The Development of an Oilspill Tracking Technique

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Les établissements des Sciences et Levés océaniques dans les régions et à l'administration centrale ont cessé de publier leurs diverses séries de rapports depuis décembre 1981. Vous trouverez dans l'index des publications du volume 38 du *Journal canadien des sciences halieutiques et aquatiques*, la liste de ces publications ainsi que le dernier numéro paru dans chaque catégorie. La nouvelle série a commencé avec la publication du Rapport n° 1 en janvier 1982.

Canadian Technical Report of

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ABSTRACT

Ages, A.B. 1982. The development of an oilspill tracking technique.
Can. Tech. Rep. Hydrogr. Ocean Sci. 8: vi + 29 p.

This report discusses a method to track oil spills by aerial reconnaissance during periods of poor visibility.

The system consists of a radio tracking buoy which can be parachuted on the spill and followed from an aircraft.

The design and subsequent testing of a variety of buoys and parachutes are described in detail.

Key words: oil spills, aerial reconnaissance, surface currents.

RÉSUMÉ

Ages, A.B. 1982. The development of an oilspill tracking technique.
Can. Tech. Rep. Hydrogr. Ocean Sci. 8: vi + 29 p.

Ce rapport traite d'une méthode de suivre une nappe d'hydrocarbure par reconnaissance aérienne pendant des périodes de visibilité bornée.

La nappe d'hydrocarbure est marquée par des petits flotteurs qui sont lancés d'un avion et descendent avec une parachute. Le flotteur se monte en transmetteur pour guider l'avion.

Les desseins et les épreuves des divers flotteurs et parachutes sont décrits en détail.

Mot-clés: nappes d'hydrocarbure, reconnaissance aérienne, courants de surface.

ACKNOWLEDGEMENTS

Over the past ten years, several groups and individuals of various expertise, participated in this rather diverse project. I am most grateful to my colleagues and friends within and outside the Institute of Ocean Sciences for their many valuable contributions, only a few of which are mentioned in the following resumê.

The very first, saucer-shaped model had its origin in our electronics workshop where John Wallace built the buoy containing the biotelemetry transmitter purchased from Davidson Electronics Inc. in Minneapolis. George Dahl of Industrial Plastics in Victoria shaped the plastic shell to accommodate the transmitter. Thanks are due to John Watt, Chief, Engineering Services and John Garrett, Head of Ocean Physics Division, for their active support and helpful suggestions. This part of the project was jointly funded by the Institute and by the Environmental Protection Service, through the Directors Dr. R.W. Stewart and Mr. R.E. McLaren, respectively.

When it became apparent that the saucer-shaped spill marker did not meet the additional requirements of an airborne operation, we approached Scott Plastics of Victoria for some new ideas. Much of the credit for the shape of our present spill marker should go to Blayney Scott who generously donated a great deal of his time and experience in building a new model. Rick Corman of Novatech Designs developed a suitable transmitter and after making some structural improvements, marketed the unit successfully.

The behavior of this and other models in open water was examined in the Strait of Juan de Fuca from chartered vessels and we appreciate the cooperation of the captains and crews of the *Sea Lion*, *Bastion City* and *Ivanhoe*. In particular, my thanks go out to Alexandra Hartley who took leave from her work at the University of Victoria to take part in these drift experiments.

The design and testing of the parachute became a project in itself. Most helpful because of his background in mechanical engineering was Bob Smith, our Industrial Liaison Officer.

Nearly all the work involving parachutes was done by Anne Harrison, who designed and sewed different types of retarding and stabilizing devices such as skirts, lampshades and streamers, and released them expertly from the cockpit of a Cougar Air Cessna flying over Saanich Inlet. Anne also helped determine the angular response pattern for our original antenna arrangement on the Cessna.

In his attempts to find an alternative for a parachute, Stewart Langton of Novatech spent several evenings shaping nylon propellers; in spite of his considerable efforts, we reluctantly had to abandon this approach. Stewart's help in other phases of the project (drift experiments, estimating drag coefficients) is also greatly appreciated.

I am especially indebted to Jim Gower, Head of our Remote Sensing Section, who, with the technical assistance of John Wallace of the same group, took an active part in the final assessment of the entire system, advising us on the location of the receiving antenna on the aircraft and determining the aircraft's position with their inertial navigator.

It was not until I consulted John Garrett that I became aware of the problems in determining velocity profiles near the air-sea interface for the computations of the drag forces on the buoy. I thank him for his words of caution and his efforts to familiarize me with previous research carried out in this field. I also wish to thank Mike Miyake of Offshore Ocanography for his encouragement and his instructive discussions on air-sea interaction.

Anne Woollard programmed the velocity profiles and the drag force computations. My thanks to her and to John Garrett for their constructive remarks in reviewing the first drafts of this report.

The cooperation of Dr. Skagel of CCIW in Burlington in making his wind-wave tank available for our tests is gratefully acknowledged. I appreciated the assistance of Terry Nutts of the Hydraulics Lab, and the helpful comments of Mark Donelan.

The second part of the project (the "airborne" phase) was entirely financed by the Tides and Currents Section and I am grateful to Willie Rapatz, the Tidal Superintendent, for his continuing support.

Finally, I would like to express my thanks to Mr. Menagie of the Dutch "Rijkswaterstaat" in The Hague, who experimented in the North Sea with the first commercially available tracking buoy based on the saucer-shaped model, and who suggested that we "come up with something better". His helpful and pointed criticism led to our second and final model.

INTRODUCTION

In the late summer of 1970, the barge *Irving Whale*, loaded with 8000 tons of Bunker C fuel oil, sank in the Gulf of St. Lawrence, creating an oilspill of over 70 square kilometres. Almost immediately after the accident, dense fog concealed the spill from aerial reconnaissance. When, after two days, the fog finally lifted, the spill had disappeared from sight, presumably because the oil had moved below the water surface due to emulsification of the relatively heavy Bunker C. Part of the submerged spill unexpectedly washed ashore in the Magdalen Islands [Ages, 1971].

Since a similar situation might well occur in the coastal waters of British Columbia, the *Irving Whale* accident generated interest at the Institute of Ocean Sciences (at that time called the Marine Sciences Directorate) to develop a small drifting transmitter which would move along the sea surface with a velocity comparable to that of the oil. Reconnaissance aircraft and ships would be able to home in on the signals and keep track of the spill without having to rely upon visual contact.

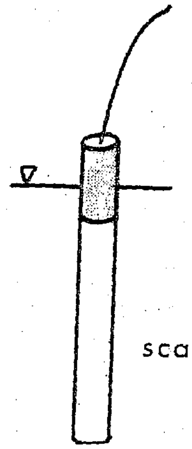
This report is a summary of different models developed and tested intermittently over the past ten years, including the most recent and acceptable design.

DESIGN

THE FIRST MODEL

During the initial stages of its development, the spill marker's design was based on the behaviour of the oilspill created by the sinking of the *Irving Whale*, i.e. partly submerged chunks of emulsified Bunker C oil, following the upper layer of the water surface with minimum direct exposure to the wind.

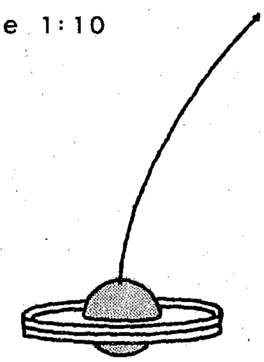
The first trials were made with sonobuoys, 60 cm long cylinders drifting vertically in the water, equipped with an underwater microphone and a transmitter to report submarine traffic to patrolling military aircraft. The partly submerged emulsified Bunker C oil was simulated by orange vinyl bags filled with fresh water.



