

Navy Strategic Systems Program Range Instrumentation Support of SSGN Demonstration and Validation Test with USS Florida

Gregory M. Horstkamp, Jerome R. Vetter,
Charles J. McSoley, and Ward J. Szerlag

The guided missile submarine (SSGN) demonstration and validation (DEMVAl) program was a first-of-its-kind at-sea test of two Block III Tomahawk missiles from a modified Trident I (C4) ballistic missile submarine (SSBN). This article focuses on the test instrumentation provided by the Strategic Systems Program (SSP) and its purpose in support of the DEMVAL. SSP provided a launch area support ship (LASS) instrumented with two Weibel X-band Doppler tracking radars, the Advanced Dual Optical Tracking System, a telemetry recording system, and a full communications suite in support of the DEMVAL at-sea tests. The X-band radar and optical systems tracked each missile from broach to the end of boost-phase flight and primarily were responsible for characterizing the trajectory of debris falling from the missiles during this phase of flight. The telemetry system acted as a backup capability, supporting the recovery of missile telemetry from first motion through the boost phase of flight. The LASS also supported RF and underwater acoustic communications with the SSBN during the test and relayed video of the launches to SSP Headquarters in real time. The DEMVAL test was conducted in January 2003 within the Gulf of Mexico from the USS Florida (SSBN 728).

BACKGROUND

The guided missile submarine (SSGN) program has converted four Trident I (C4) ballistic missile submarines (SSBNs) to be capable of launching multiple Tomahawk missiles from up to 22 of the 24 existing Trident missile tubes. One of the primary SSGN design concerns in the

early phases of the program was the amount of debris that would fall back on the submarine during the launch of significant numbers of Tomahawk missiles. The SSGN is capable of launching more than 100 Tomahawk missiles sequentially. The goals of the SSGN demonstration

and validation (DEMVAL) test were to launch Tomahawk missiles from a submerged SSBN and to study the underwater launch risks to the Trident submarine. The DEMVAL test was conducted by the Naval Air Warfare Center Weapons Division (NAWCWD) Tomahawk flight-test community by launching two missiles in the Gulf of Mexico and using Eglin Air Force Base (AFB) recovery areas to score the missiles. The Navy Strategic Systems Program (SSP) that managed the SSGN conversion provided launch area instrumentation for the SSGN DEMVAL to collect Tomahawk debris data to better understand the underwater launch risks. This test instrumentation typically supports Trident II (D5) missile testing, and the SSGN DEMVAL was one of the first times that the SSP instrumentation was used to support another missile program. The instrumentation was used in a very specialized way in an attempt to quantify the trajectory of large Tomahawk debris as it released from the missile and fell to a water impact. The data from the test instrumentation aided validation of a probabilistic computer model of the debris phenomena used to evaluate SSGN Tomahawk launch risks.

INTRODUCTION

The SSGN DEMVAL test consisted of two Tomahawk Block III missile flight tests, conducted on 2 separate days and designated C-3: FT-252/FT-253. This article describes the performance of the instrumentation systems onboard the USNS *Waters* (T-AGS 45) during the SSGN DEMVAL at-sea tests conducted in January 2003 from the USS *Florida* (SSBN 728). SSP's instrumentation unit outfitted the launch area support ship (LASS) with two Weibel X-band Doppler tracking radars, in addition to the Advanced Dual Optical Tracking System (ADOTS), telemetry recording system, and full communications suite that supports Trident II (D5) missile flight tests. Observations of the Tomahawk wing plugs, inlet cover, and shrouds as they jettison to water impact were the primary objectives of SSP instrumentation. The secondary objectives were to track the missile

during boost-phase flight and to record telemetry until loss of signal. SSP instrumentation was not required after the missiles transitioned to cruise flight. NAWCWD was solely responsible for range safety, scoring, and recovery of the missiles.

The X-band radar and ADOTS camera were assigned to track each missile from broach to the end of boost-phase flight and primarily were responsible for characterizing the trajectory of inlet covers and shrouds falling from the missiles during this phase of flight. The telemetry system acted as a backup capability supporting the recovery of missile telemetry from first motion through the boost phase of flight. The LASS also provided RF and underwater acoustic communications with the SSBN during the test and relayed real-time video to SSP Headquarters via a satellite link. This article also contains lessons learned from the planning and execution of the launch area instrumentation support for these tests.

