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HUMAN FACTORS CHALLENGES FACING UAS INTEGRATION INTO THE NAS

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The need to fly Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) is increasing at a rapid pace. In order to address some of the issues impeding regular UAS access to the NAS, the National Aeronautics and Space Administration has begun a new program to assist the FAA and stakeholder community in establishing requirements for routine operations. One of the technical pillars of this program is the Human Systems Integration (HIS) effort which will work toward two major objectives: development of a research test-bed and database to provide data and a proof of concept of a Ground Control Station (GCS) for UAS integration into the NAS; and work with standards organizations to develop human factors guidelines for GCS operation in the NAS. In addition to a brief overview of the HSI program and objectives, members from the HSI group will present what they consider the biggest human factors challenges to the integration of UAS in the NAS, and how these challenges will be addressed in the program. The authors have been chosen for their individual expertise in differing areas relevant to the issue such as: military and civil UAS operations, small UAS operations, air traffic control and airspace management, pilot/operator challenges, and guidelines development. This paper therefore attempts to provide a comprehensive overview of the wide range of human factors challenges facing the integration of UAS into the NAS for regular operation.

Continuing demand for the use of Unmanned Aircraft Systems (UAS) has put increasing pressure on airspace operations in civil airspace. The need to fly UAS in the National Airspace System (NAS) in order to perform missions vital to national security and defense, emergency management, and science, is increasing at a rapid pace. In addition to limiting UAS usage for civilian applications, current Federal Aviation Administration (FAA) restrictions on UAS access to the NAS constrain the U.S military's ability to fulfill regular training requirements to prepare UAS operators for combat. The National Aeronautics and Space Administration (NASA) has begun a new program to support the UAS community in developing a national strategy for the integration of UAS into the NAS. Program leaders aim to transition design guidelines, algorithms, technologies, operational concepts, and knowledge to the FAA and stakeholder community to assist them in establishing requirements for routine operations.

As one of the technical pillars of this new NASA program, the HSI effort will apply human factors research principles to achieve two major objectives: development of a research test-bed and database to provide data and a proof of concept of a Ground Control Station (GCS) for UAS integration into the NAS; and collaboration with standards organizations to develop human factors guidelines for GCS operation in the NAS.

The purpose of this paper is to provide a brief overview of the HSI program and how it fits within the larger program, proposed methodology, and research objectives, presented by the technical element's Project Engineer. In addition, four other members from the HSI group will present what they consider the most important human factors challenges to the integration of UAS in the NAS, and how these challenges will be addressed within the scope of the program. They will detail previous research efforts and findings, and present how this knowledge will be applied to future research in this new area of UAS integration into civil airspace. The authors have been chosen for their individual expertise in differing areas relevant to the issue, thus providing a comprehensive overview of the wide range of human factors challenges being faced. The authors' areas of expertise and backgrounds include: military and civil UAS operations, small UAS operations, air traffic control (both current and NextGen) and airspace management, pilot/operator challenges, and guidelines development.

UAS in the NAS: Human Systems Integration

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NASA is initiating a project to address the formidable technical barriers related to safety and operational challenges associated with routine access of UAS to the NAS. The program will address an increasing need to fly

UAS in the NAS to perform missions of vital importance to Homeland Security, Defense, Emergency Management as well as commercial applications, which directly supports goal six of the National Aeronautics R & D Plan (2010) to “develop capabilities for UAS NAS integration”. The overall effort will cover four key technical areas; 1) Separation assurance, 2) Human Systems Integration, 3) Communication and 4) Certification. While these technical areas will necessarily interact, the current discussion will focus on the Human-Systems Integration (HSI) element.

The focus of the HSI effort is specifically on safe access to the NAS. It seeks to provide the capabilities, meet the information requirements and allow interactions with current and NextGen airspace operations. This effort will NOT address overall human factors problems concerning Ground Control Station (GCS) design, nor offer specific solutions for a particular UAS. Instead, the primary goals are to define the information requirements for a UAS to operate in the NAS (now and future), and how to present that information in an integrated/intuitive fashion. This last step is critical to ensure that operator workload remains manageable while increasing situation awareness of the airspace and the entities operating in that airspace. A prototype display suite will be integrated with an existing ground station to serve three purposes; 1) serve as a test-bed for procedures/ displays, 2) provide data input for guideline development, and 3) serve as an instantiation/ proof of concept of those guidelines. Another key goal of this effort is for NASA to work with standards organizations to capture the lessons learned from this effort and others as guidelines for the design of GCS access to the NAS.

