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HELICOPTER PRECISION APPROACH CAPABILITY USING THE GLOBAL POSITIONING SYSTEM

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ABSTRACT

The period between 1 July and 31 December, 1992, was spent developing a research plan as well as a navigation system document and flight test plan to investigate helicopter precision approach capability using the Global Positioning System (GPS). In addition, all hardware and software required for the research was acquired, developed, installed and verified on both the test aircraft and the ground-based reference station.

The NASA Technical Officer for this grant is Harry N. Swenson, NASA Ames Research Center, Moffett Field, CA.

INTRODUCTION

The purpose of the research is to evaluate the use of (GPS) in the differential mode (DGPS), autonomous mode or coupled with an inertial navigation system (INS) and associated navigation computer in order to provide high accuracy, precision navigation and guidance for helicopter approaches to landing.

The advent of GPS has provided a highly accurate, worldwide navigation capability. The system will provide positioning accuracy of 10-20 meters to users of the Precise Positioning Service (PPS) and 20-40 meter accuracy to users of the Standard Positioning Service (SPS) (100 meter accuracy when Selective Availability is activated). By providing local corrections to the satellite range measurements via data link, even greater positioning accuracy can be obtained. This is the basis for DGPS. Using SPS along with DGPS, positional accuracy of 2-5 meters is possible.

The primary research objective is to evaluate from flight test data the precision approach capability of NASA's Rotorcraft Aircrew Systems Concepts Airborne Laboratory (RASCAL) aircraft using GPS inputs for navigation and guidance. The RASCAL aircraft is a modified UH-60 Black Hawk helicopter located at NASA Ames Research Center.

SUMMARY

As of 31 December 1992, the following items have been accomplished towards the completion of the research objectives:

1. A research plan was developed for both phases of the research.
2. A navigation system document was developed for the RASCAL aircraft for Phase 1 of the research.
3. A flight test plan was developed for Phase 1 of the research.
4. All required hardware for Phase 1 of the research was installed.
5. All required software for Phase 1 of the research was developed and is in the process of being installed and validated.
6. A flight test was flown to insure that the GPS receiver was receiving the differential uplink from the ground-based reference station. In addition, the Data Acquisition Computer (DAC) was checked to verify that all of the required data was being collected correctly.

The research flights are scheduled to be accomplished during the first two weeks in January, 1993.

APPENDIX

NASA RESEARCH PLAN

HELICOPTER PRECISION APPROACH CAPABILITY USING THE GLOBAL POSITIONING SYSTEM

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19 SEP 1992

ABSTRACT

The purpose of the research is to evaluate the use of the Global Positioning System (GPS) in the differential mode (DGPS), autonomous mode or coupled with an inertial navigation system (INS) and associated navigation computer in order to provide high accuracy, precision navigation and guidance for helicopter approaches to landing.

Preliminary data collection using the Rotorcraft Aircrew Systems Concepts Airborne Laboratory (RASCAL) will be conducted in order to obtain data for use in later phases of the research. The data will be used in the development and modification of software to integrate the GPS with other navigation and cockpit display instrumentation. Algorithms already exist from past fixed-wing research involving the integration of DGPS with an INS. These algorithms would need to be modified for use in the RASCAL aircraft. Prior to flight testing, all integration will be accomplished in a laboratory environment. Once the systems are completely integrated in the laboratory, operational flight tests may proceed using the RASCAL aircraft.

The RASCAL aircraft is a modified UH-60 Black Hawk helicopter located at NASA Ames Research Center which will be used to implement a high frequency, high accuracy, real-time navigation system. Using RASCAL, operational data can be obtained for the Federal Aviation Administration (FAA) to investigate the use of GPS for helicopter approaches to landing.

The flight test and evaluation portion of the research will be carried out at the NASA test range facility located at Crows Landing NAS, Crows Landing, CA. The project will employ commercial off-the-shelf navigation equipment along with DoD military GPS user equipment. This equipment will be installed in the RASCAL aircraft which during flight testing will be tracked by a laser tracker currently in place at Crows Landing NAS.

The test system will consist of an airborne navigation and guidance system, a ground-based differential correction system, and a post-flight data analysis system. A ground-based reference system will transmit the DGPS corrections to the RASCAL aircraft via data link. In addition, truth position data will be collected and referenced via the GPS standard time code, as will all data collected. The data analysis system will be installed in a laboratory at the NASA Ames Research Center.

INTRODUCTION

The advent of GPS has provided a highly accurate, worldwide navigation capability. The system will provide positioning accuracy of 10-20 meters to users of the Precise Positioning Service (PPS) and 20-40 meter accuracy to users of the Standard Positioning Service (SPS) (100 meter accuracy when Selective Availability is activated). By providing local corrections to the satellite range measurements via data link, even greater positioning accuracy can be obtained. This is the basis for DGPS. Using SPS along with DGPS, positional accuracy of 2-5 meters is possible.

The integration of DGPS with INS will provide a high-rate, high accuracy, real-time navigation system. Each system by itself has specific strengths and weaknesses. The GPS has excellent long term stability but has limited transient response characteristics. The INS provides excellent transient response but lacks long term stability. When integrated, the systems complement each other to provide a high frequency, high accuracy navigation system regardless of location, altitude or time of day.

The addition of GPS to the RASCAL aircraft is part of a long-term research project designed to develop an Intelligent Systems Research Facility (ISRF). This facility is designed to give the pilot flight path guidance while flying in the low altitude environment. Research involving DGPS will also support the goals of the FAA by providing data on the approach and hover performance capability of a helicopter equipped with DGPS.

OBJECTIVES

The specific research goals are as follows:

1. Provide detailed system descriptions of the GPS/DGPS, INS and navigation computer which can be used for systems software modeling.
2. Prepare a test plan for SPS DGPS, integrated SPS DGPS/INS and autonomous PPS GPS helicopter approaches to landing.
3. Develop and validate navigation and guidance algorithms.
4. Implement the hardware and software into the RASCAL aircraft.
5. Conduct flight testing with the RASCAL aircraft.

The primary research objective is to evaluate from the flight test data the precision approach capability of the RASCAL aircraft using GPS inputs for navigation and guidance. System configurations will include SPS DGPS, integrated SPS DGPS/INS and autonomous PPS GPS. To accomplish the objective, the RASCAL aircraft will need to be fitted with a permanent precision navigation system capability. Such a system will include an INS along with cockpit instrumentation to display course and glideslope deviation, a navigation computer, a data acquisition and storage computer, a GPS receiver set and telemetry for DGPS corrections from a ground-based reference station.

SUMMARY OF TECHNICAL APPROACH

The research will involve both testing and evaluation to be accomplished in an incremental, progressive manor. In the first phase, the RASCAL aircraft will collect data from the INS, DGPS, Air Data Computer (ADC), barometric altimeter and radar altimeter to be used to develop navigation and guidance algorithms. Once the algorithms are evaluated in a laboratory environment, flight tests will be flown to validate the use of SPS DGPS for helicopter approaches to landing at Crows Landing NAS. In the second phase, the RASCAL aircraft will collect data from the autonomous PPS GPS as well as the INS, ADC, barometric altimeter and radar altimeter to be used to develop further navigation and guidance algorithms. Laboratory evaluations will be required to integrate the navigation computer with the autonomous GPS as well as the DGPS/INS. Once the integration is accomplished, flight tests will be flown to validate the use of PPS GPS and SPS DGPS/INS for helicopter approaches to landing at Crows Landing NAS.

PHASE 1 APPROACH

The overall approach for Phase 1 is to:

1. Define and develop a SPS DGPS configuration for both the RASCAL aircraft and the ground-based reference system.
2. Design and develop a test and evaluation system to collect three-dimensional navigation data and truth position data for post-mission analysis.
3. Collect INS, DGPS, ADC, barometric altimeter and radar altimeter data for algorithm development.
4. Develop algorithms which utilize SPS DGPS user equipment to provide high accuracy, three-dimensional navigation and guidance in the DGPS mode.
5. Modify DGPS/INS algorithms, previously developed for fixed-wing aircraft, to provide navigation and guidance in the RASCAL aircraft.
6. Validate DGPS navigation and guidance algorithms in a laboratory environment.
7. Accomplish flight tests using the RASCAL aircraft flying approaches to landing using DGPS information only. The glideslope for these approaches will be set at 3°, 6° and 9°.
8. Perform post-mission analysis.
9. Conduct SPS DGPS evaluations for helicopter approaches to landing.

The airborne equipment will be installed in the RASCAL aircraft (Figure 1). An Ashtech XII SPS DGPS receiver will be the primary navigation sensor. Data acquisition will be accomplished by the Data Acquisition Computer (DAC). The DAC will also function as the navigation computer for Phase 1.

Guidance information will be generated and displayed to the pilot through the course deviation indicator (CDI). Diagnostics will be provided to determine flight test validity. All measurement data will be stored on a removable medium for post-mission analysis. An operator terminal is provided for system control of the data acquisition system.

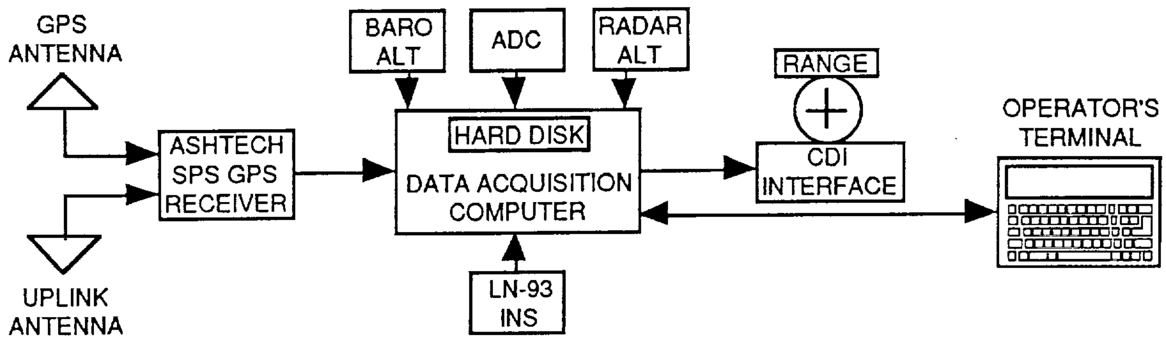

Figure 1 Airborne System

The DGPS corrections and the laser tracker truth reference data will be obtained at the ground-based reference station (Figure 2). The DGPS corrections are provided by a second Ashtech XII GPS receiver stationed at a surveyed site, while the truth reference data is provided by the laser tracker. The corrections will be sent, via data link, to the RASCAL aircraft. The laser tracker data will be collected and referenced via the GPS standard time code, as will all data collected. An operator will monitor the performance of the ground-based equipment.

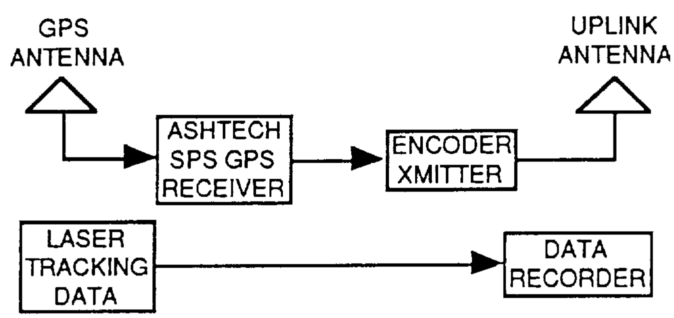

Figure 2 Ground System

A third system located in the laboratory will accept the recorded flight test data and provide plotting and statistics capability for evaluating the system performance. Since all sensor measurements are recorded, different sensor configurations can be evaluated using identical input data on reruns of the flight data. This enables comparisons to be made between the configurations.

The flight test environment is shown in Figure 3. The RASCAL aircraft will fly straight-in approaches to landing in which the glideslope will be set at 3°, 6° and 9°.

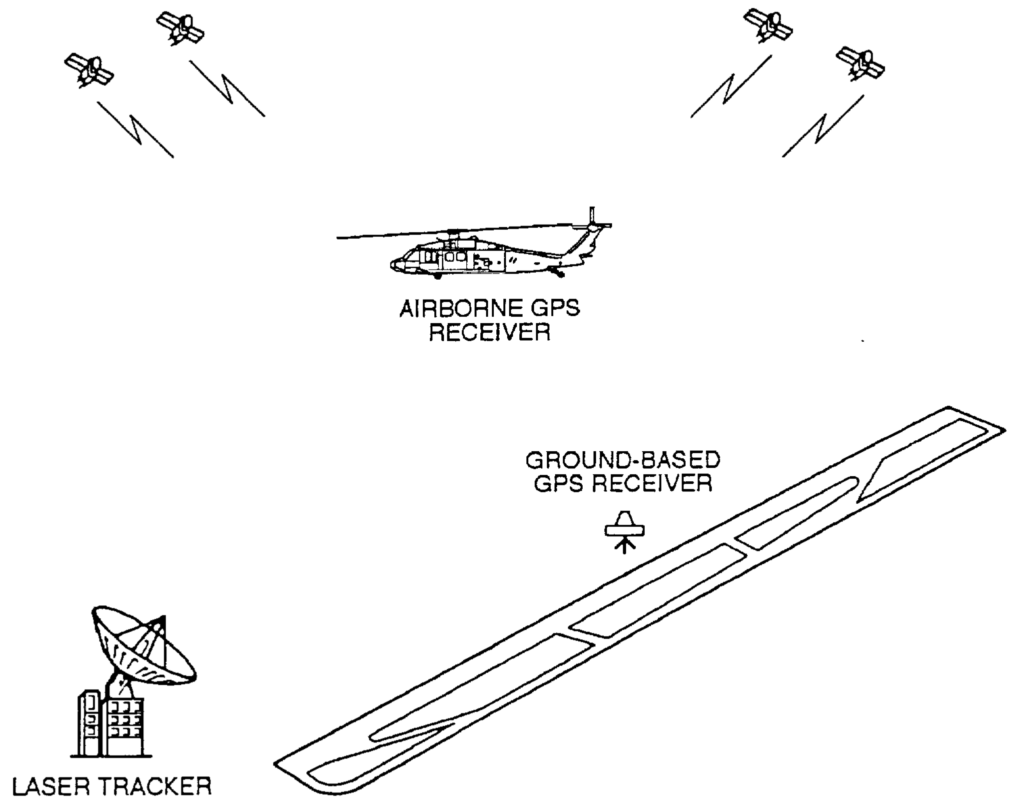

Figure 3 Flight Test Environment

PHASE 2 APPROACH

The overall approach for Phase 2 is to:

1. Define and develop a PPS GPS as well as a SPS DGPS/INS configuration for the RASCAL aircraft.

2. Collect INS, GPS, DGPS, ADC, barometric altimeter and radar altimeter data for algorithm development.

3. Develop algorithms which utilize PPS GPS user equipment to provide high accuracy, three-dimensional navigation and guidance in the autonomous GPS mode.

