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**14. ABSTRACT**

This Test Operations Procedure (TOP) is to provide general procedures and references for testing and evaluating navigation systems aboard U.S. Army Unmanned Aircraft Systems (UAS).

**15. SUBJECT TERMS**
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US ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

Test Operations Procedure (TOP) 07-2-032 27 July 2010
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# UNMANNED AIRCRAFT SYSTEMS (UAS) NAVIGATION SYSTEMS TEST

Page

1. SCOPE.

The objective of this Test Operations Procedure (TOP) is to provide general procedures and references (Appendix A) for testing navigation systems aboard U.S. Army Unmanned Aircraft Systems (UAS). The procedures are formatted in accordance with the latest regulation (Flight Test Manual, USNTPS-FTM No. 109)[1*] and based on test experience with manned-aircraft navigation systems that have not been fully proven on UAS. Also, these procedures may require frequent modification to accommodate new advances in inertial navigation systems (INS), Doppler navigation systems (DNS), and global positioning systems (GPS).

1.2 Systems.

This TOP addresses navigation systems testing for U.S. Army UAS. [**]

1.3 Restrictions.

This TOP is not applicable to Loran navigation systems. This document may require updates when significant technological advances are achieved that affect inertial measurement units (IMUs), GPS-aided inertial systems, micro-electro-mechanical systems (MEMS), or fiber optic gyroscope (FOG). Additionally, this TOP does not address terrestrial-based navigation systems.

1.4 Background.

"Modern aircraft require continuously available, accurate, 'real-time' navigation information. These requirements are a result of the nature of modern aircraft (e.g., speed and range) and of the missions they perform (e.g., rendezvous and weapon delivery). The need for 'real-time' information, combined with the need for an automated navigational process, imposes restrictions upon the manner in which the various methods of navigation are employed in modern aircraft." (See USNTPS-FTM-No. 109, quotation page 6-1). Also, target location/designation missions for UAS platforms make location accuracy extremely important. When a new navigation system is installed in a UAS, it must be tested to verify its accuracy on the host platform. When certain platform modifications are made to a UAS, the navigation system must be retested to ensure that it has not been degraded by the modification.

[*] Superscript numbers correspond to those in Appendix B, References.

[**] Actual navigation systems test experience is very limited for unmanned systems. The information contained in this TOP is based on experience with manned aircraft and the Shadow 200 TUAV.

## 2. FACILITIES AND INSTRUMENTATION.

### 2.1 Facilities.

| Item | Requirement |
|---|---|
| Infrastructure | Hangar facilities, meteorological services, data acquisition services, miscellaneous test and ground support equipment, improved take-off and landing area (in accordance with (IAW) specific UAS operator's manual). |
| Open-Air-Range | Surveyed targets suitable for flight planning and error calculation.Ground control station. Adequate operating airspace for the test, air traffic control (ATC), communications between the air vehicle operator (AVO) and ATC. Tracking radar or other time/space position and recording capability. Test control ground-to-ground and air-to-ground communications. Common range timing. Meteorological support facility. |
| Indoor Facilities | Some mini/micro class UAS that might be susceptible to wind and/or weather conditions. Indoor facilities may be required in order to control the environmental and weather effects during certain test events (See TOP 7-1-001, summary, page 4)[2]. |

### 2.2 Instrumentation.

To check the UAS navigation accuracy, a differential GPS (DGPS) instrumentation capability is required. One system that the Army has chosen for UAS based on size and power is the Open Architecture for Telemetry and Instrumentation System (OATIS). While OATIS specific design, installation, and usage information is presented in this document, acceptable navigation testing can be conducted with other DGPS systems if they can be successfully integrated onto the UAS platform being tested.

#### 2.2.1 Open Architecture for Telemetry and Instrumentation System (OATIS).

The OATIS instrumentation system is designed for use with medium to large class UAS. It has been successfully installed and operated on the RQ-5 Hunter and RQ-7 Shadow (See MASD-100-U-003)[3]. More recently OATIS has been used to support testing on the extended range multi-purpose (ERMP) UAS.

"OATIS is a modular system designed to measure, log, and transmit inertial measurements to a ground station. It includes two sub-systems, the airborne payload and the ground station. OATIS provides an independent measurement system to assist in evaluating aircraft performance. In addition, the moving map display and Telemetry viewer enhance situational awareness for the test conductor.

OATIS airborne payload comprises three primary subcomponents; the airborne control unit (ACU), the Coarse Acquisition Miniature Integrated GPS/INS Tactical System (C-MIGITS) III INS/GPS, and the smart sensor nodes. The payload also includes an RF modem to communicate with the ground station, a heavy duty enclosure, and two antennas (GPS and transmit/receive antenna).

The ACU is a ruggedized PC104 computer. The PC104 unit is a miniaturized version of a desktop personal computer that is used to control the C-MIGITS III and collect the data. The ACU runs on +28VDC power and has an onboard data logging time in excess of 16 hours. Keyboard and video connectors are available to aid in system setup and troubleshooting. After mission completion, the test data can be downloaded via the USB port or Ethernet port. The ACU is approximately 5 in x 5 in x 7 in (13cm x 13cm x 18cm) in dimension and weighs 5.1 pounds (2.3kg).

The C-MIGITS III is a miniaturized integrated GPS/INS system built by Systron Donner. The C-MIGITS III consists of a digital quartz inertial measurement unit coupled with a 12-channel coarse/acquisition code GPS receiver. The C-MIGITS III is lightweight and is ruggedized for flight operation with respect to vibration, shock, temperature, humidity and EMI. Data available from the C-MIGITS III include aircraft attitude (roll, pitch, heading), attitude rates, altitude, latitude/longitude coordinates, Universal Time Code, GPS time, and linear velocities and accelerations. Data rates up to 100 samples per second are available for selected parameters. Status information, such as Built-In-Test results, GPS signal strength, and INS state and error information, is also available. C-MIGITS dimensions are 3.5 in x 3.2 in x 4.8 in (9cm x 8cm x 12cm) and it weighs 1.7 pounds (0.8kg).

The Smart Sensor Node (SSN) is a family of distributed data acquisition products responsible for signal measurement. These devices consist of modular components for signal conditioning, measurement, and communication. A network of smart sensors are connected to the ACU via a network cable in a daisy chain topology. The nodes are placed in the UAS in close proximity to the signals being measured. Parameters such as temperature, pressure, fuel flow rate, and throttle position can be measured using the smart sensors.