Figure 1 shows the USNS *Waters* serving as the LASS with flight-test support system (FTSS) equipment installed. LASS instrumentation included 1-kW and 240-W Weibel X-band radars; ADOTS; M345 FTSS telemetry processing units (TPUs), acoustic tracking system, and communications systems; a Ku-band satellite (KuBS) communication system; and T-AGS 45 surface-weather data-collection systems.

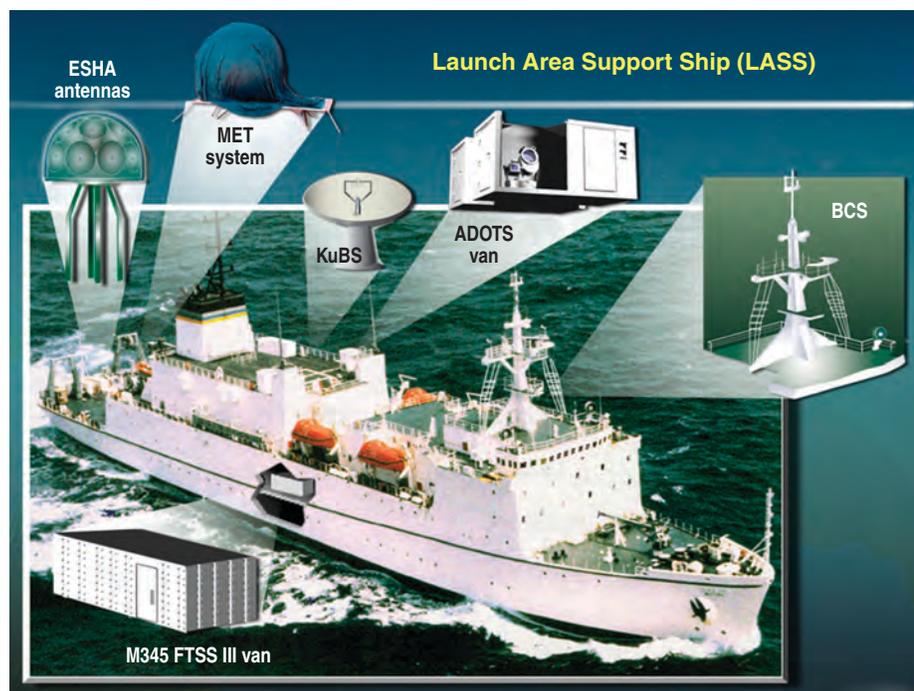


Figure 1. The USNS *Waters* is shown as the LASS with FTSS equipment installed. The electrically steered hemispheric array (ESHA) antenna and meteorology (MET) system are installed on the fantail. The KuBS, the buoyant cable antenna communication system (BCS) antennas, and the ADOTS optical system are mounted on the mid-deck. The control vans are installed inside the ship's high-bay compartment.

