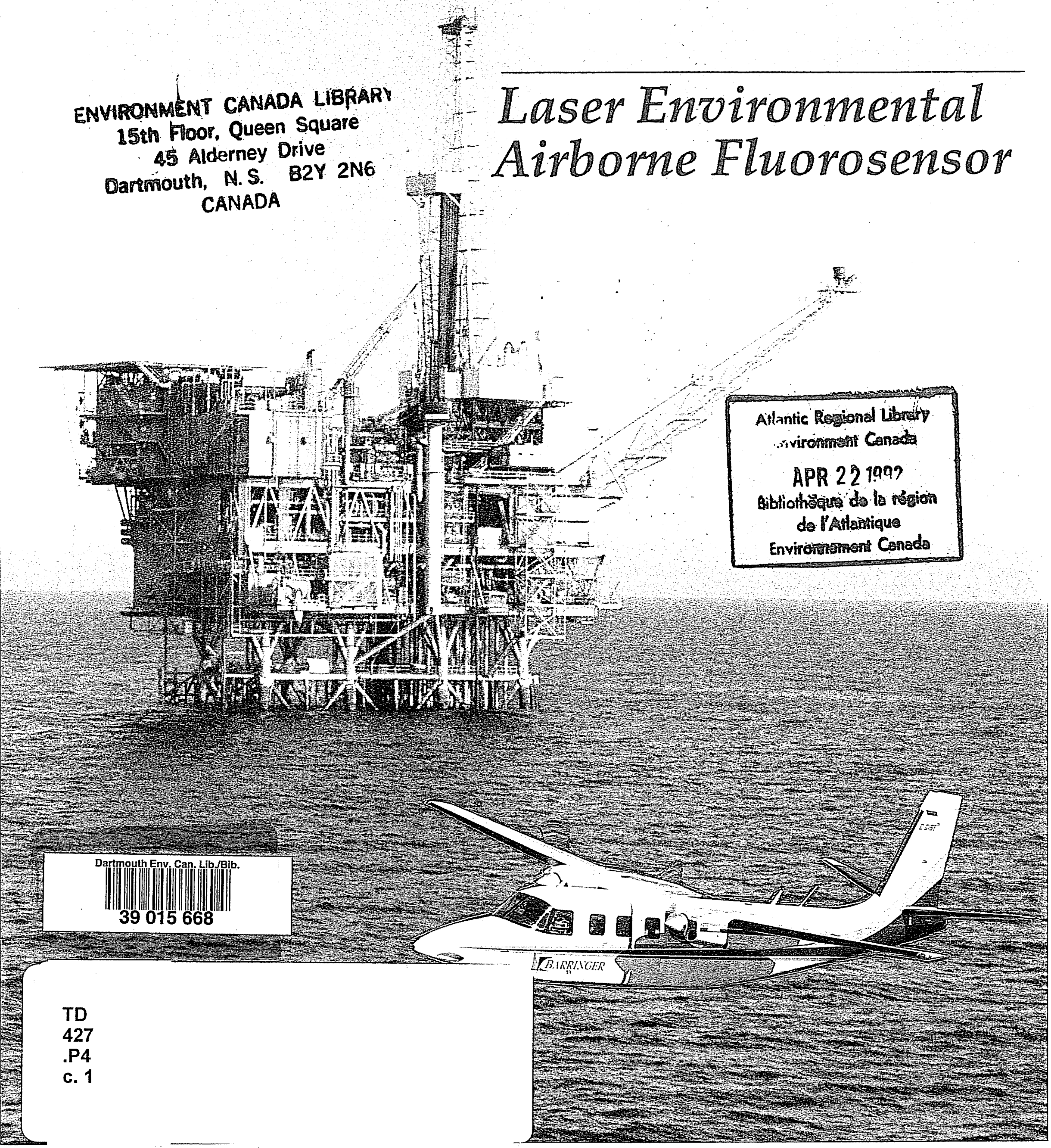
Laser Environmental Airborne Fluorosensor



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Canada

A Laser Environmental Airborne Fluorosensor for Detection and Mapping of Oil Spills on Water, Ice and Shorelines, and of Chlorophyll and Other Environmental Variables in Near Surface Water.

