

COASTAL AERIAL PHOTO-LASER SURVEY (CAPS) A NEARSHORE CHARTING SYSTEM

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INTRODUCTION

The watchwords in the Mapping & Charting world today are "Remote Sensing". It seems like everything that gathers data is a remote sensor of some kind.

Since that is the case, I would like to add another word to our remote sensing vocabulary and that word is "lidargrammetry" or, if you prefer, "hydrogrammetry". I'm not sure this is the first time either of these words has been used but I hope it is not the last, because it really describes what the Coastal Aerial Photo-laser Survey (CAPS) system is all about. Namely, making measurements from aerial photography — in this case making hydrographic measurements using a lidar system for depth control and photography for area coverage and compilation. (See figure 1).

Imagine traversing a survey area at 150 knots and taking precise lead-line measurements approximately every 10 metres along your traverse. If you can envision this, you can understand and appreciate the advantages of using an airborne laser depth sounder to provide high speed depth information in nearshore coastal waters. All one has to do then is tie this data all together with stereo photography and with positional information and make a chart. Sounds easy doesn't it? Unfortunately, it is not quite so simple. The problems of obtaining a workable CAPS system are numerous.

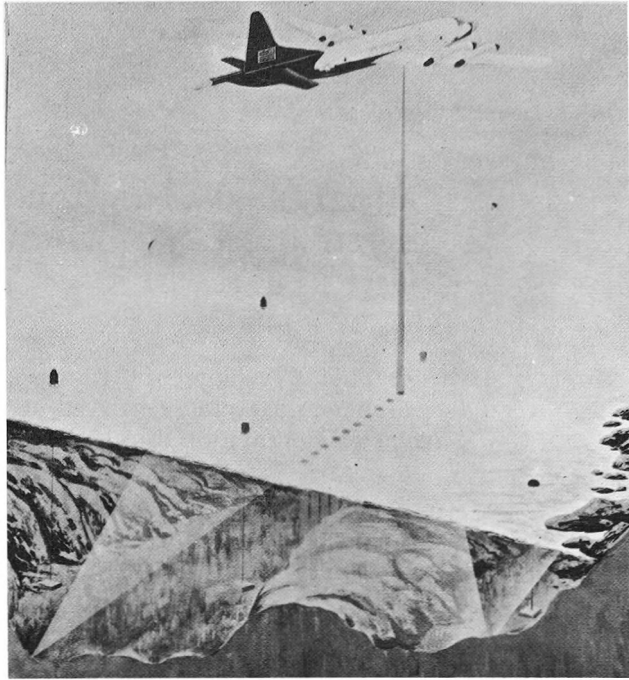


FIG. 1. — Artist's conception of CAPS.

BACKGROUND

The utilization of an airborne laser as a depth "sounder" has been studied and tested for several years at the U.S. Naval Oceanographic Office. We began studying the problem in 1966 and contracted for our first laser development in 1968. In 1969 we took delivery of the Pulsed Light Airborne Depth Sounder system (PLADS), and performed many flight tests and static tests in the lower Potomac River, Chesapeake Bay, and in the Gulf of Mexico at Panama City, Florida using one of the first YAG lasers. At the same time we were doing a lot of work with color aerial photography for water penetration studies and bottom detail enhancement. In 1973, after a couple of non-innovative years, we conceived the idea, as a result of some amphibious reconnaissance requirements, of combining these two subsystems with a positioning subsystem, and thus the CAPS concept was originated. This advanced concept of charting from laser-controlled color photography is based on the integration of an airborne data acquisition system and a ground data reduction system; an integration which we hope will permit compilation of high-accuracy planimetric charts of nearshore coastal areas in many regions around the world.

The ideal system elements are as follows :

- a. A continuous laser depth profile over a plane water surface
- b. A record of the aircraft elevation above the water surface
- c. A record of the aircraft elevation above sea level

- d. Navigational positions of the aircraft in latitude and longitude
- e. Film-speed correlated to ground speed
- f. Provision for altitude delay in the laser
- g. Synchronized laser, photo, and positional data
- h. A 9.5" film format
- i. An aerial camera with a wide angle lens.

