technical note technical note

Differential Global Positioning System (DGPS) Test Plan

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16. Abstract

The Federal Aviation Administration (FAA) Technical Center will conduct Differential Global Positioning System (GPS) tests to address the demands for high levels of accuracy in the terminal area. The tests employed a Convair 580 (CV-580) and two Motorola Eagle Mini Rangers.

With the advent of the maturing GPS constellation, the FAA is assuming a more intensive stance in addressing the many questions/problems associated with GPS. These Differential GPS tests investigate the obtainable accuracy under static and dynamic conditions. The static tests will employ surveyed points as a base line. The dynamic tests will incorporate terminal area flightpaths and non-precision approaches using a laser tracker as a base line. The Differential tests will be conducted in an effort to build an FAA Differential GPS data base to aid in addressing GPS questions/problems.

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EXECUTIVE SUMMARY

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With the advent of the maturing GPS constellation, the FAA is assuming a more intensive stance in addressing the many questions/problems associated with GPS. These Differential GPS tests investigate the obtainable accuracy under static and dynamic conditions. The static tests will employ surveyed points as a base line. The dynamic tests will incorporate terminal area flightpaths and non-precision approaches using a laser tracker as a base line. The Differential tests will be conducted in an effort to build an FAA Differential GPS data base to aid in addressing GPS questions/problems.

1. INTRODUCTION.

1.1 OBJECTIVE.

The primary objective of this test plan is to demonstrate the achievable accuracy of the Global Positioning System (GPS) in the differential mode (DGPS). A comparison between GPS and DGPS will be made in static tests and nonprecision approaches. These tests will supplement the Federal Aviation Administration (FAA) GPS data base which will aid in answering present and future National Airspace System (NAS) questions regarding CPS standards and requirements such as a reduction in aircraft separation and GPS/DGPS supported nonprecision approaches.

1.2 BACKGROUND.

The U.S. Air Force and the U.S. Navy have had satellite programs that date back to the early 1960's. In April 1973 the U.S. Deputy Secretary of Defense issued a memorandum directing the U.S. Air Force to consolidate the existing satellite programs into a global, 24-hour, three-dimensional, all-weather navigation system. This system is named: Navigation by Satellite Timing and Ranging Global Positioning System (NAVSTAR GPS), better known as GPS.

There are presently five operational Block I and five operational Block II satellites in orbit. The present orbit configuration is such that full GPS service (four or more satellites accessible to the user) is available approximately 10 hours a day. Although this 10-hour window is limited, it is used extensively for debugging and early evaluation of the system. Block I satellites will be phased out and replaced by a constellation of Block II satellites. The present Block II schedule provides for a satellite launch every 2-3 months--this schedule will configure the full constellation by 1992.

GPS is partitioned into three primary segments: space, control, and user. The space segment consists of a planned constellation of 21 operational and 3 active spare Block II satellites. The spares are provisioned to secure the probability of having 21 or more operational satellites at least 98 percent of the time. The probability of having 24 operational satellites is 0.70. The GPS signal is transmitted using spread spectrum techniques on two frequencies: L1 at 1575.42 megahertz (MHz) and L2 at 1227.60 MHz. Two types of signal spreading functions are utilized: Course/ Acquisition (C/A) code and Precise (P) code on the L1 carrier and P-code only on the L2 carrier. The C/A code is available to all users, but the P-code is only available to U.S. military, North Atlantic Treaty Organization (NATO) military, and Department of Defense (DOD) approved civilians. There has been, however, some unofficial talk about making the P-code available to all users. All FAA GPS tests discussed in this paper will employ C/A code only. The control segment incorporates a network of five monitoring stations and one master control station. The Master Control Station (MCS) is collocated with a monitor station at Falcon Air Force Station in Colorado Springs, CO, and is linked with the monitor stations via the Defense Satellite Communication System. GPS has the versatility to meet the needs of many users such as a navigation aid for space, air, land, and sea; attitude reference; time transfer; precise positioning; surveying; etc. The GPS user is passive, therefore, CPS can facilitate an unlimited number of users. The GPS user segment usuallv consists of an L-band receiver, an L-band antenna, and a control-display unit.

