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TRANSOCEANIC AIRPLANE SAMPLING FOR ORGANISMS AND PARTICLES[1]

By E. P. Holzapfel[2]

Abstract: A brief review of literature on dispersal of organisms and particles, combined with a presentation of the modes of transport across oceans, air currents and weather, and the use of aircraft to sample the atmosphere, provides an introduction to Bishop Museum's transoceanic data gathering with an air plankton retriever for insects and other organic and inorganic materials. Reconstruction of this device for sampling from a Constellation aircraft was necessary in 1966 to increase the collecting efficiency for insects and to accommodate the various attachments needed to screen the atmosphere for other organisms and particles. Results of collecting from 1966 through 1969 are presented.

Certain classical events have been documented and serve to point out the historical background for vertical and horizontal transport of organisms and particles of a diverse nature. One of the earliest authentic records of long-distance insect movement was provided by Parry (1828) who found aphids on the ice 290 km (180 miles) west of Spitzbergen in latitude 82°27′N on 16 July 1827 (Taylor 1965b, Johnson 1969).

The volcanic eruption on Krakatoa in the East Indies in August 1883 devastated several of Dust and smoke discharged from this eruption rose to an estimated height of 28 km (17 miles) and within 6 months was diffused over the earth from 30°N to 45°S latitude. In addition to data on the vertical and horizontal movement of dust particles at the time of eruption, this event provided invaluable information on the reestablishment of animals and plants on the island, where no living thing could have survived. Even Sebesy Island, some 11 km (7 miles) away, was partially and possibly completely devastated; Dr K. W. Dammerman (1922) reported data relating to the insect fauna, of which most probably came from Java and Sumatra, both approximately 32 km (20 miles) away. Felt (1928) provided a more complete record of the arrival of specimens following the eruption and Elton (1958) indicated that by 1933 there were at least 720 species of insects, 30 kinds of birds and a few species of reptiles and mammals.

Nearly a century after Parry found aphids to the west of Spitzbergen, Elton (1925), on an expedition in August 1924 to Spitzbergen, observed numbers of large black aphids and several hover flies over a broad area. Further investigation proved that the closest possible point from which they could have originated was the Kola Peninsula in Norway—a distance of about 1300 km (808 miles).

On 17 March 1963, debris was blown into the atmosphere by the eruption of Mt Agung on the island of Bali. Large amounts of fine dust were deposited in the atmosphere and spread over both hemispheres (Hogg 1963, Meinel & Meinel 1963). Particles were collected at an

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2. Bishop Museum, Honolulu, Hawaii 96818, U.S.A.

altitude of 20 km (12.4 miles) by a device mounted on a U-2 aircraft of the U. S. Air Force (Mossop 1964). The Agung eruption clearly demonstrated that volcanic dust can be carried very great distances and probably can contaminate even polar ice deposits (Hodge & Wright 1964). A more recent record of mass movement of particles in the atmosphere was provided in July 1968 when dust from the Sahara Desert was brought down in rain over much of southern Britain (Hurst 1969).

The above documented records lead one to reflect on the various methods by which inorganic as well as organic materials move over great distances. Several approaches have been made by authors who have listed the modes of dispersal of insects and other animals and plants (Elton 1925, Felt 1925, Coad 1931, Glick 1939, Kelly et al. 1951, Darlington 1957, Andrewartha 1961, Hurst 1969). Four possible means of transport exist, as follows: (1) wind, flight, or both; (2) marine drift; (3) birds or bats; and (4) man (Holzapfel & Harrell 1968). The prime question is whether the transport is active or passive.

Convective currents over land may lift small organisms and particles to heights of 6000 m (19,680 ft) or above. The low temperatures at this altitude do not damage spores and pollen, and with low terminal velocity of fall all of the small particles can be expected to travel considerable distances (Hurst 1965).

While wingless arthropods such as mites, spiders and larvae as well as small winged insects such as aphids are almost entirely at the mercy of the wind, stronger fliers such as locusts, dragonflies, moths and wasps are influenced to a lesser degree by air currents.

Weather. The primary meteorological factors are a mechanism to lift the material to an appropriate height [often over 3000 m (9840 ft) and sometimes to 6000 m (19,680 ft)] and adequate winds at the carrying height. Lifting is often a result of surface heating over land by day with consequent vertical thermals (Hurst 1969). That convection is the principal escalator was postulated, and then demonstrated, some time ago (Felt 1925, 1938, Coad 1931, Glick 1939, Wellington 1945a, b, c, Wolfenbarger 1946, Williams 1949, Andrewartha & Birch 1954, Greenbank 1957, Pienkowski & Medler 1964, French 1969). The role played by abnormal weather is less well understood, although storms do provide a means of distributing organisms (Schuchert 1935, Felt 1938, Zimmerman 1948, Williams 1949, Darlington 1957, Herring 1958, Gressitt 1958, Flitters 1963). These authors have shown that height change is affected by both turbulence and convective processes, and by mass air movements. Of special interest to Henson (1951, 1960) were the thunderstorms and the passing cold fronts which he found carried insects horizontally as far as 415 km (258 miles).

Speeds of upward movement of small particles such as spores can vary widely from 6 m/sec. (or even more for brief periods) well above the ground in a strong upcurrent to 0.3 m/sec. in turbulent exchange and to 0.05 m/sec. with lifting in a weak frontal system (Hurst 1968a). It has been found by Berry & Taylor (1968) that even small aphids require atmospheric lift of ca 90 cm/sec. (3 ft/sec.) to remain airborne without flight, whether their wings are open or closed. Lacking this lift, aphids must fly or fall, and because nearly all aphids are found below 3000 m (ca 10,000 ft) they will fall out of the airstream in less than 1 hr, irrespective of the speed of the horizontal element of the wind which contributes nothing to lift except in true gliding flight (Berry & Taylor 1968).

