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METEOROLOGICAL SATELLITES AND SOUNDING ROCKETS

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Space exploration has added a new dimension to weather reporting.

Meteorological satellites photograph the earth's cloud cover and measure infrared (heat) radiation. Sounding rockets carry weather instruments into nearby space and transmit their readings to ground stations. The result: more data from more areas; better information for reporting and forecasting.

The NASA meteorological projects are experimental and developmental, but the information gathered by spacecraft has already been put to practical use as a supplement to conventional types of weather reporting, and as a basis for studies which will advance meteorological science.

TIROS I, the first meteorological satellite, was launched from Cape Kennedy (then Cape Canaveral) on April 1, 1960, giving the weatherman his first long-term observing eye in space. Traveling in a nearly circular orbit about 450 miles from the surface of the earth, TIROS I photographed cloud patterns with a vidicon (TV) camera and transmitted its pictures to ground receivers. Fitted together into a mosaic the TIROS pictures graphically portrayed great cyclonic systems which had first been revealed by reports from ground stations, interpreted by meteorologists.

Supplementing ground reports, the TIROS I pictures provided information for areas of the world from which surface reports were meager. The pictures were especially useful in charting the origin and progress of hurricanes.

TIROS I stopped transmitting at the end of June 1960. During 1,302 orbits of the earth, it sent back 22,592 pictures, plus information of other types from other instruments.

Since TIROS I's dramatically successful demonstration, other TIROS spacecraft have gone into orbit, and a next generation weather satellite called Nimbus has been developed and launched. Still others are in development.

NASA's Meteorological Program

TIROS and Nimbus are parts of a broad program to develop space technology in both satellite and sounding rocket systems, to explore and understand the atmosphere, and to help in analyzing and forecasting the weather.

The program will apply satellite and sounding rocket techniques (and others which may be developed) to exploration of the atmosphere at higher altitudes. It will extend into interplanetary space for study of extraterrestrial influences on the atmosphere, including the sun's radiation of solar particles. Observation techniques, methods of analysis, and interpretations developed for atmospheric research on earth also are likely to be useful in exploring the atmosphere of other planets.

In this booklet, the program will be examined in terms of (1) the meteorological satellites, TIROS and Nimbus, (2) the sounding rockets, and (3) new and improved measuring and sensing instruments which function as the weather observer's "eyes and ears" aboard the satellites and rockets.

TIROS

The name "TIROS" is an acronym for Television Infrared Observation Sat-

TIROS AND NIMBUS

ellite. The satellite itself is comparable in size and shape to a bass drum about 20 inches high and 42 inches in diameter; it weighs about 300 pounds. Figure 1 shows its general interior structure and identifies the main components. Figure 2 shows the area covered by its two TV cameras when the satellite is at its normal orbital distance. Here is the method of operation of the "first generation" satellites, TIROS I to TIROS VIII:

Under radio command from ground stations, timers in the satellite activate the cameras. An electron beam converts each picture forming on the camera's vidicon tube into a TV-type signal which can either be transmitted directly to a ground station or stored on magnetic video tapes for later transmission. The tapes can store up to 96 pictures (48 per camera) during each orbit. On ground station radio command, the tapes "play back" the pictures; the satellite telemetering apparatus transmits the stored TV signal to ground receivers which pick them up and reconstruct the pictures. The process automatically erases the tapes, which rewind in preparation to record more pictures during the next orbit.

Besides making TV photographs of cloud cover and transmitting them to ground stations, TIROS measures and transmits data on infrared (heat) radiation from the earth. The infrared measurement instruments, called radiometers, feed their signals into small tape recorders, which on radio command play back the information to ground receivers. The infrared radiation data show how the sun's energy is absorbed and reflected by the earth's atmosphere. Scientists know how much of this radi-