The OATIS system also has the ability to telemeter the data to a ground station for near real-time monitoring. The system uses an RF Modem which transmits at a frequency of 900 MHZ. The RF modem provides an output of 1W and has a range of up to 60 miles (97km). A GPS and Transmit antenna will also be installed on the UAS to receive GPS data and transmit collected data from the system.

The OATIS ground station consists of an RF modem and a ruggedized laptop. The RF modem receives the transmitted data and sends it to the laptop for processing. The ground station software includes the OATIS Ground Station Control Panel, OATIS Telemetry Viewer, the Moving Map Display, and the OATIS Post Processor.

The OATIS Ground Station Control Panel provides real-time monitoring of OATIS system health. It also provides the configuration of sensor rates and logging. It controls the INS preflight alignment and controls/monitors the OATIS datalink.

The OATIS Telemetry Viewer provides real-time display of measured signals from the UAS in strip charts and in tabular format.

The Moving Map Display provides real-time situational awareness using the FALCONVIEW software which allows the user to monitor the UAS location shown on VFR maps or imagery.

The OATIS Postprocessor converts the OATIS log files into file formats compatible with Excel™ and Matlab™. (See OATIS Operator's Manual and Shadow 200 Installation Guide).[4]

2.3 Test Controls.

| Parameter | Tolerance |
|---|---|
| Time | Time synchronization of the test item and the instrumentation equipment may be achieved by linking both to GPS Coordinated Universal Time (UTC). There should be no variance in time between the two when this method is employed. If GPS/UTC synchronization is not possible, the internal clocks for the test item and the instrumentation equipment should be set to within ±0.1 second. The rationale for this tolerance is that a variance of 0.1 second equates to a 3 meter (10 ft) displacement in the air vehicle's location while flying at 60 knots. |

## 3. REQUIRED TEST CONDITIONS.

### 3.1 Test Item Preparation.

#### 3.1.1 Inertial Navigation Systems.

**"**All available publications by the manufacturer and U.S. Army should be consulted to obtain specific information on the INS system under test. The tester should time the preflight and alignment (P&A) procedures for total time required and for the time required for each individual portion. System response to inputs and indications as to status should be examined. The location and accessibility of controls and displays should be reviewed. Many of the cockpit evaluation questions should be re-examined with respect to the INS system. Built-in-Test operation should be reviewed as to time of occurrence, type of readouts provided, and fault display utility. For example, are faults displayed as they are detected or only after the test is complete? Additionally, does the test stop at a fault or can it be stepped through (a major time consideration)? What provisions are made for un-installed, optional, or improper modes of peripheral equipment? If no faults are observed, how can testing be performed to examine the BIT results with a fault condition present (pre-faulted module insertion)? The required platform conditions, such as motion, need to be reviewed." (USNTPS-FTM No. 109, page 6-6).

3.1.2 Doppler Navigation Systems.

"The appropriate publications should be followed to examine their interoperability (in general) with the specific Doppler navigation system under test. The tester should time the preflight and initialization procedures both as a whole and for individual portions. System response to inputs and indications as to status should be examined. The location and accessibility of controls should be reviewed. Many of the cockpit evaluation questions should be re-examined with respect to the Doppler navigation system. Built-in-Test operation should be reviewed as to when it occurs, what type of readouts, and whether faults are displayed as they are detected or after the test is complete. Additionally, does the test stop at a fault and must it be stepped through (a major preflight time consideration)? What provisions are made for un-installed, optional, or improper modes of peripheral equipment? If no faults are observed how can testing be performed to examine the system under a fault condition (pre-faulted module insertion)? The required platform conditions, such as motion, need to be reviewed. There are many qualitative and quantitative points to be examined in the preflight and initialization portion of testing (e.g., thoroughness, logical sequencing, and clarity)." See USNTPS-FTM No. 109, page 6-17.

3.1.3 Global Positioning Systems.

"Manufacturer and/or U.S. Army publications should be followed to examine their interoperability with the GPS system under test. The tester should time the preflight and initialization (P&I) procedures both as a whole and for individual portions. System response to inputs and indications as to status should be examined. The location and accessibility of controls should be reviewed. Many of the cockpit evaluation questions should be re-examined with respect to the GPS system. Built-in-Test operation should be reviewed as to when it occurs, what type of readouts, and whether faults are displayed as they are detected or after the test is complete. Additionally, does the test stop at a fault and must it be stepped through (a major preflight time consideration)? What provisions are made for un-installed, optional, or improper modes of peripheral equipment? If no faults are observed how can testing be performed to examine the system under a fault condition (pre-faulted module insertion)? There are many qualitative and quantitative points to be examined in the P&I portion of testing (e.g., thoroughness, logical sequencing, clarity, and time-to-first-fix under different ambient temperatures)." See USNTPS-FTM No. 109, page 6-47.

3.2 Facilities Preparation.

3.2.1 Known Points.

Confirm the payload's ability to see (from the planned flight altitude) any natural or man-made ground reference points that will be used for truth data.

3.2.2 NAVAID Reception.

The test director should ensure that NAVAID signal strength along the planned test course is adequate. The test director should document unavoidable "dead spots" that sometimes adversely affect low altitude flight operations.

3.3 OATIS Instrumentation Installation.

3.3.1 Shadow.

The OATIS system replaces the standard payload of the Shadow 200. The majority of the instrumentation is located within the surrogate payload ball. This includes a replacement forward looking camera, the ACU, and the C-MIGITS III. In addition, the GPS antenna is mounted to the top of the payload ball and the blade antenna is mounted to the bottom of the payload ball. The Smart Sensor nodes will be located near the signals being measured and will communicate back to the ACU over a CAN bus. Typical mounting locations of the Smart Sensor nodes for the Shadow 200 are the Main Fuselage and under the center wing section. Interconnects between the ACU, C-MIGITS, and antennas are internal to the payload ball. The 28VDC power for the OATIS system will be taken from the existing payload power connector. All interconnect cables between the ACU and Smart Sensor nodes will run along existing wiring and will be secured with Adel clamps or tie wraps. Detailed installation instructions for the OATIS system in the Shadow 200 are included in the OATIS Operator's Manual and Shadow 200 Installation Guide, pages 8 through 24.