EXPERIMENTATION

Having a need for additional laser testing and having extinguished the capability of our PLADS system, we entered into an agreement with NASA, Wallops Flight Center at Wallops Island, Virginia during Fiscal Year 1974 to modify and fly their existing fluorosensing neon laser for bathymetric testing. This effort has been uniquely successful in that continuous laser data has been obtained for the first time along a path several miles in length.

Our goal for fiscal year 1975 was to obtain enough field data to allow us to develop laser subsystem specifications which could be used the next year in contracting for the development of an Advanced Development Model (ADM) of a laser bathymeter. We feel that we can now accomplish our

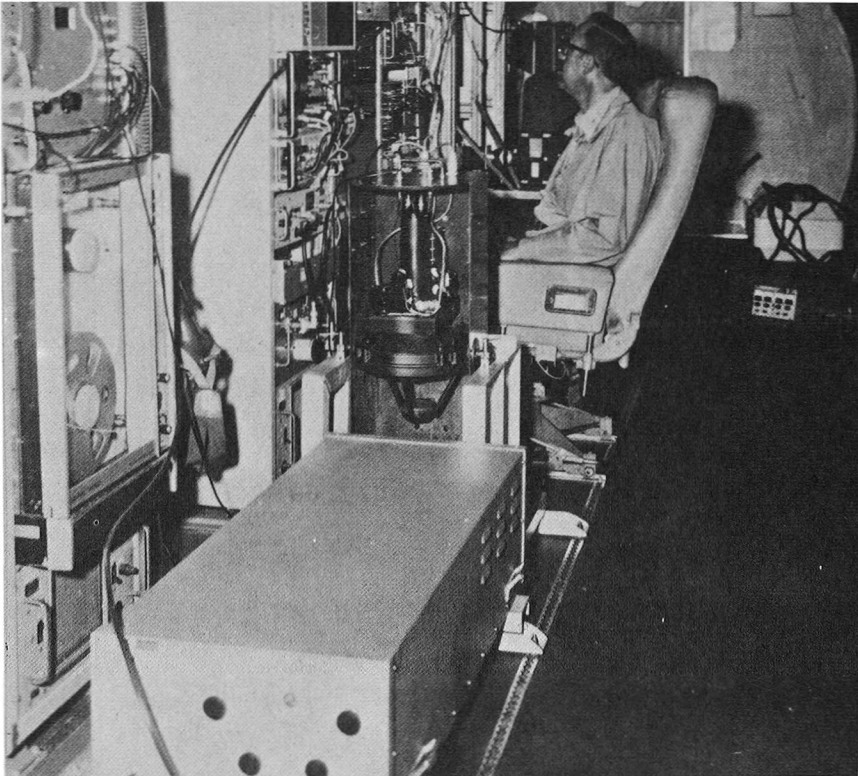


FIG. 2. — The neon laser (foreground), receiver, and operator's position in the C-54 aircraft.

goal with the information we have obtained. During August and September 1974 we conducted separate laser and aerial photographic tests at Key West, Florida. The following discussion briefly describes the activities of these tests.