Convective processes by themselves are not enough to maintain insect-sized particles at high altitudes for transport over long distances, since these violent convective upcurrents have compensatory down currents (Wellington 1945c, Hurst 1968b). Such particles are likely to gain height during the day over land but will fall steadily by night over land, and by day and night over the ocean (Williams 1949). In addition to downdrafts, insects may be precipitated out of the air by exhaustion, termination of flight response behavior, rain, or falling to the ground when cooled (Pienkowski & Medler 1964, Hurst 1969). Distribution at any time is determined by the net effect of upward transport by turbulence and downward transport by gravity plus effect of biological impulse (Johnson & Penman 1951). The contribution of the insect constitutes an equally important variable in long-distance travel, since it must actively fly for the greater part of the time if it is not to lose height and fall out of the airstream providing the horizontal component of displacement. Dead and damaged insects soon settle out of the air (Johnson & Penman 1951, French 1969). Documented proof of this is provided by Taylor, who found that of the insects caught between 305 and 1525 m (1000 and 5000 ft) at Cardington, Bedfordshire, England, 97% were alive and undamaged; 2% were alive but damaged and 1% were dead (Taylor 1960).

A vertical cross section of the atmosphere shows that the normal environmental changes upward consist of decreases in pressure, relative humidity and temperature of the air. Laboratory experiments have shown that the decrease of atmospheric pressure may be safely eliminated as either a limiting or a lethal factor for insects distributed at higher altitudes. Changes in relative humidity normally have very little effect on insects in flight except at freezing temperature when the air is saturated. Theoretically, no active flight would extend above the height of the zero isotherm, which leaves the limiting factor of temperature as the most important of the environmental changes as the insect reaches high altitudes (Wellington 1945a, b, c).

Johnson (1969) treats more completely the subject of insects, wind and flight.

Airplane collecting. Professor F. V. Theobald of the Southeastern Agricultural College, Wye, Kent, England, observed aphids sticking to parts of airplanes following flights during World War I. According to a letter dated 2 February 1927, this observation led to the use of sticky flypaper on an airplane at elevations above 300 m (985 ft) which resulted in the recovery of a number of aphids (Felt 1928).

One of the earliest records of the study from aircraft of aerial populations was by Stackman et al. (1923) who reported spores, fungi, small insects, pollen, grains and glumes of grass up to 3300 m (10,826 ft). Spores were found as high as 4850 m (15,910 ft).

An airplane trap with a collecting area of 20×25 cm was devised and attached to the lower wings of a Curtis J. M. plane in 1926. The glass slides were smeared with tree tanglefoot and could be exposed at given altitudes for a definite time. A number of flights were made and on 3 of these, insects were recovered and reported (Felt 1928).

The agricultural importance of the long-range dispersal of insects led Perry Glick to design and build a net-type trap to screen relatively large volumes of air. Collecting started in 1926 and records of specimens recovered up to 3000 m (9840 ft) were published by Coad in 1931, with a complete report of this U. S. Department of Agriculture work published by Glick in 1939.

Collins & Baker (1934) also carried out airplane trapping in the U.S., and Berland (1934, 1935) was one of the first outside the U.S. to use the airplane as a means of determining insect densities at different altitudes.

Charles Lindbergh carried out investigations of microplankton over the ocean. His flight in 1933 between the U.S. and Europe was carried out over the sea at an altitude of 750-1650 m (2460-5410 ft) and over Greenland at 2400-3700 m (7870-12,135 ft). It was found that the glass slides he exposed were studded with spores of fungi, pollen grains, unicellular algae, fragments of filamentous algae, spicules of sponges, diatoms, insect wings, volcanic ash, etc. (Meier 1935).

After World War II, Professor Hardy extended his sampling for transoceanic air-borne insects from kites on ships (Hardy & Milne 1937, 1938a, b) to trailing nets behind helicopters flying over the English Channel at heights of 150-300 m (490-985 ft), but the results were disappointing and flights were discontinued (Williams 1949).

Rather extensive sampling for bacteria and fungi was started in the late 1940's by a joint U.S.-Canadian team that resulted in a number of publications describing techniques as well as results of airplane recovery (Pady et al. 1950, Kelly et al. 1951, Pady & Kelly 1953a, b, 1954, Pady & Kapica 1955).

U. S. Dept. of Agriculture sampling continued in the mid-1950's and produced further information concerning the movement of specific insects (Glick 1957, 1960, 1965, 1967).

Odintsov (1960) stated that in the spring of 1958 a successful practical test was carried out on an entomological air trap mounted on an AN-2 airplane. He further pointed out that in the USSR no previous agricultural work had been done on collecting insects by traps installed on airplanes, but he quotes Reikhardt (1941) as a reference on this point, which is somewhat misleading.

Within the past 15 years collecting from aircraft has also been done by several institutions whose main interest has been insects of agricultural importance (Hagen 1962, Berry & Taylor 1968).

Efforts to sample air for inorganic particles have also increased in the past 15 years (Junge et al. 1961, Junge & Manson 1961, Mossop 1963, 1965). While much collecting of this type has been for particles from the earth (Mossop 1964), some has also been done for extraterrestrial particles (Dubin 1958, Hodge 1961, Hodge & Wright 1962, 1964).

I have not attempted to review the literature for all types of sampling from aircraft. However, especially with the advent of the space age, collecting has been done from the standpoint of potential medical significance of microorganisms in the upper atmosphere (Timmons et al. 1966, Fulton & Mitchell 1966). At present, a number of other groups are working on high-altitude sampling to gain information on air pollution, meteorology,

TABLE 1. Air-borne collecting time summary from 1966 through 1969.

Monthly totals		Hours	Minutes	No. of flights	No. of insects	No. of flights with insects
1966	October	?	?	1	0	0
	November	33	40	5	0	0
	December	91	15	11	4	3
Totals		124+	55+	17	4	3
1967	January	12	33	1	1	1
	February	15	20	5	0	0
	March	34	45	4	0	0
	April	58	45	10	2	1
	May	47	00	8	4	4
	June	09	15	1	0	0
	July	73	03	8	13	3
	August	21	03	5	4	3
	September	119	45	13	4	3
	October	09	55	2	1	1
	November	56	03	7	8	3
	December	95	40	11	2	1
Totals		553	107	75	39	20
1968	January	17	20	2	0	0
	February	41	15	6	9	4
	March	49	15	6	2	1
	April	60	05	11	2	1
	May	71	50	9	6	2
	June	28	30	4	7	2
	July	24	58	4	0	0
	August	75	00	9	30	2
	September	14	13	4	1	1
	October	00	00	0	0	0
	November	00	00	0	0	0
	December	00	00	0	0	0
Totals		382	26	55	57	13
1969	January	08	15	1	0	0
	February	30	25	4	1	1
	March	01	55	2	0	0
	April	?	?	2	0	0
Totals		40+	35+	9	1	1
Program totals		1099+	00+	156	101	37

astronomy and the relative numbers of particles in the atmosphere and in space. Sampling from high-flying aircraft [to 27,450 m (90,000 ft)], balloons [to 45,750 m (150,000 ft)] and space vehicles has provided a mass of data in recent years, but thus far very few biological particles have turned up in this atmospheric and space collecting.

