Remotely Piloted Vehicle Flight Test Technique Development and Training at the National Test Pilot School

Ryan T. Olson
National Test Pilot School
1030 Flight Line Bldg. 72, Mojave, CA 93501
UNITED STATES OF AMERICA

rolson@ntps.edu

Chris M. McElroy
National Test Pilot School
1030 Flight Line Bldg. 72, Mojave, CA 93501
UNITED STATES OF AMERICA

cmcelroy@ntps.edu

ABSTRACT

The National Test Pilot School (NTPS) began offering a Remotely Piloted Vehicle (RPV) flight test short course in April of 2006. Initially various flight test techniques were taught solely via simulation. To improve the value of training provided it was considered necessary for NTPS to operate a RPV. Accordingly, a Cessna 150 was converted into an Optionally Piloted Aircraft (OPA). The aircraft was certified in August of 2010 as an OPA by the Federal Aviation Administration (FAA) and following comprehensive ground testing the first flight of the OPA occurred in June 2011. Subsequently two phases of flight testing were completed the second of which was completed in early 2013. Current certification requires that the OPA be operated with a certified safety pilot on-board who can deactivate the ground-controlled autopilot system if necessary. The system is capable of being controlled via command direction or in a remotely piloted vehicle mode. This paper incorporates a description of the development, evaluation, and validation of flight test techniques using the OPA as a surrogate for RPVs. Additionally, this paper focuses on the unique considerations required for effective OPA/RPV flight test team collaboration, due to the increased complexity of Crew Resource Management (CRM).

1.0 INTRODUCTION

The primary objective of NTPS is to educate and train test pilots and flight test engineers to be able to successfully plan and execute flight test programs for their military or civilian test and evaluation organizations immediately upon graduation. The NTPS professional course is divided into two six-month phases of performance and flying qualities (P&FQ) and avionics systems. NTPS also offers specialized flight test training via scheduled and on-demand short courses of two to six weeks duration. Although specific flight test techniques are taught, the underlying philosophy of flight testing is continually reinforced throughout the course. Graduates of NTPS are capable of applying this fundamental philosophy to any flight test program or flight test technique.

The development of RPVs has been intertwined with manned flight throughout the history of aviation. Initial unmanned aircraft were typically employed as technology demonstrators used to test and evaluate theories and ideas before implementation on manned versions [1]. Thanks both to the introduction of the Global Positioning System (GPS) and technology spurred by the ever improving capabilities of microprocessors, the utility and importance of RPVs has increased apace since the mid-1990s. The value gained by preventing the loss of human life (or prisoner of war/hostage situations) during dangerous operations as well as the ability to eliminate life support and egress systems from manned aircraft has gradually exceeded the cost of integrating the required technology to support unmanned vehicles [2, 3]. RPVs have demonstrated their effectiveness in carrying out missions that are impossible for an onboard pilot. In short, RPVs are ideally suited for many missions that are deemed "*Dull, Dangerous or Dirty*" (D3) [4].

As a consequence of the rapid expansion of the RPV industry, NTPS recognized a need for RPV flight test training and began offering a two-week RPV flight test short course in April of 2006. Initially, the course was comprised of academic lectures and RPV flight test technique demonstrations, the latter taught solely via simulation. Whilst the initial courses were considered to be successful, it became clear that in order to enhance the realism, and hence, value of training it would be necessary for NTPS to acquire a RPV in order to demonstrate RPV Flight Test Techniques (FTTs) in-flight. It was therefore decided to proceed with converting an underutilized Cessna C-150 aircraft in the NTPS fleet into an OPA. The choice of OPA rather than a RPV was made in order to ensure that the vehicle could be operated from Mojave Air and Space Port, within the National Airspace System (NAS) and be free from significant weather and range limitations.

2.0 NTPS CESSNA C-150 OPA

The C-150 OPA, (Figure 2-1) has a single Continental O-200-A piston engine that produces 100 horsepower at 2750 RPM at sea-level. The aircraft has fully reversible flight controls driven by a conventional mechanical pulley system and electric flaps. In the OPA configuration the aircraft has an empty weight of 1,135lbs and a gross weight of 1600lbs, giving it a 465lb useful load. The aircraft is capable of reaching speeds up to 106kts in level flight and has a service ceiling of 12,650ft [5].

The C-150 was modified to be operated remotely via ground-based operator inputs made at a dedicated Ground Control Station (GCS). Control inputs at the GCS are transmitted to the OPA via a dedicated datalink and are input to a Cloud Cap Piccolo II autopilot on-board the OPA. The autopilot controls the OPA via vehicle elevator, ailerons, and throttle displacements.