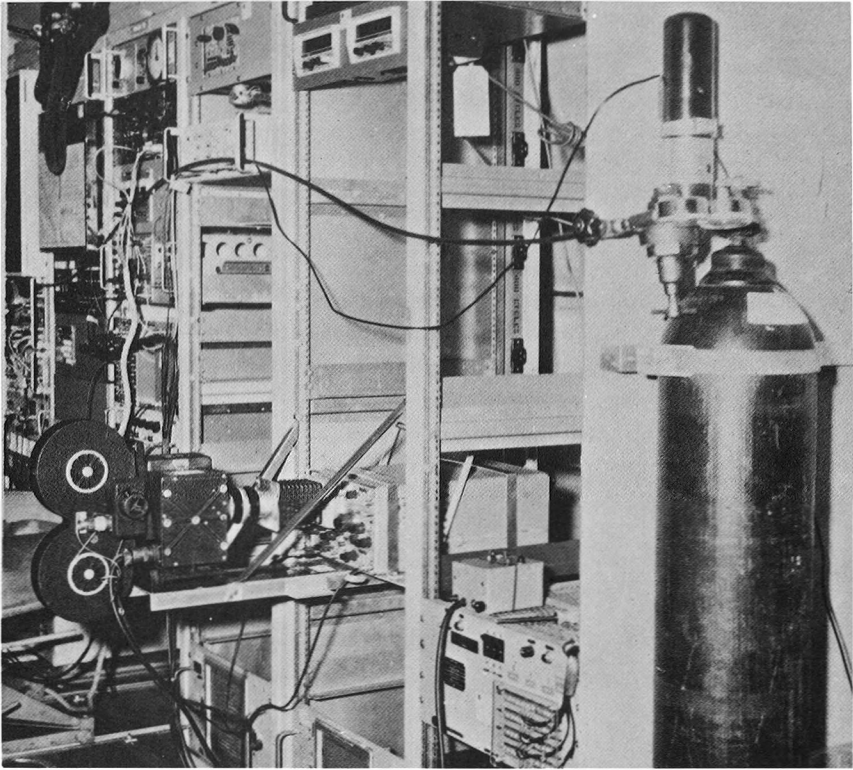


FIG. 3. — The 35 mm cine-camera on the oscilloscope. The large tank in the foreground is the cylinder for the neon used in the laser.

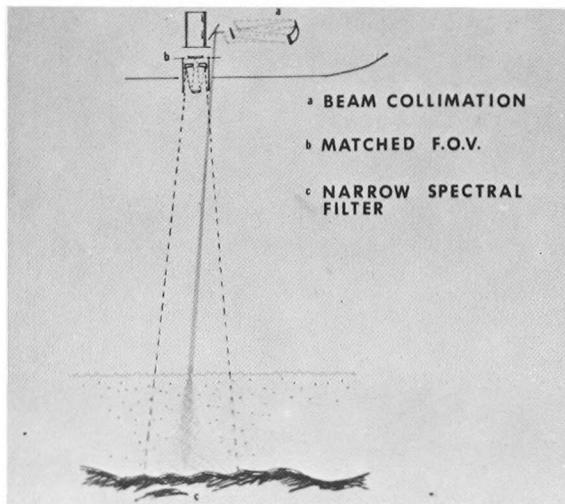


FIG. 4. — The matched field of view between the laser and the receiver.

Figures 2 and 3 are interior views of the C-54 aircraft used in the tests, showing the NASA neon laser and the receiver, along with the associated electronics, operator's console and the 35 mm movie camera used to record the signal data on film. The schematic in figure 4 shows the field of view (FOV) matched between the laser and the receiver.

Figure 5 shows the test areas off Boca Chica Key, Florida. A hydrographic boat survey was conducted here to provide the ground truth needed for subsequent comparison purposes. Figures 6 and 7 show the underwater topography below the 5 flight lines by laser and NOS chart respectively. Figure 8 compares (not at same vertical scale) one depth profile by laser and by boat sounding.