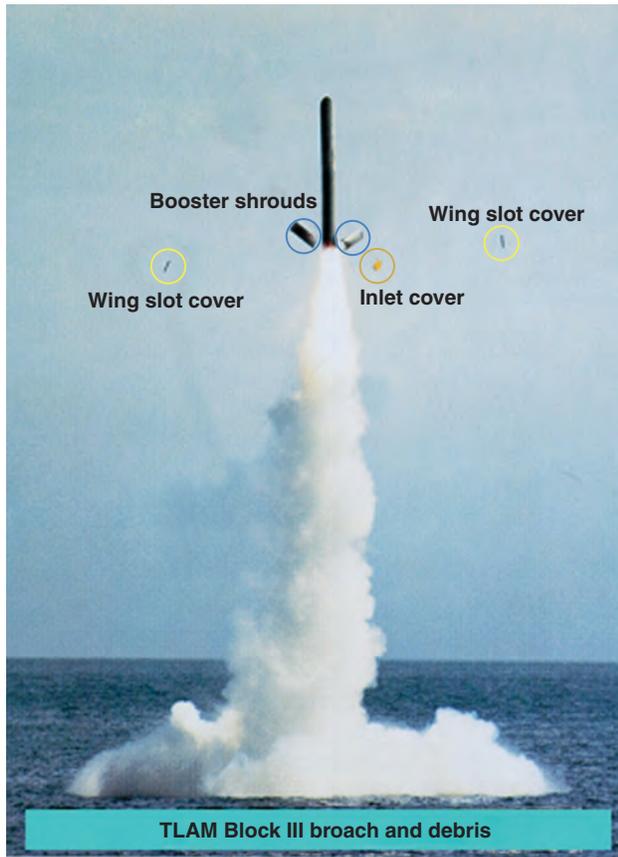


Figure 2. The Tomahawk Land Attack Missile (TLAM) Block III missile broach and significant debris are shown. The inlet cover, wing slot covers, and booster shrouds are deployed as the missile booster ignites.

Figure 2 illustrates the broach and debris pattern during a typical Tomahawk underwater launch. Figure 3 presents an overview of the flight-test scenario, showing SSP instrumentation provided in the launch area in support of the operation.

The LASS maintained UHF line-of-sight voice communications with the SSBN and the Eglin AFB range communications network via a support aircraft. Direct LASS-to-SSBN communication was established bridge to bridge on a separate frequency from the range communications network. The voice communication was not secure and required the use of appropriately coded messages. The LASS also had an AN/WQC-2 acoustic telephone to support backup communications with the SSBN.

TEST OPERATIONS SUMMARY

The DEMVAL flight tests were conducted satisfactorily by NAWCWD by using the Eglin AFB test range on 14 and 16 January 2003. SSBN 728 successfully launched both missiles from Warning Area 151. The

missiles carried a recovery exercise module (REM) and were targeted to the Eglin AFB B70 recovery area.

The SSGN DEMVAL countdown for C-3:FT-252/FT-253 began at 0000 Universal Time, Coordinated (UTC) on 14 and 16 January 2003, respectively, at $T - 120$ min. The LASS FTSS, radar, and optics instrumentation supporting the test made ready reports to the LASS test coordinator at the prescribed times. RF broach of the FT-252 missile was detected by the FTSS at 0200:01.4 UTC, and RF broach of the FT-253 missile was detected at 0325:01.0 UTC. After both broaches, radar tracking was secured at $T + 15$ s. The radars were used in a starring mode and did not actively track the missiles. ADOTS optical tracking and FTSS telemetry tracking continued until loss of view and loss of signal, respectively. FTSS tracking operations were completed at ~ 6.5 min after broach for both missiles. The LASS was used to escort the SSBN during the test period and was released from mission support within 1 h after each test launch.

The launch configuration at missile broach for C-3:FT-252/FT-253 is shown in Fig. 4. The 1-nm circle around the SSBN launch point and the 7-nm downrange area represent the hazard area for non-test participants. The LASS intended mission-support position was 2300 yards to port and 1000 yards forward of the SSBN. This position provided an approximate range of 2500 yards and a relative bearing of 115° from the LASS to the SSBN. The LASS and SSBN headings were both approximately 180° for each missile launch.

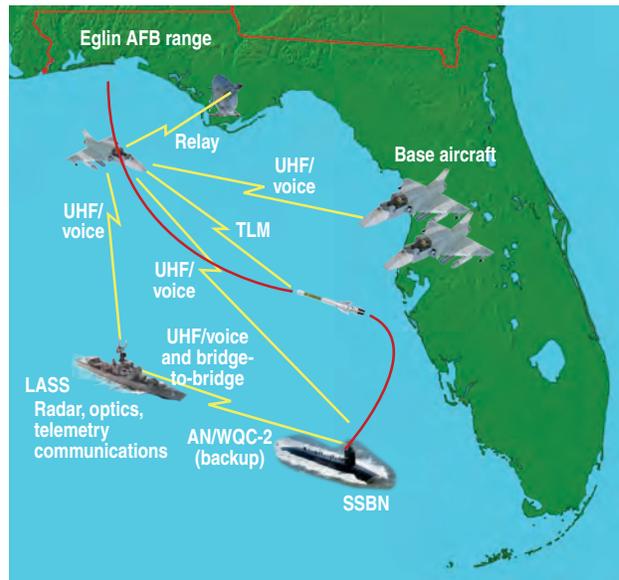


Figure 3. SSGN DEMVAL flight-test scenario. The communications relay among the submarine, LASS, E-9 relay, and chase aircraft are shown. The DEMVAL test took place in the Gulf of Mexico, in waters controlled by the Eglin AFB test range.

