

Flying Unmanned Aircraft: A Pilot's Perspective

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The National Aeronautics and Space Administration (NASA) is pioneering various Unmanned Aircraft System (UAS) technologies and procedures which may enable routine access to the National Airspace System (NAS), with an aim for Next Gen NAS. These tools will aid in the development of technologies and integrated capabilities that will enable high value missions for science, security, and defense, and open the door to low-cost, extreme-duration, stratospheric flight. A century of aviation evolution has resulted in accepted standards and best practices in the design of human-machine interfaces, the displays and controls of 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- or sub- standard design features range from “annoying” and “inefficient”, to those that are difficult to manipulate or interpret in a timely manner, as well as to those that are “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. 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 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, as well as understand the implications of current limitations. Ikhana is a Predator-B/Reaper UAS, built by General Atomics, Aeronautical Systems, Inc., and modified for research. Since 2007, the aircraft has been flown seasonally with a wing-mounted pod containing an infrared scanner, utilized to provide real-time wildfire geo-location data to various fire-fighting agencies in the western U.S. The multi-agency effort included an extensive process to obtain flight clearance from the FAA to operate under special provisions, given that UAS in general do not fully comply with current airspace regulations (e.g. sense-and-avoid requirements).

I. Introduction

This article describes one pilot’s experiences and observations flying an MQ-9 Unmanned Aircraft System (UAS), built by General Atomics Aeronautical Systems, Inc., (Poway, California). The NASA Dryden Flight Research Center (Edwards, California) acquired an MQ-9 in 2006 and called it Ikhana (ee-kah-nah) (Fig. 1), the Native American Choctaw term for “intelligence,” “awareness,” and “learning.” NASA flies this aircraft in support of UAS technology development, Earth science research, sensor development, and satellite sensor validation. Unmanned Aircraft Systems offer the unique capabilities of high altitude and long endurance, which are especially attractive to scientists desiring continuous data collection during a complete day–night cycle of the Earth (Fig. 2).

The MQ-9 Reaper (“—Predator-B” during development) —incorporates remarkable capabilities and features such as automation, stall protection, and lost-link predictability, as well as hundreds of thousands of hours of sustained operational reliability and efficiency. Indeed, accidents and mishaps associated with UAS operations are, to a large extent, related to human error; a closer examination, however, reveals that many of these human errors are the result of design shortfalls in the human– machine interfaces. These, and other issues related to automated flight are illuminated by the author’s extensive experience with UAS operations.

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II. A Room With A View: The Pilot In The Cockpit

Imagine a pilot entering the cockpit of his airplane. There are various controls through which inputs are transferred to the flight control surfaces, the engine throttle, et cetera. There are also displays that present the condition of his airplane to the pilot:—its flight parameters of speed and altitude, and data relative to its systems, such as engine rpm and temperature. There are also navigation displays and communication devices that allow the pilot to fly among other air traffic and coordinate his flight plan with air traffic controllers. Pilots typically develop habit patterns of scanning instruments for information, devoting attention to specific displays during different phases of flight. And there are windows that offer views ahead, to the sides, and sometimes above.

Although many airplanes are equipped to fly in weather conditions where visibility is very restricted (known as instrument flight), visual contact with the runway and airfield environment is always required for taxi, takeoff, and landing. During flight at altitude, a wide field of view aids in maintaining safe separation from other aircraft. During approach and landing, the most critical and demanding phase of a flight, even peripheral vision is important because wide visibility offers the pilot a sense of motion and rate of descent as he attempts to land as smoothly as possible.



Figure 1. NASA Research Pilot Mark Pestana and the MQ-9 Ikhana UAV. *The aircraft is 36 feet long, the wingspan is 66 feet, and the weight is 10,000 lb. Note the two small camera windows in the nose.*



Figure 2. Ikhana equipped with a wing-mounted pod, carrying an infrared sensor for a wildfire research mission. *The UAS is capable of transmitting imagery and locations of hot spots and fire lines directly to fire incident commanders via a satellite link.*

A. Through A Glass Darkly: The Unmanned Aircraft System Ground Control Station

In contrast to a true cockpit, consider the prospect of flying an unmanned aircraft from a ground control station (Fig. 3). The two are very different, especially regarding the pilot's place in the system, and how that system accommodates the pilot's requirements for obtaining accurate, complete, and timely information, as well as his ability to react. Ideally, the ground control station should enable safe, efficient control and decision making.