MATERIALS AND METHODS

Bishop Museum's program. Aerial collecting relative to zoogeographic and evolutionary studies by the Bishop Museum was begun in 1957. Ships were initially used for transoceanic dispersal data gathering (Gressitt & Nakata 1958, Yoshimoto & Gressitt 1959, 1960, Holzapfel & Perkins 1969, Guilmette et al. 1970). In 1960, a high-speed airplane trap was devised and built for air-borne organisms (Gressitt et al. 1961). This air plankton retriever was operated as part of the Museum's Antarctic insect-collecting program from 1960 through 1963 and the results of sampling at altitudes of up to 6100 m (20,000 ft) have already been summarized and reported (Holzapfel & Gressitt 1965). In addition to the trap for insects, microscope slides with glycerine jelly were exposed for the recovery of pollen (Smith 1964). Other samples containing inorganic material were collected and sent to the Smithsonian Astrophysical Observatory for analysis (Wright et al. 1963).

The need to improve the airflow through the all-metal duct was indicated by wind tunnel testing in the fall of 1963 (Holzapfel & Gressitt 1965). Modifications were also needed to realize the potential of the device in the retrieval and analysis of a myriad of organic as well as inorganic particles from the atmosphere of the altitude range [up to 4000 m (13,120 ft)] to be sampled. Collaboration was established with individuals at various institutions who were already involved with atmospheric research (see TABLE 2). A 3-1/2 year interruption in the airplane collecting program was caused by the above-mentioned problems, combined with some difficulties in obtaining adequate financial and logistic support.

Rehabilitation and installation of retriever. Following wind tunnel testing at Lockheed Aircraft Corporation's Burbank, California, facility in 1963, the air plankton retriever remained inoperative until rehabilitation was possible in the summer of 1966. Arrangements started in late 1965 resulted in the selection of the EC 121-K (Buno #137890) U. S. Navy Range Instrumentation aircraft (FIG. 1) based at the Pacific Missile Range, Point Mugu, California, as the vehicle to be used for Bishop Museum's continued aerial sampling. Since the forward windows of the EC 121-K (FIG. 1) to be used were about 46 cm (18 in.) closer together than those of the C 121-J used previously (Gressitt et al. 1961), shortening of the length of the 45-cm diam. section of the metal duct by about 46 cm was required. This reduced the total length of the sampler from 595 cm to 549 cm.

The gradual increase in diameter of the metal duct from its 10-cm opening (FIG. 1) to 45 cm inside the cabin, where all samples were taken (FIG. 2), was designed to reduce the air flow speed from about 200 knots to about 25 knots. Unfortunately, the micromesh screen funnel and collecting cups originally installed proved during wind tunnel testing to be too fine, thereby preventing an adequate quantity of air from being screened. Monel wire of

TABLE 2. Samplers, collaborators and periods of participation.

	ROTOROD			FILTER						IMPACTOR	KRAMER-COLLINS
YEAR OF PARTICI-PATION	USDA (Burleigh)	U. of Texas (Brown)	U. of Florida (McCaldin)	NCAR (Lodge)	U. of Hawaii (Duce)	U. of Washington (Hodge)	Adelphi U. (Dirkin)	North Texas State U. (Schlichting)	U. of Florida (McCaldin)	NCAR (Lodge)	Kansas State U. (Kramer)
1966	×										
1967	×	×		×						×	
1968		×		×	×	×	×	×		×	×
1969			×	×	×	×			×	×	×

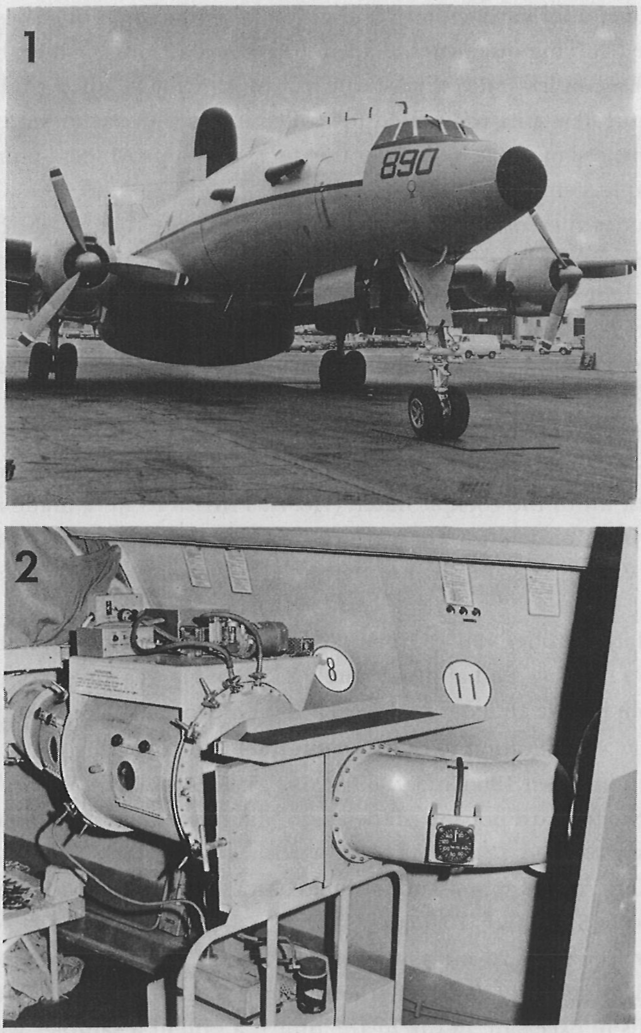

FIG. 1-2. 1. Air plankton retriever, portion mounted on fuselage of the EC 121-K (Buno #137890) U. S. Navy range instrumentation aircraft at the Pacific Missile Range, Point Mugu, California. 2. Air plankton retriever, portion mounted inside cabin of aircraft. Collecting doors each have a circular window for observation of samplers. Vacuum pumps and electrical control units are mounted atop the 45-cm diam. portion of the collecting duct and the entire Kramer-Collins sampling unit is seen beneath the rear cut-off valve and forward of its support. (Official U. S. Navy photographs).

stainless steel replaced the old screen funnel and during the change, new and larger collecting cups were fabricated. The new noncorrosive material screened all insects but did not seriously inhibit the passage of air through the duct.

