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Ikhana: A NASA UAS Supporting Long Duration Earth Science Missions

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ABSTRACT

The NASA Ikhana unmanned aerial vehicle (UAV) is a General Atomics Aeronautical Systems Inc. (San Diego, California) MQ-9 Predator-B modified to support the conduct of Earth science missions for the NASA Science Mission Directorate and, through partnerships, other government agencies and universities. Ikhana, a Native American word meaning "intelligence," can carry over 2000 lb of remote sensing and atmospheric sampling instruments in the payload bay and external pods. The aircraft is capable of mission durations in excess of 24 hours at altitudes above 40 000 ft. Redundant flight control, avionics, power, and network systems increase the system reliability and allow easier access to public airspace. The aircraft is remotely piloted from a mobile ground control station (GCS) using both C-band line-of-sight and Ku-band over-the-horizon satellite datalinks. The NASA GCS has been modified to support on-site science monitoring, or the downlink data can be networked to remote sites. All ground support systems are designed to be deployable to support global Earth science investigations. On-board support capabilities include an instrumentation system and an Airborne Research Test System (ARTS). The ARTS can host research algorithms that will autonomously command and control on-board sensors, perform sensor health monitoring, conduct data analysis, and request changes to the flight plan to maximize data collection. The ARTS also has the ability to host algorithms that will autonomously control the aircraft trajectory based on sensor needs (for example, a precision trajectory for repeat pass interferometry) or to optimize mission objectives (such as a search for specific atmospheric conditions). Standard on-board networks will collect science data for recording and for inclusion in the aircraft high bandwidth downlink.

The Ikhana project will complete GCS development, science support systems integration, external pod integration and flight clearance, and operations crew training in early 2007. A large-area remote sensing mission is currently scheduled for Summer 2007.

NOMENCLATURE

ARTS	Airborne Research Test System
GCS	Ground Control Station
GPS	Global Positioning Satellite
NASA	National Aeronautics and Space Administration
NTP	Network Time Protocol
PSO	Pilot and Sensor Operator
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle

INTRODUCTION

To support its Earth Science mission, NASA utilizes ground, airborne, and space-based sensors. Airborne measurements are traditionally taken using high altitude balloons and piloted aircraft, each with its own benefits and drawbacks. Balloon-based measurements benefit from long-duration flight time and high altitude, but suffer from an inability to control the trajectory. Piloted aircraft have precise control of the measurement locations (latitude, longitude, and altitude), but are limited by aircraft range and endurance limitations. Piloted aircraft endurance is further limited by crew duty limitations (frequently 8 to 10 hours).

Unmanned aerial vehicles (UAVs) have recently been introduced as airborne remote sensing and/or in-situ measurement platforms. In many cases, UAVs offer capabilities unable to be obtained by piloted aircraft, though these capabilities vary greatly with the configuration. Small UAVs offer very low cost missions, though they suffer from minimal payload capability, low altitude, and low speed. Some midsized UAVs have up to 24-hour endurance with increased payload and higher altitudes. The largest UAVs offer payloads in excess of 500 kg, endurance capabilities greater than 1 day, and altitude ceilings above commercial air traffic.

Unpiloted aircraft have other benefits over piloted aircraft for some missions. At present, there is a significant science data collection need for polar missions. Polar missions necessitate long endurance and range over remote areas. In the past, piloted flights over the polar regions involved greater risk because of the lack of divert landing sites during an emergency. Use of a UAV in this case would eliminate the increased threat to human life. A similar case can be made for sustained operations over many critical ocean areas.

A recent NASA-sponsored study identified capabilities and technologies that are needed to enable new or improved science missions using unmanned aerial systems (UAS). The capabilities included operational needs like access to airspace, better communication networks, and increased reliability, as well as mission capability improvements like autonomous mission management, precision trajectory, and vertical profiling. To meet the need for a dedicated UAS development platform, NASA decided to acquire an unmanned aerial vehicle.

A Predator-B was the choice for a large-scale development and science mission platform. The selection was based on payload, endurance, altitude, reliability, and cost. Both the aircraft and ground station have been procured and the systems are nearing operational status. In the summer of 2007, NASA will begin science campaigns with the aircraft.

AIRBORNE SYSTEMS

To make an unmanned aircraft system suitable for science data collection, a capable aircraft must be joined with systems to support the sensor payloads. Ikhana is being modified with instrumentation and communications systems to support payload integration, and these capabilities and interface are being documented in a handbook for experimenters.

Aircraft

General Atomics Aeronautical Systems Inc. developed the Predator medium altitude endurance UAV during the mid-1990s as an Advanced Concept Technology Demonstration for the United States Air Force. The Predator system became operational in 1996.

The Predator-B is a larger and more powerful derivative than the original Predator, flying faster, higher, and with a greater payload. Development of the Predator-B began as a private venture in 1998, but was eventually supported with NASA funding. The first flight of the prototype occurred in February 2001. Powered by the Honeywell (Phoenix, Arizona) TP331-10 turboprop engine, the Predator-B can fly at a maximum airspeed of 240 kn. At a cruise speed of 150 – 170 kn, the aircraft can stay aloft for up to 30 hours. The aircraft has a large payload bay in the nose, and multiple hard points on the wings for additional pod-mounted payloads. The inboard hard point can carry up to 680 kg (1500 lb). Redundant flight control, avionics, power, and network systems increase the system reliability and lower the risk of operations in public airspace.

