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AIRBORNE OCEANOGRAPHIC LIDAR SYSTEM

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ABSTRACT

This paper acquaints the technical community with the characteristics of an Airborne Oceanographic Lidar (AOL) developed for NASA by AERL, Inc. We describe the AOL system, discuss its potential for various measurement applications including bathymetry and fluorosensing, and invite interested investigators to become users.

INTRODUCTION

A major purpose of this paper is to acquaint the technical community with the characteristics of an Airborne Oceanographic Lidar System (AOL) which was developed for NASA by Avco Everett Research Laboratory, Inc. The system has been installed in a NASA Wallops Flight Center C-54 aircraft and is available for environmental measurements by interested users. Accordingly, this paper will discuss the potential of the AOL for various measurement applications and also invite interested investigators to arrange to become users of the AOL.

The AOL is an airborne, spatially scanning, range gated lidar system that can be operated in either of the two modes. In one mode, it can be used to measure topographical relief or water depth (bathymetry) through its range resolution capability (± 0.3 m vertical). Alternately, the system can be used as a fluorosensor to measure fluorescent spectral signatures from 3500 Å to 8000 Å, with 100 Å resolution, of targets which are irradiated by the transmitted laser pulse (e.g. water borne substances), or which passively fluoresce. The system may also be used to measure fluorescence decay times as a function of wavelength. A system description is presented. System measurement parameters are emphasized. These include for both modes as appropriate: ground coverage vs. aircraft altitude, search pattern and sampling density, minimum and maximum depth, horizontal measurement accuracy, excitation spectral range, fluorescence spectral range, spectral resolution and temporal resolution.

Figure 1 is an illustration of the operation of the system in the bathymetric mode. The system detects the laser backscattered return from the water surface and then from the bottom. A typical oscilloscope trace is shown in the figure. By measuring the time interval, between the bottom return and the water surface t_1-t_2 , the instantaneous depth can be determined. When additional information about the altitude of the aircraft is included, wave height and sea state are also determined. Figure 2 is an illustration of the system operating in the fluorosensing mode. An oil spill is used to represent a typical fluorescing material. In this mode the return is fed into a spectrometer and the characteristic spectrum is recorded. In addition to the spectral channels, there are also several time channels available so that the fluorescent decay vs time can also be monitored. These two parameters can often be used to determine the nature of the fluorescing material. In addition by using the information available from the water Raman return, it is possible to determine the absolute conversion efficiency of the material which can often be a substantial aid in identifying the fluorescent substance.⁽¹⁾

Figure 3 shows a top view and side view of the system as installed in the NASA C-54 aircraft. The system is configured in three levels, all firmly attached to one another for

optical stability. The topmost tier is the transmitter section on which is mounted the laser and an adjustable (2-20 m μ) beam expander. Because of the placement of the laser, it is very easy to interchange lasers should this be desirable. The transmitter contains a nitrogen pumped dye laser operating at 400 Hz which enables one to have a wide selection of available wavelengths. If the dye module is removed, the nitrogen laser itself can be used directly, providing a UV output at 3371 Å. If the nitrogen module is filled with neon, this gives a wavelength of 5401 Å, a wavelength very suitable for shallow water bathymetry.

The intermediate tier contains the receiver section which includes a 1220 mm f/4 telescope and a very fast (~ 1.5 nanosecond), sensitive detector for the bathymetric mode. With the insertion of a folding mirror, the system is converted to the fluorosensing mode where the beam is sent to a 40 channel spectrometer, covering the wavelength range from 3500 Å to 8000 Å.

The lowest tier, which is located beneath the aircraft floor in the cargo bay, contains the scanner assembly which consists of a rotating off-axis mirror. Figure 4 shows a typical ground pattern which can be obtained from this type of scanner. Each small circle represents a laser pulse, and the mirror angle and aircraft velocity and altitude are selected to provide an optimum interlace of the laser ground pattern. The aircraft is flying in the positive x direction. Figure 5 shows a view of the system as installed in the aircraft, looking forward. In this view one can see the placement of the electronics racks and the relationship of the scanner to the cargo hatch which already existed in the skin of the aircraft.

