# NOAA Technical Memorandum NMFS

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# DEVELOPMENT OF AN AIRBORNE LIDAR SYSTEM TO DETECT TUNAS IN THE EASTERN TROPICAL PACIFIC PURSE-SEINE FISHERY

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NOAA-TM-NMFS-SWFSC-204

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
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# DEVELOPMENT OF AN AIRBORNE LIDAR SYSTEM TO DETECT TUNAS IN THE EASTERN TROPICAL PACIFIC PURSE-SEINE FISHERY

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# Executive Summary

A method of locating tuna when they are not associated with dolphins could be important in reducing or eliminating incidental dolphin mortality because dolphins are indicator cues for 60-90% of the annual eastern tropical Pacific tuna catch. LIDAR (light detecting and ranging) is a rapidly developing technology that offers potential for detecting fish schools deeper than current visual methods allow, detecting schools missed because of environmental and human factors (e.g., whitecaps, glare, fatigue, distraction) and detecting schools during the night as well as day.

Through a series of government contracts, financial assistance from the tuna industry, and extensive cooperation with the owners and crew of the vessel <u>CAPT VINCENT GANN</u>, an airborne LIDAR system was developed, tested, and operated from a commercial tuna purse-seine vessel during normal fishing operations. Results were promising, and the details of this development are documented here to provide background and impetus for further work.

The system was tested and operated for approximately 160 hours aboard a purse-seiner between September 17 and October 20, 1992. Operations were conducted on a daily basis with as many as four two-hour flights a day. Replicate tests were performed during seven sets when tuna and other fish were captured. A total of 2,002 data files were recorded during 44 of 70 helicopter flights. Ninety-one files were selected for review (Grams and Wyman, 1993), and 13 files were selected for demonstration and discussion in this report.

We were able to detect sub-surface fish as deep as 17 meters (50-55 feet) and believe this is the first time that tuna have been detected using an airborne LIDAR. The "best" data for displaying the detection of echoes from tuna appears in file 111627.A12 (Figure 6 and Table 4), which displays echoes detected at depths between 9 and 17 meters. We were able to detect and display accurate profiles of shallow, turbid, near-shore areas of the sea as deep as 24m (75-80 feet). The "best" bottom-profile is displayed in file 150208.922 (Figure 5) for depths between 6 and 18 meters below the surface.

The potential of LIDAR systems for use in fishery applications was successfully demonstrated, and development and testing of this system and others should continue. This prototype was designed and built using commercially available parts that, with the exception of the $30,000 laser itself, are relatively inexpensive. Developmental costs for this project amounted to approximately $239,000. These expenditures include $114,000 in government contracts, $17,000 provided by Bumblebee Seafoods, Inc., and $108,000 in services provided by Caribbean Marine Service Company and Helicopter Management Company.

The combined efforts of many people over a four-year period were involved in this development. At their own expense, Mr. Ed Gann and Mr. Cary Gann of Caribbean Marine Service Company provided the purse-seiner, CAPT VINCENT GANN, and the services of the vessel's fishing master, Captain Augusto Rodrigues. Similarily, Mr. Joe Leavitt of Helicopter Management Company provided use of a Bell Jet Ranger Helicopter at various times during the development. Remote Sensing Industries Inc., (Mr. Brian Treadwell, President) received two of four government contracts. Dr. Gerald Grams and Mr. Clyde Wyman of Grams Environmental Labs Inc., designed, built and operated the system during the entire development history, and also received two government contracts.

Improvements in computer processing speed, electronic sensors, software integration, and the development of solid-state lasers, have made it feasible to build small, light, LIDAR systems for detecting fish schools from small aircraft. LIDAR systems use a laser to generate a short, high-powered pulse of light that is reflected from objects encountered by the laser beam. Some of this "backscattered light" is collected by a receiving telescope, collimated by lenses and mirrors, and directed through a narrow-band, interference-filter where the intensity of the backscattered light at the laser wavelength is measured with a photodetector. The signal from the photodetector is then amplified and directed to a device that records signal-intensity versus time-after-laser-pulsing. These recorded values can then be displayed to indicate the presence of objects (e.g., increased signal-intensity) and the range to the object from the laser source.

The design of the NMFS LIDAR system incorporates a laser transmitter and receiver attached to a custom-designed aircraft-grade aluminum frame installed in the aft seating compartment of a Bell Jet Ranger helicopter. The transmitter unit consists of a frequency-doubled, Laser Photonics Model YQL-102D Nd:YAG laser producing visible (green) light at a wavelength of 532 nm. The receiver unit consists of an eight-inch refracting telescope, collimating lens, field-stop, narrow-band interference filter, photomultiplier, transimpedance amplifier, logarithmic amplifier, and a digital oscilloscope. An interactive, menu-driven, computer program ("LIDAR.C") controls operation of the system.

The optically clear waters encountered in the offshore areas of the eastern tropical Pacific ocean will attenuate light by a factor of 0.001 for every centimeter that the beam travels (Jerlov 1968). A LIDAR is expected to be able to detect fish schools four to six times deeper than the human eye under all conditions. Tuna fishermen we have spoken with indicate they are able to detect schools at 10-20 meter depths under ideal conditions. Although we were able to detect fish as deep as 17 meters and the bottom at 24 meters, we were unable to demonstrate the expected depth capabilities of the LIDAR because of the lack of known targets. However, at an altitude of 152m, a speed of 80 knots, and with the laser pulse-rate set at 15 PPS, individual laser pulse-spots at the ocean surface would be approximately 10 cm in diameter, spaced about 3 meters apart, and capable of detecting fish at depths to 50 meters or more.

We were encouraged by the results obtained during this project and believe that the effort should continue. However, a number of significant modifications are recommended as part of any future development of a LIDAR system based upon this design and configuration. We recognize that there are alternative designs for LIDAR systems that could also meet the needs of fishery applications and these alternative designs should be explored.

# Development of an Airborne LIDAR System to Detect Tunas in the Eastern Tropical Pacific Purse-Seine Fishery

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## Introduction

As a result of the 1988 reauthorization of the Marine Mammal Protection Act and the 1990 Dolphin Conservation Act, the Southwest Fisheries Science Center (SWFSC) was directed to investigate and develop methods to find and capture large yellowfin tuna, without encircling dolphins, in the eastern tropical Pacific (ETP) tuna purse-seine fishery. The most direct method to accomplish this goal is to increase searching efficiency for tuna not associated with dolphins.

Dolphins have been indicator cues for 60-90% of the annual eastern Pacific tuna catch. A method of locating tuna when they are not associated with dolphins could be important in reducing or eliminating incidental dolphin involvement in fishing operations. The use of light detecting and ranging (LIDAR) technology to locate sub-surface fish is a technology which could be used during the day or night to detect fish schools deeper than current visual methods allow and detect schools missed because of environmental and human factors (e.g., whitecaps, glare, fatigue, distraction). The Dolphin-Safe Program at the SWFSC began investigating the use of LIDAR technology to locate sub-surface fish during 1990. Through a series of contracts, an airborne LIDAR system was developed, tested, and operated from a commercial tuna purse-seine vessel during normal fishing operations. The purpose of this report is to document the developmental history of this project and to describe the "LIDAR.C version 1.40" system as of May 1994.

Much of the material herein was obtained from non-proprietary correspondence and written reports provided by contractors during, and after, development (Grams and Wyman, 1993). We have attempted to credit the authors when we have included their material. The reader should be aware that this document is the result of the efforts of many people over a four-year period, and we have provided only a summary of these efforts.

## Concept

LIDAR systems use a laser to generate a short, high-powered pulse of light. As the pulse of light travels through some medium (atmosphere or water), light is reflected from objects encountered by the laser. Some portion of the reflected light is reflected back towards the light source. This "backscattered light" is collected by a receiving telescope, collimated with lenses and mirrors, and then directed through a narrow-band interference filter to decrease the intensity of ambient light in the medium. The intensity of the backscattered light at the laser wavelength is measured with a photomultipler. The signal from the photodetector is then amplified and directed to a device that records signal-intensity versus time-after-laser-pulsing. LIDAR systems have been used for many years in atmospheric research to provide remote observations of atmospheric constituents (e.g., Fiocco and Grams, 1964). Just as enhanced backscattering from vapors and particulate materials has been used to study aerosol layers by an atmospheric LIDAR, it appears that fish and other objects suspended in water similarly may be detected by a downward-directed laser system (e.g., Banic et al., 1987). Previous research and our efforts on this project to date indicate that the adaptation of LIDAR technology to commercial fishing as well as fishery stock assessment will be useful.

Airborne LIDAR systems have potential application in profiling sub-surface schools of pelagic fish (Squire and Krumboltz, 1981), and may be useful for species identification as well (Churnside and McGillivary, 1991). An oceanographic LIDAR system incorporates a downward-directed laser on a moving aircraft to emit short flashes of light that illuminate sub-surface water with columnar areas of light. As each light pulse passes through the water, objects suspended in the water will reflect a small amount of the laser light back to the aircraft. This light can be collected by a small telescope, detected by an appropriate photodetector and then digitized, recorded and analyzed in real time with a computer.

During the early seventies, the development of flashlamp, pumped-dye lasers requiring less power than previous ruby lasers, made it possible to build portable LIDAR systems, but these could only be operated from large, fixed-wing aircraft such as the Navy's P-3 Orion (Grams and Wyman, 1972; Grams et al., 1975). These early airborne systems were used for a number of atmospheric studies (Fox et al., 1973; Grams et al., 1975) but were too heavy and large for use on aircraft normally associated with commercial fishing operations. Fish spotters generally use single-engine fixed-wing aircraft or, as in the tuna purse-seine fishery, small helicopters. Continuing technological improvements in computer processing speed, electronic sensors, software integration, and the development of solid-state lasers, have made it feasible to build smaller and lighter LIDAR systems for atmospheric studies (Grams and Schmidt, 1990). These smaller and lighter systems have potential for detecting fish schools from smaller aircraft.

## Description of the NMFS "LIDAR.C" System

A schematic diagram of the NMFS LIDAR is shown in Figure 1. The laser transmitter and receiver are attached to a custom-designed aircraft-grade aluminum frame installed in the aft seating compartment of a Bell Jet Ranger helicopter. The frame maintains the alignment of the system relative to the direction of the output beam from the laser and the direction of the receiver's field of view.

## Hardware

The transmitter unit consists of a frequency-doubled, Laser Photonics Model YQL-102D Nd:YAG laser operating at pulse-rates of up to 20 pulses-per-second (PPS). Other switch-selected pulse-rates are 15, 10, 5, and 1 PPS. Pulse width is about 15 nanoseconds (ns). Each pulse transmits energy at the fundamental, near-infrared wavelength of 1,064 nanometers (nm) and at the frequency-doubled, visible (green) wavelength of 532 nm. Pulse energy at the green wavelength is approximately 35 millijoules/pulse (mJ). Because near-infrared energy is totally absorbed in water at only a few meters depth and is, therefore, not useful for the detection of fish, only the green light is used by this LIDAR system. Beam diameter is 5 mm and beam divergence is $\leq$ 2 milliradians from the source unit. The laser consists of two containers; a 5 kilogram (kg) transmitter housing measuring 5x4x19 inches that contains the laserhead, and a 34 kg power-supply/cooling housing measuring 8x18x19.5 inches. This model laser sells for around $30,000, but was leased for $800-1,000 per month.

The transmitter unit uses a dichroic beam splitter to direct the 1,064 nm radiation of the beam into a light trap which includes an infrared diode. The diode emits a trigger pulse for the data system at the time of laser pulsing. A dichroic mirror transmits the green light (532 nm) used by the LIDAR system and reflects the near-infrared light (1,064 nm) into the light trap. Two high-power laser mirrors placed at a 45-degree angle to the laser beam direction were held in place by a machined attachment. Their function is to direct the laser beam output to exit the transmitter unit parallel to the receiver's field-of-view. A beam-directing mirror system, attached to the frame, is constructed from various machined parts that hold a mirror at a 45-degree angle to the viewing direction of the LIDAR system.

The beam-directing system was constructed to allow the laser beam to be pointed either skyward to align the system, or downward to probe below the water surface. During flights, the beam direction was fixed at 7-15 degrees off nadir. No scanning capability is incorporated within the current configuration. Thus, the laser beam direction is affected by the changing attitude of the aircraft (Figures 2 and 3).

The receiver unit consists of an eight-inch refracting telescope with an optical axis parallel to the direction of the laser beam. The unit was fabricated using an aluminum tube with holders for an eight-inch lens at the front of the telescope and a collimating lens at the rear of the unit. A field-stop is installed between the two lenses to limit the telescope's field-of-view. When the collimated beam leaves the afocal telescope, it passes through a narrow-band interference filter attached to the rear of the telescope. This filter eliminates background light at wavelengths other than the laser wavelength, and passes the green wavelength (532 nm) light to the face of the Photomultiplier Tube (PMT). The PMT converts the light to electrical current that is then converted to voltage by a transimpedance amplifier. The AC-output voltage is coupled to a logarithmic amplifier. The output of the log amp is connected to a digital sampling oscilloscope that uses a converter to change the analog signal to an 8-bit digital signal. The converter digitizes signals at rates of up to one sample every 4 ns. The digitized signal is transferred to the computer through the General Purpose Interface Board (GPIB) which enables the computer to read, process, store and display the digitized signal.

Two computer monitors were incorporated into this system. One is used by the LIDAR operator to monitor performance of the system during tests and to make in-flight adjustments in response to changing environmental conditions. The second monitor was installed in the front cabin of the helicopter for use by the fish spotter. Comparisons between the data display and the visual observations of an expert fisherman were invaluable in the process of data interpretation and system adjustment during field tests.

## Software

An interactive, menu-driven, computer program ("LIDAR.C version 1.40") controls operation of the system and allows an operator to select from a variety of functions (Figure 4). A "RECORD LIDAR DATA" function provides the ability to observe a real-time display of the laser echoes as they are processed, and provides the operator with the capability to "tag" a specific echo for later review and analysis. A "REVIEW LIDAR DATA" function can be used during or after a flight to replay archived data. Documentation and listings of the source code and organization of the NMFS "LIDAR.C version 1.40" software is presented in Oliver (1994).

The left side of the real-time display shows a return echo for each laser pulse plotted as a vertical profile (Figures 5 and 6). This display of signal-intensity versus distance-below-the-helicopter provides a visual check on the quality of each laser echo and an indicator of sub-surface backscatter. Signal intensity increases towards the right of the screen. Distance below the helicopter increases downward from the top to the bottom of the screen. A distance-scale below the helicopter (the "LIDAR range") is displayed in a narrow area between the two plots and shows the distance from the laser source (e.g., helicopter) to the echo (e.g., surface or sub-surface object) when the display is in "normal" mode. When the display is in "expanded" mode, the range shows the distance (depth) from the ocean surface to the target.

Simultaneously, on the right half of the screen, each profile is represented as a single color-coded vertical line that moves one pixel to the right after each laser pulse. As these color-coded lines move across the screen, a two-dimensional (2-D), color-coded plot of signal-intensity versus depth-below-the-ocean-surface is created. The 2-D screen is refreshed and a new plot is started when 500 consecutive laser pulses have been displayed and stored on the computer. The color-coded, 2-D display represents the difference between the current signal, at a given range, and the previous signal at the same range. **BLACK** regions indicate that the signal is falling off with depth. **BLUE** indicates that the signals are constant or increase slowly with increasing range. **WHITE** indicates a very rapid increase (e.g., the strong reflection from the surface or the bottom). Other colors will occasionally be observed indicating a range of increases between **BLUE (smallest increase)** and **WHITE (largest increase).** Each new trace is plotted as a color-coded vertical line placed to the right of the previous line, and the pulse number for that trace (1 to 500) is displayed in the lower left corner of the 2-D plot.

## Operation

In this oceanographic LIDAR configuration, the laser pulse is directed downward toward the surface of the ocean. As the laser pulse propagates away from the LIDAR system it will be absorbed and scattered (reflected) by air molecules, atmospheric aerosols and cloud particles suspended in the air, the ocean surface, and any other scattering objects located under the surface such as suspended particulates, biological organisms, and other objects in the path of the laser beam. As the beam encounters each of these objects in its downward path, a small fraction of the light (green wavelength) will be scattered back toward the direction that it had just traversed. This "backscattered" light is collected by an eight-inch telescope that collimates the light and directs it through a narrow-band interference filter. The filter passes light that has the same wavelength as the pulse emitted by the laser and rejects light at all other wavelengths (e.g., sunlight scattered by the same objects illuminated with the laser pulse).

The filtered light from the telescope is directed onto a half-inch diameter photomultiplier tube that changes the optical signal into an electric current. The output of the photomultiplier is then passed through a preamplifier to change the current to a voltage. The signal's voltage is passed through a logarithmic amplifier to reduce the large differences in signal intensity resulting from comparing laser echoes from near the surface to those from greater depths. After passing through the logarithmic amplifier, the signal is digitized by an 8-bit transient recorder (digital oscilloscope) which is capable of digitizing the laser echoes at rates of up to one sample every 4 nanoseconds. This rate provides the capability to resolve the lidar range to within 0.45 meters in water.

As individual traces are plotted on the left side of the display, a rapid increase in signal intensity occurs at the top of the plot. This increase falls off to a nearly constant value after the first several hundred feet below the altitude of the LIDAR system. The rapid rise in the signal after the laser has pulsed is associated with laser light backscattered by atmospheric aerosols and molecules. Although the concentration of aerosol particles and atmospheric molecules usually increases with decreasing altitude, this part of the signal is subject to a significant $1/R^2$ decrease (R = range or distance of beam travel). This decrease has a much larger effect than the normal increase in the concentration of the scattering particles in the lower atmosphere. By the time the laser pulse reaches the 152-meter range-marker (the helicopter was usually flying at or near an altitude of 152 meters), the scattering profile will tend to approach a nearly constant average signal. This constant signal level is associated, primarily, with solar radiation scattered into the field-of-view of the receiving telescope by atmospheric aerosols, molecules and the surface of the sea. At night, the presence of smaller background signals could result from scattered moonlight.

When the laser pulse reaches the water surface, the echo returned again exhibits a rapid increase due to echoes from scattering objects in the water. The signal then decreases rapidly with depth below the water surface. Unlike an atmospheric return for which the observed decrease is mainly due to $1/R^2$ effects, this decrease is associated with the attenuation of the beam in the water that varies with wavelength for various water types (Jerlov 1968). Light attenuation in water results from both scattering and absorption, with absorption having the primary effect at the wavelengths used by the NMFS LIDAR system. Absorption effect on light attenuation increases with increased particulates in the water. The world's regional distribution of optical water types (Jerlov 1968) reveals that much of the ETP is Type I or IB (e.g., optically clear), and light attenuation is expected to be less than in areas with higher concentrations of particulates or dissolved minerals (e.g., coastal areas).

At the wavelength (532 nm) of the frequency-doubled, Nd:YAG laser used in this system, "mean oceanic" water will attenuate the light by a factor of 0.001 for every centimeter that the beam travels (Jerlov 1968). For an echo from a vertical beam, this means that the signal will be reduced by a factor of 0.2 per meter because of the "round-trip" required for the transmitted light to reach the scattering object and then return to the receiving telescope along the same optical path. When the above "attenuation coefficient" is introduced in the "LIDAR equation", the expected signal for a vertically propagating beam is expected to be reduced by the factor, exp (-0.2 d [meters]) **at depth** d **below the surface.** Thus, the return signal is only 0.82 of the source signal after 1 meter in water, 0.67 at 2 meters, 0.37 at 5 meters, 0.13 at 10 meters, 0.018 at 20 meters, and 0.0025 at 30 meters. Attenuation results in an echo that is only 1/1000 of the echo from the surface by the time the beam had traveled to a depth of 34.5 meters (113 feet). These calculations demonstrate the necessity of using the logarithmic amplifier in the laser detector system to reduce dynamic range requirements for digitizing the signal. They also demonstrate that at some point below the surface the attenuation of the actual laser echoes will result in a signal that is a measure of only the amount of background (constant) light collected by the receiving telescope. Thus, average values of the digitized echoes from distances that are far below the water surface can be used to establish and subtract out the background signal levels. We expect the LIDAR to detect objects at greater depths in the clear, offshore waters of the ETP than in "less clear" coastal areas. However, in all areas a LIDAR is expected to be able to detect objects at much greater depths (4-6 attenuation lengths) than the human eye is capable of detecting under ideal conditions (1 attenuation length).