SUMMARY

Offshore exploration drilling for oil and gas has been taking place in Canada for over a decade and production is imminent. Tanker traffic in Canadian waters is increasing. Past experience has shown that increased spillage of oil usually accompanies such increases in activity. If the environment is to be protected, it is essential that complete and timely information, on oil spill position and extent, be readily available to commanders of clean-up operations. Since 1987, Environment Canada, Environmental Protection, supported by API, The Canadian Panel on Energy Research (PERD) the U.S. Minerals Management Service, Fisheries and Oceans Canada, Canada Centre for Remote Sensing and the United States Coast Guard, has sponsored a programme to develop and test instrumentation capable of detection and mapping spilled oil, on water, shorelines and ice, and chlorophyll and other environmental variables in near surface waters. A prototype Laser Environmental Airborne Fluorosensor (LEAF) has been constructed and flight tested under controlled conditions. It has demonstrated reliable discrimination capability for crude oil on water, rocks, sand, gravel, and ice. Longer wavelength capacity is under development for measurement of environmental variables that have useful application in oceanography.

RÉSUMÉ

Depuis une dizaine d'années, des forages d'exploration en mer ont été mis en place au Canada pour la recherche de pétrole et de gaz naturel, et la production en est imminente. La circulation de pétroliers dans les eaux canadiennes augmente. L'expérience montre qu'une augmentation de fuites de pétrole accompagne généralement un tel accroissement d'activité. Pour protéger l'environnement, il est essentiel que les dirigeants d'opérations de nettoyage disposent promptment d'informations complètes et opportunes sur la position et l'étendue des nappes de pétrole répandues. Depuis 1987, Environnement Canada, protection de l'environnement, ainsi que l'API, le Groupe Interministeriel de Recherche et Développement pour l'Energie, "The U.S. Minerals Management Service", Pêches et Océans Canada, le Centre Canadien de télédétection, et "The United States Coast Guard", ont financé un programme de développement et d'évaluation d'appareils capables de détecter et de créer des cartes de nappes de pétrole répandues sur eau, rivage et glace ainsi que de chlorophylle et d'autres variables écologiques dans des eaux proches de la surface. Un prototype de "Laser Environmental Airborne Fluorosensor (LEAF)", un capteur aéroporté de fluorescence laser pour l'environnement, a été construit et essayé en vol dans des conditions controllées. Ces essais ont prouvé la capacité de l'appareil à discriminer de façon fiables du pétrole brut sur eau, pierres, sable, gravier et glace. Une extension des capacités de l'appareil pour des longueurs d'ondes plus grandes est en cours de développement pour la mesure de variables écologiques qui ont des applications utiles en océanographie.

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Remote Sensing of Oil Polution

In addition to natural seepage, oil enters the marine environment via;

- leakage from improperly operated equipment;
- deliberate dumping;
- disasters such as shipwreck, well blow-out or pipeline rupture.

Except for leakage from fixed installations, which can be monitored by short-range devices attached thereto [1], the affected areas are extensive, and often far from major centres. Thus, much of the data on oil in the marine environment must be acquired by Airborne Remote Sensing. Evidence of chronic or clandestine spillage, and mapping of spills to assist clean-up, are two important uses. In both cases, 24-hour operation is essential, and weather restrictions should be minimal. The policing function involves routine surveys of large areas, and the detection of thin films of oil; e.g. the discharge limit in the MARPOL convention implies films of, at most, a few microns. Identification of oil type is required to link the spill to a particular source, and a low false-alarm rate is desirable. Both real-time and archival data are required. Support of clean-up requires rapid deployment to the spill site and the timely dissemination of maps of thicker oil coverage. The detection of oil stranded on shorelines and amongst ice, as well as on water, is required during spill response.

A wide range of devices and techniques have been developed to detect and measure oil on the sea surface. These include photographic cameras, visible, infrared (IR) and ultraviolet (UV) scanners, microwave sensors, both passive and active, UV Low-Light-Level Television (LLTV), satellite imagery, and Laser Fluorosensors (LF); a comprehensive review can be found in reference [2]. Of all the sensors, only a Laser Fluorosensor responds to an intrinsic property of oil; all the others respond indirectly, via effects such as temperature or reflectance changes, or capillary-wave suppression, each of which can be produced by other factors. Thus, while all of the methods can detect oil on water, (at least under favourable circumstances), all, except the Laser Fluorosensor, have high false-alarm rates. Also, the indirect effects are either absent or more ambiguous over ice and shorelines and none of the indirect methods has detected oil in these situations. Although ice and many shoreline materials fluoresce, the spectra differ from oil, allowing it to be distinguished by a Laser Fluorosensor with suitable spectral resolution. The main disadvantages of the Laser Fluorosensor are, that it covers a much narrower swath of the surface than most of the other methods and is relatively heavy and expensive. The most useful applications of the Laser Fluorosensor to spill clean-up appear to be;