4. Validate the GPS and DGPS/INS (developed in Phase 1) navigation and guidance algorithms in a laboratory environment.

5. Accomplish flight tests using the RASCAL aircraft flying approaches to landing using GPS information only or DGPS/INS information only. The glideslope for these approaches will be set at 3°, 6° and 9°.

6. Perform post-mission analysis.

7. Conduct PPS GPS as well as SPS DGPS/INS evaluations for helicopter approaches to landing.

In addition to the airborne equipment used during Phase 1, a Collins 3A PPS GPS receiver and a dedicated navigation computer will be added (Figure 4). The navigation computer is required to integrate the GPS and DGPS receivers with other navigation and cockpit display instrumentation.

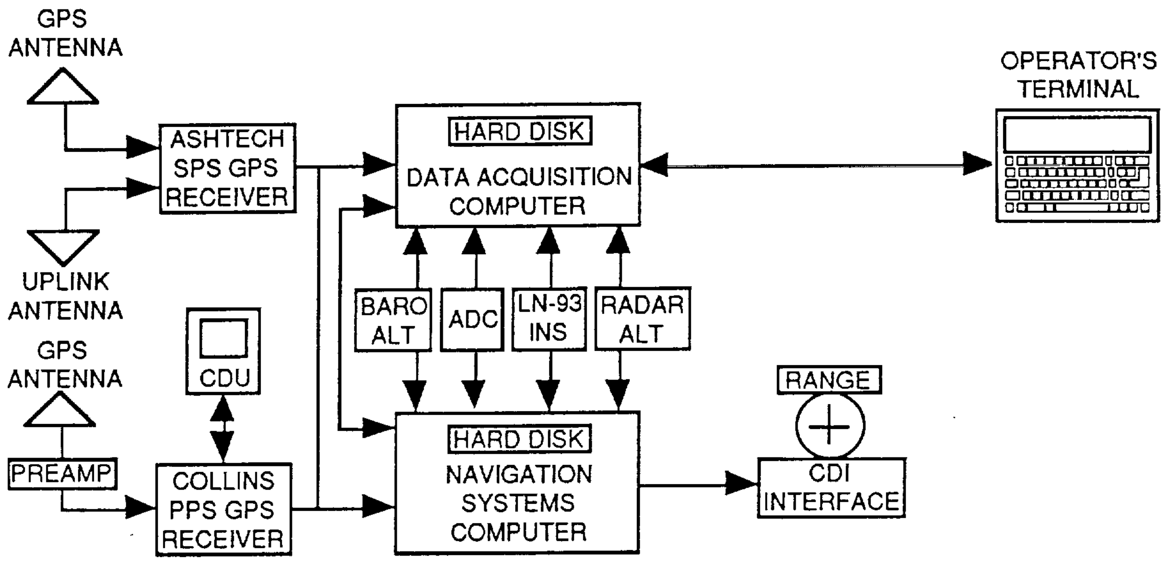

Figure 4 Airborne System

As in Phase 1, guidance information will be generated and displayed to the pilot through the CDI. Diagnostics will be provided to determine flight test validity. All measurement data will be stored on a removable medium for post-mission analysis. An operator terminal is provided for system control of the data acquisition system.

For the DGPS/INS portion of the flight test, DGPS corrections are provided by a second Ashtech XII GPS receiver stationed at a surveyed site. The corrections will be sent, via data link, to the RASCAL aircraft. An operator will monitor the performance of the ground-based equipment.

The flight test environment and the type of approaches that the RASCAL aircraft will fly are the same as in Phase 1.

SCHEDULE

Figure 5 presents the series of tasks and milestones for Phase 1 and Phase 2 of the research.

The major activities are described as follows:

PHASE 1

1. Flight Test Hardware Installation

   The assembly, installation, and checkout of the SPS DGPS receiver and antenna as well as the data acquisition system in the RASCAL aircraft.

2. Preliminary Data Acquisition

   The collection of INS, DGPS, ADC, barometric altimeter and radar altimeter data for navigation and guidance algorithm development.

3. Algorithm Development

   The development of algorithms to provide high accuracy, three-dimensional navigation and guidance in the DGPS or DGPS/INS mode. Since algorithms from previous fixed-wing research already exist for DGPS/INS integration, modifications will be made in order to adapt them to the RASCAL aircraft.

4. System Software Development

   Software design, coding, debugging and documentation.

5. System Integration and Validation

   The verification that the flight test system sensors, computers and software, and input/output devices comprising the data acquisition system are operating correctly. Laboratory tests will be accomplished to insure valid end-to-end operation of all systems.

6. Flight Tests

   The demonstration and evaluation of helicopter approaches to landing using SPS DGPS information only.

PHASE 2

1. Flight Test Hardware Installation

   The addition of the PPS GPS and a dedicated navigation computer to the equipment already in place from Phase 1.

2. Data Acquisition

   The collection of INS, GPS, DGPS, ADC, barometric altimeter and radar altimeter data for navigation and guidance algorithm development.

3. Algorithm Development

   The development of algorithms to provide high accuracy, three-dimensional navigation and guidance in the autonomous GPS mode.

4. System Software Development

   Software design, coding, debugging and documentation.

5. System Integration and Validation

   The verification that the flight test system sensors, computers and software, and input/output devices comprising the data acquisition system are operating correctly. Laboratory tests will be accomplished to insure valid end-to-end operation of all systems.

6. Flight Tests

   The demonstration and evaluation of helicopter approaches to landing using PPS GPS information only or SPS DGPS/INS information only.

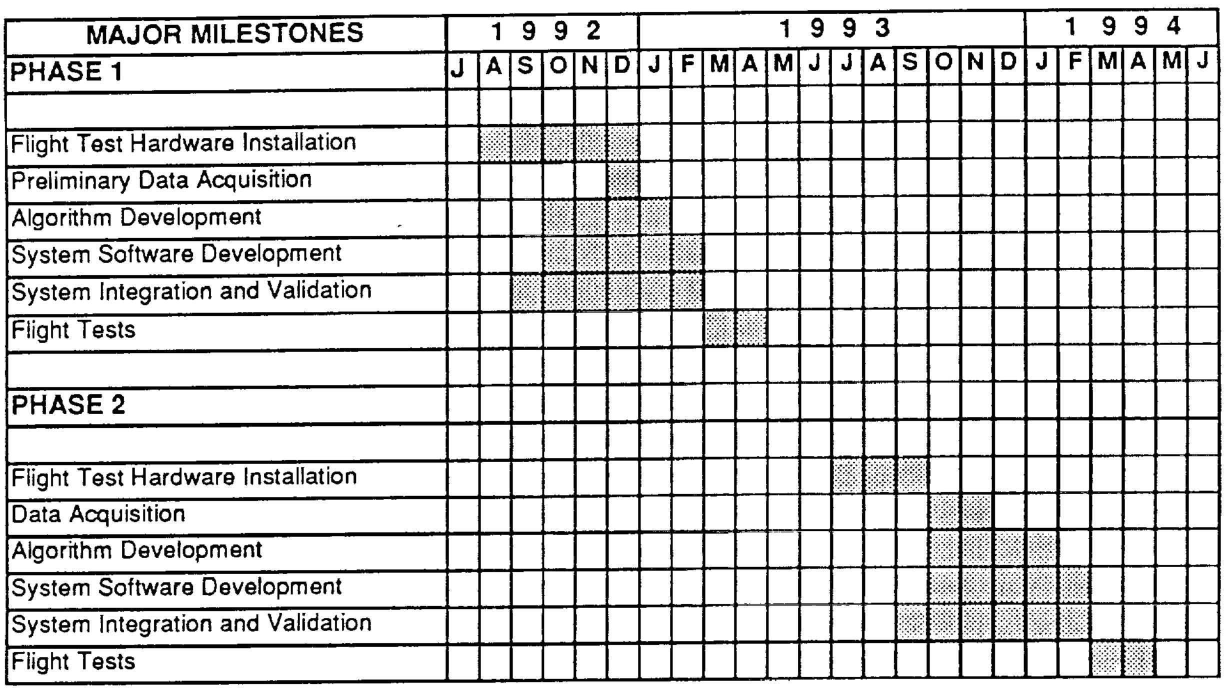

Figure 5 Research Schedule

NASA SYSTEM DOCUMENT

RASCAL
NAVIGATION SYSTEM CONFIGURATION
(PHASE 1)

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12 OCT 1992

ABSTRACT

The navigation system configuration for the Rotorcraft Aircrew Systems Concepts Airborne Laboratory (RASCAL) consists of a Data Acquisition Computer (DAC) which collects data from a Differential Global Positioning System (DGPS) receiver, an Inertial Navigation System (INS), an Air Data Computer (ADC), a barometric altimeter and a radar altimeter. In addition, the DAC supplies data to the Course Deviation Indicator (CDI) Drive and the hard disk. The DAC is in turn controlled and monitored by the laptop computer.

This document details the functional configuration of the navigation system in the RASCAL aircraft for Phase 1 of the research into helicopter precision approach capability using GPS. In Phase 1, Standard Positioning Service (SPS) DGPS information is used solely to provide navigation and guidance during helicopter precision approaches to landing. Data obtained during Phase 1 will be used in later phases of the research in the development and modification of software used to integrate the GPS with other navigation and cockpit display instrumentation.

The RASCAL aircraft is a modified UH-60 Black Hawk helicopter located at NASA Ames Research Center which will be used to implement the high frequency, high accuracy, real-time navigation system. Using RASCAL, operational data can be obtained for the Federal Aviation Administration (FAA) to investigate the use of DGPS for helicopter approaches to landing.

INTRODUCTION

The purpose of the research is to evaluate the use of DGPS equipment in providing high accuracy, precision navigation and guidance for helicopter approaches to landing. This will be accomplished using the RASCAL aircraft for data collection and flight test evaluations. In order for the flight tests to begin, the RASCAL aircraft will require a permanent precision navigation system. For this phase of the research, the navigation system will include a DGPS receiver, INS, DAC, ADC and CDI Drive.

NAVIGATION SYSTEM CONFIGURATION

The navigation system configuration for the RASCAL aircraft consists of a DAC which collects data from a DGPS receiver, an INS, an ADC, a barometric altimeter and a radar altimeter. In addition, the DAC supplies data to the CDI Drive and the hard disk. The DAC is in turn controlled and monitored by the laptop computer.

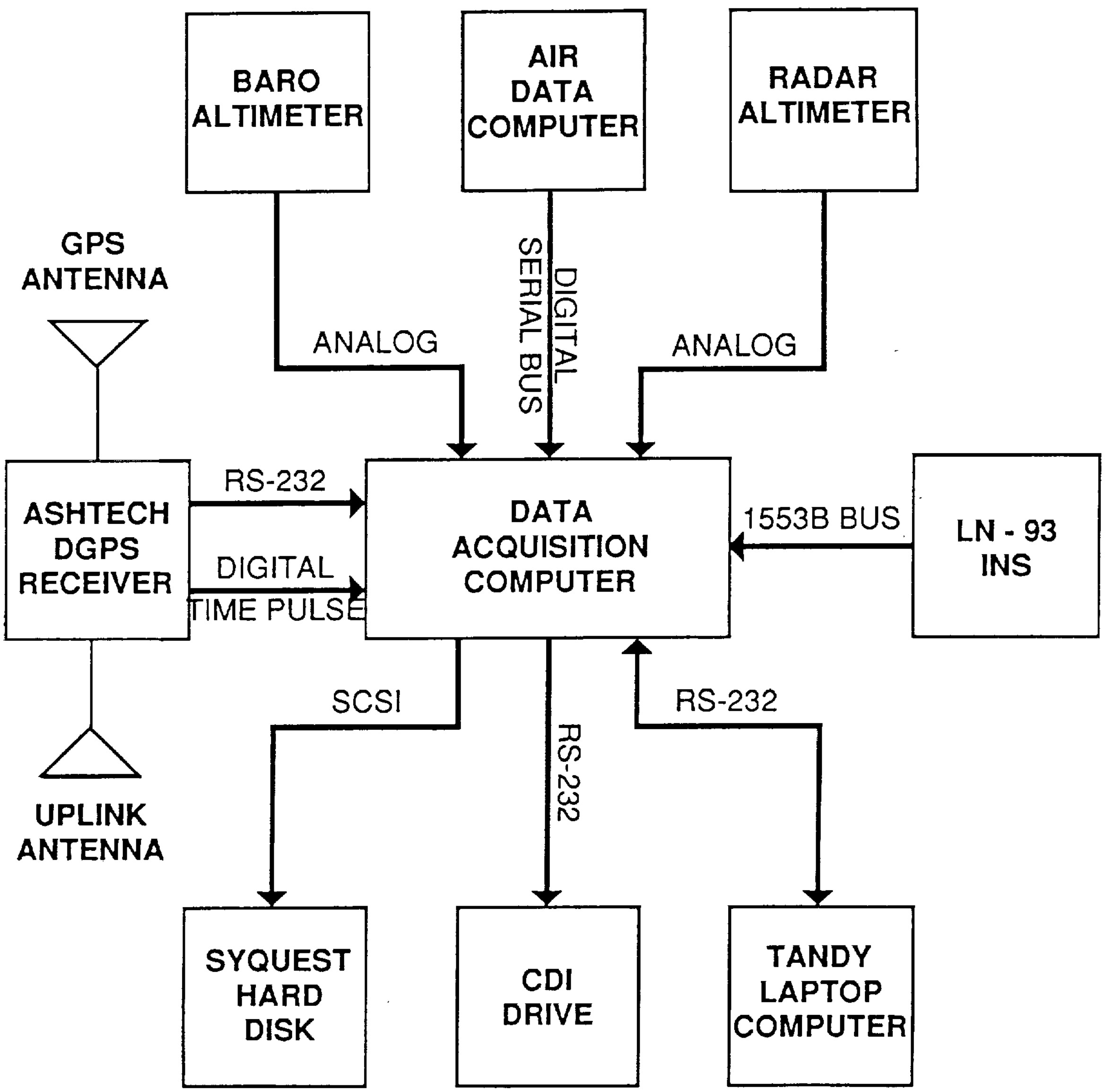


Figure 1 Navigation System Configuration

DATA ACQUISITION COMPUTER INPUT

The DAC collects data from the DGPS receiver, INS, ADC, barometric altimeter and radar altimeter. The DAC is in turn controlled and monitored by the laptop computer.

