THE GROUND CONTROL ROOM AS AN ENABLING TECHNOLOGY IN THE UNMANNED AERIAL SYSTEM

Gary Gear, Professor of Engineering
Embry Riddle Aeronautical University, Prescott, Az. 86301
ggear@erau.edu

Thomas Mace, Director, Test Systems Directorate
NASA/Dryden Flight Research Center, Edwards, Ca. 93523
thomas.h.mace@nasa.gov

ABSTRACT

Scientific flights in the National and International Airspace are dependent on authorization from the cognizant authorities in each country of over flight. Requirements for manned aircraft vary widely, and the situation becomes more difficult when unmanned aerial systems (UAS) are involved. An important key to receiving authorization to fly civil scientific missions in each country will be to convince the authorities that public safety is not compromised by using UAS platforms. The ground control station, telemetry links, and the vehicle will need features that assure at least an equivalent level of safety for UAS as exists for manned aircraft. Currently, commercial UAS do not meet this requirement sufficiently for "file and fly" authorization. This paper discusses requirements for improvements to the ground station portion of the UAS that will enhance confidence in their reliability and proposes a realistic time line for implementing them to enable science missions with UAS worldwide and ultimately pave the way for commercial remote sensing operations.

INTRODUCTION AND BOUNDARY CONDITIONS

This paper addresses time frames characterized as near-term (fly in 1 year, comfortable in 2 years), mid-term (fly in 2 years, comfortable in 4 years), and eventual-term (fly in 4 years, comfortable in 7-8 years), where comfortable means that at least the United States Federal Aviation Administration (FAA) has accepted the characteristics discussed as appropriate for NASA UAS remote sensing operations supporting earth science research in the US National Airspace System (NAS). Although the technologies involved may considerably advance the more general use of UAS in the NAS, the intent is to enable NASA's conduct of science missions using UAS technologies, not to solve the more general problem of commercial use. We will seek other Civil Agency partners, when possible, to extend the functionality of these systems for their use. The primary driver will be the development of public use UAS for global scientific research through earth observations.

It is assumed, also, that NASA will embrace the FAA intent by working through the Certificate of Authorization (COA) system. This includes the concepts of "equivalent level of safety", one pilot-one plane, and minimal or no special air traffic control (ATC) accommodations. We will also work closely with DoD to leverage all appropriate DoD developments for the UAS, developing and adapting systems and sub-systems only when necessary to meet unique Civil requirements for national and international scientific missions.

Further, this paper addresses only the larger UAS, not the smaller, remotely piloted vehicles that are used for recreational and tactical military purposes. Generally, we are addressing ground systems for aircraft that carry payloads over 100lbs and fly at altitudes of 1,000 to over 60,000 ft, MSL, although we may conduct research and test on systems that fall into the smaller category.

UAS FUNCTIONAL CHARACTERISTICS

The UAS is a system of systems. We can break this down functionally into three major subsystems which we will call the Flight Center, the Science Center, and the Simulation Center. Although the Ground Control Center (GCS) can contain all of the ground portions of the above, we will focus of this discussion on the Flight Center function.

This functional partitioning allows for a division of responsibilities compatible with FAA requirements for safe operation of UAS in NAS. The clear division of telemetry tasks between Aircraft Command and Control (C2) and the science telemetry requirements is appropriate and consistent with FAA requirements, and allows for a far better utilization of radio spectrum bandwidth during the UAS mission. The Simulation Center utilizes the Flight Center, and if appropriate, the Science Center resources for simulation activities. This has also been our traditional model for successfully operating manned systems for several decades.

