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Use of radio-controlled miniature aircraft for drifter and dye current studies in a tidal inlet[1,2]

Abstract—A commercially available radio-controlled miniature aircraft (wingspan 2.4 m) was modified and deployed as part of a field study of the ebbtidal flow characteristics of a natural, unstructured tidal inlet. To complement Eulerian current measurements within the main inlet channel, surface drifter and rhodamine dye patches were observed from the miniature aircraft and recorded with a 35-mm camera. Position reference was provided with an array of precisely located markers on land and in the water. The miniature aircraft is an inexpensive, accurate alternative for Lagrangian studies in tidal inlets and estuaries, with many advantages over alternate techniques (such as hot-air balloons, fixed platforms, manned aircraft, or chaser boat).

The investigation of sediment transport in tidal inlets has been hampered by the complex three-dimensionality of tidal inlet flow fields and the lack of instrumentation to monitor these highly nonstationary flows. A single current meter within the water column will inadequately resolve both the horizontal and vertical structure of tidal inlet flows (e.g. *see* Kjerfve et al. 1981; Ward 1981; Aubrey and Speer 1983). An array of current meters in the vertical and horizontal is necessary to adequately specify the Eulerian flow structure, a difficult task in a difficult field environment. Alternatively, a few current meters can be maintained and used to verify a model of the complex flow field; such a model would then be able to fill in the unknown current vectors at locations throughout the inlet.

Since sediment transport is a Lagrangian phenomenon, Eulerian measurements are not optimal for transport calculations. Lagrangian measurements are similarly difficult to make in an inlet and are generally accomplished by measuring drifter tracks or the dispersion of dye patches. These measurements historically have been labor-intensive and logistically difficult because of the lack of a suitable platform for making synoptic observations. For instance, single drifters are occasionally followed by at least two observers using transits or theodolites from shore, who track the sinuous path of the drifter. Line-of-sight and visibility problems are common.

We wanted an inexpensive, synoptic, high-quality system for Lagrangian flow measurement on space scales up to 1 km. The instrumentation described here is versatile, adaptable to a variety of field situations, and collects more data with less work than alternative techniques.

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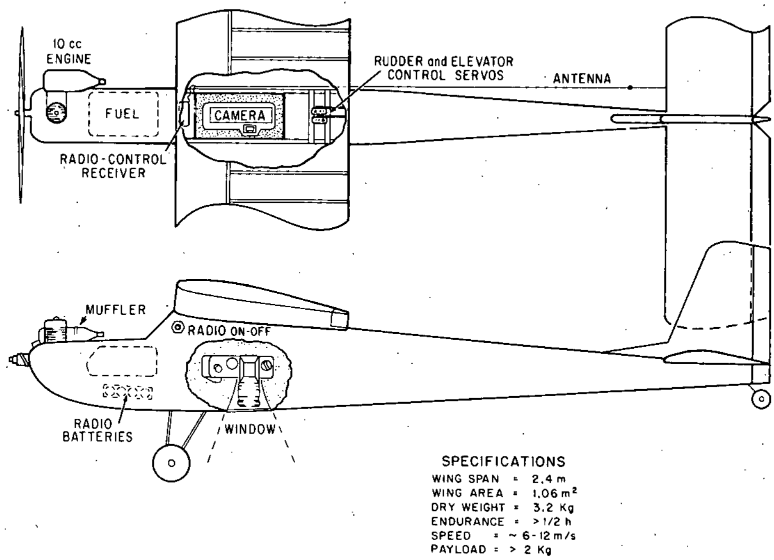

Fig. 1. Schematic of modified radio-controlled miniature aircraft used in tidal inlet studies.

The aircraft (Fig. 1) was similar to one used successfully aboard research vessels (Hess 1977). Two commercially available aircraft kits (sold for hobby purposes) bought in early spring allowed adequate time for spare-time construction and testing. Four modifications were made: a window about 11.4-cm square was mounted in the bottom of the fuselage near the center of gravity; the fuselage was widened by 1.6 cm to allow adequate space for installation of vibration isolation foam around the camera; the fuselage was torsionally stiffened to improve control response and load-carrying ability; and an oil deflector was added to keep exhaust oil off the camera window.

