UNIVERSITY-NATIONAL OCEANOGRAPHIC LABORATORY SYSTEM

An association of Institutions
for the coordination and support
of university oceanographic facilities

April, 1973

INTERIM REPORT

UNOLS WORKING GROUP ON OCEANOGRAPHIC AIRCRAFT

1. Background

At the November 1973 Meeting of UNOLS Oceanographic Aircraft along with selected other specialized facilities were identified for attention by a Working Group.

Pending a study and report by the Working Group, the UNOLS Advisory Council recommended that the Scripps Institution aircraft (DC-3) be designated and supported for about one-half of its available flight hours as an interim national oceanographic facility. The UNOLS Advisory Council in its 1972 Annual Report estimated that, pending a comprehensive report by the working group, there should be planned as tenative university aircraft operations support \$200,000 in 1974 and \$500,000 in 1975.

2. Objectives of the Working Group

- To review the state of the art of airborne oceanography
- To assess the present capability of and uses by the academic institutions and government agencies for airborne oceanography
- To identify and evaluate the need for aircraft facilities support by the academic oceanographic community, and
- To recommend to UNOLS a program to meet the needs identified above keeping in mind the presently available aircraft and their capabilities

3. First Meeting of the Working Group

The Working Group met at the National Center for Atmospheric Research (NCAR), Boulder, Colorado, 6-7 September, 1972.

Those Present:

Dr. R.A. Ragotzkie, Chairman
University of Wisconsin

Mr. R.C. Bundgaard
USAF Air Weather Service

Mr. Andrew Bunker
Woods Hole Oceanographic Inst.

M. Jeffrey Frautschy
Scripps Inst. of Oceanography

Dr. Albert Greene, Jr.
Office of Oceanographic Facilities,
National Science Foundation

Mr. John Hinkelman
Nat'l. Center for Atmos. Research

Mr. W. V. Kielhorn, Jr.
Office of Naval Research

Dr. Vincent Noble
Naval Oceanographic Office

Dr. James J. O'Brien
Florida State University

LCDR J. Paulos, USN
Antarctic Development
Squadron (VXE-6)

Dr. W.S. Richardson
Nova University

CAPT. E.W. Van Reeth, USN
Office of Polar Programs, NS

Mr. R.P. Dinsmore
Executive Secretary, UNOLS

4. State of the Art in Airborne Oceanography

Examining the history and development of this field the Working Group concluded that capabilities for airborne oceanography are markedly increasing. This follows a level period or even decline when aircraft use appeared limited to remote surface observations. Recent techniques for measuring subsurface as well as surface currents, and the introduction of wire connected probes constitute a significant breakthrough. To this are added improvements in remote sensing apparatus and processing of the huge volume of data which can be accumulated.

Oceanographic aircraft should be viewed as separate and non-competitive with ships. Aircraft use centers around its speed and areal coverage.

5. Current Aircraft Use and Requirements

The Working Group examined and is continuing to compile information on ongoing use and needs by academic institutions for aircraft in oceanographic research. It appears thusfar that most, if not all, major research activities presently use aircraft to some extent and can demonstrate the further need for a capably instrumented aircraft. Of particular note is that most major inter-institutional programs call for aircraft observations as an integral part of the program. These include CUEA, MODE, AIDJEX, NORPAC, GATE, AMTEX, JASIN.

Examples of aircraft use at academic institutions are:

Scripps Institution - Plankton blooms, coastline processes, marine meteorology, IR surface temperature analyses, aftershock monitoring instrument location.

Louisiana State U. - Coastal currents, estuarine processes, oil slick studies

Univ. Georgia - Remote sensing of saltmarsh productivity, beach and dune dynamics.

Nova University - Current measurements, temperature-depth, productivity (chlorophyll).

Oregon State U. - Fisheries studies, surface sensing.

Florida State U. - Wave dynamics, marine meteorology.

Univ. Wisconsin - Surface velocity structure, color, temperature by remote sensing.