A workshop that includes stakeholders from industry, academia, and government will be conducted to ensure that all critical issues are addressed, that no unnecessary duplication of effort takes place, and that strategic partnering is pursued to maximize limited resources. In addition to the workshop, two key tasks will be completed in the first year of the project. An information requirements task will be the crux for all the future work. Through analytical evaluation of the Federal Air Regulations (FARs), interviews with manned aircraft pilots, ATC and UAS operators, we will determine what information is required for UAS operators in a ground station to operate in the NAS, including update rates, latencies and accuracies of the information. In addition, a literature survey and review of all existing ground stations will be completed, including any fielded systems as well as R & D efforts, to ensure that the project will build on, and not duplicate, on-going efforts for operation in the NAS.

Taking the findings of these efforts into the later years of the project will serve as the basis of simulations and flight tests to develop, test and document a prototype candidate display suite that allow integration into the NAS. This work will, in turn, serve as the database with which to work with standards organizations to develop guidelines for UAS GCS operation in the NAS. The project will endeavor to use this and other forums to keep the UAS and Aviation Psychology communities abreast of our efforts.

Challenges to the Seamless Integration of UAS into NextGen: Supporting Pilot Roles and Responsibilities

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A major challenge to routine operations by UAS in the NAS is the need for special handling by air traffic control (ATC). This need is due to the discrepancies between how UAS vehicles and manned aircraft are presently managed. Today these systems are handled on a case-by-case basis and require special permission for almost all operations in positively controlled airspace (where separation is a direct responsibility of the air traffic controller), such as flight levels above 18000 ft and terminal control areas (TRACONS). In these airspaces, for a UAS vehicle to look and feel to the controller like other vehicles operating in positively controlled airspace the vehicle would have to behave like other manned vehicles. This will require UASs to:

1. File a normal flight plan: departure and arrival locations, en route routing, altitude, etc.
2. Conduct normal departure, climb-out and landing procedures; no special handling
3. Maintain see and avoid and collision avoidance from other traffic (both IFR and VFR traffic)
4. Establish and maintain routine communication with the controller, where lost comm. is a rare event.
5. In the event of lost comm. follow standard radio out procedures so that the controller can predict what control actions are needed to maintain safety of flight for the UAS and others operating near the UAS.
6. Respond to control instructions in a timely manor
7. When requested expedite responses to control instructions
8. Maintain a minimum safe distance from convective weather, icing, and turbulence

Unfortunately, UAS vehicles are not uniformly equipped with standard communication and navigation equipment, do not have see and avoid capability, and their pilots (we use the generic term ‘pilot’ without taking a stand on required training) are often not in regular direct radio communications with ATC. As a result of these and other differences between UASs and manned aircraft operations (both VFR and IFR) in the NAS, the FAA typically requires sterile corridors for UAS arrivals and departures, and blocked airspace during en route flight.

However, fitting into today’s NAS is both an easier and a harder proposition than fitting into the NAS as it evolves over the next 5-10 years. Over the next decade the system for management of positively controlled airspace will undergo a transition. This new system, called NextGen, is being designed around operational concepts that require trajectory-based operations (TBO). In TBO an aircraft is expected to maintain a 4D trajectory, or flight plan, that is sufficiently detailed to support ground-based conflict detection and resolution. The primary reasons for this is to provide automated separation assurance systems, managed by groundside automation, with intent information that will in turn enable automated conflict detection and resolution support to air traffic controllers; and to ensure schedule conformance. The job of the pilot will be to monitor and ensure conformance to the 4D trajectory. This method of controlling the aircraft is an outer-loop supervisory control function. Inner loop control will continue to be handled primarily, by automation embedded in the flight management systems and autopilots, and for lesser equipped, by the pilot, with the goal of keeping the aircraft on its flight plan.