3.3.2 ERMP.

OATIS installation on the ERMP does not require uninstall of either the electro-optical/infrared (EO/IR) or the synthetic aperture radar (SAR) payloads. Thus the replacement camera used in the Shadow install is not required. The ACU and C-MIGITS are mounted in payload bay 1 of the AV. Smart sensor nodes can be placed as needed throughout the airframe. A GPS antenna to support C-MIGITS operation is installed in the upper radome area, while a blade antenna to support the RF modem telemetry transmission is integrated underneath the aircraft near the payload bay, respectively.

3.4 Data Collection Systems Checks.

3.4.1 OATIS.

"The OATIS system can operate in two modes, Manual initialize and Auto initialize.
In Manual initialize mode, the following procedures should be followed:

(1) Turn aircraft power on.

(2) Turn OATIS power on.

(3) Open Ground Station control panel and connect.

(4) Edit the configuration file for the flight (if needed).

(5) Upload the configuration file for the flight.

(6) Align the C-MIGITS III.

(7) Set the ACU Datalink Power to high.

(8) Open Telemetry Viewer.

In Auto initialize mode, the following procedures should be followed:

(1) Turn aircraft power on.

(2) Turn OATIS power on.

(3) Open Ground Station control panel and connect.

(4) Open Telemetry Viewer.

Using the Control Panel software and Telemetry Viewer on the ground station computer, verify the data is being received properly and the individual parameters being collected are in the correct range.

Detailed setup instructions for the control panel and telemetry viewer software are located in the OATIS Operator's Manual and Shadow 200 Installation Guide, page 108.

3.4.2 Time Synchronization of UAS Test Items.

To ensure that onboard UAS collected data can be correlated with OATIS information, it is critical that the clocks for the UAS ground control station and the air vehicle will be synchronized to UTC, IRIG, etc. This will ensure that video/map data has a common date/time stamp during playback for comparison and analysis with OATIS.

3.5 Special Procedures/Limitations Explanation.

3.5.1 Preflight and Alignment.

"Preflight and alignment are two major steps in the INS ability to perform its functions. Without proper initial validation, the operators could be falsely led to believe that the system is functioning correctly. The major items checked during preflight and alignment are the warm-up and leveling times, alignment time and accuracy, self-calibration, built-in-test, controls and displays, response to transients (external to internal power sources, generator checks, mode changes, etc.), and other system interfaces. Initial testing can be done in a laboratory, but ground tests in the actual platform must also be performed. All types of alignments (e.g., normal, fast, inflight) should be examined, and ground testing (drift runs) should be done after the alignments to evaluate the accuracy of the system after performing each type of alignment. Flight testing must be done to validate the test results obtained during laboratory testing and ground testing. Since the accuracy of an alignment may depend on the amount of earth rate present during the alignment process, the alignment testing should be done at various latitudes if possible" (USNTPS-FTM No. 109, quotation page 6-5).

4. TEST PROCEDURES.

4.1 Inertial Navigation Systems.

4.1.1 Static Position Accuracy Method.

“The purpose of this test is to evaluate the static accuracy of the INS. The operator should perform a normal preflight and alignment of the INS. Upon completion and entry in a normal mode, the air vehicle position should be recorded at 5 minute intervals. The test should run a minimum of three hours through at least two complete Schuler cycles (168.8 minutes). Air vehicle location and weather conditions should be noted.” (USNTPS-FTM No. 109, quotation page 6-8).

4.1.2 Non-Maneuvering Dynamic Position Accuracy.

“The purpose of this test is to evaluate non-maneuvering dynamic accuracy of the INS. The flight should be flown from point-to-point over surveyed waypoints at the minimum altitude consistent with standard operating procedures currently in effect. Low bank angles and rates should be used with constant 1 'g' flight to establish baseline performance of the INS while in flight. Flight duration should be consistent with the projected mission length for the platform under test. Surveyed check points should be approximately 5 minutes apart but no longer than 10 minutes apart. The flight path should be planned to gain maximum separation from the point of origin at flight midpoint or terminus to exercise to the maximum extent possible the INS earth model. A north/south track should be included to exercise the ability of the system to compute and compensate for coriolis and centrifugal accelerations, and an east/west track should be included to exercise the ability of the system to compute and compensate for transport rate and to apply corrections to earth rates and centrifugal calculations. Because the meridians converge at the poles, a flight test at high latitudes would also be appropriate. If possible, transit of the equator and the 0 and 180 degree meridians should be performed to evaluate system and software tolerance of hemisphere shifts. Updates of the INS position should not be performed during the flight test.” (USNTPS-FTM No. 109, quotation page 6-9).

4.1.3 Maneuvering Dynamic Position Accuracy.

“The purpose of this test is to evaluate INS dynamic maneuvering position accuracy. A normal preflight and alignment should be performed on the INS under test. The air vehicle should then be flown at low level collecting navigation data over surveyed points as performed in nonmaneuvering dynamic flight testing to establish baseline performance for this particular alignment. The duration of the nonmaneuvering portion of this flight should approximate the air vehicle’s normal mission transit time. At the conclusion of the nonmaneuvering portion of the flight, and once established on a suitable range or in a suitable military operating area, the air vehicle should be maneuvered through various simulated mission tasks. During the maneuvering period, position data should be taken after each major maneuver by marking on top surveyed points. After a mission relatable maneuvering period, the air vehicle should be flown on a low level nonmaneuvering route over surveyed check points with navigation data being collected by marking on top of surveyed checkpoints. The return portion of the flight should be long enough to allow any errors created by the maneuvers to be manifested as position errors in the INS.

After landing, static position data should continue to be taken for 2 hours at 5 minute intervals. At the completion of this test, the air vehicle's true heading should be recorded and the INS re-aligned and true heading again recorded for comparison." (USNTPS-FTM No. 109, quotation page 6-13).

4.1.4 System Integration.

"The purpose is to evaluate the system integration (interoperability) of the INS within the platform. System integration is a qualitative investigation of the INS. Data should be gathered throughout all tests, both ground and flight. Evaluation points should include but are not limited to:

- Display of information
- Formatting
- Updating
- Interoperability with platform's**:**
  - -- Radar
  - -- FLIR
  - -- Other weapon systems
  - -- Task loading
  - -- Steering
  - -- Other navigation systems
  - -- Operator interface
  - -- System utility" (USNTPS-FTM No. 109, quotation page 6-14)

4.2 Doppler Navigation System Evaluation.

Because of size and weight constraints, today's Doppler Navigation Systems have limited potential for unmanned platforms. This section is intended for the future when technology improvements make it practical to repackage the radar-based systems for small unmanned platforms.