The aircraft is a high wing monoplane with 2.4-m wingspan. The total lifting area (including the lifting horizontal stabilizer) is about 1.06 m^2. The weight is just under 3.2 kg, with a useful payload >2 kg. The resulting low wing loading, of the order of 5 kg m^{-2}, provides a stable, low-speed flight envelope. Airspeed ranges from <20 to >50 km h^{-1}.

A conventional two-cycle model engine of 10-cc displacement uses a mixture of methanol, nitromethane, and castor oil. As the fuel contains 20% castor oil, which is not burned, the oil residue leaves with the exhaust gases resulting in a well lubricated aircraft (the oil spray necessitated the addition of the deflector previously mentioned). This engine/wing loading results in a typical takeoff run, in zero wind, of <15 m.

Radio control is by means of hobby-type equipment. A hand-held transmitter, operating in the VHF range, provides reliable control of the aircraft well beyond the ability of the pilot to see it, typically 0.5–0.7 km. In fact, the principal limitation on the operating range is the pilot's eyesight. As the aircraft-to-pilot visual path constitutes the feedback link of a servo system, the pilot must be able not only to see the aircraft as a vague form but to determine its attitude. Obviously, there is an advantage in using larger aircraft.

Four channels of the seven available in the Kraft KPT-7C system are used for aircraft control (rudder, elevators, aelerons, and throttle). The remainder are available for other functions such as shutter release as used on the aircraft described.

Both transmitter and receiver are powered by rechargeable nickel-cadmium batteries. Three to four hours of operation are possible between charges; charged battery packs can be installed in the field to extend the operational time. Larger batteries can be used, but the weight penalty is severe and the aircraft must land periodically to refuel anyway.

A Canon T-50 camera met the following requirements: automatic exposure; shutter speed priority; automatic film advance; interchangeable lenses and filters; and moderate cost. The speed priority shutter uses the maximum shutter speed possible with given lens/light conditions. This is useful in minimizing streaking due to aircraft motion while taking pictures.

Various lenses were considered. The 28-mm lens with a 73° field of view is a compromise between field of view and light-gathering ability. At 200-m altitude a total field of about 290 m is available. The fact that the photography was to be done over water, a flat, low-relief surface, allowed us to use wide-angle lenses without the distortion encountered on subjects with greater relief. Picture taking was controlled by radio link and exact exposure time noted on the ground.

We ran flight tests using Kodak Ektachrome, Kodachrome, and the new Polaroid 35-mm instant slide film and a set of 46-cm-square drifters with surfaces painted with the international code of signals flags as targets. The Polaroid film was used extensively to determine fields of view at various altitudes and to test for motion or vibration-induced streaking of images. The instant feature allowed rapid evaluation of adjustments and changes in flight technique; the Polaroid film was used extensively in the field to establish suitability of operational techniques. We compared Kodachrome 200 and Ektachrome in a series of flights over Woods Hole channel using the "flag" floats. At the typical altitude of 120–150 m the floats could be recognized. The Kodachrome 200 gave marginally better resolution and color rendition. In the field we opted for Kodachrome 64 to improve resolution even further because light levels were high.

These tests pointed up the need for a polarizing filter in the system. Solar glare off the sea surface in most cases precluded seeing, much less identifying, the floats. We installed a rotatable polarizing filter oriented roughly with the direction of the sun. Since the photo-taking runs are generally made as a series of orbits with pictures acquired on a more or less constant heading due to prevailing wind, the polarizing correction can be made. Tests showed glare to be significantly reduced.

An array of reference markers was designed to locate drifter and dye positions precisely throughout the inlet and ebbtide delta region. Since the two adjacent barrier spits are separated by 200 m, and the onshore-offshore extent of the ebbtide delta is nearly 400 m, the field of view in the camera did not consistently include land. The array of reference markers covered points on land as well as in the water along the ebbtide delta. These markers consisted of 6-m lengths of 2.5-cm-diameter galvanized pipe, with a threaded coupler on the top to which a 40- × 40-cm international orange marker was attached. The pipe was jetted into the sand, exposed enough to remain above water level at high tide. Most of these lasted through the 1-week experiment despite large waves and spring tides. In areas with high density boat traffic, we installed surface floats anchored to the bottom daily to fill out our array. All reference locations were precisely located in the horizontal plane with a microwave positioning system (Del Norte 540 DDMU with three remote transponders), yielding a positional accuracy better than 5 m. Finally, each Lagrangian experiment was accompanied by a chase boat (to deploy and recover drifters), which had the Del Norte system on-board, with automatic data logging. This chase boat provides a reference for all drifter experiments, in addition to the array of fixed markers.