For most users, GPS navigation accuracy is sufficient to meet their needs, but there are some users who demand even higher accuracies. Such improved accuracies can be obtained from a technique called DGPS. DGPS is implemented by placing a GPS receiver at a known location and configuring it to determine pseudorange errors. These errors are then broadcast to local users as corrections to facilitate a greatly improved navigation solution. The differential method can reduce or eliminate Selective Availability (S/A), atmospheric delay, ephemeris, and satellite clock errors. With the advent of S/A greatly degrading civilian accuracy, this format would be a true benefit, especially to nonprecision approaches.

The FAA has been testing GPS since 1979 to define and determine the potential role of GPS as a civil navigation system. The FAA has examined masking angle criteria, rotor modulation effects, multichannel systems, and multipath characteristics to aid in the defining of Minimum Operational Performance Standards (MOPS) for GPS receivers. Although GPS's overall performance outshines existing navigation systems, the advent of S/A and the continuing increase of air traffic demands the best accuracy available. DGPS has the potential to negate S/A and support nonprecision approaches, via its highly accurate positioning.

1.3 RELATED DOCUMENTATION.

1. Introduction to Navstar GPS, NAVSTAR GPS Joint Program Office, June 1987.

2. Kramer, B. T., Kalafus, R. M., Loomies, P. V. W., and Reynolds, J. O., Proceedings of ION GPS-89, "The Effect of Selective Availability on Differential GPS Corrections," September 1989.

3. Mini-Ranger GPS Receiver Users Manual, Motorola Inc. Document No. 68-P29027U, November 86.

4. Conner, Jerome T., Global Positioning System GPS Performance Parameters Test Plan, FAA Technical Center, DOT/FAA/CT-TN83/50, June 83.

5. Persello, Frank, Integrity Monitoring Methods for the Global Positioning System, FAA Technical Center, DOT/FAA/CT-ACD330/13, September 1990.

6. Precision Automated Tracking System, Operation and Maintenance Manual, GTE, May 1976.

2. EQUIPMENT.

2.1 AIRCRAFT.

The aircraft to be employed in these tests is a Convair 580, tail number, N-91. This aircraft was primarily chosen for two reasons: its availability and the engineering that already existed for a GPS antenna, preamp, and a secondary very high frequency (VHF) link. The VHF link is necessary to facilitate a DGPS update from the ground master station. The DCPS update is transmitted at 165.64 MHz, which is just above the VHF band. This frequency is at the 3 dB roll off point on the aircrafts' VHF antenna. The high power Mitrek Radio (110 watts transmitting power) has proven to compensate for the reduced antenna response.

APPENDIX A

GPS RECEIVER SPECIFICATIONS

ACN-371: Provide aircraft engineering for antenna and airborne rack installation.

ACN-302: Provide laser tracker manpower and data.

ACD-330: Provide personnel to conduct flight test, write the test plan, perform data analysis, design and build test rack and data collection system, and write the final reports.

JPO/YUMA: Provide GPS ground and space segment status.

2.2 GPS SET.

The GPS set is comprised of a Motorola Eagle Mini Ranger receiver, antenna, preamp, and a Tandy TRS-80 lap top computer used as a control display unit (CDU). The GPS antenna is right-hand circularly polarized, omnidirectional in azimuth, and hemispherical in elevation. The GPS set can assume one of two modes of operation autonomous or differential. The autonomous mode is the standard GPS configuration which obtains position information solely from the satellites. The differential mode of operation is described in section 1.2. The Eagle Receiver specifications and diagrams are provided in appendix A.