Figure 2-1 – NTPS Cessna C-150 OPA

The autopilot obtains vehicle navigational, aerodynamic, and environmental data from several onboard sources: Inertial Measurement Unit (IMU), GPS, dedicated Pitot-static system, Above Ground Level (AGL) laser, magnetometer, RPM Hall effect sensor, Outside Air Temperature (OAT) thermocouple, angle of attack and angle of sideslip vanes, and control surface deflection string potentiometers. The autopilot sensor installation is packaged on a removable pallet in the baggage compartment behind the pilot's seat.

The Piccolo autopilot allows the system to be controlled via Command Directed Vehicle (CDV) mode or in a Remotely Piloted Vehicle (RPV) mode. In CDV mode airspeed, altitude, heading, bank angle, vertical rate, and navigation are commanded through the Piccolo Command Center (PCC) via one of three methods: 1) through the primary flight display by clicking and dragging command flags 2) by imputing a numerical value into the command loop window and sending the command to the aircraft 3) via mouse click on the moving map. PCC also enables the aircraft to fly preloaded or modified flight plans. The software supports up to 250 waypoints that can be utilized to create multiple flight plans [6].

In RPV mode the C-150 OPA is designed to be controlled using a joystick and throttle. The autopilot supports several different types of stability augmented manual control modes known as assist modes. The controller has steering and full authority modes. In steering mode the joystick controller is solely used to command bank angle for the autopilot. Full authority adds the elevator control of vertical rate, and the throttle control position is used directly. An autopilot disconnect is incorporated into the RPV control box in front of the joystick controller. With the autopilot off, in full authority override mode, the joystick and throttle on the RPV control box directly command control surface or throttle position. The keyboard and mouse can be utilized while the RPV mode is activated, although the control loops are deactivated.

Figure 2-2 - TASE200 Gimbal

Figure 2-3 - C-150 OPA GCS

The OPA is also equipped with a sensor payload system incorporating a Cloud Cap TASE200 gimbal mounted on the vehicle's port wing strut and a fixed forward looking electro-optic camera mounted on the top of the fuselage. The TASE200 gimbal (Figure 2-2) incorporates a FLIR Systems long wave Infrared (IR) sensor and a Sony color Electro-Optic (EO) sensor. The gimbal has its own IMU, GPS receiver, and also receives sensor information from the Piccolo II autopilot. The imagery from the gimbal and forward looking camera is digitized and downlinked to the GCS via a line-of-sight Orthogonal Frequency-Division Multiplexed (OFDM) Broadband Ethernet datalink operating in the 5.8GHz band. Software is utilized to display gimbal imagery and control the gimbal in manual, geo-referenced, or multiple tracking modes from the GCS.

The GCS is located in dedicated, restricted access control room. The configuration utilizes an array of four widescreen monitors to display the PCC and a projector to display the real-time forward looking video. A typical arrangement is shown in Figure 2-3. PCC has the capability to display a variety of windows for aircraft control and situational awareness. The GCS makes use of a Very High Frequency (VHF) radio for communications link and a steerable antenna controller to automatically track the OPA. The GCS communicates with the OPA via a Command and Control (C2) line-of-sight frequency hopping datalink operating in the 900MHz band.

In order to broaden the scope and increase the realism of the OPA training provided at NTPS the training scenario was expanded beyond simple OPA direct GCS control. Accordingly, the GCS was integrated into a typical flight test mission framework controlled by a Test Conductor (TC) supported by multiple Flight Test Engineers (FTEs). An interface was developed by NTPS allowing real-time parameters from the C-150 OPA to be displayed in the NTPS control room utilizing IADS software. A networked PCC display was projected in the control room to provide high resolution moving map, primary flight display, system status lights, and command loops for student TC/FTE situational awareness. The real-time feed from the OPA forward looking camera was also displayed.

2.1 Ground Testing

Ground testing of the OPA was undertaken over a period of six months, between December of 2010 and May of 2011. Ground testing included: Pitot-static instrument calibration, motor controller optimization, surface calibration, software and hardware in the loop simulation, sensor variable validation, magnetometer calibration, and RF spectrum analysis.

The original analog servo amplifiers were found to be unacceptable and were subsequently replaced with Proportional-Integral-Derivative (PID) motor controllers which were tuned to achieve the desired response. Surface calibrations were completed for each individual axis after the motor controller settings were finalized. The initial autopilot parameters and feedback gains were determined using the Cloud Cap Software-In-the-Loop (SIL) simulator. Subsequently, Hardware-In-the-Loop (HIL) simulation was set up using the actual aircraft hardware, which helped identify several wiring and autopilot interface issues. All autopilot system sensors were tested to ensure accuracy of data output while being subjected to vibration during engine ground runs.

