LOAN DOCUMENT

PHOTOGRAPH THIS SHEET

LEVEL

INVENTORY

0

DTIC ACCESSION NUMBER

Next Generation Strategic Submarine Nav. ...

DOCUMENT IDENTIFICATION

2000

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

DISTRIBUTION STATEMENT

HANDLE WITH CARE

ACCESSION FOR
NTIS GRA&I ☑
DTIC TRAC ☐
UNANNOUNCED ☐
JUSTIFICATION

BY
DISTRIBUTION/
AVAILABILITY CODES

DISTRIBUTION	AVAILABILITY AND/OR SPECIAL	
A-1		

DISTRIBUTION STAMP

DATE ACCESSIONED

DATE RETURNED

20010201 042

DATE RECEIVED IN DTIC

REGISTERED OR CERTIFIED NUMBER

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-FDAC

DTIC FORM JUN 90 70A

DOCUMENT PROCESSING SHEET

PREVIOUS EDITIONS MAY BE USED UNTIL STOCK IS EXHAUSTED.

LOAN DOCUMENT

NEXT GENERATION STRATEGIC SUBMARINE NAVIGATOR

CDR Mark J. Ringlein
Navigation Branch Head
Strategic Systems Programs, United States Navy

Neal J. Barnett
Marvin B. May
Applied Research Laboratory, The Pennsylvania State University

ABSTRACT

For the last forty-five (45) years, Strategic Systems Programs (SSP) has been entrusted with total life cycle responsibility for the United States and the Royal (United Kingdom) Navy's Strategic Submarine (SSBN) launched ballistic missile weapons systems. SSP's successive development of POLARIS, POSEIDON and TRIDENT Strategic Weapons Systems (SWS) has driven the development of high performance navigation technology for over forty (40) years. The future challenge is to sustain this capability over the next forty (40) years. This will involve addressing such issues as aging of components and obsolescence as well as affordability of repair and maintenance. To meet this formidable challenge, SSP has laid out a roadmap that will continue to advance the state-of-the-art of navigation. This paper discusses the SSBN Navigation Subsystem of the future, starting with an initial upgrade to reduce system complexity and life cycle costs through the application of Commercial-Off-The-Shelf (COTS) electronics referred hitherto as D5 SPALTED Navigation. Science and Technology (S&T) programs that will provide the key sensors and system mechanizations for the next generation system are described, as well as geophysical navigation efforts to provide extended covert position fix capabilities.

BACKGROUND

The Secretary of the Navy established the Strategic Systems Programs (SSP) on 17 November 1955 as a Direct Reporting Program Manager. The primary mission of SSP is to design, develop, produce and support submarine launched ballistic missile weapons systems. SSP successfully developed and deployed a series of ballistic missile systems with increasing range and accuracy, which serve as the principle US strategic deterrent as well as the UK's sole nuclear weapons delivery system. The first of these missile systems was POLARIS, which was deployed in 1960 aboard the USS George Washington (SSBN 598). This was followed by more capable POSEIDON (C3), TRIDENT I (C4), and most recently TRIDENT II (D5), an even more accurate and longer range ballistic missile, now deployed on US OHIO Class and UK VANGUARD Class Fleet Ballistic Missile Submarines SSBNs) patrolling in the broad ocean area. (Figure 1). A planned Life Extension Program will enable the TRIDENT Submarine and SWS to operate well beyond 2040.

Figure 1. U. S. Navy SSBN

In support of a missile launch, the mission of SSP's Navigation Branch is to provide sustainable, affordable, highly accurate and highly available covert navigation information. This includes the provision of submarine velocity, position, attitude, time and gravity data to the missile fire control system. This navigation mission at SSP has driven the development of high performance navigation technology for over forty (40) years as demonstrated by the unparalleled performance of the current TRIDENT Navigation Subsystem.

TRIDENT COMMONALITY PROGRAM (TNCP) NAVIGATION SUBSYSTEM

The current Fleet Submarine Strategic Navigation Subsystem on the Ohio Class Submarine is designated the Trident Navigation Commonality Program (TNCP) Subsystem (Figure 2). The TNCP Navigation Subsystem is briefly described as follows:

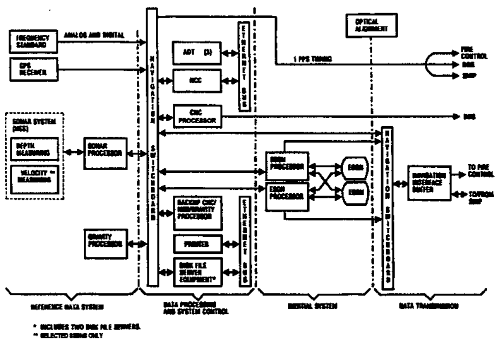

Figure 2. TNCP Navigation Subsystem

The heart of the TNCP Navigation Subsystem is the Electrostatically Supported Gyroscope Navigator (ESGN) which is the world's most accurate inertial navigator. (Figure 3) The ESGN is a space stabilized four gimbal inertial navigator. It consists of a binnacle containing the stable platform and the inertial instruments, an electronic equipment console, and a separate processor to perform the platform control, navigation, and calibration functions. Hull -mounted, redundant EM Logs provide an independent velocity reference for damping Schuler oscillations. To increase navigation subsystem reliability and availability, there are two fully redundant ESGNs. The selected Master ESGN provides the submarine navigation information to the missile fire control subsystem.

