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Navy Shipboard JTIDS Terminal Navigation Systems

TECHEVAL/OPEVAL Integration

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The Joint Tactical Information Distribution System (JTIDS) Class 2 terminal was designed for the U.S. Air Force. By government direction it has become the baseline for the terminals being developed for use by naval and other forces. This development activity includes the TECHEVAL/OPEVAL platform integration of the following systems with the Navy shipboard JTIDS terminal: shipboard navigation data sensor systsems, navigation aspects of the JTIDS message communication system, and the earth models selected as the basis for the navigation calculations. The status of this integration process is surveyed in this report. The critical issues to be resolved are described, their resolution status is given, the remaining action items are listed, and an estimated resolution time is given.

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EXECUTIVE SUMMARY

INTRODUCTION

The Joint Tactical Information Distribution System (JTIDS) program will provide the joint services with a communication system having jam-resistant digital and voice communication for command and control, platform relative positioning, and platform identification. In 1985 a decision was made to use the JTIDS Class 2 terminal (hereafter referred to as the "JTIDS terminal") designed for the United States Air Force (USAF) as the baseline for those JTIDS terminals being developed for naval and other forces.

The objective of this report is to document the status of the effort to integrate the JTIDS terminal with Navy shipboard TECHEVAL/OPEVAL systems that provide navigation data. This report includes a survey of the Navy's specifications for shipboard navigation information, a description of the significant issues raised during the integration process and their current status, the remaining action items, and the estimated resolution time for each issue. The possible applications of the resulting relative navigation (RELNAV) data produced by the terminal and the integration of the terminal with RELNAV data user systems are not addressed in this report.

JTIDS SHIPBOARD RELATIVE NAVIGATION ARCHITECTURE

The JTIDS terminal and associated RELNAV-related equipment to be installed aboard each TECHEVAL/OPEVAL ship includes a JTIDS terminal configured for Navy shipboard applications, a transmit/receive antenna, a receive-only antenna, one primary and one backup inertial navigation system (INS), a Command and Control Processor (C^2P), and a combat direction system (CDS). If the ship is an aircraft carrier (CV), then the INS will be an Aircraft Carrier Navigation System (CVNS). If the ship is either a Guided Missile Cruiser (CG) or a Guided Missile Destroyer (DDG), then the INS will be an AN/WSN-5. In addition, the dead reckoning (DR) systems aboard each ship will include an electromagnetic log (EM-Log) and a gyrocompass (gyro). These ships will also have access to a Global Positioning System (GPS) receiver connected to the INS. (A brief description of each of these terms can be found in the Glossary.)

RELATIVE NAVIGATION SPECIFICATIONS

The Navy's RELNAV specifications are derived from either the JTIDS terminal System Segment Specification (SSS) (Singer, March 1983*), the Navy Shipboard SSS Addendum (Singer, January 1988[2]), or from Navy operational requirements (communicated by the PMW/PMA-159 project office of the Space and Naval Warfare Systems Command (SPAWAR)). These RELNAV specifications include the following: the highest quality estimate of position shall have an error of at most 50 feet, a backup navigation mode operational capability, lever-arm compensation for an offset of more than 50 feet between the top of a JTIDS antenna and the ship's INS, proper lever-arm association with each arriving message depending upon the receive antenna, and a navigation capability near the earth's poles.

*A complete listing for each reference used in this document is presented as Section 2.0. Specific citations are keyed to superscript numbers by section in Section 8.0, "Endnotes."

INTEGRATION ISSUES

The issues identified from these specifications can be grouped into the following three categories:

a. Integration of navigation data from shipboard positioning systems (e.g., GPS) and dead reckoning systems (e.g., AN/WSN-5, CVNS, EM-Log) with the JTIDS terminal navigation function.

b. Transmission, reception, and processing of navigation data from messages from neighboring platforms based upon their time of arrival (TOA).

c. Selection of the earth model most appropriate for navigation position and altitude calculations.

These issues and their resolution status are summarized in the following sections.

NAVIGATION DATA INTEGRATION STATUS

Most of the navigation data received by the JTIDS terminal are available from the AN/WSN-5 and the CVNS and are transmitted to the terminal through the C^2P. Other needed data are supplied by the C^2P. However, not all required data are so readily available and an issue has been raised associated with the terminal's need for each of several types of navigation data. All of these issues have either been resolved, or the method for resolution has been agreed upon and the solution is being carried out.

A related issue that has not been resolved is the average duration of inertial "drop out" periods for the AN/WSN-5 and CVNS. These data are needed to determine the period of time the terminal should wait before initiating a reset because of excessive delay in the arrival of navigation data.

NAVIGATION MESSAGE INTEGRATION STATUS

Issues that have risen out of consideration of the affect on navigation position accuracy of message reception, transmission, and processing system components are approaching resolution. The only unresolved issue in this area is the method to be used to accommodate the cable delays and the Notch Filter Assembly (NFA) delay. Resolution of this issue awaits the contractor's presentation of its proposed method for government review.

EARTH MODEL SELECTION STATUS

The Navy has decided to use the WGS-84 earth model over the WGS-72 model in the terminal's RELNAV computations. Not changing to the WGS-84 model may result in position errors in some earth locations of as much as 90 feet. Needed approval of this change from the Joint Message Standards Working Group (JMSWG) is pending.

SUMMARY AND CONCLUSIONS

The critical navigation data integration issues have either been resolved or their resolution is in progress. However, the Navy should continue to monitor the status of the yet unresolved issues. The primary remaining navigation data integration challenge is to test the terminal for proper operation in a Navy shipboard navigation operational environment.

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1.0 INTRODUCTION

The Joint Tactical Information Distribution System (JTIDS) is a joint military service development program to provide jam-resistant digital communication of data and voice for command and control, relative positioning, and platform identification. The Naval Ocean Systems Center (NOSC) has principal responsibility for the integration of the JTIDS Class 2 terminal (hereafter referred to as the "JTIDS terminal") aboard Navy ships. The MITRE Corporation has been supporting NOSC in its role of JTIDS terminal integration with Navy shipboard systems, testbed development, testing, and installation aboard ship.

1.1 OBJECTIVE

Although the integration task is not yet complete, the portion of this effort which encompasses shipboard navigation systems, reception and processing of navigation (NAV) data from neighboring platforms (e.g., ships and aircraft), and the selection of the earth model upon which to perform the navigation calculations is approaching resolution.

For the past two years the authors have been supporting NOSC in the area of Navy shipboard relative navigation (RELNAV) integration. In this capacity, the authors have identified and verified critical shipboard RELNAV integration issues and participated in their resolution. As a part of the performance of these duties, they have participated in RELNAV Working Group (RNWG) meetings, JTIDS terminal design reviews, and other meetings. They have assisted in the development of the RELNAV portion of the Navy shipboard terminal design and program documents by reviewing these documents and participating in comment resolution meetings. The information collected, through these and other activities, forms the basis of this report.

The objective of this report is to document the current status of the integration of the Navy shipboard terminal's RELNAV function with the shipboard navigation systems and the navigation data portions of the JTIDS terminal communication system. In addition to describing each issue, the status of the issue, the remaining action items associated with its resolution, and its estimated time-to-completion are reported.

1.2 BACKGROUND

After giving a brief overview of the JTIDS system, the historical development of the current terminal, and NOSC's role in its development, testing and shipboard integration are described.

1.2.1 JTIDS System Overview

JTIDS is a radio frequency (RF)-based tactical communication system that is being developed to provide secure, jam-resistant digital communication of data and voice for command and control, relative positioning, and platform identification. It operates over line-of-sight (LOS) ranges of up to 300 nautical miles (nmi) on L-band using Time Division Multiple Access (TDMA) communication technology. Jam resistance is accomplished by the use of spread spectrum, with direct sequence and frequency-hopping techniques. Encryption is used to make it secure.

JTIDS terminals communicate over Link-16 using the (Tactical Digital Information Link) TADIL J message standard as defined in the TIDP-TE (JINTACCS, January 1986[1]) and OPSPEC 516.1 (OS 516, October 1986[2]). Each JTIDS terminal automatically broadcasts outgoing messages at predesignated and repeated intervals. When a terminal is not transmitting, it can receive messages sent by other terminals. The flexible JTIDS signal and message architecture provide a variety of distribution techniques that can be organized to satisfy the needs of the individual users.

The primary function of JTIDS within the Navy is to distribute tactical information in digital form among Navy tactical users, e.g., aircraft carriers, guided missile cruisers, and guided missile destroyers (CV, CG, and DDG, respectively) and aircraft (E-2C and F-14D). JTIDS will give the Navy powerful new capabilities in the following naval mission areas:

- Surveillance
- Over-the-horizon (OTH) targeting
- Remote targeting
- Extended combat-air-patrol (CAP) tactics
- Precise participant location and identification (PPLI)

1.2.2 Development History

JTIDS is currently being developed for joint service use by the Joint Program Office Tactical Communications Systems (JPO TCS), of the Air Force Electronic Systems Division (ESD), Hanscom Air Force Base (AFB), MA. The system was originally designed as a communication and navigation terminal for the Air Force (AF) F-15 aircraft. Although the Navy had begun development of its own JTIDS terminal, the Distributed TDMA (DTDMA) terminal, the program was canceled in 1985. Following the direction of the Assistant Secretary of Defense, the AF TDMA terminal became the baseline for development of a terminal for joint service use. Now the Navy must modify and integrate the AF terminal for use with Navy platform systems.

The development of this AF JTIDS terminal for Navy applications is managed for the Navy by a project office (PMW PMA-159) within the Space and Naval Warfare Systems Command (SPAWAR). In addition, this office is responsible for the acquisition of Navy JTIDS terminals through the Joint Program Office (JPO).

1.2.3 Naval Ocean System Center's Role

NOSC is the principal Navy Research, Development, Test, and Evaluation (RDT&E) Center for command, control, communications, ocean surveillance, surface- and air-launched undersea weapons systems, and submarine arctic warfare. NOSC has the following three major roles in the Navy JTIDS shipboard terminal development program: system engineering, testbed development and terminal evaluation, and system development and integration (Darron, February 1988[3]).

In its system engineering role, NOSC will carry out the following activities:

- Perform system engineering for the Navy shipboard terminal and for associated prime mission equipment developments.
- Conduct engineering and related analyses to ensure that the Air Force developed terminals are compatible with Navy shipboard environments.
- Lead the development of network management methods to adapt the Air Force developed terminals to satisfy Navy needs.

In its role of testbed development and terminal evaluation, NOSC will perform the following functions:

- Develop a testbed to test the JTIDS Navy shipboard terminals in a multi-platform environment prior to its installation aboard ship.
- Plan and conduct pretesting for Navy shipboard terminal technical evaluation (TECHEVAL).
- Coordinate the JTIDS TECHEVAL.
- Provide support for terminal operational evaluation (OPEVAL) planning.