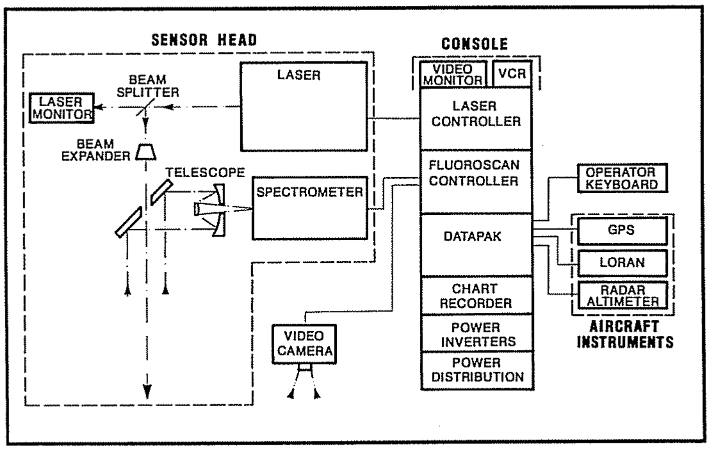
- confirming oil-on-water reports by wide-area sensors;
- locating oil on ice and on shorelines;
- locating submerged oil.

Environment Canada has had a longstanding interest in oil detection as part of its mandate to monitor pollutants, including oil, in the marine environment. Because of this interest, Environment Canada, in co-operation with API, PERD, U.S. Minerals Management Service, Fisheries and Oceans Canada, Canada Centre for Remote Sensing and the United States Coast Guard, has assumed support of the Laser Fluorosensor development originally instituted by Canada Centre for Remote Sensing, and funded the construction of a 64-channel, range-gated, Laser Environmental Airborne Fluorosensor (LEAF). This unit was built by Barringer Research Ltd., who also contributed components from a commercial fluorosensor, built for hydrocarbon exploration by Barringer Research Limited, in a joint venture with British Petroleum.

Operating Principle of the LEAF System

Laser Fluorosensors, such as the LEAF, are active sensors, i.e. they illuminate a spot on the surface with a laser and analyze the resulting fluorescence. Since it supplies its own energy, a Laser Fluorosensor can operate at night. The LEAF uses a XeCl Excimer laser, operating at 308 nm in the UV, and measures fluorescence at 64 colours between 322nm in the UV and 665nm in the red. A schematic block diagram of the LEAF system is shown in Figure 1. The laser emits a very intense short pulse of energy. This enables LEAF to distinguish the fluorescence from reflected sunlight by turning ("gating") the receiver on for only a few nanoseconds, exactly at the time when the short pulse of fluorescence arrives at the receiver in the aircraft. This way, all the fluorescence is collected, but the sunlight is limited to the small amount that can enter the receiver during the short gate period.

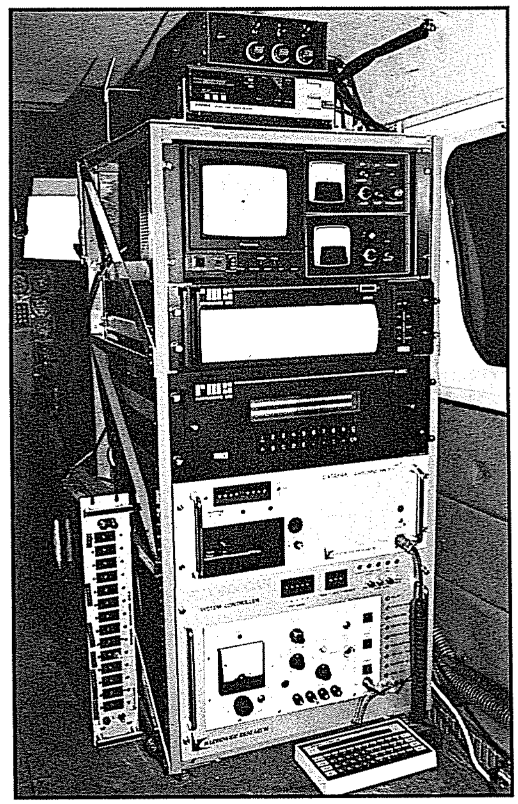
Figure 1 Schematic Block Diagram of LEAF System



Some of the laser energy is scattered upward by the surface and is collected by an auxiliary sensor (Lidar Altimeter), which measures the time taken for the pulse to make the round trip, and uses this pulse to set the timing of the gate for the fluorescence from the next pulse. Since there are 100 pulses/second, the distance to the surface, and hence the round-trip time, do not change significantly between pulses.

