NCAR Quarterly
Summer 1967

Horizontal Sounding Balloons

A French scientist in 1783, during the first feverish months of experiments with the newly invented balloon, was moved to exclaim, "Such a simple device! Why didn't someone think of it long ago!" It has turned out to be not quite that simple. The principle of balloon flight, once demonstrated, did allow the development of trustworthy flying machines, 120 years before the far greater problems of heavier-than-air flight were solved. Yet much of the history of scientific ballooning since those early days has consisted of attempts to overcome some major limitations of "simple" balloons.

In the last few years, many of these barriers have fallen. As a result, today we expect that systems involving large fleets of long-lived superpressure balloons will soon report worldwide atmospheric conditions at several levels above the earth. Heretofore such data have been available for no more than about 15 per cent of the earth's area – approximately the portion occupied by countries with well-developed national weather services. The new balloon systems will provide data frequently and rapidly, for use both in routine forecasting and in research into atmospheric processes. The scope of these radical and imminent changes warrants a brief look at the historical and technical background from which they have emerged.

Early Balloon Soundings

The earliest upper atmospheric explorations (excepting for pilot balloons) were manned flights. Beginning about the last quarter of the 19th century the development of automatic recording devices began to allow unmanned, and hence cheaper and also much higher, soundings of the atmosphere. These vertical soundings eventually led to such fundamental advances as the discovery of the stratosphere, and to our current reliance on radiosonde networks to give us three-dimensional information for weather forecasting.

In principle, at least, horizontal soundings were also possible, in which balloons would be allowed to drift across country with the wind, revealing large-scale movements of the air by their flight paths. The potential value of horizontal soundings has long been evident. Even before the invention of the balloon, observations of clouds moving at different levels indicated the presence of "contradictory currents" aloft, and one of the first scientific achievements made possible by the balloon was confirmation that such currents existed even where clouds were not present to mark them.

Horizontal Probe Requirements

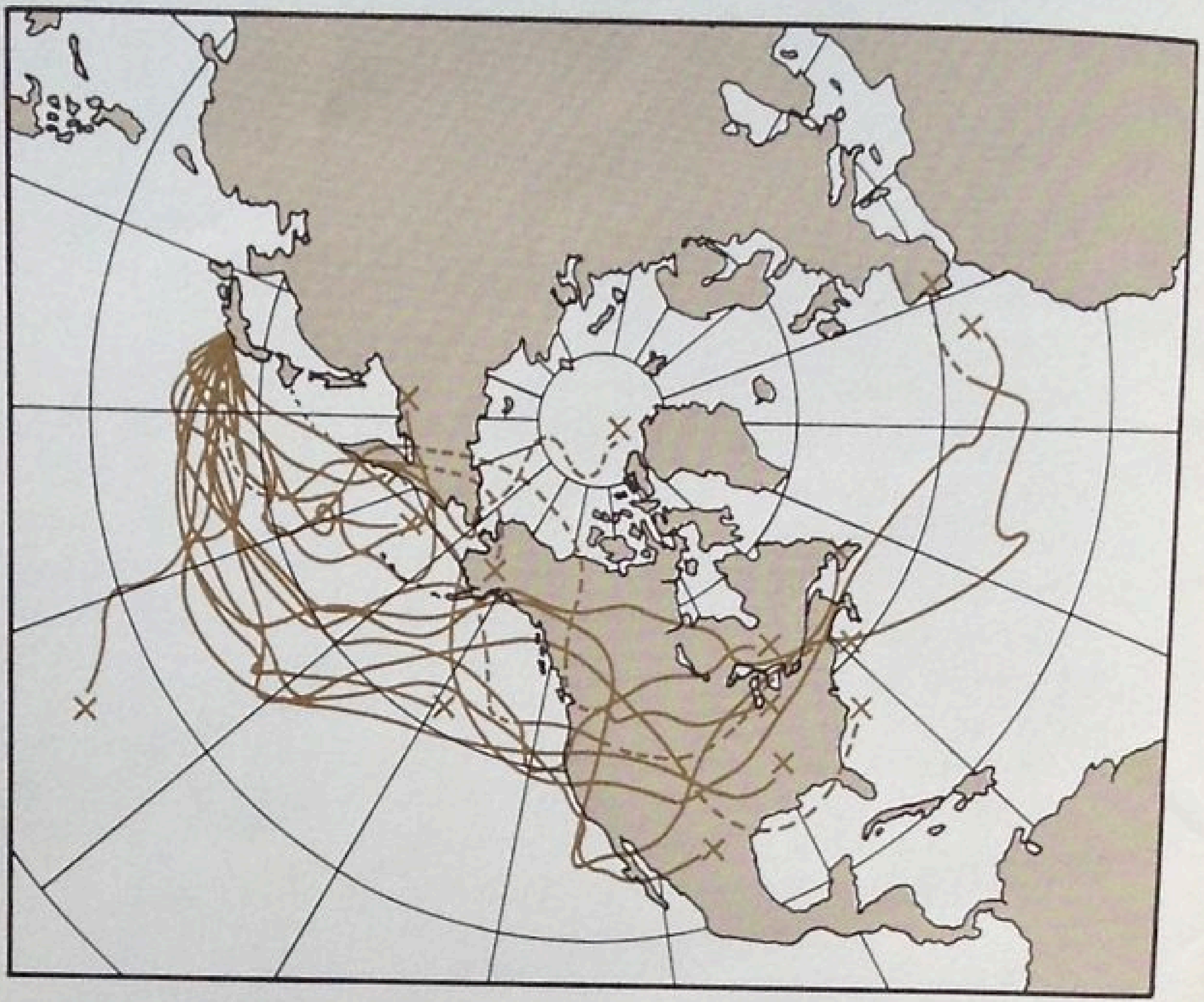
However, the various requirements for really useful horizontal soundings of the atmosphere have been extraordinarily difficult to meet. To chart a horizontal current requires the balloon to fly at a fixed level and for as long a time as possible. Then even the most carefully executed flight will be useless unless some accurate means is provided to plot the flight path beyond line of sight from the launch point. Finally, the value of a flight obviously becomes far greater if atmospheric conditions encountered by the balloon can be recorded and transmitted to the ground at frequent intervals.