4.2.1 Position Accuracy.

"The purpose of this test is to evaluate the position accuracy of the Doppler navigation system. The air vehicle should be flown from point-to-point over surveyed targets at altitudes between 500 feet[1] and 1,000 feet Above Ground Level (AGL). Low bank angles and rates will be used with constant 1 g flight to measure in-flight Doppler navigation performance baseline. Flight duration will be consistent with the projected mission length for the air vehicle. Surveyed check points will be approximately 5 minutes apart but no longer than 10 minutes. Data at each check point will include surveyed and system latitude/longitude, time, barometric altitude, Doppler navigation system advisories or warnings, and remarks. Tracks should be planned to gain maximum separation from the point of origin at flight midpoint or terminus to exercise the Doppler navigator over long ranges. Flights should be planned to allow investigation of overland and overwater performance, maximum or minimum functional altitudes or 'holes' in the altitude coverage, performance at a variety of airspeeds and at a variety of headings, and performance during mission relatable maneuvers. Doppler navigation system position updates should not be performed unless a hazard to navigation exists." (USNTPS-FTM No. 109, quotation from paragraph 6.3.4, page 6-18).

[1]Feet is the standard unit of measurement for aircraft altitude reporting throughout the world.

4.2.2 <u>Doppler Navigation Error Source Compensation Testing</u>.

The purpose of this evaluation is to examine the Doppler navigation system's error sources and to provide an overview of the common error sources that should be investigated during the test.

a. External Input of North. The external device that provides the direction of North to the Doppler navigator is usually a flux valve or a magnetic compass. If this device is not properly aligned, the Doppler navigation system will deviate from the intended course with an angular displacement that will cause an ever increasing navigation error as the air vehicle travels an increasing distance. The error due to a misalignment of the external direction reference will manifest itself as a cross-track error. The magnitude and direction of this error may vary with the direction of flight, therefore, the test plan should include flight paths which exercise all points of the compass.

b. Doppler Velocity Measurement. The Doppler navigation system attempts to measure the Doppler shift of the surface over which the air vehicle is flying with a pencil beam radar. The Doppler shift is dependent upon the depression angle of the radar beam. Because the beam is not infinitely narrow, the spread in depression angles between the leading edge of the radar beam and the trailing edge of the radar beam will cause a spread, or a "smearing" of the Doppler shift being received and being processed by the radar receiver. The spread in the Doppler shift being received will depend on the width of the radar beam. A typical Doppler navigator beam width is approximately 4 degrees resulting in a Doppler spread of about 20% at a depression angle of 70 degrees. The Doppler processor must correctly determine the center of this spread of Doppler frequencies or it will not accurately compute the velocity of the air vehicle. An inaccurate computation of air vehicle velocity will result in the computed position being ahead of or lagging the true vehicle position and will exhibit itself as an along-track error as the flight progresses. The magnitude of a Doppler measurement error may vary as the velocity of the air vehicle changes, hence the magnitude of the center of the Doppler spread changes, therefore, the test plan should include flights at a variety of vehicle velocities that cover the mission relatable ground speeds that are expected.

c. Overwater Operation.

(1) Operating a Doppler navigation system overwater creates difficulties for the system processor. Water tends to reflect the radar energy away from the receiver rather than backscatter it toward the receiver. This generally results in a lower signal level at the receiver, and may result in the receiver not having enough energy to process. This loss of signal will often cause a Doppler navigator to go into a memory mode of operation until energy levels are restored. While in the memory mode, the system uses previous velocity data to dead reckon the air vehicle. A flight test that forces the Doppler navigator into the memory mode would seem appropriate to determine how well the system 'navigates' while in memory.

(2) Another overwater effect is that the backscatter coefficient of the water's surface can be a strong function of the angle of incidence of the radar beam. This effect is more pronounced as the sea state decreases. Overwater, the returned energy is reduced and skewed. Many systems have an overland/overwater switch to compensate for the effect that overwater operation causes. In order to fully test a Doppler navigator, flights should be conducted both

overland and overwater. A 'failure' mode or compromise mode of operation could be examined by deliberately placing the overland/overwater switch in the wrong position to simulate the effects on the navigation accuracy if a flight were to be conducted in both environments and the switch was set in on position and left there for the duration of the flight.

(3) The third effect of overwater flight that causes problems for the Doppler navigator is the motion of the water itself. If the water is moving relative to the surface of the earth, the computed velocity based on Doppler shift will be relative to the water, but the computed position will be relative to the earth. It is very important to note events which would affect the motion of the water relative to the surface such as tidal flow and prevailing currents. Strong winds that are blowing droplets may influence the Doppler navigator's computation. Surface conditions should be noted for each overwater flight." (USNTPS-FTM No. 109, quotations, pages 6-19 through 6-23).

d. Altitude Effects. "Doppler navigation systems are either pulsed modulated or continuous wave modulated. Pulsed system radar returns are subject to 'eclipsing' which results in 'blind ranges' or 'altitude holes' in the system coverage. When the radar return is eclipsed, the Doppler navigator will not be receiving a signal with which to navigate. If the return is only partially eclipsed, a shift in system calibration can result since the leading edge and the trailing edge of the beam have different Doppler characteristics. These effects can be minimized by varying the pulse repetition frequency as a function of time, but the first blind range, the one near zero time delay, or minimum altitude, will always be present. A flight test on a pulsed Doppler navigation system should include operations over the altitude range where the host vehicle is expected to operate during its mission. Minimum altitude mission profiles should be flown to ensure that the minimum altitude hole is not a factor. CW Doppler navigation systems sometimes suffer transmitter-to-receiver leakage. Most CW systems solve this problem by frequency modulating the transmitted signal so that after the time delay incurred by the signal during its flight time to the surface and back, the received signal is at a different frequency than the signal currently being transmitted. A problem may still arise at very low altitudes where the delay time of the signal is very short and the transmitter is still very near the received signal frequency. A flight test of the CW Doppler navigation system should include a close look at the minimum operating altitude." (USNTPS-FTM No. 109, quotation, page 6-22).

e. Maneuvering Effects. "In order for a Doppler navigation system to function properly, it is a fairly obvious prerequisite that the Doppler radar beams illuminate the ground below the aircraft. It is possible that by vigorously maneuvering the aircraft, the beams can be rotated so that they are no longer pointed at the surface, and consequently, the system can no longer measure the Doppler shift needed to compute the velocity of the host platform. The test plan should therefore include a maneuvering flight phase that will exercise the Doppler navigation system to the prescribed limits of the platform in which it is installed. The test plan should include maneuvers in pitch and roll to examine the limits of the system, and it should include maneuvers in yaw to examine the effects of excursions in that axis." (USNTPS-FTM No. 109, quotations, pages 6-22 through 6-23).