Univ. California (Davis) - Distribution of plankton by remote sensing.

Woods Hole Inst. - Air-sea interaction, sea color, magnetic anomolies, marine meteorology, instrument location.

Univ. Michigan - Multi-spectral biostudies.

Federal agency use in aircraft centers around the major flight facilities which include NCAR (Boulder); Naval Research Lab. (Washington); NSF-Navy Antarctic Support Force (Quonset Point); NOAA-Flight Research Facility (Miami); NASA Flight Facility (Houston). Aircraft from all of these activities have participated in oceanographic projects and have made aircraft time available to academic institutions both on a programmed and opportunity basis. Federal aircraft are chiefly multi-engine high performance aircraft. These include the Electra, P3 (Orion), C-130 (Hercules), C-121 (Constellation) types. The working group concluded that these aircraft mostly outfitted for meteorological and remote sensing studies have commonality with the needs fo oceanographic research and the requirements by academic institutions can be met by these aircraft on a shared or other cooperative basis. Furthermore the Working Group concluded that the maintenance and operation of multi-engine high performance aircraft is not feasible for academic institutions.

Other types of aircraft to meet the requirements of research laboratories are the medium twin (DC-3, Buffalo, Twin Otter, Convair 580,); Light Twin (Piper, Beechcraft, Cessna, Britten-Norman); and the small single engine types. The twin engine aircraft appears to be the type which most occurs to serve the needs for major research projects. This is based on performance and instrument carrying capability. Presently no single institution can justify the full and dedicated operation of such an aircraft which is estimated at a minimum of 400 flight hours annually (and costing from $250-350/hour).

Community use does appear to justify the need for at least one and possible two twin engine aircraft at this time. Projected needs certainly indicate two. Such aircraft should then be in the category of National Oceanographic Facilities whose use can be shared. The operation and maintenance of such aircraft are within the capability of existing institutions.

The Working Group concluded that small singel engine aircraft are essential tools for individual project research but that these should be project funded by individual institutions as required.

6. Recommendations

Tentative recommendations by the Working Group at this time are

(a) The commonality between requirements of multi-engine meteorological and oceanographic aircraft indicates joint use of these aircraft in meeting the requirements of major programs such as CUEA, GARP, NORPAC, etc. These aircraft should be operated by existing Federal Flight Facilities.

(b) The National Center for Atmospheric Research (NCAR) should include oceanographic research in its mission and provide flight services of high performance well instrumented aircraft on the same basis as it now provides to meteorological research. This may require the addition of one additional aircraft which oceanographic research requirements should justify.

(c) The NOAA - Flight Research Facility should include academic oceanographic research within its mission and its aircraft should be available to the academic community on a programmed and budgeted basis.

(d) The Scripps aircraft (DC-3) should become a full National Oceanographic Facility for at least half its flight availability. Its equipment should be upgraded to a bsic suite of modern instruments.

(e) In 1974-1975 the academic research community should acquire a second twin engine aircraft which should be operated by a member institution as a National Oceanographic Facility. This facility should include a complete instrument capability and technicians.

(f) Light aircraft should be utilized by laboratories on a project basis and justified and funded on an individual institutional basis.

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THE CAPABILITIES OF AIRCRAFT IN OCEANIC EXPLORATION AND SURVEYING

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I. Introduction

The use of aircraft in certain facets of marine exploration and surveying is, of course, well established. One thinks especially of cartography and the study of marine meteorology (i.e. hurricane reconnaissance) as fields where aircraft have had their greatest applicability. However, it may not be generally realized that recent technological advances have given aircraft many new capabilities for measurements in the open ocean; it is the purpose of this paper to direct attention to these capabilities and discuss their impact on marine exploration and surveying.