DGPS RECEIVER OUTPUT

The Ashtech XII DGPS receiver sends the PBEN (position) data file via an RS-232 cable at a rate of 2 Hz.

The PBEN data file contains the following:

" $PASHR,PRN,"	header string
long pbentime	receive time of data (10^{-3} sec)
char sitename [4]	4 character site name (operator entered)
double navx	position (ECEF X) (m)
double navy	position (ECEF Y) (m)
double navz	position (ECEF Z) (m)
float navt	clock offset (m)
float navxdot	velocity in ECEF X (m/sec)
float navydot	velocity in ECEF Y (m/sec)
float navzdot	velocity in ECEF Z (m/sec)
float navtdot	clock drift (m/sec)
unsigned short pdop	PDOP
unsigned short checksum	checksum (sum of words from pbentime to pdop)
char	carriage return
char	line feed

In addition, a precise GPS time pulse is sent to the DAC via a digital line at a rate of one pulse per second.

INS OUTPUT

The Litton LN-93 INS sends the IO1 data via a 1553B data bus at a rate of 64 Hz.

The IO1 data contains the following:

IO1-01	INS mode word
IO1-02	INS control word 2 (ms) (timetag)
IO1-03	x velocity (ft/sec)
IO1-04	x velocity (ft/sec)
IO1-05	y velocity (ft/sec)
IO1-06	y velocity (ft/sec)
IO1-07	z velocity (ft/sec)
IO1-08	z velocity (ft/sec)
IO1-09	platform azimuth (rad)
IO1-10	roll (rad)
IO1-11	pitch (rad)
IO1-12	present true heading (rad)
IO1-13	present magnetic heading (rad)
IO1-14	x acceleration (ft/sec^2)
IO1-15	y acceleration (ft/sec^2)
IO1-16	z acceleration (ft/sec^2)
IO1-17	CNE_{xx}
IO1-18	CNE_{xx}
IO1-19	CNE_{xy}

IO1-20	CNE_{xy}
IO1-21	CNE_{xz}
IO1-22	CNE_{xz}
IO1-23	longitude (rad)
IO1-24	longitude (rad)
IO1-25	internal altitude (ft)
IO1-26	great circle steering error (rad)
IO1-27	x-axis residual tilt (arc sec)
IO1-28	y-axis residual tilt (arc sec)
IO1-29	mode word II
IO1-30	roll rate, p (rad/sec)
IO1-31	pitch rate, q (rad/sec)
IO1-32	yaw rate, r (rad/sec)

ADC OUTPUT

The ADC sends the following data via a digital serial bus at a rate of 2 Hz.:

adc1.1	Vu_tas	x-axis true air speed (cts)
adc1.2	Vv_tas	y-axis true air speed (cts)
adc2.1	Vw_tas	z-axis true air speed (cts)
adc2.2	Pabs	absolute pressure (cts)
adc3.1	T_air	air temperature (cts)
adc3.2	Vdnwash	downwash velocity (cts)
adc4.1	Pstat1	static pressure (cts)
adc4.2	Pstst2	static pressure (cts)
adc5	baro_alt	barometric altitude (ft)

BAROMETRIC ALTIMETER OUTPUT

The barometric altimeter is sampled at a rate of 80 Hz and sends the altitude data via an analog interface.

RADAR ALTIMETER OUTPUT

The radar altimeter sends the altitude and valid altimeter data via a buffer amplifier at a rate of 80 Hz. Since the DAC is tapping into the radar altimeter signal, the buffer amplifier is used to ensure that the radar altimeter's performance is not affected.

LAPTOP COMPUTER INPUT/OUTPUT

The Tandy 102 laptop computer is responsible for the control of the DAC and is connected via a RS-232 cable. The laptop computer, via the RASCAL Data Acquisition Program, is first used for initialization, and then cycles data to and from the operator. Initialization involves; defining variables, opening a log file, checking data storage availability, locking the program in memory, checking the program version number and defining the aircraft's present location. After initialization, a six character branch code and flight number is entered followed by two comment lines to enter such data as name, location, scenario, etc. At this point, the Data Run Menu is displayed (Figure 2).

t elapse = 30			time = 30:06		t tgo = 308
STATUS inu : NAV			data : OFF		pgm : INUNV
			DGPS uplink : new		
RNWY	GS	HDG	ALT	RANGE	
R35	3	355	1200	3.0	
enter S(tart), R(nwy), G(s), Q(uit)					

Figure 2 Data Run Menu

The display and commands are described as follows:

t elapse	time from start or stop of run (sec)
time	time of day (min and sec) (hours not displayed)
t tgo	time available for recording (sec) (during runs it counts down, between runs it remains fixed
RNWY	runway currently in use
GS	glideslope (deg)
HDG	aircraft heading (deg)
ALT	aircraft altitude above the aim point (ft)
RANGE	horizontal range to the aim point (NM)
S(tart)	start data collection
R(nwy)	enter desired runway
G(s)	enter desired glideslope (3°, 6° or 9°)
Q(uit)	quits the data acquisition program

Entering S(tart) begins the data collection and updates the operator's screen approximately once every second. Entering S(top) stops the data collection and displays the following commands:

F(ile)	stores the data along with six comment lines onto the hard disk
D(iscard)	discards the data
Q(uit)	quits the data acquisition program

Following a F(ile) or D(iscard) command, the following commands are displayed:

R(eadyrun)	sets up the Data Run Menu for another run
Q(uit)	quits the data acquisition program

DATA ACQUISITION COMPUTER OUTPUT

The DAC records all collected data onto the hard disk and also functions as the guidance and navigation computer. In this capacity, the DAC first takes the aircraft position and velocity supplied by the DGPS receiver (in Earth Centered Earth Fixed (ECEF) coordinates) and converts them into the Crows Landing Runway Coordinate System (RCS). This conversion is accomplished by a transformation matrix. The ECEF coordinate frame has the origin located at the center of the earth, while the x axis is oriented outward through the equator along the Prime Meridian, the y axis being 90° to the East and the z axis oriented up through the North Pole. The RCS has the origin located at the Aim Point (See Figure 3), the x axis runs in the direction of and parallel to Runway 35, the y axis being 90° to the East and the z axis oriented down to the center of the earth.

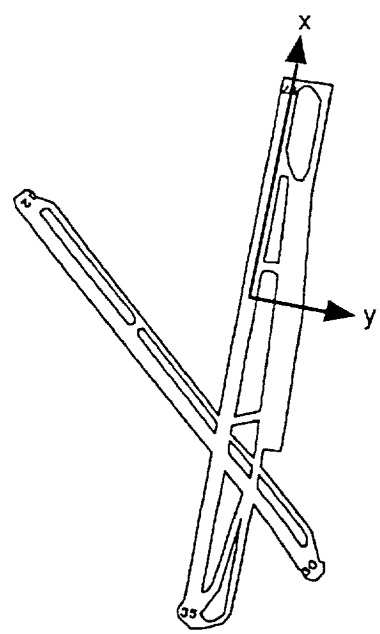


Figure 3 Crows Landing Runway Coordinate System

After the aircraft position and velocity are converted into the RCS, the relationship between the aircraft position and the desired aim point, glideslope and course are evaluated and a deviation for the glideslope and localizer is computed. Since the aircraft position is supplied to the DAC at a rate of 2 Hz, the glideslope and localizer deviations will be derived using a digital filter to provide a smooth input to the CDI (See Appendix).

HARD DISK INPUT

The Syquest hard disk records all data acquired by the DAC on a removable hard disk. The hard disk is connected to the DAC via a Small Computer System Interface (SCSI).

CDI DRIVE INPUT

The Leaky ILS accepts the localizer and glideslope deviation data via a RS-232 cable. The RF output frequencies of 108.1 MHz. (localizer) and 334.7 MHz. (glideslope) are used in conjunction with the navigation radios to provide guidance using the CDI.

APPENDIX

CDI FILTER DESIGN

Prior to sending the DGPS position (in RCS) to the CDI Drive, the position data is smoothed by a digital filter. The filter accepts the DGPS positions and velocities at a rate of 2 Hz and outputs the filtered data at a rate of 12 Hz, which is the maximum rate at which the CDI Drive can accept data.

$$\begin{bmatrix}\hat{x}\\ \hat{y}\\ \hat{z}\end{bmatrix}_{t+1} = \begin{bmatrix}\hat{x}\\ \hat{y}\\ \hat{z}\end{bmatrix}_{t} + \begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{z}\end{bmatrix} \times \Delta t + (2.0 \times \Delta t \times \delta)$$

where :

$\begin{bmatrix}\hat{x}\\ \hat{y}\\ \hat{z}\end{bmatrix}_{t+1}$ is the filtered DGPS data at a time of t+1

$\begin{bmatrix}\hat{x}\\ \hat{y}\\ \hat{z}\end{bmatrix}_{t}$ is the filtered DGPS data at a time of t

$\begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{z}\end{bmatrix}$ is the DGPS velocities

Δt is the delta time increment of .08333 seconds

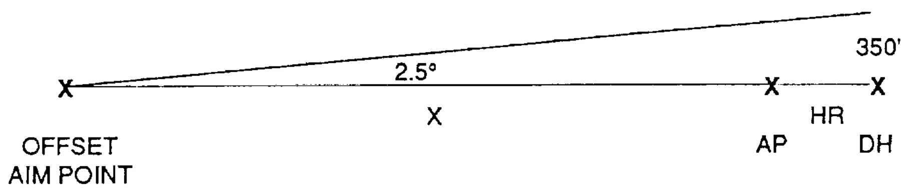
δ is the error at the time of the DGPS update between the DGPS position and the last filtered DGPS data prior to the DGPS update

The above equation is iterated starting at each DGPS update (every half second). The result of the above equation is then used to compute the glideslope and localizer error which is in turn sent to the CDI Drive.

CDI SENSITIVITIES

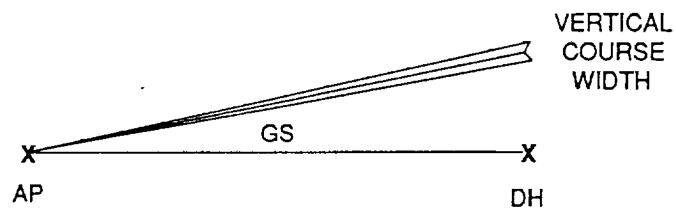
Previous flight tests involving helicopters flying steep approaches displayed the need to provide a lateral course width (full-scale deflection (± 2 dots)) of ± 350 feet at DH. In addition, the flight tests also indicated the need to provide vertical angular course widths of ± 1°, ± 2° and ± 3° for the 3°, 6° and 9° glideslopes, respectively. This corresponds to a full-scale deflection (± 2 dots). These sensitivities will be incorporated into the CDI drive input.

To provide a ± 350 feet lateral course width at DH, an offset aim point for the localizer angular course width is required (See Figure 4). The touchdown aim point will be used to provide the vertical angular course widths (See Figure 5).



GS	X (ft)	HR (ft)
3°	7069.8975	954.0568
6°	7072.5184	951.4364
9°	7076.8921	947.0627

Figure 4 Localizer Geometry



GS	VERTICAL COURSE WIDTH
3°	± 1°
6°	± 2°
9°	± 3°

Figure 5 Glideslope Geometry

NASA FLIGHT TEST PLAN

HELICOPTER PRECISION APPROACH CAPABILITY USING THE GLOBAL POSITIONING SYSTEM (PHASE 1)

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17 NOV 1992

ABSTRACT

The purpose of the test is to evaluate the use of the Global Positioning System (GPS) in the differential mode (DGPS) in providing high accuracy, precision navigation and guidance for helicopter approaches to landing.

Functional flight tests involving the Rotorcraft Aircrew Systems Concepts Airborne Laboratory (RASCAL) and the airborne systems required for the test will be conducted prior to any data collection or operational flight tests. Preliminary data collection will be conducted in order to obtain data for use in later phases of the research. Operational flight tests will be required in order to evaluate helicopter approaches to landing using only DGPS information for navigation and guidance.

The RASCAL aircraft is a modified UH-60 Black Hawk helicopter located at NASA Ames Research Center which will be used to implement a high frequency, high accuracy, real-time navigation system. Using RASCAL, operational data can be obtained for the Federal Aviation Administration (FAA) to investigate the use of DGPS for helicopter approaches to landing.

The flight test and evaluation will be carried out at the NASA test range facility located at Crows Landing NAS, Crows Landing, CA. The project will employ commercial off-the-shelf navigation equipment along with DoD military GPS user equipment. This equipment will be installed in the RASCAL aircraft which during flight testing will be tracked by a laser tracker currently in place at Crows Landing NAS.

The test system will consist of an airborne navigation and guidance system, a ground-based differential correction system, and a post-flight data analysis system. A ground-based reference system will transmit the DGPS corrections to the RASCAL aircraft via data link. In addition, truth position data will be collected and referenced via the GPS standard time code, as will all data collected. The data analysis system will be installed in a laboratory at the NASA Ames Research Center.

INTRODUCTION

The advent of GPS has provided a highly accurate, worldwide navigation capability. The system will provide positioning accuracy of 10-20 meters to users of the Precise Positioning Service (PPS) and 20-40 meter accuracy to users of the Standard Positioning Service (SPS) (100 meter accuracy when Selective Availability is activated). By providing local corrections to the satellite range measurements via data link, even greater positioning accuracy can be obtained. This is the basis for DGPS. Using SPS along with DGPS, positional accuracy of 2-5 meters is possible.

