The U-2 as an Instrumented Aircraft for Geophysical Research

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DURING recent years, the Geophysics Research Directorate of the Air Force Cambridge Research Laboratories has used a number of aircraft to gather geophysical data needed in attacking practical and theoretical problems. Studies have been or are now being made of thermal radiation, gravity, ozone, auroral activity, arctic surveys, etc., as well as of a variety of meteorological phenomena. This article will discuss some of these studies, especially in relation to investigations being conducted using a specially-equipped Lockheed U-2 research aircraft as a data-gathering vehicle.

The present program is, of course, built upon past experience which includes the jet stream research flights of 1953–1955 and 1956–1958, the Sierra wave research flights of 1954–1955, and the hurricane research flights of 1954–1955. During these programs, the use of Doppler automatic navigation equipment to measure winds was introduced and perfected. Instrumentation also included facilities to measure and record free-air temperature, turbulence, pressure, absolute height above terrain, and to obtain cloud photographs. Calibration techniques, recording systems, and data processing procedures were gradually evolved; however, complete data processing and packaging lagged flight programs by a year or more. These programs had the advantage of using large bomber-type aircraft, both piston and jet powered, so that there was usually ample space for equipment and observers. Disadvantages of these aircraft were their high initial cost, high operating expenses, large air crews, and the scarcity of convenient operating bases.

Developments in miniaturizing equipment (particularly the Doppler auto-navigation system) and in building more versatile and compact recording systems which provide automatic data readout have continued since the early days of the studies. Moreover, instruments have been recently developed with Air Force support for measuring ozone, humidity, radiation, dust concentrations, and sky brightness. The availability of a U-2 aircraft as a controllable platform has enabled the Geophysics Research Directorate to assemble an accurate, complete, and relatively inexpensive system of obtaining all of these data. Advantages of the U-2 are its small size and maneuverability, low operating costs, need for only short runways, and ability to operate at altitudes above those of conventional aircraft.

The studies which are being conducted naturally emphasize problems of special interest to the Air Force. Meteorological studies include the statistics of wind and temperature fields, the structure of circulation patterns, cloud patterns and their relation to synoptic phenomena, and the distribution of turbulence, ozone, water vapor, and other elements of the atmosphere. Particular emphasis is being placed on a study of stratospheric humidity.

In the field of thermal radiation, the aim is to determine the infrared transmission of the atmosphere at altitudes in excess of 40,000 feet and over a range of latitudes. The spectral region of interest is the 1–15 micron region. For these studies, two spectrometers equipped with a sun seeker are being utilized.

In the study of the distribution of radioactive particles, a sampling system has been used. In particular, these studies focus on the chemical mechanism of the stratosphere, storage of debris, and its eventual downward transport through the troposphere.

In support of studies concerned with meteorological satellites and application of satellite data, the aircraft is used to obtain photographs of clouds and measurement of radiation emitted and reflected by the earth and its atmosphere. A camera and a four-channel scanning radiometer marking the