To the extent that the operation of future UAS systems will also tend to be an outer-loop function, the HSI challenge for these systems will very likely parallel those being encountered in the non-UAS elements of NextGen. There are positives and negatives to this new situation. On the plus side, the GCS is not volume and weight limited in the same way as is typical for a flight deck. Subject to basic ergonomic limits, there is a lot of space in which to put displays, automation (computers), and controls (a mouse!). Also, you needn’t worry about hardening systems to deal with turbulent encounters (the aircraft may bounce but the ground station does not). So the UAS pilot is not encumbered by in-flight environmental factors that make interacting with advanced controls and displays difficult for pilots. Then there are the challenges, including those to immediate situation awareness (e.g., no window for direct viewing of traffic, weather, terrain, and other environmental hazards); no direct vestibular, visual, or auditory information that pilots typically use to monitor such things as aircraft accelerations, rotations, turbulence, loss of lift, and engine performance (sputtering, engine spikes, etc.); and those that can be traced to loss of continuity and lags in communications between the aircraft and the ground station (radio communication delays and lags, lost link).

Not all of the above challenges affect the ability to fit seamlessly into the present day and future NAS, but several elements can be identified and need to be worked. First, traffic and hazard awareness, and the ability of the UAS pilot to respond to these in a manner similar to a pilot of a manned aircraft. For present day operations this means a flight management system (FMS) and associated interface that keeps aircraft on planned trajectories, displays for weather and terrain, and conformance to the current flight plan, and an on-board system that can handle the see-and-avoid maneuvers. For NextGen operations this means displays of weather and terrain to allow pilots to effectively plan trajectory modifications; and probably displays of traffic, with conflict detection and resolution tools, that will allow them to plan conflict free modifications. Also, if there are times when the UAS must act autonomously to deal with the “see-and-avoid” traffic hazards, the problem of smooth transition of roles and responsibilities back and forth between the UAS and the operator will need to be supported.

Research Steps Towards Operating Small Unmanned Aircraft Systems in the National Airspace System

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Work within the Human Systems Integration element of the NASA Unmanned Aircraft Systems program at the NASA Langley Research Center (LaRC) will evaluate candidate “on-the-loop” Ground Control Stations that will allow UAS operators to maintain safe separation between the unmanned aircraft and other vehicles in the National Airspace System. The LaRC work has a focus on small UAS (sUAS) which present unique requirements due to portable GCS that are often equipped with point-and-click interfaces, with inner loop control handled by vehicle software. “On-the-loop” control, as opposed to “in-the-loop” control, incorporates outer-loop control, or control of higher level and typically slower changing vehicle dynamics, which requires a high level of vehicle autonomy. This high level of autonomy leads to a central problem of integrating UAS into the NAS – a potential automation mismatch between UAS and ATC. In the current system, immediate execution of ATC commands is possible because the commands typically include functions quickly accessible to the pilot on the flight deck, especially through manual control. This ability to easily execute ATC commands is likely due to evolution of piloted flight decks in concert with the NAS. sUAS, however, have evolved in user communities outside of the NAS such as the military. This evolution of system design coupled with portability requirements from both the military and hobbyists, led to operator systems with limited display space, limited vehicle system status, and limited trajectory management. Hence, quickly executing typical ATC commands can be difficult since the operator must often traverse several command menus, and possibly perform mental calculations to translate the ATC command into actions using current day interfaces, which are typically more “point and click” with minimal trajectory definition rather than “stick and rudder.”

The above characteristics – an automation mismatch between the UAS and ATC, a high level of autonomy, and portable GCS – will drive the Concepts of Operations (CONOPS) and information requirements for sUAS. The primary driving force behind the CONOPS and information requirements for the GCS will be the need for the UAS to respond directly to ATC in a timely manner. This operating condition will help define the information UAS operators need in order to aviate, navigate, communicate, and manage the systems of the vehicle in the NAS. Initially, research will establish response time requirements for ATC to the vehicle operator, and operator to the UAS for on-the-loop UAS operations. ATC to UAS command response was chosen because this response time is seen as generating the most restrictive requirements in controlled airspace. In addition, operator hand-off protocols (a change in GCS for a given vehicle) will be defined to accommodate differences in operational endurance and in some cases line-of-sight operational requirements. This effort will define procedures necessary for UAS response to vehicle specific operations during operator handoff while maintaining high levels of safety through situational awareness of the vehicle, mission, and the characteristics of the aerospace in which the vehicle is operating. Lastly, the HSI effort will incorporate off-nominal operations into any recommended guidelines. This will aid in showing the robustness and limitations of proposed concepts.

