MONITORING OF PLANKTON PRODUCTIVITY MIGRATION OF JUVENILE SALMON AND OIL POLLUTION USING A NEWLY-DEVELOPED AIRBORNE FLUORESCENT SENSOR

EE-142

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MONITORING OF PLANKTON PRODUCTIVITY MIGRATION OF JUVENILE SALMON AND OIL POLLUTION USING A NEWLY-DEVELOPED AIRBORNE FLUORESCENT SENSOR

by

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ABSTRACT

A 64 channel, range-gated laser Environmental Airborne Fluorosensor has been developed for Environment Canada to enhance its oil spill response capabilities. The new gated diode array spectrometer provides much improved spectral resolution when compared to earlier 5 channel dichronic units. The variable gating feature allows for sampling at different depths (ie. detection of submerged oil) as well as strong rejection of scattered sunlight. A series of test flights were undertaken to verify the integrity of the airborne system and for the detection of oil on water, on ice, and on beach environments. Simple algorithms, based on correlation of in-flight and reference spectra, allow oil to be discriminated from water, ice, sand, gravel and rocks, on a single-shot basis including cases where the background spectra are comparable in intensity to the oil fluorescence spectra.

RÉSUMÉ

Environnement Canada a fait mettre au point un fluorocapteur environnemental aéroporté à laser à créneaux de distance de 64 canaux pour mieux intervenir en cas de déversement d'hydrocarbures. Le nouveau spectromètre à réseau de diodes à déclenchement périodique produit une bien meilleure résolution spectrale que les appareils dichroïque à canaux précédents. Le déclenchement variable permet d'échantillonner à des profondeurs différentes (donc de détecter des hydrocarbures immergés) et d'éliminer efficacement la lumière du jour diffuse. Une série de vois d'essai ont été entrepris pour vérifier l'intégrité du système aéroporté et détecter la présence d'hydrocarbures sur l'eau, la glace et les plages. Des algorithmes simples, basés sur la corrélation entre les spectres en vol et les spectres de référence, permettent de distinguer d'un seul coup les hydrocarbures de l'eau, de la glace, du sable, du gravier et des roches, notamment lorsque les spectres de fond sont camparables en intensité aux spectres de fluorescence des hydrocarbures.

Résumé

Environnement Canada a fait mettre au point un fluorocapteur environnemental aéroporté à laser à créneaux de distance de 64 canaux pour mieux intervenir en cas de déversement d'hydrocarbures. Le nouveau spectromètre à réseau de diodes à déclenchement périodique produit une bien meilleure résolution spectrale que les appareils dichroïque à canaux précédents. Le déclenchement variable permet d'échantillonner à des profondeurs différentes (donc de détecter des hydrocarbures immergés) et d'éliminer efficacement la lumière du jour diffuse. Une série de vois d'essai ont été entrepris pour vérifier l'intégrité du système aéroporté et détecter la présence d'hydrocarbures sur l'eau, la glace et les plages. Des algorithmes simples, basés sur la corrélation entre les spectres en vol et les spectres de référence, permettent de distinguer d'un seul coup les hydrocarbures de l'eau, de la glace, du sable, du gravier et des roches, notamment lorsque les spectres de fond sont camparables en intensité aux spectres de fluorescence des hydrocarbures.

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1. SCOPE

This is the Final Technical report on Contract #KE144-0-6477/01-SS, covering the period 06th March 1991 to 31st March 1992.

2. INTRODUCTION

At the time this contract was let, there were already in existence,under various ownerships, a number of aircraft-compatible hardware and software modules related to Airborne Laser Fluorosensing. In general terms, these were:

- Aircraft-certified Excimer Laser Transmitter;
- Dall-Kirkham Receiver Telescope;
- 64-channel Gated Diode-Array Spectrometer (GDAS);
- Datapak data recorder and system controller;
- 5-channel fluorosensor software package for the Datapak;
- Field-station data-reduction software for a 5-channel fluorosensor;
- Operators Console, containing the Datapak, the controller for the Excimer Laser,and a digital chart recorder;
- Kit of parts for a dye laser;
- Support units, such as power inverters, track-recovery video, GPS receivers, and spares.

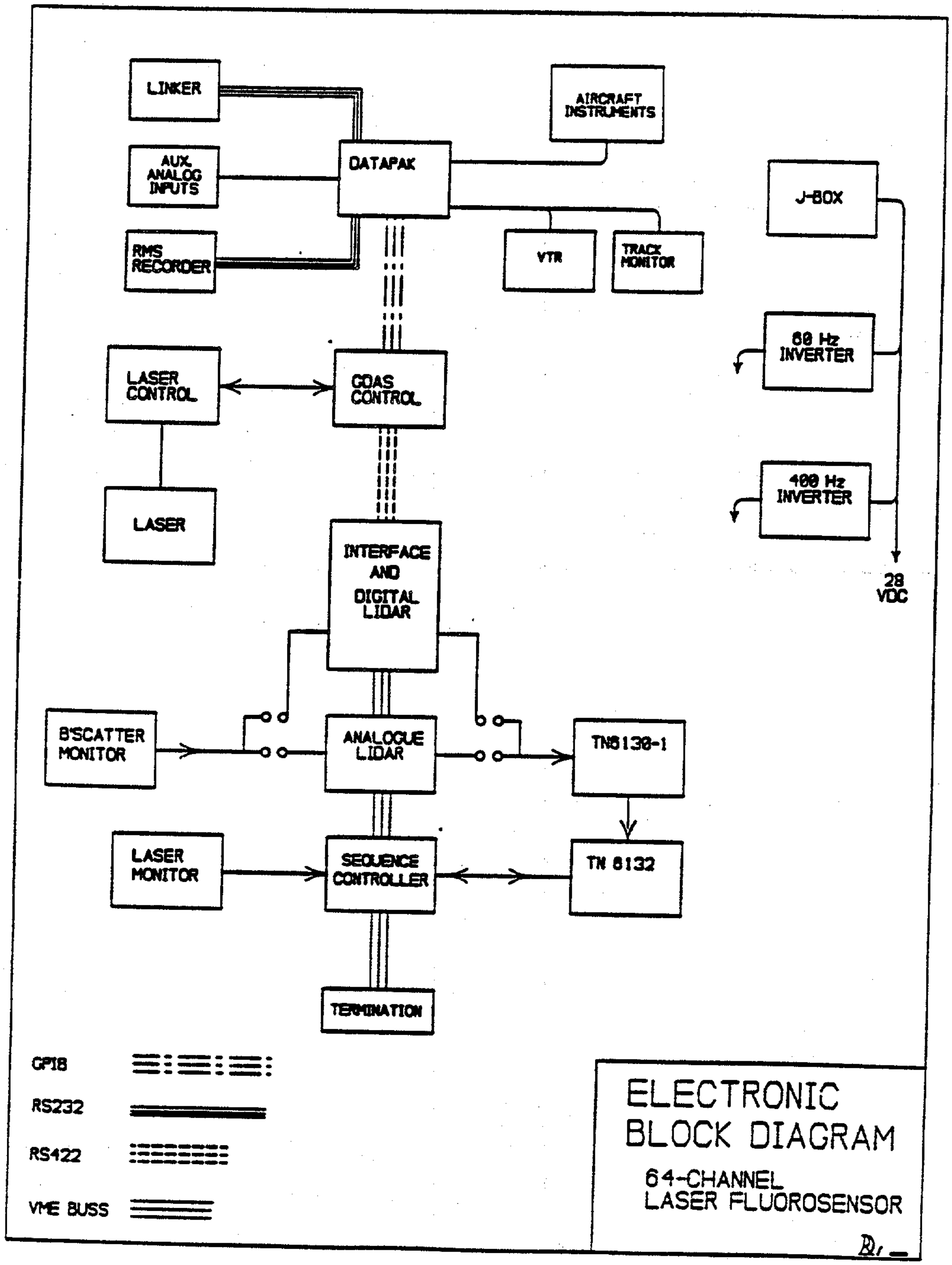
The objectives of this contract were:

- Upgrade existing units and code, where appropriate, to 64-channel operation;
- Integrate them to form a self-contained, 64-channel, range-gated, Laser Environmental Airborne Fluorosensor (LEAF);
- Design for the future addition of a dye laser;
- Flight-test the system for the detection of oil on water, on shorelines, and on ice.
- Prepare a design study for an operational LEAF.

3. SYSTEM CONSTRUCTION AND CHECK-OUT

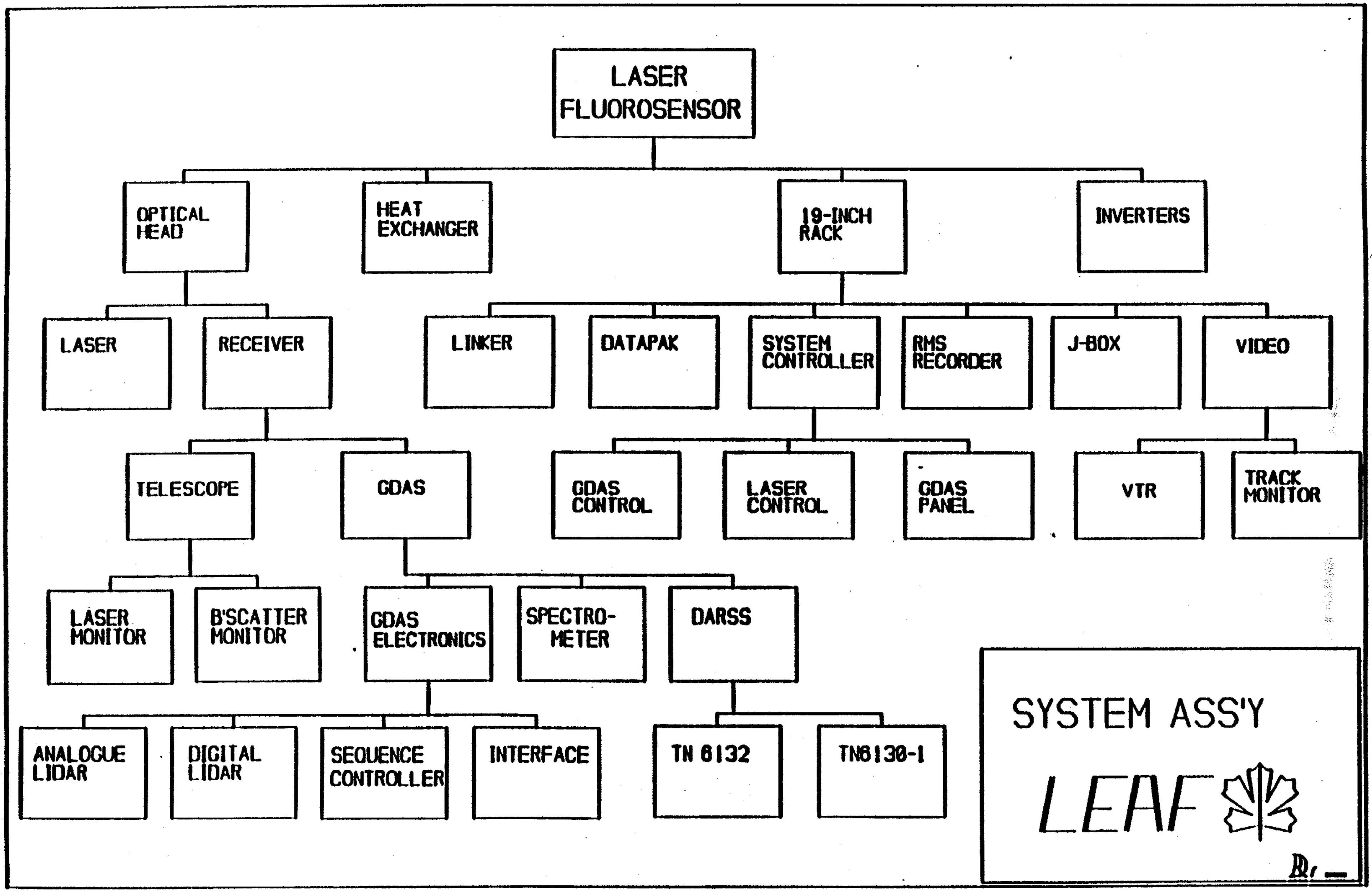
3.1 System Description

The Block Diagram for LEAF is shown in Fig. 1, the mechanical assembly tree in Fig.2 and the general arrangement in an Aerocommander in Fig.3. Structurally, the system resembles the Barringer FLUOROSCAN(R) hydrocarbon exploration system, but an entirely new Gated Diode Array Spectrometer has replaced the 5-channel dichroic unit, an in-flight calibration facility has been added, and substantial upgrades have been made to the software for control, data-logging and real-time display. As is evident from Table 1, the array gives the system much better spectral resolution than earlier units, and the adjustable gating feature gives



LINKER
AUX. ANALOG INPUTS
RMS RECORDER
DATAPAK
AIRCRAFT INSTRUMENTS
VTR
TRACK MONITOR
J-BOX
60 Hz INVERTER
400 Hz INVERTER
28 VDC
LASER CONTROL
GOAS CONTROL
LASER
INTERFACE AND DIGITAL LIDAR
B'SCATTER MONITOR
ANALOGUE LIDAR
TN6130-1
LASER MONITOR
SEQUENCE CONTROLLER
TN 6132
TERMINATION
GPIB
RS232
RS422
VME BUSS
ELECTRONIC BLOCK DIAGRAM
64-CHANNEL LASER FLUOROSENSOR

Fig. 1



LASER FLUOROSENSOR
OPTICAL HEAD
HEAT EXCHANGER
19-INCH RACK
INVERTERS
LASER
RECEIVER
LINKER
DATAPAK
SYSTEM CONTROLLER
RMS RECORDER
J-BOX
VIDEO
TELESCOPE
GDAS
GDAS CONTROL
LASER CONTROL
GDAS PANEL
VTR
TRACK MONITOR
LASER MONITOR
B'SCATTER MONITOR
GDAS ELECTRONICS
SPECTRO-METER
DARSS
ANALOGUE LIDAR
DIGITAL LIDAR
SEQUENCE CONTROLLER
INTERFACE
TN 6132
TN6130-1
SYSTEM ASS'Y
LEAF

Fig. 2

Table 1 - LEAF Parameters

Telescope		
Diameter	203mm	
f\#	f\3.1	
Field of View	1 x 3 mrad	
Spectrometer		
Optics	Catadioptric Czerny-Turner	
Grating(s)	600\mm, blazed @ 400nm	
	900\mm, blazed @ 525nm	
	600\mm	900\mm
Resolution	5.3nm	3.5nm
Spectral Range	328-665nm	530-710nm
Gatewidth	20-150ns	
Gate Delay	±100ns (rel. to laser)	
Gain Range	256.:1 in 15 steps	
Laser		
Type	XeCl excimer @ 308nm	
Pulse Rate	100pps	
Av. Power	1 watt (max)	
Peak Power	1Mw	
Beam Divergence	1 x 3 mrad	
Weight & Power		
Power	< 60A @ 24 - 32VDC	
Installed Weight	750lb	

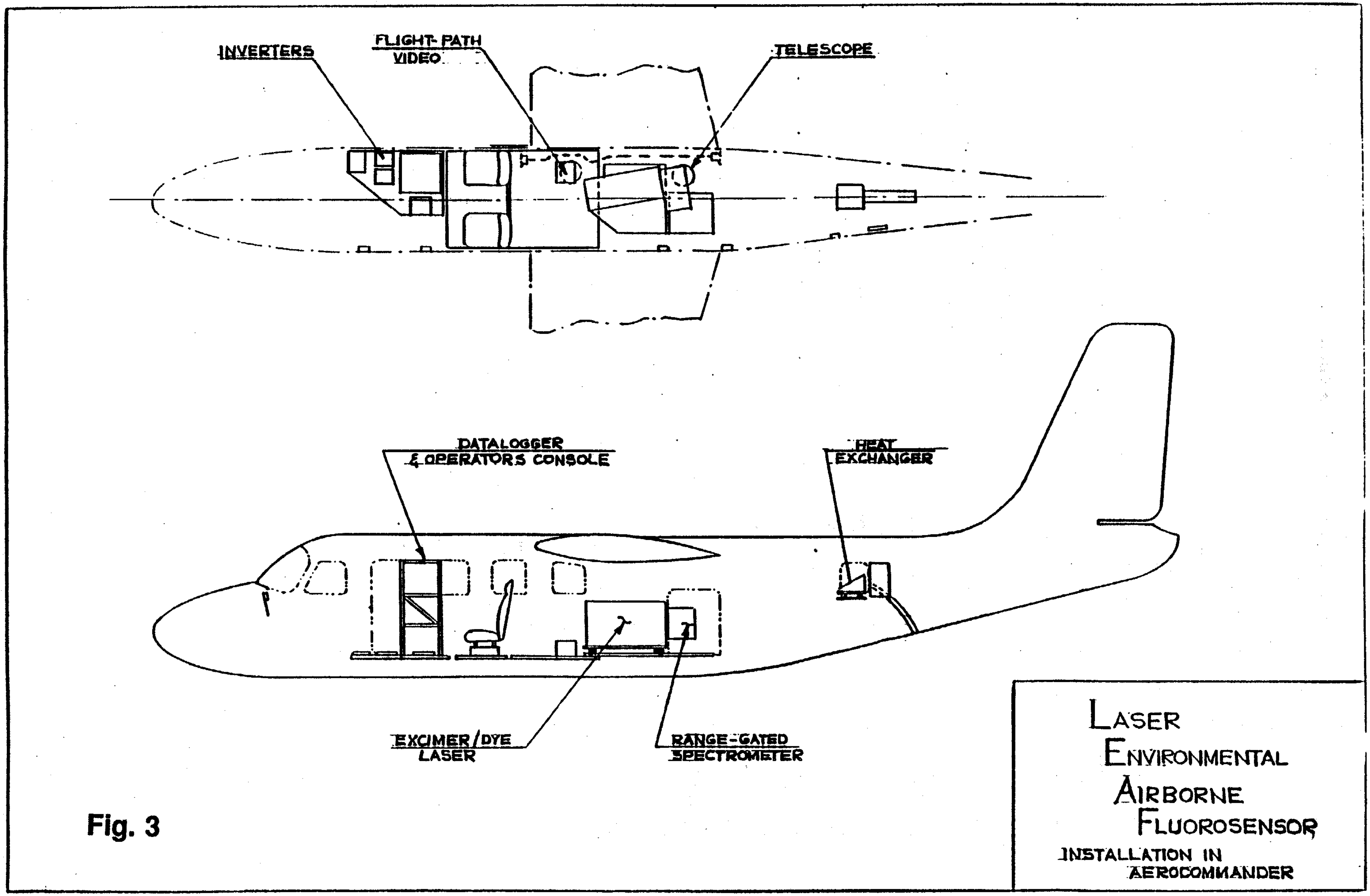

INVERTERS
FLIGHT-PATH VIDEO
TELESCOPE
DATALOGGER & OPERATORS CONSOLE
HEAT EXCHANGER
EXCIMER/DYE LASER
RANGE-GATED SPECTROMETER
LASER
ENVIRONMENTAL
AIRBORNE
FLUOROSENSOR
INSTALLATION IN
AEROCOMMANDER

Fig. 3

strong rejection of scattered sunlight and allows sampling at different depths. Depth sampling allows the detection of submerged oil, (within the limits set by the absorption coefficient of water at the laser wavelength) and will be most useful in future water-quality, water temperature and biomass measurements.

In flight, the system operator controls the system by means of commands entered into the DATAPAK via a hand-held, RS-232 terminal. The DATAPAK is an STD-buss data-logging and control system, designed for airborne remote sensing. Having entered the desired conditions, the operator sets the DATAPAK 'ON-LINE', and it sends a set-up message to the System Controller, followed by a stream of trigger messages at a 10Hz rate. Communication between the units is via an IEEE-488 link, using slave processors, with Direct Memory Access, at each end. On receipt of each trigger, the System Controller sets up the conditions (gain, gate-width etc.) requested by the message, and proceeds to fire the laser 10 times, at a 100Hz rate. A fraction of the laser photons goes to the Laser Monitor and generates the START pulse, which starts the Lidar Altimeter. After a suitable delay, calculated from the last measured altitude and the desired penetration depth, the Altimeter gates the intensifier of the diode array 'ON' in anticipation of the arrival of the fluorescence excited by the laser. When the backscattered laser photons return to the telescope, the Backscatter Monitor issues the STOP pulse, which stops the Altimeter and starts the sequence which reads the analogue video from diode array. This video, which represents the spectrum of the laser-excited fluorescence plus the scattered sunlight, is then digitized (12-bits) by the System Controller. The read-out and digitization of the video takes about 5msec, half the period between laser shots. By this time, all fluorescence has died out, so that,when the array is again gated 'ON', the spectrum acquired is that of the scattered sunlight background. In this way, a 'SIGNAL+BACKGROUND' and a 'BACKGROUND' are acquired for each laser shot.

In the intervals of servicing the video digitizer, the System Controller does a substantial amount of processing; it examines the data and flags overflows and other doubtful values; applies background correction; calculates the spectral and temporal averages used for the real-time display; digitizes the altitude, laser energy, and other housekeeping data; and, finally, formats everything pertaining to the previous group of ten laser shots into a data message, which it returns to the DATAPAK. The DATAPAK combines the fluorosensor data with navigation and aircraft attitude data, a listing of the current value of all the system variables (gain, gate-width etc.), and a time-stamp, and records them on 1/2 inch cassette tapes. One cassette holds about 20 megabytes, which is about 20 minutes' worth of data. The DATAPAK also drives the operator's real-time display. Details of sub-system parameters can be found in Appendix 'A'.

3.2 Design of Dye Laser Modification

It is intended, as part of a separate programme, to use the LEAF to study bio-oceanographic phenomena, and this requires the addition of a dye laser (pumped by the existing excimer) and the conversion of the GDAS to cover the longwave end of the visible spectrum. This modification must be modular, so that the LEAF can quickly and easily be switched between operating modes. The optical/mechanical design of this modification has been completed under this contract. The dye laser is based on a Lambda-Physik Model FL3002. The optical elements of the Model FL3002, (omitting the second of the two amplifier stages) were mounted on a new, compact, optical bench, and an extra fold was added to the pump-beam path to the amplifier, to allow the dye-laser to be packaged into a volume matching that of the receiver telescope optics. Several of the Lambda-Physik optic mounts, which were designed for laboratory use, were modified to better survive the shock and vibration of aircraft use. The mounting interface for the LEAF receiver (telescope and GDAS) was redesigned so that the receiver can be mounted either at the top or bottom of the end panel of the excimer laser package. With the receiver in the upper position, the system is in the 'oil' configuration, using the excimer to excite fluorescence. Lowering the receiver allows the dye laser to be mounted in the upper position and pumped by the excimer, with its output beam exiting along the axis of the receiver to excite water fluorescence. In this latter configuration, 'oil' operation can easily be restored by removing the lower mirror of the periscope, re-installing the Excimer Beam Expander and Laser Monitor on the Receiver Telescope, and replacing the Backscatter Beamsplitter with the unit matched to the excimer wavelength. The modification has been built and satisfactorily bench-tested under a separate contract.

3.3 Software Upgrades and Maintenance

The System Controller software has been upgraded to deal with 64-channel data, to control gated operation via the Analogue Lidar Altimeter, and to operate the calibration system. The details of the operation of the controller software are given in Appendices 'B' and 'C'. The Datapak software was also upgraded to handle 64-channel data and provide a calibration capability. There was also an ongoing maintenance activity, as integration of the systems revealed that the timing of some portions of code ,which did not affect stand-alone operation, became critical when the different sub-systems were inter-connected.

3.4 Assembly and Bench Tests

The first stage of integration involved the modification of several of the subsystems and of the inter-connecting cabling. The STD-buss portion of the System was extensively re-wired to accept the new signals and to provide the new front-panel and test functions associated with 64-channel operation. It had been hoped, in the interests of economy, to repackage the laboratory version of the Sequence Controller cards (which mediate communication between the STD-buss and the Gated Diode Array and the other electro-optic sub-systems) and use them directly in the airborne system. However, these cards, which use wire-wrap connection, were found to become increasingly subject to intermittent faults, particularly if the cards were flexed or vibrated. It was concluded that the cards were unsuitable for airborne use and they were remade as Printed Circuit Boards in VME-buss format. Other subsystems also required maintenance or refurbishment. Occasional erratic operation of the clock-driver circuit in the Tracor-Northern Gated Diode Array were eventually traced to an under-rated transistor, and were cured by the substitution of a more suitable type. Air leaks into the Excimer laser were a frequent irritant until a number of fittings in the gas-fill plumbing were replaced. Increasingly frequent arcing in the laser was traced to a gradual change in the optimum proportion of HCl in the gas fill, and the mixture was adjusted accordingly.

The system was initially aligned and tested over a 100ft range indoors. The receiver field-of-view was aligned with the laser and the laser beam expander focused to match the beam divergence to the field-of-view. Fluorescence from variety of targets, including water, crude oil (Dover and IP Sweet) and Quinine Bisulphate solution, were used to check system operation and set signal levels and timing. A number of timing and ground-loop incompatibilities between the sub-systems were found and rectified.

3.5 Aircraft Installation and Flight Check.

The system was installed in the AeroCommander, C-GISS, owned and operated by BrucelandAir International of Wiarton. This is the aircraft used, by Barringer, for earlier commercial fluorosensor surveys for hydrocarbons. Mechanical installation was rapid and without problems. Initial testing was at 120 feet with the aircraft parked in the MillardAir Hangar at Pearson airport. As usual with a new aircraft installation, some minor cabling and ground-loop problems were found and corrected. The first test flight, over Lake Ontario about 5 miles off-shore of Toronto Island, on 24th December, confirmed operation on aircraft power and established gain and offset settings for operation of the Lidar Altimeter over water at altitudes around 300ft. Ground tests continued with measurements of the spectra of clean snow and gravel, and of these materials coated with oil. Figure 4 shows samples of these spectra, as they appear on the operator's in-flight chart display; the contrast between 'clean' and oiled materials is considerable, even in this raw data. In all cases, about 15-20ml of oil was poured onto the clean surface and immediately soaked in. On the gravel, which was of a light fawn colour, the oil appeared, visually, as a dark brown stain; on the snow it showed as a light yellowish-brown. The layer of snow was about 10cm thick and the laser beam penetrated to the bottom, so that, even when the layer was stirred, so that the oiled snow was at the bottom of the layer and the upper surface showed only a faint discolouration, the oil fluorescence signal was still strongly registered.

Each of the traces, labelled GFL0.... GFL4 in Figure 4, represents the average over ~70nm, as follows;

GFL0	650 - 580
GFL1	580 - 510
GFL2	510 - 440
GFL3	440 - 370
GFL4	370 - 313

Some of the signal in GFL0 from snow is actually due to backscattered laser energy. The diffuse reflectance of snow is high, so that the laser backscatter is sufficiently intense to be seen in the second-order spectrum of the grating; the effect is not seen for oil, since its reflectance is so much less. The addition of an absorption filter, consisting of 3mm of Schott glass WG335 just in front of the spectrometer entrance slit, reduced this below the system noise at all gain settings. In addition to the hangar tests, the relative alignment of the laser and the backscatter and spectrometer optics of the receiver were optimized at 350ft. The altimeter was calibrated over the same range, along with the dependence of signal on range (Fig. 5), system relative gain (Table 2), signal/noise ratio (Fig. 6) and system spectral responsivity (Fig. 7).

TABLE 2:	LEAF Relative Gain									
Gain#	5	6	7	8	9	10	11	12	13	14	15
Rel. Gain (G#5 = 1)	1.000	1.534	2.182	2.943	3.819	4.808	5.911	7.127	8.458	9.902	11.460
Gain Step		1.534	1.422	1.349	1.297	1.259	1.229	1.206	1.187	1.171	1.157

Two more checkout flights (Flights 2 & 3) took place during January '92 and established that the system operated in the aircraft with the same performance as on the ground. Flight #2, off Toronto Island, on 2nd January, was used to check gain and offset settings chosen on the basis of data from Flight 1, and to train a new operator. Flight #3, on 22nd January, was a training run for the Tests at the Nanticoke facility of Imperial Oil. Briefly, the results were as follows;

Navigation: This went very well. Four passes were made over the Contaminated Surge Pond, three from the South and 1 from the North, at altitudes between 270 and 300ft, and in each case, the pilot kept the ground track within less than 30 feet from the diagonal of the pond.

Equipment Operation: Except for a computer glitch, which only affected the operators display, and was cured by resetting the system, the equipment operated satisfactorily. Various settings of lidar gain were tried, in order to confirm that there was a value which could be used both over the land and the lake. During these tests it was noted that, at higher gains, the lidar would show a range close to the aeroplane, presumably due to aerosol scattering. Although there were no visible plumes crossing the flight-path, some elevation of aerosol levels would not be surprising in the vicinity of a refinery and a major thermal generator. The effect was only seen sporadically, and at higher than normal lidar gain settings, but as a precaution, a circuit was subsequently added to inhibit lidar response to returns from ranges less than 80ft.

Fluorescence: Where the ground is snow covered, the fluorescence is low, and the spectrum is the same as observed for snow in ground tests. Within 20-30ft of the edge of the pond, there was moderate to strong fluorescence, peaking in the blue. No data was obtained from the water in the pond, for reasons dealt with in the next paragraph.

Effect of Mirror-like Water Surface: The wind was very light, and this, combined with the relatively small size of the pond, meant that the water surface was glassy calm. This, in turn, meant that the laser beam was reflected from the water as from a mirror. Since the maximum beam divergence is only 0.17 degree, and since the angle of incidence in general differs from 90° by more than this for a number of reasons, the reflected laser beam missed the telescope aperture and therefore the lidar was not triggered. This problem did not occur over Lake Erie adjacent to the plant, where the operators chart shows continuous altimeter reading up to 350ft. and, with a slight increase in backscatter gain, up to 400ft. This is in line with previous experience over many hundreds of survey kilometres over lakes and ocean. It is very rare for the surface to be absolutely free of ripples in natural bodies of water. Although an oil-

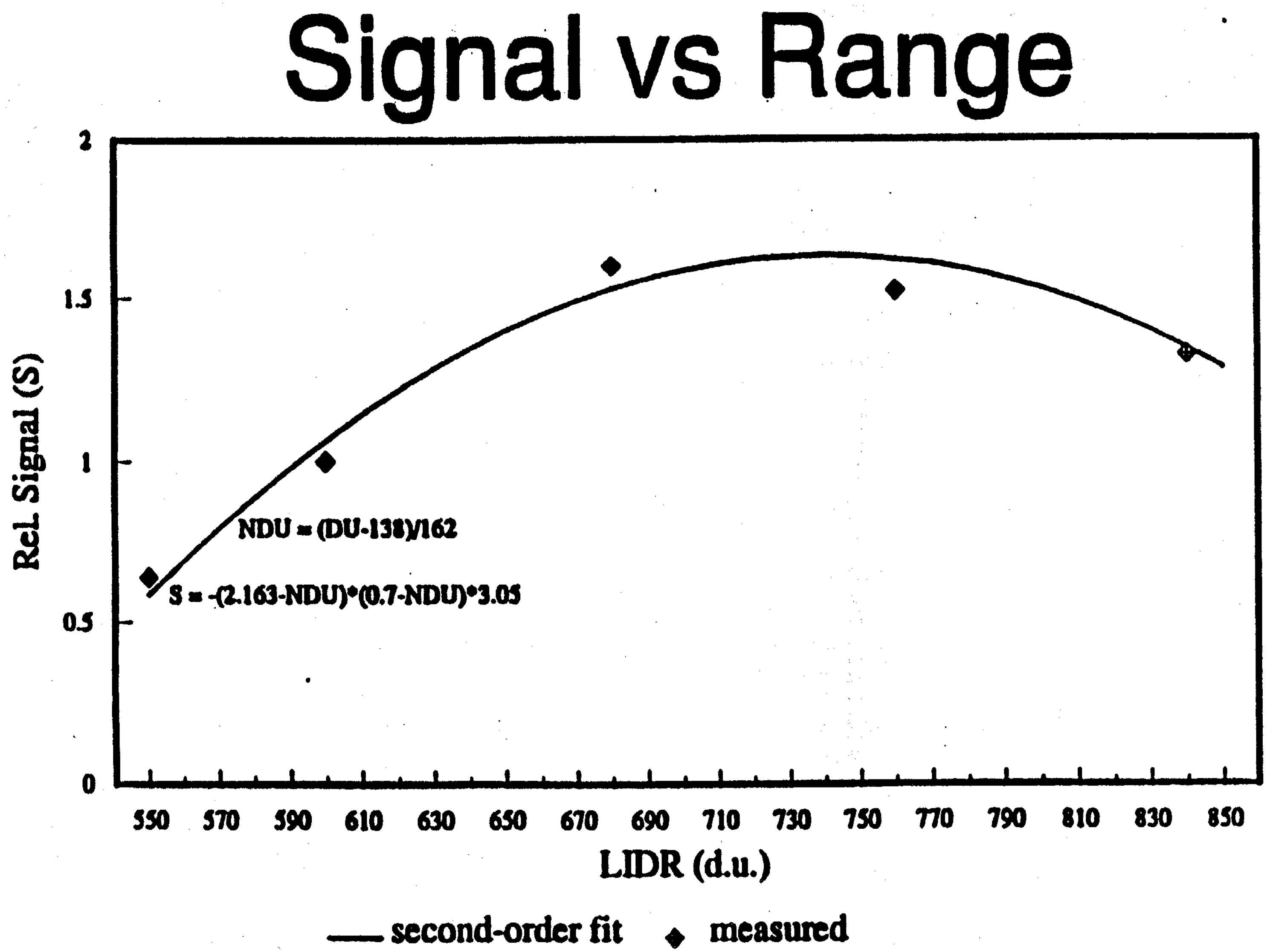
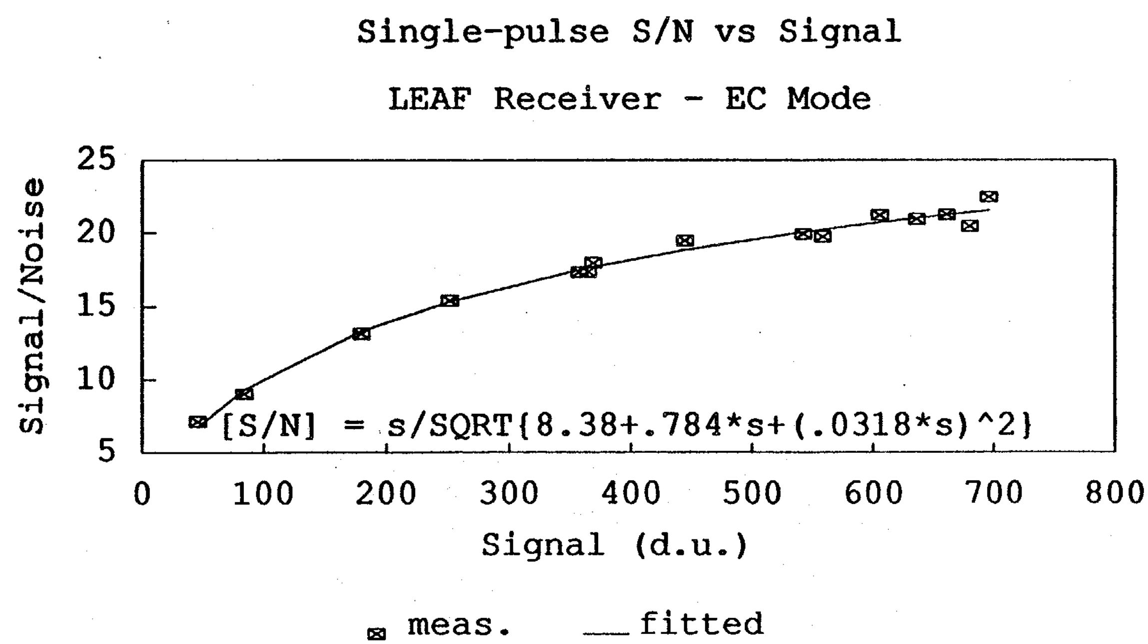