Figure 6 is a block diagram of the basic AOL Electronics system. The heart of the system is a 32 K memory Hewlett Packard 2125A computer which both controls the experiment and gathers the data. The data are immediately recorded on a 15 megabyte disc, and subsequently transferred to magnetic tape. This feature allows the system to handle the very large incoming data rate engendered by the 400 Hz maximum operating repetition rate. The data are then available on magnetic tape for post flight analysis. This feature allows the system to have a high area interrogation rate. To the left of the interface, the system consists of high speed state-of-the-art electronics. The 40 channels available can be used either for time or spectral resolution. The interface is standard Camac equipment which translates the output of the high speed electronics into computer language and vice versa. The computer interfaces with a real-time display and can be used to support some real-time processing.

Table 1 is a summary of the optical features of the system, and Table 2 is a summary of the system's electronic features. Table 3 is a listing of the AOL measurement capability and performance characteristics in the bathymetric mode, and Table 4 is a listing of the system's measurement capabilities and performance characteristics in the fluorosensing mode.

Table 5 is a listing of the various applications which have been suggested for the AOL system in the bathymetric mode, and Table 6 is a listing of the various applications which have been suggested for the use of the system in the fluorosensing mode. Suggestions for other possible applications from interested readers would be very welcome. Some additional detailed information on performance requirements, specifications, and design are included in Ref. 2.

Figure 7 is an illustration of the data which were obtained with the system during laboratory tests. In this particular test, a lucite sheet was used to simulate the water surface located at a distance of 25.25 M from the system, and a second target was used to simulate the ocean bottom at a distance of 35.75 M. The peak surface return appeared in channel 4 and the peak bottom in channel 33 giving a ΔR , without signal processing, of 10.8 M. More sophisticated analysis of the data would provide a value closer to the actual 10.5 M.

We have described a remote sensing lidar system mounted on an airborne platform which has the versatility and speed to perform a large number of remote sensing experiments. We expect that it will be a useful tool for the remote sensing community to perform a variety of experiments in order to establish the feasibility of using an airborne lidar to solve remote sensing problems. Interested potential users are invited to contact the authors.

REFERENCES

- (1) R. T. V. Kung and I. Itzkan, Absolute Oil Conversion Efficiency, Appl. Opt. 15, 409-415 (1976).
- (2) NASA Contractor Report CR 141407, "Airborne Oceanographic Lidar System" Final Report Avco Everett Research Laboratory, Inc. (Oct. 1975) Contract Number NAS6-2653.

TABLE 1
SUMMARY OF AOL OPTICAL SYSTEM CHARACTERISTICS/FEATURES

Transmitter

- Laser-Flexible, to provide broad wavelength variability
 - 3371 Å with N₂
 - 5401 Å with Ne
 - 3500-6700 Å with dye module
- PRF variable 0-400 Hz
- Beam Expander - Adjustable 2-20 mr
- Polarizer - Removable and rotatable through 90°
- Folding Mirrors - Kinematic mounting with 3-point adjustments for ease of alignment

Receiver

- Telescope - Externally adjustable baffle (2-20 mr) for daylight S/N optimization
- Field Stop - Electrically adjustable (0-20 mr) for daylight S/N optimization
- Polarizer - Removable and rotatable through 90
- Detector Assembly - Mode changes between bathymetry and fluorosensing achievable thru quick insertion of folding flat
 - Bathymetry: Single, high speed channel
 - Fluorosensing: 40 channel spectrometer (3500-8000 Å); Resolution - 140 Å/Channel; active or passive
- Check Lamp - Allows quick check of PM response prior to data taking
- Filters - Slide mounted for ease of replacement

Scanner

- Scan Angle - Adjustable at 0°, 5°, 10° or 15°
- Rotational Position - Readout accuracy 2.6 min
- Mounting - Fixed to optical platform for alignment stability

TABLE 2
SUMMARY OF AOL ELECTRONICS SYSTEM CHARACTERISTICS/FEATURES

Control and Data Acquisition Subsystem

- Data Acquisition Electronics
 - Contains 48 channels, 41 presently in use
 - Flexible (2.5 - 100 nsec continuously adjustable channel width)
 - Common Electronics used for both bathymetry & fluorosensing
 - Low jitter (< 200 psec)
 - Fast (< 1.5 nsec risetime)
 - Modularly expandable
- Altitude Intervalometer
 - ± 0.3 m altitude accuracy