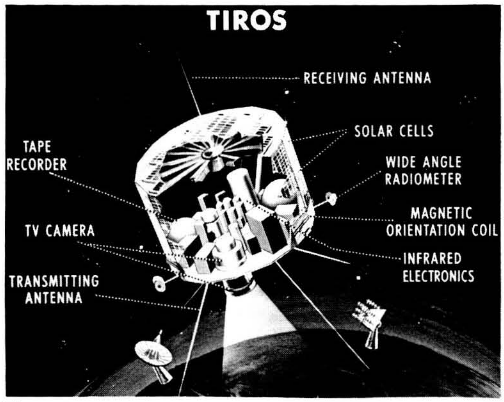


Figure 1

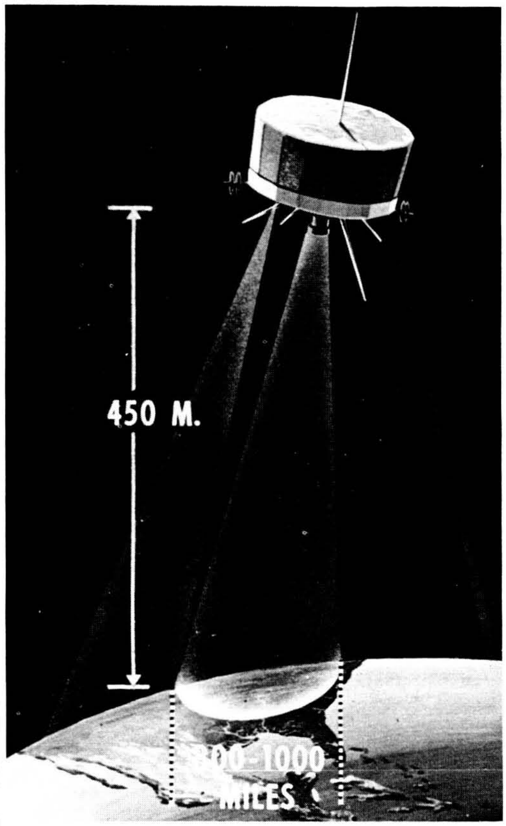
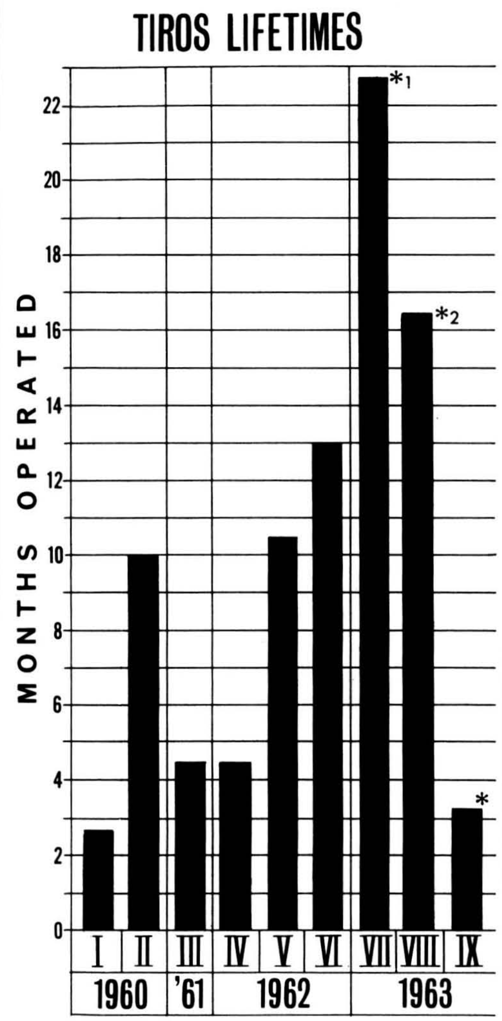


Figure 2

TIROS SENSORS

- ★ TWO TV CAMERAS — CLOUD COVER
- ★ MULTI-CHANNEL SCANNING RADIOMETER
  - WATER VAPOR — NIGHT CLOUDS
  - REFLECTED SUNSHINE — EMITTED HEAT
  - LOW RESOLUTION CLOUD MAPPING
- ● NON-SCANNING RADIOMETERS
  - TOTAL RADIATION
  - THERMAL RADIATION



NUMBER OF PICTURES TAKEN

I	22,952
II	36,156
III	35,033
IV	32,593
V	58,226
VI	66,674
VII	97,892
VIII	66,912
IX	38,943

*-AS OF 30 APR 65

1-STILL OPERATING

2-SUCCESSFULLY LAUNCHED 21 DEC 63

Figure 3

ation the earth receives. Hence, on the basis of TIROS data for infrared reflection and reradiation, they can estimate how much the earth retains and evaluate its effect on weather.