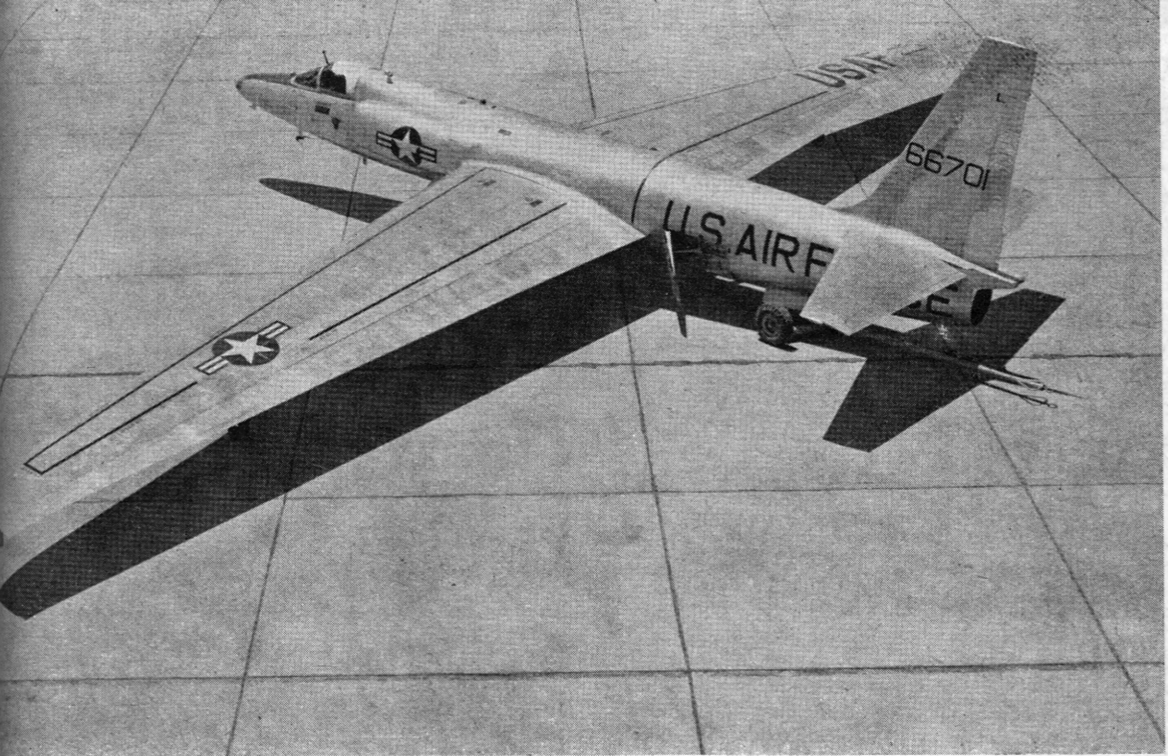


FIG. 1. A U-2 Aircraft as employed for research flights.

earth-atmosphere indicator over the range 0.2 to 4.0 microns will be used. These data will aid in the interpretation of cloud photographs taken from satellites and in relating the meteorological conditions to radiation.

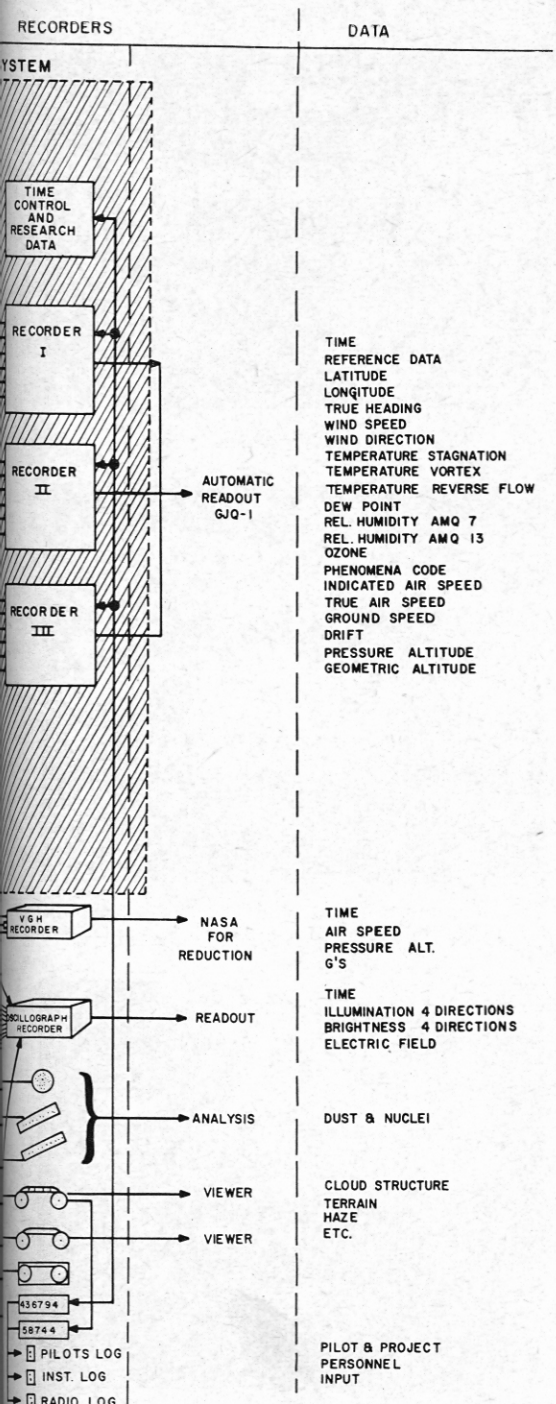
In the studies of atmospheric optics, the aim is to determine how, when, where, any object—at any place and under any circumstances—could be detected in the visible or near-visible wave length.