The 64 values of fluorescence generated by each pulse are digitized, combined with the values of the laser energy for that pulse, the altitude measured by the Lidar Altimeter, the time, the aircraft position (LORAN/GPS), and housekeeping data, and written to a Data Cassette Tape. Averaged data, updated at 10Hz, are presented to the operator on a strip chart and also as alpha-numeric text at the bottom of the video screen which shows the surface, as seen by a downward-looking camera. This video, combined with the audio communication on board of the aircraft, is recorded on standard 1/2-inch video cassettes. The operator's instrument console on board of the aircrft is shown in Figure 2. Typical fluorescence response characteristics of oil and sea water are shown in Figure 3.

Figure 2 LEAF Operator's Console in the AeroCommander



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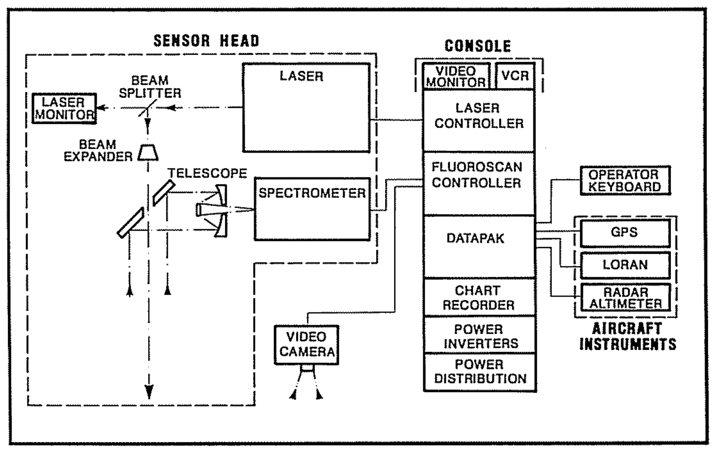

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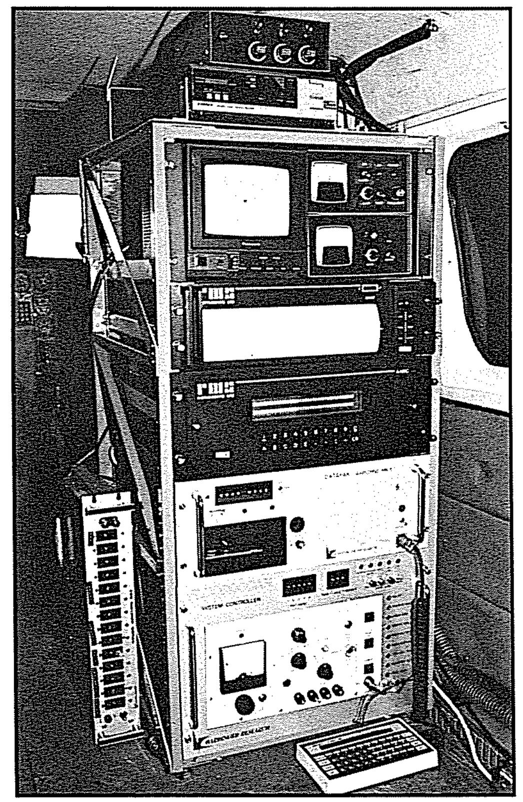