Signal vs Range
Rel. Signal (S)
2
1.5
1
0.5
0
550
570
590
610
630
650
670
690
710
730
750
770
790
810
830
850
LIDR (d.u.)
NDU = (DU-138)/162
S = -(2.163-NDU)*(0.7-NDU)*3.05
second-order fit
measured

Fig. 5

s	s*s	n*n	rms	s/rms	fit
46.1	2125.21	41.74747	6.461229	7.134866	6.748178
83.94	7045.924	86.50141	9.300614	9.025211	9.308292
179.6	32256.16	186.9091	13.67147	13.13685	13.31752
251.81	63408.28	267.711	16.36188	15.39004	15.32266
357.72	127963.6	426.1026	20.64225	17.3295	17.48482
364.83	133100.9	442.0819	21.02574	17.35159	17.60698
369.18	136293.9	422.7754	20.5615	17.95491	17.68055
444.58	197651.4	521.7208	22.84121	19.46394	18.83178
542.44	294241.2	740.9358	27.22014	19.9279	20.04895
558.37	311777.1	800.4375	28.292	19.73597	20.22378
605.44	366557.6	816.3701	28.57219	21.18983	20.70865
635.46	403809.4	922.756	30.3769	20.91919	20.99544
660.54	436313.1	966.0893	31.08198	21.25154	21.22296
679.65	461924.1	1105.28	33.24576	20.44321	21.38946
695.56	483803.7	961.5418	31.00874	22.4311	21.5238

Regression Output:

Constant		8.379173
Std Err of Y Est		41.63326
R Squared		0.987579
No. of Observations		15
Degrees of Freedom		12
X Coefficient(s)	0.783822	0.001014
Std Err of Coef.	0.224789	0.000283



G= 15
25/04/92

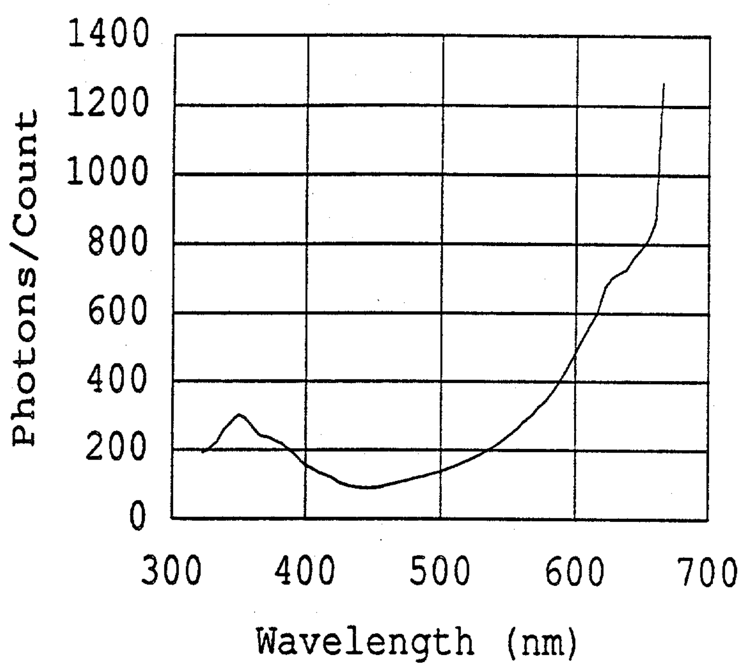
Fig. 6

LEAF Radiometric Calibration
(G=15, W=15)

Ch#	Wavelength (nm)	Photons./DU
0	665	1266.19
1	659.56	864.45
2	654.12	815.85
3	648.68	784.76
4	643.24	761.95
5	637.8	726.54
6	632.36	716.05
7	626.92	702.39
8	621.48	673.39
9	616.04	603.44
10	610.6	565.05
11	605.16	525.94
12	599.72	485.10
13	594.28	443.84
14	588.84	406.59
15	583.4	373.35
16	577.96	344.98
17	572.52	325.92
18	567.08	300.53
19	561.64	283.25
20	556.2	261.81
21	550.76	244.54
22	545.32	227.03
23	539.88	211.70
24	534.44	200.33
25	529	186.86
26	523.56	175.87
27	518.12	166.61
28	512.68	156.33
29	507.24	149.02
30	501.8	140.14
31	496.36	133.56
32	490.92	127.73
33	485.48	121.96
34	480.04	116.66
35	474.6	110.60
36	469.16	106.14
37	463.72	101.02
38	458.28	95.84
39	452.84	90.85
40	447.4	89.71
41	441.96	88.79
42	436.52	92.31
43	431.08	95.79
44	425.64	102.47
45	420.2	116.79
46	414.76	125.78
47	409.32	134.01
48	403.88	146.90
49	398.44	156.90
50	393	181.28
51	387.56	199.64
52	382.12	218.24
53	376.68	225.84
54	371.24	236.01
55	365.8	239.96
56	360.36	265.31
57	354.92	290.19
58	349.48	303.17
59	344.04	279.42
60	338.6	258.72
61	333.16	222.32
62	327.72	204.54
63	322.28	190.46

LEAF (EC Mode)

Radiometric Calibration



G=15, W=15
25/04/92

Fig. 7

covered surface tends to suppress the smaller ripples, it contains enough scattering centres to adequately spread the return beam. Scattering from snow and ice is more than adequate. Based on the results of these checkout flights, the system was considered to be ready for the Flight Test programme, as described in Section 4.

4. FLIGHT TESTING

Five test flights took place, totalling about 6.7 hours of system on-line operation. Table 3 summarises the flight testing, and a detailed account is given in Appendix 'D'.

TABLE 3: Flight Tests

Flt.#	Date	Time On-Line (hrs)	Location	Objective
1	24Dec91	0.4	Lake Ontario, off Toronto Island.	System shake-down
2	2Jan92	1.0	Lake Ontario, Ajax to Burlington.	Altimeter & gating check. Operator Training
3	22Jan92	1.5	Lake Erie, off Nanticoke; Surge Ponds, Nanticoke Refinery.	Practice flying for small targets. Data for clean & polluted water.
4	31Jan92	2.0	Lake Erie, off Nanticoke; Surge Ponds, Nanticoke Refinery	Data for oil on water & land, and for clean ice and snow.
5	14Feb92	1.8	ESD Test Site, SW of Ottawa.	Controlled simulation of oil on shorelines and ice.

The analysis of data from the flight trials warrants the following conclusions:

1) In flights over the Nanticoke facility, the *LEAF* detected reproducible and distinct signatures from fresh oily material floating in a Contaminated Sludge pond, and the more aged material on the shore of the pond, the nearby roadway, and the snow and ice on an adjacent clean-water pond;

2) In small contained bodies of water, such as the sludge ponds, on a calm day, the surface may become so smooth that insufficient laser energy may be returned to operate the Lidar Altimeter. This effect is not a problem over open water; it was not encountered over nearby Lake Erie on the same day and the effect was only observed once, briefly, during 20,000 km of exploration flying over the North Sea, the English Channel, and the Gulf of Mexico;

3) In flights over the Ottawa test site, the *LEAF* measured reproducible and distinct signatures from gravel, gabion stone, sand, shallow fresh water, and ice, and from the same materials when coated with Aberta Sweet Mixed Blend crude oil: the oil was applied at an average rate of ~320ml/m^2, which would imply a thickness of 0.3mm on a flat surface, but the actual thickness on the sand and gravel and ice was much less, due to the roughness of the surface;

4) In addition to the differences in spectral shape, the fluorescence from the 'clean' targets was distinguished by being between 10 and 30 times weaker than that from the same materials when coated with oil.

5) Changes in spectral shape due to weathering can be detected, from flight data, using simple algorithms, even from small areas which receive less than 10 laser shots per measurement.

6) Simple algorithms, based on correlation of in-flight and reference spectra, allow oil to be distinguished from water, ice, and shoreline materials such as sand, rocks, and gravel, on a single-shot basis, even when the background spectra are comparable in intensity to the oil spectra.

The possibilities for emergency re-deployment of the Aerocommander LEAF have been discussed, informally, with BrucelandAir. Permanent installation of some items, such as the heat-exchanger navigation antennas and interwiring cable harness would significantly reduce time for re-deployment, and it appears that this could be compatible with other uses of the aircraft. Brucelandair has no objection against leaving the components in the aircraft during its normal use on other projects.

At this point of time the Aerocommander would be ideally suited for the possible emergency response. It has the pay load required for this equipment and the range required for long dead head to distant offshore sites. Its low fuel consumption and simple operation permits 7.5 hours sorties with single pilot crew. It is equipped with full de-icing equipment and can be mobilized from its base in Wiarton (or Toronto) to the west coast within 12 hours. The cost of ferry runs typically at $2.70 per mile.
Provided that the laser is periodically maintained durings its storage time, the system can be reinstalled in the Aerocommander, tested for functionality and mobilized within 24 hours of emergency call. Barringer offers to maintain the laser transmitter for the remainder of 1992 free of charge to Environment Canada. This could be an inexpensive concept to secure the use of the laser fluorosensor equipment in the cases of environmental emergencies and to gain operational experience until the next generation of fully operational systems is designed and constructed.

5. Design for Operational LEAF System

5.1 General

This study suggests a primary and a secondary mission for an operational Laser Environmental Airborne Fluorosensor system, details the functional capabilities which these missions require, and outlines how a suitable LEAF system could be constructed from commercially available hardware and software modules. It is intended to form the basis for discussions, between users and manufacturers, leading to a formal Systems Requirements Specification. It is to be expected that the LEAF would be used in conjunction with other sensors; the subject of associated sensors is briefly explored, mainly from the point of view of synergy with the LEAF and compatibility of operational constraints such as altitude and airspeed.

5.2 Baseline Mission Statement

The primary use for an operational LEAF system is as part of an Airborne Remote Sensing package for the mapping of spilled oil;
a) during clean-up operations, to aid in the optimal deployment of resources, and
b) following clean-up, to aid in impact assessment.

The secondary use is, to serve as a research tool for development of other applications of Laser Fluorosensing, such as, bio-oceanography, fisheries management, off-shore hydrocarbon exploration, forensic identification of clandestine spills, mapping of spilled pollutants other than oil, measurement of vegetation stress. In addition to its intrinsic utility, this secondary use will support the maintenance and upkeep of a system which, in its primary role, must be instantly available although mostly idle.

5.3 User Requirements

5.3.1 Primary Mission

The primary mission imposes the following requirements;
Speed of Deployment: To be useful in support of clean-up operations, the system must be on-site, and operational, as soon as possible, preferably within 24 hours of the occurrence; after 48 hours, in many cases, all that remains is impact assessment. The time required for ferry will depend on aircraft type, number and base locations, but will likely fall in the range of 5 to 10 hours. This means that the LEAF must be brought from standby to fully operational status in 15 to 20 hours. While suitable system design is necessary to meet this goal, it is not sufficient; also required is a commitment of resources to regular maintenance and test, both of the equipment and operating personnel, and to spares inventory.

To be rapidly deployable, the system must have the following properties;

- consumables must be minimal, and be readily available or have a long shelf-life;
- components should, as far as possible, be 'stock' items;
- maintenance must be simple, and infrequent;
- in-service alignment or tuning, if any, must use minimal special skills or equipment, and not require hangarage;
- operation must be simple, so as to minimize operator re-learning time.

In addition, the system should be compatible with a variety of aircraft, and be easily installed and removed. This holds even if an aircraft is dedicated to the system, since it may be unserviceable when needed, making it desirable to have an alternative. If the system were installable in any aircraft having an RC-10 camera hatch, this would give access to a considerable fleet of aerial survey aircraft.

Cross-Track Scanning: This is desirable because it increases the rate of areal coverage for a given ground speed. However, for an active optical system such as LEAF, increasing the rate of areal coverage, for a fixed pixel size, is expensive, since it requires higher average laser-output power, as well as higher speed in the (mechanical) scanning mechanism. (All the basic components for non-mechanical scanning are available, but integrating them into a system would require significant design effort).
Since scan capability is expensive, the design should be matched to those aspects of the mission where it will be of greatest utility. Oil on water can be detected by several systems which are inherently wide-angle, but prone to false alarms, and the role of LEAF will be to confirm suspected targets. Effectiveness in this role will not be dependent on scan capability. Shorelines, however, have several properties which make scanning highly desirable and also constrain the choice of scan amplitude and pixel size. Although narrow, typically 10 to 100 meters wide, they may be highly sinuous, so that adequate sampling with a profiling system would require an impractical amount of aircraft manoeuvre. Also, due to wave action, and trapping in beach structures, oil, particularly heavy or weathered oil, may be piled up so that small areas may contain significant amounts of oil, compared to similar areas of open water; Owens and Teal [13th AMOP, p411, (1990)] report that most of the oil found on shorelines, following clean-up of the Valdez spill, was in a band less than 10m wide. Oil in ice will spread much less than on open water; Venkatesh *et al.* [13th AMOP, p139, (1990)] quote areas of $35m^2$ per m^3 of spill, about 1/100 of those for warm water. If the oil is denser than the water, then only small areas of material in the interstices of the pack will be visible.

Target Size and Thickness: The nature of the 'minimum target' varies with the conditions of use. On shore lines, and in ice, oils (with the possible exception of light refined products such as diesel) will be present in smaller patches, of greater thickness, than in open water. The "Nestucca" shoreline classification of Owens [13th AMOP, p444, (1990)] describes significant oil as 'brown or black' i.e. visibly opaque, and rates thickness in centimetres; areal coverage is rated as 'light ' at >10, $1cm^2$ blobs per m^2, and 'moderate' at >1, $300cm^2$ blobs per m^2. On open water, Allen [11th AMOP, p297, (1988)] indicates that oil less than .025mm thick is unlikely to be targeted for clean-up. Venkatesh [loc cit] quotes Fay's spreading relation, which implies that a spill as small as 80bbl will spread about to about $0.8km^2$, with a mean thickness of .02mm, on warm water, whereas experimental data cited by the same author indicate thicknesses of 10 to 100 times this figure on cold water.

Aircraft Safety: The minimum operating altitude varies with conditions. Over open water, surveys are routinely flown at 100m in daylight; at night, and over ice or close to shorelines, most pilots would set a minimum of 200 - 300m. All installations must be certified for mechanical and electrical safety, and non-interference with avionics. In addition, if any hazardous materials are used, the design must ensure that they will vent outside the aircraft in the event of a leak.

Laser Safety: The interior of the aircraft must be shielded from direct or scattered laser energy during flight. The operating protocol, and the laser pulse energy and pulse rate must be such that persons on the surface are not exposed to dangerous levels of radiation.

Environmental, Operating: The system, installed in the aircraft, must operate correctly under the following conditions;

Temperature	0 to +40C
Humidity	0 to 95% RH, non-condensing
Survey Altitude	300 to 10,000ft MSL 300 to 1000ft above surface
Vibration	± 0.5g peak, 15 - 5000Hz ± 0.02ins, 5 - 15Hz
Weather	all conditions safe for aircraft operation at minimum survey altitude

Environmental, Non-operating: The system must not be damaged by, and must operate correctly after, exposure to the following conditions;

Temperature	-40 to +50C
Humidity	0 to 100% RH, condensing
Altitude	0 to 10,000ft MSL
Transportation	airfreight

Sensitive components may be removed and suitably handled, provided that replacement, including any realignment, can be carried out in less than two hours, under airport conditions.
Size, Weight and Power: Size, weight and input electrical power should be as small as consistent with achievement of the other goals and the maximum use of 'off-the-shelf' modules.

Reliability and Maintainability:Reliability must be high, and maintenance requirements should be comparable to those of normal aircraft avionics. This implies that, as far as possible, the system should be built up from commercial, off-the-shelf modules, with some history of successful use in industrial or field applications.
Data Products: The system must be capable of generating map overlays showing oil distribution in the surveyed area as nearly as possible in real time. As a minimum, the maps must be available in hardcopy when the plane lands, and the oil data must be available on a display in the aircraft with, at most, a 5-second delay, so as to allow the on-board Mission Manager the

possibility of adjusting the flight plan and of reporting oil locations via radio-telephone. It would be an advantage if the maps could be telemetered to the command centre while the plane is in flight.

5.3.2 Secondary Mission

The requirements for the secondary, R & D mission, are less specific. They come under the general headings of, adaptability, resolution, dynamic range, and accuracy, and may be summed-up in the phrase "maximum information capacity". The system should be easily adapted to different uses, with a modular construction which allows subsystems to be exchanged with little or no realignment, e.g. interchangeable kinematically-mounted gratings for different receiver spectral passbands, or, different lasers, or other means of changing excitation wavelength, such as Raman-shifters. Spectral and temporal resolution capability of hardware should be maximized; if a particular task requires that resolution be sacrificed for sensitivity, this can be achieved by data-averaging. Similarly, the dynamic range capability should be matched to the application with the largest requirement. This does not mean that the dynamic range must accommodate all conceivable applications at once; the range can be repositioned with attenuators. Accuracy should be maintained via calibration procedures, with the frequency of calibration matched to the time scale of system stability.

5.4 Tx/Rx Subsystem

5.4.1 Minimum Targets

Based on the data cited in the preceding paragraph, the following have been selected as Minimum Targets;

Target Type	Oil Type	Quantum Efficiency η (nm^{-1})	Thickness (mm)	Patch Area (m^2)	Patches/(m^2)
Oil on Water	Heavy	4E-5	0.02	1000	-
Oil in Ice	Heavy	4E-5	0.20	100	-
Oil on Shoreline (in 5m wide band @ tideline)	Heavy	4E-5	1.00		
"Light" coverage				0.0004	10
"Moderate" coverage				0.04	1

Heavy oil was chosen because it has the lowest fluorescence quantum efficiency, and all oils come to resemble heavy crude or Bunker Fuel after weathering. The value of η is taken from Schwarz [Environment Canada DAD Tech. Note 1982-07, p78, (1982)]. Based on the typical absorption coefficients cited by Rayner [EnvCan Tech. Dev. Rpt. EPS 4-EC-80-3, p8, (1980)], all the targets are 'optically thick' at all relevant excitation wavelengths; this means that:

a) fluorescence will be independent of thickness;

b) the substrate will not be visible through the oil, this, in turn, means that received fluorescence will be a linear addition of oil and substrate fluorescence, without any 'cross terms' of substrate fluorescence modified by oil transmittance.

It is appreciated that the first priority in a clean-up situation will be to locate the most heavily-oiled areas, which will have much denser coverage than the targets in the table. However, as will be discussed below, and has been demonstrated in the recent trials, dense coverage, where the oiled area overfills the instantaneous field of view of the system, is easily detected, so the listed targets were chosen as being typical of the requirements for post-cleanup assessment.

5.4.2 Signal/Noise, Data Rate and Laser Power

The criteria for reliable detection is taken as;

$$S/N \geq 3$$

If the field of view, Ω (steradians), of a gated receiver, of collecting area A (m^2), contains a fraction K coated with 'optically thick' oil of quantum efficiency η_1 (nm^{-1}), and is illuminated by a short laser pulse of strength J (joule) and sunlight of irradiance H ($w/m^2/nm$), then the total signal, S (photoelectrons), in a single channel of spectral bandwidth b (nm), is given by

$$S_T = \{b*A*\varepsilon/\xi/\pi\}*\{H*\Omega*\tau*(1+K*(q-1)) + J/h^2*K*\eta_1 + J/h^2*\eta_2*(1-K)\} + d \quad [1]$$

where

- h is range (m)
- τ is gate time (s)
- q is oil reflectance coefficient for sunlight
- ε is system quantum efficiency (photoelectrons/photon)
- ξ is photon energy (joules)
- d is system dark charge (photoelectrons)

Re-writing [1] as

$$S_T = C*(S_S + S_O + S_C) + d \quad [2]$$

the three terms in the () arise from scattered sunlight, fluorescence of oil, and fluorescence of clean substrate, respectively.
The signal due to oil is

$$S_o = C*s_O = C*J/h^2*K*\eta_1 \quad [3]$$

The root-mean-square noise is

$$N = \sqrt{(d + S_T + (g_n*S_T)^2)} \quad [4]$$

and the single-shot signal/noise ratio is

$$R = S_o / N \quad [5]$$

The first term in the expression for N accounts for Schott noise, the second for photon noise and the third for multiplicative noise, such as fluctuations in gain or in the measurement of laser power.
Of the listed targets, 'Oil on Water' is the easiest to detect. The size of significant targets is sufficient to fill any practical field of view, so that the s_C term in [2] is zero and the s_S term is small because of the low reflectance of oil (< 5%). Fig. 8 shows the single shot S/N for this target, as a function of laser pulse energy and field-of-view (FOV), at two altitudes; H was set at the value for 550nm, mid-latitude summer, the bandwidth and collecting aperture diameter were 5.4nm and 20cm (as in the current LEAF). The range of pulse energies covers that obtainable in portable UV lasers at repetition rates of several tens to hundreds of pulses per second. For example, the obsolescent XeCl excimer in the current LEAF gives 10mJ @ 100Hz, a typical tripled Nd:YAG will give 30mJ @ 50Hz, and the newer XeCl excimers range from 70mJ @ 70Hz to 250mJ @ 200Hz to 100mJ @ 600Hz. The flattening of the S/N curve at lower altitude and higher energy is due to the quadratic term in [4]; the values of g_a and d used were those measured on the GDAS in the current LEAF system.

The Oil-on-Ice and Oil-on-Shoreline targets are more difficult, due to their small spot size and spot density. Reducing the field of will increase K and make smaller spots detectable, but will also increase the likelihood that the field-of-view will fall entirely in the clean space between spots, unless the sampling density, and hence, the laser pulse rate and average power, are increased to compensate. Fig. 9 shows, as a function of altitude, FOV, and pulse energy, the fraction K, of the field of view, FOV, which must contain oil to ensure detection, defined as a single-shot signal/noise ratio of 3:1. A given target, consisting of blobs of diameter D_s (m), uniformly distributed with average density p (m^{-2}) can be detected, in n tries, with probability ϕ, if the probability is ϕ, or greater, that a randomly placed circle of area $n*h^2*\Omega$ contains oilspots whose total area equals or exceeds the Minimum Detectable Area, defined by

$$MDA \equiv h^2*\Omega*K \qquad [6]$$

It can be shown that this will occur, with $\phi \geq 70\%$, for densities which satisfy

$$p*A_b \geq (K+A_b/h^2/\Omega)/n/(1-\sqrt{K})^2 \qquad [7]$$

where

$A_b = \pi/4*D_s^2$ is the area of a typical oil spot

for a high density of small spots this reduces to

$$p*A_b \geq K/n/(1-\sqrt{K})^2 \qquad [8]$$

Figs. 10a-e show this Minimum Detectable Fractional Coverage, $p*A_b$, as a function of energy, altitude, and field of view. For low-density targets, such as the Nestucca classes, it is necessary to apply [7], and Figs. 11a-d show the combinations of energy and FOV required to detect these

Single-shot S/N vs Pulse Energy & FOV

(Oil fills FOV; gate = 20ns; 20cm telescope)

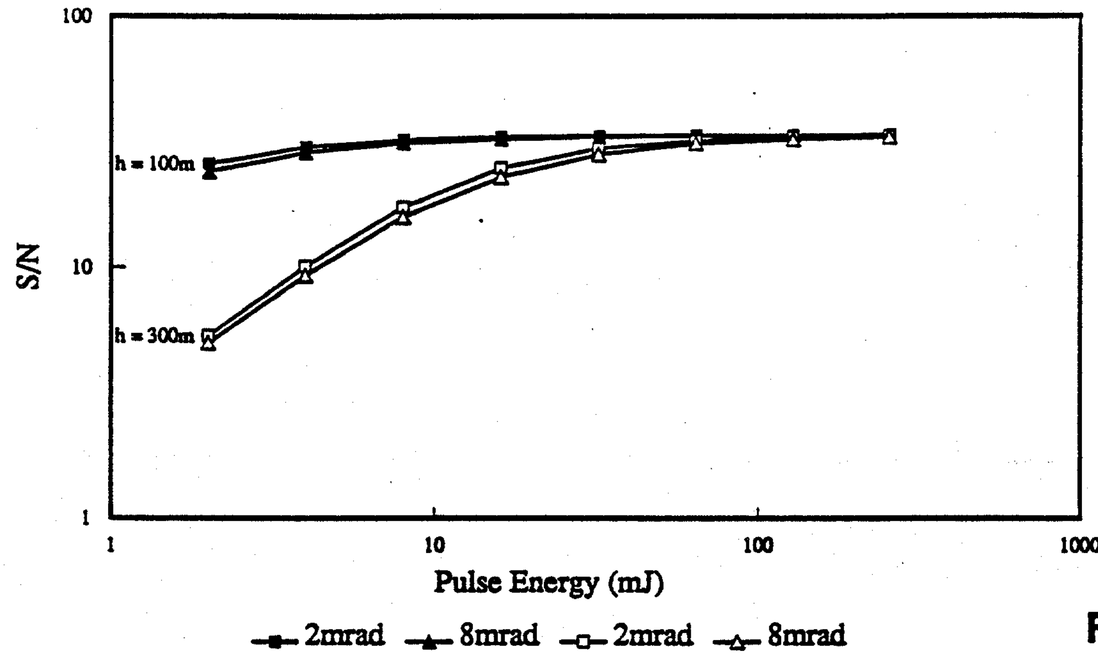
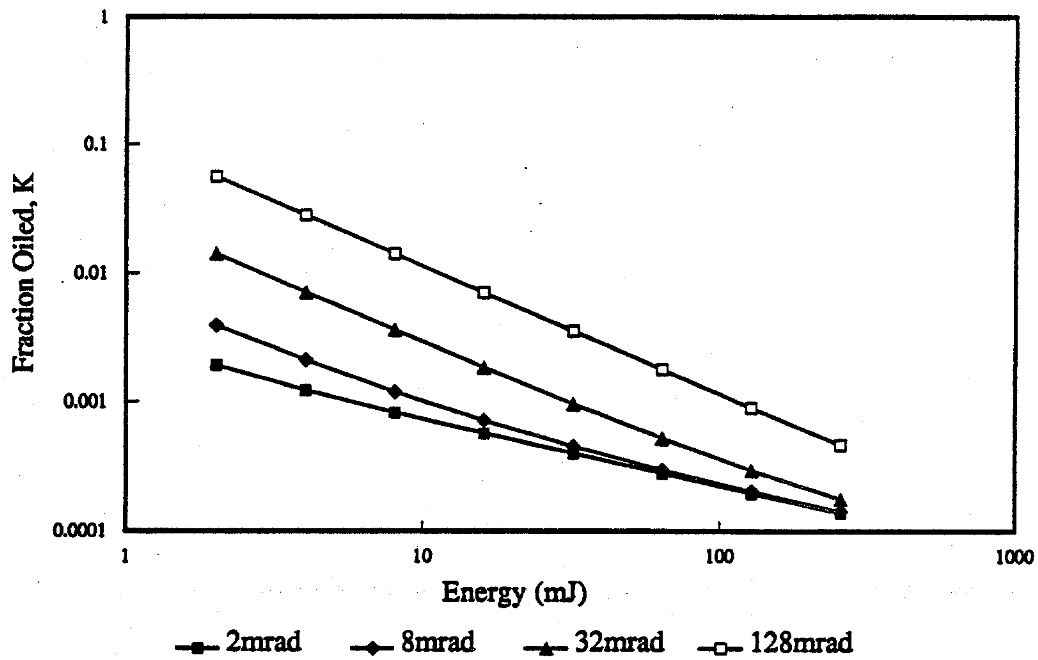


Fig. 8

920604

Min Detectable Fraction of FOV vs Energy & FOV

(h = 100m; S/N=3)



Min Detectable Fraction of FOV vs Energy & FOV

(h = 300m; S/N=3)