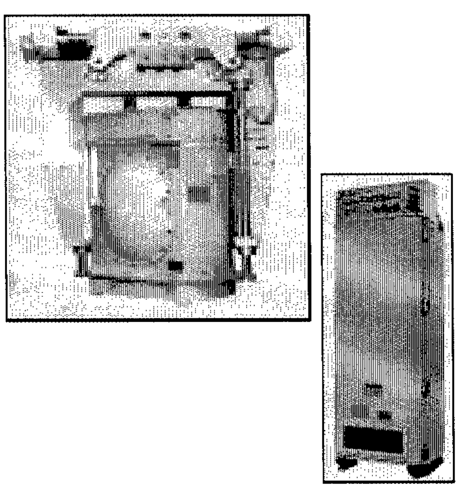

Figure 3. ESGN

The navigation subsystem also includes equipments that provide position fix information for resetting the inertial system and a correlation sonar that provides independent corrections to the inertial navigator's velocity outputs to Fire Control.

GPS or bathymetry provides Independent position fix information. The GPS system consists of an antenna system and a GPS electronics cabinet containing the GPS receiver. Computations to obtain position fixes, satellite selection, etc. are performed in a separate processor within the Central Navigation Computer (CNC).

A Navigation Sonar System (NSS) (Figure 4.) does double duty by providing both a bathymetric fix capability and velocity measurements. The NSS consists of hull-mounted, redundant TR-143 transducers and a 16-channel hydrophone array. In addition, there are two electronic consoles and a dedicated processor for signal control and processing. Depth measurements provided by the TR-143 transducer, along with stored bathymetric maps, are processed through automated map matching algorithms for Bathymetric Position Fixing. Velocity measurements are developed by signals received by the 16-channel hydrophone array from the TR-143 transducer utilizing a correlation technique.

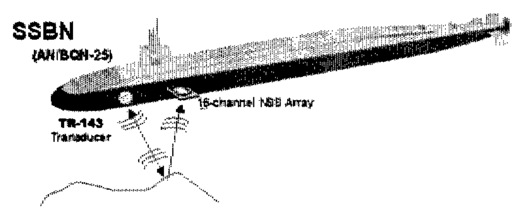

Figure 4. Navigation Sonar System (NSS)

The CNC performs processing functions associated with overall navigation subsystem management, performance monitoring, auxiliary display, data recording, and input-output data management. It also performs the inertial navigator reset processing. A separate computer processes stored gravity map data to generate vertical deflection corrections for the inertial navigators and to provide the gravity data required by Fire Control. An additional (sixth) processor serves as a backup to the CNC, NSS and gravity computers.

The Navigation Subsystem is controlled and operated by a Navigation Control Console (NCC). In addition, there are two Auxiliary Display Terminals (ADTs) that can be used as backups to the NCC. The Navigation

Interface Buffer (NIB) in a separate cabinet functions as the interface between navigation and other ship systems.

Frequency Standard (FS) equipment provides precision frequency and discrete time signals necessary for navigation subsystem processing as well for fire control system processing.

A Disk File Server (DFSE) cabinet contains the optical and magnetic drives and performs the navigation subsystem file server functions.

Navigation subsystem interconnection is accomplished via three switchboard cabinets.

NAVIGATION ROADMAP FOR SUSTAINING THE STRATEGIC CAPABILITY

SSP's Navigation Branch has developed a stepped approach for sustaining the strategic submarine navigation capability beyond 2040. A roadmap of this plan is provided as Figure 5. and will be discussed in some detail in the reminder of this paper.

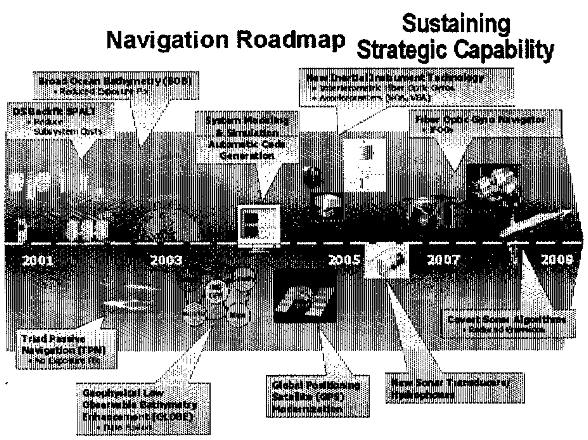

Figure 5. Navigation Roadmap

D5 SPALTED NAVIGATION SUBSYSTEM

The first step in this plan is an upgrade to the TRIDENT Submarine Navigation Subsystem as part of the TRIDENT Submarine D5 Backfit Program. This D5 SPALTED Navigation Subsystem (Figure 6.) is being implemented as a major cost reduction initiative and is currently under development. It is scheduled for a FY 2002 IOC on the USS Alaska (SSBN 732). The D5 SPALTED Navigation Subsystem is primarily a major COTS electronics upgrade to replace development item navigation system electronics that are part of the existing TNCP Navigation Subsystem.

