DEVELOPMENTAL TEST AND EVALUATION OF HELICOPTERS USING A PRECISION DIFFERENTIAL GLOBAL POSITIONING SYSTEM

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ABSTRACT

Development of new and innovative applications for high precision differential global positioning systems (DGPS) has exploded in the last two years. Real-time three-dimensional accuracy's of under three centimeters and processed position update rates in excess of four hertz, along with position update latencies of under eighty milliseconds are now commercially available. Immediate position information of this high accuracy and rate opens up tremendous possibilities for automated machine control applications. Over the last two years, MDHS has been developing the "Portable Test Range", a DGPS based aircraft position and velocity data archiving tool. When required, the system provides the flight crew with three-dimensional guidance and power cues integrated into a simple but highly effective flight director. The Portable Test Range has been used on numerous FAA certification flight test efforts, including noise certification, height-velocity curve development, and Category A profile development. In the Fall of 1996, the Portable Test Range was used as a flight director for a variety of complex landing approach profiles at NASA Crow's Landing airfield. This flight test program allowed for the simultaneous acquisition of laser position data, and was an opportunity to demonstrate the system to FAA, NASA, Army, and John Volpe Department of Transportation Technical Center staff. Certification of the "Portable Test Range" for all types of fixed wing and rotary wing flight test activities is ongoing.

NOTATION

ADS	Aeronautical Design Standard
C/A Code	Clear Acquisition GPS Code Broadcast
CDI	Course Deviation Indicator
CDP	Critical Decision Point
DGPS	Differential Global Positioning System
FAA	Federal Aviation Administration
FEC	Forward Error Correction
FM	Frequency Modulation
G	Acceleration
GDI	Glideslope Deviation Indicator
H-V	Height Velocity
IFR	Instrument Flight Rules
LAACO	Los Angeles Area Certification Office
LDP	Landing Decision Point
L1	GPS Frequency at 1575.42 Megahertz
L2	GPS Frequency at 1227.670 megahertz
NASA	National Aeronautics and Space Administration
OEI	One Engine Inoperative
OEM	Original Equipment Manufacturer
PTR	Portable Test Range
MDHS	McDonnell Douglas Helicopter Systems
Reference Station	The Fixed Receiver of a DGPS
RF	Radio Frequency
RITA	Rotorcraft Industry Technology Association
Rover(s)	The Mobile Receiver(s) of a DGPS
RTK	Real-Time Kinematic
RTO	Rejected Takeoff
V_{BLSS}	Balked Landing Safety Speed
V_H	Maximum Continuous Power Horizontal Speed
V_{NE}	Velocity Never to Exceed
V_{TOSS}	Velocity Takeoff Safety Speed
V_Y	Best Rate-of-Climb Speed

INTRODUCTION

Differential global positioning systems (DGPS's) have been commercially available for several years, but until recently only the land surveying community has fully exploited this technology. Initially, autonomously collected GPS data was simultaneously archived for perhaps forty-

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five minutes at a control reference station as well as a new point of interest (the rover station). Post processing of the data provided surveying accuracy's of approximately one centimeter. As the technology progressed, real-time kinematic (RTK) surveying techniques were developed that require a data link be maintained constantly between the reference station and the rover station. Occupation times on the rover station of as little as ten seconds can now yield position accuracy's of one to two centimeters. Disciplined surveying techniques including periodic return to known control points, as well as some post processing of data, verify and guarantee that this level of accuracy is maintained.

The evolution of DGPS hardware and software has made it possible to use this technology for highly dynamic applications. Several manufacturers offer equipment with processed position update rates of between two and ten hertz. Latency times, that is the time between position data acquisition and data availability at a communications port to a computer are as low as seventy milliseconds. These high update rates and low latency times allow for a variety of real-time guidance applications, including machine control for agriculture, construction, and mining.

The navigation and position information availability from high precision DGPS can also be integrated into flight director systems, allowing for the design and execution of almost any flight pattern imaginable. MDHS has demonstrated extremely precise complex landing approaches using only DGPS for guidance and position data archiving. Cues have been developed to increase the safety and repeatability of a variety of flight test programs including height-velocity, Category A, and noise certification. Applications such as aircraft handling qualities evaluation for maneuvers called out in Aeronautical Design Standard 33C are being examined. The efficiency of all test applications has been greatly enhanced by the real-time display of critical data to both the flight crew and the ground-based test director.

DGPS FUNDAMENTALS

The GPS satellite constellation is maintained by the United States Department of Defense (DOD). The GPS satellites broadcast information on 2 frequencies, L1 (1575.42 MHz) and L2 (1227.60 MHz). The L1 carrier is modulated by the clear acquisition (C/A) code and the precise (P) code. The L2 carrier is modulated with only the P code. The P code is encrypted for U.S. military and other authorized users. The C/A code is available to civilian users of GPS equipment. The accuracy of a C/A code GPS receiver may be as poor as 40 meters in the horizontal plane. This accuracy is sometimes much better, and is subject to the effects of selective availability (S/A). S/A is a technique that the DOD uses to degrade the accuracy of C/A code receivers. References 1 - 3 offer the reader much background information regarding GPS and DGPS.

Used autonomously, GPS is of little use in precision flight test applications. However, by installing a second GPS receiver on a control point and merging data from both receivers, very high position data accuracy's in all three dimensions can be achieved. This data merging process can occur real-time or in a post processing fashion, and is denoted as a Differential Global Positioning System.