The UAS in the NAS research steps in HSI at LaRC include batch simulations with a pilot model, simulations with human-in-the-loop (HITL) or on-the-loop, and flight-testing. The batch simulations will allow for refinement of GCS concepts before HITL testing. The testing of the concepts generated will follow an incremental process such that initial testing will be with a single UAS pilot operating a vehicle alone in the NAS, then a single UAS pilot operating a vehicle with other simulated vehicles in the NAS, and finally multiple vehicles operating in the NAS that will include vehicles with varied missions and performance characteristics. This testing will provide a proof of concept and design requirements for sUAS operations in the NAS.

Flying NASA Unmanned Aircraft: A Pilot’s Perspective

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A century of aviation evolution has resulted in accepted standards and best practices in the design of human-machine interfaces - the displays and controls which serve to optimize safe and efficient flight operations and situational awareness. The current proliferation of non-standard, aircraft-specific flight crew interfaces in UAS, coupled with the inherent limitations of operating UAS without in-situ sensory input and feedback (aural, visual, and vestibular cues), has increased the risk of mishaps associated with the design of the “cockpit”. The examples of current non/sub standard design features range from “annoying” and “inefficient”, to those that are difficult to manipulate/interpret in a timely manner, as well as “burdensome” and “unsafe”. A concerted effort is required to establish best practices and standards for the human-machine interfaces, for the pilot as well as the air traffic controller.

For example, the presentation format of information is critical. Any teacher knows that the digital clock is no way to teach a classroom to tell time; children barely know the relationships between the numerical symbols, much less their values. In contrast, the traditional analogue display offers all the numbers at once, in order of their relationship, and the hands point to current time. Moreover, the ‘‘trend’’ of time is indicated by the movement of the second hand. Similarly, traditional cockpit displays —mostly analogue gauges—have needles that point at numerical values. Many gauges are labeled with ‘‘green arcs’’ and ‘‘red lines,’’ indicating the normal range of values, or limits, respectively. During typical flight the pilot routinely devotes time and attention to the assessment of information. A quick glance across analogue gauges affords the pilot a ‘‘normal’’ assessment if gauges are pointing in normal directions, without needing to read the actual numbers. In the same glance, the pilot can detect a needle pointed in ‘‘abnormal’’ or ‘‘unsafe’’ directions, and assess the condition by noting the value. In digital presentations typical of UAS , precise numbers are displayed, but the pilot must take precious moments to determine whether a number is in the normal range or is trending toward abnormal.

Terminology used in the displays is also vitally important. In these software-intensive systems, development engineers refer to interface control documents to develop the menu-driven commands and displays. When pilots are not part of the development process, the resulting terminology can be baffling. Words such as ‘‘enable’’ or ‘‘inhibit,’’ probably derived from the software coding, supplant standard ‘‘on’’ or ‘‘off’’ commands. Sometimes, clicking the cursor on a command results in the familiar, ‘‘Are you sure?’’ dialogue box common to certain PC-based operating systems. Sometimes, the results are less benign. An infamous case involved a fuel heater switch labeled, ‘‘FUEL HEAT INHIBIT.’’ The pilot was given two choices for the fuel heater command: ‘‘ENABLE’’ or ‘‘DISABLE.’’ To turn on the fuel heater required the pilot to ‘‘disable’’ the ‘‘inhibit’’ … a double negative! This protocol has been changed to, ‘‘FUEL HEATER,’’ ‘‘ON’’ or ‘‘OFF.’’

In addition, roles, responsibilities, knowledge and skill sets are subject to redefining the terms, “pilot” and “air traffic controller”, with respect to operating UAS, especially in the Next Gen NAS. The knowledge, skill sets, training, and qualification standards for UAS operations must be established, and reflect the aircraft-specific human-machine interfaces and control methods.