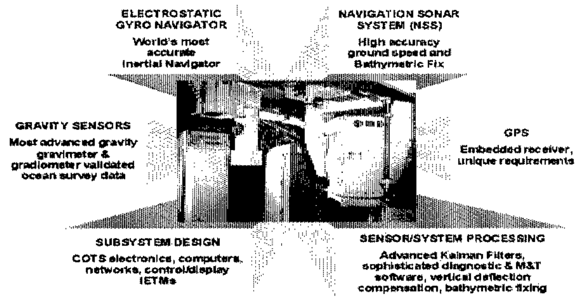

Figure 6. D5 SPALTED Navigation Subsystem

The D5 SPALTED Navigation Subsystem will provide the equivalent functionality and performance of the current TNCP Navigation Subsystem, but with significantly less equipment and complexity. (See Table 1.) The advantages are increased reliability, reduced maintenance and repair costs, and a reduction in the number of specialized personnel (and their associated training costs) required to operate and maintain the system. Using state-of-the-art, COTS electronics and open architecture, many of the individual equipments have been consolidated, and a high-speed data network using FDDI standard communication hardware has replaced numerous and complex interconnections.

Table 1. D5 SPALTED Navigation Subsystem Characteristics vice TNCP

Characteristic	D5 SPALT	TNCP
Major Equipments	8	22
Number of Modules	138	2665
COTS	112	15
Developed	26	2650
Series MTBF (Hrs)	2.0K	0.8K
Failures per Ship-Year (Diagnostic No-finds)	0.4	0.8
Documentation (Pages)	5,600 (Electronic)	18,600 (Print)
Training Time (Hrs)	150	760

The ESGNs will retain the same binnacles, but the Electronics Equipment Console (EEC) has been reengineered using COTS VME based hardware. The ESGN processing currently performed by a separate computer will be embedded in the new EEC. The navigation interface buffer cabinet electronics and software functions are also planned to be embedded in each new EEC. This is designated as the Navigation Interface Function (NIF).

Similarly, the two NSS equipment cabinets were extensively redesigned, modified and combined into one NAVAIDS Console. The NSS processor functions were also integrated into this new cabinet. Further, because of the recent strides in miniaturization, new dual redundant GPS receiver cards, the gravity processor functions, and the central computer functions will also be contained in the NAVAIDS Console.

The militarized NCC and ADTs are being replaced by three identical COTS workstations. The DFSE will be embedded in each of the workstations. One workstation will function as the NCC and the others will serve as backups and support routine maintenance and trouble shooting activities.

The Frequency Standard Equipment will be retained unmodified.

Most of the current Trident Navigation Subsystem and equipment software was reengineered using COTS software development tools. It is estimated that all the upgrades described herein will result in an estimated $400M life cycle cost savings for the D5 SPALTED Navigation Subsystem over that of the TNCP Navigation Subsystem. (Figure 7.)

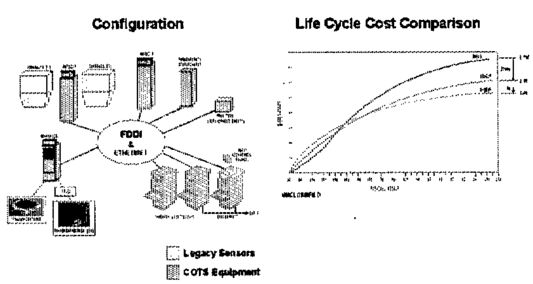

Figure 7. D5 SPALTED Navigation Subsystem Life Cycle Savings

NEW SUSTAINMENT INITIATIVES

Recently, a decision was made to extend the TRIDENT submarine hull life beyond2040. The heart of the TRIDENT Submarine Navigation Subsystem that supports the D5 Missile Weapon System is the ESGN. When designed, the service life of the existing ESGN was specified at 20 years with no modification. It is noted that only the ESGN electronics is being updated as part of the previously described D5 SPALTED Navigation Subsystem. Core instrument technology used in the ESGN binnacle includes Electrostatically Supported Gyros (ESGs) and Electromagnetic Accelerometers (EMAs) (Figure 8.) designed in the sixties and seventies. There is a risk that these components will not be supportable over the extended life of the TRIDENT program.

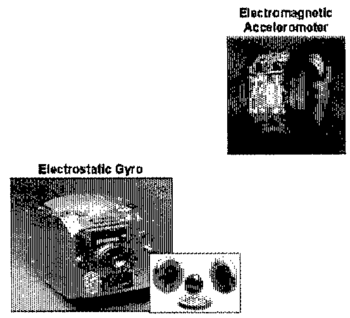

Figure 8. ESG & EMA

Accordingly, SSP is pursuing sustainment initiatives that address navigation hardware aging, maintenance and high cost of repair issues due to the TRIDENT life extension. These are shown on Figure 5. (Navigation Roadmap) and include: a) an Interferometric Fiber Optic Gyro (IFOG) development and test program to establish an affordable and producible replacement for the ESG; b) a high accuracy accelerometer development to establish an affordable and producible replacement for the EMA; c) system designs for the insertion of these technologies into the inertial navigator binnacle; and d) a new technology broadband frequency navigation sonar transducer to replace the expensive and no longer in production TR-143 NSS transducer.