In this discussion we will focus on the capabilities of fixed-wing aircraft, but it should be borne strongly in mind that, within its range capability, the helicopter has many unique features. Its ability to hover, lower cables into the water, take water samples and fly at widely varying speeds makes it a logical choice of vehicle for many of the applications discussed below. In general it can be stated that, except in applications where speed and range are important, the helicopter is more versatile than the fixed-wing aircraft. We will not consider the use of lighter-than-air craft here, since there are so few opportunities to use such machines these days. But again, major changes in the technology of such vehicles might drastically change the picture presented here. There are many esoteric vehicles which have been talked about in recent years such as combination air/sea surface/submersible machines. Again, a breakthrough in this technology might change the picture dramatically, certainly to enhance applicability to oceanic exploration. If we content ourselves to consider the fixed-wing aircraft, we are discussing minimum capabilities.

II. Operational Consideration

The attractiveness of the aircraft as a platform for oceanographic measurements is two fold: First, its high speed gives a potential for synopticity of data which is not possible with other vehicles; Secondly, its cost, on a per mile basis, is typically an order of magnitude less than that for ships ($1-2 per mile vs $10-20 per mile). Interestingly, the cost per mile is, also, nearly independent of the size of the aircraft, larger more expensive aircraft being typically much faster than small inexpensive ones.

There are, of course, many operational limitations to aircraft which must be considered, the principal one being weather. Many of the capabilities discussed below are weather limited; in particular, all of those which require a clear view of the sea surface. The ocean is typically cloud covered, with cloud base at about 1500 feet. This drastically limits the applicability of high flying jet aircraft and, unfortunately, large aircraft capable of economical flight at low altitudes (i.e. 1000 feet) are not currently being manufactured. However, the DC-3 and DC-4 and the smaller Beech 19 are still readily available and make excellent oceanographic research aircraft, as do several of the older amphibians. The modern light twin is very economical to operate and has excellent applicability to the methods described below at ranges up to 1500 miles. As with ships, but somewhat more so, there are diplomatic/political problems with respect to the operations of aircraft in some ocean areas.

As an operational example, let us consider a modern, light, twin-engine aircraft (recognizing that we are generalizing somewhat). The cost of a well-equipped machine is (within a factor of two) $100,000; its operating cost, provided it is used more than 500 hours per year, is about $1 per mile. With a scientific payload of three people and 500 pounds of equipment, it has a typical range of 1000 miles which can be extended to 1500 miles at the expense of payload. Its typical airspeed is 150 knots and it can be flown safely and continuously at altitudes from 500 to 12,000 feet. Slow flight, at about 80 knots, is possible for short periods of time and occasional low passes to about 50 feet are perfectly safe (although sustained flight below 500 feet should not generally be attempted). Night operations over water are perfectly feasible but tiring and should probably be limited to two to three hours.

Navigation is a serious problem involving a considerable amount of dead reckoning between fixes. Equipment is available for Loran A and C and the new Omega System should have great utility because of its extensive coverage. Communications are excellent at short range, but rudimentary at long range (a constraint which would not necessarily apply to a somewhat larger aircraft such as a DC-3).

III. Measuring Capabilities

It is difficult to categorize all of the aircraft capabilities since there are many possible interactive modes of operations such as joint ship/aircraft, buoy/aircraft, subsurface float/aircraft. Such systems will ultimately have wide applicability.

In this paper, we will categorize by the measurandrecognizing that one technique (i.e. photography) may be the method for several of them. Again, since there are no clear dividing lines between physical, chemical, biological or geological surveys, we will be arbitrary with respect to the assignment of measurand to field of endeavor (i.e. salinity will be considered a physical quantity while other chemical species may appear as chemical or biological). We will not specifically consider measurements of the marine atmosphere assuming these capabilities to be well known. Also, we will not consider problems of searching although we recognize that a considerable percentage of the time aircraft are flown over water is for this purpose (i.e. search and rescue, ice reconnaissance, etc.).

