The Proposed Use of Unmanned Aerial System Surrogate Research Aircraft for National Airspace System Integration Research

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Research is needed to determine what procedures, aircraft sensors and other systems will be required to allow Unmanned Aerial Systems (UAS) to safely operate with manned aircraft in the National Airspace System (NAS). This paper explores the use of Unmanned Aerial System (UAS) Surrogate research aircraft to serve as platforms for UAS systems research, development, and flight testing. These aircraft would be manned with safety pilots and researchers that would allow for flight operations almost anywhere in the NAS without the need for a Federal Aviation Administration (FAA) Certificate of Authorization (COA). With pilot override capability, these UAS Surrogate aircraft would be controlled from ground stations like true UAS's. It would be possible to file and fly these UAS Surrogate aircraft in the NAS with normal traffic and they would be better platforms for real world UAS research and development over existing vehicles flying in restricted ranges or other sterilized airspace. These UAS surrogate aircraft could be outfitted with research systems as required such as computers, state sensors, video recording, data acquisition, data link, telemetry, instrumentation, and Automatic Dependent Surveillance-Broadcast (ADS-B). These surrogate aircraft could also be linked to onboard or ground based simulation facilities to further extend UAS research capabilities. Potential areas for UAS Surrogate research include the development, flight test and evaluation of sensors to aide in the process of air traffic "see-and-avoid". These and other sensors could be evaluated in real-time and compared with onboard human evaluation pilots. This paper examines the feasibility of using UAS Surrogate research aircraft as test platforms for a variety of UAS related research.

INTRODUCTION

Due to the already large and growing numbers of UASs flying for the military, research and development organizations and others, the pressure is growing for the integration of UAS into the NAS. The military is flying more and more increasingly sophisticated UASs on a fixed number of test ranges. It is also increasingly difficult to move UAS assets around the country and between ranges due to the NAS restrictions. There is also pressure to fly UASs in the NAS from law enforcement agencies, research organizations, academia and commercial interests. It is very likely that the NAS will eventually safely share space with manned and unmanned aircraft at some unknown time in the future. It may be years before the systems, rules and regulations are developed and in place to allow NAS integration. Research is required to develop the necessary

systems, sensors, procedures, and regulations to make NAS integration possible and safe. Currently, NASA and other organizations are developing research plans to aid the NAS integration process. Surrogate UAS are increasingly playing a major part in the development, test and evaluation of various systems needed in the process. This paper will examine how these UAS surrogate aircraft are currently being used. The paper will also highlight the work in progress at the NASA Langley Research Center and the development and use of the Cirrus SR22 Surrogate UAS Research Aircraft.

WHY USE A UAS SURROGATE?

Under the current FAA rules, unmanned aircraft can only fly in segregated airspace, either on special test ranges or through the COA process. This segregated airspace only situation is a real dilemma for UAS system development. How do you test and evaluate unmanned systems on aircraft which cannot fly in the intended airspace? This is a real dilemma for those developing UAS systems intended for UAS NAS integration. This dilemma can be partially solved by using manned UAS surrogate aircraft.

With one or more qualified pilots aboard, the UAS surrogate can "file and fly" under existing visual or instrument flight rules along with most other aircraft in the NAS. The surrogate can intermingle with other aircraft according to existing FAA rules. The pilots and air traffic controllers are responsible for separation assurance. However, the surrogate is able to fly as normal traffic and is able to test and evaluate UAS systems and procedures in real world situations. Flying under visual flight rules will generally offer greater freedom and flexibility of operation. Additional observers, researchers, operators, and other technical personnel could possibly fly on UAS surrogates as required and according to the size and capacity of the vehicle. The additional personnel can operate or monitor UAS systems for proper operation, make necessary system changes, and compare UAS system operations to expected behavior. Safety can also be improved by having an experienced crew member aboard to disable or override automated systems when necessary. The ability to make changes or adjustments in real-time when using a manned surrogate can greatly speed the development, test and evaluation time. A real UAS must be flight tested, recovered, changed, and retested. The UAS surrogate aircraft is a very flexible tool that can be used to speed the research, development and evaluation process and improve safety[1].