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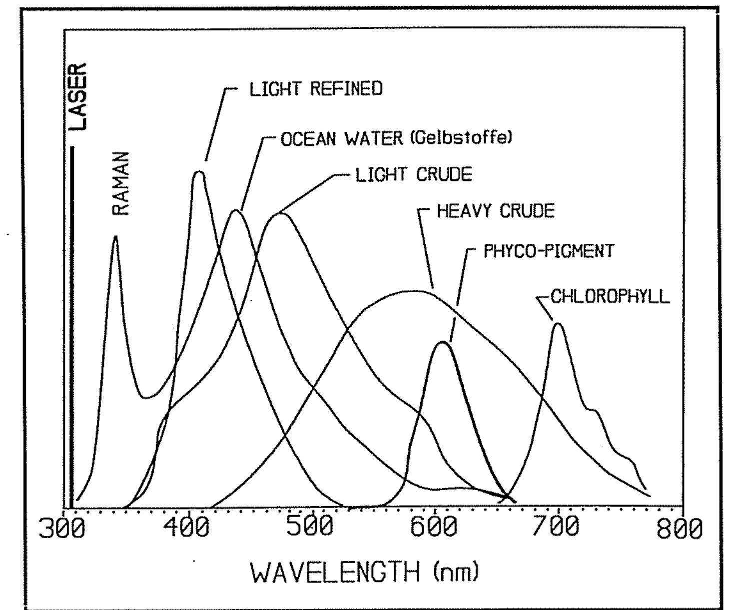
The excitation wavelength of 308nm in the ultraviolet was chosen because it is well-suited to the stimulation of fluorescence in oils. Laser fluorosensing can also be

Figure 3 Distinctly Different Fluorescence Characteristics of Oil and Ocean are Used by LEAF to Detect and Map Oil



applied to problems in oceanography and fishery, which require operation at longer wavelengths, and a programme is in progress, funded by Fisheries and Oceans Canada, which will extend the utility of the LEAF system to these tasks. A Dye Laser and a modification kit for the receiver are being added, which will;

- allow selection of excitation wavelength anywhere in the blue/green region;
- shift the receiver bandwidth to longer wavelengths, to cover the fluorescence of chlorophyll and other bio-pigments;
- improve the receiver spectral resolution, so as to allow measurement of the shape of the Raman band of water, which is related to temperature.

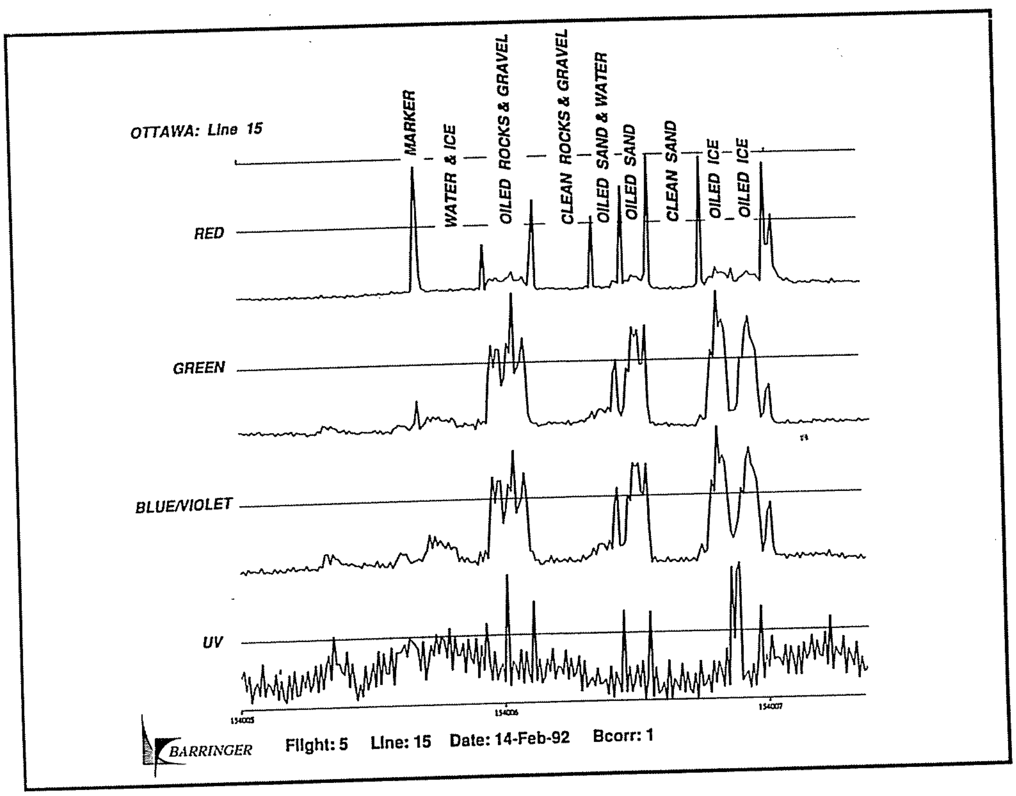
These new sub-systems are modular, to permit rapid conversion between long-wave and short-wave operation.