Unfortunately, a level and long-sustained mode of flight is quite unnatural for conventional zero-pressure balloons, the type we have had to rely on for horizontal drifting from the days of Montgolfier almost until the present. Such balloons are partially inflated on the ground, and as they rise their lift gas expands until the balloon is fully inflated. With any further rise the excess gas is vented from an open appendix, so that pressure inside and outside the balloon envelope remains equalized. With careful control, the balloon will level off and drift along a surface of constant atmospheric density, but such a flight cannot last long without correction. If the balloon passes under clouds, or remains aloft at sunset, the lift gas cools and shrinks in volume. Any such loss of volume of the fully inflated balloon results in an unfavorable loss of equilibrium. The balloon starts down, and can only be restored to trim by dropping ballast, whether by the pilot or, in an unmanned balloon, by some automatic device. Flight duration is limited strictly by the amount of ballast that can be carried, and until the 1890s no balloon flight lasted as long as 24 hr.

Automatic Ballasting

After World War II large-capacity plastic film balloons led to modern scientific ballooning, with the ability to take heavy payloads to altitudes in the range of 70,000 to 140,000 ft for flight durations of at least several hours. Thus vertical probes were extended to meet modern needs. At the same time the new balloons, which were still zero-pressure devices, became the basis for an important interim step in horizontal probes, with the development of automatic ballasting systems controlled by barograph switches. In the late 1940s and early 1950s such balloons made flights lasting up to a couple of weeks, carrying heavy payloads of meteorological instruments, batteries, and transmitters, as well as ballast.

The most successful of these programs was the Navy's Transosonde system, which made a number of flights from Japan across the Pacific toward North America at altitudes of around 40,000 ft, and provided a good deal of valuable meteorological information. The several hundred pounds of payload and ballast carried by these balloons caused them to be banished from the skies as flight hazards when jet aircraft began to fly the Pacific, and many people felt then that hopes for any sort of horizontal balloon-sounding system were finally ended.



Flight paths of twenty 300-mb Transosonde flights launched from Japan, January and February, 1956.

The Superpressure Revolution

The way out of these difficulties came rather unexpectedly as the result of three unrelated technical developments. During the mid-1950s much of the interest in balloon design development in this country was concentrated in a small group of engineers and meteorologists at the Air Force Cambridge Research Laboratories. In 1958 two members of this group, Maj. Thomas Haig and Vincent Lally, pointed out that the then-new developments of Mylar film and microelectronics might be combined into a worldwide system using many balloons at several levels to record and transmit timely meteorological information to ground stations. The following year Lally suggested that artificial earth satellites offered an efficient means of rapid communication between large numbers of balloons and a few ground centers.

This complex of ideas, which has undergone rapid development and has become a major key to planned future international cooperation in meteorology, is known as the GHOST concept, for Global Horizontal Measurement Technique. In 1961 Lally moved to NCAR, which has become the headquarters for GHOST system development.

Mylar and Microelectronics

The first key to the GHOST concept was Mylar film, which is much tougher than polyethylene and relatively inelastic. These properties suggested that a Mylar balloon could be completely sealed, with no appendix to vent excess gas. Internal pressure would therefore build up if the balloon continued to rise after becoming fully inflated during ascent. Diameter and weight could be adjusted so that the balloon would level off at some desired altitude with only moderate superpressure, to avoid any danger of bursting.

A superpressure balloon has the valuable characteristic of floating at a constant atmospheric density level as long as it maintains excess pressure. The balloon's volume is virtually constant, and the effect of clouds or sunset, or their reverse, is to diminish or increase the degree of superpressure – ballast is unnecessary. The cold temperature of flight altitudes renders Mylar brittle so that it shatters on impact, and a thin enough balloon will present no hazard to aircraft. Thus, sustained level flights with simple balloons, far smaller and lighter than the Transosonde types, became possible for the first time.

Even so, superpressure balloons might have become little more than curiosities without means at the balloon to record and transmit data, and without some means to concentrate the data on the ground. Thin-film electronics have filled the balloon-borne part of these requirements, by making possible extremely lightweight instruments for sensing balloon position and atmospheric variables, and for transmitting the information. The small amount of mass added to the balloon presents no hazard to aircraft.

Tracking

The problem of reading transmissions from many far-flung balloons is essentially the modern version of the old problem of tracking any horizontal flight. (During the 1890s a French experimenter designed a drift balloon system carrying dozens of postcards tied at intervals to a slow match cord, which he ignited at launch. Enough cards were returned from an afternoon's flight to give some idea of the balloon path over central France, but the method did not become popular.)

In the GHOST system the changing position of each balloon is revealed by a sun-angle sensor, which controls the rate at which the balloon's identifying call letters are transmitted. With rather simple equipment, the flight path can be charted to acceptable accuracy from this information. Successive position measurements, of course, indicate movement of the air mass in which the balloon is floating.