In its development and integration role, NOSC will contribute the following:

- Develop and test the JTIDS shipboard antennas.
- Conduct shipboard topside engineering and installation planning.
- Provide the lead for shipboard integration activities through OPEVAL.

A portion of NOSC's system engineering and integration responsibility involves the integration of the RELNAV functions of the terminal with Navy shipboard navigation, communication, and command and control systems.

1.3 JTIDS SHIPBOARD RELATIVE NAVIGATION SYSTEM ARCHITECTURE

The JTIDS terminal will be installed aboard selected Navy ships (an example configuration is shown in figure 1-1). This installation includes the necessary JTIDS antennas, *one primary and one backup inertial navigation system* (INS), the Command and Control Processor (C²P), and either an existing or planned Combat Direction System (CDS). The conceptual layout of these systems aboard ships is explained in this section. Although variations from the description presented here may occur from ship to ship, this description will provide the background necessary to understand the integration issues presented later in this report.

The JTIDS terminal is located generally amidships. A transmitted signal passes through the Notch Filter Assembly (NFA) and out through the transmit cable running to Antenna B. The NFA is needed to prevent JTIDS transmission signal interference with two Identification, Friend or Foe (IFF) sub-bands positioned within the range of the JTIDS band. Because Antenna B will also receive signals, a received signal is redirected by a circulator in the Antenna Interface Unit (AIU) before the NFA and returns directly to the terminal (Singer, April 1988[4]). Antenna A is receive only, therefore, the incoming signal to Antenna A passes through a second cable directly to the terminal.

There are two AN/WSN-5 INSs installed on DDG and CG class ships. The AN/WSN-5s are positioned in the forward and after parts of the ship, as shown in figure 1-1. If the ship is a CV, then the INS is an Aircraft Carrier Navigation System (CVNS) and the two CVNSs are located side by side.

Each INS contains ports to connect it to other navigation devices: a gyrocompass (gyro), an electromagnetic log (EM-Log), and a Global Positioning System (GPS) receiver. A connection to the EM-Log is shown in figure 1-1. The INS, EM-Log, and gyro are each known as dead reckoning (DR) systems because the data from these systems are used to provide navigation data between navigation fixes on objects with known locations, such as landmarks or satellites. A fix may come from GPS or be manually entered from the ship.

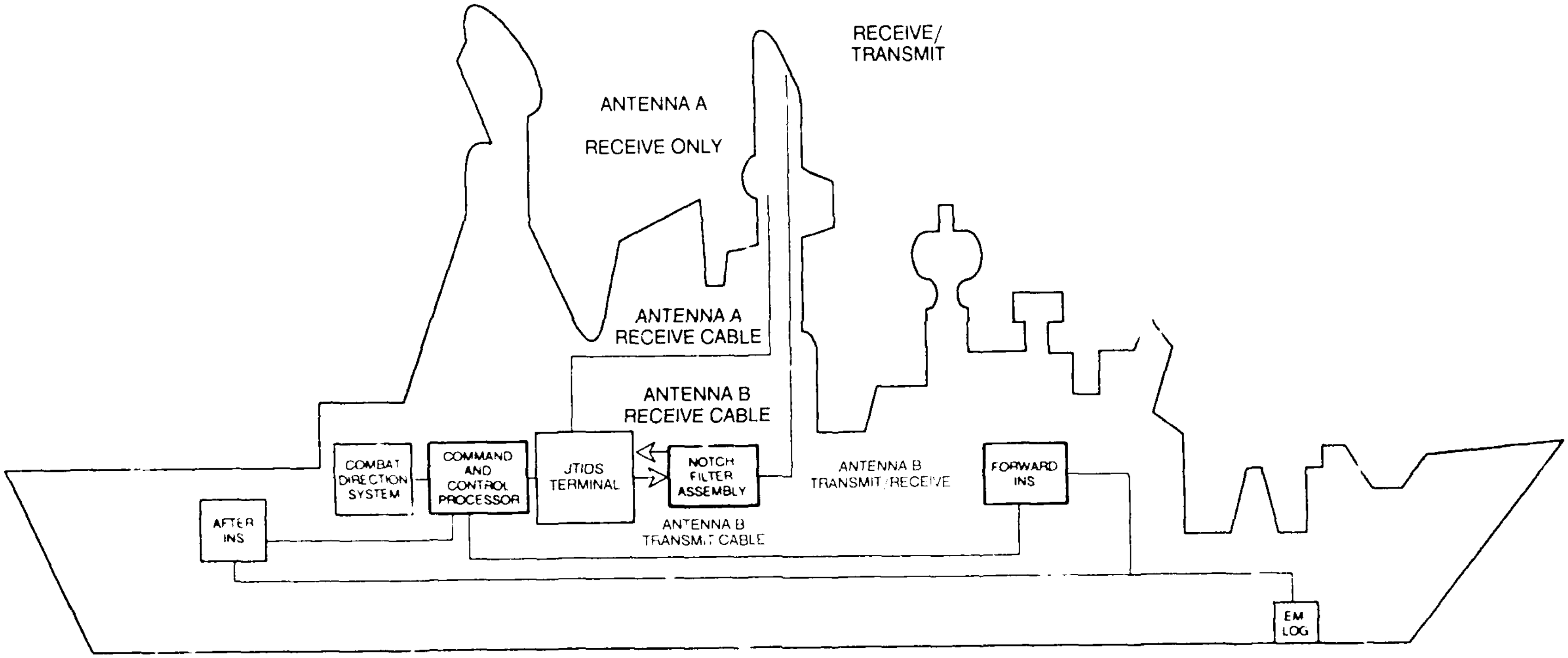

Figure 1-1. Shipboard relative navigation architecture.

1.4 JTIDS TERMINAL SYSTEM ARCHITECTURE

Each JTIDS terminal consists of the following major software system components: the Net Interface Computer Program (NICP) and the Subscriber Interface Computer Program (SICP) (see figure 1-2). The NICP is common to all terminals across the forces. Its major functions are communication between JTIDS terminals and RELNAV processing.

The SICP is tailored for each platform type (e.g., CV, CG, F-14D, F-15, and E-2C). It will be initialized with parameters that are local to the individual platform on which the terminal is installed. The SICP communicates with the C^2P on the host platform via the 1553B multiplex (MUX) bus. The C^2P is connected to the other shipboard systems. Some of these systems supply the navigation data to the terminal via the C^2P (e.g., INSs, EM-Log, and gyro). Other systems may use improved RELNAV data from the terminal in performing their mission (e.g., CDS and Link-11).

1.5 SCOPE

The scope of this report is limited to a description of the status of the integration of the following with the navigation functions of the Navy shipboard JTIDS terminal: (1) shipboard navigation sensor systems (e.g., GPS, DR systems), (2) navigation and timing messages received through the antennas from neighboring platforms, and (3) the navigation earth models. The technical issues involved in the RELNAV processing (e.g., Kalman filter processing) by the terminal are not considered here. Neither are the potential uses of the improved RELNAV data produced by the terminal or the integration of the terminal with RELNAV data users (e.g., CDS, Link-11).

The Navy's shipboard navigation data requirements, the integration of shipboard navigation systems, and the JTIDS system architecture are the subjects of section 3.0. This section includes the navigation data required for calculating the improved RELNAV estimates, the Navy's special needs for RELNAV data, the restrictions placed upon the navigation data processing caused by the shipboard antenna and terminal architecture, and the earth models selected for use in the calculations.

The degree to which the navigation sensor systems, the accommodations for shipboard system architecture, and the earth model selection have been successfully integrated with the JTIDS terminal navigation calculation algorithms is described in section 4.0.

In section 5.0, the remaining unresolved issues are delineated. The impact of not resolving each issue is described, its current resolution status is revealed, and the action items and responsible parties for their resolution are listed.

The key issues and their short- and long-term solutions are summarized in section 6.0. It is asserted there that the steps remaining to resolve these issues are clearly defined and are being pursued by cognizant parties. Satisfactory solutions to all of these issues are expected to be completed before the Navy's product acceptance testing period begins (e.g., Formal Qualification Test 4 (FQT-4)).

In section 7.0, the conclusion is expressed that the principal remaining task is to test the terminal in a Navy shipboard navigation environment for evidence of successful implementation of the agreed-upon solutions and integration with the INS, C^2P and CDS.

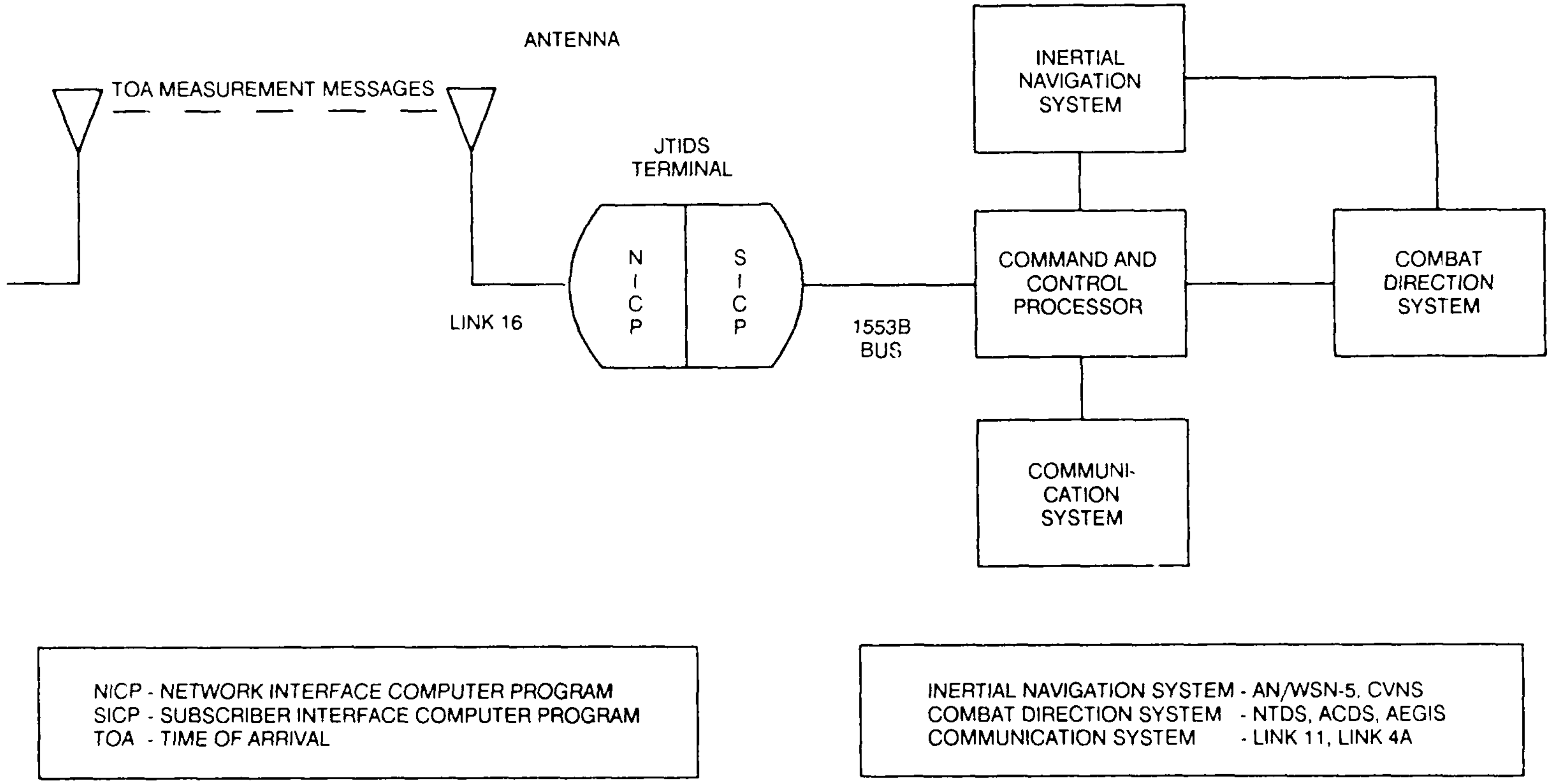

Figure 1-2. JTIDS terminal system architecture.