A comprehensive Radio Frequency (RF) spectrum analysis was completed throughout the OPAs intended geographical operating area prior to the first datalink flight test. Spectrum analysis testing utilized the GCS steerable antenna to evaluate individual radials with the transceiver’s built-in spectrum analysis feature. Concurrent with the spectrum analysis, areas of potential antenna blanking due to obstruction/blockage were investigated by employing a camera mounted on the antenna rotator. Potential sources of interference were further investigated using a spectrum analyzer to aid in the selection of the desired frequency band for the C2 datalink.

2.2 Flight Testing

Following the successful completion of the ground testing activity the OPA entered its first phase of flight testing. This flight test effort was undertaken over a period of five months, between June and October of 2011. Twenty days of ground testing and 24 test flights totaling 28.8 flight hours were undertaken. The primary focus of the initial flight testing was to ensure autopilot controls were suitably optimized for both RPV and CDV modes. This initial period of flight testing also incorporated the following tests and evaluations: pitot-static differential between the aircraft and autopilot systems, navigation accuracy, laser altimeter accuracy,

command and control datalink envelope, baseline response determination, inflight motor controller optimization, autopilot gain tuning, control authority and limit confirmation, flight plan track navigation logic validation, failure state testing, and RPV flying qualities evaluations.
The aim of the first flight was to ensure that the autopilot sensors, i.e. the IMU, GPS, dedicated pitot-static system, etc. transmitted timely and accurate data to the GCS and that the sensor outputs observed at the GCS concurred with those observed by the safety pilot onboard the OPA. The second through sixth flights focused on testing and refining the C2 and sensor payload datalinks. Without the benefit of the onboard safety pilot these vital confidence building tests would have been impossible.

Having confirmed the accuracy of the autopilot sensor data and operational range for the C2 datalink the seventh flight engaged the autopilot inflight for the first time. Engagement of the autopilot was initially found to be problematic as the autopilot was designed to be in the loop from takeoff to landing. The autopilot was taken out of the loop by selecting a full authority RPV override or rate command mode, prior to and throughout the engagement procedure. Once the clutches were engaged the override mode was disengaged immediately and introduced into the loop.

The remainder and majority of the first phase of flight testing focused on refining the parameters within the autopilot to enable smooth controllable flight. Within each axis, a standard series of tests were conducted to evaluate required adjustments. From these tests data was obtained to ensure an informed modification to control gain was made. The safety pilot onboard remained in control of the disengaged axes throughout the incremental testing. Eventually all axes were engaged and the final gain modifications were completed. The autopilot was tested for control authority and limit confirmation to ensure the autopilot mandates avoidance of set limits. Testing was also conducted to evaluate the system response to loss of GPS and C2 datalinks.

The second phase of flight testing focused on the integration of the TASE200 gimbal sensor payload system. This phase was completed over a period of eight months, between July of 2012 and March of 2013. Fifteen days of ground testing, six taxi tests, and 11 test flights totaling 15.2 flight hours were undertaken. Ground testing for the TASE200 dual sensor EO/IR gimbal was analogous to testing a similar gimbal on a manned aircraft, however the testing was conducted both at the aircraft and from the sensor control station through the sensor datalinks. An extensive victim source Electromagnetic Interference (EMI)/Electromagnetic Compatibility (EMC) matrix was completed to ensure that all OPA electronic systems were unaffected by EM interference. The majority of the flight testing was focused on improving sensor payload datalink performance.

2.3 Certification and Limitation Reduction

The C-150 OPA initially received a standard Experimental Airworthiness Certificate in 2009 before the creation of the OPA category. In the spring of 2010 the FAA requested that NTPS surrender the experimental aircraft airworthiness certificate for the C-150 and contact the Production and Airworthiness Division, AIR-200, for recertification as an OPA. The OPA regulations had been recently established for any aircraft that could be controlled via datalink from a GCS. NTPS submitted the required program letter and safety checklist which was followed by an inspection from a team of subject matter experts from FAA engineering, operations, production and airworthiness, and air traffic management. Following the inspection NTPS complied with a list of required action items and received an OPA Special Airworthiness Certificate on August 11, 2010. This was only the third such certificate issued by the FAA. The initial certification imposed over 50 operating limitations including a restriction requiring that the OPA be operated at altitudes above 1,500ft AGL.

FAA OPA certification is valid for 12 months requiring re-certification each year. Although burdensome from a paperwork point-of-view the re-certification process afforded the opportunity to present results from OPA flight test together with revised standard operating procedures to the FAA with the aim of removing limitations and restrictions attendant to the prior certification. Accordingly, the 2012 certification reduced the minimum operating altitude to 500ft AGL for both day and night operations. This minimum altitude was essential for the testing of the EO/IR sensor gimbal. With the most recent certification in July 2013, by providing a Flight Test and Safety Plan with the required certification paperwork, the minimum operating altitude has been reduced to 50ft AGL. This reduction in altitude was required in order to facilitate future RPV Pitot-static FTT testing, i.e. tower fly-by. With supporting flight test data and the development of appropriate safety procedures it is hoped that the NTPS OPA will eventually be permitted to execute automatic takeoff and landings.