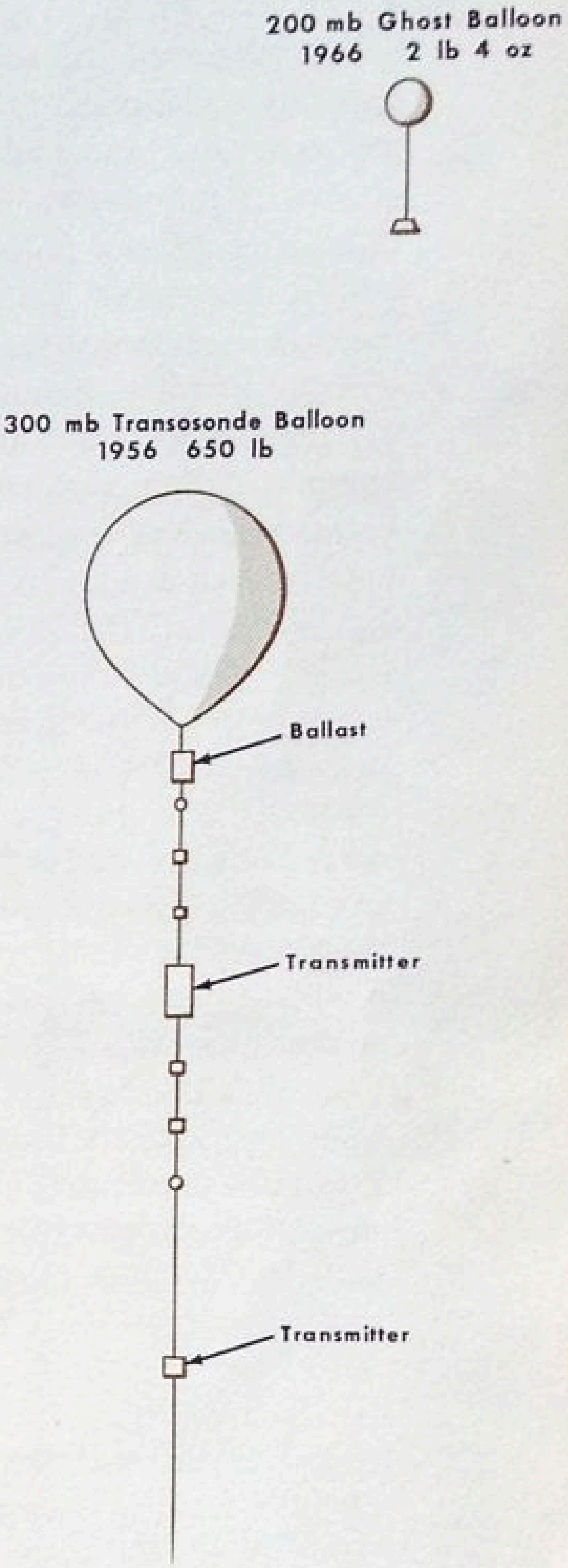
Operational GHOST balloons will also transmit data on air temperature and on the very slight changes in balloon volume which occur with variations in superpressure as the lift gas warms and cools.

The currently projected GHOST system envisions about 6000 balloons airborne at any one time, with dropouts replaced systematically. To be useful in forecasting, timely data from these balloons must be available at plotting centers.

Tests with GHOST and the related French EOLE balloons have relied upon ground-based receiving stations, but for thousands of widely dispersed balloons in a future operational system, ground stations would be both costly and slow.

GHOST system planners feel sure they have found their answer in communication satellites, whether in medium-altitude random orbiting systems, or in synchronous systems, and they have felt free to concentrate for now on the balloon and electronics aspects of the future systems, while satellite development goes on rapidly at other centers.

The first international flight tests of the GHOST system began early in 1966, from Christchurch, New Zealand and are expected to continue from there for the next few years. These tests have already led to intensive further development of the GHOST system, some aspects of which are described in the accompanying article.



Transosonde system flights at 300 mb averaged 7000 n mi distance and 80 hr of flight time. The far lighter and cheaper GHOST balloons flying at 200 mb should stay up for a year or more, and each balloon should make about thirty circuits of the earth during its lifetime.