About 24 surface drifters were built for the drifter experiments. Drifter design assured zero windage, with a current cross extending about 30 cm below the surface to couple with the water column. The surface plate was flush with the water surface, buoyancy being provided by polystyrene sheets mounted on the current cross. The current cross and surface plate were made of thin plywood. In order that each drifter have a unique design, easily identifiable from the air, the international signal flags formed the top surfaces of the drifters; we chose those patterns most readily identifiable for use during drifter experiments.

In addition to discrete drifters, we also

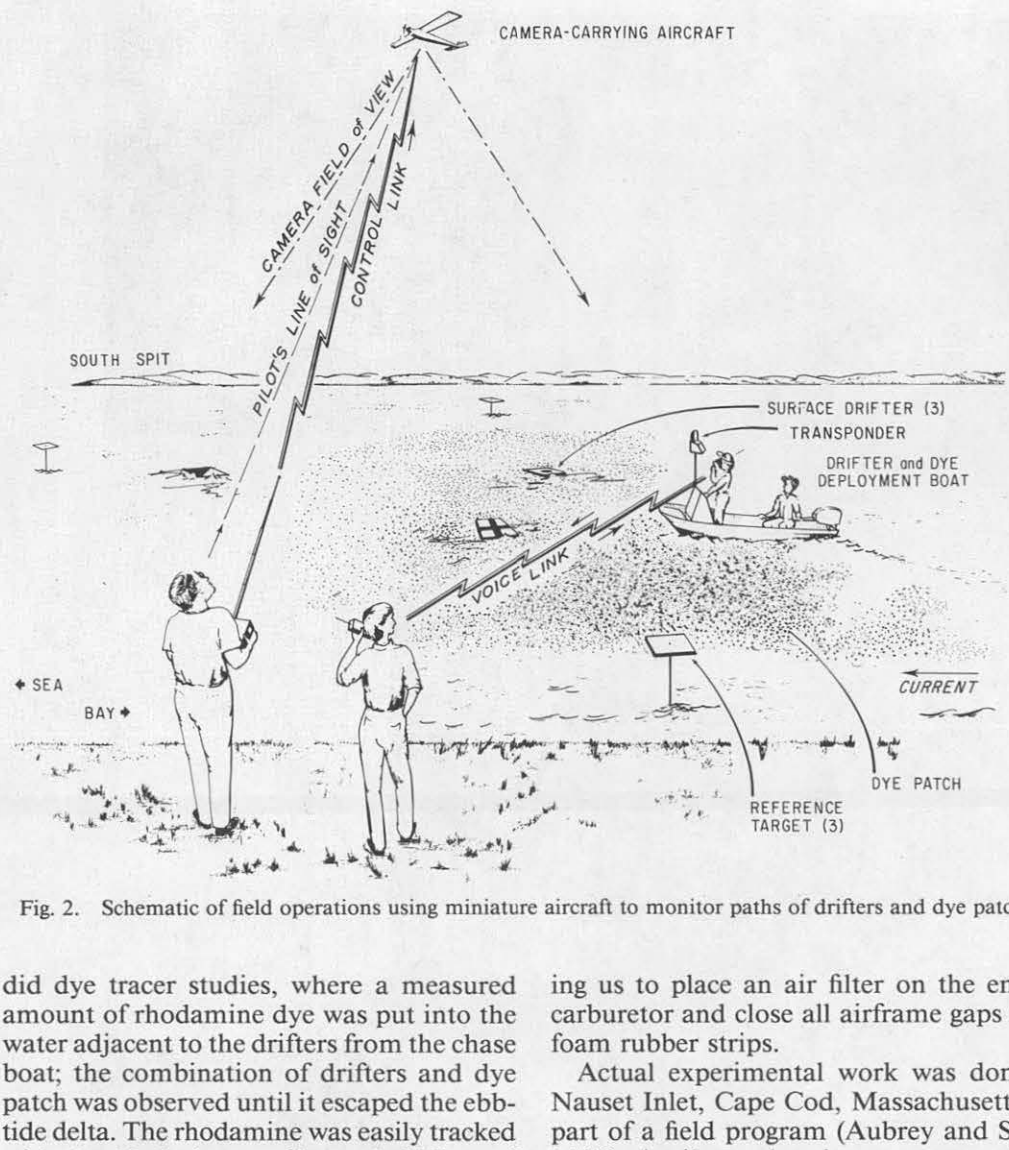

Fig. 2. Schematic of field operations using miniature aircraft to monitor paths of drifters and dye patches.