Real-time DGPS consists of a reference station receiver located on a control point and any number of rover receivers installed on vehicles or points of interest.. The reference station GPS receiver compares its known location to the currently determined location generated from the latest GPS satellite information broadcast. The reference station develops correction factors that can be broadcast to the rover GPS receivers. When these correction factors are applied by the rover receivers in a timely fashion, the three-dimensional position accuracy's for these rover receivers are immensely improved.

Transmitting the differential correction from the reference station to the rover station(s) typically requires some sort of radio frequency (RF) modem data link. This link may be provided by cellular telephone, VHF, UHF, 900 megahertz spread spectrum, or other radio systems. RF modems that can reliably transmit this type of data are often equipped with forward error correction (FEC), an error checking technique that insures the correction is received just as it was broadcast. Most difficulties in using DGPS effectively are due to inadequate data linking of the differential corrections. Selection of an appropriate radio frequency band should be based upon the test requirements. Higher frequency signals are more quickly attenuated by the atmosphere, and have a more stringent line-of-sight requirement. Also, some radio frequency bands, such as 900 megahertz, are restricted in transmit power so that the reliable radio range is severely limited. Integration of GPS receivers with a particular RF modem system is often left to the end user, hence it is important to discuss with the GPS receiver manufacturer the particular requirements of a system for such things as FEC. For users that desire to downlink data from the air vehicle to the ground based test director, cellular telephone data links are not an option, since broadcasting from an aircraft with a cellular telephone is prohibited by FCC regulations.

Federal Communications Commission licensing of discrete radio freqencies is sometimes difficult or impossible to obtain, hence systems such as 900 megahertz that do not require RF licenses are sometimes advantageous. If the radio user chooses to work on an unlicensed radio frequency and is apprehended by the FCC, penalties are severe and can include confiscation of all equipment, large civil fines, and more. Large corporations typically own several radio frequency licenses for their regional operating areas. Small companies and individuals, especially located in RF rich environments typically found around metropolitan areas, are at a distinct disadvantage for obtaining radio frequency licenses suitable for differential correction broadcast. In some areas, surveying groups have pooled their resources to obtain a single licensed frequency, and installed a DGPS reference station that broadcasts corrections to be used by all DGPS users in the area. Differential correction logs are not always standardized between manufacturers, hence it is important to research this aspect carefully prior to selecting a particular manufacturer's product. In some parts of the world, subscription services are available for differential corrections at reasonable cost.

The distance between the DGPS reference station and any rover station, known as the baseline, must be controlled to maintain the system accuracy claimed by the manufacturer. Assuming the differential correction data link can operate over the baseline, the accuracy of the DGPS can still degrade due to unpredictable elements of the processing algorithm. Manufacturers of DGPS create ionospheric propagation delay models that are only reliable over limited baseline distances.

System initialization, or the time that it takes for the DGPS to arrive at its most accurate solution accuracy, is another operational consideration when selecting a manufacturer's equipment. Receivers that only work in the L1 band typically require substantial initialization times when initialization occurs in a dynamic situation, such as steady state flight. The same system might initialize much faster if the initialization occurs in static circumstances, such as with the aircraft parked on the flight ramp. Initialization can only occur after the differential correction data link is established. Given the limitations of whatever RF modem is in use, operations must be planned which accommodate the initialization requirements of the DGPS in use.

Receivers that operate using both the L1 and L2 bands are typically able to initialize in dynamic situations with a very short delay. However, the user is cautioned that such systems typically are limited to the same baselines as L1 only systems. Use of the L2 carrier during the initialization process greatly reduces the errors induced by unpredictable ionospheric propagation delay, however this advantage is minimized as the baseline increases.

DGPS that takes advantage of L1 only is capable of accuracy's in 3-dimensions of up to 20 centimeters while operating real-time. Those systems that use both L1 and L2 can yield accuracy's in the range of 2 - 3 centimeters. As might be expected, the cost and complexity of the L1/L2 systems are much greater that the L1 only systems, and some operational limitations arise due to the less robust signal broadcast on the L2 band. Figure 1 depicts the basic DGPS components.

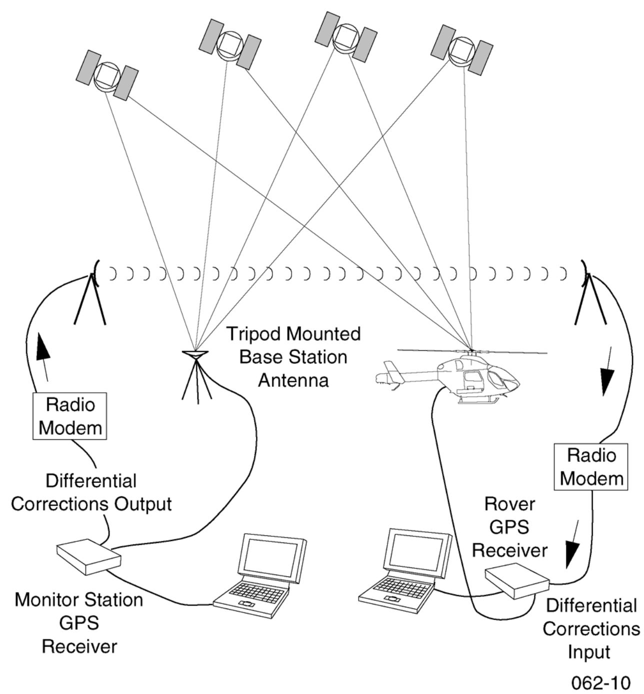

Figure 1. Basic Components Of A DGPS.