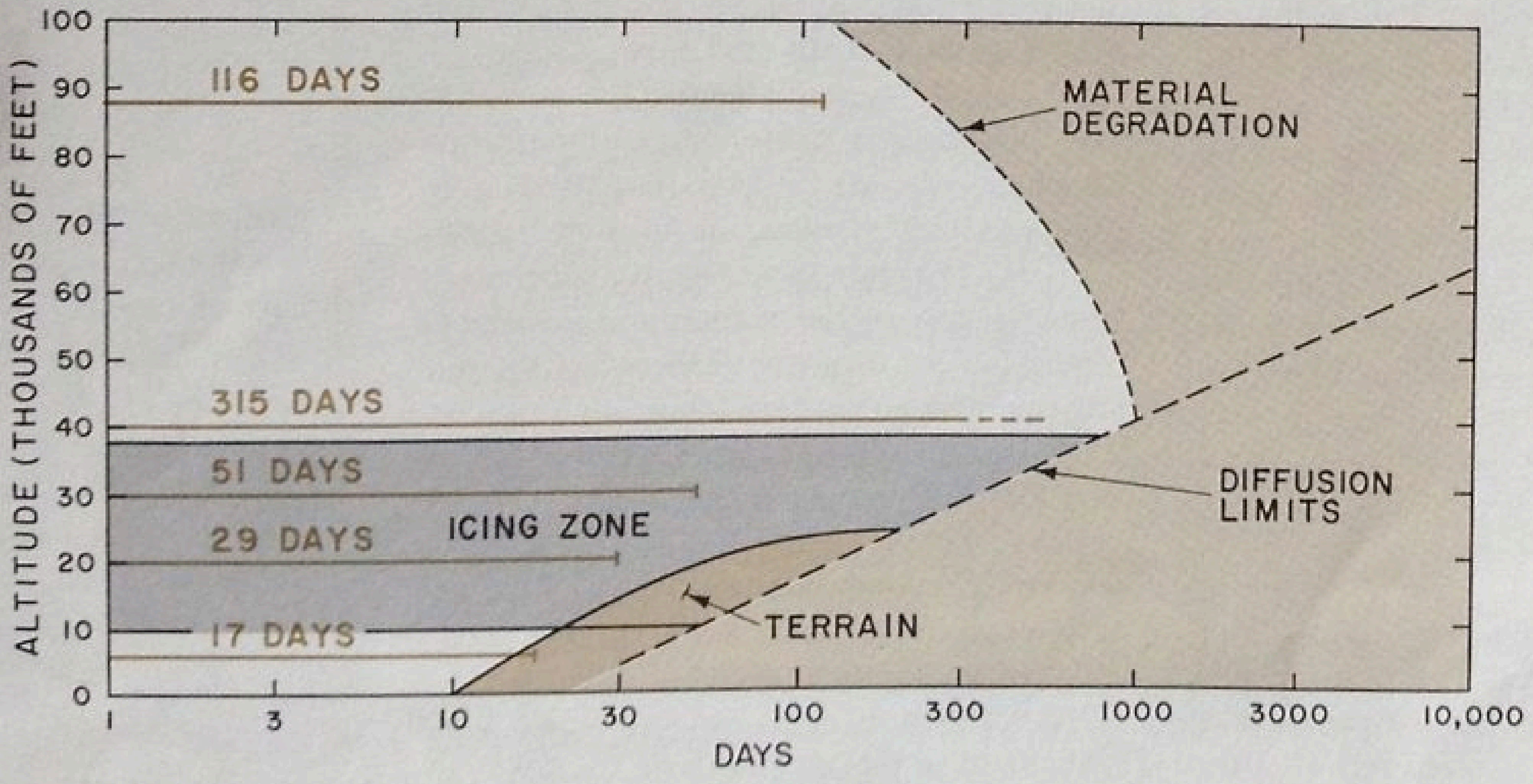
Balloons Against Ice

About ten years ago practical realization of the superpressure balloon concept opened the prospect of launching horizontal probes which would float for long periods at various pre-planned elevations in the atmosphere. As the preceding article points out, a worldwide horizontal atmospheric measuring system using such balloons will soon be possible, thanks to concurrent developments in thin-film electronics and in communication satellites. However, in preliminary tests of the two presently developing horizontal systems, the U. S. GHOST and French EOLE systems, a number of hazards to the balloons have been encountered, some of them anticipated and some not. At NCAR the Global Atmospheric Measurements Program, directed by Vincent Lally, is currently devoting a great deal of effort to balloon designs intended to overcome the worst of these drawbacks.

Lally and his associates at NCAR, in cooperation with ESSA and the New Zealand Weather Service, have carried on a flight test program from Christchurch, New Zealand since March 1966, with superpressure balloons carrying sensors and transmitters. In favorable cases, the balloons have stayed aloft for periods up to several months, and have regularly reported their changing positions. (Sometimes the transmissions have been interrupted and later resumed, when, for example, the balloons entered the Antarctic night where their solar cells no longer provided transmitter power.) Lally's principal concern, of course, has been with unfavorable cases. He recently diagrammed the hazards to GHOST balloon lifetimes, to demonstrate where current design efforts are being made, and why. Certain hazards were anticipated before the flight test program began. These included terrain effects, radiation damage to the balloon envelope material, and diffusion.

Known Hazards

Terrain effects are obvious: the balloon runs into a mountain and ceases to function. Balloons flying above 29,000 ft have no such problems. The proposed horizontal systems usually involve balloons at 500 mb (about 18,000 ft) and at higher levels, so that even the lowest fleet of balloons would face only minor hazards from



Hazards to GHOST balloons. Some actual maximum flight durations at different altitudes are shown in color.

terrain. However, it may be desirable to make measurements at considerably lower levels. In that event terrain hazards can only be calculated and allowed for by providing additional balloons for the system.

Degradation of the balloon film is most likely to come from *ultraviolet radiation*, the intensity of which increases at higher elevations. The possible effects on balloon film are largely unknown, and Lally and his associates are seeking ways to measure and, if necessary, counter them. The current long lifetimes achieved by a good number of balloons, including some which are now flying at 30 mb (about 80,000 ft), indicate that the effect is, at least, not disastrous.

Diffusion is a continuous process which eventually will put an end to any flight. In a perfectly leak-free balloon, the lift gas diffuses through the envelope and into the atmosphere at a rate which depends on film material and thickness, type of lift gas, gas temperature and pressure, and balloon diameter. Fortunately, Mylar, which (like other plastic films) has a fairly high diffusion rate at room temperature, also has one of the lowest rates of diffusion of any film at the low temperatures encountered in the upper atmosphere. For 500-mb balloons, diffusion will limit lifetimes to somewhere between three months and one year—quite acceptable periods for the planned horizontal systems.

