Potential Impact of USAF atmospheric interceptor technology (*ait*) Launches from the Kodiak Launch Complex, Kodiak Island, Alaska

Monitoring of Noise Levels During the Launch of *ait*-2, 15 September 1999

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Foreword

This work was performed by Dr. Ann Bowles of the Hubbs-Sea World Research Institute under Purchase Order W62N6M-9243-8992 issued by the Department of the Army Corps of Engineers, Sacramento (1325 J. Street Sacramento, CA 95814-2922), under the direction of Carl Lang, Project Engineer. The work was performed for the U.S. Air Force, Space and Missile Systems Center [AFSMC], Los Angeles Air Force Base (Authorization Number MIPR#NKIRT 996209817). Collaborators in this work were Thomas T. Huynh (AFSMC), the project manager, and Dr. Valerie Lang (The Aerospace Corporation). The work was conducted in parallel with a larger monitoring effort by the University of Alaska's Environment and Natural Resources Institute (ENRI). Acoustic data collected by ENRI were provided for this report by Sal Cuccarese and Mike Kelly. Dr. Ken Plotkin (Wyle Laboratories) provided predictions of launch noise (RNOISE).

Acknowledgments

Many people provided support during the conduct of this study, for which I am very grateful. Sal Cuccarese and Mike Kelly offered much helpful advice and information about the wildlife and working conditions on Kodiak Island. In addition to giving me a wealth of technical information about the *ait* program, Valerie Lang and Thomas Huynh helped haul gear and collect data, braving pouring rain, blowing salt spray, large mammals, and logistic nightmares. Allan Deller of PCB Piezotronics and Hans Hellsund and Tom Dobson of Larson-Davis provided many hours of technical consulting; some of them very odd hours indeed. Maritime Helicopters Pilot Tom Walters was kind enough to fly a group of gear-heavy bioacousticians to Ugak Island at nightfall when there was no other way to deploy a monitoring system. The *ait*-2 launch staff at Kodiak Launch Complex, including both Alaska Aerospace Development Corporation (AADC) and U.S. Air Force (USAF) personnel, were very kind - they helped deploy monitors on the day of the launch and provided invaluable technical information. Jacque Rice and Don Hunsaker, II, of The Environmental Trust were kind enough to lend me two of the Larson-Davis 820 instruments used during the study. Many thanks to Larry Wolski for his excellent analysis of the acoustic data, helpful comments, and endless cogitating over a battery with reversed polarity. Thanks also to Rindy Anderson for help with the analysis. Brent Stewart, Valerie Lang, Thomas Huynh, and James Williamson made helpful comments on the draft of this report.

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Executive Summary

Introduction

The U.S. Air Force (USAF) atmospheric interceptor technology (*ait*) program must conduct protected species monitoring during periods immediately before and after *ait* rocket launches from the Alaska Aerospace Development Corporation's Kodiak Launch Complex (AADC/KLC). Monitoring and mitigation efforts for two protected species, the endangered Steller sea lion (*Eumetopias jubatus*) and the threatened Steller's eider (*Polysticta stelleri*), are a condition of the FONSI for the program (AFSMC 1997) and were conducted by the University of Alaska's Environment and Natural Resources Institute (ENRI) in the days before and after the *ait*-2 launch.

The study reported herein was conducted from 12-15 September, 1999, before, during, and immediately after the *ait*-2 launch on 15 September. It ran in parallel with the ENRI effort and was designed to provide the USAF with detailed information about the acoustic characteristics of the ait-2 launch, in part for future prediction of animal impacts and in part for comparison with RNOISE model outputs (Wyle Laboratories). Opportunistic observations of animal behaviors were obtained during this effort as well.

Methods

Larson-Davis sound monitors (LD 820, 824) were deployed to collect noise data automatically at four sites within the Safety Exclusion Zone (SEZ) for the launch, including two sites on Narrow Cape, the portion of Kodiak Island extending closest to Ugak Spit. A fifth monitor on Ugak Spit failed. A real-time DAT recording was collected just outside the SEZ, close to the Launch Control Complex (LCC).

HSWRI and AFSMC cooperators were able to count and observe the behavior of marine mammals on 9/12 from Narrow Cape using a Meade ETX-90EC Telescope (Lang 2000). They also collected behavioral observations during helicopter approaches and landings on Ugak Island 9/14 (2000-2130 h) and 9/15 (1330-1350 h). Sea lions were observed at Ugak Spit after the launch from 1345 to 1500 h on 9/15 using the Meade telescope.

Results

<u>Noise monitoring:</u> The evening and night immediately preceding the launch were marked by moderate to high winds and rainsqualls. At the time of launch, skies were clear and wind close to the ground was from the west (230°) at low speed (9 kt). Ambient noise on 9/14 and 9/15 was similar during hours when there was little wind (<10 kt), with hourly L_{eq} measurements ranging from 43 to 55 dB(A). Only 0.6% of the samples exceeded 70 dB(A) at Site 1 while 4% of sample levels exceeded 70 dB(A) at Site 2, the two HSWRI monitoring sites closest to Ugak

Spit.

Launch ignition occurred at 12:59:59.34 h ADT (local time). At the LCC real-time monitoring site (Site 4), low-amplitude roar was detected on the real-time recording beginning at approximately 2 s after ignition; at 8-9 s, the noise level rose steeply, peaking at 127.5 dB(A). The real-time monitoring site was 3,130 m from the launch stool, leading to a predicted arrival time of 9 s. Thus, when the launch time was assumed to correspond to the peak in launch noise, propagation time was as expected. A-weighted maximum level of the noise was 107.9 dB (unweighted, slow L_{max}; 107.1 dB(A)). The time course of the launch noise was as expected, rising rapidly to an initial sharp peak and declining gradually over a period of 35-40 s.

There were two broad spectral peaks in the noise, one centered at around 30-120 Hz and one at 200-1100 Hz. Levels exceeded the local ambient out to approximately 22,000 Hz at Site 4, the closest to the launch stool. Using the sea lion's estimated threshold at 1000-8000 Hz and the highest 1/3-octave spectral level in that range, the signal-to-noise ratio (SNR) of the launch noise would have been more than 50 dB from the perspective of a sea lion close to Narrow Cape at the surface. However, by the time the vehicle reached its closest point of approach to Ugak Spit, the high-frequency component of the noise had attenuated, making the worst-case SNR at the site of the Steller sea lion haulout 36.5-47.2 dB.

Levels collected by ENRI LD 875 sound meters were compared with the HSWRI data. A-weighted levels measured from paired instruments on Narrow Cape were very consistent, particularly the A-weighted sound exposure levels (ASEL), which came within 1 dB of one another. A-weighted L_{max} and peak levels varied somewhat more (within 4 dB), but were still very consistent for field measurements. The levels measured at all sites were somewhat higher than predicted by the RNOISE launch model, particularly at the sea lion haulout on Ugak Spit. ASEL measured at that site by ENRI was 92.2 dB, 8.1 dB higher than predicted.

<u>Observations of Steller sea lions:</u> The sea lions on the spit at Ugak Island were approached twice on 9/14 in a Bell 206 helicopter to place equipment. According to the pilot, both landings were similar. The helicopter did not overfly the sea lions on the spit directly, instead making an oblique approach from the southwest, landing a few hundred meters from them. The animals congregated tightly and stood alert as the helicopter landed and observers approached. They did not enter the water immediately. A few eventually abandoned the beach as observers worked, but there was no general exodus, nor were individuals seen rafting - congregating in the water close to shore - as observers left the area.

ENRI staff and a NMFS observer (ENRI/NMFS observers) surveyed the haulout on Ugak Spit before, during and after the ait-2 launch. On 9/15, these observers overflew the spit at 0800 h, estimating 76 animals from the air. Aircraft and vessels were cleared from the area thereafter, with the possible exception of overpasses of Ugak Channel by support helicopters patrolling the SEZ. No observers were present on Ugak Island during the launch, so it is difficult to know what the sea lions saw from the spit. At LCC, 3 km from the launch site, the launch was not simply a noisy event - there were also striking visual and tactile stimuli. The burning rocket engines produced a bright light that climbed rapidly into the sky and a white exhaust plume. A shock wave from the launch was quite palpable at LCC, 3 km away.

At 1327 h observers returned to Ugak Island to retrieve equipment. From the air, no sea lions were visible on the spit. Once observers were on the ground, some sea lions were found in the area, rafting among kelp floats 10-15 m offshore. These sea lions were congregated in 3 groups, tightly rafted, swimming alongshore with heads frequently oriented towards the intruders on the spit. They remained in the water staring at the shore until at least 1500 h. However, by the time of the ENRI/NMFS survey the following morning (0845 h on 9/16), 70-80 animals were back on the spit.

<u>Gray Whales (*Eschrichtius robustus*):</u> As observers scanned the island with telescope and binoculars on 9/12, numerous whales were sighted. They did not appear to be migrating through Ugak Pass or around the outer side of the island, but rather were surfacing in the same general location time after time. Surfacing animals were examined carefully with the telescope whenever they arched or fluked; all of these were found to be gray whales. A few were concentrated at the southwest end of Ugak Island, but most were in the broad entrance to Ugak Bay seaward of Gull Point. The greatest number counted at the surface at any time was 38; the actual number of whales in the area was probably larger.

<u>Conclusions:</u> The rafting behavior observed on Ugak Spit - congregating tightly in the water while watching a potential danger on shore - is a common otariid (sea lion) defensive behavior in the face of a surprising or threatening event. When a large proportion of the sea lions in a group enter the water defensively (‘stampede’), rafting is the usual result. When animals enter the water singly or in small groups, as is typical of foraging trips, rafting typically does not involve a large proportion of the hauled animals. Therefore, an empty beach with many of the animals rafting immediately offshore is strong evidence that sea lions have been surprised or frightened into the water *en masse*.

Unfortunately, the evidence available on the responses of sea lions on 9/15 is equivocal. Although the beach was empty, only 25% of the animals sighted on the beach early that morning were rafting offshore at 1330 h on a warm afternoon. The behavior of the sea lions conceivably could be interpreted as a thermoregulatory response.

In addition, due to an equipment failure, no video was available of sea lion responses at the time of the launch, nor were any direct observations made. ENRI (2000) reports that many of the sea lions entered the water shortly before the monitoring system failed at 0930 h; however, their account lacks the kind of detail needed to evaluate the response, nor was the video made available. Therefore, it is difficult to interpret their observations. It is possible that this behavior was thermoregulatory in nature, or that one or more unknown events occurring on the morning of the launch could have contributed to the rafting observed, for example uncontrolled overflights by the helicopter guarding the SEZ. However, the complete absence of animals on the beach and the tight rafts close inshore at 1330 h argue for some type of disturbance in the relatively recent past (say, within the past hour).

Since the sea lions were already in the water with the beach empty when the helicopter approached at 1330 h, it is also quite likely that the launch was a contributing factor, if not actually a triggering event for long-term evacuation of the spit (they stayed in the water until at least 1500h). In other studies, pinnipeds have reacted similarly when exposed to unusual stimuli (noise, overflights, *etc*.)

Without monitoring noise at Ugak Island over a long period, it is difficult to know what levels would have been unusual from the sea lions' perspective; however, considering only the monitoring period (9/14-9/15) and typical noise levels in remote areas, the SNR of the launch was unusual. Moreover, the launch presented sea lions with novel visual and possibly tactile stimuli. In the face of these novel, high-intensity stimuli, evacuation of the beach and rafting would not be at all surprising.

If sea lions were actually stimulated to enter the water or to remain in it as a result of the *ait*-2 launch, from a legal point of view they would have been harassed. This does not mean that sea lions on Ugak Island necessarily would have been harmed, however. Disturbances of this kind, occurring infrequently and unaccompanied by protracted harassment on the beach, are not known to cause abandonment of favored hauling areas - usually, the animals return to their previous hauling patterns within a day, as was observed by NMFS survey crews on the morning of 9/16 (ENRI 2000). Occasional launch-related harassment would not be likely to have any biologically-significant effect on sea lions outside crucial phases of the breeding season.

The launch of ait-2, 9/15/99, 13:00:00. Photo by A. Bowles

Monitoring of Noise Levels During the Launch of *ait*-2, 12:59:59.34 ADT, 15 September 1999

Introduction

The U.S. Air Force (USAF) atmospheric interceptor technology (*ait*) program must conduct protected species monitoring during periods immediately before, during, and after *ait* rocket launches from the Alaska Aerospace Development Corporation's Kodiak Launch Complex (AADC/KLC) (Space and Missile Systems Center [AFSMC] 1997). The results of acoustic measurements collected in support of this monitoring effort are reported herein, with additional observations of protected animal behaviors.