The LEAF has been designed specifically for airborne use, and embodies the experience from over 20,000 line kilometres of exploration flying with the earlier commercial instrument. The size, weight and power have been minimized to allow operation in small economical aircraft such as the AeroCommander. A detailed description of the LEAF system is given in reference [3].

Flight Trials

In 1992, Environment Canada and the other sponsors funded a series of flight tests of the LEAF system over several targets. The LEAF was installed and operated by Barringer Research Limited in a small twin engine AeroCommander aircraft owned and piloted by Brucelandair International. Functional testing of the LEAF system was carried out over Lakes Ontario and Erie in 1991 and in the early part of 1992. Detailed evaluation flights were also flown in February 1992 over two controlled sites; (1) over contaminated and clean-water ponds at the Nanticoke refinery of Imperial Oil and (2) a multi-sample site, near Ottawa, specially commissioned by Environment Canada, Emergency Sciences Division, who designed the test programme, supervised the building of the Ottawa test site, and characterised the samples used as targets. The contaminated-water pond at Nanticoke was unfrozen and had oily material at the waterline and floating in one corner; an analysis of the pond material was not available. The clean-water pond was frozen, with snow drifts at the edges.

Figure 4
Low Resolution Fluorescence Profile over Ottawa Test Site. Each Channel is Scaled to the Same Displayed Height. The Spikes in the RED Channel are Fluorescent Markers Separating the Samples



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

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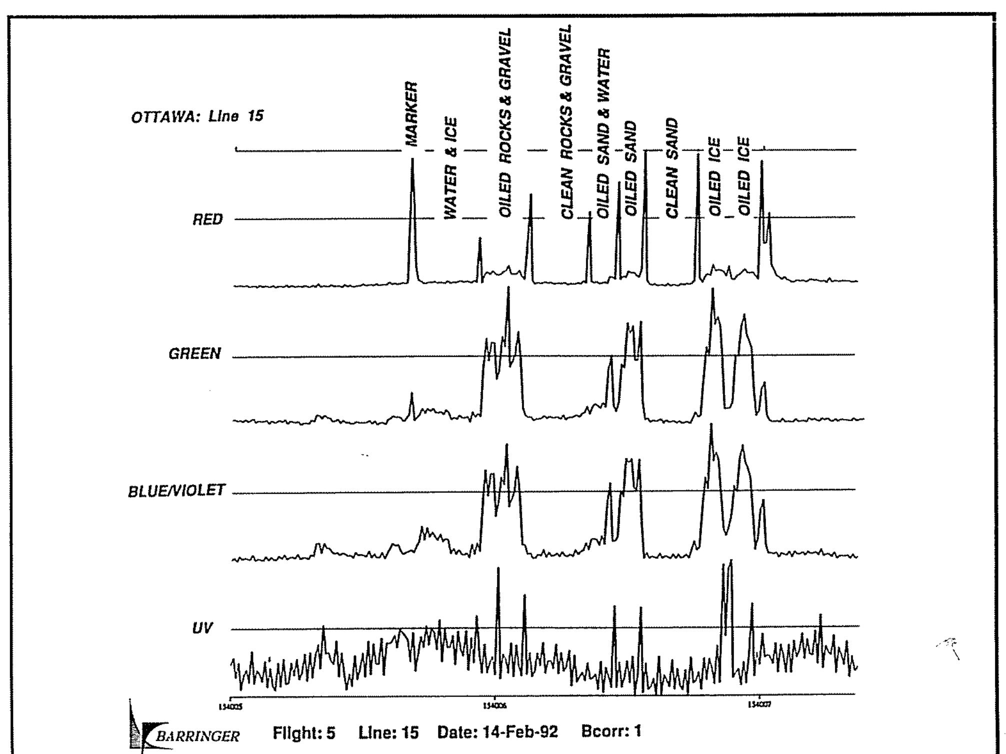

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The analysis of data from the flight trials warrants the following conclusions:

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 Light 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.