When using the review function provided by the NMFS "LIDAR.C" software, certain expectations exist which will help to interpret the data displayed on the computer screen (Grams and Wyman, 1993). If the echo signal is constant (e.g., a signal with only background light and no laser echo) it should be displayed as a straight vertical line. The photomultiplier has inherent background noise fluctuations caused by statistical fluctuations of the instantaneous rate of arrival of photons from all sources (e.g., the light from the laser echo itself for which the intensity will vary with range). This "noise" includes any scattered sunlight that happens to lie within the narrow band of wavelengths passed by the interference filter. This scattered sunlight will, on the average, be constant and will not be synchronized with the time of laser pulsing.

The output of the PMT will be a series of randomly-emitted, closely-spaced pulses that can appear to be a constant signal under conditions when pulse-rates are high and when the resolution of the digitizer cannot differentiate small differences in amplitude from one point to the next. If, on the other hand, one were to carry out any number of operations to look at the signal in more detail (e.g., increase the voltage supplied to the PMT, increase the gain of the logarithmic amplifier, adjust the gain of the digital oscilloscope using a more sensitive switch-setting, etc.) the digitized points that had been plotted in a straight vertical line would eventually take on the character of a series of points scattered randomly on either side of that vertical line. As the overall gain of the system is increased, the position of the plotted points will be randomly distributed at larger and larger distances away from the vertical line drawn through the average value of the digitized points.

The expected appearance of an oceanic laser echo from a uniform distribution of scattering particles (constant concentration with decreasing depth) would exhibit a signal that would be strongest at the surface. This signal would rapidly decrease in a monotonic fashion (without local increases) until it approached a constant value representing a level of background noise resulting from scattered sunlight that is collected and transmitted to the detector system by the receiving telescope. When the PMT voltage is set too high, "noise" appears as widely scattered data points in the bottom portion of each trace in the 2-D display. This part of the trace should be a plot of a constant background value (a vertical line) associated with the signal strength from ranges corresponding to depths where laser echoes are no longer a possibility. When the gain is set too high, problems can occur in obtaining accurate digitized values of the series of voltages that define each lidar echo. When signals are passed though the PMT, or the various amplifiers in the system exceed certain operating ranges, a variety of problems can occur. For example, the output of the device may become nonlinear. False "tails" may appear with signals that are falling off rapidly or a "rounded-off" curve may replace the abrupt change that should mark the beginning of a rapid increase in signal level (as at the surface of the water). In addition, a strong signal might saturate the output of an electronic component, or the signal might be "clipped" to a constant voltage value, causing those regions of the signal that exceed a certain level to be replaced with a constant number. Large fluctuations in background noise and a "rounded appearance" to the signal trace from the sea surface may indicate settings that are not in the proper range to detect near-surface objects.

If the oscilloscope's "time-sweep" setting is double the "normal" speed, an error in the range-marker value occurs between the LIDAR trace profile and the 2-D plot display. This will appear as a slower increase in signal strength near the LIDAR's altitude (at the helicopter's altitude) and a slower decrease in the atmospheric return at lower altitudes (below the helicopter). At faster sampling speeds, with a fixed number of data points stored for each pulse, the reflection from the surface layer of the water will be absent. Normally, the reflection would have been detected and stored in digitizer-channels ("range-bins") but, because the values for the "range-bins" are beyond the maximum memory location for which data were recorded, these data are not stored and therefore not displayed. Echoes normally associated with the surface reflection would be located below the maximum depth indicated on the display.

Such effects require a considerable amount of testing and adjustment to select the proper combination of settings for the electronic components to optimize the overall performance of the system. These settings need to be adjusted so that the sensitivity is high enough to detect and record small changes in signal levels for echoes from objects that are located well below the surface. At the same time, the gain must be kept small enough to avoid saturation and nonlinear effects for the larger echoes that are expected from the surface layers. Large changes in altitude or the optical clarity of the ocean generally require some adjustment to the system's settings (Grams and Wyman, 1993).

## Laser safety

According to the contractors, the operation of the "LIDAR.C" system was conducted according to the American National Standards Institute (ANSI) criteria for safe operation of lasers (Grams and Wyman, 1993). The frequency-doubled Laser Photonics Model YQL-102D Pulsed Nd:YAG laser generates 150 mJ at 1,064 nm and 35 mJ at 532 nm with a pulse width of approximately 15 ns. The 1,064 nm energy was trapped so that no external emission of this wavelength occurred. A beam expander was employed to expand the 532 nm wavelength so the emitted beam will not burn the thin aluminized coating of the transceiver mirror. The two lenses used to expand the beam are uncoated, resulting in a 10% loss in power at each lens, thereby reducing the net output to about 28 mJ.

Both the visible, emitted light (532 nm) and the invisible, infrared, non-emitted light (1,064 nm) are capable of inflicting permanent eye damage that could result in total blindness. The light output can burn skin tissue and may cause spontaneous ignition of chemicals on some common materials (Laser Photonics, 1991). Laser radiation can result in corneal or retinal burns with acute exposure, and corneal cataracts, lenticular cataracts, or retinal injury from constant exposure to excessive levels (Laser Institute of America, 1992). Skin burns and skin carcinogenesis are also potential hazards associated with the laser output. Chemical and electrical hazards are also present when operating the laser system. It is unclear if other organisms can be harmed by lasers in ways similar to the potential danger to human eyes and skin tissue. We are unaware of any "eye safe" or "tissue safe" standards for cetaceans, fish, birds, or turtles.

The following passage, taken from a Laser Safety Guide (Laser Institute of America, 1992) addresses laser safety for the human eye.

> "From a safety point of view the laser can be considered as a highly collimated source of extremely intense monochromatic electromagnetic radiation. Due to these unique beam properties, most laser devices can be considered as a point source of great brightness. Conventional light sources or a diffuse reflection of a Class 2 or Class 3 laser beam are extended sources of very low brightness because they radiate in all directions. This is of considerable consequence from a hazard point of view, since the eye will focus the rays from a point source to a small spot on the retina while rays from an extended source will be imaged, in general, over a much larger area. Only when one is relatively far away from a

> diffuse reflection (sufficiently far that the eye can no longer resolve the image) will the diffuse reflection approximate a 'point source.' Diffuse reflections are only of importance with extremely high-power Class 4 laser devices."

The specifications for the laser used in this system indicate that ANSI safety rules applicable to "high power" (Class 4) lasers should be observed. Human safety required that power was not supplied to the lidar system until the helicopter was beyond a safe, minimum distance from the ship. Once the system was powered, the laser output could be temporarily stopped without turning the power off by using an on/off control switch that was easily accessible to both the lidar operator and the pilot. The laser output was generally terminated whenever the helicopter passed over the vessel or marine mammals. However, on a few occasions the purse-seine vessel was used as a target to obtain data on the system. Laser safety procedures were employed during these tests so that personnel on the vessel were not harmed.

The diameter of the laser beam on the sea's surface depends upon the altitude of the laser-equipped helicopter and a number of other factors. For this particular system, the spot could be as small as a few inches depending upon beam divergence. The beam expander incorporated into this unit will reduce the beam divergence depending upon how large the beam is expanded. Divergence is controlled by de-focusing one of the two lenses in the beam expander. As the divergence angle is increased the laser energy (per/cm$^2$) at the spot is decreased. Thus, the lidar system can be configured to be "eye safe" (ANSI standards) by a combination of changes to beam divergence and altitude. For this system, the laser beam spot at the surface would have to be expanded to a 3-meter diameter with the helicopter at 152m (500 feet) in order for the laser energy within the spot to be "eye safe". Any decrease in altitude would cause the spot to exceed "eye safe" standards.

The contractor calculated that with the helicopter flying at an altitude of 152m, at a speed of 80 knots (KTS) with the laser pulse-rate set at 15 PPS, individual laser pulse-spots at the ocean surface would be approximately 10 cm in diameter and spaced about 3 meters apart. Although the laser beam exceeded "eye safe" standards at virtually any operational altitude during the tests, it is doubtful that more than one pulse could contact an individual animal when the aircraft was moving.

The contractors estimated that the probability of an individual pulse striking a life form at the surface or in the air was low, given the cross-sectional size of the laser beam, the frequency of the laser pulses, and the aircraft's forward motion. Moreover, a single pulse should not damage the skin of an animal. Conceivably, optical damage might result from looking directly into the beam. Because animals in and over the tropical marine environment are oriented to look downward and to the side as they respond to predators, prey, and others of their species, the likelihood of encountering an animal that is exactly in line with an oncoming laser pulse and is looking directly upward at an aircraft passing over at high speed is remote. However, on a few occasions during testing, the lidar beam detected objects above the ocean's surface that may have been birds.

## Contract History

### OSPREY-1 (52ABNF000126)

On August 16, 1990, NOAA solicited (52ABNF000126) proposals to develop an airborne system for detecting and classifying schools of tuna. After review of four proposals, a $45,000 award was made to Remote Sensing Industries (RSI), Inc. of Eastham, Massachusetts on September 28, 1990, to provide an airborne prototype incorporating a laser-based LIDAR designed to fit in the aft passenger area of a Hughes 500D helicopter. RSI subcontracted at least part of the development to Dr. Gerald Grams and Mr. Clyde Wyman. A final report and the prototype system were due in seven months (April 30, 1991), and monthly reports were required. Major hardware and assembly purchases totaled $27,777.19 (Table 1). Following a number of contract modifications, a 21-page final report was received on August 12, 1991.

During May 1991, the "OSPREY-1" LIDAR system was shipped to the west coast and installed in a Bell Jet Ranger helicopter owned by Helicopter Management Company (HMC), El Cajon, California. HMC leases helicopters to tuna seiners owned by Caribbean Marine Service Co., Inc. (CMS) of San Diego, California. HMC modified a helicopter door to fit around the directing mirrors, constructed a frame to support the LIDAR components within the helicopter, and provided wiring to accommodate the inverters necessary to run the prototype off the helicopter's power supply.

The "OSPREY" system was tested during flights made on three consecutive days (May 26-28, 1991) over the coastal waters of southern California. HMC and CMS assumed all costs for these tests. The goal of these initial tests was to record bottom contours and investigate adjustments necessary to compensate for backscatter from the surface of the water. Bottom contours were to be profiled for use as a preliminary baseline for making adjustments to system's components.

A pilot experienced in tuna purse-seine fishing operations, a spotter/data recorder, and the project engineer who operated the system and made mid-flight and post-flight adjustments to the hardware components, accompanied each flight. Flights were made at an average altitude of 152m. A combination of problems, including wide fluctuations in the strength of the laser pulses, resulted in poor or no data for several of the initial flights. Refinements and modifications were made during the test period to adapt to the turbid inshore waters, hazy air conditions, and a change in water color and clarity influenced by the presence of plankton blooms along the coastline (e.g., "red tide" associated with Gonyanlax spp.). Adjustments to the system led to several successful test flights, but the first laser unit itself eventually failed.

This first field test of the system was successful in many respects. Assembled largely from off-the-shelf parts, it was modified for installation in the Bell Jet Ranger helicopter, operated for three days, and performed well in detecting fish and other reflecting elements in the water. Bottom profiles were recorded to depths of approximately 25 meters during the first series of test flights, and surface-schooling fish were profiled after visual detection from the helicopter. There were sufficient problems with the laser to delay further tests until another laser could be obtained and additional modifications incorporated into the system.

During the period September 10-20, 1991, the "OSPREY-1" system was shipped to the west coast, installed in a HMC helicopter, and additional flights of the modified system were conducted. Modifications included a change in the beam direction system and a redesigned receiving telescope. Tests were made to compare results obtained from use of a linear versus logarithmic amplifier, and an avalanche photodiode versus a photomuliplier. Testing consisted of operating the system and attempting to record bottom contours as well as profiles of schooling fish that were spotted visually. All the support costs for helicopter time and installation were borne by HMC and CMS, and totaled approximately $18,000 for the May and September 1991 flights combined. The unit was again returned to Dr. Grams' in Atlanta, Georgia.

Because of the progress made during the contract and the test results obtained during May and September 1991, the SWFSC and tuna industry (Bumblebee Seafoods, HMC, and CMS) decided to further develop and eventually deploy the unit aboard a commercial tuna purse-seine vessel. CMS offered to provide ship, helicopter, and logistic support to deploy the system at sea, but RSI declined the offer during late 1991 because there was no additional funding for RSI's involvement. After consulting with the SWFSC, CMS, and HMC, Bumblebee Seafoods Inc., provided another $5,000 to RSI during December 1991.

## OSPREY-2 (43ABNF200692)

NOAA subsequently issued a "Request for Quotations (RFQ)" on February 4, 1992, to continue development. The RFQ was aimed at "ruggedizing" the system to withstand the physical and environmental conditions inherent in deployment at sea, provide additional hardware and software modifications, and demonstrate these capabilities during tests off California. Contract 43ABNF200692 was awarded to RSI on February 25, 1992, in the amount of $24,500. Hardware modifications included use of a more powerful laser, installation of a Global Positioning System (GPS) Board and software, development and installation of a new beam-expander system, and the addition of another video monitor. "Ruggedization" included modifying the beam-directing mirror and adding weather seals, supports, and dampeners to isolate the system from the environment and vibration. Software modifications included adding a number of display functions and incorporating the GPS display.

There were a number of disputes concerning contract 43ABNF200692 involving the work performed, the time of performance, and the purchase and ownership of various components. Dr. Gerald Grams and Mr. Clyde Wyman performed the work for RSI. During the week of April 5, 1992, the "OSPREY-2" (also called "OSPREY.C") system was tested in Atlanta, Georgia and then shipped to the SWFSC. The "OSPREY-2" system was installed in a HMC helicopter on April 15, 1992, tested, and operation of the computer system was demonstrated to the participants. No test flights were flown, because none of the participants was willing to bear the flight costs, and data were not collected during the tests. The unit was removed from the HMC helicopter on April 20, 1992, and placed in possession of the SWFSC. Major hardware and assembly costs totaled $4,195 (Table 1).

Completion of these shoreside tests was acknowledged on April 21, 1992. A three-page final report, marked 'proprietary', was prepared for RSI by Dr. Grams and accepted by the SWFSC on May 6, 1992. The title page of this report referenced an "OSPREY-3" system, but the source code and all other references reflect the "OSPREY-2" system (also called "OSPREY.C").

## LIDAR.C (43ABNF201797)

Although the system was deemed ready to be deployed for extended sea trials and the contract with RSI was closed, Dr. Grams offered to document the additional programming and refinements to the software display incorporating the GPS feature and requested the system be sent to him directly. On April 24, 1992, the SWFSC loaned Dr. Grams the equipment with the written understanding that there was no contractual agreement and no work was requested or authorized by NOAA.

During April 1992, the SWFSC began development of a "Memorandum of Agreement (MOA)" between the SWFSC and CMS whereby CMS, in cooperation with HMC, would provide ship, helicopter, and other logistical support for field tests of the LIDAR at no cost to the government. The MOA was signed by both parties on August 17, 1992. The tuna purse-seine vessels <u>BOLD ADVENTURESS</u> and <u>CAPT VINCENT GANN</u> were identified as potentially available during September 1992. Each of these vessels carried a HMC helicopter pre-wired for the LIDAR system. Also during April 1992, the SWFSC initiated a "Request for Quotations" to operate the system aboard a tuna purse-seiner for 30-40 days and prepare a report on the results. Contract 43ABNF201797 ($24,500) was awarded to Grams

Environmental Labs on September 2, 1992, to operate the "LIDAR.C" system at sea and report on the results. A final report was accepted on December 17, 1993.

On September 7, 1992, RSI raised a protest concerning the development process, contract awards, and ownership rights to the hardware and software that constitute the "LIDAR.C" system. RSI and NOAA signed an agreement on December 7, 1992, which provides government ownership of all existing hardware and commercially purchased software, authorizes RSI to copyright "OSPREY" software developed by RSI under contracts 52ABNF000126 and 43ABNF200692, and grants the government and others acting on the Government's behalf, a license to reproduce any developed software, prepare derivative works, and publicly perform and display this software.

Installation, testing, and extensive software modifications of the "LIDAR.C" system occurred in Balboa, Republic of Panama, during September 17-24, 1992. The "LIDAR.C" system was operated for approximately 8 hours and data were collected on bottom contours and unidentified, sub-surface fish schools. The display software was modified to incorporate a "tagging" function, additional display features, and a new "signal-color-display" algorithm was developed. Modifications were made to the software to provide an "expanded display mode". This modification corrected the erroneous range-marker distances displayed on the 2-D plot by accounting for the difference between the speed of light in air and the speed of light in water. Bottom contours were detected in the very turbid waters of the Bay of Panama at depths to approximately 21m (70 feet). Dr. Grams and Mr. Wyman certified that the system's performance was satisfactory and ready to be tested at sea, although the GPS system was inoperative. Dr. Grams prepared a report on the pre-deployment activities, provided some of the data files, and delivered a copy of the executable "LIDAR.C" software to the SWFSC.

The "LIDAR.C" system was deployed aboard the CMS purse-seiner <u>CAPT VINCENT GANN</u> during the period September 25 through October 20, 1992, and operated on a daily basis (as many as four two-hour flights a day) as well as during replicate tests over the net during seven sets when tuna and other fish were captured. Sub-surface tuna were profiled by the system on several passes. Estimates of tuna tonnage were obtained from the fish-spotter in the helicopter and compared with the catch loaded aboard the vessel. The unit was used for approximately 160 hours. The objectives of the sea trials were to test the "LIDAR.C" software, the durability of the hardware during normal fishing operations at sea, and to attempt to detect and record signals from sub-surface fish schools. We had planned to conduct a large number of replicate tests over fish captured in the net during the sea trials to compare recorded signal strengths and signatures with known fish species and tonnage. Tuna fishing during the sea-trials was slow with only 12 sets during 30 days of fishing. Although fewer sets were made than anticipated, we were able to conduct seven replicate tests during the 30 days at sea before the system failed.

The "LIDAR.C" system was returned to the SWFSC at the conclusion of the cruise. Dr. Grams provided a final report (Grams and Wyman, 1993) on October 28, 1993, which includes his report on the pre-deployment activities in Panama, an analysis of the results from the sea tests, his recommendations, and a "LIDAR Operators Manual" (Appendix 1). The SWFSC scientist's field notes for both the pre-deployment and deployment periods are included as appendices in this report. CMS estimated the added weight of the "LIDAR.C" system and operator resulted in a 20 percent increase in fuel consumption, or approximately 1,000 gallons during the trip. CMS and HMC estimated their contribution to the research at $90,000, primarily for helicopter use.

During March 1993, Dr. Grams provided the SWFSC with source code for the NMFS "LIDAR.C v1.20" software used during the September-October 1992 sea trials. Additional modifications to the review and display functions were included in this software "LIDAR.C v1.40). Dr. Grams also provided source code for the "OSPREY.C" software (also called "OSPREY-2" and "OSPREY-3"). He identified the latter as the untested software that existed at the completion of the last RSI contract (43ABNF200692) in April 1992. The SWFSC never received source code for any of the prior "OSPREY" software, but does possess executable copies for some versions. Both versions of the "LIDAR.C" software have been documented (Oliver 1994) and are archived with the LIDAR custodian, Southwest Fisheries Science Center, P.O. Box 271, La Jolla, CA 92038-0271.

An executable copy of the "LIDAR.C" program and two data files are available. Execution requires a 386-PC with color VGA and the MSDOS-5.0 operating system. Requests should be directed to the LIDAR custodian at the SWFSC and include both a DOS-formatted 3.5-inch diskette and an addressed, postage-paid return mailer.

## Field Tests During September-October 1992

The purposes of the Panama tests were to install the LIDAR in a helicopter, make final adjustments to the system, and verify that the system was ready to operate at sea. During the sea trials we were to: 1) operate the LIDAR system while the crew and vessel conducted fishing operations, 2) collect information on the performance of the LIDAR, and 3) assess its practical use to increase searching efficiency. We identified a number of potential uses for the system and planned to collect data to address these uses. These potential uses included:

1. Rapid assessment near natural logs and flotsam from a LIDAR-equipped helicopter to determine fish presence, the amount of fish, the depth of the school, the vertical and horizontal movements of the school, and eventually, the species and size of fish present.

