Maximizing NOAA's Ship Productivity Through the Use of Airborne Laser Hydrography

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Key words: Airborne, Hydrography, LIDAR, Laser, NOAA.

ABSTRACT

The National Oceanic Atmospheric Administration (NOAA) is responsible for surveying over 3.4 million miles of the United States Exclusive Economic Zone. With only three in house hydrographic survey vessels, NOAA has had to incorporate the use of Airborne Laser Hydrography (ALH) to maximize annual survey production. ALH has developed over the past twenty-five years into a reliable, cost effective method for augmenting ship hydrography. With an understanding of the limitations of an ALH system, the hydrographer can utilize an ALH survey to determine the need, line spacing, and with what frequency the ship hydrographic surveys will be conducted.

NOAA has utilized an ALH system to conduct a variety of hydrographic surveys including post storm assessment in Florida, remote area assessment at Midway Island, and near-shore hydrography and reconnaissance in Alaska. The results from these surveys have reduced the need for the time consuming launch based survey and even prevented the need to deploy a vessel at all.

Ship hydrography will not be replaced by present technology ALH systems, the two methods of conducting hydrographic surveys will be an integral part of future NOAA surveys.

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1. BACKGROUND

The National Oceanic and Atmospheric Administration (NOAA) maintains the Nation's suite of 1005 nautical charts covering 3.4 million miles of the United States Exclusive Economic Zone. Since the mid-1970's, NOAA's fleet of hydrographic ships has dropped from eleven to three active ships, ranking NOAA's hydrographic capabilities 38th in the world. With limited resources, NOAA has had to prioritize the nation's survey needs. The priority areas are those areas deemed "navigationally significant", approximately 500,000 square nautical miles, specifically the near-shore areas with threat to marine navigation. NOAA has further defined 43,000 square nautical miles as "critical" areas where the greatest threats of natural or manmade hazards exist to marine navigation.

With current funding levels, it is projected it will take the United States more than 15 years to complete accurate, high-resolution hydrographic surveys over the critical area using ship hydrography alone. NOAA has had to explore the use of alternative technologies to ensure the fleet production is maximized. Since the mid-1970's, NOAA has been involved in the development of an Airborne Laser Hydrography (ALH) (Guenther, 1978) system for near-shore bathymetry. The development of ALH systems in the United States and other countries has resulted in six ALH operational systems (LaRocque, 1999).

ALH systems were introduced as a cost effective means of obtaining bathymetry in shallow water. They are not designed to disprove, beyond any doubt, the existence of potential hazards on the ocean floor (Guenther, 2000). Tenix Corportation's LADS (Laser Airborne Depth Sounder) Mark II system (McKenzie, 2001) and the Scanning Hydrographic Operational Airborne LIDAR (Light Detection and Ranging) Survey (SHOALS) (Riley, 1995), however, have been demonstrated to meet the International Hydrographic Organization (IHO), Special Publication 44, Order 1 survey accuracies and object detection criteria. NOAA, however, requires the use of high frequency sonar with high spatial resolution (Guenther, 1996) to ensure the safety of the mariner in areas where hazardous cargo transits or minimal under-keel clearances exist.

In Alaska, ALH systems are an ideal complement to ship hydrography. The majority of the Alaskan coast is included in the critical survey area, since a large percentage of the prior surveys were performed before 1940. Those surveys were accomplished with technology that only charted approximately 5% of the ocean floor. With a rocky ocean floor known to exist in Alaska and retreating glaciers leaving an uncharted ocean floor, ALH systems were chosen to provide a margin of safety for the ship hydrographers and a means of obtaining a denser data set in the near-shore environment.

2. PRODUCTION

NOAA's goal is to provide the mariner with the most accurate, high-resolution nautical chart data possible. In order to accomplish this goal, NOAA's three hydrographic ships need to be utilized effectively and efficiently. By integrating an ALH system into operations, the ships can concentrate on collecting the needed accurate, high-resolution data in the critical survey areas.

NOAA's use of an ALH system for hydrographic applications, during the fiscal year 2001, has been for reconnaissance and safety, as well as shoreline mapping. The other non-hydrographic application has been for coral reef mapping. All the uses have contributed to overall increased production from NOAA's hydrographic fleet.