Unlike the cloud cover pictures, which are immediately usable in day-to-day meteorological studies and forecasts, TIROS infrared radiation data must be reduced, analyzed, and plotted. Thus they cannot be made available quickly enough for forecasting. Eventually infrared nighttime cloud cover maps will supplement the daytime TV pictures for operational use. (See Nimbus, page 8).

TIROS uses solar energy to power its operation. Its 9,000 solar cells convert the sun's rays to electricity, operating the satellite's equipment and recharging the nickel-cadmium batteries which power the satellite when it is in the earth's shadow.

TIROS Types

TIROS I to VIII have essentially been developmental spacecraft, intended not only to furnish meteorological data but to advance the "state of the art" in design and operation of meteorological satellites. Figure 3 shows graphically how the durability of TIROS satellites has increased. TIROS I, intended chiefly to demonstrate the feasibility of the meteorological satellite idea, orbited for two-and-a-half months; TIROS VI lasted 13 months; TIROS VII—23 months in orbit—was still going strong as these words were written. TIROS VIII, launched in December 1963 was also still operating.

TIROS VIII, a relative newcomer launched on December 21, 1963, incorporated a new feature—automatic picture

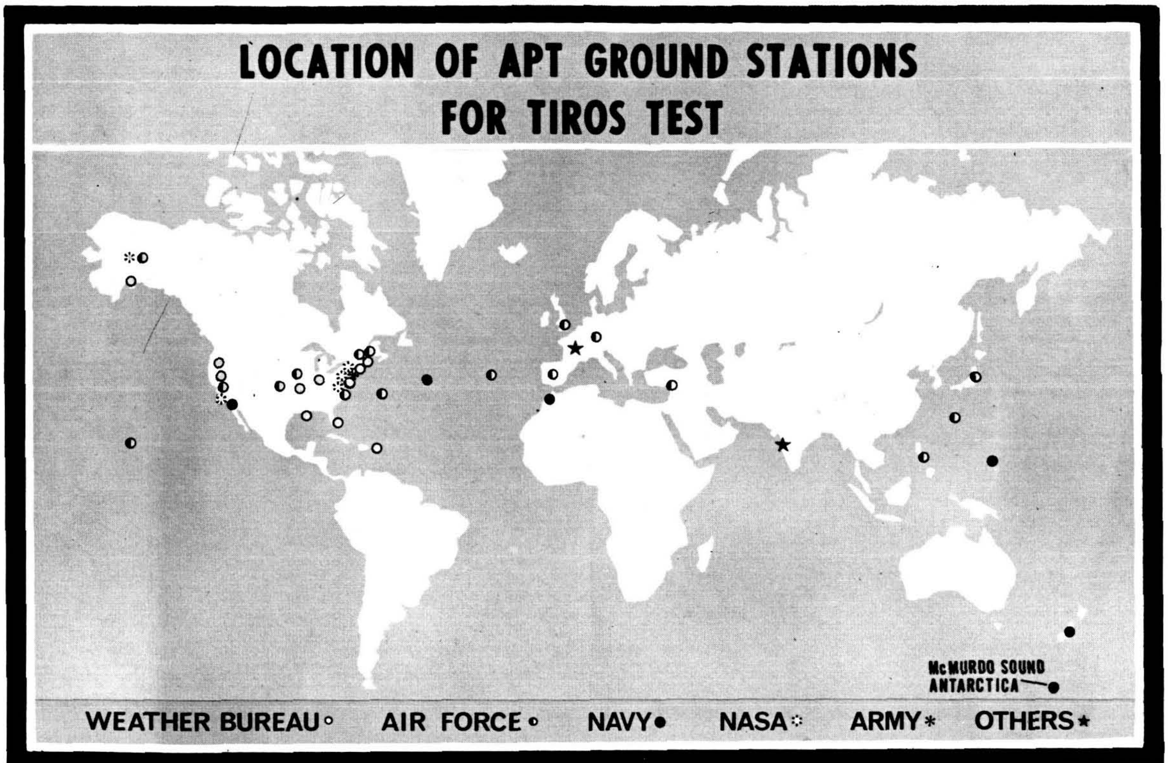
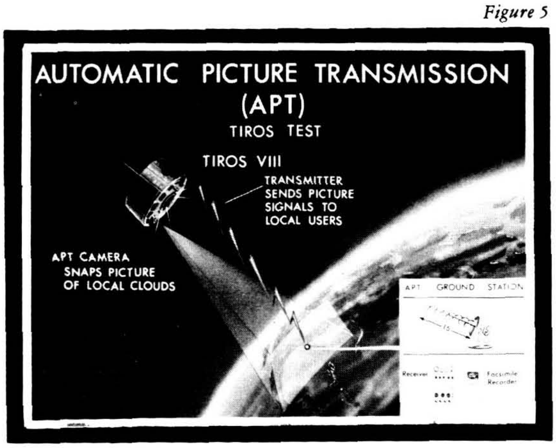