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3.0 RELATIVE NAVIGATION SPECIFICATION

Some of the Navy's specifications for navigation data can be traced directly to either the JTIDS terminal System Segment Specification (SSS) (Singer, March 1983[1]) or the Navy shipboard SSS Addendum (Singer, January 1988[2]). Other needs are derived from the Navy's RELNAV operational requirements, as communicated on a case-by-case basis to the JTIDS RELNAV community by PMW PMA-159. Before discussing the unresolved issues in section 4.0, the applicable Navy JTIDS shipboard RELNAV specifications are described in the following paragraphs.

3.1 POSITION ACCURACY

All JTIDS terminals evaluate the quality of the position estimate, with the highest geodetic position quality being an estimate with an error of at most 50 feet (Singer, March 1983[3]). This error is measured along the semimajor axis of the position error ellipse as computed from the Kalman filter covariance matrix. The goal of providing the highest accuracy in position estimates produces many areas that need special consideration. Not heeding the demand for the highest accuracy in any one of these areas may render unattainable the possibility of staying within the allowable 50-foot error of the estimate. The specific issues raised by this accuracy specification are listed below and discussed in section 4.0.

a. Notification of INS damping of inertial velocity data using EM-Log data.

b. Notification of a switch between dead reckoning systems.

c. Terminal reset from receipt of invalid data.

d. Terminal reset from delayed receipt of data.

e. Expected duration of terminal reset time.

f. Accounting for data accuracy and aging.

g. Notification of INS velocity and tilt corrections and the magnitude of these corrections.

h. Compensation for antenna-cable-length caused delay.

i. Compensation for NFA caused delay.

j. Selection of JTIDS altitude reference model.

k. Conversion to the World Geodetic System (WGS) 1984 model.

3.2 BACKUP NAVIGATION MODES

If both INSs are inoperative, then the Navy shipboard JTIDS terminal needs dead-reckoning data from the EM-Log and the gyro alone. However, if this dead-reckoning data is not available, then the JTIDS terminal specification (Singer, January 1988[4]) requires that a backup mode be provided that enables navigation based upon navigation data derived from the arrival of PPLI messages alone. This mode is required to help maintain the 50-foot position accuracy and time synchronization during long-term passive operations.

3.3 LEVER-ARM COMPENSATION

The distance between two JTIDS platforms is measured between the reference point on each platform. However, ranging between platforms, based upon the time-of-arrival (TOA) measurements on messages, is measured between the respective antennas.

The Navy shipboard JTIDS terminal specification (Singer, January 1988[5]) requires that the distance between the ship's reference point and the receiving or transmitting antenna (antenna B) be accommodated in any distance calculations to other platforms which are derived from TOA measurements on messages. Because the shipboard antenna may be greater than 50 feet from the ship's reference point, this compensation is needed to maintain the highest accuracy in position estimates. The vector offset between the ship's reference point and a JTIDS antenna is termed a lever arm (see figure 3-1).

3.4 TWO RECEIVE ANTENNAS

The Navy has a requirement for two shipboard JTIDS receive antennas to reduce radio frequency (RF) signal multipath effects. The difference in height between these two antennas may be more than 50 feet. This expands the lever-arm compensation requirement by adding a requirement for a second lever arm (from the reference point to the second, receive-only, antenna (Antenna A in figure 3-1)). It also adds a requirement that the terminal be able to associate the appropriate lever arm with the antenna which is receiving the message with the clearest reception characteristics (Singer, January 1988[6]).

3.5 NAVIGATION DATA TIME TAGS

The Navy shipboard JTIDS terminal specification (Singer, January 1988[7]) requires that all navigation data have time tags associated with them giving the time that the data was valid. Also, the same specification requires that the improved position estimates, i.e., the RELNAV data from the JTIDS terminal, have a time-of-validity time tag.

3.6 NAVIGATION REQUIREMENT NEAR THE EARTH'S POLES

The Navy has an operational requirement that its platforms be able to navigate near the earth's poles. This implies that the JTIDS navigation algorithms must be able to produce accurate position estimates at latitudes above +60 and below 60 degrees latitude.

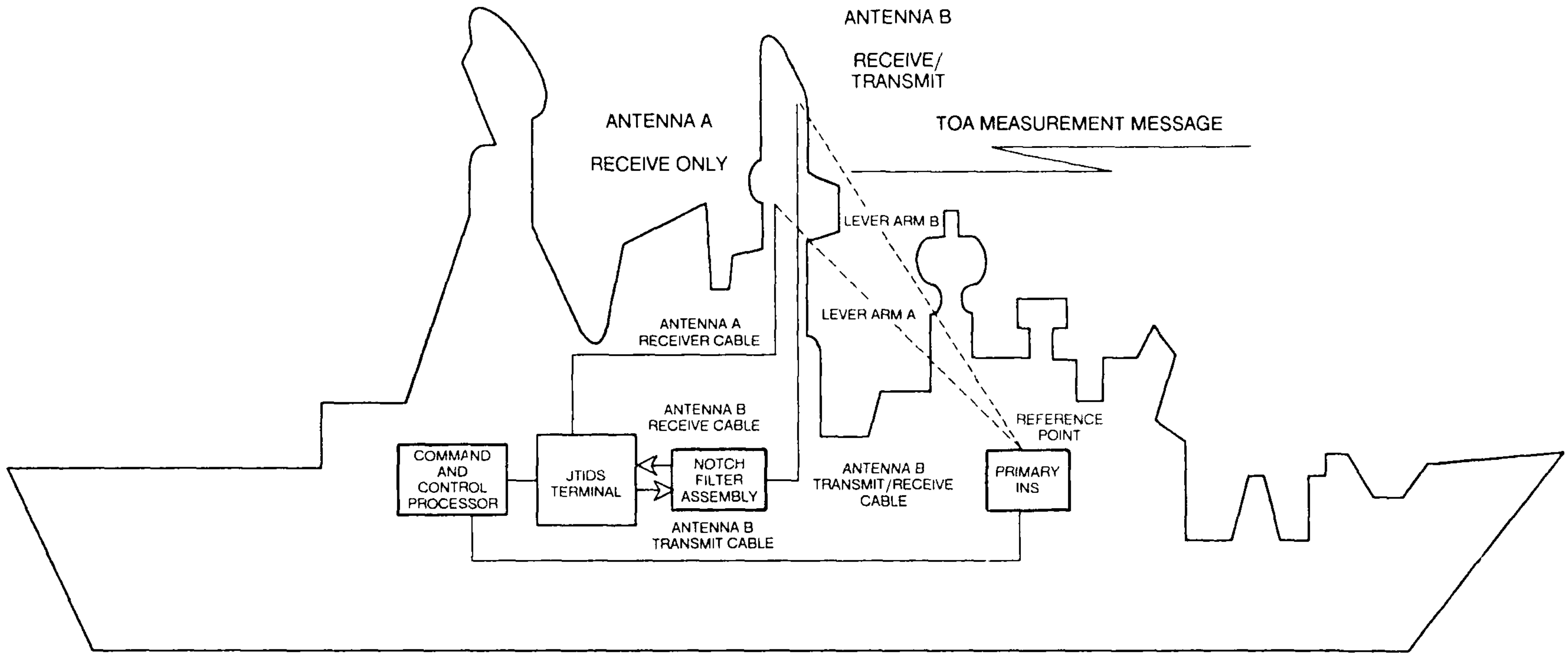

Figure 3-1. Time-of-arrival measurement message integration.

4.0 INTEGRATION STATUS

The issues identified in section 3.0 were grouped under their associated requirement, whether the requirement was given as a system specification or as a Navy operational requirement. However, evaluation of the integration status of shipboard sensor systems, communication systems, and earth navigation models is more easily considered if the issues are grouped relative to the applicable system or earth model.

The integration issues discussed here can be partitioned into three categories. These categories are listed below and discussed in the subsequent paragraphs:

a. The integration of navigation data from shipboard positioning (e.g., GPS) and dead-reckoning systems with the JTIDS terminal.

b. The transmission, reception, and accurate processing of navigation data from messages based upon their time of arrival.

c. The selection of the earth model most appropriate for navigation position calculations.

4.1 NAVIGATION SYSTEM DATA INTEGRATION

Many of the navigation input parameters to the JTIDS terminal, as specified in the JTIDS Navy Shipboard Class 2 Terminal Interface Control Document (ICD) (Singer, April 1988[1]), are available directly from AN/WSN-5 or CVNS navigation output parameters. Other ICD parameters are readily supplied by the C²P. The degree of integration *currently* achieved is shown in table 4-1. The first column gives a short description of each navigation input parameter from the Navy shipboard JTIDS terminal ICD[2].

The entries in columns two and three of table 4-1 indicate the current availability of the ICD parameter from the AN/WSN-5 or CVNS output interface, respectively (NAVSEA, August 1982[3]; NAVSEA, March 1987[4]). The entry "N" indicates that the parameter is available as a direct output from the navigation system, possibly after a minor format conversion. An entry of "C" indicates that the parameter is supplied by the C²P. The current status and remaining actions needed to resolve the use of those navigation parameters that are marked with an "I" are discussed as issues in this paper under the paragraph listed in the fourth column. No entry means that the parameter is not applicable to operation of the terminal when connected to the indicated INS.

Several issues have been raised by the need to provide these parameters to the terminal. The relationship of these issues to the Navy shipboard navigation data sources is shown in figure 4-1. These issues are listed below and are discussed in detail in paragraphs 5.1 through 5.4 and 5.7:

a. Notification of INS damping mode in use.

b. Computation of the reference velocity for use in the terminal's damping model.

c. Notification of the navigation system in use.

d. Notification of a switch between active INSs.

e. Notification of a switch to EM-Log and gyro navigation data upon failure of both INSs.

f. Assurance of a switch to TOA-measurement message-only (TOA-only) mode upon notification of failure of all DR systems.