From a managerial and human engineering prospective, the clear separation of responsibilities between the Flight Center and the Science Center avoids the possibility of science related activity asking the Pilot in Command (PIC) for a deviation without proper consideration for Contingency Planning. The Science Center can request a deviation or change in the flight plan or UAS behavior through the Flight Management function, but the ultimate responsibility for the safety of the aircraft and mission falls squarely on the PIC. The PIC can then respond or decline the request as prudence dictates. The PIC is not involved in the collection of the science data or operating the science sensor suites, and therefore is available 100% for the prudent, safe operation of the UAS. Presently FAA mandates one pilot per UAS and requires continuous communications with the PIC[1].

The Flight Center

The Flight Center, as the name suggests, is responsible for the safe and appropriate operation of the UAS throughout all stages of the mission. The manager of the Flight Center is by policy, the PIC[2]. Some UAS platforms will require that portions of the Flight Center be distributed physically at different locations. A common example is that Global Hawk operations may utilize separate buildings for the launch and recovery phases of the mission, and the mission flight planning and operations may also be located in separate facilities. The responsibility of coordination and correct procedural hand-offs between multiple facilities falls entirely within the scope of the Flight Center.

UAS operations must conform to existing air traffic management facilities and procedures. Therefore, the interface with and behavioral characteristics of a UAS to be identical to that of manned aircraft. In that context, the Flight Center is designed to appear as a virtual pilot to the air traffic control system (ATC).

The principal areas of activity for the Flight Center are as follows:

- Mission Planning
- Mission Operations (PIC)
- Flight Management

Each of the principal areas of activity for the Flight Center are discussed in more detail below:

Mission Planning. The mission planning process is well understood and needs no particular elaboration here. There are published documents on what is required for a Certificate of Waiver or Authorization (COA).[3] Until UAS technology matures and the FAA allows "File and Fly", a COA will be required for operations involving US Public UAS[4].

What is particularly critical is that the UAS be completely predictable in its behavior in the even of total loss of C2 telemetry. Until a "Flight Executive" level of intelligence can be implemented in UAS platforms, different flight algorithms[5] will be required for contingency management depending on the class of UAS, area of flight operations, and other factors regarding safety of a compromised flight mission. Currently, among the large UAS, only the Global Hawk essentially flies totally autonomously. Prior to flight, all possible contingencies must be worked out and pre-programmed in the Autopilot. This process is very time consuming and mission specific. Contingency Planning is presently the limiting factor in Global Hawk deployment.

Extending the Global Hawk example, as higher degrees of decision intelligence along with the requisite databases can be incorporated into the Flight Executive, the degree of contingency planning required for any particular mission can be reduced, or delegated to the Flight Executive. The UAS will be more capable of making socially responsible decisions on its own in the event of a mission compromise.

Ultimately, a flight plan can be created, flushed through the Flight Executive, and the Flight Executive provide a list of actions it intends to take in the event of any and all possible compromise conditions. At that point in time,

---

[1] FAA Memorandum AFS-400 UAS Policy 05-01
[2] FAA Notice of Policy, Federal Register Vol 72, No 29. Feb 13, 2007.
[3] FAA Memorandum AFS-400 UAS Policy 05-01
[4] FAA Notice of Policy, Federal Register Vol 72, No 29. Feb 13, 2007.
[5] Preprogrammed set of flight maneuvers

the behavior of the UAS in a compromised mission position would be far more predictable than a manned aircraft – because it won't get tired, be distracted by personal issues, or other things that enter into human thought.

Mission Operations. Presently, all UASs except the Global Hawk require a pilot to contact fly, or minimally closely oversee the takeoff and landing of the UAS. Additionally, the FAA is requiring an appropriately qualified pilot (PIC) be in charge of – in control of (not necessarily hands on) the UAS at all times. The PIC must also maintain continuous radio communications with ATC and follow directives that may be given from time to time. It is appropriate then that the PIC be given a suitable flight control console for that purpose.

In general, it makes sense that this same console be used for the flight control of the entire mission, although presently there are exceptions. The PIC has three primary areas of responsibility during the flight: situational awareness, navigation, and communications.