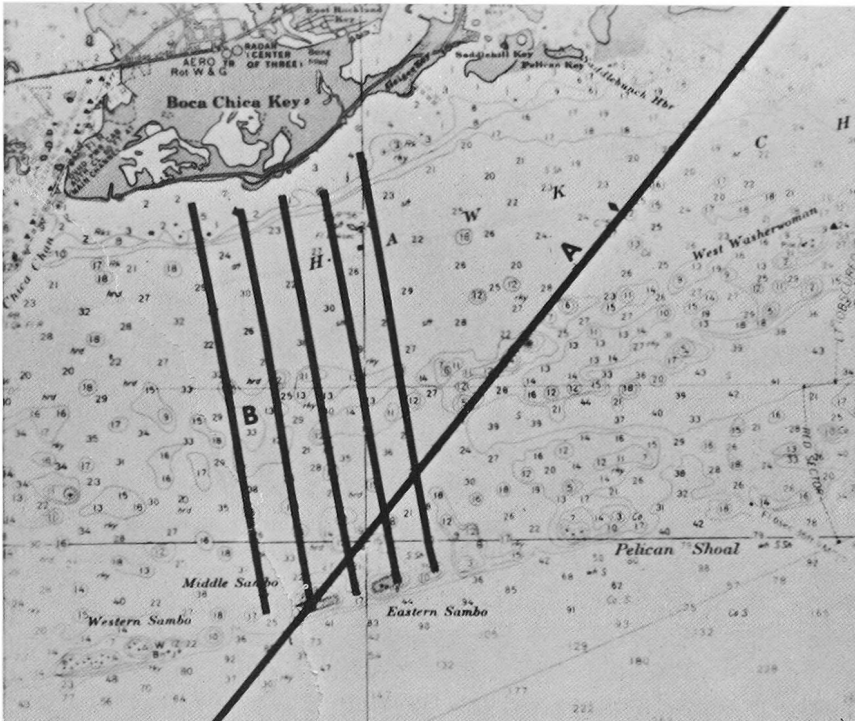


FIG. 5. — The test areas off Boca Chica Key, Florida. Line A is the laser test range. Lines B mark the photo-laser test area, 2 × 7 miles.

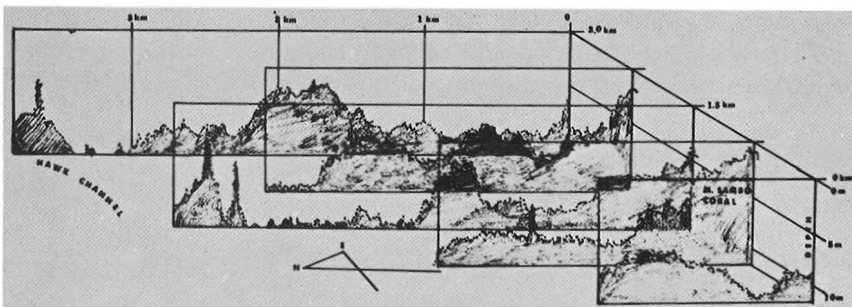


FIG. 6. — Underwater topography beneath the 5 flight lines as created by the airborne laser bathymeter (viewed from the West). Note the coral ridges running across the area in a NW-SE direction.

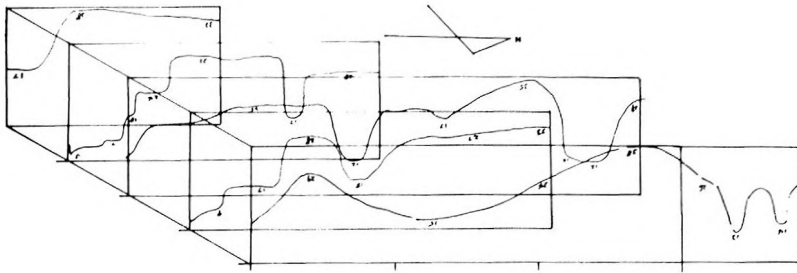


FIG. 7. — The same profiles from the 1963 National Ocean Survey chart. Note the similarity of the ridge true data but the significantly less definitive profile lines.

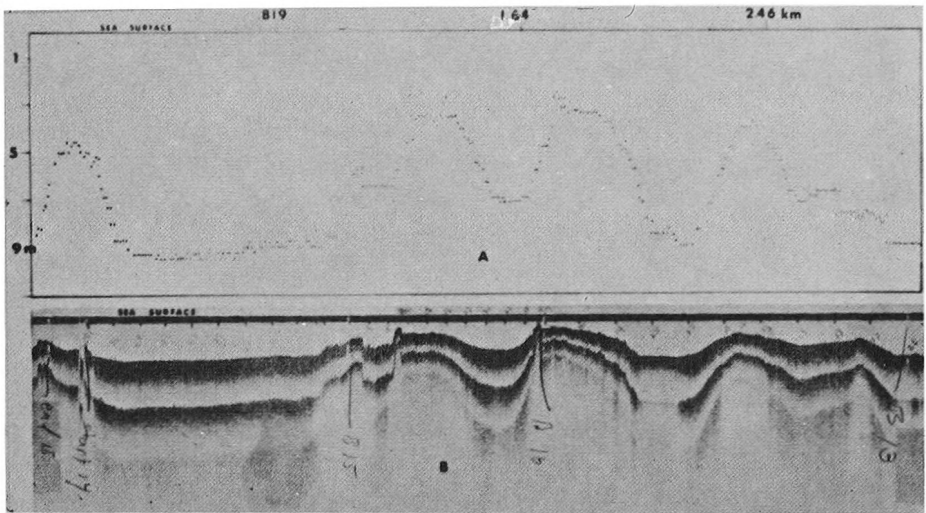


FIG. 8. — A comparison of laser profile (above) with echosounder (below). The depth data is not at the same scale.

