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MITRE PRODUCT

Reconstruction of Acoustic Collection Missions Against Three Cruise Missiles

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Abstract

Between July 1996 and June 1997, The MITRE Corporation planned and directed the collection of acoustic data on cruise missile flights as part of a corporate Mission-Oriented Investigation and Experimentation (MOIE) study examining the feasibility of using off-board sensors for over-the-horizon detection of low flying cruise missiles. The Offboard Sensing Initiative (OSI) MOIE proposed to identify and develop methods for exploiting non-traditional signatures associated with low-flying, anti-ship cruise missiles. The concept envisioned an improved detection capability, against these increasingly stealthy threats, using deployed sensors to provide early cueing, longer detection timelines, and an extended depth-of-fire. While many different sensor types were considered, MITRE and government resources limited the collection of information to acoustic signatures. The MOIE was performed under the auspices of the Program Executive Officer, Theater Air Defense PEO(TAD), with the support of the Office of the Chief of Naval Operations for Air Warfare (Opnav N88) and the Commander, Patrol Wings U.S. Pacific Fleet. Each of the three missions targeted a different cruise missile. Two August 1996 missions collected acoustic data on the MQM-8G Extended-Extended Range (EER) VANDAL and the Russian-built MA-31. A June 1997 mission collected acoustic data on a Navy Special Engineering Test Target (SETT) SETT-8A. This report presents a reconstruction of the acoustic collection missions.

KEYWORDS: cruise missile, detection, acoustic, MQM-8G EER VANDAL, MA-31, SETT-8A

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Section 1

Introduction

Between July 1996 and June 1997, The MITRE Corporation planned and directed the collection of acoustic data on cruise missile flights as part of a corporate Mission-Oriented Investigation and Experimentation (MOIE) study examining the feasibility of using off-board sensors for over-the-horizon detection of low flying cruise missiles. The Offboard Sensing Initiative (OSI) MOIE proposed to identify and develop methods for exploiting non-traditional signatures associated with low-flying, anti-ship cruise missiles. The concept envisioned an improved detection capability, against these increasingly stealthy threats, using deployed sensors to provide early cueing, longer detection timelines, and an extended depth-of-fire. While many different sensor types were considered, MITRE and government resources limited the collection of information to acoustic signatures. The MOIE was performed under the auspices of the Program Executive Officer, Theater Air Defense PEO(TAD), with the support of the Office of the Chief of Naval Operations for Air Warfare (Opnav N88) and the Commander, Patrol Wings U.S. Pacific Fleet. This report presents a reconstruction of the acoustic collection missions.

Three collection events resulted from opportunities to leverage PEO(TAD) cruise missile tests scheduled in Warning Area 289 (W-289) of the Southern California (SOCAL) Fleet Operating Area (OPAREA), Figure 1-1. Participation in the tests was permitted on a not-to-interfere basis with the Commander, Patrol Wings Pacific (CPWP), providing P-3[1] assets to collect the acoustic data. Data was collected from (1) an MQM-8G Extended-Extended Range (EER) VANDAL, a variant of the U.S. Navy's TALOS surface-to-air missile, on 13 August 1996 (PST)[2], (2) an MA-31, based on the Russian Zvezda/Strela M31, an aerial target version of the Kh-31 surface-to-air missile (NATO AS-17 'Krypton'), on 14 August 1996 and (3) a SETT-8A, Special Engineering Test Target, on 17 June 1997. Figure 1-2 shows the locations of the three events relative to San Nicolas Island in W-289.

This report is organized into three sections. Each section describes one of the three missile collection missions and discusses (1) the planning associated with the mission, (2) the actual sonobuoy collection patterns and relative track of the missile, as reconstructed from aircraft and Range Control logs and records, and (3) examples of recorded acoustic signals.

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1 The P-3 Orion is a U.S. Navy land-based, multi-mission, tactical aircraft with an onboard acoustic processing system. This acoustic system is normally employed during submarine hunting operations.

2 Unless otherwise noted, all dates and times are referenced to Greenwich Mean Time (GMT).

Separate appendices contain additional detail. Appendices A, B, and C contain sonobuoy positions for the acoustic detection patterns employed on the VANDAL, MA-31, and SETT-8A missions, respectively. Appendix D contains oceanographic profile information. Appendix E contains atmospheric profile information.

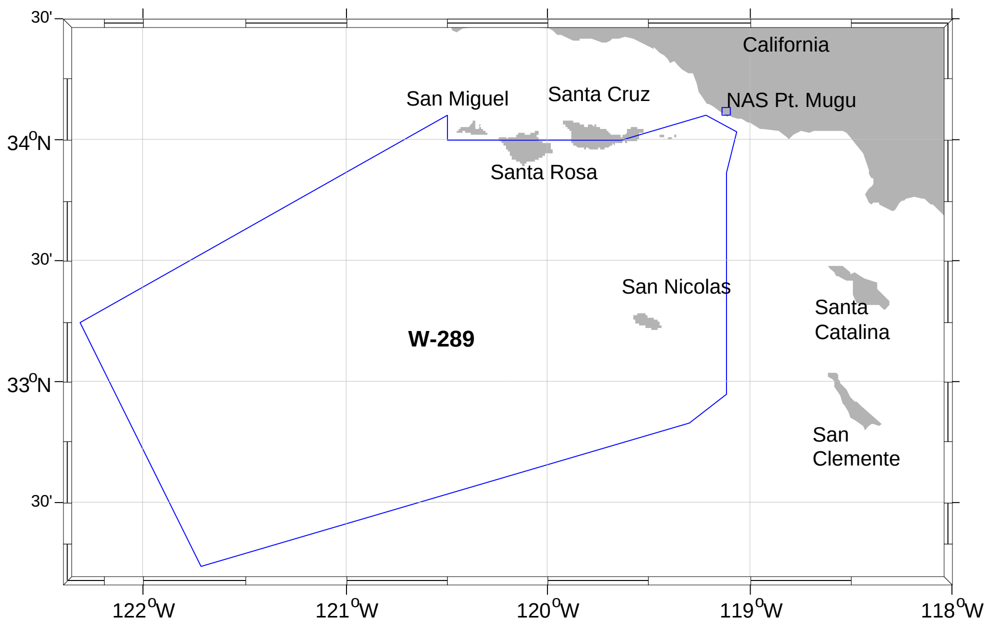

Figure 1-1. NAWCWPNS Test Range in the Southern California (SOCAL) Operating Area

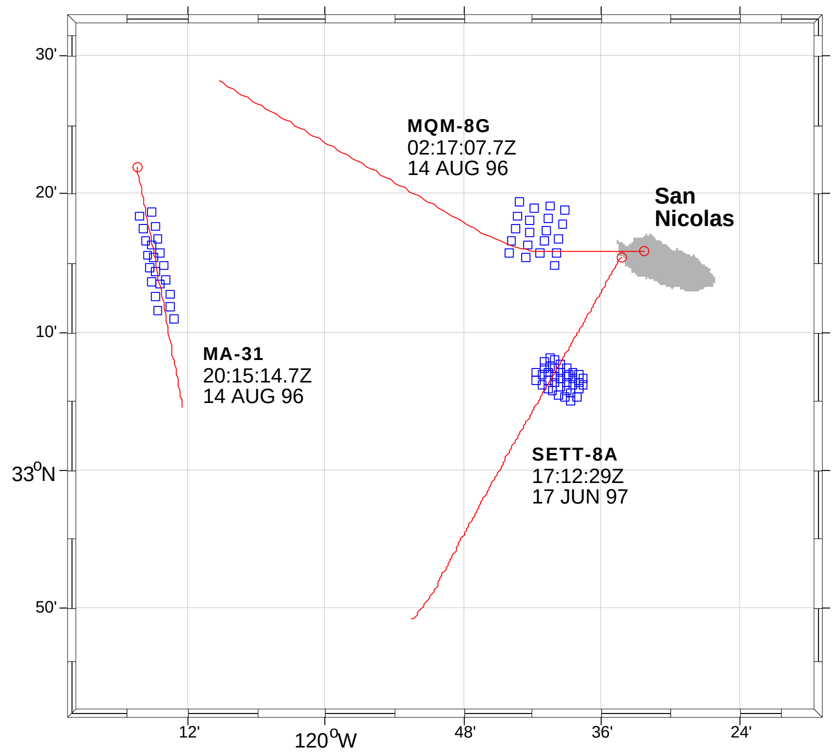

Figure 1-2. Approximate Sonobuoy Pattern Location and Missile Track for Each of the Cruise Missile Acoustic Data Collection Missions, including Greenwich Mean Time and Date of Missile Launch

Section 2

MQM-8G EER VANDAL

The first collection event, a 13 August, 1996 (Pacific Standard Time) MQM-8G EER VANDAL flight test, occurred west of San Nicholas Island in warning area W-289[3]. This test, a production verification test (PVT) whose primary purpose was to evaluate recent modifications to the missiles' navigation and guidance systems, involved neither warships nor other surface craft. The VANDAL cruise missile, a variant of the TALOS surface-to-air missile, is used extensively by the Navy for surface ship Anti-Air Warfare (AAW) training. Launch[4] and tracking facilities located on San Nicholas Island provide telemetry information to and from the missile during tests and training exercises.

2.1 Mission Planning

The VANDAL was programmed to fly a west to north-westerly route for 41 nautical miles at Mach 2, and an altitude of 15 feet. To ensure maximum flexibility in avoiding possible interference on the range, the initial launch bearing was not precisely specified until shortly (minutes) before launch. For planning purposes, the potential launch bearing ranged from 265˚ to 295˚. This circumstance compelled us to select a pattern and location for the sonobuoy field which would ensure over-flight by the missile for any given initial bearing within the specified range. These conditions forced us to use a rectangular pattern fairly close to the island launch site.

Commander, Patrol Wings Pacific provided a P-3 and combat air crew to place and monitor a pattern of sonobuoys in the path of the missiles' intended track for recording sound transmitted to the water during the test.

The pattern planned for this event consisted of five rows of six buoys with a king-pin (KP) position of 33˚ 14' 40" N, 119˚ 40' 00" W. The bearing of the first row out of the KP was 010˚ T. Spacing between rows and buoys was 2000 yards. An offset stagger of 1000 yards between adjacent rows was designed to cover gaps in the pattern and increase the likelihood of the missile flying directly over the buoys. LOFAR and DIFAR buoys were interspersed throughout the pattern to provide both bearing and accurate source level measurements from the same pattern. This pattern was developed without the benefit of an accurate picture of the bottom topography or depth in the area due to lack of an available chart. For planning purposes, depth settings for each buoy were selected and an adjustment

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3 A warning area in the Southern California Fleet Operating Area (SOCAL OPAREA).

4 Launch pad located at 33° 15' 51"N, 119° 32' 20"W.

was planned, as necessary, once the MITRE team arrived at NAS Pt. Mugu. From east to west, sonobuoys in rows one, two and five would be set to a depth of 400 feet, while rows three and four placed LOFAR at a depth of 60 feet and DIFAR at 90 feet. Figure 2-1 shows the intended sonobuoy pattern for this collection event.

The MITRE team acquired a bottom topography chart upon arrival at NAS Pt. Mugu. The chart revealed depths ranging between 100 and 300 feet (30 to 90 meters) in the sonobuoy drop zone. This circumstance forced all buoy depths to the shallow setting for LOFAR and DIFAR, that is, 60 and 90 feet, respectively.