I'm often asked what it's like to fly a UAS, or what it "feels" like. For the nonflier, I can best describe the overall "feeling" as somewhat removed, or more accurately, I cannot "feel" anything—except for apprehension at the prospect of flying an aircraft with only ONE of my five senses. That's right; four of the senses don't count. The pilot can't hear the engine, can't smell fuel vapors from a leak, can't taste the acrid smoke from an electrical fire, and can't feel the sensations of motion, vibration, and accelerations (or decelerations). In contrast, a pilot in a standard cockpit uses all five senses, in varying degrees, to determine aircraft performance and systems status. When flying an unmanned aerial vehicle (UAV), the one remaining sense—vision—must accommodate all needs, and information normally obtained with the help of other senses is now obtained by one sense alone. Moreover, the remaining sense of sight is relayed through just one, narrow-field forward camera, very different from binocular human vision. As a consequence, the view lacks three dimensions, depth perception, and peripheral vision. In essence, the pilot has ONE eye, looking down a pipe, allowing just a 30-degree field of view!



Figure 3. NASA Research Pilot Mark Pestana in the Ikhana Ground Control Station. *The Ground Control Station is equipped with two pilot positions for redundancy. Nontraditional digital systems displays are above the keyboard. The center screen displays a Head Up Display (HUD) overlay on the camera view, and the upper screen is a moving map display.*

The challenge of flying a UAS can be aggravated further by the functioning of the controls and displays, especially if they were designed without accommodating shortfalls in feedback methods. The art of designing the cockpit to enhance pilot perception and comfort, commonly referred to as human factors engineering, is a specialty that emerged after World War II, when many accidents were associated with poor human interface design features. Since then, a landing gear handle looks like a small wheel, and a flap handle looks like a small flap, and the pilot can feel their unique shapes. This practice resulted from cases in which identically-shaped toggles were easily mistaken as task saturation peaked during critical flight phases. Uniquely shaped actuators enable a pilot to multitask, to maintain visual attention to an instrument, or to look out the window, while simultaneously activating a switch. After all, humans are visual, tactile, and analog beings, continuously stimulated by the sense of touch, as well as by sound, pressure, temperature, motion, and vision. Humans inserted into the digital world of UASs must be accommodated somehow.

Finally, flying from a ground control station brings with it some unique people problems. In the cockpit, I have a “private office” in the sky. But in the UAS control station, people come and go, resulting in casual conversations when the flight crew’s attention is not saturated, and demands for silence when things get busy (Fig. 4). Moreover, hushed approaches and landings can be interrupted by ringing telephones, and there are times when whispered remarks behind the pilot’s console—“Monday Morning Quarterback-ing”—can undercut concentration. Some onlookers also liken UAS flying to a video game. They are not wrong—with a big exception. Flying is much more than moving a stick and throttle. Pilots possess a body of knowledge sometimes called “airmanship,” which is a complex of skills involving FAA regulations, air traffic control and communications protocols, weather forecasting and aircraft performance, navigating in the National Air Space, and very important aircraft systems knowledge and knowledge of emergency procedures.



Figure 4. NASA Ikhana Ground Control Station. Engineers and technicians monitor aircraft systems and science instrument in the foreground, while pilots fly the aircraft at the far end.

B. More is Less

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 analog 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. In analog, the child learns situationally.

Similarly, traditional cockpit displays (Figs. 5 and 6)—mostly analog 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 analog gauges affords the pilot a “normal” assessment if gauges are pointing in normal directions; the pilot does not need to read the actual numbers. In the same glance, the pilot can detect a needle pointed in an “abnormal” or “unsafe” direction, and assess that condition by noting the numerical value. In digital presentations, precise numbers are displayed, but the pilot must take precious moments to determine whether each number is within the normal range or is trending toward the abnormal.



Figure 5. Manned aircraft, with multiple windows, provide a wide field of view to pilots. Digital information can be displayed in human-friendly analog format on the multifunction display screens.