We had planned to operate the system over the net during pursing and net-roll to determine if tuna could be visually identified on the computer monitor. The amount and species of fish present could be verified when the catch was loaded. We hoped to determine whether yellowfin tuna, skipjack tuna, sharks and other species produce a unique "LIDAR signature" due to different reflective properties, and to discover if fish of different sizes produce different signatures. We hoped to profile the bottom of the purse-seine to measure how deep the laser penetrated the water and to determine how depth-of-penetration was affected by various oceanographic conditions such as water clarity, surface winds, and glare.

We had planned to operate the system near "logs" before and after a set and compare performance with existing fish-finders aboard the vessel.

2. Track "schoolfish", not associated with dolphins, using a LIDAR-equipped helicopter.

We had planned to operate the system over schools of tuna, or other fish, to determine whether fish could be tracked. This effort was intended to ascertain if the system would allow us to track and relocate fish schools even when a school was no longer visible to the human eye due to depth or sighting conditions.

3. Supplement searching effort by detecting sub-surface fish not associated with "normal" visual cues (e.g., birds, animal splashes) or overlooked because of poor sighting conditions.

We had planned to operate the system while randomly searching over open water to detect fish that would have otherwise been overlooked.

After each lidar flight, data recorded and stored on the computer were transferred to a tape cassette using a Colorado Memory Systems JUMBO 120 Tape Backup System. Table 2 summarizes all the data files collected during the field tests. The column on the right side of this table shows the name of the tape used to store each data set (e.g., the PANAMA tape contains data for the tests in Panama; tapes from the sea trials are named NOAA1, NOAA2, etc.). The PANAMA tape has data stored in a directory called "PANAMA". When that directory was created, a file compression program (PKZIP.EXE) was used to create files named PAN918.ZIP, PAN919.ZIP, PAN920.ZIP, PAN921.ZIP, and PAN922.ZIP. Table 2 includes the name of the compressed ("zipped") data files on each backup tape. The "zipped" files can be transferred from the backup tapes to a computer using the utility program provided for the Colorado Tape Backup System. Then, it is necessary to use the auxiliary de-compression program (PKUNZIP.EXE) to restore the "zipped" files to their original form. These files then must be placed in a subdirectory named "C:\DATA" to be reviewed with the NMFS "LIDAR.C" program. Other information provided by Table 2 includes the size of each "zipped" file, the original size of the data set that had been stored in the "zipped" file, the number of files in each set, names of the first and last files in each set, and the filename extension needed to fully identify every data file in the set.

The name of each file indicates the date and time of the first pulse in the file (e.g., the file named "150208.922" started at the 24-hour clock time of 15:02:08 on the 22nd day of the 9th month. To accommodate the 3-character limit that DOS places on the extension for a file name, hexadecimal numbers were used for months after September. Thus, the extension ".A11" indicates a file recorded on the 11th day of the 10th month.

The computer data archived with the NMFS LIDAR during the system tests in Panama (September 17-22, 1992) and the sea trials in the Pacific Ocean (September 23-October 20, 1992) amounted to 495 megabytes (MB) of data in 2,002 separate files (Table 2). These data were collected during the Panama tests and during 44 of 70 helicopter flights during the sea trials. A final contract report (Grams and Wyman, 1993) provides detailed information on all the data files including the name assigned to each file, the file size, and the date and time that each file was recorded. The NMFS scientist (Armstrong) who participated in these tests provided detailed written comments on these data (Grams and Wyman, 1993). Ninety-one data files (22.6MB) obtained during these tests were selected for review. A complete review of all 91 files and the field notes recorded during these tests is included in Grams and Wyman (1993). A subset of 13 files (4 from the Panama tests and 9 from the sea trials) containing 3.3MB of data was selected for demonstration purposes (Table 3) and are discussed later in this report.

Seven sets were made where tuna were captured and the LIDAR system was repeated flown over the net in attempts to obtain data. The locations of these seven sets are shown in Figure 7, and the data collected are presented in Table 4. The system was able to detect sub-surface fish during some of these sets. The system operated for over 160 hours before a low-voltage, power-supply module failed. Because the module was broken and we did not have a spare, the tests were concluded on October 20, 1992.

## Equipment Performance During Tests

Several potentially disastrous equipment malfunctions occurred. The NAVSTAR Global Positioning Satellite (GPS) system board and software had been installed and integrated into the "LIDAR.C" software by Dr. Grams prior to the Panama tests, but he was unable to initiate the GPS system board once the LIDAR was installed in the helicopter. The GPS was intended to provide the fish-spotter with the precise position of signals suspected to be fish so the target could be relocated and assessed easily from the helicopter.

During the pre-deployment tests in Panama, a problem developed with one of the helicopter's two, 25-ampere, circuit breakers.

These circuit breakers are used with our static inverters to transfer power from the helicopter to the LIDAR. A circuit breaker repeatedly tripped whenever the laser pulse-rate was set between 15 and 20 PPS and operated for more than a few minutes. The system was operated at rates less than 15 PPS (generally at 10 PPS) with the helicopter airspeed reduced to 55 knots to partially compensate for the reduction in pulse-rate. This problem continued to occur during the sea trials until the circuit breaker was replaced on October 10, 1992.

During the first week at sea, the laser unit began misfiring and emitting random laser pulses. Because the contractor was unable to isolate the problem, we suspended use of the LIDAR for all but flights over the purse-seine net when fish were captured. This resulted in numerous lost opportunities to collect data while the helicopter searched for fish, and even prevented us from obtaining data during some of the replicate tests (Table 4; Replicate Tests 1, 3, and 4). On October 10, 1992, the laser head and power supply units were removed from the helicopter and opened. A number of computer boards were removed and inspected, contacts were cleaned with a rubber pencil eraser, and the boards were then reseated. A board connected to the power supply/heatsink was located near two large capacitors, and was identified as the source of the random emissions. Apparently, vibration caused by helicopter during takeoff, flight, and landing resulted in a poor connection for this board. Two rubber shims were placed between the board and the power-supply cover to anchor and isolate the board. After these repairs, random misfiring did not occur.

Problems with formatting archival tapes developed with the 120MB tape backup system late in the sea trials. Because the LIDAR system creates a new 250KB-file every minute during operation, and stores these files on the computer's disk, it was necessary to transfer the files to a tape at the end of most flights, and then delete the files from the disk in preparation for the next flight's data collection. Unfortunately, the contractors had configured the computer's disk for only 60MB of the 90MB available. Without formatted tapes, or the ability to format tapes, they were unable to archive additional data. As it turned out, this was not a problem because the system failed shortly after this malfunction surfaced.

## Laser Images Obtained During Tests

We have excerpted and paraphased much of this section from Grams and Wyman (1993). Thirteen of the ninety-one data files reviewed by the contractors were identified as excellent examples of the capability of a downward-looking airborne LIDAR for oceanographic studies (Table 3). The LIDAR was able to map profiles of islands and sea-bottom contours as part of the installation and testing activities in Panama before the sea trials (Figure 5). Laser echoes from tuna were obtained during the sea trials (Figure 6 and Table 4). Although we were unable to adequately reproduce the color images displayed by the system in these black-and-white figures, we hope they will provide some idea of the visual capabilities of the system. This section summarizes these 13 files and describes the display for each file.

The "best" bottom-profile obtained in Panama is shown in file **150208.922** (Figure 5). If this data set is reviewed with the display in the "expanded" mode to show the signal-intensity of laser echoes versus depth, the bottom profile is clearly defined. The echoes are clearly above system noise levels for depths to approximately 18m (60 feet). Using the default color-display, background noise registers as a "random" blue and black pattern for depths greater than 18m. Somewhere near Pulse #209 (Tag #47), reflections from the bottom begin to appear as short vertical lines that are either bright blue or cyan in color. As these highlighted lines are traced across the rest of the screen, the bottom profile is displayed. This profile starts at a depth of about 18m. It rises to a peak at about 6m (20 feet) below the surface, and then falls off until the signal merges into the background noise.

Our "best" data showing the detection of echoes from tuna is file **111627.A12** (Figure 6 and Table 4). The "normal" display mode (signal versus range) shows the helicopter at altitudes varying between 76m and 84m (250-275 feet) with two vertical red lines (Tags 23 and 24) located near the middle of the plot. In the dark region on the screen, immediately below the white line that indicates the range to the surface, several vertical, color-coded lines in the 2-D display stand out as indicators of strong echoes from below the surface. Echoes of special interest in this data file include Pulse #288 and the entire sequence of echoes between Pulse #276 and Pulse #288. Using the "expanded mode" (signal versus depth below the surface) to display this file displays the echoes from fish detected in Pulse #285 at depths between 9m and 15m (30-50 feet). For Pulse #288, the echo is found between 11m and 17m (35-55 feet). This particular data set clearly shows that the LIDAR system is capable of detecting sub-surface fish.

### File 025058.919 - September 19, 1992.

File **025058.919 (flight over island)** shows the ability of the system to map topographical features over land, using the display software in the "normal (not expanded)" mode. The progression of data profiles indicates the helicopter was slowly descending as it approached an island. The beginning of the 2-D display (Pulse #1) shows the helicopter at about 158m (520 feet) above the surface. Altitude decreased steadily until the helicopter was a little over 152m above the surface at Pulse #60. The island's profile along the aircraft flight path is displayed by the series of profiles from Pulse #60 to Pulse #136. This topographical profile shows a maximum height of about 55m above the sea's surface. The aircraft appeared to be some 91m above the highest point on the island. As the aircraft passes the island's shoreline at 146m and moves out over the water, bottom contours on either side of the island are evident. However, the bottom-contour profiles were not detected continuously in the nearshore areas around the island. This might be because turbid water near the shoreline increased light attenuation, thus preventing the laser beam from penetrating far enough to continue the mapping process in these areas.

### File 030446.919 - September 19, 1992.

File **030446.919 (strong signal from bottom)** was obtained late in the day in an attempt to verify that the system could produce a profile of the bottom of the sea at depths that should be detectable to the system. It is not clear that this particular profile represents a good bottom profile.

### File 131039.921 - September 21, 1992.

File **131039.921 (strong signal from the bottom)** shows a bottom profile of the channel between Toboga and Urava Islands (Tags 27, 28, and 30). These data were obtained after numerous changes and adjustments were made to the system to reduce background noise which at times was as much as 20 percent of the full scale. The traces in these data were quite close to being optimized for the conditions encountered in the waters near the coast of Panama. Background noise appears to be about only one percent of the maximum signal strength. The gain settings for the PMT and the various amplifiers were apparently set so that the largest echoes from the atmosphere at close ranges, and from the sea surface at longer ranges, were almost full-scale on the digital oscilloscope without being "clipped" at some constant signal level. A short burst of noise occurred between Pulse #215 and Pulse #220, probably caused by interference from the aircraft's communication radio. Bottom traces begin to appear as a small "blip" in the signal profile at a depth of about 18m below the surface. The "blip" signal moves higher and higher until it is approximately 6m below the surface near Pulse #30 (Tag 29). At Pulse #428, the depth of the observed echo begins to decrease, disappearing into the background noise somewhere near the 21m depth.

### File 150208.922 - September 22, 1992.

File **150208.922 (good bottom profile)** was recorded during the last day of tests in Panama. Before this collection, final adjustments were made to the PMT and amplifiers to optimize the system's settings. The helicopter flew over a channel between the islands Toboga and Urava, and obtained a good bottom contour. The displays of the single-trace profiles on the left side of the display show that noise was limited to approximately one percent of the full-scale oscilloscope readings, and the overall signal is very well behaved.

Tag 47 (Pulse #208) displays echoes from the sea bottom as the helicopter approaches an area used to obtain a bottom profile. The profiles show a rapid decrease in signal-intensity versus depth for the first 4-5m below the surface. This decrease is expected and results from the attenuation of the light beam as it propagates deeper and deeper into the water. As the 2-D display develops, sharp, well-defined echoes appear which are associated with reflections from the sea bottom. Pulse #156 is a very clear indication of a reflection from a depth of 20m. This abrupt "blip" in the single-trace profile becomes the short **CYAN** portion of the vertical line for this trace on the 2-D plot. This **CYAN** marker is located about half way between the **GREEN** horizontal lines that indicate depths of 15m and 23m (50 and 75 feet). We estimate the depth of the sea bottom at 20m for this pulse. The "blip" in the signal from the bottom is not quite as obvious in the next few pulses, but it is clearly present, and the signal-to-noise ratios are still quite small at these depths. The bottom reflection seems to disappear altogether somewhere between Pulse #160 and Pulse #190, and what appears to be occasional bottom reflections from the 27 meter region appear, followed by a series of unambiguous, very strong reflections from the sea bottom. These reflections start at a depth of about 20m at Pulse #206 and move steeply upward to a depth of about 4m to 6m (15-20 feet) from Pulse #310 to Pulse #330. The signal then decreases rapidly to a depth of about 18m at Pulse #375, although there appear to be faint signals detected from even lower depths for the next few pulses.

### File 132112.926 - September 26, 1992.

File **132112.926 (strong signal near a FAD)** was recorded while the helicopter was circling a fish aggregating device (FAD) equipped with a radio "beeper". The file shows some interesting sub-surface reflections, but because the helicopter was flying at an unusually low altitude when the observations were taken, there are some problems with the display. The aircraft altitude was so low that the signal was unable to fall anywhere near the background noise level (as happens with the helicopter at 152m). This makes it impossible to use the 2-D display mode showing lidar signal-intensity versus depth-below-the-surface because the software looks for a sudden increase over the background noise level due to the reflection from the sea surface to establish the channel number for the start of the display **(depth = 0)**. We are, therefore, limited to using the "normal display" mode (signal intensity versus range or "distance away from the helicopter") to discuss this data file.

The first trace in the display shows the sea surface to be about 61m below the helicopter. The aircraft altitude then decreases rapidly to about 15m at Pulse #120. On Pulse #191, the oscilloscope **"sweep-speed"** setting of 5 usec (full sweep) appears to have been reset to 2 usec and then, a few pulses later (at Pulse #201), to 1 usec. These changes caused the signal to be displayed over a larger vertical distance. The range-scale on the left side of the display does not change between these events.

The oscilloscope settings are recorded at the beginning of each 500-pulse recording, and changes to these settings in the middle of recording a 500-pulse data file are not included in the data file. The effect of said changes appear in the display but are not reflected in the scales. The software should be modified so that the indicated ranges are proportionally changed whenever the **"sweep-speed"** is changed. At Pulse #455, the oscilloscope was reset to a 2 usec setting where it remained for the rest of the data file.

### Files 064839.A06, 065023.A06, and 065349.A06 - October 6, 1992

These files were collected during the third set of the cruise (Replicate test 2). The catch consisted of small yellowfin and skipjack tuna, dolphinfish, wahoo, small sharks, one turtle, and two marlin (Table 4). Each of these files **064839.A06, 065023.A06, and 065349.A06** exhibit a strong signal above the surface of the water when viewed using the "normal" display mode. None of these files should be viewed in the "expanded" mode since the features of interest are the signal observed **above the surface.**

Between Tag #14 and Tag #15 (Pulses 354-385) in file **064839.A06** there are two pulses (370-371) where the echo profile changes from its "normal pattern" for the range to one where the signal suddenly begins to increase rapidly over the background noise level. The peak signal-intensity profile moves approximately 8-9m (25-30 feet) closer to the helicopter and then rapidly falls to background-noise levels for ranges beyond the peak intensity. This occurs without a display of any of the "sub-surface structure" that follows each of the peaks observed in the "normal" echoes from the water. Our notes suggest that these "abnormal" echoes resulted from the beam reflecting off the net suspended on the vessel's "power-block boom", or the boom itself. Pulses recorded on either side of the two traces described above (Pulse #369 and Pulse #372) show echoes from 6-9m above sea level that were added to the "typical" sub-surface backscattering profile, suggesting that the beam was only partially obscured by the net and boom. At least a fraction of the lidar beam reached the water's surface and continued downward, thus producing the "normal" underwater echoes shown in the display.

The display of file **065023.A06** indicates that the laser pulse struck and penetrated a puff of exhaust emissions from the vessel, a small cloud or aerosol layer, or, perhaps, a flock of birds circling the fish captured in the net. The profile obtained at Pulse #272 shows a sharp increase in the scattered signal more than 15m (50 feet) above the water. The signal falls off with increasing range and then suddenly increases again at the water's surface. The "atmospheric layer" is observed for the next two pulses for a total of three (3) consecutive traces, before the backscattering profiles return to the "normal pattern" for the rest of the file. The "atmospheric layer" was not "optically thick" since all three consecutive profiles showed that the laser pulse had penetrated the "layer" without a significant amount of attenuation. The echoes were still quite strong at the sea surface, and the backscattering profile below the "layer" had approximately the same signal intensity that it had before and after the "atmospheric layer" was observed.

File **065349.A06** also shows strong signals from above the water. These traces were collected as the helicopter deliberately passed over the bow of the vessel to obtain data on echoes from opaque objects at or above the ocean's surface. At Pulse #134 (Tag 22), the range at which a rapid increase in signal intensity occurs, usually associated with backscattering at the surface, "jumped" upward by 6 to 9m. These echoes exhibit a pattern similar to the profiles described for Pulse #370 and #371 in file **064839.A06** collected on October 6, 1992. This "new" echo profile continues until Pulse #141, before the backscattering profiles return to the "normal" profiles observed in other files.

### Files 074218.A11, 074454.A11, and 075243.A11 - October 11, 1992

Files **074218.A11 (persistent layer 12-15m below the surface)**, **074454.A11 (persistent layer 12-15m below the surface)**, and **075243.A11 (possible fish signal 9m below the surface)**, were recorded during "Replicate Test Five" while the helicopter made repeated passes, and hovered over captured tuna in the net. The catch consisted of small-medium yellowfin and skipjack tuna, dolphinfish, wahoo, small sharks, triggerfish, and one marlin (Table 4). The observer noted the "pulse hits cork line" for file **074218.A11**, and "the pulse appeared to miss the fish" for file **074454.A11**. The pulse traveled directly over the top of a ball of tuna as the helicopter hovered when file **075243.A11** was recorded.

The 2-D display set up in the signal versus depth mode displays a "signal enhancement" at depths of 12 to 15 meters (40-50 feet) for all the data files collected during the day, including these three files. It is likely the electronics were being overdriven and an oscillation resulted from the output signal of an amplifier. The presence of a "real persistent layer in the 12-15m region" of these files is suspicious.

The observer noted a possible fish signal 9 meters below the surface for file **075243.A11**, and provided the following description (Grams and Wyman, 1993).

> "The helicopter hovered over the net. Fish were observed inside the net from the helicopter. The laser pulse traveled directly over the top of the tuna school. I estimated 40 tons of tuna were in the net during the data run."

Although these echoes are not very strong, they do appear to be real. Stopping the 2-D difference-signal display at Pulse #362, shows an increase in the echo from the 6-9m region. These signals are present in almost all of traces from Pulse #362 to Pulse #386. There is no indication of an output-signal oscillation at these depths as was detected in the 12-15m depth range. The helicopter was hovering directly over a school of fish while this file was recorded.

### Files 111351.A12 and 111627.A12 - October 12, 1992.

These are some of the best signals recorded during the sea trials, and were collected during "Replicate Test Six" during which repeated passes were made over fish captured in the net. The catch consisted of small to medium skipjack tuna, small yellowfin and bigeye tuna, and small black skipjack tuna (Table 4). All hints of an oscillation are gone in these data files. The amplitude of the echo from the surface is nearly full-scale on the digital oscilloscope reading and the background noise is hardly more than one or two digits of the digitized signals. The observer noted scattered "shiners" (a term used to described a fish school from which light is reflected upwards from the sides of individual fish as they rotate their body axis) and net-webbing above the surface while file **111351.A12** (strong signal above the surface) was being recorded. The observer noted deep "shiners" (25 tons of tuna) under the helicopter and a strong return (fish signal stretching from 9-24 meters) while file **111627.A12** was recorded. This latter file represents the best sub-surface fish signal observed during the sea trials (Figure 6).

