A PRECISION FLIGHT TEST APPLICATION OF A DIFFERENTIAL GLOBAL POSITIONING SYSTEM

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ABSTRACT

MDHS has developed and integrated a precision flight test guidance and tracking system using a Differential Global Positioning System. Designated the "Portable Test Range", this system acquires, archives, and processes three-dimensional aircraft position data in real-time. Cueing information regarding position, direction, velocity, and acceleration referenced to a selected coordinate system is immediately presented to the flight crew on analog and digital indicators. Information latency and update rate is adequate to avoid pilot induced oscillation for highly dynamic maneuvers. Position data is available for integration into a flight director or autopilot system, however the effectiveness of the information presentation allows precise manual control of the aircraft. Installation of the aircraft instrumentation is relatively simple. A test location can be chosen virtually without regard to topography, and can be surveyed in a day - quickly creating a precision test range.

NOTATION

ADS	Aeronautical Design Standard
ASCII	American Standard Code For Information Interchange
C/A-Code	Course Acquisition GPS Code Broadcast
CDI	Course Deviation Indicator
CDP	Critical Decision Point
DGPS	Differential Global Positioning System
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FM	Frequency Modulation
GDI	Glideslope Deviation Indicator
GPS	Global Positioning System
HARN	High Accuracy Regional Network
H-V	Height Velocity
IFR	Instrument Flight Rules
IRIG	Inter-Range Instrumentation Group
LAACO	Los Angeles Aircraft Certification Office
L-Band	Radio Frequencies From 390 - 1550 Megahertz
LDP	Landing Decision Point
L1	GPS Frequency at 1575.42 Megahertz
L2	GPS Frequency at 1227.60 Megahertz
NASA	National Aeronautics and Space Administration
NGS	National Geodetic Survey
OEI	One Engine Inoperative
OEM	Original Equipment Manufacturer
P-Code	Precision GPS Position Code Broadcast
PIO	Pilot Induced Oscillation
PTR	Portable Test Range
MDHS	McDonnell Douglas Helicopter Systems
Reference Station	The Fixed Receiver Of A DGPS
RF	Radio Frequency
Rover(s)	The Mobile Receiver(s) Of A DGPS
RTK	Real-Time Kinematic
RTO	Rejected Takeoff
V_{BLSS}	Balked Landing Safety Speed
V_H	Max Continuous Power Horizontal Speed
V_{NE}	Velocity Never to Exceed
V_{TOSS}	Velocity Takeoff Safety Speed
Vy	Best Rate-Of-Climb Speed

INTRODUCTION

A variety of Federal Aviation Administration (FAA) certification flight tests either require or are more efficiently accomplished with the availability of highly accurate 3-dimensional aircraft position data. Execution of test programs such as Federal Aviation Regulation (FAR) Part 36, Appendix H "Noise Certification" are further enhanced by the addition of precise 3-dimensional flight crew guidance. In this particular certification test program, 3 precision flight profiles are required: level; takeoff, and 6° approach to landing. Historically, the 6° landing approach

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profile has been the most the difficult to perform within regulatory specifications.

From 1986 until 1991, McDonnell Douglas Helicopter Systems (MDHS) operated a highly modified microwave based space positioning system for acoustic flight testing programs. System limitations included no real-time 3-dimensional position feedback or flight crew guidance. Post processed data revealed that only about 25% of the 6° landing approaches executed for FAR 36-H met regulatory specification. Test range location choices were limited by system component geometry and line-of-site requirements. Temperamental performance of the equipment due to the ambient environment - including changes in ambient temperature and multipath effects also contributed to rejected data runs. All these factors combined to create extremely inefficient flight testing activity.

In 1995, MDHS purchased the components of a Differential Global Positioning System (DGPS). This system has been integrated with additional hardware and software to create a “Portable Test Range” (PTR). The PTR serves as a high precision position archiving and real-time flight crew guidance system to accommodate a variety of flight testing requirements. The FAR 36-H Noise Certification flight test of the MD 900 Explorer helicopter was the first operational use of the PTR. The PTR will greatly enhance execution of the upcoming FAR Part 29 Category A certification of the MD 900 Explorer. The PTR can also be exploited for applications involving pitot/static system error detection and maneuver grading for Aeronautical Design Standard 33C.

DGPS FUNDAMENTALS

For basic primers on GPS and DGPS, the reader is directed to references 1 and 2. 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 course acquisition (C/A) code and the precision (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.

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 GPS receiver, denoted the reference station, that is located on a control point. This 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 other nearby GPS receivers, known as rovers, that are not at fixed control points. When these correction factors are applied by the rover receivers in a timely fashion, the 3-dimensional position accuracy’s for these rovers are drastically improved.

Transmitting the differential correction from the reference station to the rover station(s) requires some sort of radio modem data link. Radio modems that can reliably transmit this type of data are required to be equipped with forward error correction (FEC), an error checking technique that insures the correction is received just as it was broadcast. Figure 1 depicts the basic components of a DGPS.

SYSTEM COMPONENT SELECTION

Research into the componentry required to properly integrate a DGPS began in the summer of 1994. The annual Institute of Navigation conference and trade show proved to be a most efficient opportunity for one stop shopping, with all the key industry players under one roof. Vendors of DGPS capable receivers, radio modem links, post processing software, antennas, and related peripheral equipment were all in attendance at this exposition.

To avoid pilot induced oscillation (PIO), MDHS required a basic DGPS that provided a high position data update rate with very low data latency times. A requirement for a 3Σ (i.e. 99% of the time) position eliminated virtually all of the manufacturers of DGPS accuracy in 3-dimensions of better than 1 meter equipment. The two best known precision DGPS manufacturers had equipment available, however each manufacturer’s systems had inadequacies regarding data update rate, data latency time, or absolute position accuracy. Both manufacturers had directed their resources towards developing real-time kinematic (RTK) systems of extreme accuracy for the professional land surveyor’s market, but with only 1 or 2 position updates per second and unacceptable data latency times.