Situational Awareness is provided through the forward panoramic cameras (Collectively +/- 110 ^{o}), the HUD, flight and engine health instrument displays, fuel burn, GPS, ADS-B, and the non-cooperative sensing suite. From this, the PIC can manage most aspects of the flight. Generally the PIC will be monitoring for nominal UAS behavior and watching for possible traffic conflicts. If a Sky Ball is required for adequate Sense and Avoid capability, a Sky Ball used for that purpose must be installed and exclusively under the control of the PIC[6]. The PIC must be equipped and capable of contact flying the UAS in the event of an Autopilot or other avionics failure.

The situational awareness data can be made available to the Science Center on a Read Only basis so that it can be integrated with the science data and perhaps made available on line through the Science Center WEB server if appropriate. However there is no back channel by which the Science Center can command the UAS.

Navigation is generally accomplished way point to way point. Therefore the routine portion of the PIC task is monitoring the UAS progress along the programmed flight path. Work load becomes higher if the programmed flight path must be modified in route.

ATC Communications are principally accomplished through a "radio repeater" in the UAS. This enables ATC to communicate with the PIC as if he were actually in the UAS. Handoffs can be made controller to controller, and center to center exactly the same as piloted aircraft. Radio traffic will generally consist of handoffs, transponder squawk, altitude confirmation, and possible conflicting traffic callouts. These are activities identical to that of PIC for a manned aircraft.

Information about the actual flight may be concurrently sent to the Simulation Center for recording. This includes PIC and Autopilot inputs to the UAS, aircraft response in the form of Situational Awareness including DGPS and Inertial Navigation information, and images captured real time from the forward looking cameras. These recordings can be used at a later time to validate the simulation models and provide a more realistic simulation environment.

Flight Management. Flight Management tasks may be appropriately be assigned to a co-pilot so that the person covering flight management tasks can function as a backup to the PIC. If this is to be the case, the co-pilot would have to possess the same qualifications and ratings as the PIC. There are three principal areas of responsibility:

- Mission Planning
- Contingency Management
- Communications with the Science Center

If nothing changes, the mission planning portion would have been completed prior to flight launch. However ATC may direct a flight plan amendments, the Science Center may request a change, or there may be an equipment failure or weather situation that creates a mission compromise. In this case, the mission needs to be quickly re-planned, and most importantly the contingency plans need to be reevaluated and appropriate changes programmed into the Autopilot.

Contingency Management again falls in the category that if nothing changes or goes wrong, the contingency planning has already been done prior to flight launch. However there are several factors that could require a revision of the contingency plan. These include:

- A change in winds or weather
- Unexpected conflicting air traffic
- Equipment failures
- C2 Telemetry link frailties – perhaps unexpected interference
- Additional manned aircraft traffic in shared airspace
- Radio communications failure (with control link still operational)

[6] FAA Memorandum AFS-400 UAS Policy 05-01

Ultimately, all UAS's should be capable of autonomous landing in the event of a total C2 telemetry loss. Alternate airports, approaches, etc. should be part of the contingency plan and may require updates enroute.

Communications with the Science Center will also have to take place. In order to not overburden the PIC, this communications task has been assigned to the Flight Management function within the Flight Center, or through a designated Mission Manager in the Science Center. This further isolates the PIC from requests made by the Science Center so that safety, flight planning, and contingency planning can properly take place before flight changes are made.

Necessary Features for the Flight Center

The feature set of the Flight Center presented here is specifically architected to facilitate UAS access to United States National Air Space (NAS)[7], although it is assumed that the requirements for international airspace will be very similar. The FAA has been quite specific and inflexible on a number of topics that directly apply to safe UAS operation. Several key requirements directly apply to this document:

- One Pilot – One Aircraft[8]
- An Equivalent Level of Safety (ELOS) to that of manned aircraft including sense and avoid capability[9]
- Crew member technical and medical qualifications[10]
- Total predictability in the event of lost C2 telemetry
- Resources required for safe flight operations are to be dedicated to flight operations and under total control of the PIC. Information required by the Science Center should be collected by sensor suites installed for science purposes

These features need to start out as the best we can do and fly within one year. They also need to evolve into the richer feature set we would like in place 4 to 7 years from now. In many cases, the mid timeframe is really just a meaningful step toward the eventual implementation desired. They all interact but are grouped here under the functional capabilities for situational awareness, compromise management, telemetry/communications, and the flight executive.