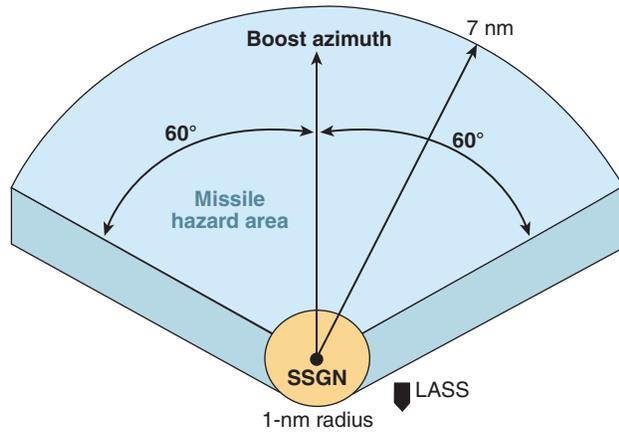


Figure 4. The SSGN DEMVAL launch configuration illustrates the SSGN and LASS relative positions during the test sequence. The missile launch hazard area extends for 7 nm down range. The 60° angles shown from the boost or launch azimuth indicate the expansion of the downrange hazard area.

SSP LASS INSTRUMENTATION PERFORMANCE OBSERVATIONS

Weibel 1-kW and 240-W X-Band Radars

The 1-kW and 240-W X-band radar systems onboard the LASS were required to record/track launch debris from broach to broach plus 15 s. The radars were configured to stare at the launch azimuth at a small elevation above the horizon. All radar operations were secured 15 s after broach. Collection and analysis of radar data were performed by XonTech, Incorporated, now a division of Northrop Grumman Corporation.

The 1-kW and 240-W X-band radars are commercial units designed and built by the Danish company Weibel Scientific of Copenhagen. These X-band radars are continuous-wave, multiple-object Doppler radars. Both radars were positioned on the fantail of the LASS. Figure 5 shows the larger 1-kW radar installed on the fantail. The radars each have a camera mounted in the upper center axis position to record an optical image of the radar’s field of view. Proper timing information and video imaging assist in the interpretation of the radar data.

For the first missile launch, both the 240-W and the 1-kW Weibel radars successfully acquired the TLAM/C missile immediately after broach. For launch support, the radars were positioned 0.5° to the right in azimuth and 0.5° up in elevation from the SSBN multifunction mast to view the TLAM/C launch debris. Both upper and lower shroud pieces were observed on the video from the cameras mounted on each radar.

For the second missile launch, the 240-W Weibel radar successfully acquired the TLAM/C missile immediately after broach. The 1-kW Weibel was inoperative

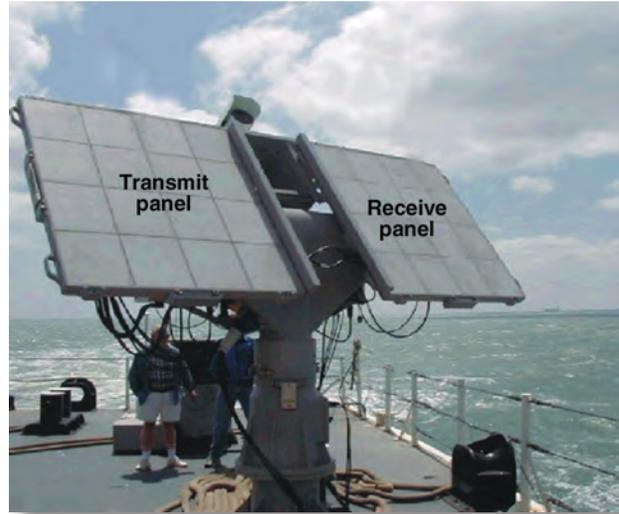


Figure 5. The 1-kW Weibel X-band radar is shown installed on the LASS. The radar uses two large antenna panels to transmit and receive X-band signals.

for this test. The 240-W Weibel radar camera observed at least three large pieces of debris, from separation to impact, and radar data were collected.