Figure 9 gives a better comparison of the sonar and laser data to scale. There is a fairly constant agreement between the two profiles with the laser indicating a somewhat deeper profile. We can only attribute this to the fact that it was difficult to fly exactly along the same track as traversed by the sounding boat even though an effort was made to follow the course, which was flagged with floats. During this flight we also took absorption coefficient (α) measurements at each of the buoy stations. α (h) is a measure of the system capability, where "h" is the depth of the water. With an α (h) of 5 it is theoretically possible to get 10 metre depths in water with an α reading of 0.5. You can see that around α (h) of 5 we lost the signal

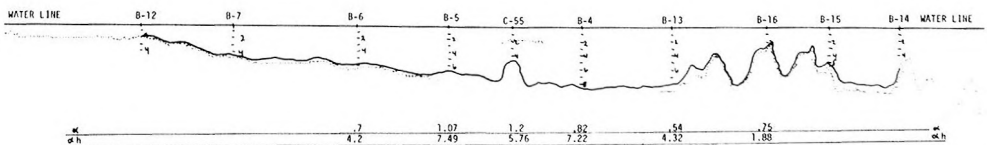


FIG. 9. — Laser depth determination plotted against sonar soundings along a Key West survey line, August 1974.

— sonar All depths (h) in metres.

... laser All α values extrapolated from Secchi disc readings.

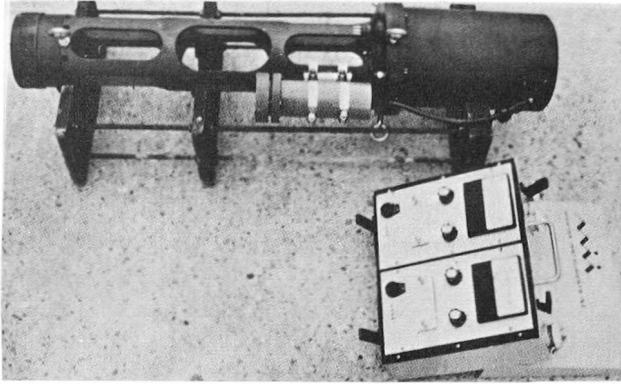


Fig. 10. — Transmissometer.

between stations B-6 and B-5 and regained the signal between B-4 and B-13. It has been estimated that coastal waters around the world have an average α reading of 0.3 [1] so it appears that 10 metre depths are not an unreasonable goal for this type of system. A concerted effort was made to obtain as much sea truth data as possible during the laser tests to check the true capability of the system. Boat operations during the flight included bottom reflectivity measurements, on the bottom α measurements gathered with a one-metre folded transmissometer (figure 10), upward and down-

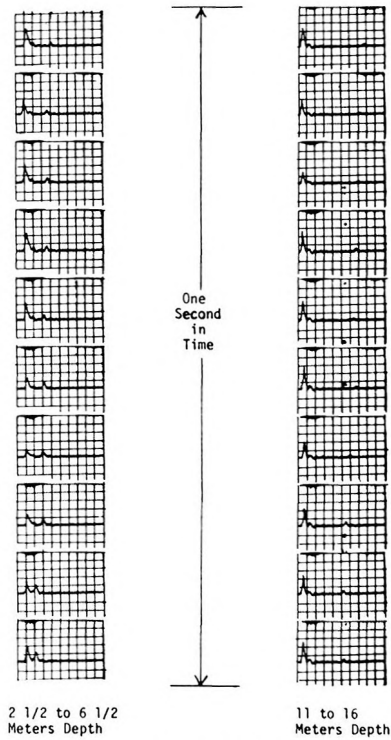


Fig. 11. — Two representative groups of signals from the oscilloscope display, showing the surface return (large peak) and the bottom return (smaller "blip"). The distance measured between these two is the water depth. Each grid intersection is approximately 2.25 metres.

ward irradiance and ambient light readings from three photometers and Secchi disc readings. Bottom samples were also taken to check their reflectivity characteristics. We are also trying to correlate absorption and scattering parameters.