The successful development of new core inertial technology will lead to the implementation of a new strategic submarine grade Fiber Optic Gyro Navigator (FOGN) as early as FY-2007. A roadmap for this FOGN development is shown in Figure 9.

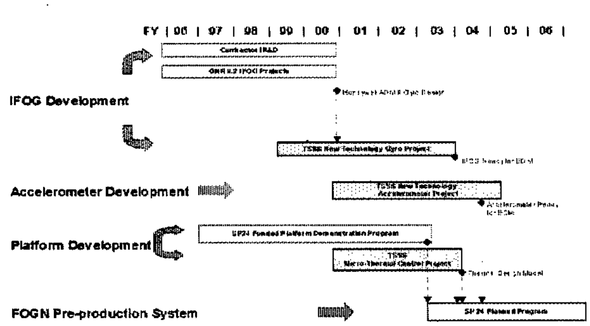

Figure 9. FOGN Development Roadmap

Interferometric Fiber Optic Gyro (IFOG) Development and Test Program

Over the years, the cost to support the ESGN has significantly escalated. The cost for each new build ESG is currently estimated at greater than $400K per gyro. (Note: the last build for ESGs was in 1987 and cost $348K per gyro). The repair cost for each ESG is currently $148K per gyro.

With Office of Naval Research (ONR) support a five-year exploratory development program was initiated in FY 96 to determine the feasibility of developing IFOG technology as an ESG replacement. The Submarine IFOG Development Program was accomplished by a Navy / Industry partnership and sponsored by both ONR and SSP. The Program was conducted by Boeing, using ARL as IFOG technical agent, NRL as IFOG technical consultant, and Honeywell as the contractor responsible for the design and fabrication of the IFOG Advanced Development Models (ADMs).

This Program was accomplished in two phases. The primary goal of the first phase was to reduce the optical head size (to about 3 inches in diameter) while maintaining the Angle Random Walk (ARW) at less than 300 micro-degree per root-hour (state-of-the-art performance level in 1996 with larger diameter gyros), using breadboard electronics. Results of comprehensive testing of the two ADM I IFOGs showed that this performance level was met and also identified needed performance improvements to be addressed in the second phase.

The objective of the second phase was to reduce the Angle Random Walk to Strategic Navigation System requirements, and reduce the electronics size such that three gyros would fit into a Boeing designed navigator testbed. Figure 10. shows a Honeywell developed ADM II IFOG, which meets the size requirement by combining the optical components and electrical circuits into a single package. To date, testing at ARL Penn State and Boeing of these ADM II gyros indicates that the ARW is within reach of the SSBN accuracy requirement. However, testing also showed large environmental sensitivities and scale factor trends which will be addressed as part of the follow-on DDR&E sponsored Technology for Sustainment of Strategic Systems (TSSS) Program that is described in the next paragraph.

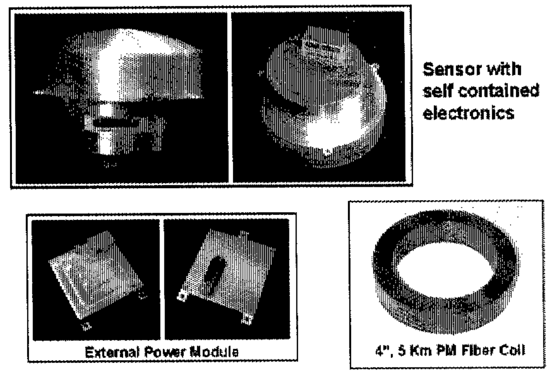

Figure 10. Honeywell ADM II IFOG

The TSSS Program New Technology Gyro (IFOG) Project was initiated in July 1999. The ADM II IFOG, as described above, will be used as a baseline for this TSSS Project that consists of Science and Technology (S&T) Tasks that mitigate design risk and provide for an IFOG that can be affordably produced (<$50K). These S&T tasks will pursue the development of an ESG replacement IFOG with significantly reduced temperature and temperature rate sensitivity; significantly reduced magnetic sensitivity; increased scale factor stability over long periods; and a broadband erbium fiber light source that provides significantly increased stable output power.

An engineering development phase for the IFOG is anticipated at the conclusion of the TSSS effort. IFOG performance achieved to date and expected performance improvements in these later stages of development are shown in Figure 11.

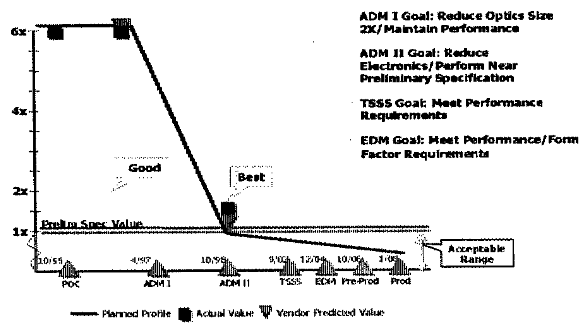

Figure 11. IFOG Performance

High Accuracy Accelerometer Development

As part of the TSSS Program, there is a Project for a high accuracy accelerometer development to establish an affordable and producible replacement for the EMA. This multi-year Project is planned to be accomplished in two phases. Phase I is to study and establish the most promising technology approaches and award contract(s) to industry. During Phase II, design, fabrication, and test of feasibility model accelerometers (two iterations) will be conducted. Performance in prototype test beds will also be evaluated.