Figure 4

transmission, or APT. APT permits any ground station within radio range of the satellite to receive a picture of the local cloud cover. Relatively low in cost (around $30,000 each), about 50 APT receiving sets have been purchased by Government agencies such as the Weather Bureau and the Defense Department, as well as by the International Indian Ocean Expedition, the French Government, and similar organizations. Using a much slower TV scan process than earlier TIROS satellites, the APT System sends signals to facsimile recorders similar to those used in recording photographs transmitted by wire or radio. Figure 4 shows the current APT stations. Figure 5 shows the elements of the APT system in simplified form. (The TIROS VIII APT camera stopped producing useful pictures in May 1964.)

Figure 5



TIROS IX represents further steps in the evolution of improved operational meteorological spacecraft. TIROS IX, which was launched on January 23, 1965, is designed to photograph the entire area of the earth directly beneath the satellite, as opposed to earlier TIROS models whose cameras, mounted on a flat base

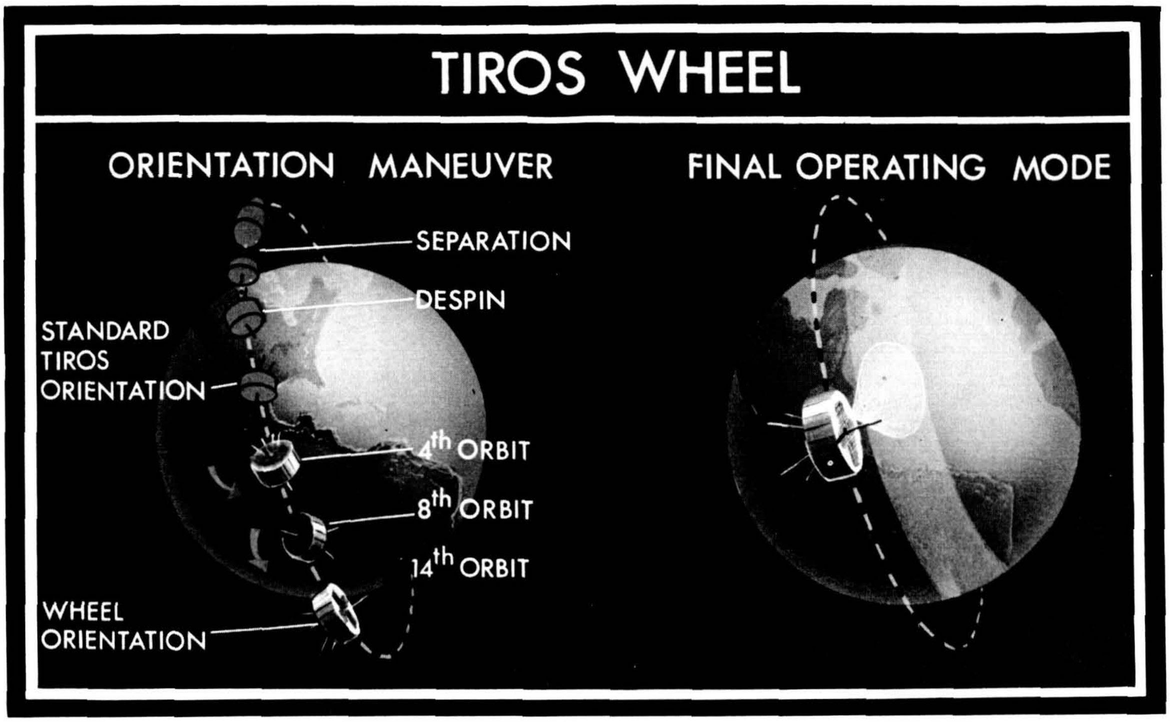


Figure 6

plate and pointed parallel to the satellite's spin axis, could take effective pictures only when the base was pointed toward the earth—about 25 percent of each orbit.