However, the sonobuoys, because of their 50 cm draught, did not follow the oil simulators;they moved out of position by several hundred meters in a matter of hours, at less than moderate wind speeds.

To stay with the spill, the marker's centre of buoyancy clearly had to be raised, implying a lighter power supply pack and hence a decrease in signal strength or working life. The small transmitters used by the Canadian Wildlife Service to tag and track animals appeared to be a suitable alternative for the more powerful but much heavier and bulkier transmitter packs in the sonobuoys. These biotelemetry transmitters, manufactured by Davidson Company in Minneapolis, Minnesota, operate at a number of frequencies near 150 MHZ, requiring a 45 cm whip antenna. Using three penlight batteries at 1.4 volt each, they have a power input of 12 mw and an output of 5 mw.

Transmitter and batteries (weighing approximately 35 grams) were built into a spherical, 10 cm diameter plastic case, weighted with buckshot to keep the whip antenna upright. A 7-1/2 cm horizontal flange with a 2 cm vertical lip at the circumference was added to minimize rocking and to increase the area in contact with the water surface.

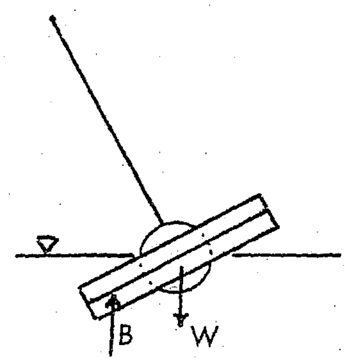


The buoy consisted of two identical plastic shells bolted together, one half above the water, the other submerged. By blowing hot air into the upper half during manufacturing, its size and hence the projected area normal to the wind direction could be increased. In this fashion, strictly by trial and error, the drift velocity of the marker could be made to match that of oil. Small quantities of actual crude oil were used, rather than the previously mentioned waterbags which simulated emulsified Bunker C, because an oil-spill in the B.C. coastal waters would more likely consist of crude oil than of Bunker C.

To locate the spill markers at sea, a chartered Cessna 170 float plane was equipped with two whip antennas, one on each wing strut. In addition, a receiver was installed which could be switched to either antenna. The direction of the spill marker was determined by comparing the two signal strengths. The transmitter's range was about five kilometres, at a flying altitude of 200 m. Some major problems had yet to be solved; e.g. a method of positioning the aircraft, an option to drop the transmitter from the air, a larger range and a more accurate direction finder. However, in spite of their considerable shortcomings, the markers would at least enable us to continue aerial monitoring of an oilspill, even if the frequent periods of fog in the Strait of Juan de Fuca or elsewhere along the B.C. coast would inhibit visual reconnaissance.

One of the buoys was sent to the Nova Scotia Research Foundation who passed it on to Orion Electronics at Saulnierville in Nova Scotia for further research. While maintaining the physical shape of the buoy, Orion changed some of the electronic features. A conspicuous modification was the internal loop antenna which replaced the whip antenna, making the marker easier to handle and more sea-worthy. Combined with a more sophisticated receiver, the Orion buoy was successfully marketed in Canada and abroad.

The saucer shape had been selected not only because of its similarity with that of a partly submerged emulsified blob of oil but also because of its large righting moment. The vertical lip at the flange's edge, which was added to increase the drag in the surface water, contributed significantly to the stability of the buoy. In an inclined position, the lip helped move the centre of buoyancy further away from the centre of gravity. The marker could not capsize, and the whip antenna remained perpendicular to the water surface, even in strong winds. Moreover, the two shells making up the main body of the marker were inexpensive and could be reshaped separately to vary the drag, and hence the drift velocity.

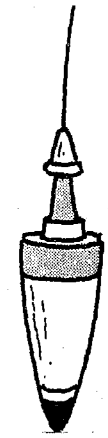


However, when further tests revealed certain flaws in our original design, we decided to try a new approach, completely departing from the saucer shape.

THE SECOND MODEL

An important disadvantage of the saucer-shape model was its structural weakness, which made an airdrop risky, even with a parachute. Since an oilspill in remote waters almost certainly would call for an airdrop of the transmitters, we had to search for a more rugged, streamlined model which could be dropped from any reasonable altitude without shattering upon impact on the sea surface and with limited penetration to prevent imploding. Among the small floats marketed by the commercial fisheries and marine industry, a lifebuoy light manufactured by a local firm, Scott Plastics, seemed to be the most promising unit. This "Scotty" light consists of a plastic case for three 1.5 volt D-cell flashlight batteries with a mercury switch and a plastic top containing the light. Its over-all length is approximately 40 cm. The foam plastic float body surrounding the battery case was machined into a more streamlined shape and a lead weight was attached to the bottom for stability. The same transmitter used in the original marker was now built into the light top which also provided a base for the whip antenna.

Drift tests in the Strait of Juan de Fuca showed that at moderate westerly winds of 30 to 40 km/hr at a wave height of 1.5 to 2 m, the saucer-shaped marker was superior to the Scotty buoy in simulating the spill's movement, obviously because of its shallower draught (the increase in draught from the saucer's 7 cm to Scotty's 20 cm was a sacrifice to produce a more impact-resistant shape). Both markers had a tendency to lag behind the spill at a rate of about 200 m/hr for the Scotty buoy and 100 m/hr for the saucer type buoy. At light winds (less than 10 km/hr), spill and markers stayed together. For these experiments, small quantities of 20 litres of Alberta crude oil were used, not only to test the spill markers but also to examine the performance of a variety of oilspill simulators. The experimental patches of oil were later replaced by clusters of hula hoops covered with orange signal cloth, which we had selectd as the best simulators. At night, these clusters were attached to floating lights set in plywood disks.



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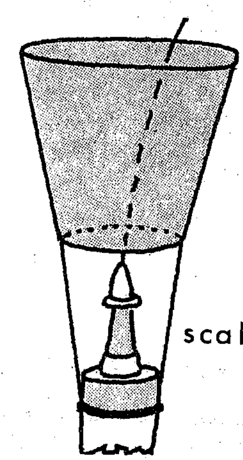
To examine their resilience, both markers were dropped from a Cessna 180 float plane over Saanich Inlet (Figure 1) at an altitude of 150 m. The Scotty buoy survived the fall but the saucer model disintegrated upon impact. Subsequent drops of the Scotty buoy from an altitude of 300 m proved less successful, particularly when the buoy did not hit the water "nose first" but came tumbling down on its side, snapping the top containing the transmitter.

A series of airdrops with a variety of retarding devices followed: nylon streamers prevented tumbling but did not provide sufficient friction to prevent damage when dropped from an altitude of 300 m; upon impact, the inner case with weight and batteries slipped through the foam plastic flotation collar. A 30 cm high, 30 cm diameter nylon lampshade type parachute performed well but had



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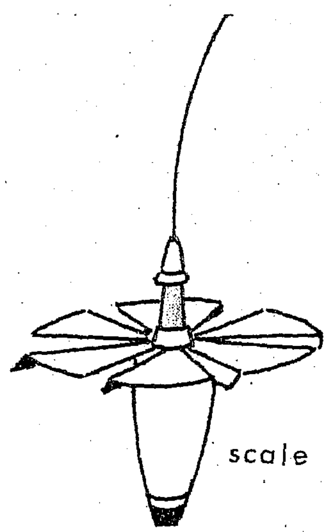
to be released after landing lest it would entangle the antenna. Water soluble Pepo-mint Lifesaver candies proved to be an effective self-releasing mechanism.