I/O Controller Subsystem

- Computer
 - Real time disc operating system
 - Performs scheduling, priorities, interrupts; allows operator interaction
 - Flexible software, easily modified for existing experiments or to implement new experiments
 - Good data gathering endurance with 15 MByte disc
 - Bathymetry mode: 3 min per run
 - Fluorosensing mode: 6 min per run
 - Keyboard with printer provides easy operator access & capability for quick-look data dumps
- Display
 - Provides real-time raw data presentation for system operators
- Recorder
 - All data recorded in IBM/ANSI compatible digital format for ease in off-board data processing
 - Good tape endurance
 - Bathymetry mode: 9 min per tape
 - Fluorosensing mode: 18 min per tape
 - Data taking limited by aircraft endurance

TABLE 3
AOL MEASUREMENT CAPABILITIES & PERFORMANCE CHARACTERISTICS

BATHYMETRY

Measurement Depth	6 m with $\alpha = 2 \text{ m}^{-1}$; 10 m with $\alpha = 1 \text{ m}^{-1}$
Area Coverage	One data point per 20 m^2 , $\pm 5 \text{ deg}$ from nadir Capability to $\pm 15 \text{ deg}$
Minimum Measurement Depth	0.6 m
Vertical Measurement Accuracy	$\pm 0.3 \text{ m}$
Horizontal Measurement Accuracy	1.07 m RMS ⁽¹⁾
Sea State	Measurement Provided
Transmitter Wavelength	5401 Å (with neon)
Transmitter Bandwidth	$< 1 \text{ Å}$
Transmitter Pulse Width	3 nsec
Transmitter PRF	$\leq 400 \text{ Hz}$
Transmitter Peak Output Power	10 kW
Transmitter Beam Divergence	2-20 mr Variable with beam expander
Receiver Spectral Resolution	$5401 \pm 2 \text{ Å}$
Receiver Field of View	1-20 mr, variable
Receiver Temporal Resolution	2.5 nsec
Polarization	Available for transmitter & receiver
Measurement Altitude	$\leq 600 \text{ m}$
Measurement Velocity	280 km/hr
Measurement Background	Day & night
Ground truth	Interface for footprint camera provided

(1) System contribution. Total accuracy 5 m RMS

TABLE 4
AOL MEASUREMENT CAPABILITIES & PERFORMANCE CHARACTERISTICS

FLUOROSENSING

Transmitter Wavelength	3371 to 6600 Å, variable
Transmitter Bandwidth	1 Å at 3371 Å, 2 - 10 Å elsewhere ⁽¹⁾
Transmitter Pulse Width	10 nsec at 3371 Å, 2-8 nsec elsewhere
Transmitter PRF	$\leq 100 \text{ pps}$
Transmitter Peak Output Power	100 kW at 3371 Å, 3-30 kW elsewhere
Transmitter Beam Divergence	3-20 mr at 3371 Å, 1-3 mr elsewhere
Receiver Bandwidth	3500-8000 Å (40 channels)
Receiver Spectral Resolution	140 Å/channel over spectral range
Receiver Field of View	1-20 mr, variable
Receiver Temporal Resolution	8-100 nsec, variable
Sea State	Measurement provided
Measurement Altitude	150 m
Measurement Velocity	280 km/hr
Measurement Background	Day & night
Ground Truth	Interface for footprint camera provided

(1) Varies with dye in dye laser module

TABLE 5
POTENTIAL AOL APPLICATIONS
BATHYMETRIC MODE

Bathymetry and Ocean Physics

- Coastal and Channel Charting
 - Quick Check and Reconnaissance
- Sea State Measurement
- Water Transparency and Turbidity Measurement
 - Sediment Concentration
- Solar Glitter vs Sea State Measurement

Fish School Detection and Track

Height Assessment

- Crops
- Forests
- Terrain

TABLE 6
POTENTIAL AOL APPLICATIONS
FLUOROSENSING MODE

Oil Identification

- Crude and Refined Petroleum Products
 - Survey and Surveillance
- Fish Oils

Water Quality

- Pollutant Identification
 - Industrial Effluents
 - Sewage
 - Hazardous Materials
- Algae Detection and Measurement