Fore and aft valves in the cabin portion of the duct prevented passage of air while the trap was not being operated and during change of collecting cups. The rubber gaskets on these metal valves failed to function properly at high-altitude pressures and low temperatures, so, during modifications in 1966, they were replaced with teflon gaskets.

An air-flow indicator was added near the rear port opening, with the pressure-static pickup near the exterior exhaust, so that the volume of air passing through the duct could be continuously monitored.

Additional modifications included a forward collecting door (FIG. 2) and a series of gas jet-type cut-off valves which permitted varying quantities of air to be removed from the duct by vacuum pumps, filtered and/or sampled and then returned to the main duct to be exhausted from the aircraft. In this new area to be used for collecting, a bar was mounted vertically in the forward end of the 45-cm diam. section of the duct, which provided a point of attachment for the various samplers employed.

During sampling at high altitudes the entire 45-cm diam. portion of the duct could be sealed off by the large fore and aft cut-off valves and the pressure equalized with that of the cabin by a release valve. The air-tight collecting doors on the side of the cylinder could then be opened and the various samples removed and samplers serviced as needed.

When Lockheed Aircraft had completed modifications in August 1966, the retriever was moved to the Pacific Missile Range, Point Mugu, California, to await installation. The Technical Support Department at Point Mugu mounted the retriever on the starboard side of the aircraft. As when mounted on the C 121-J, the forward opening was held in place about 15 cm from the fuselage just aft of the cockpit hatch (FIG. 1). Provisions were made at this time for all the electrical wiring outlets for the various samplers, although only the Rotorod sampler was available during the initial installation. The other samplers were added as they became available.

Test flights were conducted in late October 1966. Over 1000 flight hours were logged from October 1966 through April 1969 (TABLE 1), and approximately 2 km^3 of air was screened for insects. Aliquot samples were taken for the analyses of several other types of particles.

Supplementary sampling devices. In addition to the screen funnel and collecting cup for insects, 4 other samplers were used between 1966 and 1969 (TABLE 2). A model 60A Rotorod sampler (FIG. 3a) was mounted in the forward portion of the 45-cm diam. section of the duct. This sampler consisted of a constant-speed 12-volt DC motor with a hub which accepted several types of removable collecting rods of metal and/or lucite (FIG. 3b). Without rods, the overall dimensions of this device were 3.7 × 3.7 × 10.1 cm (1-1/2 in. × 1-1/2 in. × 4 in.).

Since ram pressure provided by the forward movement of the aircraft was the mode by which air passed through the collecting duct, and since the Rotorod sampler did not function at its optimum at wind speeds in excess of 56 km/hr (35 mph), a hub of a sampler was installed in the same general region which depended only on the natural air flow and served as a check on the revolving sampler.

Since most of the organic materials to be collected were larger than 10 μ in size, only the 1.59-mm wide U-shaped collecting rods were mounted on the sampling hubs. When rotated in the usual manner at 2400 rpm, the U-shaped rods had a linear velocity of 10 m/sec. and were approximately 65% efficient for density 1 material in the 10 to 100 μ range size of particles.

The National Center for Atmospheric Research (Dr James P. Lodge) designed and built 2 samplers which were mounted inside the front portion of the 45-cm diam. section of the duct but which connected with their vacuum pumps through the gas jet cut-off valves (FIG. 2). A filter sampler (FIG. 4) was used to collect both inorganic and organic particles in a wide

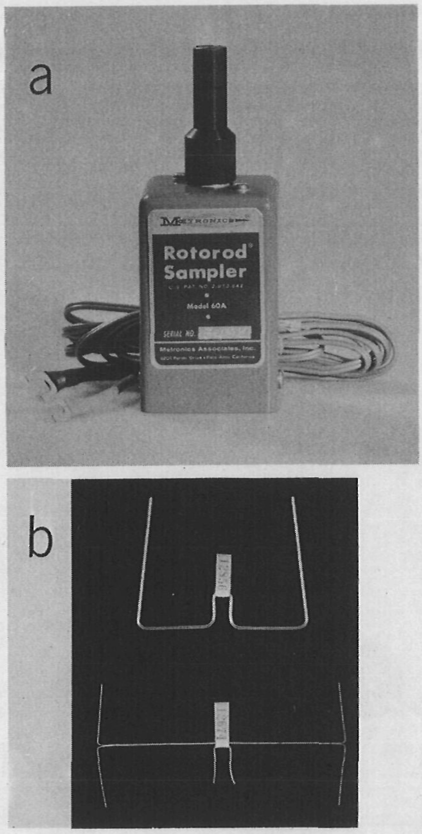

FIG. 3. a, Rotorod sampler; b, U-shaped collecting rods. (Photos supplied by Metronics Associates.)

range of types and sizes. Millipore filters 47 mm in diameter were exposed for various periods of time and were shipped to several institutions for analysis (TABLE 2).

A 2nd NCAR sampler (FIG. 5) was designed to collect particles for electron microscopy. This impacting device used copper grids mounted on a larger plastic plate as the mode of recovering the desired particles from the sampled air.

A Kramer-Collins Sampler (FIG. 6) was provided by the Microbiology Department of Kansas State University and became operational in the spring of 1968.

TABLE 2 provides a list of the collaborators who used the various devices, together with the period during which each analyzed material. Summaries of results are given later in this report.

Aerial collecting. TABLE 1 provides a monthly summary of flight information as well as the number of insects collected for the period during which the air plankton retriever was mounted on the Pacific Missile Range aircraft from October 1966 through April 1969.

During the fall of 1966 a concentrated effort was made to obtain as much knowledge as possible about the air flow through the duct at various points where samplers were to be located. Unfortunately, data on flight times and numbers of insects consequently suffered to some degree. No records of time were kept during test flights in October, and 3 samples were taken (each containing 2 insects) during late 1966 that have no valid data (TABLE 4). Some unsolicited assistance from the plane's crew, such as the recovery of a potato bug or a mole cricket, increased doubt concerning the validity of this early collecting.