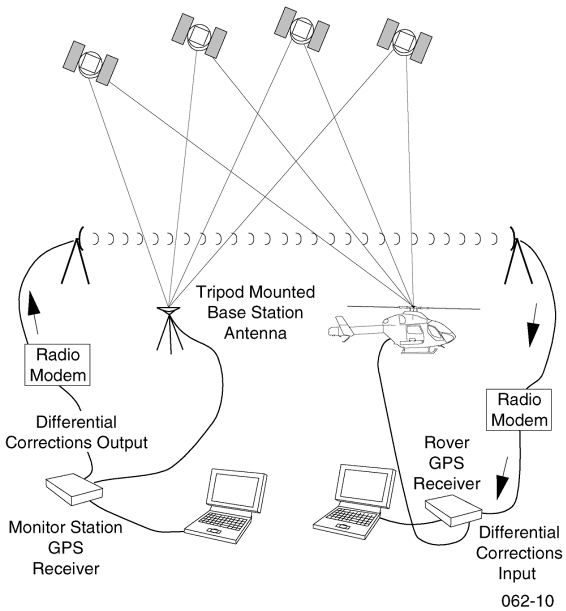

Figure 1. Basic Components Of A DGPS

One company, NovAtel, was found to have developed a niche market DGPS product known as the RT-20. This DGPS is designed to provide 1Σ accuracy's of 20 centimeters or better in 3-dimensions. This DGPS operates using a technique involving narrow correlation of the course acquisition (C/A) code, which is broadcast at a rate of 1000 hertz on the L1 carrier (1575.42 megahertz). The system has a processed position update rate of 5 hertz, with a processed data latency time of approximately 70 milliseconds.

The DGPS equipment chosen had not been integrated and packaged with a radio modem link. Because DGPS is not possible without a highly reliable data link between the reference station and the rover, the selection and integration of a radio modem system is not a trivial matter. Three manufacturers of radio modem systems with the performance and features necessary for a reliable DGPS were located. All offered necessary features such as RS-232 control, forward error correction, and transmitter/receiver power up to at least 25 watts.

Discussions with local land surveyors using DGPS for RTK work reveals that radio modems present the biggest challenge to system reliability. Most users attempt to operate with 900 megahertz spread spectrum radios for the data link, but the range of such systems is severely limited. The FM radio band from 450 - 470 megahertz is available for data transmissions, however FCC licenses for a discrete frequency in the Phoenix metropolitan area are virtually impossible to obtain, and significant expense and delays are present even when the applicant is successful. Fortunately, the McDonnell Douglas Corporation owns continental United States licenses to 4 discrete frequencies in the 450 - 470 megahertz bandwidth.

The success that the SATLOC Corporation of Tempe, Arizona has had using G.L.B. radios and NovAtel DGPS systems in an airborne agricultural application was noted. As well papers produced by Sierra Technologies[3,4], Wilcox Electric[5], and NovAtel Communications Ltd.[6] were reviewed and the equipment purchase decisions were completed.

To develop a cockpit interface for real-time guidance as well as for programming and debugging efficiency, "Labview For Windows" by National Instruments was chosen as the programming environment to provide the graphical user interface. An analog output card, to be installed in a full size computer expansion slot, was purchased to drive the chosen analog cockpit indicator - a simple course deviation / glideslope deviation indicator (CDI/GDI), depicted in Figure 2. A portable hardened computer was selected to run the system software and provide a remote mounted sunlight readable display and mouse/keyboard for cockpit installation during system development. GPS and radio modem antennas were selected based on anticipated flight speed and radio frequency (RF) transmit/receive patterns required.

TEST RANGE DEVELOPMENT

Upon purchase of all components of the DGPS based flight guidance system, a developmental test range was established. For logistical considerations, the MDHS flight ramp and control tower were chosen. The DGPS reference station antenna and radio modem link antenna were installed on the MDHS control tower, the highest point on the plant property. This location affords an unobstructed view of the sky from horizon to horizon, for optimum satellite and aircraft coverage.

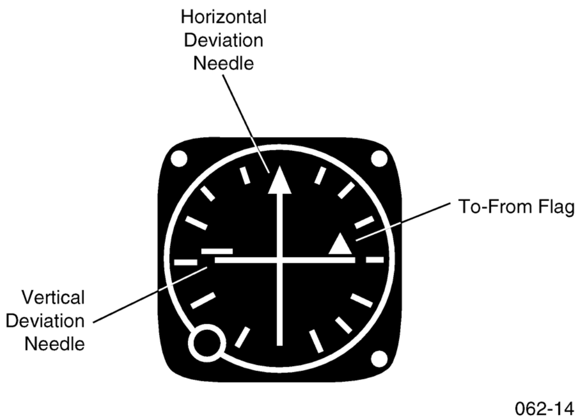

Figure 2. Course And Glideslope Deviation Indicator

A National Geodetic Survey (NGS) survey marker was located approximately 5.3 kilometers from the MDHS control tower location. This particular marker is designated as a High Accuracy Regional Network (HARN) “A” station, indicating that the absolute position of the marker (on planet Earth) is known within 1 centimeter or better. A static survey was completed with the control tower receiver collecting range and ephemeris data continuously, while data was collected at the NGS marker for about 1 hour, then the center point at each end of the MDHS flight ramp was occupied for 1 hour each. Post processing of the static survey data allowed establishment of the new reference station at the MDHS control tower. Further processing of the flight ramp endpoints created highly accurate waypoint coordinates referenced to the MDHS reference station. These waypoints were projected several kilometers past the runway ends to create an extended runway centerline.

It is important to note that a DGPS system can be used effectively by establishing a local reference station and then surveying other points relative to it. This creates a local coordinate system that is not referenced to any absolute Earth fixed system. This technique is adequate if no necessity exists to relate the aircraft position data to any absolute coordinate system. Because MDHS uses the control tower reference station when surveying navigation courses for the AH-64 aircraft, absolute coordinates were required for this location. For FAR Part 36 or FAR Part 29 flight testing activities, a locally established coordinate system is satisfactory.

GUIDANCE / ARCHIVING SOFTWARE DEVELOPMENT

The GPS receivers selected by MDHS are an original equipment manufacturer (OEM) product. OEM GPS equipment manufacturers typically make a large variety of data logs and receiver commands available to the designer of a custom DGPS application.