The NASA Predator-B, seen in figure 1, was given the name "Ikhana," a Choctaw Native American word meaning intelligent, conscious, or aware. Other than the absence of a weapons system, the aircraft is a standard Predator-B.

ED07-0038-052

Figure 1. The NASA Ikhana unmanned aerial vehicle.

Payload Support Systems

A key Ikhana project objective is the ability to rapidly reconfigure the aircraft to support science and technology demonstration missions. This is achieved through a variety of aircraft infrastructure modifications and integration support tools, some of which are described in the following subsections.

Instrumentation and Networking

Ikhana will be equipped with some basic instrumentation and networking capabilities that will support the integration of sensor systems. The aircraft will have eight available Global Positioning Satellite (GPS) antenna connections for sensor system usage. To time-correlate all sensor and aircraft systems, a network time protocol (NTP) time server will provide a common GPS-based time source for all sensors to utilize over a common Ethernet experiment network. This network will connect sensors in the aircraft payload bay together with sensors mounted in the aircraft avionics bay. The experiment network also hosts a flight data recorder capable of receiving data streams from multiple sources, time tagging the data, and archiving it on solid-state memory. In cases where the Airborne Research Test System (ARTS) is installed, aircraft state parameters (such as airspeed, altitude, heading, roll and pitch angle, accelerations, angular rates, and many aircraft mode and condition indications) can be made available on the experiment network. The experiment network makes it possible for collections of sensors to share data or for one system to send commands to other systems.

Communication

The experiment network also hosts a module that has the capability to gather data streams from multiple sources over the experiment network and integrate the messages into a common downlink stream utilizing the aircraft Ku satellite communication system. The required message structure for this interface will be documented in the Ikhana experimenter's handbook.

Payload Pods

Although the aircraft avionics bay has volume available for sensor payloads, this space will generally be reserved for long-term aircraft systems. In most cases, mission-specific sensor suites will be installed in wing-mounted pods. These pods allow payloads to be integrated without interrupting aircraft activities until the integration is complete. Once integrated, the entire payload suite can be loaded or unloaded from the aircraft as needed. Aircraft power, experiment Ethernet network, GPS antenna cable, and other electrical wiring are routed to the pod wing stations to support the sensor suite.

The first of these pods is shown in figure 2. The pod has approximately 0.68 m^3 (24 ft^3) of usable payload volume with access from 2 panels on each side. The side panels can be modified to allow windows or external sensing devices such as pitot tubes to be added to the pod as needed to meet sensor requirements. The entire lower surface of this pod is also removable, allowing the

payload to be integrated onto the tray and loaded into the pod. The ability to remove the entire sensor payload allows the sensor developers to work on the systems in a laboratory environment between flights. The removable tray also would support the ability to swap between payloads rapidly. This would be useful when a payload is standing on-call for a particular weather event (for example, a hurricane) or ground observation event such as volcanic activity.

Photo courtesy Trent Theriault

Figure 2. The NASA under-wing Fire Pod.

Avionics Bay

The Ikhana avionics bay has several available locations for sensor integration, allowing for a total weight of over 180 kg (400 lb). The avionics bay is vented to the atmosphere, so environmental qualification can be critical. The project has developed a computer-aided design model of the bay to aid in sensor integration.

Experimenter Handbook

An experimenter handbook is in development to provide information to potential users of the Ikhana aircraft. This handbook will document the aircraft capabilities (altitude, endurance, payload volume, payload and weight limits, and power) and the payload requirements (temperature, vibration, electro-magnetic interference, materials limitations, communications, etc.). The handbook will also outline the aircraft operations concept, including the logistics associated with deploying the aircraft system to remote locations.

Airborne Research Test System

A recently completed UAV capability assessment study attempted to define suitable UAV science missions and identify the capabilities and technologies required to enable the missions. Many of the high priority technologies identified require the use of a mission or flight control computer to host software computations. As an example, the most often-cited enabling UAV technology, sense and avoid, needs to be able to analyze sensor readings, make decisions on possible evasive maneuvers, and execute the maneuvers.

The Airborne Research Test System (ARTS) was developed to meet the need for a research mission computer capable of hosting developing UAV technologies. The ARTS hardware includes three processor boards and an input/output board. In combination, the ARTS can support communication to external systems using Ethernet, RS-422, Mil-Std-1553, ARINC-429, analog, and digital protocols. The ARTS will be integrated with the standard Predator-B flight control system, receiving aircraft state data on a continuous basis over a dedicated RS-422 link.