Of the 156 flights taken, during which the retriever was in operation, 47 covered local range operations out of Point Mugu. There were 17 down-range return trip flights to the island of Oahu, Hawaii, and there were 16 tracking operations covered from Hawaii. While

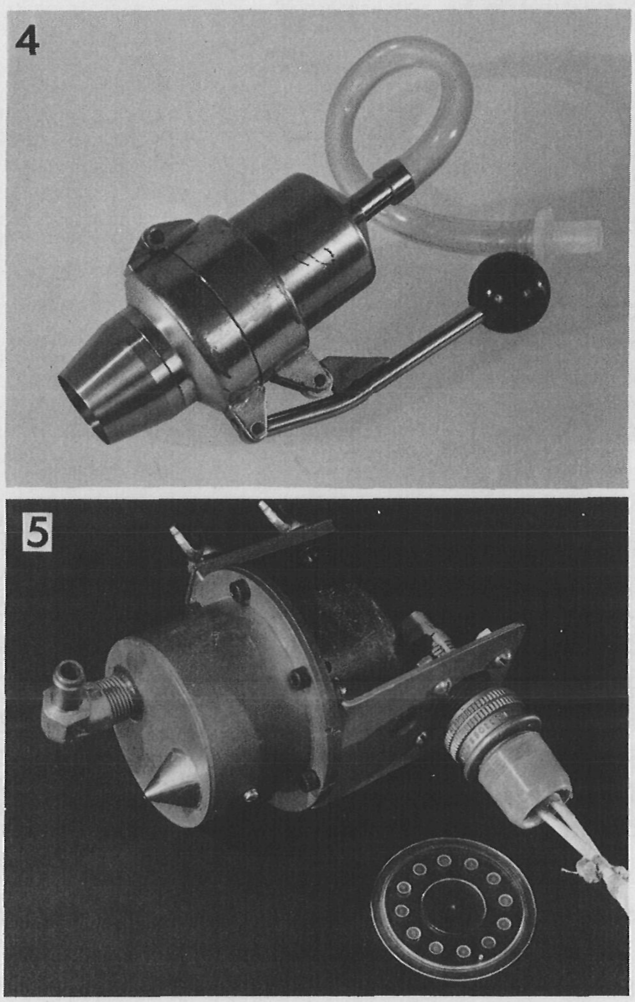

FIG. 4-5. 4. Filter sampler supplied by the National Center for Atmospheric Research which would accommodate any filter 47 mm in diam. Rubber tubing connected the sampler to a vacuum pump which regulated the volume of air sampled. 5. Impactor sampler supplied by the National Center for Atmospheric Research. The small opening on the face of the sampler permitted sampled air to be impacted on the copper grids mounted sequentially on the plastic plate seen in the lower right. Rubber tubing connected the sampler to a vacuum pump which regulated the rate of sampling. (Photos supplied by NCAR).

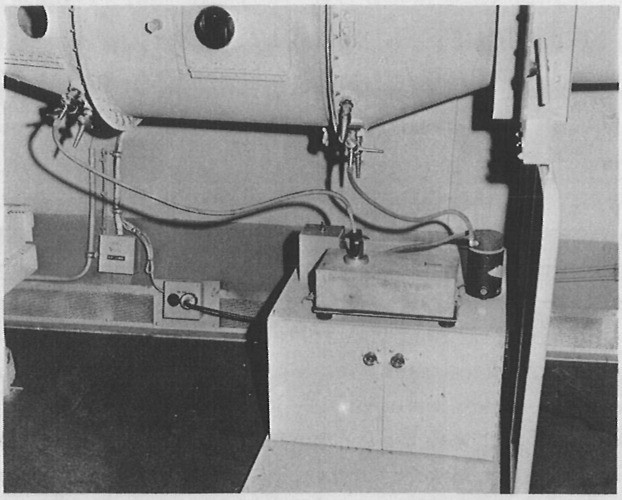

FIG. 6. Kramer-Collins sampler with control unit and vacuum pump mounted atop gear storage box and connected to the retriever by rubber tubing. (Official U. S. Navy photograph.)

operating in the Oahu area, Barber's Point Naval Air Station was normally used, though on several flights the aircraft used Kaneohe Marine Corps Air Station. A total of 7 down-range flights which landed on Oahu continued on to Kwajalein Atoll in the Marshall Islands and 2 continued past Oahu to Wake and Guam with 1 of those continuing to Townsville, Australia. In addition to operations from Kwajalein, 2 flights were made to Enewetak.

A transcontinental flight was made in September 1968 from Point Mugu, California to New York City with intermediate stops en route at San Diego, California; El Paso, Texas; Norfolk, Virginia; and Philadelphia, Pennsylvania. Following maintenance of the aircraft in New York, a return flight was made in January 1969 with a single stop at Abilene, Texas.

The cut-off valves were opened for insect recovery previous to takeoff and remained open until the technician was released from his seat belt after touchdown. The length of sampling time varied and depended on the rate at which the aircraft changed height during periods of attaining and descending from cruising altitudes.

TABLE 2 outlines the collecting with each of the 4 accessory sampling devices. Initially the sampling period for these units was less than 30 min. and some were for as short a period as 2 min. Within a relatively brief time it was determined that very few particles were found after the plane had passed through the inversion layer and had attained cruising altitude, so sampling time was gradually increased to 1 hr for all but the impactor sampler for trace acids, which required a sampling period of only 15 min. Some spore samples were exposed for up to 2 hr, when recovery approached zero for 1-hr samples. Additional information on sampling with each unit for each institution can be found in the Results section.

A Hastings Raydist air flow meter, which had been unavailable earlier, was used during the 2 final flights in April 1969 in a continued effort to obtain an accurate measurement of the quantity of air sampled.

SAMPLING TECHNIQUES AND RESULTS

From the time sampling started in October 1966 until it was terminated in April 1969, 1001 hr of flight time were logged. With wind speeds during flight averaging 190 knots, approximately 2 km^3 of air was screened.

Previous to each flight, a dust cover was removed from the intake duct and the 2 cut-off valves were opened. The 1st sample on every flight was taken immediately following technician release from seat belt and the 2nd sample was taken upon reaching cruising altitude, which was usually between 1525 and 3050 m (5000 and 10,000 ft) over the ocean. After several test flights it became apparent that hourly samples at cruising altitudes were adequate, though collecting for other particles often was for shorter periods and the collecting cup was checked each time the retriever was opened.