Figure 11 shows how the depth by laser is measured, as the distance between the surface return and the bottom return.

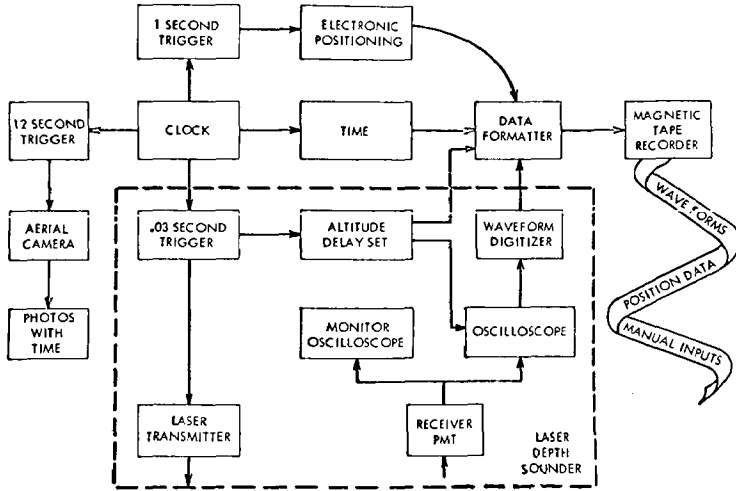


FIG. 12. — Block diagram of CAPS.

Figure 12 gives a schematic of the CAPS concept. In order to integrate the laser, photo, and positioning data a timing mechanism is used to trigger the camera and positioning system to assist in the data reduction. Data from the receiver photo-multiplier tube is fed into the monitoring oscilloscope and the wave-form analyser which is displayed on a second oscilloscope. The digital data along with the altitude delay and timing data will be formatted and recorded on magnetic tape.

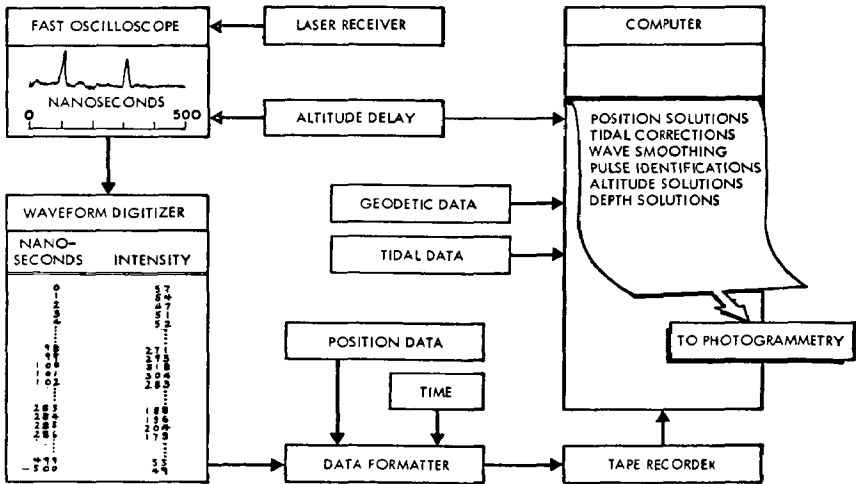


FIG. 13. — CAPS data reduction diagram.

The CAPS data reduction concept is shown in figure 13. The altitude delay is removed to facilitate data logging and subsequent data processing. The geodetic data, tide data and digital data are fed into the post-processing computer which then computes the parameters required for the lidar-grammetric compilation. Contouring and planimetric detailing can then be accomplished for the finished product.