Support to a study of interplanetary matter is being given by the collection of dust particles in the stratosphere. These samples allow for a study of: the probable hazards of interplanetary matter to high altitude missiles; the basic physics of the interaction of meteoroids with solid surfaces within the atmosphere as a means of extending the velocity range of aerodynamics into the hypersonic region; the geophysics of interplanetary particles which may have far-reaching importance in determining the role of dust on rainfall and on the heat balance of the earth.

The size and number of the instruments required to support these studies exceed the space available in the U-2 aircraft. Consequently, the instrumentation has been divided into several packages, each of which is designed to provide the complete requirements for one or a number of studies. Each package can be removed and another substituted without the need for a major change in the aircraft. The total weight of each package is less than 1000 pounds. The equipment is miniaturized and is almost completely automatic.

Figure 2 is a block diagram of the meteorological package. This diagram indicates the source of the measurement, the computers and amplifiers required, and the recording facilities. To the extreme right is a listing of the various parameters obtained by this instrument system.

The automatic navigational system provides measurements of latitude, longitude, wind speed, wind direction, ground speed, drift, heading, and true air speed. It is composed of a Doppler radar, compass, magnetic variation computer, true air speed meter, wind computer, and a dead reckoning computer. This equipment weighs about 168 pounds and measures six cubic feet. With proper calibration and attention, wind speed is accurate within about three knots and wind direction within about five degrees. The primary errors are due to the aircraft flight



characteristics at high speed and at high altitudes.

Static (ambient) pressure and total (static plus differential pressure produced by the motion of the aircraft) are sensed, using two separate pitot-static systems. Transducers (which weigh about ten pounds) are employed to record indicated air speed and pressure altitude. The inputs of pressure altitude (PA) and indicated air speed (IAS) required by the True Air Speed meter are taken from this same system. The accuracy of PA and IAS measurements depends upon the location of the static ports. With proper ground and air calibration, PA can be measured within two millibars, and IAS within two knots.

An APN-42 radar altimeter will be used to measure geometric height above underlying surface; however, this instrument is not yet operational.

Temperature is measured by four sensors: one, a flush-bulb type, is used to provide temperature to the true air speed computer. A stagnation-type probe, AN/AMQ-7, an axial flow, vortex-type probe, AN/AMQ-13, and a reverse flow probe are used for temperature measurements. All three are used to insure accurate temperature measurements under various conditions. With proper ground and air calibrations, these thermometers will provide absolute temperature measurements within one degree of each other. Gradients or changes are accurate to tenths of a degree.

Humidity is being measured with an infrared hygrometer which employs a small computer to indicate results in terms of dew-point. To date, the instrument has not been operationally tested, but preliminary tests indicate it will be successful. The AMQ-7 and AMQ-13 sets measure relative humidity, utilizing carbon strip-type sensors. However, these are ineffective above 25,000 or 30,000 feet.

Two types of ozone analyzers have been successfully flown on a KC-135. One is the Regener chemical type; the other is a unit produced by Armour Research Foundation. The latter unit consists of two thermistors, one of which is chemically treated. The difference in temperature caused by the destruction of ozone near the treated element is a measure of the amount of ozone. One of these, or a third type being developed by Professor Regener, will be used depending upon the results of tests in the U-2.