TIROS IX was launched into a near-polar orbit designed for viewing the earth from its side, turning like a wheel at 10 rotations per minute, as if it were rolling along its orbit (see Figure 6, left-hand view). Two cameras 180 degrees apart each view the earth once during a revolution. (See the right-hand view in Figure 6).

This arrangement allows the satellite to photograph the cloud cover of the entire earth at the maximum rate of one picture every 32 seconds. The orbit is sun-synchronous, meaning that the satellite passes over the same point on the earth at approximately the same time each day.

(The same techniques are planned for use in the TIROS Operational Satellite (TOS), projected for the U.S. Weather Bureau's informational system. While the spacecraft to be used in the TOS system will be based on the TIROS wheel configuration, it will use the automatic picture transmission (APT) camera and Advanced Vidicon Camera System (AVCS) developed for Nimbus.)

What TIROS Has Achieved

Since April 1, 1960, nine experimental meteorological satellites of the TIROS series have been launched and operated, all of them successfully. The results to date of this program may be summarized as follows:

1. It has proved the feasibility and value of using spacecraft for meteorol-

ogy—both in research and in weather observation and forecasting. The original concept has, in fact, proved to be so sound and flexible that it has been possible to include functions far beyond those originally contemplated. Moreover, the first operational weather satellite will be, essentially, a modified TIROS.

2. As a data gatherer, TIROS has furnished entirely or contributed to the basic information for more than:

a. 450,000 usable cloud cover pictures.

b. 13,000 cloud cover analyses.

c. 1,510 special storm advisories.

d. 665 weather analysis improvements.

e. 25 hurricanes.

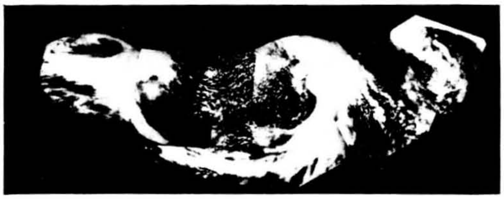
f. 50 typhoons.

Figure 7 shows a mosaic (spliced-together set) of TIROS photographs, and a weather map superimposed on it. Figure 8 shows an APT picture and a weather map which includes the photographed area. (The crosses in the photograph are reference marks.)

3. It is difficult to evaluate the "social usefulness" of any invention or technological advance. In the case of meteorology, however, it is possible to state that annual savings running perhaps into the billions of dollars might result from accurate weather predictions five days in advance.

TIROS has contributed materially to achieving these savings; it has also saved lives through its improved information on approaching hurricanes. Information from TIROS III in September of 1961 gave warning of Hurricane Carla in time to make possible the largest mass evacuation ever to take place in the United States. More than 350,000 people fled from the path of the storm, and only a relatively small number of

STORMS AND FRONTS
A Family of Weather Systems



MOSAIC OF TIROS PHOTOGRAPHS

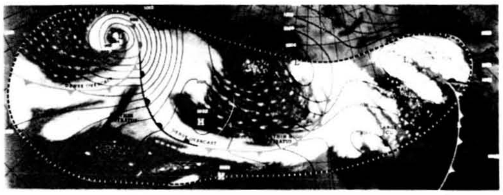
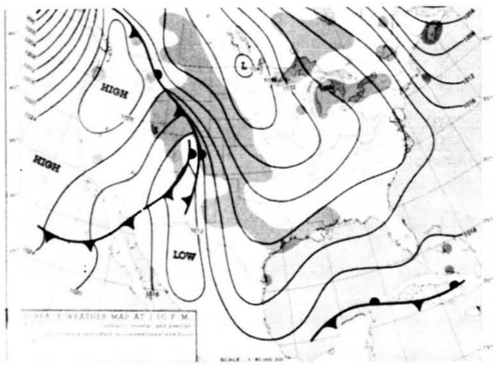


Figure 7

WEATHER MAP, MAY 20, 1960, WITH TIROS CLOUD DATA

FIRST FLIGHT DEMONSTRATION
Automatic Picture Transmission (APT) Subsystem
TIROS VIII, 21 Dec. 1963