did dye tracer studies, where a measured amount of rhodamine dye was put into the water adjacent to the drifters from the chase boat; the combination of drifters and dye patch was observed until it escaped the ebb-tide delta. The rhodamine was easily tracked with the Kodachrome film, a half liter of rhodamine providing sufficient concentration for aerial mapping. These experiments were done only on ebbing tides, to avoid build-up of rhodamine in the estuary.

Initial tests using the miniature aircraft were run in Woods Hole off a small pocket beach 3–4 m wide. Altitudes of 120–150 m were selected to optimize areal coverage and resolution of different marker patterns. Landing and takeoff on the narrow, short stretch of beach presented few problems, since the controller is an experienced miniature aircraft pilot. The tests pointed out the potential damage of blowing sand, causing us to place an air filter on the engine carburetor and close all airframe gaps with foam rubber strips.

Actual experimental work was done at Nauset Inlet, Cape Cod, Massachusetts, as part of a field program (Aubrey and Speer 1983). A pilot and assistant on one of the barrier spits adjacent to the inlet were generally positioned so that the pilot would be between the flight path and the sun (Fig. 2). Two assistants were in a Boston Whaler equipped with a navigation system, a supply of dye, and enough drifters for the day's work. The beach crew and boat crew communicated through hand-held radios. On signal, the boat crew released three or four drifters and a container of rhodamine dye while the plane was in position. Because of the difficulty of positioning the airplane immediately over the tracer, both the beach assistant and the boat crew continuously