FOGN System Development

In parallel with the above component development efforts, SSP has been supporting several initiatives exploring potential affordable system (stable element) mechanizations for insertion of IFOG and new accelerometer technology. A Stable Platform and Housing Technology Infusion Project (STIP)[1] was initiated in FY 97 at Boeing to serve as an experimental test bed. The STIP mechanization includes three (full freedom) axes, two conventional gimbals, a hybrid conduction/convection instrument mount thermal control system, and a local level trajectory (LLT) for the instrument mount in a continuously rotating autocompensation mechanization (CRAM). This mechanization incorporates autocompensation and coherent filter operation suitable to IFOG technology.

To date, the STIP has completed several navigation runs in the laboratory with promising results. Early in FY01, the STIP is scheduled to commence at-sea testing on SSP's Consolidated Support Ship[2], USNS WATERS (Figure 12).

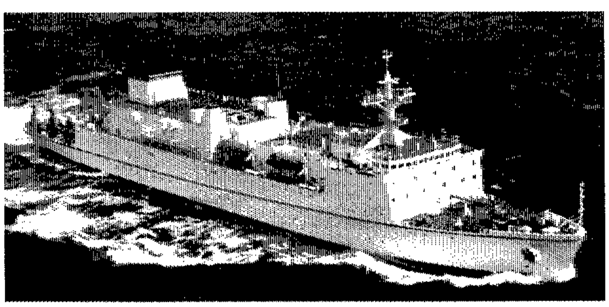

Figure 12. USNS WATERS

Recently, SSP initiated a Spherical Gimbal Demonstrator (SGD) Project at Boeing that investigates a stable platform mechanization that eliminates convection and fans in the vicinity of the instrument mount which is used in the ESGN and STIP. It is expected that test results will confirm that the SGD using conduction cooling will allow for improved microthermal control of the instrument mounts. The SGD features three (full freedom) axes, two spherical gimbals, a conduction-only instrument mount thermal control system, and a LLT for the instrument mount in a CRAM. The SGD is shown in Figure 13.

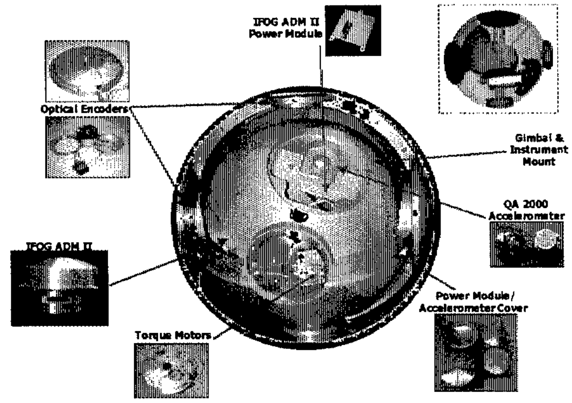

Figure 13. Boeing Spherical Gimbal Demonstrator (SGD)

A 3-year system level sustainment project was also recently initiated as part of the TSSS Program. The objective of this Micro-thermal Control Project is to develop an inertial navigation platform thermal modeling and design tool capability to reduce design iterations and allow for the rapid evaluation of new inertial instrument/instrument mount technologies. At the completion of this effort, a computer model and design tool will be available for the high accuracy inertial navigation system designer to allow for an affordable insertion of IFOGs into an inertial platform suitable for use in the TRIDENT submarine inertial navigation system.

As can be seen in Figure 9. (FOGN Development Roadmap), all the TSSS efforts feed into the follow-on FOGN Pre-production System Development.

New Technology TR-143 Transducer Replacement Development and Test Program

As mentioned earlier in this paper, the Navy's Strategic Systems Program (SSP) has also identified a need for an affordable replacement for the expensive and no longer in production TR-143 Transducer last Production Run in 1993) (Figure 14.) employed in the AN/BQN-25 NSS on SSBNs.

With Office of Naval Research (ONR) support, an initiative to build and test a low cost (< $150K) prototype TR-143 Transducer replacement was initiated in FY 99. The replacement transducer will retain all current performance while providing for improved covert capabilities.

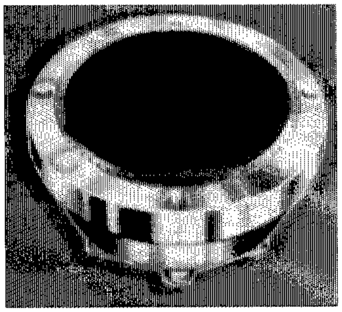

Figure 14. TR-143 Transducer

A survey of candidate new transducer element technologies (Figure 15.) was conducted and it was determined that the Magnetostrictive Piezoelectric Tonpilz (MPT) technology in development at ARL Penn State provided advantageous large bandwidth, high source level and high efficiency (Figure. 16.).