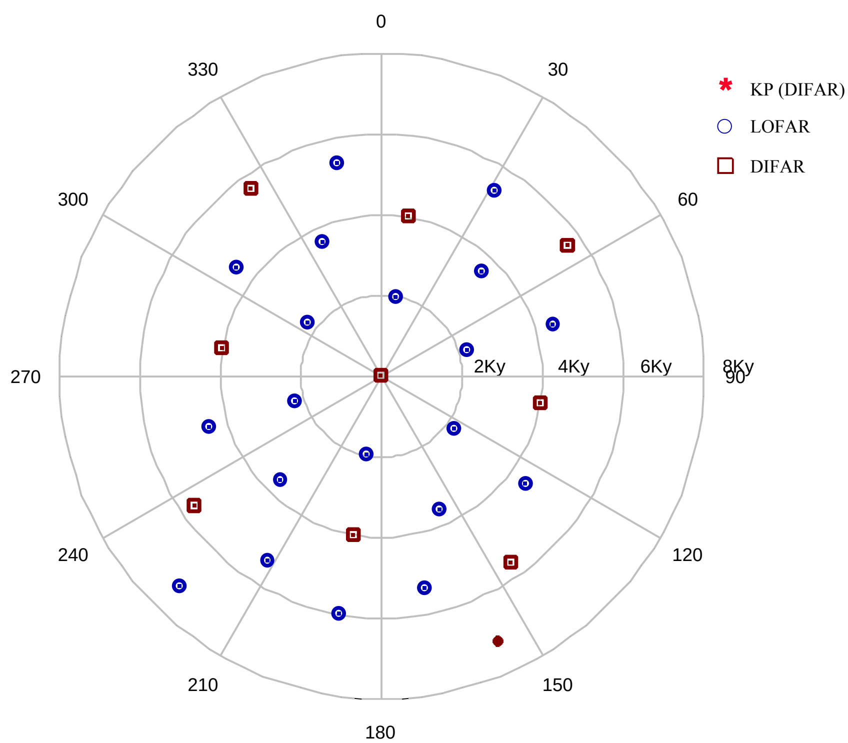

Figure 2-1. Planned VANDAL Sonobuoy Data Collection Pattern (Degrees True)

2.2 Mission Reconstruction

The pattern depicted in Figure 2-1 was deployed. However, an extended launch delay ensued due to unauthorized fishing boats on the range and the pattern expired prior to missile launch. A shortage of buoys on the P-3[5] resulted in a modification to the original pattern. The replacement pattern consisted of four rows of five buoys instead of five rows of six buoys, as originally planned. As there were not enough DIFAR to intersperse throughout the pattern, the decision was made to place the available DIFAR on the periphery of the pattern to better capture missile track. Figure 2-2 shows the track of the missile and the proximity of the final sonobuoy pattern to San Nicolas Island.

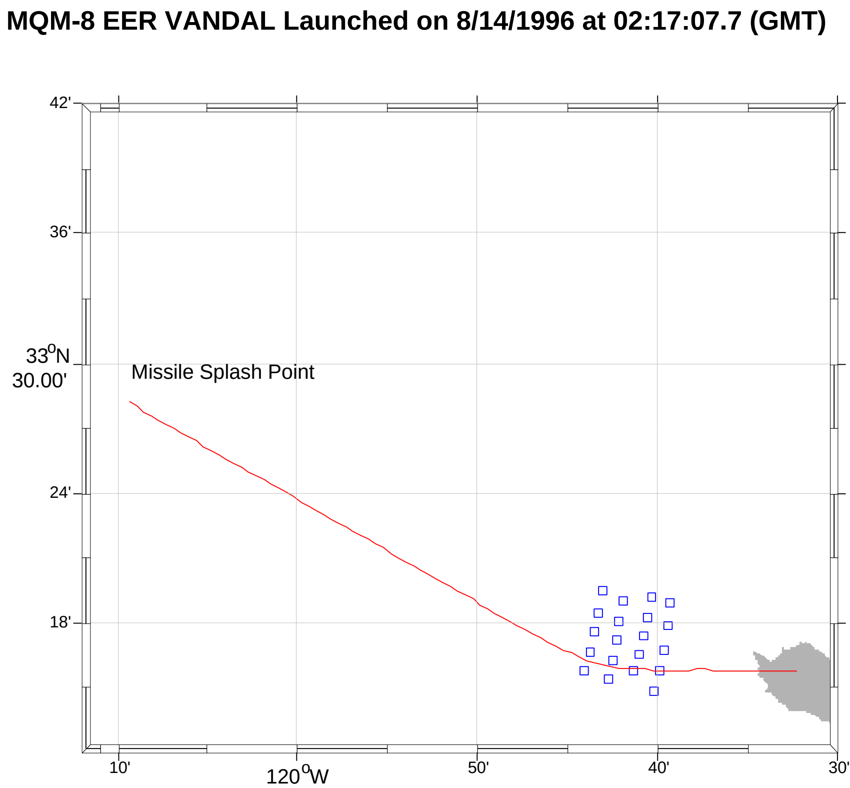

Figure 2-2. Track of VANDAL and Proximity of Sonobuoy Pattern to San Nicolas Island

The VANDAL was launched at 0217 07Z, 14 August Greenwich Mean Time (GMT), on an initial bearing of 270˚ T. Figure 2-3 depicts the portion of the missile track passing through the sonobuoy pattern.

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5 This was the third pattern deployed by the crew on this flight.

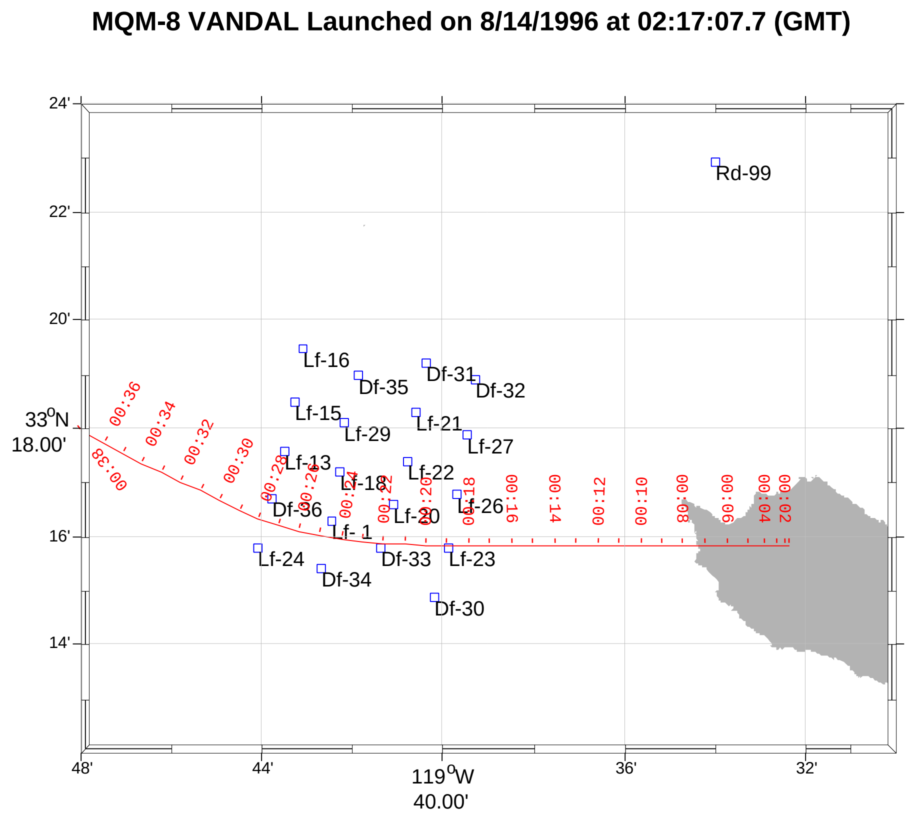

Figure 2-3. Detailed View of VANDAL Sonobuoy Pattern and Missile Track Through the Field

Missile launch time corresponds to t = 0. A solid line with ‘tick’ marks represents missile track, where time t (in seconds) indicates missile progress since launch. A combination of symbol and label serve to distinguish sonobuoys by type. A square and label ‘Lf’ followed by buoy radio frequency (RF) channel number identify LOFAR buoys. A square and label ‘Df’ followed by buoy RF channel number identify DIFAR buoys. See Appendix A for VANDAL sonobuoy latitude and longitude.

Figure 2-4 captures VANDAL flight profile information. As in the previous figure, $t = 0$ corresponds to missile launch time.

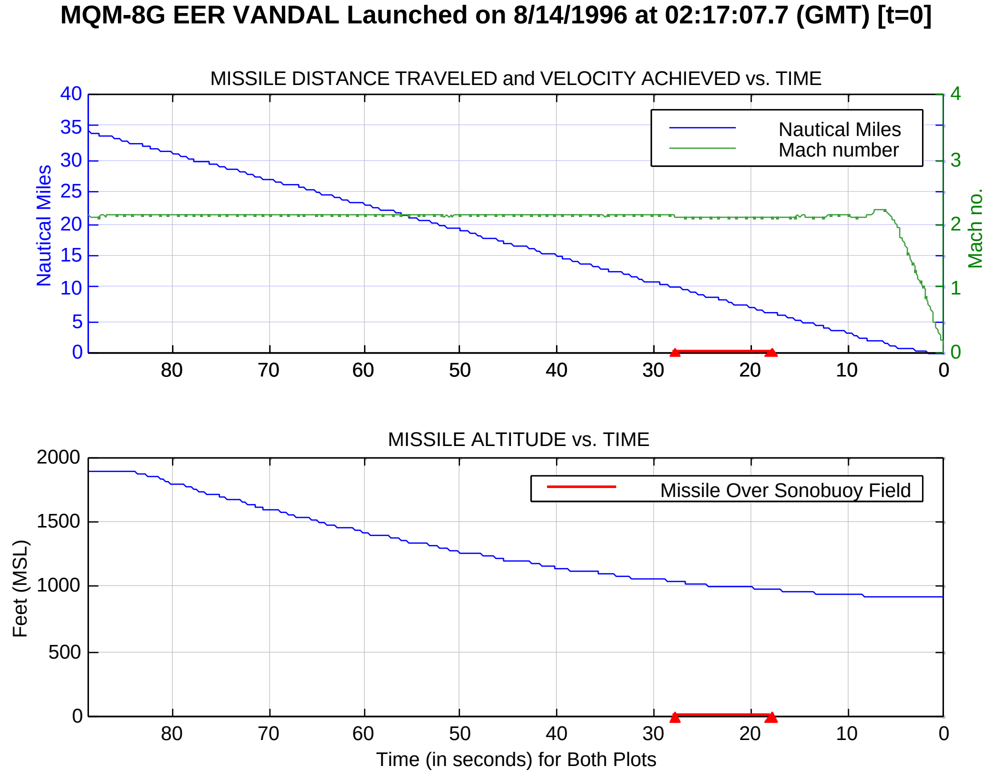

Figure 2-4. Actual VANDAL Flight Profile

This figure indicates that the test did not proceed as planned. Early in the flight, telemetry revealed an unspecified malfunction leading range controllers to prematurely detonate the missile at a safe altitude. Despite the malfunction, the missile achieved Mach 2 within seconds after launch and maintained this velocity for the duration of the flight, including that portion of its track which passed over the sonobuoy field (the 18 to 28 second timeframe), albeit at ~1000 feet, rather than 15 feet as originally planned.

2.3 Acoustic Data

Equipment aboard the P-3 receives analog acoustic information from sonobuoys via RF data link and records it onto magnetic tape. We extracted and digitized portions (snippets) of this analog acoustic information from the tapes for each sonobuoy in the pattern using a sampling rate of 4000 Hz[6]. Snippets extracted from the VANDAL tapes begin 60 seconds prior to missile launch. Figure 2-5 depicts time series amplitude information from these snippets for all of the operable buoys in the VANDAL pattern. Buoys not depicted either failed or appeared to contain no usable information.