3.0 RPV/OPA FTT DEVELOPMENT

To date flight test techniques (FTTs) specifically designed for RPV testing have not been published. Although many of the unique aspects of flight testing RPVs have been acknowledged, for example as discussed in [7, 8], specific practical techniques have yet to be fully developed. The diversity in RPV vehicle size, operating envelope, flight control modes, and missions adds significant further complexity to the development of such RPV FTTs.

In the absence of dedicated RPV FTTs, following certification, ground and flight testing of the C-150 OPA, it was necessary to develop appropriate RPV FTTs which could be demonstrated during the school's RPV course. The starting point for this endeavor was to attempt to apply FTTs for manned aircraft to the OPA with the aim of identifying those manned FTTs which transferred readily from the manned to RPV regime and those that did not. The initial RPV FTT development effort focused solely on P&FQ FTTs employing the NTPS Volume X, Fixed Wing Flight Test Handbook [9] as the primary reference for the accepted manned fixed wing P&FQ FTTs.

Numerous FTTs incorporated in the Volume X could immediately be excluded as they were considered to be inapplicable to RPVs. For example, as RPVs typically have a limited operational speed envelope, testing the nonlinear portion of the envelope, e.g. stall speed determination, stall characteristics, and spins, was considered to be inapplicable and hence FTT for such tests were excluded.

As discussed in [7], RPV vehicle performance can be tested in two main ways: testing of the full integrated system or testing of the capability of the baseline aircraft-power plant combination. RPV vehicle performance FTT development with the OPA was focused on the baseline aircraft-power plant combination. Baseline aircraft-power plant combination is analogous to developmental flight test and evaluation of manned aircraft. The P&FQ subjects evaluated to date include: pitot-statics, cruise performance, climb performance, longitudinal static stability, dynamic stability, and RPV mission task related flying qualities evaluations.

The OPA is ideally suited for RPV FTT development due to the vehicle being capable of being operated in both CDV and RPV methods of control. The CDV mode can be used to emulate a range of vehicles, e.g. from one that is limited to autonomous preloaded flight plans to one with direct command loop control. The RPV mode is currently limited to vertical rate being controlled by longitudinal stick displacement. With basic software upgrades and autopilot tuning the RPV control can be upgraded to pitch attitude control with longitudinal stick displacement.

The succeeding paragraphs summarize results and observations from several of the P&FQ FTT development tests undertaken to date.

3.1 PEC Testing

Multiple manned FTTs for Pitot-static testing were evaluated using the OPA.

The GPS method Position Error Correction (PEC) FTT was found be most appropriate technique for measuring airspeed position error (ΔVpc). The RPV method of control could directly execute the traditional manned GPS method FTT. Although the CDV method of control typically commands track as opposed to heading this was found to be inconsequential as long as both heading and track were stable for each test point.

The modified tower flyby FTT was found to be the most appropriate technique for directly measuring altitude position error (ΔHpc). This technique can be safely executed on a CDV by commanding height above ground level using a laser/radar altimeter or by commanding DGPS altitude. It is recommended to determine the airspeed position error prior to conducting such testing at low altitude. The required precision and requirement to conduct the test at low altitudes over a known reference would likely preclude an RPV from safely executing the technique.

A FTT specifically designed to test RPV Pitot-statics is under development. This FTT would combine the two suggested methods, i.e. GPS for ΔVpc and modified tower flyby for ΔHpc, and be applicable to any type of unmanned system without any additional onboard instrumentation. Additionally, due to the digital nature of RPVs potential certification criteria directly related to the errors in measured static and total pressure are planned to be proposed for varying RPV categories.

3.2 Cruise Performance Testing

Through flight testing conducted with the OPA it was determined that the manned P_{iw}-V_{iw} FTT for evaluating reciprocating engine cruise performance was applicable albeit with proper implementation. Using the RPV method of control the pilot directly controlled throttle position, allowing stable trim shots to be obtained at different speeds. Using the CDV method of control it was not possible to set a fixed throttle position free from oscillation. Therefore, testing cruise performance in CDV mode required stable air to prevent throttle oscillation. Forcing the CDV to the backside method of control where airspeed is controlled with the elevator and altitude is controlled with the throttle was found to be successful when performing cruise performance testing.