2.3 DATA COLLECTION.

The tests will incorporate two sources of data: the CPS data from the Eagle Receiver, and the base line or truth data from the laser tracker facility. The GPS data will be collected by tapping into the transmit and signal ground lines from the Eagle Receivers' control port. A line tap or "T" had to be employed due to the control port being occupied by the CDU cable. The two tap lines are connected to an RS232 port on a Compaq SLT/286 lap top computer. The Compaq will utilize Smart Term 240 communication software to collect the data. The Eagle Receiver data parameters and format that will be collected can be seen in appendix B. The base line data is collected on a 9-track tape and converted to VAX binary in the Clark 1866 reference elipsoid X,Y,Z coordinates and local time tags.

2.4 RADAR FACILITY.

The General Telephone and Electronic (GTE) Precision Automated Tracking System, (PATS) uses an infrared laser beam to illuminate an aircraft mounted retroflector and automatically track cooperative targets. System accuracy is 20 arc seconds in azimuth and elevation angle. Range accuracy is 1 foot for target ranges to 5 nautical miles (nmi), 2 feet for target ranges from 5 to 10 nmi, and 5 feet for target ranges at 25 nmi. Due to visibility conditions, range is limited to between 7 and 10 nmi during normal operations at the FAA Technical Center.

3. TEST PROCEDURES.

3.1 BENCH TESTS.

The bench tests will begin by configuring the Motorola receivers in the autonomous mode on the bench and then monitoring the performance. If performance is satisfactory, the Eagle Receiver will then be configured in the Differential mode. This will employ a Differential Master Station only. The reason for this configuration is to observe the transmit signal. The signal strength, duty cycle, and Voltage Standing Wave Ratio (VSWR) measured to the antenna will be verified. The antenna for the differential correction link will be adjusted to minimize signal reflections (VSWR).

3.2 GROUND TESTS.

The Motorola receivers will be installed in the FAA Test Van in an autonomous configuration. At least two to five existing FAA survey points will then be used as a truth source. For comparison and base line purposes, the Test Van will park directly above a survey point and approximately 100 data records per point will be obtained before moving to the next point. Collecting data from the set of two to five survey points will be referred to as a run. Five runs a day for two to three days will be conducted to collect enough data for a complete statistical analysis and to provide a thorough check of the equipment. The differential mode will then be employed with the master station in the hanger roof top meteorological booth and the slave station in the Test Van. A minimum of 1 mile between the master station and slave station is desired. Five runs a day for two to three days will be conducted in a similar manner as described for the autonomous mode.

3.3 FLIGHT TESTS.

A GPS/DGPS equipment rack will be constructed to meet aircraft installation requirements. The aircraft rack will consist of the Motorola Eagle Receiver and associated 18 volts of direct current (Vdc) power supply, a TRS 80 lap top computer, a Compaq SLT/286 lap top computer, a Mitrek radio and associated power supply, a Mitrek speaker, control head, and modem. The rack will require from the VHF antenna, the GPS antenna, and 110 volts of alternating current inputs (Vac) at 60 hertz (Hz). The equipment rack will then be installed in N-91. Due to the anticipated high level of DGPS accuracy the laser tracker will be used as a base line. The flightpath will be limited to approximately 10 nmi from the laser tracker. This is due to the laser trackers' limited ability to track at a distance. The equipment will be initially installed in the autonomous mode, tested, then switched to the differential mode. The flightpath will be an ascending spiral centered at the tracker with a radius of approximately 7 nmi. The second phase of the flightpath will be nonprecision approaches. The final flight will attempt to determine the effective range of the master station transmission of pseudorange corrections. Accuracy and ability to maintain lock on the master station signal will be analyzed.

4. DATA ANALYSIS AND REDUCTION.

Final results of data statistical analysis will be presented as: mean error of latitude longitude and altitude; standard deviation of latitude, longitude, and altitude; circular error probability (CEP) spherical error probability (SEP); and 2 distance root mean squared (drms). The Motorola GPS and DGPS position error, as defined by the laser tracker, will be plotted as latitude, longitude, and altitude error. The results will become part of a data base being established to aid in the analysis of DGPS for terminal flight and nonprecision approaches.

5. AREAS OF RESPONSIBILITIES.

ASA-130: Provide funding and program management to ACD-330.