TEST RANGE SELECTION AND ARRANGEMENT

Historically, systems such as microwave trisponders, grid cameras, or encoding optical theodolites have required large open areas for proper system setup and operation, severely limiting the selection of test range locations. DGPS operations are much less restrictive with regards to test range selection. The reference station GPS antenna should have an unobstructed view of the sky from horizon-to-horizon, as much as buildings or natural obstacles permit. In real-time applications, the RF antenna for the differential correction link should be located so that the radio system in use can maintain a high integrity data link between the air vehicle and the reference system. For most radio systems, it is best to insure direct line-of-sight between the ground reference system and the air vehicle. Cellular telephone modems should be used such that the air vehicle will be in range of a broadcasting/receiving station.

In some cases it is necessary to relate the selected test range to a regional geodetic coordinate system. This situation might occur when working on an instrumented test range such as NASA Crow's Landing or the Army's Yuma Proving Ground. Often, the DGPS data needs to be correlated with other range assets such as laser tracking equipment or weapons targets. Should this situation occur, the DGPS reference station must be surveyed relative to a high accuracy monument on the location. This can be done with conventional surveying techniques, RTK DGPS techniques, or post-processed DGPS techniques. Once the new monument is located for the DGPS reference station antenna, all DGPS data should match the test range monuments within the limitations of the range survey and the stated performance of the particular DGPS.

In the case where a locally established coordinate system is adequate for the test program, the reference station GPS antenna should be located in such a way that the installation can be accurately and precisely repeated on a daily basis. Afterwards, the reference station GPS receiver should be allowed to acquire its position. Typically, the latitude and longitude will be more accurate if the vertical position of the GPS antenna is fixed in the GPS receiver. This vertical information can usually be derived in an adequately accurate fashion from local topographical maps or airport facilities directories. After the reference station GPS receiver has acquired a position fix, the latitude and longitude can be recorded and input to the receiver as an absolute location. Once this is accomplished, the reference station can begin broadcasting differential corrections to any rover GPS receivers in use.

Any other monuments on the test range, such as microphone locations, landing pad locations, runway ends, etcetera, should be surveyed using a rover GPS receiver used in differential mode. This will insure that all critical locations on the test range are properly related to local coordinate system. Most GPS receivers provide waypoint navigation functions that will allow the user to establish "From" and "To" waypoints in the receiver and then the receiver will output such information as distance from the "To" waypoint, lateral deviation from the line between the "From" and "To" waypoints, vertical and horizontal velocities, ground track, and so on. The system engineer can then design software that will archive and manipulate this data to meet the needs of the test program.

FLIGHT TEST SOFTWARE AND HARDWARE DEVELOPMENT WITH AIRCRAFT INSTALLATIONS

There are a large number of manufacturers of commercially available GPS equipment. Many GPS receivers now available, even small hand-held units, offer a variety of features including parallel six channel satellite receivers and serial interfaces for input of differential corrections and output of various position and velocity information. Depending upon the needs of the user, these devices, some only costing several hundred dollars, might be quite adequate for many applications. However, because the designers of these GPS receivers intended to meet the needs of a certain market segment, the usefulness of these devices is limited in developmental flight test or machine control applications. Even expensive and sophisticated DGPS equipment designed for precision land surveying applications lack many of the features necessary to be applied to dynamic flight test applications.

MDHS researched the GPS equipment market extensively in 1994, focusing on the offerings at the international conference of the Institute of Navigation. The objective of the market survey was to locate a differential global positioning system designed for dynamic machine control and tracking applications that had adequate accuracy in three-dimensions. A position update rate of at least 4 hertz, data latency time of less than 100 milliseconds, position accuracy of better than 0.5 meter in all three dimensions, and flexibility in use were major goals of the search. Only one company, NovAtel Communications, Limited, of Calgary, Canada offered a product that met the requirements. The product offered was designated as the RT-20, an L1 only receiver, and was designed to meet the needs of the original equipment manufacturer (OEM).

The RT-20 system was sold as a pair of receivers with accessories such as reference station and aircraft antennas, power supplies, and a simple software package designed to get the user started with system familiarization. NovAtel did not offer an integrated DGPS including the differential data link equipment, and software for any custom applications of the system was left to the development of the user. NovAtel did recommend purchasing radio data linking equipment that included forward error correction (FEC) because of the complexity of the differential correction messages required to be broadcast by the reference station to the rover. The RT-20 system specifications included a 5 hertz data update rate, 70 milliseconds data latency time, and a one sigma standard deviation in three-dimensional position of 20 centimeters. Novatel recommended a 9600 baud rate modem system to broadcast differential corrections.

MDHS was left with researching the data modem radio market for a suitable differential data link. Long range plans for the system included not only uplinking differential correction messages from the reference station to the receiver, but also downlinking processed aircraft position and velocity data for immediate archiving and plotting for review by a ground-based test director. This desire led to the requirement for extremely flexible radio modems with the capability of very high duty cycles. A market search turned up only one company, G.L.B. Electronics, that offered a product that would fulfill the requirement. After researching available licensed radio frequencies within the McDonnell Douglas Corporation, a pair of UHF radio modems, programmable in 12.5 kilohertz steps between 460.000 megahertz and 470 megahertz was selected. These radios were equipped with 9600 baud rate, forward error correction, and a 99% data throughput rate.