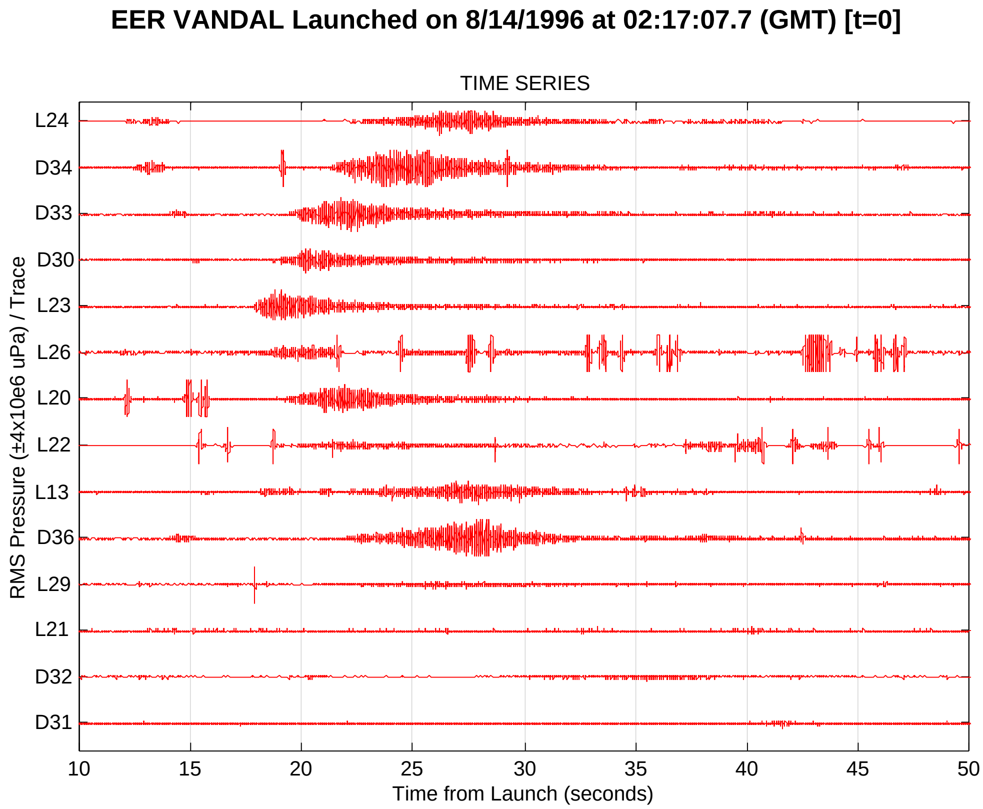

Figure 2-5. Signal Amplitude Recorded from VANDAL Mission by Sonobuoy

In Figure 2-5, L-24 identifies the adjacent signal as having been recorded from LOFAR RF channel 24. Similarly, D-34 identifies the adjacent signal as having been recorded from DIFAR RF channel 34.

6 This is the Nyquist sampling rate intended to recover frequency content from 0 to 2000Hz.

Section 3
MA-31

Our second acoustic collection event occurred against a Russian built MA-31[7] missile on 14 August 1996. This missile, the first of its type to be tested by NAWC WPNS Division, was launched from a QF-4, a variant of the F-4 Phantom. The missile was launched northwest of San Nicolas Island. Tracking facilities on the island recorded telemetry information on the missile and aircraft during the test.

3.1 Mission Planning

The test plan for the MA-31 flight incorporated a hazard pattern template without a fixed geographic location or missile launch bearing. Figure 3-1 depicts the planned sonobuoy drop locations overlaid upon the hazard pattern template.

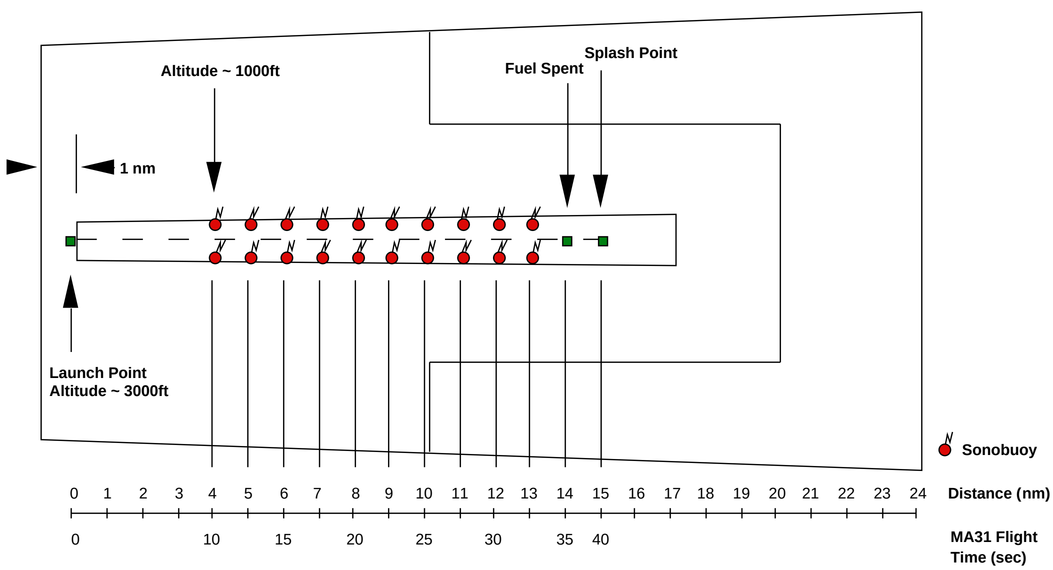

Figure 3-1. MA-31 Hazard Pattern and Planned Sonobuoy Data Collection Pattern

This template provided Range Control personnel the flexibility necessary to dynamically select a clear area in W-289 moments before the QF-4 was airborne. When safety criteria

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7 McDonnell Douglas is the contracted supplier.

were satisfied and a clear area on the range located, the template would be fixed by specifying the launch position and bearing. According to the plan, the QF-4 would launch the MA-31 from an altitude of 3000 feet and follow the missile to its splashpoint. On this occasion, the range of the MA-31 was deliberately limited to approximately 15 nautical miles (nm). Upon launch, the missile would descend to 1000 feet and accelerate to supersonic velocity. The flight was scheduled for the morning of 13 August 1996.

The P-3 would have very little time to deploy a sonobuoy pattern for this mission due to the limited flight time of the QF-4 and the dynamic placement of the hazard pattern. The sonobuoy pattern selected for this collection event consisted of approximately twenty LOFAR and DIFAR buoys, ten each bracketing the intended missile track, offset 1000 yards either side of centerline.

3.2 Mission Reconstruction

On the morning of 13 August, the P-3 was airborne and in position to deploy the planned sonobuoy pattern. As the QF-4 with MA-31 approached the runway for take-off, Range Control fixed the hazard pattern location and the P-3 proceeded to deploy the sonobuoys. Target Operations personnel detected a malfunction associated with final MA-31 telemetry preflight checks within minutes after the P-3 completed deployment of the sonobuoy pattern. Target Operations decided to postpone the test for 24 hours. By the end of the day, 13 August, most of the remaining buoys had been dropped on the VANDAL collection event and there was not enough ordnance to support the MA-31 collection scheduled for the next morning.

Throughout the evening and into the next morning the MITRE team sought permission to procure additional ordnance (sonobuoy and CADs[8]). Armed with accounting data from OPNAV N880 to pay for more sonobuoys, VP-65, the local reserve P-3 squadron, provided us with 39 buoys and CADs from their buoy locker making further data collection efforts possible. We modified our original MA-31 sonobuoy pattern to tighten buoy spacing and accommodate changes in buoy type loadout since we now had more DIFAR than LOFAR. The P-3 was airborne at 1917Z. At 1938Z, the MA-31, mounted on the QF-4 at the runway hold-short area, passed its telemetry checks. Range Control authorized a missile launch heading of 155M°/169°T from position 33° 22’ 32” N, 120° 16’ 36” W, which fixed the hazard pattern location. Target Operations cleared the P-3 to deploy the sonobuoy collection pattern at 1941Z. The QF-4, with MA-31, took off at 1947Z. Pattern deployment commenced at 1956Z and was completed by 2009Z. Missile launch occurred at approximately 2015Z. The QF-4 followed the missile, thereby flying over some or all of the

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8 Cartridge-Actuated Devices (CAD) are used to explosively propel sonobuoys out of the aircraft so as to minimize the possibility of a sonobuoy striking the fuselage.

sonobuoys in the pattern. A possible bird strike on the P-3 prevented (1) marking the geographic location of buoys in the water and (2) the deployment of a bathythermograph (BT) buoy to collect an oceanographic temperature profile. The post-flight debrief of the P-3 crew was completed by 2300Z (1600 local), upon their return to Pt. Mugu. The remaining sonobuoys were audited and returned to VP-65.

Figure 3-2 depicts reconstructed missile track and sonobuoy pattern geometry relative to San Nicolas Island from flight logs and missile telemetry[9]. Sonobuoy positions are recorded in Appendix B.

MA-31 Launched on 8/14/96 at 20:15:14.7 (GMT), WNW of San Nicolas Island"

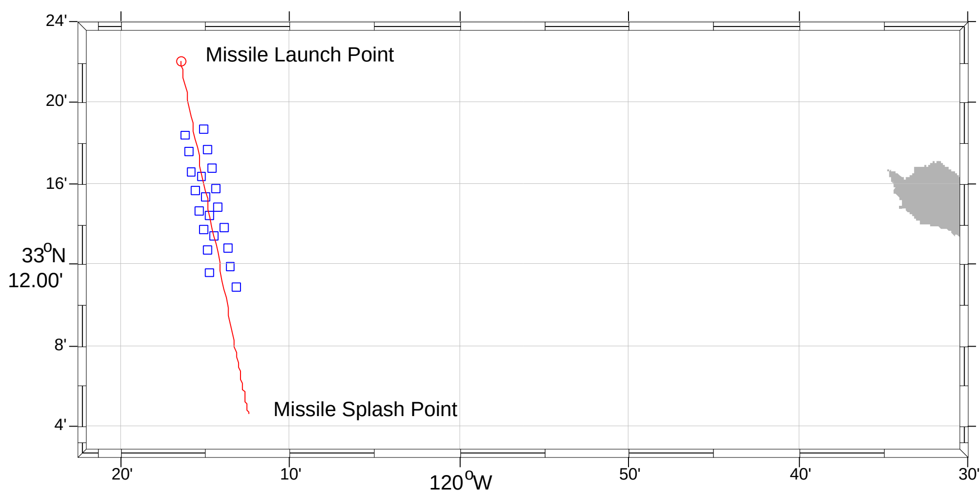

Figure 3-2. Proximity of MA-31 Missile Track and Actual Sonobuoy Field to San Nicolas Island

During the mission, four additional sonobuoys were added to the original pattern. These buoys were placed on centerline in the middle of the pattern to increase the opportunity for

9 The westernmost row of buoys, third buoy position from the bottom, contains two, inadvertently co-located buoys; one LOFAR and one DIFAR.

over-flight by the missile. Figure 3-3 provides a detailed view of the missile track over the buoy field.

Note that the actual pattern differs from the planned pattern in Figure 3-1 in several respects. First, there is no buoy opposite DIFAR 43 due to a deployment error which occurred during the placement of buoys in the western row, the last row deployed. The P-3 laid this row of buoys from North to South and inadvertently dropped two buoys simultaneously prior to the last drop point. When the final buoy drop point was reached, there were no more DIFAR available and insufficient time to return and drop a LOFAR in its place.

Another difference between the planned and actual patterns is the number of rows. During the mission, four additional sonobuoys were added and placed on centerline in the middle of the pattern to increase the opportunity for over-flight by the missile.

Finally, note that the outer two rows contain nine buoys per row vice ten.