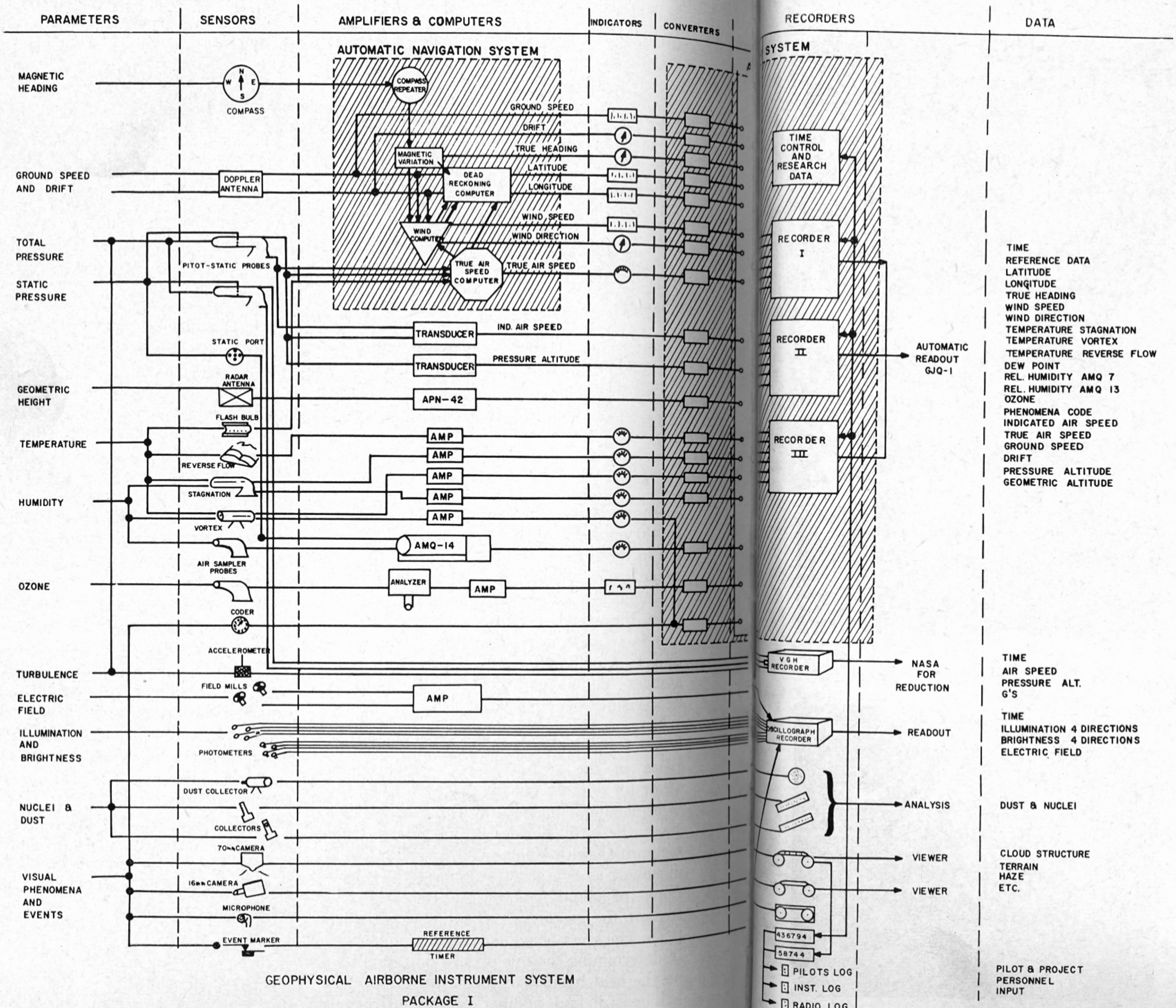


FIG. 2. GEOPHYSICAL AIRBORNE INSTRUMENT PACKAGE—PACKAGE I.

The photometers used to measure illumination and brightness are mounted in pairs on the top, bottom, and sides of the aircraft. Narrow angle (20°) photometers are used for measuring brightness, and wide angle (180°) are used for illumination.