The *ait* program provides sub-orbital missile launches as part of the development effort for the USAF National Missile Defense tracking system. The *ait* launches simulate inbound ballistic missiles. The second ait (*ait*-2) vehicle was scheduled for launch on 15 September 1999 at 13:00:00 h ADT. It was 56 ft 10 in long, weighing 31,912 lb at liftoff. The booster stack consisted of two solid rocket motors, a Thiokol Castor IVB (with flexseal) as the first stage and an M57A1 as the second. It was launched at 13:00:00 (local time) on September 15, 1999, with a launch trajectory angle of 120°, which carried it over the Gulf of Alaska to splash down in the sea offshore of Portland, OR.

The present study was conducted from 12-15 September, 1999, before, during, and immediately after the *ait*-2 launch. It ran in parallel with a more extensive study by the University of Alaska, Environment and Natural Resources Institute (ENRI), and was designed to provide the USAF with detailed information about the acoustic characteristics of the *ait*-2 launch, in part for future

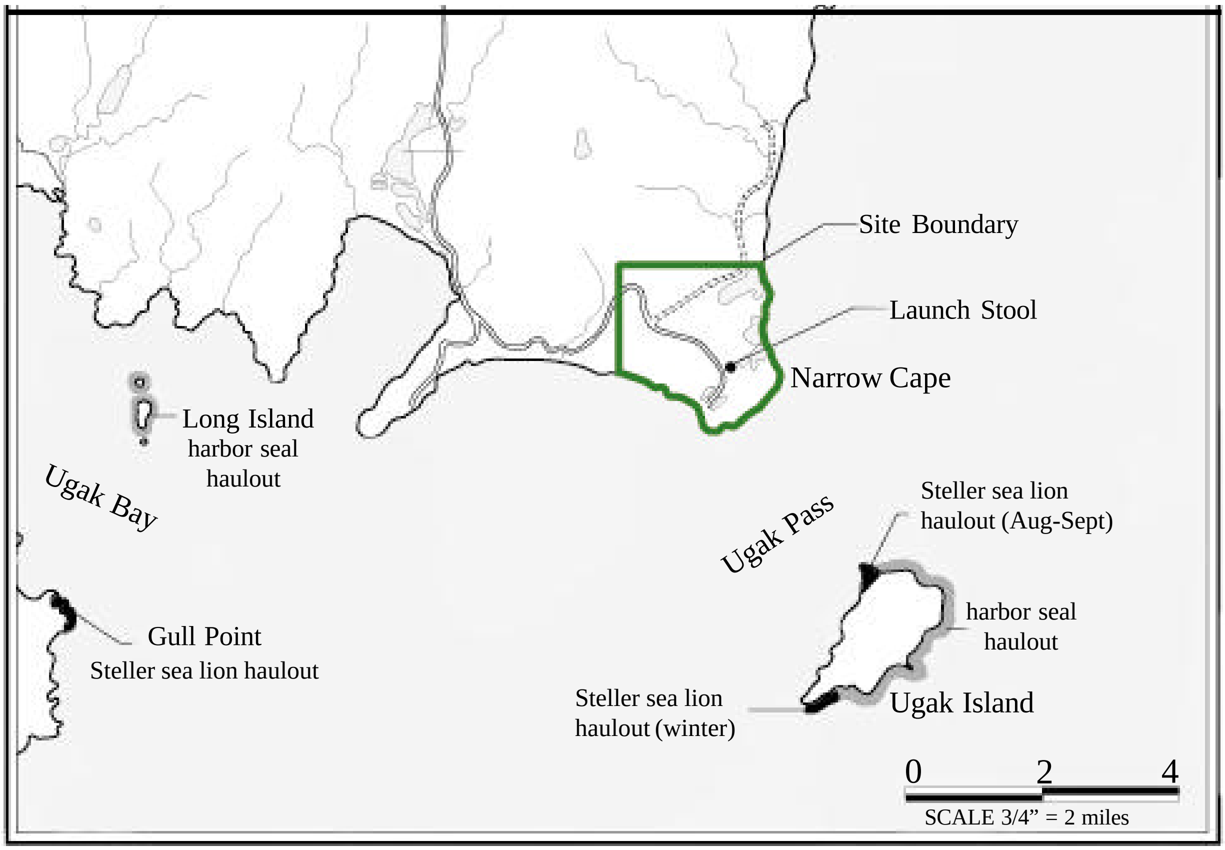


Figure 1. Study area, including the Kodiak launch site boundary, launch stool, geographic areas discussed in the text, and pinniped hauling sites.

prediction of potential animal impacts and in part for comparison with RNOISE model outputs (RNOISE is a launch noise model developed by Wyle Laboratories).

Monitoring and mitigation efforts for two protected species, the endangered Steller sea lion (*Eumetopias jubatus*) and the threatened Steller’s eider (*Polysticta stelleri*), were a condition of the FONSI for the program (AFMC 1997) and were duly conducted before, during, and after the launch (ENRI 2000). The Steller sea lion has 4 major rookeries (breeding colonies) and 17 haulout sites in the general area of the launch site. The closest haulout lay on the northeastern-most point of Ugak Island (Ugak Spit), 5.4 km from the launch stool. It was surveyed using light aircraft by the National Marine Fisheries Service (NMFS) and ENRI before and after the launch. Steller’s eiders (*Polysticta stelleri*) also occur in the area, although none were present at the time of the launch. The harlequin duck (*Histrionicus histrionicus*) was treated as a surrogate species and was surveyed from the coast immediately before and after the launch by ENRI personnel.

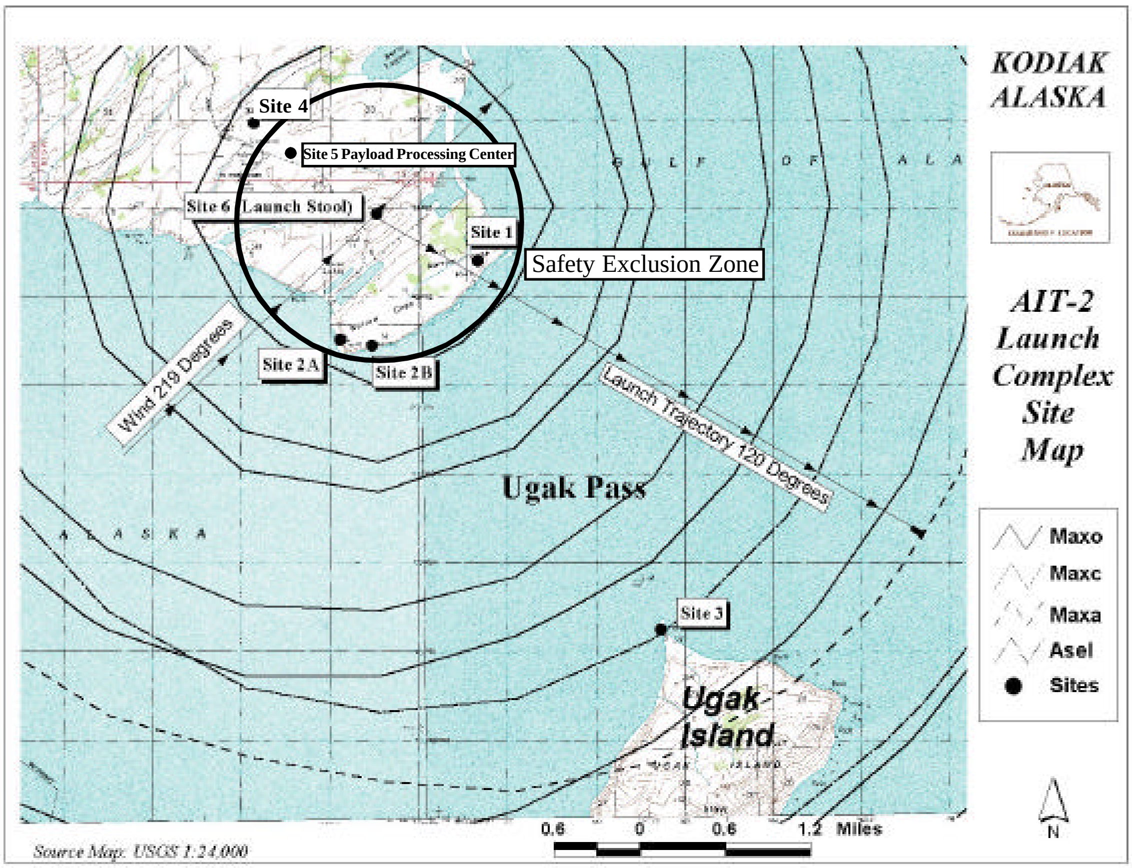


Figure 2. Map of study sites showing launch trajectory and wind direction on day of launch and the limits of the Safety Exclusion Zone. Map provided by The Aerospace Corporation.

Anticipated Launch Noise

The predicted launch trajectory (120°) extended out over Ugak Pass and into the Gulf of Alaska (Figure 2). Its point of closest approach to the Steller sea lion haulout on Ugak Island, was predicted to be 3.1 km expressed as horizontal range. Because the noise of the launch was expected to extend over a broad range of low frequencies, flat and C-weighted maximum sound pressure level (L_{max} and L_{Cmax}) were expected to be similar (85-90 dB range, Figure 3a, b). However, A-weighted, maximum sound pressure level (L_{Amax}) was expected to be considerably lower, in the 70-75 dB range (Figure 3c). A-weighted sound exposure level (ASEL), a measure of the A-weighted acoustic energy in the launch noise, was expected to be close to 85 dB (Figure 3d).

Noise was expected to propagate roughly spherically on the ground in the general vicinity of the launch site (USAF 1997, pp. E-11). Propagation from the moving aircraft aloft was more complex. The initial thrust *vs*. time curve of the launch vehicle was expected to have a very steep upward slope (AADC 1996, Figure 2.1-16; Plotkin unpub). Thus, during the initial seconds of

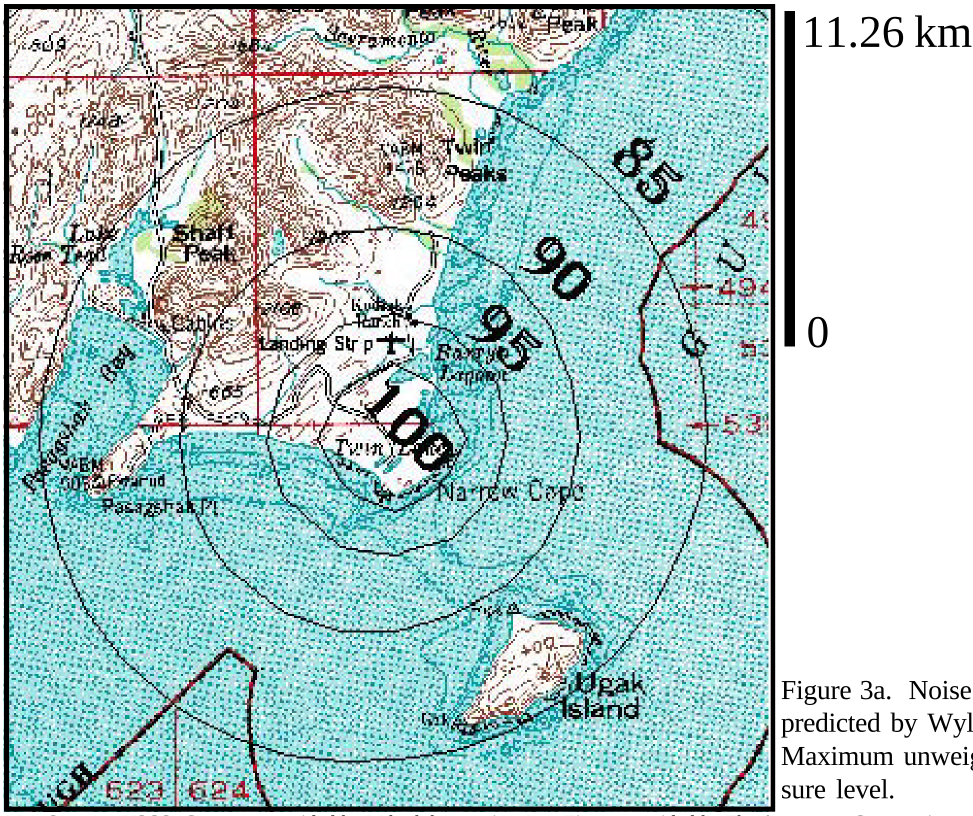


Figure 3a. Noise level contours predicted by Wyle Laboratories. Maximum unweighted sound pressure level.

Map Source: USGS; Contours provided by Wyle laboratories, Inc; Figure provided by The Aerospace Corporation.