PHASE II TESTING

In summer 1974, prior to the tests just described, we placed an order with International Laser Systems for a new YAG laser. The impetus for this was based on the improvement in reliability of these lasers over the YAG we used with our PLADS system plus the possibility of flying at

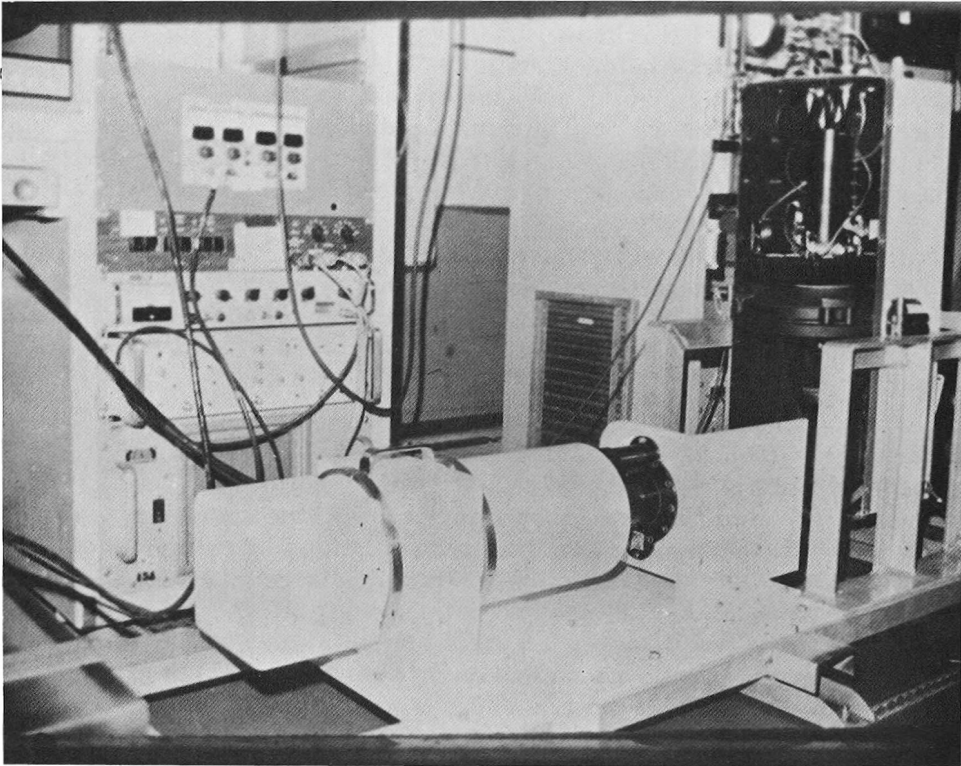


FIG. 14. — The YAG laser (left), receiver (right) and electronics, mounted in the aircraft.

higher altitudes where color aerial photography would be more effective. In February 1975, we were conducting tests with the new NAVOCEANO frequency-doubled, neodymium, YAG laser which had been delivered in December. This laser is 1000 times more powerful than the neon laser tested in August. See figure 14.

These new tests, which were originally designed to check only the penetration capability of the YAG laser from higher altitudes were significantly expanded to include a camera system and a positioning system, which was a difficult task considering we had only six weeks to prepare. Because of the altitude problem it was felt advantageous to have a super-wide-angle camera mounted in the airplane to give us maximum coverage of the area, as well as a good resolution capability. Finding such a camera with a 9.5" film format was not easy. However, a Zeiss RMK-23, 85 mm focal length lens camera with a reseau grid was finally rented for this purpose and installed in the aircraft. At 2000 feet altitude we could blanket our test area with 80% forward lap and 65% sidelap to give us plenty of redundancy. The reseau was to be used to compute film shrinkage and lens distortion. Also, due to the speed of the aircraft we had to use the *minus blue* film which was the only film fast enough to preclude image motion at these altitudes.

Thirty-five underwater targets made from 125 cm × 245 cm sheets of plywood and painted white, with a black 45 cm diameter circle, were placed in Hawk Channel to help bridge this turbidity gap and give us true depths to check our laser. This channel has always been a problem on this test area due to the murky bottom conditions. The center dot on each target was calculated to show up as a 60 micron dot on the aerial photographs, which could thus give us very precise location data. These targets were held in place by over 5 tons of concrete block and anchored with steel cable 3 m above the muddy channel bottom, in approximately 9 metres of water. They could be seen easily from the surface when implanted. Each target was then marked with a cluster of three fishing-net floats. In addition, several points were targeted on the reefs and two additional test targets were placed near the reefs. A team of three divers placed the targets on the bottom, and cleaned them before each flight in order to assure their being seen from the air.