3.3 Climb Performance Testing

The manned climb performance FTTs, including sawtooth climbs and level accelerations, were found to be directly applicable to both CDVs and RPVs. Forcing the CDV to the backside method of control was once again found to be required for sawtooth climbs. Alternatively, forcing the CDV to the frontside method of control was found to be required for level accelerations. This allowed the altitude to be held constant with elevator deflection with maximum throttle. It was also found that executing sawtooth climbs through a larger band of altitudes provided acceptable data as the vehicle was always on the commanded condition. It was possible to execute approximately five sawtooth climbs at different speeds and cover the desired airspeed range for a RPV.

3.4 Dynamic Stability Testing

Dynamic stability of the baseline aircraft-power plant combination could not be directly evaluated in either CDV or RPV modes since both modes are stability augmented resulting in a modified dynamic response. Consequently, the dynamic stability of the OPA was evaluated by directly injecting commands to a specific control surface using a special application within the GCS software. PCC allows for singlet or doublet inputs of a specified amplitude and frequency. The system is capable of executing an extremely precise input that would likely be challenging for a test pilot in a conventional manned aircraft. The dynamic aircraft modes were evaluated by commanding varying frequency sweeps, doublets, and singlets. Following a doublet or singlet input the controls were held fixed at the trim position for a specified period of time. Each of these commands was able to be terminated during the maneuver, with the autopilot resuming control at the initially commanded condition, if a test limit was reached.

3.5 Flying Qualities

It was identified that RPV/OPA flying qualities is one of the areas of flight testing which has the most significant differences from manned aircraft. The flying qualities evaluation has focused on the five C-150 OPA GCS pilot control interfaces (Mode 1: Command Directed Autonomous Flight Plan, Mode 2: Command Directed Command Loops, Mode 3: Remotely Piloted Stability Augmented Steering, Mode 4: Remotely Piloted Stability Augmented Full Authority, and Mode 5: Remotely Piloted Manual Control) for the Intelligence, Surveillance, and Reconnaissance (ISR) mission. The limited evaluation focused on the transit and orbit Mission Task Elements (MTEs).

The transit MTE evaluated the capability to track a straight, climbing and descending, flight segment. Desired and adequate task requirements were defined for lateral and vertical deviation at 50 and 100ft respectively. A desired and adequate task requirement was also set for Indicated Airspeed (IAS) at ±3kts and ±5kts respectively. The flight plan shown in Figure 3-1 was devised to ensure identical test setup for each mode evaluated. The mode under evaluation was engaged between WP0 and WP1 prior to the data leg. The data leg was completed between WP1 and WP3. Following each data leg the highest level of automation (Mode 1: Command Directed Autonomous Flight Plan) was implemented to provide the required spare capacity for the GCS Pilot to complete ratings, provide comments, and brief the subsequent test point.