Another good reason to use a UAS surrogate is to compare human and machine reactions to certain situations. For example, systems designed to perform the traffic "see and avoid" function as a human pilot must do according to the current FAA rules can be directly compared. The current Federal Aviation Regulation Section 91.113 specifies the see and avoid responsibilities of the human pilot and will likely serve as a basis for comparison to equivalent UAS systems. Until new rules specifically designed for UAS are created to augment or replace the existing rules, man and machine must be compared using the current rules. Comparison data such as response times and traffic detection distances under varying conditions could be gathered for direct man-machine comparison. Other relevant statistical data can also be gathered in this manner for more detailed analysis and comparison. This kind of direct comparison work will be very important to help demonstrate that UAS systems can operate in the NAS to an equivalent level of safety as manned aircraft.

EXAMPLES OF UAS SURROGATE USE

There are many examples of the growing use of UAS surrogates to aide in the development of UAS technology and more are under development. The vast majority of UAS surrogates flying today are built from standard manned aircraft that were modified to perform

some UAS function such as remote control or autonomous operation. These UAS surrogates are being used to develop complex UAS systems for a variety of functions normally performed by manned aircraft. Currently, UAS surrogate aircraft are being used to develop and evaluate air traffic see and avoid systems. They are also being used to develop the systems to make air-to-air refueling possible between manned and unmanned aircraft. Surrogates are also being used to develop a variety of automated intelligence, surveillance and reconnaissance (ISR) systems.

The Air Force Research Laboratory is conducting a multi-year, multi-phased Automated Aerial Refueling (AAR) program involving several contractors. The goal of the AAR program is to develop systems to enable unmanned aircraft to autonomously rendezvous with a manned or unmanned tanker and refuel. Phase one of the program has already demonstrated a UAS can autonomously maneuver between the seven standard positions behind a modified tanker using a Calspan Corporation Learjet as a UAS surrogate. Using a precision GPS/INS and special relative navigation software, the Learjet UAS surrogate has demonstrated that the system can maintain position behind a manned tanker as it flies a standard refueling route. The goal of Phase-2 is to autonomously refuel a UAS surrogate from a standard tanker[1]. A Calspan VISTA F-16 will serve as the UAS surrogate for this test since the Learjet cannot refuel in flight. The Northrop Grumman LN-251 relative GPS/INS navigation system used for these tests exchanged data between surrogate and tanker aircraft using a redundant high speed data link system. The system demonstrated a level of reliability and repeatability across data link drops and varying time delays[2].

The use of surrogates for these flight tests was critical and allowed for close human monitoring and intervention if necessary. In addition to gathering data, the Learjet surrogate also allowed the crew to directly compare the performance of the automated systems with the human techniques used to fly the same refueling missions. The humans on-board the surrogate also improved the safety of these tests with the capability of overriding or disabling the automated systems if needed. It is difficult to imagine a flight test such as this without experienced test pilots aboard to closely monitor the automated systems. The surrogate Learjet allowed repeated testing, verification, and fine-tuning of the systems to prove safety, reliability and predictability.

Another example of UAS surrogate use is in the development of the Northrop Grumman X-47B Unmanned Combat Air System (UCAS) for the U.S. Navy. The X-47B is part of the Navy's program to develop an unmanned, autonomous, stealthy, carrier based, combat aircraft. First flown in February, 2011, the X-47B is a tailless, subsonic, jet aircraft with a wingspan of 62 feet. The UCAS will be able to take off from and land on U.S. Navy aircraft carriers and inter-operate with manned Navy combat aircraft. The UCAS will perform a variety of Navy operations including intelligence, surveillance, and reconnaissance (ISR) and other armed combat missions. The UCAS will also have the capability to perform aerial refueling from tanker aircraft. A modified Boeing F-18 aircraft is serving as a UCAS surrogate to test the UCAS systems and software. The UCAS surrogate aircraft has already flown open-loop and closed-loop carrier approaches using X-47B software. On July 2, 2011, the F-18 UCAS Surrogate made the first full