Initially, simple setup commands regarding waypoint navigation were issued to the rover GPS unit, and ASCII formatted data was logged over the RS-232 buss. Once computer displays were functioning properly and the data was archiving successfully, the analog output card was activated to drive the CDI/GDI instrument. The rover portion of the DGPS, destined to be installed in the aircraft, was temporarily installed on an aircraft tug, and waypoint navigation techniques were used to maneuver the tug around the MDHS flight ramp. Electrical power was provided by a generator in tow connected to a 28 volt DC power supply to provide aircraft quality power.

Debugging of the system guidance software continued until the product was ready for the aircraft development stage (read more expensive). The radio modem antenna was installed on the belly of the test helicopter, and the GPS antenna was installed at the top center of the main rotor hub on a stand pipe (Figure 3). The computer’s flat panel sunlight readable display was installed in front of the flight test engineer position, and the CDI/GDI was mounted on the instrument panel in front of the pilot and within the close scan of critical flight instruments (Figure 4). The GPS receiver, radio modem, and portable computer were packaged in a portable shipping case, floated on foam rubber for vibration isolation, and provided conditioned power and cooling air. This package was mounted in the cargo bay.

System initialization to the DGPS high order solution took approximately 3 minutes with the helicopter rotor blades not moving or at ground idle on the flight ramp. Initial flights within the MDHS traffic pattern demonstrated that the DGPS solution remained virtually as accurate in dynamic as in static situations, even during extreme short period pitching and rolling maneuvers.

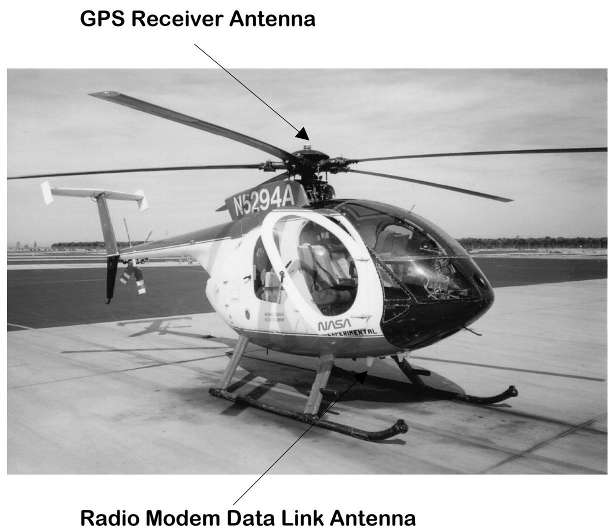

Figure 3. Test Aircraft With Antenna Installations

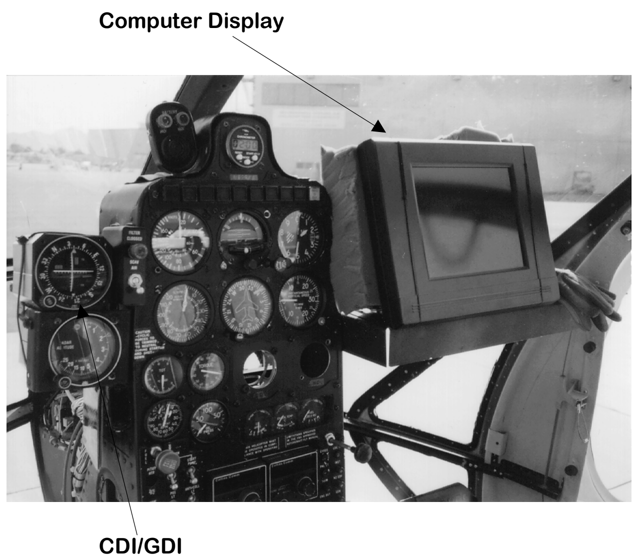

Figure 4. Test Aircraft Instrument Panel

FAR PART 36 APPENDIX H FLIGHT TEST PROFILES

FAR Part 36 Appendix H "Noise Certification of Helicopters" involves flight testing with 3 different reference profiles. A microphone array, consisting of 3 microphones spaced 150 meters apart in a linear fashion, is installed on a relatively level test range. The aircraft is flown perpendicular to this microphone array, over the top of the center microphone. Stringent requirements exist regarding vertical and horizontal aircraft position errors relative to the reference flight profiles.

The level flight profile is flown at 150 meters above the center microphone ground level and is depicted in Figure 5. The 6 approach-to-landing profile is flown with a center microphone overhead altitude of 120 meters (Figure 6). The takeoff profile (Figure 7) is begun with a level flight segment 20 meters above the center microphone ground level, then takeoff power is applied at the position necessary to intercept the reference climb profile, as determined from aircraft climb performance data. The level flight profile is flown nominally at $0.9(V_H)$ speed. Both the landing approach and takeoff profiles are flown at V_Y speed.