MA-31 Launched on 8/14/96 at 20:15:14.7 (GMT), WNW of San Nicolas

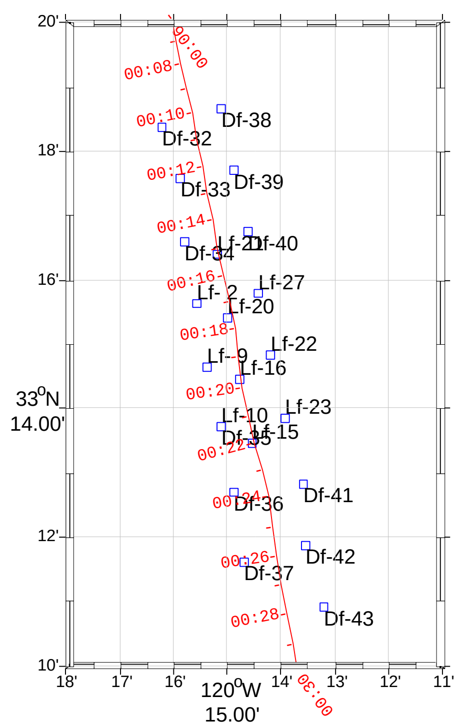

Figure 3-3. Detail View of MA-31 Missile Track and Sonobuoy Field

Figure 3-4 depicts missile range, velocity, and altitude attained during the flight. Based upon the telemetry data used to generate these plots, the missile appears to have performed as programmed.

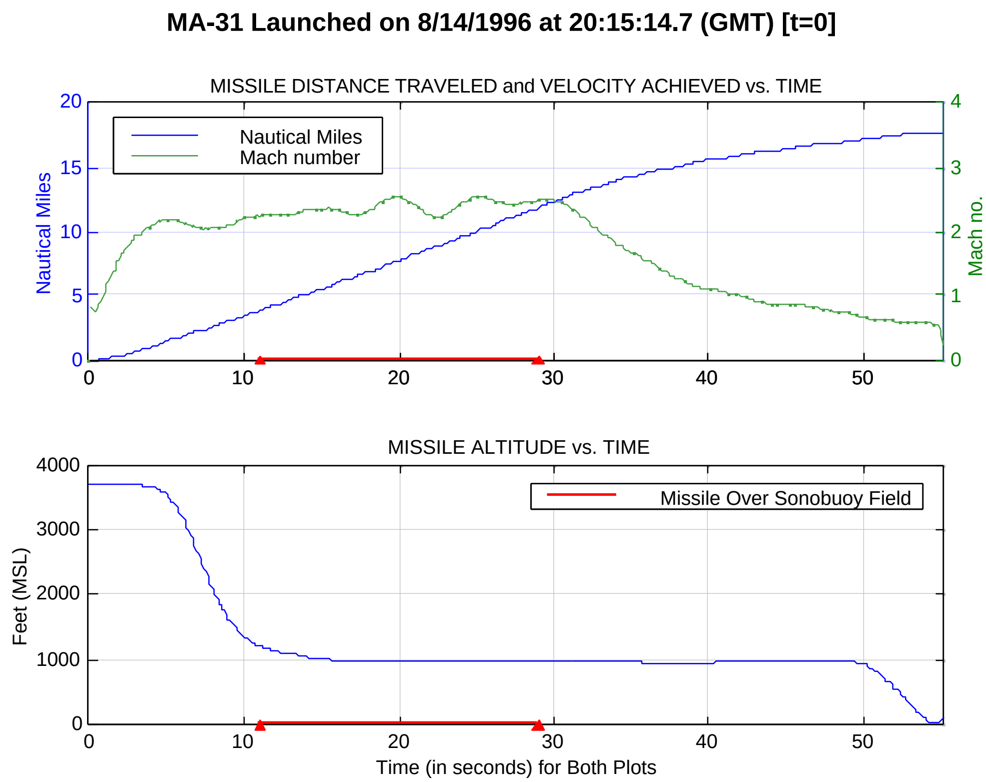

Figure 3-4. Actual MA-31 Flight Profile

3.3 Acoustic Data

Post-flight analysis of the MA-31 acoustic tapes revealed time code information, recorded from the P-3's Time Code Generator, to be in error. Without this information we have been unable to associate a specific time with the acoustic data in order to correlate it in time with missile telemetry data. Two approaches to obtain such a correlation will be the subject of a future report. (1) It might be possible to associate a spectrogram frequency shift from one of the other missions with missile CPA of a buoy[10] and thereby synchronize the MA-31 acoustic data with the associated missile telemetry data. (2) Another approach would be to look for a correlation between the velocities of similar signals across multiple buoys and the known velocities of the speed of sound in water, the speed of the missile and the speed of the launching aircraft.

Figure 3-5 contains a sample of the signals recorded during the MA-31 mission.

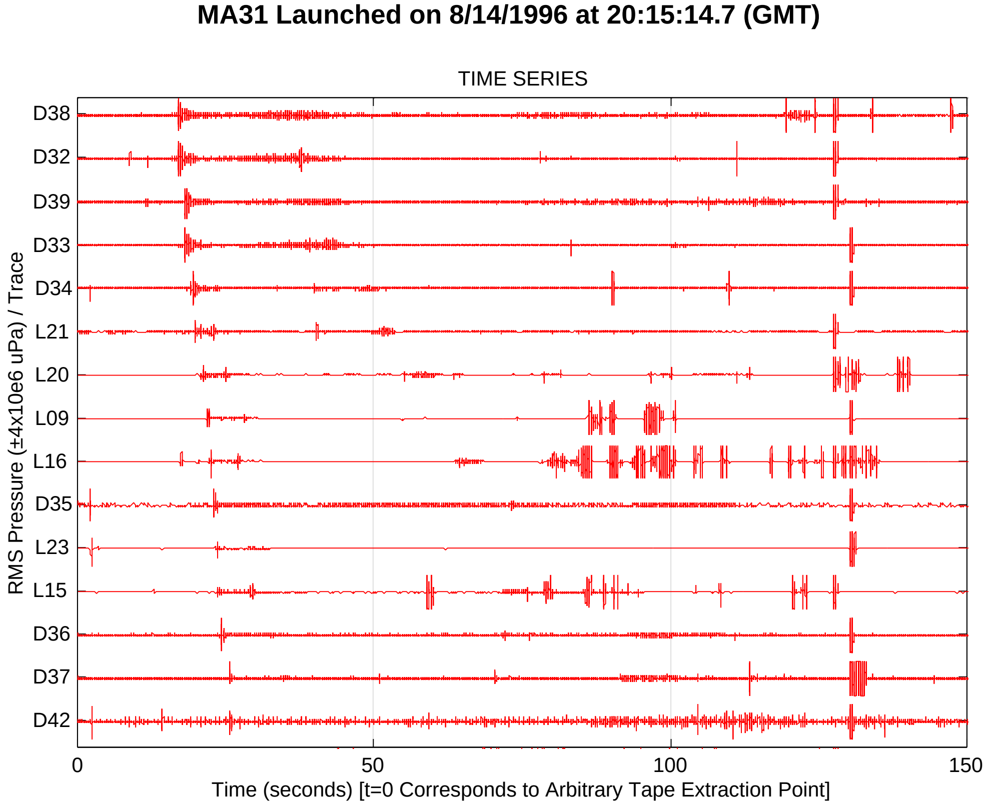

Figure 3-5. Signal Amplitude Samples Recorded from MA-31 Mission and Listed by Sonobuoy

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10 A distinct doppler shift in acoustic frequency occurs as a target approaches, passes, and recedes from a sonobuoy. At CPA, the closest point of target approach to the sonobuoy, velocity of the target relative to the sonobuoy is zero and, as a result, doppler shift at the receiver goes to zero and source frequencies are discernable. Refer to Ziomek, L.J., *Underwater Acoustics: A Linear Systems Theory Approach*, Academic Press, Orlando, Florida, 1985

Signals are plotted from top to bottom generally according to the order in which the missile overflew the buoys. Not depicted are buoys from the sonobuoy pattern that either failed or contained data seriously corrupted by interference.

In the figure, D38 identifies the adjacent signal as having been recorded from DIFAR RF channel 38. Similarly, L21 identifies the adjacent signal as recorded from LOFAR RF channel 21. Time zero is not related to missile launch, since we lack accurate time code information for this acoustic data. Rather, it corresponds to an arbitrary tape extraction point approximately one to two minutes prior to missile launch.

As in the VANDAL case, digitization of MA-31 acoustic data occurred at a sampling rate of 4000Hz.

Section 4

SETT-8A

The U.S. Navy has developed a series of threat representative targets, called Special Engineering Test Targets (SETTs), for use in test and evaluation. The SETT-8A launch on 17 June 1997 tested AEGIS and a modified Vulcan Phalanx (CIWS[11]) system mounted on the Self Defense Test Ship (SDTS)[12] against a subsonic cruise missile fired from San Nicolas Island.

4.1 Mission Planning

The purpose of MITRE's involvement in this test was to collect additional acoustic data to support threat detection analysis and also to collect in-air acoustic measurements of the missile to extend our understanding of the physics of the shock dynamics at the air-sea interface. In addition to the buoy types used for the previous collections, i.e., SSQ-53 DIFAR, SSQ-57 LOFAR, and SSQ-36 BT, we sought permission to modify some of the SSQ-57's for in-air measurement of missile acoustics. NAVAIR agreed and NAWC Patuxent River designed and tested a modified LOFAR sonobuoy for this purpose. The modification consisted of buoyant material attached to the sonobuoy hydrophone which, after sonobuoy deployment from a P-3 and subsequent water entry, caused the microphone to float on the surface of the water. About a dozen LOFAR sonobuoys were modified in this way and provided for use on the SETT-8A data collection mission.

According to the SETT-8A Flight Test Plan, a single SETT-8A would be launched from a launch pad[13] on San Nicolas Island on a bearing of 210° True. The SDTS, 30 NM down the launch bearing from the launch site, towing a radar decoy barge 300 feet astern, would attempt to engage the SETT-8A with CIWS; see Figure 4-1for timeline diagram[14].

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11 CIWS, Close In Weapon System., is a gatling gun mounted on surface ships for point defense.

12 The former USS DECATUR (DDG 31) converted in 1988 to provide the Navy with an at-sea, remote controlled, Self-Defense weapon test and evaluation platform for conducting advanced weapons evaluation without risk to personnel.