The situation is remarkably different for 30-mb balloons, which will float at around 80,000 ft. To secure the needed lift for that altitude, these balloons must be about 20 ft in diameter, compared with 5 or 6 ft for 500-mb balloons. The considerable gain in surface-to-volume ratio gives the 30-mb balloons a much lower rate of diffusion loss. This advantage is greatly compounded by the low ambient pressure which requires only a modest amount of superpressure to keep the balloon fully inflated. As a result, the 30-mb balloons have theoretical lifetimes of dozens of years, and will probably give in to radiation effects long before they do to diffusion.

Icing

When the New Zealand flight test program got underway, it seemed that, according to these calculated hazards, flight durations should average at least 80 days or more for 500-mb balloons. Instead, these balloons when launched, usually reported their changing positions for a few days, and then in most cases abruptly ceased communication. Lally and his associates traced the problem to icing when the balloons encountered clouds of supercooled water—a possible hazard at elevations from 10,000 to 35,000 ft—and they have investigated a wide range of remedies.

For example, it might be possible to coat the balloons with substances which deter icing. Waxes and silicones have made some improvement, but have not solved the problem. Another possibility might be a brute force solution: make balloons big enough and strong enough to withstand any possible ice load. Blimps have survived severe icing, and balloons could be made to do so, too. Unfortunately, a Mylar balloon of the necessary size and strength (about five times the diameter and thickness of present 500-mb balloons) could be a hazard to aircraft.

Different balloon materials offer some promise, also, particularly the often-ignored plastic, cellophane. The original plastic balloon, made in 1936 by Jean Piccard and John Ackerman, was of cellophane, but the material has not been used in modern balloons because dry cellophane is brittle and tears easily. However, moist cellophane retains its strength, and Lally is intrigued with the thought that it might be possible to make fairly thick-walled cellophane balloons under humid conditions, ship them to the launch site in a wet container, and allow them to dry during ascent. Thus they would arrive at their design altitude in a brittle condition which would cause them to shatter readily in the unlikely event they were hit by an aircraft. An additional reason for such interest is the fact that the cold-temperature gas diffusion characteristics of cellophane are even more favorable than for Mylar.

In another approach, Lally has suggested a pontoon balloon, a concept which has been picked up and flight tested with some success by the French in their EOLE program. In the southern hemisphere, which is largely a water hemisphere, balloons

NCAR Quarterly

No. 18, Summer 1967

Published quarterly by
the National Center for
Atmospheric Research,
University Corporation
for Atmospheric Research,
Box 1470, Boulder,
Colorado 80302