2.1 Alaska Survey

The NOAA Ship Rainier is NOAA's largest and most productive hydrographic vessel. The Rainier spends most of its operating season performing hydrographic surveys in the waters off the coast of Alaska, the most complex coast in the United States. Consequently, the Rainier spends approximately 50% of its operational effort working around the complex shoreline in shallow water obtaining only 10% of its total hydrographic production output.

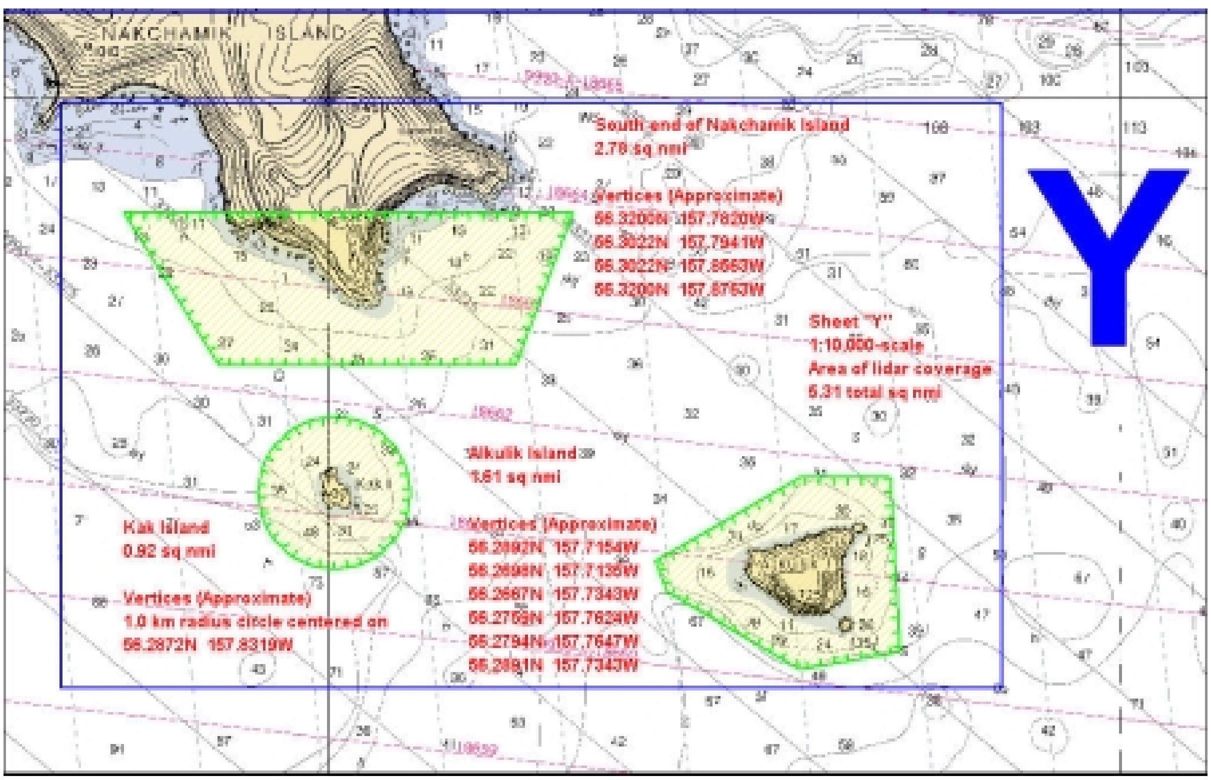

Figure 1: Survey Limits for LIDAR Sheet Y

To help increase production, NOAA, through a contract with Thales Geo Services, obtained LIDAR from the Tenix Corporation's LADS Mark II ALH system. LIDAR was performed at 4 x 4 meter spot spacing with 200% coverage in the near-shore environment, as well as over potential hazards charted in the survey area. Denser coverage of 3 x 3 meter or 2 x 2 meter spot spacing were used to develop shoals and potential obstructions hazardous to navigation.