Table 4-1. Navigation data integration: terminal-to-inertial navigation system.

Navy Shipboard JTIDS Terminal Navigation Data	AN WSN-5	CVNS	Paragraph(s)
Navigation System In Use	I	I	5.2, 5.7
Damping Mode In Use	I	I	5.1
Corrections Used	I	I	5.3
Data Validity Bits			
Tilt Corrections Valid	I	I	5.3
Velocity Corrections Valid	I	I	5.3
Wander Angle Valid	I		5.4
Pitch and Roll Valid	C	C	
Heading Valid	C	C	
Velocity Valid	C	C	
Geodetic Position Valid	C	C	
Horizontal Position Fix Quality	C	C	
Geodetic Position Fix Presence	C	C	
Time of Update	N	N	
Platform Latitude	N	N	
Platform Longitude	N	N	
Time of Computation - Attitude	N	N	
Platform Roll	N	N	
Platform Pitch	N	N	
Platform Heading	N	N	
Time of Computation - Velocity	N	N	
Platform North Velocity	N	N	
Platform East Velocity	N	N	
Platform Azimuth Wander Angle	I		5.4
Correction Values Used			
North Velocity	I	I	5.3
East Velocity	I	I	5.3
North Tilt	I	I	5.3
East Tilt	I	I	5.3
Azimuth	I		5.4
Ocean Current North Velocity	N	N	
Ocean Current East Velocity	N	N	
Reference North Velocity	I	I	5.1
Reference East Velocity	I	I	5.1

Key: N - Navigation System Output Data
C - C²P Supplied Data
I - Issue Addressed In Cited Paragraph(s)

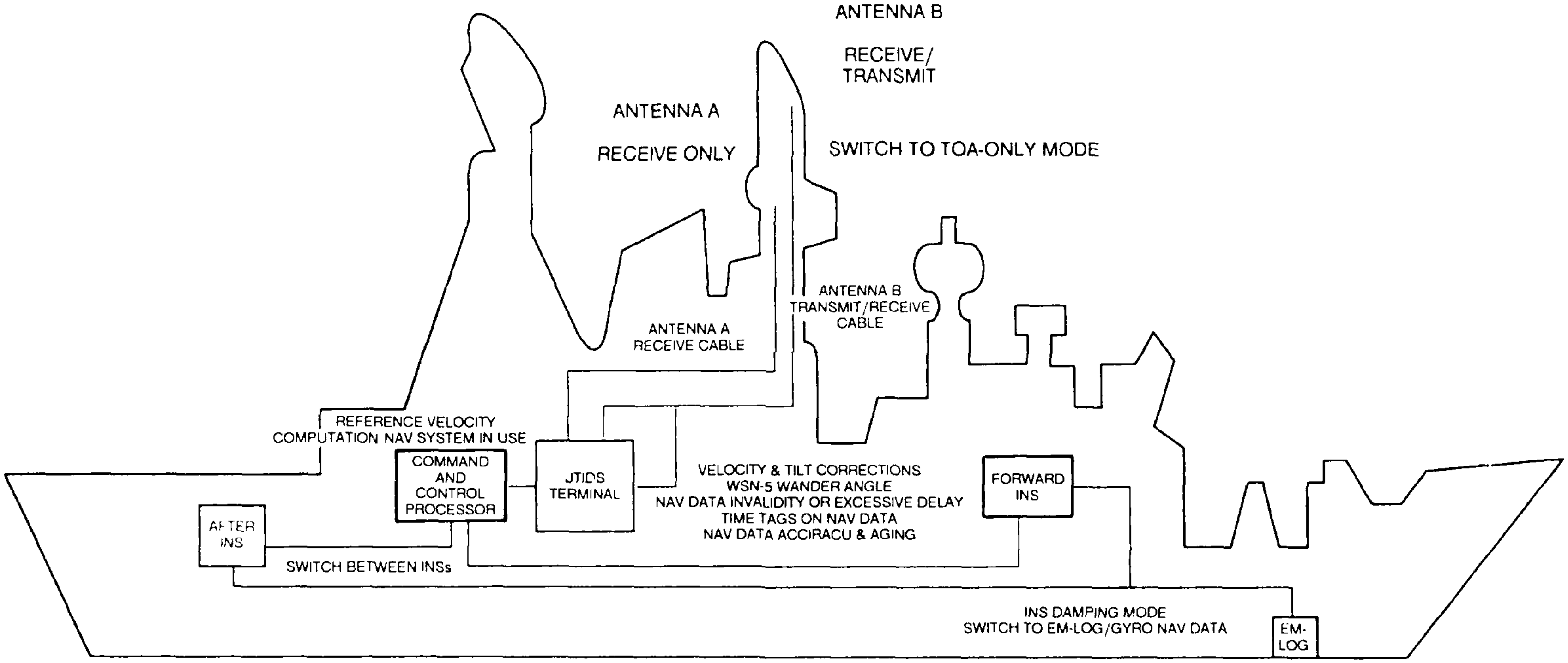

Figure 4-1. Navigation data souice integration.

g. Notification of corrections to the INS velocity and tilt data and the time of correction.

h. Communication of the AN WSN-5 wander angle and notification of wander angle corrections.

Related issues that are covered in this paper are isted below and are discussed in paragraphs 5.2 and 5.5:

a. Parameter data for triggering terminal resets from invalid navigation data or from excessive arrival delay.

b. Expected duration of the terminal reset period.

c. Accurate time tagging of NAV data.

d. Accounting for NAV data aging and accuracy.

4.2 TIME-OF-ARRIVAL (TOA) MEASUREMENT MESSAGE SYSTEM INTEGRATION

Issues that have risen out of consideration of the affect of TOA-measurement message reception and transmission system components (see figure 3-1) are approaching resolution. The resolution of these issues is discussed in paragraph 5.6. These issues are derived from the need for the terminal's design to accommodate the following items:

a. Compensation for message delay through the antenna-to- terminal cables and through the NFA.

b. Selection of the navigation reference point location.

c. Compensation for the lever-arm offset between the ship's navigation reference point and the antenna which transmits receives the TOA-measurement message.

d. Precise calculation of the affect of the ship's roll, pitch, and heading changes on the antenna's location.

4.3 JTIDS NAVIGATION EARTH MODEL

The decision has been made by the Navy to use the 1984 WGS (WGS-84) earth model over the 1972 WGS (WGS-72) model in the terminal's RELNAV computations. Not using the WGS-84 model may introduce position errors in some earth locations of as much as 90 feet. The status of approval for this change is discussed in paragraph 5.8.

5.0 REMAINING ISSUES

Those NAV data integration issues remaining to be resolved are discussed in this section. If a general risk issue includes specific risk issues that have been addressed, then these specific issues are enumerated and discussed individually.

The RELNAV Working Group agreed upon short- and long-term solutions to these issues are given in the following subparagraphs. Each discussion includes a description of the issue, the expected impact on JTIDS RELNAV of not resolving the problem, a discussion of factors which influence the solution(s), the current status of the issue, and the action items currently assigned to the Navy and Singer in order to achieve its resolution.

5.1 ELECTROMAGNETIC LOG VELOCITY DAMPING MODEL

The velocity data coming from the ship's INS may be damped using output from its EM-Log. The damping operation tends to smooth the fluctuations that normally occur in the INS accelerometer output data. However, the damping process may add a bias to the velocity data. Both the AN WSN-5 and the CVNS operate in velocity damped modes. The AN WSN-5 and CVNS each have two modes: damped and undamped.

5.1.1 Issue

The accuracy of the navigation solution obtained by the JTIDS terminal depends upon proper modeling in the terminal of the INS damping behavior. However, the velocity damping by the AN WSN-5 and CVNS navigation systems cannot be modeled adequately in the terminal without having the correct information in the following three areas:

a. The details of the velocity damping mechanization used by the INS (damping equations, gains, etc.).

b. Real-time notification of the damping mode in use by the INS.

c. The components of the reference velocity along with a time-tag consistent with the INS data.

5.1.2 Impact

If the terminal does not receive notification of the INS operating mode and contain the proper mechanisms and data for modeling this mode, then the accuracy of the JTIDS terminal navigation position estimates will be seriously reduced.

5.1.3 Discussion

Singer must be provided with the proper velocity damping mechanisms and data. Further, the AN WSN-5 mode of operation indicator (damped or undamped) is currently available only as a discrete output value. A hardware change will be required to provide this value through the AN WSN-5 to external computer interface. Finally, the reference velocity is not available from the AN WSN-5 in the form required by the JTIDS terminal.

The C²P can monitor this discrete and report a change in its value to the terminal. Should this mode indicator become available through the INS to external computer output interface, the C²P can pass its value to the terminal.

5.1.4 Status

The velocity damping information issue is approaching resolution status. The required document changes have been made and the navigation mechanization equations and data have been provided to Singer as follows.

a. The requested AN/WSN-5 Inertial Measurement Unit (IMU) error model information (damping mechanization equations and gains) was received by Singer on 18 June 1987 (Singer, October 1987[1]).

b. A damping mode indicator has been added to Terminal Input Message (TIM) 17 (word 1, bits 4-5) in the Navy shipboard terminal ICD (Singer, April 1988[2]).

c. The north and east components of the reference velocity have been added to TIM 17 (words 31-32) in the Navy shipboard terminal ICD (Singer, April 1988[3]). The north and east components of the reference velocity can be calculated by the C²P using the INS-reported ownship speed and ownship heading.

Section 5.1.1 lists three categories of missing information. Of these three items, b and c have yet to be completely resolved. As a short-term solution to item b, the AN/WSN-5 damped mode indicator will be read as a discrete signal by the C²P and forwarded to the terminal in TIM 17 over the 1553 MUX bus.

For the long-term solution to item b, as requested by PMW/PMA-159 in a letter to the Naval Sea Systems Command (NAVSEA) 61Z2 (Ault, 1 June 1987[4]), a damping mode indicator has been added to the (redlined) AN/WSN-5 ICD. The actual changes to the AN/WSN-5 system will occur at the same time that the GPS field changes are made to the AN/WSN-5 (Zivich, January 1988[5]). A damping mode indicator for the CVNS output interface will be investigated.

To resolve item c, the C²P will make the reference velocity component calculations and forward these components to the terminal in TIM 17 (Ault, July 1987[6]) (Ault, 30 June 1987[7]).

5.1.5 Action Items

Solution of the problem requires the following actions by the Navy and the Singer Company (Singer, April 1987[8]).

Navy. For the short-term solution, the Navy will request that the C²P read the AN/WSN-5 damping mode change discrete signal and forward its value to the terminal using the damping mode indicator provided by Singer in TIM 17.

For the long-term solution, the successful addition of a damping mode indicator to the AN/WSN-5 to external computer interface will provide the desired method of notification of the mode change to the terminal. The Naval Air Development Center (NADC) will determine the feasibility of adding a damping mode indicator to the CVNS to external computer output interface.