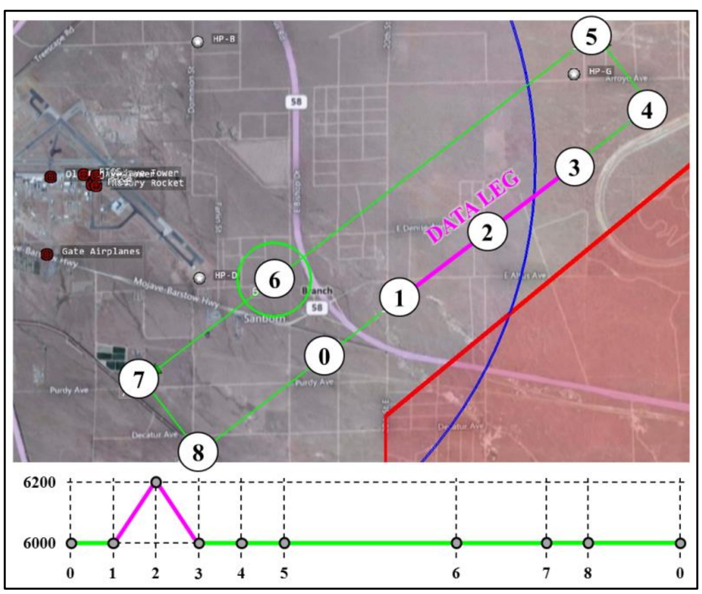

Figure 3-1 – ISR Transit MTE Flight Plan

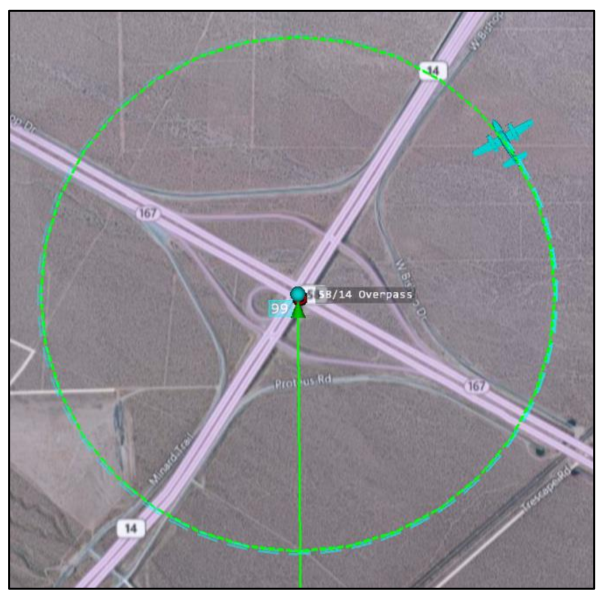

Figure 3-2 – ISR Orbit MTE Flight Plan

The Orbit MTE evaluated the capability to orbit a fixed target at a lateral radius of 3,000ft, which was defined based on the EO/IR sensor performance. Desired and adequate task requirements were defined for lateral and vertical deviation at 150ft/300ft and 75ft/150ft respectively. A desired and adequate task requirement was also set for Indicated Airspeed (IAS) at ±3kts and ±5kts respectively. The evaluation of each mode was initiated from the highest level of automation, shown in Figure 3-2, to ensure identical test setup for each mode evaluated. The GCS pilot was given time to familiarize with each mode prior to conducting the orbit for score. Once again, following each data leg the highest level of automation (Mode 1: Command Directed Autonomous Flight Plan) was implemented to provide the required spare capacity for the GCS Pilot to complete ratings, provide comments, and brief the subsequent test point.

Due to the complexity of evaluating significantly differing modes of control, following each evaluation four rating scales were implemented. First, the internationally recognized Cooper Harper rating scale was implemented however; it becomes less suitable when the GCS pilot is further removed from being directly involved in executing the task. Second, the Cotting Modified Cooper Harper Rating Scale designed for evaluating RPV flying qualities was employed [10, 11]. Third, the Bedford Workload Rating Scale was implemented to independently evaluate the workload of the GCS pilot. Finally, a RPV Display Qualities Rating Scale was implemented to assess the GCS pilot's sole feedback from the aircraft [12]. The combination of the ratings from these scales, task performance, and GCS pilot comments were found to effectively compare flying qualities for each of the modes of control.

3.6 OPA FTT Development – Outcomes & Observations

P&FQ FTT development with the OPA is still ongoing and evolving, but already several significant outcomes and observations have resulted.

Many of the fundamental considerations and flight test techniques employed for the flight test and evaluation of manned aircraft are congruent for RPVs, but the fact that the RPV pilot is withdrawn from the aircraft is significant and requires unique approaches to effectively execute RPV flight testing with minimal risk. An on-vehicle test pilot's cognizance, judgment, and experience provide an inherent flexibility to react to unanticipated events that simply cannot be replaced by an automated system. A substantial part of a pilot's conscious and subconscious feedback from aural, visual, and proprioceptive cues is eliminated when the pilot is repositioned to a GCS. Furthermore, the RPV pilot may be burdened by the time delay induced by the C2 datalink to the aircraft and any system latency of the flight instruments and video viewed at the GCS. Although such factors warrant at least cursory consideration when testing CDVs, their effects must be carefully examined and fully understood when testing RPVs since they play a significant role within the human-vehicle control-loop while operating under RPV control.

A key outcome of the FTT development effort was that different methods of control require significant differences in the required modification to manned FTTs. It was found in some cases that the CDV was well suited to a particular FTT, while in others the RPV was preferred. It was found that the primary issue with executing a particular FTT under a specific method of control was the inability to maintain constant control position. This could be overcome via short-term modification of simple control system settings, such as forcing the aircraft to the frontside or backside methods of control. It was also found that it would be of significant benefit if an application allowing particular modes of control and direct inputs to the flight control system is incorporated for testing.

4.0 RPV/OPA FLIGHT TEST TEAM COLLABORATION

To date flight test techniques (FTTs) specifically designed for RPV testing have not been published. Although many of the unique aspects of flight testing RPVs have been acknowledged, for example as discussed in [7, 8], specific practical techniques have yet to be fully developed. The diversity in RPV vehicle size, operating envelope, flight control modes, and missions adds significant further complexity to the development of such RPV FTTs.

During the OPA development and academic module integration flights related above several issues concerning test team collaboration/effectiveness during test execution were identified. As these issues were identified appropriate steps were taken to ensure that the issues were suitably addressed in order that maximum test team effectiveness was achieved during subsequent test execution. Several aspects relating to the issues observed are outlined in the succeeding paragraphs.

As with many other RPVs, the C-150 OPA missions were found to require significantly more personnel than an equivalent mission with a manned aircraft. A nominal instructor only sortie with the C-150 OPA involved no less than five personnel: Safety Pilot, a GCS Instructor Pilot, Sensor Instructor, Instructor Test Conductor, and a TM/Auto tracking operator. As with any flight test event with a large amount of participants, strict test discipline, e.g. strict adherence to checklist, test cards, and pre-briefed mission limitations, was found to be imperative in order to achieve the highest level of OPA mission success.