Attempts to slow down the descent by mounting a nylon propeller on the marker were abandoned even though a propeller might well be the most promising attachment. The purpose of the propeller was not only to decrease the velocity of descent but also to provide the marker's body with more drag near the surface by remaining attached after landing. Varying the number of vanes, their shape and pitch, we tested about a dozen different propellers. Results were inconsistent. The same model would descend slowly during one experiment, only to tumble down the next time, and break up on the water surface. We surmised that the centre of gravity of the body was too close to the centre of drag to suppress tumbling, and that a successful descent depended on the way the marker was launched from the aircraft.

Lowering the centre of gravity would add to the draught of the buoy and partly undo the propeller's function of increasing the drag of the upper surface layer. We considered a small self-releasing drogue tied to the antenna and a weight suspended from the bottom to suppress tumbling; this combination, although intriguing, seemed somewhat unwieldy for an airborne operation.

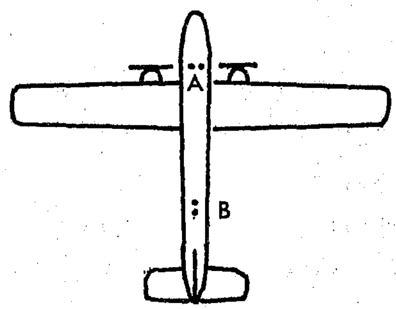


Lacking proper facilities to examine the rotor attachment in more detail, we finally abandoned this approach and developed a parachute which, upon landing, would remain attached to the buoy without becoming entangled with the antenna.

The parachute consisted of a 30 cm diameter hoop connected to the spill marker with nylon cloth. The marker with this parachute was successfully dropped from altitudes up to 300 m.

A Victoria firm, Novatech Designs, was subsequently commissioned to further develop and manufacture the new type of spill marker (Figure 2 and plate I). Novatech also supplied the receivers for locating the tracking buoys.

The receiver system was installed in a Britton Norman Islander aircraft of Flight Centre Victoria. It consisted of two receivers, each connected to a set of two external antennas arranged as follows: one "directional" set of two unipoles, 1/4 wavelength apart, built on top of the cockpit in a line perpendicular to the plane's axis; a second "fore-aft" set of two unipoles, 1/4 wavelength apart, installed on the fuselage behind the first set, in line with the axis of the plane. The first unit indicated the direction of the tracking buoy's signal; the second one would determine the moment when the buoy was exactly underneath the aircraft. This arrangement proved to be quite dependable and the aircraft has now been permanently equipped with the tracking antennas. The land-based Islander aircraft was selected because it was the only aircraft available with the necessary space and power supply for an Inertial Navigation System to fix the aircraft's position. The I.N.S., operated by our Remote Sensing Section, computed positions with an accuracy of about 500 m, which was adequate for our type of drift observations.



COMPUTATIONS

THE DRAG FORCES

For an evaluation of the buoy's movement with respect to the wind (and hence of its suitability to track oilspills or surface currents) the driving and resisting drag forces had to be determined for a reasonably large range of wind forces.

The forces acting upon the various components of the drifting buoy are a function of the wind velocities close to the sea surface and the wind-induced current velocities in the upper water layers, i.e.

$$\text{DRAG} = C_D A \frac{\rho u^2}{2}$$

where C_D is the drag coefficient (dimensionless, about 1.1 for cylinders), A is the projected area normal to the velocity, ρ the density of the medium (air or water), u the relative velocity of the buoy.

a) Wind Velocities

Among the several expressions for wind profiles proposed in the literature [Rijkoort] the most commonly used one is the logarithmic equation for flow over a hydrodynamically rough surface:

$$u_z = \frac{u_*}{\kappa} \ln \frac{z}{z_o}$$

In this equation, u_z is the windspeed at height z above the sea surface, κ the von Karman constant, a dimensionless number (0.4) derived directly from the Reynolds number separating turbulent and laminar flows [Kraus].

By definition, the friction velocity, $u_* = \frac{\tau}{\rho}$, specifies the tangential stress τ across the interface in terms of the velocity, ρ being the density. Although u_* cannot be measured directly, its value can be computed from wind profile observations.

u_*, as well as z_o, can be obtained by measuring u_z for several values of z, and subsequently plotting u_z against ln z. Rewriting the logarithmic profile as $u_z = \frac{u_*}{\kappa}(\ln z - \ln z_o)$, we can find u_* and z_o by linear regression.

Ruggles collected wind profile observations at the M.I.T. oceanographic platform over a period of two years and found the linear relationship $u_* = 0.04\ u_{10}$ for light to moderate winds.

The roughness length z_o is a measure of the surface roughness. Its physical interpretation is again somewhat vague but it might be useful to examine its significance to the velocity distribution from which the drag forces are derived.

In fluid flow, a hydrodynamically smooth surface has roughness projections which are submerged in a laminar film. The surface becomes "rough" when these projections protrude through the film and generate turbulent eddies. The roughness of the surface not only depends on the size of the roughness elements but also on the Reynolds number, in other words the flow velocities: at high velocities, the viscous film becomes depressed, exposing the projections and causing the turbulent flow regime to move closer to the surface. The term z_o then represents the scale of the turbulent eddies associated with the roughness projections, in our case the capillary waves with which the wind interacts. We would expect z_o to vary with the Reynolds number.

The concept of aerodynamical roughness of the sea surface has its analogy in hydraulic engineering where head losses in a pipe are a function of its relative roughness $\frac{\varepsilon}{D}$ (the ratio between the size of the roughness projections ε and the pipe diameter D) and where the flow distribution is expressed by a similar equation.

$$\frac{u}{u_*} = \frac{1}{k} \ln \frac{y}{\varepsilon} + \text{empirical constant.}$$

In this formula, ε has actually been measured (the size of sand grains glued to the wall of a pipe [Nikuradse].

Mathematically, the introduction of the roughness length shifts the velocity profile a distance z_o upwards from the sea surface because a value of z less than that of z_o would cause u_* to become negative. The logarithmic equation then does not apply to the layer of air immediately above the sea surface.

However, substitution of the estimated ratio of 4% for $\frac{u_*}{u_{10}}$ in the wind profile equation suggests that the value of z_o should be of the order of 0.5 mm. Therefore, strictly for the evaluation of the drag force, we ignored the roughness length. This approximation does not imply any change in the wind profile in our computations, it implies that the profile was not extended through the z_o layer to the water surface, because of the insignificant contribution of that portion of the drag force. An important consideration was also that we know little about the dynamics immediately above (and below) the sea surface, particularly in the presence of waves.

b) Wind-generated Surface Currents

As the tracking buoy is driven along the sea surface by the wind, its movement is resisted by the upper water layers, which themselves move in the same direction at a rate which decreases rapidly with depth. The resisting drag forces can be determined from water velocities relative to the absolute velocity of the buoy; they may be negative (i.e. support the wind drag) near the surface if the velocity of the uppermost water layer exceeds that of the buoy.

Unfortunately, our present knowledge of the water velocity distribution close to the sea surface is even more sketchy than that of the wind profiles immediately above the surface. So far, almost all experimental work on wind-induced surface flow has been carried out under controlled conditions in the laboratory and it would be questionable to apply these results to the open sea. Obvious dissimilarities are the wave-generated component of the surface drift and the effect of a fetch of several miles which cannot be simulated in a tank. However, the laboratory data are at least an indication of the logarithmic shape of the current profile associated with the resisting drag forces. Moreover, to estimate these drag forces, we may be justified in making assumptions much less stringent than those made for the analysis of other boundary-layer processes such as mass and heat transfer across the interface.