ACN-360: Provide aircraft pilots and scheduling support.

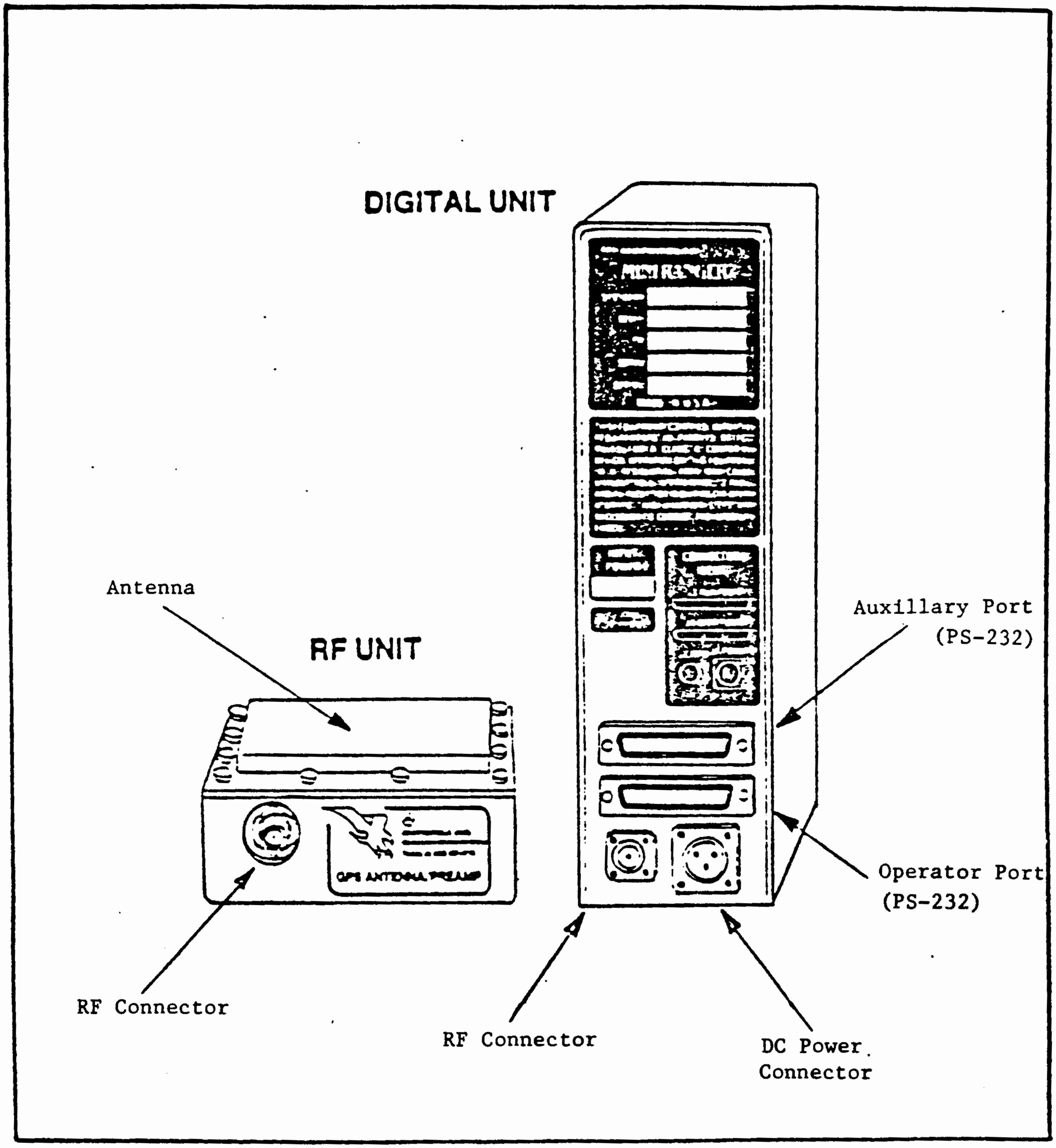

FIGURE A-1. EAGLE GPS RECEIVER

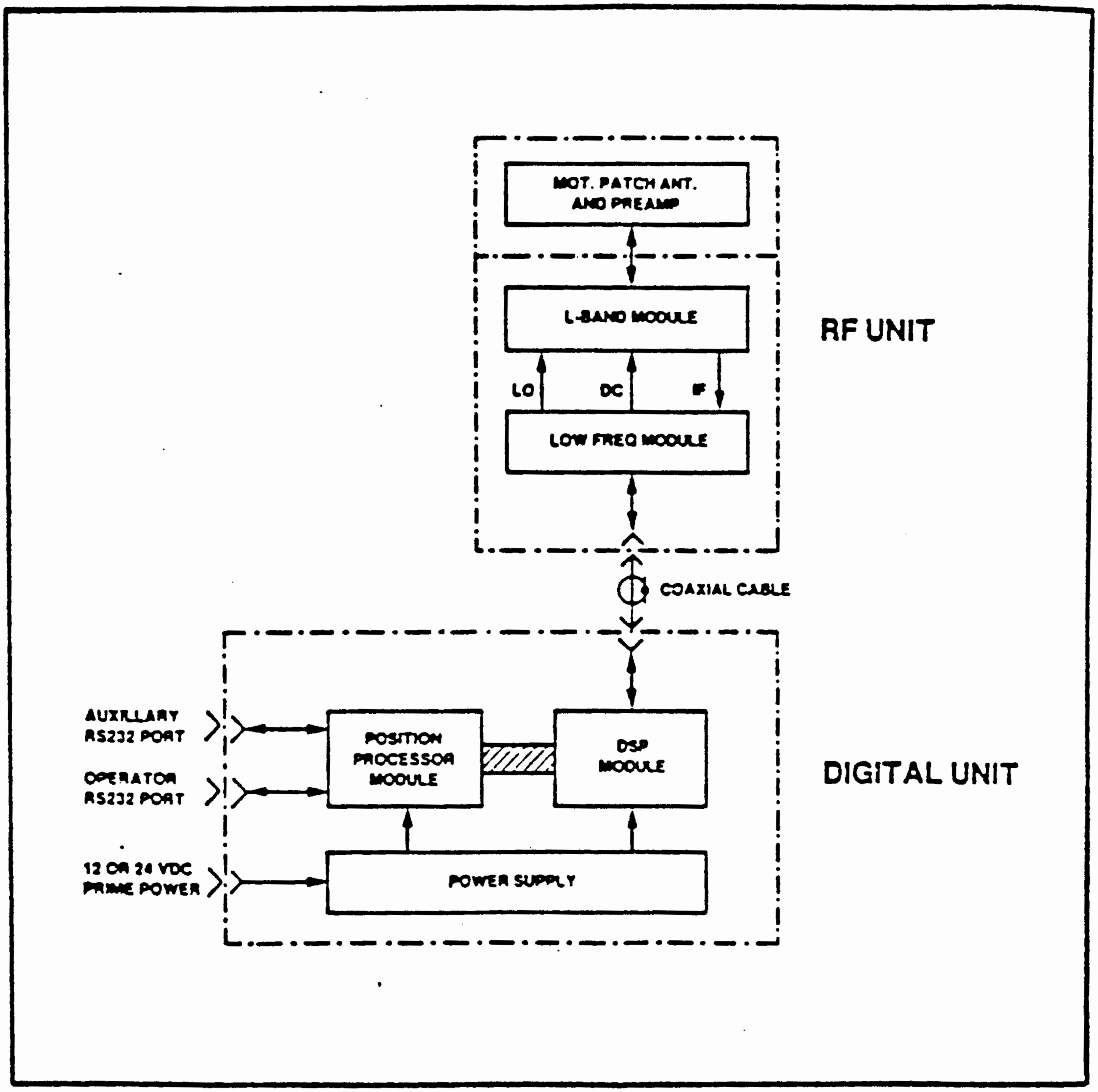

FIGURE A-2. EAGLE GPS RECEIVER BLOCK DIAGRAM

Eagle

GPS Receiver

MINI-RANGER

GPS RECEIVER SPECIFICATIONS

SYSTEM PERFORMANCE

Receiver Type	4-channel simultaneous, L1, C/A code with carrier tracking
Operating Modes	Autonomous/real-time differential
Solution Type 3 Dimensional 2 Dimensional (altitude hold)	8-state Kalman update With 4 SV's With 3 SV's
Accuracy Autonomous Real Time Differential	 Less than 25 meters SEP 2–5 meters SEP
Position/Velocity Update Rate	 1 second
Interrogation time to: First Fix (with almanac available)	 2 minutes nominal
Position Output Types	Geodetic (Latitude, Longitude, Height) Earth-Centered-Earth-Fixed (ECEF) Local XYZ (feet or meters) Universal Transverse Mercator (UTM) – All zones State Plane Coordinates (CONUS, Alaska and Hawaii)