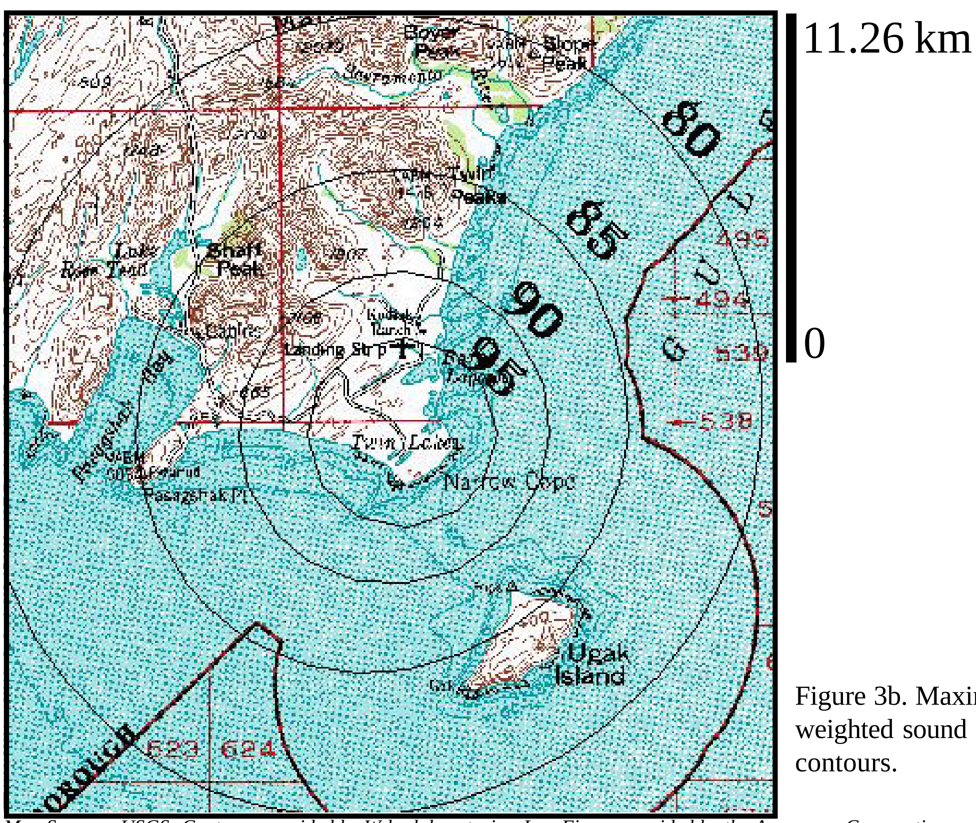


Figure 3b. Maximum, slow C-weighted sound pressure level contours.

Map Source: USGS; Contours provided by Wyle laboratories, Inc; Figure provided by the Aerospace Corporation.

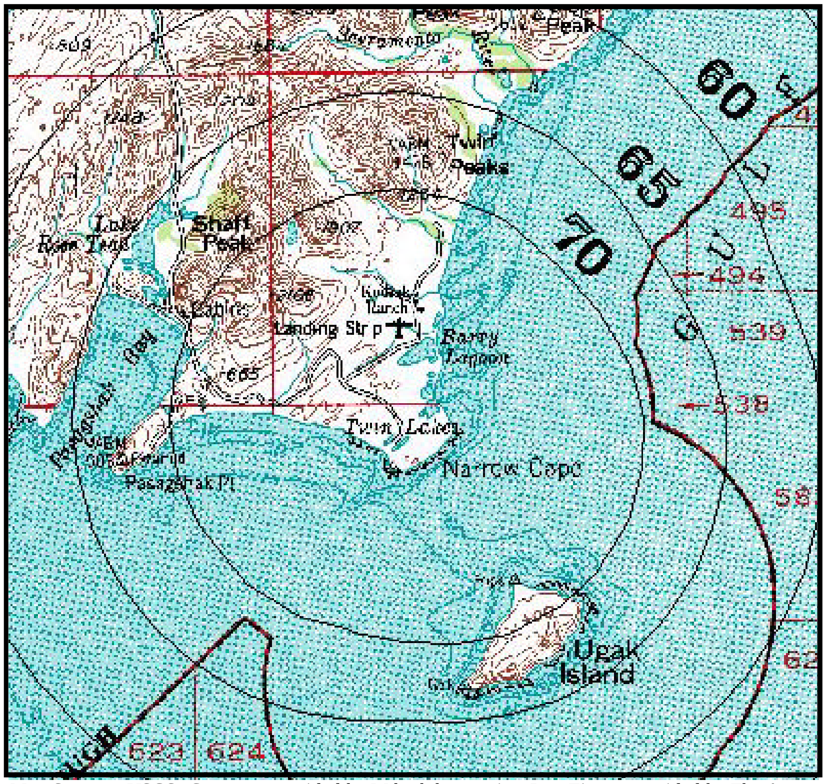


Figure 3c. Maximum, slow A-weighted sound pressure level contours.

Map Source: USGS; Contours provided by Wyle laboratories, Inc; Figure provided by The Aerospace Corporation.

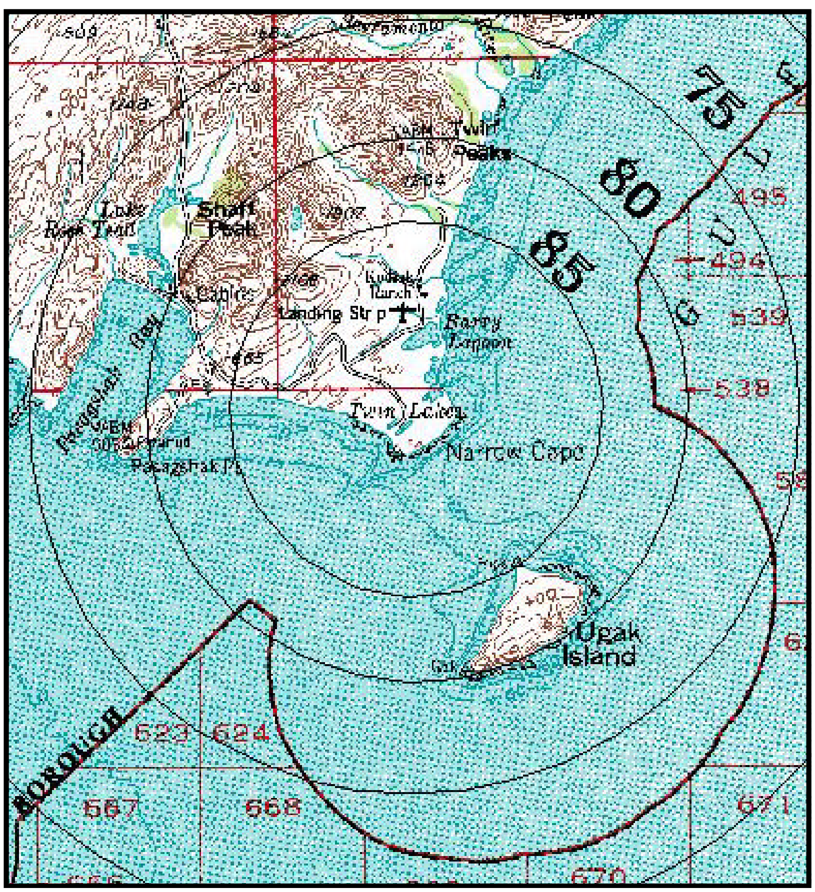


Figure 3d. A-weighted sound exposure level (ASEL) contours.

Map Source: USGS; Contours provided by Wyle laboratories, Inc; Figure provided by The Aerospace Corporation.

the launch, when noise levels on the ground would be highest, noise was expected to radiate more or less omnidirectionally away from the launch stool. The noise was expected to have a short rise time, starting a few milliseconds after ignition, with the greatest noise produced when the vehicle was at maximum thrust close to the ground. Time of arrival at the various monitoring sites could be calculated from the time of ignition and the speed of sound within a few hundred meters of the ground.

However, the vehicle was expected to rise to ~8 mi by the time it passed over the spit at Ugak Island. The predicted point of closest approach to the Steller sea lion haulout was 14.8 km. At that point, it would also have begun to rotate downrange, leveling off at fairly constant thrust, followed by gradual burn-out. Thus, launch noise would be expected to rise quickly to a peak close to the ground, then decline slowly, due both to the gradual decrease in energy output and increased altitude. Low-amplitude roar could be expected to persist for several minutes after the launch under quiet conditions. From the perspective of the sea lions, the crucial period would occur within 20 seconds of the launch, but the vehicle would be audible for some minutes thereafter. The vehicle was not expected to produce a focused boom that could reach the ocean surface until it had passed well beyond Ugak Island, ~ 40 nautical miles (nm) downrange.

Rationale for the Noise Monitoring Effort

Biologically-significant effects are changes in behavior, distribution, foraging, *etc*., that have significant consequences to the health, survivorship, reproductive output, feeding, or habitat use of animals. Unfortunately, very few previous studies have examined the possible impact of launch noise on either pinnipeds (seals and sea lions) or sea ducks, making accurate predictions of effect difficult. Thresholds for biologically-significant physiological (auditory and non-auditory) effects and behavioral changes are still not well-documented for these or any other wild animal. Thus, monitoring efforts are typically required for programs of this kind, providing much-needed information, including: a) ground-truthing data for predictive models; b) noise dosage measures appropriate to the species of interest; and c) measures of response. With this information, dose-response models may be developed eventually.

Predictive models for launch vehicles are available and relatively well-tested (K. Plotkin, Wyle Laboratories). However, obtaining appropriate noise dosage estimates is not straightforward - noise dosage measures and the techniques for collecting them are not standardized for animals as yet. Potentially-useful measures include maximum sound pressure level, onset time, sound exposure level (a measure of the energy in the sound referenced to a 1-s interval), and peak level. Where noise is continuous or intermittent, long-term averages can be collected as well. Most published standards for humans are based on the equivalent-continuous sound level (L_{eq}), a measure of average noise exposure over a standardized period (*e.g.*, A-weighted level over an 8-hr working day, L_{Aeq8}).

Because transients often have substantial energy at frequencies inaudible to humans, the noise must be filtered (‘weighted’) to include only those frequencies that elicit responses or cause effects on hearing in humans. For human community noise applications, such filters are derived from human equal-loudness contours, most often the 40-phon equal-loudness contour (A-weighting)(Bowles 1994). This filter de-emphasizes frequencies below 100 Hz and above 8 kHz, which humans hear poorly. However, it passes more such noise than a comparable filter derived from the human auditory threshold function, accounting for loudness recruitment at high and low frequencies as level increases.

Similar filter functions must be determined and standardized for animals. In the meantime, investigators have adopted a variety of *ad hoc* weighting strategies. Some simply integrate noise within a range of frequencies moderately audible to the animal of interest. Some use A-weighting because it is at least a recognized standard and because it eliminates low frequencies that many mammals cannot hear. Others have simply taken the level in the highest 1/3-octave band. This strategy is reasonable when the noise has most of its energy in the animal's best range. Finally, some have used the animal's own auditory threshold function as a filter. Each of these techniques has its advantages and disadvantages. However, until standards have been agreed upon, the best strategy will be to collect data that permit calculation of any exposure estimator after the fact.

Thus, another goal of the present study was the collection of as many measures of exposure as possible, including 1/3-octave-band levels and real-time recordings that would allow new measures to be calculated in the future.

In summary, the goals of the present study were:

1 To provide noise measurements needed to ground-truth predictive models (A-, C-, and unweighted maximum level; unweighted peak level; ASEL).

2 To provide measurements of ambient noise in the period immediately before, during, and after the launch.

3 To collect as many measures of exposure as possible, including 1/3-octave-band levels and real-time recordings.

4 To make opportunistic observations of Steller sea lions and other protected species.

Methods

Monitoring Sites

Five noise monitoring sites were selected (Figure 2, Table I). Helicopters provided the only access to Ugak Island and all air traffic was restricted on the morning of the launch. Therefore, equipment on Ugak Island had to be set running the day before (9/14). Doing so also insured that the sea lions were disturbed as little as possible on the day of the launch. Replicate monitors (HSWRI Larson-Davis [LD] 820 sound monitor and ENRI LD 875) were placed on Ugak Island, the most distant monitoring site (Site 3). They were placed as close to the sea lion haulout as possible, on a grass flat overlooking the spit at the northeastern tip of the island. An ENRI video monitoring system was mounted there as well. Two LD 820 monitoring sites were placed on Narrow Cape; these sites were as close to the sea lions as possible on the Kodiak Island side, one at the southeast end (Site 1) and the other at the northwest end (Site 2). ENRI placed a replicate meter at Site 2. Monitors at both sites were set running the day before the launch to obtain data on ambient noise.

Site 4 was located at the very edge of the exclusion zone near the Launch Control Complex (LCC); real time monitoring was conducted from this site starting an hour before the launch and running for an hour afterwards. Site 5 was within the safety exclusion zone, as close to the launch site as possible (Payload Processing Center [PPC]; LD 824).

Data Collection

Larson-Davis sound monitors (LD 820, 824) were used to collect noise data at 4 of the 5 sites. These integrating sound level meters are battery-operated, consisting of a microphone, an analog to digital converter, a microprocessor to accumulate data and calculate metrics and summary statistics, and a memory to store the resulting data. In addition to their capabilities as sound level meters, they are programmed to collect community noise metrics over long periods.