For instance, the hydrodynamic roughness length for the water current has been estimated or computed by several authors [Wu, Kondo, Spillane] to be comparable with the aerodynamic roughness length for the wind, i.e. in the order of 0.5 mm. Considering the cross-sectional area acted upon by the drag force, any error in this minute portion of the velocity profile would have a negligible effect upon the total drag. Consequently, the roughness lengths on both sides of the air-water interface were neglected and the logarithmic wind velocity profile was assumed to continue through the interface into a surface water velocity profile which differed in shape from the wind profile because of the friction velocities (in other words the densities of air and water).

If we assume an equation of the water velocity $\upsilon = \upsilon_s - \frac{\upsilon_*}{\kappa} \ln \frac{z}{z_o}$, where υ_s = surface water velocity, then υ_* follows from the expression for the tangential stress at the air-water interface: $\tau_o = \rho_a u_*^2 = \rho_w \upsilon_*^2$, ρ_a and ρ_w being the densities of air and water, a ratio of about 0.0012.

Again substituting $u_* = 0.04\ u_{10}$ and relating υ_* to u_* by the equation for tangential stress, we can estimate a profile for the wind driven surface currents as a function of u_{10}.

Logarithmic profiles of two representative wind velocities and their corresponding surface drifts are sketched in Figure 3.

From the equations representing these logarithmic profiles, the drag forces acting upon the various components of the buoy can be calculated, as shown in Tables I and II, and in Figure 4.

TABLE I. DATA FOR DRAG FORCE COMPUTATIONS

(With Skirt)

Wind $F_A = C_D \, XA \, \frac{\rho u^2}{2}$ $u = \frac{u_*}{\kappa} \ln \frac{z}{z_o}$

Component of buoy	XA (cm^2)	C_D	Action Point (cm)	u_{10}= 18m/sec u (cm/sec)	u_{10}= 2m/sec u (cm/sec)
antenna	9	1.1	25	1140	130
base	2	1.1	5	850	90
top	20	1.1	2	680	80
ring*	200	1.1	1.5	630	70

Water $F_W = C_D \, XA \, \frac{\rho \upsilon^2}{2}$ $\upsilon = \upsilon_s - \frac{\upsilon_*}{\kappa} \ln \frac{z}{z_o}$

battery pack	80	1.1	24	15	2
styrofoam	120	1.1	7	23	3
parachute*	1134	0.003	0	54	6

* excluded when considering drag on buoy without skirt (parachute).

We tried to establish a drag coefficient of the skirt and its styrofoam ring, by towing it alongside the wharf at Patricia Bay, and by observing its drift at known airspeeds in the wind-water flume, but the results were inconsistent. We finally assumed the skirt, stretched below the water surface, to act as a flat plate with a drag coefficient depending on the Reynolds number, while the ring's drag coefficient would be that of a cylinder.

The absolute velocity x of the buoy follows from a force equilibrium:

$$\text{Drag}_{\text{air}} = \text{Drag}_{\text{water}} ,$$

$$\sum_i (C_{D_i})\ (XA_i)\ \frac{\rho_{air} u_i^2}{2} = \sum_j (C_{D_j})\ (XA_i)\ \frac{\rho_{water}(x-\upsilon_j)^2}{2}$$

This computation may have to be done by iteration if one or more values of υ_j exceed that of x.

The buoy's velocities were calculated for two representative wind velocities, u_{10} = 18 m/sec (40 mph) and 2 m/sec (4.5 mph). The results are tabulated in Table II which also illustrates the effect of the skirt upon the drift.

TABLE II. COMPUTED BUOY VELOCITIES

u_{10} m/sec	Buoy velocity - % u_{10} with skirt	without skirt
18	2.3%	1.7 %
2	2.3%	1.65%

One of the assumptions leading to these results was the universally accepted water surface velocity of 3% of the wind-speed at 10 metres height. The calculated buoy velocities suggest that the buoy would slightly lag behind a very thin slick of a few microns depth such as an oilspill in its third phase of spreading (a phase governed by the balance of surface tension and inertia).

As indicated by the computations, the buoy's velocity can easily be adjusted to 3% of u_{10} by increasing the diameter of the skirt, or (less easily) by shortening the cylinder containing the batteries. For the time being, the design was left unchanged; a larger skirt would be difficult to handle from an aircraft and a shorter cylinder would imply a lower stability and a decrease in power supply. Moreover, these theoretical percentages were rather conservative without considering the effect of Stokes drift, fetch and the occasional wind thrust on the skirt when whisked off a wave crest.

LABORATORY TESTS

Preliminary tests to observe the Novatech buoy's performance at different wind velocities were carried out in a wind-wave flume in 1980 and 1981. The flume, located in the hydraulic laboratories of the Canada Centre for Inland Waters at Burlington, Ontario, has a length of 83 metres, a height between roof and bottom of 3.08 m and a width of 4.57 m. The location of access doors, observation windows and built-in anemometer permitted the use of only a small portion of the tank for this experiment.

The drift velocity was obtained by timing the distance travelled between transit marks on the flume's wall at selected airspeeds measured by a cup anemometer. At a water depth of 55 cm, the anemometer was mounted two metres above the water surface, 53 cm below the ceiling. This arrangement was not set up to represent conditions in the open ocean but to provide us with an opportunity to observe the behaviour of the buoy and the effect of certain components on the drift velocity, such as the skirt and the draught (i.e. the length of the battery case). Included in the tests was the original saucer type spill marker, modified by Orion.

The wind speeds, measured at two metres above the water surface were 3.8 m/sec and 12.2 m/sec, generating waves of four and eight cm height, respectively. Each model was tested at least three times, with variations from the mean not exceeding 4%. Attempts to measure the drift of the water surface by tracking small vinyl strips dipped in Vaseline were unsuccessful because of the lack of agreement between the runs.

TABLE III. BUOY VELOCITIES MEASURED IN CCIW FLUME

(Percentages of Airspeed at 2 metres height)

FLOAT:	AIRSPEED 3.8 m/sec	12.2 m/sec
Standard Novatech buoy, draught 35 cm, with skirt	1.9%	1.3%
Standard Novatech buoy, draught 35 cm without skirt	1.4%	0.7%
Short Novatech buoy, draught 25 cm with skirt	2.4%	1.6%
Short Novatech buoy, draught 25 cm without skirt	1.9%	1.2%
Orion buoy	2.8%	1.3%

The inconsistency in the behaviour of these strips (and other small objects which we tried) might be due to local perturbations in the airflow caused by the walls and ceiling of the tank. These perturbations might not be "felt" by the much larger floats. The discrepancies were particularly noticeable at higher fan speeds. A peculiar trend in the data was the significant decrease of the "percentage wind speed" of the buoy's movement with an increase in wind speed, which contradicted our computations as well as our experience with drifting objects in the open sea. This hehavior could again be due to the wall effect*. However, the tests were successful in one important aspect: the results, tabulated in Table III, clearly demonstrate the effect of the skirt upon the speed of the buoy, and confirm the earlier computed estimate of 25%. The influence of the draught seems exaggerated, perhaps by the shallow water depth.

It would be tempting to extend this exploratory work to a series of detailed measurements of the three-dimensional distribution of the airflow and associated surface currents in the tank. Using much more sophisticated equipment than a stop watch and a set of marks on the wall of the tank, we might be able to detect flow patterns at different fan speeds and thus explain the behavior of the indicator strips. These data could produce a reasonably accurate relationship between the movements of the buoys and the water surface in the tank. However, we would still be left with the elusive question as to what extent the surface flow in a wind-wave flume can be identified with that in the open ocean.

Therefore, rather than launching into a complex laboratory project with an academic outcome, we moved our experiment to open water, a compromise between more realistic conditions and a loss of accuracy due to tidal currents and local variations in the wind field.