4.3 Global Positioning Navigation System Evaluation.

4.3.1 Position Accuracy.

"The purpose of this test is to evaluate the position accuracy of the GPS system. The usual method of flying from point-to-point over surveyed landmarks at altitudes between 500 and 1,000 feet AGL will not be precise enough to determine the position accuracy of a GPS receiver. The system will need to be flown on a range with a laser tracking station or another highly accurate tracking device to provide time, space, position information (TSPI) for post-flight processing. If possible, flights should be planned at various times to allow investigation of geometric dilution of precision with various satellite geometry configurations, multipath error, and atmospheric noise. If the GPS test flight is not combined with INS testing, aircraft maneuvers in excess of 1 g, within airframe limits, are allowed." (USNTPS-FTM No. 109, summary, page 6-48).

4.3.2 GPS Position Error Sources.

"The purpose of these evaluations will be to examine the GPS navigation system's error sources and to provide an overview of the common error sources that should be investigated during the testing process.

a. The satellites' clock bias accounts for approximately 3.0 meters of error for Standard Positioning Service (SPS) users. This is reduced to zero for differential GPS (DGPS) users.

b. Ephemeris (satellite position) inaccuracy accounts for approximately 2.6 meters of error for SPS users. This too is reduced to zero for DGPS users.

c. Ionospheric delays account for approximately 4.0 meters of error for SPS users. This is reduced to approximately 0.15 meters for DGPS users.

d. Tropospheric delays account for approximately 1.0 meters of error for SPS users and 0.15 meters for DGPS users.

e. Receiver error - most receivers can achieve a predicted error of approximately 0.5 meters.

f. Multipath error (caused by reflections from surrounding objects) can be expected to generate a 1.0 meter error for both SPS and DGPS users.

g. Selective availability creates an intentional 30.6 meter predicted error for SPS users. This is reduced to zero for DGPS users.

Military DGPS systems should be able to achieve an overall horizontal error of 2.2 meters and a vertical error of 5.5 meters. SPS users' overall errors are significantly more (61 meters and 153 meters, respectively). Errors discovered during testing that fall within these ranges are considered acceptable." (USNTPS-FTM No. 109, summary, page 6-49).

## 5. DATA REQUIRED.

### 5.1 Recorded Data.

#### 5.1.1 Inertial Navigation Systems Test Data.

a. Preflight and Alignment.

Qualitative:

(1) Thoroughness.

(2) Logical sequencing.

(3) Clarity.

(4) Equipment location.

(5) Display condition during different lighting conditions.

(6) Qualitative views.

Quantitative:

(1) System serial number.

(2) Alignment location (specifically latitude).

(3) Alignment heading.

(4) Ambient temperature.

(5) Wind velocity and direction.

(6) Time to complete preflight.

(7) Time required to complete alignment.

(8) Fault indications.

(9) Magnetic variation.

(10) Warm-up time allowed.

(11) Motion/movement of aircraft during alignment.

(12) Large metal object(s) in vicinity of the aircraft.

(13) Power (type and source) requirements.

b. Static Position Accuracy Method.

(1) The time that the alignment mode is exited and the navigate mode is selected.

(2) Elapsed time from navigate mode start.

(3) Actual latitude and longitude (truth data) (1 meter accuracy).

(4) INS indicated latitude, longitude, and groundspeed.

(5) INS advisory/warning indications.

(6) Any changes in original conditions.

c. Non-Maneuvering Dynamic Position Accuracy.

(1) Time.

(2) System position (test data).

(3) Surveyed position (truth data) (1 meter accuracy).

(4) Altitude.

(5) Heading, airspeed, winds.

(6) Method of observation.

(7) Comments on observation accuracy.

d. Maneuvering Dynamic Position Accuracy.

(1) The same data should be recorded as specified in the Preflight and Alignment and Non-maneuvering Position Accuracy sections. In addition, the following items should be recorded.

(2) Transit time (before maneuvering).

(3) Maneuvering time.

(4) Maneuver type.

(5) Transit time (after maneuvering).

e. System Integration.

(1) Qualitative comments throughout testing.

(2) Format examples.

(3) Time required to interact between systems.

5.1.2 Doppler Navigation Systems Test Data.

a. Preflight/Initialization.

(1) Time to preflight.

(2) Equipment locations.

(3) Display condition under various lighting conditions.

(4) Fault indications.

(5) Power (type and source) requirements.

(6) Qualitative views.

(7) System serial number(s).

b. Position Accuracy.

(1) Time (Zulu).

(2) Position – surveyed and Doppler navigation system.

(3) Heading.

(4) Altitude.

(5) Method of observation.

(6) System status (warnings/cautions).

(7) Mode of operation.

c. Doppler Navigation Error Source Compensation Testing.

(same as paragraph 5.1.2b)

d. Doppler Navigation System Error Sources.

(same as paragraph 5.1.2b)

5.1.3 Global Positioning Navigation System Test Data.

a. Preflight and Initialization.

(1) Time to preflight.

(2) Equipment location.

(3) Display condition under various lighting conditions.

(4) Fault indications.

(5) Power (type and source) requirements.

(6) Qualitative views.

(7) System serial numbers.

(8) Ambient temperature.

(9) Time-to-First-Fix.

(10) Geometric Dilution of Precision (GDOP) (if available).

b. Position Accuracy.

(1) TSPI.

(2) Latitude/Longitude/Altitude.

(3) Time.

(4) Advisories/warnings.

(5) GDOP (if available).

(6) Remarks.

## 5.2 Data Forms.

Data forms should be tailored to follow a logical sequence that matches the planned test sequence and enough entry prompts so the non-recorded data are captured as they appear during the test. An example test and test conditions table for an AH-64A GPS/INS demonstration is provided. The test and test conditions information helps in the development of data forms.