System integration was relatively trouble free, with most difficulties involving cabling and power supply problems. Software to control data archiving and display was written using National Instruments Labview for Windows, a graphical users interface programming language offering a multitude of analog and digital display options for the computer screen. As the software development progressed, an analog output card was added to the aircraft computer to drive an analog cockpit indicator to guide the flight crew over a microphone array as required by FAA FAR Part 36 noise certification testing. To stabilize and quicken data processing and display time on board the aircraft, binary rather than ASCII data logs from the RT-20 were requested and decoded. Eventually, downlinking of critical aircraft position and velocity data to a real-time plotting and archiving package at the ground-based test director's station was added.

Currently, MDHS operates the RT-20 system at a position update rate of 4 hertz, which is processed, archived, and decimated on board the aircraft, and then downlinked to the ground station at a 2 hertz rate. This update rate has proven adequate and highly effective for flight crew guidance as well as for all certification and developmental testing attempted.

MDHS has located the GPS receiver antenna at the top and center of the rotor head (Figure 2). This location requires the installation of a special stand pipe through the center of the main rotor drive shaft, something usually available only to helicopter manufacturers. When the instrumented rotor head hardware has not allowed for this installation, a tail boom location for the GPS receiver antenna has been used (Figure 3). Both antenna locations offer distinct advantages and disadvantages. The main rotor head location most nearly approximates the aircraft center-of-gravity (C.G.) and is generally not influenced by yawing of the tail in gusty conditions or pitching motions during acceleration and deceleration maneuvers. The main rotor head location also allows for a completely unobstructed view of the sky, thus optimizing the reception of GPS satellite signals.

Figure 2. MD900 Explorer With Antenna Installations.

The tail boom location for the GPS receiver antenna is subject to obstructions such as the upper forward fuselage and rotor head, as well as the tail empennage. Reception of GPS satellite signals passing through the rotor disk causes no particular problems for the NovAtel RT-20 receiver, however several high precision DGPS surveying systems have demonstrated an inability to function under the rotor disk at certain rotor RPM's. This seems to be a function of blade number, chord length, passage frequency, and percent time that the GPS signal is masked. MDHS has worked with a local manufacturer of GPS receivers to understand this problem. Disadvantages of the tail boom location include artificially induced accelerations due to pitching and yawing motion of the aircraft that are not indicative of the aircraft C.G. One particular advantage, however, is that when examining maneuvers such as low speed controllability, this information can be related to pilot workload and ability to control the aircraft.

Figure 3. Tailboom Installation For GPS Antenna

MDHS has created a crash worthy DGPS instrument pallet (Figure 4) for helicopters that is stand-alone from any other aircraft instrumentation that might be installed. This pallet includes a twelve volt lead-acid sealed gel cell battery to power the GPS receiver and radio modem. The battery power to the GPS receiver and radio modem facilitates system initialization without requiring aircraft power, notorious for power glitches when switching from external power to aircraft battery and generators. A static inverter is included to power the hardened computer required by the system. A control panel is installed within reach of the flight crew that allows for power control of all devices, and also includes GPS valid position and radio function status lights. A sunlight readable color display (Figure 5) is mounted in the front cockpit for system control by the flight test engineer. System operating software is designed so that the computer keyboard is not required; all file selection and control functions are effected by using a remoted tracking pad with selector switches.

DGPS data is tagged with the exact time the information was generated, accurate to within several picoseconds in the RT-20 system. Because of the delay in polling the computer serial port, processing the information, and generating the log file to be downlinked and archived aboard the aircraft, MDHS has chosen to not integrate the data stream into the onboard instrumentation data package. The MDHS system design and operation philosophy has been to integrate the DGPS data with other aircraft state data in a post-processing fashion.

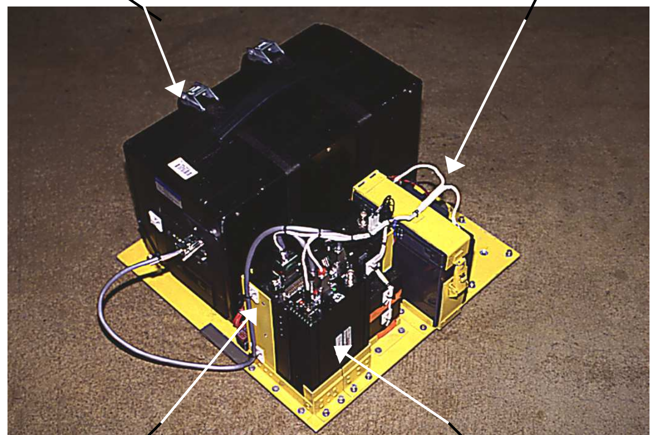

Figure 4. DGPS Instrumentation Pallet

Figure 5. Cockpit Display And CDI/GDI's

SYSTEM PERFORMANCE AND SOFTWARE VALIDATION ISSUES WITH FAA AND DOT VOLPE TECHNICAL CENTER

Initial performance verification of the MDHS Portable Test Range was conducted to satisfy the FAA Los Angeles Aircraft Certification Office (LAACO). Time encoded, vertically oriented video, and vertical and horizontal photoscaling techniques were used to demonstrate the time versus position accuracy in three-dimensions of the Portable Test Range system. FAA officials witnessing noise certification flight testing activities reviewed test range survey techniques and verified the accuracy of the aircraft position data with respect to the microphone locations.