Position computed utilizing alternate ellipsoids embedded in the receiver	WGS-84 datum WGS-72 Clarke 1866 (NAD27) Clarke 1880 Australian National Airy Bessel Everest Fischer 1960 Hough International South American 1969 Special (user entered)
Dynamic Maximums Velocity Acceleration	 600 knots max 1g max
Shock	15g, 11 msec, 1/2 sine wave
Vibration	1g, 50 to 500 Hz

GPS RECEIVER SPECIFICATIONS

ELECTRICAL PARAMETERS

Operating Voltage	10 to 17 volts dc standard 18 to 32 volts dc optional (no charge)
Operating Power	19 watts maximum (antenna/preamplifier unit powered from receiver)

PHYSICAL PARAMETERS

System Part Number	01-P28960U001
Size and Weight Receiver-Processor (P/N 01-P28923U001)	 7.7 X 2.3 X 12.4 inches H.W.D. (19.6 X 5.8 X 31.5 cm) 4.5 lbs (2.0 Kg)
Antenna/Preamplifier (P/N 01-P28924U001)	2.0 X 4.5 X 4.5 inches H.W.D. (5.1 X 11.4 X 11.4 cm) 2.5 lbs (1.14 Kg)
Antenna/Preamplifier Cable (P/N 30-P29030U050)	50 ft. standard (150 ft. maximum, optional)
Temperature Receiver Operating Storage Antenna/Preamplifier Operating Storage	 −20°C to +55°C −40°C to +100°C −40°C to +85°C −55°C to +100°C