[1]Warwick, Graham (2008, June 19), AFRL Advances Autonomous Aerial Refueling. *Aviation Week*, Retrieved June 1, 2011, from http://www.aviationweek.com/aw/jsp_includes/articlePrint.jsp?headLine

[2]Leeuwen, Marcel Van, (2011, April 7), Northrop Grumman Navigation Capabilities Exceed Requirements for Automated Aerial Refueling Program Flight Tests. *Aviationnews.eu*, Retrieved June 17, 2011, from http://www.aviationnews.eu/2011/04/07/northrop-grumman-navigation

stop carrier landing on the USS Eisenhower using the UCAS software[3]. A modified King Air aircraft is also serving as a UCAS surrogate for some of the X-47B system testing including carrier approaches. In this case, the King Air surrogate has the additional capability of carrying additional technical personnel to operate, monitor and evaluate the UCAS systems and software. Current plans call for the F-18 surrogate to demonstrate air-to-air refueling by early 2013 as well as the carrier landings. The UCAS is expected to be operational with the Navy by 2018[2].

COMMERCIAL UAS SURROGATE SERVICES

The increasing use and requirements for UAS surrogates has generated several commercial ventures which can supply a variety of UAS surrogate aircraft for use in a variety of UAS research and development programs. The majority of these firms are providing their services to the Department of Defense and other U.S. Government agencies. One of these service companies is Airtec Incorporated, based in California and Maryland. Airtec operates a fleet of modified general aviation and business class aircraft to support the military in areas of airborne telemetry, range safety, and maritime radar surveillance. Airtec is also providing a modified King Air UCAS surrogate to test and evaluate the Navy's X-47B systems under development. The Airtec King Air is being used to make carrier approaches to test and evaluate UCAS systems and software.

Aurora Flight Sciences has developed and is marketing a modified version of the Diamond DA42M aircraft named Centaur. The Centaur is an Optionally Piloted Aircraft (OPA) and is designed to perform unmanned or manned missions as required. Aurora is providing the Centaur to MISTIC, Inc. to serve as a UAS surrogate for ISR, and other military training and testing activities on restricted ranges in New Mexico. Located in Roswell, New Mexico, MISTIC operates ranges and testing facilities and other services for the U.S. Government[4].

Proxy Aviation Systems in Gaithersburg, Maryland is also a manufacturer of OPAs primarily for military applications. Proxy makes the Sky Raider which is a small, 2000 pound, single-engine, composite-construction OPA with the capability to perform UAS surrogate missions. Proxy has developed a Virtual Pilot system which allows one ground station to manage and control a network of one to 12 cooperative aircraft. These cooperative aircraft may have different capabilities but cooperate in a common mission by using a combination of automation, information sharing and ground station commands to accomplish the missions[5].

While not a commercial entity, the Civil Air Patrol (CAP) has modified two Cessna 182 general aviation aircraft to serve as surrogates for the U.S. Air Force MQ-1 Predator and MQ-9 Reaper military UAS. Under the U.S. Air Force's $2.5 million "Predator Surrogate" program, the two aircraft were modified to carry the military UAS surveillance and targeting systems under the left wing. Predators and Reapers not only provide aerial surveillance to troops in Iraq and Afghanistan, they also carry laser designators and several types of bombs and missiles, including the AGM-114 Hellfire. The modified aircraft have been used to train Air Force ground crews in the

[3]Rosenberg, Zach (2011, July 5), US Navy Demonstrates UCAS-D Software. *Flight International*, Retrieved July 6, 2011, from http://www.flightglobal.com/articles/2011/07/05359159/us-navy-demonstrates-ucas-d-software.html

[4]Gil, (2010, March 1), Aurora Flight Sciences Completes Surrogate UAV Contract. *Planenews Aviation News*, Retrieved June 23, 2011, from http://planenews.com/archives/12546/

[5]Osborn, Kris, (2009, June 29), Virtual Pilot Could Guide Multiple UAVs. *Defense News*, Retrieved July 10, 2011, from http://www.defensenews.com/story.php?i=41606808&c=FEA&s=TEC

US in place of the real military aircraft which are in short supply and primarily deployed to support the war efforts in Iraq and Afghanistan[6].