Paul M. Sears, Editor

Second class postage paid
at Boulder, Colorado

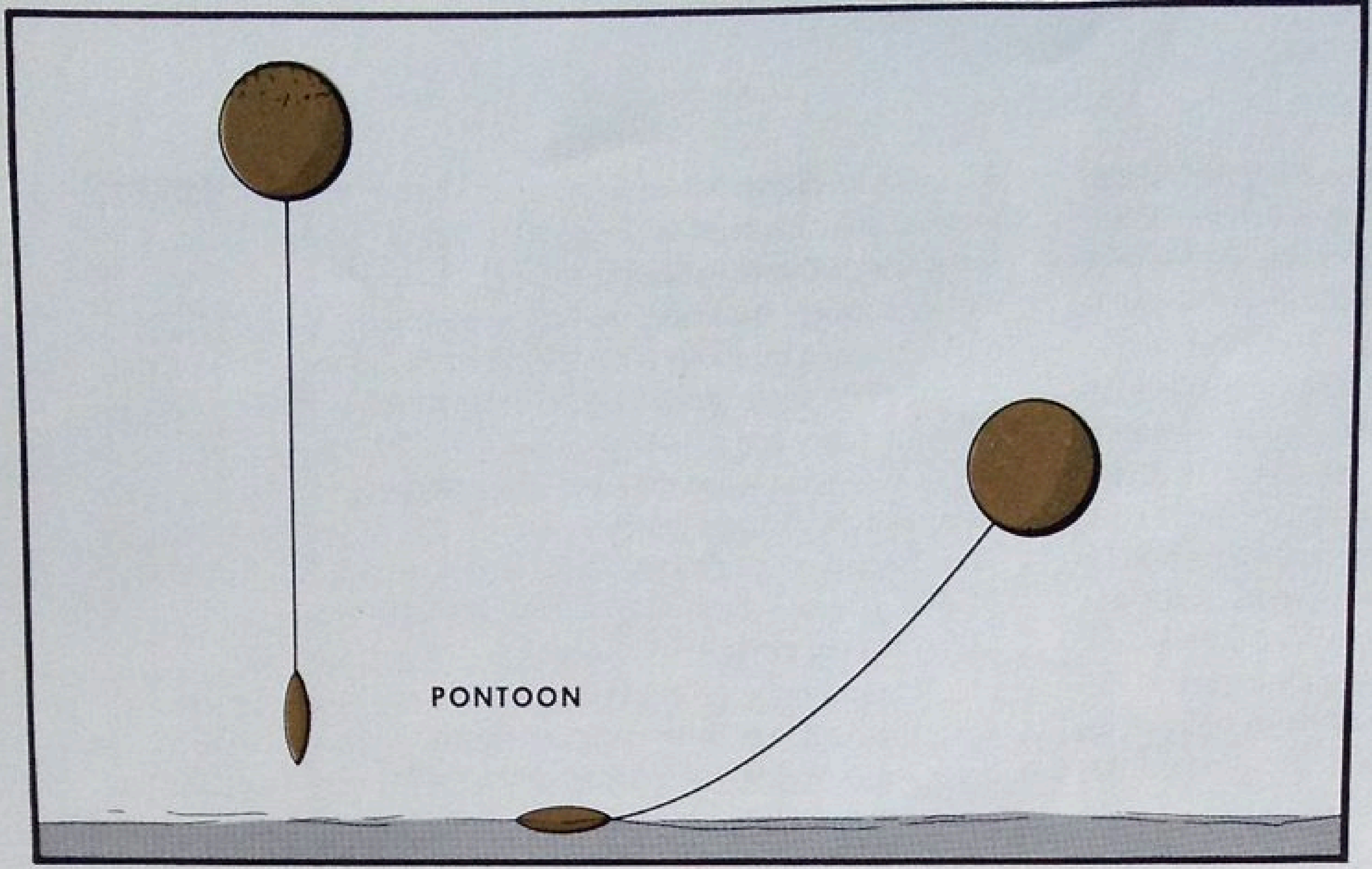
Sent without charge
on request

The National Center for Atmospheric Research was established in 1960 to conduct and foster basic research in the atmospheric sciences, to supplement and augment the research and educational programs of universities and research groups in the United States and abroad, and to work toward increasing the effectiveness of atmospheric research efforts as a whole. It is operated by the University Corporation for Atmospheric Research, a private non-profit organization, and sponsored by the National Science Foundation.

In pursuit of its goals NCAR seeks to develop interdisciplinary research programs across the broad spectrum of the atmospheric sciences; to develop major research facilities essential to national and international interests in the atmospheric sciences, and to carry on strong and continuous communications and cooperation with universities and the scientific community.

NCAR is comprised of four scientific divisions: the Laboratory of Atmospheric Sciences, the High Altitude Observatory, the Facilities Laboratory, and the Advanced Study Program. NCAR receives primary support from the National Science Foundation. Contracts, grants and gifts are also provided by other government agencies, and by individuals, corporations, and foundations.

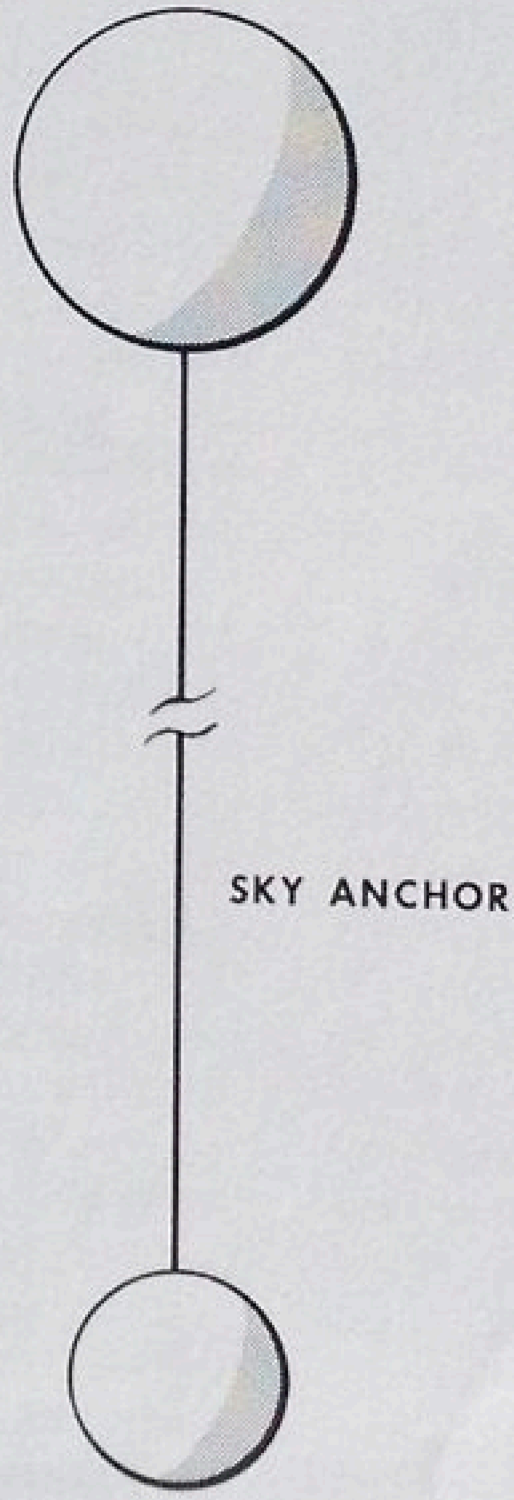
UCAR Member Universities
University of Alaska
University of Arizona
University of California
University of Chicago
Colorado State University
University of Colorado
Cornell University
University of Denver
Florida State University
University of Hawaii
The Johns Hopkins University
Massachusetts Institute of Technology
University of Michigan
University of Minnesota
New York University
University of Oklahoma
Pennsylvania State University
Saint Louis University
Texas A and M University
University of Texas
University of Utah
University of Washington
University of Wisconsin