WEATHER MAP SHOWING STORM SYSTEM NORTHWEST OF LABRADOR

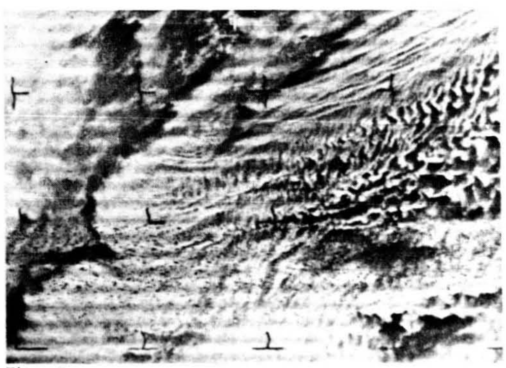


Figure 8

APT PICTURE SHOWING CLOUD STRUCTURE AROUND STORM

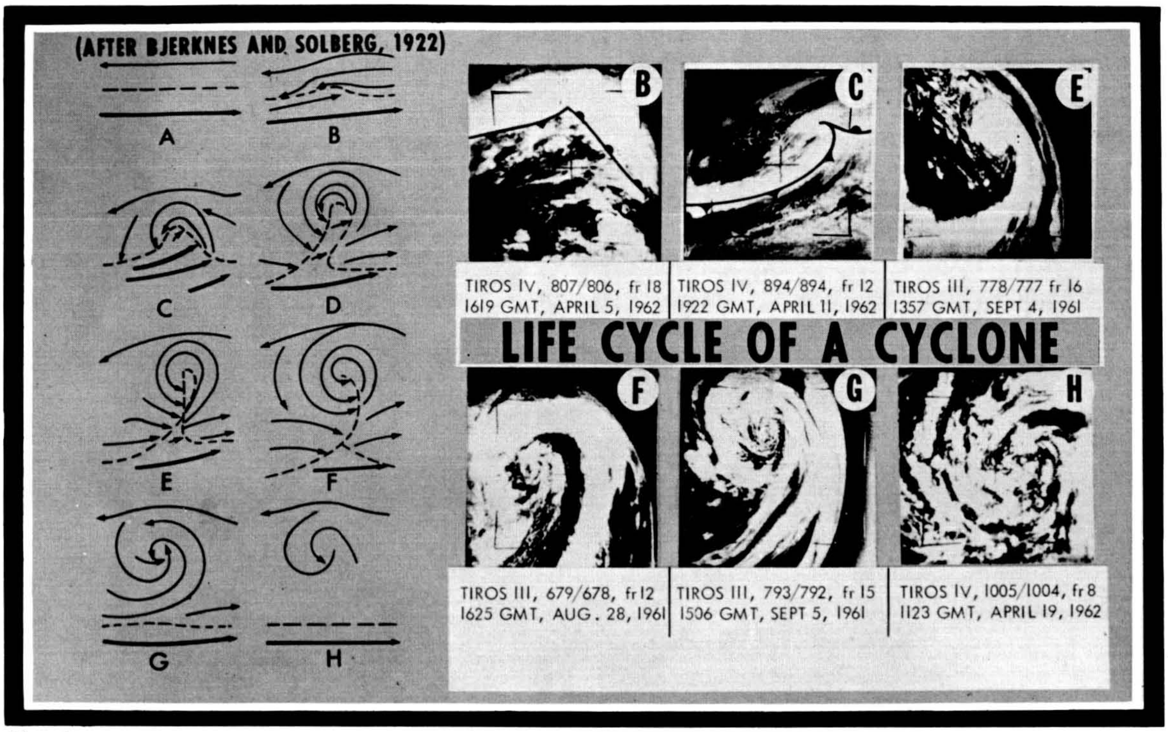


Figure 9

deaths was attributable to Carla as it swept across the country.

The TIROS program has demonstrated the global value of space research through the usefulness of its weather information, and as a working example of international cooperation both in space and on the earth.

4. In the science of meteorology itself, the TIROS program has confirmed earlier theories and provided the groundwork for improved weather theory. An interesting case in point is the theory of cyclone development advanced jointly by Jacob Bjerknes, a Swedish scientist who pioneered in the area of synoptic weather observations, and his American associate, Harry Solberg, a specialist in the study of high-pressure steam viscosity. Figure 9 shows, on the left, stages in the development of a cyclone as formulated theoretically and sketched by Bjerknes and Solberg in 1922. On the right are selected TIROS pictures with cloud patterns so similar in configuration that the two authors might have used them as models for their diagrams. (In the figure, corresponding letters identify the diagrams and photographs.)