LASS Optics Support (ADOTS)

ADOTS successfully supported and met all test objectives for SSGN DEMVAL tests C-3:FT-252/FT-253. Collection and analysis of the optical data collected during the SSGN DEMVAL were performed by Lockheed Martin Space Systems Company.

The ADOTS mount A and B cameras are listed in Table 1. Camera locations, film/tape formats, lens focal lengths, frame rates, and film types are given. All cam-

Table 1. ADOTS camera specifications.

Camera location	Film/tape format	Lens focal length (in.)	Speed (FPS)
Mount A	35 mm	150	100
	16 mm	32	100
	Video	5	30
	Video	100	30
Mount B	Video	20	30
	35 mm	150	100
	16 mm	40	100
	Video	5	30
	Video	100	30
	Video	12	30

FPS, frames per second.



Figure 6. One of the ADOTS camera mounts is shown, deployed above the control van. The mount contains five lenses used to capture still and video images of a missile launch.

eras used color film and IRIG-B (inter-range instrumentation group B) timing. One of the mounts is shown in Fig. 6.

ADOTS mount A operated in a staring mode and maintained a fixed position to collect data on broach and debris. ADOTS mount B operated in tracking mode and collected broach, debris jettison, and coverage to and including booster jettison. Optical coverage of both TLAM/C missiles continued until loss of view.

Video, engineering film, and still photograph coverage was obtained from both mounts. In addition, live video coverage was sent from ADOTS to SSP headquarters via a KuBS communication system.

LASS Telemetry Systems

The two SSGN DEMVAL at-sea test missiles were Tomahawk Block III missiles, with Mark 111 and Mark 106 rocket motor assemblies, respectively. The missiles were configured to carry a customized module that transmits telemetry during flight. The LASS telemetry systems were configured to record this telemetry in the launch area.

The LASS telemetry systems included the M345 TPU and ESHA antennas normally used to support Trident II test missile launches. This system (as shown in Fig. 7) is used to track and record telemetry from the missile in the launch area. It processes range safety functions and records up to three missile and four reentry body telemetry links. The telemetry processor was developed by L3/Interstate Electronics Corporation (L3-IEC), and the telemetry systems were operated by L3-IEC. The ESHA antennas were developed by Lockheed Martin Missile Space Company and consist of 24 helicone antennas mounted on a 36-in.-diameter base with a 24-in. radome. The antenna system is omnidirectional



Figure 7. FTSS control van with ESHA antennas inset. The FTSS van contains telemetry and GPS tracking equipment. The ESHA antennas provide the S-band RF feed for these systems.

and computes the direction of the signal source. ESHA antenna specifications are as follows:

- Frequency range, 2.2–2.3 GHz
- Gain/temperature, –14 dB/K
- Noise floor, –85 dBm

Recovery of all telemetry, from first motion to the end of boosted flight, was required for the DEMVAL at-sea tests. LASS telemetry support was a backup capability to the telemetry receive/record capabilities provided by Eglin AFB. The LASS M345 ESHA was assigned to record all telemetry links. Both polarizations and combined output data were recorded.

FTSS telemetry recorder performance in support of the SSGN DEMVAL at-sea tests was satisfactory. Both redundant FTSS telemetry systems covered each of the two missile launches. The missile broaches were detected normally, and their frequencies were properly identified. Antenna tracking performance was satisfactory during the expected support period. Telemetry recording was successful during both missile flights. A pair of Sypris digital recorders were temporarily installed on the LASS with the M345 to redundantly record telemetry from the TPUs. The Sypris recorder performed satisfactorily during the mission and recorded data from TPUs 1 and 2, and the data were archived.

The telemetry data were recorded with IRIG-B timing formats on all telemetry tapes. In addition, receiver automatic gain control, voice annotations, and antenna azimuth/elevation data also were recorded.

Submarine Tracking and Communications

The LASS SSBN tracking system, the M345 Acoustic Tracking System (ATS), was used to track the position of the SSBN for ship operations. The ATS can use signals from an array of deep-ocean transponders to track the SSBN position. For the DEMVAL, the ATS was operated in the manual mode with operator entry of SSBN range and bearing received from the SSBN via bridge-to-bridge communications. There were no issues with this process during the test period.