Table 1. Tests and Test Conditions

| Environment | Test[1] | True Airspeed (kt) | Altitude (AGL)[2] (ft) | Data Requirements | Remarks[3,4] |
|---|---|---|---|---|---|
| Ground | Land[5] Alignment | 0 | 0 | Date; GPS[6] time; surveyed location (truth data); GPS PP[7]; No. of satellites tracking; GPS EHE[8]; GPS EVE[9]; EGI[10] EPE[11]; GPS FOM[12]; qualitative observation accuracy; time to align | IAW[13] operator's manual (ref 1c) |
| | Simulated Water Alignment | 0 | 0 | Date; GPS time; surveyed location (truth data); GPS PP; No. of satellites tracking; GPS EHE; GPS EVE; EGI EPE; GPS FOM; qualitative observation accuracy; time to align | Align stationary first. Pull EGI CB[14], ground taxi to simulate ship movement. Select water mode reset EGI CB. Record time from EGI CB reset to INS[15] Align (GO). |
| | HaveQuick Radio Timing | 0 | 0 | Ability to time radio, transmit, and receive radio traffic | IAW operator's manual (ref 1c) during static position accuracy |
| Ground and Flight | Static[5] Accuracy | Stationary on Ground and Hover | 0, 5 | Date; GPS time; surveyed location (truth data); GPS PP; No. of satellites tracking; GPS EHE; GPS EVE; EGI EPE; GPS FOM | Conducted at startup before flying route. Record data at 5-min intervals for at least 1 Schuler cycle (84 min). Conduct hover with the mast over the surveyed point. |
| Flight | Maneuvering Dynamic Position Accuracy[5] | 70 | 50 | Date; GPS time; surveyed location (truth data); GPS PP; No. of satellites tracking; FOM; GPS EHE; GPS EV; EGI EPE; GPS FOM; qualitative observation accuracy | Overflight of waypoint in unaccelerated, nonmaneuvering 1-g flight |
| | Target Acquisition | Stationary Hover | 25 to 200 | Date; GPS time; surveyed location (truth data); GPS PP; target location (truth data); No. of satellites tracking; FOM; GPS EHE; GPS EVE; EGI EPE; GPS FOM | With the mast over the surveyed point, the coordinates of a predetermined target at a known location will be stored manually via the keyboard on the CDU[16]. The TADS[17] will be used to slave to the target. |
| | Inflight Reset | Stationary Hover | 25 to 200 | Date; GPS time; surveyed location (truth data); GPS PP; No. of satellites tracking; GPS EHE; GPS EVE; EGI EPE; GPS FOM; qualitative observation accuracy; time to align | IAW operator's manual (ref 1c) |
| | Flight Symbology | Low Airspeed/ Hovering Turns | 5 to 30 | Qualitative comments regarding the usability of the flight symbology for the specific maneuver and any differences between the behavior of the symbology for each EGI software version | Low airspeed flight and stationary hovering turns will be conducted to qualitatively evaluate the flight symbology (acceleration cue and velocity vector) with respect to visual flight cues. Hovering turns will be conducted about the mast, nose, and tail using appropriate visual references. |

Table 1. Tests and Test Conditions (cont)

NOTES:

[1]The aircraft configuration will be four wing pylons with two Hellfire launchers and two rocket launchers installed. The aircraft test weight will be approximately 15,500 lb and the center of gravity (cg) will be approximately 205.6 in. All available mission equipment will be activated to the fullest extent possible.
[2]AGL – above ground level
[3]Each embedded global positioning system inertial (EGI) system will be loaded with the group user variable (GUV) and verified before flight. A normal preflight and stationary land alignment of the EGI will be conducted before each flight. The aircraft will be flown point-to-point along an approximately 150 km navigation route containing three surveyed waypoints (table 3 and fig 1). The route will be flown once clockwise and once counter-clockwise to exercise the ability of the inertial navigation system (INS) portion of the EGI to compute and compensate for coriolis, transport rates, centrifugal accelerations, and earth rotation rate.
[4]The flights will be conducted IAW the limits of the operator's manual (ref 1c) and the Aircrew Training Manual (ref 1m).
[5]Test procedures will be conducted IAW the U.S. Naval Test Pilot School Flight Test Manual (USNTPS-FTM)-No. 109 (ref 1j).
[6]GPS – global positioning system
[7]PP – present position
[8]EHE – estimated horizontal error
[9]EVE – estimated vertical error
[10]EGI – embedded global positioning system inertial
[11]EPE – estimated position error
[12]FOM – figure of merit
[13]IAW – in accordance with
[14]CB – circuit breaker
[15]INS – inertial navigation system
[16]CDU – computer display unit
[17]TADS – target acquisition and designation system" (Technical Manual, TM 9-5895-YYY-10, Page E-6)[5]

## 6. PRESENTATION OF DATA.

### 6.1 Reduction Methods.

#### 6.1.1 Inertial Navigation Systems.

"Position errors in latitude and longitude should be computed and converted to errors in units of nautical miles. A simple method of doing this is to assume that one arc minute of latitude is 1 nautical mile. Even though this method ignores the true shape of the earth and assumes that it is a sphere, the results are reasonably accurate. Thus, the north/south and east/west errors can be computed as follows:

$$\text{Error}_{Lat} = (\text{Lat}_{INS} - \text{Lat}_{TRUTH}) \times 60 \text{ nm/deg}$$

$$\text{Error}_{Long} = (\text{Long}_{INS} - \text{Long}_{TRUTH}) \times \text{Cos(Lat)} \times 60 \text{ nm/deg}$$

Radial error computation can similarly be simplified by assuming a flat earth over the fairly short distances involved in the error computations. This method will not work at high polar latitudes but should be accurate at lower latitudes. Thus, the radial error can be computed as follows:

$$\text{Error}_{Radial} = (\text{Delta}_{Lat}^2 + \text{Delta}_{Long}^2)^{1/2}$$

If more accuracy is required or desired, data reduction methods using geodesy are available. The computed errors should then be plotted as a function of time to determine INS drift rates. Statistical operations should be utilized as required to provide mean INS error with the required confidence level." (USNTPS-FTM No. 109, Paragraph 6.2.4.5, page 6-8).

6.1.2 Doppler Navigation Systems.

"Position errors should be computed and converted to errors in units of nautical miles using the techniques discussed in paragraph 6.1.1 on inertial navigation data reduction. The primary errors of concern are the along-track and the cross-track components of the position errors at the waypoint and the total radial error. The along-track components results from an error in the computation of the true velocity over the ground, and the cross-track component results from an error in the independent determination of North. The computed errors should be plotted as a function of distance traveled to determine Doppler navigation system error rates under nonmaneuvering flight conditions. Distance traveled is an appropriate independent variable since the errors tend to accumulate as a function of distance traveled rather than as a function of time. For example, if an error exists in the determination of true heading, then the cross-track position error of the Doppler navigator will grow linearly with displacement from the original starting position and will not depend upon how long it took to achieve that displacement. The appropriate statistical operations should be utilized as required to provide a mean error with the required confidence level." (USNTPS-FTM No. 109, Paragraph 6.3.4.5, page 6-18).