Material	*Advantages*	*Disadvantages*	*Status (re: broadband)*
MPT (Magnetostrictive Piezoelectric Tonpilz)	High Source Level High Efficiency ~60% at the Two Resonances	————	Elements and Arrays Built in Small Numbers
1-3 Composite	Moderate Source Level High Efficiency ~ 50%	Need Large Area For High Source Level Matrix Melting Issues at High Duty Cycles	Many Arrays Built
Single Crystal Relaxor Ferroelectric	High Source Level High Efficiency ~ 50%	Material Only Modeled DC Bias Required	Material Not Available for 2-5 Years
PVDF Copolymer	Very Thin (.080") High Receive Sensitivity	Low Source Level Low Efficiency	Raytheon is Using in Multiple Stacks
Cymbal Transducer	Thin (<.25") Moderate Source Level Efficiency Unknown	Pressure effects on Transducer Not Quantified	Need 1-2 years to Characterize

Figure 15. Candidate Transducer Element Technologies

Prior to a decision to design and fabricate a prototype TR-143 replacement transducer with MPT technology, ARL Penn State assessed the capability of the MPT transducer element technology to meet the submarine shock requirement via the conduct of a finite element analysis. Study results show that the MPT elements can withstand the TRIDENT Submarine Shock Spectra.

Three different 7-element MPT transducer arrays are currently being designed and fabricated for high power and shock tests. The results of this testing will be used to select the most appropriate MPT element for the TR-143 Replacement transducer. A full up TR-143 broadband Replacement Transducer will then be designed and fabricated in FY 01. This transducer will have the potential for improved bathymetric capabilities, specifically in the area of covert navigation. The new transducer is being designed to have sufficiently high source levels over a large bandwidth (fractional bandwidth approximately 200%) and will be capable of generating both low frequency broad beams and high frequency narrow beams. This new transducer will also retain the current capabilities and current performance of the existing TR-143 transducer. After bench testing, the prototype transducer will be integrated with the NSS electronics and tested at-sea on USNS WATERS. Results from these tests will determine the suitability of the prototype transducer for a follow-on SSBN test needed for Strategic Navigation Subsystem certification.

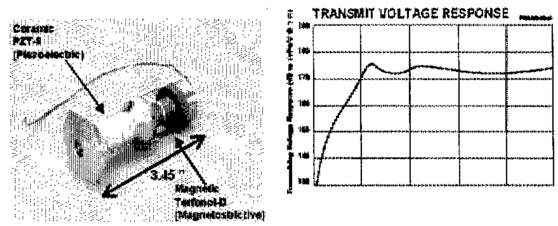

Figure 16. MPT Transducer Element

INITIATIVES THAT ADDRESS FUTURE WARFIGHTING CONCERNS.

Geophysical Navigation

The last remaining element of the Strategic Submarine Navigation Roadmap (Figure 5.) to be discussed is Geophysical Navigation. Geophysical Navigation (Figure 17.) involves the correlation of real-time sensor measurements with apriori surveyed maps of the corresponding geophysical quantities. The ability of performing this operation, and thereby bounding the inertial navigator's error growth, while staying submerged has made the pursuit of these techniques a continuing quest for submarine navigation. Analogous to Terrain Contour Matching (TERCOM) (1-2) used on cruise missiles, bathymetric navigation aboard FBM submarines has been employed for several decades (3). Demonstration of the concept feasibility of gravity magnitude submarine navigation was shown in the late 1970's (4D)[3] and a similar concept feasibility demonstration using scalar magnetometers was shown in the late 1980's[4]. Gravity gradiometer[5] (5) data has also been used within map matching algorithms aboard submarines in addition to applications for vertical deflection compensation and mass proximity estimation.

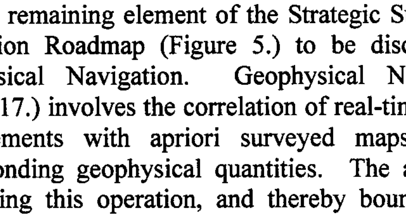

Figure 17. Geophysical Navigation

This section addresses three ongoing related efforts involved in extending the availability and cost effectiveness of geophysical navigation. The three efforts are Triad Passive Navigation (TPN)[6789 10] (6), Broad Ocean Bathymetry (BOB) [11](7) and Geophysical Low Observation Bathymetric Enhancement (GLOBE) (8). As will be refined subsequently, TPN and BOB, are TRIDENT initiatives being executed principally by Boeing and Lockheed Martin, respectively. GLOBE is a new initiative sponsored by the ONR that will focus on attack and strategic submarines as well as potentially some surface applications. This effort will be conducted by ARL Penn State. The following seven considerations are common to all geophysical navigation techniques and are examined from the standpoint of BOB, TPN and GLOBE. [12]

a) Survivability/Vulnerability: Each of the techniques strive for the ideal of a "port to port" navigation capability without approaching the surface or depending on radionavigation aids. Quantitative measures of effectiveness for survivability / vulnerability are complex and involve factors including the necessity for performing communications independent of navigation requirements and the ability of an adversary to detect and prosecute as a result of antenna exposure. Qualitatively, each of the techniques represents an alternative navigation strategy in consonance with the OPNAV/ONR thrust for Balance Navigation. Only TPN truly represents a fully passive capability and therefore represents the ultimate in covertness. BOB necessitates sonification and therefore theoretically presents some detection risk. BOB, in potential conjunction with the covert sonar mentioned earlier, and with the incorporation of the advanced pinging and power selection protocols, minimizes the probability of detection. Another issue related to survivability/vulnerability is the compromise of the locations of discrete sites, which would enhance the effectiveness of an adversary's loitering strategy. BOB has addressed this issue by expanding the number of potential sites (Figure 18). Both TPN and GLOBE are nominally operated in a spatially continuous fashion subject to availability considerations.