NASA’s recent experiences with flying its MQ-9 Ikhana in the NAS for extended duration, has enabled both NASA and the FAA to realize the full potential for UAS. Ikhana is a Predator-B/Reaper UAS modified for research. After several years of planning and negotiation, in 2007 the FAA granted a Certificate of Authorization (COA) to NASA which enabled the use of Ikhana for wildfire geo-location missions while flying in Class A airspace in the NAS. The technology which was demonstrated, coupling a NASA infrared sensor with the aircraft satellite data-link system, provided unprecedented information to fire-fighting agencies in near real-time. The concerted planning effort involved detailed analyses to optimize expected flight routes without significant impact to air traffic lanes, or flight over dense population centers, and demonstrate a safe return to home base in the case of loss of the command-and-control link. Additionally, to prepare for systems emergencies (e.g. generator failure, engine failure) which would prevent Ikhana from returning to its primary landing site at Edwards AFB, detailed analyses were performed to locate remote landing sites and selected military bases within a 50-mile glide distance of the flight route. Four initial demonstration missions, of up to 20 hours, were flown in August and September, reaching as far as Montana, Wyoming, Idaho, and Washington, covering several fires on each mission. In October, when Southern California “exploded” in multiple wildfires, Ikhana flew four missions in a five-day period. The overall success of this campaign is measured best by the feedback from the fire incident commanders- e.g. “…lives and property saved… because of NASA’s Ikhana”. The efforts by NASA and the FAA brought about a greater understanding of the implications of current limitations (e.g. lack of sense-and-avoid capabilities) in mitigating the risks and tackling the challenges associated with integrating UAS in the NAS.

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Ground control stations of a UAS range from small commercial off-the-shelf laptops, to sophisticated purpose-built shelter trailers or control facilities. The GCS, which is essentially a ground-based cockpit, must provide the pilot with the information needed for safe flight, and enable the pilot to make the necessary control inputs in a timely and accurate manner. A challenge for the designers of GCS is to enable the UAS pilot to maintain situational awareness in the absence of the rich perceptual cues available to the pilot of a conventional aircraft (Pestana, 2008).

Many of the display requirements for a GCS are similar to those in conventional aircraft, such as airspeed, attitude and the performance of on-board systems. In other cases however, the GCS must provide the UAS operator with unique classes of information. Examples are: the strength of the communication link, the frequency band in use for aircraft commands, radio spectrum activity, and the status of the GCS itself. The pilot may also require visual information on the surrounding environment, either for landing or takeoff, collision avoidance, or weather avoidance (Cooke, et al. 2006, Hobbs, 2010).

Since the early days of aviation, design principles were identified for cockpit displays and controls (e.g. Fitts and Jones, 1947). With the introduction of "glass cockpit" aircraft, much was learned about the optimal interface between human and automation (Wiener, 1988). Traditional cockpit displays and controls will have a reduced place in GCS, as unmanned aircraft are increasingly designed to be controlled via automation, with the operator making command inputs using "point and click" devices, text-based menus, and dialog boxes. Already, significant design deficiencies are being identified in GCS built using computer interfaces. Problems have included error-provoking control placement, non-intuitive automation interfaces, an over-reliance on text displays, and the need for complicated sequences of menu selection to perform minor or routine tasks (Pedersen, Cooke, Pringle, & Connor, 2006).

In summary, the design of the GCS presents several sets of challenges for NAS integration. These relate to the changed experience of the pilot (notably the reduction or complete elimination of direct perceptual cues), the unique information requirements associated with teleoperation, the heavy reliance on automation, and the introduction of displays and controls adapted from consumer electronics devices. Human factors guidelines for GCS design will help to reduce design-induced errors, maintain pilot situational awareness and ensure that pilot workload is manageable.

There are several on-going efforts to develop standards for GCS by groups external to NASA. These include RTCA special committee SC203, EUROCAE Work Group 73, and workgroups reporting to ICAO, and NATO. A difficulty faced by these groups is the wide variety of UAS and the "moving target" nature of the field as rapid technological developments continue to occur. The current project will involve coordination with these existing external groups to avoid duplication, while also coordinating with NASA research groups, notably the "GCS Database and Proof of Concept" team. While other workgroups focus on airworthiness or operational problems, the HSI workgroup will bring NASA's unique human systems integration perspective to focus on the human factors issues of GCS design.

Guided by CONOPS information, our objective is to develop best practice design guidelines for GCS, initially focusing on the human/system interface issues relevant to Medium Altitude Long Endurance (MALE) systems. This will commence with the development of broad guiding design principles for human system interface, under which will nest more specific guidelines. For example, a broad principle may relate to requirements for avoiding adverse weather. Under this would be guidelines concerning the weather challenges facing the pilot, and the information and control capabilities that must be available to the pilot to enable these challenges to be overcome.

The work will draw on existing guidelines and standards documents, including design standards for conventional aircraft cockpits and also industrial control systems, where relevant. The project will also draw on lessons learned from UAS operational experience, incident and mishap reports and direct observations of pilot interactions with existing GCS.

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