File **111351.A12** displays a strong signal from above the surface which first appears at an altitude of about 6m above sea level in Pulse #385. The echo becomes somewhat stronger and remains visible until Pulse #398. The signal was associated with reflections from the net hanging on the power-block boom of the purse-seine vessel. Apparently only part of the beam was reflected by the apparatus since the lidar profiles for these pulses show the ocean's surface and sub-surface backscatter at ranges beyond the echo from the net and boom. The observer recorded the following comments for this file.

> "Fish were observed inside the net from the helicopter. Tuna were observed rolling (shiners) and the laser pulse entered the water above the shiners so we should have gotten a signal. I estimated there were 5 tons of fish in the net. There is a lidar signal recorded above the surface of the water. It is a return from a swath of net webbing, corks, and chainline that was hanging out of the water as we passed over (tags 19/20)."

File **111627.A12** contains signals from fish that stretches from 9 meters to 24 meters and is the best sub-surface fish signal obtained. The observer recorded the following comments for this file.

> "Fish (shiners) were observed deep beneath the surface inside the net from the helicopter. The laser pulse was not visible because of glare, but it passed over the tuna

> during the data run. This was the strongest return signal from tuna during the entire sea trials. I estimated 25 tons of tuna were visible during this data run (tags 23/24)."

This data set is also one of the most well behaved lidar traces observed while at sea. The signals are sharply defined with a very rapid increase in the intensity of the echo at the surface. The oscilloscope was set such that the peak of the signal from the surface is almost at the full-scale reading for the oscilloscope, and background-noise fluctuations are just one or two digits in the output of the digital scope. Signal-strength falls rapidly with depth with the **difference-signal** display providing a solid **BLACK** background in the 2-D plot until reaching a depth of about 12 meters. Below 12m, small, background-noise fluctuations provide the **BLUE/BLACK-speckled** appearance recognized as background noise contributions displayed when the LIDAR settings have been optimized. In the "zero" to 15m region of the 2-D display, a few, short, **BLUE**, vertical lines (3 pixels in height) are visible that signify the presence of a small "wiggle" in the LIDAR profile. This description applies to the plot for the traces recorded up to Pulse #279. Then, a small local increase in signal level is observed at depths from about 18m to 21m. The magnitude of this signal increases in the next couple of pulses and becomes a very sharp, distinct feature in the profile as the display advances to Pulse #280. This signal fluctuates back and forth in intensity for the next few pulses and then becomes stronger and stronger until Pulse #285 for which a plot of an echo from fish is obtained at the 9-15m depth. Another excellent example of an echo from fish is shown in the trace for Pulse #288 (for depths between 11m and 17m).

### Apparent "Sub-surface Scattering Layers"

During the pre-deployment tests in Panama, and during the subsequent sea trials, there was initial elation followed by growing suspicion over the "detection of backscatter" from what appeared to be "sub-surface scattering layers". Although the final contract report provides great detail on these events, the contractor now believes they are merely artifacts produced when the laser-echo signal-amplifier was being overdriven. The contractor identified the last data file **(075756.A11)** collected on October 11, 1192, as representative and provided the following description in support of his analysis that these "layers" are not real echoes (Grams and Wyman, 1993).

> "File **075756.A11**: In the regions displaying the strongest reflections from the surface (indicated by a **RED** and **WHITE** line), both plots show a persistent enhancement of the signal from depths between 12-15m. However, for about one-half of this data, the signals from considerable distances along the surface have a smaller intensity, but do provide a large enough difference from channel-to-channel to register the **RED** or **WHITE** color displayed. In these cases,

> **CYAN** or **BRIGHT-BLUE** colors are used to indicate the surface. No **BRIGHT-BLUE** "ghost" signal is displayed in the 12-15m region for those traces that did not exhibit a strong surface reflection. This supports the suggestion that those signals which appear at depths of 12-15m should not be regarded as real echoes."

We have edited descriptions, obtained from Grams and Wyman (1993), for some of the thirteen "best" files that exhibit these "sub-surface scattering layers", to provide additional emphasis for the need for thorough analysis and collaborative data during future development of these systems.

File **030446.919 (strong signal from bottom):** What is obvious are multiple "sub-surface scattering layers". Using the "expanded mode" display there is quite a bit of structure with two and three layers moving apart and coming together at different locations in the 2-D display. The corresponding signal-intensity plot shows the bottom of the **BRIGHT BLUE** band moving from a depth of about 15m to about 18m at the end of the plot. Concurrently, the highest-intensity echoes (e.g., the **MAGENTA** band) near the surface at the beginning of the sequence increase in intensity and expand downward from the surface as the display progresses. These returns eventually appear as a layer that is some 3m to 4.5m thick, with the highest-intensity echoes produced at a depth of about 4.5m.

File **131039.921 (strong signal from the bottom)** Shortly after Pulse #180, the traces begin to show "sub-surface scattering layers" similar to those observed on September 20, 1992. The "sub-surface scattering layer" persists until Pulse #344 where the traces begin to display a small "blip" in the signal profile at a depth of about 18m below the surface. Using the expanded display mode, displaying signal versus depth, reveal an interesting pattern. The "sub-surface scattering layer" observed before the laser beam encountered the bottom profile is distributed over depths between 4-8m below the surface. At the same time, the peak of the bottom contour occurs at a level that is about 6m below the surface, in the center of the observed "sub-surface scattering layer". The expanded 2-D display shows a "plume" of material originating from the highest point of the bottom profile in the area scanned. Unfortunately, the nature of these "sub-surface scattering layers" remains unknown.

File **150208.922 (good bottom profile):** As the 2-D plot develops, a persistent, well defined, "sub-surface scattering layer" is visible. The backscatter-profile is enhanced in a region that is about 6m thick, and the top of the "layer" is located at depths between 4.6-9m. However, at the 4.6-6m depth, the decrease suddenly stops and the display shows an almost constant signal level for the next 6 meters. Then, at a depth of about 9-11m, the signal-intensity begins decreasing again. In the 2-D display, this part of the profile is a region that has many **BLUE** dots in the display (indicating constant signals or signals with very small increases from one digitizer-channel to the next) instead of a dark **(BLACK)** region that would be associated with a monotonic decrease in the signal from greater and greater depths. The nearly constant scattering-profile in the 4.6-9.0 meter region represents a very significant enhancement in the amount of scattering over what was expected at these depths.

The 2-D display of this bottom profile also displays one of the many "sub-surface scattering layers" detected during the tests in Panama and during the sea trials. This "layer" appears as an echo that is nearly constant with depth in the region between 4.6m and 9m. This file, and the bottom profile delineated in file **131039.921**, show these "sub-surface scattering layers" as a "plume" of material originating from the shallowest point in the bottom profile within the area scanned. The tops of these apparent "sub-surface scattering layers" coincide (approximately) with the depth of the sea at the shallowest point in the bottom profiles obtained. These "sub-surface scattering layers" were observed during the Panama tests and during the sea trials, but their exact nature is unknown. The contractors were uncertain if they represented echoes from biological organisms, from suspended particulates, or were artifacts resulting from operation of the laser system itself.

File **132112.926 (strong signal near a FAD):** The signals show strong scattering from the surface, a rapid decrease for the first 3-5m, and a rapid rise in signal intensity indicating a strong "sub-surface scattering layer" approximately 4.6m thick. The signal then decreases as the depth increases. There is a great deal of variability in the observed "sub-surface scattering profile", compared with the persistent, slowly changing "sub-surface scattering layers" that were observed during the Panama tests. This suggests a much wider variety in the type and concentration of scattering objects below the surface than had existed in the "sub-surface scattering layers" near Panama.

Files **074218.A11 (persistent layer 40-50 12-15m below the surface), 074454.A11 (persistent layer 12-15m below the surface),** and **075243.A11 (possible fish signal 9m below the surface):** The 2-D display set up in the signal versus depth mode displays a "signal enhancement" at depths of 12-15m for all the data files collected during the day, including these three files. It is likely the electronics were being overdriven and an oscillation resulted from the output signal of an amplifier. The presence of a "real persistent layer in the 12-15m region" of these files is suspicious.

FILE **111627.A12 (best fish signal):** A number of the lidar traces show very strong "sub-surface scattering layers" with the best of these traces at Pulse #285.

During the cruise, the contractor and observer detected the presence of sub-surface "layers" at depths ranging from 6m to 125m using the ship's fish-finder. These readings reinforced their belief that the LIDAR was also detecting these "layers" despite the differences in depths indicated by the sensors (e.g., LIDAR versus fish-finder). Independent data should be collected for a thorough analysis on the performance of future LIDAR systems.

## Recommendations

The potential use of LIDAR systems for fishery applications was successfully demonstrated during our sea trials, and development and testing of this system and others should continue. This prototype was designed and built using commercially available parts that, with the exception of the $30,000 laser itself, are relative inexpensive. Although the unit currently weighs around 125 kg, it was successfully used aboard a helicopter deployed from a tuna purse-seine vessel. We believe this in itself is a significant result as previous LIDAR systems have required much larger aircraft, and further weight reductions can easily be obtained.

We were disappointed during the field tests by the relatively "slow" fishing which provided only a few opportunities to obtain data on captured fish schools while the system was operational. This LIDAR was, however, able to detect sub-surface fish as deep as 17 meters (50-55 feet) during these tests. We believe this is the first time that tuna have been detected using an airborne LIDAR. During the installation and testing activities in Panama, this LIDAR was able to detect and display accurate profiles of shallow, turbid, near-shore areas of the sea as deep as 24m (75-80 feet).

Developmental costs for this project amounted to approximately $239,000. These funds include $114,000 in government contracts, $17,000 provided by Bumblebee Seafoods, Inc., and $108,000 in services provided by Caribbean Marine Service Company and Helicopter Management Company. Most of the latter services were related to use of a Bell Jet Ranger helicopter.

We were encouraged by the results obtained during this project and believe that the effort should continue. However, a number of significant modifications are recommended as part of any future development of a LIDAR system based upon this design and configuration. We note that there are alternative designs for LIDAR systems that could meet the needs of fishery applications and these alternative designs should be explored.

**First, replace the digital oscilloscope and GPIB with a currently available digitizing computer board.** The present approach for digitizing and recording the laser echoes uses a digital oscilloscope with a General Purpose Interface Board (GPIB) installed in the computer to transfer the digitized data from the oscilloscope memory for real-time display and recording. This approach was dictated by cost considerations and by the state-of-the-art for transient recorders that were commercially available at the time this system was designed. The current hardware allows data to be digitized and recorded at rates up to 20 traces-per-second (the maximum pulse-rate of the laser used in the system). However, the time it takes to use the GPIB to probe the oscilloscope for data on sweep speeds, gain settings, etc., is too long to permit a determination of these parameters for each pulse. The oscilloscope settings are sampled only once every 500-

pulses, and these settings are then stored at the beginning of each data file. Although it was possible for the lidar operator to change settings in the middle of any 500-pulse data file, the display program is not able to adjust the scaling to any such changes. Thus, the display scales cannot be reset to reflect the updated parameters until the beginning of the next data file.

This problem can be solved with computer boards that now exist which can digitize signals as 8-bit numbers recorded every 10-nanoseconds. This would provide the system with a range-resolution of 0.15m in the atmosphere and 0.1125m in water. The current system cannot resolve signal variations for times shorter than the laser's pulse-length (nominally 10 or 20 nanoseconds for the unit used in the NMFS LIDAR). Spatial resolution offered by these boards will therefore represent the maximum resolution that could be obtained using the present laser. These plug-in boards were not available when the system was designed. Such a board would occupy the slot now used by the GPIB and would eliminate the need for the digital oscilloscope and GPIB. These boards are less expensive than the digital oscilloscope used in the present system, and their use would reduce the cost, weight, size, and power consumption in future versions of the system. Furthermore, the associated problem of recognizing changes in the oscilloscope settings would be eliminated, since the settings for the board could be provided directly by computer software. Software could monitor changes made to the digitizing parameters and provide the parameter changes to the entire system. Using such a board, the computer should be able to analyze individual echoes and make appropriate adjustments of system settings (e.g., voltage supplied to the photomultiplier tube and the gain of the digitizing board) to accommodate changes in environmental conditions. This would greatly reduce, if not eliminate, the need for an experienced LIDAR operator to "fine tune" the system during operation.

**Second, modify the laser's beam-direction system to allow some operator control.** Although the direction of the laser beam can be altered between flights, it is essentially fixed in the current system because the beam-directing hardware is mounted to the helicopter. Changes in the helicopter's attitude result in corresponding changes in the beam's direction. When the helicopter banked at an angle of 30-35 degrees (a common occurrence if something was detected) the LIDAR was useless because most of the beam's energy was reflected, and did not penetrate the ocean's surface. As a searching tool, this configuration may suffice if an accurate position can be associated with a detected fish school to allow the aircraft to return to the sighting location, but certainly would be less than ideal. The current configuration is inadequate to track moving targets, even while hovering, since there is no directional information contained in the narrow-beam laser echoes. The configuration poses similar problems for use in rapidly assessing targets when the aircraft must alter its flight attitude (e.g., bank or turn) to stay on the target.

There are a number of improvements that might be incorporated into the system to mitigate these problems. Gimballing the beam-direction hardware could provide a relatively stable beam direction for small changes in the aircraft's attitude. Potentially, a gyro-controlled mount could be incorporated to provide even more stability, but these systems are expensive, prone to damage, and add considerable weight. It may be possible to attach the beam-direction hardware to a "joystick" device that would allow an operator to steer the beam over an area where a target has been detected, and thereby relocate and track the target. The military has systems that allow devices to be pointed where a pilot is looking, but again, this technology is probably too expensive for our use.

**Third, increase the laser pulse-rate to decrease the inter-spot distance, or dramatically increase the spot-diameter to increase the area of coverage.** The current system produces a pulse at the ocean's surface with a diameter of about 10cm, provides pulse-rates up to 20 PPS with the current laser, and is capable of determining the range to an object within 0.45m. As aircraft speed increases, the distance between pulse-spots on the oceans' surface lengthens. At a speed of 80KTS, each 10cm spot is spaced about 2m apart at 20 PPS, 3m at 15 PPS, and 4m at 10 PPS. These limitations contribute to the problems the current system presents in attempting to detect and track objects. There are some obvious solutions to these limitations that should be addressed during any future development. Increasing the pulse-rate would reduce the inter-spot distance at any given aircraft speed without loss of spot-diameter or laser power which would affect depth penetration. Dramatically increasing the spot-diameter at the ocean's surface would also reduce the inter-spot distance, but would result in a loss of laser power (and therefore depth penetration) unless a different laser was used.

**Fourth, use modeling to design and analyze systems that are specific to the needs of tuna fishermen and maximize the area and depth of coverage.** Our system is analogous to poking a needle into a haystack. Increasing the number of times the needle is poked (pulse-rate), directing the needle at particular areas (beam direction and scanning), and increasing the needle's width (spot-diameter) or length (depth penetration) are potential improvements for the current configuration. Ideally, we desire a system that can detect and track commercial quantities of tuna (5-10 tons or more) in very clear water at depths down to 50 meters. An image of a fish school with depth and location may prove more useful to fishermen than a vertical display of the presence and absence of reflective material within a series of 10cm-columns of water, and may provide the capability to track the fish school. Framing the target image for display could provide directional information to aid in tracking as the observer (pilot or fish spotter) could direct the aircraft to "center" the image within the display frame. A two-dimensional image of the target should also provide the observer with an estimate of the relative amount of fish present, although this will be based upon prior experience. We suggest modeling the various parameters that are related to laser power, spot-diameter, water-clarity, depth penetration, image resolution, and area coverage by some comparable unit of time, in the context of what tuna fishermen need. Similar modeling may be appropriate for other applications be they commercial fisheries or scientific assessment of fishery resources. The purpose of modeling is to resolve some of the necessary tradeoffs in time, money, and research effort before embarking on another development process.

**Fifth, improve the electrical configuration of the LIDAR system and its interface with the aircraft's power supply and electrical components.** The electrical requirements of future systems should be adequately engineered and specified so that the necessary power can be provided by the aircraft. All electrical connections should be subjected to vibration tests and protected from environmental hazards such as humidity, saltwater corrosion, and vibration. During our sea trials, there were numerous malfunctions that resulted in lost time and data directly related to either inadequate power availability, electrical overloads, or poor electrical connections.

**Sixth, incorporate a Global Positioning System.** It is imperative that a GPS be incorporated into the system so that a position is associated with a detected target and displayed to the pilot in a manner that is useful for relocating the target.

**Seventh, improve the viewing options for the fish spotter and pilot.** The color monitor used by the fish spotter and pilot to view the LIDAR display was not very useful to them, primarily because of excessive vibration, glare on the screen, and the display's current resolution. Future development should eliminate the vibration and glare issues (dampening and hoods), but the display's configuration requires some innovative design to provide useful information to fishermen.

**Eighth, incorporate audible fish detection alarms.** The current display is useful to a LIDAR operator, an engineer, and possibly others, but provides little useful information to fishermen. Clearly the system detects sub-surface targets. Fishermen need to know when and where targets are detected, and very little else. We suggest that an audible signal could be initiated when a target is detected, and the fishermen's display could present enhanced information about the target and how the helicopter can relocate it (e.g., target position and depth, helicopter position and altitude, course and distance to target location). As the technology develops, additional information may be available to discriminate between false targets (e.g., cetaceans, sharks) and fish species, and possibly the capability to estimate the amount of fish detected.

**Ninth, reduce the system's weight and size.** The current system weighs approximately 125 kg. With a 91kg LIDAR-technician, pilot, and fish spotter, the Bell Jet Ranger helicopter was very heavy for takeoff and landing on the purse-seine vessel. In fact, it was necessary for the vessel to steam into the wind at full speed and for the helicopter to use 110% of power during takeoff and landings. Although this system is smaller and lighter than previous systems, further weight reductions will be needed if the unit is to be deployed in small aircraft. The contractors conducted some experiments that indicate a 4-inch mirror could be substituted for the current 8-inch mirror without degrading resolution. The ZEOS 386/33 desktop computer and color monitor can be replaced by a faster, lighter, and smaller computer. Elimination of the digital oscilloscope would further reduce both the physical size and weight of the next system. While an experienced LIDAR technician may be required during future development and testing, every effort should be made to incorporate software features which will allow the system to ultimately be operated by either the pilot or fish spotter.

**Tenth, improve laser safety requirements.** Laser safety requirements should be identified before any future field tests involving persons who are unfamiliar with lasers. If lasers are used which will exceed "eye safe" levels, then appropriate safety procedures should be implemented and protective eyewear obtained. Safety eyewear is available for purchase at a cost of around $150-$300 per pair. Eyewear should be selected that meets or exceeds the minimum level of attenuation needed to reduce the power of the beam to a safe level. Attenuation is related to a deterministic factor referred to as "optical density (OD)" which results from solving a mathematical formula using the laser wavelength, power, beam diameter, pulse duration and pulse-rate. ANSI standards for laser safety are available from the Laser Safety Institute (Orlando, Florida) which can also provide guidelines for training, operations, and safety equipment purchases.

**Eleventh, improve data archiving procedures and equipment.** While reviewing the large amounts of data collected during the sea trials, it quickly became apparent that the Colorado Memory Systems JUMBO 120 Tape Backup System was not very convenient or efficient for carrying out the review process. The LIDAR system creates a new 256KB datafile every 50 seconds at a pulse-rate of 10 PPS, every 33 seconds at 15 PPS, and every 25 seconds at a pulse-rate of 20 PPS. During a typical two-hour flight, between 36 and 72 megabytes of data could be collected if the system was operated continuously. It took a great deal of time to transfer data from the computer to the backup tape unit for archival, and subsequently, from the archived tapes to the computer for review. For an operational system used only to detect fish, this is probably not a concern since the operator would be most interested in locating the fish and not concerned with archiving or reviewing data files after the aircraft returned to its base of operations. However, in the present state of development, it is desirable to archive the data for subsequent review after the aircraft flights. Future tests should incorporate a different approach for archiving data. One possibility is to take advantage of new advances in high capacity data storage systems that write data files directly to an external optical disk. The optical disk can be removed, stored, copied, and used in a second computer to review the data. The amount of data that could be stored and the speed at which the data could be transferred to the storage unit should be addressed during design of another system. The cost of any storage unit, and the cost of disks, tapes, or other medium that would be used by the system to record and achieve the data should also be addressed during design.