13 The launch pad is located at 33° 15' 30.6"N, 119° 34' 18.6"W.

14 Figure 5-3 from the SETT-8A Test Plan.

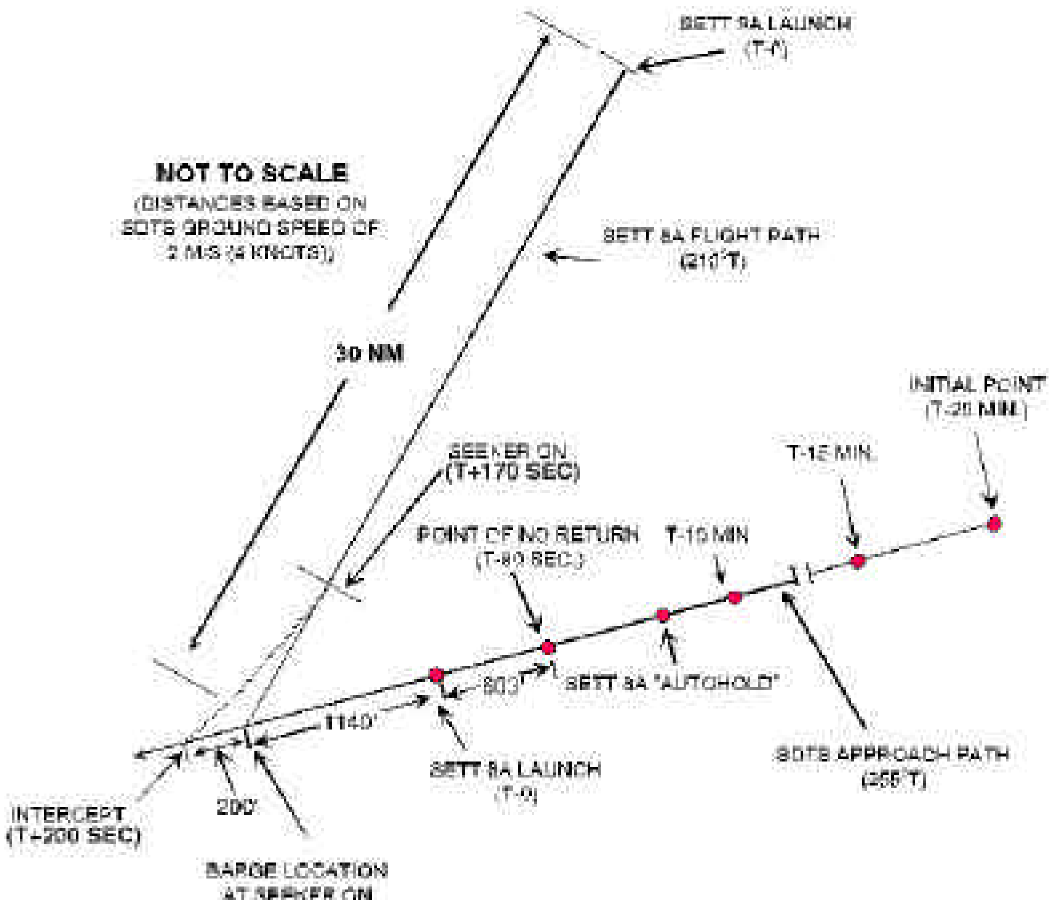

Figure 4-1. Planned SETT-8A Timeline

The SETT-8A would perform a terminal maneuver while homing on the decoy barge. The planned vertical and horizontal trajectories of missile flight are depicted in Figure 4-2[15]. Actual missile travel down range would be 30 nautical miles (NM) vice the 15 NM shown here. Ordinate values in Figure 4-2 for the horizontal and vertical trajectories are in meters.

15 Figure 5-2 from the SETT-8A Test Plan.

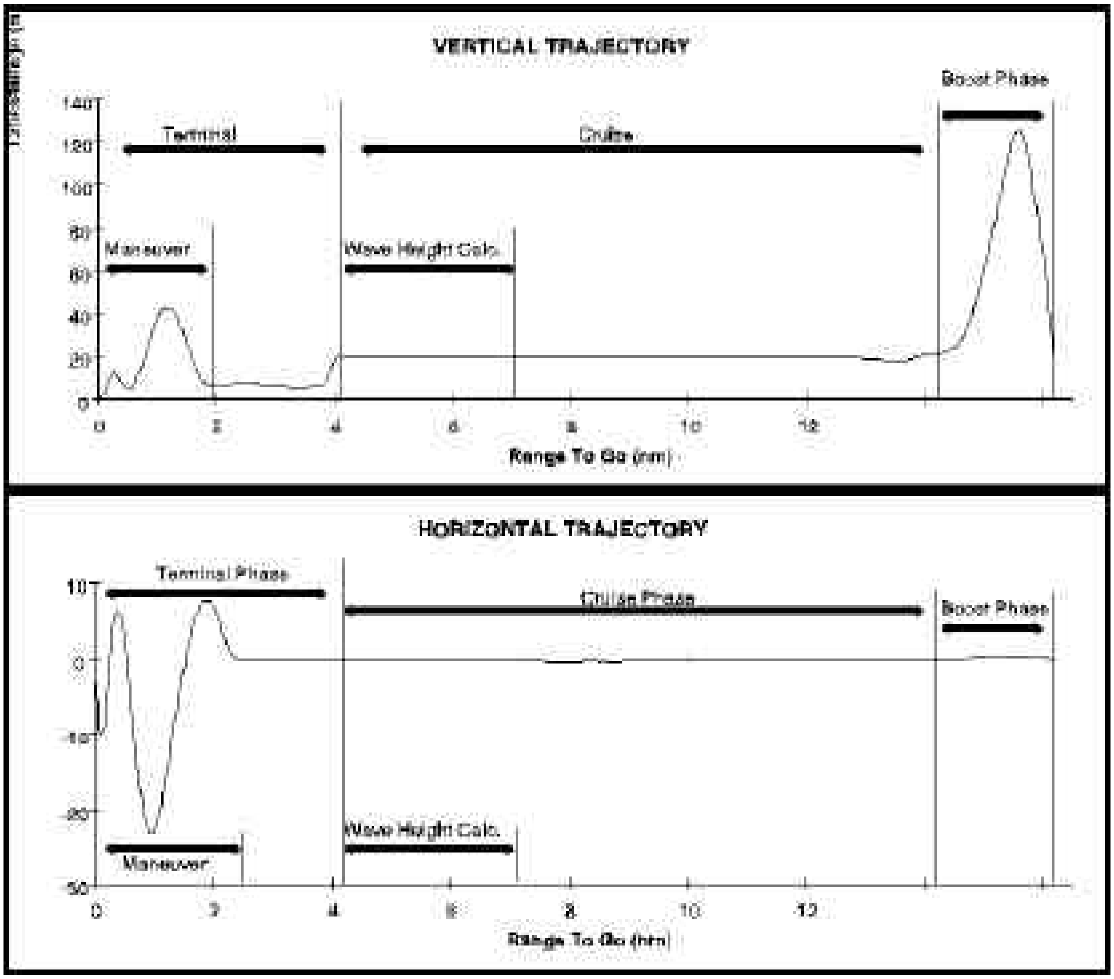

Figure 4-2. Planned SETT-8A Flight Profile

The SETT-8A is equipped with missile telemetry in place of the warhead, a tracking beacon, GPS, and a range destruct flight termination package. Figure 4-3 depicts the SETT-8A hazard pattern and flight termination boundaries[16].

[16] Figure 5-5 from the SETT-8A Test Plan.

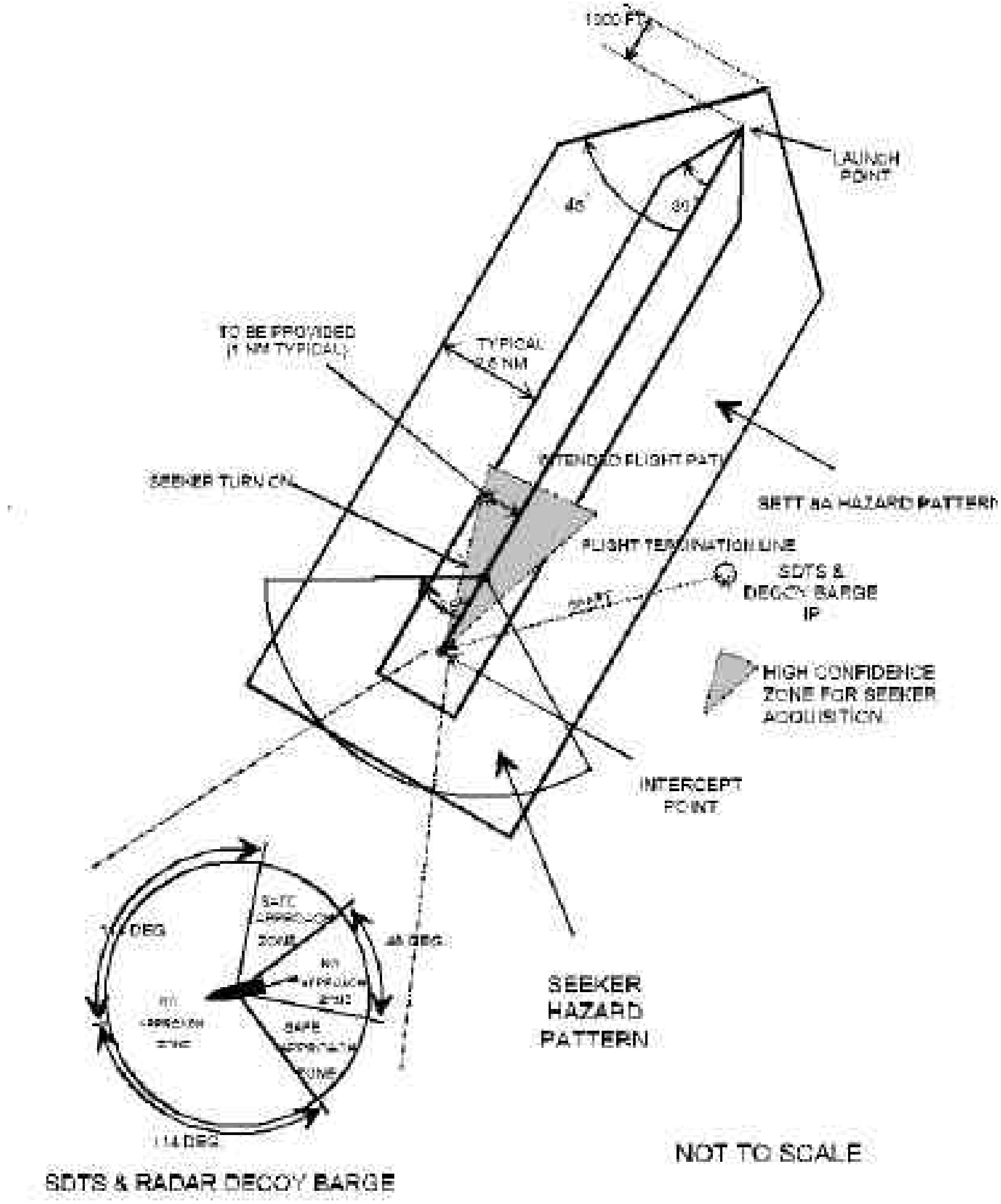

Figure 4-3. SETT-8A Hazard Pattern

Figure 4-4 depicts planned pattern orientation and sonobuoy placement for this acoustic collection event. The plan located the pattern approximately 9 to 11 NM down range (210°T) from missile launch point on San Nicolas Island.