The addition of GPS to the RASCAL aircraft is part of a long-term research project designed to develop an Intelligent Systems Research Facility (ISRF). This facility is designed to give the pilot flight path guidance while flying in the low altitude environment. Research involving DGPS will also support the goals of the FAA by providing data on the approach and hover performance capability of a helicopter equipped with DGPS.

OBJECTIVES

The primary goal of the flight test is to evaluate the precision approach capability of the RASCAL aircraft using only DGPS information for navigation and guidance. A secondary goal is to collect data for use in later phases of the research. For a more detailed description of the overall research and objectives, refer to the Research Plan.

FUNCTIONAL FLIGHT TEST

The navigation system configuration for the RASCAL aircraft during Phase 1 of the research consists of a Data Acquisition Computer (DAC) which collects data from a DGPS receiver, an Inertial Navigation System (INS), an Air Data Computer (ADC), a barometric altimeter and a radar altimeter. In addition, the DAC supplies data to the Course Deviation Indicator (CDI) Drive and the hard disk. The DAC is in turn controlled and monitored by the laptop computer.

Prior to the functional flight test, ground checks will be performed to insure correct installation of the navigation system into the RASCAL aircraft. Upon the successful completion of the ground checks, a functional flight test will be required to confirm that the systems are operating satisfactorily and consistently.

DESCRIPTION

The functional flight test will be conducted at the NASA test range facility located at Crows Landing NAS, Crows Landing, CA. Data from the navigation system will be collected to insure the data acquisition capability. In addition, GPS guidance capability will be tested by comparing the CDI to the desired glideslope and course (See Figure 1). Post-flight data analysis will be required to insure that the correct data is collected.

One flight is anticipated, however, additional flights will be flown as necessary. The duration of the flights will be approximately two hours and 30 minutes. Each flight will proceed only after a successful pre-flight check of all aircraft and navigation systems. All flights will be flown in Visual Meteorological Conditions (VMC).

COMPLETION CRITERIA

The functional flight test will continue until all systems are operating correctly and data collection capability is demonstrated.

DATA ACQUISITION/OPERATIONAL FLIGHT TEST

The data acquisition portion of the test is designed to collect INS, DGPS, ADC, barometric altimeter and radar altimeter data for future navigation and guidance algorithm development. At the same time, operational flight tests will be conducted to evaluate helicopter approaches to landing using only DGPS information for navigation and guidance.

DESCRIPTION

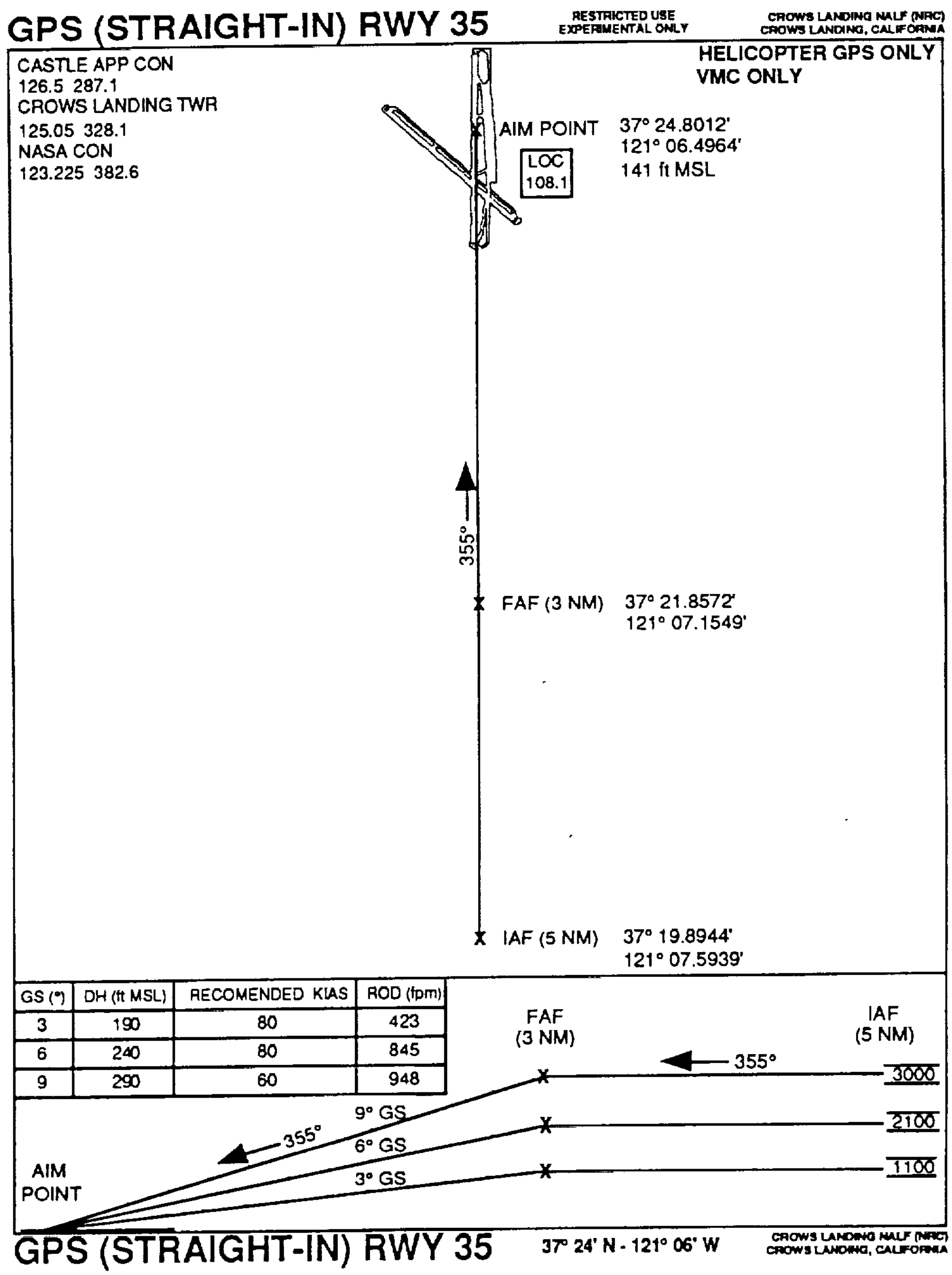
Data acquisition and operational flight tests will also be carried out at Crows Landing NAS. All test flights will begin data collection abeam the Initial Approach Fix (IAF), which is located five Nautical Miles (NM) out along the active runway heading, and will cease collecting data at the initiation of the go-around (See Figure 1). All approaches will be flown at 80 Knots Indicated Air Speed (KIAS) except for the 9° glideslope approaches, which will be flown at 60 KIAS. Twelve separate approaches will be flown at a glideslope of 3°, 6° and 9° for a total of 36 approaches.

Each approach flown will begin at the IAF with the RASCAL aircraft established on speed, on course and at the hard altitude associated with the glideslope to be flown. Upon crossing the IAF, the pilot will proceed inbound to the Final Approach Fix (FAF) located three NM out along the active runway heading. After crossing the FAF, the pilot will intercept the appropriate glideslope and fly the approach down to the DH corresponding to the glideslope just flown. After descending through the DH, a go-around will be initiated at which time the pilot will fly the RASCAL aircraft back to the IAF, to set up for another approach.

Three flights consisting of 12 approaches each are anticipated, however, additional flights will be flown as necessary. Each flight will have a duration of approximately two hours and 30 minutes, and will land at Crows Landing NAS for refueling. Upon refueling completion, the RASCAL aircraft may continue data acquisition and operational flight testing (if required), or return to Moffett Field. Each flight will proceed only after a successful pre-flight check of all aircraft and navigation systems. All flights will be flown in VMC.

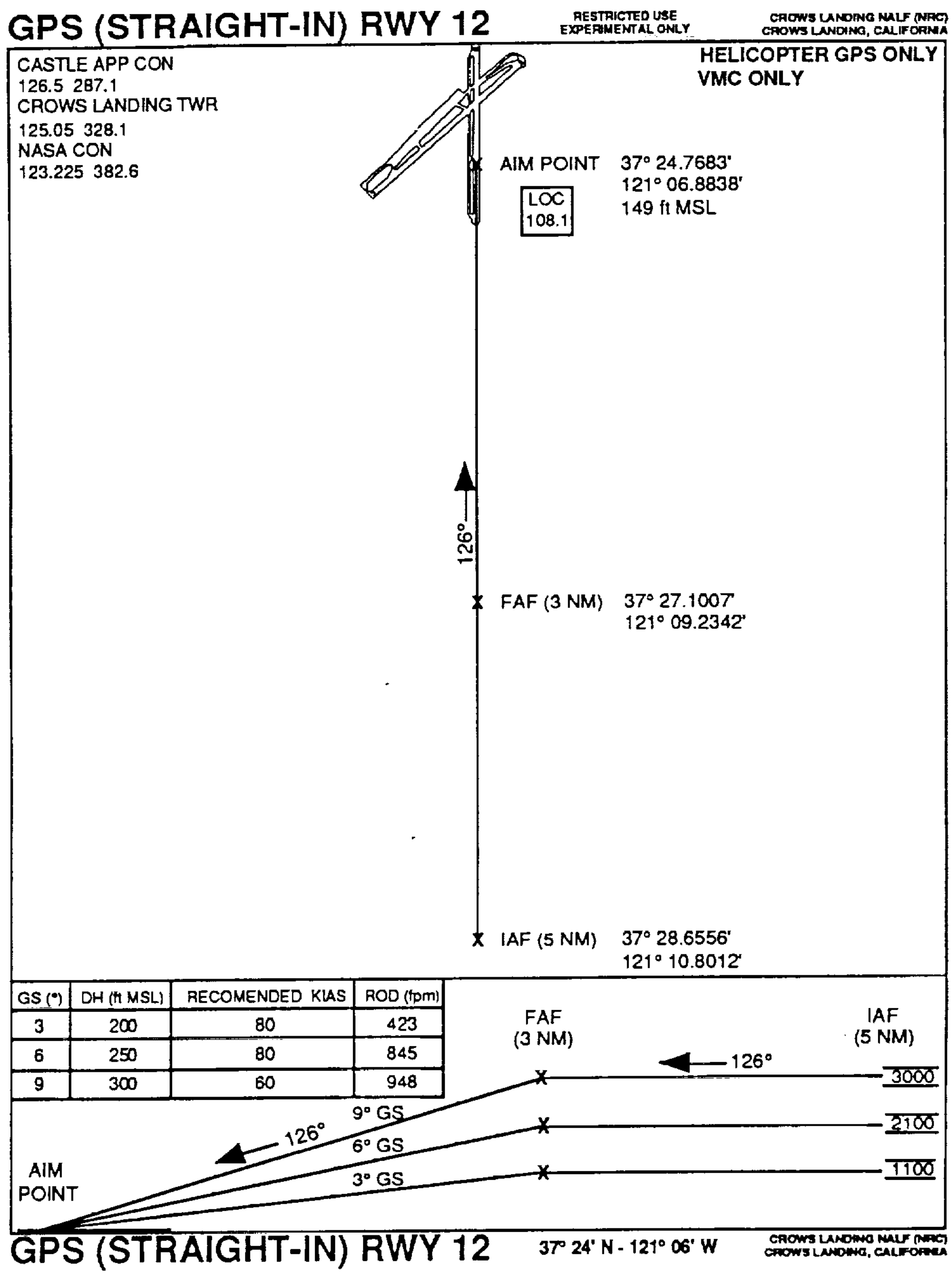
COMPLETION CRITERIA

The data acquisition/operational flight test will continue until at least a minimum of ten successful approaches each have been flown at a glideslope of 3°, 6° and 9°. At the completion of the tenth successful approach of each type of glideslope, efforts will be made to safely accomplish the last two approaches if possible.



GS (°)	DH (ft MSL)	RECOMENDED KIAS	ROD (fpm)
3	190	80	423
6	240	80	845
9	290	60	948

Figure 1a Functional Flight Test/Data Acquisition/Operational Flight Test Approach Profile



GS (°)	DH (ft MSL)	RECOMENDED KIAS	ROD (fpm)
3	200	80	423
6	250	80	845
9	300	60	948

Figure 1b Functional Flight Test/Data Acquisition/Operational Flight Test Approach Profile

INSTRUMENTATION

No special instrumentation in addition to that onboard the RASCAL aircraft or located at the test facility at Crows Landing NAS is required. The test will require onboard as well as ground-based data recording of selected parameters for post-flight data analysis. Specifically, the following data are of interest:

DGPS PBEN (position) data file
INS IO1 data
ADC data
Barometric altimeter data
Radar altimeter data
Laser tracker truth data

SAFETY

All aircraft safety of flight, critical design reviews and test procedures will be properly approved prior to the start of flight testing. No critical safety of flight modifications to the RASCAL aircraft will be made during the installation of the navigation system.

Each flight will include a briefing and debriefing. Flight test data cards will be prepared and given to each crew member at the beginning of each flight test briefing. The flight test data cards will include all test items to be accomplished during the flight test.

A discrete VHF or UHF radio frequency will be used during the flight tests to minimize interference and confusion. Each crew member will have primary responsibility to see and avoid other air traffic. Air traffic advisory services will be used to the maximum extent possible to aid in air traffic separation.

All flights will be conducted in day VMC with a visibility of at least five NM. A clearance of at least one NM horizontally and 1000 feet vertically will be maintained from clouds.

The safety pilot (Pilot-in-Command) must be alert to his duties as the primary safety observer. The safety pilot should have no other duties to perform during the approach to landing phase of the flight test.

SCHEDULE

The one functional flight test is scheduled for 01 DEC 1992. The GPS Satellite Visibility and Geometry Analysis, SATVIZ (Figure 2) indicates that the flight should occur between 0715 and 1245 local time (Universal Coordinated Time (UTC) minus eight hours).