**Twelfth, increase the capability to perform a rigorous signal analysis of the LIDAR signal returns.** It may be beneficial to capture and archive more data from the laser echoes for subsequent signal analysis. Our system digitizes each signal return, converts the signal to an 8-bit number between 0 and 255, and archives this value. A thorough analysis of the entire signal return may provide information on the potential for identification of species and, possibly, estimation of the size and amount of fish present.

## Acknowledgments

This report describes the results of a development process to design, build, and deploy a LIDAR system in a helicopter operated from the tuna purse-seine vessel CAPT VINCENT GANN. We gratefully acknowledge the help that we received from Mr. Joe Leavitt and his employees at the HMC Jet Center in El Cajon, California, during all phases of the installation and testing of the system in California, in Panama before the sea trials, and the operation of the system on his helicopter during the sea trials.

We also acknowledge the unique opportunity that was provided by Mr. Ed Gann of CMS, Inc. who, by way of a Memorandum of Agreement, allowed this LIDAR demonstration project to be based on his purse-seiner, CAPT VINCENT GANN. The interest of the fishing master on this vessel, Captain Augusto Rodrigues, in the use of advanced technology to locate fish greatly aided this project.

We express our appreciation to Elizabeth Edwards of NOAA's Southwest Fisheries Science Center for reviewing this document and for the guidance and encouragement provided while the report was being written. Douglas DeMaster, currently at NOAA's National Marine Mammal Laboratory, provided the initial support to explore this development while he was at the Southwest Fisheries Science Center.

Mr. Brian Treadwell, President of Remote Sensing Industries Inc., approached NMFS with the idea of developing an airborne LIDAR during 1990 in response to inquiries. Mr. Treadwell was instrumental in promoting the idea of using a LIDAR in this fisheries' application. Although many people and companies contributed to the development, two individuals are responsible for the design, construction, operation, and analysis this LIDAR system. Dr. Gerald Grams has been using lasers and designing LIDAR systems for over 20 years and Mr. Clyde Wyman has built and operated LIDAR systems for an equal time. Much of what we have presented in this report was provided by these two individuals. We wish to acknowledge their essential contributions to the implementation of this technology to a fisheries' application, and their willingness to unselfishly share their knowledge and ideas with us. Thank you Gerry and Clyde.

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Table 1. Major hardware and assembly costs for the prototype NMFS lidar developed under contracts 52ABNF000126 and 52ABNF000692.

| | |
|---|---|
| Hamamatsu Photomuliplier assembly and 532 filter | $ 1,361.77 |
| PMT Train | $ 511.77 |
| Two Avionics Inverters | $ 6,952.18 |
| Power supply amplifiers | $ 245.00 |
| Tektronix digital oscilloscope | $ 6,851.25 |
| National Instruments AT-GPIB board and software | $ 637.50 |
| ZEOS 386-33 computer system | $ 4,748.22 |
| Zortech C++ compiler upgrade | $ 134.50 |
| CVI Beamsplitter | $ 305.00 |
| Telescope tube | $ 130.00 |
| Machinist assembly | $ 3,800.00 |
| Detector Assembly (preamplifier & receiver) | $ 850.00 |
| Misc aluminum mounting brackets | $ 250.00 |
| 8-inch receiving telescope | $ 1,000.00 |
| Total | $27,777.19 |
| Navstar XR4-PC Global Positioning Board & software | $ 1,950.00 |
| HA-1205LM Color VGA Monitor, cabling, and splitter | $ 1,500.00 |
| Patch antenna | $ 495.00 |
| Shipping | $ 250.00 |
| Total | $ 4,195.00 |

Table 2. Archival of data files recorded during field tests in Panama and aboard the tuna purse-seine vessel *CAPT VINCENT GANN* during September and October 1992. A total of 2,002 data files (495 megabytes) were collected.

| NAME | EXT | START | FINISH | FILES | FULL-SIZE | ZIP-SIZE | J120 TAPE | J250 TAPE |
|---|---|---|---|---|---|---|---|---|
| PAN918 | 918 | 123744 | 133724 | 40 | 9,881,088 | 6,623,412 | PANAMA | NMFS4 |
| PAN919 | 919 | 021358 | 030602 | 38 | 9,473,792 | 5,296,003 | PANAMA | NMFS4 |
| PAN920 | 920 | 091753 | 103319 | 61 | 14,898,816 | 10,603,996 | PANAMA | NMFS4 |
| PAN921 | 921 | 120113 | 131604 | 55 | 13,831,398 | 9,884,025 | PANAMA | NMFS4 |
| PAN922 | 922 | 103227 | 150753 | 66 | 15,581,014 | 4,720,935 | PANAMA | NMFS4 |
| TUNA1 | 925 | 113946 | 171735 | 17 | 4,098,560 | 2,387,562 | NOAA1 | NMFS1 |
| TUNA2A | 926 | 095433 | 113950 | 128 | 32,027,008 | 18,191,976 | NOAA1 | NMFS1 |
| " | 926 | 071612 | 090519 | " | " | " | NOAA1 | NMFS1 |
| TUNA2B | 926 | 131929 | 170317 | 90 | 22,434,256 | 13,070,901 | NOAA1 | NMFS1 |
| TUNA3 | 927 | 055841 | 104839 | 35 | 8,320,442 | 5,377,264 | NOAA1 | NMFS1 |
| TUNA4 | 928 | 005232 | 023036 | 59 | 14,724,608 | 11,425,792 | NOAA1 | NMFS1 |
| TUNA4B | 930 | 093217 | 170752 | 91 | 22,287,575 | 18,403,441 | NOAA2 | NMFS1 |
| TUNA5 | A05 | 055102 | 060056 | 106 | 26,273,455 | 19,176,293 | NOAA2 | NMFS1 |
| " | A06 | 063911 | 014752 | " | " | " | NOAA2 | NMFS1 |
| " | A07 | 065059 | 071649 | " | " | " | NOAA2 | NMFS1 |
| " | A07 | 143315 | 144720 | " | " | " | NOAA2 | NMFS1 |
| " | A07 | 024931 | 035400 | " | " | " | NOAA2 | NMFS1 |
| TUNA7 | A09 | 063027 | 094244 | 43 | 10,816,384 | 7,813,776 | NOAA2 | NMFS1 |
| TUNA8 | A11 | 073548 | 120742 | 133 | 33,568,063 | 15,687,246 | NOAA3 | NMFS3 |
| " |  | 021906 | 023347 | " | " | " | NOAA3 | NMFS3 |
| TUNA9 | A12 | 065300 | 112021 | 179 | 45,361,020 | 25,646,327 | NOAA3 | NMFS3 |
| " | A12 | 023505 | 042344 | " | " | " | NOAA3 | NMFS3 |
| TUNA10 | A13 | 082547 | 164215 | 115 | 29,114,196 | 16,802,486 | NOAA3 | NMFS3 |
| TUNA11A | A14 | 080647 | 121436 | 136 | 34,256,907 | 26,585,800 | NOAA4 | NMFS2 |
| TUNA11B | A14 | 134201 | 144056 | 43 | 10,075,787 | 7,972,611 | NOAA4 | NMFS2 |
| TUNA11C | A14 | 153140 | 171312 | 69 | 17,162,891 | 13,365,803 | NOAA4 | NMFS2 |
| TUNA12A | A15 | 073135 | 084306 | 59 | 14,628,809 | 10,594,021 | NOAA4 | NMFS2 |
| TUNA12B | A17 | 083107 | 173754 | 121 | 30,232,366 | 21,956,200 | NOAA5 | NMFS2 |
| TUNA13A | A16 | 110022 | 115134 | 43 | 10,896,768 | 8,342,388 | NOAA5 | NMFS2 |
| TUNA13B | A16 | 143721 | 173718 | 83 | 20,931,287 | 15,863,850 | NOAA5 | NMFS2 |
| DATA19A | A19 | 062425 | 074912 | 40 | 9,781,632 | 5,652,096 | NOAA6 | NMFS4 |
| DATA19B | A19 | 103544 | 110605 | 18 | 3,952,035 | 2,410,298 | NOAA6 | NMFS4 |
| DATA19C | A19 | 113618 | 145913 | 33 | 7,317,011 | 4,096,899 | NOAA6 | NMFS4 |
| DATA19D | A19 | 150030 | 160050 | 46 | 11,331,384 | 6,551,204 | NOAA6 | NMFS4 |
| A20 | A20 | 091453 | 170941 | 55 | 12,275,160 | 7,244,269 | NOAA6 | NMFS4 |
|  |  |  |  | 2,002 | 495,533,712 | 321,746,874 | 7 | 4 |

Table 3. Archival of 13 selected data files (3.3 megabytes) recorded during field tests in Panama and aboard the tuna purse-seine vessel CAPT VINCENT GANN during September and October 1992.

| Filename | Size(KB) | Date | Time | COMMENTS |
|---|---|---|---|---|
| **025058.919** | 256128 | 09-19-92 | 2:52a | Flight over Isla Melones, Panama |
| **030446.919** | 256128 | 09-19-92 | 3:06a | Strong bottom signal |
| **131039.921** | 256128 | 09-21-92 | 1:12p | Strong bottom signal |
| **150208.922** | 256128 | 09-22-92 | 3:03p | Good bottom profile |
| **132112.926** | 256128 | 09-26-92 | 1:22p | Strong signal below surface of water near a FAD |
| **064839.A06** | 256128 | 10-06-92 | 6:50a | Strong signal above surface of water |
| **065023.A06** | 256128 | 10-06-92 | 6:52a | Strong signal from object above surface of water |
| **065349.A06** | 256128 | 10-06-92 | 6:55a | Strong signal above surface of water |
| **074218.A11** | 256128 | 10-11-92 | 7:43a | Persistant signal 12-15 meters below surface of water |
| **074454.A11** | 256128 | 10-11-92 | 7:46a | Persistant signal 12-15 meters below surface of water |
| **075243.A11** | 256128 | 10-11-92 | 7:54a | Possible signal from fish 9 meters below surface of water |
| **111351.A12** | 256128 | 10-12-92 | 11:15a | Strong signal above surface of water |
| **111627.A12** | 256128 | 10-12-92 | 11:17a | Signal from fish (tuna) 9-24 meters below surface of water. Best subsurface fish signal. |

Table 4. Data on set locations, tons of fish captured and the collection of LIDAR data during replicate tests during each set. Replicates consisted of repeated helicopter passes over the fish school captured within the purse-seine net.

| Set # | Rep # | Date mm/dd 1992 | Position | LIDAR Signal Obtained ? | LIDAR Filename | Fish Tonnage and Species (t=short tons) (YF-yellowfin tuna) (SK-skipjack tuna) (BE-bigeye tuna) |
|---|---|---|---|---|---|---|
| 2 | 1 | 09/30 | 02 42N<br>88 25W | No | Malfunction | 33t 5-10kg SK<br>14t 3-40kg YF<br>5t 4-6lb YF and SK<br>20 2m-sharks, 1 thresher shark<br>1 2.5m-mobula, 1 sea turtle |
| 3 | 2 | 10/06 | 03 06N<br>80 56W | Yes | 064839.A06<br>065023.A06<br>065349.A06 | 4t 1-3kg YF<br>1t 1-3kg SK<br>2t 4-8kg dolphin fish<br>1t 2 marlin, 1 sea turtle, a few wahoo and 0.5m-sharks |
| 4 | 3 | 10/07 | 02 13N<br>80 38W | No | Malfunction | 8.5t 3-8kg SK<br>1.5t 3-4kg YF<br>6.0t <3kg YF<br>4.0t dolphinfish, triggerfish, sharks, wahoo, 1 marlin, rainbow runners, and other forage fish |
| 5 | 4 | 10/09 | 02 55N<br>86 50W | No | Malfunction | 5.0t 4-8kg SK and 1 20kg-YF<br>17.0t <3kg SK and YF<br>3.0t 20 triggerfish, 1 marlin, 75 dolphinfish, 3 sharks, 10-20 wahoo, and 10 other forage fish |
| 7 | 5 | 10/11 | 03 22N<br>86 14W | Yes | 074218.A11<br>074454.A11<br>075243.A11 | 23.0t 6-9kg SK<br>1.5t 4-5kg SK<br>0.5t 20-35kg YF<br>12.0t <3kg SK and YF<br>3.0t dolphinfish, wahoo, 1 marlin triggerfish, 1 blue shark, 1 hammerhead shark, other small sharks and forage fish |
| 8 | 6 | 10/12 | 03 25N<br>87 08W | Yes | 111351.A12<br>111627.A12 | 32.0t 6-10kg SK<br>2.5t 3- 5kg SK and YF<br>0.5t > 2kg BE<br>31.5t < 3kg SK and YF<br>3.2t < 2kg BE<br>0.3t small black skipjack tuna |
| 9 | 7 | 10/20 | 02 47N<br>84 48W | No |  | 5.0t 4-9kg SK<br>18.0t <3kg YF, SK and BE<br>2.0t sharks, wahoo, 2 marlin, dolphinfish, triggerfish, log cabrilla, 1 sea turtle |

Note: Fish were present during each of the replicate tests and additional data files were obtained during all of these tests. The files presented here were identified by the contractor as representative of the data collected during these tests (Grams 1993). During replicate tests 1, 3, and 4, the laser malfunctioned and data were not archived.

Figure 1. Schematic of the NMFS "LIDAR.C" laser system

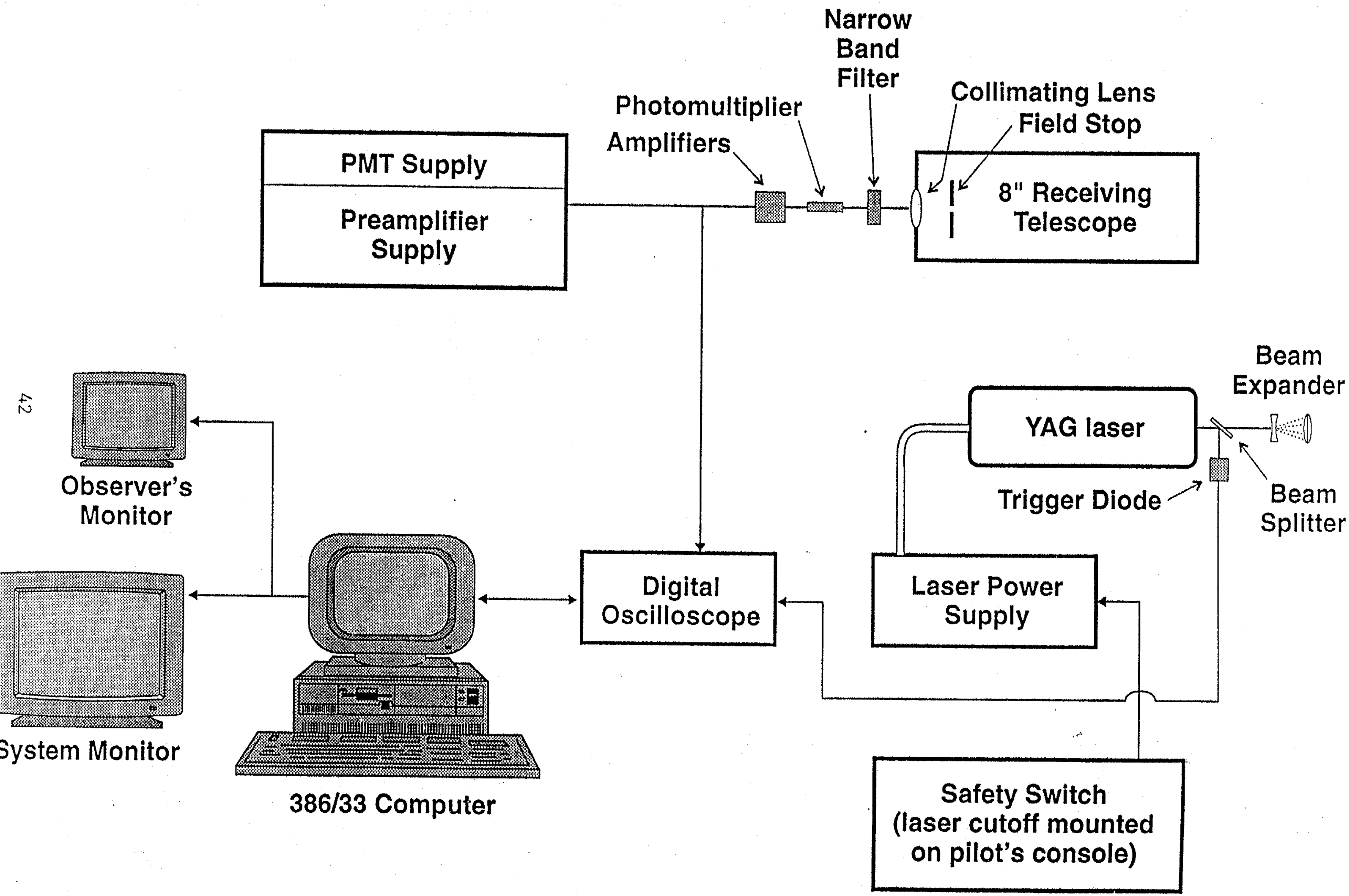


Figure 2. Laser beam displacement due to helicopter attitude (pitch)

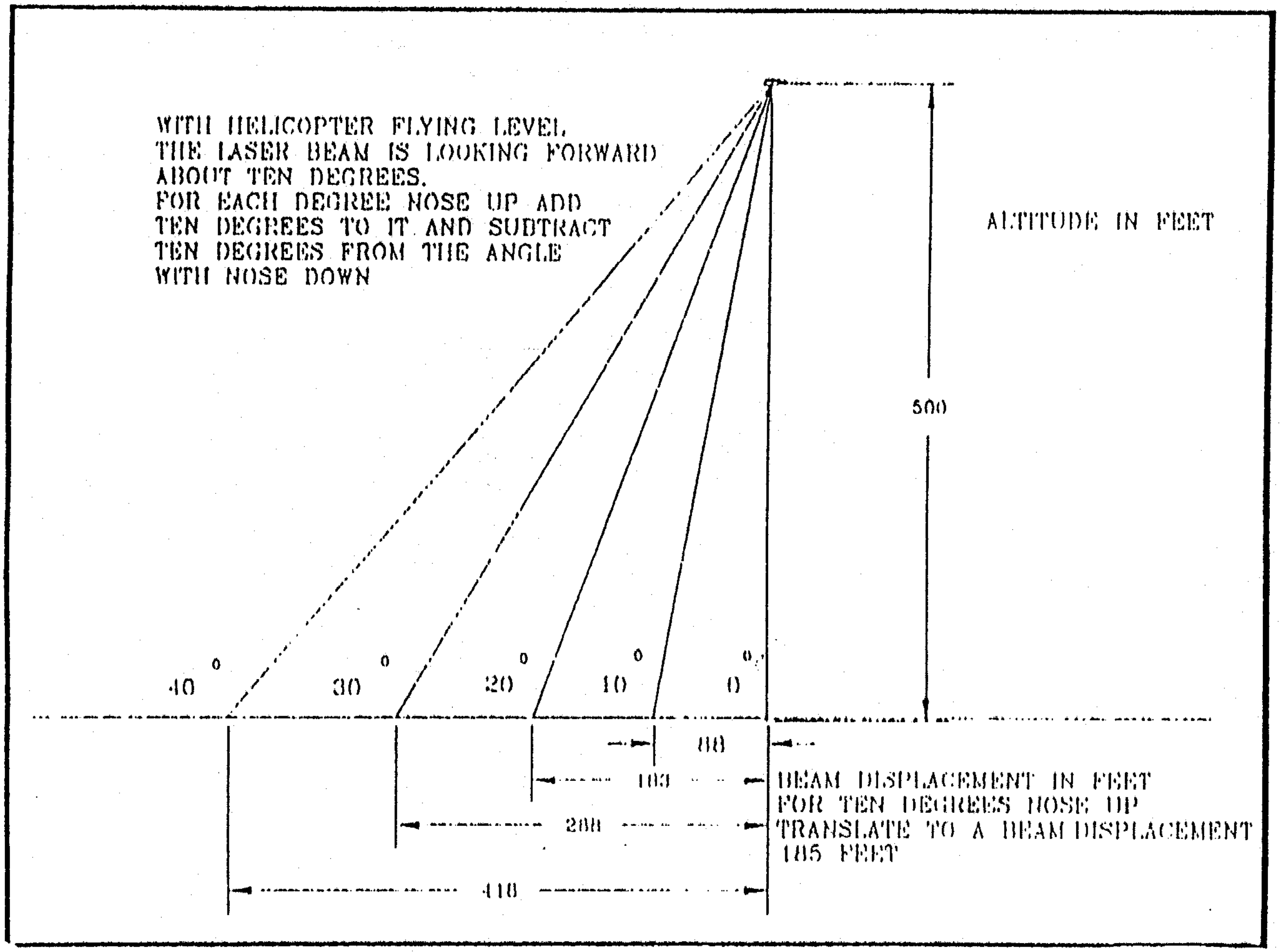


Figure 3. Laser beam displacement due to helicopter attitude (bank or roll)