The instrument microphone was mounted 1.4 m (4 ft) above ground level atop a galvanized pole (Figure 4). Each microphone was covered with a windscreen, a 15-cm open-pore foam windball that reduced spurious data by wind noise. Measurements side-by-side with an anemometer have shown that the wind-screen effectively eliminates most wind-related pressure transients at wind speeds up to 10-15 kt, as long as intrument thresholds are set correctly.

In addition, each microphone housing was filled with a dessicant package and the windscreen was enclosed in a close-fitting, thin (15 µm) plastic bag to prevent water seepage. Previous experience had shown that heavy rain could saturate the windball and cause condensation within the microphone housing, causing damage and lost data. The plastic bag reduced effective micro-

Table I. Summary of monitoring sites, including location, instrumentation, monitoring period and distance from the launch site.

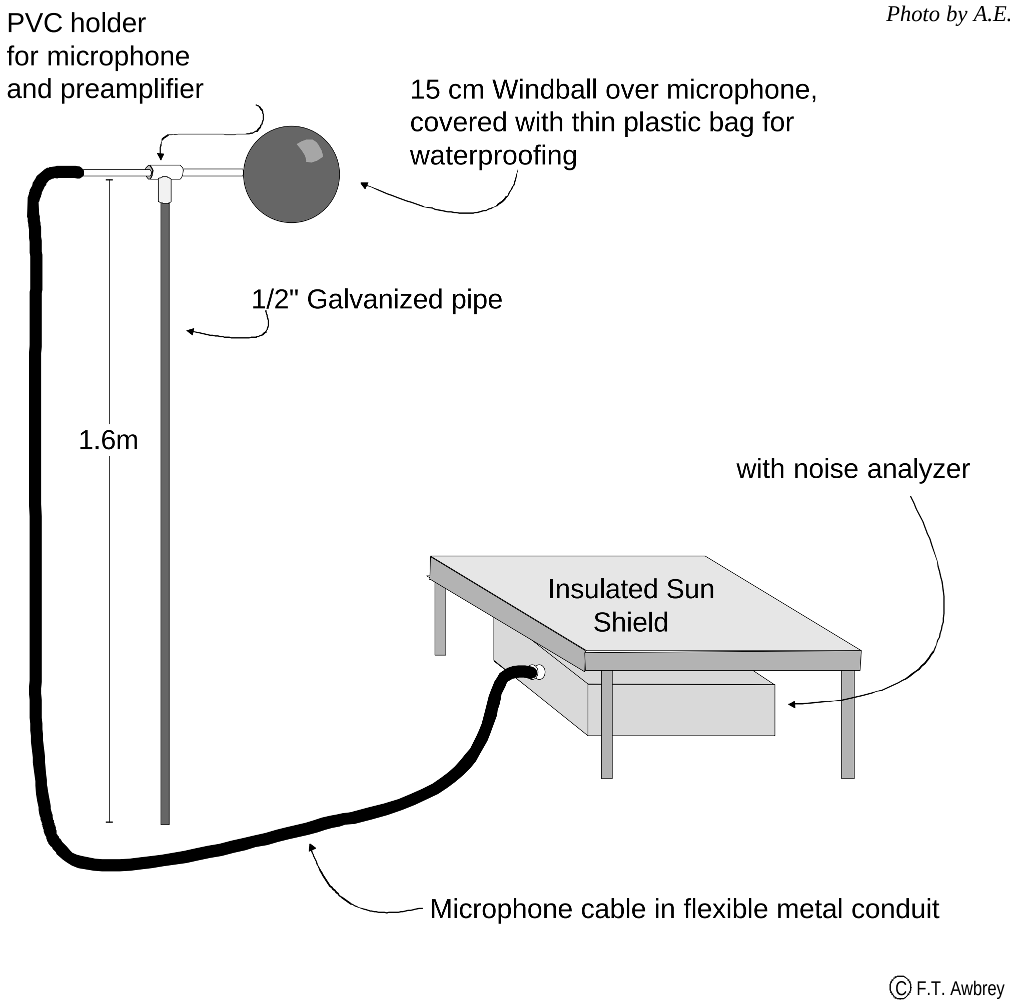
SITE	MONITORING INSTRUMENT (ORGANIZATION) ^	LOCATION	DISTANCE FROM LAUNCH SITE (M)	EXPECTED ARRIVAL TIME OF LAUNCH NOISE ^^ (S)	MONITORING PERIOD (HH:MM:SS)
1	LD 820 (HSWRI)	Under launch trajectory, east end Narrow Cape 57° 25.769' x 152° 19.356'	1261	4	9/14:15:08:43 to 9/15:14:12:26 23:03:43 run time
2a	LD 820 (HSWRI)	WW II Bunkers, west end Narrow Cape 57° 25.308' x 152° 20.922'	1474	4	9/14 (13:52:45) to 9/15 (24:09:13) 24:09:13 run time
2b	LD 875 (ENRI)	Under launch trajectory, east end Narrow Cape	1487	4	
3	LD 875 (ENRI)	Ugak Island 57° 23.52' x 152° 17.34'	5668	17	
4	LD 824 (HSWRI)	Payload Processing Center 57° 26.62' x 152° 21.87'	1716	5	9/15 09:56:29-15:10:49 5:14:20 run time
5	real-time recording (HSWRI)	Launch Control Complex 57° 27.27' x 152° 22.69'	3130	9	9/15 11:13-14:14 3:01 run time
6	-	Launch Site	0	0	-

^ LD = Larson-Davis; HSWRI = Hubbs-Sea World Research Institute; ENRI = University of Alaska Environment and Natural Resources Institute

^^ The speed of sound in air was calculated as follows:
c = (49.03 * sqrt(459.7 + °F) ft/s)*(0.3048 m/ft); at ground level F = 49.82°, yielding c = 337.33 m/s. Distance d*c = TOA in s. The formula for calculating speed of sound is given in Cowan (1994). Temperature data were provided by Robert J. Nagy, meteorologist, NAWCWPNSdiv, Pt. Mugu, CA.

Figure 4. Setup of LD 820 sound monitoring system (diagram). System as deployed at the northeast end of Narrow Cape (Site 1, photograph).

Photo by A.E. Bowles



phone sensitivity by only 0.6 dB at frequencies produced by launch noise (< 8 kHz; Awbrey unpub.) Microphone cables were encased in flexible metal tubing to shield against electromagnetic interference (*e.g.*, from radar) and damage by chewing animals. To prevent overheating, the weatherproof enclosure for the analyzer and its battery were placed under a reflective sun shield.

The LD instruments have been designed to allow unattended collection of noise events, intense transients produced by sources such as the *ait* launch. When the incoming signal from the microphone exceeds a software-settable threshold, data collection begins (triggering threshold). When it drops below a lower limit (offset threshold), data collection ends. If the interval between triggering and offset is long enough, the event is stored in memory. On Kodiak Island, the triggering threshold was 70 dB, the offset threshold at 61 dB, and the duration threshold at 5 s.

All the Larson-Davis meters met American National Standards Institute (ANSI) S1.4-1983 type I specifications for general noise measurement (Acoustical Society of America 1983). To insure that the accuracy and precision of each instrument remained high, each HSWRI sound meter was calibrated before it was deployed and checked immediately afterwards. This was done with a B&K 4230 acoustic calibrator that undergoes annual recalibration by the manufacturer. Instrument time was taken from the countdown clock in the LCC or a weather station.

Once in place, noise monitors gathered acoustical data continuously until retrieved (the two LD 820's were deployed for approximately 24 h and the LD 824 for 5 hr).

A real-time recording of the launch noise was collected using a TEAC RD101T DAT connected to two ACO 7013 calibrated microphones. The microphone inputs were split at the recorder so that the incoming signal could be recorded at gain settings ranging from low to high, using all 4 channels of the DAT. Multiple gain settings insured that both ambient noise and the roar of the launch were recorded with adequate signal to noise ratio.

<u>Opportunistic observations of animals</u>: HSWRI and AFSMC cooperators were able to count and observe the behavior of marine mammals on 9/12 from Narrow Cape using a Meade ETX-90EC Telescope (Lang 2000). They also collected information during helicopter approach and landing on Ugak Island during one trip on 9/14 (2000 to 2130 h) to deploy the LD 820 and one trip on 9/15 (1330 h) to retrieve equipment. Lang also observed the sea lions on Ugak Spit from 1345 to 1500 h on 9/15 using the Meade telescope.

Results

<u>Ambient noise</u>: Real-time recordings and measurements made by the LD instruments could be used to characterize ambient noise levels. The results of the LD instrument monitoring are given here; ambient spectra from the real-time recordings will be reported in the following section.

Storms are frequent at Kodiak Island. The *ait*-2 launch occurred on a clear day with little wind, but the afternoon and night immediately preceding were marked by moderate to high winds and rain. Close to the ground at 2030 h on 9/14, winds at the LCC were from the north (340 degrees) at 18 kt, skies were overcast, and there were occasional rainshowers. During this stormy period, both LD 820 instruments on Narrow Cape reported many 'events' (Site 1: 230 events, Site 2: 918 events; Table II), most of which were likely triggered by wind rather than noise *per se*. Site 2, on the windward side of the Cape during the monitoring period, recorded the bulk of these wind-driven events.

At the time of launch, skies were clear and wind close to the ground was from the west (230 degrees) at 9 kt. The temperature was 51 degrees Fahrenheit. Ambient noise 9/14 and the following morning were similar during hours with few noise events (<20), with hourly L_{eq} measurements ranging from 43 to 55 dB(A). Hourly L_{eq} rose to 64.8 and 68.6 dB(A) during the windiest hours (1400-1800 h on 9/14).

Several measures of ambient noise level were collected during the monitoring period (Table IIIa, b). The LD instruments reported background L_{Aeq}, the L_{Aeq} for the whole monitoring period minus the L_{Aeq} collected during noise events. This measure is disproportionately affected by subthreshold noise pulses and wind-induced artifacts. $L_{50,}$ the level exceeded by 50% of the time units in the sample, is not often used in community noise applications, but it is an accurate measure of ambient level when wind or brief, high-intensity transients are present. When graphed in the form of a histogram, the reason becomes clear: noise almost always exceeds low levels (usually, 20-40 dB range), whereas it infrequently exceeds high levels (>65-70 dB). Most

Table II. Summary of effort at sites monitored by HSWRI Larson-Davis 820 instruments.

Site: Date	Number of Events	Hourly L_{AEQ}	Hourly Leq 1 hr before Launch	Back-ground L_{AEQ}	L_{50}	Event Time	% Time at or Above 70 dB	Notes
1: 9/14 9/15	230 9	48.9-64.8 (1500 hr to 2400 hr) 47.9-53.8 (0000 hr to 1200 h)	52.1	54.3	48.8	14:35	0.6%	Site in lee of Narrow Cape
2: 9/14 9/15	918 182	43.3-68.6 (1500 hr to 2400 hr) 47.4-59.6 (0000 hr to 1200 h)	47.4	57.2	43.2	1:50:42	4.1%	Site on windward point of Narrow Cape

Table IIIa. Launch noise measurements collected at Sites 1 and 2 on Narrow Cape by LD 820 instruments. Estimated signal-to-noise ratio (SNR) of A-weighted launch noise measurements indicated as well. Estimated ambient noise level was 49.3 dB(A).

	Time of Launch Event Trigger (hh:mm:ss)	**Time of Launch Event Peak (hh:mm:ss)**	**Duration (s)**	**L_{maxA} (dB)**	**ASEL (dB)**	**A-weighted Peak (dB)**	**Unweighted Peak (dB)**
Site 1	13:00:02	13:00:10	37.6	103.5	109.8	120.9	124.6
SNR				54.2	60.5	71.6	-
Site 2	13:00:03	13:00:07	38.4	105.3	109.4	123.5	123.2
SNR				56.0	60.1	74.2	-

Table IIIb. Launch noise measurements collected at Site 4 (PPC) by the LD 824 instrument at 13:00:10. The estimated SNR of A-weighted measurements is indicated as well. Estimated A-weighted ambient level was 49.3 dB(A).

Measure (in dB)	**A-weighted**	**SNR**	**C-weighted**	**Flat weighted**
SEL	109.7	60.4	119.2	120.2
Peak	127.5	78.2	127.1	127.5
Lmax (slow)	103.8	54.5	112.0	112.6
Lmax (fast)	107.9	58.6	113.9	114.5
Lmin (slow; for whole period)	44.1	-	44.8	48.7

sample levels are in the midrange, producing a peak in the histogram of sample levels (Figure 5). L_{50} (statistically, the median) shifts little when a few extreme events are recorded, whereas L_{Aeq}, which is a measure of average sound exposure, would be greatly affected. Thus, L_{50} is a good measure of 'typical level' of exposure regardless of occasional intense artifacts. In outdoor settings where high-amplitude exposures are infrequent, this may prove to be the most useful measure of background exposure.