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* Wind velocity profiles measured in the tank by a contractor for CCIW may provide at least a partial explanation. As the fan speed was increased, there appeared to be a negative shift of the measured wind profiles with respect to the logarithmic "open water" profiles computed for the corresponding anemometer readings. This shift would proportionally decrease the wind drag and hence the speed of the buoy relative to the anemometer reading.

FIELD TESTS

DRIFTING

The test site was the central portion of Saanich Inlet (Figure 1). This site was chosen because of its relatively insignificant tidal currents and its proximity to the Institute.

To measure the wind at a height of ten metres above sea level, a Lambrecht anemometer was installed on the head of the Institute's wharf, ten metres above mean sea level. This location implied that the Lambrecht data were useful only during periods of on-shore winds. Preferable, but not essential, were periods of slack water.

The field experiments were conducted in the spring and summer of 1982. Spill markers were released from a launch about two kilometres off shore and tracked with sextant fixes during periods of one to three hours. Currents were measured from a nearby mooring buoy, with a Marsh-McBirney electromagnetic current meter. Since the winds at the site might differ somewhat from those recorded at the dock, wind readings were also taken on the launch with a hand-held anemometer, three metres above the water surface. Test periods were kept relatively short because of the variability of the wind field and because the floats were to stay within a reasonable distance from the mooring buoy where we could monitor the tidal currents. Several trials had to be scrapped because of unexpected wind shifts.

To follow the movement of the sea surface, we used the vinyl strips. In addition, a cluster of hula hoops covered with orange signal cloth was tracked.

The results of two acceptable test runs are listed in Table IV. The winds, monitored from the launch, remained steady during the periods indicated.

The tabulated results are still somewhat of an approximation because it was physically impossible to measure variations in either winds or currents at the exact location of the buoys: the launch had to remain at a distance from the floats to avoid disturbing the wind field while current observations could only be made from an anchored buoy in the vicinity.

TABLE IV. BUOY VELOCITIES MEASURED IN SAANICH INLET

DATE & TIME	WIND (U_{10}) (km/hr)	CURRENT (cm/sec)	BUOY VELOCITY (%U_{10}) with skirt	without skirt
11/3/82; 10h - 11h	270° - 29	-	2.4%	2.1%
*11/8/82; 12h - 12^{30}	080° - 17	320° - 24.4	2.2%	1.7%
*(Figure 5 shows this test in detail)				

Regardless of these disadvantages of an experiment in open water, certain practical aspects were noteworthy because they were essentially what the project was all about:

The spill marker with skirt consistently moved at the same velocity as the vinyl strips. Without the skirt, its drift velocity decreased by about 20% (compared with a computed 26%, Table II). The hula hoops and a skirt by itself moved faster by about 10%.

Among the various types of oilspill simulators which we tried out in recent years, the vinyl strips appear to be the most realistic ones; they are only a fraction of a millimetre thick and remain part of the sea surface without being whisked off wave crests by the wind. It would be difficult to compare the velocities of strips and oil on the sea experimentally: surface tension would keep the strips trapped in oil and prevent them from drifting independently.

The strips disappear within hours, either into the water column by orbital motion or along the surface by dispersion, thus limiting their usefulness. For a drift exercise of several hours or days, the hula hoops are preferable, in particular because they can be equipped with strobe lights for night work.

RANGE AND DIRECTION

Flying at an altitude of 300 m over Satellite Channel, north of Saanich Inlet, we found the maximum range of the spill marker's transmitter to be 40 km in optimum conditions (clear weather, calm sea). Although the angular precision of the signal was difficult to evaluate from a moving aircraft, only minor adjustments in the aircraft's heading were needed to approach the buoy. Once the aircraft was oriented by the receiver's directional unit, its passage over the buoy was clearly indicated by the locating unit.

The maximum range over water was found to be six kilometres. This distance was determined in Saanich Inlet from a launch equipped with a receiver while a spillmarker was left on the shore. The sea was smooth. The elevations of receiver and transmitter were respectively two and six metres above the water surface, suggesting a line of sight of 16 km. Increasing the length of the whip antenna from 1/4 to 5/8 of the transmitter's wave length would improve the range over water by lowering the signal's radiation lobe more towards the horizontal [Taylor]. However, a longer antenna is difficult to handle and does not improve the range during an airborne operation for which it was originally designed.

WORKING LIFE

To examine their range and condition after a prolonged period of exposure, one of the spill markers was left in the water, with the transmitter turned on. After two months of continuous transmission, its signal (powered by four 1.5 volt D cells) still had a range of 2.2 km and, apart from being covered with barnacles, the buoy was in good condition.

AIRBORNE EXERCISE

On July 28, 1980, four spill markers were parachuted in a line across the Strait of Juan de Fuca (Figure 4). The purpose of the experiment was not only to test the entire airborne technique but also to verify a numerical oilspill model developed at the Institute in earlier years [Ages, 1981].

The spill markers were released from an Islander aircraft flying at an altitude of 200 metres in light westerly winds. Six hours later, they were located again by the same aircraft using the two tracking receivers and the Inertial Navigator. During the next morning, all four were tracked close to the shore of Washington State, where three of the buoys were eventually retrieved by the public and returned to the Institute. Apart from major discrepancies between the actual tracks and the model-predicted paths, the operation itself went well and no further exercises of this magnitude were carried out.

SOME FINAL REFLECTIONS

Although the design of the tracking buoy was tested by a great deal of field work and had to be modified several times, it would be wrong to conclude that the final product is the only acceptable one.

During our trials at sea, we found that almost any floating object with a draught of a few centimetres will at one time or another stay with an oilspill; and at one time or another wander off on its own. Even an oilspill itself rarely retains its cohesion but moves about in streaks and patches several kilometres apart.

However, we also noticed that there were certain restrictions to the draught of the float: the sonobuoy with a draught of 50 cm was a poor simulator and the much smaller Scotty and Novatech floats needed a horizontal drogue (skirt) on the sea surface to keep up with the surface drift. The skirt has two essential functions: it serves as a parachute during the spill marker's descent from the aircraft and, once in the water, it adds to the drift velocity as it remains attached to the buoy.

The buoy's drift velocity can be modified simply by changing the diameter of the skirt, a useful feature since not all types of oil may move at the speed assumed by our design. As its specific gravity increases due to emulsification and evaporation, any type of oil will eventually sink below the sea surface and move at a slightly lower velocity. The skirt could then be adjusted to certain stages of decomposition of an oilspill. We left this refinement to some future research project.

Since an oilspill moves with the upper layers of the water surface, the spill marker may equally well be used to track surface currents, provided that one recognizes the limitations of the airborne technique. Its accuracy does not so much depend on the aircraft's positioning system (INS, Decca etc.) as on our ability to exactly determine when the aircarft passes over the buoy for a fix. In that respect, measuring surface currents is much more demanding than the surveillance of an oilspill. An alternative would be a shore-based receiver system, fixing the position of the buoy with bearings from two shore stations. We tried this approach but found the radio bearings much less accurate than the angles obtained by a conventional theodolite.

Because of our sketchy knowledge of the spill marker's drag coefficients and of the velocity profiles of winds and currents near the sea surface, the drag force analysis rested on some broad assumptions which might well be proven inadequate by future research. The final adjustments in the design were therefore inspired more by the results of our experiments than by those of our computations. Still, the empirical approach had its drawbacks: the laboratory data were inevitably distorted by the wall effect and shallow depth; at sea, the winds and currents had to be observed at some distance from the buoy and could not always represent the conditions nearby.