The standard Predator-B flight control software is currently being modified by the manufacturer to accept aircraft control commands from the ARTS, rather than the ground control station, following the engagement of the ARTS. Typically, the ARTS will be engaged for a period of time at a specific test flight condition or during the collection of scientific data. To ensure safety, there are multiple ways to disengage the ARTS and return control of the aircraft to the ground pilot. Disengagement can be initiated from three sources: the pilot, through a switch on the control stick; the ARTS, based on monitoring of aircraft dynamics or internal health monitoring; and the basic aircraft flight control system, following the detected degradation of an aircraft system. The ARTS is programmed to command the aircraft using any of the modes currently available to the pilot: waypoint command, autopilot command, or stick/rudder/throttle. These modes can be used by an experimental ARTS software load to enable a new UAS capability. Some examples of technology development that can utilize the ARTS capability are listed below.

- Autonomous Mission Management: Increased autonomy in UAV systems will increase the capability and efficiency of mission execution, while lowering the cost by reducing the work hours required to plan and execute the mission. The ARTS could host algorithms that autonomously plan and execute missions based on high-level objectives defined by the user. The system would also have algorithms to handle contingencies caused by weather or system degradation.

- Collision Avoidance: The single greatest impediment to routine UAS operations in the public airspace is the lack of sense and avoid systems to prevent midair collision. The Ikhana could be used as a testbed to assess various detection sensors. The sensors would be networked to the ARTS where the analysis software would reside. The ARTS would also host the algorithms that make decisions on the need to execute an evasive maneuver, and, if true, send the control commands directly to the flight control computer.
- Precision Trajectory: A precision trajectory autopilot has several benefits for some UAS missions. Some solid Earth mapping missions using synthetic aperture radar require the aircraft to navigate a precise trajectory while data is being collected. An analysis technique called repeat pass interferometry can be used to measure changes in the solid Earth terrain over weeks, months, or years, given that the same trajectory is flown. In this scenario, the ARTS would host the precision navigation and precision autopilot control laws.

GROUND SYSTEMS

The Ikhana Ground Control Station (GCS) consists of both standard operational components and research support components. A standard U.S. Air Force-style pilot and sensor operator (PSO) station handles standard aircraft command and control. The PSO station utilizes redundant, C-band, line-of-sight antenna to perform take-off, landing, and local flight operations. For longer range operations (greater than 50 mi), the aircraft command and control is transferred to the Ku satellite communication (SatCom) system. A 32-inch Ku SatCom dish antenna is located in the aircraft avionics bay. This system communicates to and from a ground-based antenna located near the GCS via geosynchronous Ku-band satellites. Both commercial and military satellites can be used to control the aircraft. As seen in figure 3, the PSO is installed in a mobile trailer that is suitable for over-land, ship, or airborne (compatible with both C-130 and C-17 airplanes) shipping. The PSO station is redundant in hardware and power. Both a shipping crate for the aircraft and a 4.5-m trailer-mounted ground antenna, which can be collapsed for ground or air deployments, have been procured by NASA.

The GCS trailer was modified to include six engineering monitoring workstations, large overhead displays, pilot internet access, intercom systems, a printer, and telephones. The engineering workstations can be configured with displays to monitor aircraft systems and research payloads.

Photo courtesy Brent Cobleigh

Figure 3. Ikhana mobile ground control station.

CONCEPT OF OPERATIONS

Policies and procedures to allow safe and routine access to public airspace for UAVs are under development. Presently, UAV missions must begin airspace coordination several months prior to the planned operations, although exceptions can be made for emergency response missions. At the current time, operation of UAVs in airspace that does not require air traffic control participation from all aircraft (below 18 000 ft in the United States) usually requires a chase aircraft or a ground observer to minimize the potential for a midair collision. Though development of certification criteria for sense and avoid systems will eventually open this airspace to UAVs, current long-duration or long distance flight usually requires the UAV to climb into controlled airspace accompanied by a chase aircraft or transition into class-A airspace from segregated airspace (for example, a military restricted area). Further restrictions are often imposed to avoid flight over populated areas and to stay clear of busy commercial traffic corridors. Access to airspace outside the United States may be more or less restrictive. As confidence and familiarity with UAV operations increases, it is believed that airspace access issues will improve.

For some science and most technology development missions, the Ikhana will be operated from the NASA Dryden Flight Research Center in Edwards, California. Dryden's location within restricted airspace boundaries allows the aircraft to avoid airspace access issues. For missions in the U.S. national airspace, the restricted area is used to climb to an altitude allowing direct transition into class-A airspace. As discussed, the Ikhana support systems have been developed with a requirement for deployability. The aircraft, ground station, and antenna systems are all built for shipment using ground, ship, or air methods.

CONCLUDING REMARKS

The NASA Ikhana unmanned aerial system has begun flight operations to support in-situ and remote sensing science missions, as well as develop capabilities and technologies to improve the utility of unmanned aerial systems. The aircraft's Airborne Research Test System is a unique test capability that can network with a wide variety of aircraft and scientific sensors, and host mission or flight control software capable of commanding the aircraft trajectory and systems. To accompany the project, NASA has also developed a ground control station capable of hosting research monitoring and mission support displays for up to six people. Although the initial flight activity will originate from the NASA Dryden Flight Research Center, NASA expects to deploy the aircraft to remote sites to support Earth science objectives starting in 2008. The aircraft, ground control station, and command and control antennas have been selected based on their ability to be shipped by land, air, or sea.

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