Systems Consultants (SCI), headquartered in Fallon, Nevada, provides surrogate UAV services to the U.S Navy and other DOD clients using a variety of manned aircraft. System Consultants provides specialized training as well as UAS systems development and evaluation services using UAS surrogate aircraft.

NASA UAS RESEARCH

NASA is developing a five year, $157 million dollar UAS Integration in the NAS Project to promote NASA's vision of "a global transportation system which allows routine access for all classes of UAS". The project is intended to reduce technical barriers related to safety and operational challenges preventing routine UAS deployment in the NAS. The scope of the project will include technology development and demonstrations in four specific areas. The four technology elements include Separation Assurance, Human Systems Integration, Communications, and Certification. The first element will assess how Next Generation (NextGen) separation assurance systems with different functional allocations could perform for UAS in mixed operations with manned aircraft. Also, an assessment will be made of the applicability to UAS and the performance of NextGen separation assurance systems in flight tests with realistic latencies and trajectory uncertainty. The Human Systems Integration element will develop a research test-bed and a database to provide data and proof of concept for Ground Control Station (GCS) operations in the NAS. The Communications element will try to obtain dedicated UAS communications frequency spectrum and develop and validate UAS secure safety critical command and control systems. Also, provide analysis to support integrated command and control systems and ATC communications in the NAS. The Certification element will define a UAS classification scheme and approach to determining airworthiness requirements applicable to UAS avionics. There will also be an Integrated Test and Evaluation element which will test and evaluate concepts from the other technical elements in a relevant environment. Split into two phases, the first part of the project from 2011 to 2012 will focus on initial modeling, some flight testing and simulation. The second phase, between 2013 and 2015, will continue with additional simulation, more flight tests and integrated modeling. Current planning will utilize UAS surrogate aircraft to flight test many aspects of the project. Simulation will be used to test separation assurance algorithms. The algorithms will then be flight tested and evaluated using manned UAS surrogate aircraft[3].

NASA UAS SURROGATE RESEARCH AIRCRAFT

Three NASA research centers are in various stages of modifying existing research aircraft to serve as UAS surrogates. The NASA Dryden Research center in California is building a UAS surrogate from a Ximango TG-14 Motor Glider. The Dryden aircraft will serve as a low operating cost UAS research tool. The NASA Glenn Research Center in Ohio is modifying a Beech T-34 to serve as a UAS surrogate research aircraft as well. The Langley Research Center in Virginia is currently flying a modified Cirrus SR22 configured as a UAS surrogate research aircraft. The Langley Research Center currently has a research project to flight test separation assurance

[6]Cox, Steve, (2009, September 17), CAP Pilots To Fly 'Surrogate Predators' To Assist Military. *Civil Air Patrol Volunteer Now*, Retrieved June 25, 2011, from
http://www.capvolunteernow.com/todays_features.cfm/cap_pilots_to_fly_surrogate_predators_to_assist_military?show=news&newsID=5998

algorithms using two Langley Research Center aircraft. A Cessna 206 aircraft will serve as an intruder aircraft while the Cirrus SR22 will serve as the UAS surrogate. The research will make use of on-board sense-and-avoid and separation assurance algorithms and ADS-B traffic data to autonomously generate flight maneuvers to maintain separation. Both aircraft are equipped with Universal Access Transceiver (UAT) ADS-B systems. The research flight tests are scheduled for the fall of 2011. Currently, several other potential research projects for the Langley surrogate aircraft are in planning or under discussion.