A. Physical Measurements

1. Surface temperature. This variable, which is of meteorological as well as of oceanographic interest is readily measured by infrared radiometry in the 8-13 micron band using optical systems of a few inches diameter and bolometers or thermopiles as detectors. Comparison is normally to a black body source in the aircraft. The measurements apply to a "skin depth" of a few microns thickness at the sea surface, but numerous comparisons with ship measurements show that this is not normally different from a ship's "bucket temperature" by more than a few tenths of a degree. Differential sensitivity along short flight paths of a .001°C or less have been achieved and accuracy is typically a few tenths of a degree when operating at 1000 feet in reasonably clear weather. Operation through clouds is not possible. Measurements in the nearer infrared, with faster more sensitive detectors, has been used and microwave radiometry has been employed in an effort to work through clouds and haze. It seems likely that 8-13 micron window will be the most used, despite its weather limitations. Numerous papers in the literature discuss the errors in the technique.

2. Subsurface temperature. Two methods exist for measuring temperature as a function of depth, both employing expendable probes. In the air-expendable bathythermograph (AXBT) the instrument free-reels a temperature sensor and the surface float radios temperature vs time (depth) back to the aircraft. The method is standard in the U.S. Navy but expensive.

Recently the helicopter XBT system has been used from fixed-wing aircraft. In this the aircraft is wire connected to the falling temperature probe just as in the case of the shipborne XBT. At an air speed of 80 knots and an altitude of 100 feet, a depth of 200 meters was achieved. The quality of the data is comparable to a standard XBT. The depth limitation is strictly in the amount of wire contained in the probe and depths to 500 meters should be readily achievable with no basic change of technique. As will be noted below, the wire connection between the aircraft and the sea has potential in many other types of measurement.

Attempts have been made to cable lower temperature and other sensors into the ocean from a circling aircraft (similar to the mail pickup system sometimes employed in remote locations). While some success has been achieved the method is cumbersome and to a large extent cancels the aircraft's speed advantage. The method will probably have research application but is not well adapted to survey.

3. Surface salinity (conductivity). Some progress has been made in measuring the surface conductivity by high frequency radio reflectivity measurement. The surface salinity can be inferred from the conductivity and temperature. The measurement will probably continue to be crude by oceanographic standards, but may have extensive application to estuarine circulation problems.

4. Subsurface salinity. There have been several suggestions for adding electrical conductivity to the shipborne XBT system and these would be equally applicable to the wire connected (HXBT) system described above. There appears to be no technical reason why this development cannot proceed to give salinity vs depth from aircraft.

5. Surface and subsurface currents. Color photographs often reveal considerable information on the circulation patterns within estuaries and along shore lines. Two methods exist for the direct measurement of currents using aircraft. The first is simply the tracking of a drifting object or dye by whatever means of navigation is available. If no adequate navigation is available an anchored reference marker can be set by the aircraft and the rate at which the float or dye moves away from it determined by two successive photographs. The method is generally limited to shallow water, but long term drifts in the open ocean have been tracked by aircraft.

The movement of drifting buoys with deep sea-anchors have been tracked by aircraft; normally parachutes are used as sea-anchors. The method is limited to depths of a thousand meters or so and the current at the depth of the sea-anchor is not simply related to the buoy movement because of the distributed drag of the cable between the anchor and the buoy.

In the second method an expendable probe is dropped from the aircraft and falls to the bottom. At the bottom, a float is released which rises to the surface and emits fluorescein dye. After a known time delay a second identical float is released and when it has arrived on the surface the relative positions of the two dye patches are photographed. The surface current direction is the direction from the second to the first float and the speed is the separation divided by the time delay. In order to take advantage of the aircraft's ability to survey long sections, two aircraft are used, the first dropping the probes and the second following sometime later to photograph the dye patches. The method is independent of the depth of water.

A modification of this air-dropped probe provides an additional part which separates from the probe at the sea surface when it is dropped. The separation of this part from the first float which returns from the bottom is related in a known way to the difference between the surface current and the average current over the entire water column (transport). Since the surface current is determined by the two floats that go to the bottom, the average current over the depth can be determined. Modifications to the probe adding floats which are released at preselected mid-depths permits measurement of the current vs depth. Again, the type of measurement is normally carried out by two aircraft, one dropping and one photographing.