Situational Awareness can be confined to those things that affect flight safety and the ability to properly respond to compromised conditions.

Near term, the concept of "pilot in a bubble" is introduced in the context that the ground PIC would have the same or better visibility as a pilot in a manned aircraft. The pilot in a bubble would require substantially more telemetry bandwidth than current systems to support the additional video channels, but the PIC visual presentation could be substantially enhanced by fusing a synthesized image of the peripheral views to provide the pilot a more panoramic view perhaps reducing the demand on video telemetry bandwidth. Further, adding center RADAR and ADS-B[11] data to the visual bubble in the form of graphic objects positioned in the PIC field of view appropriately, would add to the quality and completeness of the PIC picture.

The mid time frame could involve the fusing of on-board radar data to provide information on non-cooperative platforms operating in proximity. Other sensor suites are likely to come available within this time frame that could additionally enhance situational awareness. Again the output data would ultimately be fused into the visual image presented to the PIC.

Eventually, the situational awareness information needs to be digitized and presented to the Flight Executive in a usable form such that the Flight Executive can make autonomous decisions regarding compromise management in the event of total loss of communications with the PIC. The intent is to always leave the PIC in the loop and in charge of all aspects of the flight safety, the autonomous capability of the flight executive only comes into play in the event of total loss of communications with the PIC.

Compromise Management As in manned aircraft, compromise management would be handled by the PIC, unless communications between the platform and the PIC is totally lost.

Near Term, the UAS will be highly dependent on redundant telemetry links so that loss of one link path does not create an unnecessarily dangerous situation.

.
[8] FAA Memorandum AFS-400 UAS Policy 05-01
[9] http://www.cgar.org/information_research.asp?E=1&PROJID=55, et.al.
[10] ibid.
[11] Until FAA deployment of ADS-B is adequate, a Ground Based Transponder (GBT) will have to be included as part of the UASGCF feature set

Mid term, the Flight Executive will have a richer feature set with which it can handle lost C2 situations. Here the Flight Executive should be able to make choices between several mission abort scenarios.

Eventually, the Flight Executive will be able to handle a wide range of flight compromises and make socially responsible decisions as to what action to take. In order for this to take place, the information presented to the PIC will have to be made available digitally to the Flight Executive so that responsible decisions can be made.

Telemetry/Communications Near Term, enhancements will have to be made to both the C2 telemetry links and the various telemetry links required to support the transport of science data. The existing C2 on HALE/MALE (high altitude long endurance and medium altitude long endurance) class UAS's will not adequately support the Pilot in a Bubble. Additional video links will be required and, because they are necessary for flight safety, they will have to be regarded as C2 and probably qualified class A software. Science telemetry should be routed using separate hardware and networking to avoid the Class A requirement. This would enable data routing through various channels, onboard storage, and limited communications through Iridium, or other, relatively low-speed modem links.

Mid Term, C2 may have to be enhanced with augmented line of sight techniques such as air-air-ground hops. This will enable the expansion of range without reliance on satellite resources. The capabilities or the science telemetry stream will be expanded to include both lossy and lossless compression techniques. Protocols will evolve such that airborne networking capabilities will become available. While networking technology in its various forms greatly increase the utility of the telemetry links, they do not, by themselves, decrease the bandwidth requirements.

Eventually, bandwidth needs will continue to increase as bandwidth availability continues to erode. There will be continuous pressure to make optimal use of the bandwidth we are able to obtain while developing alternate technologies such as spread spectrum or narrow beam line of sight.