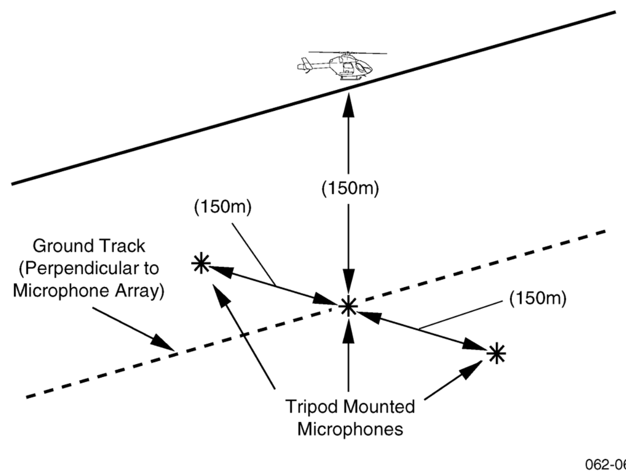

Figure 5. Level Flyover Test Profile

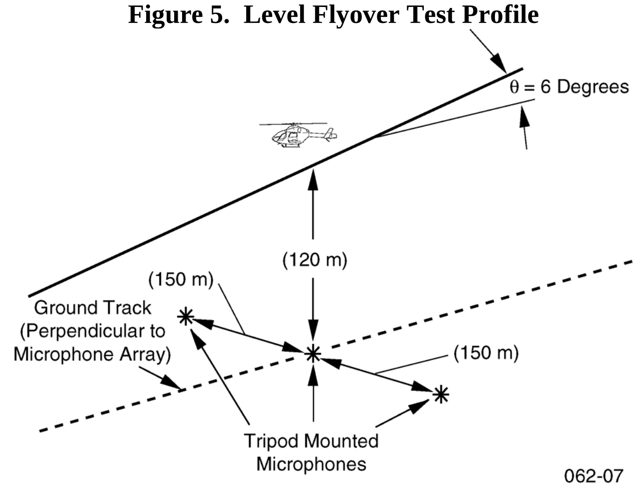

Figure 6. Approach-To-Landing Test Profile

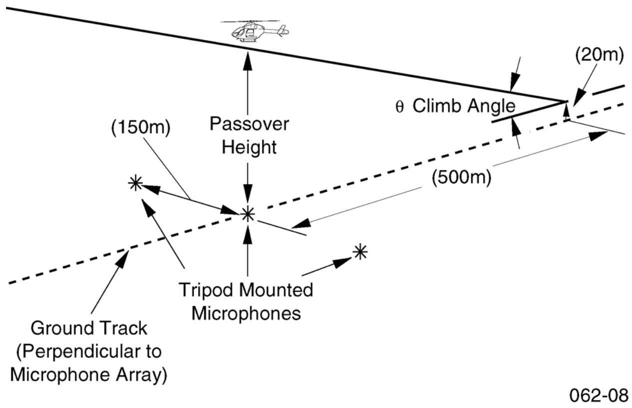

Figure 7. Takeoff Flight Test Profile

GUIDANCE SYSTEM REFINEMENTS

Initial flight testing of the PTR centered on straight and level flight. Waypoint navigation techniques were used to create 3-dimensional vectors, and the pilot was requested to follow the direction of the CDI/GDI to maintain flight at various altitudes and courses. One unruly test pilot was punished by being required to fly a pre-programmed level course for over 30 kilometers at an extreme CDI/GDI sensitivity. Several iterations of CDI/GDI sensitivity were investigated to balance pilot workload against requirements of FAR Part 36-H for allowed vertical and horizontal deviation from the reference level flight path. Concurrently, the radio modem absolute range was examined as well as the increase of the X, Y, and Z solution standard deviations output by the DGPS. A developmental engineering information screen was created that displayed a variety of statistics regarding system performance, satellites in view, latency of differential correction data, etceteras.

Given good air quality, it was found that a needle sensitivity of 10 meters from needle centered to full scale on the GDI, and 15 meters from needle centered to full scale deviation on the CDI provided an appropriate pilot workload. The horizontal deviation needle was made less sensitive to reflect its relative importance to the FAR Part 36 Appendix H regulation. This change had the effect of changing the shape of the spatial vector from a perfectly circular cylinder to that of a flattened cylinder. Using this approach, the pilot could focus attention on both needles equally, typically keeping the aircraft within 4 meters of horizontal and vertical position. At this point the sensitivity of the CDI/GDI needles remained constant over any length segment.

To allow for easier course intercept, a second modification was made to the indicator sensitivity. After reviewing data from previous noise certification flight test programs as well as predictions of the MD 900 Explorer noise levels a subroutine was installed that degraded the CDI/GDI sensitivity outside a ±1500 meter window of a defined point in space. This change created a funnel at each end of the precision course segment, which was already shaped like a flattened tube (Figure 8). The degraded needle sensitivity combined with some knowledge of ground references and course headings allowed the pilots to very easily stabilize the aircraft on the course. The gradual change from degraded needle sensitivity to maximum needle sensitivity also allowed the pilot to "tune up" for each precision flight segment.

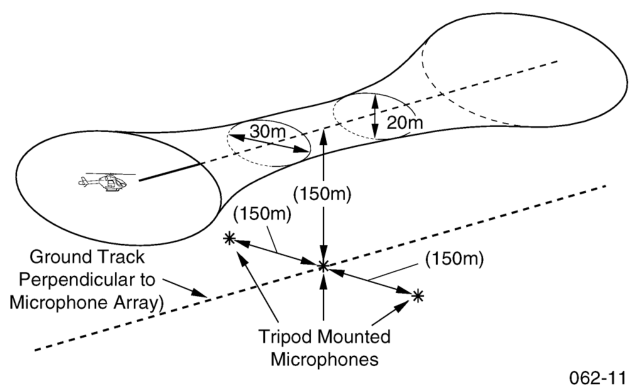

Figure 8. CDI/GDI Sensitivity Design

At this point, 6° approaches to landing were programmed and practiced. The intercept point of the flight path with the ground plane was defined relative to the desired center microphone overflight altitude (120 meters). A subroutine was installed that compared current aircraft position against desired position and computed the difference. Deviation needle sensitivity for the approach profile was left the same as the level profile.

Takeoff profiles were programmed to provide a 20 meter level flight segment at standard needle sensitivity, followed by a full scale up deflection of the GDI needle as a cue for takeoff power application. This profile began to demonstrate the degree of latency of the DGPS - computer - CDI/GDI combination, which seemed variable with demands on the computer hard drive, etc. Anticipation was added to the software with less than spectacular results. Eventually, changes in data archiving technique and data format minimized and stabilized display latency.

PERFORMANCE DEMONSTRATION TO THE FAA LOS ANGELES AIRCRAFT CERTIFICATION OFFICE

Prior to the FAR Part 36 Appendix H noise certification flight test program for the MD 900 Explorer, MDHS was required to demonstrate the performance of the DGPS to the satisfaction of the Los Angeles Aircraft Certification Office (LAACO) Flight Test Department. This requirement was similar to that made for the Motorola Mini Ranger microwave tracking system that MDHS had operated previously.

A test was designed using both a still camera and a video camera. Both cameras were vertically oriented and plumbed directly beneath a large crosshair target device aligned with the flight path. Photoscaling techniques were used to determine aircraft altitude and lateral offset from the flight path at camera overhead. Range time inserted on the video camera image was compared with the DGPS position versus time in an attempt to show correlation.

To primarily examine DGPS performance at different horizontal velocities, several 6° approach profiles were flown overhead the camera site, with an overhead altitude of 53.12 meters. The flights varied in speed from approximately 60 to 140 knots. At the ground intercept point, a HELI-PLASI precision glideslope lighting system was installed to verify the 6° approach glideslope.