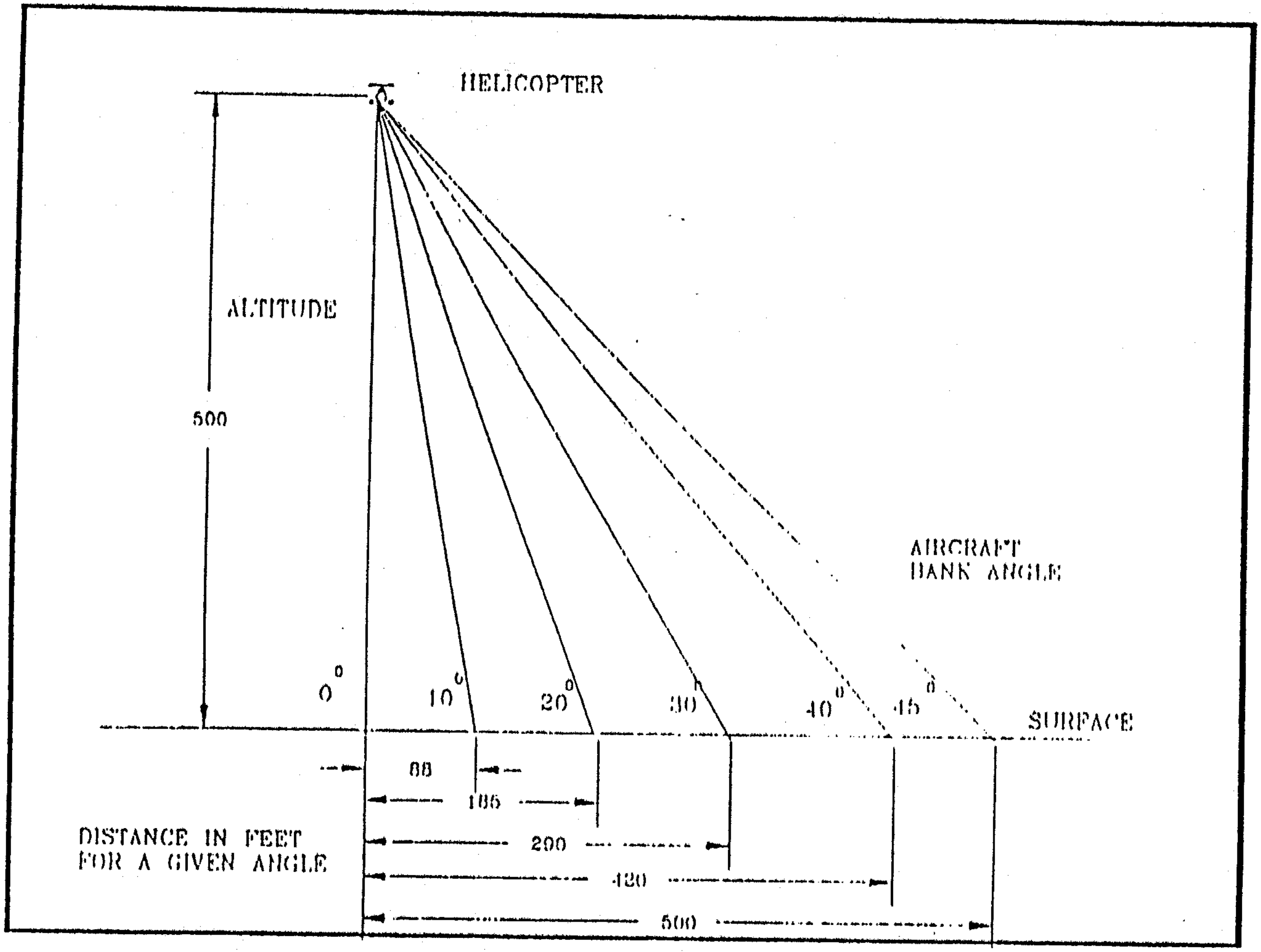
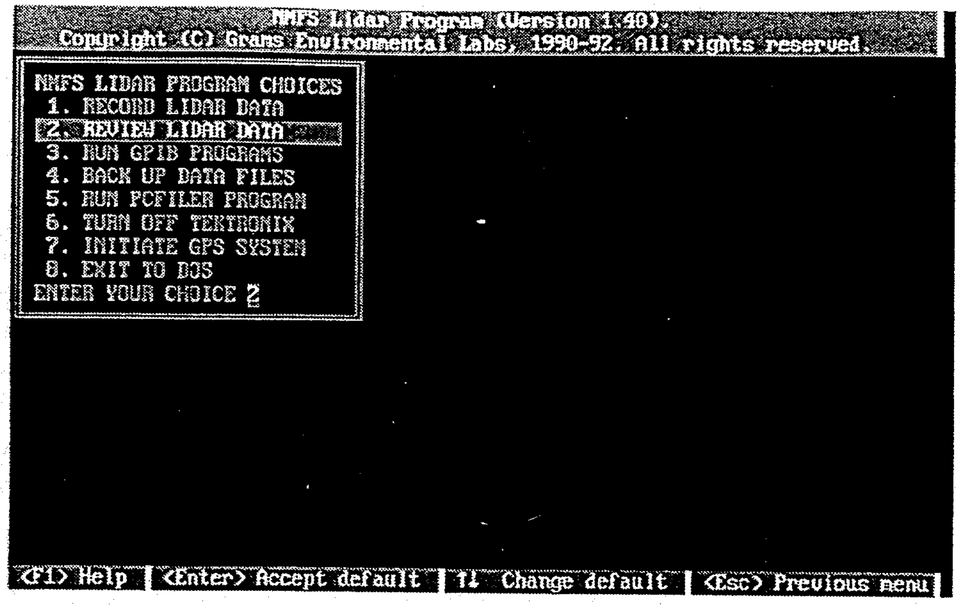


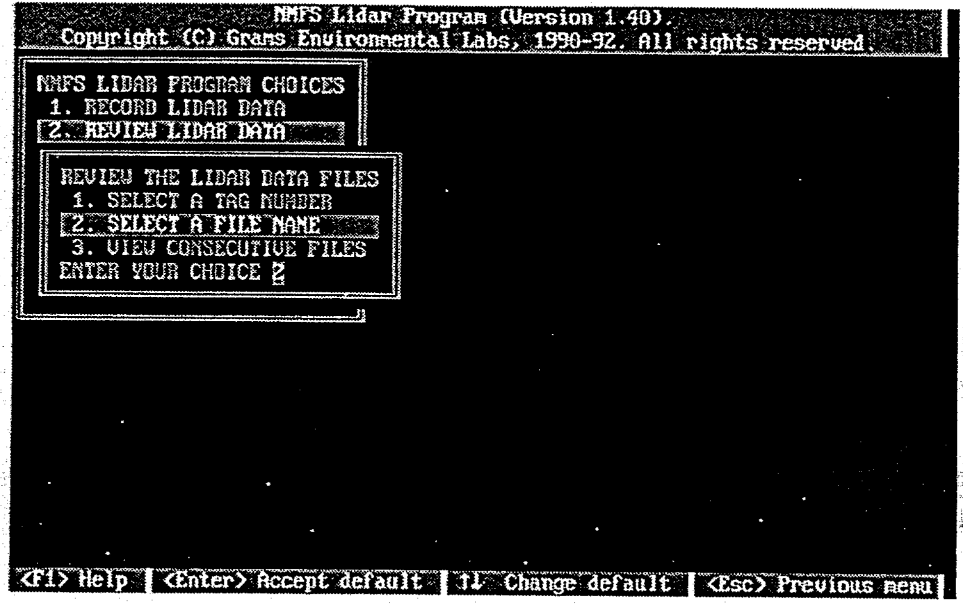
Figure 4. Menu screen options for the NMFS "LIDAR.C version 1.40" software program.



```
NMFS Lidar Program (Version 1.40).
Copyright (C) Grams Environmental Labs, 1990-92. All rights reserved.

NMFS LIDAR PROGRAM CHOICES
 1. RECORD LIDAR DATA
 2. REVIEW LIDAR DATA
 3. RUN GPIB PROGRAMS
 4. BACK UP DATA FILES
 5. RUN PCFILER PROGRAM
 6. TURN OFF TEKTRONIX
 7. INITIATE GPS SYSTEM
 8. EXIT TO DOS
ENTER YOUR CHOICE 2

<F1> Help | <Enter> Accept default | ↑↓ Change default | <Esc> Previous menu
```

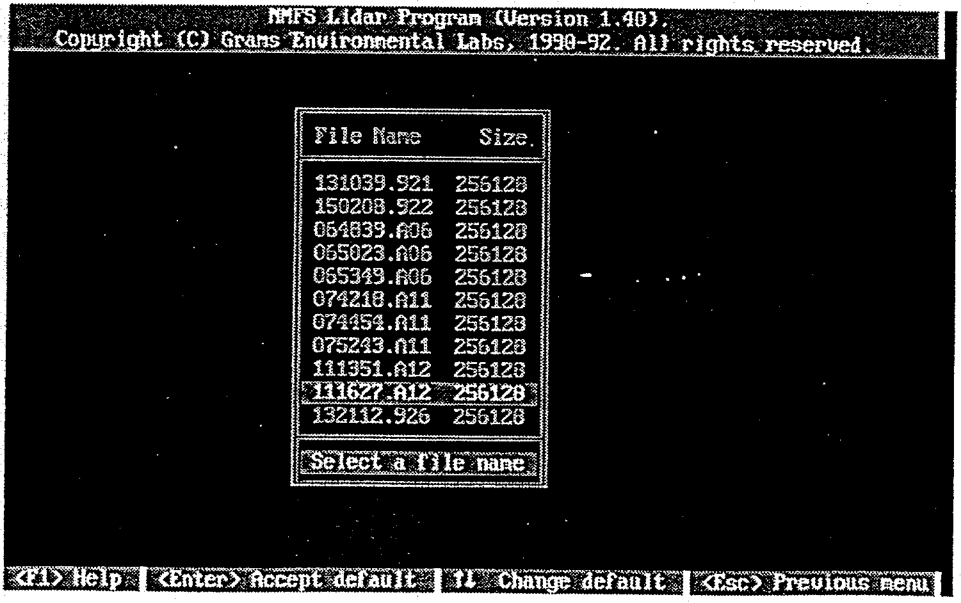


```
NMFS Lidar Program (Version 1.40).
Copyright (C) Grams Environmental Labs, 1990-92. All rights reserved.

NMFS LIDAR PROGRAM CHOICES
 1. RECORD LIDAR DATA
 2. REVIEW LIDAR DATA

  REVIEW THE LIDAR DATA FILES
   1. SELECT A TAG NUMBER
   2. SELECT A FILE NAME
   3. VIEW CONSECUTIVE FILES
  ENTER YOUR CHOICE 2

<F1> Help | <Enter> Accept default | ↑↓ Change default | <Esc> Previous menu
```



```
NMFS Lidar Program (Version 1.40).
Copyright (C) Grams Environmental Labs, 1990-92. All rights reserved.

File Name     Size.

131039.921   256128
150208.922   256128
064839.A06   256128
065023.A06   256128
065349.A06   256128
074218.A11   256128
074454.A11   256128
075243.A11   256128
111351.A12   256128
111627.A12   256128
132112.926   256128

Select a file name

<F1> Help | <Enter> Accept default | ↑↓ Change default | <Esc> Previous menu
```

Figure 5. LIDAR display of bottom contour in "expanded mode" from file 150208.922 showing a detected depth of 18 meters at pulse 209 (Figure 5A) rising to a detected depth of 6 meters at pulse 325 (Figure 5B).

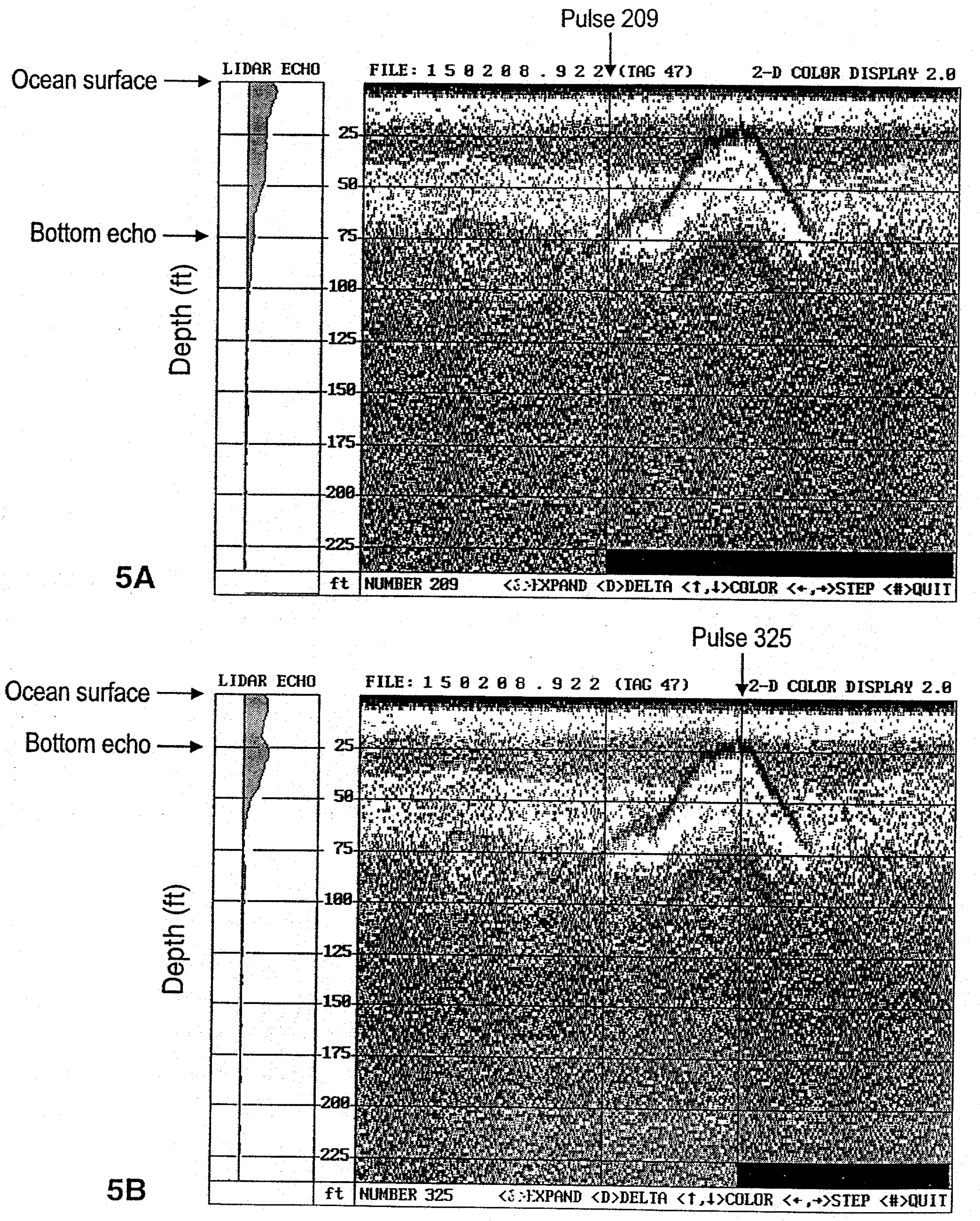


Figure 6. LIDAR display of fish school in "expanded mode" from file 111627.A12 showing subsurface fish detected at depths between 9-15 meters at pulse 285 (Figure 6A) and between 11-17 meters pulse 288 (Figure 6B).

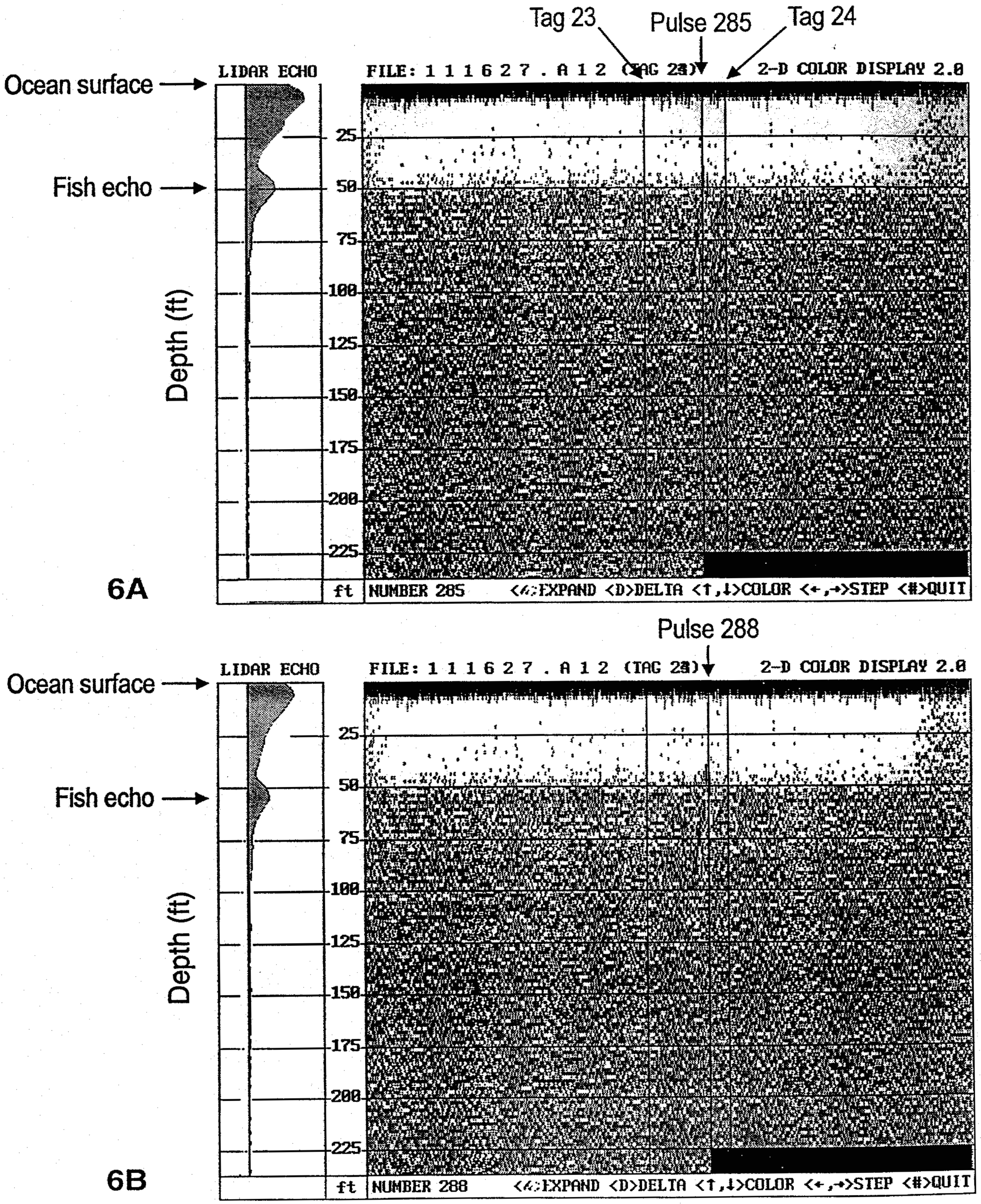
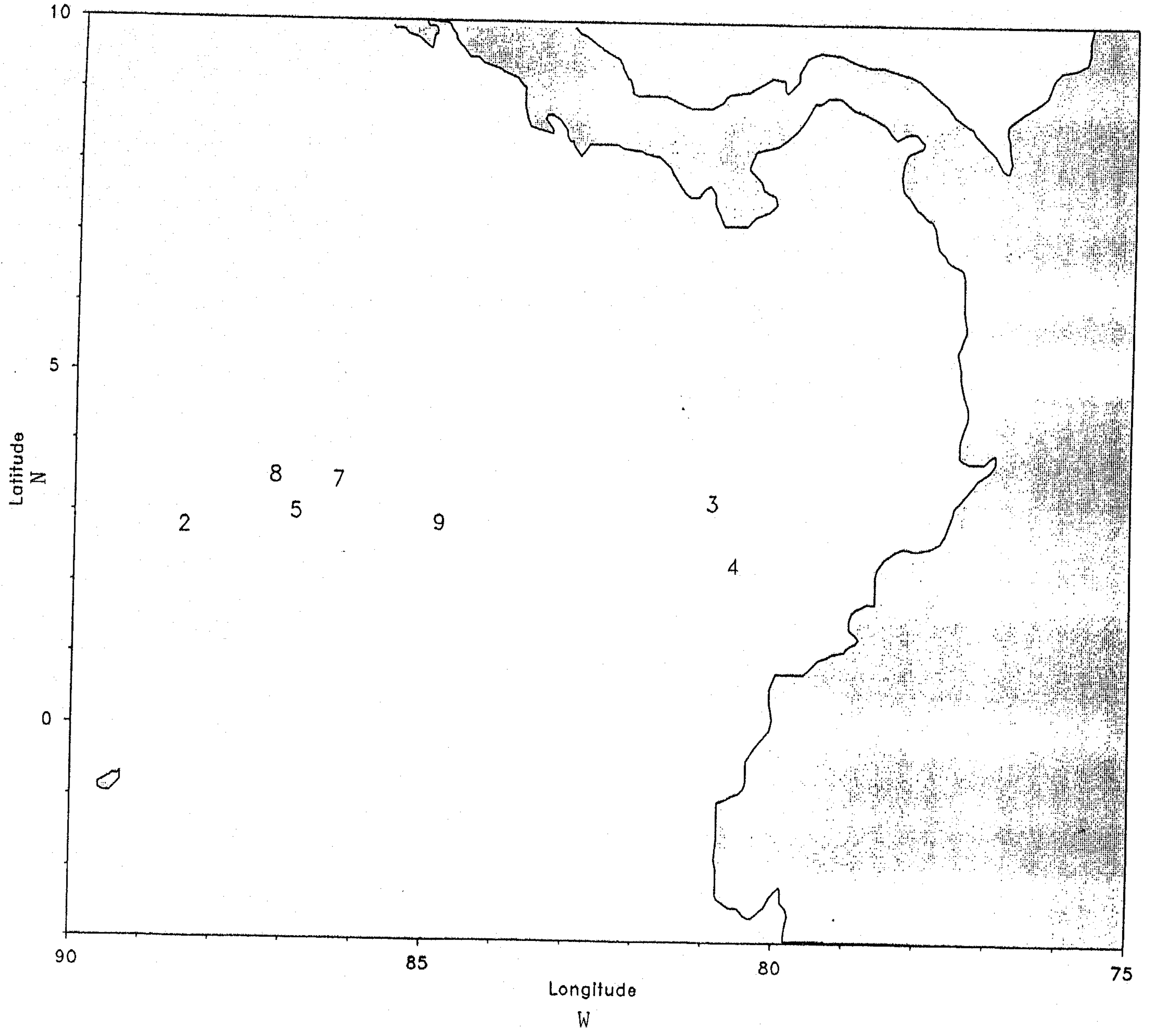