Water and Tidal Conditions

- Currents and Temperature

Crop Cover and Forest Assessment

- Type Identification
- Health

Geological Exploration

- Resource Discovery and Survey

Other

- Use of Dye Seeding to Support Other Measurements

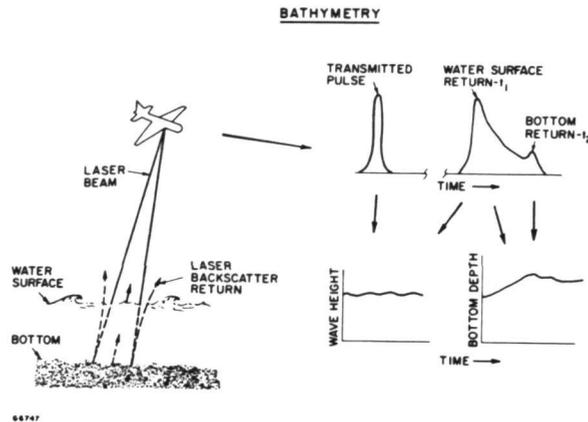


FIGURE 1

SYSTEM OPERATION IN BATHYMETRIC MODE.
Time interval between bottom and surface returns
provides depth information on a per pulse basis.

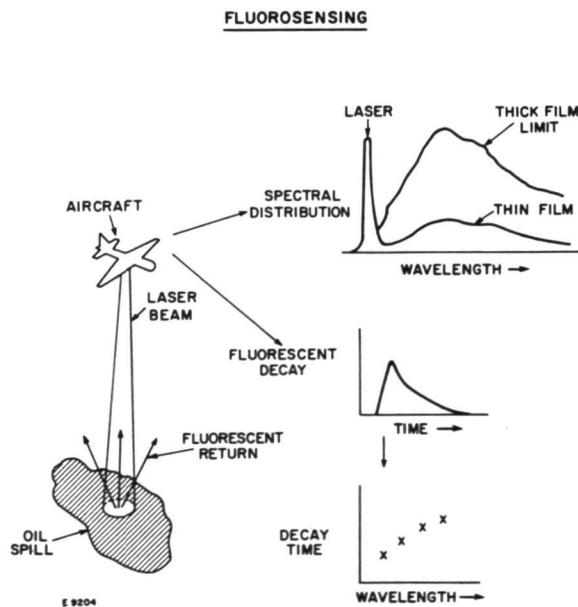
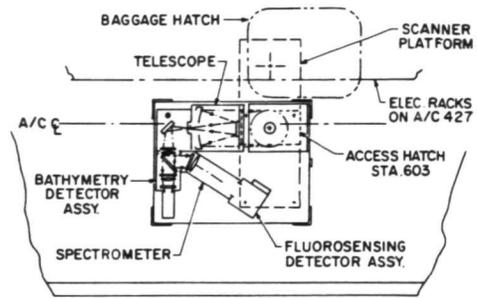


FIGURE 2

SYSTEM OPERATION IN FLUOROSENSING MODE.
Fluorescent spectra and fluorescent decay time vs
wavelength are measured.



SEC A-A

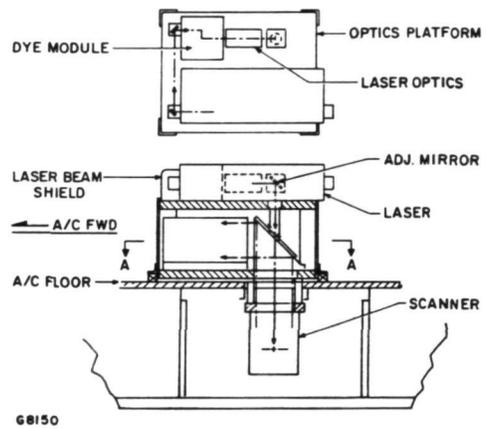
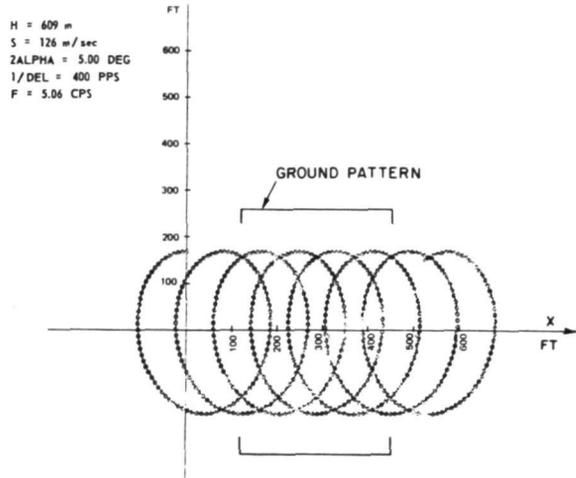


