duration	Critical Services	6 seconds
	Essential Services	10 minutes
	Routine Services	1.68 hours.

Frequency of Loss of Service. The frequency of occurrence goal for any loss of service shall not exceed one per week.

From the discussion on Availability in section 4.2 of this white paper "five nines" availability can be achieved by the use of multiple parallel communications mechanisms. Multiple data links will also achieve the single failure criteria required by the above redundancy statement. Loss of Service Duration and Frequency will be dependant on the technology used for the voice and C2 communication system. The six second requirement for Loss Of Service is approximately the time for the longest temporary link drop-out after which time most data link systems have declared a permanent "Lost Link". Frequency of Loss of Service information for current HALE ROA systems is not readily available but with 0.99999 Availability representing six seconds over a week's duration it is probably unlikely that current systems achieve this single loss per week criteria. It should also be clear that with typical missions lasting 10 to 30 hours the likelihood of a loss of service during any particular mission is low.

5.2. LATENCY.

The only latency requirement that exists in a released sense is contained in NAS-SR-1000.

Section 3.6.1 A5 states that;

"Voice and data communication shall have the following response capabilities:

a. Initiation of one-way air-ground voice transmissions shall be possible within 250 milliseconds of keying the specialist microphone.

b. The ground-air transmission time for data messages shall not exceed 6 seconds."

However other systems such have VDL Mode 3 (Very High Frequency Digital Link Mode 3) that digitally implement both voice and data communication between ATC and aircraft have similar 175 to 250 millisecond requirements on both up and down link latencies.

Further valuable information is contained in a report issued in January 2003 called "The effect of Voice and Communications Latency in High Density, Communications-Intensive Airspace". This report concludes that one-way delays of up to 350 milliseconds did not significantly degrade the service that was provided compared to the current analog delays of below 200 milliseconds. The report also concluded that delays in the region of 750 milliseconds had a noticeable effect on the ATC operator. This report is focused on High Density Communications-Intensive situations such as near busy airports. It is probable that longer communications latencies would not have such a significant effect in less communication-intensive situations.

No regulations currently exist that define the latency associated with the pilot in command performing any aircraft maneuvers. This is an area that will need review in the case of HALE ROAs.

From the discussion on Latency in section 4.5 of this white paper the LOS one way ATC voice communication latencies for current HALE ROA systems are very similar to the latencies for systems such as VDL Mode 3. However BLOS one way ATC voice communications latencies for current HALE ROA systems can extend up to the 750 millisecond times that caused some degradation in ATC service noted in the referenced report.

5.3 OTHER METRICS.

Of the remaining metrics discussed in Sections 3 0 and 4.0 Quality of Service, Reliability and Security are three important parameters whose performance limits need to be determined and regulated.

Quality of Service parameters can be found in RTCA/DO-I86A, Minimum Operational Performance Standards For Airborne Radio Communications Equipment Operating Within The Radio Frequency Range 117.975 - 137.000 MHz. The limits for voice communication Distortion (<7.5%), Noise Level (<25dB), Frequency Response (<6dB from 350Hz to 2500Hz) and Hum Level (< 40dB) given in RTCA/DO-186A are almost certainly met by all current HALE ROA voice communication systems since the majority of the equipment used is approved under TSO-C169 (or its predecessors C38d and C37d) that cites DO-186A as its technical standard. The additional communications link required to pass the voice traffic from the ground to the aircraft in BLOS situations is unlikely to degrade the voice performance to unacceptable levels.

Reliability may not need to be specifically defined as Availability is covered under published regulations but the Security requirements for future HALE ROA systems need to address as was described in Sections 3.10 and 4.10 of this white paper.