Evolution of the Portable Test Range has continued so that developmental flight testing for height-velocity and Category A can be more efficiently and safely conducted. Because these test programs involve flight safety related issues, not just environmental impact as is addressed by FAR Part 36, FAA scrutiny of the position data accuracy has been more extreme. MDHS is currently going through the process of developing a completely documented and approved Portable Test Range operating procedure. This process includes a standardized procedure for hardware installation on the aircraft and the test range as well as the test range survey for relevant monuments and waypoints. Techniques must be outlined to demonstrate proper system operation and performance in whatever environment the system is operated, including fixed wing heavy jet operations.

The Portable Test Range operating software has evolved to access relevant navigation information from documented data files, and to archive this information into the test data file. Manipulation of the DGPS data prior to archiving must be documented and raw data demonstrating performance of the system must be recorded. The software version must be completely documented and controlled, and an executable version of the software must be tested and approved by engineers at the Volpe National Transportation Systems Center.

Performance validation of the particular DGPS receivers must be completed as well. MDHS initially used time encoded photoscaling techniques to verify X, Y, and Z position versus time. More recently, MDHS completed a research flight test program at NASA Crow's Landing, demonstrating a variety of complex landing approaches using the Portable Test Range for flight crew guidance and aircraft position documentation, while simultaneously the NASA laser tracking system documented the aircraft position. A comparison of Portable Test Range versus laser tracking data is presented in Figure 6. Reference 4 reports on NovAtel RT-20 flight testing on a fixed wing jet aircraft. Additional supporting test and evaluation results are included in References 5 - 8.

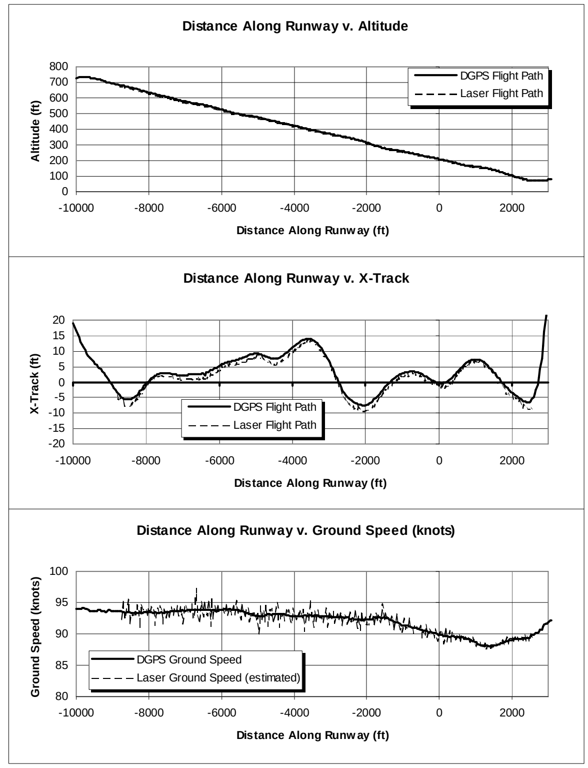

Figure 6. DGPS Versus Laser Tracking Data

COMPLEX APPROACH PROFILES FOR RITA TESTING

In the Fall of 1996, MDHS participated in a flight program involving a variety of complex landing approaches. The purpose of the program was to develop quiet landing approach techniques that fell within the normal operating envelope of the MD902 Explorer. This program was performed with joint government and industry funds available through the Rotorcraft Industry Technology Association (RITA).

A variety of landing approaches were designed, varying from constant angle constant speed to constant rate-of-descent constant deceleration. The approaches began with a transition from steady state level flight 10,000 feet from a helipad, and terminated with a 30 second in-ground-effect (IGE) hover at the landing point. An array of over 40 microphones was installed beneath the flight path, and the noise data were used to develop noise contour maps for the various landing approach techniques. The objective of the flight test program was to develop ways to minimize the noise impact that terminal area operations have on a surrounding community.

The flight test program was executed at NASA Crow's Landing airfield located in central California. Crow's Landing is an instrumented test range with a fixed base data system for aircraft state data, atmospheric data equipment, and a laser tracking system. The laser tracking system is equipped with a data link and aircraft guidance system, allowing pre-programmed landing approaches to be compared to aircraft position. The difference data is transmitted back to the aircraft and used to drive a course and glideslope deviation indicator installed in view of the aircraft pilot.

Rather than take advantage of this system, MDHS chose to further develop the Portable Test Range to provide the complex landing approach guidance to the flight crew. Because of the decelerating landing approaches planned for the test program, the airborne guidance system was modified by adding an analog to digital conversion card to the hardened computer, as well as a second analog indicator in view of the flight crew. The A/D card was used to acquire a DC voltage signal from the indicated airspeed transducer installed on the aircraft instrumentation package. The two analog course and glideslope deviation indicators, King KI206's, were installed directly above the standard flight instruments in the direct view of the pilot (Figure 5). Initially, one indicator was used for vertical and lateral guidance, while the vertical deviation bar on the second indicator was used to indicate deviations from the target airspeed. The lateral deviation bar of the second indicator was used to provide warning to the pilot that a change in flight condition was about to occur.

After several practice decelerating landing approaches, the test pilot requested that the lateral deviation bar and airspeed deviation bar be collocated on the right indicator, and the vertical deviation bar and warning needle be collocated on the left indicator (Figure 5). After this change was effected, the pilot commented that a simple but effective flight director had been created. The right side indicator provided cues for the pilot's right hand on the cyclic, while the left side indicator provided cues for the pilot's hand on the collective. The pilot's comments were that no thinking was required other than to adjust to the amount of control deflection required to keep the needles centered. Lateral and vertical deviation needle sensitivity was initially set at a needle centered to full scale value of ±50 feet. After some practice, it was determined that an increased sensitivity of ±25 feet reduced pilot workload. The airspeed deviation was set at a needle centered to full scale deviation value of ±10 knots indicated airspeed. This relatively low sensitivity compensated for the high noise floor of the relatively inexpensive A/D card installed in the airborne computer.