Flight Executive. From a technology point of view, the Flight Executive capabilities and authority under compromise conditions will have to evolve from primarily PIC to onboard computer decision making.

The near term implementation of the Flight Executive will be hardware capable of monitoring platform position and altitude, and have the capability of commanding flight to a predetermined location for the purpose of reestablishing C2 communications, or alternately terminating flight.

Mid Term, software databases and fault tree logic will be added such that the Flight Executive can make more informed recommendations to the PIC (assuming good C2). Alternate strategies in the event of a compromise can be considered and in the event of lost C2, the platform can choose among several flight termination options.

Eventually, the Flight Executive must have available all of the data necessary to make the same decisions that a PIC could make in the event of a compromise. This would include digital terrain data, population data, ATC data, awareness of other aircraft in the area, aircraft health, and other things a PIC would be expected to know. Based upon that information and a pre-programmed decision tree, the Flight Executive would be capable of making responsible decisions in the absence of a PIC.

Enabling Technologies

Telemetry. Near Term, the immediate telemetry related implementations include an expansion of the C2 links to include additional bandwidth required to support the Pilot in a Bubble. It is expected that the additional bandwidth will be implemented line of sight The additional video links will use MPEG compression to reduce bandwidth requirements substantially below that required for uncompressed video. Science telemetry should utilize the capabilities available today in the REVEAL (Research Environment for Vehicle-Embedded Analysis on Linux—a vehicle-independent communication gateway for payload networks—see companion paper). This includes the ability to subsample, record, and route data through multiple available transport schemes like satellite, line of sight, and the various frequency bands presently available.

Mid Term, the additional C2 bandwidth required might be somewhat reduced through the use of simulation techniques to fill out the Pilot in a Bubble panoramic field of view. These techniques might allow for the subsampling of video data with intermediate data images synthesized. Line of sight range can be increased using Augmented Line of Sight (ALS) techniques like air-air-ground hops thus reducing the reliance on satellite resources. Science telemetry will be greatly enhanced through the expansion of REVEAL capabilities including lossy and loss-less compression, network like packetizing of data. Capabilities like subsampling of data for real time transmission concurrent with full bandwidth recording, although available to some degree Near Term, will be more fully developed and utilized. Telemetry data management will become more like a menu of choices where a client can choose what means (or combination of means) he wants to utilize based upon his operating budget.

Eventually, C2 telemetry will become more integrated and less vendor proprietary so that NASA has the ability to manage the C2 link in a manner far more consistent with the requirements of the Ground Control Facility. Science telemetry will begin looking much more net-centric but very likely not internet aware. The Internet awareness will be supported within the Ground Control Facility where servers can reside and security concerns can be more classically addressed. The issue of bandwidth (or channel allocations) will continue to be a substantial problem and clearly the limiting item for real time science telemetry. Techniques like spread spectrum and higher frequency bands (above KU) will have to be exploited.

Situational Awareness. Near Term, the first implementation of the Pilot in a Bubble will be deployed. This will include panoramic monitors in the PIC console. Displays will incorporate center RADAR and perhaps ADS-B data in the form of visual objects overlaid on the video display.

Mid Term. the side monitors of the panoramic view will contain graphic images synthesized using simulation techniques. The intent is to have the primary image synthesized but aligned and augmented with the cameras on the platform. In this way, terrain features and graphics representing other aircraft will not be obscured by prevailing weather or smoke. This decreased reliance on the video downlinks will reduce the bandwidth requirements for the C2 telemetry links. Video compression rates can be adjusted up or down depending on the quality of resolution required of the video link at the PIC bubble. Compact radar should become available greatly enhancing our ability to sense non-cooperating aircraft. The RADAR data will be fused with the cooperating aircraft data from center RADAR and ADS-B and displayed in the PIC bubble as graphic objects.