The Navy will request that the C²P be modified to make the reference velocity component calculations.

Singer. Singer has proposed implementation of EM-Log velocity-damped INS operation in the NICP by FQT-4 (Singer, June 1987[9]). Singer noted that this may require using two new filter states in the RELNAV Kalman Filter (RNKF). However, the modifications made by Singer for the new Grid Drift Markoff model have freed two filter states that can be used here.

5.2 TERMINAL RESET CONDITIONS AND DURATION

A terminal reset causes the terminal to enter a reinitialization period. During this time the terminal's production of RELNAV data is temporarily interrupted; therefore, RELNAV data is not available to the host platform. However, reinitialization of the terminal is needed whenever major changes occur in either the source or the nature of the arriving navigation data.

5.2.1 Issue

The terminal will reinitialize itself under several different conditions. In some cases a reset will occur unconditionally because it is caused by a major change in the source of the data, e.g., a switch in the active INS, a switch from INS mode to EM-Log and gyro mode, or a switch to TOA-only mobile mode from DR mode. In each case the terminal must be notified of the change.

Two other conditions under which a reset can occur are the arrival of invalid data and a large variation in the data interarrival time. The terminal software is designed to continue navigation calculations even though a number of pieces of invalid navigation data arrive. However, after the arrival of several invalid pieces of data a reset is initiated by the terminal. Similarly, if a long interval passes between the arrival of successive pieces of data, then a reset is initiated. The circumstances under which these resets will occur may be tuned to the host environment by adjustment of the appropriate parameters in the SICP portion of the JTIDS terminal software. The values for these parameters need to be determined.

5.2.2 Impact

Failure by the terminal to reset when major changes occur in the nature of the arriving navigation data may cause significant, erroneous jumps in the resulting RELNAV data. However, frequent resets due to small fluctuations in the data will make the RELNAV data virtually unavailable to the host platform. Therefore, the conditions under which the terminal will reset must be clearly identified and adjusted for optimum RELNAV data accuracy and availability.

5.2.3 Discussion

The primary factors to be discussed here are the situations under which a reset can occur and the expected length of time required to complete a terminal navigation reset.

a. The primary INS is the default system source of navigation data. If the data from the primary INS are invalid or unavailable, then a switch to the secondary INS is made. If both INSs are passing invalid data or are unavailable, then the gyro with the EM-Log is the default. If no DR navigation data is available, then the terminal switches into TOA-only mobile mode.

   In each case, a switch from one dead-reckoning system to another causes a navigation reset in the SICP portion of the JTIDS terminal software (Ault, 1 June 1987[10]). A mechanism is needed to enable the host computer to communicate the currently active navigation data source to the SICP.

b. If the host computer marks the geodetic or relative grid navigation data it is sending to the SICP as invalid, then the SICP changes to a "FLYWHEEL" state. This means that the data from the SICP's Data Store (saved from a previous cycle) is passed to the NICP in place of the invalid data from the host. The SICP maintains a count of the number of recent times that invalid data has been received from the host. The number of times invalid data are received before a reset is triggered needs to be identified.

c. The smooth flow of data coming from the AN/WSN-5 or CVNS may be interrupted. The optimum length of the wait interval in the NICP before the NICP declares a navigation failure, based upon the nonavailability of valid navigation data, needs to be determined (Ault, July 1987[11]).

d. The average length of time required to complete a navigation reset needs to be established.

5.2.4 Status

Singer's current methods for determining the conditions under which a reset will occur and their current estimate of terminal reset time are summarized in this section.

a. Singer has included a NAV SYSTEM IN USE field as bits 0-3, word 1, in TIM 17 of the Navy shipboard ICD to be used by the C^2P to communicate the identity of the active communication system to the terminal. By monitoring this field the SICP can detect a switch from one INS to the other, a switch from INS mode to EM-Log and gyro mode, or that no navigation systems are available (Singer, April 1988[12]). This resolves the subissue.

b. If the host sends invalid data signals for 1 second (4 NICP cycles), then the SICP causes a navigation reset to occur. In addition, 5 observation validity failures out of 10 successive inputs from the host will also cause a navigation reset (Ault, April 1987[13]). Two successive validity failures will result in a covariance matrix adjustment. This logic is currently *not* an independent validity check for geodetic grid, relative grid, and time (Singer, June 1987[14]). Singer-proposed modifications to this policy for FQT-4 are listed in paragraph 5.2.5.

c. Singer is awaiting receipt of average inertial dropout estimates for the AN/WSN-5 and the CVNS from the Navy. These estimates will be used to determine a maximum inertial system dropout time before a navigation reset is initiated by the NICP.

d. Singer reported at the Navy shipboard JTIDS terminal Preliminary Design Review (PDR) that, if the SICP causes a navigation reset due to invalid data coming from the host computer, then the length of time required to complete this reset is from 10 to 15 minutes (Ault, April 1987[15]).

5.2.5 Action Items

Solution of the unresolved portions of these issues requires the following actions by the Navy and the Singer Company.

Navy. NADC was tasked at a RELNAV Working Group meeting to provide Singer with either current operational or laboratory estimates of the average duration of inertial drop-out periods for the CVNS and the AN/WSN-5 (Ault, July 1987[16]). The data is needed by Singer to determine the maximum flywheel time period before a "missing data" reset is signaled in the NICP. The information was not provided by the Navy shipboard JTIDS terminal Critical Design Review (CDR), and the issue is currently unresolved (Singer, October 1987[17]).

Singer. The following modifications have been proposed by Singer for implementation by FQT-4 (Singer, June 1987[18]).

- Provide separate data validity failure count windows for geodetic- and relative-grid navigation.
- Provide validity failure covariance adjustments as a function of the DR type, i.e., inertial, noninertial, TOA-only mobile, TOA-only fixed.
- Do not count Round-Trip Timing (RTT) (Non-NAV message time updates) failures toward a navigation reset in the passive mode.

5.3 VELOCITY AND TILT CORRECTIONS AVAILABILITY

The AN/WSN-5 uses the results from its Kalman filter processing of periodic satellite observations to correct its position, velocity, and tilt values (Engelhart, March 1987[19]). The CVNS also corrects its velocity and tilt values.

5.3.1 Issue

Velocity and tilt corrections applied to the ship's INS, together with their time of validity, must be considered in JTIDS terminal navigation processing. However, the current INS to external computer interface does not include parameters which provide the magnitude of these velocity and tilt corrections. The only applicable parameter currently available from either INS is the Time of Gyro Reset (TGR), and it gives the time of validity of these resets.

5.3.2 Impact

Without proper modeling in the terminal, INS velocity and tilt corrections may be interpreted by the JTIDS terminal as an indication that the platform is turning. This mistake will cause additional errors in position and direction to be included in the RELNAV data reported by the terminal (Zangaro, March 1986[20])

If the corrections are large enough, not providing these velocity and tilt correction parameters to the terminal may result in a terminal navigation failure requiring a total navigation restart. The restart delay will seriously degrade the usefulness of JTIDS navigation data to the ship (Ault, July 1986[21]).

5.3.3 Discussion

Originally, NADC reported the following estimates of the frequency and magnitude of the velocity and tilt corrections. The magnitude of the velocity corrections normally applied to the INS is on the order of 0.1 knot. These corrections are applied anywhere from every 20 minutes up to every 6 hours, with the typical interval being every 1½ to 2 hours and a duration of 41 milliseconds (ms) (Singer, April 1987[22]). The tilt corrections are predominantly caused by gyro drift. They are applied at the same time as the velocity corrections and have a magnitude on the order of one arc minute (Singer, April 1987[23]).

The Navy's preferred solution was to provide the magnitude of the velocity and tilt corrections externally to the AN/WSN-5. This solution would have been difficult to implement in the AN/WSN-5 because (1) these correction values are stored as AN/WSN-5 software Kalman filter reset states and (2) the current nearly one hundred percent utilization of the AN/WSN-5's Central Processing Unit (CPU) by existing processing demands leaves little CPU capacity to pass these software states out of the AN/WSN-5 (Ault, 1 June 1987[24]).

Although most INSs are typically "1-knot systems," the Navy shipboard INS is an exception because its velocity and tilt corrections are usually less than 0.1 foot per second (fps). Further, the magnitude of the velocity and tilt corrections applied to the shipboard INS are only 3 percent of the INS Kalman filter estimate of velocity and tilt errors. Therefore, these corrections may be modeled as process noise in the JTIDS terminal navigation algorithms (NADC, May 1988[25]).

5.3.4 Status

Singer has added a CORRECTIONS USED indicator to TIM 17 (word 1, bit 7) to communicate the values of the TGR, which must be forwarded by the C^{2}P from the INS to the terminal. Singer will keep the existing velocity and tilt correction parameters in TIM 17 (words 24-27) available for future use. The velocity and tilt correction validity bits are in TIM 17, word 1, bits 8-9.

5.3.5 Action Items

The solution to this problem will require the following actions by the Navy and the Singer Company.

Navy. NADC will determine the feasibility of having the C^{2}P send a CORRECTIONS USED indicator to the terminal based upon a change in the TGR parameter from the INS (Ault, April 1987[26]).

Singer. The magnitude of the velocity and tilt corrections will be modeled in the NICP as process noise by FQT-4.

5.4 WANDER AZIMUTH NAVIGATION DATA AVAILABILITY

A wander-azimuth INS is different than a north-slaved system because the orientation of the wander-azimuth system is allowed to deviate slightly from true north. The amount of this deviation is called the wander angle.

5.4.1 Issue

The AN/WSN-5 is a wander-azimuth system, but the wander angle is not currently available as output over the AN/WSN-5 to external computer interface. If the wander angle is not provided to the terminal, the JTIDS navigation solution values may cause navigation problems above 60 degrees latitude. However, the Navy requires JTIDS navigation information for operations above 60 degrees latitude. The problem is equally true for operations below -60 degrees latitude and it is understood that this condition is included in the following discussion.

5.4.2 Impact

The potential inaccuracy of the JTIDS navigation solution, if the AN/WSN-5 wander angle is not provided to the terminal, will seriously restrict the applicability of JTIDS RELNAV to Navy platforms operating above 60 degrees latitude.

5.4.3 Discussion

The AN/WSN-5 operates as a north-slaved system during alignment, and thereafter operates as a wander-azimuth system. The azimuth may be torqued up to 3 degrees per day (Piazza, December 1986[27]).

Because the CVNS operates as a north-slaved system, the problem expressed here for the AN WSN-5 does not apply to the CVNS.

5.4.4 Status

The DR error models requested by Singer have been supplied. The data include CVNS accelerometer data, AN WSN-5 accelerometer and gyro data, and EM-Log performance data (Singer, October 1987[28]). However, Singer has requested additional CVNS accelerometer data and gyro data (Zivich, January 1988[29]).

In response to a letter to NAVSEA 61Z2 from PMW PMA-159 (Ault, 1 June 1987[30]), the AN WSN-5 wander-angle parameter has been added to the (redline) AN WSN-5 ICD.