UHF and VHF radio communications performed adequately and supported the entire test period. The AN/WQC-2 series sonar underwater communications system was available to support communications but was not used during the test period. AN/WQC-6 series sonar and buoyant cable antenna communications systems were not installed on the Trident submarine for this test.

USNS Waters Surface-Weather Reporting

The T-AGS 45 surface-weather instrumentation successfully supported the SSGN DEMVAL at-sea test operation. The meteorological support for this flight test included only surface-weather observations from the LASS. No weather balloon launches were planned or performed. The weather data included air temperature, pressure, relative humidity, wind velocity and direction, visibility, cloud cover, and wave height. These observations were made at $T - 120$, $T - 100$, and $T - 0$ min. A single report was given to the SSBN at $T - 95$ min during each countdown. The SSBN used this report to satisfy the weather requirements of the test.

RADAR AND OPTICS RESULTS

Analysis of the X-band radar data collected during the SSGN DEMVAL did not produce usable results. The LASS was positioned almost parallel to the submarine during launch. The near-vertical trajectory of the missile at this time meant that the radars were not optimally positioned to observe Doppler data from the

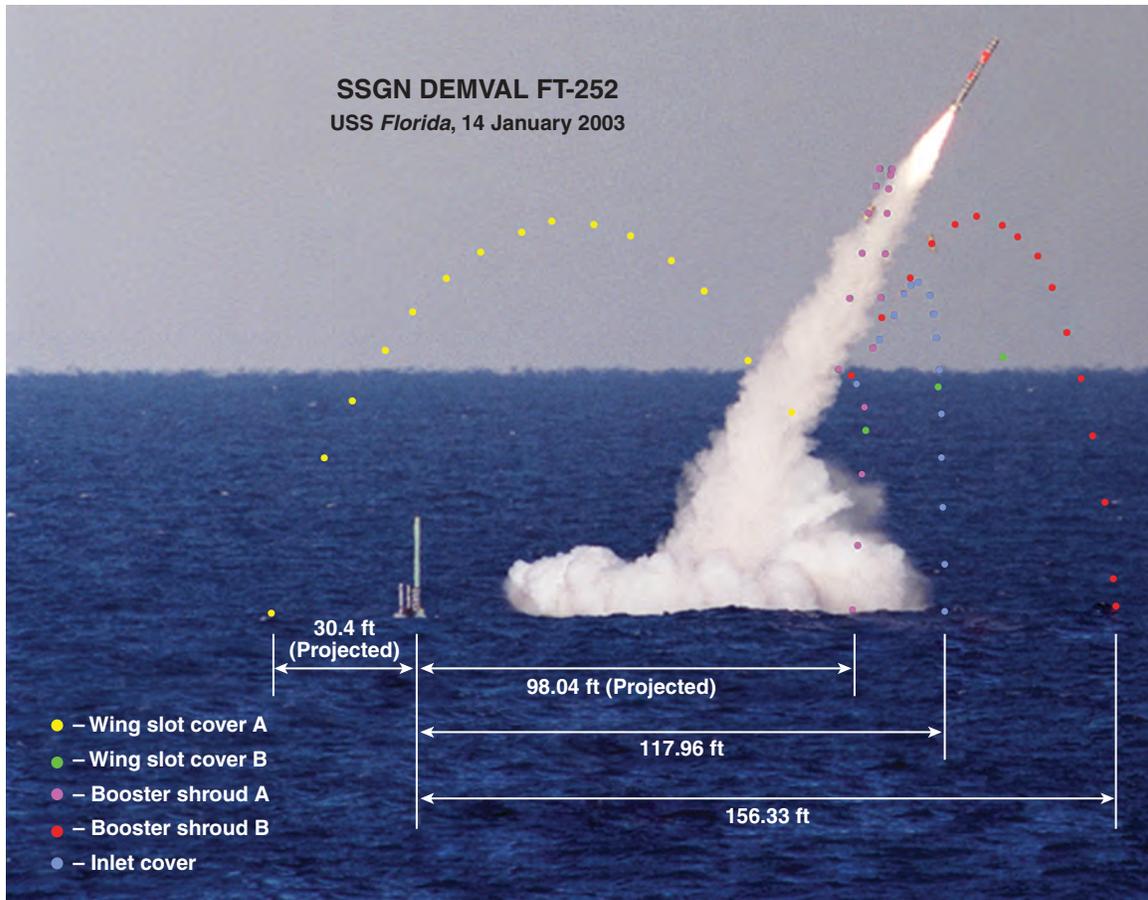


Figure 8. The first SSGN DEMVAL launch (FT-252) as seen from ADOTS with a time history of the trajectory of the launch debris.