The locations of the targets were determined with an Autotape DM-40 positioning system. Our original intention was to use a helicopter for this purpose by hovering over the targets at 10 metres altitude. We were able to do this for several targets by lowering the antenna out of the sonobuoy hole. However, there was no viewing port so it became extremely difficult to look out the side and then try to find the target through the small opening in the deck. We finally mounted the antenna in a boat and accomplished the task in less than three hours. I should mention that the Autotape antenna was then mounted on a "stinger" at the tail of the C-54 aircraft while conducting the remainder of our flight tests and it worked beautifully in all three configurations.

GOOD NEWS !

Now as you hear in so many stories these days, I have some good news and some bad news ! First the good news ! The good news is that the neodymium laser worked exceptionally well from 2000 feet. We had really

strong signals from the bottom, and although we did not penetrate completely over the whole channel we did get signals where the neon laser failed to penetrate. But, not only that, it operated in bright sunlight between 1100 and 1200 hours which was a significant fact. By computing the receiver signal strength required *versus* the strength of the signal we received, it is anticipated that we can expect to fly at 2500 feet without a significant loss of bottom detection and perhaps even at 3000-4000 feet, depending on the water clarity or time of day. Also, with a peak power output of approximately 1.5 to 2.0 megawatts which we presently have with this YAG, we probably can penetrate much deeper. Also, we believe it is now feasible to record depths to several hundred feet if necessary, which would increase the potential of this laser system for other bathymetric applications as well. Another advantage to higher altitude flights is the relative safety of using the laser without the fear of someone looking directly up into the beam.

One of the key tests to be performed was to digitize the laser signal data onto magnetic tape so that it could be handled automatically and efficiently for subsequent processing. Since off-the-shelf wave-form analyzers to meet this requirement were just not available, a breadboard digitizer was built using components from other NASA equipment and some engineering ingenuity. By utilizing and combining an optical multispectral scanner, an oscilloscope, a prism and some sophisticated electronics it was possible to digitize the intensity of the signal across 500 channels, in time, where each channel is integrated over a maximum of 250 discrete elements in the vertical dimension. This intensity information was then digitized for recording on a 9-channel magnetic tape unit. It was a rather exciting experiment to watch this data being recorded in real time. We know now that it can be done.

BAD NEWS !

And now for the bad news. The bad news is that after placing and positioning 35 targets in the Hawk Channel area, a storm with 35-knot winds moved in and really churned up the water, making it impossible to see any bottom detail for the remainder of the test period. However, at the very last possible moment, and I mean the *last* moment, before returning, we were able to get off a final flight around 1800 hours and flew a complete CAPS type mission. Five runs were made over the range at 2000 feet and all systems were "go". So in spite of the water which was beginning to clear somewhat by that time, we did have all systems working together and working very well. The laser was triggering at 10 pps and digitizing the signal on the magnetic tape, the Autotape was printing out range data at one position per second, and the camera was taking a picture once every four seconds; all at 2000 feet altitude. This was a significant accomplishment and strengthened my belief that the concept is sound and that with diligence we can anticipate using this type of data acquisition system for operational surveys in the very near future.

CONCLUSION

I trust that this is only the beginning of what will someday be a truly high-speed, nearshore, hydrographic data acquisition system. We still have a long way to go and we are always open to suggestions or assistance. Let me *cap off* this paper by saying — our CAPS off and running, and our *caps off* to the *International Hydrographic Review* for allowing us to share our findings with their readers.

ACKNOWLEDGEMENTS

1. The experimentation and testing of the laser depth sounders was accomplished by a joint agency group (NAVOCEANO/NASA/CDC Contractors) under the expert direction of Mr. Honsuk KIM, Principal Investigator for NASA.

2. The laser, aerial camera and Autotape installation, and the job of making them work together, is a credit to the expertise of Mr. Frederic DARLING, electronic engineer and aircraft equipment installer for the U.S. Naval Oceanographic Office.

REFERENCE

- [1] LEPLEY, L.K. : Coastal Water Clarity from Space Photographs. *Photogrammetric Engineering*, Vol. 34, No. 7, 1968, pp. 667-674.