In conclusion, while we may have succeeded in developing a suitable technique to track an oilspill from the air, some design aspects require additional experimental work, perhaps by a more specialized research group. The literature shows a disappointing lack of information on wind-induced surface currents, as well as on wind profiles over ocean waves. This report suggests the continuing need for such research, in particular if the tracking technique is to be applied to a study of surface currents.

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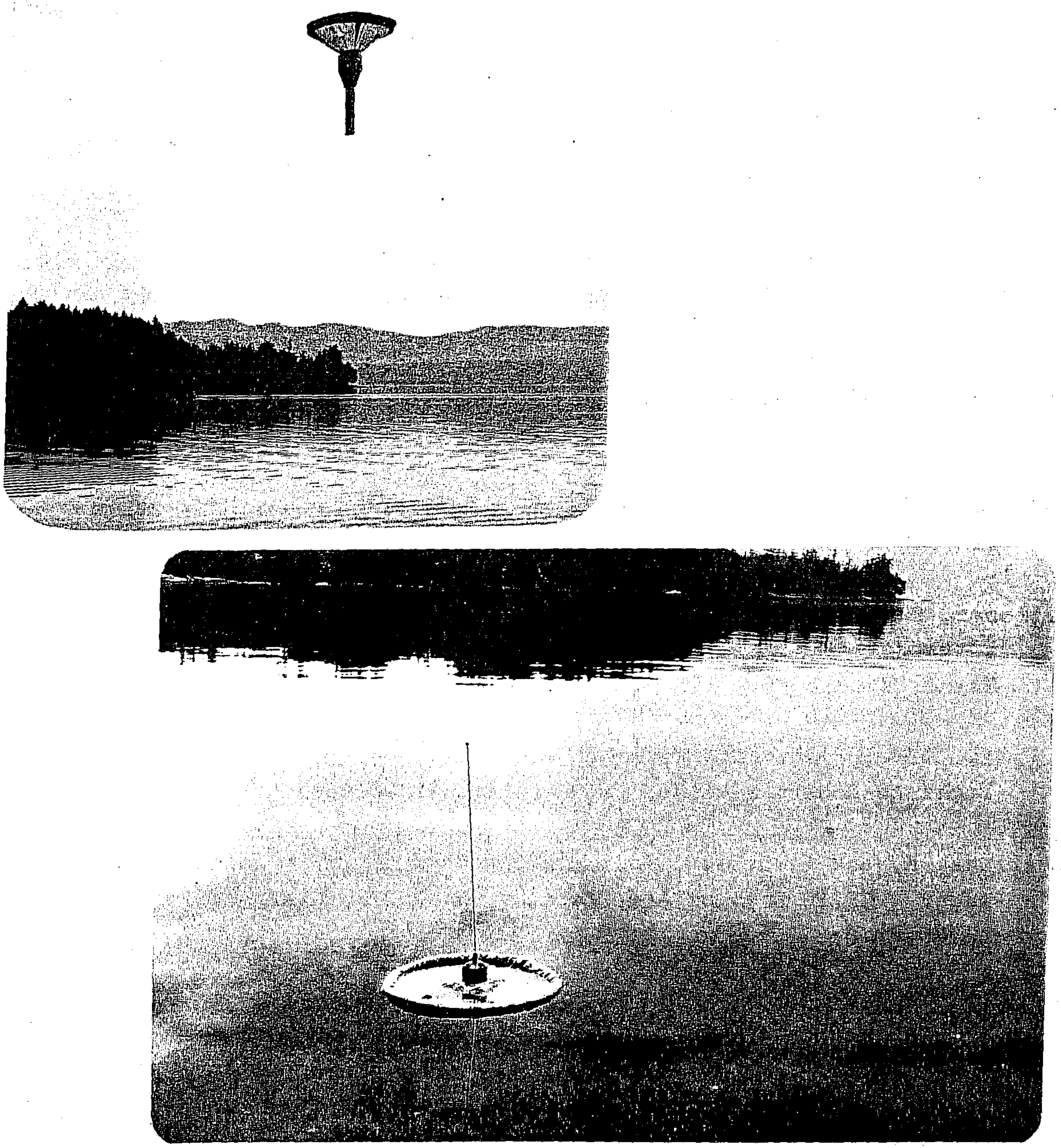

PLATE I

TRACKING BUOY IN OPERATION

(As manufactured by Novatech Designs Ltd.)