In addition to noting that the C-150 OPA missions were found to require significantly more personnel than an equivalent mission with a manned aircraft it was also observed that individual test team members had an individual level of situational awareness related to their individual test team responsibility e.g. the sensor operator was aware of senor performance but not necessarily of traffic conflictions; the safety pilot was aware of traffic conflictions but not of ground antenna pointing angles, etc. Accordingly, it was assessed that no one team member had a complete and full appreciation of *every* aspect of the test at any given point in time, a condition that demanded efficient and concise of intra-team communications in order to share pertinent information. Such sharing of information allowed team members to increase their overall situational awareness beyond the limited scope of their own responsibility.

Of particular note regarding situational awareness was the contrasting level of awareness encountered by the GCS Pilot regarding autopilot status and aircraft feedback cues. The GCS Pilot had a very high level of situational awareness with respect to autopilot control but lacked normal conscious and subconscious aural, visual, and proprioceptive feedback cues afforded to a pilot onboard an aircraft. The lack of such onboard feedback cues required the GCS Pilot to seek surrogate feedback information from GCS displays in order to complete the command feedback loop. In some cases such surrogate feedback information was not presented by the GCS, e.g. in-flight turbulence levels, and could only be obtained via enquiry with the Safety Pilot. This interaction between the GCS Pilot and Safety Pilot allowed the GCS to apply autopilot control in keeping with the airborne environment but, more importantly perhaps, highlights the fact that a GCS Pilot may have very high situational awareness in one regard, e.g. autopilot, but may be lacking in other regards, i.e. flight conditions.

In several cases it was found that the Test Conductor and supporting Discipline Engineers had better situational awareness than the GCS Pilot. This condition was due in part to the ability to design Test Conductor and Disciplined Engineer flight test displays specifically for the test mission to be flown. In contrast, the GCS Pilot operated a largely unmodifiable software package for aircraft control that was not easily tailored to specific mission requirements. Accordingly, the Test Conductor was able to monitor mission-specific *Abort* and *Knock-it-Off* criteria and hence was furnished with a higher level of situational awareness in this regard. Clearly, in order to realize the benefits of such improved awareness the Test Conductor required a direct VHF communication link to the Safety Pilot.

For an OPA special care should be given to defining and briefing *Abort* and *Knock-it-Off* criteria. It is essential to define under what conditions the GCS Pilot will attempt to *Abort* a test point versus when the Safety Pilot will disengaging the system and take control of the aircraft, i.e. a *Knock-it-Off* event.

Deciding upon next steps following recovery from an *Abort* or *Knock-it-Off* event may take an extended period of time requiring discussion between affected/key team members in order to debrief the situation prior to continuing (if appropriate) with the OPA mission. During this discussion period control of the OPA must still be maintained. Hold/sanctuary points, defined in terms of geographical position and altitude, have proven essential to OPA operations allowing the test team to command the aircraft to autonomously orbit at a defined hold point until such times as the test team have agreed upon the next step in the mission.

5.0 CURRENT RPV FLIGHT TEST COURSES

NTPS has integrated the C-150 OPA into both the yearlong professional course and RPV short courses. The professional course now has two independent RPV modules utilizing the C-150 OPA. In the final module of the P&FQ portion of the course students are given instruction and then tasked with a project evaluating Pitot-statics, cruise performance, climb performance, dynamic stability, RPV handling qualities, human factors, and workload. The final module of the avionics systems portion of the professional course includes instruction and flight test techniques for evaluating avionic systems on RPVs. The final portion of the course is a capstone project evaluating the remotely operated EO/IR sensor and RNP in various control modes. The students have been extremely satisfied with their experience with the OPA and have even requested further OPA implementation providing hands on experience to the future of aviation.

6.0 LESSONS LEARNED

Many valuable lessons have been learned throughout the development of the C-150 OPA and evaluation of RPV FTTs. The benefit of having a safety pilot onboard the OPA for the initial testing and FTT development has proven to be instrumental. Having a safety pilot onboard can allow for real-time control parameter modification to safely take place in flight, as the safety pilot can easily recover from an unexpected response. With a truly unmanned system similar testing would need to be approached more cautiously. Less time and cost is required to prefect a high fidelity model when a safety pilot is onboard. The optimized response of a RPV is not the traditional manner which a pilot flies an aircraft for passenger/pilot comfort. The control system design engineer's optimized response is traditionally utilized for RPVs. This coincides with pilot comments from chasing other unmanned platforms. Tuning of a RPV or OPA is dependent on the actual mission of the system. For an optionally piloted system it may be necessary to reduce the response of the aircraft for pilot comfort. At the same time, utilizing the safety pilots qualitative assessment of vehicle response may need to be limited if the vehicle will eventually be operated as a RPV. The entire learning experience for FTE students has been expanded significantly with IADS software integration. FTE students are now able to gain real world experience conducting missions and participating in each RPV flight from the control room.