To examine DGPS performance in the vertical dimension during rapid vertical maneuvers, vertical climbs were executed within view of a time encoded video camera equipped with a crosshair target. This camera was mounted at the MDHS control tower in a horizontal orientation approximately 60 feet above ground level. Vertical climbs were executed within view of this camera at speeds varying from extremely slow climb rate up to the maximum climb rate available (100 - 3000 feet per minute).

Photoscaling is thought to be useful for resolving distance to within 2 or 3 feet. Commercial video time synching is hampered by the standard rate of 30 frames per second. Timecode inserted on the video record had a resolution of 1 millisecond. Time slices of video were interpolated to best determine overhead crossing time (vertical camera) or vertical climb crossing time (horizontal camera). Within the resolution of the photographic and video images, and the abilities of the test personnel to interpret the results, the DGPS position data fell within the deviation range of the scaled results.

DGPS OPERATIONAL CONSIDERATIONS

DGPS Accuracy Issues

Currently, state-of-the-art real-time DGPS systems utilizing only the L1 carrier frequency are limited in accuracy to about 60 centimeter (3Σ). Occasionally, accuracy on the order of 1 centimeter (3Σ) is desired or required. Also, as the separation (baseline) between the DGPS equipped aircraft and the DGPS reference station increases, a degradation of the position accuracy is experienced with a single frequency (L1) system.

Flight test applications with baselines longer than perhaps 10 kilometers, or those requiring extreme real-time accuracy should utilize a dual frequency (L1 and L2) DGPS. These systems are typical of those used in the land surveying profession. Systems that utilize both L1 and L2 are capable of virtually eliminating ionospheric propagation errors, a major source of error in DGPS's. Regardless of the system capability, it is critical that both the reference station and the rover receive an adequate number of the same satellites to achieve a good 3-dimensional solution. This restriction places some limitations on the distance and terrain between the reference station and the rover.

DGPS Initialization

One operational limitation of the DGPS operated by MDHS is that the system requires a finite time period for initialization. This time period is on the order of 3 minutes in the static mode when the GPS antenna is not experiencing motion and the differential data link is fully functional. If the differential data link becomes active after the aircraft is in a dynamic mode, the system initialization time can be as long as 20 minutes.

Given the capabilities of a rotorcraft, this does not typically create an operational concern, since the helicopter can usually be landed at the test range where the DGPS reference station is located. This allows an opportunity to remain stationary for the time necessary to allow the DGPS to initialize. However, fixed wing flight testing activities, especially transport category jet aircraft do not typically allow for the aircraft to be launched within data link range of the test facility. In this case, the aircraft is usually required to loiter within differential data link range for an extended time period to allow the DGPS to complete the initialization process.

Once initialized, the DGPS provides highly accurate 3-dimensional data on the order of 0.5 meters 3Σ. Without this initialization period, once the differential data link becomes fully active, the DGPS begins the solution convergence with a 3Σ of about 3 meters in 3 dimensions. The standard deviations converge in a fairly steady fashion until the solution reaches the completely initialized state.

MDHS intends to improve the DGPS capability to overcome this deficiency by eventually upgrading the existing system to a dual frequency (L1 and L2) receiving system. This will allow the initialization process to be completed in just a few seconds, even in a dynamic operating mode. Thus, the delays incurred with an L1 only system while awaiting the highest accuracy operating mode will be eliminated. As well, system accuracy on both short and long baselines will be improved by more than an order of magnitude.

Differential Data Log Linking

Methods do exist that allow the aircraft to be initialized while not in direct line-of-site with the reference station. A second ground based radio modem can be located within site of the test aircraft launch location so that a DGPS can be initialized with the aircraft parked on the flight ramp. If a telephone hard-line exists, the differential correction data logs from the reference station can be ported both to the test range based radio modem, as well as a telephone modem. At the launch airport end, another telephone modem can be coupled in series with the second ground based radio modem to complete the link to the test aircraft. Radio coverage must be maintained so that the test aircraft will maintain the data link to either the airport radio modem or the test range modem, so that as the aircraft climbs in altitude after takeoff, the test range modem radio becomes receivable. Once this situation has occurred, the telephone modem link at the test range can be deactivated.

In some locations, reference station correction logs may be available by subscribing to a commercial service. This service utilizes the sideband of a commercial FM radio station carrier wave to broadcast the differential correction logs for one or more manufacturer's DGPS equipment. To effectively use this service for precision flight testing, arrangements must be made to broadcast the differential corrections from the test range over a telephone modem to a FM radio station that has coverage at the launch airport. The DGPS operator on board the aircraft must then use a special FM modem as the source for the differential correction data until the aircraft has launched and is within radio modem range of the test location. At this point, the aircraft system operator has the option of shifting from the FM broadcast differential corrections to the system operator's own radio modem system if concerns of continued reception of the FM source are warranted.

It is imperative to understand that the differential corrections must all come from the same ground based reference station for a DGPS to remain in the initialized mode. Furthermore, the interruption of the differential correction signal reception must be less than 30 seconds, or the DGPS will reset to the autonomous mode and system initialization will start fresh.

Another option, depending upon the capability of the radio modem system, is to bridge the line-of-site gap between the reference station and the aircraft launch site by using a digipeater. This is simply another simplex or duplex radio transmitter/receiver that will listen for the differential correction logs broadcast from the ground reference station, and then immediately re-broadcast the data logs once the reference site radio modem is silent. Digipeaters can be installed in series to accommodate difficult challenges in line-of-site maintenance caused by high terrain or urban structures.

Position Data Downlinking

Grading of flight maneuvers by the test director is most efficiently accomplished immediately upon completion of the maneuver. MDHS has the hardware and is completing software development to allow real-time data link over the simplex radio modems that will broadcast critical grading information immediately to the test director's location. Both vertical (side view) progress and horizontal (look down view) progress plots will be generated as the flight progresses, as well as a ground speed plot. The plots will be in a local coordinate system that demonstrates the aircraft position relative to important ground reference points, such as microphones or runway thresholds (Figure 9).