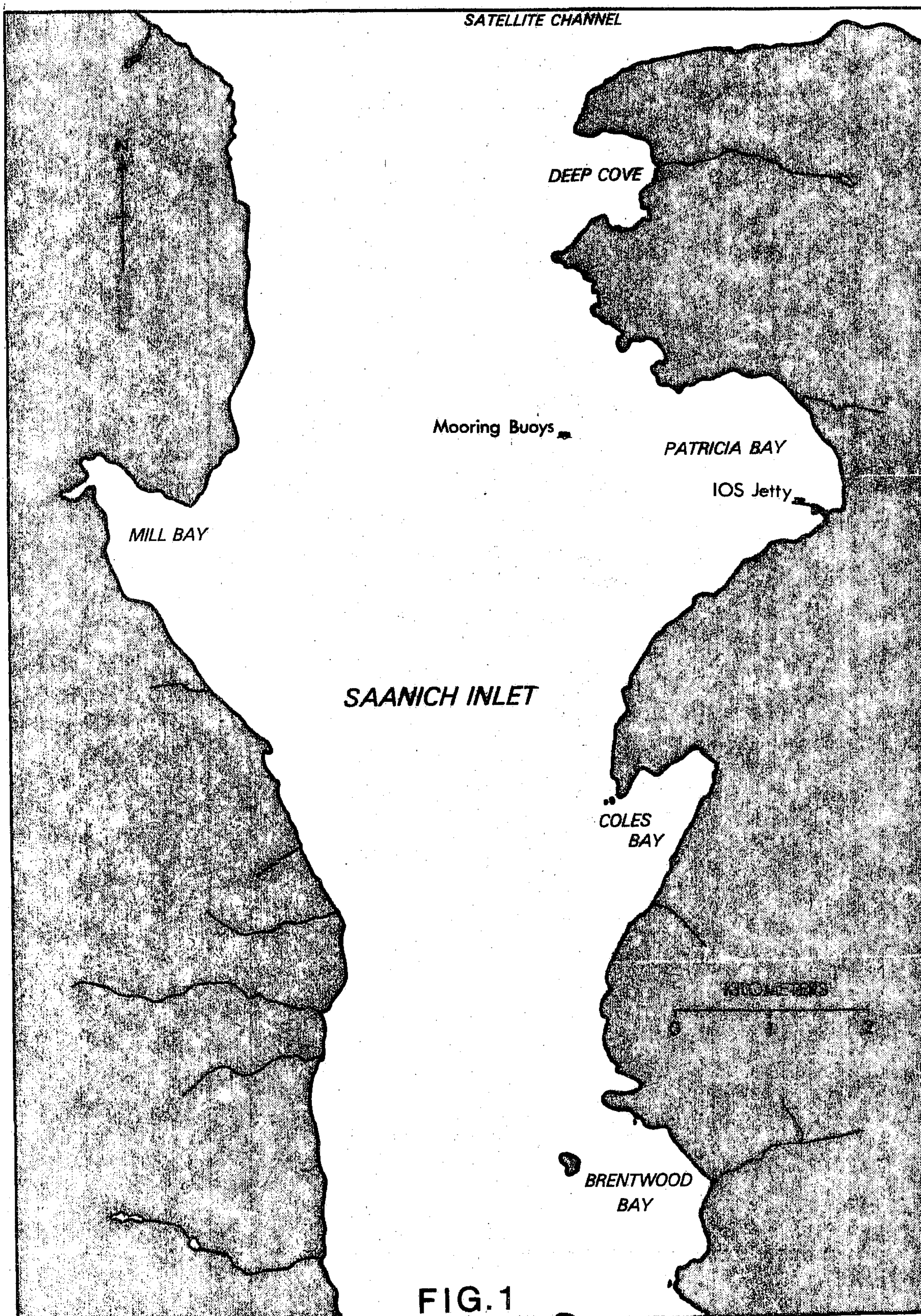

FIG.1

LOCATION OF TEST SITE

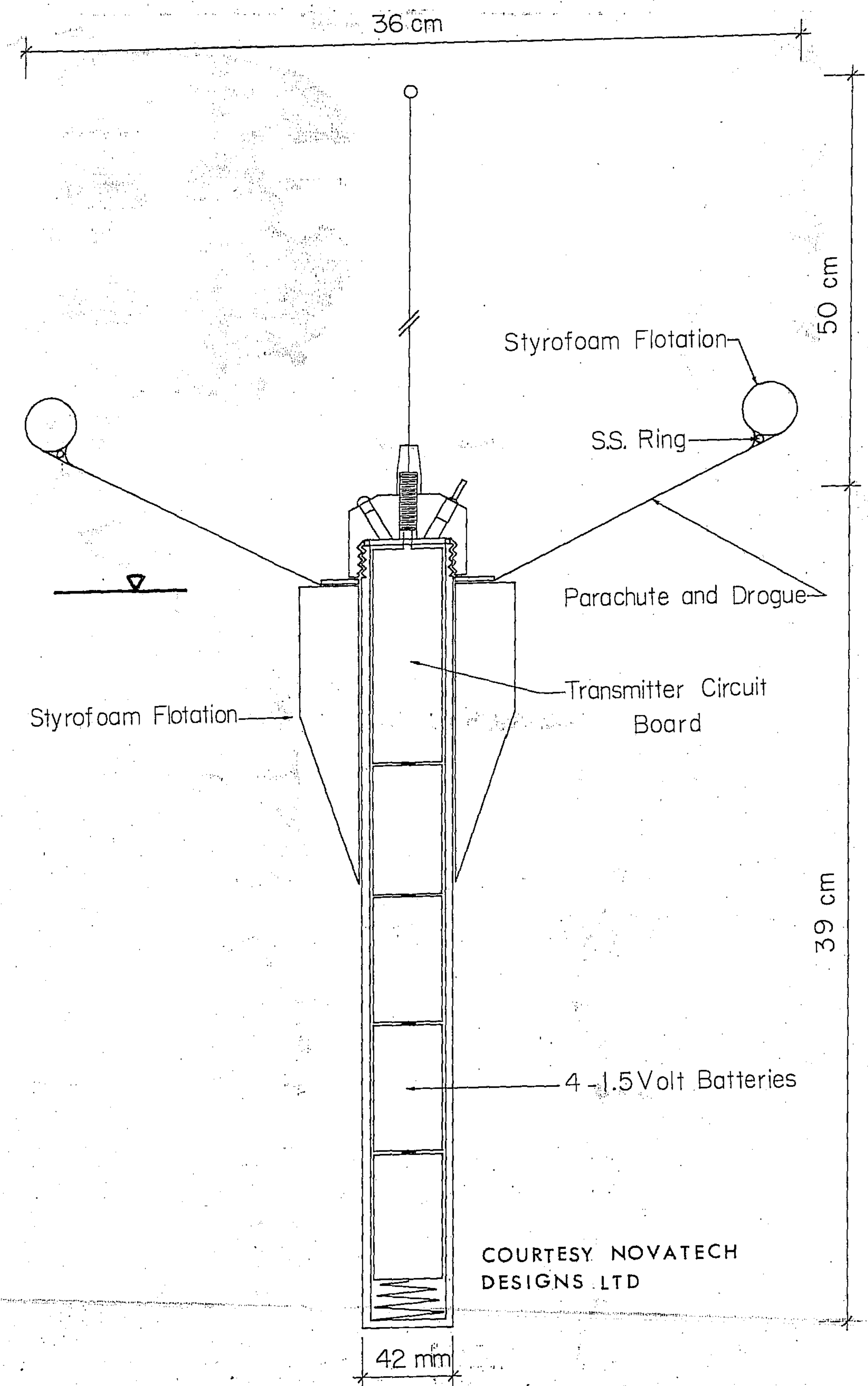

FIG 2. NOVATECH SPILL MARKER

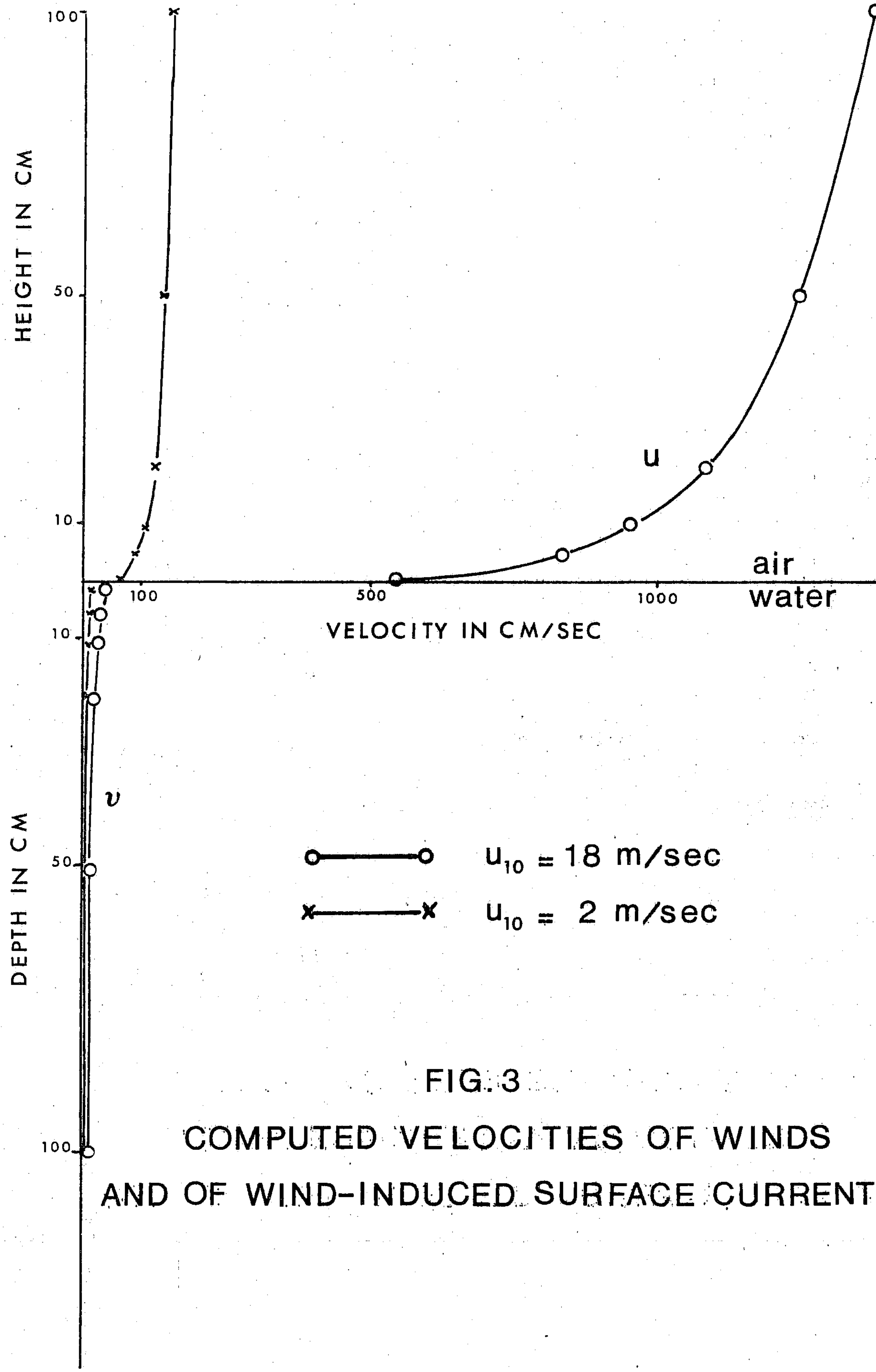

FIG. 3

COMPUTED VELOCITIES OF WINDS