5.4.5 Action Items

Solution of this problem will require the following actions by the Navy and the Singer Company.

Navy. NADC will supply Singer with the requested additional CVNS accelerometer data and gyro data (Zivich, January 1988[31]).

Singer. Singer will maintain the wander-angle parameter, which is currently in word 23 of TIM 17, for future use. The wander-angle validity bit will remain in TIM 17, word 1, bit 10, and the azimuth correction used parameter in TIM 17, word 28.

5.5 NAVIGATION AND RELATIVE NAVIGATION DATA TIME TAGGING

Navigation data is supplied by the INS through the host computer to the JTIDS terminal. RELNAV data is returned from the terminal to the host computer.

5.5.1 Issue

The Navy requires that "all platform navigation system data passed into the terminal and RELNAV data passed out of the terminal shall be explicitly or implicitly time-tagged with Net Time" (Singer, January 1988[32]).

In addition, Singer has requested that the system maximize the data accuracy and minimize data aging of all navigation data which is passed to the terminal. Singer requested an indication of the accuracy and staleness of the host time-tagged data (Singer, February 1987[33]).

5.5.2 Impact

Less accurate data or data that has aged significantly is of little value in the Kalman filter RELNAV update process.

5.5.3 Discussion

The C²P will translate Greenwich Mean Time (GMT) to JTIDS time. All navigation data time tags are to be in JTIDS time and are to be measured in slots (Ault, April 1987[34]).

"Full navigation parameters (e.g. position, velocity) presented to (the) Host must always have some time-tag identification presented with the data to be useful. Since time information is available in the SICP, each unique terminal configuration can resolve this question to suit the Host data requirements" (NADC, 1986[35]).

5.5.4 Status

The 14 July 1987 Navy terminal ICD provides the following three parameters in TIM 17: "Time of Update" for geodetic position; "Time of Computation - Attitude" for roll, pitch, and heading; "Time of Computation - Velocity" for the platform's north and east velocity (Singer, April 1988[36]). The latter time parameter is also valid for the ocean current and reference velocities. In fact, because the shipboard INS velocity and attitude parameters are produced at the same time, the value received in each of these two "Time of Computation" parameters will be the same (Zivich, January 1988[37]).

Word 2 of Terminal Output Message (TOM) 30 in the Navy JTIDS terminal ICD contains one time-tag for all the navigation data reported in TOM 30 (Singer, April 1988[38]).

Singer accepts a promised time-tag accuracy from the INS of (plus or minus) 3 seconds and a time-tag staleness of less than 1 second. This acceptance resolves the issue.

5.5.5 Action Items

Because the issue has been resolved, no further actions are required by either the Navy or the Singer Company.

5.6 MESSAGE TRANSMISSION AND NAVIGATION COMPUTATIONS

PPLI messages are received and sent by the JTIDS terminal to communicate each platform's identity and location to neighboring platforms. The data received on position and range of other platforms, which is of higher quality than that held by the receiving platform, may be used in the platform's Kalman filter RELNAV processing to help improve its own position estimates.

5.6.1 Issues

Assurance of accurate reception and transmission of PPLI messages requires the following considerations.

a. The cable length transmission reception delay between the JTIDS terminal and the sending receiving antenna, and the transmission delay due to the NFA must be accommodated in the platform's message transmission reception time calculations. The use of two antennae for receiving TOA-measurement messages and the difference in the cabling distances from each antenna to the terminal gives rise to the following problem. If the two antenna-to-terminal cabling distances are different, then the appropriate time delay must be accounted for in the message reception calculations depending upon the receiving antenna.

b. Knowing the exact position of each antenna requires that lever arms be calculated from the ship's navigation reference point to each antenna.

c. The navigation reference point must be chosen so that the ship's movement is accurately represented by the locus of motion of this point.

d. Precise calculation of each antenna's location at the time of message reception transmission requires data on the ship's roll, pitch, and heading.

5.6.2 Impact

The impact of not resolving each numbered issue from paragraph 5.6.1 is explained in the corresponding numbered subparagraph below.

a. Not compensating for cable and notch filter delays may cause serious position error from ranging using PPLI messages.

b. Not providing lever-arm compensation from an appropriately selected reference point will cause position error calculations that are incorrectly based upon TOA-measurement distance reports. This is because the RELNAV filter position calculations will adjust position estimates to account for the errors in perceived velocity from the TOA-measurement messages as compared to the ship's own INS velocity data. This degraded performance contributes to the following navigation problems (Veda, July 1986[39]):

   a. Incorrect position quality reporting.

   b. Erroneous TOA-measurement message processing and potential Kalman filter instability.

   c. Failure to maintain time synchronization during long-term passive operations.

   If lever-arm compensation is provided for only one of the 2 antennas and the antennas are more than 50 feet apart, then the TOA-measured distance for messages received through the noncompensated antenna will show an unacceptable error.

c. Selection of an improper ship's reference point will result in an inaccurate representation of the ship's course. This will produce inaccuracies in reported position and velocity estimates.

d. Inaccurate computation of the ship's roll, pitch, and heading may introduce additional errors in the ship's position estimates.

5.6.3 Discussion

A discussion of the relevant points relating to each of the four identified aspects of accurate PPLI message reception and transmission is presented in this section.

a. The notch filter is in the path of the one transmit antenna and will affect message transmit time. This delay is dependent upon the transmission frequency. Eight frequencies of 51 are affected the most. These eight frequencies are located near the notch filter cutoff band. The delay variation is not large enough to prevent satisfactory reception of the signal (Post, February 1987[40]).

   The maximum allowable delay through the notch filter for all 51 transmission frequencies (i.e., the group delay) in the JTIDS band is 75 ns. The specification for the mean is 25 ns (plus or minus 10 percent) and the maximum allowable standard deviation is 15 ns (Singer, March 1987[41]).

   Test data from the first NFA (Unit NFA SN 001) has been made available by the NFA manufacturer, RS Microwave Company, Inc. Calculations by A.E. Post of MITRE Bedford, using this test data, show a maximum delay of 64 ns, a mean of 16 ns, and a standard deviation of 12 ns. Although these figures are promising, they do not guarantee that future NFA units will satisfy the NFA performance requirements.

If the notch filter is inoperable and transmission is continued, then the transmission time delay will no longer be affected by this filter. This change must be taken into account in any design.

b. Singer has agreed to make the needed changes to the SICP and the NICP to accommodate lever-arm calculations (Ault, 1 June 1987[42]). The NICP's Source Management Function will tag each incoming PPLI message with the ship's antenna lever-arm compensation values corresponding to the receiving antenna (Ault, July 1987[43]).

c. In response to a question raised during a *Technical Interchange Meeting* (TIM) on 3 December 1986, PMW PMA-159 requested that the lever-arm initialization data reference point be one of the ships INSs to simplify the calculations. In addition, PMW PMA-159 suggested that the determination of the ship's reference point did not have to be complete in order to complete the ICD (Piazza, December 1986[44]).

d. The computation of roll, pitch, and heading gimbal angles is not dependent upon either the center-of- gravity, the INS location, or the location of the center of reference for those angles. The computation is performed with respect to the ship's metacenter, which varies depending upon the load conditions or displacement of the ship. Thus, the gimbal angles represent the same heading, pitch, and roll values throughout the ship and for all magnitude of disturbances. The computation is performed in such a manner as to guarantee that these angles are the same for all locations on the ship and under all displacement conditions (Piazza, December 1986[45]).

Singer asked if roll, pitch, and heading data will have separate time tags. They claim that this could affect lever-arm compensation calculations (Singer, February 1987[46]).

5.6.4 Status

The current status of each of the four components of PPLI message transmission reception is described below.

a. A cable delay parameter for each antenna has been included in the initialization section of the ICD (initialization data block 1, words 28-29) (Singer, April 1988[47]). The values communicated in these parameters will be used by the terminal in its message transmission delay computations to compensate for the applicable cable delay.

A transmit cable delay parameter (initialization data block 1, word 31) has been included in the ICD. However, it is noted there that this word is "for test purposes only" (Singer, April 1988[48]).

Although the above mentioned parameters are included in the Navy shipboard ICD, Singer has not clearly specified how they will be used along with the notch filter delay to accommodate for the two receive and the one transmit cable delays.

b. Ship's body coordinates for each of the two inertial navigation systems on board, the EM-Log, and for the two antennas are provided as vectors in initialization block 59 (Singer, April 1988[49]). The origin of the ship's body coordinates will be centered at the ship's navigation reference point (see paragraph 5.6.4.c).

c. It has been resolved that the ship's navigation reference point will be at the primary (i.e., first active) INS (Zivich, January 1988[50]). If the INS is an AN/WSN-5, then the first active INS will be the forward AN/WSN-5. If the terminal is operating in either non-inertial or TOA mode, then no navigation reference point is needed because of the substantially lower level of position accuracy achievable under these modes (Ault, April 1987[51]).

d. It has been resolved that the gimbal angles are the same for all locations on the ship and the Navy shipboard JTIDS terminal includes one time of computation (TIM 17, words 11-12) for the three parameters: platform roll, pitch, and heading (TIM 17, words 13-15) (Singer, April 1988[52]).

5.6.5 Action Items

Solution of the problem requires the following actions by the Singer Company.

Singer promised that the notch filter delay will be accounted for upon transmit in the NICP and will be incorporated in FQT-4 software (Singer, June 1987[53]).

At the Navy shipboard JTIDS terminal CDR, Singer proposed implementing TOA lever-arm corrections for FQT-4 (Singer, June 1987[54]).

5.7 *TIME-OF-ARRIVAL MEASUREMENT MESSAGE ONLY MOBILE MODE*

Without TOA-only mobile mode, the baseline USAF Class 2 JTIDS terminal's navigation system stops if both the onboard INS and the DR systems fail.

5.7.1 Issue

Both the JTIDS terminal SSS (Singer, March 1983[55]) and Navy operational needs require a TOA-only mobile mode (Olenick, April 1986[56]).

5.7.2 Impact

TOA-only mobile mode is necessary for the following reasons:

- It is required for achieving fine synchronization in passive mode when all onboard navigation systems are inoperative.
- It is used for performing passive updates on a platform already in fine synchronization, but not operating onboard navigation systems.

Maintenance of fine synchronization for long periods of time aboard a ship without a navigation source might be compromised without this mode (Olenick, April 1986[57]).

5.7.3 Discussion

The TOA algorithm, as currently implemented by Singer, will provide TOA-only mobile mode at speeds not greater than 60 knots because the optimal Kalman filter is effective only at these speeds. This capability will satisfy the requirements of ships, but not of most aircraft. A suboptimal filter is reported to work at speeds above 60 knots. However, there is currently no TOA-only mobile mode in the Navy Air Interface Unit (IU). Therefore, both the air SICP and the NICP require changes to enable implementation of this feature for use by Navy aircraft.