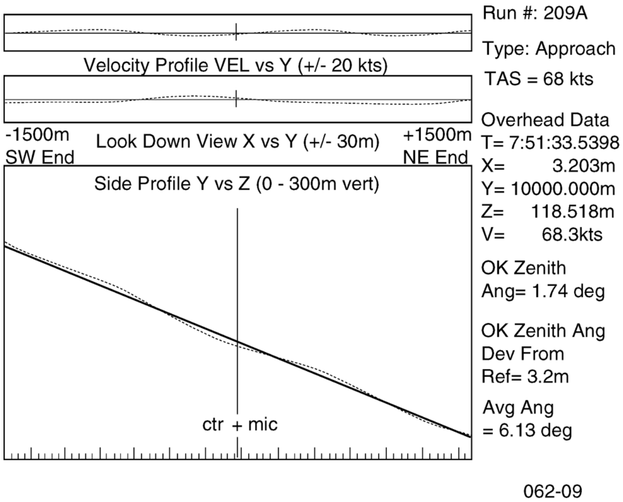

Figure 9. Real-Time Position And Velocity Plot

MORE RIGOROUS DPGS PERFORMANCE VERIFICATION

Issues regarding the true dynamic accuracy of DGPS's always surface. The industry standard for test range spatial position data seems to be a laser system such as that operated by the ARMY at Yuma Proving Ground in Arizona, or NASA at Crow's Landing in California. Another flight test will compare the position data from a survey grade Trimble 4000 SSI DGPS against the MDHS owned system. The Trimble unit can provide RTK data within 2 centimeters in 3-dimensions either in real-time or using a post processing technique. MDHS will be comparing spatial position data between these systems and the DGPS during tests to be conducted during 1996. Results of these experiments will be reported in a future publication.

The ability of a DGPS to demonstrate continued precision and accuracy is also of interest. Furthermore, the ability of the system to reacquire satellites lost during highly dynamic maneuvers, and to continue to generate a high quality 3-dimensional solution must be examined to determine the robustness of the position solution software. MDHS has planned a series of tests involving an amusement park roller coaster, complete with loops and spiral rolls, to examine these issues.

ADDITIONAL FAA CERTIFICATION APPLICATIONS

FAR Part 29 Helicopter Flight Test Requirements

As in the FAR PART 36 Appendix J and H helicopter noise flight testing, the PTR lends itself perfectly to the 3-dimensional space data requirements of certain Part 27 and Part 29 performance tests. These tests include Height Velocity (H-V), take-off, rejected take-off and landing distance, take-off and landing over 50 foot obstacles, vertical take-off, and abuse testing.

The Applicant is required to show certain flight profile data in three-dimensional space. This data is typically height above ground and distance from the take-off point and/or the point in space at which a simulated engine failure occurs. In addition to the flight profile height and distance data, airspeed, rate of climb, engine power and take-off weight must be documented. The FAA places strict wind limitations on testing in addition to requiring the flight profile data to be demonstrated over a range of density altitudes.

One entire test point often encompasses an area greater than the distance of the available runway. Traditional data recording methods involve the use of grid cameras, photo theodolite, and trisponder equipment in order to obtain aircraft position data over such a large area.

The PTR data can easily be time synched to the aircraft on board instrumentation IRIG time. The aircraft on-board data system, recording all non-position data (i.e. rate of climb, aircraft engine power etc.) need not be part of the PTR package. With time synched data packages, data output can be formatted to provide flight manual descriptive profile charts such as shown in Figures 10 - 14.[7]