It is interesting that this capability of aircraft to make rapid, direct measurements of surface and subsurface currents is not matched by either ships or submersibles.

6. Sea state. Stereophotography and glitter photographs from aircraft have been used to study ocean waves. Considerable information on sea state can be gleaned from ordinary photographs, particularly with regard to refraction patterns along coastlines. The laser altimeter (resolution of a few inches) has been used on long ocean sections and permits the determination of the energy density spectrum and (by flying different headings) the directional spectrum of swell and the larger wind-driven waves. Again, this is a capability not matched by ships.

B. Chemical Measurements

1. Chemical species. The use of wire connected probes from aircraft has been discussed along with the potentiality for salinity vs depth measurements. There are a number of other chemical species (oxygen and various ions) for which specific electrodes exist and, while little has been done to exploit the use of these from aircraft, there appears to be no reason why it would not be feasible to do so.

Several techniques have been tried for snatching surface water samples from aircraft. This appears to be entirely feasible and, of course, allows all of the usual chemical analyses for surface water.

The increasing interest in chemical pollutants at sea has generated interest in both direct sampling and remote sensing. This is particularly so in the case of oil slicks, where color and false-color infrared photography and microwave radiometry all show some promise. It seems likely that this will be a rapidly expanding field of endeavor.

C. Biological Measurements

1. Fish spotting. This is one of the oldest applications of aircraft in work at sea and is carried on extensively (with marginal equipment) at the present time. Many programs under which aircraft are flown on long overwater sections at low altitudes include the plotting of the location of large fish. It seems likely that more refined techniques involving photographic interpretation will be used in fisheries exploration in the near future. The bioluminescence excited by large schools of fish is presently being studied as a nighttime survey technique.

2. Chlorophyll standing crop. The color of the sea, as observed from the air, is generated by a combination of physical, chemical and biological causes. Principal among these is the commonly observed change from deep blue to grayish green which occurs as the standing crop of phytoplankton increases. Since the phytoplankton are the primary food producers, their presence is a strong indication of animal productivity as well.

The standing crop of chlorophyll-a (the dominant pigment in marine algae) can be measured from aircraft either by spectrophotometers or by the densitometric analysis of color or multifilter black-and-white photographs. The sensitivity of all of these methods is entirely adequate for assessing the primary productivity of a region of the sea. These techniques combined with color photography, have applications in assessing the standing crop of floating seaweeds and, in shallow water, bottom growing grasses.

D. Geological Measurements

1. Cartography. The application of aerial photography in charting the coastline is, of course, a standard technique. With increasing use of the shoreline, specialized problems are arising, however. One of the more difficult of these is the location of the land-sea boundary in swampy areas (i.e. the coastline of the Everglades in Florida), where techniques other than black and white photography will be required.

2. Underwater topography. Considerable progress has been made recently in determining the topography of the bottom in depths up to 100 feet or so. Stereophotography, differential color photography and laser distance measuring are all applicable techniques. Isolated depth measurements in deeper water can be made by expendable probes (by timed rate of fall and rise, by wire connected bottom contactors or by echo sounding with respect to an air-launched sonabuoy). The possibility of echo-sounding with an airborne source has, despite the serious impedance mismatch at the surface, been under consideration for a number of years and is probably not impractical.

IV. Summary

The applicability of aircraft to oceanic exploration and surveying is based on four methods of information retrieval:

1. Remote sensing in various parts of the electromagnetic (and possibly acoustic) spectrum.
2. Expendable probes.
3. Wire links between the aircraft and the ocean.
4. Snatching water samples.

There has been considerable recent progress in all of these techniques and together they give aircraft an extensive capability in oceanic measurements, both surface and subsurface. In many cases these capabilities exceed those of ships, buoys, submersibles or satellites. Because the aircraft is the most economical vehicle, on a per mile basis, which has reasonably intimate contact with the sea, its potential in oceanic exploration and surveying is very great and we can forsee an extensive and expanding use in the future.