The sensitivity of the lateral and vertical deviation needles was reduced at a linear rate farther out than 12,000 feet from the landing pad, to effect easy course intercept. Target airspeed was maintained until the beginning of the run by referencing the aircraft airspeed indicator. Pilot comments regarding needle sensitivity were that the increased sensitivity allowed for immediate detection of trends away from the target flight path, which in turn allowed for corrections to be made with very slight control deflections. This actually reduced pilot workload and produced true flight path and speed profiles very close to the reference profiles. A flight test profile example is presented in Figure 7.

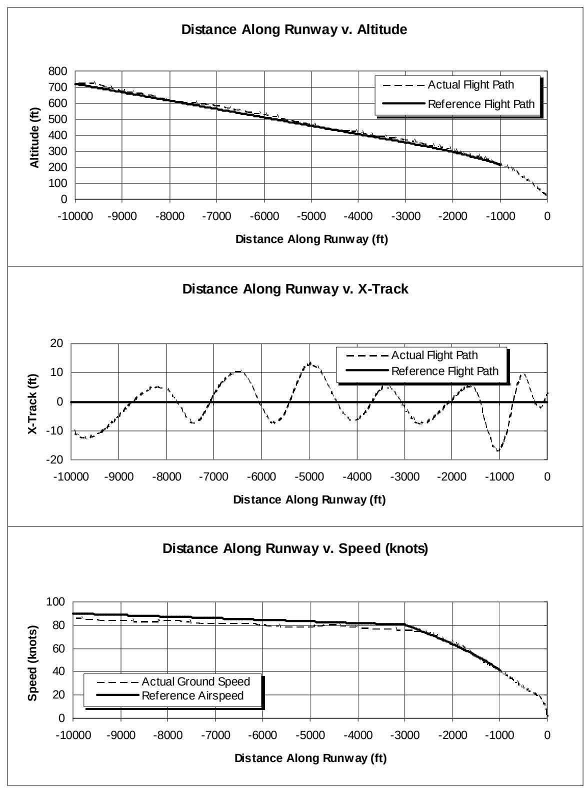

Figure 7. Complex Flight Test Profile

It should be noted that the pilot's workload was limited to flying the aircraft with reference to the instruments. Distractions such as radio communications were virtually eliminated during the test runs. The flight test engineer provided the pilot with verbal and indicator warnings of upcoming changes in the flight profile, so the pilot's eyes could remain constantly glued to the instruments. Obviously, this situation in real instrument flight rules (IFR) conditions is not the norm, and any full scale excursions of the deviation needles would make executing a missed approach mandatory. However, in the interest of repeatability of the noise data, MDHS philosophy was to fly the most precise approach possible. The pilot's comments were that regardless of the deviation needle sensitivity, the amount of deviation from needles centered remained the same, however the looser the deviation needle tolerances, the higher the magnitude of the control input and amplitude of oscillations about the reference flight path. With the high sensitivity of ±25 feet in effect, the pilot was typically able to keep the aircraft within 10 feet of the reference flight path. It is important to note that the Portable Test Range was configured to acquire the true aircraft position at a 4 hertz rate. However, due to the high precision of the position data, no smoothing was necessary, and no deviation needle twitchiness was noted.

Laser tracking data was acquired at 100 hertz rate and decimated to 4 hertz for comparison. The laser cube was mounted on the right side step to the passenger compartment (Figure 2), and the data was translated to the same position as the GPS antenna (top center of the rotor head) for comparison. It is important to note that this translation did not take into consideration aircraft heading, hence in strong cross winds, occasionally experienced during the flight test program, the simple X-Z translation from the laser cube to the GPS antenna would generate some degree of error due to aircraft crab angle.

CATEGORY A PROFILE DEVELOPMENT

MDHS is currently conducting developmental flight testing on the MD902 Explorer to demonstrate Category A capabilities. Typical Category A takeoff and landing profiles for an elevated helipad are depicted in Figures 8 and 9. Documentation of the helicopter's flight path relative to the helipad structure is required for this test activity (Reference 9).

The Portable Test Range allows the test team to precisely place the helicopter for the initiation of each test point, and to record the exact flight path of each take-off or landing attempt. Three-dimensional position and velocity profile plots are available to the test team between take-off and landing runs, allowing the ground monitoring team to coach the pilot regarding subtle differences in each test point. Slight differences in altitude, acceleration, airspeed and climb rate are highlighted to the cockpit crew between data points, allowing very fine tuning of the techniques used by the pilot.