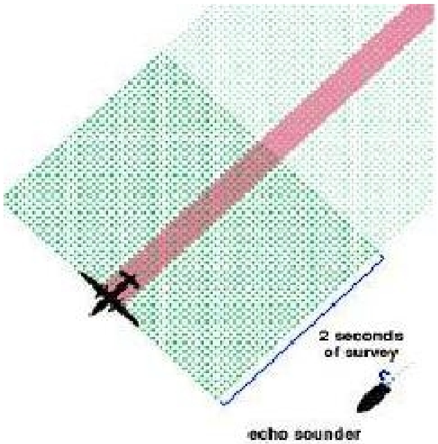

Figure 2: Comarison of 2 seconds of acquisition of ALH vs. echo sounder

Since the primary hydrographic data collection method on the NOAA Ship Rainier is multibeam echo sounders, to mitigate the risk of damaging a costly echo sounder, the hydrographer depends on reconnaissance to plan the survey mission in the rocky and shallow near-shore region. Normally the hydrographer would deploy a survey launch, equipped with a less costly single beam echo sounder, from the ship to acquire the necessary reconnaissance data. This method, although effective, takes considerable time away from full production as well as potentially placing the launch and crew in harms way along the rocky coastlines. An ALH system replaces the need for near-shore launch reconnaissance by providing the ship's hydrographer with contours out to the ALH limits and a list of areas that require further investigation.

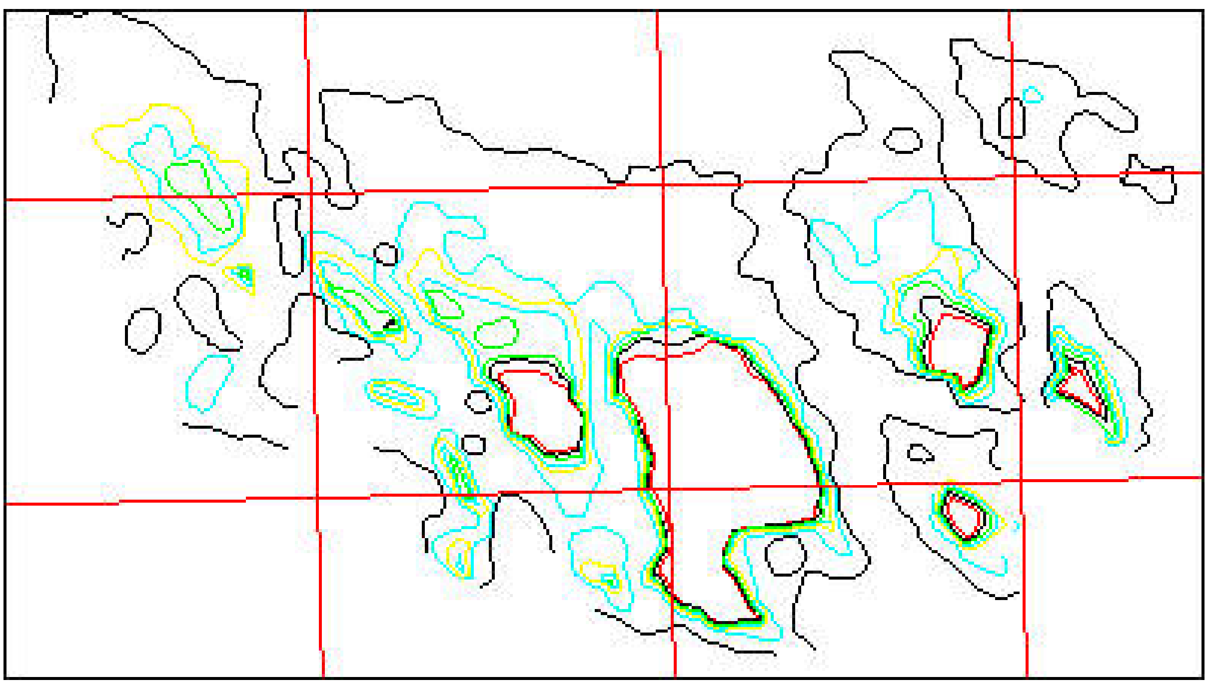

Figure 3: Preliminary Contours Provided from LIDAR

The survey operation area in Alaska also contained areas on the chart where potential hazards were reported as late as 1995. The ALH system was used to clear the area of hazards so the ship could perform its hydrographic operations over the potential hazards without fear of hitting an obstruction. This was accomplished by collecting LIDAR over the questionable areas, processing the data to a mid-water depth and then ensuring there were no returns shallower than the mid-water depth. In the Alaska operations, a mid-water depth of 10 meters was chosen as a safe depth for ship operations. Any returns more shallow than the mid-water depth indicated that a potential hazard exists and will require further investigation by the ship. The ALH system disproved all charted hazards assigned.