b) Survey Logistics: As all techniques require apriori maps, their availability and accuracy is often the most critical consideration. For TRIDENT applications the Naval Oceanographic Office over the past 35 years has performed the most detailed gravimetric and bathymetric ship surveys. These will be the cornerstones for TPN and BOB. As shown in Figure 19, the preponderance of ship surveys was accomplished prior to the GPS era. The relative and absolute (registration) pre-GPS era navigation errors are a dominant and common source of error for both TPN and BOB. The expense, however, of an open ocean new ship surveys would be prohibitive. Therefore, techniques for reregistering any survey navigation offsets and examining auxiliary databases will be studied. As also shown in Figure 19, satellite altimetry sources have grown in recent years, and there is some expectation that they can be used for determination of longer wavelength gravimetric and bathymetric features.

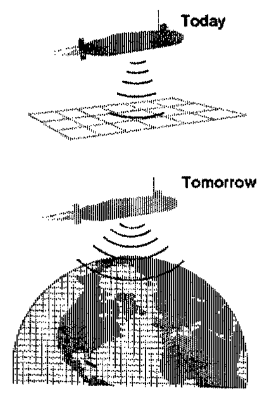

Figure 18. Broad Ocean Bathymetry (BOB) Concept

c) Site Availability: This consideration involves the suitability of features that have the necessary gradients and asymmetry to perform unique map matching. These analyses must take into account both the distribution and density of sites as a function of the quality of the inertial navigator and the operational constraints of the platform. Studies have been performed for both TPN and BOB indicating which areas can be used to achieve requisite accuracies. Inherently, bathymetry has superior signature to noise ratios than gravimetry for which the high frequency signature power is exponentially decreased as a function of distance to source. GLOBE's objective includes combining, where appropriate for the platform, both bathymetry and gravity measurements/maps accounting for their theoretical and empirical correlations. For several reasons, including the availability of appropriate maps, the overall system availability utilizing the GLOBE approach will enhance the discrete availability of separately using gravimetry and bathymetry. In certain areas, for example, the slope of the topography is too high for a bathymetric return, but would be ideal for gravimetric fixing.

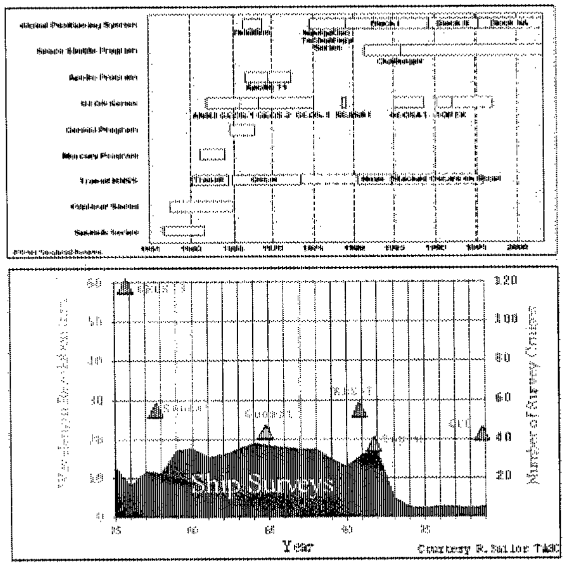

Figure 19. Ship Surveys

d) Equipment Considerations: TPN and BOB, and for many platforms GLOBE, will involve software modifications only. The combination of no new hardware and no new dedicated surveys make these approaches economical.

e) Software Algorithm Implementation: Fundamentally, most correlation navigation techniques employ first a correlation search algorithm to reduce the regions of uncertainty, followed by an Extended Kalman Filter for fine parameter estimation. One of the principal challenges from a system level standpoint is how to integrate separated functions such as TPN and BOB, along with other separated sensors such as GPS, into an efficient, synergistic, non-incestuous operating system. Although a centralized filter would ensure non-divergent filter behavior and would take advantage of commonality amongst the separate functions, the existence of legacy software (for TRIDENT), distributed contractor software development, and graduated funding profiles will probably mandate a combination of cascaded and federated filter arrangements.

f) Operational Constraints: Figure 20 indicates some of the myriad of factors that a submarine navigator would have to negotiate. Clearly an intelligent software fusion of these factors should be developed to make the decision making process more tractable. Inherent in the GLOBE concept is the coordination of navigation requirements with geophysical availability. Ultimately, a navigator should be able to make the seamless transition between the bipodal situations of no constraints on exposure or radionavigation availability to the eventuality when submerged operations and no acoustic emissions are dictated.