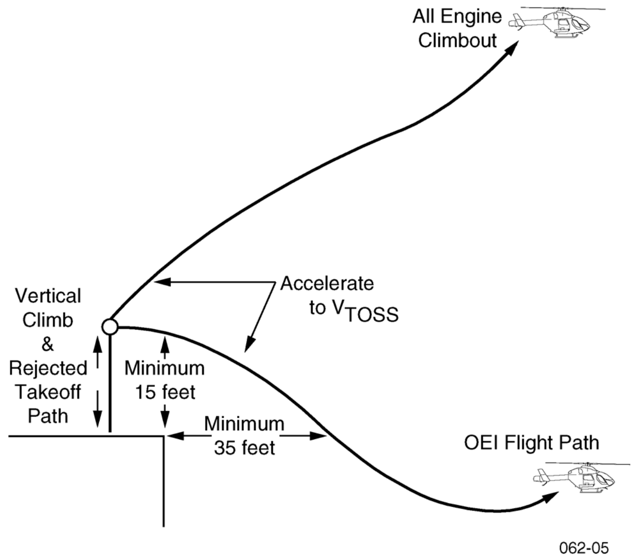

Figure 8. Category A Vertical Takeoff Profile - Pinnacle

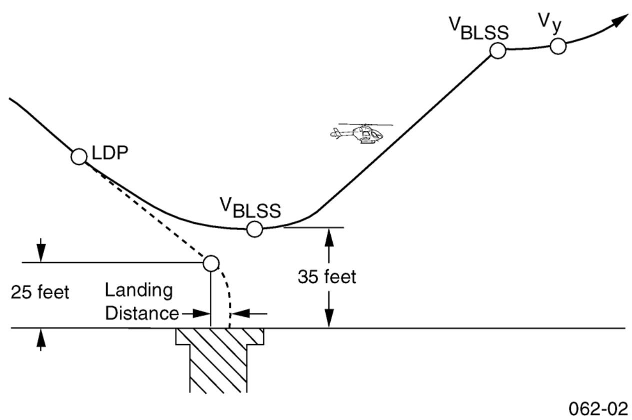

Figure 9. Category A Vertical Landing

Typically during the execution of ground referenced flight test activity, local winds are measured within several hundred feet from the flight operations area. As anyone who has ever operated at off a runway with a wind sock at each end can attest to, it is not uncommon for the indications to be in contradiction to one another. Because atmospheric conditions can be extremely localized, MDHS compares the test aircraft's horizontal and vertical speed acquired from the Portable Test Range with the aircraft's true airspeed to develop a detailed profile of the winds aloft. Knowledge of this wind profile gives the flight test team a greater understanding of the variation in flight profiles from one data point to the next.

ADS 33D MANEUVER GRADING AND CUEING

Flight control law development and handling qualities evaluations have traditionally centered around flight test techniques which could repeatably measure the static and dynamic response characteristics of an aircraft. Recently these time domain test techniques have been augmented by frequency domain tests which are more appropriate for advanced fly by wire or heavily augmented flight controls. Standard data requirements for this type of testing normally include attitudes, angular rates, velocities, accelerations and control position information. Coupled with the standard environmental data of altitude, airspeed, and temperature repeatable tests can be performed which will document the flight characteristics of the aircraft. These carefully measured and documented tests are then used to support the qualitative data gathered during handling qualities testing in which representative tasks are performed and rated. Standard data requirements for rating the handling qualities tasks is normally a copy of the Cooper-Harper handling qualities rating scale and a hand held data card. If the handling qualities are exceptional (either good or bad) control position and environmental data might also be presented to support the conclusions.

Evaluation of an aircraft's performance and handling qualities while performing tasks representative and critical to the mission is the final measure of an aircraft. Considering how much is resting on the qualitative opinion of the evaluator it makes sense to document the aircraft's performance in the accomplishment of these tasks. The Portable Test Range allows the test team to do exactly that and provide feedback to the crew as to the performance level actually achieved. The data is immediately available to the crew and can be used to assist in rating the handling qualities using the standard Cooper Harper Scale. Several maneuvers performed using the facilities at Crow's Landing were designed to evaluate and document handling qualities tasks outlined in ADS-33D (Reference 10).

Figure 10 shows the cross track and altitude error incurred while performing the pirouette maneuver. The aircraft completed the maneuver within the time allowed and within the desired performance standards. Completing a pirouette maneuver within desired standards was rated as easy requiring small, infrequent cyclic and pedal inputs. Figure 11 shows the data for a Bob Up/Bob Down. The maneuver was modified from ADS 33D by requiring a much greater altitude. Note the total error of less than 33 feet while performing a bob-up/bob-down with an altitude change of greater than 200 feet. This maneuver was performed in gusty winds with poor visual references. This maneuver is a good example where cockpit cueing provided by the Portable Test Range could allow the pilot to maintain much tighter tolerances on horizontal position. Because the data is gathered and presented nearly simultaneously during the performance of the maneuver, the pilot knows conclusively whether or not he is achieving desired or adequate standards and where his problem areas are. The precise and virtually instantaneous feedback is invaluable in producing accurate handling qualities ratings.