Figure 6. Typical cockpit displays and controls. Analog gauges marked with normal (green arc) and red-line ranges of values (upper left). Distinctively shaped flap handle, landing gear handle (below the three green lights), and autopilot switches (lower center) enable multitasking without diverting attention to look at them. Green landing gear lights are “mapped” in relative positions to nose and main landing gear.

In the case of the MQ-9 control station, which is contained in a mobile trailer or a building, almost all of the “switches” are activated by a keyboard (essentially, identically-shaped “switches”) and a trackball. The switches are menu-driven commands, embedded in software, and displayed on various screens. The pilot faces four screens. One screen displays a forward-facing camera’s view, another displays maps with a moving aircraft icon; two others display systems information, cautions and warnings, and operations menus that are selectable through a keyboard and mouse or trackball (Fig. 3). On these informational-cautionary screens, one “page” of information is shown at any time, but more than 60 additional pages are available. Each page contains different types of information about systems performance (for example, servo amperages, fuel tank quantity, rudder deflection, and planned route of flight). The control station is also equipped with traditional control stick (Fig. 3), throttle or prop levers, and rudder pedals required to fly the aircraft from taxi, through takeoff, cruise, descent, and landing. Also

provided are flap and landing gear handles. An autopilot is typically used for cruise flight, especially during long-range, long-endurance missions. The autopilot can be commanded to alter aircraft flight parameters in much the same way as that of a manned aircraft.

The MQ-9 can also fly preprogrammed flight routes, which can be reprogrammed in flight. In response to the loss of the command uplink, the aircraft will automatically revert to a “lost link” flight plan that is loaded before flight.

Obviously, to generations trained on flying practices that date, in many cases, to the Wright Brothers, piloting the UAS is a challenging experience. Often, my attention is diverted from the primary flight displays (the forward screen camera view is overlaid with “head up” flight information) because I’m “head down” using a keyboard to access the information screen displays and activate “switches.” Or I’m moving the trackball cursor on the upper map screen to access menus for changing radio frequencies. This nontraditional arrangement and display format can cause formidable challenges. It becomes absolutely imperative that the software feedback be timely and that the display be user-friendly. Embedded menus can add to the time required to accomplish time-critical actions, and divert attention from primary piloting tasks.

The 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.” My reaction: “Come on! Do I really have to think about this?” Until recently, the answer has been “yes.” To turn on the fuel heater required the pilot to “disable” the “inhibit” ... a double negative! Thankfully, this protocol has been changed to- “FUEL HEATER” “ON” or “OFF.”

III. To Boldly Go...Where No Unmanned Aircraft System is Normally Allowed

As the capabilities and performance of UASs have improved, the user community has been transitioning from strictly military operations in restricted airspace, to other government, academic, and commercial operators in the National Airspace, or NAS. Unmanned aircraft systems now compete with the traditional aircraft flown by onboard pilots—airliners, military planes, and general aviation aircraft—for a place in the NAS. Whether the purpose is border surveillance, wildfire location, university research, disaster assessments, or other nonmilitary objectives, the unique capabilities of UASs are attracting many potential users.

The Federal Aviation Administration (FAA) has established an office to explore and resolve regulatory issues regarding UASs, and to approve specific flight plans within the NAS. The FAA’s signature motto, “do no harm,” reflects the agency’s obligation to protect the public from unsafe conditions. The FAA establishes regulations and directives that govern the design standards of aircraft, airports, and the allocation of air-space; and sets standards for pilot training, qualification, currency, and proficiency.

In governing the flight of UASs, the FAA must consider a vast range of aircraft, from “hobby” rated radio controlled aircraft to fully autonomous aircraft, which are as different from each other as an ultralight is from a jumbo jet. Policies that regulate UAS operations must allow for the broad range of capabilities, otherwise, “blanket” UAS regulations could inhibit the effective use of these versatile aircraft. One example, cited during a meeting attended by NASA UAS operators, involved a volcanologist. During increased volcanic activity, the FAA typically establishes a no-fly zone that prohibits flight in hazardous areas, which is a logical measure to ensure safety. The rule, however, frustrated attempts by this scientist to operate a small UAS designed to transmit vital data. Although the researcher in this case was willing to accept the loss of the small UAS given the importance of the data, current FAA regulations lack the flexibility to accommodate unique cases—a typical frustration among many potential UAS operators. Nonetheless, the FAA has a sense of urgency toward establishing guidelines that enable the expansion of UAS flight in the NAS while still preserving public safety.