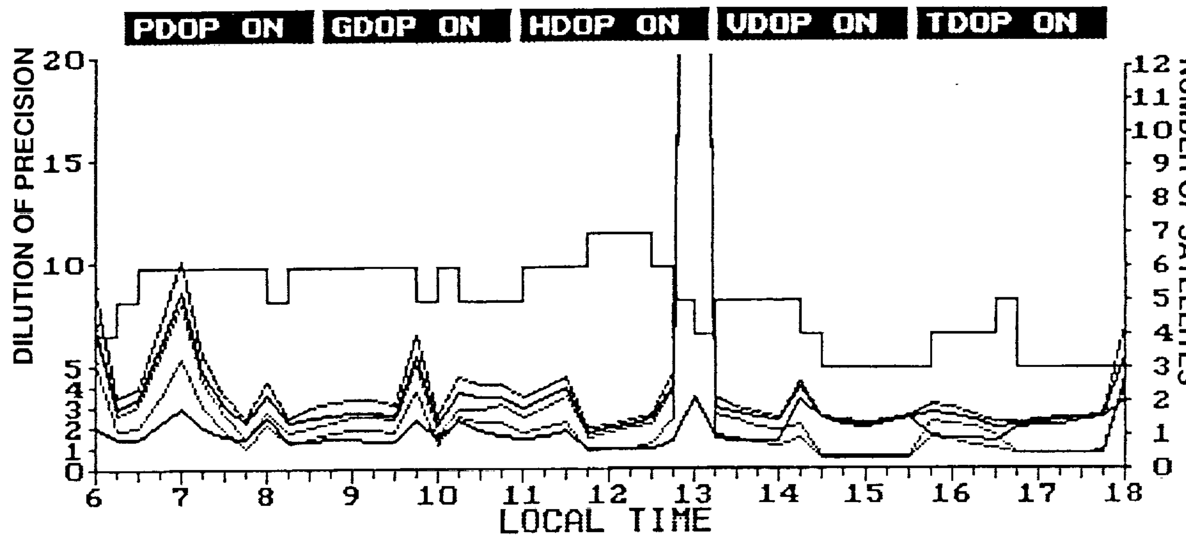


Figure 2 Functional Flight Test GPS Satellite Visibility

The back-up functional flight test is scheduled for 03 DEC 1992 (if required). The SATVIZ (Figure 3) indicates that the flight should occur between 0700 and 1230 local time (UTC minus eight hours).

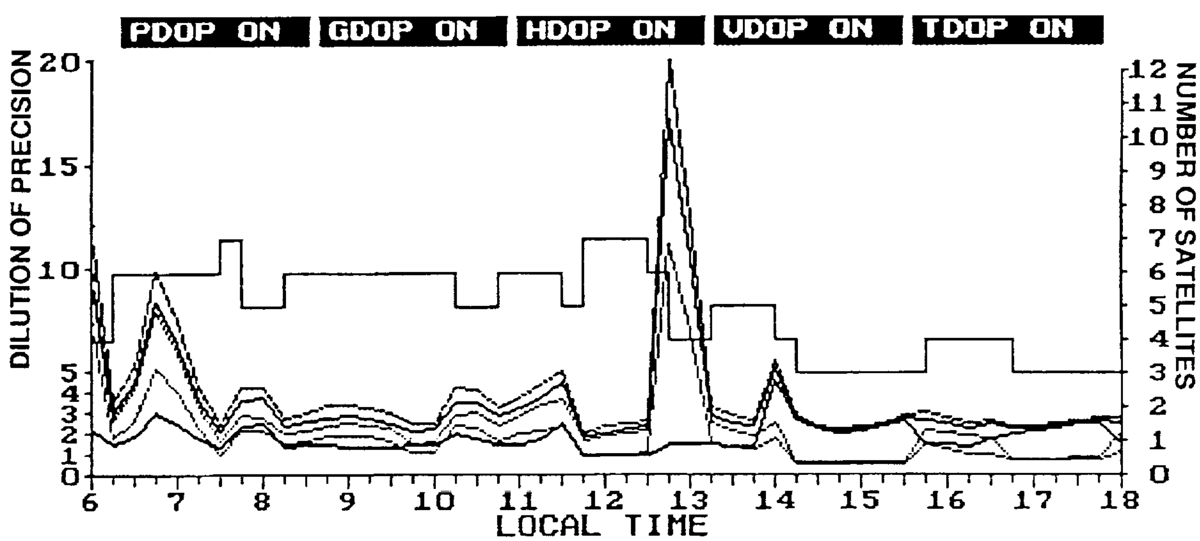


Figure 3 Back-Up Functional Flight Test GPS Satellite Visibility

The first data acquisition/operational flight test is scheduled for 08 DEC 1992 and the SATVIZ (Figure 4) indicates that the test should occur between 0645 and 1215 local time (UTC minus eight hours). All approaches during this flight will be flown using a 3° glideslope.

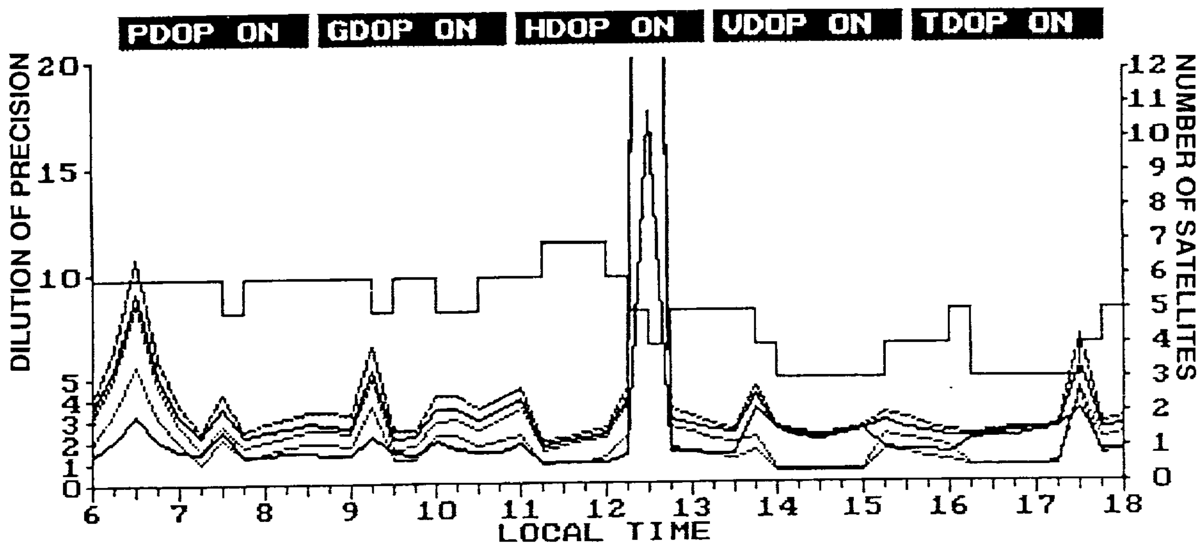


Figure 4 Data Acquisition/Operational Flight Test #1 GPS Satellite Visibility

The second data acquisition/operational flight test is scheduled for 10 DEC 1992 and the SATVIZ (Figure 5) indicates that the test should occur between 0645 and 1200 local time (UTC minus eight hours). All approaches during this flight will be flown using a 6° glideslope.

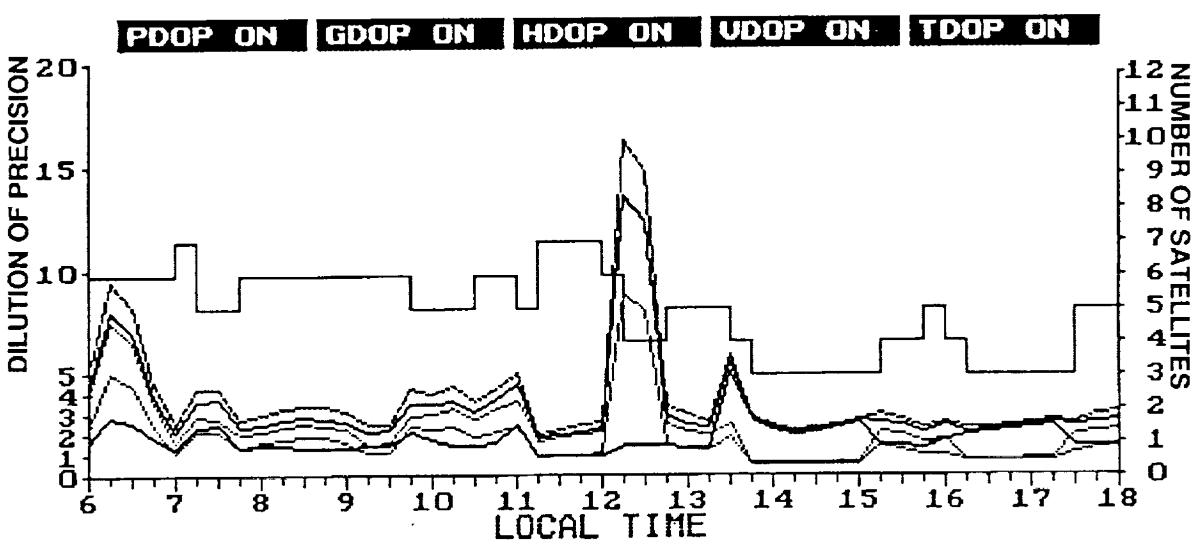


Figure 5 Data Acquisition/Operational Flight Test #2 GPS Satellite Visibility

The third data acquisition/operational flight test is scheduled for 15 DEC 1992 and the SATVIZ (Figure 6) indicates that the test should occur between 0615 and 1145 local time (UTC minus eight hours). All approaches during this flight will be flown using a 9° glideslope.

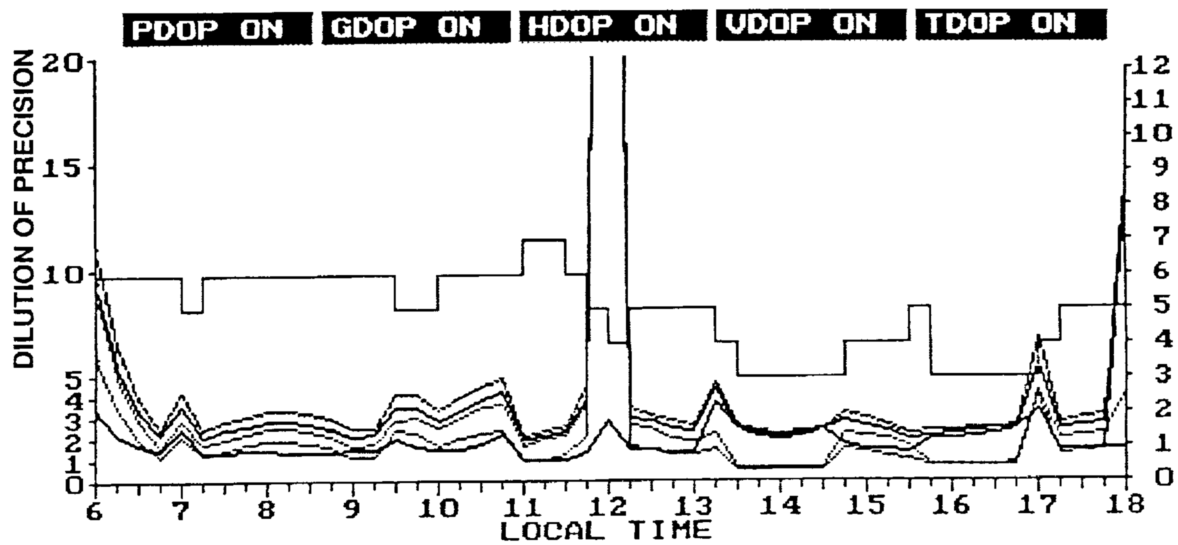


Figure 6 Data Acquisition/Operational Flight Test #3 GPS Satellite Visibility

The back-up data acquisition/operational flight test is scheduled for 17 DEC 1992 (if required) and the SATVIZ (Figure 7) indicates that the test should occur between 0615 and 1145 local time (UTC minus eight hours).

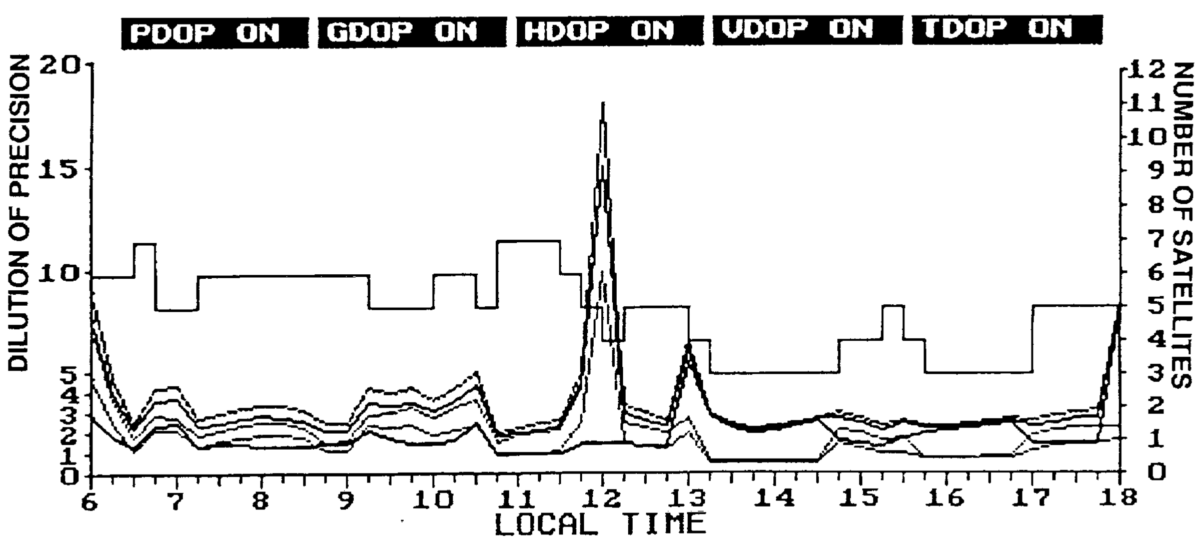


Figure 7 Back-Up Data Acquisition/Operational Flight Test GPS Satellite Visibility

The above times are based on having a minimum of five functioning satellites in view at all times and having a Geometric Dilution of Precision (GDOP) of less than or equal to a value of six.