5.7.4 Status

Singer has included TOA-only mobile mode as a navigation system type in the Navy shipboard terminal SICP (Singer, July 1987[58]), thereby making it available to the ship. However, as of the Navy shipboard terminal CDR, a satisfactory description of the associated SICP processing has not been provided.

Singer reported considering making NICP modifications by FQT-4 to use the Joseph-form of the Kalman filter covariance update. They said that this form change is necessary for TOA-mobile mode availability for all platforms. This form is algebraically identical to the previous approach, but uses more stable, nonsingular matrices (Singer, June 1987[59]).

5.7.5 Action Items

Solution of the problem requires the following actions by the Singer Company.

By FQT-4 Singer is to complete air and ship terminal modifications to incorporate the Joseph-form of the Kalman filter to provide TOA-only mobile mode in all Navy platforms.

5.8 CONVERSION TO WORLD GEODETIC SYSTEM 1984 MODEL

The JTIDS terminal uses WGS-72 based algorithms for calculating geodetic position. The CVNS and the new GPS use the WGS-84 model.

5.8.1 Issue

To be compatible with the CVNS and the new GPS system, the JTIDS terminal should be modified to use WGS-84 for its geodetic position calculations.

5.8.2 Impact

Not converting to WGS-84 will introduce position errors of as much as 90 feet in some locations to the JTIDS geodetic calculations.

5.8.3 Discussion

The GPS has been using the WGS-84 (rather than the WGS-72) spheroid model since 1 January 1987. Deployment of all 24 GPS satellites is expected by 1995, depending upon approval of funding. The 18-satellite constellation is planned to be operational by September 1990, and the 3 active spares by November 1990 (Klass, October 1987[60]).

With 24 satellites in position, every location on the earth's surface can "see" 4 satellites. Twenty-four is the number of satellites required for accurate positioning (3 dimensions plus a time fix) (Widnall, January 1982[61]). If only 18 satellites are in position, some earth locations can "see" only 3 satellites and this situation implies an outage.

The WGS-72 and -84 models differ by approximately 5 feet over most of the earth's surface. However, the difference approaches 90 feet in some places. Implementing the 1984 model in the JTIDS terminal is expected to require a change to only the following two NICP computer program parameters: semi-major axis and eccentricity squared (Post, April 1987[62]).

5.8.4 Status

The Navy has agreed to propose to the JTIDS Message Standards Working Group (JMSWG) changing the JTIDS terminal spheroid model from WGS-72 to WGS-84.

5.8.5 Action Items

The solution to this problem will require the following actions by the Navy and the Singer Company.

Navy. The Navy took an action item to propose the change from WGS-72 to WGS-84 to the JMSWG (Ault, April 1987[63]).

Singer. Singer agreed to make the necessary changes following receipt of Navy approval (Ault, April 1987[64]).

6.0 SUMMARY

The task of integrating the RELNAV functions in the Navy shipboard JTIDS terminal with the ship's navigation data sensor systems, the TOA-measurement message reception/transmission system, and the selection of earth model chosen for navigation calculations has been largely successful. However, there remain a number of issues in each of these three areas which have not been completely resolved.

In each case, a short-term solution has been proposed. "Short-term" means that the solution will be implemented by FQT-4. In many cases, the short-term solution resolves the issue. In all cases, the terminal is expected to be operable based upon the short-term solution, and will, therefore, be ready for TECHEVAL and OPEVAL. If the issue is not resolved by the short- term solution, then a long-term solution has been proposed. The time frame for completion of each long-term solution has not been stated.

6.1 NAVIGATION SYSTEM DATA INTEGRATION

There exists a strong correspondence between the navigation input parameters required by the Navy shipboard JTIDS terminal and the navigation output parameters currently available from the AN/WSN-5 and CVNS INS; however, the following problem areas remain.

a. INS data is needed to enable the terminal software to model the effects of EM-Log velocity damping.

b. Parameter values are needed to be used to determine terminal reset conditions.

c. The magnitude of the AN/WSN-5 wander angle must be made available to the terminal.

d. Implementation of the Joseph-form of the Kalman filter to enable TOA-only mobile mode for Navy aircraft, as well as ships, has yet to be completed.

Issues b and d are expected to be resolved by FQT-4. Issues a and c can be resolved in the long term by appropriate modifications of the INS navigation output parameter interface. In each case, a short-term solution is being pursued. The individual short-term solutions are explained in the paragraphs below, and the short and long-term solutions are summarized in table 6-1.

6.1.1 Electromagnetic Log Velocity Damping Model

To enable the terminal software to model the effects of EM-Log velocity damping, the C²P will monitor the AN/WSN-5 damping mode indicator as a discrete signal and forward its value to the terminal. The reference velocity will be calculated by the C²P from the INS ownship speed and ownship heading. It will be passed to the terminal. The terminal will employ the appropriate INS damping mechanization equations, constants, and gains to model the effect of EM-Log velocity damping.

6.1.2 Terminal Reset Conditions

The parameter values under which a terminal reset occurs due to invalid data will be counted independently for geodetic and relative grid navigation. Validity failure covariance matrix adjustments will be made as a function of the DR type. Further, RTT failures

Table 6-1. Integration issue solution summary.

Issue	Short-Term Solution	Long-Term Solution
FM-Log Velocity Damping Model	CP will monitor INS discrete signal & notify terminal of damping mode change	INS to external computer interface will be modified to provide a damping mode indicator
	CP will calculate reference velocity for the terminal	Same as Short-Term-Solution
	INS damping mechanization will be modeled in the NICP by FQ1-4	Same as Short-Term-Solution
Terminal Reset Conditions	Independent NAV data validity checks implemented by FQ1-4	Resolved by Short-Term Solution
	NADC to provide estimates of INS intertial dropout periods to Singer	
Velocity and Tilt Corrections Availability	CP will monitor the IGR indicator & notify the terminal of a reset	Resolved by Short-Term Solution
	NICP will model the velocity and tilt corrections as process noise	
Wander Azimuth Navigation Data Availability	Navy will supply Singer with needed CVNS & gyro data	AN/WSN-5 to external computer interface will be modified to provide the wander angle
		CP will pass the wander angle to the terminal via an existing TIM parameter
Navigation & RELNAV Data Time Tagging	Resolved	Resolved
Message Transmission & Navigation Computations	Cable & NFA delays added to NICP software by FQ1-4	Resolved by Short-Tem Solution
	Lever-arm compensation algorithm added to NICP software by FQ1-4	
TOA-Only Mobile mode	Joseph-form of Kalman filter in NICP for all Navy platforms by FQ1-4	Resolved by Short-Term Solution
Conversion to WGS-84 Model	Continue using WGS-72 model	Proposal to JMSWG to change to WGS-84 model
		Modify NICP software to use WGS-84 model upon JMSWG approval

will not be counted toward a navigation reset in the passive mode. Also, the time that the SICP will allow between successive valid data arrivals before a reset is initiated will be determined from estimates of the INS average inertial dropout period lengths.

6.1.3 Wander Azimuth Navigation Data Availability

The absence of the AN/WSN-5 wander angle is a serious problem for the Navy. In the short term, Singer will model the AN/WSN-5 as a north-slaved system. However, the JTIDS navigation output data will not be applicable to platforms operating above +60 degrees or below -60 degrees latitude.

6.1.4 TOA-Only Mobile Mode

The current status of providing TOA-only mobile mode for ships alone will be improved to include this mode for aircraft as well. This will be accomplished by modifying the NICP software to use the Joseph-form of the Kalman filter.

6.2 TIME-OF-ARRIVAL MEASUREMENT MESSAGE SYSTEM INTEGRATION

Compensation for TOA-measurement message reception and transmission delays through the antenna-to-terminal cables will be included in NICP software by FQT-4. Further, lever-arm compensation will be added by FQT-4.

6.3 JTIDS NAVIGATION EARTH MODEL

The planned conversion to WGS-84, upon approval of the JMSWG, will resolve the position error issue which could occur from using two spheroids, WGS-72 and WGS-84, as earth models.

7.0 RECOMMENDATIONS

The issues in the nine remaining areas will be resolved either in the short term or through eventual modifications to the INSs or the JTIDS terminal in the long term. However, the Navy should monitor the resolution status of these issues to assure itself that each issue is resolved as planned. The primary remaining navigation data integration challenge is to test the terminal for proper operation in the Navy shipboard navigation environment.

8.0 ENDNOTES*

Executive Summary

1. Singer, March 1983
2. _____, January 1988

Section 1.0

1. JINTACCS, January 1986
2. OS 516, October 1986
3. Darron, February 1988
4. Singer, April 1988, paragraph 20.4.2.20

Section 2.0

Not applicable

Section 3.0

1. Singer, March 1983
2. _____, January 1988
3. _____, March 1983, paragraph 3.2.1.5.4.5
4. _____, January 1988, paragraph 3.2.1.5.4.5.6
5. _____, January 1988, paragraph 3.2.1.5.2.1
6. _____, January 1988, paragraph 3.2.1.5.2.1
7. _____, January 1988, paragraph 3.2.1.5.4

Section 4.0

1. Singer, April 1988, paragraph 30.8.1.7.2
2. _____, April 1988, paragraph 30.8.1.7.2
3. NAVSEA, August 1982
4. _____, March 1987

Section 5.0

1. Singer, October 1987, item 14
2. Singer, April 1988, paragraph 30.8.1.7
3. Singer, April 1988, 30.8.1.7
4. Ault, 1 June 1987, item 18
5. Zivich, January 1988
6. Ault, July 1987, attachment 1, item 5
7. _____, 30 June 1987, paragraph 5.1.3
8. Singer, April 1987, attachments 2 and 3
9. Singer, June 1987, page 8
10. Ault, 1 June 1987, attachment 1, issue 16

*Full citation for each document listed here appears in Section 2.0, "Applicable Documents."