Figure 7. Locations of sets where tuna were captured and replicate LIDAR tests were conducted. Numbers indicate the location and the chronological set number for all sets made during the cruise.



Appendix 1. Description of System and Operating Procedures for the NMFS "LIDAR.C" Oceanic Lidar. Taken from: Grams, G.W. and C.M. Wyman. 1993. Final Report, NOAA Purchase Order No. 41ABNF2-01797. Extended field tests of an airborne lidar during tuna purse-seine fishing operations in the eastern tropical Pacific ocean. 252p.

# Descripition of System
# and
# Operating Procedures
# for the
# NOAA/NMFS Oceanic LIDAR

Gerald W. Grams and Clyde M. Wyman
Grams Environmental Labs
5767 Brooklyn Lane
Norcross, GA 30093

October 28, 1993

# NMFS LIDAR SYSTEM

## Table of Contents

# NMFS LIDAR SYSTEM

## *SYSTEM OVERVIEW*

The LIDAR consists of four major components:

- Transmitter (laser and transmitting optics).
- Receiver (telescope, detectors and amplifiers).
- Data system (digitizing oscilloscope and computer).
- Power supply.

## *TRANSMITTER*

The lidar transmitter contains the following major components:

- A **frequency-doubled Nd:YAG laser** manufactured by Laser Photonics of Orlando, Florida (Model YQL-102D). The laser pulse rate is adjusted by a selector switch mounted on the front panel of the laser power supply (see laser manual for instructions on setting up and operating the laser).
- A **beam splitter** to split off and trap the energy emitted by the laser at the 1.064 μm wavelength and to pass the energy emitted at the 0.532 μm wavelength. The energy emitted at 1.064 μm would penetrate only a few meters into the water and would be of little value for detecting fish or other items of interest below the surface of the water.
- A **beam expander** consisting of two lenses separated by the sum of their focal lengths (i.e., an afocal telescope). The beam is expanded to reduce the energy per unit area to prevent the beam from burning the reflective coatings on the beam-directing mirrors.
- Several **beam-directing mirrors**. Two (2) one-inch diameter, first-surface mirrors are used to control the direction of the laser pulse. One mirror, placed directly in front of the laser, redirects the beam onto a second mirror which is on an x-y mount that can be used to "fine-tune" the transmitted beam to be parallel to the field-of-view of the receiving telescope (coaxial configuration). A third mirror is mounted approximately 45 degrees from the horizontal in a tube that extends through the helicopter window to direct the coaxial beams from the transmitting and receiving telescopes downward toward the surface of the sea.

- A **trigger diode** for triggering the digital oscilloscope. An IR diode is located in the light trap for the 1.064 µm beam. This diode converts a fraction of the light pulse to a voltage pulse which then serves as an external trigger to synchronize the oscilloscope used to digitize the lidar echoes.

## *RECEIVER*

The lidar receiver contains the following major components:

- The **optical telescope**. The primary lens is a 7 7/8 inch plano-convex glass lens. A smaller collimating lens is used to create an afocal telescope (with lenses separated by the sum of their focal lengths). These lenses are mounted in an eight-inch diameter aluminum tube. Light baffles are mounted inside the tube to block stray light and a field stop is placed in the focal plane of the primary lens to reduce the field-of-view of the receiving telescope to match the divergence of the transmitted laser pulse.
- A **narrow band interference** filter centered at the laser's 0.532 µm wavelength. The afocal telescope described above produces a highly collimated beam (which is required for proper operation of an interference filter). This part of the optical system will reject light from all wavelengths outside of the bandpass of the filter (e.g., solar radiation scattered by air molecules, atmospheric aerosols or the surface of the water) and will transmit only the light that has the same wavelength as the laser.
- A **photomultiplier tube** (Hamamatsu Model R647 HA). Light transmitted by the interference filter is directed onto the photomultiplier which is used to convert the lidar echo (photons received as a function of time after laser pulsing) to an electrical current.
- A **transimpedance amplifier** (Analog Modules Model 114) matches the impedance of the photomultiplier to the impedance of the circuits coupled to it. This device converts the photomultiplier current to a voltage.
- A **logarithmic amplifier** (Analog Modules Model 382) is used to amplify the signal from the transimpedance amplifier and to increase the dynamic range of the system.

## *DATA SYSTEM*

The data system contains the following major components:

- A **digital oscilloscope** (Tektronix Model 2431L) is used to digitize the output of the logarithmic amplifier. This oscilloscope provides the necessary digitizing speed and bandwidth needed to get the required temporal resolution. It is capable of digitizing (and storing in memory) up to 1024 consecutive 8-bit voltages at sampling rates of up to 200 Megasamples per second).

- A **GPIB (General Purpose Interface Board)** computer interface card (National Instruments GPIB-AT) is installed in the computer used to operate the lidar. This card is used to read the data points stored in the digital oscilloscope's memory.
- An **IBM-type personal computer** (ZEOS 386/33) is used to operate the system. It reads lidar echoes recorded by the digital oscilloscope, displays the data in real time and records the data on its hard drive for future analysis. It incorporates two monitors for operator and observer positions on the helicopter and it uses a tape backup system (Colorado Memory Systems Jumbo 120MB) to store data after each flight. The computer software for operating the system is menu driven and, as each step for setting up and operating the system is selected, another menu is displayed to guide the operator to the next step.
- A **GPS (Global Positioning System)** was installed to add global position information to the data files to establish the location of each data sequence recorded by the computer. The GPS system consists of a computer card, antenna, amplifier, and cable.

## *POWER SUPPLY*

- The lidar system is operated from the 28-volt DC aircraft generator on the Bell Jet Ranger helicopter used for the tests. The power is supplied through two 25-amp circuit breakers whose outputs are wired in parallel in order to supply the required current to two 28-VDC to 60-Hz single phase static inverters (Avoinic Instruments Model 2AI600-IA-I-HR) connected in a master/slave configuration. This arrangement meets the following aircraft safety standards:

  FAA TSO-C73
  RTCA DO-160A
  Cat. F2B/RTY/EXXXFXXZAZZ

## *SYSTEM CONFIGURATION*

- A detector assembly (consisting of optical components, the photomultiplier tube, the transimpedance amplifier, and the photomultiplier power supply) is mounted on the telescope by four screws that protrude from a disk mounted on the rear of the telescope.
- The logarithmic amplifier is mounted on the transmitter/receiver frame. There is a solid, copper-shielded, coaxial cable which connects the output of the transimpedance amplifier to the logarithmic amplifier; care must be taken to not to crimp or do other damage to the coax. The solid coax is used to keep RF noise from getting into the system. The output of the logarithmic amplifier is connected to the oscilloscope by a short piece of coax with a BNC connector on one end and a TNC connector on the other.

- The Tektronix oscilloscope is connected to the GPIB computer interface board by a cable from the back of the oscilloscope to the back of the computer. Care must be exercised when installing or removing the cable to avoid breaking off or bending the pins in the connectors.
- The beam splitter / beam expander is attached to the face of the laser head. The IR diode used to trigger the oscilloscope when the laser is fired is mounted on the short tube that is part of the beam splitter mount. The trigger pulse is fed to the oscilloscope through a coaxial cable.

- The laser head is mounted to the receiver by two pieces of aluminum angle. One angle is mounted to the bottom of the laser head by two 1/4-20 x 1/2-inch bolts (use 1/4-inch internal tooth lock washers under the bolts to prevent the bolts from vibrating loose) and to the frame of the LIDAR with four 10-32 screws. The following sketch shows the relative positions of the mounting pieces.

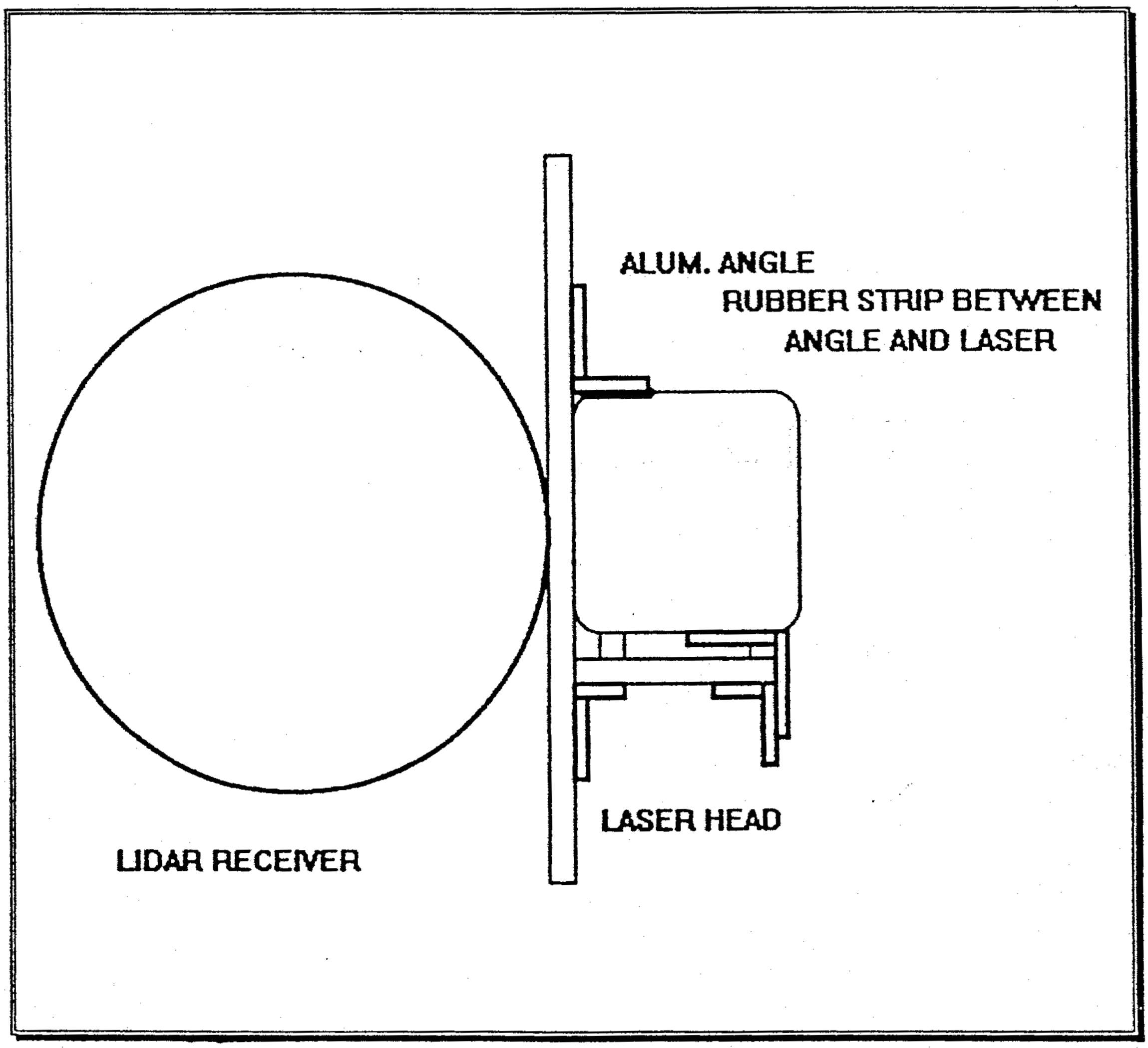


*Figure 1: Hardware used for mounting transmitting and receiving units.*

## *LIDAR SYSTEM ALIGNMENT*

The first step is to mount and align the **beam splitter/expander** on the laser head. The procedure to establish that the beam is centered in the aperture is as follows:

- In a lab with an area that is 15 feet or more in length, set up the laser on a stable work surface with the laser pointed at a distant vertical surface (e.g. a wall) that is not reflective enough to give a specular reflection.

- Install a laser power meter in line with the laser beam to measure the output power of the laser and to block the laser beam to keep it from burning a hole in the wall. Allow the laser to run until it is stabilized in temperature (check the manual provided by the laser manufacturer for additional information). Note that the beam splitter is not yet installed and the beam includes energy at both the 1.064 µm and 0.532 µm wavelengths during this part of the alignment procedure.

- Hold a 3 x 5-inch index card near the laser head with the laser running. Look at the back of the card (relative to the direction of the laser beam) at the green spot of light showing through the card to confirm that the beam is centered in the exit hole on the front of the laser.

- Tape a large sheet of dark paper on the wall where the laser beam will strike and fire the laser at it until it burns enough to create a visible mark on the paper.

- Mount the beam splitter on the laser head by itself. The splitter contains an optical element which transmits the 0.532 µm (green) light and reflects the 1.064 µm (invisible, near-infrared) light. The 1.064 µm radiation will be split off and directed out of the short tube on the side of the splitter mount to be trapped so that it does not burn someone or something.

- With an index card placed immediately after the location where the beam leaves the beam splitter, check to make sure that the green output beam is not being occulted.

- Observe where the green output beam is located with respect to the burn on the paper on the wall after the beam splitter has been installed (there may be an offset).

- Cover the original burn with some more dark paper and run the laser to get a new burn. This will take more time than it did for the original burn as you are now using only the 0.532 µm energy. If no burn is possible, with the laser running, mark the spot by drawing a circle around the green spot visible on the paper.

- Mount the beam expander and make sure that the new spot on the wall is centered on the previous spot. If not, loosen the mounting screws on the beam expander and move the beam expander until the new spot is positioned over the location of the previous spot. Tighten the mounting screws to hold the beam expander in the new position.

Prior to installing the laser, check the laser **beam directing mirrors** to see if they need to be cleaned (more than likely). If it is necessary to clean the two (2) one-inch, first-surface mirrors, use the following procedures:

- Use filtered air to blow any loose dirt off of the surface.
- Rinse the surfaces with distilled water to dissolve any salt particles.
- Clean the surfaces with isopropyl alcohol using sponge tipped "Q-Tips" (do not use the cotton tipped variety as they can scratch the surface and degrade the mirrors).

Clean the **telescope lens**, the thin **plastic window** and the front surface of the large **beam-directing output mirror** (the reflective coating is on the backside of the mirror, so cleaning will not cause any problems). This step can be carried out using distilled water and isopropyl alcohol with a soft cloth, lens tissue, etc.

When the system is reassembled, the **final alignment** can be checked by mounting the output mirror in the upward-looking position and operate the system as an atmospheric lidar. This can be done any time day or night, although late afternoon or nighttime conditions give better signal for this purpose (less sky background). The alignment procedure is as follows:

- Remove the GPIB cable from the back of the oscilloscope.
- Apply power to the lidar system.
- Place (tape) a sheet of white paper (colored paper will burn) on the upward-looking beam directing mirror at the point where the laser pulse will hit the mirror surface.
- Set the laser power pulse selector to the remote position so that the laser can be fired by a single pulse.
- Pulse the laser to determine where the laser pulse hits the output mirror. When you confirm that the pulse strikes the paper on the mirror, hold a small piece of paper over the one-inch diameter laser-beam exit tube to check whether or not the beam is being occulted. When the paper is placed against the end of the tube, you can observe the spot from the back side of the paper. It is permissible for the beam to be off-centered in the tube, as long as the full beam can be observed.
- With the paper still in place on the mirror, run the laser at 5 PPS and then at 10 PPS for a few seconds to see how the laser beam behaves. If things seem O.K., return the laser to the "REMOTE" position and close the shutter to prevent the laser from firing.
- Remove the paper from the mirror so that the laser beam can propagate into the atmosphere.

*BE ABSOLUTELY SURE THAT THE SKY IS CLEAR OF AIRCRAFT WHILE OPERATING THE SYSTEM AS AN ATMOSPHERIC LIDAR.* During the alignment tests, you should have an observer stationed near the system who is responsible for notifying the operator if an aircraft approaches so that the system can be turned off for eye-safety considerations. Set up the LIDAR per operating procedures described in the last two pages of this manual (with GPIB cable still removed from the system).