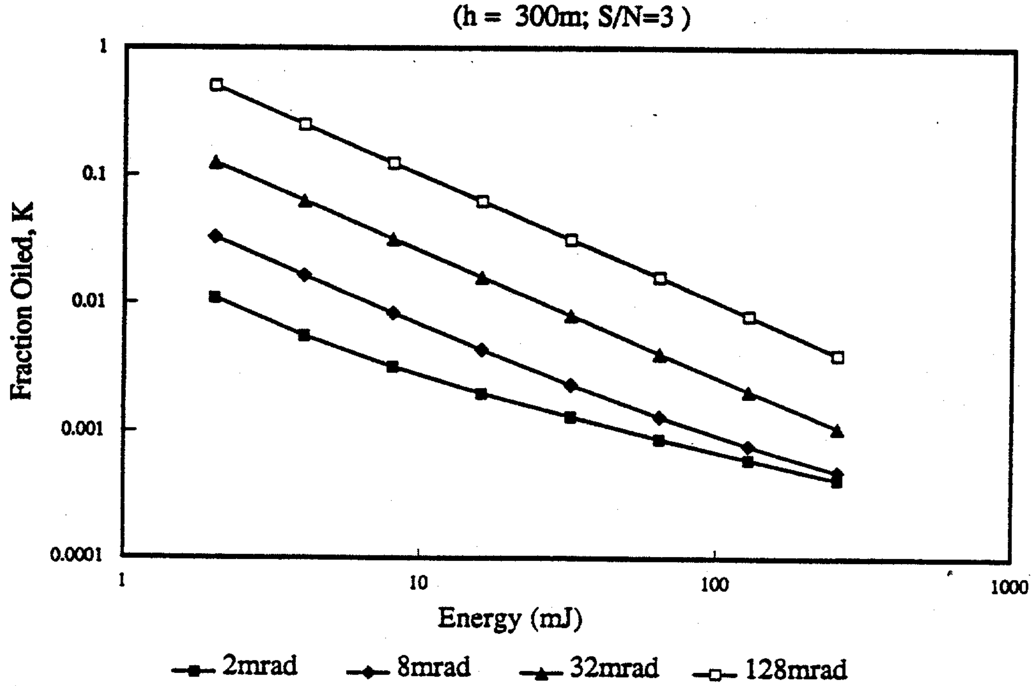


Fig. 9

Fig. 10a

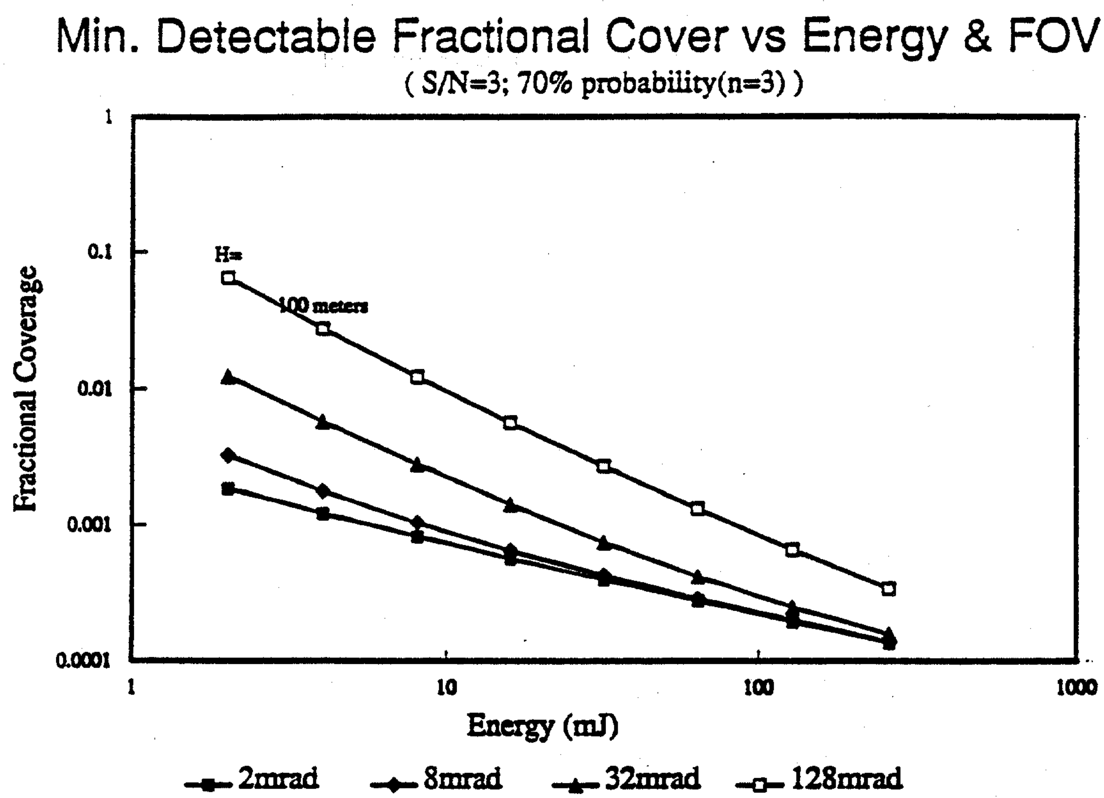


Fig. 10b

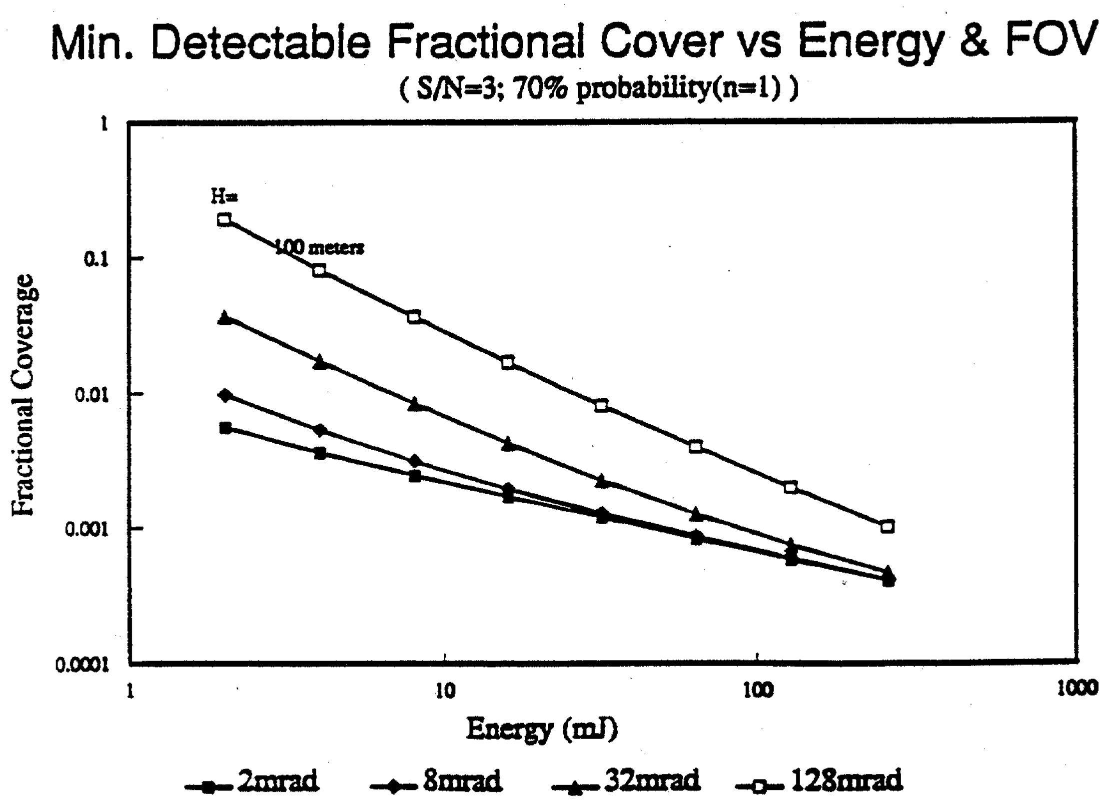


Fig. 10c

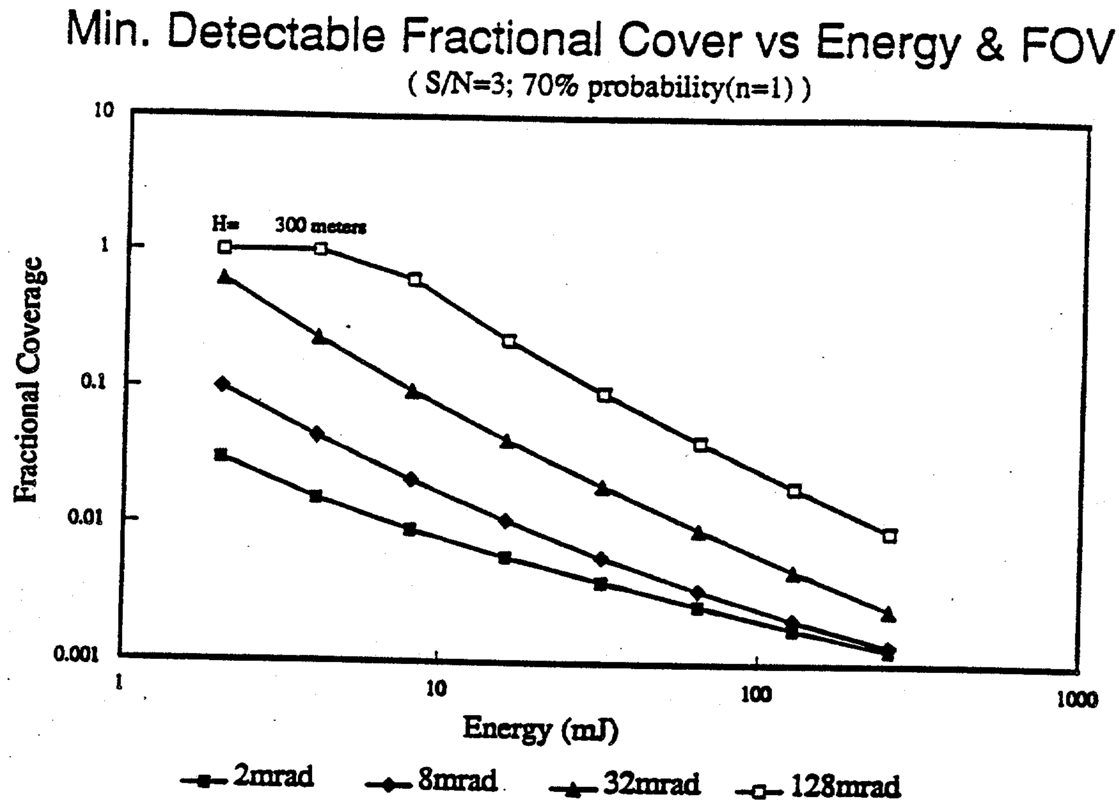


Fig. 10d

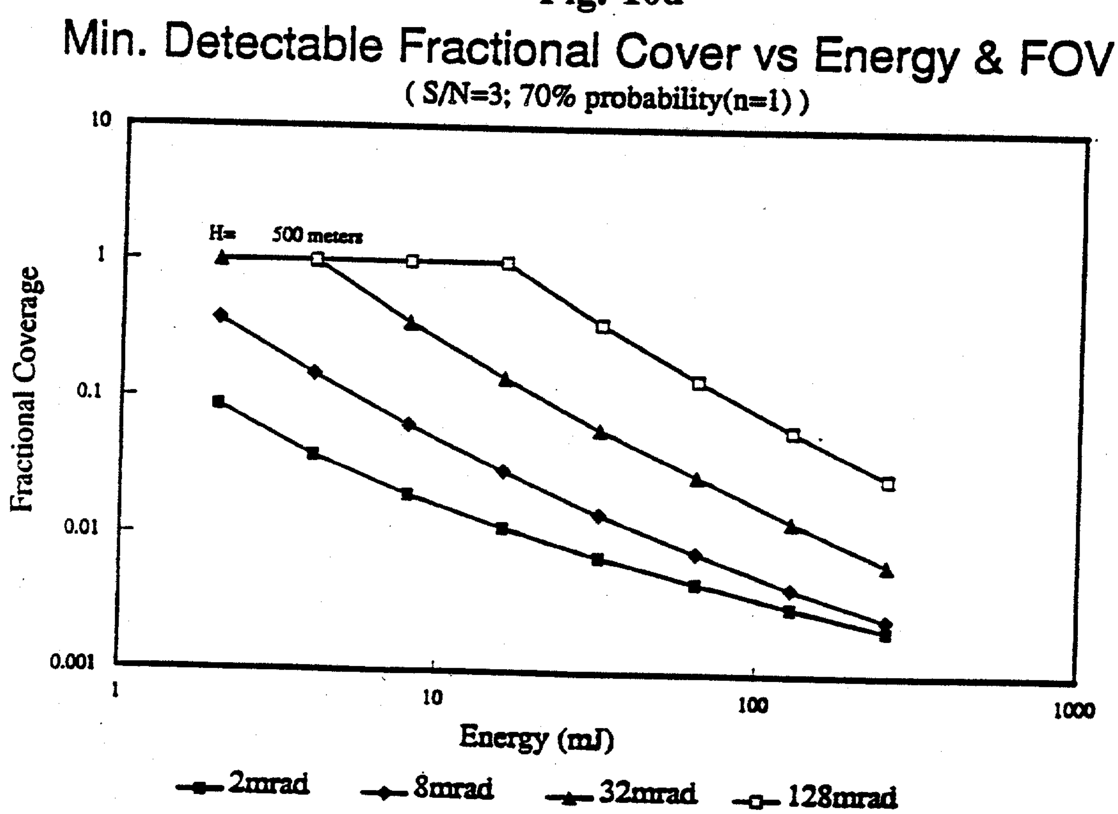


Fig. 10e

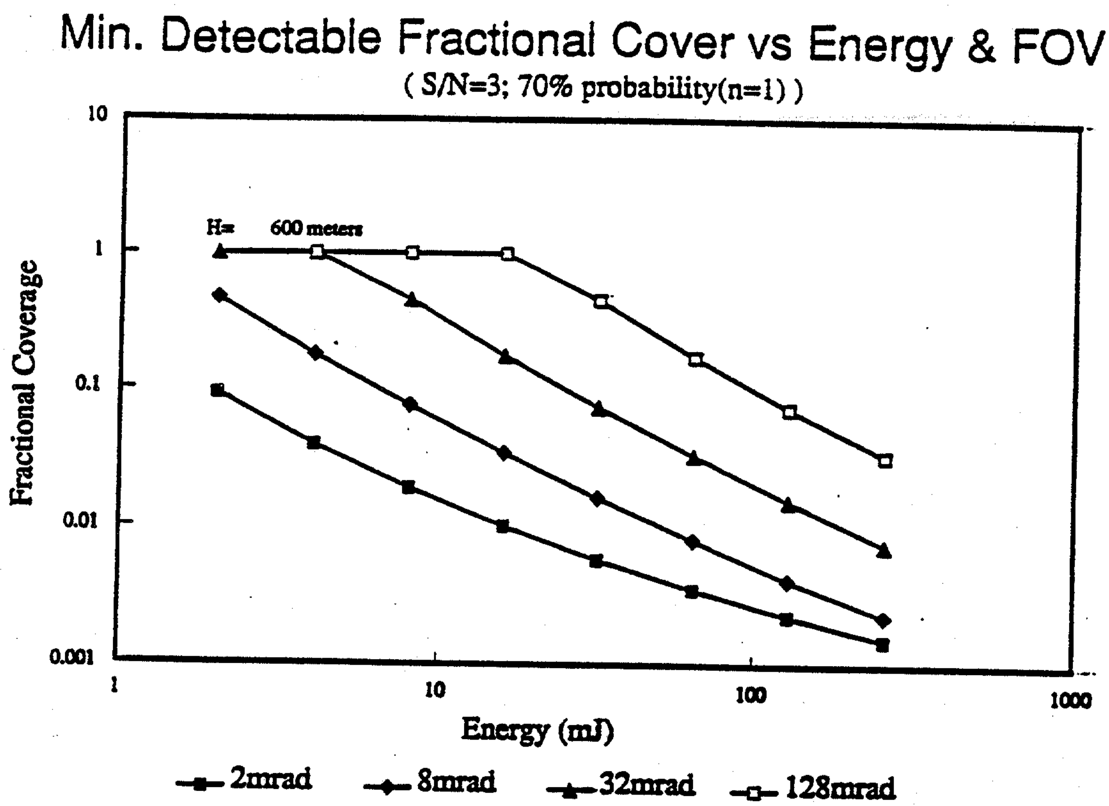
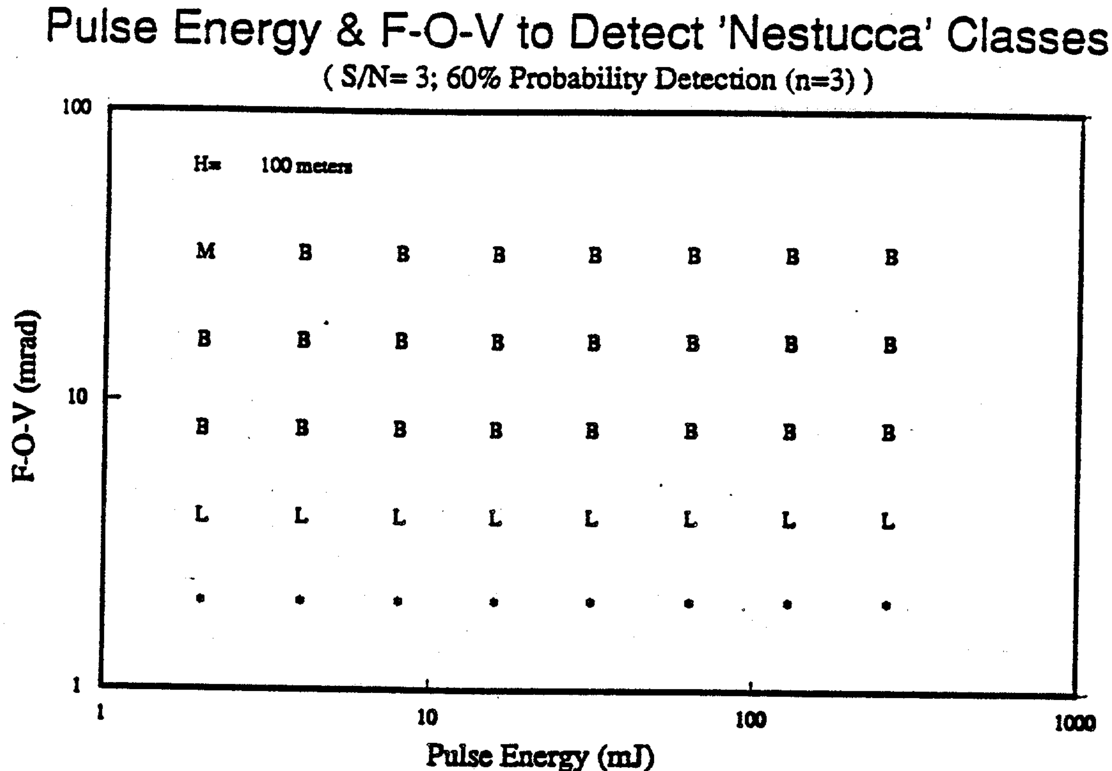
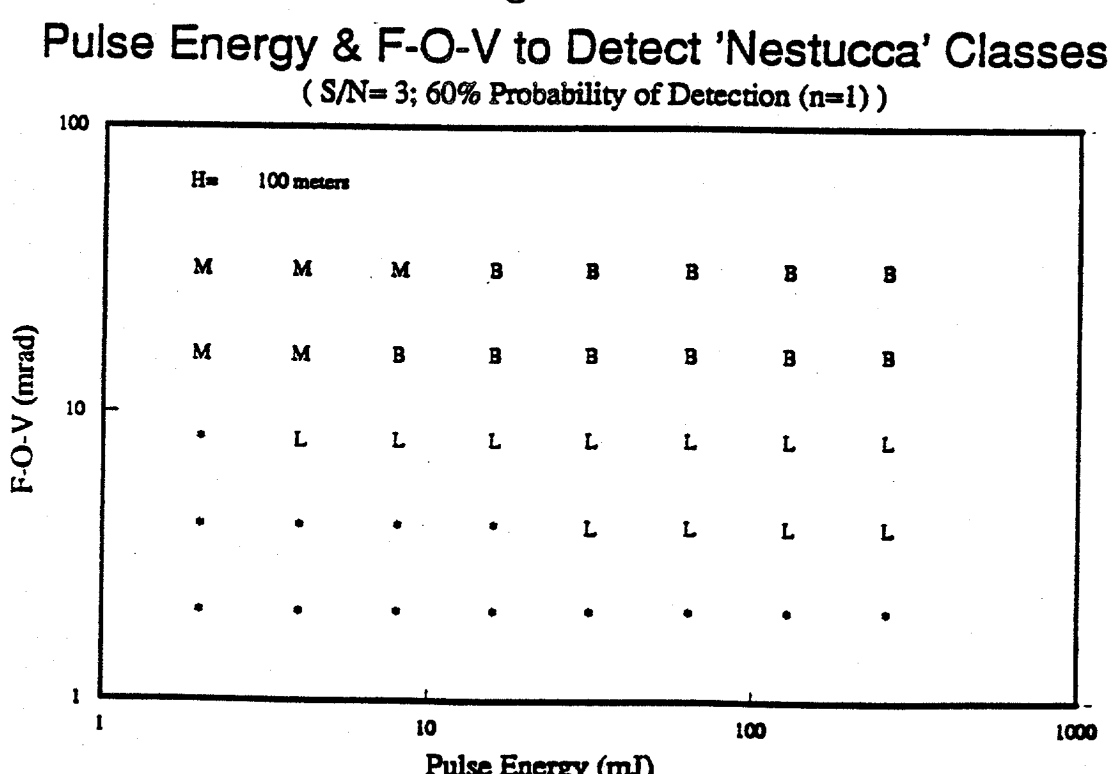

Min. Detectable Fractional Cover vs Energy & FOV
(S/N=3; 70% probability(n=1))
H= 600 meters
Fractional Coverage
10
1
0.1
0.01
0.001
1
10
100
1000
Energy (mJ)
2mrad
8mrad
32mrad
128mrad

Fig. 11a



M - moderate; L - light; B - both; * - no detection

Fig. 11b

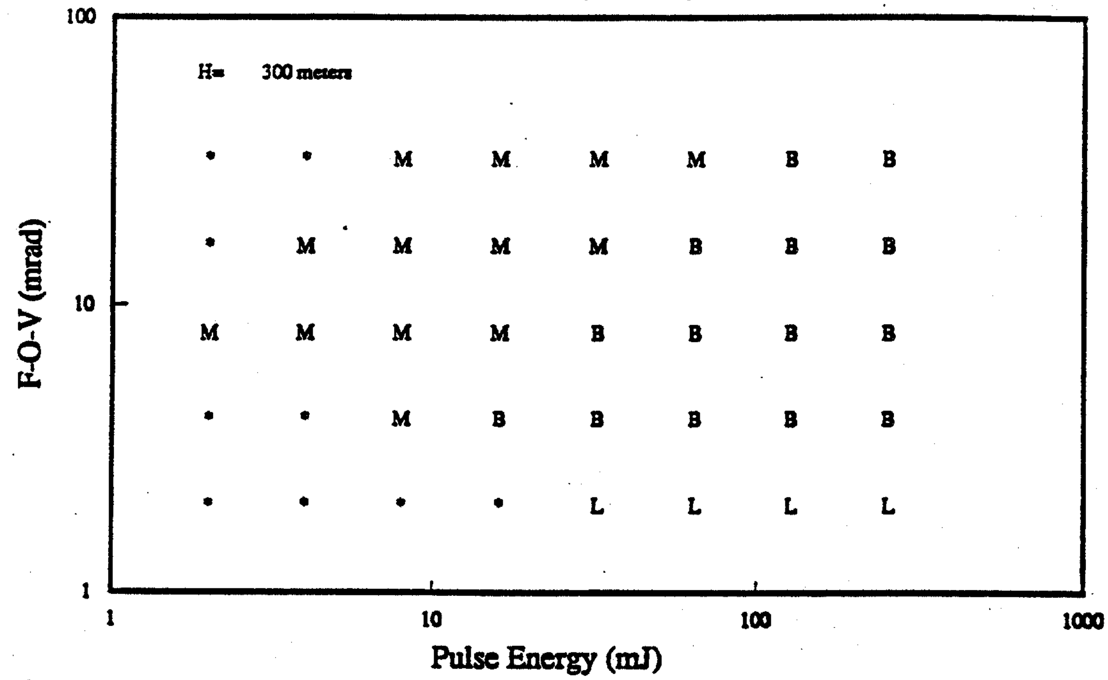


M - moderate; L - light; B - both; * - no detection

Fig. 11c

Pulse Energy & F-O-V to Detect 'Nestucca' Classes

(S/N= 3; 60% Probability of Single-shot Detection)

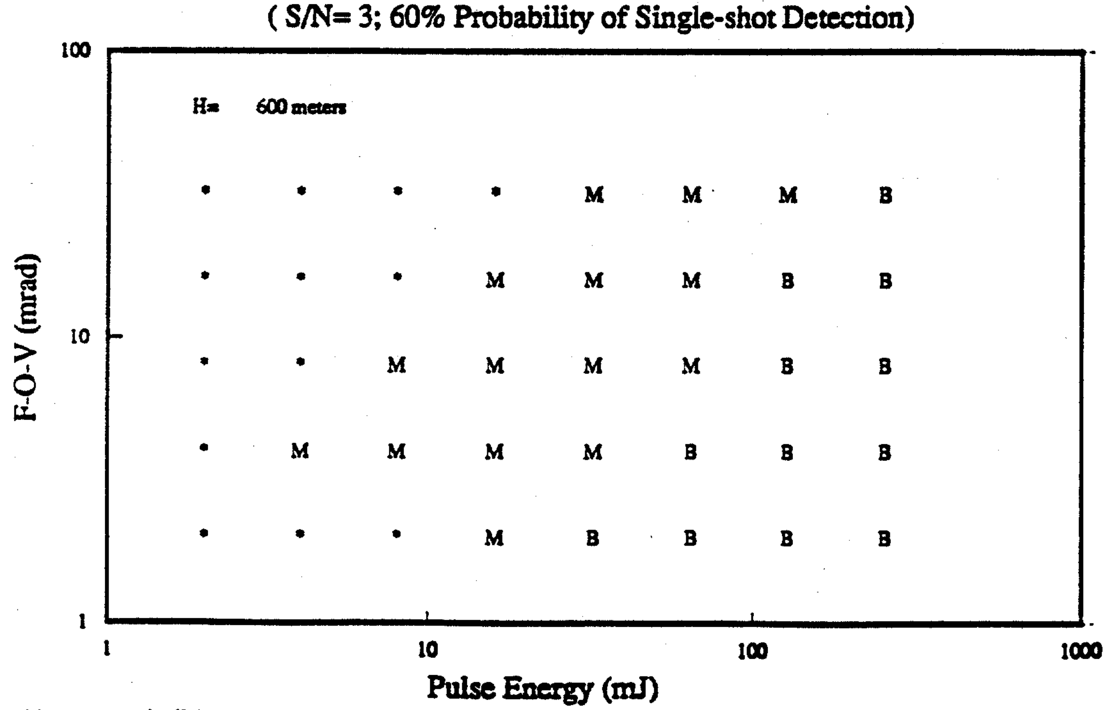


M - moderate; L - light; B - both; * - no detection

Fig. 11d

Pulse Energy & F-O-V to Detect 'Nestucca' Classes

(S/N= 3; 60% Probability of Single-shot Detection)



M - moderate; L - light; B - both; * - no detection targets from various heights. It appears that, for these 'sparse' targets, there is an optimum altitude; at lower altitudes, less energy is required to detect a spot, but the chances that it will be missed altogether are greater, at higher altitudes the reverse is true, it is more likely to be looked at but less likely to be seen.

The other important parameter is the sampling density and rate. The oiled zone on a shoreline is often narrow, and, if the sampling points are too far apart, many cross-track scans will be required to ensure that it is sampled at all; if the sample rate is low, the aircraft will advance a long distance between samples, and short lengths of oiled shore may be missed. A higher sample rate implies a higher laser average output power. Based on a similar analysis to the foregoing, a sample spacing of 5m (10 samples across a 50m swath) will give better than 90% probability of sampling a typical oil zone at least once per scan. At this cross-track spacing, and an aircraft ground-speed of 60m/s (120kt), a repetition rate of 50Hz implies a 12m along-track spacing between samples.

The Oil-in-Ice target represents an intermediate case. For oil spreading on open areas in pack ice, the oiled area will fill the FOV, and we have the same situation as on warmer water. Where the ice fragments are touching it is more difficult to define a spot size and density; to the extent that the fragments are roughly circular in shape, the small leads and spaces will total about 20% of the total area. In any event, it appears unlikely that oil in ice will present more difficult target than the "Low" and "Moderate" Nestucca classes.
In summary, a baseline specification for the Electro-optic portion of an operational LEAF would appear to be;

General

Operating Altitude	300 - 1000ft (100 - 300m) AGL
Ground Speed	100 - 150kt (50 - 75m/s)
Total System Weight	< 800lb (364kg)
Size Optical Head Control Console	 compatible with RC-10 camera hatch 19" rack, < 50ins (1.3m) high
Input Power	< 80amp @ 24-32VDC

Receiver

Telescope Diameter	0.2m
Field Of View Diameter	2mrad
Spectral Resolution	5nm
Spectral Coverage	370 - 670nm
Gate Width	20ns
Overall Quantum Efficiency	0.02

Transmitter

Laser Type	Tripled, flash-lamp pumped, Q-switched Nd:YAG
Excitation Wavelength	355nm
Pulse Energy	30mJ
Pulse Rate	50Hz
Pulse Length	<10ns
Beam Divergence	2mrad

Scanner

Scan Type	Conical
Scan Rate	2.5rps
Scan Radius	5deg

A draft specification, for a tripled Nd:YAG laser for LEAF, has been generated and sent to various manufacturers for quotes and comments. The only serious objections have been to the temperature range, which was specified as 0 to 40C operating, -50 to +60C non-operating. This is to be expected, since the harmonic generating crystals are; a) tunable by temperature and, b) susceptible to thermal shock. The solution appears to lie in improved insulation on the crystal ovens, use of standby power during brief on-ground stops in cold conditions, and removal of the crystal assemblies if the aircraft is to be unheated for extended periods.

5.5 Data Interface

It is assumed that, at least in its primary mission, the LEAF will be a part of an oil-spill monitoring package incorporating several sensors. In this case, the need for a real-time, 'user-friendly' data product, and the desirability of a single-operator system, make it imperative that

there be a central control and data-processing/recording/display system that communicates with all sensors. The control function accepts operator directives, sends appropriate instructions to the sensors, and keeps a log of all transactions and the state of all control and housekeeping parameters. The data-processing function synthesizes sensor outputs into data product, and the recording function formats all raw and processed data, position information, system status and operator annotation, into a time-stamped object on a permanent medium.
The display function has two subdivisions; firstly, to provide the Operator with an 'instrument panel' to monitor system operation, and, secondly, to provide the Mission Manager (probably the same person) with real-time, scrolling, oil-coverage data, to aid in direct assistance to surface units and in decisions to modify the flight profile. In the interests of maintainability, communication between the sensors and the central unit should, if at all possible, be via a single, industry standard protocol, such as GPIB or RS422. Not only does this simplify system structure, but it means that sensors can be tested independently of the system, using any general-purpose computer as a 'smart' terminal. Beyond the general requirements outlined above, the design of the Data Subsystem is strongly dependent on details of user requirements for real-time display and hard-copy products, and on the mix of sensors making up the total system, and is outside the scope of the present study.

In multi-sensor systems there is always a question as to the optimum distribution of processing power; is it preferable to have 'simple' sensors sending raw data, at high rates, to a powerful central processor, or should processing occur in the sensors, so that they output fully corrected data, usually at a significantly lower rate, to a simpler central unit functioning only as recorder/display/control-console? In experimental systems, it is usually preferable to record all raw data, to aid in post-flight trouble-shooting and in testing of new algorithms. In fully operational systems, only fully processed data and status logs need be recorded, thought it is still advisable that the capability to output raw data be retained, to assist in maintenance and repair. While the LEAF sensor considered herein will be 'operational' in its primary role of oil-spill monitoring, its secondary role is undoubtedly experimental, and thus it should have the capability to output raw as well as processed data. The LEAF is unique amongst the sensors which can be applied to detection of spilled oil, in that it can easily be made to contain a simple, robust, algorithm, which can run in real-time and give an accurate 'oil/no-oil' decision for each laser pulse. Several algorithms are available, some of which, in addition to classifying each pixel as 'oil' or 'not oil', can provide a measure of oil typing, at least into broad classes such as 'light refined', 'crude', 'heavy crude or bunker'. The accuracy of some of these algorithms has been demonstrated on data from the flight tests (see Appendix 'D'). For a 64-channel system, running at 100pps, the execution of a simple 'oil/no-oil' decision requires less than 1.0E+5 floating-point operations per second, which is well within the capabilities of currently available VME-buss single-board computers.

In summary, a baseline specification for the data-processing portion of an operational LEAF would appear to be;

Input/Output

An input control message, from the central console, at a rate of 10Hz, elicits a string of three output messages, (which can, if necessary, be addressed to different listeners), with formats as in the following table (10**Nmax* is the maximum pulse rate for the laser):

Message Description	Bytes/Message
Control Input Fire *N* (≤ *Nmax*) Laser Pulses, then output data Scan Rate Laser Pulses/Scan Gain, Gate Width, Gate Offset (for each pulse) Background Correction Flag Use j[th] Algorithm, k[th] Reference Spectrum {Run a Calibration} {Acquire a Spectrum, store as i[th] Reference} {Update Stored Constants}	128
Raw Data FLUORESCENCE or BACKGROUND or F - B Lidar Altitude Laser Energy Backscatter Energy Gain, Gate Width, Gate Offset Scanner Position Status Flags Current Values of Stored Constants Time	128**Nmax*
Averaged Data (for operator) F - B in selected spectral band Lidar Altitude Laser Energy Backscatter Energy Gain, Gate Width, Gate Offset Status Warnings Housekeeping (temperatures, etc.)	128
Oil Detection Probability Pixel Contains Oil (High, Medium, Low) Signal Strength Scanner Position Status Flags	16**Nmax*

For a laser pulse rate of 50Hz, the data rate is about 10Kbyte/second. If both raw and processed data are recorded, the recording rate is 35Mbyte/hr; if only oil detection data is recorded, the rate is ~3Mbyte/hr.

5.6 Auxiliary Sensors

The limitations on laser average power imply that, even with scan capability, a LEAF cannot achieve 100% area coverage at normal ground-speeds of fixed-wing aircraft, and should be supplemented by wide-area sensors. The selection of sensors must take careful account of

compatibility and complementarity; it is most desirable that all sensors share a range of altitudes and ground-speeds at which they operate at maximum performance, and, as far as possible, the weaknesses of one should be supported by the strengths of another. The physical mechanisms which have demonstrated some level of response to oil on water, under field conditions, are;
- UV reflectance, 300 - 400nm;
- IR emittance/reflectance, 3 - 5 and 8 - 10micron;
- visible/nearIR reflectance, 400 - 1100nm;
- microwave thin-film interference 10 - 50 GHz;
- supression of radar scatter by capilliary-wave damping.

With the exception of radar, the sensors for these effects have comparable swath widths, which include the nadir, and can operate well in the same range of altitudes and ground speeds (100 - 300m AGL, 50 - 100m/s) as the LEAF. Radar, while it is invaluable for surveying large areas in a short time, is inherently side-looking, and operates best at higher altitudes and speeds than the other systems, so that any attempt to use radar and the other sensors simultaneously is liable to be an unhappy compromise. The following table attempts to rank the methods, other than radar, in terms of their potential to meet key requirements of the oil-spill monitor task; in many cases, the scores are, at best, "engineering estimates", since field test data is incomplete. A score of 3 indicates fully adequate capability, 0, negligible.

Sensor	cross-track coverage?	detects sheen?	measure relative thickness?	contextual data?	24-hour operation?	oil on shoreline ?	SCORE
UV	3	3	1	2	0	1	10.00
Thermal	3	0	2	1	3	0	9.00
Visible	3	1	1	3	0	1	9.00
Microwave	0	0	2	0	3	0	5.00
Laser Fluorescence	2	3	1	0	3	3	12.00

Given that there is, as yet, no fully adequate method for thickness measurement, the minimum combination of methods to achieve 'fully adequate' capability for all tasks appears to be UV, Thermal, Visible and Laser Fluorescence. A 'Visible' sensor allows for human interpretation of doubtful cases, will be necessary for shoreline navigation and provides valuable supplementary data, such as accessability and trafficability of beaches, and position of surface vessels.

General recommendations regarding passive imaging hardware are;
- it should use array technology;
- if cooling is required it should be thermo-electric or closed-cycle;
- video output should be NTSC or PAL or RS-170 RGB;
- effective pixel size should be ≤1mrad for UV/visible and ≤2mrad for Thermal sensors, *including* the effect of image motion, for V/h ≤ 0.4rad/sec;

- Minimum Resolvable Temperature Difference for thermal sensors should be ≤0.3C @ 0.5cy/mrad.

5.7 Development Areas

Several possibilities for enhanced performance might usefully be explored in the course of construction and test of an 'operational' LEAF, such as;

Multiple Excitation Wavelengths: Some secondary excitation wavelengths could be generated relatively easily, e.g. by Raman-shifting an excimer output, or, may even be 'free issue', as 1060 and 533nm from a tripled Nd:YAG. These might be used to investigate such concepts as;

- extending the range of oil thickness measurement via water Raman attenuation by using longer wavelengths, at which oil absorption coefficients are lower;
- using the two-photon up-conversion effects in oil-water interfaces, reported by Korenowski & Frysinger [1st Thematic Conf. Remote Sense. Marine and Coastal Environments, New Orleans, (1992)];
- resolving effects of species-dependent variations in optical properties of algae on fluorosensor measurement of primary productivity [Dudelsak, private comm.];

Synergy of Active and Passive Sensors: Missed targets and false alarms from passive optical and thermal sensors can occur because their responses to oil and to background can vary with factors such as illumination conditions or air or water temperature. However, if a certain passive signal is confirmed to be 'oil' (or 'not-oil') by fluorosensing, then it seems likely that all passive-sensor pixels, *in the immediate vicinity,* which give the same signal might safely be interpreted as being in the same class. If the 'immediate vicinity' proved to be, say, the type of shoreline and the season involved in a particular spill, then the effectiveness of the passive sensor would be greatly enhanced by 'normalization' by the fluorosensor.

6. CONCLUSIONS

A Laser Environmental Airborne Flurosensor, using an XeCl excimer Transmitter and a 64-channel, range-gated Spectrometric Receiver has been built, has been flight-tested at altitudes of 300 - 400ft AGL, and has demonstrated, in-flight, single-shot discrimination of Alberta Sweet Mixed Blend crude oil from water, ice, and shoreline materials such as rocks, gravel and sand.

Discrimination amongst the non-oil background materials, and detection of changes in oil fluorescence associated with weathering, have also been demonstrated using flight data, and variations of oil fluorescence spectra with decay time have been measured in ground tests.

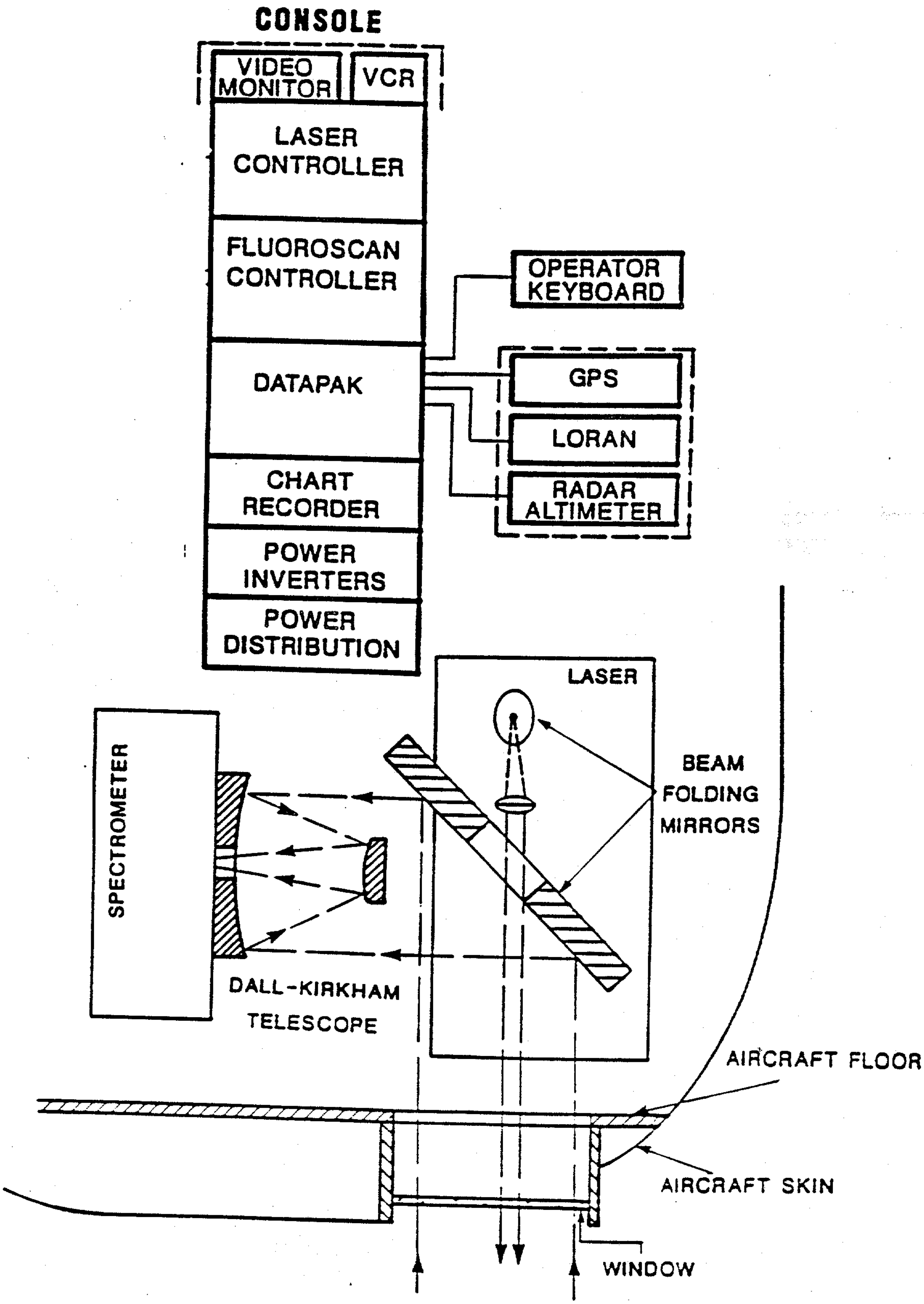
The results of the test programme indicate that a Laser Fluorosensor offers a viable, and perhaps the only reliable, means for remotely mapping spilled oil on beaches and in ice, and confirming reports of oil on water from other sensors.