6.1.3 Global Positioning Navigation Systems.

"Position errors in latitude and longitude should be computed and converted to errors in units of meters using the techniques discussed in paragraph 6.1.1. Position error data should be further reduced to provide a circular error of probable (CEP) figure and a spherical error probable (SEP). CEP is defined as the 50th percentile value of the horizontal (radial) position error population and SEP is defined as the 50th percentile value of the three dimensional position error population. In addition to CEP and SEP, for comparison to other GPS test results, a commonly used parameter is to compute the RMS value of the individual errors and double this distance. This value is called the 2drms value and is purported to contain 95% of the data points. These methods are desirable because of their robustness under various test conditions and because an efficient estimate of its value (in the statistical sense) can be attained with a modest quantity of test data." (USNTPS-FTM No. 109, Paragraph 6.5.5.5, page 6-48).

6.2 Analysis and Statistical Techniques.

6.2.1 Inertial Navigation Systems.

6.2.1.1 Preflight and Alignment.

"The average time to complete the preflight checklist, the average alignment time, and the amount of time the operator must dedicate specifically to the navigation system should be mission related to other aircraft preflight items and checklists. The accuracy and clarity of fault indications and the effects of failures on systems operation and accuracy are details that should also be considered.

Confidence levels for timed tests will be from the specification. Sampling size has a direct impact on the confidence level." (USNTPS-FTM No. 109, page 6-7).

6.2.1.2 Non-Maneuvering Dynamic Position Accuracy.

"The test data are assumed accurate, however several sources of error can be present during the data taking process. Sources of error include the procedure used to fix the aircraft position, time delays in recording data, display accuracy, and surveyed data accuracy. These sources combine to create an error in the accuracy of each data point.

The usual data taking procedure is to fly over a surveyed waypoint (e.g., radio tower, a building) at test altitude and when that point appears to pass under the aircraft, the pilot (operator) calls 'mark,', the INS position display is frozen at that point, and the data recorded. The inaccuracy in flying over a surveyed point is assumed to be one-half the flight altitude above the waypoint (i.e., at 1,000 ft above the waypoint, the error is estimated at $\pm$500 ft). The delay in freezing the INS display and recording data can be as long as 0.5 sec, which equates to $\pm$200 ft at 240 kt groundspeed. The accuracy to which INS data is presented to the aircrew is generally 0.1 min of latitude and longitude, the least significant digit in the data readout is generally tenths of minutes. At a latitude of 40 deg, longitude measurements rounded to 0.1 min equate to an accuracy of $\pm$230 ft and latitude measurements rounded to 0.1 min equate to an accuracy of $\pm$300 ft. The accuracy of the survey which was used to define the position of the waypoint will vary from a few feet to perhaps hundreds of feet depending on the waypoint and the purpose for which it was surveyed. If this error is available, it should be obtained when the survey data is obtained.

Combining errors from all these sources is usually done by assuming that the errors are random in nature and the mean error can be computed by taking the square root of the sum of the squares of all of the error sources. This method will give an average error that can be expected, but the error inputs can also be summed to yield a worst case maximum error that can be expected. For this example, the square root of the sum of the squares method would yield an error of approximately 600 ft whereas the summation of errors would yield approximately $\pm$1,000 ft in the north/south direction and approximately $\pm$930 ft in the east/west direction.

Very coarse 'truth' data can be obtained by measuring the radial and DME to a TACAN station with a known latitude and longitude. This truth data is derived from equations which assume a flat earth model and account for the aircraft altitude, range and true bearing from the TACAN station. This 'truth' data can be computed as follows:

Compute lateral range to the TACAN: $R_L = (R_S^2 - ((ALT_{A/C} - ALT_{TACAN})^2/6076)^{1/2}$

where:

$R_L$ = Lateral Range to the TACAN
$R_S$ = Slant Range to the TACAN
$ALT_{A/C}$ = Aircraft Altitude in feet
$ALT_{TACAN}$ = TACAN Altitude in feet

Next compute Latitude using the following equation: $\Delta LAT_{(nmi)} = R_L \text{ x } \cos(\varphi)$

where $\varphi$ is the acute angle created by the intersection of the North/South axis and the line between the air vehicle and the TACAN, and convert $\Delta$LAT from nmi to degrees with the following conversion equations:

The number of nmi per degree of latitude is:

$$M = [111132.09 - 566.05*COS(2*LAT) + 1.20*COS(4*LAT) - 0.002*COS(6*LAT)]/1852$$

$$\Delta LAT_{(deg)} = \Delta LAT_{(nmi)}/M$$

To obtain the actual latitude of the airplane, take the latitude of the TACAN station and ADD ΔLAT if North of the station or SUBTRACT ΔLAT if South of the station.

Next, compute longitude using the following equations:

$$\Delta LONG_{(nmi)} = R_L*SIN(\varphi)$$

and convert ΔLONG from nmi to degrees with the following conversion equations: The number of nmi per degree of longitude is:

$$P = [111415.13*COS(LAT) - 94.55*COS(3*LAT) + 0.012*COS(5*LAT)]/1852$$

$$\Delta LONG_{(deg)} = \Delta LONG_{(nmi)}/P$$

To obtain the actual longitude of the airplane, take the longitude of the TACAN station and ADD ΔLONG if West of the station or SUBTRACT ΔLONG IF East of the station.

The errors involved in obtaining 'truth' data in this manner are dependent upon the accuracy of the range bearing reading to the TACAN station, which can be in error by as much as 2,000 ft and 2 deg depending on the range between the aircraft and the TACAN. The error in the 'truth' data could then exceed the navigation error in the system under test.

Statistical analysis shows that increasing the confidence of the data to represent the true population's mean (fleet average for the INS system) does not mean simply improving the error bandwidth. In statistical terms the more degrees of freedom associated with the data the more confident we are that it portrays the true population's mean. INS is a DR system with each INS data point dependent on the time elapsed since the system entered its navigation mode. To increase the degrees of freedom (2 times sample population), we must increase the number of data points (test flights). Eighteen test flights would be required before a 90% confidence that the data was within 20% of the true population's mean." (USNTPS-FTM No. 109, pages 6-10 through 6-12).