Sampling for insects was done on every flight, with the specimens recovered listed in TABLE 3 and 4. Of the 101 insects identifiable to order, 63 were Diptera, 10 were Hymenoptera, and 6 were Thysanoptera. In addition to the above totals, several live insects escaped from the collecting cup before they could be aspirated, and at least 5 were taken from the cabin of the aircraft near the end of 1 downrange flight to Hawaii.

Insects were recovered during 37 of the 156 flights and of the 101 identifiable specimens screened by the retriever, 93 were removed from samples following takeoffs and landings, which indicates that they may have been near ground level when entering the collector.

Only the Rotorod sampler was installed by Lockheed during rehabilitation in 1966 and in consequence was the only sampler available throughout the entire time the retriever was in operation. Dr James R. Burleigh of the U. S. Department of Agriculture at Kansas State University in Manhattan received exposed U-shaped metal rods from this device from December 1966 through December 1967. Dr Burleigh's primary interest was the movement of wheat rust spores and he used double-edged Scotch tape as the adhesive mechanism on each U rod. This tape could be removed from the rods and placed on microscope slides for easy scanning. Though initial sampling time varied from 2 to 20 min., it was increased to 1 hr when it was found that very few spores were in the ocean air at the altitudes sampled. A total of 60 rods were exposed and shipped to Manhattan, Kansas.

Dr R. Malcolm Brown of the Botany Department of the University of Texas supplied I-type Lucite rods ($1.59\,mm^2 \times 60.0\,mm$) and modified U-shaped brass rods which were used on the Rotorod sampler for algal recovery during 1967-1968. The Lucite rods were sterilized in alcohol on the aircraft, a thin layer of silicone grease was applied and exposures made in the retriever duct for varying periods of time up to 1 hr.

Previous to scheduled down-range flights, plastic petri dishes containing culturing media were prepared and shipped from Austin, Texas. These were stored under refrigeration both in California and aboard the aircraft until they were ready to be streaked by the exposed Lucite rods. As soon as possible after each flight, the streaked plates were shipped by air mail to the University of Texas for culturing. During early collecting both I rods were streaked on the same plate, but when special shipping containers for the rods became

TABLE 3. Results of airplane trapping, 1966 to 1969.

Date	Starting altitude	Ending altitude	Nearest land	No. specimens	Order	Family
1966						
9. XII	On deck, Barber's Pt.	2440 m (8000 ft)	Barber's Pt., Oahu	2	Diptera	frags.
18. XII	2440 m (8000 ft)	2440 m (8000 ft)		1	Psocoptera	
19. XII	On deck, Guam	2745 m (9000 ft)	On deck, Guam	1	Lepidoptera	Noctuidae
1967						
30. I	On deck, Pt. Mugu	915 m (3000 ft) over Mugu	Pt. Mugu, Calif.	1	Hemiptera	Lygaeidae
27. IV	On deck, Pt. Mugu	2745 m (9000 ft) over Mugu	Pt. Mugu	1 1	Homoptera Diptera	Aphididae Chironomidae
15. V	1525 m (5000 ft)	915 m (3000 ft) over Mugu	Pt. Mugu	1	Hymenoptera	Pteromalidae (alive)
16. V	2900 m (9500 ft)	On deck, Pt. Mugu	Pt. Mugu	1	Diptera	Chironomidae
17. V	On deck, Pt. Mugu	1220 m (4000 ft) over Pt. Mugu	Pt. Mugu	1	live insect escaped from vial	
18. V	On deck, Pt. Mugu	1525 m (5000 ft) over Pt. Mugu	Pt. Mugu	1	Homoptera Coleoptera	Aphididae Cuculidae
5. VII	On deck, Pt. Mugu	1160 m (3800 ft) over Pt. Mugu	Pt. Mugu	1 1 1 1 2	Homoptera Hemiptera Thysanoptera Hymenoptera Araneida	frag. Lygaeidae. Thripidae Braconidae
5. VII	1160 m (3800 ft)	2440 m (8000 ft) over Pt. Mugu	Pt. Mugu	1 2	Hemiptera Thysanoptera	Lygaeidae (frag.)
21. VII	1525 m (5000 ft)	On deck, Barber's Pt.	Barber's Pt.	3	Hymenoptera	Agaontidae
23. VII	On deck, Barber's Pt.	915 m (3000 ft) over Barber's Pt.	Barber's Pt.	1	Hymenoptera	Agaontidae (frag.)
14. VIII	155 m (500 ft) spiraling	3205 m (10,500 ft) off S. Calif. coast	Pt. Mugu	1	Diptera	head frag.
21. VIII	On deck, Pt. Mugu	1525 m (5000 ft) over Pt. Mugu	Pt. Mugu	1	Diptera	Chironomidae
21. VIII	1525 m (5000 ft) over Pt. Mugu	1375 m (4500 ft) near San Diego, Calif.	Pt. Mugu	1	Diptera	Chironomidae
28. VIII	On deck, North I. NAS, San Diego	915 m (3000 ft) over San Diego, Calif.	North I. NAS, San Diego, Calif.	1	Hemiptera	Lygaeidae
4. IX	1830 m (6000 ft)	On deck, Barber's Pt.	Barber's Pt.	1	Diptera	Chironomidae

TABLE 3 (continued).