Appendix 'A' - Subsystem Parameters

Table 1:- Fluorosensor Evolution

Function	*LEAF*	FLUOROSCAN	Mk. III
Gating	Adjustable	N/A	Fixed
Resolution	4.7nm @ 400 OR 2.7 @ 550	5 bands, 50 to 150nm	20nm
Spect. range	320 - 635nm OR 525 -696nm	344 - 700nm	380 - 700nm
Laser	XeCl @ 308nm OR Dye* @ 490-520nm	XeCl @ 308nm	N_2 @ 337nm
Display	Video of target ID* + strip-chart	Strip-chart	Video, Corr. Fn.
Scanning	Conical, 15°*	N/A	N/A

* *Future up-grade*



View Looking FWD.

SPECTROMETER

Optics Type ....Out-of-plane Czerny-Turner

F - Ratio ....Entrance, f/3.1 ; Exit, f/2.2

Grating ....600g/mm; blazed @ 400nm, 1st order
OR
923g/mm; blazed @ 500nm, 1st order

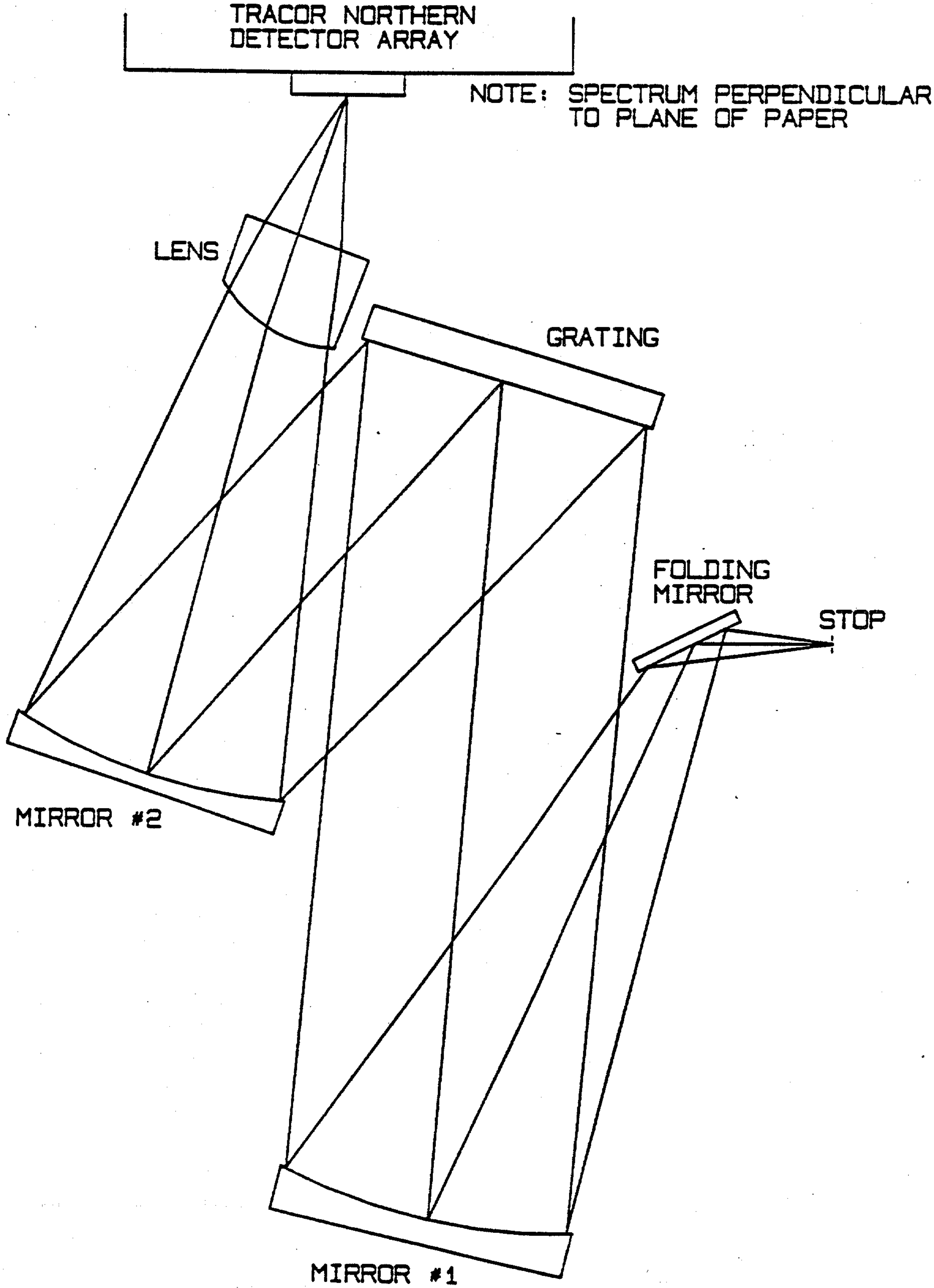
Detector ....Gateable, intensified diode array
1024 diodes, read in pairs.

Gate Width ....$\geq$20nsec

Spectral Range ....320 - 635nm OR 525 - 696nm

Channels ....32 to 64, user-selectable

Resolution ....4.7nm @ 450nm (64 channels)
OR
2.8nm @ 600nm (64 channels)



GDAS SPECTROMETER

ANALOGUE ALTIMETER

Range ....100 to 1000ft

Cal. constant 10mv/ft

Resolution ....± 0.5ft RMS (single shots)

Temp. coeff. ....0.013 ft/C

Accuracy ....± 0.5ft @ 25C (after calibration)

Gate Offset Range .... Surface ± 30ft in 5ft steps

Gate Width .... 20 to 180nsec in steps of 10nsec

Self-check .... On command; uses internal crystal

Fluorosensor Calibration

Function	Freq.	Cal. Reference	Shutter
Dark Current	10Hz	none	X
Laser EMI	10Hz	none	X
CW Gain	10Hz	Internal LED	X
	End-of-Line	Internal LED	X
CW Spectral Response	Pre-flight	Ext. std.lamp	O
	Monthly	Ext. std.lamp	O
Pulse Response	Pre-flight	Std. tgt @50m	O
Laser/Rx. Align't	Pre-flight	Std. tgt @50m	O
Laser Monitor	Pre-flight	Calorimeter	X
Altimeter	Monthly	Std.tgt.30-150m	O
Gate Offset	A/R	Std tgt	O
Range law	A/R	Std. tgt.	O
Receiver F-O-V	A/R	Point Source	O
System F-O-V	A/R	Pt. fluor. tgt.	O

CHART DISPLAY

"ALARM" - an eye-catching string @ chart margin if following TRUE:-

2 MIN. TAPE REMAINING	
NEXT LINE ID REQUIRED	
CTM_ERR	[case temp]
DTI_ERR	[delay timer]
FAN_ERR	[stirring fan]
HOF_ERR	[h2o flow]
HST_ERR	[heatsink temp.]
HTT_ERR	[h2o temp.]
HVT_ERR	[HV off]
INT_FAIL	[gate too long]
TOT_OVFLS > NSAMPS	[too many o'flows]
FLUOR' NO RESPONSE	[COM fail or sys error]

These represent conditions requiring either
Operator action (e.g., change tape) OR Operator decision (e.g. go home)

CHART DISPLAY

Set-up Tables

Set-up #1 :

Raw data either Background Corrected, Uncorrected, or Background Only, group- and spectrally-averaged but not otherwise processed, and plotted at 10Hz.

Set-up #2 :

Normalized data, Background Corrected, group- and spectrally-averaged, normalized to a reference altitude and laser energy, and plotted at 10 Hz.

(The spectral bands for all data will be of operator-selectable widths of 0 - 64 basic spectral channels, without overlap.)

CHART DISPLAY

Standard;

- Time hh:mm:ss
- Lidar Alt. @ 50ft/inch, 'wrapped' @ 150ft, 300ft, ,
- Laser Energy @ 2048du/inch
- Gain @ 5step/inch
- Gain Change as Gxx
- Warning messages hh:mm:ss Wnn *text*
- B'kgnd Corr. Status as Bx, (x = 0,1,2)
- Normalization Status as Dx, (D = 0,1)
- Fluoresence, 5 spectral bands of group-average data (may be normalized)
- B'scatter @ 3413du/in (4096 = 1.2in)
- Spectral Av. B'kgnd @ 4096du/in.
- Peak Fluorescence (the largest value in the 64 group-averages) @ 5120du/in.(4096 = 0.8in)

Appendix 'B' - System Controller Software

GDAS/LEAF System Controller

The GDAS controller is an STD bus micro-computer based on an SBC188 cpu which contains an Intel 80188 cpu, 8087 math coprocessor and sufficient ram and eprom to handle all of the requirements of the control function. Communication with the sequence controller is through two BRL built isolating driver/receiver boards refered to as GDAS Interface Board #1 and #2. Video (diode array) data from the sequencer is digitized by a modified 12-bit analog to digital convertor board (Analog Devices RTI1260). This board has been modified to allow for transfer of data to the cpu board ram through DMA. Other analogue signals from the sensor head and the laser houskeeping signals are digitized through a second unmodified RTI1260 board using its 16 channel multiplexing capability. Communication with the Datapak is carried out through a GPIB interface consisting of a slave cpu (Ziatech ZT8830) and a GPIB interface driver (Ziatech zSBX20). The firmware for the slave cpu is similar to that used in the Fluoroscan System. The front panel indicators, thumbwheel and push button switches are handled by an STD parallel I/O card (MICROSYS SBC8466) and a BRL built opto-isolator board.

Each of these systems is described below.

SBC188 CPU Card

The GDAS controller uses an SBC188 cpu card with 96k onboard ram, 32k onboard EPROM and an 8087 NDP. The cpu requires no external ram and no ram card should be installed in the system which overlaps with the cpu memory space (see Memory Map below). The following are the jumpers to be installed on the board.

J1	1-2	DRQ1
	3-4	DRQ0
	5-6	TMR1 IN
	7-8	TMR0 IN
	9-10	TMR1 OUT
	11-12	TMR0 OUT
	13-14	EXTINT
J2	1-3	serial RxD
	2-4	TxD
J3	1-3	serial *CTS in
	2-4	RTS out
J4	2-3	set RTS
J5	4-5	MUART int to cpu INT2
	2-3	STD *INTRQ to cpu INT1
J6	2-3	set STD asynchronous *WAITRQ
	4-5	
J8	2-3	cpu *LCS used for U8
J9	1-2	NDP accesses U8

```
J10,11,12 3-8  U8,U9,U10 all 32K x 8 static rams
          4-5
          9-10
          13-14
J13   2-4      U11 32K x 8 eprom (27256)
      3-5
      9-10
      13-14
J14   2-3      *MEMEX controlled by cpu *PCS5
J15   nc       *INTAK not active
J16   1-2      enable *MEMEX
      3-4      enable *IOEXP
```

At reset, the memory and I/O select control registers of the CPU are all initialized for no wait states, use external ready. The latter is not needed since the onboard ram and I/O do not generate wait requests but offboard I/O using the IOEXP line might. From the above jumper selection, the STD bus *MEMEX line is controlled by I/O accesses that activate *PCS5. This range should not be used by the cpu resulting in the *MEMEX line being tied high.

The STD bus *IOEXP line is controlled by *PCS6. This simplifies use of 8 bit addressed peripherals which make use of *IOEXP. These peripherals will be located in the address range $0300 to $037F, the range that corresponds to *PCS6. The peripherals should thus all reside in the bottom half of their 256 byte address range (ie. A7 must be low).

The STD bus interrupt request is fielded by the CPU INT1 input which is configured in non-cascade mode. The bus *INTAK line is thus inactive and the CPU INT3 interrupt line is not used. The INT0 and INT2 inputs also do not generate acknowledge signals. INT0 is tied to the NDP interrupt request while INT2 is connected to the front plane EXTINT input.

The two MUART parallel ports P1 and P2 are not used.

GDAS MEMORY MAP

```
$FFFFF
        SBC188 eprom
$F8000
        not implemented
$F0000
        slave ram
$E0000
        not implemented
$38000
        ram CPU U11
$30000
        ram CPU U10
$28000
```

ram CPU U9
$20000
not implemented
$08000
ram buffers CPU U8, 8087 ram
$00800
interrupt vectors
$00000

GDAS I/O MAP

$FFFF
not implemented
$0400
not used, *MEMEX active
$0380
video ADC, parallel boards
$0300
not implemented
$0280
CPU clock (not present)
$0200
CPU muart
$0180
not used
$0100
auxilliary ADC card
$00F0
not implemented
$0000

VIDEO RTI1260 ADC Card

An RTI1260 12-bit adc card is used to digitize the GDAS video analogue signal. It is I/O mapped at a base address of $0300 with the following jumpers:

52-53, 45-47, 49-50	I/O normal (use *IOEXP)
1-2, 7-8, 9-10, 15-16	base address $0300
23-24, 20-21	bipolar, 2's complement
39-40, 27-29	
41-34, 35-37, 30-31	differential input

This card is extensively modified to bring control lines out to I/O interface board 2. These modifications are documented in DRWG.NO.373EXP045 while the schematic for Interface Board #2 is shown in DRWG.NO.211EXP058.

The use of the card by the cpu is modified somewhat from the description in the manual in that the data is read by two consecutive reads from the lsb port address. After writing the channel number to the mux address port, the first read of the lsb data port returns the lsb of the data while the next read returns the msb of the data and the busy status bit, described in the manual. The next read returns the lsb and so on, alternating lsb and msb data with each read.

No matter how many reads of the data port are made, writing to the channel address port resets the read f/f such that the next read of the data port returns the lsb data. For a description of the operation in DMA data acquisition mode, refer to the Interface Board #2 discussion below.

AUXILLIARY RTI1260 ADC Card

An RTI1260 12-bit adc card is used to digitize the laser energy, backscatter, analogue lidar, water temperature and laser HV signals. It is I/O mapped at a base address of $00F0 with the following jumpers:

52-53, 45-46, 49-50	I/O normal (ignore *IOEXP)
(addr selects out)	base address $00F0
23-24, 20-21	bipolar, 2's complement
39-40, 27-29	
41-34, 35-37, 30-31	differential input

This board is used exactly as described in the manufacturer's manual: writing the 8-bit channel address (0 to 15) to port address base+$0B sets the multiplexor address and starts a conversion; reading the 8-bit port at base+$0D returns the busy status in D7; when the busy status is low, reading port base+$0C gives the lsb (d0-d7) of the result while port base+$0D gives the lsb (d8-d14). The resulting word should be sign extended from d14 to d15.

BRL I/O Interface Board #1

This board provides parallel I/O communication for the sequencer using differential line driver/receiver capability. The board schematic is shown in DRG.NO.211EXP057. It is an STD-bus compatible board with fixed access type: I/O mapped using the IOEXP* line and occupying address $0314 to $0317. The port assignments are as follows:

$0314	read	LIDARPORT - 8 bit digital Lidar Board altitude data
$0314	write	GATEOFFSET - 8 bit sensor gate offset value
$315	read	STATUSPORT - sensor and board status bits
$315	write	LAMPCNTL - sensor head calibration led control and board control bits

The use of these boards is as follows:

LIDARPORT input altitude code from Digital Lidar board. This data and the gate offset output data for the sequencer are multiplexed onto a single 8-bit bidirectional bus to the sequencer. A hardware reset of Interface Board #1 forces the port to the input status. Strobing the RESET line to the sequencer forces the port at the sequencer end to be input to the sequencer as well. Control of the direction of the port is controlled by bits in the LAMPCNTL port - see below.

GATEOFFSET output port for controlling the intensifier gate position relative to the surface - works in conjunction with the ABOVE bit on Interface Board #2. The data written depends on the type of lidar board in use. Refer to the LIDAR CALIBRATION discussion. This port is multiplexed with the input LIDARPORT. Control of the direction of the port is controlled by bits in the LAMPCNTL port - see below.

STATUSPORT input port giving status lines from the sequencer and the direction of the bidirectional port LIDARPORT/GATEOFFSET as follows:

D0 LIDARTYPE - set if digital lidar board, reset if analogue. Valid only if controller connected to sequencer.

D1 COOLR - extra status line from sequencer. Current application not defined. The status of this line is reflected in the COOLR indicator on the front panel in all but the test modes.

D2 INTFAIL - set if sequencer senses a fault. The line is reset in response to strobing the RESET line on Interface Board #2. Can be set during the subsequent data cycle.

D3 not used, always read high

D4 not used, always read high

D5 not used, always read high

D6 EOS2 - end of scan 2 strobe from sequencer. This bit reflects the instantaneous state of the line which should be reset after strobing the sequencer RESET line. The signal is pulsed high at the end of the complete data collection sequence by the sequencer. This can set the bidirectional port for input (read LIDARPORT) depending on the status of the control lines in LAMPCNTRL.

D7 LIDSTAT - set if LIDARPORT is input, reset if port is output. Reflects on the port direction on the board, not necessarily the direction of the port at the sequencer end.

LAMPCNTRL output port controlling direction of bidirectional LIDARPORT/GATEOFFSET port and 4 bit code for sensor illuminating lamp. Bit assignments as follows:

D0 - D3 4-bit code controlling the array illuminating lamp in the sensor head. Value 0 is lamp off. This value is latched and only takes effect when the RESUVA line on Interface Board #2 is strobed. Hardware reset forces low.

D4 - D5 not used. Can be any value.

D6 - OFFSOUT - strobe high to force the LIDARPORT/GATEOFFSET port to be output if LIDIN is high. Should not ever be high if LIDIN is low. Hardware reset forces low.

D7 - LIDIN - Strobe low to force LIDARPORT/GATEOFFSET port to be input. A low value causes the direction logic to ignore the EOS2 pulse from the sequencer. Should never be low if OFFSOUT is high. Hardware reset forces low.

From the above port description, it can be seen that for normal operation of the sequencer, after strobing RESET to the sequencer, a zero should be written to the LAMPCNTRL port. This forces the bidirectional port to be output. The LIDSTAT bit in STATUSPORT should be reset as should the EOS2 bit. A byte with the D0-D4 containing the desired lamp control code and D7 (LIDIN) set should be written to LAMPCNTRL. The LIDSTAT status bit should remain reset. Write the appropriate code to the GATEOFFSET port (and the ABOVE bit in Interface Board #2) then strobe RESUVA high to implement and latch the lamp control code and to latch the offset code. After the data cycle completes in the sequencer, the EOS2 line should pulse. This will be latched in the LIDSTAT bit which should then be set. If the digital lidar board is being used, the lidar altitude code can be read from the LIDARPORT.

An internal test mode is also possible in which data can be written to the GATEOFFSET port then read back to verify the data. This test only works on the signal path up to the TTL data latches and input buffer, not on the differential buffer drivers. Writing a control byte with LIDIN reset and OFFSOUT set to LAMPCNTRL forces the board to be output. In this state, any byte written to GATEOFFSET should be reflected in a read of LIDARPORT.

BRL I/O Interface Board #2

This board provides parallel I/O communication for the sequencer and logic to allow analogue data acquisition of the video signal using DMA. The board schematic is shown in DRG.NO.211EXP058. It is an STD-bus compatible board with fixed access type: I/O mapped using the IOEXP* line and occupying address $0310 to $0313. The port assignments are:

$0310	write	WIDGAIN - gate width and signal gain
$0310	read	SEQSTAT - status port
$0311	write	CONTROLPORT - control lines
$0312	write	CONTROLPORT1 - control lines

The use of the ports is as follows:

WIDGAIN intensifier gate width and video signal gain controls. D0 to D3 is the gate width value, 0 to 15. D4 to D7 is the gain control value, 0 to 15.

SEQSTAT status port information as follows:

D0 - unused. Always read high.
D1 - unused. Always read high.
D2 - unused. Always read high.
D3 - unused. Always read high.
D4 - unused. Always read high.
D5 - unused. Always read high.

D6 - Read the status of the Busybit to the sequencer. This bit holds off the next data ready signal from the sequencer during video data acquisition. It is set by the start of data conversion when started by an external request and reset by the second read (msb) of the data port. It is also reset by a hardware reset of the system and by the RESET signal to the sequencer in CONTROLPORT.

D7 - Read the latched SSTART (synthetic start) signal from the sequencer. This bit is held reset by *INTCLR in CONTROLPORT low. When *INTCLR and LOCALTEST are both high, a rising edge on the SSTART sets this status bit.

CONTROLPORT control bits as follows:

D0 - Calibrate control line to sequencer. Used only by analogue lidar board.

D1 - Shutter control to sensor head. A rising edge turns the shutter on.

D2 - LOCAL/*REMOTE control to sequencer. Set for local control, reset for remote.

D3 - TRIGGER signal to sequencer. Strobe high to start sequencer cycle.

D4 - RESUVA signal to sequencer. Strobe high to latch gate width, gain, lamp control and offset lines in sequencer.

D5 - RESET signal to sequencer. Resets sequencer and latched SSTART signal in SEQSTAT.

D6 - ABOVE signal to sequencer. Set to make gate above the surface, reset for below the surface. Actual offset above or below surface defined in GATEOFFSET port on Interface Board #1.

D7 - *INTCLR signal. Reset to hold latched SSTART low. Set to allow rising edge of SSTART from sequencer to latch bit in SEQSTAT.

CONTROLPORT1 control bits as follows:

D0 - not used

D1 - not used

D2 - not used

D3 - not used

D4 - LOCALTEST control bit. Set to enable SSTART and DATARDY receiver. Reset to turn SSTART and DATARDY off. Setting this bit might cause an external data convert request.

D5 - LOCAL_CNV control bit. If LOCALTEST is reset, then setting this bit causes an external conversion request. If LOCALTEST is reset then this bit gates the DATARDY signal: set to allow DATARDY to generate external convert requests.

D6 - not connected.

D7 - not connected.

SB8466 Parallel I/O

This card provides up to 48 TTL I/O lines through two Intel 8255 PIA chips. It is I/O mapped with jumpers as follows:

J8	1-2, 3-4	base address $0330 (*IOEXP used)
J9	9-13	port 3 input

The board occupies 10 consecutive bytes in I/O space. The board is used to provide the logic interface to the front panel and the laser control (Lumonics) system. One port is used to control the front panel indicators: System Fault, COOLR, RUN, REMOTE and ILLEGAL Entry. A single bit controls the COF signal to the laser controller. The thumbwheel and pushbutton switches on the front panel and the laser housekeeping status lines from the laser control system are written or read through a multiplexed 4-bit bus with up to 16 different addresses provided by a 4-bit address bus. The port addresses and uses on the board are as follows:

$334 read	d0-d3 interface bus data. Data read depends on interface address specified
$335 write	d0-d3 interface bus address, 0 to 15 d4 COF control line to laser control
$336 write	indicator control. Setting a bit as follows turns the indicator on: D0 - System Fault D1 - ILLEGAL entry D2 - COOLR status D3 - RUN D4 - REMOTE
$337 write	PIA control byte. Data written is $90.

The data read at address $334 depends on the address specified in port $335. The address is latched at the port and subsequent reads of the data port reflect the current status of the input lines when the data port is read. The addresses and data read are as follows:

ADDRESS	DATA
0	push button switch and LTR status as follows: D0 - ENTER push button D1 - RUN push button D2 - ONLINE push button D3 - LTR status from laser control system
1	BCD thumbwheel switch, sign of offset: 0='-', 1='+'
2	BCD thumbwheel, offset digit, msb
3	BCD thumbwheel, offset digit
4	BCD thumbwheel, offset digit, lsb
5	BCD thumbwheel, MODE selector, 0 to 9
6	BIN thumbwheel, GATE selector, 0 to 15
7	BIN thumbwheel, GAIN selector, 0 to 15

8 BIN thumbwheel, LAMP control, 0 to 15

9 Laser housekeeping status bits lsb:
D0 - set if FAN error
D1 - set if water temperature too high
D2 - set if gas pressure out of range
D3 - set if High voltage not on

10 Laser houskeeping status bits msb:
D0 - set if delay timer inhibit active
D1 - set if heat sink temperature too high
D2 - set if case temperature too high
D3 - set if water flow error

The BCD and BIN thumbwheel data is the one's complement of the thumbwheel setting; ie, a thumbwheel value of 9 is read as $F5.

The data ports of this board are optically isolated from the laser control system and front panel interface boards mounted near the front panel. The opto-isolators used have a propogation delay of approximately 1 us so that after writing a new address to the interface bus address port, a delay of 3 or 4 us should be inserted before reading the data port.

SYSTEM DEVELOPMENT

The software was developed and debugged using the Systems&Software SP86/TX Debugger. This is a source level debugger that consists of a small EPROM-based monitor program resident on the target 8088/80188 system and a driver program resident on the host PC development computer which communicate through an RS-232 interface.

The host program is supplied as a DOS executable file sp86.exe which requires no user modification. The target system monitor, however, needs to be ported to the specific target system. It is supplied as two assembler source files, MON_INIT.ASM and MON_SYS.ASM. The later contains routines which would not normally require any user modification. Board specific routines, such as the muart type and address are contained in the file MON_INIT.ASM. SSI supplied several versions of this file for various commercial boards on the SP86/TX distribution disk.

The modified version of MON_INIT.ASM used to generate the target system eprom is stored in the DEBUG subdirectory. It is sufficiently annotated to describe the implementation of the serial link. The directory also contains a DOS MAKE file, MAKE_RLC, that assembles then uses SSI Link&Locate++ utilities to link then locate the object code in the correct memory space and generates a binary file ready to burn the EPROM. Refer to the SSI Link&Locate++ Manual for a discussion of these utilities.

The monitor is created using the MS-DOS MAKE utility using the following files from DEBUG.ARC:

MAKE_RLC ascii input for MAKE utility.

MON_INIT.ASM source code for serial drivers and 80188 cold start vector and memory control register initialization.

MON_SYS.ASM source code for non-target dependent routines.

README.DOC documentation supplied by SSI.

MON_256K.BIN binary file for programing 32k eprom.

The monitor is programmed in a 32k eprom labelled GDAS/LEAF Debug SP86 and the above code only needs to be used to create a new eprom.

Refer to the SSI Softprobe 86/TX Reference manual for use of the debugger. The debugger expects to load a program in Intel OMF format. Generation of this file is described in the next section.

Software Description

The software for the controller resides in the 32k eprom on the cpu board. The program is written in assembler source for the Microsoft Macro Assembler V5.1. Two slightly different sets of commands are used to link and locate the object modules: one for the debug version and the other for the final eprom version. The debug version does not have the 80188 startup code (since this is done by the resident debug eprom), is located in memory starting at $2000 (the bottom of the contiguous resident RAM) and is finally converted to Intel OMF86 format to be loaded by the debugger. The eprom version has the 80188 startup code, is located starting at $F8000 in memory (the top 32K) and is finally converted to a binary file for burning into an eprom.

The assembly, linking and locating of the debug and final versions are carried out using the MS-DOS MAKE utility using files GDAS or GDASP for the debug and final versions, respectively. The various files are as follows:

GDAS ascii control input for MAKE to produce the Intel .OMF file for debugging.

GDASP ascii control input for MAKE to produce the .BIN file for programming the eprom.

GDASLOC.IN ascii control input for SSI xloc86 utility for debug version.

GDASPLOC.IN ascii control input for SSI xloc86 utility for final version.

GDAS.ASM source code for program start and the mainline housekeeping loop. The assembler variable EPROM, defined at the start of the file needs to be set to 1, if GDASP is being used to generate the eprom version, or 0 if GDAS is being used to generate the ram loadable debug version.

GDASINC.MAC system equates and structure definitions, INCLUDED in all .ASM files.

DPROC.MAC macro definition of the group averaging code for the different combinations of corrected and uncorrected raw data and group averages. INCLUDED in the DPROC.ASM file.

DPROC.ASM routine to calculate the group averages, and format and store the transmit buffers for the GPIB slave.

INT.ASM interrupt initialization and handlers.

UTIL.ASM routines to initialize the default control parameters for LOCAL operation and the constants for the 8087 NDP, to change between LOCAL and REMOTE modes and other utilities.

DISPATCH.ASM routines that handle each of the operating modes of the controller.

SWITCH.ASM routines that change the operating mode of the controller.

TEST.ASM test routines used during startup and testing modes.

SLAVERAM.ASM definition of GPIB slave ram. Consists of a template of EQU definitions of variables in the slave segment. Defined in this fashion so that no actual initialization data is included in the .OMF file during debugging so the loader does not write anything to the slave's ram.

GDAS.OMF the Intel load module that can be downloaded to the cpu by the SP86/TX debugger for software development.

GDAS.BIN the binary format file to program the eprom.

GDAS Segment Map

The following table gives a memory map of the gdas controller in the form of a segment map. The first column gives addresses and some labels used by the startup code. The next column shows the class names for the segments: in this and the following discussion, class names are all given in single (') quotes. The next column gives segment names. The right side contains a description of the segments.

```
- FFFF:F      ---------
|             |       |
| FFFF:0      ---------                           <- Bootstrap code
|             |       |        XCODE              <- Initialization code for the 80188.
| FFC0:0      ---------                              Ends with far jump to label start
|             :       :
|             ---------                           <- Top of program part of eprom
R             | [CONST] |                         ^   This area of ROM contains initializers
O             ---------                           |  that are used by startup code to
M             | [DATA]  |                         |  initialize segments with these class
|             ---------                           |  names (see discussion below).
|             | [DATA_BEG] |                      v
|             ---------
|             | 'CODE_END' |   C_ETEXT            <- This class contains one segment of
| _etext      ---------                              zero length to label end of code
|             | 'CODE' |       _TEXT              <- Text segments with class name CODE
~ start:      ---------
              :       :
~ _efdata     ---------                           <- end of far initialized data
|             | 'FAR_DATA_END' | ENDFDATA         <- This class contains one segment of
|             ---------                              zero length to mark end of class
|             | 'FAR_DATA' |   FAR_DATA_START     <- Initialized far data of FAR_DATA class
|             ---------                              This data is included by INITDATA control
|             | 'FAR_DATA_BEG' | BEGFDATA         <- Class of one segment to label start of
| _bfdata     ---------                              far initialized data.
|             | 'DATA_END'  |  ENDDATA            <- Class of one segment to mark end of DGROUP
| _edata      ---------                              and end of initialized data
|             | 'MSG' |        EPAD               <- Headers for C error messages
|             ---------                           ^
|             | 'MSG' |        PAD                |
R             ---------                           |
A             | 'MSG' |        MSG                |  These four classes of segments contain
M             ---------                           |  initialized data. They are initialized
|             | 'MSG' |        HDR                |  from ROM by the startup code
|             ---------                           |
|             | 'CONST' |      CONST              |
|             ---------                           |
|             | 'DATA' |       _DATA              |
|             ---------                           |
|             | 'DATA_BEG' |   BDATA              v
| _bdata      ---------
| stack_top   | 'STACK' |      STACK              <- This segment contains the stack
|             ---------
|             | 'BSS_END' |    ENDBSS             <- This class just labels the end of
| _end        ---------                              uninitialized data
|             | 'BSS' |        _BSS               <- This class contains uninitialized data
|             ---------
|             | 'BSS' |        NULL               <- 8 bytes of zeros to allow null pointer
|             ---------                              checking. This is the start of DGROUP
|             :       :
| 0040:0000   ---------
|             |       |                           <- These are the interrupt vectors
- 0000:0000   ---------
```

The above segments are not all used but are included to allow the possible use of C programs. The Microsoft C Compiler puts all code into segments with class name 'CODE' so all of the code except for the special startup code for the 80188 is put into segment _TEXT of class 'CODE'. The segment C_ETEXT (class 'CODE_END') is included just to provide a label _etext which marks the end of all the normal code that will end up in eprom. This is needed to allow the use of the INITCODE control for the SSI locating program XLOC86 (see below).

The Microsoft C Compiler puts all uninitialized data into default segments with the class name 'BSS'. The exact data put here depends on the memory model being used (refer to the Microsoft C Compiler Users Reference, Working with Models). Initialized data is put into classes 'DATA' and 'CONST'. If the math coprocessor is used, then there are error message segments associated with run-time math errors that are put into segments of class name 'MSG' (refer to the SSI math library documentation) which also contain initialized data: ie, the actual messages. The C compiler assumes all the above data and the stack will be less than 64K; ie, all the data fits into a group.

In this implementation we have also included the segment NULL which is placed at the very beginning of the default data area. This is not used but is expected by some of the C run-time routines in order to check for a null pointer error. This segment just contains 8 bytes of zeros. If a null pointer assignment occurs (DS:0) then these bytes can overwritten and so checking for non-zero values indicates an error. This checking is not performed here.

Data segments with class names 'STACK', 'DATA_BEG', 'DATA', 'CONST', 'MSG', 'BSS' and 'BSS_END' belong to a group named DGROUP. Since these segments belong to a group, it follows that the total memory space occupied by them cannot exceed 64K.

Object files from C may contain data segments with class names 'FAR_DATA', 'FAR_BSS' and 'HUGE_BSS' depending on the use of 'far' and 'huge' data objects in the C source.

Data segments with class names 'FAR_BSS' and 'HUGE_BSS' contain 'far' and 'huge' uninitialized data, respectively. These segments do not belong to any group. They can be placed either before or after DGROUP in memory, whichever is more convenient. Segments with either class name are not included in this implementation since no C code requires them.

Data segments with class name 'FAR_DATA' contain 'far' and 'huge' initialized data. It is a single class that is not a group and can be placed before or after DGROUP as required. Although no C source code uses this class, it is included in the implementation since the use of the INITDATA control with the locator XLOC86 described next requires it.

When a program is written in C for a DOS type machine, initialized ram data is included in the .EXE file and ram is initialized when the program is loaded by the operating system. In an embedded application, however, there is no .EXE file or operating system to initialize ram. For the embedded application, the initializers for ram need to be included in eprom and a startup routine needs to copy these values into the appropriate locations in ram. This is also required in this implementation in order to copy constants used by the math coprocessor to the bottom ram chip due to the hardware requirements of the 80188, 8087 and the bus controller chip 80288; refer to the 80188 Implementation discussion.

For a C application, initializers for segments with class names 'DATA_BEG', 'DATA', 'CONST' and 'FAR_DATA' have to be placed in eprom so that the startup routine can copy them to ram. SSI provides a mechanism for doing this by specifying the INITDATA control for the XLOC86 locator program. If INITDATA is specified, then the locator places all data from labels _bdata to _edata and _bfdata to _efdata at the end of the 'CODE' class (eprom) starting at the label _etext. These labels are shown in the segment map above.

The class 'CODE_END' is defined just to provide the label _etext. It is given a separate class name since the order of classes can be specified for the locator. This class is placed immediately after the class 'CODE' so the initializers are placed in eprom above the actual code.