Figure 3 is a picture of a meteoric dust collector used in the past. When the aircraft has reached flight level, a cover is removed, and air passes through the instrument depositing the dust on a millipore filter whose contents are later analyzed in a laboratory. Improved instruments are now installed which periscope a calibrated cylinder from the top of the aircraft, see figure 4. These instruments will collect samples of dust found in the atmosphere which not only can be analyzed for chemical composition but also for concentration and distribution in the atmosphere.

Turbulence is being measured through the use of NASA VGH meters. Electric field is sensed by two field mills. A 16mm time-lapse camera and a 70mm camera are used to film visual phenomena, such as clouds (figures 7 and 8). In addition, a tape recorder and a weather coder are installed for recording the pilot's information and observations.

The recording system primarily consists of an AJH-1 recording system, a NASA VGH recorder for turbulence, and an oscillograph recorder for the photometer and electric field mill outputs. The AJH-1 system provides time and a synchronous signal to other recorders. It also provides a signal which operates a sequence counter in the cockpit used by the pilot to synchronize visual observations. The record of this system can be visually scrutinized for preliminary evaluation. Not only are trends recognizable, but actual values can be determined by totaling the marks in each column which represent a digit of a measured parameter; e.g., just below the line inscribed on figure 6, the value of the indicated air speed is 128. Time and reference data are repeated each 60 printings. Data can be recorded at various intervals up to 30 seconds. For detailed post-flight evaluation, a GJQ-1 reader is available for automatic readout of all recorded data in the form of teletype tape, IBM cards, and tabulation by an electric typewriter.

Figure 5 shows the temperature and pitot probes mounted in the skin of the aircraft; also visible is the radome for the Doppler radar.

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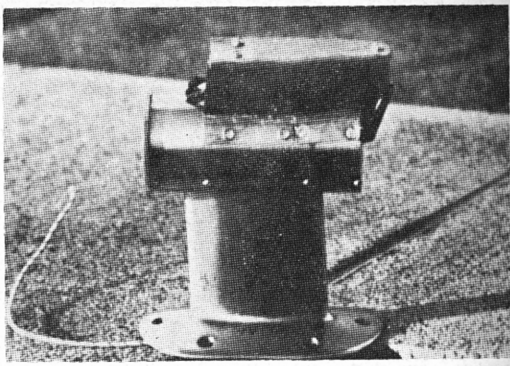

Fig. 3. The Meteoric Dust Collector.

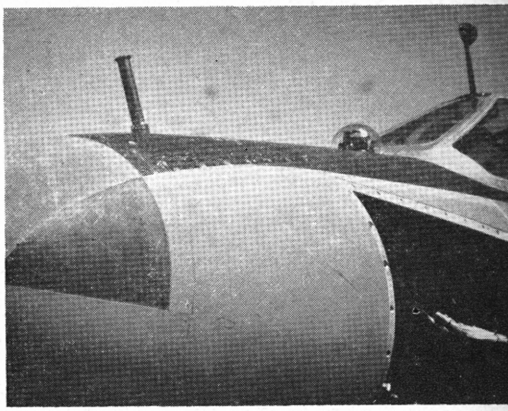

Fig. 4. Improved cylindrical dust collector shown installed and exposed in nose of aircraft.

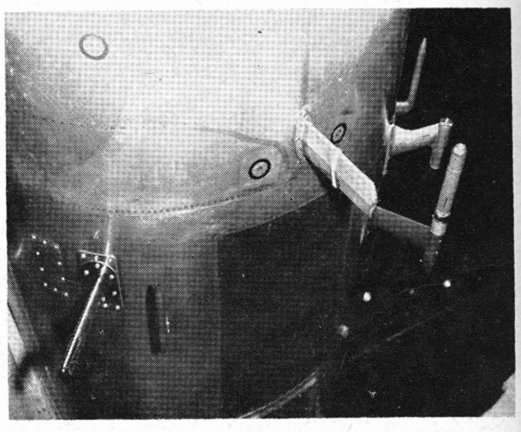

Fig. 5. Underside of aircraft showing probes. From left to right: reverse flow, pitot static, radio antenna, stagnation type temp., vortex type temp., pitot static, and radome for doppler radar shown as honeycombed area at right center.