7.0 LESSONS LEARNED

NTPS converted a Cessna 150 into an OPA, which operates with a certified safety pilot on-board who can deactivate the ground-controlled autopilot system at any moment. The system is certified by the FAA as an OPA and is capable of being controlled via command direction or in a remotely piloted vehicle mode. Many of the FTTs employed for manned aircraft are congruent for RPVs, but the fact that the pilot is withdrawn from the aircraft is significant and requires unique approaches to effectively execute RPV flight testing. Once the C-150 OPA was certified and had completed the initial phase of ground and flight testing, it was necessary to develop and analyze FTTs that would be demonstrated utilizing the system. The initial endeavor focused solely on performance and flying qualities FTTs. The majority of the manned FTTs evaluated were found to be applicable with slight modification and additional considerations. Future research with the system intends to focus on designing FTTs specifically catered to RPVs as well as proposing regulating criteria for RPVs. The C-150 OPA has proven to be an effective RPV flight test training platform for NTPS. The benefit of having a safety pilot onboard the OPA for the initial testing and FTT development has proven to be invaluable. NTPS has found that OPAs are an essential evolutionary step from flight testing manned aircraft to RPVs.

8.0 ABBREVIATIONS

AGL	Above Ground Level
C2	Command and Control
CDV	Command Directed Vehicle
CG	Center of Gravity
CRM	Crew Resource Management
D3	Dull, Dangerous or Dirty
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EO	Electro-Optic
FAA	Federal Aviation Administration
FTE	Flight Test Engineer
FTT	Flight Test Technique
GCS	Ground Control Station
GPS	Global Positioning System
HIL	Hardware-In-the-Loop
IMU	Inertial Measurement Unit
IR	Infrared
ISR	Intelligence, Surveillance, and Reconnaissance
NAS	National Airspace System
NTPS	National Test Pilot School
OAT	Outside Air Temperature
OFDM	Orthogonal Frequency-Division Multiplexed
OPA	Optionally Piloted Aircraft
P&FQ	Performance & Flying Qualities
PCC	Piccolo Command Center
PEC	Position Error Correction
PID	Proportional-Integral-Derivative
RF	Radio Frequency
RNP	Required Navigation Performance
RPV	Remotely Piloted Vehicle
SIL	Software-In-the-Loop
TC	Test Conductor
VHF	Very High Frequency

9.0 ACKNOWLEDGEMENT

Through the generous support of the NTPS Board of Trustees and CEO, all infrastructure including the required software, equipment, laboratories, and operating costs necessary to complete this study have been provided.

10.0 REFERENCES

[1] Flying Qualities Built-In-Test For Unmanned Aerial Systems. Chiu, A.P., California Polytechnic State University, 2012.

[2] Air Force UAVs the Secret History. Ehrhard, T.P., Mitchell Institute, 2010.

[3] Unique Aspects of Flight Testing Unmanned Aircraft Systems AG-300-V22. North Atlantic Treaty Organization, 2010.

[4] Unmanned Aircraft Systems Roadmap 2011-2036. United States Department of Defense, 2011.

[5] Cessna 150 N18531 Flight Manual, Publication of National Test Pilot School, Cessna Aircraft Company, Wichita, Kansas USA.

[6] Piccolo System User's Guide, Software v2.1.4.f. Cloud Cap Technology, Alex Barchet, Dan Bridenbecker, Van Miley, Bill Vaglienti, 15 October 2012.

[7] Unique Aspects of Flight Testing Unmanned Aircraft Systems AG-300-V22. North Atlantic Treaty Organization, 2010.

[8] The Role of the Society of Experimental Test Pilots in the Development and Flight Testing of UAVs. Smith, R., Society of Flight Test Engineers, 2012.

[9] NTPS Vol. X FW Flight Test Techniques. National Test Pilot School, 2012.

[10] Evolution of Flying Qualities Analysis - Problems for a New Generation of Aircraft. Cotting, C., Virginia Polytechnic Institute and State University, 2010.

[11] UAV Performance Rating Scale Based on the Cooper-Harper Piloted Rating Scale. Cotting, C., Virginia Polytechnic Institute and State University, 2011.

[12] Modified Cooper Harper Evaluation Tool for Unmanned Vehicle Displays. Cummings, M.L., Myers, K., Scott, S.D., Massachusetts Institute of Technology, 2006.