Classes 'FAR_DATA_BEG' and 'FAR_DATA_END' are also only defined to provide the labels _bfdata and _efdata. Although there is no far initialized data, these labels must be defined or XLOC86 quits with an error message.

Classes 'DATA_BEG' and 'DATA_END' provide the labels _bdata and _edata, respectively. These provide the markers for initialized data in DGROUP. Part of the startup code copies data from eprom into this part of ram. The same startup code also zeros all other ram locations from the start of DGROUP up to the label _bdata, ie. all non-initialized data in RAM including the stack. If the startup code should not zero the stack, then it should write zeros from the start of DGROUP up to the label _end.

Constants used by the math coprocessor are all placed in the CONST segment so that they can be initialized by the startup code.

Software Tasks

The GDAS Controller software can best be described by itemizing the required tasks, describing the general outline of how the software performs these tasks then giving a detailed description of how each section of the software works. The following are the general tasks that the controller needs to perform:

1. Initialize the GDAS sequencer and default control parameter

values.

2. Service front panel push button and thumbwheel switches to allow for either LOCAL (stand alone), REMOTE (DPAK control through GPIB link) or TEST operations.

3. Control the sequencer to produce scanning of the detector at variable gain, gate width, delay and offset values.

4. Digitize the analog signals from the sequencer.

5. Calculate the group averages and transmit the data to the remote host through the GPIB interface.

6. In REMOTE mode, receive setup and trigger signals from the remote host and implement the gain, width, delay, offset, rate and gain correction values supplied.

7. Post error conditions to the front panel.

The data rate from the sequencer combined with the computational requirements for the group averages indicate that the cpu would be occupied significantly greater than 90% of the time computing the group averages and formatting the data for the GPIB link. Under these circumstances, the data needs to be double buffered, with the cpu formatting one set of data while the second set is being collected. A slave processor is necessary to handle the actual communications on the GPIB. The data acquisition from the sequencer needs to be handled by DMA in order to accommodate the data rate and most aspects of servicing the sequencer, the slave processor and the front panel needs to be handled by interrupts.

In controlling the sequencer, the controller needs to operate as a stand alone device in order to test the operation of the sequencer and detector and report data out the GPIB to a listen only data logger. It is also required to allow remote control of the detector through commands sent from a remote host through the GPIB, transmitting data to the host through the same link. These two modes are referred to as LOCAL and REMOTE and represent two different states of the controller. In LOCAL mode, the controller collects data from the sequencer using gate width, gain, etc. values specified through the front panel switches. In REMOTE mode, the controller expects at least one setup command from the host computer each time it enters the REMOTE mode. It can then accept trigger commands from the host, each of which can produce up to 10 cycles of the sequencer and result in one block of data to be transmitted to the host.

The overall program flow thus consists of an initialization sequence, a main housekeeping loop including a routine that calculates the group averages and formats the data buffer, and several interrupt handlers: one to service the front panel, one to service interrupts from the slave processor and one to generate the individual pulses to the sequencer. Each of the above is described in more detail in separate sections below.

NDP Implementation

The use of the 8087 NDP in the cpu board will be described here since it differs somewhat from the more standard 808X/8087 implementation that most people will be familiar with from PC type computers. For a complete description of the combination of an 80188 and 8087, refer to the Intel data sheets for the I80188, 8087 and i82188.

The 80188 cpu combines an improved 8088 cpu along with an interrupt controller, dma controller and counter/timer. It also can generate several select lines for memory and I/O devices. Because of some timing differences between the 8088 and 80188, the latter requires a different bus arbitrator than the 8088 when used with an 8087 NDP. This chip is the i82188 which is used on the SBC188 cpu board to allow for the 8087 and also bus requests on the STD bus. The SBC188 board uses only the select lines from the 80188 cpu to access the onboard ram/eprom, muart and optional clock. In the GDAS implementation, the cpu board provides all of the ram, except for the slave ram which is reserved only for the transmit buffers.

In the multi-processor 80188/8087 combination, the 8087 requests the bus whenever it requires to write results to or read data from ram. It does this by gaining control of the data and address busses then writing directly to ram addresses, generating the correct address specifications, then relinquishes the bus back to the 80188. Since the only address decoding provided for the onboard ram is generated internally to the 80188, the 8087 generated addresses will not result in accesses to the onboard ram and hence the NDP cannot be used if it tries to access the onboard ram to save or read data.

This deficiency is handled by the *CSIN/*CSOUT lines of the i82188. When the i82188 is allowing the 80188 to control the bus, the *CSIN line is routed out through the *CSOUT pin. *CSIN is connected to one of the memory select output lines of the 80188 which normally would be connected to the select input of a bank of ram or a single static ram. The *CSOUT line is connected to the ram select input instead. When the 80188 is active, the 80I88 connections are transparent to the system and the 80188 accesses the selected ram as normal. However, when the 82188 grants the bus to the 8087, it activates the *CSOUT line whenever the 8087 writes to or reads from memory. Thus no external chip select decoding is required, allowing the 8087 access to the onboard ram.

From the above, it can be seen that the 8087 can only access memory that is mapped into whichever memory select line from the 80188 is connected to the *CSIN line of the bus arbitrator. From the memory map, this corresponds to ram socket U8, corresponding to addresses $00000 to $08000. Hence programming for the 8087 must be carried out more carefully than would normally be the case. For example, constants used for calculations cannot be stored in eprom; they must be copied to the ram that the 8087 can access or the 8087 will not be able to read them. Similarly, all locations that are used for storage and retrieval of data by the 8087 must be mapped into the selected ram. The 8087 cannot attempt to access the slave ram without causing bus contention since the on board ram will always be active no matter what the address generated by the 8087 actually is.

To assist debugging, the 8087 CONTROL WORD is initialized to allow interrupts for invalid operation, zero divide, overflow and overflow. The 8087 interrupt is fielded by the INT0 input of the 80188 (fixed vector type $12). No attempt is made to recover from such an interrupt since this should only result from a programming fault; the interrupt handler saves the 8087 environment in a buffer then displays a fault code on the front panel indicators and halts. During debugging, the programmer can put a break point in the interrupt handler and examine the saved environment to determine where the fault occured. In the final version, interrupts of this sort should only occur if there is a firmware error or hardware fault.

Initialization

Initialization of the GDAS consists of two main steps. The 80188 control registers that set the ranges for the memory select lines need to be initialized first in order for the cpu to access the ram and eprom correctly. At reset, the high memory select line of the 80188 is only active for the top 1k of memory, ie. addresses $FFC00 to $FFFFF. This allows the cpu to access the cold restart vector locations starting at $FFFF0. The initialization code for the memory select line control registers is placed in the separate segment XCODE (GDAS.ASM) so that it can be easily located in the top 1k of the firmware eprom. This part of the program exits by a far jmp to bottom of the eprom where the initialization of the controller firmware starts. This segment is not present in the debug version since the resident debug monitor has already set up the registers correctly.

The initialization of the controller software itself starts at the beginning of the _TEXT segment in GDAS.ASM and consists of the following steps:

1. init stack and segment registers

2. reset the sequencer

3. configure the muart ports to service the front panel

4. call INIT_RAM (UTIL.ASM) which sets up default values for the setup and trigger parameters, initializes the buffers and buffer ptrs in the slave ram and copies constants required for the NDP processing to ram locations accessible to the NDP (see NDP Implementation).

5. call INIT_INTS (INT.ASM) which sets up the interrupt vectors, initializes flags and variables for the interrupt handlers, sets the interrupt priority registers for each of the interrupts and starts the TMR2 counter to generate the front panel service interrupt.

6. enter the main housekeeping loop.

The interrupt structure is described in the section on the interrupt handlers and the main housekeeping loop is described in the next section.

Main Housekeeping

The mainline code loop in GDAS.ASM merely calls the appropriate mode handler in DISPATCH.ASM and also places calls to the mode switching routines if the ENTER key is pressed.

The cooler status led is controlled just to mimic the state of the COOLR_STB line from the sequencer.

Error conditions noted by the interrupts are flagged by putting code values in the variable ERR_TYPE. The mainline loop posts a single error condition to the front panel leds, sets the ERR_SET flag and keeps the error displayed for a length of time controlled by the value put into the counter ERR_COUNT. This counter is decremented by the keyboard interrupt at 50 Hz. When the counter times out, the interrupt handler clears the ERR_SET flag. When this flag is clear, the main loop will check to see if a new error condition needs to be posted. If not, the fault leds are cleared; otherwise the fault is posted. This means that only a single error code will ever be displayed at one time on the fault leds.

Changing between LOCAL and REMOTE mode is controlled by the user pressing the front panel mode button. This action is flagged by the keyboard interrupt by making the variable KEY_PRESS non-zero. The main loop checks this variable and toggles between the two modes whenever the key is pressed.

The two routines that transfer from LOCAL to REMOTE and vice versa are GO_REMOTE and GO_LOCAL. Both routines follow basically the same pattern which is: wait for any current cycle to complete by checking the status of the DMA controller then setting or clearing the appropriate flags and counters to control the interrupts. In LOCAL mode, the slave interrupt is disabled, the 100 Hz trigger interrupt is restarted and the CLRINT and LOCAL control lines to the sequencer are set. In going to LOCAL mode, any NEWG_PEND flag set by the keyboard interrupt in response to the operator incorrectly pressing the ENTER key while in REMOTE mode is cleared. In REMOTE mode, the 100 Hz interrupt is disabled while the slave interrupts are enabled and the CLRINT and LOCAL control lines are reset.

Since any failure in the data acquisition system in LOCAL mode is only handled by the trigger interrupt handler (see below), it is possible for the DMA channel never to be turned off. Hence the GO_REMOTE routine only polls the DMA channel for approximately a second with the trigger interrupt disabled. If the DMA does not terminate, then the routine just stops the dma channel before completing.

The calculation and formatting of the transmit buffers are synchronized with data collection through the BUF_DONE flag and, in LOCAL mode, the TX_DELAY counter. Whenever the appropriate interrupt handler notes that a complete data buffer is filled, it sets the BUF_DONE flag, indicating that the data is available for processing. In LOCAL mode, the calculation of group averages is delayed two complete buffer cycles so that calculations are attempted only after correct data has been collected. This is accomplished through the counter TX_DELAY. This is not necessary in REMOTE mode since the raw data buffers are zeroed when a setup command is received.

The calculation of the group averages and formatting of the transmit buffers is carried out by the routine TX_REC_UPD (DPROC.ASM). This routine must be capable of gain correcting the raw data, background correcting raw signal data and group averages independently of each other and reporting either background, signal or background corrected raw data. It must also calculate the total background average, post overscale flags and report other flags to the remote host. The most time consuming part of the calculation is the inner loop that puts the gain corrected background, signal or corrected signal in the raw data section of each laser pulse and adds the background, signal or corrected signal to the group average accumulators. This part is repeated 640 times in the 100 ms between each trigger in REMOTE mode. A generalized routine that tests for the various combinations of background, signal and corrected signal in the raw data and group averages was found to be too slow. The program is thus written with 9 different versions of this inner loop optimized to carry out the different calculations. The actual routine is written as a macro (DPROC.MAC) that is used 9 times in the main calling routine in DPROC.ASM.

The main part of the routine formats the group average part of the transmit buffer and calculates the group averages since this is the same no matter what raw data is reported and averaged. It calculates a subroutine address based on the GMODE and BMODE flags in the trigger command for this set of data and branches to the optimized handlers only once for the whole data buffer. This results in a significantly larger program but is necessary to obtain the required execution speed.

INTERRUPT Structure

The interrupts used to handle the various tasks of the controller consist of two interrupts generated internally by the cpu and one external interrupt input line. The associated handlers are as follows:

Keyboard Interrupt generated by cpu Timer 2, vector type 19, priority 6. 50 Hz handler for front panel servicing.

COF Interrupt cpu Timer 0, vector type 8, priority 6. Variable frequency interrupt that generates cycle start pulses to the sequencer in REMOTE mode.

Slave Interrupt fields the STD bus INTRQ line through cpu INT1 input, vector type 13, priority 4. The STD bus backplane interrupt is activated by the GPIB slave processor when a command is received from the remote host.

8087 Interrupt fields 8087 interrupts through cpu INT0 input, vector type 12, priority 8. The 8087 is programmed to generate an interrupt on all bad faults. The handler saves the environment in XXXX, turns on the SYSTEM FAULT indicator and uses the other indicators to show fault type X, then halts.

Keyboard Interrupt

CPU timer 2 is initialized to run in continuous mode at 50 Hz, generating an interrupt every time the timer count register reaches the value in the timer 2 maximum count A register. This interrupt is fielded by the keyb_int handler. This handler provides software de-bounce of the front panel push buttons.

De-bounce of the push buttons is accomplished through a four step process, only one of which is carried out each time the interrupt handler is called. The particular step to be carried out is set in the variable key_flag.

key_flag 0 this is the initial state at reset and the normal condition of the handler when no key is depressed. This part of the handler checks to see if any key has been depressed and, if one is, saves the key identity and sets key_flag to 1 to make the handler enter the next step the next time it is invoked.

key_flag 1 the handler checks to make sure that the same key is still depressed. If not, key_flag is set back to 0 and the handler exits. If the key is still depressed, the action is recognized and appropriate action is carried out. If the ENTER button was pressed, the flag newg_pend is set for the trigger interrupt. If the MODE or RUN switch is pressed, the handler just sets the key_press variable to 1 for the mainline code. The handler completes this step by setting key_flag to 2.

key_flag 2 this step, and the next, provide de-bounce for releasing a key. If the key is released, the handler sets key_flag to 3, otherwise it leaves key_flag unchanged.

key_flag 3 if the key is still released, the key release is assumed complete and the handler sets key_flag back to 0 to return to the normal state. If a key is found to be depressed, the handler sets key_flag back to 2.

The handler completes servicing of the interrupt controller by issuing a specific eoi command to the cpu EOI register.

Mode Dependent Interrupts

As can be seen from the descriptions of the interrupts, only the keyboard interrupt is independent of the mode of the controller. The remaining interrupts that are active and what the active interrupts do depends on the mode of operation, so it is best to discuss these interrupts and their timing separately for the two modes.

Interrupts in LOCAL Mode

The timing of the interrupts, other processes and certain flags and variables is shown in the Local Mode Timing Diagram. In this diagram, control lines to and from the sequencer are shown in capitals (eg. TEST), handlers and subroutines are shown in capitals with a * (eg. TRIG_INT* is the trigger interrupt handler) while software flags and variables are shown in small letters (eg. buf_done).

A data acquisition cycle is started by the external TEST signal to the sequencer which clocks through the EXTINT signal to the cpu. This is fielded by the trigger interrupt handler (TRIG_INT) which is only active in the LOCAL mode. This routine (described in more detail below) controls the sequencer to start a data acquisition cycle and, if a set of 10 cycles have completed, starts the data transmission on the GPIB and sets the flag buf_done to cause the mainline program to start processing the completed set of data.

Normal termination of the data acquisition cycle occurs when the dma controller reaches terminal count and invokes the interrupt DMA_INT. If a fault in the sequencer causes the data transfer to be slow, then the TRIG_INT interrupt will find that the dma channel is not terminated indicating that the DMA_INT handler has not been invoked for the previous data cycle. In either case, the interrupt handlers update the cycle counter variable cur_cycle for the next cycle trigger interrupt.

The mainline program starts actively processing data when the buf_done flag is set. It resets the buf_done flag and starts processing data based on the state of the buf_tog flag. As can be seen from the timing diagram, when buf_tog is set, the processing routine TX_REC_UPD uses data collected in dma_buf1, and parameters in the local trigger image local_trig1, to create a transmit buffer tx_buf1 in the slave ram. The same buf_tog value causes the trigger interrupt to collect new data in dma_buf2 and transmit the already completed tx_buf2 out the GPIB. When buf_tog is reset, all the above processes toggle to the other buffers ensuring no conflicting use of incomplete data by any process.

LOCAL Mode Trigger Interrupt

The trigger interrupt handler (TRIG_INT) is only active during LOCAL mode. To alleviate the problems of clearing unacknowledged interrupt requests in the CPU, the interrupt is constantly enabled, but the handler does nothing but complete the servicing of the interrupt to clear the IRQ register as long as the LOCAL mode flag is reset.

When the LOCAL mode flag is set indicating that the controller is in LOCAL mode, the interrupt handler first checks that the dma channel is off indicating that the previous data cycle completed correctly. If it didn't, then the handler stops the dma channel, posts the dma error flag for the main line code and updates the cycle counter.

It pulses the CLRINT line to reset the interrupt request line EXTINT from interface board 1. If the counter cur_cycle, normally incremented by the DMA termination interrupt, has reached the terminal value of 10, the handler resets the counter to zero, toggles the buf_tog flag to cause all processes to toggle their buffer usage and sets the buf_done flag for the main line code. It also starts the data transmission out the GPIB by setting the appropriate buffer address for the slave cpu and sets the RDY_TO_GO flag.

If the newg_pend flag (see timing diagram) has been set by the keyboard interrupt in response to the user pressing the enter key, the handler now copies the new gains and gate width values into the local trigger images for subsequent implementation and clears the flag. The handler sets up the gain and width control lines to the sequencer, pulses the reset control line to the sequencer and sends a TRIGGER pulse to the sequencer by cycling timer 0 once. It then sets up the dma controller in preparation for the sequencer data transfer cycle. The destination address for the dma controller is calculated based upon the state of the buf_tog flag (reset for dma_buf1, set for dma_buf2) and the value of the cycle counter cur_cycle.

LOCAL Mode DMA Interrupt

This interrupt is invoked by the terminal count of the DMA controller which occurs when 64 channels of data have been digitized. It has a higher priority than the failsafe timer which it disables as soon as it is invoked. The handler updates the cycle counter for the trigger interrupt handler and finishes by servicing the interrupt controller through a specific eoi command.

Interrupts in REMOTE Mode

The timing of the interrupts, other processes and certain flags and variables is shown in the Remote Mode Timing Diagram. In REMOTE mode, data acquisition is controlled by the Trigger commands sent from the remote host through the GPIB. Every time the slave cpu receives a complete command from the remote host, either Setup or Trigger, it sets the STD bus INTRQ line invoking the SLAVE_INT handler.

The Setup command sets, among other things, the rate at which data acquisition cycles need to be run. The slave interrupt handler uses this rate value to calculate the counter value required for timer 0 to generate this rate. Upon receipt of a Trigger command, the slave handler loads this value into timer 0 and starts it in a modulo-n fashion with the first cycle truncated to a short period of 2.5 uS. Each time timer 0 counts out, it generates the trigger pulse to the sequencer, starting a data cycle triggering the COF_INT interrupt handler.

The COF_INT handler sets up the DMA channel and failsafe timer in preparation for the data transmission from the sequencer. This handler keeps track of how many times it has been invoked by the cur_cycle counter and when the number of cycles specified in the Setup command have been completed, it disables itself in preparation for the next Trigger command.

The termination of a data cycle can, as in LOCAL mode, be handled either by the DMA complete or FAILSAFE interrupts. There are, however, differences in the specific timing and tasks of the handlers which are detailed in the following.

REMOTE Mode Slave Interrupt

In order to alleviate problems in clearing unacknowledged requests in the CPU interrupt controller, the slave interrupt is constantly enabled but does nothing except service the interrupt controller except when the LOCAL flag is reset, indicating that the controller is in REMOTE mode. When in this mode, the SLAVE_INT handler resets the interrupt request in the slave, and determines whether the command received is a Trigger or Setup.

If it is a Setup, the handler copies the appropriate parts of the setup command to local buffers and to the two transmit buffers in the slave ram. It also calculates the counter value for timer 0, saving it as cof_freq before finishing the interrupt controller service.

It the command is a trigger, the entire command is copied to the appropriate local image buffer; either local_trig1 or 2 depending on the status of the buf_tog flag. The handler then sets up the appropriate send buffer address for the slave and starts the transmission of the data out the GPIB. It then checks for a possible error condition which could arise if the mainline code has not finished calculating the last complete set of data. This could happen if the trigger arrived too early. It then starts the data acquisition cycles by resetting the sequencer, setting up the counter for the COF interrupts, loading the maximum count register of timer 0 with the value in cof_freq, loading this value minus 5 into the timer 0 counter register and enabling the counter in the continuous mode. Because the timer 0 counter is only 5 below the maximum count, the first COF interrupt occurs 2.5 uS later.

REMOTE Mode COF Interrupt

This interrupt is invoked when the Trigger signal has been sent to the sequencer by timer 0. It sets up the DMA controller to handle the data from the sequencer and starts the FAILSAFE timer, timer 1. After it has been invoked the correct number of times to complete one 100 ms cycle of data collection, it disables Timer 0 and thus itself so that the next set of data can be synchronized with the arrival of the next Trigger command from the remote host.

LIDAR CALIBRATION

There are two possible lidar boards that can be used. The digital lidar board uses a 100 MHz clock to make all measurements. The analogue board has a finer resolution. There are two calibration values that are implemented in the System Controller firmware: the calibration of the gate offset in feet above or below the surface and the calibration of the lidar altitude returned by the lidar boards. The following presents the calculations used for both values for each board.

LIDAR ALTIMETER

DIGITAL: read from 8-bit LIDARPORT on interface board #1
1 bit = 5 feet
maximum range = 255 du = 1225 feet

ANALOGUE: analogue value through 12-bit ADC
10 V = 1000 feet
maximum range = 2047 du = 1000 feet

GATE OFFSET

The gate offset is controlled by writing an 8-bit code to the OFFSET port on interface board #1 and the single ABOVE bit in SEQSTAT on interface board #2.

DIGITAL: ABOVE bit set = offset above surface
reset = below surface
OFFSET is distance in feet*10:
1 = 10 feet above or below
2 = 20 feet, etc.

NOTE: if offset is below the surface, the sum of the LIDAR value and the offset cannot exceed 255 or the gate will not be timed correctly.

ANALOGUE: range is +-5V corresponding to +- 50 feet where -'ve is above surface, +'ve below.
ABOVE and OFFSET form a 9-bit word with ABOVE being the msb. This 9-bit word is presented to a 9-bit DAC as offset binary. The DAC output +-5V. The resulting gate offsets for a given code are thus:

Code decimal	Code hex	VOLTS	OFFSET feet
+255	1FF	+4.980	49.8 below
+254	1FE	+4.961	49.6 below
:	:	:	:
+1	101	+0.020	0.2 below
0	100	0.000	0.0
-1	0FF	-0.020	0.2 above
:	:	:	:
-255	001	-4.980	49.8 above
-256	000	-5.000	50.0 above

GATE OFFSET CONVERSION ROUTINE

The gate offset for each laser pulse is supplied in the TRIG_LAS structure as a signed integer, DELAY, for distance in feet*10 above (-'ve) or below (+'ve) the surface. A conversion routine is provided to convert the DELAY value into a code written to the lidar board to provide the appropriate offset as follows:

DIGITAL LIDAR:

$$OFFSET=\frac{|DELAY|+50}{100}$$

$$if\ (DELAY<0)\ then\ ABOVE=1$$

ANALOGUE LIDAR:

$$CODE=\frac{[(DELAY+500)*512]+500}{1000}$$

where CODE is the 9 bit value of OFFSET and ABOVE.

LIDAR ALTIMETER CONVERSION ROUTINES

The LIDAR altitude reported to the Datapak in FLUOR_AUX and summed in GLIDAR and the LIDAR_MIN/LIDAR_MAX values sent by the Datapak in the SET_UP command are all binary values in feet*2. Two types of conversion routine are needed for each lidar type: 1) convert LIDAR_MIN/LIDAR_MAX to a binary word corresponding to the LIDAR code value read from the sequencer and 2) convert the code read from the sequencer to a 12-bit integer in feet*2 for the FLUOR_AUX and GLIDAR values. The conversions are carried out as follows:

DIGITAL LIDAR:

LIDAR_MIN/LIDAR_MAX to LIDARPORT code:

$$CODE=\frac{LIDAR\_MIN+5}{10}$$

minimum code = 0; maximum code = 255, corresponds to 1275 feet

LIDARPORT code to LIDAR value (feet*2):

$$LIDAR=\frac{(CODE*2550)+128}{255}$$

max reported value = 2047 feet*2, corresponds to CODE value 205.

ANALOGUE LIDAR:

LIDAR_MIN/LIDAR_MAX to ADC value:

minimum ADC value = 0; maximum = 2047, corresponds to

$$ADC\ value = \frac{(LIDAR\_MIN * 2047) + 1000}{2000}$$

1000 feet.

ADC value to LIDAR value (feet*2):

$$LIDAR = \frac{(ADC\ value * 2000) + 1024}{2047}$$

minimum value = 0; maximum = 2000 feet*2 (1000.0 feet).

Appendix 'C' - DATAPAK

1. DATAPAK MK-II DATA ACQUISITION AND CONTROL SYSTEM

1.1 GENERAL SYSTEM SPECIFICATIONS

The DATAPAK Mark II data acquisition system was designed as a lightweight, high-speed device to perform system control and data recording functions for airborne offshore oil exploration surveys. The DATAPAK unit itself is illustrated in Figures 1.1 and 1.2. The subsystems which can be interfaced to the DATAPAK are summarized in Tables 1.1, 1.2 and 1.3. A functional block diagram of the DATAPAK controller (version 2, as of Jan/88) is shown in Figure 1.3.

The DATAPAK hardware and software are both modular in design (See Tables 1.4 and 1.5). The central control is a combination INTEL 8088/8087 CPU and floating point processor which communicates with modular memory, I/O, and peripheral control boards via an STD-bus. The recording medium is a CIPHER cartridge tape drive with a capacity of 25 megabytes/cartridge, a potential recording speed of up to 20 kilobytes/sec, and automatic error correction (for single sector CRC errors) on play-back. Full read-after-write error checking is available in real-time at lower data rates (5.8 kilobytes/sec for the initial implementation).

The VS-2 system uses 5 of the available 8 RS-232 ports to handle I/O from the operator's terminal, a LORAN-C receiver, a Trimble GPS-Loran 10X receiver, an RMS chart recorder and an IBM XT (required for development purposes only). A GPIB interface permits high-speed GDAS data acquisition via a slave CPU board on the STD-bus. Up to 24 A/D input channels are available for low-speed (50Hz) sampling of analog signals. However, only 15 channels are used in the VS-2 system.

The operator controls the system through menu-driver software via a hand-held terminal. The RMS chart recorder provides

real-time display of up to 32 analog or digital channels, with warning and error message logging. Critical system parameters are displayed in real-time on a colour video monitor along with the image of either of two flight-path tracking cameras. The video images from both colour cameras, together with superimposed ASCII text (see section 3.3), are recorded independently on two colour video recorders.

Other convenience features include:

-TEST/OFF-LINE/ON-LINE mode switch
-activation/deactiviation of individual subsystems
-update capability for (sub-) system parameters via menudriven software
-capability for saving the system configuration in non-volatile memory or on tape for later recall
-updating (in real-time while ON-LINE) the current (or next) LINE ID, AREA ID, and selected system control and monitoring commands

-automatic logging of survey lines flown, in a directory on tape
-automatic time-keeping via battery backed-up real-time clock.
-entry and logging (on tape and chart recorder) of operator messages in real-time
-optional continuous real-time display of any digital data channel on the operator's terminal
-automatic data range verification and warning capability for each channel
-sonalert alarm to warn of serious error conditions
-automatic logging (on tape, chart recorder and operator's terminal) of warning and error messages.

1.2 HARDWARE CONFIGURATION

The DATAPAK uses a 22-slot card cage with an STD bus configured as in Table 1.5. The main components of the DATAPAK are the following:

Processors:Intel 8088/8087 master CPU, (IBM PC compatible)
Software is upward compatible with more advanced Intel architectures eg. 80188, 8086, 80286/80287).
Intel 8088 slave CPU (for GPIB interface)
Intel programmable VLSI peripheral chips (i.e., PIC 8259, 8254 TIMER)

Memory:768 kbytes DRAM
32 kbytes SRAM (battery backup)
48 kbytes ROM

Analog input channels:16 12-bit A/D channels*
8 12-bit (mantissa) + 4-bit (gain control) A/D channels*#
Max sampling rate/chan = 50 Hz

Digital input channels:1 32-bit parallel port for magnetometer
1 synchro/digital converter for heading gyro#

---

* Second order AA filters are included for all channels.

\# Not part of DATAPAK VS-2 configuration.

Communication channels:8 RS-232 ports (max. baud rate depends on system load). The VS-2 configuration services the ports by polling at the following data rates:
-50 bytes/sec max for the operator's terminal
-200 bytes/sec max for the LORAN-C receiver
-450 bytes/sec max. for the RMS recorder
-100 bytes/sec. max. for the Trimble receiver

1 GPIB port (capable of up to 15 kbytes/sec.)

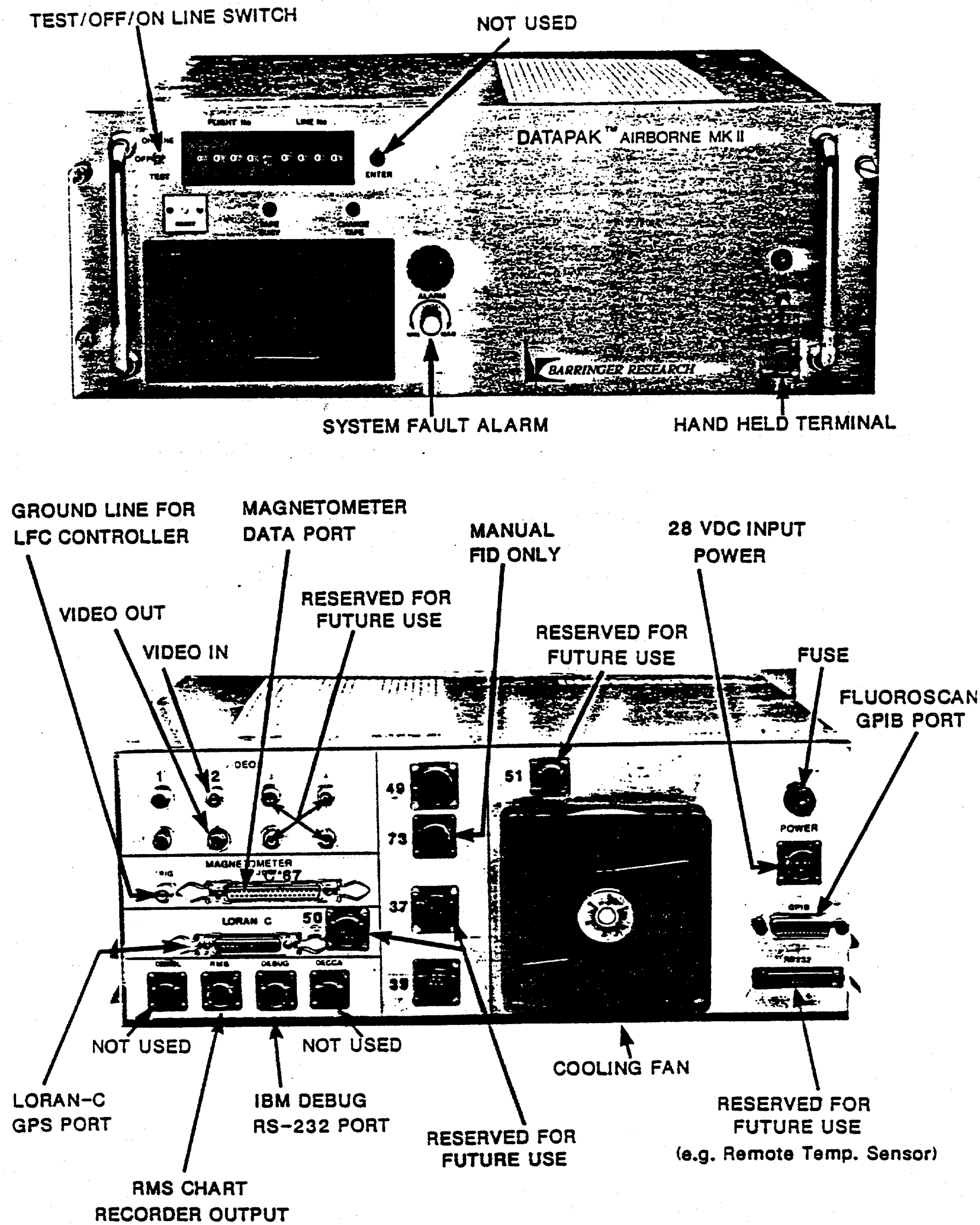

TEST/OFF/ON LINE SWITCH
NOT USED
DATAPAK ™ AIRBORNE MK II
ENTER
BARRINGER RESEARCH
SYSTEM FAULT ALARM
HAND HELD TERMINAL
GROUND LINE FOR LFC CONTROLLER
MAGNETOMETER DATA PORT
MANUAL FID ONLY
28 VDC INPUT POWER
VIDEO OUT
VIDEO IN
RESERVED FOR FUTURE USE
RESERVED FOR FUTURE USE
FUSE
FLUOROSCAN GPIB PORT
1
2
49
51
73
37
33
50
MAGNETOMETER
LORAN C
POWER
NOT USED
NOT USED
COOLING FAN
LORAN-C GPS PORT
IBM DEBUG RS-232 PORT
RESERVED FOR FUTURE USE
RESERVED FOR FUTURE USE (e.g. Remote Temp. Sensor)
RMS CHART RECORDER OUTPUT