The background L_{eq} at Site 1 was 54.3 dB(A) and the L_{50} was 48.8 dB(A). Only 0.6% of the samples exceeded 70 dB(A). Site 1 was situated on a cliff edge but was at slightly lower elevation than Site 2 and was protected from the prevailing wind by the mass of Narrow Cape to the south and west. The number and incidence of short events indicated that wind noise was less prevalent at Site 1 than at Site 2 (Table II). At Site 2a, the background L_{eq} was high (57.2 dB[A]), as expected in the presence of many wind-driven events (almost 4% of sample levels exceeded 70 dB(A)), but the L_{50} was consistent with values from Site 1 and Ugak Island (43.2 dB(A)).

Unfortunately, the LD instruments did not report L_{50} hourly. However, since wind speed was low (< 10 kt) in the hour before launch, the L_{Aeq} during that hour could be used as a reasonable estimate of ambient level at launch at Narrow Cape. L_{Aeq1h} before the launch at the two Narrow Cape sites was 52.1 and 47.4 dB(A)(Site 1 and 2, respectively). The mean of the two L_{Aeq1h} values (49.3 dB(A)) was close to the L_{50} value at Site 1. This value was taken as the best estimate of background noise during the launch for Narrow Cape.

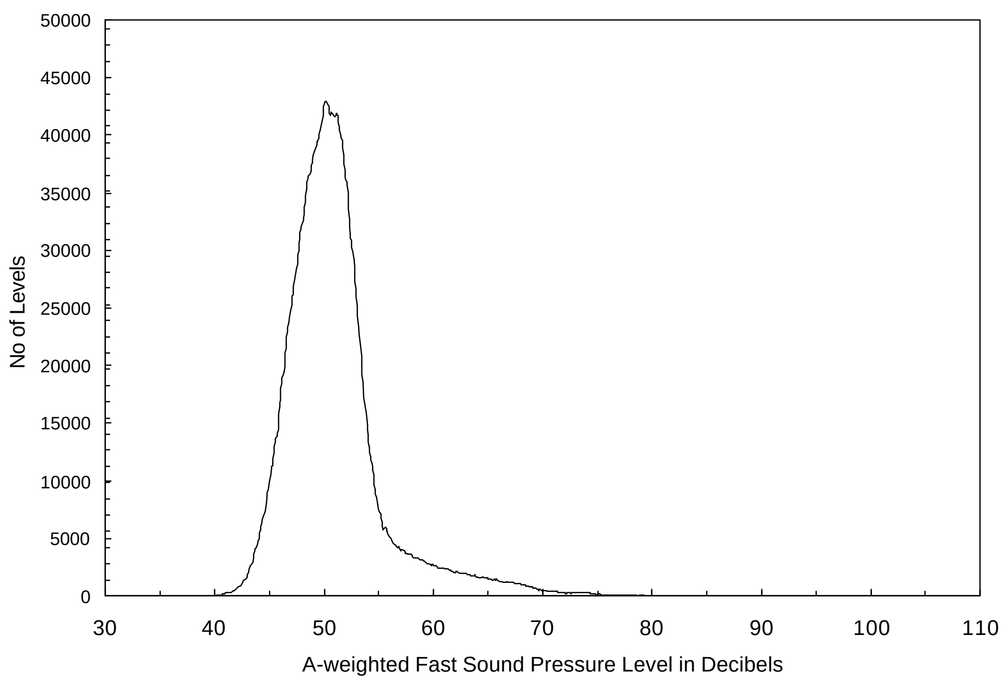


Figure 5. Histogram of sample levels *vs*. A-weighted fast SPL (1/32-s samples).

Ambient levels on Ugak Island should have been comparable to those at the two sites on Narrow Cape. By looking at initial levels in the event-time history of the launch collected by ENRI's LD 875, broadband (12.5 Hz - 20 kHz) background noise levels (slow integration time = 1 s) could be estimated, ranging from 43-49 dB (N=8). These values are entirely consistent with levels collected at protected Site 1 on Narrow Cape. Unfortunately, the HSWRI LD 820 instrument on Ugak Island malfunctioned, so integrated background L_{Aeq} could not be obtained. The median of initial event-time history values for the launch was taken as an estimate of ambient noise at Ugak Spit (45 dB(A)).

Launch noise: The launch was scheduled for 13:00:00 h ADT; actual ignition occurred at 12:59:59.34 h. The real-time recording (Site 5, LCC) was analyzed treating this as the precise time of engine ignition. A low-amplitude roar was detected on tape beginning at approximately 2 s after ignition (Figure 6a); at 8-9 s, the noise level rose steeply, peaking at 127.5 dB(A)(Table III, Figure 6b). The real-time monitoring site was 3,130 m from the launch stool, leading to a predicted arrival time of 9 s (Table I). Thus, when the launch time was assumed to correspond to the noise peak, propagation time was as expected.

Given that Larson-Davis instruments are known to experience significant and persistent drift in their internal clocks after deployment, the time for L_{Amax} could not be expected to match arrival

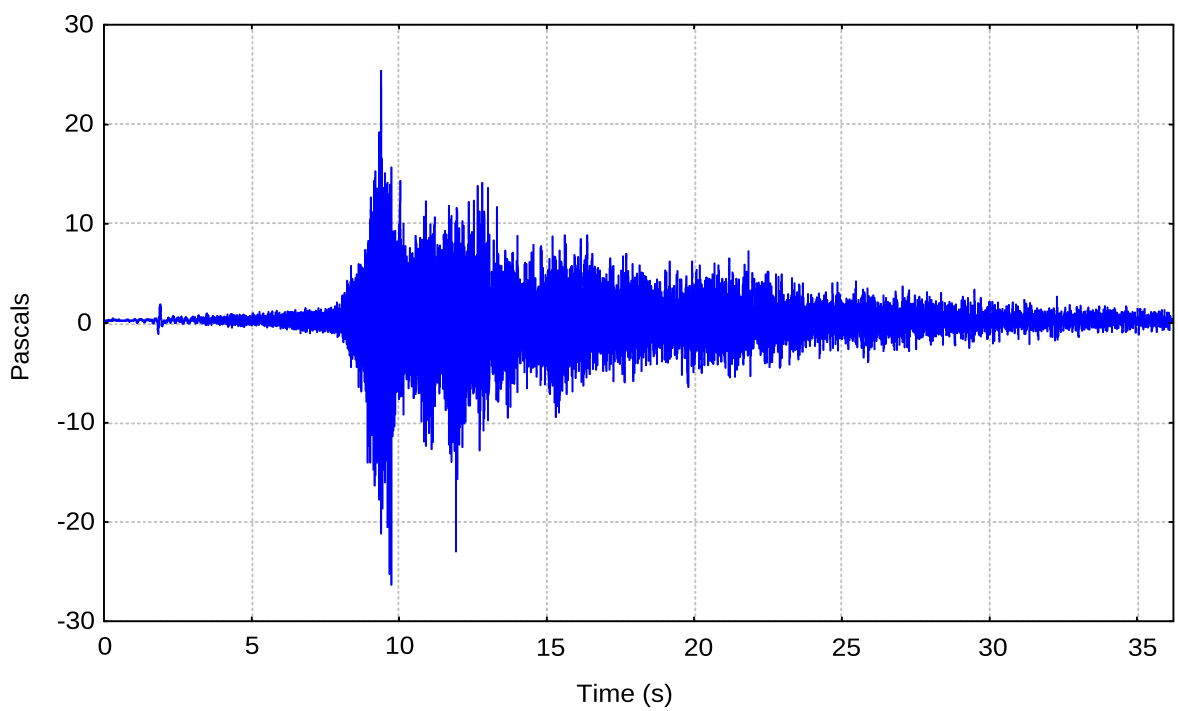


Figure 6a. Oscillogram for *ait*-2 launch.

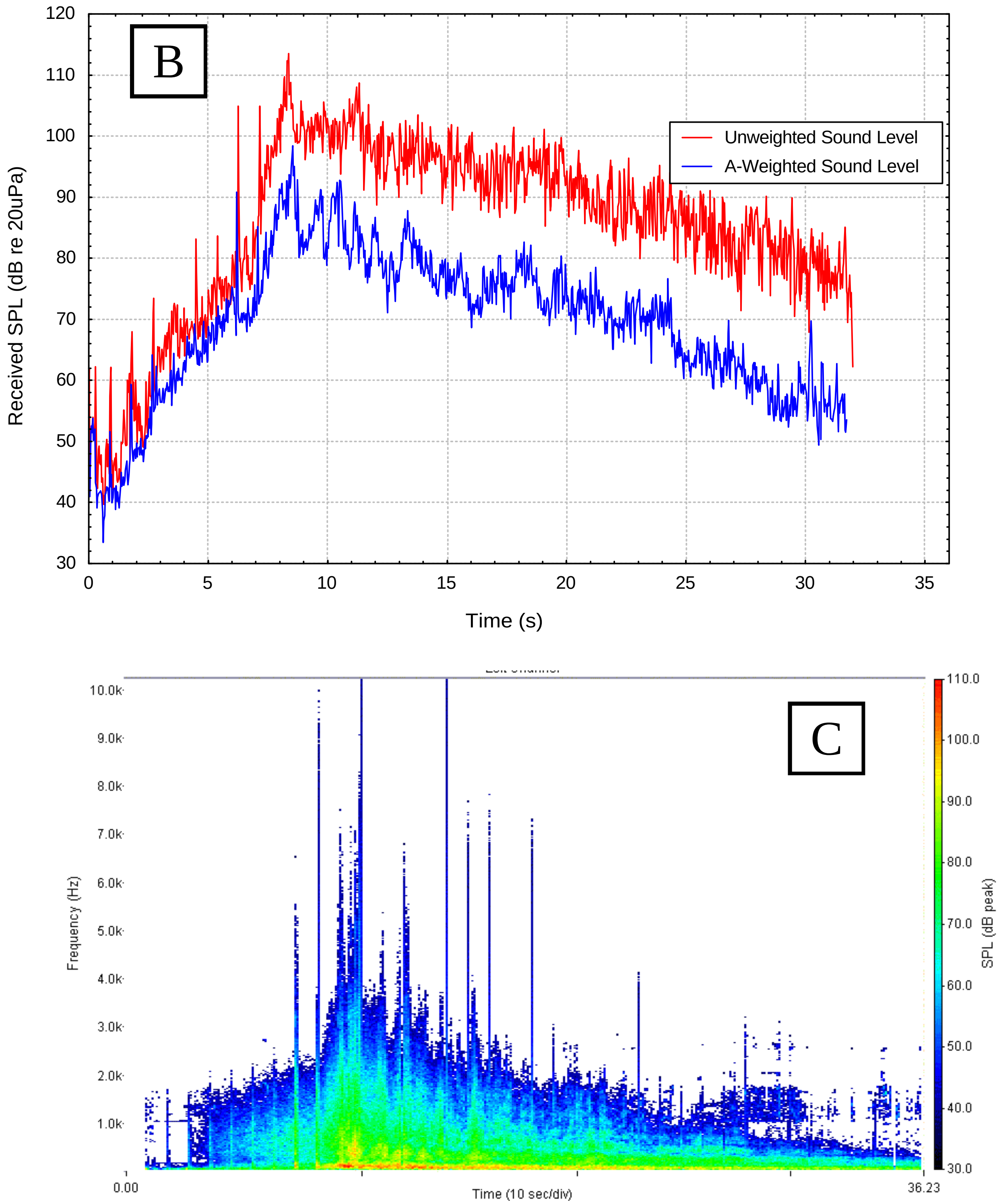


Figure 6. Level-time graph (B) and spectrogram (C) for *ait*-2 launch.

Table IV. 1/3-octave-band levels reported by the LD 824. Levels taken from the one-second period of the overflight with the highest level.

FREQUENCY (Hz)	1/3-OCTAVE BAND LEVEL (dB)	OCTAVE BAND LEVEL (dB)
12.5	82.1	
16.0	84.1	87.8
20.0	82.5	
25.0	90.2	
31.5	93.3	97.4
40.0	93.6	
50.0	99.3	
63.0	98.4	105.5
80.0	102.4	
100	101.5	
125	99.6	104.4
160	96.2	
200	94.2	
250	89.1	96.4
315	89.7	
400	96.3	
500	98.8	103.1
630	99.4	
800	96.9	
1000	93.6	99.2
1250	90.8	
1600	92.8	
2000	89.0	94.7
2500	83.5	
3150	82.6	
4000	79.2	85.1
5000	77.9	
6300	74.5	
8000	70.8	76.8
10000	68.7	
12500	65.1	
16000	60.1	66.8
20000	56.8	

time predictions to better than a few seconds, and none did. The two LD 820 instruments on Narrow Cape lay at 1261 and 1474 m from the launch site (Table I), with expected arrival time of 4 s at both meters. They triggered 2-3 s after 13:00:00 h and reported peaks at 13:00:07-10. The LD 824 instrument at the Payload Processing Center (Site 4; at 1716 m) reported the main peak (L_{AFmax}) at 13:00:10, whereas the expected arrival time was 5 s.