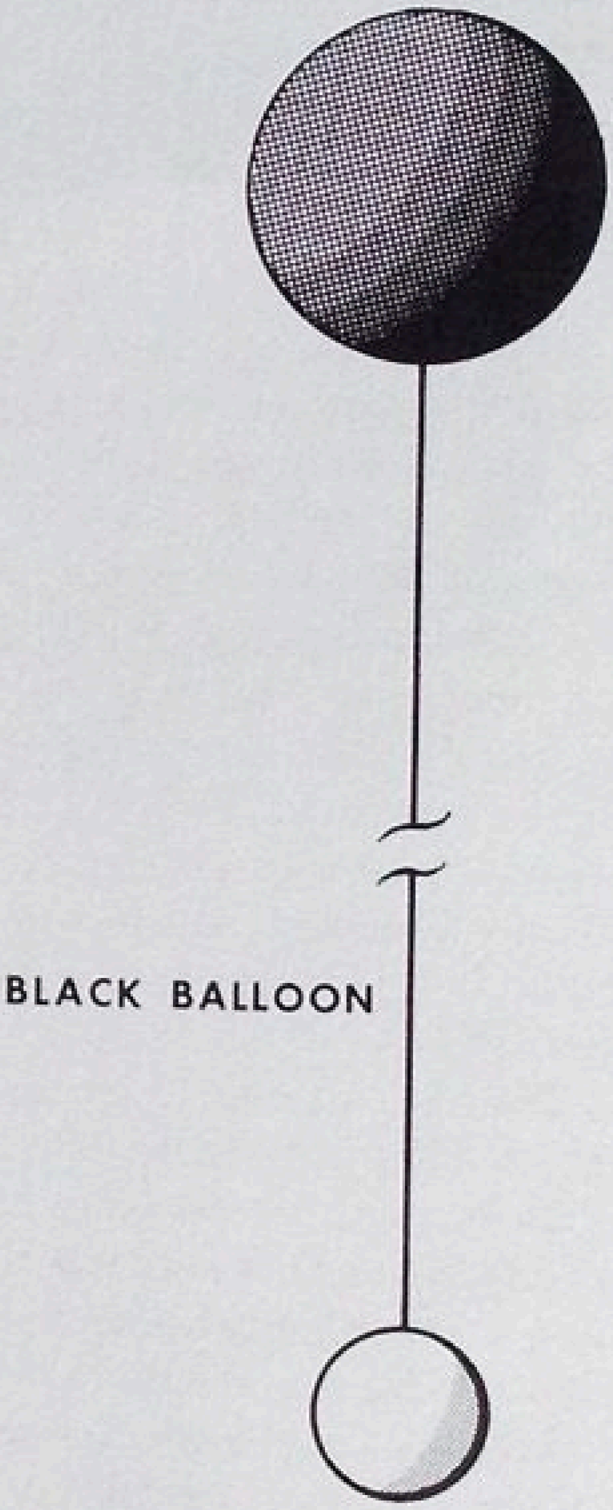


spend most of their time over the ocean. When they ice up, the load forces them to descend to the surface. Contact with the ocean probably often frees the balloon of ice so that it can return aloft. The damage is principally in wetting the electronics system, which can then no longer function.

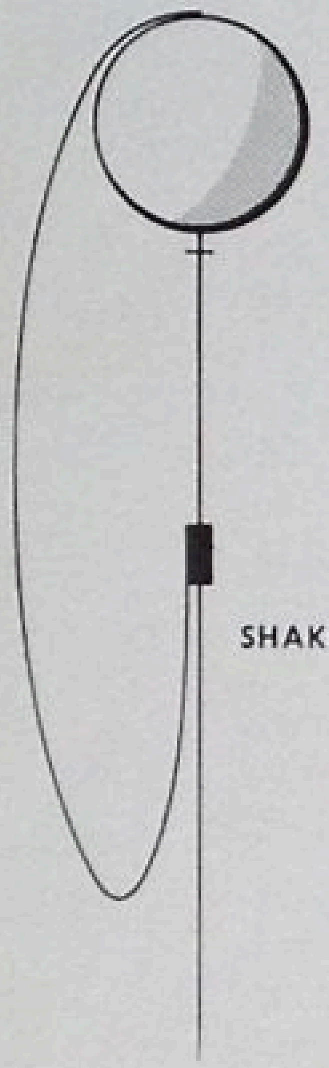
Lally thought that a pontoon of Styrofoam or similar material might be suspended on a line a few hundred feet below the balloon, so that when the pontoon hit the water the reduced weight would allow the balloon to stay aloft and sail along, tethered to the floating pontoon until the ice melted and the balloon resumed free flight. In the French tests with pontoons the data from the sun-angle sensors on the balloon instrument package occasionally indicated that the package must be whipping about erratically, which would be the case if the balloon were tethered to a float. With such balloons, normal sun-angle data transmission often resumed. One EOLE balloon was thus recovered from the surface three times.

A modification of the pontoon is the sky anchor, in which a small superpressure balloon is suspended on a line below the main balloon. The small balloon begins to acquire its superpressure when the system rises to about 5000 ft. Thus when the main balloon ices and the system loses altitude, at about 5000 ft the small balloon becomes heavy and acts as a pontoon suspended in the air. The obvious advantage of this system is that it should work over land as well as water.