THE NASA LANGLEY SR22 UAS SURROGATE RESEARCH AIRCRAFT

The NASA Langley UAS Surrogate is based on a Cirrus Design SR22 aircraft. The SR22 is a small, single-engine, four-place, composite-construction aircraft that NASA Langley previously acquired to support general aviation flight-research programs. Several unique systems were installed to support flight test research and data gathering. These systems include: research power provided by an alternator and power distribution system separated from the certificated aircraft power; multi-function flat-panel displays; research computers; research air data and inertial state sensors; video recording; data acquisition; data link; S-band video and data telemetry; Common Airborne Instrumentation System (CAIS); Automatic Dependent Surveillance-Broadcast (ADS-B); instrumented surfaces and controls; and a systems operator work station. The transformation of the SR22 to a relatively low cost UAS Surrogate was accomplished in phases. In the first phase, the existing autopilot was modified to accept external commands from a research computer that was connected by radios to a ground control station. Software was simultaneously developed for the aircraft and the ground control station. An electro-mechanical auto-throttle was added in the second phase to provide ground station control of airspeed. Additional phases are in progress to add way-point navigation and long range satellite voice and data communications. The aircraft will be used as a UAS systems research and development platform.

Remote control of the aircraft is accomplished by feeding commands from an on-board research computer into a modified Cobham S-TEC 55X two-axis autopilot. The autopilot was modified to accept mode control, lateral steering, and vertical speed commands from the research computer. The research computer receives the commands from the UAS ground station via redundant VHF data link radios or from the on-board systems operator in the case where data link communications is not desired. Using a modified autopilot increases the safety of the system since the limited authority autopilot can be overridden or disabled by the safety pilot.

Auto-throttle

The auto-throttle system was designed to be simple, safe, and removable while maximizing the single lever control for propeller and throttle. The auto-throttle system components include a modified roll servo, a drive rod connected to the throttle handle, an in-house fabricated servo amplifier, and a commercial off the shelf digital-to-analog converter. A lever arm was fabricated for the servo to hold the throttle drive rod. The drive rod is connected to the servo lever at one end and the throttle lever at the other end. The rod is held in place by easy to remove cotter pins located at both ends. The auto-throttle system can easily be disabled by removing power from the clutch via switch located on the center console or by removing one or both cotter pins thereby disconnecting the throttle drive rod. The pilot can also override the 41.3 inch pounds of clutch friction set to operate the throttle lever. The adjustable servo clutch friction was set high enough to move the throttle and low enough to allow the pilot to easily override. The auto-throttle servo is mounted to a removable structure located on the rear of the aircraft center console and anchored to the rear seat mounting pins. The entire auto-throttle drive can be easily

removed from the aircraft for non-research flights. The servo amplifier and digital-to-analog converter are mounted to the top of the general purpose computer that is located where the left rear seat is normally installed.

Data Link Radios

The data link radios are commercial Teledesign TS4000 VHF radios. These programmable radios operate in the 150-175 MHz band; output a maximum of 5-W, and have a signaling rate of up to 19,200 bits/sec. Two sets of these radios, two in the Ground Station and two in the aircraft, are used to provide redundancy. Two frequencies spaced 5 MHz apart are currently authorized and provide redundancy and frequency separation. The computer applications software is configured to use any radio that will pass two-way RS-232 serial data. Therefore, the radios can be changed to a different type without changing to the software.

Surrogate UAS Software

All UAS software was developed using the Langley Standard Real-time Simulation in C++ (LaSRS++) software development framework and test facilities. The surrogate UAS is operated from a PC-based Ground Station which presents the operator with a moving map having a sectional chart as the background, a primary flight display (PFD), and a graphical user interface (GUI) for entering altitude, vertical speed, heading, and speed commands. The aircraft software includes identical moving map and PFD, and a similar GUI. The moving map is presented to the Safety Pilot on the Avidyne multi-function display (MFD) when the display is switched to the Research Mode, allowing the Safety Pilot to monitor commands as they are received from the Ground Station. In addition, the research software operator is presented with the PFD, and a GUI that is an extended version of the Ground Station GUI.