AND OF WIND-INDUCED SURFACE CURRENTS

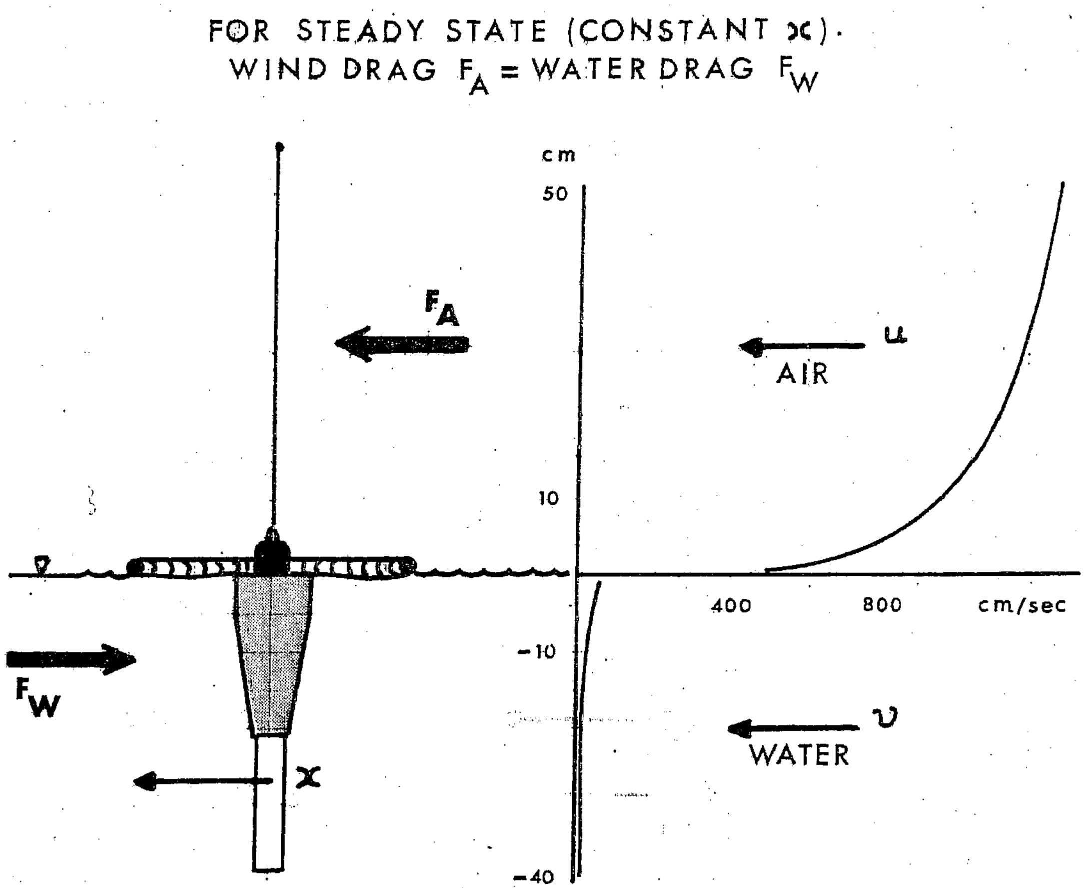

FIG. 4
DRAG FORCES

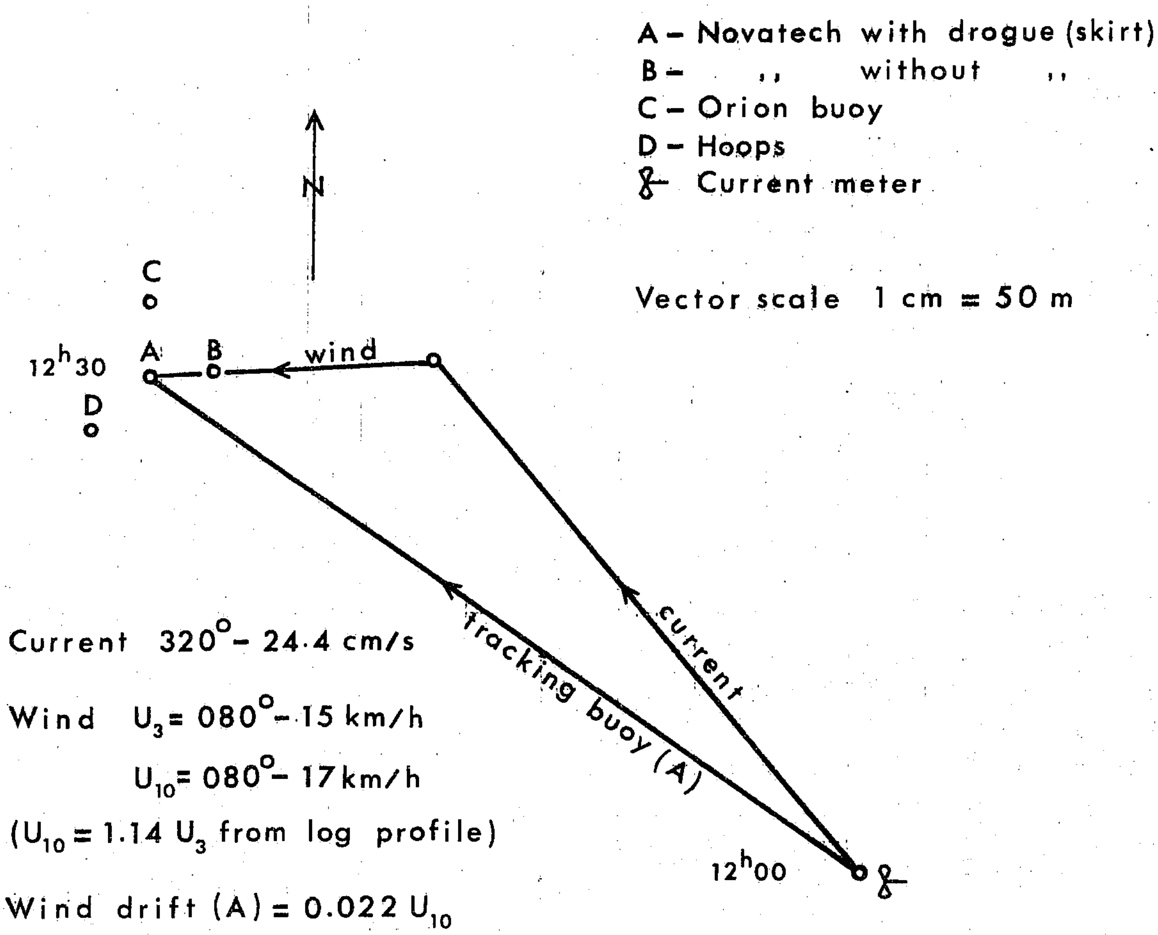

FIG. 5

FLOAT TRAJECTORIES

SAANICH INLET, AUGUST 11, 1982