The TIROS pictures not only confirm the Bjerknes-Solberg hypothesis but enable weather analysts to predict the future of cyclones, including typhoons and hurricanes, which are the most violent of the great spirally-moving storm systems characteristic of the earth's temperate and subtropical zones.

Nimbus

"Nimbus," in meteorology, is a rain cloud formation which covers the entire sky. Applied to meteorological satel-

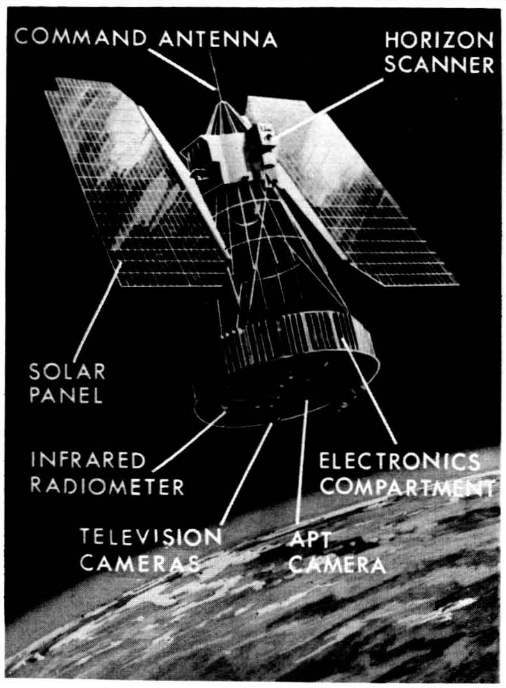


Figure 10

NIMBUS

GROSS WEIGHT	835 LBS
SENSOR WEIGHT	150 LBS
PEAK POWER	470 WATTS
STABILIZATION	ACTIVE 3 AXIS
DESIGN LIFE	SIX MONTHS TO ONE YEAR
LAUNCH VEHICLE	THOR-AGENA B
ORBIT	APOGEE-574 MI. PERIGEE-263 MI. PERIOD-98.2 MIN. INCLINATON-98°
FIRST FLIGHT	AUGUST 28, 1964

lites, the name designates a second generation satellite: Nimbus I was launched on August 28, 1964.

The basic objectives of the Nimbus development program have been:

1. To design, build, launch, and operate a fully-instrumented, earth-oriented meteorological laboratory in space.
2. To furnish operational meteorological data.
3. To furnish research data to advance the atmospheric sciences.

In general, these objectives resemble those of TIROS, except that Nimbus was not required to demonstrate feasibility, and its "full" instrumentation makes it more versatile.

Nimbus—larger, more complex, and more flexibly-designed than TIROS—lacks the simple TIROS shape and is more highly departmentalized than its predecessor. Figure 10, which also gives some of Nimbus' vital statistics, shows its principal features, a sensory ring below and a stabilization-control assembly above, connected by an open tripod type framework. Attached to the stabilization-control assembly, somewhat like a pair of wings, are two solar panels (sometimes called paddles) covered with solar cells to produce electric power. The panels are designed to rotate so as to face the sun whenever the satellite is in sunlight. The stabilization-control unit keeps the cameras on target by orienting the satellite so that the sensory ring faces the earth at all times and the solar paddles are at right angles to the orbital path.

The sensory ring, which contains the cameras, sensors, and experiment apparatus, is "modular," meaning that its design provides for easy interchange of units. An individual instrument such