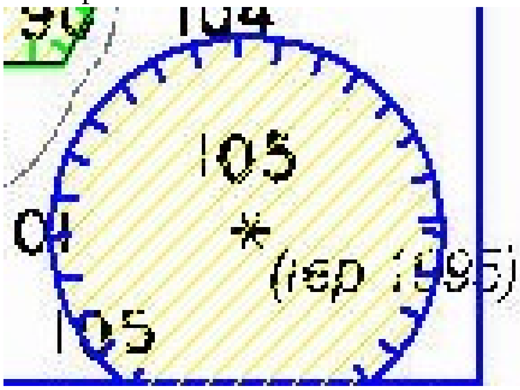

Figure 4: Charted Hazard Reported 1995

The ALH system was also employed to map the shoreline in the project area. LIDAR defined the Mean High Water (MHW) and Mean Lower-Low Water (MLLW) shoreline, as well as mapping rocks, ledges, reefs, and other hazardous areas of the shoreline. Historically, NOAA used photogrammetry, or more recently, Synthetic Aperture Radar (SAR), in order to map the shoreline. Both systems have their limitations. Photogrammetry must be flown with the stage of tide at or below MLLW in order to detect hazards submerged at higher stages of tide, and to map the MLLW shoreline. Photogrammetry, however, also requires little or no cloud cover. In Alaska, the correct weather window often does not coincide with the ideal tidal window, and the photogrammetric mission is forced to choose the clear skies. The result is that the hydrographer must spend many vessel hours supplementing the photogrammetry. SAR, while able to map the shoreline through cloud cover, must also depend upon tide-coordinated flight schedules. An ALH system with a combined bathymetry and topography capabilities, such as Tenix Corporation's LADS Mark II system, need not rely on tide-coordinated flight schedules. Also, ALH systems are less susceptible to lost flight time due to cloud cover, since flight altitudes are much lower than that of photogrammetry.

The NOAA Ship Rainier benefited from the use of an ALH system. The ship not only was able to transit potential hazards safely, but also optimized their hydrographic mission with the provided near-shore bathymetry. If LIDAR is able to effectively survey the shoreline and obtain near-shore bathymtery, it represents a 50% increase in production thereby, reducing the critical survey backlog through redirected resources. Further efficiencies are to be gained from alleviating the hydrographer from shoreline mapping tasks.

2.2 Midway Survey

Midway Island is located 1100 nautical miles from Kauai, the closest of the eight main Hawaiian Islands. The survey was conducted through a contract with Tenix Corporation's LADS Mark II ALH system. The purpose of the survey was two-fold. The first purpose was to show the capabilities of an ALH system deploying to a remote area and operating independent of a major support network. The other purpose of the survey was to provide the Hawaiian Pilots with updated information of the channel and approach into Midway Island without needing to deploy a hydrographic vessel.