Date	Starting altitude	Ending altitude	Nearest land	No. specimens	Order	Family
5. IX	1830 m (6000 ft)	On deck, Guam	Guam	1	Homoptera	Aphididae
25. IX	On deck, Pt. Mugu	1375 m (4500 ft) over Pt. Mugu	Pt. Mugu	1	Diptera	Ephydridae
10. X	On deck, Pt. Mugu	610 m (3000 ft) over Pt. Mugu	Pt. Mugu	1	Diptera	Chironomidae
6.XI	On deck, Pt. Mugu	1220 m (4000 ft) over Pt. Mugu	Pt. Mugu	3	Diptera	Chironomidae
8. XI	On deck, Pt. Mugu	460 m (1500 ft) over Pt. Mugu	Pt. Mugu	2	Diptera	Chironomidae
29. XI	On deck, Pt. Mugu	765 m (2500 ft) over Pt. Mugu	Pt. Mugu	2	Diptera	Chironomidae
				1	Diptera	Ceratopogonidae
3. XII	On deck, Pt. Mugu	1830 m (6000 ft) over Pt. Mugu	Pt. Mugu	1	Diptera	Chironomidae
3. XII	1525 m (5000 ft)	On deck, Barber's Pt.	Barber's Pt.	1	Lepidoptera	Tineidae
1968						
23. II	765 m (2500 ft)	On deck, Pt. Mugu	Pt. Mugu, Calif.	1	Diptera	Ephydridae
25. II	1830 m (6000 ft)	On deck, Barber's Pt.	Barber's Pt., Oahu	1	Diptera	Sciaridae
				1	Diptera	hd. & abd. frag.
26. II	On deck, Barber's Pt.	2745 m (9000 ft)	Barber's Pt.	1	Psocoptera	
				2	Diptera	Ceratopogonidae
29. II	On deck, Barber's Pt.	1220 m (4000 ft)	Barber's Pt.	1	Diptera	Sciaridae
				1	Coleoptera	Staphylinidae
29. II	1220 m (4000 ft)	2745 m (9000 ft)	Oahu	1	Diptera	Sciaridae
17. III	1830 m (6000 ft)	On deck, Barber's Pt.	Barber's Pt.	1	Thysanoptera	
				1	Diptera	Ephydridae
2. IV	On deck, Pt. Mugu	915 m (3000 ft)	Pt. Mugu	2	Diptera	Chironomidae
15. V	2135 m (7000 ft)	On deck, Barber's Pt.	Barber's Pt.	1	Hymenoptera	Eulophidae
				1	Araneida	
16. V	915 m (3000 ft)	On deck, Pt. Mugu	Pt. Mugu	1	Homoptera	Aphididae
				1	Diptera	Ephydridae
				1	Coleoptera	Cuculidae
				1	Hymenoptera	frag.
15. VI	610 m (2000 ft)	2290 m (7500 ft)	Pt. Mugu	1	Diptera	thorax and abd.
16. VI	On deck, Pt. Mugu	1005 m (3300 ft)	Pt. Mugu	2	Thysanoptera	
				1	Diptera	Agromyzidae
				1	Diptera	Chironomidae
				1	Hymenoptera	Eulophidae
				1	Araneida	
16. VI	1005 m (3300 ft)	1375 m (4500 ft)		1		wing frag.

TABLE 3 (continued).

Date	Starting altitude	Ending altitude	Nearest land	No. speci-mens	Order	Family
12. VIII	On deck, Pt. Mugu	1220 m (4000 ft)	Pt. Mugu	1	Coleoptera	Staphylinidae
				14	Diptera	Chironomidae
				1	Hymenoptera	Agaontidae
17. VIII	On deck, Barber's Pt.	1525 m (5000 ft)	Barber's Pt.	14	Diptera	Chironomidae
23. IX	765 m (2500 ft)	On deck, Philadelphia	Philadelphia	1	Diptera	Scatopsidae
1969						
5. II	2440 m (8000 ft)	On deck, Barber's Pt.		1	Diptera	Ceratopogonidae

available, one was used to streak the culture media while the other was shipped for microscopic scanning for spores.

Normally, streaking was done on the aircraft following exposure, but on several occasions all rods were stored until the aircraft was back in California, at which time both the rods and the media were taken to Santa Monica City College's sterile room so that the plates could be streaked under controlled conditions. Petri plates which served as checks were exposed both inside the cabin of the aircraft and inside the retriever duct.

More than 50 petri plates were sent to Austin where they were incubated in a culture chamber under fluorescent illumination of 22 lumen/m^2 with a 12:12 hr diurnal light-dark cycle and a constant temperature of 22°C. No algal colonies were observed during periodic checks over several weeks.

Early in 1969, Dr Roy O. McCaldin of the Environmental Engineering Department of the University of Florida provided a plastic microscope slide holder which fitted atop the firm-mounted hub of the Rotorod sampler. Sampling to check on particles causing air pollution was done by preparing the edge of a slide with silicone grease aboard the aircraft, fitting it into the plastic holder, and mounting it in the duct with its edge facing the ram pressure of the air during exposure. The sampled slide was then returned to its slide box and shipment made when the last slide had been exposed. A single box of 24 slides was exposed in this manner in January and February of 1969 and returned to Dr McCaldin for scanning. Though the slides became contaminated, on several slides exposed near Hawaii some dust particles as well as a number of small spheres (less than 1-2 μ diam.) were found.

Dr James P. Lodge of the National Center for Atmospheric Research at Boulder, Colorado, had been cognizant of the retriever and its potential in atmospheric sampling as early as 1963. Following several personal contacts, he had sampling devices built that could be used to collect in the main airstream of the duct as a monitor for extraneous volcanic ash and salts as well as trace acids.

Type EH Millipore filters 47 mm in diam. with a pore size of 0.5 μ were inserted into a specially built holder (FIG. 4) which had a 25-mm opening. Mounted inside the main sampling duct, rubber tubing provided the connecting links with a vacuum pump which was

TABLE 4. Results of miscellaneous airplane trapping, 1966–1969; questionable records.

No.	Date	Label information	Collection data	No. specimens	Order	Family
1	1966	No label	Caught either in cabin or during takeoff	1 1	Hemiptera Hymenoptera	Lygaeidae Braconidae
2	1966	No label	Removed from debris from a fall 1966 sample	1 1	Homoptera Hymenoptera	Aphididae damaged
3	1966	No label	Removed from debris from a fall 1966 sample	1 1	Hemiptera Hymenoptera	legs and wing Encyrtidae
4	26. IV. 1967	?	Date and flight do not correlate. Probably taken at Barber's Pt. on a flight to Pt. Mugu.	1	Homoptera	Aphididae
5	8. XI. 1967		Caught live in aircraft on a flight from Pt. Mugu to Barber's Pt.	5	Diptera	Drosophilidae

mounted atop the 45-cm diam. portion of the duct (FIG. 2). These were initially installed in January of 1967, but technical difficulties with the power source aboard the aircraft made early collecting of questionable value and this problem was not solved until a conversion was made from AC to DC power in 1968.

Since several collaborators were more interested than NCAR in transpacific filter samples, permission was obtained from Dr Lodge to supply them with material for analyses. Dr Robert A. Duce of the Chemistry Department of the University of Hawaii was sent a total of 13 exposed filters during 1968–1969 from both transoceanic and transcontinental flights. When analyzed, the quantity of residue salt was too low, when compared with the check filters, to be meaningful. According to Dr Duce, the quantity of ambient air filtered was probably too low for adequate salt recovery.