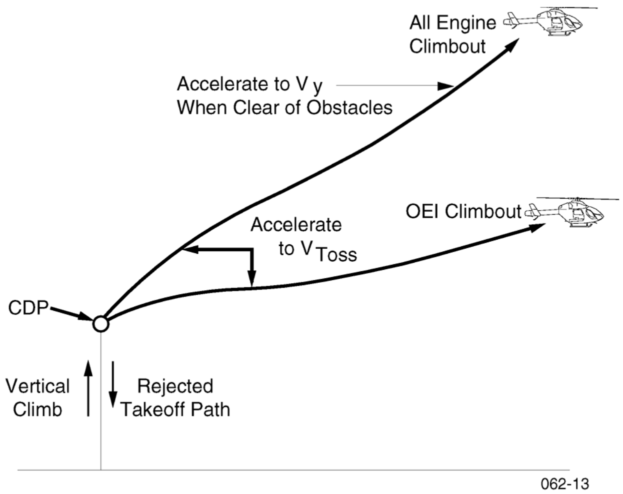

Figure 10. Category A Vertical Takeoff Profile - Ground Level Heliport

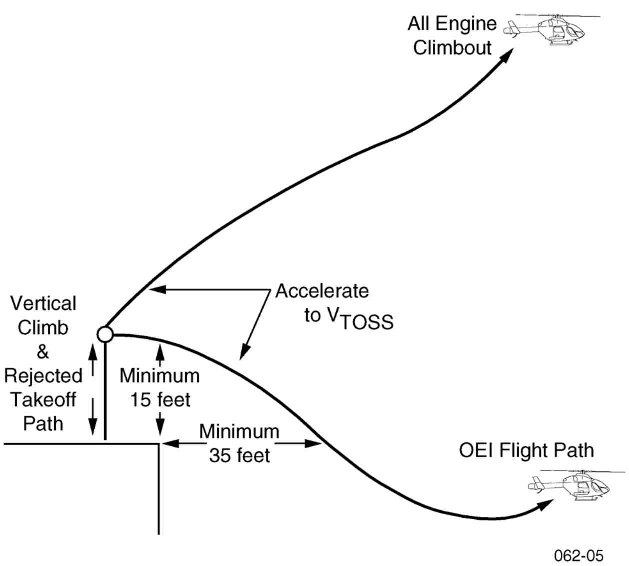

Figure 11. Category A Vertical Takeoff Profile - Pinnacle

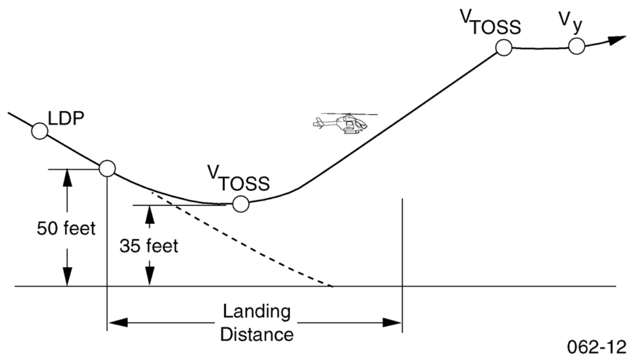

Figure 12. Category A Conventional Landing - Clear Heliport

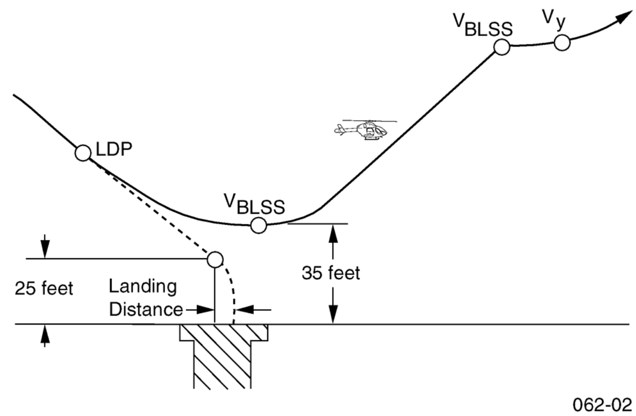

Figure 13. Category A Vertical Landing

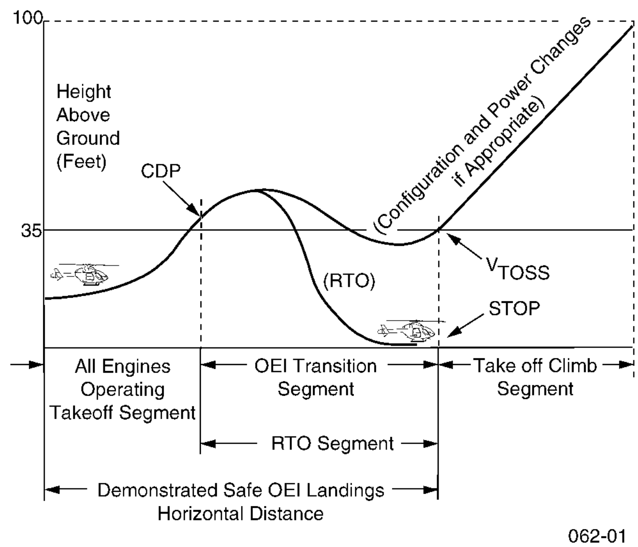

Figure 14. Category A Takeoff Performance

FAA data requirements include wheel (or skid height) accuracy to within a foot. This can make traditional methods of data reduction tedious for vertical flight profiles. Specific limits are specified in FAR Part 29 in order to meet acceptable performance regulations. For instance the FAA requires the Critical Decision Point (CDP) for a Category A take-off profile to be a point in space at an airspeed (determined by testing) above and beyond which an engine failure can occur which would allow the pilot to accelerate to the Vertical Take-Off Safety Speed (V_{TOSS}) without descending to a point 35 feet above the take-off surface. This testing requires many attempts using different techniques of power and control application to determine the best technique with which to meet the requirements. In addition many more test points are required to satisfy the "abuse" testing criteria. This criteria dictates that variations of the take-off technique, which might be reasonably expected in service, do not significantly increase the established take-off (or landing) distances or minimum height requirements. These requirements place a heavy workload on test engineers using traditional data reduction methods.

The ability to merge flight profile position data with aircraft dynamic data such as airspeed, rate of climb, engine power or throttle position data in a real-time or post-test data reduction routine reduces on-site test time as well as the number of required data points, which reduces risk. Certain types of performance tests, such as height-velocity testing, requires data to be presented in the height versus airspeed format shown in Figure 15. Determination of helicopter autorotation speed for best glide angle and minimum rate of descent requires data to be presented as descent rate versus airspeed (Figure 16).

Height-velocity testing requires one engine to be "failed" at a given height above the ground, and the aircraft to be landed, or in the case of some multi-engine helicopters, flown off using the remaining engine(s). For most helicopters there is a height and velocity combination within which an engine failure would be disastrous. The FAA requires this "Avoid" area to be determined. Needless to say the testing is quite risky, and the data accuracy crucial. In addition, the FAA requires height velocity tests to be conducted at a minimum of 7000 feet density altitude, requiring a remote test site.