APPENDIX

CROWS LANDING NAS SURVEY DATA

Previous research involving DGPS applications to fixed-winged aircraft required that two points be surveyed at Crows Landing NAS in 1990. These points are the Aim Point (AP) on Runway 35 and survey point LA on the East side of the ramp area. The research involving the RASCAL aircraft will use the survey data obtained for the fixed-winged research as well as additional survey data derived from the two previously surveyed points.

Survey point AP is located on the Runway 35 centerline approximately 3440 feet short of the departure end (See Figure 8). Survey point LA is located approximately 6.9 meters West of the East edge of the concrete ramp (See Figure 9). The station mark is the center of the head of a nail sunk into the junction of two expansion joints of the concrete slabs forming the ramp. Survey point L (from which survey point LA is defined) is located 2.579 meters South and 4.712 meters East of survey point LA (See Figure 9).

The expansion joints are oriented 350.2° magnetic (based on the current magnetic variation of 15.3° East), 355.495° relative to the RCS and 5.594° True.

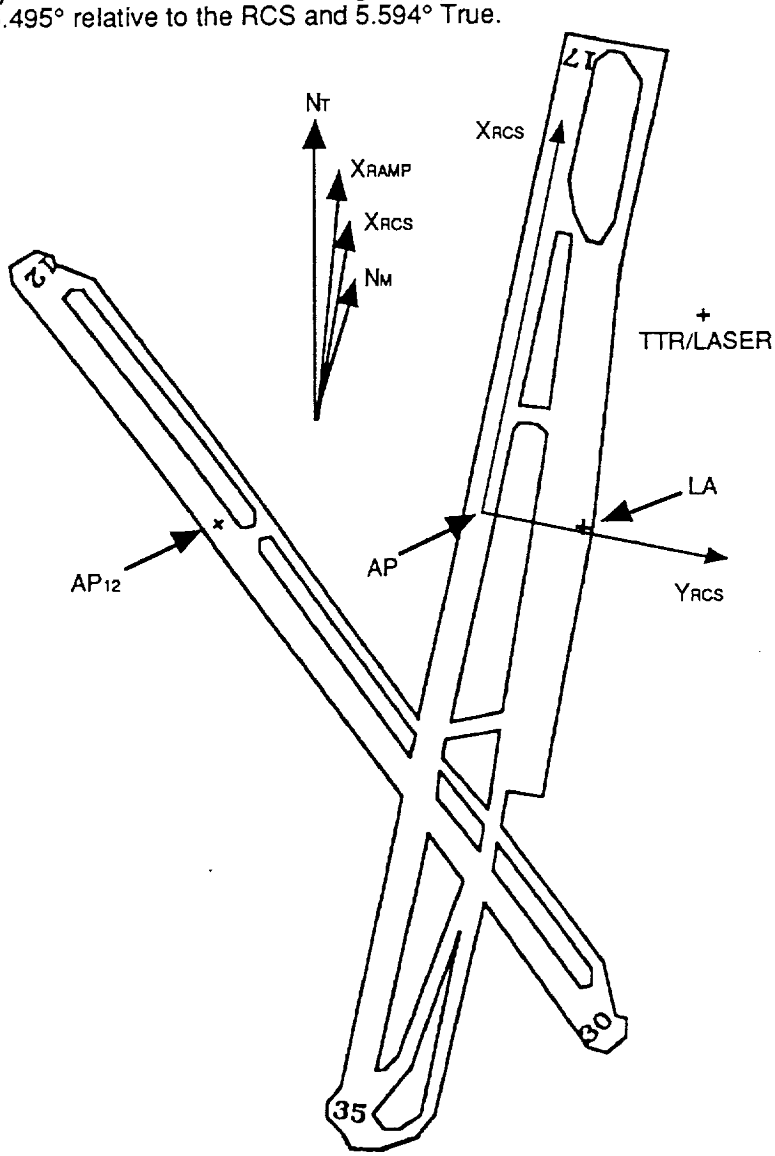


Figure 8 Crows Landing NAS Facility

If required to fly approaches to Runway 12, an aim point is positioned on the centerline, approximately 2460 feet down the runway (See Figure 8). The aim point location and elevation were derived from laser measurements and was not surveyed.

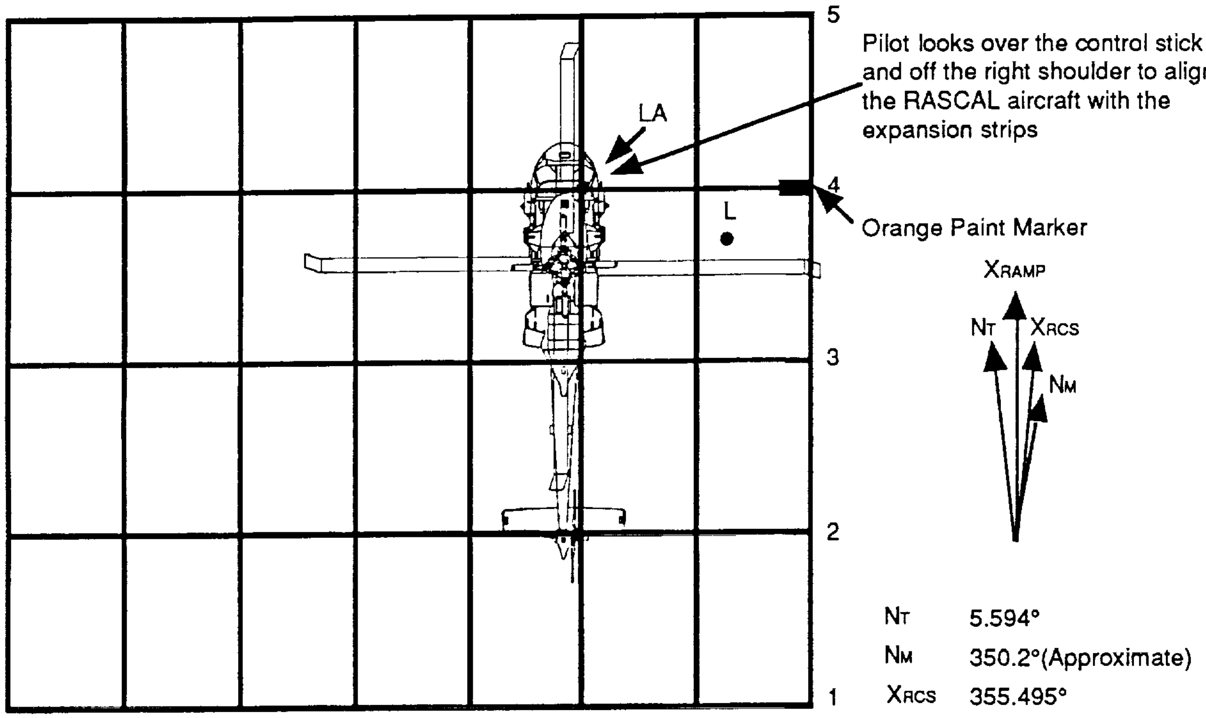


Figure 9 RASCAL Location At Survey Point LA

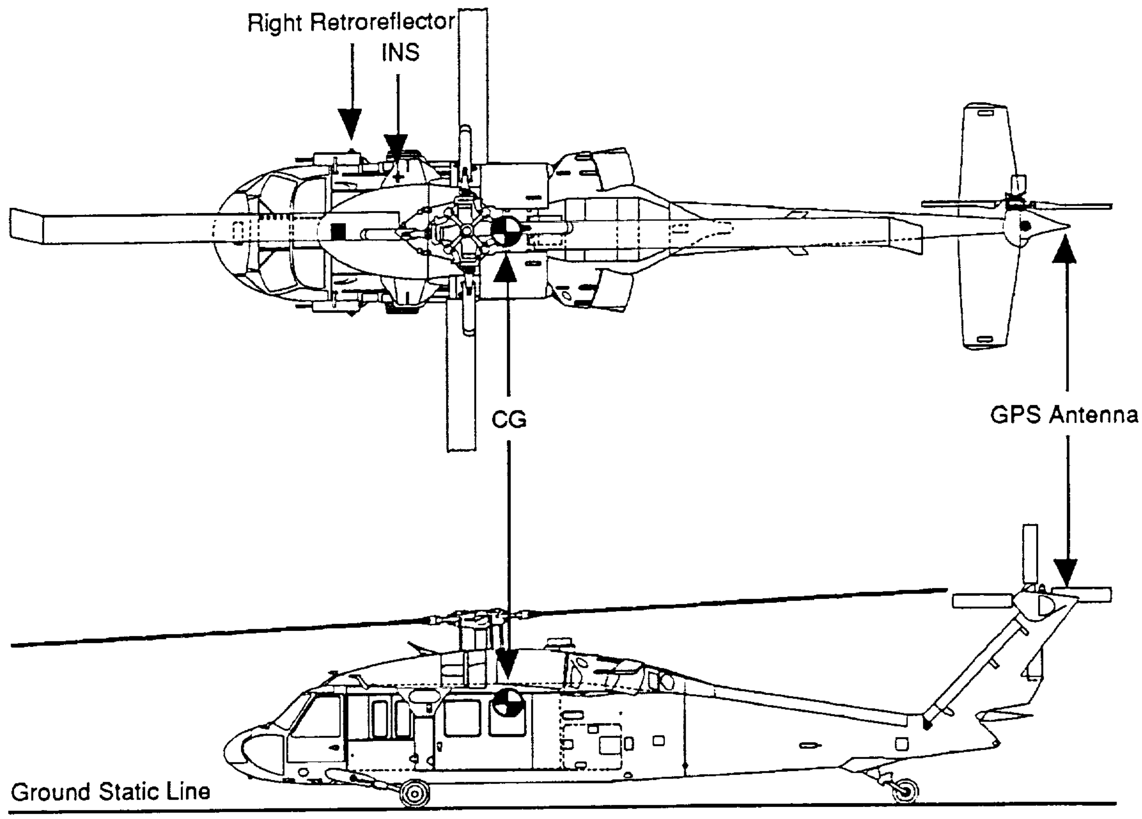
The latitude and longitude are given in the World Geodetic System, 1984 (WGS 84) reference system. The elevation is given in National Geodetic Vertical Datum of 1929 (NGVD 29) Elevation (the local elevation reference system). The locations are also given in the Crows Landing Runway Coordinate System (RCS) (the origin located at the survey point AP, the x axis running in the direction of and parallel to Runway 35, the y axis being 90° to the East and the z axis oriented down to the center of the earth).

LOCATION	X_{RCS} (m)	Y_{RCS} (m)	Z_{RCS} (m)
AP	0.0	0.0	0.0
TTR/Laser	524.8016	352.4311	0.4846
LA	2.582	220.056	0.762
Right Retroreflector	2.0348	220.9102	0.1905
INS	0.7778	220.3977	0.0381
CG	-0.8243	219.7086	-1.1366
GPS Antenna	-10.9909	220.5097	-3.0480

Figure 10 RCS Coordinates For The RASCAL Aircraft Components At Survey Point LA

LOCATION	LATITUDE (N)	LONGITUDE (W)	NGVD 29 ELEV (m)
AP	37° 24' 48.073"	121° 06' 29.781"	43.0
AP_{12}	37° 24' 46.100"	121° 06' 53.029"	45.6
TTR/Laser	37° 25' 02.830"	121° 06' 11.930"	42.5
Base GPS Antenna	37° 25' 04.144"	121° 06' 12.142"	46.9
LA	37° 24' 46.904"	121° 06' 20.953"	42.2
INS	37° 24' 46.846"	121° 06' 20.952"	43.0
GPS Antenna	37° 24' 46.471"	121° 06' 21.031"	46.1

Figure 11 Geodetic Coordinates



LOCATION	STATION (in)	BUTTLINE (in)	WATERLINE (in)
Ground Static Line	N/A	N/A	184.00
LA	229.00	+24.00	N/A
Right Retroreflector	251.00	+56.00	206.50
INS	298.75	+32.00	212.50
CG	359.50	0.00	258.75
GPS Antenna	761.00	0.00	334.00

Figure 12 RASCAL Component Body Coordinates

When required to align the INS at Crows Landing NAS, the pilot will taxi the RASCAL aircraft so that the Pilot-in-Command (right seat) is directly over survey point LA. This is accomplished by having the pilot look over the control stick and off the right shoulder to align the RASCAL aircraft with the expansion strips (See Figure 9). This procedure will also be used to verify the laser tracker accuracy as well as the accuracy of the DGPS receiver.