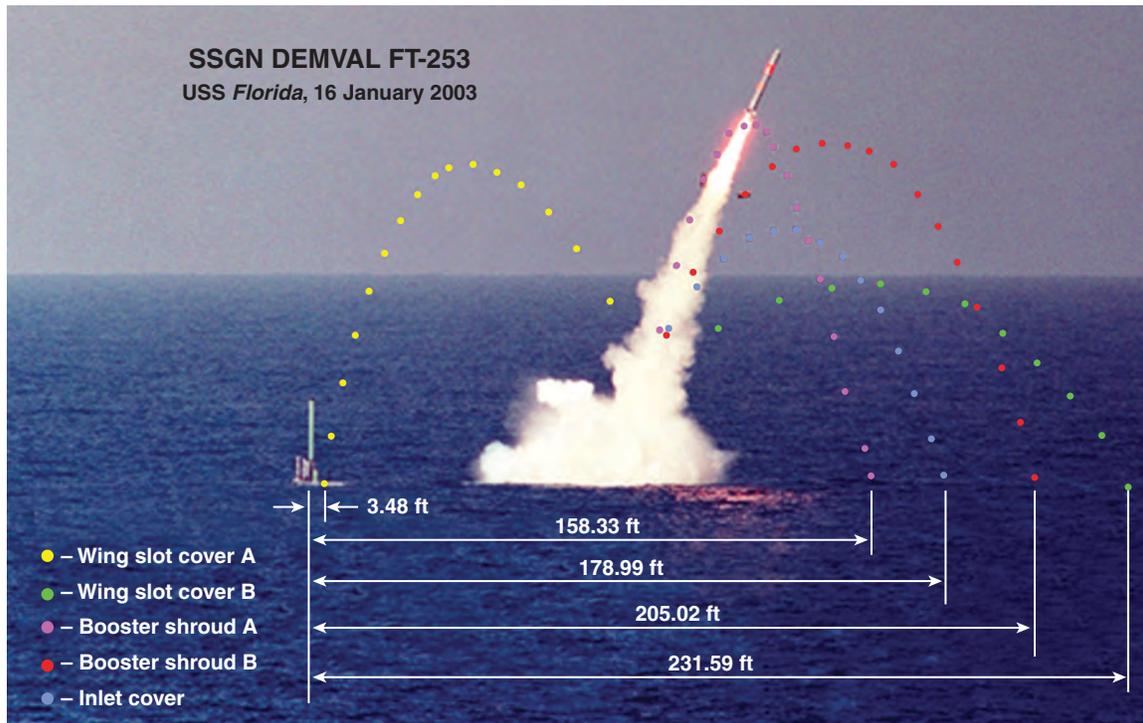


Figure 9. The second SSGN DEMVAL launch (FT-253) as seen from ADOTS with a time history of the trajectory of the launch debris.

missile. However, the ADOTS camera captured video of all expected debris from jettison to water impact. The images were analyzed, and scales were used to estimate the trajectory and final impact distance from the SSGN submarine. Figures 8 and 9 show the results for both missile test launches.¹

The LASS mission-support position was negotiated during the test-planning phase. As often is the case, conflicting instrumentation requirements added to the complexity of the selection of the mission-support position. For the SSGN DEMVAL, the SSGN would cruise at periscope depth on a set course during the launch of the TLAM/C missiles. The LASS would have to meet instrumentation requirements while remaining on station with the SSGN.

This position compromised the radars' support position requirements, to some degree. The radar instrumentation team requested a position 45° or more forward of the SSGN. The actual support positions were 25° to 30° forward of the SSGN. The Weibel X-band Doppler radar performance is optimal when the debris is traveling toward or away from the radar itself. In the case of the DEMVAL, the debris was traveling almost perpendicular to the radar. Positioning the Doppler radar in a better location to observe the debris, significantly more forward or aft of the SSGN,

was not considered because of the launch and collision hazard zones.