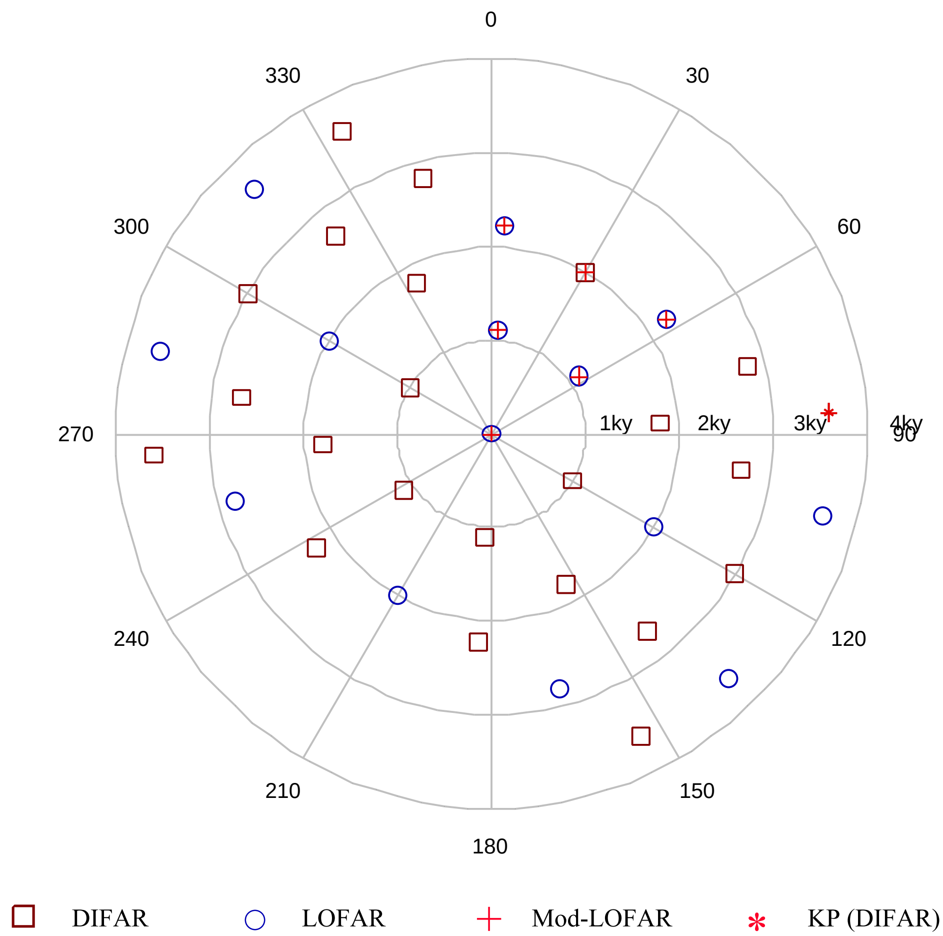

Figure 4-4. Planned SETT-8A Sonobuoy Data Collection Pattern (Degrees True)

According to the plan, the pattern consists of 43 sonobuoys[17] (23 DIFAR [SSQ-53D], 14 LOFAR [SSQ-57B], and 6 modified LOFAR) laid in five rows. The sonobuoys are dropped in five rows oriented from southeast to northwest and numbered one to five from top to bottom. Rows one, three, and five contain seven buoy positions, while rows two and four

17 Basic P-3 recording capability is limited to 28 tracks. This pattern requires the 48+ track recording capability of a BEARTRAP configured P-3.

contain eight buoy positions. The six mod-LOFAR buoys are co-located with other buoys in the pattern. Location of DIFAR, LOFAR, and mod-LOFAR buoys are as indicated in the figure. The King Pin (KP) Position is 33° 06′ 30′′N, 119° 37′ 40′′W. Road is 300° True. Row spacing is 1000 yards. Buoy spacing within rows is 1000 yards. Depth settings for the standard buoys are a mixture of medium (400 feet) and shallow (60 feet for LOFAR and 90 feet for DIFAR) settings. Depth settings for the modified LOFAR buoys must be selected shallow to enable the hydrophones to float. Payout of the additional line for medium or deep depth settings weigh the hydrophone down, causing it to sink.

4.2 Mission Reconstruction

Of the three data collection events, the plans for the SETT-8A required the least modification. Figure 4-5 depicts the track flown by the SETT-8A relative to San Nicolas Island and the deployed sonobuoy pattern.

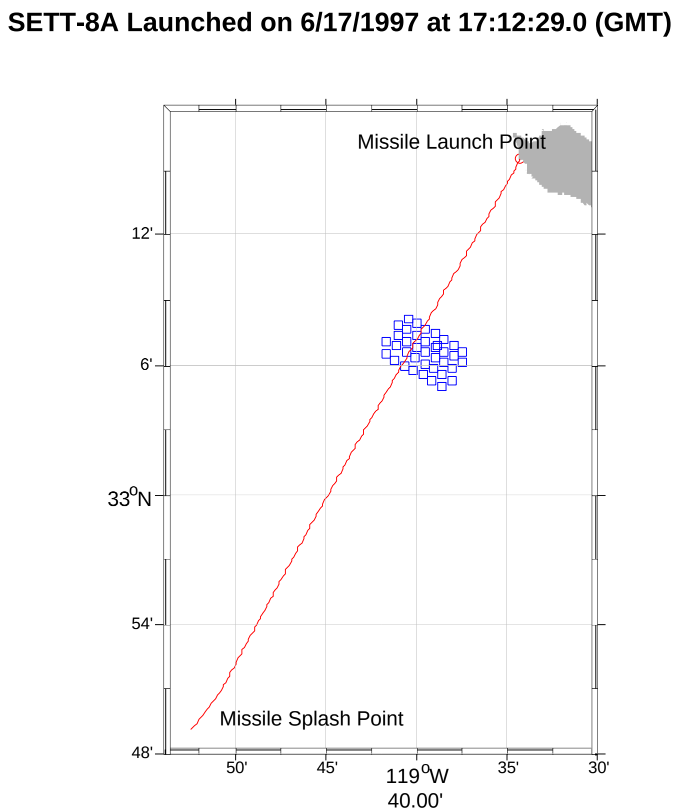

Figure 4-5. Flight Track of Subsonic Special Engineering Test Target (SETT-8A) Cruise Missile

Figure 4-6 provides a detailed view of the sonobuoy pattern and that portion of the missile track that passed over it. The actual pattern differs from the plan in Figure 4-4 at the location of LOFAR 10 in the top most row, below. The plan was to place a modified LOFAR sonobuoy at this location. This was accomplished. However, the buoy failed and there was insufficient time remaining prior to missile launch for the deployment of a replacement. Also, note that missile track does not pass through the center of the pattern. This is the result of an error in planning. Pattern placement was based upon the assumption that the SETT-8A launch point would coincide with that of the MQM-8G EER VANDAL of the preceding year. This assumption was false. Fortunately, the difference was not significant enough to prevent the missile from flying over the sonobuoy pattern.

Appendix C contains the listing of sonobuoy positions for this pattern.

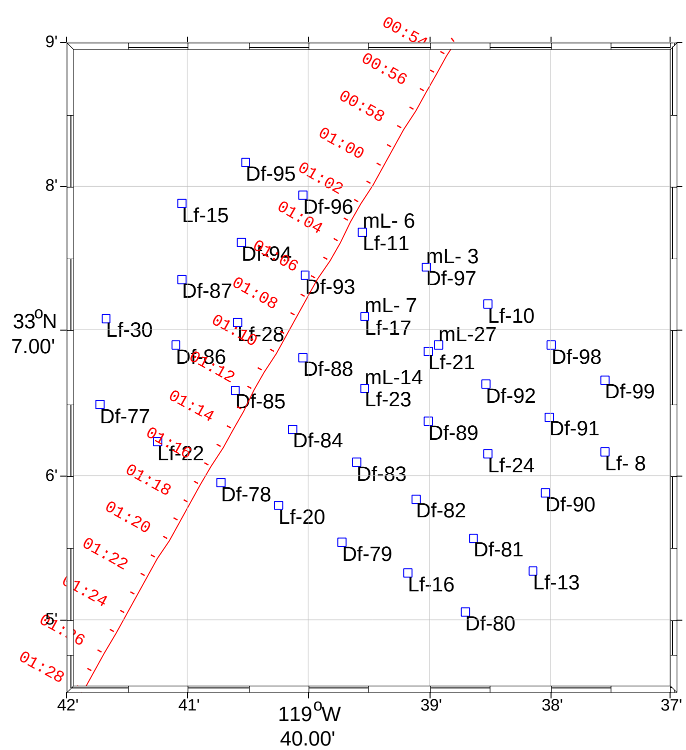

Figure 4-6. Detail View of SETT-8A Cruise Missile Track Over Acoustic Sonobuoy Field of LOFAR and DIFAR Buoys.

Figure 4-7 depicts missile range, velocity, and altitude attained during the flight. There are a couple of spikes in the velocity data within the first few seconds of flight. It is not known whether this is real or due to some anomaly in the data. Based upon the telemetry data used to generate these plots, the missile appears to have performed as programmed.

SETT-8A Launched on 6/17/1997 at 17:12:29.0 (GMT) [t=0]

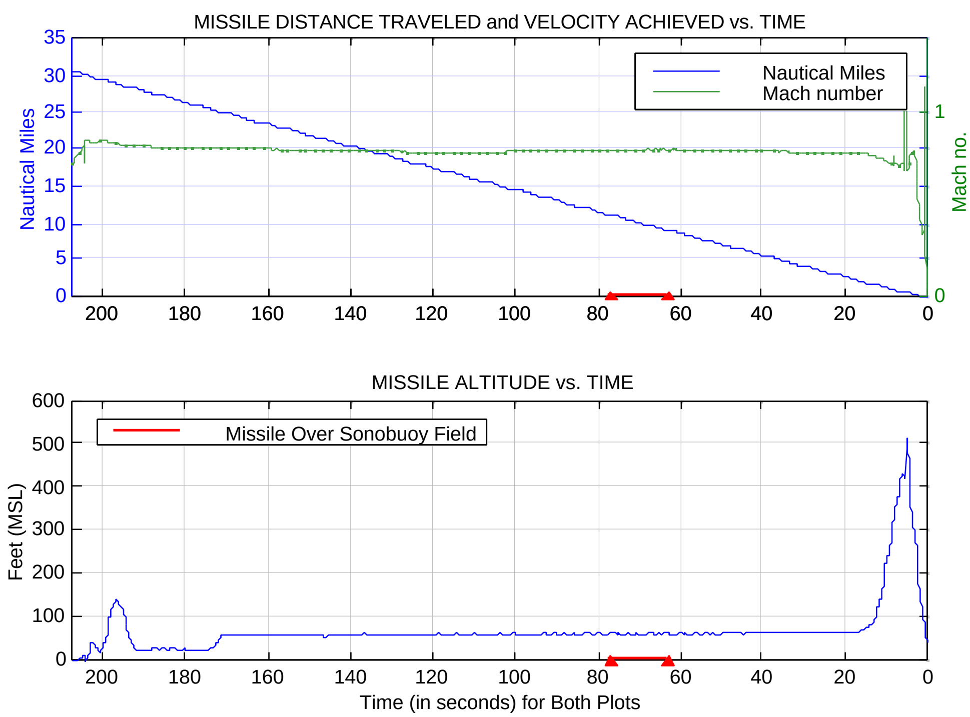

Figure 4-7. Actual SETT-8A Flight Profile

4.3 Acoustic Data

Post-flight analysis of the SETT-8A acoustic tapes revealed a significant level of interference on over half of the buoys in the pattern. The interference manifested itself in many forms; mostly voice radio and citizen band transmissions, morse code, and biologics. Some of the biologics sounded like seals, which are seasonal visitors of San Nicolas Island. Figure 4-8 contains a sample of the signals recorded during the SETT-8A data collection mission. Signals are plotted from top to bottom generally according to the order in which the missile overflew the buoys.

As for previous missions, digitization of acoustic data from the tapes occurred at a sampling rate of 4000Hz.