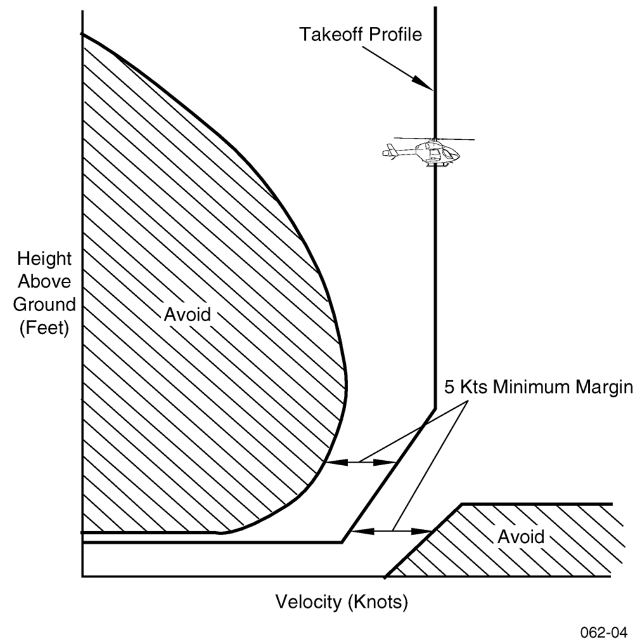

Figure 15. Height-Velocity Diagram

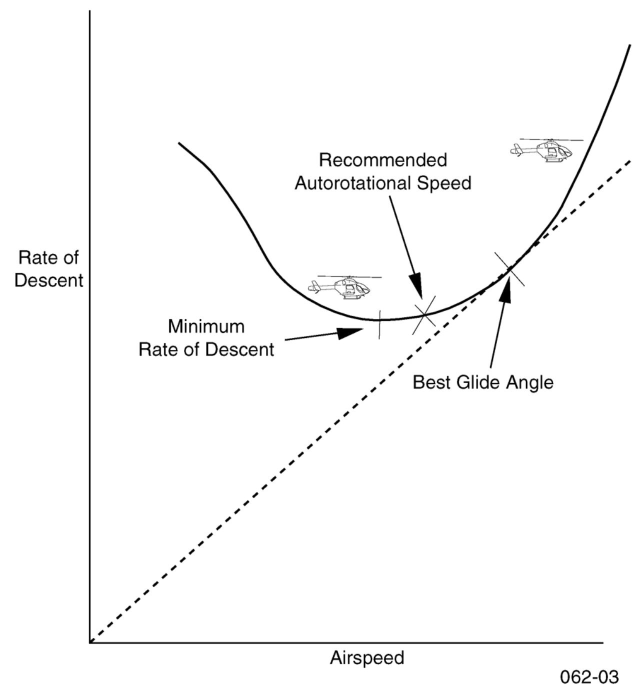

Figure 16. Typical Autorotational Characteristics

Spatial Data Requirements For IFR Systems Certification.

Fixed wing aircraft certified under FAR Part 23 and 25 have requirements for 3-dimensional aircraft position data. Accelerate-stop distance following an engine failure, noise, and take-off and landing distance testing requirements are similar to those required for helicopters, and there exist similar data requirements in order to demonstrate the performance to the FAA.

Another area of testing that requires PTR quality 3-dimensional aircraft position data is Instrument Flight Rules (IFR) systems certification testing. Federal Regulations are changing to allow state of the art of GPS navigation equipment to aid IFR flight. Certification of the equipment that a pilot uses to stay on his assigned precision approach or departure flight path will require a PTR type system to prove the applicant's product meets FAA guidelines. Precision approach paths are being designed which resemble long funnels having several turns, constantly decreasing in cross sectional area as they near the runway threshold. New regulations have been proposed and are under review which tighten existing 'funnels' to accommodate the increasing air traffic. As more accurate DGPS based precision navigation systems are developed, portable and cost effective flight checking systems of even greater accuracy must be available for certifying the navigation aids.

MILITARY AERONAUTICAL DESIGN STANDARD 33C

ADS 33C originally attempted to quantify handling qualities without the use of mission maneuvers[8]. However, as the specification matured, mission maneuvers were developed and rated using the standard Cooper-Harper rating scale. The condition and standard for each task was developed initially for reconnaissance and attack aircraft. Later, each task was tested using simulation and available aircraft. As much as possible, handling qualities ratings were derived as substantiated quantitative data.

When the specification was tested using the AH-64A Apache by the Airworthiness Qualification Test Directorate at Edwards Air Force Base, the qualitative portion of the testing was minimized using several methods. First, engineering test pilots, trained and experienced in evaluating handling qualities and using the rating scale, were used to perform the evaluation. Second, control positions were recorded for analysis following the flight and the magnitude and frequency of control inputs were used to substantiate the pilot's ratings. Finally, whenever practical, aircraft spotters were used to confirm or assist the pilot in determining whether or not desired or adequate standards were repeatably met. As many as 6 spotters were used for some maneuvers. Their level of judgement was limited by the type and condition of the maneuver performed. In a dynamic maneuver such as a transient turn or slalom, the spotters were at a tremendous disadvantage to judge altitude or airspeed changes.

In more dynamic maneuvers, the standard pitot-static systems and radar altimeter are rendered temporarily unreliable. If the maneuvers are performed in a degraded visual environment (night) the ability of the spotters is limited by natural illumination level. In either case, the quantitative data is reduced to a more qualitative nature because the determination of whether or not desired or adequate standards are met is reduced to the pilot's judgment.

The PTR developed by MDHS provides the ability to determine 3-dimensional position performance and provides immediate feedback to the test team. The ability to rapidly and accurately plot 3-dimensional position performance can greatly help to quantify handling qualities ratings. Handling qualities data can be collected which includes both the frequency and magnitude of control inputs as well as aircraft 3-dimensional position versus maneuver performance criteria. This combination of data can greatly enhance the ability of experienced personnel to make a quantitative judgment regarding a handling qualities evaluation.

ADS 33-C used stylized mission maneuvers to determine the usable cue environment. Spotters have been used to assist the flight crew in the performance evaluation of these maneuvers with the same limitations as in the handling qualities evaluation. The use of the PTR can assist in much the same manner. However, during development of an aircraft and its systems, determination of the usable cue environment may be delayed until quite late in the aircraft's test program. Integration of symbology aids is typically not completed when control law development and handling qualities are being determined. The PTR can drive simple cockpit indicators which can help simulate the systems proposed for the advanced aircraft. This can aid the flight crew in performing tasks and simulating the more advanced systems and "usable cue environment" proposed but not yet developed.

The DGPS based "Portable Test Range" is relatively inexpensive, easy to integrate, and provides the test and evaluation community with another tool with which to perform handling qualities evaluations. It not only removes the problem of determining and documenting desired and adequate performance, but can be used to simulate more advanced flight direction aids not yet developed for an advanced airframe. Advantages of the PTR include extreme accuracy, immediate data availability, and the ability to provide dynamic three-dimensional position information to the flight crew for pilotage. This is a light, inexpensive, and flexible system which can advance handling qualities and useable cue environment determinations, and assist in the development of advanced aircraft systems.

CONCLUDING REMARKS

More complex flight profiles are envisioned for noise research flight testing. Straight segment, curved segment, and even urban canyon spiraling flight can be easily executed in a repeatable fashion using the Portable Test Range for guidance. The system also provides an alternative to traditional techniques for airspeed calibration out to V_{NE} speed, typically performed using a trailing bomb or pace aircraft, both of which pose potential safety issues. Additionally, static port errors vary with airspeed and aircraft attitude, causing erroneous altimeter indications which can be determined using this system.

Tremendous flexibility of choice in test locations, superior position data accuracy, and real-time three - dimensional flight crew guidance make the “Portable Test Range” superior to a grid camera or a trisponder system integrated with radar altimeter. The DGPS based “Portable Test Range” meets the test requirements of a variety of FAA certification flight tests and opens doors to more quantitative methods of handling qualities evaluation for ADS 33-C.

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