The time course of the launch was as expected (Figure 6b), rising rapidly to a sharp peak and declining gradually over a period of approximately 36 s. Noise from the public address system 0.5 km from the recording site contaminated the end of the real time recording, making this estimate approximate. The LD 820 instruments reported durations of 37.6 s (Site 1) and 38.4 s (Site 2). Noise during the first few seconds was marked by a readily-audible series of modulations (crackle or rumble), which were also evident during the declining phase of the noise in a spectrographic representation of the launch (Figure 6c). At the LCC (Site 5), launch noise peaked at 113.5 dB (unweighted; 98.5 dB(A)). A-weighted maximum level of the noise was 107.9 dB (unweighted, slow L_{max}; 107.1 dB(A)). Ambient noise at the site in the 4 min prior to launch had an L_{Aeq} of 49.3 dB(A).

Spectral information was collected 2 ways. First, a 3 s segment centered on the peak of the real time recording was collected and a spectrum calculated using Spectra Plus Pro (Figure 7a). Second, the LD 824 collected a 1 s segment at the peak and calculated 1/3-octave and 1-octave band levels (Table IV, Figure 7b). Both methods showed two broad peaks in the spectrum of the noise, one at around 30-120 Hz, and one at 200-1100 Hz. Levels exceeded the ambient out to 22,000 Hz (at Site 4, the closest to the launch stool). Based on the noise floor of the recording, ambient noise at the LCC in the 4 min immediately prior to launch had an L_{eq} of 49.3 dB(A), consistent with the estimate obtained from the LD 820 machines at Narrow Cape. Above 500 Hz, in the range heard best by sea lions and birds, the noise floor was considerably lower, ~ 20 dB SPL (Figure 7a).

Levels collected by ENRI LD 875 sound meters were compared with the HSWRI data (Table V). A-weighted levels measured at the sites on Narrow Cape were very consistent, particularly the A-

Table V. Comparison of levels measured by HSWRI LD 820 and ENRI LD 875 sound meters with results of RNOISE predictive model.

Site (Organization)	Launch ASEL (dB)	D*	L_{AMAX} (dB)	D*	$PEAK_A$ (dB)	Trigger Time (HH:MM:SS)	Time at Max Level (HH:MM:SS)	Duration (s)
1 (HSWRI)	109.8		103.5		120.9	13:00:02	13:00:10	37.6
2 (HSWRI)	109.4		105.3		123.5	13:00:03	13:00:07	38.4
RNOISE prediction	101.3	8.1	91.9	13.4	-			
2 (ENRI)	110.7		103.2		124.1	13:00:23	13:00:28	34.4
RNOISE prediction	101.3	9.4	91.9	11.3	-			
3 (ENRI)	92.2		81.5		101.5	13:00:39	13:00:56	30.1
RNOISE prediction	85.1	7.1	73.4	8.1	-			

ENRI data provided by Mike Kelly; RNOISE predictions provided by Ken Plotkin, Wyle Laboratories.
* Difference between observed (HSWRI and ENRI data) and expected (RNOISE) values.

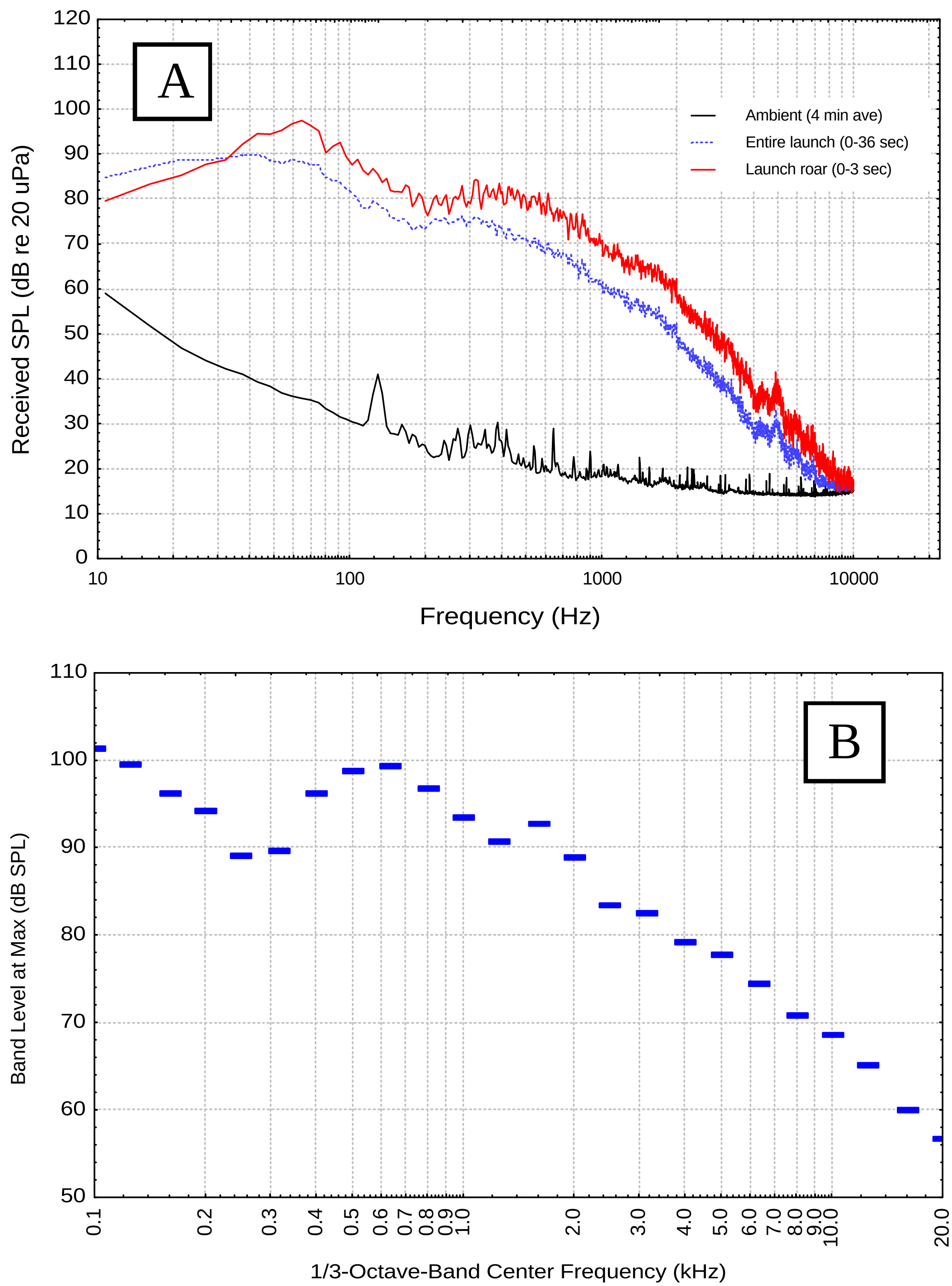


Figure 7. (A) Spectrum of launch noise from the real-time DAT recording (Site 4). (B) 1/3-octave band spectrum recorded by the HSWRI LD 824 at PPC (Site 5; Table IV).

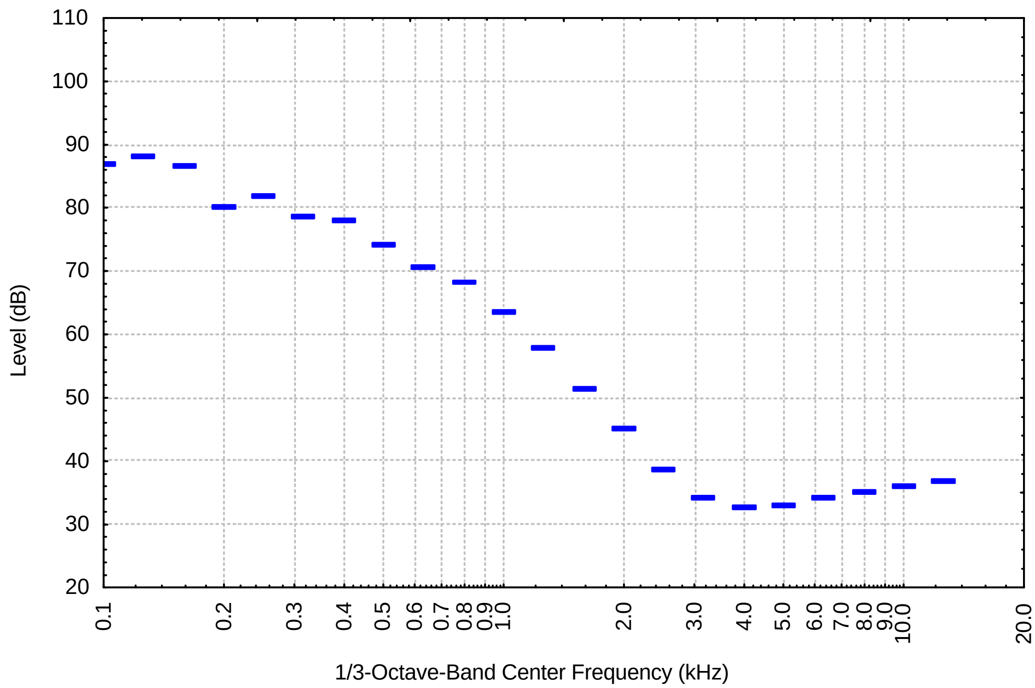


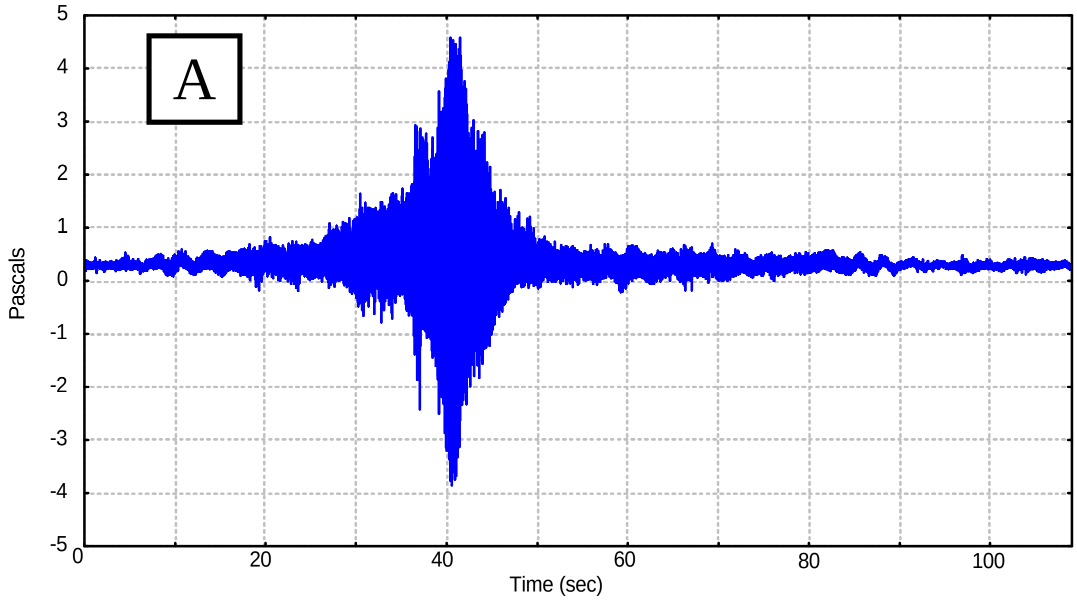
Figure 7C. 1/3-octave band spectrum of launch recorded by LD 875 at Ugak Island.

weighted sound exposure levels (ASEL), coming within 1 dB of one another. A-weighted L_{max} and peak levels varied somewhat more (within 4 dB), but were still very consistent for field measurements.

Based on broad-band A-weighted levels, launch SNR was high at Sites 1 and 2 (Table III), in excess of 50 dB. The same was true at the PPC (Site 5). Further out at Ugak Island, the broad-band SNR was estimated at 36.5-47.2 dB (L_{Amax} and ASEL minus ambient level).

Other noise: A Bell 206 BIII Jet Ranger helicopter operated by Maritime Helicopters in Kodiak was flown to and from Ugak Island twice on 9/14 to ferry teams setting up equipment. The flight in support of the HSWRI effort approached the sea lion haulout at 2000 h. The pilot approached with care and landed several hundred meters from the animals. A second Jet Ranger helicopter flew to Ugak Island to retrieve all equipment after the launch. It approached the island at 1327 h on 9/15 and landed in tussock grass immediately southwest of the equipment placement, less than 50 m from the haulout site.