CONCLUSION

Navy SSP range instrumentation significantly aided launch support of the SSGN DEMVAL Tomahawk flight tests. The submarine tracking and communication systems unique to the SSP LASS greatly simplified test operations. The ADOTS optical coverage of the Tomahawk launches supplied debris-tracking data that were useful to the risk-reduction process. The addition of radar tracking did not prove fruitful but provided some beneficial experience for operations planning with this instrumentation.

ACKNOWLEDGMENTS: We would like to acknowledge the LASS SSGN DEMVAL support team, which included Art Sanders and Mark Mathews of APL, Chris Dalquist and Jim Neiger of XonTech, Incorporated/Northrop Grumman Corporation, and Darin Kubo and Chris Agler of Lockheed Martin Space Systems Company.

REFERENCE

¹Kubo, D., and Agler, C., *SSGN DEMVAL Optical Instrumentation Report*, Lockheed Martin Space Systems Company (23 June 2003).

The Authors

Gregory M. Horstkamp holds a B.S. in aerospace engineering from the University of Virginia (1987) and an M.S. in mechanical engineering from George Washington University (1995), and he is a member of the Senior Professional Staff in APL's Global Engagement Department. He is the FTSS Project Manager for the Strategic Systems Business Area's Range Systems Program. Mr. Horstkamp joined APL in 1996 and currently supports evaluation of range systems during Trident II (D5) missile flight tests and development of new sensor systems for the Navy's SSP. **Jerome R. Vetter** earned a B.S. in aeronautical engineering from St. Louis University (1960) and an M.S. in applied physics from The Johns Hopkins University (1974), and he completed graduate studies in the Ph.D. program in astronomy at Georgetown University (1968). He worked at Bell Telephone Laboratories from 1960 to 1962 on the Titan guidance system and at BellComm Inc. from 1962 to 1965 on Apollo lunar trajectory design for NASA Headquarters. From 1965 to 1974, Mr. Vetter worked at Wolf Research and Development Corporation on satellite orbit determination for NASA Goddard Space Flight Center. He joined APL in 1974, has been associated with the SATRACK program since its inception, and is a member of APL's Principal Professional Staff. He is currently the Assistant Program Manager for Range Systems Programs as well as Project Manager of the high-frequency ground wave/buoyant cable assemblies project in the Strategic Systems Business Area. His research interests include space geodesy and satellite navigation, applications of Kalman filtering, missile inertial navigation and guidance analysis, and radio and optical astronomy. **Charles J. McSoley** (not pictured) has a B.S. in electrical engineering from the University of Rhode Island (1983) and an M.S. in electrical engineering from the Virginia Polytechnic Institute (2002). He worked for the Naval Sea Systems Command (SEA-92) as a field engineer from 1983 to 1989 on the Trident Submarine Command and Control System Maintenance Activity. Mr. McSoley joined the SSP in 1989, holding a number of positions, including U.K. Flight Test Manager, Deputy Program Manager of the Advanced Land Attack Missile, and Engineering Manager of RF Systems. He currently is head of the Test Instrumentation, Operations, and Facilities Unit (SP-2744) at SSP Headquarters in the Missile Systems Engineering Branch. **Ward J. Szerlag** (not pictured) holds a B.S. in aerospace engineering from the University of Michigan (2000) and a M.S. in space systems from the Florida Institute of Technology (2003). He served on active duty in the U.S. Navy from 1988



Gregory M. Horstkamp



Jerome R. Vetter

to 1994 and currently is a lieutenant in the U.S. Navy Reserve. Mr. Szerlag worked for Lockheed Martin from 1998 to 2000 on the F-16 Air Vehicle Integration program. He joined the Naval Ordnance Test Unit from 2000 to 2007, holding a number of assignments in the Flight Safety and Analysis Division and as deputy to the chief engineer. In 2007, he joined the SSP, where he currently serves as a general engineer as a member of the Flight Test and Range Operations unit. For further information on the work reported here, contact Mr. Horstkamp. His e-mail address is gregory.horstkamp@jhuapl.edu.