6.2.1.3 Maneuvering Dynamic Position Accuracy.

"The accuracy of the data should be the same as for nonmaneuvering dynamic position accuracy if it is collected in the same manner.

Complete INS testing will require other dedicated test events/points. A full system may provide ground speed, track, waypoint/steering, and other features. These functions would require more examination in functionality, accuracy, and operator interface. Data would also be collected for specification compliance during developmental testing." (USNTPS-FTM No. 109, pages 6-13 through 6-14).

6.2.2 Doppler Navigation Systems.

6.2.2.1 Preflight and Initialization.

"Determine: (1) the average time to complete the checklist and the initialization, (2) Operator dedicated time and mission relation to other preflight times, (3) Mission relation of preflight and initialization procedures, fault indications, fault effects on system operation/accuracy." (USNTPS-FTM No. 109, Summary, page 6-17).

6.2.2.2 Position Accuracy.

"Test data is assumed accurate, however several error sources can combine to create a worst-case error. Sources of error include the procedure used to fix the aircraft position, time delays in recording data, display accuracy, and surveyed data accuracy. A discussion on how these inaccuracies combine and an example of their magnitudes has previously been presented in paragraph 4.2.2." (USNTPS-FTM No. 109, Summary, page 6-19).

6.2.3 Global Positioning System Navigation Systems.

6.2.3.1 Preflight and Initialization.

"Determine: (1) the average time to complete the checklist and the initialization, (2) Operator dedicated time and mission relation to other preflight times, and (3) Mission relation of P & I, fault indications, fault effects on system operation/accuracy." (USNTPS-FTM No. 109, Summary, page 6-47).

6.2.3.2 Position Accuracy.

"Test data is assumed accurate, however several error sources can combine to create a worst case error. Sources of error include: (1) the difference in position on the aircraft between the laser reflector and the GPS receiving antenna, (2) time offsets in recording data, (3) display accuracy, (4) on-board data recording accuracy, (5) TSPI data accuracy, (6) Clock Bias Errors, (7) Ephemeris Errors, (8) Geometric Dilution of Precision, (9) Ionospheric Propagation Errors, (10) Tropospheric Propagation Errors, (11) Multipath, and (12) Receiver Errors. In-depth analyses of these error sources are found in Reference 1" USNTPS-FTM No. 109, pages 6-49 through 6-53.

6.3 Charts, Tables, Graphs, and Photographs Required.

6.3.1 Inertial Navigation Systems.

6.3.1.1 Preflight and Alignment.

Preflight and alignment test analyses usually require photographs and tables to describe the multitude of tasks involved.

6.3.1.2 Static Position Accuracy.

Static position accuracy test analysis requires charts, tables, and sometimes graphs to capture the differences between the positions defined by UAS onboard navigation system and the positions defined by the "truth" data.

6.3.1.3 Non-Maneuvering Dynamic Position Accuracy.

Charts, tables, graphs, and photographs are all potentially useful in understanding the non-maneuvering dynamic position accuracy test results. If the analysis reveals significant discrepancies (errors), it may be helpful to include appropriately scaled sketch maps that show the true location of the UAS in contrast with the location indicated by the onboard INS. The map technique is especially useful in understanding the magnitude of error (drift) growth.

6.3.1.4 Maneuvering Dynamic Position Accuracy.

The same techniques used in the non-maneuvering dynamic position accuracy apply to maneuvering dynamic position accuracy with annotations that correlate turn rates and g-loading.

6.3.2 Doppler Navigation Systems.

6.3.2.1 Preflight and Initialization.

Preflight and initialization test analysis usually requires photographs and tables to adequately describe the multitude of tasks involved.

6.3.2.2 Position Accuracy.

An analysis of position accuracy test results is best explained using charts and tables that help the reader quickly understand the DNS performance under various conditions (e.g., speed, altitude, surface, attitude, and bank).

6.3.3 Global Positioning System Navigation Systems.

6.3.3.1 Preflight and Initialization.

Preflight and alignment test analyses usually require photographs and tables to adequately describe the multitude of tasks involved.

6.3.3.2 Position Accuracy.

An analysis of position accuracy test results is best explained using charts and tables that help the reader quickly understand the GPS performance under various conditions (e.g., speed, altitude, surface, attitude, and bank).

7. SUPPLEMENTAL NOTE.

UAS navigation testing should not be confused with target location error. Even though the ability of the UAS to accurately determine target location is dependent upon the accuracy of the UAS navigation system, additional calculations and pointing errors affect the development of target locations. The magnitude of those additional errors is dependent on the distance from the UAS to the target, laser stability, and turbulence.

# APPENDIX A. ACRONYMS.

| | |
|---|---|
| ACU | airborne control unit |
| AGL | above ground level |
| ATC | air traffic control |
| AVO | air vehicle operator |
| BIT | built-in-test |
| CEP | circular error probable |
| C-MIGITS | coarse acquisition miniature integrated GPS/INS tactical system |
| CW | continuous wave |
| DGPS | differential global positioning system |
| DME | distance measuring equipment |
| DNS | Doppler navigation system |
| DR | dead reckoning |
| drms | double root mean square |
| FOG | fiber optics gyroscope |
| GPS | global positioning system |
| IMU | inertial measurement unit |
| INS | inertial navigation system |
| MHZ | megahertz |
| MEMS | micro-electro-mechanical system |
| MPI | mean point of impact |
| nmi | nautical mile |
| OATIS | open architecture for telemetry and instrumentation system |
| P&A | preflight and alignment |
| P&I | preflight and initialization |
| PC | personal computer |
| RF | radio frequency |
| SEP | spherical error probable |
| SINS | ship inertial navigation system |
| SPS | standard positioning service |
| SSN | smart sensor node |
| TACAN | tactical air navigation |
| TSPI | time, space, position information |
| UAS | unmanned aircraft system |
| UTC | universal coordinated time |
| VDC | volts direct current |

# APPENDIX B. REFERENCES.

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c. DTC Regulation 25-30, Development, Publishing, and Use of Test Operating Procedures (TOPs) and International Test Operations Procedures (ITOPs), 24 April 2008.

Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Test Business Management Division (TEDT-TMB), US Army Developmental Test Command, 314 Longs Corner Road Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: US Army Aviation Flight Test Directorate (TEDT-RT-ATC), Cairns Army Airfield, Fort Rucker, AL 36362-5276. Additional copies can be requested through the following website: http://itops.dtc.army.mil/RequestForDocuments.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.