These helicopters were also the area in support of the launch effort. In the 15 min before and after the launch, they circled the Safety Exclusion Zone, watching for unauthorized intruders before the launch and fires afterwards. While circling, a real-time recording of one of these helicopters was made as it passed directly overhead at an altitude of 50 m. Rotor thump could be heard for a long time before and after the direct overflight (out to the edge of the exclusion zone



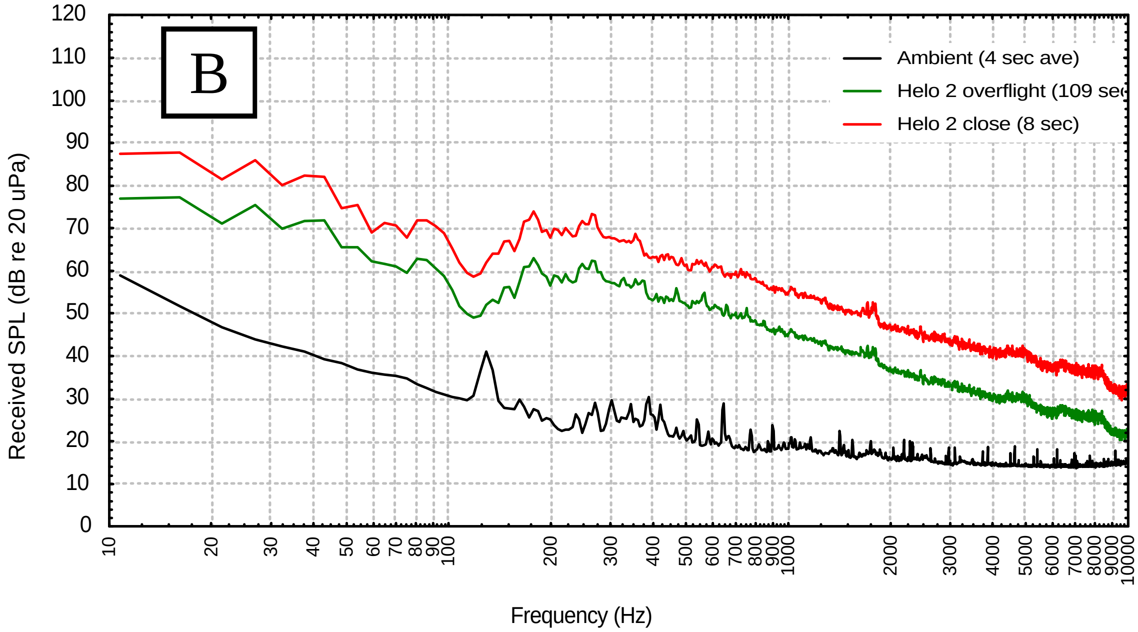


Figure 8. Oscillogram (B) and spectrum (B) of Bell 206 helicopter.

over Ugak Pass). However, most of the energy was detected in a 20 s period centered on the time of closest approach (Figure 8a). The noise was fairly broad-band, but with the highest levels at low frequencies, peaking at 20-30 Hz and 150-300 Hz (Figure 8b). Levels reached 92.5 dB (unweighted) and 76.9 dB(A) in the 8 s period when noise was greatest. The aircraft was in level flight at the time.

The helicopter landed 50 m from Site 1, triggering an event at 13:56:30 (L_{Amax} at 81.5 and ASEL at 91.9 dB). At 14:12:34, when the helicopter approached and landed 20 m from Site 2, the LD 820 instrument registered an event (L_{Amax} at 92.6 and ASEL at 101.4 dB). Thus the highest exposures to helicopter noise at any given distance were experienced when the aircraft was landing.

Sea lions on Ugak Island were also exposed to several overflights of a Beaver light aircraft at 500 ft during surveys. Characteristics of this aircraft were not measured by HSWRI monitors. In data provided by ENRI from Ugak Island, the morning overflight on 9/15 appears to have triggered the LD 875 first at 07:59:26 h ADT (corrected to 07:59:46 h). It reported an L_{eq} of 70.3 dB(A), ASEL of 79.1 dB, and A-weighted peak at 83.9 dB. Thus, the survey aircraft produced lower levels than either helicopters or *ait*-2 launch.

Observations of marine mammals: Marine mammals were observed during an initial reconnaissance of the monitoring sites on 9/12 from 1330 to 1530 h. Observations were conducted using the Meade ETX-90EC Telescope from Site 2, encompassing the sea lion haulout on Ugak Island, the waters of Ugak Pass, and the mouth of Ugak Bay.

Steller sea lions (9/12) - There were over 40 Steller sea lions congregated on the spit at Ugak Island. The best counts made with the Meade telescope (Lang 2000) gave a range of 37-45 animals (note that counts made from a lateral perspective rarely detect as many animals as counts made from overhead). The sea lions were loosely congregated on the berm of the spit, standing or lying among weathered driftwood that made accurate counts difficult. Two were obviously large bulls. The rest were subadult males (or possibly females) and juveniles. When observers arrived, most of the animals were dry on the upper side of the body, as though they had been hauled out for some time. Waves washed across the spit periodically, but the count of animals remained consistent throughout the observation period.

Gray whales (Eschrichtius robustus)(9/12) - As observers scanned Ugak Island and environs, it became clear that numerous whales were in the area. They did not appear to be migrating through Ugak Pass or around the outer side of the island, but rather were surfacing in the same general location time after time. It is possible that they were feeding, although no surface evidence of this activity could be detected (mud plumes, *etc*.). A few were concentrated at the southwest end of Ugak Island, but most were in the broad entrance to Ugak Bay seaward of Gull Point. Scans were made from the end of Ugak Island to Gull Point to get a rough idea of the number of whales present. The greatest number counted at the surface during any given scan was 38. Surfacing times were short, with animals blowing 1-2 times and then submerging for 3 min or less. Thus, the actual number of whales in the area was probably larger than the maximum scan count. Surfacing animals were examined carefully with the telescope whenever they arched or fluked; all of these were gray whales.

Steller sea lions (9/14) - The sea lions on the spit at Ugak Island were approached from 2000 to 2047 h on 9/14 in a Bell 206 helicopter to place a HSWRI LD 820 sound meter. This was the second flight of the evening, a previous flight having ferried the ENRI crew to deploy an LD 875 and video monitoring system. According to the pilot (T. Walters), both landings were similar. The helicopter did not overfly the sea lions on the spit directly, instead making an oblique approach from the southwest, landing several hundred meters from the spit. Observers approached quietly from upwind, arriving at the monitoring station hidden in tussock grass 50 m from the animals.

Sea lions could not be counted before observers arrived as a result of the indirect manner of approach. However, when observers reached the spit, there appeared to be 20-25 animals present, lying among the timbers on the high point of the beach. The best count available (21) was taken from photographs by Dr. Lang (Lang 2000, Figure 4d).

As can be seen from Figure 9, weathered timbers were strewn over the raised center of the spit above the high tide line, making counts difficult except from close range. Based on size and the appearance of the head and shoulders, most were juveniles and subadult males (or possibly females); there were still two large bulls in the group. About half were dry on the upper part of the body. The animals congregated tightly and stood alert as the helicopter landed and observers approached. Observers did not see them entering the water during approach, nor did they abandon the beach *en masse* once observers reached the monitoring equipment. A few (less than 5) eventually abandoned the beach as observers worked. None were seen rafting (congregating in the water close to shore) as observers left the area. The weather was cool and windy, as it had been all afternoon.

Steller Sea Lions (9/15) - ENRI/NMFS observers overflew the spit at 0800 h on 9/15 to count sea lions, which were still present in number (estimated at 76 from the air; ENRI 2000). Aircraft and vessels were cleared from the area after the survey overflight by a second Bell 206 Jet Ranger (also operated by Maritime Helicopters, T. Walters, Pilot), which was responsible for clearing the Safety Exclusion Zone (10,000 ft radius, Figure 2) before the launch. It also surveyed the area for fires afterwards. This helicopter did not go out to Ugak Island in the course of its duties, but observers at the LCC saw it swing out over Ugak Pass both before and after the launch, as would be expected as it travelled the margin of the exclusion zone. Observers were not allowed to stay on Narrow Cape during the launch because it lay within the exclusion zone.

No observers were present on Ugak Island during the launch, so it is difficult to know what the sea lions would have seen from the spit. At LCC, 3 km from the launch site, the launch was not simply a noisy event - there were also striking visual and tactile stimuli. The burning rocket engines produced a bright light that climbed rapidly into the sky and a white exhaust plume (Figure 10a, b, c). A shock wave from the launch was quite palpable at LCC, causing resonance in the lungs and gut. Any of these stimuli could have arrested the attention of animals on Ugak Spit, either immediately before or after their attention was captured by the launch roar (the

Figure 9. Photographs of the launch of ait-2.

A) Launch of *ait*-2

B) Climbing above the level of Narrow Cape

C) An exhaust plume remaining after the vehicle had disappeared downrange

Figure

vehicle would have been visible before the roar arrived at the site). The roar might have been audible for several minutes after launch under the prevailing quiet conditions. Observers at LCC, uprange of the launch, were still able to detect the roar at low amplitude 3 minutes after launch. RNOISE predictions projected audible levels out to at least 6 min after launch at Ugak Island.

At 1320 h, after the launch and after the helicopter had completed its post-launch check of the area, ENRI, FAA, and HSWRI observers returned to Ugak Island to retrieve equipment. They arrived at 1327 h. Even over the channel, at a distance of ~1 km, it was clear that no sea lions were on the spit. The helicopter circled briefly at close range to look for them. None were seen on the spit (Figure 11), to the extent that animals could be distinguished from timbers on the beach. Observers did not see the sea lions in shallow water either, but they could have been present - the heads of animals were difficult to distinguish from bobbing kelp floats in the bed of bull kelp just offshore. The helicopter landed in tussock grass immediately adjacent to the monitoring station.

Once observers were on the ground, they saw that some sea lions were still in the area, rafting immediately offshore. Most were seen to the southwest, 10-15 m offshore among the kelp floats. These sea lions were of mixed size, including females or subadult males and smaller juveniles. They were congregated in two groups, one of 10-15 individuals and another of 5-7. They re-mained tightly rafted, swimming short distances up and down the shore as a group, or rolling together, heads frequently oriented towards the shore. Two bulls were seen rafting together on the opposite side of the spit. They remained in the water staring at the shore for as long as the helicopter was present (~20 min).

The NMFS observation aircraft overflew the area again at 1415 h, at which time no animals were seen on the spit. Dr. Lang observed the spit with the Meade telescope from Narrow Cape from 1345 until 1500 h (Lang 2000). The sea lions were still rafting in the water throughout this observation. At most, one individual mounted the beach at 1455 h, but was not seen clearly. However, by the time of the next NMFS survey (0845 h on 9/16), 70-80 animals were back on the spit.

Photo by A.E. Bowles

Figure 11. Spit at Ugak Island photographed from the air at 1324 h on 9/15.

Discussion

Noise Monitoring

Ground-truthing: HSWRI and ENRI sound levels agreed well at Site 2 (HSWRI LD 820, ENRI LD 875; Table IV). After correction for a 20 s offset in the ENRI clock relative to the launch clock, trigger times and time at max level agreed well between the paired instruments as well. A-weighted levels measured at the sites on Narrow Cape (Sites 1, 2) were very consistent, particularly the A-weighted sound exposure levels (ASEL; Table VI), which came within 1 dB. A-weighted L_{max} and peak levels varied somewhat more (within 4 dB), but were still very consistent for field measurements. Thus, measurements collected by both sets of instruments appeared to be accurate and could be used to ground-truth the Wyle RNOISE model.

The levels measured at Ugak Island (Site 3) were somewhat higher than predicted by the RNOISE model (Table V). ASEL measured by ENRI was 92.2 dB, 7.2 dB higher than the predicted value, while the L_{Amax} value differed by 8.1 dB (81.5 *vs*. 73.4 dB). Levels were also higher than those observed by Stewart during *ait*-1 (1999). Some level of overage was expected, as the *ait*-2 vehicle had roughly twice the thrust of the model vehicle (Plotkin, pers comm.)

Measurement of noise dosage: Unfortunately, it is difficult to compare the value of various noise metrics quantitatively without the appropriate psychophysical data on Steller sea lions. However, a simple graphical analysis comparing the hearing of a related species (the California sea lion, *Zalophus californianus*) with the spectrum of launch noise (Figure 12a) makes it clear that A-weighting is not an ideal filter for sea lions. Sea lion hearing is most sensitive in the range from 4-20 kHz, with an unusual flattening at the low end (below 1 kHz) at about 30 dB above best sensitivity. On the other hand, A-weighting (shown inverted for comparison; Figure 12), emphasizes frequencies below the best range of sea lions and cuts off higher frequency sounds that they can hear.