Probably the single greatest hindrance to the FAA allowing unrestricted UAS flight in the NAS is the inability to satisfy the FAA requirement to “see and avoid,” or, with UASs, “sense and avoid,” other aircraft. The major problem lies not with UAS flight in Class A airspace, where all aircraft have transponders that reveal their position on radar and all are communicating with air traffic controllers, but with the airspace below Class A, which can be populated by airplanes not having transponders, and within which pilots must be able to see and avoid other aircraft. Unfortunately, this challenge is difficult to measure and quantify. Depending on the situation, an aircraft can be virtually invisible. Characteristics such as lighting conditions, visibility, contrast, color, distance, motion,

size, texture, atmospheric filtering, contrails, reflectivity, visual acuity, weather, and external lights affect our ability to see other airplanes (Figs. 7 and 8). Indeed, on the same day that I saw a contrail over 80 miles away, Air Traffic Control told me that a light aircraft was detected less than 2 miles away from me, 1,000 ft below my altitude. I searched desperately for it against the background of a densely populated city, but never did see it.



Figure 7. With the exception of seeing a contrail against a clear sky, visually tracking other air traffic can be difficult. A number of factors (for example, lighting, atmospheric filtering, color, contrast, et cetera) contribute to the challenges of visually recognizing potential conflict, especially against a “busy” background of variable shapes and colors. Note airliner at upper center of photograph.

Figure 8. Airliner seen against city background. This particular airliner is painted in bright colors, which helps in distinguishing it against the background. UASs, in order to comply with FAA procedures and regulations regarding “sense and avoid” capabilities, will likely require a fusion of data sources (that is, visual, radar, and infrared) provided to both UAS pilots and air traffic controllers.



IV. Western States Fire Mission: Success in the National Airspace System

After several years of planning and negotiation, in 2007 the FAA granted a Certificate of Authorization or Waiver (COA) to NASA which enabled the use of Ikhana for wildfire geo-location missions while flying in Class A airspace in the NAS^{1,2,3}. The technology that 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, no flight over dense population centers, and a demonstrated safe return to home base in the case of

loss of the command-and-control link. Additionally, to prepare for systems emergencies (for example, a generator failure or an engine failure) which would prevent Ikhana from returning to its primary landing site at Edwards Air Force Base, detailed analyses were performed to locate remote landing sites and selected military bases (Fig. 9) within a 50-mile glide distance of the flight route, from the assigned altitude of 23,000 ft (FL 230). NASA performed a detailed assessment of proposed remote landing locations, meeting specified conditions for minimum population density and distance from high-value assets. The MQ-9 having no anti-icing or de-icing systems, the NASA team was also challenged by adverse weather conditions along assigned flight routes. Real-time coordination with the FAA allowed for safe deviations.

Utilizing a schedule of one flight every other week, four initial demonstration missions were flown in August and September, 2007, flying for up to 20 hours and as far away 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: “...lives and property saved...because of NASA’s Ikhana...” California’s Governor visited the NASA Ames Research Center (Moffett Field, California), where the infrared scanner was developed, and recognized the value of this UAS demonstration in a press release.⁴