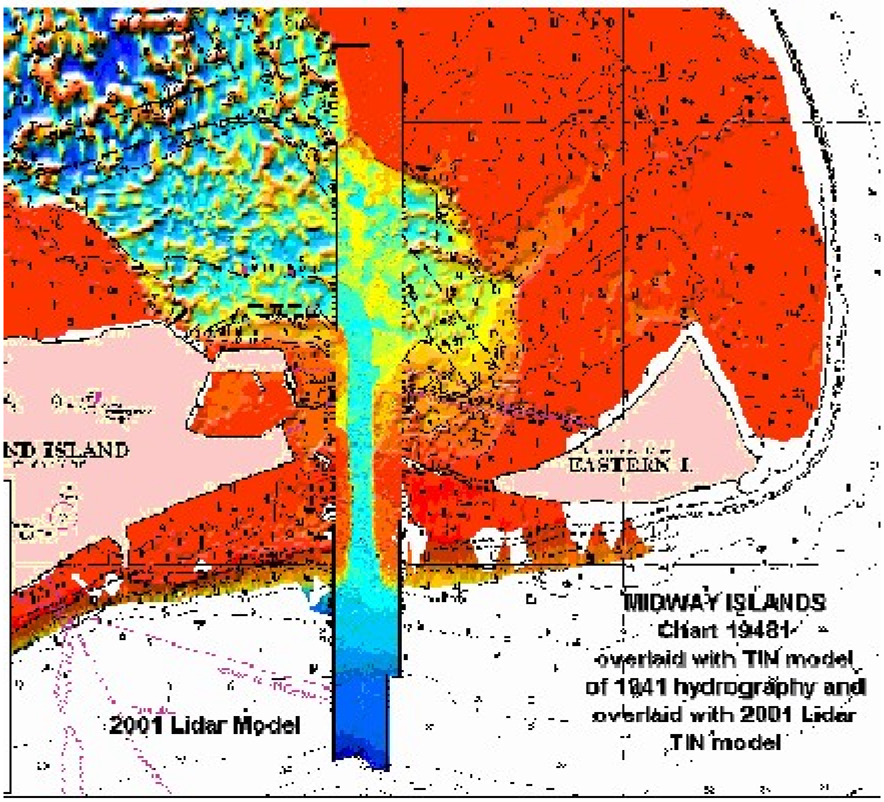

Figure 5: Midway LIDAR Overlaid with Prior Survey

The mission was successful on both counts. The aircraft deployed to Midway with the ALH system and ground processing system onboard. The flights were conducted within 36 hours of arrival in Midway and the water quality was such that depths greater than 70 meters were obtained. Since it was the objective of the mission to complete a survey without the need of ship hydrography, the data was collected at 3 x 3 meter spot spacing at 200% coverage to increase object detection capabilities. Following a comparison with the chart and prior surveys, it was determined that additional ship hydrography was not required.

The ALH system alleviated the need for the NOAA Ship Rainier, NOAA's only west coast hydrographic vessel, from transiting from its normal operation area to Midway Island. Without the ALH capabilities, the Rainier would have lost at least 14 days of production due to deadhead transit requirements.

2.3 Coral Reef Mapping

Ninety percent of our nation's coral reefs are associated with the Western Pacific islands of Hawaii, Guam, American Samoa and the Northern Marianas. A key component of environmental health, coral reefs face significant stresses from human impacts such as ship groundings, marine debris, polluted runoff and sedimentation. With coral bleaching and mortality at unprecedented levels, the 1998 Coral Reef Protection Executive Order directs Federal agencies to map, research, monitor, manage and restore coral reef ecosystems. The Coral Reef Task Force (CRTF) followed the Executive Order with a National Action Plan to map all the coral reefs by 2009.

NOAA, in partnership with the U.S. Navy, is leading the mapping effort in order to chart the reefs accurately for safe navigation. Accurate charts are crucial to the protection of the coral reefs as well as national security. The value of coral reef ecosystems has been estimated economically in the billions and environmentally is priceless. A single ship grounding could devastate a small island community and have long-term environmental impacts.

The majority of coral reef areas have not been accurately located, adequately charted, or mapped, nor has their condition been assessed or characterized. Obtaining baseline maps are essential to sound, science-based management decisions and evaluation of coral protection policy effectiveness. Bathymetry, or depth, information is the critical element for all coral reef mapping activities.

Satellite remote sensors offer an attractive way to gather comprehensive data over wide areas of reef structure. Unfortunately, interpretation of that imagery remains a difficult task with current technology. The sensor measurements rely on reflected sunlight, which attenuates differently in each spectral band as the reflected light travels to the water surface from varying depths.