FIGURE 11

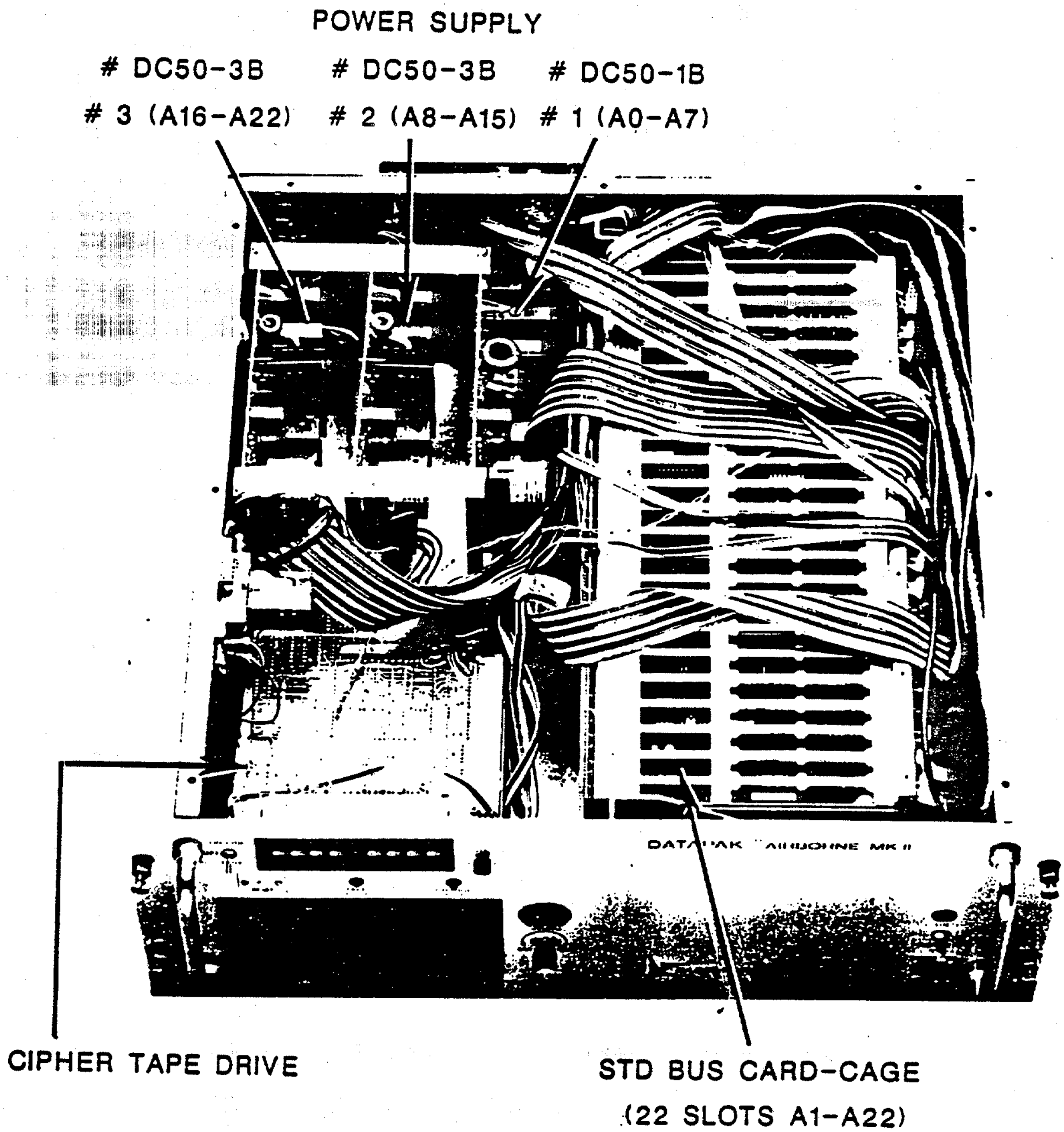
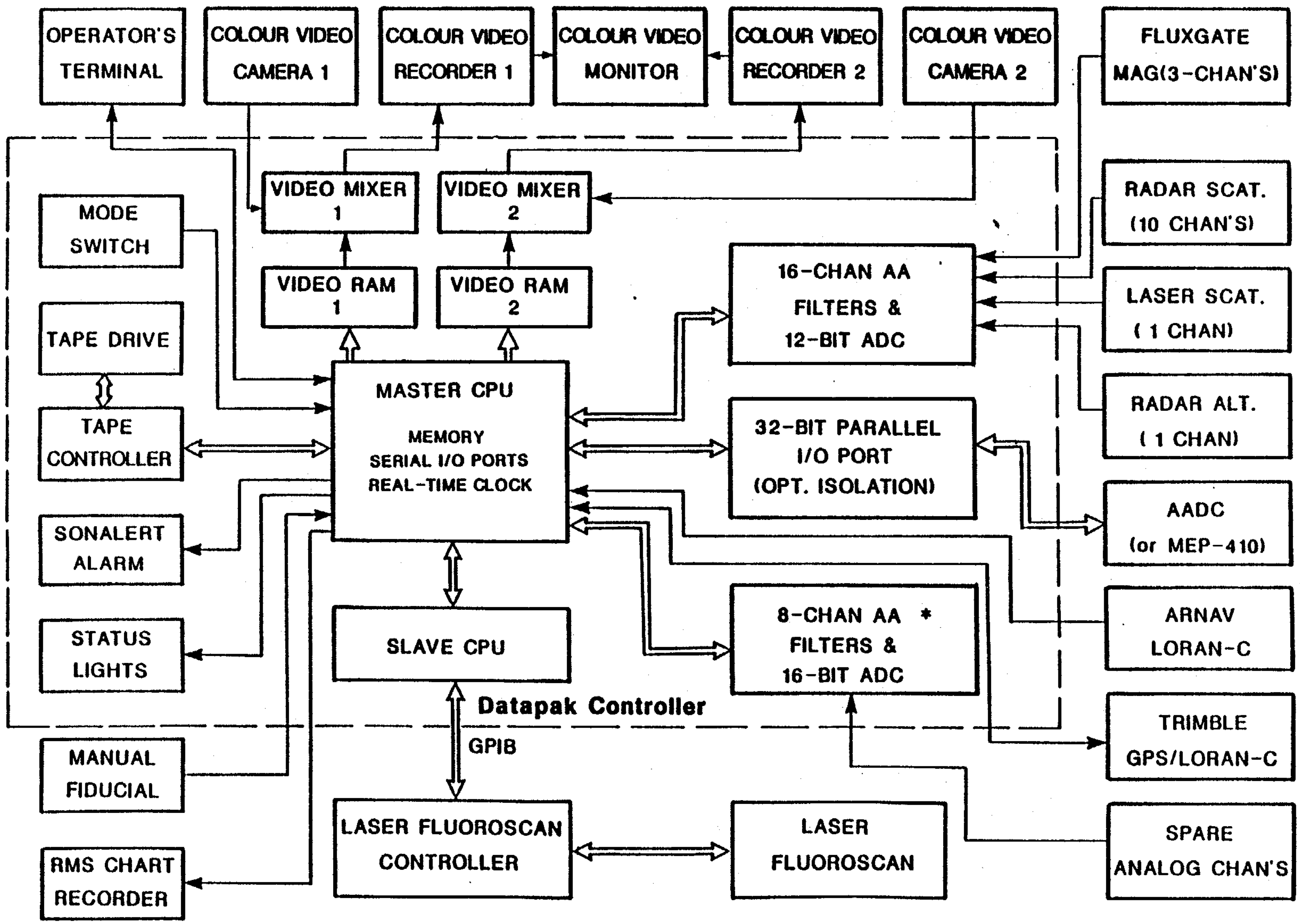

POWER SUPPLY
DC50-3B
3 (A16-A22)
DC50-3B
2 (A8-A15)
DC50-1B
1 (A0-A7)
CIPHER TAPE DRIVE
STD BUS CARD-CAGE
(22 SLOTS A1-A22)

FIGURE 1.2



*Not installed in DATAPAK VS-2

FIGURE 1.3 FUNCTIONAL BLOCK DI'^GRAM OF DATAPAK CONTROLLER

Tape Drive:1 1/4" cartridge tape drive and controller with:
-25 Mbytes/cartridge
-20 kbytes/sec max. transfer rate
-76 minutes of continuous recording time per tape at 5.8 kbytes/sec.
-optional real-time read-after-write and verify software
-1 XOR (redundancy) sector for every 16 data sectors (1024 bytes/sector) permits automatic error corrections for single-sector CRC errors (within 17 sector segment)

Chart recorder:GR33 12" RMS recorder with up to 32 analog and/or digital channels. Channel selection and attributes are under operator control via terminal.

Video Monitor:JVC TM-22U colour video monitor (interfaced via video RAM and custom mixer boards in DATAPAK STD BUS). Monitor may be switched between cameras 1 and 2.

Operator's terminal:Linker 100 terminal with dual 40-character display and alphanumeric keyboard

The physical characteristics of the DATAPAK (excluding the colour video monitor, operator's terminal and RMS chart recorder) are as follows:

Size:18 cm (high) x 48 cm (wide) x 50 cm (deep) (mounts into a 19" rack)

Weight:9 kg nominal (configuration dependent)

Power:3.5 Amps nominal (5.0 Amps max.) at 24 VDC (configuration dependent)

<u>TABLE 1.1</u>

<u>CLASSIFICATION OF ON-BOARD SENSORS INTERFACED TO DATAPAK</u>

<u>DESCRIPTION</u>

<u>1. Navigational Sensors</u>

(a)Altimeter(10 Hz sampling)
(b)LORAN-C (approx. 0.2 Hz asynchronous sampling)
(c)Manual Fiducial(2 Hz sampling)
(d)Air Speed #(1 Hz sampling)
(e)Flight Path Camera (30 Hz Sampling)
(f)Directional Gyro #(1 Hz sampling)
(g)Trimble GPS-Loran(1 Hz asynchronous sampling)

<u>2. LEAF GDAS System</u>

(a)64 Fluorescence Channels

(b) backscatter
(c) Laser Pulse Energy*
(d) Lidar Altitude*
(e) Misc. Status Sensors (1, 10 or 100 Hz sampling)

---

* All GDAS channels are sampled at a rate selected by the operator (50-100 Hz). Not all channels were implemented in the initial configuration (see Section 3.5 and Appendix G).

TABLE 1.1 (continued)

CLASSIFICATION OF ON-BOARD SENSOR INTERFACES TO DATAPAK

3. AIRTRACE #

(a) High-pass F.I.D. (25 Hz sampling)
(b) Low-pass F.I.D. (1 Hz sampling)
(c) Analog gain setting for high-pass F.I.D. signal (1 Hz sampling)

4. Magnetics

(a) Total Field H8 Cesium magnetometer (8 Hz sampling via AADC or MEP)
(b) 3-comp. rate gyros # (10 Hz sampling)
(c) 3-comp fluxgate magnetometer (8 Hz sampling via AADC; 25 Hz sampling via DATAPAK 12-bit ADC)

5. Meteorological Sensors #

(a) Rel. humidity (1 Hz sampling)
(b) Ambient temp. (1 Hz sampling)
(c) Remote temp. (.5 Hz sampling)

6. Scatterometers

(a) 5-Channel K-band microwave radar scatterometer
(b) 5-Channel X-band microwave radar scatterometer
(c) 1-Channel laser scatterometer

\# Not part of VS-2 airborne system configuration.

TABLE 1.2

SUMMARY OF ON-BOARD RECORDING/DISPLAY/WARNING MEDIA

DESCRIPTION

1.RMS Recorder
2.CIPHER Cartridge Tape Drive
3.Tape Status Lights
4.Sonalert Alarm
5.Linker 100 Terminal
6.Colour video monitor (with alphanumeric display for GDAS and general system status)
7.Two Hitachi colour video cassette recorders

TABLE 1.3

SUMMARY OF OPERATOR CONTROL SYSTEMS

DESCRIPTION

1.Mode switch (TEST/OFF-LINE/ON-LINE)

-TEST mode is used for updating system parameters, system initialization and start-up.
-OFF-LINE mode is used to configure all subsystems ready to go ON-LINE (data acquisition is active but data are not recorded and the chart recorder is off).
-ON-LINE mode is used to record data on tape and display it on the chart recorder.

2.Linker 100 Terminal

TABLE 1.4
OPERATIONAL SUMMARY OF DATAPAK SUBSYSTEMS

1.Compulsory Subsystems

(a)Linker 100 terminal
(b)Front panel controls
(c)Real-time clock

2.Subsystems Selected by Operator #

(a)Colour video monitor
(b)Colour video cassette recorders (not controlled by Datapak)
(c)RMS chart recorder
(d)Cipher cartridge tape drive (with or without real-time read-after-write and verification)
(e)LEAF GDAS system
(f)ARNAV AVA 1000 LORAN-C receiver
(g)AIRTRACE system (analog signals only)*
(h)Automatic Aeromagnetic Digital Compensator (AADC)
(i)MEP-410 Cesium Magnetometer Processor
(j)Rate gyros*
(k)Remote temperature sensor*
(l)ADC's and misc. channels (radar altimeter, manual fiducial)
(m)Trimble GPS 10X Receiver
(n)Laser and Radar Scatterometers

* These are separately identified for possible future implementation of real-time processing.

\# The specific set of subsystems available will vary with the software and hardware configuration of the DATAPAK.

1.3 SOFTWARE OVERVIEW

The entire DATAPAK software was written in ASSEMBLER language on IBM XT's and, upon completion of debugging, down-loaded to EPROM's on memory boards and slave CPU boards in the DATAPAK and GDAS card-cages. For software development, Microsoft's Macro Assembler (See Volume 4 of "DATAPAK MKII Technical Manual") was used to create load modules for direct transfer into DATAPAK Dynamic RAM (DRAM) memory via a 9600 baud serial I/O port (development mode) or into EPROM memory via Ziatech's LOCATE software and an EPROM programmer (operational mode). Software listings (for the main CPU) are supplied in 3 separate volumes accompanying this manual. Software listings for the slave CPU's are included in the manual on the GPIB communication link between the DATAPAK and GDAS controller.

1.3.1 Interrupts and Priority Levels

The software (on the DATAPAK master CPU) is organized to effectively run at three priority levels: high, medium and low. High priority tasks are initiated by System Timer interrupts which occur 400 times per second. Upon completion of time-critical code for each interrupt, medium priority code may commence execution (after re-enabling interrupts, but prior to exiting the interrupt service routine). When all outstanding medium priority tasks have been executed, control returns to background low priority tasks. The capability of logging execution times for code at any priority level has been implemented to facilitate debugging and ensure that all subtasks complete within their alloted time windows. Extensive monitoring of potential time-outs associated with time-critical tasks has been implemented in order to trap and report such errors.

1.3.2 Message Handling

Buffered, multiple-priority message handling routines were developed to handle high and low priority output to the RMS recorder and operator's terminal. All messages are queued and transmitted according to their priority. Warning messages are queued separately for output at a maximum rate of 1 per sec to permit them to be logged in each data record on tape, on the RMS recorder, as well as on the operator's terminal. The minimum time lapse between repeat issuing of the same message may be set for each message type independently as a simple software update. The time when each type of error (resulting in a warning message) occurred is reported with the warning message. Fatal error conditions are reported on the operator's terminal and on the chart recorder, together with any critical data values needed for subsequent trouble-shooting. Execution terminates, the tape and RMS recorder stop, and the alarm sounds on a fatal error. System operation may then be restarted (using a new data tape).

1.3.3 DATAPAK Data Channels

All data channels sampled by the DATAPAK, from whatever subsystem, are assigned a "DATAPAK" channel number for unique identification purposes. The descriptions and attributes of these channels may be listed on the RMS chart recorder by requesting a log of all system parameters. One or more channels may (optionally) be checked automatically to verify that they fall within specified (valid) ranges. A warning message will be issued for any out-of-range data value. The operator may also continuously display any channel on the terminal (updated once per second).

1.3.4 RMS Data Channels

The operator may select any group of DATPAK channels for output to the RMS recorder. Data will then be transmitted every 0.2 sec for all channels (in block mode), irrespective of their original sampling rates. Most of the DATAPAK and RMS channel assignments, and channel attribues may be updated by the operator when necessary. Provision exists for setting up 3 separate parameter tables controlling 3 alternative displays to the RMS recorder; any of these set-up tables may be selected prior to system start-up.

1.3.5 Real-Time Operator Commands

The commands listed in Table 1.6 may be issued via the operator's terminal without interrupting data acquisition (in OFF-LINE or ON-LINE mode, or in TEST mode after the start-up command has been issued) or recording (in ON-LINE mode). Other system control parameters may only be updated after terminating data acquisition (ie by switching back to TEST mode).

1.3.6 System Debugging Tools

The ability to activate/de-activate individual subsystems (see Table 1.4) is a useful debugging tool which permits each subsystem to be exercised independently. Otherwise, a failure in one subsystem could cause the DATAPAK to halt without any means of isolating the cause of the problem. This capability also maximizes the CPU time available for real-time processing of data for a given system configuration.

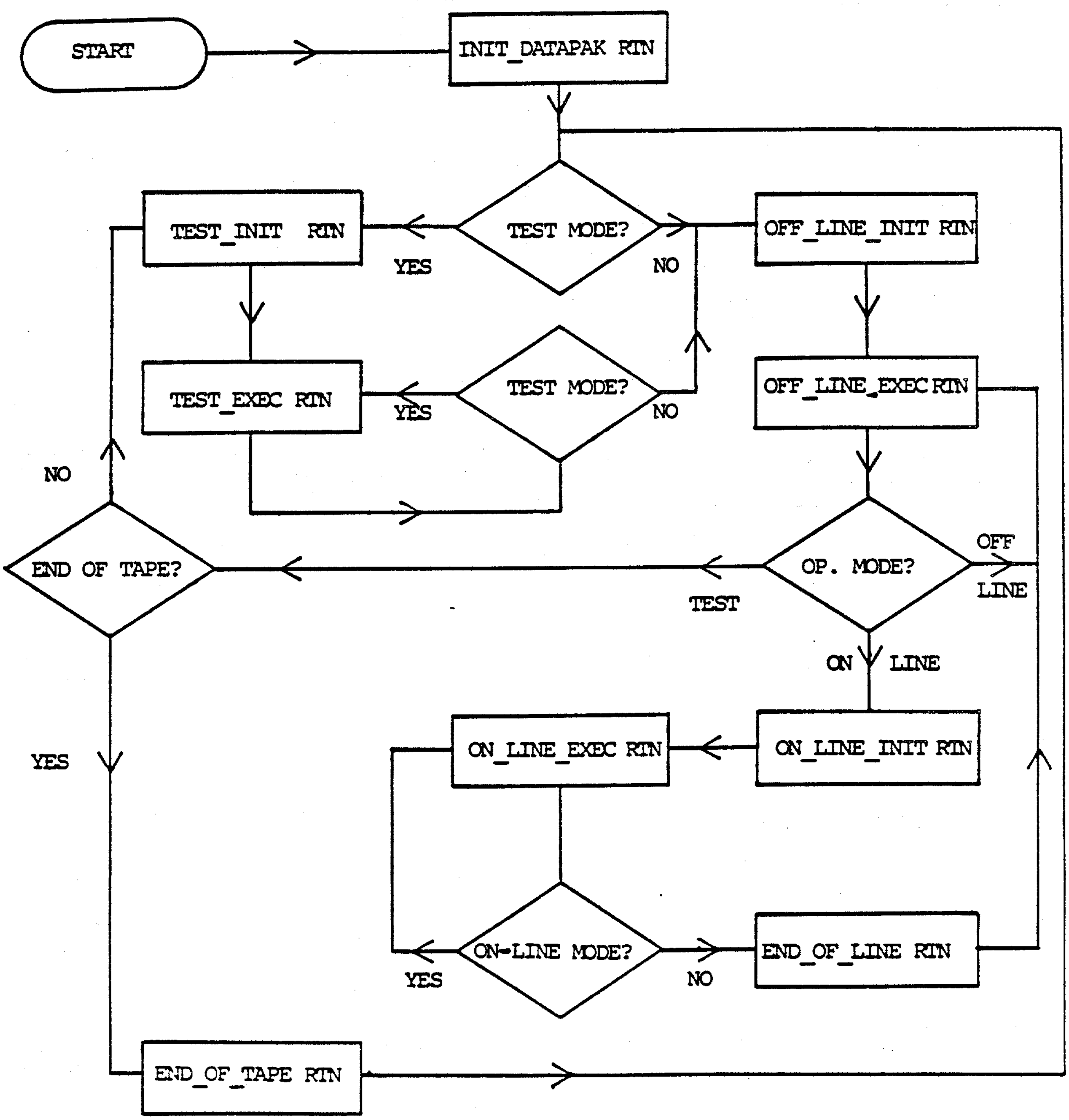
Software switches exist for logging any of the following for subsequent printout and trouble-shooting of specific problems:
-logging of minimum and maximum execution times for all time-critical code segments
-logging of the complete data stream to the RMS recorder
-logging of all command and response bytes to/from the cartridge tape drive.

These capabilities have proved essential during initial software development.

TABLE 1.6 REAL-TIME COMMANDS AND OPERATOR MESSAGES

COMMAND	DESCRIPTION

FIGURE 1.4 FLOW CHART OF DATAPAK MAIN EXECUTIVE PROGRAM



A xx...x	-enter new AREA ID 'xx...x ' (1 - 16 characters long)
B n	-turn GDAS Background removal on (n=1) or off (n=0), or display background only (n=2) for group-averaged data. This will affect data displayed on the terminal and RMS recorder as well as the 10 Hz data recorded on tape.
C nnn	-display DATAPAK Channel 'nnn' on the operator's terminal (omit 'nnn' to turn off display)
D x	-change the GDAS display mode to 'X', where 'X' is a hexidecimal number in the range '0'-'F' (see Appendix G for definition of LF_DISP_MODE options)
F n	-change the cut-off frequency used to compute RMAG (n=0 for default .04 Hz cut-off; n=1 for .2 Hz cut-off)
G n	-change the GDAS common Gain setting to n (1 n 8)
L xxxx	-update current LINE ID 'xxxx' (1-4 characters long)
M xx...x	-enter operator Message 'xx....x' (1-38 characters long)
N xxxx	-enter NEXT LINE ID 'xxxx' (1-4 characters long)
R n	-replace the AADC chan CMAG (from which RMAG and NMAG are computed) for temporary test purposes to A_HT (n=0), CMAG (n=1=default), UMAG (n=2), A_HL (n=3), A_HV (n=4).
S n	-change sensitivity (on RMS recorder) of all channels having variable sensitivity (e.g. CMAG, NMAG, RMAG) to (listed sens.) X (SENS_FACTOR)$^{'n-3'}$ where 0 n 5.

1.3.7 Data Integrity

Two data recording options are provided. Both cause the tape drive to operate in streaming mode for 10- 30 second bursts at a time (to minimize errors due to faulty tape tension, tape stiction etc. which increase dramatically with frequent stopping, starting and repositioning of the tape). Both options also write a sector of exclusive-OR data for every 16 sectors of system data so that single-sector CRC errors in reading a 17-sector segment can be fully corrected through use of this redundant data.

Option 1 (Read-After-Write OFF) writes data to tape but does not verify it in any way. This provides maximum potential recording rates (up to 20 kbytes/sec) as required for operation with LEAF GDAS. Any segment on tape containing two or more bad sectors will not be recoverable. Our experience to date indicates that this event is very rare indeed (approximately once per 100 tapes).

Option 2 (Read-After-Write ON) writes a burst of data to tape, rewinds the tape and reads the same data back into memory, corrects any single-sector errors in memory by using the exclusive-OR sector, and verifies that each (corrected) segment read is identical to the memory image of the segment which was written. A non-recoverable read error will result in the bad segment on tape being skipped, and the process of writing, reading and verification being repeated. An error in verification (which has not occurred yet) would indicate a probable failure in the tape controller or tape drive; if this occurs, a fatal error message will be generated which will halt the system and alert the operator.

Although this option generates a few warning messages due to recoverable errors when reading or writing, it is a viable recording mode with tapes in reasonable condition. A bad tape will eventually cause a fatal error due to tape I/O buffer overflow which will be reported to the operator.

1.3.8 Main Executive Routine

Overall software control of the DATAPAK is managed by the executive program, MAIN (refer to flow chart in Figure 1.4).

On power-up, the DATAPAK automatically initializes itself via the INIT_DATAPAK routine (see Section 2.1). The flow of the program is determined by the operator's responses to the various menus and directives displayed via the operator's terminal, and by the setting of the MODE switch.

Each time the MODE switch changes state, an initialization routine is entered (i.e. TEST_INIT, OFF_LINE_INIT or ON_LINE_INIT). The flow then cycles through a background executive routine (i.e. TEST EXEC, OFF__LINE__EXEC or ON__LINE__EXEC) which manages all low priority tasks, including formatting and scheduling of tape I/O. The framework has been created within these executive routines to implement future real-time filtering, compensation or other tasks which may require processing of data within a time window of up to 3 seconds.

The END__OF__LINE routine manages the transition from ON-LINE to OFF-LINE mode in such a way as to ensure that all data from the line just completed are transferred to tape. This transition can take up to 50 seconds in normal operation.

The END__OF__TAPE routine writes an EOT block (see Appendix D) on tape and prompts the operator to change tapes. The executive progam, MAIN, is continuously running in background mode whenever no medium or high priority code is queued for execution.

System timer interrupts are automatically intitiated 400 times per second. These are serviced by the SYSTICK_SERV_RTN routine which supervises execution of all time-critical tasks, whether of high or medium priority. Medium priority tasks may be interrupted (by subsequent system timer interrupts), and queued on the system STACK for delayed execution. It is only after all queued medium priority tasks have been serviced that control returns to the MAIN executive routine - to the instruction it was about to execute when last interrupted.

Appendix 'D' - Flight Test Report

I.. Scope

This is the technical report on the flight testing of the 64-channel Laser Environmental Airborne Fluorosensor (LEAF), under contract (066SS.) KE144-0-6477/01-SS, during the period 1 November '91 to 31 March '92. It describes the objectives of the tests, the location and extent of the test flying, and the data obtained, and draws such conclusions as appear warranted by a preliminary analysis of the data.

II.. Objectives

The objectives of the flight testing were;

- identify causes and solutions for any problems associated with airborne operation of LEAF;
- acquire data which would allow an assessment of the ability of LEAF to detect crude oil on water, beaches, and ice, and thereby assist oil-spill assessment and clean-up;

III.. Test Sites

A. Lakes Ontario and Erie

The waters of Lake Ontario, between Oshawa and Hamilton, and of Lake Erie near Nanticoke, provided easily acessible, extended, relatively uniform, targets for the assessment of system operation in flight.

B. Refinery Ponds at Nanticoke

Esso Canada Ltd. graciously permitted flights over a Storm Surge Pond and a Contaminated Surge Pond at their Nanticoke Refinery, on the North shore of Lake Erie. These ponds are each approximately 120m long and 60m wide, and are positioned side-by-side, separated by a narrow walkway, with their long axes oriented roughly North-South. The Storm pond contains clean water, and was ice-covered at the time of the test, the Contaminated pond was un-frozen, presumably due to a high concentration of dissolved substances, and had oily material floating in one corner.

C. Ottawa Test Site

The Ottawa site consisted of a series of ponds separated by berms of rock-dust specially built for this test in a quarry. The ponds were rectangular, either 20x50 or 40x50 feet in extent, and were arranged to form a rectangle, 240ft. long by 50ft. wide. The aircraft flew along the long axis of the rectangle, which was oriented approximately North-South. The berms between the ponds were painted with fluorescent paint, to delimit the samples both in the fluorosensor data and the track-recovery video.The larger ponds contained clean samples of water and broken ice, gravel and gabion rock, and sand, and the smaller ponds contained samples of the same materials, coated with Alberta Sweet Mixed Blend crude oil. The oil was applied at an average rate of ~320ml/m^2, which would imply a thickness of 0.3mm on a flat surface, but the actual thickness on the sand and gravel and ice was much less, due to the roughness of the surface. The ponds containing the oiled samples were lined with plastic film, coated with a layer of ice, so as to ensure that all of the oil remained in the pond, and could be removed, for safe disposal after the tests. In addition to supervising the construction, operations and clean-up of the test site, Environment Canada, Emergency Science Division, conducted a programme of sampling and analysis. The oil was applied just prior to the first pass by the aircraft. The oil was sampled at regular intervals throughout the overflights and the samples analyzed for weight loss and compositional changes.

IV.. Flight Statistics

Five test flights took place, totalling about 6.7 hours of system on-line operation, as summarized in Table 1.

TABLE 1: Flight Tests

Flt.#	Date	Time On-Line (hrs)	Location	Objective
1	24Dec91	0.4	Lake Ontario, off Toronto Island.	System shake-down
2	2Jan92	1.0	Lake Ontario, Ajax to Burlington.	Altimeter & gating check. Operator Training
3	22Jan92	1.5	Lake Erie, off Nanticoke; Surge Ponds, Nanticoke Refinery.	Practice flying for small targets. Data for clean & polluted water.
4	31Jan92	2.0	Lake Erie, off Nanticoke; Surge Ponds, Nanticoke Refinery	Data for oil on water & land, and for clean ice and snow.
5	14Feb92	1.8	ESD Test Site, SW of Ottawa.	Controlled simulation of oil on shorelines and ice.

V.. Results

A. Lakes

The system was installed in the AeroCommander, C-GISS, owned and operated by BrucelandAir International of Wiarton. This is the same aircraft as was used for earlier commercial fluorosensor surveys for hydrocarbons. Mechanical installation was rapid and without problems. Initial testing was at 120 feet with the aircraft parked in the MillardAir Hangar at Pearson airport. As usual with a new aircraft installation, some minor cabling and ground-loop problems were found and corrected. The first test flight, over Lake Ontario about 5 miles off-shore of Toronto Island, on 24th December, confirmed operation on aircraft power and established gain and offset settings for operation of the Lidar Altimeter over water at altitudes around 300ft.

Two more checkout flights (Flights 2 & 3) took place during January '92 and established that the system operated in the aircraft with the same performance as on the ground. Flight #2, off Toronto Island, on 2nd January, was used to check gain and offset settings chosen on the basis of data from Flight 1, and to train a new operator.

B. Refinery Ponds

Flight #3, on 22nd January, was a training run for the Tests at the Nanticoke facility of Imperial Oil. Briefly, the results were as follows;

Navigation: This went very well. Four passes were made over the Contaminated Surge Pond, three from the South and 1 from the North, at altitudes between 270 and 300ft, and in each case, the pilot kept the ground track within less than 30 feet from the diagonal of the pond.

Equipment Operation: Except for a computer glitch, which only affected the operators display, and was cured by resetting the system, the equipment operated satisfactorily. Various settings of lidar gain were tried, in order to confirm that there was a value which could be used both over the land and the lake. During these tests it was noted that, at higher gains, the lidar would show a range close to the aeroplane, presumably due to aerosol scattering. Although there were no visible plumes crossing the flight-path, some elevation of aerosol levels would not be surprising in the vicinity of a refinery and a major thermal generator. The effect was only seen sporadically, and at higher than normal lidar gain settings, but as a precaution, a circuit was subsequently added to inhibit lidar response to returns from ranges less than 80ft.

Fluorescence: Where the ground is snow covered, the fluorescence is low, and the spectrum is the same as observed for snow in ground tests. Within 20-30ft of the edge of the pond, there was moderate to strong fluorescence, peaking in the blue. No data was obtained from the water in the pond, for reasons dealt with in the next paragraph.

Effect of Mirror-like Water Surface: The wind was very light, and this, combined with the relatively small size of the pond, meant that the water surface was glassy calm. This, in turn, meant that the laser beam was reflected from the water as from a mirror. Since the maximum beam divergence is only 0.17 degree, and the angle of incidence in general differs from 90° by more than this for a number of reasons, the reflected laser beam missed the telescope aperture and therefore the lidar was not triggered. This problem did not occur over Lake Erie adjacent to the plant, where the operators chart shows continuous altimeter reading up to 350ft. and, with a slight increase in backscatter gain, up to 400ft. This is in line with previous experience over many hundreds of survey kilometres over lakes and ocean. It is very rare for the surface to be absolutely free of ripples in natural bodies of water. Although oil covered surface tends to suppress the smaller ripples it contains enough scattering centres to adequately spread the return beam. Scattering from snow and ice is more than adequate.

Flight #4 was flown on 31 January. Just prior to this, it was learned, from Environment Canada, that, due to changes in plant operations at the Nanticoke facility, it was unlikely that the planned emplacement of oil targets could occur at the time originally scheduled. However, after further discussion, it was agreed that it would be useful to make a limited series of runs over the Contaminated Surge Pond, and to add to this a small grid of lines over Lake Erie, parallel to the shore, just to the south of the refinery and the thermal generator.

In addition to the fluorescence from the "beach" at the edge of the pond, which was detected in Flight #3, floating oil was detected in the South-east corner of the pond. Four passes were flown along the N-E / S-W diagonal of the Contaminated Sludge Pond, two in each direction. The water in the pond was unfrozen, and appeared black to the eye, except for a small area in the S-E corner, which had a diffuse yellowish-brown appearance. Both of the lines on a N-W heading passed directly over this area, while the others passed just to the north of it. Figures 1-4 show the fluorescence profiles for each pass. The data is spectrally averaged into four bands, with the top three traces being 100nm, bands, corresponding to Red, Green, and Blue/Violet, while the bottom trace shows a 20nm band centred on the water Raman peak. Strong signals were received from the edge of the pond and from the material floating on the water in the south-east corner. The water itself in the remaining part of the pond was too calm to give a lidar return. Figure 5 shows the spectral changes along the diagonal of the pond. Both passes in the SE/NW direction are shown, and display a comforting degree of reproducibility. Starting on the left, the first spectrum is on the roadway adjacent to the pond, the second is at the waters edge, the third and fourth are from the floating material in the SE corner. The fifth spectrum is at the water edge in the NW corner and the final three are from adjacent roadway. There appear to be three distinct signatures; the third spectrum on each line strongly resembles a light crude oil. The fourth and fifth spectra, which show higher proportions of red, suggest the same material after aging. The first two and the last three spectra appear to be of a mixture of an aged product and a light fuel or diesel oil.

Spectra from the edge of the pond, the material floating in the S-E corner of the pond, and water and ice in L. Erie are shown on an expanded scale in Figures 6 - 9. The signature at the edge (Fig. 6) suggests a mixture of ice (note the small Raman peak) and aged oil.

Several lines were also flown E-W, so as to pass, in turn, over the contaminated and clean water ponds. The Contaminated pond was unfrozen,and, to the eye, appeared black. The sloping 'beach' and the walkway between the ponds appeared dark grey. The clean water pond was frozen, with snow at the edges. The ice on the clean pond was darker in the middle, suggesting that it was thinner there. Fig. 10 shows fluorescence profiles across the area, with data spectrally averaged over Red, Green, Blue/Violet, and Raman, as before. Figure 11 shows sample spectra from the east edge of the sludge pond, the roadway between the ponds and the snow and ice on the clean pond. The various zones are clearly distinguishable. The reddish spectrum from the 'shoreline' of the contaminated pond resembles aged or heavy oil; the snow and ice spectra clearly show, in addition to a blue spectrum presumably due to dissolved impurities, the characteristic sharp Raman band of $H2O$ which appears at 343nm for excitation at the XeCl wavelength of 308nm.

C. Test Site

Flight #5 was flown, on 14th February, over a test site set up by Environment Canada, Emergency Science Div., on the floor of the gravel pit at the Beaver Road Builders facility on Regional Road 8, Gloucester, Ontario. The aircraft arrived overhead the test site at 11:52 EST and flew a total of 33 passes, in a South- North direction, as close as possible to the long axis of the 240x50ft. sample area. The altitude over the sample area was in the range of 300 - 400ft, as measured by the Lidar Altimeter in the fluorosensor. The first 13 passes were completed by 13:00EST, when the plane landed to refuel. Flying resumed at 15:16EST and the last pass was completed at 16:49EST, after which the aircraft returned to Toronto. The aircraft was piloted by Merv Cowen, of Bruceland Air, and BRL personnel acted as navigator and equipment operator.

Navigation for the passes over the samples was entirely visual; on the approach to each pass, the pilot aligned the aircraft with a line of lead-in and lead-out markers, in the form of orange fluorescent cards, which had been surveyed-in, by Environment Canada, as extensions of the long axis of the sample area. The samples were not visible until the range decreased to about 3000ft, since the floor of the gravel-pit is some 50-60 feet below the surrounding terrain. Closer than 1000ft, the samples disappeared from the pilot's view beneath the nose of the aircraft, and final direction was taken from a video display driven by a forward-looking camera.

The samples (Fig. 12) were laid out in 9 adjacent rectangles, each 50ft. wide, perpendicular to the flight-path, and extending either 20 or 40ft along it. Of the 33 passes, all but 9 passed over one or more of the sample areas, and 15 passed over all nine. No sample was measured less than

17 times. Considering the size of the samples, this gratifying success rate is a tribute to the skills of pilot and navigator; indeed, the pilot did better than the numbers indicate, since, as was found later from careful comparison of the fluorescence data and the video record from the nadir camera, the laser was striking the ground about 10 feet to the left of the centre line of the video display, so that, on several passes, it missed the samples, even though the pilot had kept the aircraft ground-track entirely within the sample area.