SURVEY CALCULATIONS

The difference in body coordinates of each of the aircraft components with respect to survey point LA is multiplied together with the transformation matrix and then added to the RCS coordinates of survey point LA to yield the aircraft components in RCS coordinates.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{RCS} = \begin{bmatrix} 2.528 \\ 220.056 \\ 0.762 \end{bmatrix}_{RCS} + \begin{bmatrix} \cos(4.505°) & \sin(4.505°) & 0 \\ -\sin(4.505°) & \cos(4.505°) & 0 \\ 0 & 0 & 1 \end{bmatrix}_b^{RCS} * \begin{bmatrix} \Delta STA \\ \Delta BL \\ \Delta WL \end{bmatrix}_b$$

Once the components are in the RCS, a transformation into the vehicle-carried coordinate system (the origin located at the survey point AP, the x axis running in the direction of True North, the y axis being 90° to the East and the z axis oriented down to the center of the earth) is required in order to apply the latitude and longitude correction factors.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_v = \begin{bmatrix} \cos(10.099°) & -\sin(10.099°) & 0 \\ \sin(10.099°) & \cos(10.099°) & 0 \\ 0 & 0 & 1 \end{bmatrix}_{RCS}^{v} * \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{RCS}$$

In the vicinity of survey point LA, the latitude correction factor is 111180.79872 m/deg and the longitude correction factor is 88528.5504 m/deg. Since the survey point AP is the origin of the vehicle-carried coordinate system and the latitude and longitude are precisely known, the component latitude and longitude are obtained as follows:

$$\text{Latitude} = AP_{LAT} - X_v / 111180.79872 \text{ m/deg}$$
$$\text{Longitude} = AP_{LON} - Y_v / 88528.5504 \text{ m/deg}$$

In order to obtain the latitude and longitude of the aim point on Runway 12, the x, y and z components (measured from the TTR/Laser to the aim point with respect to the Runway 12 coordinate system (the origin located at the aim point, the x axis running in the direction of and parallel to Runway 12, the y axis being 90° to the East and the z axis oriented down to the center of the earth)) of the aim point are transformed into the vehicle-carried coordinate system, which is required prior to applying the latitude and longitude correction factors.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_v = \begin{bmatrix} \cos(141.255°) & -\sin(141.255°) & 0 \\ \sin(141.255°) & \cos(141.255°) & 0 \\ 0 & 0 & 1 \end{bmatrix}_{12RCS}^{v} * \begin{bmatrix} -229.545 \\ 1111.636 \\ -3.048 \end{bmatrix}_{12RCS}$$

Since the latitude and longitude of the TTR/Laser are precisely known, the Runway 12 aim point latitude and longitude are obtained using the same latitude and longitude correction factors from above.

$$\text{Latitude} = TTR/LASER_{LAT} - X_v / 111180.79872 \text{ m/deg}$$
$$\text{Longitude} = TTR/LASER_{LON} + Y_v / 88528.5504 \text{ m/deg}$$

```
»%a, Angle between Xramp and Xrcs (rad)
»a=2*pi*4.505/360;
»%LArcs, Coordinates of survey point LA in the RCS (m)
»LArcs=[2.528;220.056;.762];
»%Cramprcs, Transformation matrix from the ramp coordinate system to the RCS
»Cramprcs=[cos(a) sin(a) 0;-sin(a) cos(a) 0;0 0 1];
»%GPSb, Position of the GPS antenna with respect to survey point LA in the body
»%coordinate system (m)
»GPSb=[-13.5128;-.6096;-3.81];
»%CGb, Position of the CG with respect to survey point LA in the body
»%coordinate system (m)
»CGb=[-3.3147;-.6096;-1.89865];
»%INSb, Position of the INS with respect to survey point LA in the body coordinate
»%system (m)
»INSb=[-1.77165;.2032;-.7239];
»%RRRb, Position of the Right Retroreflector with respect to survey point LA in the
»%body coordinate system (m)
»RRRb=[-.5588;.8128;-.5715];
»%H, Angle between True North and Xrcs (rad)
»H=2*pi*10.099/360;
»%Crcsv, Transformation matrix from the RCS to the vehicle-carried coordinate system
»Crcsv=[cos(H) -sin(H) 0;sin(H) cos(H) 0;0 0 1];
»%APlat, Latitude of the Aim Point (deg)
»APlat=37.4133536;
»%APlon, Longitude of the Aim Point (deg)
»APlon=121.1082725;
»%dLAT, Latitude correction factor (m/deg)
»dLAT=101.324*.3048*3600;
»%dLON, Longitude correction factor (m/deg)
»dLON=80.68*.3048*3600;
»%GPSrcs, Position of the GPS antenna in the RCS (m)
»GPSrcs=LArcs+Cramprcs*GPSb

GPSrcs =

  -10.9909
  220.5097
   -3.0480

»%CGrcs, Position of the CG in the RCS (m)
»CGrcs=LArcs+Cramprcs*CGb

CGrcs =

   -0.8243
  219.7086
   -1.1366

»%INSrcs, Position of the INS in the RCS (m)
»INSrcs=LArcs+Cramprcs*INSb

INSrcs =

    0.7778
  220.3977
    0.0381

»%RRRrcs, Position of the Right Retroreflector in the RCS (m)
```

```
»RRRrcs=LArcs+Cramprcs*RRRb

RRRrcs =

   2.0348
 220.9102
   0.1905

»%GPSv, Position of the GPS antenna in the vehicle-carried coordinate system (m)
»GPSv=Crcsv*GPSrcs;
»%CGv, Position of the CG in the vehicle-carried coordinate system (m)
»CGv=Crcsv*CGrcs;
»%INSv, Position of the INS in the vehicle-carried coordinate system (m)
»INSv=Crcsv*INSrcs;
»%RRRv, Position of the Right Retroreflector in the vehicle-carried coordinate system (m)
»RRRv=Crcsv*RRRrcs;
»%LAv, Position of the survey point LA in the vehicle-carried coordinate system (m)
»LAv=Crcsv*LArcs;
»%GPSlat, Latitude of the GPS antenna (deg)
»GPSlat=APlat-(abs(GPSv(1,1)/dLAT))

GPSlat =

  37.41290849696332

»%GPSlon, Longitude of the GPS antenna (deg)
»GPSlon=APlon-(abs(GPSv(2,1)/dLON))

GPSlon =

 121.1058420311716

»%CGlat, Latitude of the CG (deg)
»CGlat=APlat-(abs(CGv(1,1)/dLAT))

CGlat =

  37.41299978550254

»%CGlon, Longitude of the CG (deg)
»CGlon=APlon-(abs(CGv(2,1)/dLON))

CGlon =

 121.1058308020561

»%INSlat, Latitude of the INS (deg)
»INSlat=APlat-(abs(INSv(1,1)/dLAT))

INSlat =

  37.41301288552292

»%INSlon, Longitude of the INS (deg)
»INSlon=APlon-(abs(INSv(2,1)/dLON))

INSlon =
```

```
 121.1058199655112

»%RRRlat, Latitude of the Right Retroreflector (deg)
»RRRlat=APlat-(abs(RRRv(1,1)/dLAT))

RRRlat =

 37.41302320790727

»%RRRlon, Longitude of the Right Retroreflector (deg)
»RRRlon=APlon-(abs(RRRv(2,1)/dLON))

RRRlon =

   121.1058117769228

»%H12, Angle between True North and X12rcs (rad)
»H12=2*pi*141.255/360;
»%AP12rcs, Coordinates of Runway 12 aim point wrt the TTR/LASER in the12 RCS (m)
»AP12rcs=[-229.54488;1111.6361;-3.048];
»%C12rcsv, Transformation matrix from the 12 RCS to the vehicle-carried coordinate system
»C12rcsv=[cos(H12) -sin(H12) 0;sin(H12) cos(H12) 0;0 0 1];
»%TTR/LASERlat, Latitude of the TTR/LASER (deg)
»TTR/LASERlat=37.41745278;
»%TTR/LASERlon, Longitude of the TTR/LASER (deg)
»TTR/LASERlon=121.10331389;
»%AP12v, Position of the Runway 12 aim point in the vehicle-carried coordinate system (m)
»AP12v=C12rcsv*AP12rcs;
»%AP12lat, Latitude of the Runway 12 aim point (deg)
»AP12lat=TTR/LASERlat-(abs(AP12v(1,1)/dLAT))

AP12lat =

  37.41280546276788

»%AP12lon, Longitude of the Runway 12 aim point (deg)
»AP12lon=TTR/LASERlon+(abs(AP12v(2,1)/dLON))

AP12lon =

 121.1147302112065
```

RASCAL DGPS FLIGHT TEST CHECKLIST

BEFORE ENTERING AIRCRAFT

(ACCOMPLISH PRIOR TO ARRIVING AT AIRCRAFT)

1 Install 4 AA batteries in Operator Terminal
2 Get pre-formatted Syquest cartridge

BEFORE ENGINE START

(ACCOMPLISH PRIOR TO APU START)

1 Install pre-formatted cartridge into bottom drive
2 Confirm flight disk is in top drive
3 Connect RS232 cable to Operator Terminal and confirm cable is connected to computer (J5)
4 Primary IRIG - B ON/OFF Switch - ON (Inboard)
5 Transceiver Power Supply ON/OFF Switch - ON
6 Project Power Panel Setup

On front of panel

a OPERATOR PROJECT POWER Switch - OFF
b INS Circuit Breaker - IN
c PC COMP Circuit Breaker - IN
d ± 15 SIG/C Circuit Breaker - IN
e ± 10 SIG/C Circuit Breaker - IN
f BATT CHG Circuit Breaker - IN
g ± 15 INST Circuit Breaker - IN
h + 5 INST Curcuit Breaker - IN
i 60 Hz Switch - ON
j 115 v 60 Hz Circuit Breaker - OUT
k VIDEO Circuit Breaker - OUT
l 60 Hz OUTLET Circuit Breaker - OUT
m GPS XCVR Circuit Breaker - IN
n PROJ INT Circuit Breaker - IN
o IRIG - B Circuit Breaker - IN
p TRANSPONDER Circuit Breaker - IN
q ADC Circuit Breaker - IN

r VIDEO Circuit Breaker - OUT

s GPS RCVR Circuit Breaker - IN

t LEAKY ILS Circuit Breaker - IN

u INS BATTERY Switch - ON

v INS BATT Circuit Breaker - IN

On side of panel

a 115 VAC 400 Hz 3 PHASE Circuit Breaker - IN

b 400/60Hz CONVERTER SUPPLY Switch - ON

c 28 VDC Circuit Breaker - IN

d 28 VDC INS BATT Circuit Breaker - IN

7 Secondary IRIG - B ON/OFF Switch - OFF (DOWN)

(ACCOMPLISH AFTER APU HAS BEEN STARTED, AND PILOTS HAVE SELECTED PILOTS PROJECT POWER SWITCH - ON)

8 OPERATOR TERMINAL Switch - ON (Located on side of terminal)

9 OPERATOR PROJECT POWER Switch - ON (GREEN LIGHT - ON)

10 Confirm hard disk spinup (Blinking red followed by solid green light)

11 When terminal stops scrolling, press <CR>

12 INS - ALIGN

a When prompt (>) appears, type ***NAV2A*** and press <CR>

b Press <CR> to finish scrolling

c Enter the number of the selected alignment site and press <CR>

d When the prompt for fgnd config appears, press <CR>

e Type ***A*** for alignment when computer prompts and press <CR>

f After the INS is aligned (approximately 8 min.), press <CR> twice

g When the Data Run menu appears, type ***Q*** to quit and press <CR>

h Wait for prompt (>)

13 OPERATORS PROJECT POWER Switch - OFF

14 Inform pilots that:

Alignment checklist complete

INS in Nav Mode

Computer Off

AFTER ENGINE START

(ACCOMPLISH AFTER ROTOR RPM HAS BEEN SET TO 100 % AND PILOTS HAVE SELECTED PILOTS PROJECT POWER SWITCH - ON)

DGPS SETUP

1 ON/OFF Switch - ON
2 Go to MODE CONTROL Screen - [4] [e]
3 Go to PULSE GENERATION Subscreen - [e]
    Enter the following (If required):
        PERIOD - [0][1][0][0]
        OFFSET - [+][0][0][0][0][0][0][0] [e]
4 ON/OFF Switch - Cycle OFF then ON ***(NOT REQUIRED IF NO CHANGES WERE MADE IN PREVIOUS STEP)***
5 Go to SYSTEM CONTROL Screen - [8] [e]
    Enter [7][3][7] [e]
6 Go to MODE CONTROL Screen - [4] [e]
    Enter the following:
        REC INT - [0][0][0]
        MIN SV - [3]
        ELEV MASK - [1][0]
        RNGR - [0] [e][e]
7 Go to POSITION Subscreen - [e]
    Enter the following:
        POSITION MODE - [0]
        PDOP MASK - [9][9]
        ALTD FIX MODE - [0]
        HDOP MASK - [9][9]
        USE UNHLTHY SV - [1]
        VDOP MASK - [9][9] [e][e]
8 Go to DIFFERENTIAL Subscreen - [e]
    Enter the following:
        FORMAT - RTCM
            Options - [1]
                Enter the following:
                    MODE - REMOTE

TYPE6 - OFF

SEQ - [1]

MAXAGE - [1][2][0]

QAFREQ - [1][0][0] [e]

OUTPUT - ON PORT A

Options - [1]

Enter the following:

NMEA - OFF

Options - [1]

Enter the following:

GSN - ON

SEND INTERVAL - [0][0][0] [e]

BAUD RATE - 9600

REAL TIME - OFF

Options - [1]

Enter the following:

MBEN - OFF

FORMAT - BINARY

PBEN - ON

SNAV - OFF

SALM - OFF [e]

VTS - OFF [e]

OUTPUT - ON PORT B [e][e]

9 Go to DATUM SELECT Subscreen - [e]

Enter DATUM - WGS84 [e][e]

10 Go to MODEM SETUP Subscreen - [e]

Enter PORT - A [e]

11 Go to WAYPOINT CONTROL Screen - [6] [e]

12 Go to SET DISPLAY Function

Options - [0]

Enter DISPLAY UPDATE MODE - MANUAL [e]

13 Go to EDIT WAYPOINT Function - [e]

Enter the following:

CROWS LANDING RWY 35 AIM POINT

Waypoint # - [0][1]

Waypoint - ^^^^[3][5]^[0]^[6]

Latitude - [3][7] [2][4] [8][0][1][2] [6]

Longitude - [1][2][1] [0][6] [4][9][6][4] [2] [e]

CROWS LANDING RWY 35 IAF

Waypoint # - [0][2]

Waypoint - ^^^^[3][5]^[8][0][5]

Latitude - [3][7] [1][9] [8][9][4][4] [6]

Longitude - [1][2][1] [0][7] [5][9][3][9] [2] [e]

CROWS LANDING RWY 12 AIM POINT

Waypoint # - [0][3]

Waypoint - ^^^^[1][2]^[0]^[6]

Latitude - [3][7] [2][4] [7][6][8][3] [6]

Longitude - [1][2][1] [0][6] [8][8][3][8] [2] [e]

CROWS LANDING RWY 12 IAF

Waypoint # - [0][4]

Waypoint - ^^^^[1][2]^[8][0][5]

Latitude - [3][7] [2][8] [6][5][5][6] [6]

Longitude - [1][2][1] [1][0] [8][0][1][2] [2] [e]

MOFFETT RWY 14L AIM POINT

Waypoint # - [0][5]

Waypoint - ^^^^[1][4]^^[2]

Latitude - [3][7] [2][5] [6][1][0][0] [6]

Longitude - [1][2][2] [0][3] [1][4][5][0] [2] [e]

MOFFETT RWY 14R AIM POINT

Waypoint # - [0][6]

Waypoint - ^^^^[1][4]^^[8]

Latitude - [3][7] [2][5] [3][9][5][0] [6]