Humidity	0 to 90% noncondensing

Specifications subject to change upon product improvement.

User achievable position, time, and velocity accuracies are dependent on G.P.S. system control and space segment integrity and assumes a G.D.O.P. of less than four.

FIGURE A-3. EAGLE SPECS

MOTOROLA INC.

Government Electronics Group

APPENDIX B

EAGLE DATA PARAMETERS AND FORMATS

HEADER	L4,	
TIME	hh_mm_ss,	
TOTAL REJECTS	rr,	
LATITUDE	_-dd_mm_ss.sss,	
LONGITUDE	-ddd_mm_ss.sss,	
NORTH or X	-ddddddd.dd,	(Coordinate type
EAST or Y	-ddddddd.dd,	set in Set
HEIGHT OR Z	-hhhhhhh.hh,	Configuration
SPEED	sss.ss,	Mode,
HEADING	hhh.h,	Section 5.6.1)
PDOP	ppp.p,	
# OF SATELLITES USED	n,	
MESSAGE ID	dd (see message table in 6.1)	
TERMINATOR	R	

dd - is a receiver status message identification number and is interpreted as follows:

MESSAGE ID	MESSAGE
0	NO MESSAGE
1	not used
2	not used
3	BAD ALMANAC
4	COMPUTING ALERTS
5	STORING NEW ALMANAC
6	DATA LINK MESSAGE

FIGURE B-1. RECORDED EAGLE DATA PARAMETERS