Fig. 13 shows a low-resolution profile over the test site, with each channel scaled to the same displayed height. The spikes in the 'RED' channel are fluorescent markers used to separate the samples; the spikes in the UV channel are from the exposed edges of the plastic sheets used to line the areas containing the contaminated material. Fig. 14 shows the spectra for individual pulses from the same line (#15) as Fig. 13, starting at pulse 80 of the second between 15:40:05 and 15:40:06EST. Pulses #80 through #85 are from the first area of oiled ice (Area 7 of Fig. 12), Pulse #86 is the plastic liner, Pulse #87 is the fluorescent paint marker between Area 7 and Area 8, #88 & #89 are the liner, #90 through' #96 are the second oiled ice, #96 is probably the plastic showing faintly through a thin film of oil, #98 is plastic, with a small red-orange peak, probably due to overspray of the fluorescent paint, and Pulse #99 is the final marker. Pulses are scaled to the same displayed height, the relative signal strengths are given by the second number in the second line of the header, and cover a range of 10:1. Successive pulses are about 60cm apart along the flight line; in normal survey operation, 10 pulses would be averaged to give 6m 'pixels', but the limited dimensions of the samples require the use of individual pulses.

Analysis

A principle objective of the test programme was to asses the capability of the *LEAF* to distinguish oil from natural backgrounds, such as ice and shoreline materials. While, in general, the oiled samples in the tests were clearly distinguishable by a much greater fluorescence intensity, it would clearly be unwise to rely on this alone. Also, there is interest in attempting to identify the age and type of spilled oil, to aid in determining its source. Several types of algorithms are being tested on the flight data. Fig. 15 shows the data from two passes over the Nanticoke ponds on a log-log plot of the Raman/Red ratio versus the spectrally-integrated fluorescence intensity. Each label represents the average over 10 laser shots, and is not corrected for variations in altitude or laser power. The various types of target identifiable on the ground cluster in non-overlapping groups on the plot.

While the principle effect of weathering, over the test period, is a reduction in fluorescence intensity, as shown in Fig 16, it is expected, on theoretical grounds, as well as the work of Raynor (loc. cit), that there should also be changes in spectral shape. The fluorescence spectra of oils resemble statistical distribution functions, and we are studying the use of moment functions to quantify small variations in spectral shape. Considering the 64 values of fluorescence intensity as a discrete function, F(c), where c ($0 \leq c \leq 63$) is the channel number, its first moment, or mean, is

$$\mu_1 = {}_{c=0}\sum^{c=N} c*F(c) / {}_{c=0}\sum^{c=N} F(c)$$

and higher moments are usually defined relative to the mean by

$$\mu_r = {}_{c=0}\sum^{c=N} (c-\mu_1)^r * F(c) \; / \; {}_{c=0}\sum^{c=N} F(c)$$

Skewness, defined as

$$S = \mu_3 / (\mu_2)^{3/2}$$

may be visualized as a measure of asymmetry, -ve if the left side of F(c) is larger, +ve if the right side. Fig. 17 shows preliminary results for the time history of the spectral skewness of two of the Ottawa target areas. The gravel, upper plot, was oiled only once, at $t = 0$, while the plywood was oiled at $t = 0$ and again at $t = 3.5$hrs. The gravel shows an initial steep rise in skew, levelling out in the afternoon, while the plywood shows a rise each time it was oiled. A move toward more positive values of skew indicate the fluorescence is becoming bluer. The long term effect of weathering on oil fluorescence spectra has to be a reddening, since the lighter, more volatile, components fluoresce blue and the heavier, less volatile, red. However, in the short term, the situation is more complex, since there are also volatiles, such as alkenes, which absorb blue and UV and do not fluoresce. If a strong shortwave absorber evaporates rapidly, the oil will become more transparent, the fluorescent materials will see more laser photons, and the shortwave fluorescence will have a better chance to exit the oil without being absorbed. Raynor (loc. cit.) shows several crude oils which fluoresced bluer and more intensely after a short period of weathering, then faded and reddened in the longer term.

VI.. Conclusions

The analysis of data from the flight trials warrants the following conclusions:

1) In flights over the Nanticoke facility, the *LEAF* detected reproducible and distinct signatures from fresh oily material floating in a Contaminated Sludge pond, and the more aged material on the shore of the pond, the nearby roadway, and the snow and ice on an adjacent clean-water pond;

2) In small contained bodies of water, such as the sludge ponds, on a calm day, the surface may become so smooth that insufficient laser energy may be returned to operate the Lidar Altimeter. This effect is not a problem over open water; it was not encountered over nearby Lake Erie on the same day and the effect was only observed once, briefly, during 20,000 km of exploration flying over the North Sea, the English Channel, and the Gulf of Mexico;

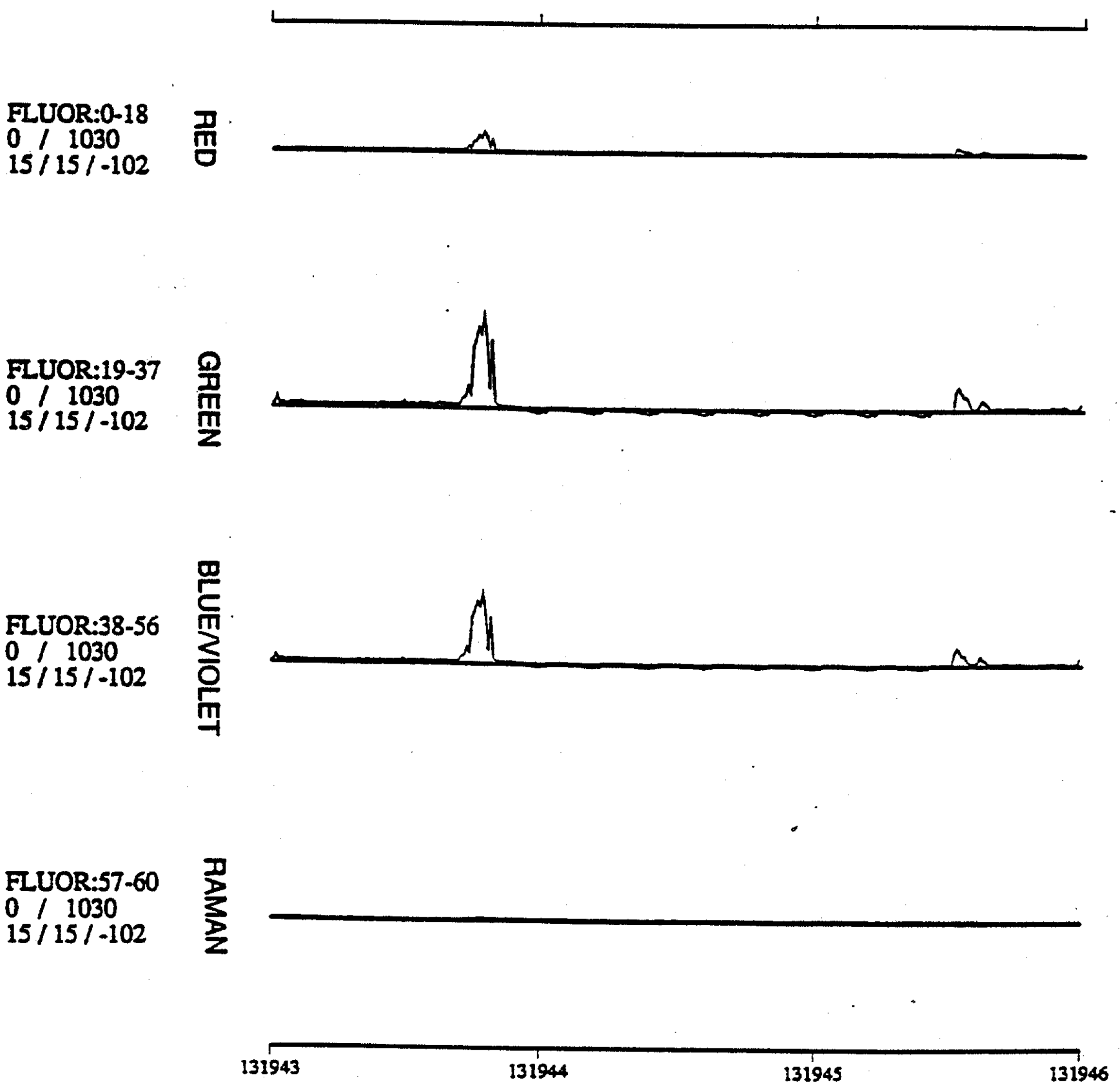
3) In flights over the Ottawa test site, the *LEAF* measured reproducible and distinct signatures from gravel, gabion stone, sand, shallow fresh water, and ice, and from the same materials when coated with Aberta Sweet Mixed Blend crude oil: the oil was applied at an average rate of ~320ml/m^2, which would imply a thickness of 0.3mm on a flat surface, but the actual thickness on the sand and gravel and ice was much less, due to the roughness of the surface;

4) In addition to the differences in spectral shape, the fluorescence from the 'clean' targets was distinguished by being between 10 and 30 times weaker than that from the same materials when coated with oil.

5) Changes in spectral shape due to weathering can be detected, from flight data, using simple

algorithms, even from small areas which receive less than 10 laser shots per measurement.
6) Simple algorithms, based on correlation of in-flight and reference spectra, allow oil to be distinguished from water, ice, and shoreline materials such as sand, rocks, and gravel, on a single-shot basis, even when the background spectra are comparable in intensity to the oil spectra.

Nanticoke : Sludge Pond, heading N-W

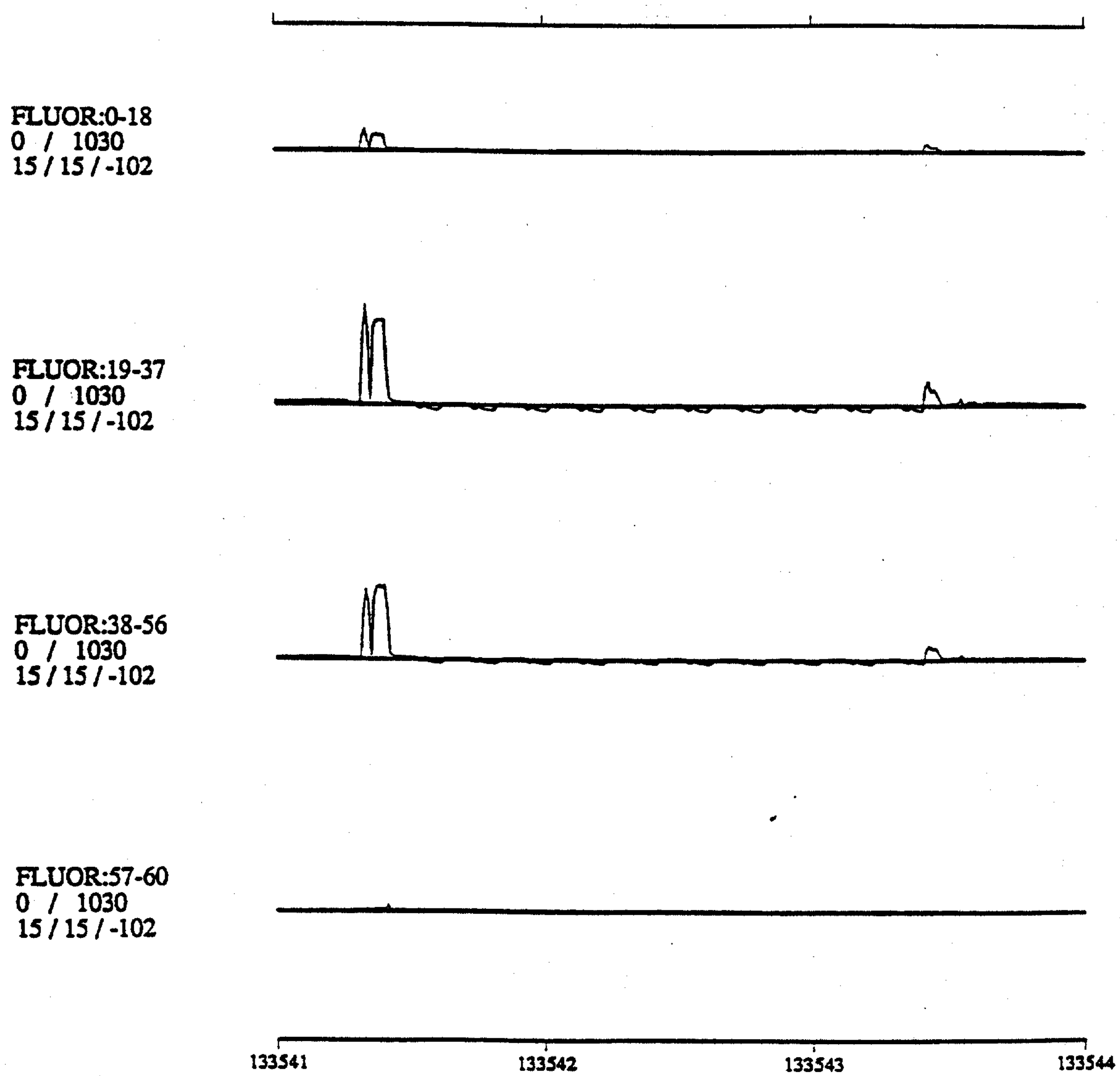


BARRINGER

Flight: 4 Line: 01 Date: 31-Jan-92 Bcorr: 1

Fig. 1

Nanticoke : Sludge Pond, heading N-W

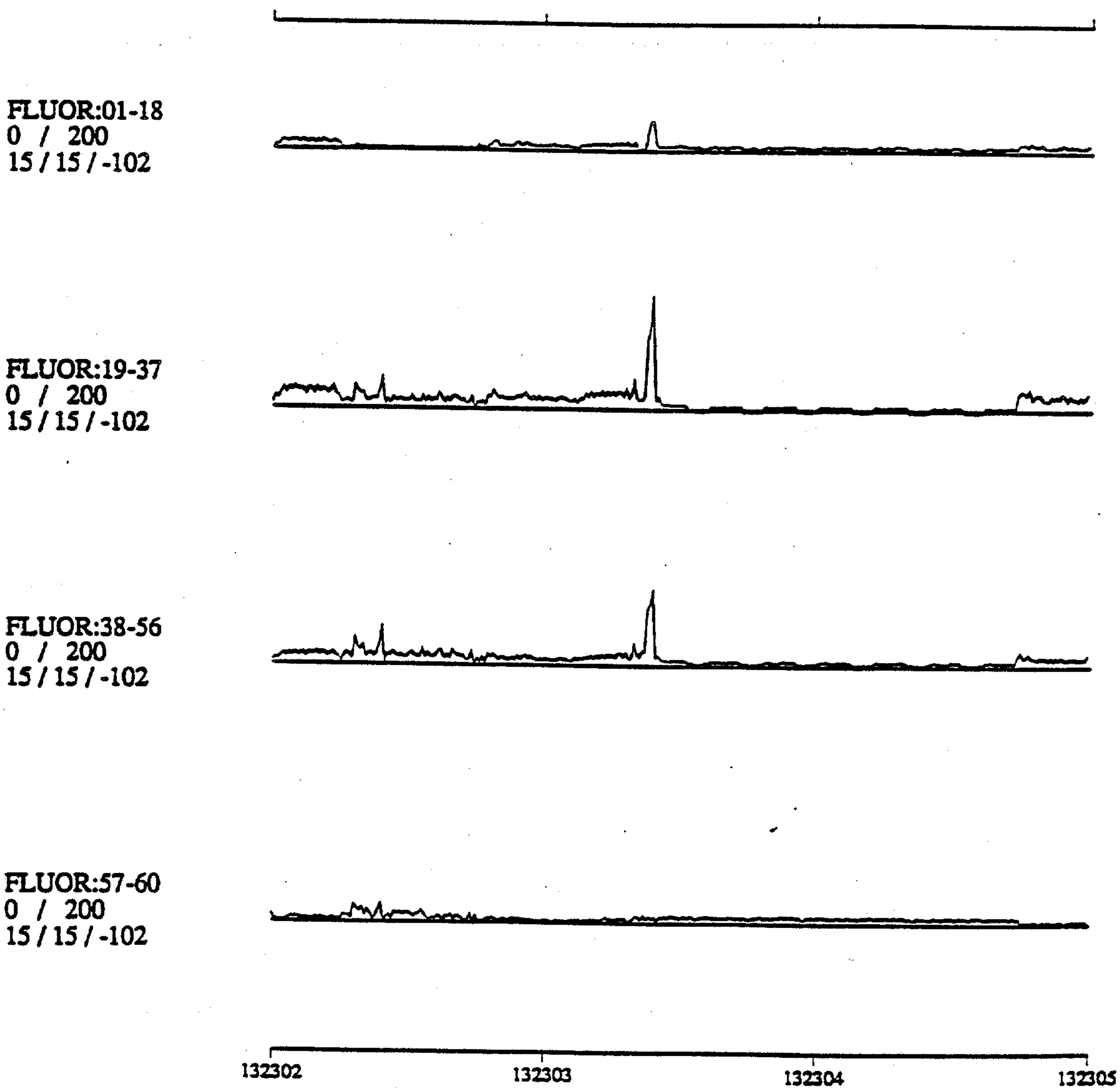


BARRINGER

Flight: 4 Line: 2 Date: 31-Jan-92 Bcorr: 1

Fig. 2

Nanticoke : Sludge pond, heading S-E

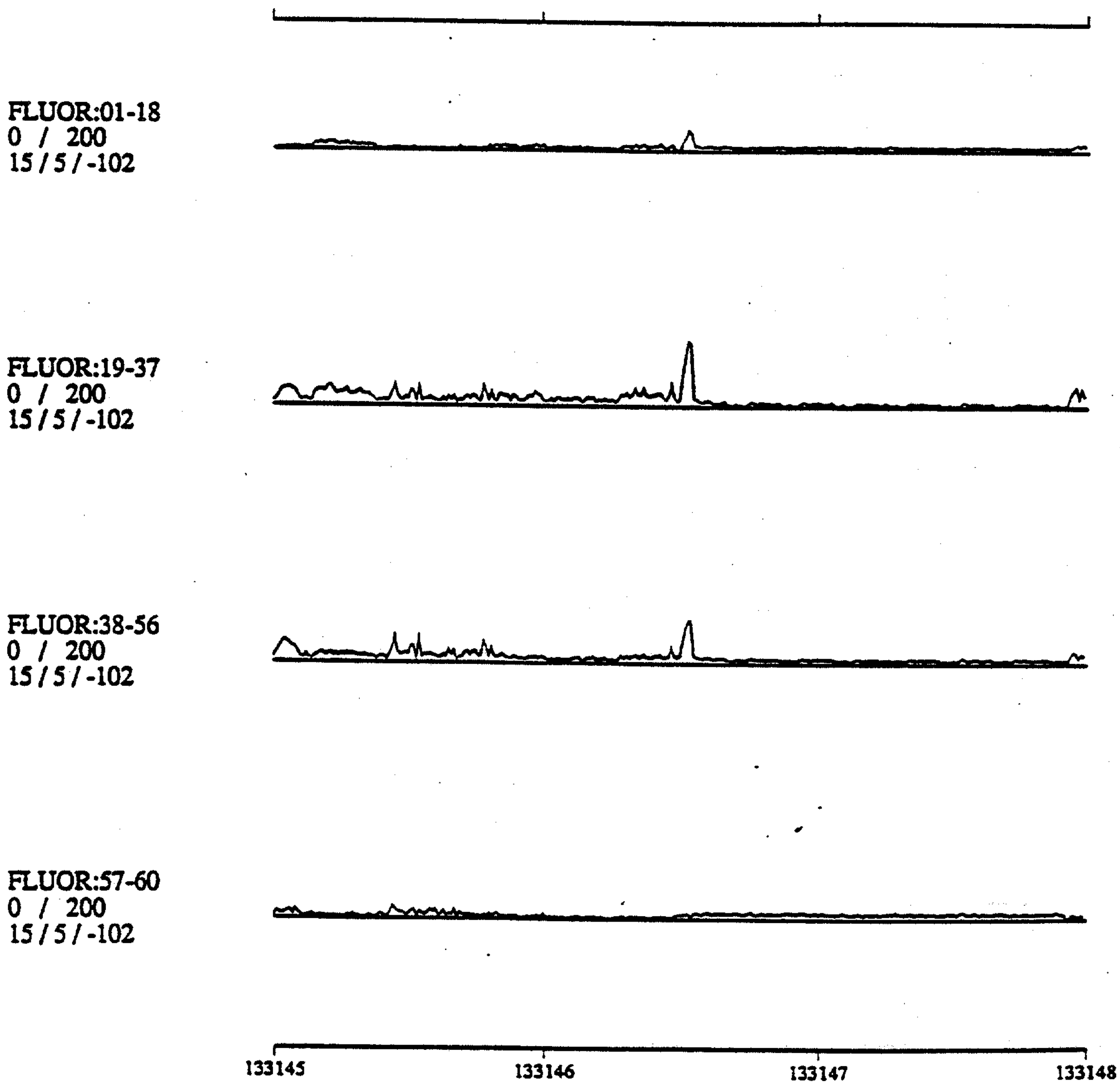


BARRINGER

Flight: 4 Line: 3 Date: 31-Jan-92 Bcorr: 1

Fig. 3

Nanticoke : Sludge pond, heading S-E



BARRINGER

Flight: 4 Line: 1 Date: 31-Jan-92 Bcorr: 1

Fig. 4

Nanticoke : S-E corner of sludge pond

Nanticoke : N-W corner of sludge pond

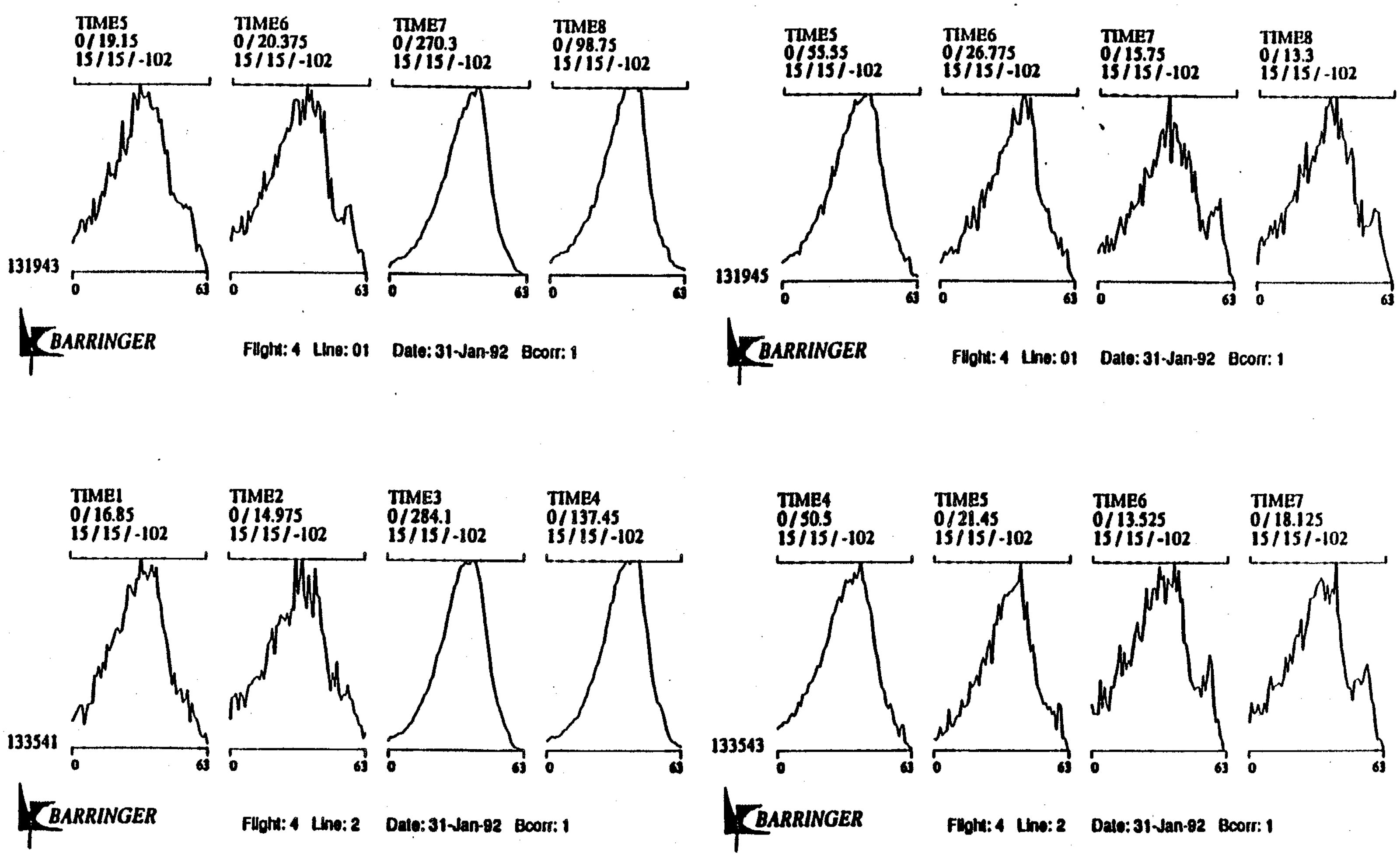
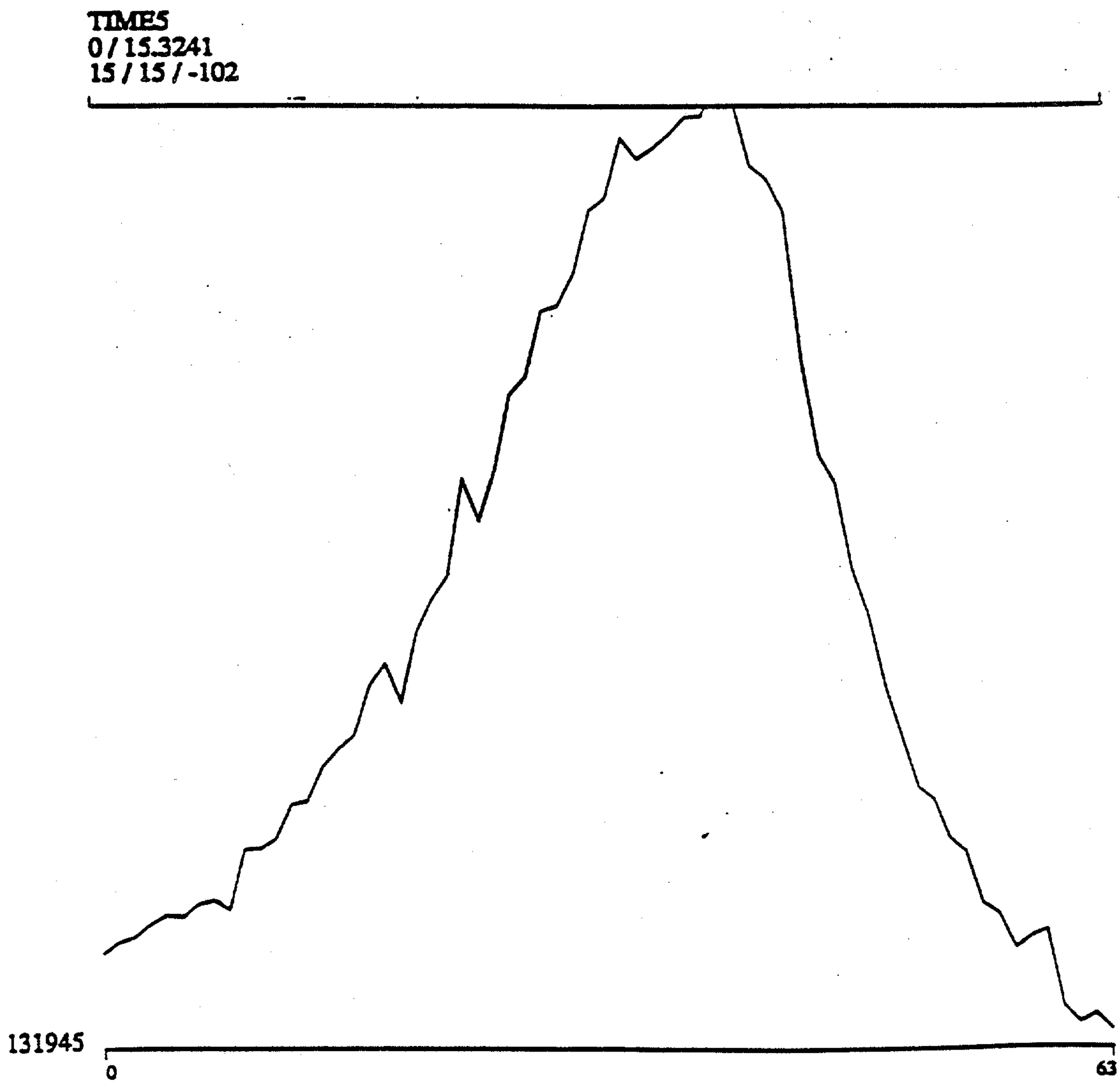


Fig. 5

Nanticoke : edge of sludge pond



BARRINGER

Flight: 4 Line: 01 Date: 31-Jan-92 Bcorr: 1

Fig. 6

Nanticoke : oily corner of sludge pond

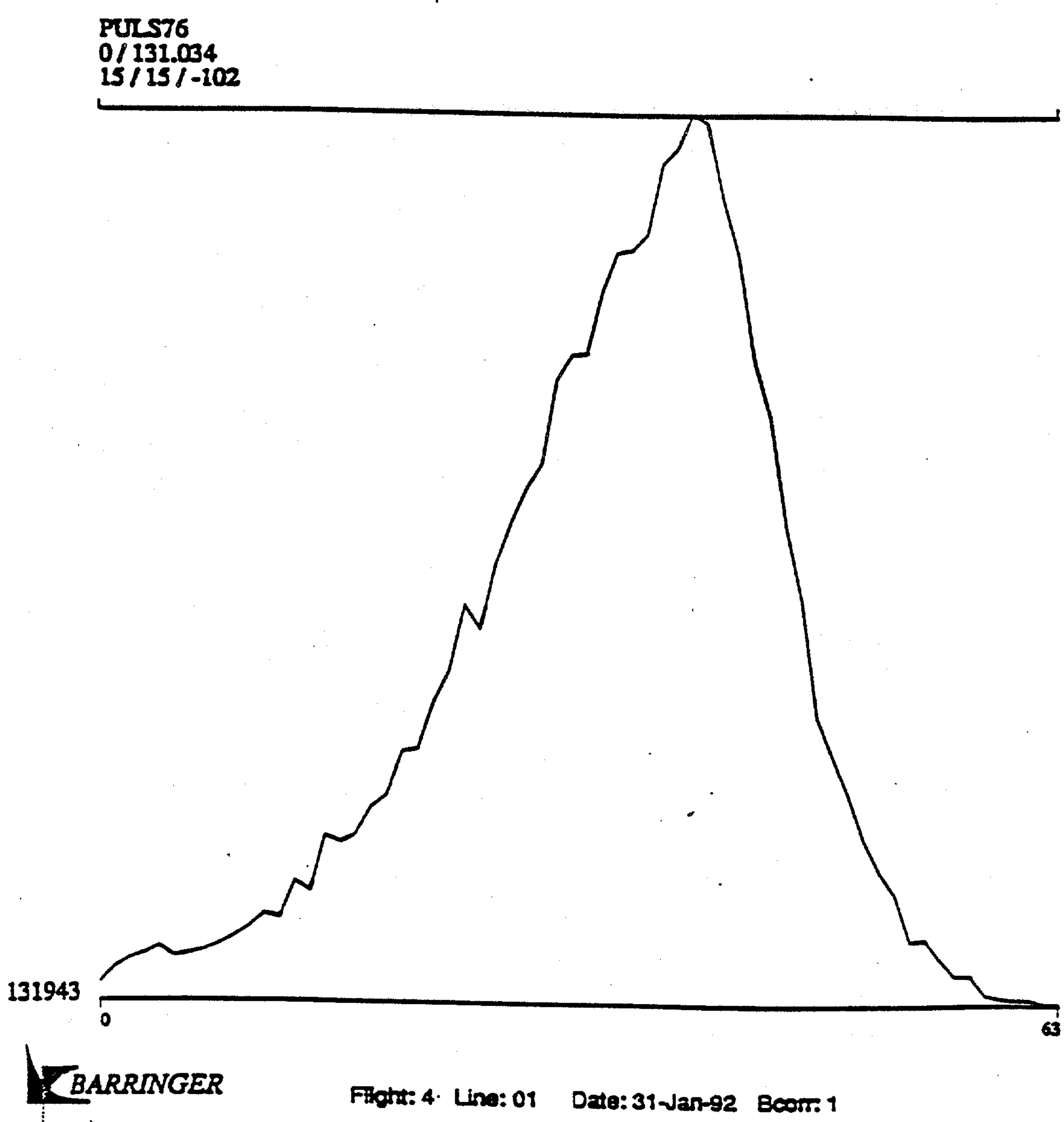


Fig. 7

ice on line from hydro plant

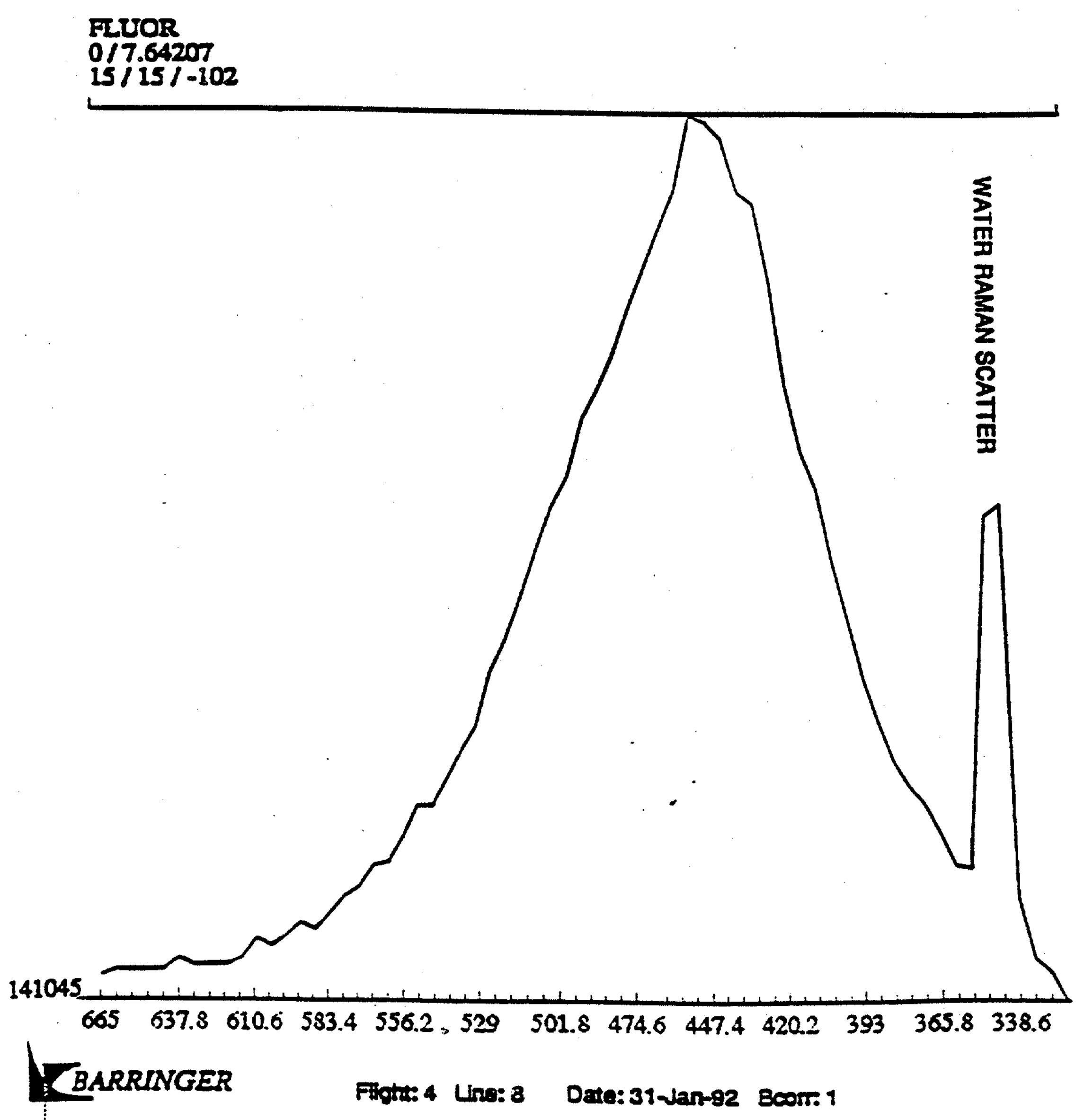
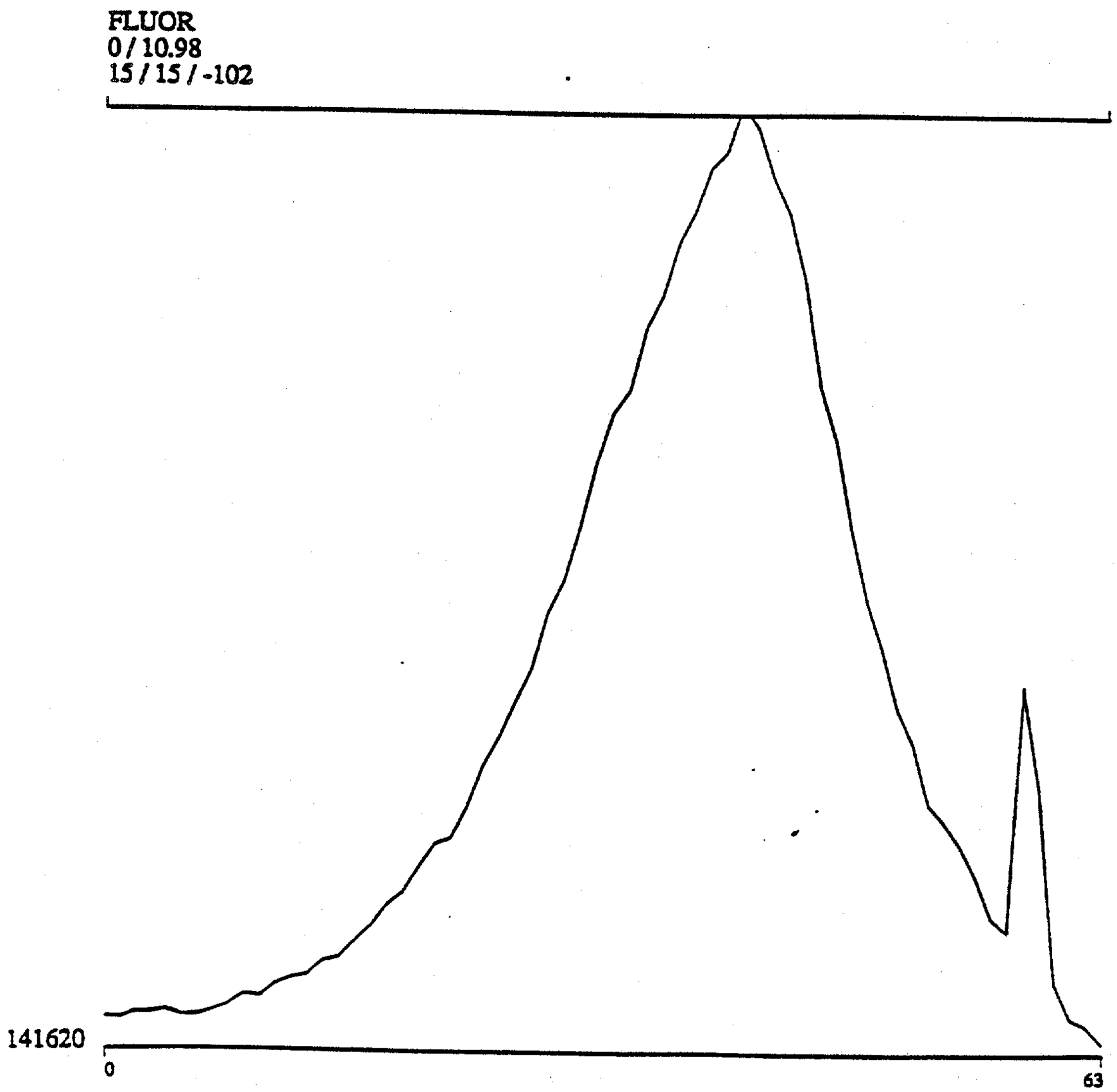