Longitude - [1][2][2] [0][3] [1][7][5][0] [2] [e]

MOFFETT RWY 32L AIM POINT

Waypoint # - [0][7]

Waypoint - ^^^^[3][2]^^[2]

Latitude - [3][7] [2][4] [3][8][0][0] [6]

Longitude - [1][2][2] [0][2] [7][0][0][0] [2] [e]

MOFFETT RWY 32R AIM POINT

Waypoint # - [0][8]

Waypoint - ^^^^[3][2]^^[8]

Latitude - [3][7] [2][4] [4][4][0][0] [6]

Longitude - [1][2][2] [0][2] [5][8][0][0] [2] [e][e]

14 Go to EDIT ROUTE Function - [e]

Enter ROUTE - [0][1] [e][e]

15 Go to WAYPT SWITCH Function

Options - [0]

Enter ADVANCEMENT CRITERIA - MANUAL [e]

16 Go to UNIT SELECTION Function - [e]

Enter UNITS OF - KNOTS [e]

17 Go to NAVIGATION INFORMATION Screen - [2]

TRANSCEIVER SETUP

1 ON/OFF VOLUME CONTROL Switch - Rotate CW to desired volume level

2 SQUELCH CONTROL Switch - Rotate CW until noise disappears

3 CHANNEL SELECT Switch - 1

4 AUX Switch - OUT

5 MONITOR Switch - OUT

DAC SETUP

1 OPERATORS PROJECT POWER Switch - ON (GREEN LIGHT - ON)

2 After computer has initialized, press <CR>

a When prompt (>) appears, type ***NAV2A*** and press <CR>

b Press <CR> to finish scrolling

c Enter the number of the selected alignment site and press <CR>

d When the prompt for fgnd config appears, press <CR>

e Type ***N*** for navigate when computer prompts and press <CR>

f When the prompt for branch code and flight # appears, type ***FSN00X*** and press <CR>

g Enter up to two lines of comments (Time, Date, Pilots Names, Engineers Names etc.) and press <CR>

DATA ACQUISITION

> ***NOTE***
>
> ***BEFORE FIRST RUN***
>
> *Ensure localizer frequency is set to 108.1 MHz*
>
> *Ensure correct runway is entered into the DAC*
>
> ***BEFORE EACH RUN***
>
> *IRIG - B ON/OFF Switch - ON (UP), confirm synchronization, then OFF (DOWN)*
>
> *Ensure correct glideslope is entered into the DAC*

1 While in the Data Run menu:
  - a Type ***S*** to start data collection and press <CR>
  - b Type ***S*** to stop data collection and press <CR>
    - i Type ***F*** to file the collected data and press <CR> ***(IN STRAIGHT AND LEVEL FLIGHT ONLY)***
    - ii When the prompt for filename appears, type ***Y*** and press <CR>
    - iii Enter up to six lines of comments (Runway, Glideslope, Approach Number, etc.) and press <CR>
    - iv Type ***R*** to setup for another run or type ***Q*** to Quit (After last run of the flight) and press <CR>

BEFORE SHUTDOWN

(ACCOMPLISH PRIOR TO ENGINE SHUTDOWN)

1 Type ***Q*** to quit program after saving last data run

2 At prompt (>) , OPERATOR PROJECT POWER Switch - OFF

3 OPERATOR TERMINAL Switch - OFF

4 INS BATTERY Switch - OFF

POST FLIGHT

(ACCOMPLISH PRIOR TO LEAVING AIRCRAFT)

1 Disconnect Operator Terminal

2 Extract cartridge from bottom drive

3 Take Operator Terminal and cartridge to post-processing computer

GROUND STATION CHECKLIST

DGPS SETUP

1 Ensure antenna is connected via the Antenna Port

2 Ensure transceiver is connected via Serial Port A

3 Ensure power supply is turned on and connected via the Power In Port

4 ON/OFF Switch - ON

5 Go to SYSTEM CONTROL Screen - [8] [e]

  Enter [7][3][7] [e]

6 Go to MODE CONTROL Screen - [4] [e]

  Enter the following:

    POS - [3][7] [2][5] [0][6][9][1] [6] [1][2][1] [0][6] [2][0][2][4] [2] [+][0][0][0][1][6][3]

    REC INT - [0][0][0]

    MIN SV - [3]

    ELEV MASK - [1][0]

    RNGR - [0] [e][e]

7 Go to POSITION Subscreen - [e]

  Enter the following:

    POSITION MODE - [2]

    PDOP MASK - [9][9]

    ALTD FIX MODE - [1]

    HDOP MASK - [9][9]

    USE UNHLTHY SV - [1]

    VDOP MASK - [9][9] [e][e]

8 Go to DIFFERENTIAL Subscreen - [e]

  Enter the following:

    FORMAT - RTCM

      Options - [1]

        Enter the following:

          MODE - BASE

          SPEED - 200

          STID - [0][0][0][0]

          STHE - [0]

          TYPE6 - OFF

SEQ - [1]

FREQ - [0][1] [0][0] [0][0] [0][0] [e]

OUTPUT - ON PORT A [e]

Options - [1]

Enter the following:

NMEA - OFF

BAUD RATE - 9600

REAL TIME - OFF

VTS - OFF [e][e][e][e]

9 Go to DATUM SELECT Subscreen - [e]

Enter DATUM - WGS84 [e][e]

10 Go to MODEM SETUP Subscreen - [e]

Enter PORT - A [e]

11 Go to DIFFERENTIAL INFORMATION Screen - [5]

TRANSCEIVER SETUP

1 Ensure antenna is connected

2 Ensure DGPS Receiver is connected

3 Ensure power supply is turned on and connected

4 ON/OFF VOLUME CONTROL Switch - Rotate CW to desired volume level

5 SQUELCH CONTROL Switch - Rotate CW until noise disappears

6 CHANNEL SELECT Switch - 1

7 AUX Switch - OUT

8 MONITOR Switch - OUT

WARNING

DO NOT APPROACH WITHIN TWO FEET OF THE ANTENNA
WHILE THE TRANSCEIVER IS OPERATING

LINEUP CARD

NOTE: ALL ITEMS DENOTED BY X WILL BE FILLED IN PRIOR TO FLIGHT

AIRCRAFT	NASA 750	BRIEF	XXXX /______
FLIGHT	92 - XX	PRE-FLIGHT	XXXX /______
DATE	XX Dec 1992	START APU	XXXX /______
PILOTS	XXXX, XXXX	TAXI	XXXX /______
ENGINEERS	XXXX, XXXX	NUQ TAKE-OFF	XXXX /______
GPS WINDOW	XXXX - XXXX	NRC LANDING	XXXX /______

1 Prior to take-off, accomplish all items on the RASCAL DGPS Flight Test Checklist up to and including DAC Setup of the After Engine Start section.

2 Upon arrival at Crows Landing NAS, accomplish the following:

   a Taxi to Survey Point LA

   b Verify Ground Station Checklist is complete

   c Check laser truth coordinates and GPS position

X - 2.0348 m	__________	Latitude	- 37° 24.7745 '	____________
Y - 220.9102 m	__________	Longitude	- 121° 06.3505 '	____________
Z - 0.1905 m	__________	Altitude	- 50.56 feet	____________

3 Depart Crows Landing NAS for the IAF XXXX /______

4 Run the Data Acquisition Section of the RASCAL DGPS Flight Test Checklist

   a Start data acquisition abeam the IAF at XXXX feet MSL

   b Intercept the X° glideslope at the FAF at XX KIAS

   c Stop data acquisition upon the initiation of the go-around

   d Store the data file on the downwind portion of the flight test pattern

5 Repeat step 4 as required

6 Land at Crows Landing NAS to re-fuel XXXX /______

7 Re-accomplish steps 1 through 5 if a second test flight is to be flown, otherwise, depart Crows Landing NAS for Moffett Field XXXX /______

8 Land at Moffett Field XXXX /______

9 Post-Flight Debrief XXXX /______

APPROACHES

Approach Number - 1
Glideslope - X°
Comments -

Approach Number - 2
Glideslope - X°
Comments -

Approach Number - 3
Glideslope - X°
Comments -

Approach Number - 4
Glideslope - X°
Comments -

Approach Number - 5
Glideslope - X°
Comments -

Approach Number - 6
Glideslope - X°
Comments -

Approach Number - 7
Glideslope - X°
Comments -

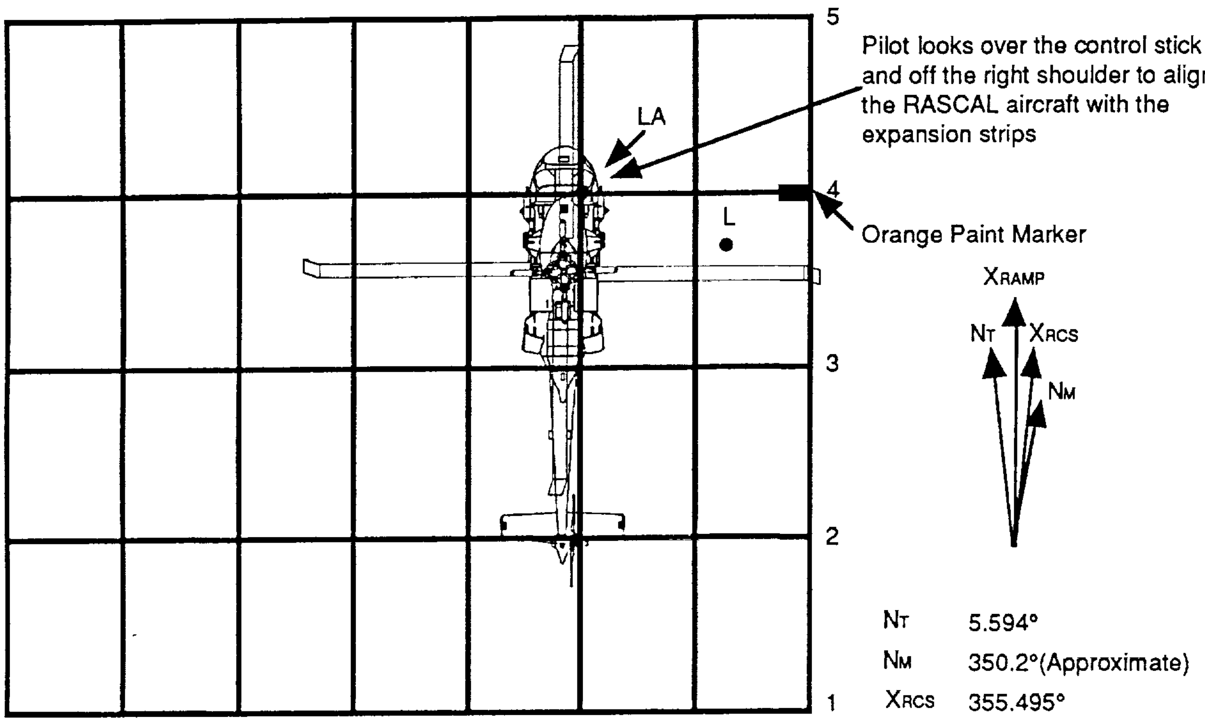
Approach Number - 8
Glideslope - X°
Comments -

Approach Number - 9
Glideslope - X°
Comments -

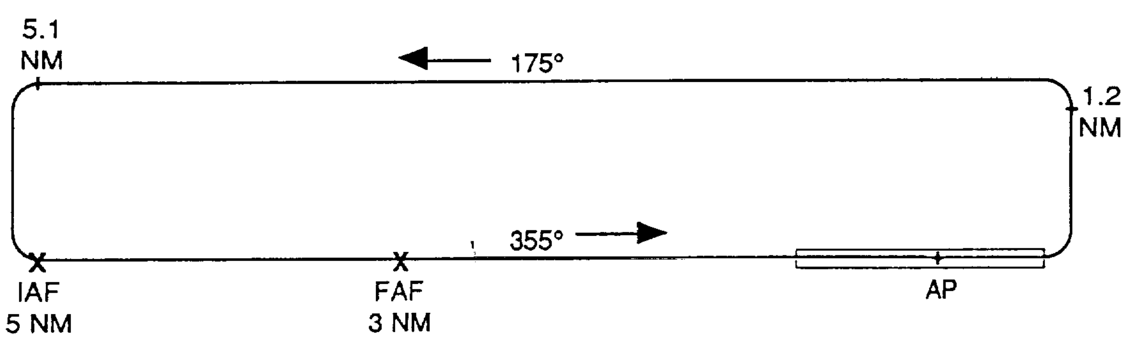
Approach Number - 10
Glideslope - X°
Comments -

Approach Number - 11
Glideslope - X°
Comments -

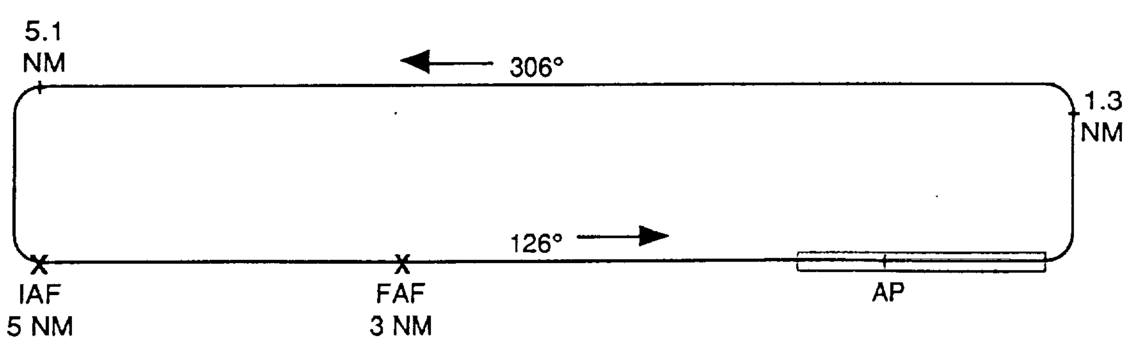
Approach Number - 12
Glideslope - X°
Comments -



RASCAL Location At Survey Point LA



RASCAL DGPS Flight Test Traffic Pattern For Runway 35



RASCAL DGPS Flight Test Traffic Pattern For Runway 12