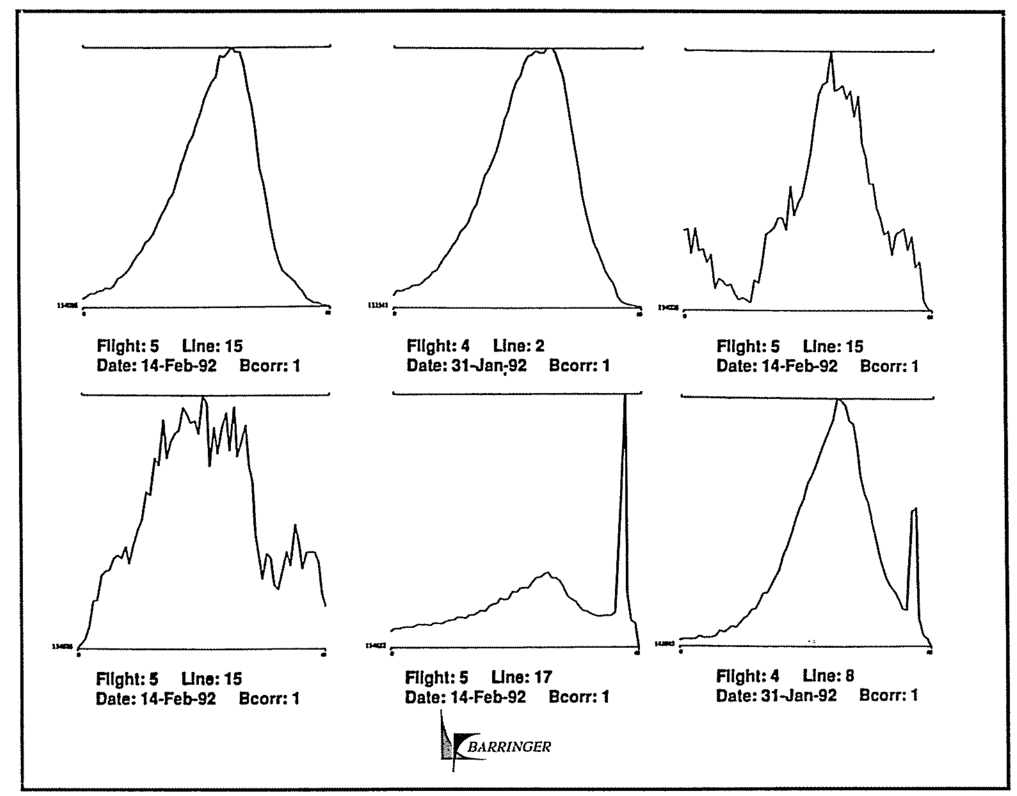

Figure 5
Typical Spectra from Test Flights. From Upper Left these are; Fresh Crude Oil, Material on Sludge Pond, Sand, Gravel, Snow, L. Erie Water

Future Developments

The LEAF system has therefore demonstrated reliable discrimination of crude oil amongst shallow fresh water, ice, and a limited set of sand and rock types. If, as expected, this capability is maintained over a wide variety of beach materials, including vegetation, serious consideration should be given to the construction of one or more operational systems, which could be rapidly deployed to assist in oil clean-up activities anywhere in North America.

The LEAF has many other possible applications in oceanography, fishery or environmental chemical surveillance. A programme, funded by the department of Fisheries and Oceans Canada, is presently under way to add longer-wavelength capability to the LEAF system in order to measure environmental variables such as chlorophyll and other phyco-pigments which, combined with measurements of particulate and dissolved organic matter and the light attenuation coefficient, could provide reliable inputs to models designed for the estimation of primary production in the surface waters of coastal areas. Fisheries and Oceans also intend to pursue further the development of other future applications which may include, for example, detection of fish oil and of various chemical contaminants discharged in the aquatic environment.

More Information:

For more information on the results of these tests, or on other systems for monitoring oil on water, please contact;

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418-775-0595

REFERENCES

[1] 'Detection of Accidental Oil Discharges in the Offshore', Environment Canada, Conservation and Protection (1989)
[2] Fingas, M., Proc. 13th AMOP Technical Seminar, Edmonton, Alberta, p361-386 (June 1990).
[3] Dick, R., R. Jackson, F. Kuja, A. Loveless, M. Paul and S. Wiles, R., 13th AMOP Technical Seminar, Edmonton, Alberta, p315-328 (June 1990)