The Ground Station UAS Control GUI has four panels for entering Vertical Speed, Altitude, Heading, and Airspeed Commands. An "OFF / ON" box is also included to control individual commands. Command numbers may be changed with a mouse and left clicking the respective "+" or "-"buttons. The operator may also left click inside one of the respective command boxes and enter a number from the keyboard. There are also indicators for the number command transmissions from the Ground Station, the number of received messages from the aircraft, the number message cyclic redundancy check (CRC) errors, the number of message bytes skipped, and the aircraft GPS Time. Other GUI panels are optionally available to the Ground Station operator to display additional data and status information.

A similar UAS Control GUI is also displayed to the Systems Operator in the aircraft. This GUI has a few additional controls. An "Enable Software Control of Aircraft" button is used to enable or disable any software commands. When the "Enable UAS Control Entries" option is selected, command entries may be made from the Operator's Work Station on the aircraft, and are disabled at the Ground Station. A "Local Altimeter Settings" box allows the Systems Operator to set the current altimeter setting. The remainder of the GUI is the same as for the Ground Station. Several optional GUI panels are also available to the Systems Operator for the display and control of several software parameters. These additional GUI panels allow the Systems Operator to change gains, time constants and other control law and filter related parameters.

Data Link Messages

The aircraft-to-Ground Station down-link message is designed to provide the necessary information regarding the aircraft state and status to give the Ground Station operator good situational awareness. Most of the information in the message comes from the Air Data and Heading Reference System (ADAHRS) and includes aircraft GPS position, attitude, velocity,

acceleration, and air data. The message length is 124 bytes for the aircraft status down-link message. The aircraft message update rate is programmable but defaults to 3 Hz. This rate is sufficient to update the Ground Station displays to give the Ground Station operator good awareness of what the UAS Surrogate is doing without exceeding the radio bandwidth or duty cycle. The Ground Station up-link messages contain the four commands, synchronization information, a sequence number, mode/status information and a CRC field. The up-link messages are sent only when there is a new command issued by the Ground Station operator. The four commands that are up-linked to the aircraft are returned to the Ground Station by the aircraft system to serve as confirmation for the up-linked commands and for display on the Ground Station moving map display.

Ground Station

The Ground Station uses a nearly identical computer to the one installed in the aircraft and is connected to two VHF data radios via dual RS-232 serial links. The Ground Station computer has dual video outputs for dual displays, although only one is required. The dual display configuration allows more separation and arrangement of the various display and GUI elements. These display elements include the moving map display, a PFD, and a GUI panel for entering the heading, altitude, vertical speed, and airspeed commands. Additional GUI panels can be activated by the Ground Station operator to display state and status information residing in the computer or sent from the aircraft.

Future Modifications

Future upgrades planned for the UAS Surrogate include a flight management and way-point navigation capability. This upgrade will give the Ground Station operator the capability to build, modify, and upload to the aircraft complete 3-D flight plans. The UAS Surrogate will be able to automatically fly the flight plan including transitions back and forth between flight management and vector mode as required. A satellite-based communications system for over the horizon command and control is also a planned upgrade. The satellite communications system will have simultaneous voice and data capabilities. Other capabilities may be added as required by specific research requirements.

CONCLUSION

The use of UAS Surrogate aircraft have proven to be valuable research tools to help solve complex problems such as autonomous air-to-air refueling and aircraft carrier landings. The use of UAS surrogates is increasing in areas of training for various UAS operations and for the development and testing of many UAS systems. Several commercial firms are building optionally manned aircraft which can be used as UAS surrogates and other are providing UAS surrogate services. Also increasing is the use of UAS Surrogates to perform research to find ways to integrate UAS into the NAS. The capability to mimic a UAS while flying safely with experienced test pilots has been demonstrated and proven to be very valuable. Although many people and institutions are working on these and other UAS related problems, there is room for more research and the use of manned UAS surrogates.

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