The limitations of A-weighting were particularly obvious at the Ugak site. At PPC and LCC (Sites 5, 4), the launch noise spectrum showed that there was considerable energy out to 15 kHz (Figure 7; Figure 12, PPC). At Ugak Island (Figure 12, Ugak), the spectrum of a 1 s segment centered on the peak of the overflight (ENRI LD 875) rolled off rapidly at 1-3 kHz; the leading and trailing edges had similar spectra. Thus, sea lions on Ugak would have perceived launch noise as rumble rather than the broadband roar detected by human observers at LCC and PPC (Sites 5 and 4).

It is not known how low frequency rumble and broadband roar, common experiences in an area frequented by storms (thunder, ocean noise), affect sea lion behavior. The only data available comparing responses to broadband noise to low frequency transients (sonic booms) suggest that low frequencies are less disturbing to these animals (Wolski 2000). However, sonic booms are a poor model for launch noise, since most of the energy in a sonic boom is at lower frequencies and their duration is considerably shorter (a few hundred milliseconds). In launch noise, SNR at low frequencies was still at least 15 dB above the animals' threshold and would thus have been readily audible. Without a good weighting function for the species, it is difficult to know what perceived dosage would have resulted from the exposure at Ugak.

Opportunistic Observations of Marine Mammals

Gray whales: Although gray whales and other cetaceans (dolphins and whales) are known to transit through the waters around Kodiak Island, they have not been reported in concentrations from the vicinity of the KLC at any time of year. Thus, the concentration of gray whales sighted during this study was unexpected. Although non-breeding gray whales commonly occupy the waters around coastal islands in Washington State and Oregon year-round, similar behavior is not known for the Gulf of Alaska. The present observation suggests that cetaceans should be considered more fully in future environmental assessments.

Steller sea lion behavior: There is surprisingly little published information on Steller sea lion defensive responses (Richardson *et al.* 1995) even though they are often characterized as especially susceptible to human disturbance. Withrow *et al.* (1985) described a stampede of over 1000 animals into the water after distant (>1.6 km) approach by a Bell 205 helicopter. Calkins (1979) reported that approaching aircraft usually frighten some or all Steller sea lions into eva-

Table VI: Summary of A-weighted acoustic measurements, trigger times, durations, and expected latencies to trigger.

Site	**Launch** ASEL (dB)	**Launch** L_{AMAX} (dB)	**Launch** $PEAK_A$ (dB)	**Trigger Time** (HH:MM:SS)	**Time at Max Level** (HH:MM:SS)	**Duration** (s)	**Estimated Latency (s)** Observed	**Estimated Latency (s)** Expected
1 (Narrow Cape)	109.8	103.5	120.9	13:00:02	13:00:10	37.6	2	4
2 (Narrow Cape)	109.4	105.3	123.5	13:00:03	13:00:07	38.4	3	4
2^ (Narrow Cape)	110.7	103.2	124.1	13:00:03 (corrected from 13:00:23^^)	13:00:08 (corrected from 13:00:28^^)	34.4	3^^	4
3^ (Ugak Island)	92.2	81.5	101.5	13:00:19 (corrected from 13:00:39^^)	13:00:36 (corrected from 13:00:56^^)	30.1	19^^	17
4 (Launch Control)	107.9	-	122.4	13:00:02	13:00:09	36.2	2^^^	9
5 (Payload Center)	109.7	103.8	127.5	-	13:00:10	-	-	5

^ Data provided by Mike Kelly, ENRI.

^^ ENRI times appear to have been offset from launch clock by 20 s. This offset was corrected before observed value was calculated.

^^^ Time at which level on recording was estimated to exceed 70 dB; gradual increase in noise preceding engine ignition and presence of crackle made an exact measurement difficult.

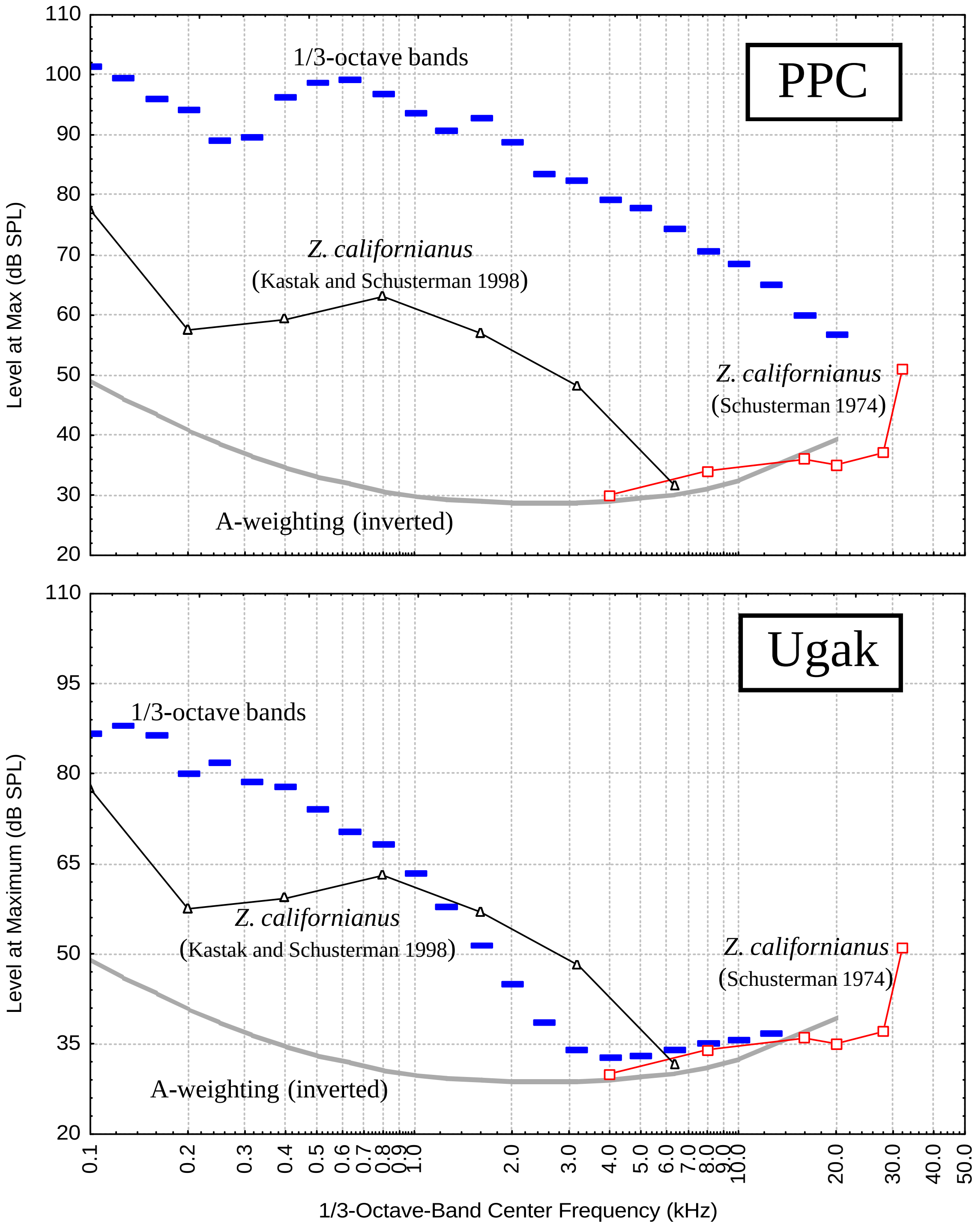


Figure 12. Comparison of California sea lion hearing thresholds, the A-weighting function (inverted), and 1/3-octave-band spectra of launch noise at Site 5 (PPC) and Site 3 (Ugak).

sive entry into the water.

Given these anecdotes, the behavior of Steller sea lions on Ugak Island on 9/14 and 9/15 was unexpected. They tolerated light aircraft overflights, helicopter approaches within 500 m, and human approach within 100 m without stampeding. However, several factors should be considered. First and foremost, tendency to stampede is strongly influenced by previous experience. The haulout on Ugak Spit had been overflown by light aircraft and small helicopters intermittently, particularly since the KLC was constructed. Steller sea lions are also approached by humans unpredictably in the vicinity of Kodiak Island (*e.g*. for scat sampling), so it seems likely that many had experienced human approach at some time in their lives. Therefore, the failure of Steller sea lions on 9/14 and 9/15 to stampede after two helicopter landings and repeated light aircraft overflights could be explained most parsimoniously by familiarity with these events.

Second, there is good evidence from studies of sea lions that both time of day and temperature alter the probability of entry into the water (Sandgren 1970, Gentry 1970, Withrow 1982, Higgins 1988, Bowles and Stewart 1980, Millette 1999). Animals are particularly likely to enter the water *en masse* when already overheated. In the case of the Steller sea lion, most foraging trips take place at night, between 1800 and 0600 h, but the night of 9/14 was cold and blustery. Thus, when the helicopter approached on the evening of 9/14, it was expected that the population of Steller sea lions on the spit would be reduced, but that those individuals still present would not be especially disposed to enter the water. This is exactly what was observed.

Rafting - congregating tightly in the water while watching a potential danger on shore - is a common sea lion defensive behavior in the face of a surprising or threatening event. When a large proportion of the sea lions in a group enter the water defensively, rafting is the usual result. When animals enter the water singly or in small groups, as is typical of foraging trips, rafting does not occur or does not involve a large proportion of the hauled animals. Therefore, an empty beach with many of the animals rafting immediately offshore is strong evidence that sea lions have been surprised or frightened, whether or not they were predisposed to enter the water by temperature conditions. This certainly appeared to be the situation on 9/15 when the colony was visited after the ait-2 launch. A total of 15-25 were present in the water just offshore and they remained in the area until at least 1500 h.

Unfortunately, it is unclear what event triggered the behavior. Any one or more of a number of events occurring after the time of the NMFS survey overflight could have contributed to the rafting observed. Roughly 25% of the animals sighted on the beach early that morning were rafting offshore at 1330 h, after the overflights. Thus, the behavior of the sea lions could conceivably be interpreted as a thermoregulatory response. Due to an equipment failure, no video was available of sea lion responses at the time of the launch, nor were any direct observations made. ENRI (2000) reports that many of the sea lions entered the water shortly before the monitoring system failed at 0930 h; however, their account lacks the kind of detail needed to evaluate the response, nor was the video made available. Therefore, it is difficult to interpret their observations.

The complete absence of animals on the beach and the tight rafts close inshore at 1330 h argue for some type of disturbance in the relatively recent past (say, within 1 h of the observation). The animals were already in the water when the helicopter approached at 1330 h and continued to raft at least until 1500 h, so there is a strong possibility that the launch was a contributing factor, if not actually the triggering event.

Such behavior would be consistent with previous observations. Steller sea lions have been observed evacuating the beach, followed by rafting, after exposure to a surprising aircraft overflight (Withrow *et al*. 1985). On the California Channel Islands, where pinnipeds are intermittently exposed to sonic booms from large launch vehicles and fighter jets, booms at levels experienced frequently do not cause rafting, but occasional, unusually-intense booms readily stimulate evacuation and rafting by large numbers of animals (Bowles and Stewart 1980, Stewart *et al*. 1996). Whether this is the result of the greater audibility of intense booms or the result of their unexpectedness has not been determined. California sea lions on the Channel Islands were more likely to enter the water *en masse* on hot days, but complete evacuation of the beach was diagnostic of disturbance in that study.

Without monitoring levels at Ugak Island over a long period (several weeks at minimum), it is difficult to know what levels would have been unusual from the perspective of the sea lions. It is telling that the launch exceeded the maximum level (L_{Amax}) in every other hour of monitoring during this study by at least 20 dB(A) and that levels in excess of 70 dB(A) were unusual at all monitoring sites where ambient noise was quantified. In addition, the launch presented sea lions with novel visual and possibly tactile stimuli as well as an unusually loud sound - the bright light of the burning rocket, the white exhaust plume (Figure 10), and possibly even the feel of the shock wave. In the face of these novel, high-intensity stimuli, evacuation of the beach and rafting would not be at all surprising.

If sea lions were actually stimulated to enter the water or to remain in it as a result of the *ait*-2 launch, from a legal point of view they would have been harassed (MMPA, 16 U.S.C. §1361 et seq). This should not be taken to mean that sea lions on Ugak Island would have been harmed necessarily, however. They are adapted to spend hours or days at sea (Schusterman 1981). Disturbances of this kind, occurring very infrequently and unaccompanied by protracted harassment are not known to cause abandonment of favored hauling areas - usually, the animals return to their previous hauling patterns within a day, often within a few hours of exposure (see review in Richardson *et al*. 1995). This was certainly the case at Ugak Spit, which was fully repopulated by the morning of 9/16. Because *ait* launches are rare and transient events, launch-related harassment would not be likely to have any biologically-significant effect on sea lions outside time-sensitive phases of the breeding season (*e.g*., during formation of the mother-pup bond).

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