- Start pulsing the laser at the 10 PPS rate.
- Observe the oscilloscope to see if it is triggering properly. You should see a sweep trace only when the laser fires and none if the laser is not firing.
- When it is confirmed that the system is triggering properly, look for the type of signal displayed in the following example:

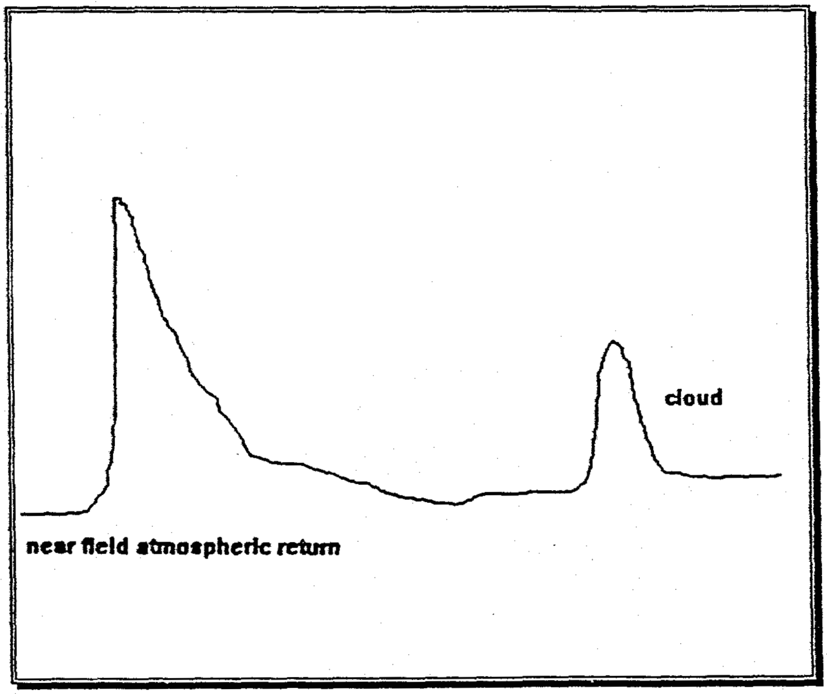


*Figure 2 Illustration of the type of signal that should be observed on the Tektronix digital oscilloscope while testing the system as an atmospheric lidar. The signal should display a rapid rise at the beginning of the sweep with a rapid exponential decay following the rise. If a cloud layer is overhead, another rapid rise at the base of the cloud followed by a decaying signal from higher altitudes should be observed.*

- If no signal is present, check to verify that the PMT and amplifier are on as follows: (a) With both switches in the "up" position, observe the oscilloscope signal. (b) Turn the first switch down. If this is the correct switch, the "noise" should increase; if not then repeat the process with the second switch. If this is not the answer, the oscilloscope vertical gain may need to be increased.

The following procedures should be followed to align the system using atmospheric scattering to test the alignment.

- Remove the thin window.
- Remove the tape covering the X-Y positioner located next to the telescope lens and just behind the one-inch tube.
- Using a sheet of white paper against the end of one-inch tube, run the laser at a low rate and check where the spot is located.
- Rotate one of the adjusting screws slightly (the adjustment is very sensitive and a small turn will have a large effect).
- Remove your arm and hand from the adjusting screw and turn the laser on to see if the signal on the oscilloscope increases. This sometimes can be a very slow and frustrating procedure.
- Adjust alternately between the X and Y screws. As the signal increases, adjust the PMT and oscilloscope gains to keep the signal in a range that avoids saturation of the electronics (as evidenced by flat, "clipped" traces after the rapid rise from the near-field echoes).
- As the signal increases, switch the sweep time to pick up returns from boundary layer clouds and aerosol layers (within the first kilometer of the atmosphere). The density of the clouds can change very rapidly so, after acquiring clouds, observe the signal for awhile before making another adjustment to "peak" the signal. The adjustment may not cause any change or the signal may drop due to a change in density.
- After the alignment is completed, retape the X-Y positioner to reduce the amount of stray light that can get into the telescope. Check that nothing moved when you were retaping the positioner by running the LIDAR again.
- Turn off the oscilloscope and connect the GPIB cable.
- Turn the oscilloscope back on and start the computer program. The program will detect that the LIDAR is looking at atmospheric returns by reading the sweep time setting from the digital oscilloscope. The display will be drawn from the bottom of the screen upward and the range will be displayed as kilometers above the lidar. The program will draw the display from the top of the screen downward and will display the proper scale for the distance below the helicopter when flying with the system looking downward.

# NMFS LIDAR SYSTEM

*PRIOR TO OPERATING THE LIDAR READ ALL SUPPLIED MANUALS AND FOLLOW ALL SAFETY INSTRUCTIONS – BE ALERT – THE LASER CAN BLIND AND/OR BURN YOU!!!*

## OPERATING PROCEDURES

1) **INSURE ALL POWER SWITCHES ARE IN THE OFF POSITION.**

   *A) POWER STRIP.*
   *B) LASER.*
   *C) COMPUTER.*
   *D) OSCILLOSCOPE.*
   *E) POWER SUPPLY FOR AMPLIFIERS.*
   *F) POWER SUPPLY FOR PHOTOMULTIPLIER.*

2) **ONCE AIRBORNE, PILOT SUPPLIES POWER THROUGH BREAKERS AND ONLY THE D-C TO A-C INVERTERS ARE POWERED UP.**

   *NOTE: THE INVERTERS ARE NOT NEEDED WHEN A-C POWER IS SUPPLIED BY DISCONNECTING THE POWER STRIP FROM THE INVERTERS AND CONNECTING DIRECTLY TO A 60-HZ SOURCE. THIS IS USEFUL FOR CHECKING ALIGNMENT OF THE SYSTEM, REVIEWING DATA, RETREIVING DATA, ETC.*

3) **ENERGIZE EACH SWITCH (A, B, C, D, E, F) AND WAIT FOR CONFIRMATION FROM THE PILOT AS TO POWER LOAD. TURN ON THE OSCILLOSCOPE, COMPUTER AND POWER SUPPLIES FOR THE AMPLIFIERS AND PHOTOMULTIPLIER TUBE IF NOT ALREADY ON.**

   *NOTE: AS THE POWER SWITCHES ARE TURNED ON, THE DEVICES WILL COME UP IN EITHER A PROGRAMMED OR RANDOM STATE.*

4) **SET UP OSCILLOSCOPE PER TEKTRONIX OPERATOR'S MANUAL.**

   *A) **TRIGGER SOURCE:** EXTERNAL.*
   *B) **TRIGGER POSITION:** 1/4.*
   *C) **TRIGGER:** PLUS.*
   *D) **SWEEP SPEED:** 200 NANOSEC OR LESS WHEN LOOKING FOR FISH. THIS SETTING IS ADJUSTED FOR BEST RESOLUTION, DEPENDING ON WHAT ALTITUDE THE AIRCRAFT WILL BE FLYING. SETTINGS FROM ONE TO FIVE MICROSEC ARE GOOD STARTING POINTS WHEN THE MIRROR IS TURNED UP TO ALIGN THE SYSTEM USING CLOUDS.*

*E) VOLTAGE RANGE: 100 MILLIVOLTS OR ADJUST FOR BEST DISPLAY ON THE 'SCOPE IN CONJUNCTION WITH THE POTENTIOMETER ON THE PHOTOMULTIPLIER POWER SUPPLY (LOCATED UNDER THE PMT). NOTE:.THE SWITCH FOR THE PMT POWER SUPPLY IS INVERTED (UP IS OFF, DOWN IS ON); THE SWITCH FOR THE AMPLIFIER IS NORMAL.*
*F) BANDWIDTH: FULL.*

5) **SET TRIGGER LEVEL FOR STABLE OPERATION.**

6) **THE COMPUTER WILL PRESENT A MENU OF CHOICES: SELECT FROM THE MENU AS TO WHICH OPERATION IS TO BE ACTIVATED (I.E., "RECORD LIDAR DATA").**

7) **START LASER PER INSTRUCTION MANUAL.**

   *NOTE: MAKE SURE THAT THE LASER BEAM WILL NOT HIT REFLECTING SURFACES THAT MIGHT CAUSE THE BEAM TO BE DIRECTED INTO A PERSON'S EYES.*

8) **ADJUST PHOTOMULTIPLIER VOLTAGE TO OBTAIN THE DESIRED SIGNAL LEVEL.**

   *NOTE: THE SIGNAL LEVEL RANGE CAN BE DETERMINED ALONG THE COAST AND/OR AT SEA.*

9) **SET OSCILLOSCOPE LEVEL FOR PROPER RANGE TO GIVE THE MOST RESOLUTION ON THE COMPUTER DISPLAY.**

   *NOTE: THIS IS DONE IN CONJUNCTION WITH STEP 8. THE OSCILLOSCOPE LEVEL IS ADJUSTED BY CHANGING THE VERTICAL VOLTAGE GAIN. IF THE SIGNAL FROM THE PHOTOMULTIPLIER SATURATES, THE WAVEFORM WILL HAVE A "FLAT" TOP - REDUCE PMT VOLTAGE TO PREVENT SATURATION AND MAKE CORRESPONDING INCREASES IN OSCILLOSCOPE GAIN TO PROVIDE FULL-SCALE RESOLUTION FOR THE DISPLAY.*

10) **SELECTION OF LASER PULSES PER SECOND CAN BE VARIED AT THE TIME OF DATA TAKING TO CONSERVE SPACE ON THE HARD DRIVE.**

    *NOTE: AFTER THE PULSE RATE IS SELECTED, THE LASER OUTPUT WILL STABILIZE AFTER A MINUTE OR TWO. THE LASER MANUFACTURER NORMALLY HAS THE LASER TUNED FOR MAXIMUM OUTPUT POWER AT THE HIGHEST PULSE RATE. THE OUTPUT POWER MAY BE REDUCED AND IT MAY FLUCTUATE WHEN THE SYSTEM IS OPERATED AT LOWER PULSE RATES.*

11) **PROCEDURES FOR REMOVING DATA TO MAKE MORE ROOM ON THE DISK ARE LOCATED ON THE LIDAR MENU – FOLLOW THE INSTRUCTIONS AS PRESENTED.**

*NOTE: IF THE COMPUTER NEEDS TO BE RESET USE THE RESET BUTTON ON THE COMPUTER (The GPIB board needs to be reset and the standard <Ctrl><Alt><Del> combination will not reset the GPIB ).*

## SHUTDOWN PROCEDURES

1) **RETURN COMPUTER TO THE MENU.**

2) **TURN OFF LASER.**

3) **TURN OFF POWER SUPPLIES.**

4) **TURN OFF OSCILLOSCOPE.**

5) **TURN OFF COMPUTER.**

7) **TURN OFF BREAKER ON POWER STRIP AND INFORM THE PILOT THAT THE SYSTEM IS OFF AND TO TURN OFF POWER BREAKERS.**

- END -

## Appendix 2. NMFS LIDAR Hardware and Software Components Inventory as of May 1994

NMFS LIDAR Hardware and Software Components Inventory, May 1994
Southwest Fisheries Science Center
P.O. Box 271
La Jolla, California 92038-0271

ITEM #

### GREEN METAL BOX

1. Modgraph VGA Color Monitor
Serial number: HA 883773
Box #2, D-113

### SOUTHWEST FISHERIES SCIENCE CENTER

2. Zeos VGA Color Monitor
Model number: ECM-5414S
Bar code: 038DA1C0063
D-316

3. Zeos 386 Computer
Serial Number: 99461
DOC bar code: CD0000159181
Value... $5385.72
D-316

### WOODEN BOX #2 - 33x25x24 INCHES

4. Hamamatsu Photomultiplier assembly with 1 nanometer narrow band interference filter and 1/2 inch multiplier tube, preamplifier, receiver
Model number: R 647H
Value... $1361.77
Box #4, D-113

5a/5b. Dichroic beamsplitter assembly
Box #4, Bag 1, D-113

6. Computer cable (National Instruments 763061-03 Rev C, type-X2) 4.1 meters
Box #4, D-113

7. Black coaxial cable (several feet)
Box #4, D-113

8. Avionics Static Invertor
Model number: 2A800-1G
Serial Number: BMO891403
DOC bar code: CD0000159185
Value... $3476.09

Box #4, D-113

9. Avionics Static Invertor
Model number: 2A800-1G
Serial number: BMO8914029
DOC Bar code: CD0000159186
Value... $3476.09
Box #4, D-113

10. Eight inch refracting telescope and collimating mount
DOC bar code: CD0000159182
Value... $1,000.00
Box #4, D-113

11. Aluminum mounting frame for laser head and refracting telescope
Box #4, D-113

12. Ring for plastic window
Box #4, D-113

13. Mounting frame component
Box #4, D-113

14. Mounting frame component
Box #4, D-113

15. Plastic telescope cover
Box #4, D-113

16. Plastic telescope cover
Box #4, D-113

17. Surge protector
Model Number: 207 BC
Box #4, D-113

**WOODEN BOX #3 - 38x32x19 INCHES**

18. NAVSTAR Antenna
Model Number: N72-1
Serial number: 0092
DOC bar code: CD0000159184
Box #5, D-113

19. NAVSTAR Remote Pre-Amp and cable and mounting bracket
Part Number: A02 - 429.G1
Box #5, D-113

**20. Analog Devices Low Voltage Power Supply and mounting frame**
**Model Number: 974**
**Value... $245.00**

**This unit failed during field trials.**

Box #5, D-113

21. Beam expander/Laser firing barrel,
532 nm optical filter, Edmunds
Scientific alignment adjustment device,
and mounting frame
Value... $673.00
Box #5, D-113

22. Spotters monitor frame
Box #5, D-113

23. Electronic couplings
MS3116F14 - 155
Box #5, D-113

24. AMPHENOL electronic couplings
Model number: MS 3106A-24-115-8912
Box #5, D-113

25. Tektronics coupling
Model number: P6136
Box #5, D-113

26. External mirror and rotating housing
Box #5, D-113

27. Tektronics Digital Oscilloscope
Model number: 2431L 250 MS/s
Serial number: C9C10B1
DOC bar code: CD0000159183
Value... $6851.25
Box #5, D-113

28. Mounting component for spotters
monitor
Box #5, D-113

29. Framing component
Box #5, D-113

30. Ring clamp
Box #5, D-113

31. Ring clamp
Box #5, D-113

32. Copper coaxial cable
Box #5, D-113

33. Cardboard shade for spotters monitor
Box #5, D-113

34. Black coaxial cable
Intercomp RG 223/U MIL-C-17D

Box #5, D-113

35. Electric cable
    Ching Shuang electric cable
    Box #5, D-113

**WOODEN BOX #4 - 39x23x15 INCHES**

36. Frame for Laser power unit and digital oscilloscope
    Box #6, D-113

37. Large color monitor bracket
    Box #6, D-113

38. Large color monitor bracket
    Box #6, D-113

39. Various nuts and bolts/attachment hardware inside Bag 2
    Box #6, D-113

40. Mounting frame component
    Box #6, D-113

41. Mounting frame component
    Box #6, D-113

All of the previously inventoried aluminum mounting brackets were custom cut and assembled. Value... $250.00

Supplemental list of government-owned software and computer equipment for the NMFS-LIDAR system as of 05/16/94.

**BOLDFACE denotes NOT AVAILABLE**

## WOODEN BOX #5 - 37x27x19 INCHES

### ZEOS Computer Purchase

1. ZEOS 386; 4mb RAM; 5.25/3.5 drives; 94mb disk; 387 math chip Serial #99461; Bar code CD0000159181
2. ZEOS color VGA monitor; model ECM-5414S; Bar code 038DA1C0063
3. ZEOS Users Manual
4. **ZEOS Utilities Disk provided with ZEOS computer**
5. **Registration and warranty papers for ZEOS computer**
6. **Registration and warranty papers for ZEOS VGA monitor**

7a. MSDOS 4.01 disk & manual purchased with ZEOS computer
7b. MSDOS 5.0 disk & manual purchased as upgrade

8. **Microsoft Windows 3.0 software, manuals, & registration**
9. **Microsoft Serial Mouse, software, manual, & registration**

### COLORADO MOUNTAIN TAPE Purchase

10. Jumbo 120mb tape backup; serial # AAA0025543; manfu 3/9/91
11. Jumbo 120mb Hardware Installation Guide
12. Jumbo 120mb Software Installation and Operation Guide
13. Jumbo 120mb Compatibility and Accessory Guide
14. AB-10 Tape Adapter Board Hardware Installation Guide
15. Colorado Mountain Tape software disk(s) for 120mb tape system
16. Colorado Mountain Tape Adapter Board kit including:
    a. tape adapter board (AB-10)
    b. Y-power cable
    c. tape adapter cable
    d. internal data cable

## GREEN METAL BOX

### NATIONAL INSTRUMENTS GPIB

17. AT-GPIB Interface Board; serial # 012284
18. Getting Started with Your AT-GPIB and the NI-488.2 MS-DOS Handler (part #320284-01)
19. NI-488.2 MS-DOS Software Reference Manual (part #320135-90)
20. Universal Language Interface Using HP-Style Calls Manual (part #320135-90)
21. 3.5-inch NI-488.2 Distribution Disk for AT-GPIB MS-DOS Handler, BASICA, QuickBASIC, BASIC, C & Universal Interfaces (part number 422186-55)

### NAVSTAR XR4-PC GPS

22. XR4-PC Receiver Board; serial # 37970 (Type No. A81-000GI)

23. XR4-PC 3.5-inch Utilities & Applications disk (A81-061/02)
24. na
25. na
26. XR4-PC Installation and User Manual (H81007/02)
27. XR4-PC registration and warranty papers (H02439/01)

### MODGRAPH VGA COLOR MONITOR

28. Model HA-1205LM color VGA monitor; serial #HA 883773
29. Model HA-1205LM color VGA monitor Operating Instructions
30. **Model HA-1205LM registration and warranty papers**

### TEKTRONIX DIGITAL OSCILLOSCOPE

31. Tek 2431L Operators Manual, registration/warranty papers
32. Tek 2431L GPIB Pocket Guide (part #070-7699-00; group 37)
33. Tek 2431L Digital Oscilloscope User Reference Guide
    (part #070-7698-00; group 37)
34. Tek 2431L Programmers Reference Guide
    (part #070-7700-00; group 37)

### ZORTECH C++ Compiler Version 2.0 manuals
### Version 2.10 software

35a. C++ Installation Guide V2.0
35b. C++ Function Reference V2.0
35c. C++ Compiler Reference V2.0
35d. C++ Compiler Disk #1 V2.18
35e. C++ Compiler Disk #2 V2.18
35f. C++ Library Source #1 V2.18
35g. C++ DEBUG and TOOLS diskettes as part of Developer's Ed.

### MICROSOFT OVERLAY LINKER Version 3.64

36. LINK.EXE 65475kb; 2/1/88; 13:00pm C:\GWG directory

### PCFILER.EXE

37. PCFILER.EXE 48468kb; 3/29/86; 12:54pm C:\GWG directory

PCFILER.EXE is a "public domain" program.

### G_GWG.LIB

38. C_GWG.LIB 88064kb; 12/27/91; 9:03am C:\GWG directory

### LASER PHOTONICS LASER

39. Model YQL-102D Pulsed ND:YAG Laser Operator's Manual Feb 1991

# RECENT TECHNICAL MEMORANDUMS

Copies of this and other NOAA Technical Memorandums are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22167. Paper copies vary in price. Microfiche copies cost $9.00. Recent issues of NOAA Technical Memorandums from the NMFS Southwest Fisheries Science Center are listed below:

NOAA-TM-NMFS-SWFSC-194 Economic effects of the United Nations moratorium on high seas driftnet fishing.
D.D. HUPPERT and T.W. MITTLEMAN
(December 1993)

195 Report on cetacean aerial survey data collected between the years of 1974 and 1982.
T. LEE
(January 1994)

196 A test of two photogrammetric measuring instruments used to determine dolphin lengths from vertical aerial photographs.
J.W. GILPATRICK, JR. and M.S. LYNN
(January 1994)

197 Hook-and-line fishing study at Cordell Bank, California, 1986-1991.
M.B. ELDRIDGE
(February 1994)

198 Small cetacean dissection and sampling: A field guide.
T.A. JEFFERSON, A.C. MYRICK, JR., and S.J. CHIVERS
(April 1994)

199 A recharacterization of the age-length and growth relationships of Hawaiian snapper, *Pristipomoides filamentosus.*
E.E. DEMARTINI, K.C. LANDGRAF, and S. RALSTON
(May 1994)

200 Report on cetacean sightings during a marine mammal survey in the eastern tropical Pacific ocean aboard the NOAA ships *McArthur* and *David Starr Jordan.*
K.F. MANGELS and T. GERRODETTE
(May 1994)

201 Research plan to assess marine turtle hooking mortality: Results of an expert workshop held in Honolulu, Hawaii, November 16-18, 1993.
G.H. BALAZS and S.G. POOLEY
(June 1994)

202 Status of populations of odontocetes along the coast of California in 1994.
K.A. FORNEY
(June 1994)

203 Recent information on the status of large whales in California waters.
J. BARLOW
(June 1994)