Also, in order to obtain the needed reflected light, the area had to be cloud free between the sun and survey area. Coordinating satellite passage with completely clear days is an almost impossible task, especially with limited funding and satellite availability. Other methods had to be explored to map the areas clouded over. Since the majority of the coral reef ecosystem is not in the predefined critical survey area, the deployment of a ship would require removing the asset from the task of reducing the critical survey backlog. An ALH system was proposed as a viable option. The Tenix Corporation's LADS Mark II system was used to fly track lines over the area collected by satellite imagery where known cloud cover existed.

The ALH system results were compared with the satellite bathymetry to assist the development of satellite algorithms and to ensure the viability of this option. The initial review of the data by NOAA's Special Programs Office showed that satellite bathymetry was capable of obtaining depths and positions of the coral reef environment to approximately 20 meters.

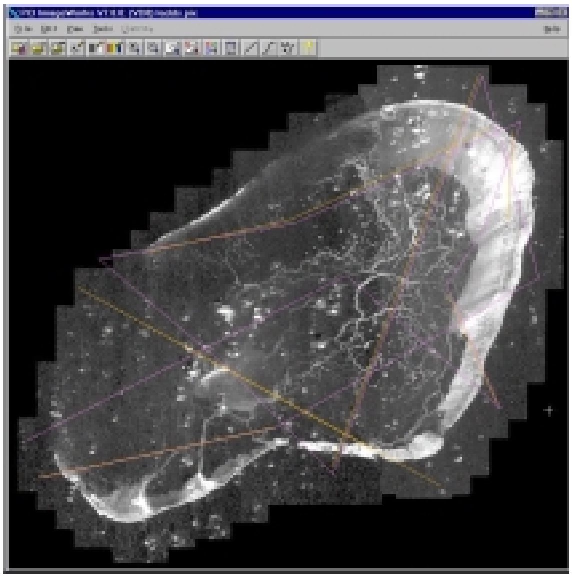

Figure 6: LIDAR Survey Lines Overlaid on Satellite Imagery

3. RESULTS

The introduction of an ALH system into NOAA's operation has shown promise for increasing overall production. The actual production increase has not been quantified, since the final survey results from the past season have not been submitted.

The NOAA Ship Rainier's preliminary evaluation from 2001 was that LIDAR was very effective in detecting rocks, reefs, kelp areas, and ledges along the shoreline, and was accurate in defining the shoreline. This success, if proven, potentially could alleviate the hydrographer from having to spend numerous vessel-hours in the near-shore region verifying and supplementing traditional methods of shoreline data, enabling him/her to utilize those resources more productively.

Future ALH reconnaissance missions will be accomplished independent of ship hydrography. This past year's operations have shown that preliminary data provided only a limited amount of information to the ship's hydrographer. The ship had to spend a considerable amount of time analyzing the results that would normally have been accomplished by the ALH system processing team in the final product. A submission of a final product to the ship prior to the start of the field season could, in estimation, reduce the total time necessary for obtaining complex shoreline data from 50% acquisition time to 25% or less.

It is clear that the use of LIDAR for accomplishing additional missions, such as coral reef mapping, has proven to be an effective use of the resource. Every day that a hydrographic ship is used for transits and surveys not directly related to reducing the critical survey areas, adds time to the overall production schedule needed to accomplish the critical survey backlog.

Even though final survey results from the past season are not complete, ALH has improved overall ship production. An ALH system has made it possible for the NOAA Ship Rainier to spend less time in the coastal zone, provided complete surveys that prevented deployment of vessels to remote areas, such as Midway Island, and also provided necessary survey data for coral reef mapping. All these applications have shown NOAA that an ALH system has significant value to a hydrographer as another tool in the hydrographer's toolbox.

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BIOGRAPHICAL NOTES

Lieutenant John Longenecker joined NOAA in 1992 after spending over 8 years with the U.S. Navy. He holds a Bachlor of Science degree in Mechanical Engineering from Auburn University. Lieutenant Longenecker served as a Mission Commander in NOAA's Twin Otter research aircraft program where he commanded mission using atmospheric LIDAR, topographic LIDAR, and bathymetric LIDAR. In 2000, he was transferred to NOAA Headquarters working in the Hydrographic Services Division as a Field Manager, LIDAR Surveys. During this assignment, he has had oversight on all of NOAA's hydrographic LIDAR missions as well as working with other agencies in the development of new technology.