FIGURE 3

SYSTEM INSTALLATION - Top and Side Views.
The ready accessibility of the dye modules is
evident in this figure.

SCANNING PATTERN FOR CONDITIONS SHOWN



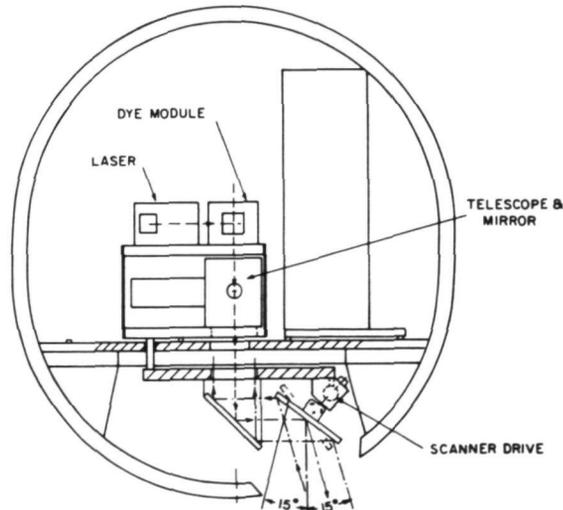
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FIGURE 4

TYPICAL SCANNING PATTERN

The ground scan pattern can be adjusted to match coverage requirements. The aircraft velocity lies along the x axis.



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VIEW LOOKING FWD

FIGURE 5

SYSTEM INSTALLATION - Forward View.
The scanner configuration in the C-54 cargo hatch is clearly shown.

AOL
BASIC ELECTRONICS SYSTEM BLOCK DIAGRAM

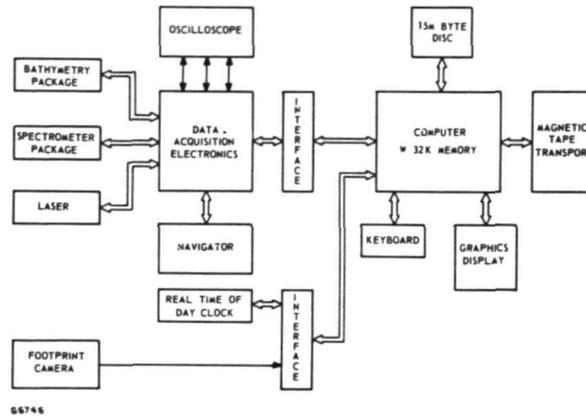


FIGURE 6

AOL ELECTRONICS
The electronics provide for high data rates and large data storage capacity with real-time display for operational ease.

AOL LABORATORY TESTS
BATHYMETRY MODE

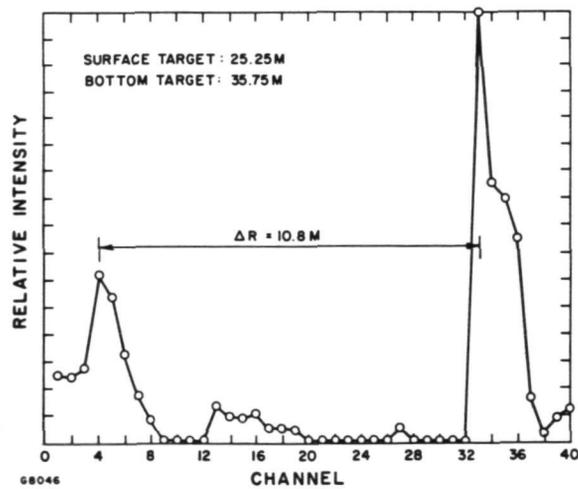


FIGURE 7

AOL LABORATORY DATA BATHYMETRY MODE
Simulated surface and bottom returns are shown.