8.0 Endnotes (Continued)

Section 5.0 (Continued)

11. _____, July 1987, attachment 1, item 10
12. Singer, April 1988, paragraph 30.8.1.7.2
13. Ault, April 1987, attachment 2, item 8
14. Singer, June 1987, page 2
15. Ault, April 1987, attachment 2, item 8
16. _____, July 1987, attachment 1, item 10
17. Singer, October 1987, item 4
18. _____, June 1987, page 6
19. Engelhart, March 1987
20. Zangaro, March 1986
21. Ault, July 1986
22. Singer, April 1987, attachment 3
23. _____, April 1987, attachment 3
24. Ault, 1 June 1987, attachment 1, item 19
25. NADC, May 1988
26. Ault, April 1987, attachment 6, item 1
27. Piazza, December 1986, attachment 4, item 1
28. Singer, October 1987, item 1
29. Zivich, January 1988
30. Ault, 1 June 1987, item 17
31. Zivich, January 1988
32. Singer, January 1988, paragraph 3.2.1.5.4
33. _____, February 1987, issues 3 and 8
34. Ault, April 1987, item 8
35. NADC, 1986, proposed change 60.6.4
36. Singer, April 1988, paragraph 30.8.1.7.2
37. Zivich, January 1988
38. Singer, April 1988, paragraph 30.8.2.6.2
39. Veda, July 1986, pages 8-13
40. Post, February 1987
41. Singer, March 1987, volume I, page 196
42. Ault, 1 June 1987, attachment 1, item 20
43. _____, July 1987, attachment 1, item 7
44. Piazza, December 1986, attachment 4, issue 6
45. _____, December 1986, attachment 4, issue 7
46. Singer, February 1987, issue 7
47. _____, April 1988, paragraphs 20.4.2.19-20
48. _____, April 1988, paragraph 20.4.2.22
49. _____, April 1988, paragraph 20.4.15
50. Zivich, January 1988
51. Ault, April 1987, attachment 3, issue 11
52. Singer, April 1988, paragraph 30.8.1.7.2
53. _____, June 1987, item 1.b
54. _____, June 1987, page 8
55. _____, March 1983, paragraph 3.2.1.5.4.5.6
56. Olenick, April 1986

8.0 Endnotes (Continued)

Section 5.0 (Continued)

57. _____, April 1986
58. Singer, July 1987
59. _____, June 1987, page 5
60. Klass, October 1987
61. Widnall, January 1982, page 8
62. Post, April 1987, attachment, page 3
63. Ault, April 1987, attachment 3, item 9
64. _____, April 1987, attachment 3, item 9

Section 6.0

Not applicable

9.0 GLOSSARY

9.1 TERMS

1553B bus	A digital time-division command response multiplex data bus: MIL-STD-1553B.
Aircraft Carrier Navigation System	An inertial navigation system for an aircraft carrier. Specifically, an adapted Dual Mini-Shipboard Inertial Navigation System (SINS).
Attitude	The roll, pitch, and heading of a platform.
Azimuth	The angle (measured clockwise) between a distant object and (true or magnetic) north.
Band	A contiguous range of radio frequencies.
Circular Error of Probability	For an estimated location (x,y), it is the radius Error of the smallest circle centered at (x,y) which has a 50% probability of containing the true location.
Combat Direction System	Combat decision and control system.
Command and Control Processor	Navy shipboard computer system which acts as a Control host computer to the JTIDS terminal.
Course	The direction of movement of a platform.
Covariance Matrix	A matrix (A) in which the A(i,j) entry is the statistical variance between row and column components A(i) and A(j), respectively.
Damping	The activity of diminishing the amplitude of a signal.
Dead Reckoning	A method of estimating the location of a platform, without the aid of celestial or satellite observations, from its course and the distance traveled over that course.
Distributed Time Division Multiple Access	Navy-developed communication system that provides jam-resistant secure communication link upward-compatible with Link-11, Link-4, and TDMA.
Electro-magnetic log	An electromagnetic instrument used to measure a ship's speed through the water.
Fix	A position determined from terrestrial, electronic, or astronomical data.
Flywheel	To hold a state for a period of time irrespective of the arrival of new data.

GLOSSARY (CONTINUED)

Formal Qualification Test	Final test of a product before acceptance for Qualification delivery by the procuring agency.
Gain	A multiplication or improvement factor.
Geodetic Position	Location of an object in the earth's latitude, longitude and altitude coordinates.
Geoid	An equipotential model of the earth's surface that coincides with mean sea level over the oceans.
Gimbal	A contrivance for permitting a body to incline freely in any direction.
Greenwich Mean Time	Mean solar time at the meridian at Greenwich, England.
Global Positioning System	A collection of (24 planned) satellites placed in orbit so that a fix using 4 satellites may be taken from any position on earth.
Group Delay	The average of a set of delays through the Notched Filter Assembly experienced by the 51 transmission frequencies in the JTIDS band.
Gyrocompass	A compass consisting of a continuously driven gyroscope whose spinning axis is confined to a horizontal plane, so that the earth's rotation causes it to assume a position parallel to the earth's axis, and thus point to true north.
Heading	The direction in which the longitudinal axis of a platform is pointed.
Host	Pertaining to the platform on which the JTIDS terminal is installed.
Interface Control Document	A document which specifies the format and exchange rules for signals or messages passed between two pieces of equipment, e.g. computers.
Identification, Friend or Foe	A military communication system for exchanging information on friendly or hostile forces.
Inertial Measurement Unit	The sub-unit in an inertial navigation system that measures the magnitude of the host platform's acceleration.
Inertial Navigation System	A navigation system which provides position, velocity and attitude data based upon the operation of sensors aboard the platform.

GLOSSARY (CONTINUED)

Kalman Filter	One of a class of linear minimum-error-variance sequential state estimation algorithms, originally developed by R. E. Kalman.
Lever Arm	The vector between two points, in particular an antenna and the ship's reference point.
Link-4A	A UHF channel used as an air control link between ships, E-2Cs and F-14s.
Link-11	A secure, HF UHF EHF channel used for sharing track data, establishing gridlock, and for sending force orders, status and intelligence information.
Link-16	A high-capacity, secure, jam-resistant, channel for data transfer between battle force units.
Mean Sea Level	The average height of the surface of the sea for all stages of the tide.
Mechanization Equations	Mathematical equations and formulas to perform a specific function.
Metacenter	The point of intersection of the vertical through the center of buoyancy of a floating body with the vertical through the new center of buoyancy when the body is displaced however little.
Multipath	The multiple paths that a radio wave may take from a single source to an antenna, because of reflection from sea or sky. The path length difference may cause a time delay in the signal's arrival over one path as compared to another.
Multiplex	Pertaining to a system of transmitting several message over the same channel.
Nautical mile	Maritime measure of distance (6076 feet).
Navigation	Determination of a platform's position and velocity relative to some reference coordinate frame.
Notch Filter Assembly	An electronic device used to minimize the JTIDS broadcast band interference on the two IFF sub-bands.
Net Interface Computer Program	The computer program in the JTIDS terminal that performs the system-wide network communication and navigation functions.
Over-The-Horizon	Pertaining to an object which is not in line-of-sight because of the earth's curvature.

GLOSSARY (CONTINUED)

Ownship	Referring to the ship under discussion.
Pitch	The rotation of a platform about its lateral axis.
Precise Participant Location and Identification	A JTIDS message for communication between platforms, whose contents identify the sender and and the sender's perceived position.
Redlined	Changes marked by hand (in red) directly in a document.
Reference Velocity	North and east components of ownship speed.
Relative Navigation	Determination of a platform's position and velocity relative to a common grid system, positioned on the earth's surface at an arbitrary, but fixed location.
Relative Position	Location of one platform with respect to another independent of their location on an absolute earth coordinate system.
Radio Frequency	Communication channel using a band of the radio spectrum as the carrier.
Roll	The rotation of a platform about its longitudinal axis.
Round Trip Timing	A method of achieving JTIDS time synchronization between two platforms by sending and receiving a specified set of messages.
Singer	The Singer Company, Electronic Systems Division.
Sub-band	A radio frequency band which is contained within another band.
Sub-optimal Filter	A filter which produces less than optimal error for its estimation states.
Subscriber Interface Computer Program	A JTIDS terminal computer program designed and initialized to interface the terminal to its host platform.
Systems Integration Facility	JTIDS terminal multi-platform integration testbed located at NOSC.
System Segment Specification	System requirements specification document.
Tilt	Measure of misalignment of an inertial system.
Time Division Multiple Access	Access to a communication channel is allocated in predefined time slots.

Time of Gyro Reset	Time that the gyrocompass is realigned.
Terminal Input Message	Any number of formatted messages sent by the C^2P to the JTIDS terminal over the 1553B bus.
Time of Arrival	Time that a message arrives at a platform. Because the time of transmission of some classes of messages is known, the distance traveled can be calculated knowing the message's time of arrival at the receiving platform.
Terminal Output Message	Any of a number of formatted messages sent by the Output JTIDS terminal to the C^2P over the 1553B bus.
Wander Angle	The (small) amount that the orientation of an inertial navigation system is allowed to deviate from true north.
World Geodetic System	A number of models of the earth's natural or physical surface. The specifications of these models vary by year of definition (e.g., WGS 1972, WGS 1984) and by type (e.g., ellipsoid, geoid).

9.2 ACRONYMS AND ABBREVIATIONS

ACDS	Advanced Combat Direction System
AEGIS	Navy Advanced Surface-to-Air Missile System
AF	Air Force
AFB	Air Force Base
AIU	Antenna Interface Unit
AN WSN-5	Inertial Navigation Set
C^2P	Command and Control Processor
CAP	Combat Air Patrol
CDR	Critical Design Review
CDS	Combat Direction System
CEP	Circular Error of Probability
CG	Guided Missile Cruiser
CPU	Central Processing Unit
CV	Aircraft Carrier
CVNS	Aircraft Carrier Navigation System
DDG	Guided Missile Destroyer
DR	Dead Reckoning
DTDMA	Distributed Time Division Multiple Access
EM-Log	Electromagnetic Log
ESD	Electronic Systems Division

GLOSSARY (CONTINUED)

fps	Feet Per Second
FQT	Formal Qualification Test
GMT	Greenwich Mean Time
GPS	Global Positioning System
gyro	Gyrocompass
Hz	Hertz
ICD	Interface Control Document
IFF	Identification, Friend or Foe
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
IU	Interface Unit
JMSWG	JTIDS Message Standards Working Group
JPO	Joint Program Office
JTIDS	Joint Tactical Information Distribution System
LOS	Line-Of-Sight
MPIT	Multiplatform Integration Testing
ms	Millisecond(s)
MSL	Mean Sea Level
MUX	Multiplex
NADC	Naval Air Development Center
NAV	Navigation
NAVSEA	Naval Sea Systems Command
NFA	Notch Filter Assembly
NICP	Net Interface Computer Program
nmi	Nautical mile
NOSC	Naval Ocean Systems Center
ns	Nanosecond(s)
NTDS	Naval Tactical Data System
OPEVAL	Operational Evaluation
OTH	Over-The-Horizon
PMA	Program Manager at Naval Air Systems Command
PDR	Preliminary Design Review
PMW	Program Management Office at SPAWAR
PPLI	Precise Participant Location and Identification

GLOSSARY (CONTINUED)

R T	Receiver Transmitter
RDT&E	Research, Development, Test, and Evaluation
RELNAV	Relative Navigation
RF	Radio Frequency
RNKF	RELNAV Kalman Filter
RNWG	RELNAV Working Group
RTT	Round Trip Timing
SICP	Subscriber Interface Computer Program
SIF	Systems Integration Facility
SPAWAR	Space and Naval Warfare Systems Command
SSS	System Segment Specification
TADIL	Tactical Digital Information Link
TCS	Tactical Communications Systems
TDMA	Time Division Multiple Access
TECHEVAL	Technical Evaluation
TGR	Time of Gyro Reset
TIM	Technical Interchange Meeting
	Terminal Input Message
TOA	Time Of Arrival
TOA-only	TOA-measurement message-only mobile mode
TOM	Terminal Output Message
USAF	United States Air Force
WGS	World Geodetic System