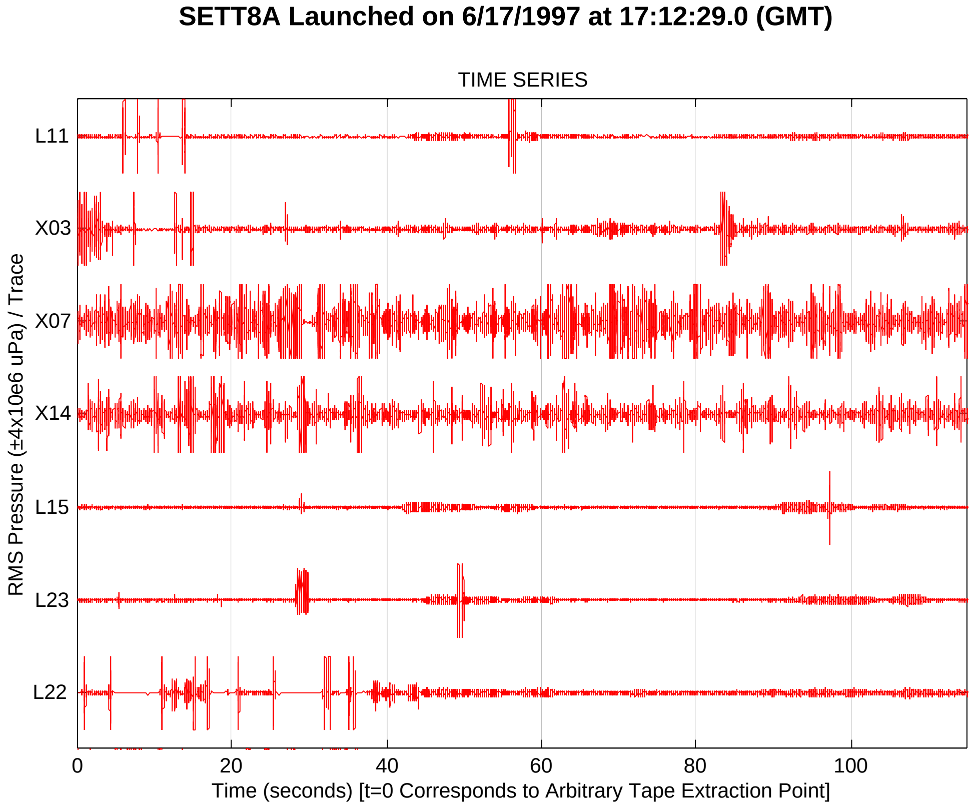

Figure 4-8. Signal Amplitude Samples Recorded from SETT-8A Mission by Sonobuoy (Signals Clipped to Prevent Overlap)

In Figure 4-8, L11 identifies the adjacent signal as having been recorded on LOFAR 11. X03 identifies the adjacent signal as having been recorded on modified LOFAR RF channel 3. This is the signal recorded from a floating hydrophone. For presentation purposes, the signals in all the samples above were clipped at $\pm$ 4 x 10^6 μPa to prevent an overlap of signals in the figure.

Section 5

Conclusions

A thorough analysis of the information collected on these missions must be conducted before definite conclusions can be drawn regarding the efficacy of adding an acoustic dimension to sensor suites designed to extend surface ship battlespace, by providing acoustic detection and early warning of cruise missile attack.

It is possible to draw three preliminary conclusions from the data we have already examined.

(1) Examination of the acoustic information extracted from the analog tapes yield visible and audible indications of the presence of a cruise missile. Further analysis should be directed at determining the range of detection, the signal excess available, and the frequencies generated. The latter is likely to be influenced as much by the missiles' physical dimensions, as by its propulsion characteristics.

(2) If analysis of existing data warrants further examination, additional collections should be authorized against the same missiles to expand our ensemble of data and improve the quality of the statistical characteristics which describe each missile.

(3) Acoustic collections should be authorized for as many different missiles as possible to identify their acoustic characteristics, generate detection probabilities, and provide insight into the most general characteristics (those common to most or all missiles).

Appendix A

MQM-8G EER VANDAL Sonobuoy Positions

The following table contains information on the location of the sonobuoy collection pattern deployed West of San Nicolas Island between 0140Z and 0200Z, on 14 August 1996 (GMT), to collect acoustic data from the over-flight of the MQM-8G EER VANDAL missile.

Latitude and longitude are listed in decimal degrees, North and East positive, and depth in feet below the water's surface. Buoy type corresponds to the designations in the legend.

Table A-1. MQM-8G EER VANDAL Sonobuoy Positions

Type	Buoy RF	Latitude	Longitude	Depth
2	30	33.2483	-119.67	-90
1	23	33.2633	-119.665	-60
1	26	33.28	-119.6617	-60
1	27	33.2983	-119.6583	-60
2	32	33.315	-119.655	-90
2	31	33.32	-119.6733	-90
1	21	33.305	-119.6767	-60
1	22	33.29	-119.68	-60
1	20	33.2767	-119.685	-60
2	33	33.2633	-119.69	-90
2	34	33.2567	-119.7117	-90
1	1	33.2717	-119.7083	-60
1	18	33.2867	-119.705	-60
1	29	33.3017	-119.7033	-60
2	35	33.3167	-119.6983	-90
1	16	33.325	-119.7183	-60
1	15	33.3083	-119.7217	-60

Type	Buoy RF	Latitude	Longitude	Depth
1	13	33.2933	-119.725	-60
2	36	33.2783	-119.73	-90
1	24	33.2633	-119.735	-60
4	16	33.2622	-119.6644	-1000
5	99	33.3822	-119.5664	0

Type	Designation
1	LOFAR buoy
2	DIFAR buoy
3	Modified LOFAR buoy
4	Bathythermograph buoy
5	Radar Contact

Appendix B

MA-31 Sonobuoy Positions

The following table contains information on the location of the sonobuoy collection pattern deployed Northwest of San Nicolas Island between 1956Z and 2009Z, on 14 August 1996 (GMT), to collect acoustic data from the over-flight of the MA-31 missile.

Latitude and longitude are listed in decimal degrees, North and East positive, and depth in feet below the water's surface. Buoy type corresponds to the designations in the legend.

Table B-1. MA-31 Sonobuoy Positions

Type	Buoy RF	Latitude	Longitude	Depth
2	32	33.3061111	-120.27056	-90
2	33	33.2933333	-120.265	-90
2	34	33.2763889	-120.26333	-90
1	2	33.2608333	-120.25972	-60
1	9	33.2444444	-120.25667	-60
1	10	33.2286111	-120.25222	-60
2	35	33.2286111	-120.25222	-90
2	36	33.2116667	-120.24833	-90
2	37	33.1936111	-120.24472	-90
1	15	33.2247222	-120.24222	-60
1	16	33.2408333	-120.24639	-60
1	20	33.2569444	-120.25028	-60
1	21	33.2733333	-120.25333	-60
2	38	33.3113889	-120.25222	-90
2	39	33.2952778	-120.24806	-90
2	40	33.2791667	-120.24389	-90
1	27	33.2633333	-120.24056	-60
1	22	33.2472222	-120.23667	-60

Type	Buoy RF	Latitude	Longitude	Depth
1	23	33.2311111	-120.2325	-60
2	41	33.2138889	-120.22667	-90
2	42	33.1980556	-120.22583	-90
2	43	33.1822222	-120.22028	-90

Type	Designation
1	LOFAR buoy
2	DIFAR buoy
3	Modified LOFAR buoy
4	Bathythermograph buoy
5	Radar Contact

Appendix C

SETT-8A Sonobuoy Positions

The following table contains information on the location of the sonobuoy collection pattern deployed Southwest of San Nicolas Island between 1613Z and 1703Z, on 17 June 1997 (GMT), to collect acoustic data from the overflight of the SETT-8A missile.

Latitude and longitude are listed in decimal degrees, North and East positive, and depth in feet below the water's surface. Buoy type corresponds to the designations in the legend.

Table C-1. SETT-8A Sonobuoy Positions

Type	Buoy RF	Latitude	Longitude	Depth
3	27	33.1151	-119.6489	0
2	77	33.1083	-119.6956	-90
1	22	33.104	-119.6875	-400
2	78	33.0993	-119.6787	-400
1	20	33.0966	-119.6708	-400
2	79	33.0924	-119.6622	-90
1	16	33.0887	-119.6529	-400
2	80	33.0843	-119.645	-90
1	13	33.0889	-119.6358	-400
2	81	33.0928	-119.6439	-90
2	82	33.0972	-119.6518	-400
2	83	33.1016	-119.6602	-90
2	84	33.1053	-119.6689	-400
2	85	33.1098	-119.6769	-90
2	86	33.1151	-119.6852	-400
1	30	33.1182	-119.6946	-60
2	87	33.1228	-119.6842	-400
1	28	33.1178	-119.6766	-60

Type	Buoy RF	Latitude	Longitude	Depth
2	88	33.1136	-119.6676	-400
3	14	33.1102	-119.6591	0
1	23	33.1102	-119.6591	-60
2	89	33.1064	-119.6503	-400
1	24	33.1026	-119.6419	-60
2	90	33.0981	-119.634	-400
1	8	33.1028	-119.6258	-60
2	91	33.1067	-119.6334	-400
2	92	33.1105	-119.6423	-90
1	21	33.1144	-119.6502	-400
3	7	33.1184	-119.659	0
1	17	33.1184	-119.659	-60
2	93	33.1231	-119.6673	-400
2	94	33.1271	-119.6759	-90
1	15	33.1314	-119.6843	-400
2	95	33.1362	-119.6753	-400
2	96	33.1325	-119.6675	-400
3	6	33.1281	-119.6592	0
1	11	33.1281	-119.6592	-60
3	3	33.1242	-119.6504	0
2	97	33.1242	-119.6504	-400
1	10	33.1198	-119.6419	-400
2	98	33.1152	-119.6333	-400
2	99	33.1112	-119.6258	-90

Type	Designation
1	LOFAR buoy
2	DIFAR buoy
3	Modified LOFAR buoy
4	Bathythermograph buoy
5	Radar Contact

Appendix D

Oceanographic Profiles

Water column temperature samples were collected using a bathythermograph (BT) sonobuoy during the VANDAL and SETT-8A data collection missions. One BT sonobuoy was deployed in the VANDAL pattern area (33˚ 15' 44" N, 119˚ 39' 49" W) at 0249 20Z to record water temperature and permit the calculation of sound velocity profile (SVP). Two BT sonobuoys were deployed in the SETT-8A pattern area, one each before and after missile launch. The first SETT-8A BT buoy was deployed (32˚ 50' 34" N, 119˚ 27' 22" W) at 1601 29Z (GMT). The second was deployed (33˚ 02' 02"N, 119˚ 28' 48"W) at 1822 10Z. Data from the latter are erratic and, therefore, will not be presented.

These BT buoys are capable of measuring water temperature to a depth of 1000 feet (304.8 meters). Sound velocity in water can be calculated with measured temperature data using the following equation[18],[19]:

$$c = 1449 + 4.6T - .055T^2 + .0003T^3 + (1.39 - .012T)(S - 35) + 0.017z \qquad (1)$$

where

c = sound speed, m/sec,
T = temperature, ˚ C,
S = salinity, parts per thousand,
z = depth, meters

Figure D-1 shows VANDAL water temperature and the associated SVP. Readings at depths greater than 45 meters (150 feet) become erratic, reflecting the fact that the BT buoy was resting on the bottom. Water depth at the drop location is roughly 40 fathoms (~70 meters).

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18 Burdic, W.S., Underwater Acoustic System Analysis, 2nd ed., Englewood Cliffs, N.J.: Prentice Hall, 1991, Chap. 5.