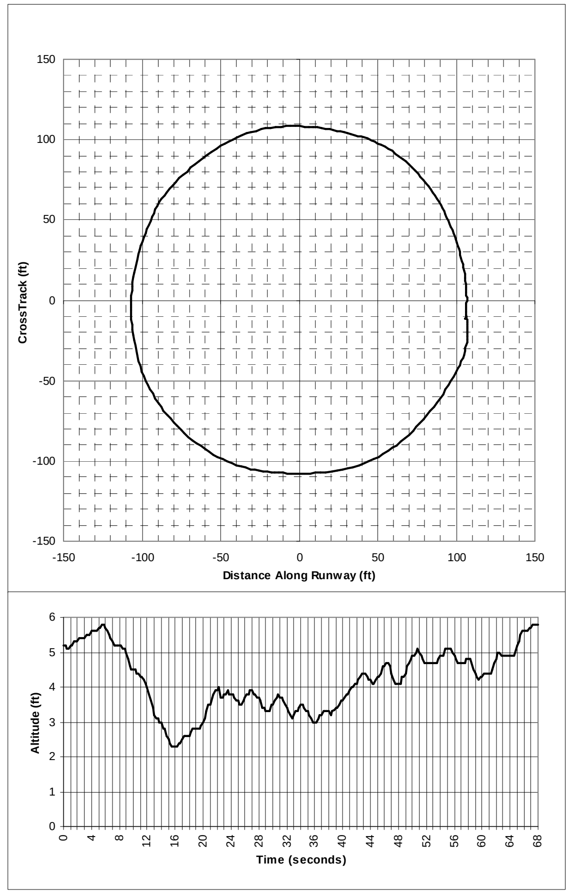

Figure 10. Pirouette Maneuver

Figure 12 shows the performance of an acceleration/deceleration maneuver. Note the 12 foot deviation in altitude during the acceleration portion of the maneuver followed by a partial recovery in altitude, then a 20 foot sag in altitude at the end of the deceleration. Maintaining altitude during this maneuver was not particularly difficult, however, perceiving the change in altitude was. Without adequate cueing (the radar altimeter is rendered useless because of the large pitch deviations) the altitude deviated from desired standards before it was apparent to the pilot. Again, the acceleration-deceleration maneuver is a perfect example of how the Portable Test Range might be used to supplement the usable cue environment. By shifting handling qualities evaluations more from subjective to objective rating criteria, this system can be used to not only assist in the determination of handling qualities ratings but can also be used to determine the problem area causing less than desired results.

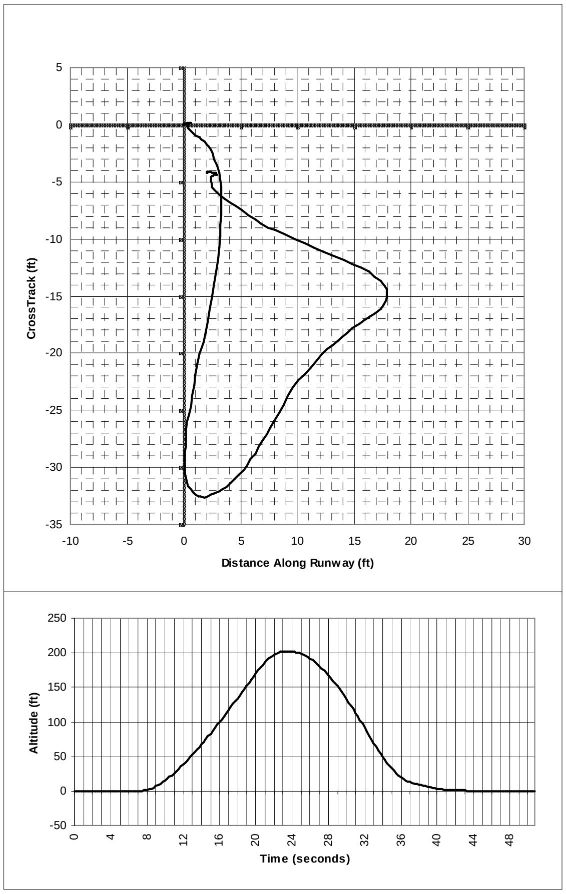

Figure 11. Bob Up/Bob Down

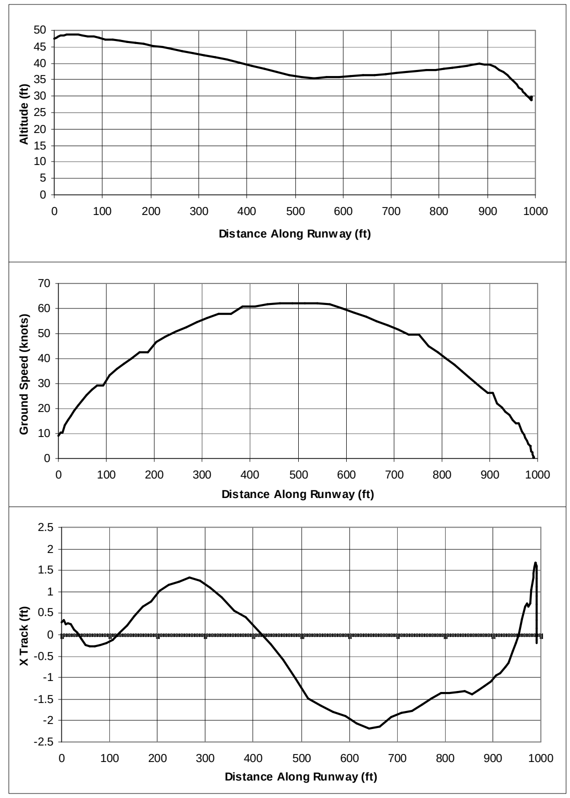

Figure 12. Acceleration/Deceleration Maneuver

CONCLUSION

The Portable Test Range has been utilized extensively and to great advantage by MDHS Engineering Flight Test during 1996 and early 1997. MDHS has invested considerable financial resources in creating an operational custom guidance and position documentation system. This system has become an exclusive and mandatory requirement for Category A, height-velocity, and noise certification testing. Without this system, these tests simply would not have been accomplished within any reasonable cost, schedule, or degree of accuracy.

The Portable Test Range has proven to be very valuable in handling qualities evaluations. The accuracy of the data and ease and timeliness of the presentation makes it very useful in validating the handling qualities performance of an aircraft. This in turn leads to much more realistic performance standards. Once realistic performance levels are documented it provides a much better basis of “truth data” for the determination of level one, two, or three handling qualities.

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