Eventually, all of the knowledge displayed visually in the PIC bubble will be made available in digital form to the Flight Executive such that the Flight Executive is able to make responsible recommendations [or decisions in the absence of a PIC] to reflect flight plan changes due to conflict management or compromised conditions.

Flight Executive. Near Term, suitable computational hardware can be assembled and configured appropriately for the Flight Executive function. Software algorithms can be implemented that satisfy the Flight Termination function, which might now be more appropriately be termed Flight Recovery Function. These might include a simple fault tree with several recovery options, one of which is flight termination.

Mid Term, appropriate databases such as Digital Terrain, Population, and ATC will be added to the Flight Executive knowledge base. More involved fault tree and decision tree algorithms will be incorporated such that the recommendations made to the PIC or decisions (in the absence of the PIC) are better informed and more socially responsible. The cooperating and non-cooperating aircraft data available to the PIC display bubble will be up linked to the Flight Executive so that this knowledge can be incorporated in the decision tree.

Eventually, we would like the Flight Executive equipped with the requisite knowledge, the aircraft specific fault tree, and the government standards-based decision tree algorithms incorporated in the Flight Executive such that the Flight Executive is making socially responsible recommendations, or in the absence of the PIC, socially responsible decisions regarding the management of the aircraft flight.

CURRENT DEVELOPMENT

The NASA Dryden Flight Research Center (DFRC) has operated Remotely Piloted Vehicles for decades as part of its flight research and test operations. Some have been quite sophisticated, such as the recent X-43 (Mach 10 scramjet powered vehicle) and the X-45 (Unmanned Combat Air Vehicle, tested jointly with the USAF and Boeing), and others are of the model class used to develop and demonstrate various prototype airframes and flight technologies.

Building on this legacy, DFRC has conducted Airborne Science Missions jointly with other entities, to develop mission capabilities using the Altair (Predator prototype) UAS under contract with General Atomics. Currently, we have acquired a Predator-B aircraft (named Ikhana) and associated GCS and anticipate delivery of two Global Hawk prototypes for Earth Science Missions. We also have an ultralight RPV and several scaled models for use in pilot training and C2 research. Each system has its own unique command and control system.

Within our Simulation Facility, we have begun developing a UAS Simulation Laboratory, where we are working on some of the elements described, above. The intent is to develop a robust Universal Ground Station for use across all UAS platforms that will set standards for commercial systems within the NAS. The rate of development will depend on funding profiles. In the meantime, we will be conducting science missions initially using Ikhana and its commercial ground station. It is anticipated that, as the UASGCS develops further, and as the FAA becomes more familiar with UAS science operations, the COA process will become much shorter, and UAS will become an integrated tool with manned aircraft and satellites in addressing important research questions in environmental science.

We expect UAS development will continue to be dominated by Military applications. Civil uses will depend greatly on how effectively the civil agencies can operate through the COA process. Commercial use will require “file and fly” authorization, which is unlikely within this decade. Unless significant progress is made in developing and standardizing the UASGCS as a robust and accepted part of the UAS, it unlikely that UAS will become part of the routine platforms for environmental observations.[12]

REFERENCES

FAA Memorandum AFS-400 ‘‘Unmanned Aircraft Systems Operations in the U.S. National Airspace System—Interim Operational Approval Guidance’’ (UAS Policy 05–01).

DEPARTMENT OF TRANSPORTATION, Federal Aviation Administration. 2007. 14 CFR Part 91, Docket No. FAA–2006–25714; Notice No. 07–01], “Unmanned Aircraft Operations in the National Airspace System” Federal Register Vol 72, No 29.

http://www.cgar.org/information_research.asp?E=1&PROJID=55.

[12] These opinions and conclusions are only the authors and, as such, do not necessarily reflect the views of NASA, the Federal Government, or Embry Riddle University. They do not necessarily reflect U.S. Policy.