19 Kinsler, L.E., and A.R. Frey, *Fundamentals of Acoustics*, 2nd ed. New York: John Wiley & Sons, Inc.,1962.

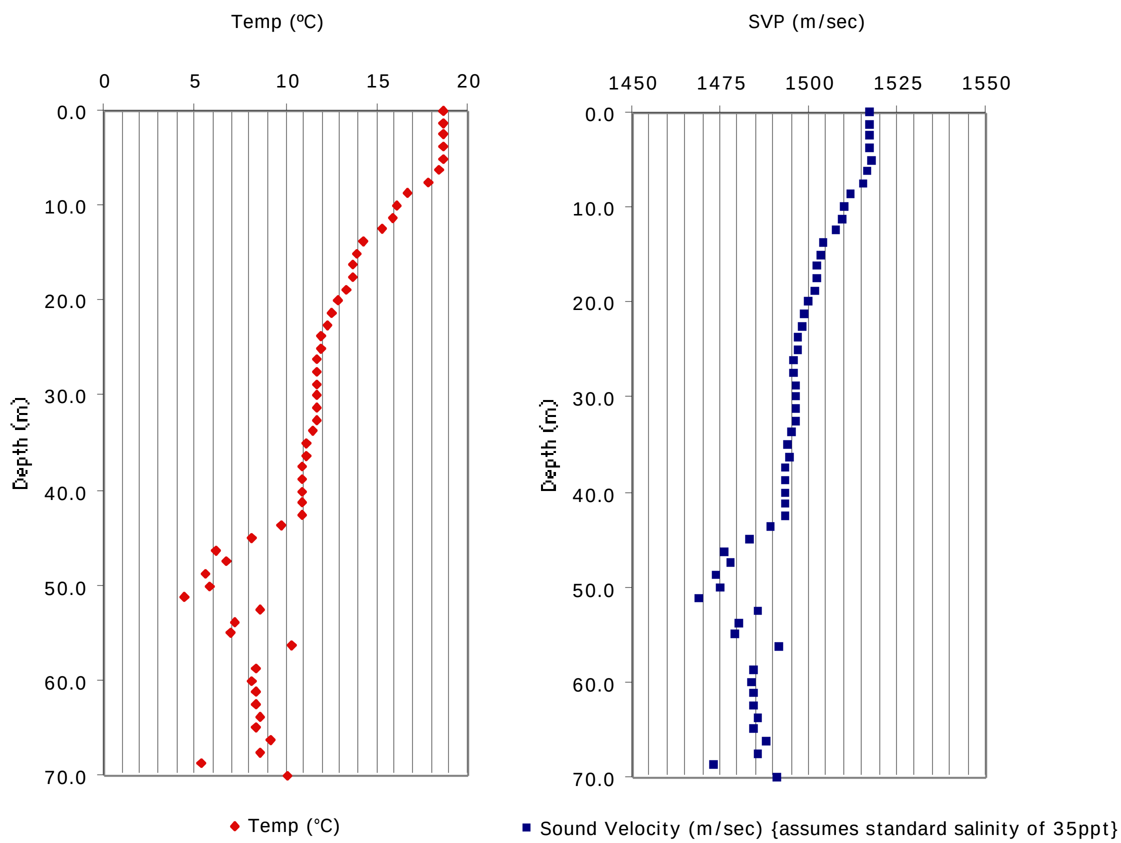

Figure D-1. Temperature and Sound Velocity Profile from Bathythermograph Sonobuoy Deployed in the Vicinity of the VANDAL Acoustic Collection Pattern

Figure D-2 shows SETT-8A water temperature from the first BT buoy and the associated SVP. Depths in the drop area exceeded 335 meters (1100 feet).

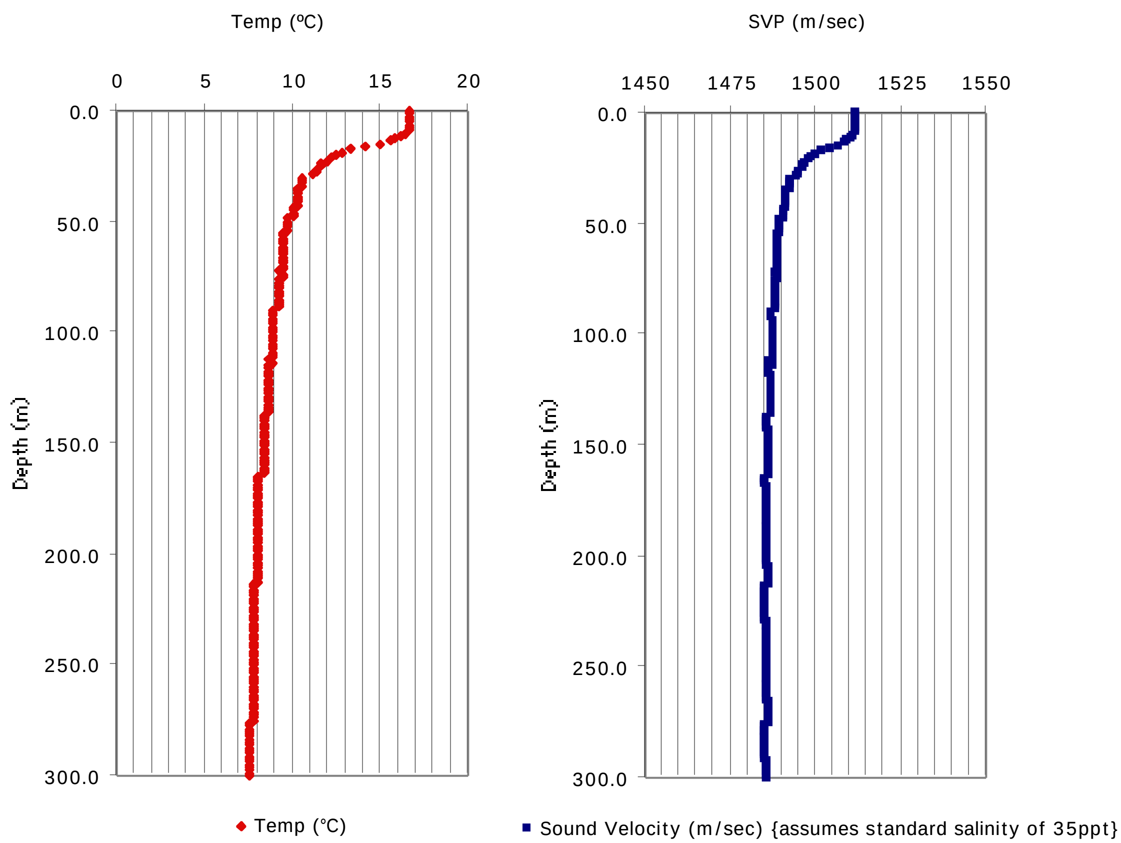

Figure D-2. Temperature and Sound Velocity Profile from Bathythermograph Sonobuoy Deployed in the Vicinity of the SETT-8A Acoustic Collection Pattern

Appendix E

Atmospheric Profiles

Data from rawinsonde atmospheric soundings for MA-31 and SETT-8A missions are included in this appendix. A rawinsonde (*ra*dar + *win*d + radio*sonde*) is a radiosonde tracked by a radio direction-finding device to determine the velocity of winds aloft. The radiosonde is a miniature radio transmitter that is carried aloft by an unmanned balloon with instruments for broadcasting by means of precise tone signals, the humidity, temperature, and pressure.

E.1 MA-31 Atmospheric Profile

Table E-1 contains data from one rawinsonde sounding[20] taken at 1523 38Z from San Nicolas Island on 14 August 1996. Data provided in increments of 1000 feet, up to 63,000 feet. Only the first 5000 feet are included in the table, below.

Table E-1. Rawinsonde Sounding of 14 August 1996 at 1524Z

Altitude FT	Wind Direction DEG	Wind Speed KTS	Temp DEG C	Pressure MBS	Density G/M3	Index of Refraction N	Speed of Snd KTS
46	140	8	24.8	1014	1178	336	672
1000	-	-	20.7	981	1154.50	339	668
2000	-	-	28.0	947	1091.70	280	676
3000	-	-	28.4	915	1051.60	288	676
4000	211	5	27.9	884	1018.50	273	676
5000	-	-	26.2	854	989.60	264	674

E.2 SETT-8A Atmospheric Profiles

Table E-2 contains data from a rawinsonde sounding[21] taken on 17 June 1997 at 1551Z, prior to the launch of SETT-8A. Soundings are recorded, initially, every 50 feet up to an

20 Sounding identification number 960814 2026 2 3.

21 Rawinsonde sounding RS751681551.

altitude of 92,000 feet. However, only the first 3000 feet (at increments of 200 feet) are included in the table below. The data provided by NAWC WPNS Division for these soundings include more detail than that provided for the MA-31 mission, above.

Table E-2. Rawinsonde Sounding of 17 June 1997 at 1551Z

Altitude FT	Wind Direction DEG	Wind Speed KTS	Temp DEG C	Dew Point DEG C	Pressure MBS	Relative Humidity PCT	Absolute Humidity G/M3	Density G/M3	Index of Refraction N	Speed of Snd KTS
7	155	2	18.2	14.7	1012	80	12.44	1202.56	343	665
200	137	2	16.6	15.6	1005.11	94	13.26	1200.48	348	663
400	114	3	16	15.7	997.91	98	13.37	1194.28	347	662
600	95	4	15.6	15.6	990.8	100	13.28	1187.51	345	662
800	81	5	15.2	15.2	983.79	100	13.02	1180.57	342	661
1000	72	5	14.9	14.9	976.71	100	12.73	1173.67	339	661
1200	67	5	15	14.6	969.71	97	12.54	1164.72	336	661
1400	67	5	15.8	13	962.79	84	11.24	1154.1	325	662
1600	74	4	17.1	11.1	955.95	68	9.87	1141.39	314	664
1800	88	4	19.2	11.5	949.19	61	10.06	1125.12	311	666
2000	104	2	21.2	12	942.48	55	10.3	1109.11	308	668
2200	108	2	23.3	12.5	935.88	51	10.58	1093.47	306	671
2400	104	3	24.7	11.8	929.44	44	10.06	1080.89	300	672
2600	99	2	24.7	11	923.05	42	9.55	1073.86	295	672
2800	99	2	24.9	10.1	916.67	39	8.98	1066.02	290	672
3000	100	2	25.4	8.5	910.37	34	8.07	1057.45	283	673

Table E-3 contains data from a rawinsonde sounding[22] taken on 17 June 1997 at 1826Z, after the launch of SETT-8A. This sounding recorded atmospheric conditions to an altitude of 69,000 feet. However, only the first 3000 feet (at increments of 200 feet) are included in the table below.

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[22] Rawinsonde sounding RS751681826.

Table E-3. Rawinsonde Sounding of 17 June 1997 at 1826Z

Altitude FT	Wind Direction DEG	Wind Speed KTS	Temp DEG C	Dew Point DEG C	Pressure MBS	Relative Humidity PCT	Absolute Humidity G/M3	Density G/M3	Index of Refraction N	Speed of Snd KTS
7	200	10	20.1	16.6	1012	80	13.96	1193.81	349	667
200	183	10	17.3	15.6	1005.08	90	13.24	1197.62	347	664
400	166	9	16.7	15.6	997.91	93	13.25	1191.46	346	663
600	155	7	16.1	15.6	990.85	97	13.28	1185.39	345	662
800	161	7	15.8	15.5	983.77	98	13.21	1178.13	343	662
1000	161	7	15.6	15.4	976.8	99	13.09	1170.82	340	662
1200	144	5	15.3	15	969.81	98	12.81	1163.56	337	662
1400	112	5	15.3	15	962.9	98	12.79	1155.36	335	662
1600	89	7	15.9	13.7	955.99	87	11.76	1145.1	326	662
1800	71	9	17.5	13.1	949.29	76	11.28	1131.12	320	664
2000	62	11	20	11.7	942.57	59	10.18	1113.89	309	667
2200	55	10	22.9	11.9	935.92	50	10.19	1095.13	304	670
2400	40	8	25.1	10.2	929.42	39	9.04	1080.02	294	673
2600	33	6	25.9	8.7	922.99	34	8.17	1070.13	286	674
2800	29	2	26.1	8.6	916.66	33	8.09	1062.24	284	674
3000	27	2	25.7	8.3	910.37	33	7.92	1056.57	282	673

Distribution List

Internal

W090

Burt, J.

Haug, A.

Jacyna, G.

Polk, S.

W096

Brock, M.

Carley, M.

Colella, D.

Creekmore, J.

W097

Bethel, R.

Burmaster, C.

Christou, C.

Lowen, D.

McAdow, K.

Pawlukiewicz, S.

Wrick, V.

External

ARL/UT

Penrod, C.

A&T

Ghen, C.

ASTO

Hommel, A.

Thompson, J.

Zarnich, R.

BA&H

Oliver, T.

DSR

Gallemore, B.

JHU/APL

Stapleton, J.

PMS 401

Smerchansky, J.

PMS 425

Johnson, B.