Fig. 8

lake Erie water near hydro plant



BARRINGER

Flight: 4 Line: 9 Date: 31-Jan-92 Bcorr: 1

Fig.9

Nanticoke : Sludge pond & clean pond

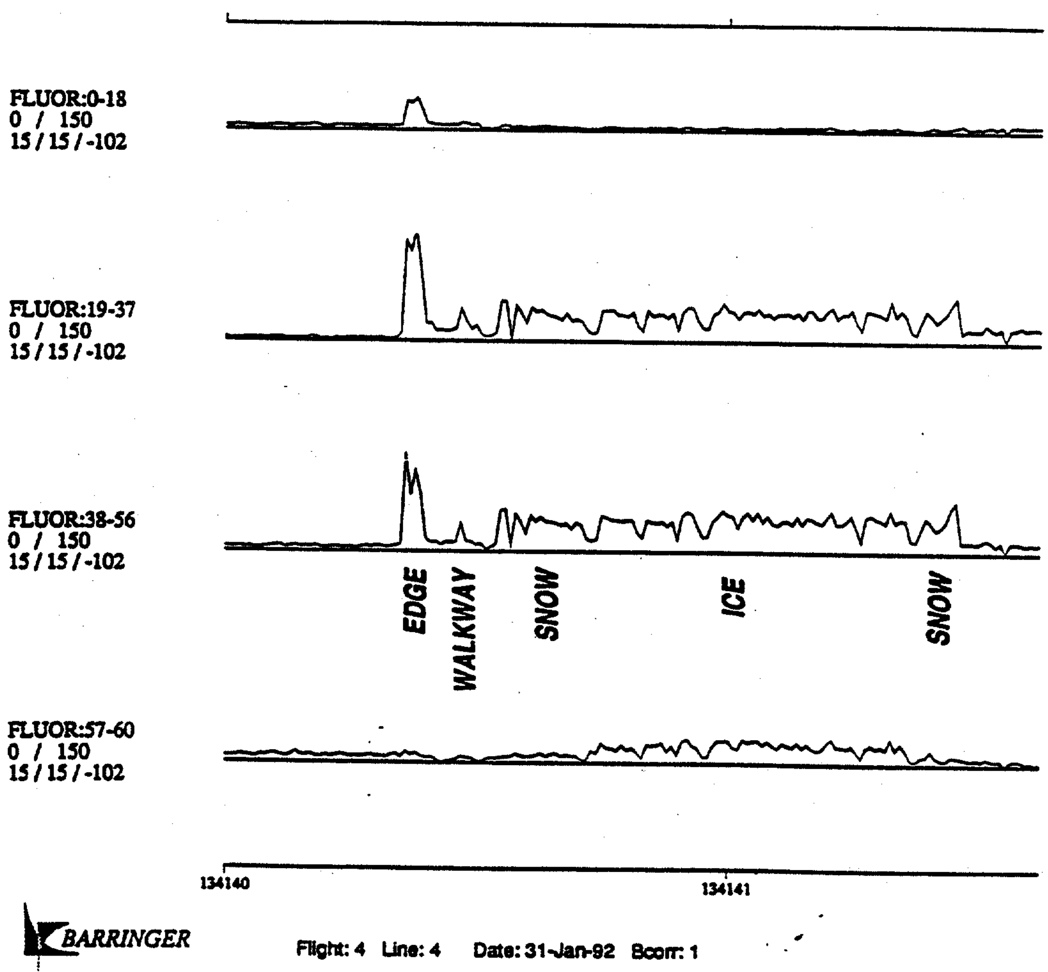


Fig. 10

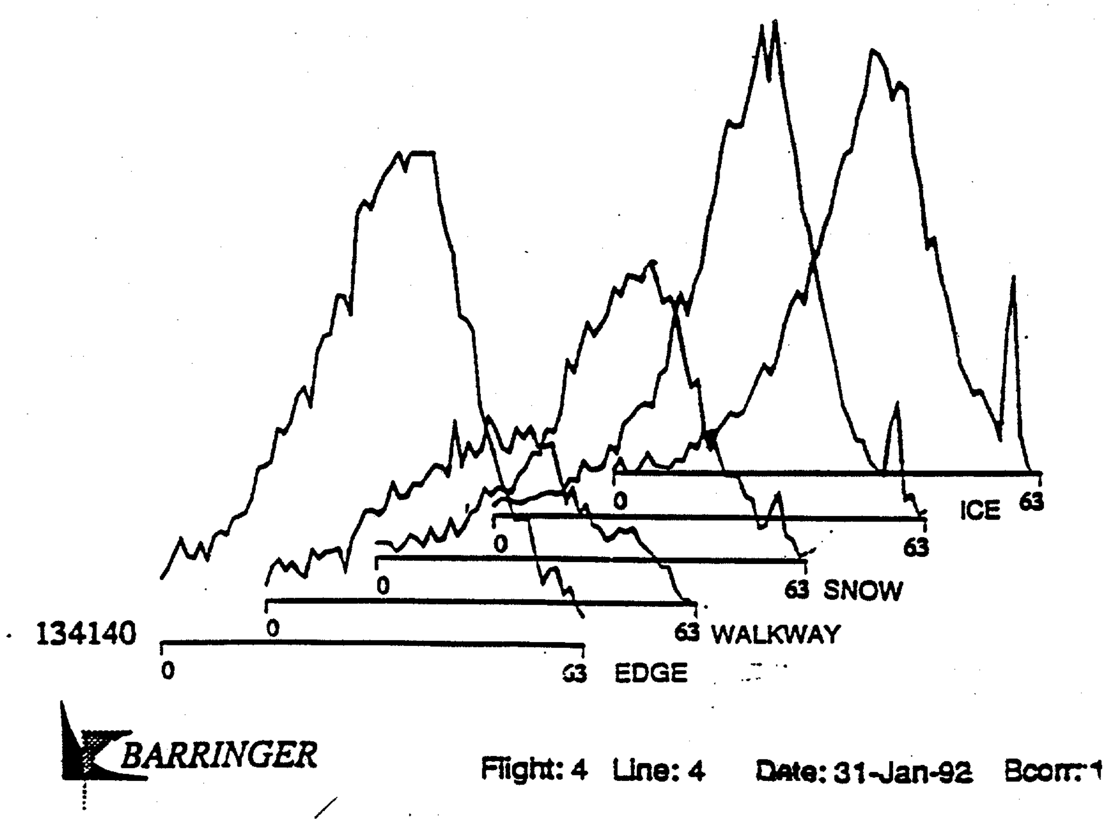
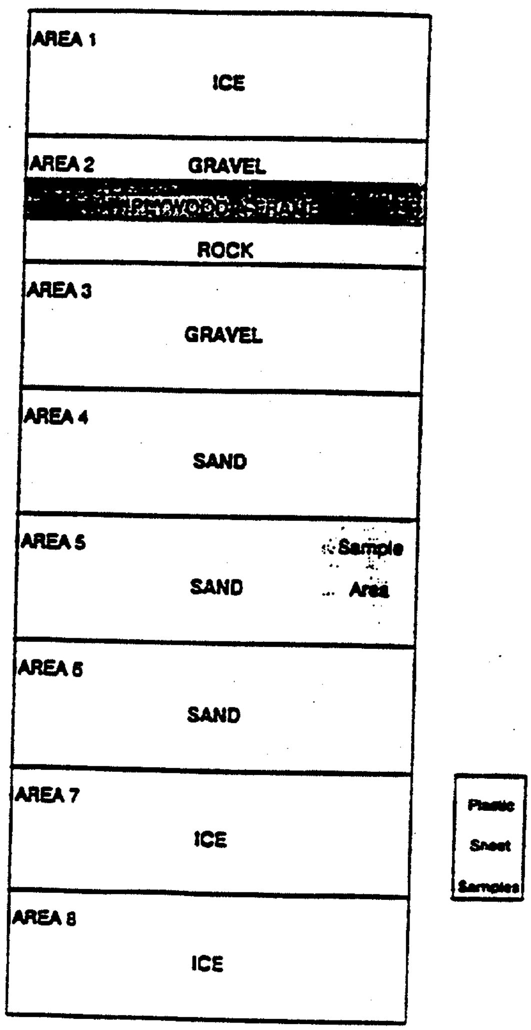

ICE
63
0
63
0
63 SNOW
0
63 WALKWAY
134140
0
0
63 EDGE
BARRINGER
Flight: 4 Line: 4 Date: 31-Jan-92

Fig. 11

Fig. 12

Remote Sensor Test: Schematic Diagram and Oil Application Times

Schematic Diagram



Application Times

Ice	not oiled
Gravel	10:47 to 10:54
Plywood	10:40 to 10:47 (initial)
& Rock	10:54 to 10:55 (2nd coat)
	10:55 to 11:04 (other side)
	15:38 to 15:45 (recoat)
Gravel	not oiled
Sand	11:21 to 11:27
	12:31 to 12:40 (recoat)
Sand	11:04 to 11:21
Sand	not oiled
Ice	11:58 to 12:10
Ice	11:49 to 11:58

Fig. 13

FLUORESCENCE PROFILE
OTTAWA TEST SITE

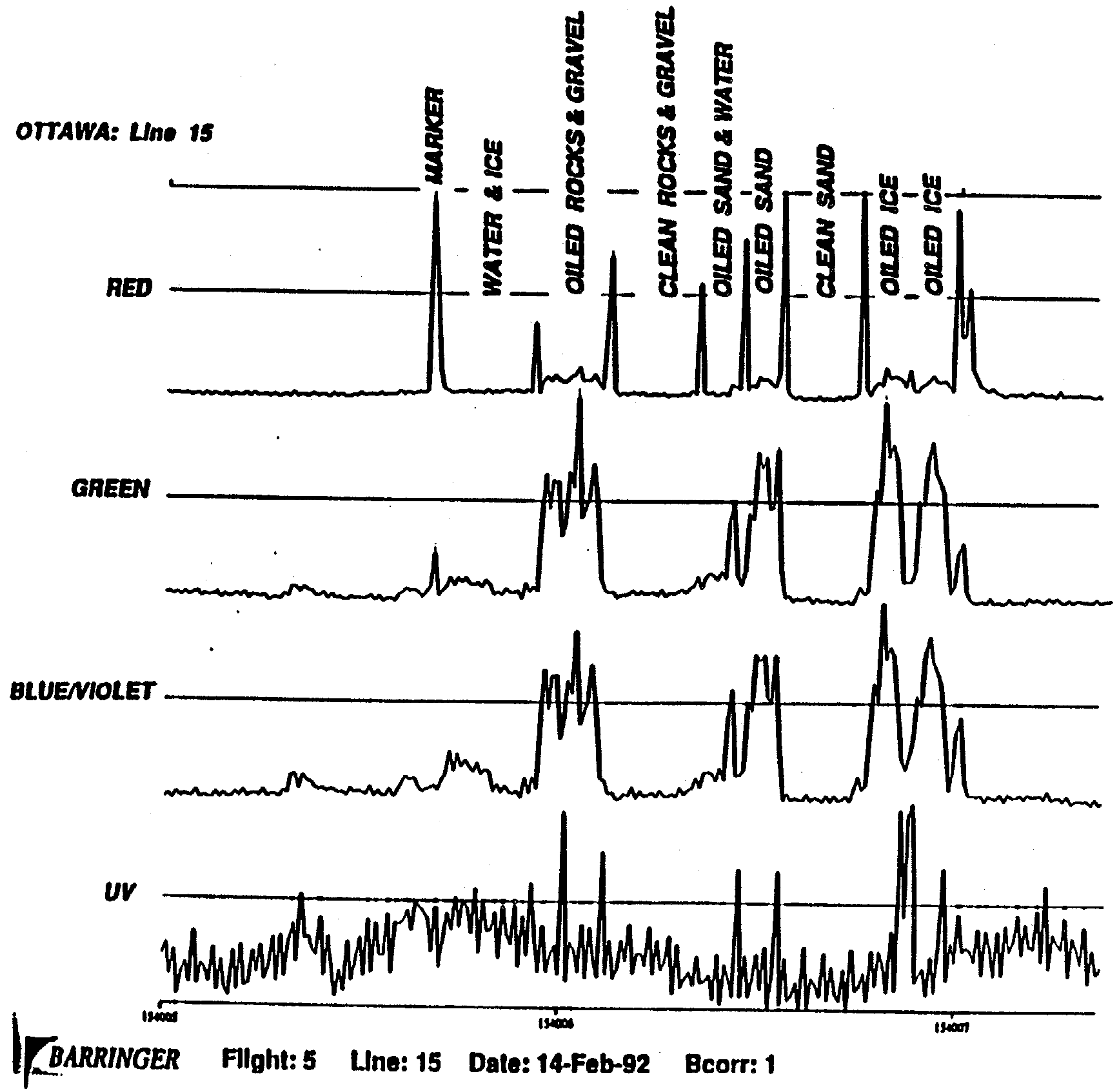
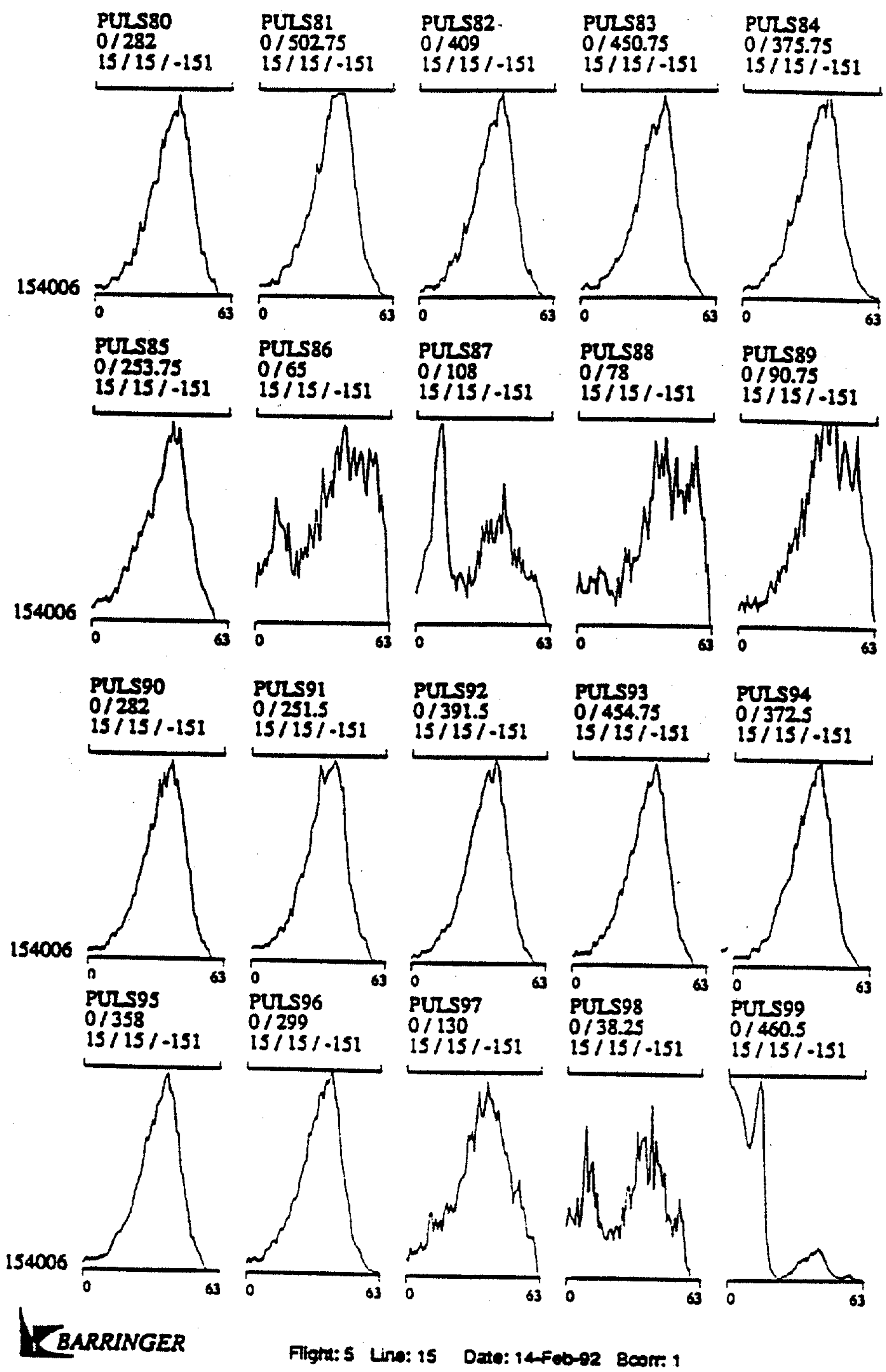
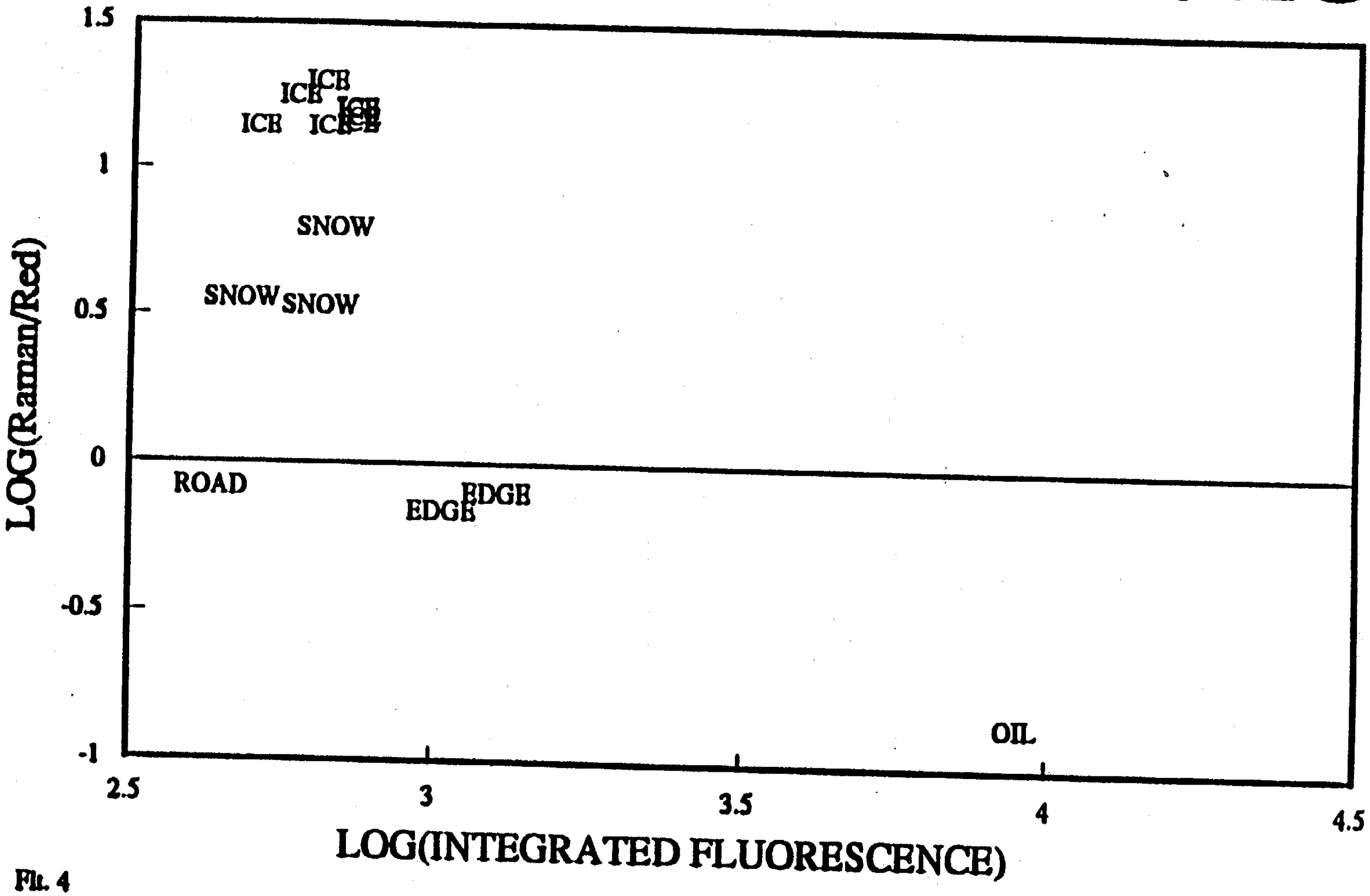


Fig. 14


PULS80
0 / 282
15 / 15 / -151
PULS81
0 / 502.75
15 / 15 / -151
PULS82
0 / 409
15 / 15 / -151
PULS83
0 / 450.75
15 / 15 / -151
PULS84
0 / 375.75
15 / 15 / -151
PULS85
0 / 253.75
15 / 15 / -151
PULS86
0 / 65
15 / 15 / -151
PULS87
0 / 108
15 / 15 / -151
PULS88
0 / 78
15 / 15 / -151
PULS89
0 / 90.75
15 / 15 / -151
PULS90
0 / 282
15 / 15 / -151
PULS91
0 / 251.5
15 / 15 / -151
PULS92
0 / 391.5
15 / 15 / -151
PULS93
0 / 454.75
15 / 15 / -151
PULS94
0 / 372.5
15 / 15 / -151
PULS95
0 / 358
15 / 15 / -151
PULS96
0 / 299
15 / 15 / -151
PULS97
0 / 130
15 / 15 / -151
PULS98
0 / 38.25
15 / 15 / -151
PULS99
0 / 460.5
15 / 15 / -151
154006
0
63
BARRINGER
Flight: 5 Line: 15 Date: 14-Feb-92 Bcom: 1

SIGNATURE CLASSES



Fit. 4

Fig. 15

OIL SPECTRA vs TIME

(raw data)

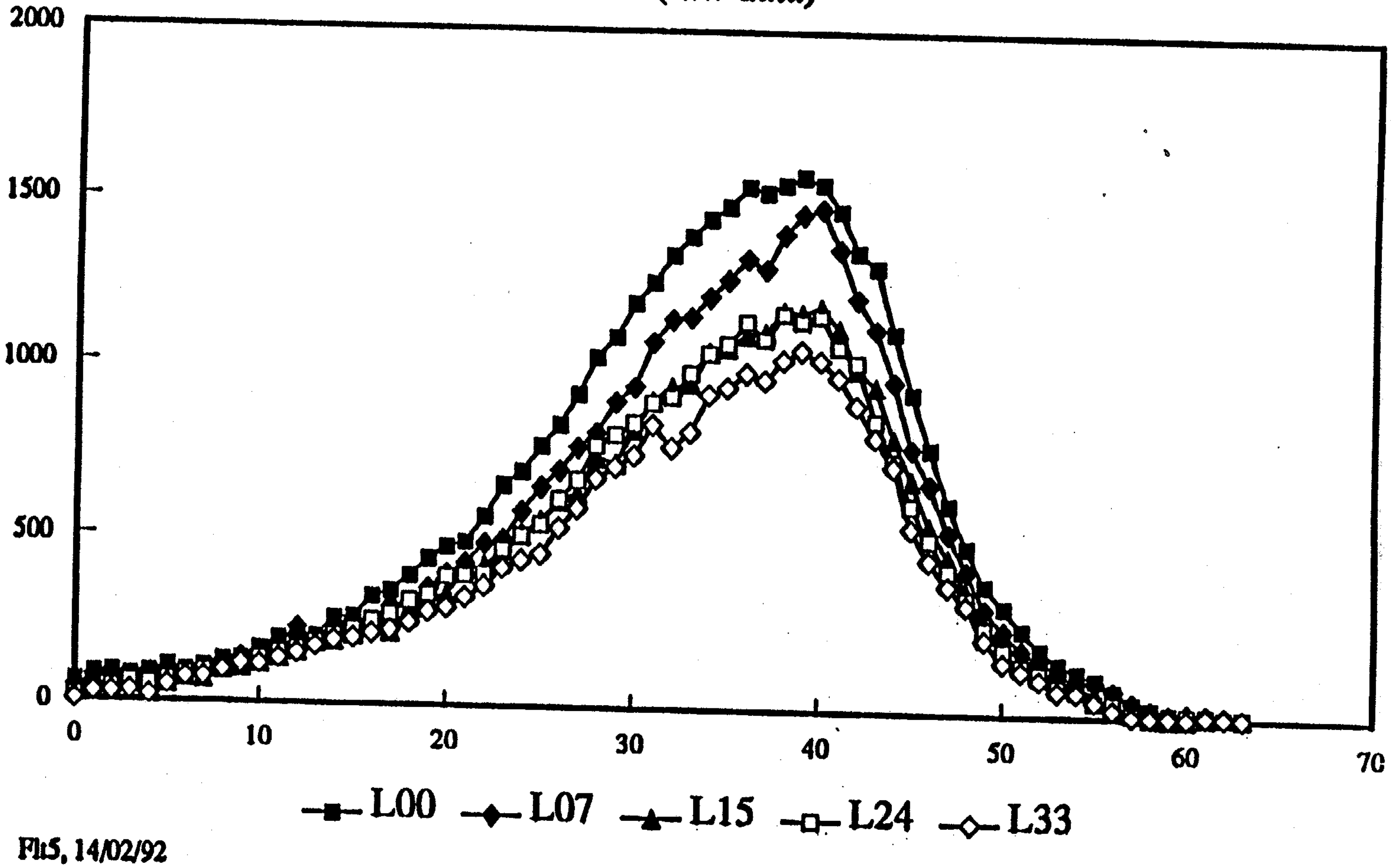
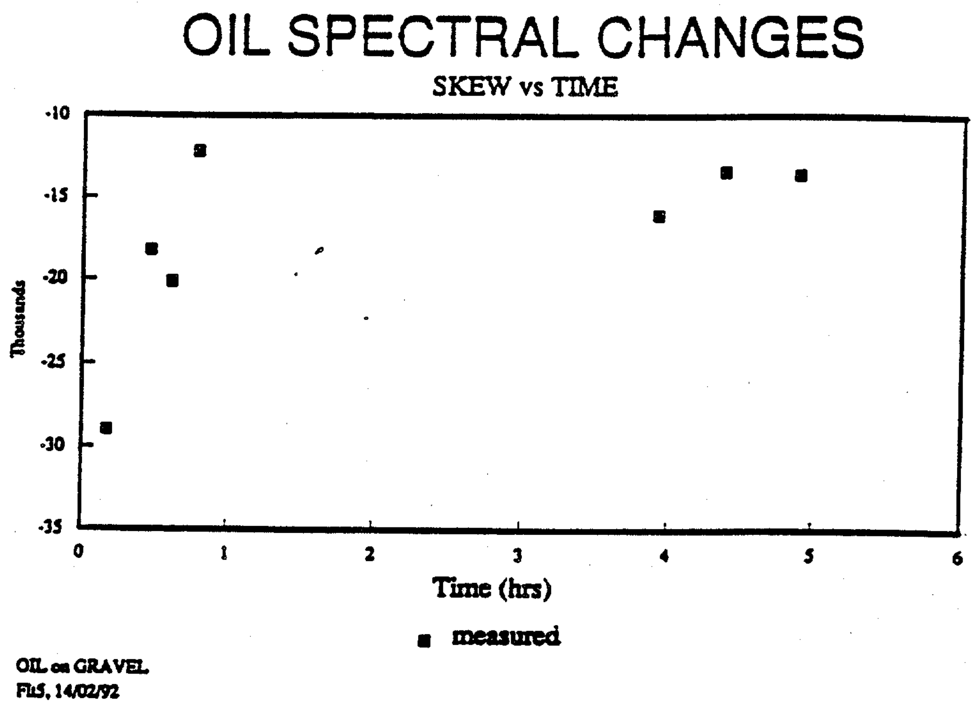
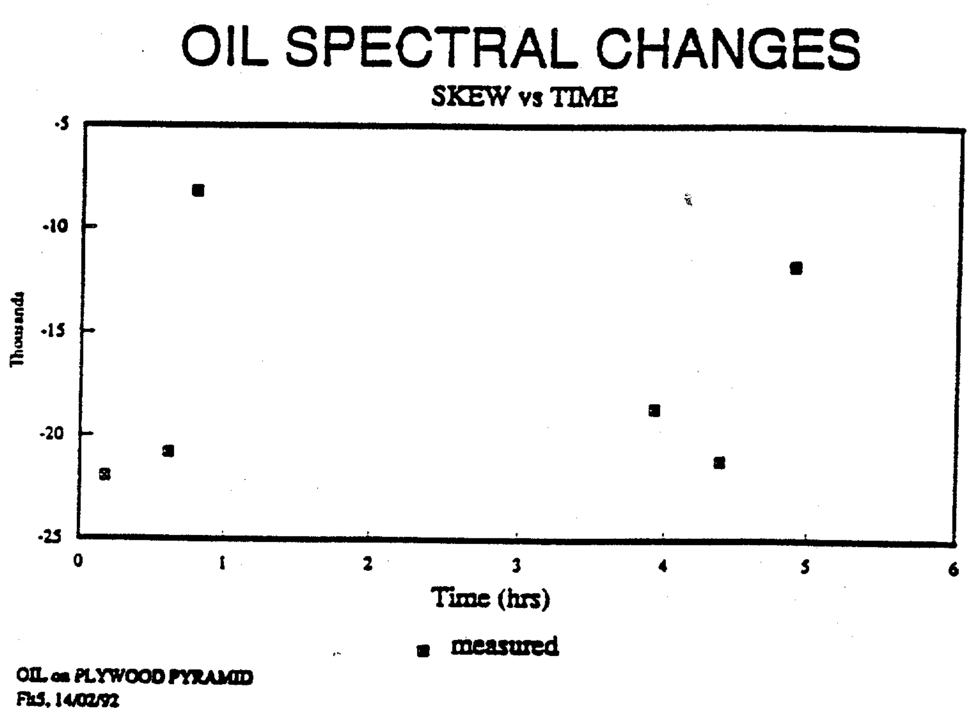


Fig. 16



OIL SPECTRAL CHANGES
SKEW vs TIME
-10
-15
-20
-25
-30
-35
Thousands
0
1
2
3
4
5
6
Time (hrs)
measured
OIL on GRAVEL
Flt5, 14/02/92

Fig. 17



OIL SPECTRAL CHANGES
SKEW vs TIME
-5
-10
-15
-20
-25
Thousands
0
1
2
3
4
5
6
Time (hrs)
measured
OIL on PLYWOOD PYRAMID
Flt5, 14/02/92