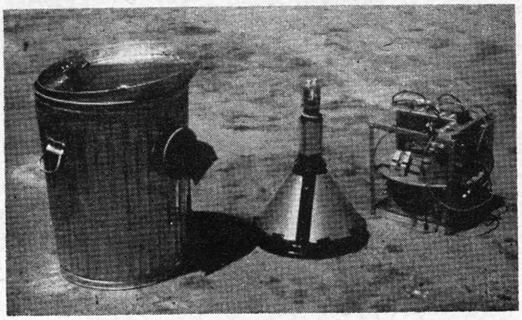

Fig. 6. Cosmic radiation equipment units to the right are contained in the ash can which is mounted in the aircraft instrument bay.

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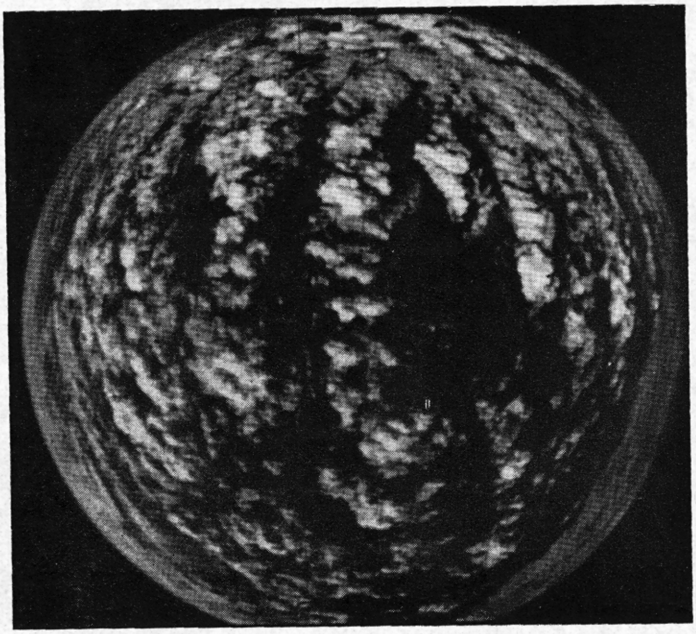
Figure 6 shows the cosmic radiation measuring equipment used as a separate package.

For correction and conversion of indicated values to basic data, it is necessary to perform calibrations of all instruments. These calibrations can be divided into two types: ground or instrument calibrations and flight calibrations. The ground calibrations can be considered conversions from a measurement of some effect to a corresponding value of the desired parameters; e.g., the measurement of temperature is based upon the electrical resistance of a thermistor which varies with temperature. Ground calibrations relate a specific resistance to a specific temperature.

Flight calibrations are the type made to determine the effect of the motion of the aircraft on the measurements; e.g., in the measurement of ambient (free air) temperature, the temperature at the sensing point is increased by the speed of the aircraft. Calibration is necessary to determine the factor used in correcting the indicated temperature to obtain ambient temperature. Flight calibrations are performed to correct measurements of: temperature, true air speed (and, effectively, wind speed and direction), pressure altitude, and indicated air speed.

At the present time, many flights have been performed successfully using selected portions of the equipment. It is anticipated that operation of the complete system will become routine in the near future. Data obtained by this aircraft will be corrected and tabulated in booklet form and made available for exhaustive studies by all interested meteorologists. The booklet will contain all information pertinent to the particular flight, including a flight path, weather maps, tabulated data, and graphs of the various parameters.

In summary, it can be stated that measurements of any atmospheric phenomenon of the troposphere or lower stratosphere and larger than a few miles can be obtained by use of the system described above. Comparatively speaking, one is able to bring a microscope to bear in studying meteorological problems of practical importance and of broad scientific interest.



Left.

Fig. 7. Black and white sample of a 16mm color photograph taken with wide-angle time-lapse camera.

Right, on opposite page.

Fig. 8. Sample of consecutive photographs taken with the 70mm camera.