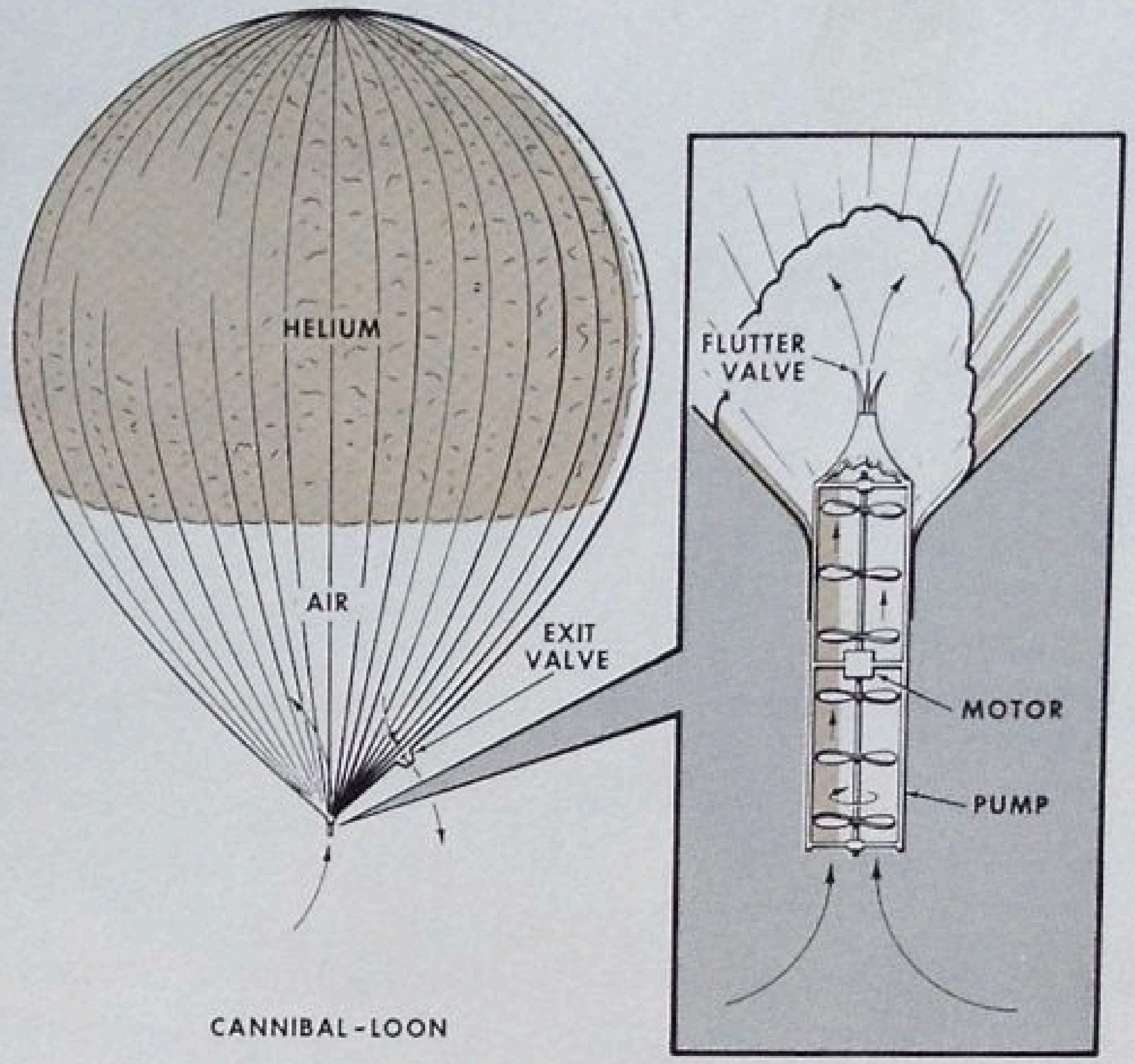


A different type of sky anchor is based on radiation characteristics. French experimenters have suggested making the balloon of black plastic, designed so that it will be slightly buoyant on the ground in the dark. In sunlight this black envelope will pick up enough heat to reach its design altitude, where it will be about 20 per cent overpressured. But it will reach this altitude only during daytime and only on sunny days. In poor weather and at night it always descends to lower altitudes. While an ideal superpressure system should report data from the design altitude at all hours, it might be well worth a compromise such as this to overcome the icing problem.



SHAKE-FREE

Some other possible solutions do not have these evasive aspects, but attack the ice more directly. Thus it might be possible to shake off ice accumulations by agitating the balloon. One way to do this would be to provide a rigging with a motor (which could be solar-cell powered), so that the motor assembly would climb a vertical line below the balloon, reeling the line in as it climbs. When the motor reaches a trip device it drops and the shock as it reaches the end of the line flips the balloon vigorously, removing any ice that has formed. The balloon then rights itself and the motor starts climbing again, with a complete cycle taking possibly 30 min.



CANNIBAL-LOON

The most ingenious of Lally's proposals he terms the Cannibal-loon, a device intended to send the balloon out of harm's way *above* the icing level whenever the threat of icing appears. This device consists of an unpressured helium balloon enclosed in a larger superpressure balloon (hence its name) which is filled with air, and fitted with a simple external valve and pump. The air balloon is an anchor which holds the system to a fixed altitude. If air is released from the valve, the system becomes light and rises. If air is pumped in, the superpressure does not increase, because the system responds by moving to a lower altitude. A humidity sensor indicates danger when 100 per cent humidity is approached, and the valve then releases air until the system rises above the icing level. The air pump operates whenever the balloon is above its design level *and* the sensor indicates no danger of icing. The pump designed at NCAR will take two days to return a balloon to the 400-mb level from 200 mb, a delay which should allow the system to drift away from the region of icing.

If all such approaches fail, there remains the expedient of flying balloons above icing zones, and trailing long lines from them which will carry sensors in the lower levels. Considerations of cost and aircraft flight safety will have much to do with the designs to be finally adopted. Meanwhile Lally presides over a brisk market in novel ideas.