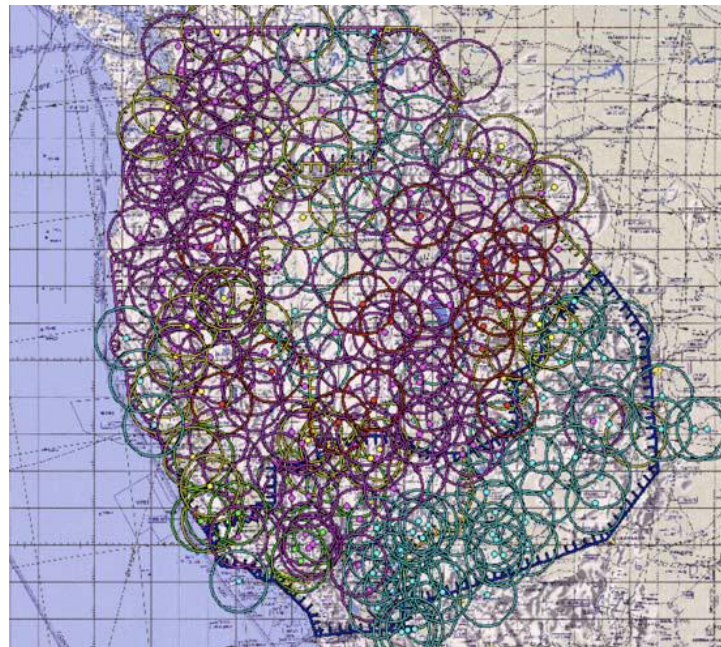


Figure 9. Emergency landing sites for Ikhana wildfire missions. Each circle represents the 50-mile glide distance from the assigned mission altitude, 23,000 ft. A subset of sites were chosen for specific flight routes. Pilots practiced landings in a simulator with satellite signal latency, and described it as “learning to land a few seconds into the future.” Adverse weather also caused challenges associated with flight planning and re-routing, since the MQ-9, like many UASs, is not equipped with anti-icing or de-icing systems.

V. What Lies Ahead?

The utility of UASs is growing, along with the number of potential users. The UASs offer the ability to serve niches in which manned systems are limited or are not safe. Whether the mission is boring, mundane, routine, long-duration, or in a hostile, high-risk environment, the UAS is here to stay. The FAA continues to try to accommodate the UAS community, but much remains to be done. Sense-and-avoid technology and frequency allocation are the most difficult challenges. Additionally, the systems themselves must take into consideration the human element. Boredom, fatigue, and minimal sensory stimulation during long-duration, automated flight continue to be impediments. If UASs are to join the ranks of passenger jets, military aircraft, and general aviation aircraft that currently share the NAS, human factors engineering will need to provide pilots something similar in appearance and function to a complete cockpit, as opposed to a static and detached ground station. The ultimate NAS-compliant UASs will require technology to autonomously sense and avoid other traffic, re-route around adverse weather, and choose alternate and emergency landing airports...while humans “monitor.”

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The viewpoints expressed in this article are the author's and do not necessarily reflect those of NASA.

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⁴Press Release GAAS:525:08, "Governor Schwarzenegger and NASA Highlight Infrared Scanning Technology Helping to Fight California's Wildfires," Statement from the Office of the California State Governor, July 14, 2008.

⁴This statement was released to news media on July 14, 2008 from the Office of the California State Governor.

07/14/2008 GAAS:525:08 FOR IMMEDIATE RELEASE

Governor Schwarzenegger and NASA Highlight Infrared Scanning Technology Helping to Fight California's Wildfires

Governor Arnold Schwarzenegger today joined NASA and federal and state fire officials at the NASA Ames Research Center in Moffett Field to tour the facility and discuss the important role of NASA's remotely piloted aircraft, named Ikhana, to California's firefight. The unmanned aircraft carrying a NASA infrared scanning sensor flew over much of California this past week, gathering information that was delivered to fire commanders in the field-helping them understand the terrain and behavior of the state's most dangerous fires. "California's unprecedented number of fires this early in the season make it all the more important that we use every tool at our disposal to protect property and save lives," Governor Schwarzenegger said. "NASA's Ikhana is one more incredible tool that we are able to use this year to bring real-time pictures and data to fire commanders, even when our other aircraft are unable to fly. The federal government has been an active partner in helping California fight fires, and NASA's assistance is one more example of that cooperation. " The Ikhana's most recent mission was on Tuesday, July 8. It flew for more than nine hours and covered approximately 10 individual and complex fires along a route over the Sierra Nevadas, west to the Cub Complex fires and south to the Gap Fire in Santa Barbara County. The images are collected onboard the Ikhana and transmitted through a communications satellite to NASA's Ames Research Center in Moffett Field, CA, where they are superimposed over Google Earth and Microsoft Virtual Earth maps to better visualize the location and scope of the fires. The imagery is then transmitted to the Multi-Agency Coordination Center in Redding and the State Operations Center in Sacramento, which distributes it to incident commanders in the field, so they can deploy resources where it will have the greatest benefit. NASA satellites are also capturing imagery of the wildfires to fill in gaps in airborne imagery. For these images and additional information, visit:

www.nasa.gov/topics/earth/features/fire_and_smoke.html