Collaboration with Dr Frances W. Wright of the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts, commenced in 1961 (Wright et al. 1963, Holzapfel & Gressitt 1965) and was resumed in 1968. Dr Paul W. Hodge of the Astronomy Department of the University of Washington (formerly of the University of California, Berkeley) has been a coworker with Dr Wright since the early samples were taken in 1961–1963. When sampling was resumed in May 1968, 8 filters and several checks were sent to him for analysis.

All samples were completely scanned at 200 power with positions, sizes and descriptions being noted for all particles larger than 10 μ in major dimensions. Samples were collected between Kwajalein Atoll and Point Mugu, California. There were significant differences between the particle density encountered out of Kwajalein and that out of Oahu, Hawaii, which was an intermediate stop. This difference is surprising and its explanation must await the chemical analysis of particles that is now being undertaken with the electron microprobe. Further studies of these and 7 subsequent samples taken in early 1969 will be described when chemical analysis and aerodynamical considerations are more advanced.

Dr Leslie A. Sirkin of the Earth Science Department of Adelphi University of Long Island, New York, was contacted in the fall of 1966 and agreed to accept exposed filters to scan for pollen. In March of 1968 he sent 100 triacetate metricel filters, GA-4, 47-mm diam., which were used for his samples. Of the 4 filters monitored from a transoceanic flight in March 1968, none contained pollen grains. One composite pollen grain was found from the 5 filters exposed on the transcontinental flight in September 1968.

Unfortunately, the program was terminated before an adequate quantity of samples could be taken, but the negative results for pollen points either to the quantity of air samples being too small or to the actual absence of pollen in the atmosphere at the altitudes flown. A check of meteorological data and the time of year pointed out that neither flight occurred during a fortuitous pollen rain.

Dr Harold E. Schlichting, Jr., of the Biology Department of North Texas State University, supplied gridded AA Millipore filters, 0.45μ pore size, 47-mm diam., in 1968 which sampled at a rate of 0.1 to 1.0 ft^3/min. One series of samples was taken over California on 24 May 1968 at altitudes of 2745 and 3505 m (9000 and 11,500 ft) while other samples were taken over the Pacific Ocean on 15 April 1968 at 2135 m (7000 ft) and on 20 June 1968 at 2440 m (8000 ft). These filters were used to screen the atmosphere for algae and Protozoa, and were exposed for 1 hr. All samples were shipped to Denton, Texas, where they were sectioned and cultured in soil-water medium, Bold's basal medium and sterile filtered sea water. Periodic microscopic examinations over a 3-month period showed no algal or protozoan growth (Schlichting 1969).

In addition to the aforementioned slide samples exposed on the Rotorod hub, Dr Roy O. McCaldin received filters exposed over the continental U. S. as well as over the Pacific. As with the slides, spheres of indeterminate origin were observed when scanned with the 100-power lens of a microscope.

An impactor sampler from NCAR (FIG. 5) was designed to recover small inorganic particles from the atmosphere. Using a vacuum pump to impact air against electron microscope grids, the orifice was designed for isokinetic sampling at the flow rate measured. Twelve copper grids were fastened to a circular plastic plate which was removable from the sampling unit. These plates with copper grids were sent to Boulder for analysis following exposure.

The first grids were installed aboard the aircraft in January 1967; subsequently, over 100 grids were exposed and returned to Boulder. Unfortunately, mechanical malfunctions and electrical problems with this prototype device prevented the recovery of valid samples.

Dr Charles L. Kramer of the Division of Biology at Kansas State University provided a Kramer-Collins Sampler (FIG. 6) for fungal spores (Kramer & Pady 1966) in 1967. This sampler was installed aboard the aircraft in February 1968 and functioned properly from the start, though the vacuum pump was switched from AC to DC electrical power later in the year.

A microscope slide with a thin layer of silicone grease was placed in the sampler upon reaching cruising altitude, and once the stopcocks were opened and the vacuum pump turned on, particles down to 3μ in size were impacted past a slit opening (14×0.75 mm) onto the slide; the sampled air was then exhausted back into the main retriever duct. The flow rate was set to sample approximately $1.4/m^3$ (50 ft^3) of air/hr. Collecting was continuous, with bands of sampled material representing 1 hr of collecting being deposited. A timed trip mechanism advanced the slide to start each new sampling band. A total of 17 slides, each with up to 12 hr of bands, were shipped for analysis from 1 March 1968 to 1 March 1969.

According to Dr Kramer, there was considerable variation among samples but there appeared to be little difference in the concentration or composition of air biota over the continental United States and the Pacific Ocean at the altitudes flown, which indicated a rather stable population. *Cladosporium* was the most consistently present fungal spore, with *Alternaria,* ascospores, hyphal fragments, pollen and rust urediospores occurring on most flights (Kramer & Holzapfel 1973, Kramer et al. 1973).

DISCUSSION

Designed to screen the ambient air through which the aircraft passed, the air plankton retriever performed as expected following rehabilitation in 1966. Though the 10-cm diam. intake opening permitted limited quantities of air to be sampled on each flight, the volume of air sampled was sufficient to allow several conclusions to be drawn.

The negative results at cruising altitudes over the ocean serve to document the observation that ocean air at altitudes between 1525 and 3050 m (5000 and 10,000 ft) is normally free of insects. While transoceanic migrations have been documented through insect flights (Johnson 1969), no such flights were encountered while the retriever was in operation from 1966 through 1969. The role played by the inversion layer over and near land masses and the effects of storms and other abnormal weather conditions are still not adequately understood.

Since all insects recovered from the retriever at altitudes over 915 m (3000 ft) were within close proximity of land, I have made no attempt to formulate trajectories to points of origin. While no back tracks will be attempted, when insects were collected at altitudes above 915 m (3000 ft) off the coast of California in May and July 1967, local winds were blowing from the desert and these were no doubt responsible for lifting and carrying these specimens out over the ocean.

Problems with electrical power aboard the aircraft did much to reduce the total value of sampling for the various disciplines involved. The aliquot air samples for each accessory collecting device were taken from the 45-cm diam. section of the duct and, as a consequence, the total volume of ambient air screened was too small to adequately sample the already relatively clean ocean air. The filter sampler provided by the National Center for Atmospheric Research produced some positive results, but the Kramer-Collins sampler for spores proved to be the most efficient of any used in the air plankton retriever.

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