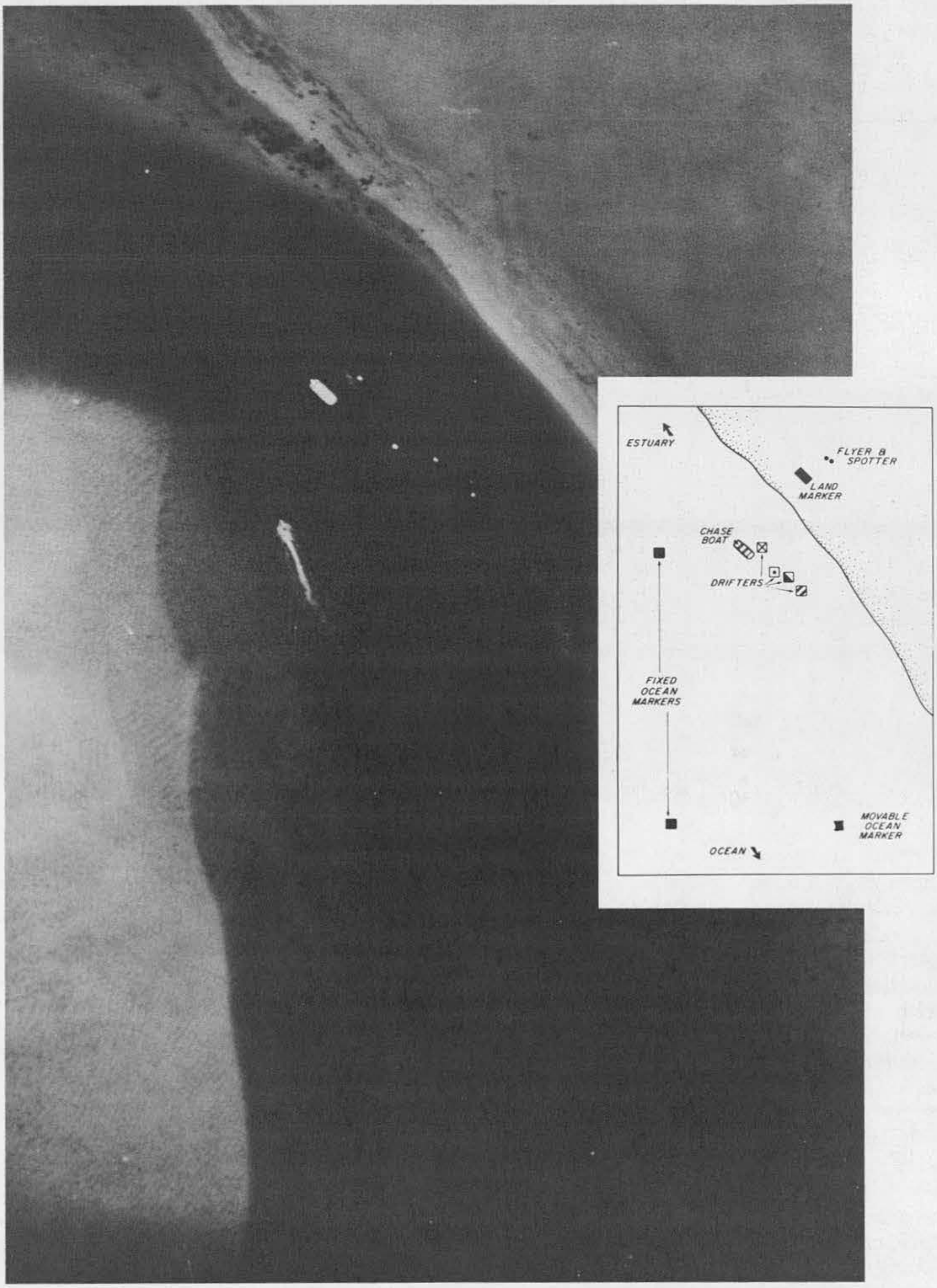

Fig. 3. An example typical of the aerial photographs taken at the Nauset Inlet site. Camera attitude is about 200 m. Objects in view are identified in the inset. This is a black-and-white reproduction of an original color photograph; resolution is lost in the reproduction, as is the color differentiation that distinguishes individual drifter designs.

provided positioning information to the pilot. Once the aircraft overflew the tracer, another approach and photo run would be made. Each run lasted about 20 min, which allowed the tracers to reach the limits of the ebbtide delta. The plane then landed and was refueled. Film was changed every other drifter run.

Over a typical 7-h ebbtide at Nauset Inlet, we made 8–12 drifter and dye runs, representing 32–48 individual drifter tracks, and 8–12 independent estimates of dispersion in the ebbtidal jet. This coverage is much better than that obtainable by more conventional tracking techniques, such as transits or theodolites, where only a single drifter can be followed during any run. Synoptic Eulerian current measurements are available along at least one spot on the drifter and dye tracks, so the Lagrangian estimates can be compared with Eulerian estimates.

The airplane could be flown in winds up to 8–10 m s^{-1} with good results, at these higher wind speeds in effect being able to hover over the tracer paths. One difficulty encountered during high winds was sandblasting of the fuselage and camera hole during takeoffs and landings. Cloud (other than fog) did not impose severe restrictions on aircraft operations, since flight was at an altitude of 120–150 m (monitored during flight with a hand-held optical distance measuring instrument). There was no rain so we have no experience with that.

Film was developed commercially (except for the instant Polaroid slides). An example showing typical area and coverage is reproduced in Fig. 3. The slides were first projected onto a digitizing table, the position of the reference markers and the individual drifters (or dye tracer outline) digitized, and then, with software, we reduced tracer position to *x-y* coordinates. Sequential slide series then were merged to present a time series of drifter tracks, since the interval between photographs is accurately known. The entire set of slides provides Lagrangian tracks as a function of position along the inlet/ebbtidal delta and flow stage (discharge), which is known from the Eulerian measurements made continuously near the throat of the inlet. Dispersion can be quantified similarly, as a function of position along the inlet/ebbtidal delta and discharge. These results are then used in numerical studies of ebbtidal jet development and resultant sediment transport.

The remote-controlled miniature aircraft has proven a useful alternative for documentation of Lagrangian flow patterns in a tidal inlet/estuarine system. Low cost, availability, reliability, and accuracy combine to make this technology appealing for a variety of applications in such environments. Data processing is relatively uncomplicated and easily automated. Field operations can be conducted in various weather conditions, and large quantities of data can be rapidly acquired. Over a tidal cycle, up to 50 drifter tracks and 12 independent dispersion observations can be acquired easily. Labor requirements are much less than for alternative techniques, and repairs can be easily made in the field. The lack of sophisticated equipment suggests that this technology can be widely used without sophisticated technical support.

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