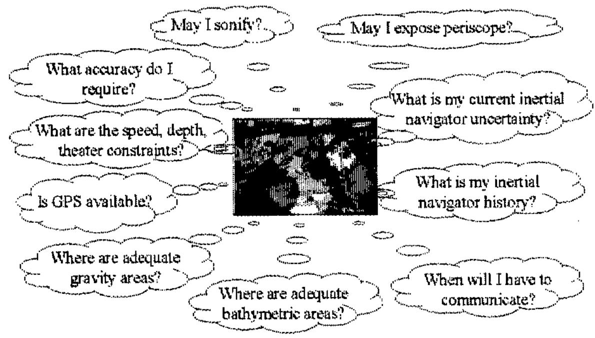

Figure 20. Operational Considerations

g) Concept Demonstration and Testing: In the development of most new capabilities, the extent of testing that is necessary is often underestimated. This is especially critical for Geophysical Navigation techniques because of the inherent spatial diversity of the geophysical phenomena. Simulation and modeling can provide extrapolations on performance projections but they necessarily categorize the entire world into a few province characteristics. Experience to date with Geophysical Navigation techniques has often found unique concerns in specific areas particularly when using survey maps created with diverse navigation references.

These geophysical capabilities will be complemented by the development of a secure sonar capability that will reduce submarine vulnerability to detection and utilizes the broadband transducer replacement for the TR-143.

SUMMARY

The mission of SSP's Navigation Branch is to provide sustainable, affordable, highly accurate and highly available covert navigation information in support of a Trident missile launch. This includes the provision of submarine velocity, position, attitude, time and gravity data to the missile fire control system. This has driven the development of high performance navigation technology for over 40 years and is reflected in today's TRIDENT Submarine having the world's most accurate inertial navigation system. Due to the extended life of the Trident submarine, SSP has developed a roadmap to sustain affordable navigation for the SSBN for the next 40 years. The first step in this plan will soon be implemented in the Fleet; the D5 SPALTED Navigation Subsystem (2002 IOC) is expected to provide a $400M life cycle cost savings via the utilization of COTs technology and reduced system complexity. Other steps in the plan have also been initiated and include: a) a development of a FOGN to replace the ESGN; b) a new technology broadband TR-143 Sonar Transducer replacement; and c) geophysical navigation initiatives to address future warfighting concerns.

---

[1] Heckman, D.W, Baretela, M, "Improved Affordability of High Precision Submarine Inertial Navigation by Insertion of Rapidly Developing Fiber Optic Technology", IEEE Plans, 2000

[2] Hertelendy, C., Barnett, N.J., Epstein, B., "The U.S. Navy Strategic Systems Programs Consolidated Support Ship (USNS WATERS) and its Capabilities as an At-sea Navigation test Vehicle", IEEE Plans, 1998

[3] May, M. B., "Gravity Navigation", IEEE Plans, 1980

[4] May, M.B. "A Submarine Magnetic Navigation Experiment" Joint Services Data Exchange, November 1992

[5] Metzger, E.H., Jircitano, A. , "Inertial Navigation Performance Improvement Using Gravity Gradient Matching Techniques," AIAA Paper 75-1092, Boston, Mass., Aug. 1975

[6] J.A. Lowrey, J.C. Shellenbarger, "Passive Navigation Using Inertial Navigation Sensors and Maps", Naval Engineers Journal, May 1997

[7] Hinrichs, P. R., "Advanced Terrain Correlation Techniques", IEEE PLANS 1976

[8] Clautice, W. , "FBM Navigation System", Journal of the ION, Vol. 25 No.1, Spring 1978

[9] Vajda, S., Zorn, A., "Survey of Existing and Emerging Technologies for Strategic Submarine Navigation", IEEE PLANS 1998

[10] May, M. B., "Geophysical Low Observation Bathymetric Enhancement", ONR Proposal BAA-00-006, 28 April 2000

[11] Moryl, J., "Advanced Submarine Navigation Systems", Sea Technology, Vol. 37, No. 11, November 1996

[12] A. Pue, Pritchett, J., "Robust Guidance and Navigation for Airborne Vehicles Using GPS/Terrain Aiding", IEEE Plans 2000

Government Disclosure Authorization Form

Disclosure authorization is required for all presentations. If this form is not received prior to the meeting the presentation will be canceled.

PART I

Name of Author(s) CDR MARK J. RINGLEIN, NEAL J. BARNETT AND MARVIN B. MAY

Title of Paper: NEXT GENERATION STRATEGIC SUBMARINE NAVIGATOR

Classification of Paper/Presentation (circle one) SECRET CONFIDENTIAL (UNCLASSIFIED)

Author's Signature: [signature]

****

PART II RELEASING OFFICIAL

Name of Releasing Official: CAPT DANIEL C. ELLIOTT

Title: TECHNICAL DIRECTOR (SP-20)

Address: STRATEGIC SYSTEMS PROGRAMS
NEBRASKA AVENUE COMPLEX 287 SOMERS COURT NW
SUITE 10041 WASHINGTON, DC 20393-5446

Telephone Number: 202-764-1566

The Releasing Office, with the understanding that all attendees have current security clearances and that all attendees have approved need-to-know certification, and that no foreign national will be present, confirms that the overall classification of this paper is UNCLASSIFIED and authorizes disclosure at the meeting.

Classified by: CAPT DANIEL C. ELLIOTT Declassify on: N/A

Distribution Statement: NONE (NO RESTRICTIONS)

Releasing Official's Signature: [signature] 9/25/00