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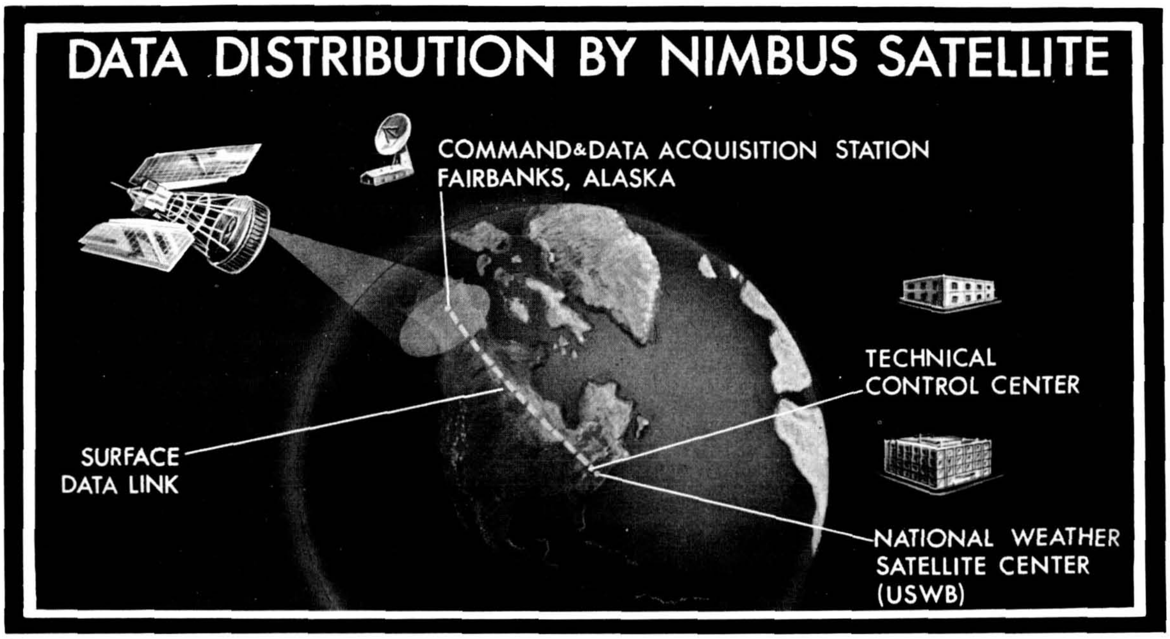


Figure 11

as a camera, for instance, can easily be removed and replaced by an improved version. The principle applies to the remainder of the satellite as well, so that all principal elements are replaceable without major redesign.

In its original design (NIMBUS I), the satellite has an advanced vidicon camera array, a high resolution infrared radiometer (HRIR), and an automatic picture transmission (APT) system.

The advanced vidicon system uses three cameras. These are so arranged that their combined field of view is about 1,600 miles wide. Their resolution (the actual size of the smallest feature which can show up on the picture) is about one-half mile when the satellite is in its specified orbit. The camera records its cloud cover pictures in daylight on magnetic tape for readout on command from earth, (i.e., transmission when a signal is given).

HRIR gives Nimbus a capability which no TIROS has had. With HRIR, Nimbus can, in effect, make nighttime photographs of cloud cover with a resolution of about five miles. As with the vidicon system, HRIR data are recorded on magnetic tape for readout upon command.

Vidicon and HRIR data are transmitted, on radio command, to the Command and Data Acquisition station in Fairbanks, Alaska. Fairbanks retransmits them to NASA Technical Control Center in Greenbelt, Maryland, thence to the Weather Bureau for use in weather analysis and forecasting. (See Figure 11).

The APT system, which has its own camera, independent of the advanced vidicon cameras, is the same as the APT facsimile transmission system flight-tested aboard TIROS VIII. Its signals, whenever Nimbus is within radio range, are available to any ground station suitably equipped to receive them and reproduce the cloud cover photograph facsimile.

Nimbus I had a short but useful life. Approximately three weeks after its launch, it was discovered that its solar paddles had failed to maintain orientation to the sun. During its lifetime, however, it had recorded:

Number of AVCS pictures (individual frames)	12,137
Estimated number of APT cycles	1,931
Minutes of HRIR Data	6,881

Data from the Automatic Picture Transmission System

About nine hours after Nimbus was launched from the Western Test Range, the pictures in Figure 12 were transmitted by APT. They show Texas on the left in the lower picture and the circulation around Hurricane Cleo on the right. In the center, down the middle of the United States, there is a well-defined cold frontal system. The weather map is shown at the right, with the area corresponding to that of the pictures enclosed. The correlation between the frontal system shown on the weather map and pictures by the APT system is considered to be unusually good. Weather Bureaus in Boston, New York, Suitland, Md., and San Francisco received this first transmission and quickly expressed enthusiasm for the high quality and value of the pictures.

The full potential of the APT system was graphically illustrated the following day by photographs received from two passes of the satellite over the Eastern Coast of the United States. Figure 13 shows these two passes as a gridded mosaic. The extent of the APT coverage is demonstrated by the fact that the pass to the left covers a strip from Venezuela to Canada, with contin-

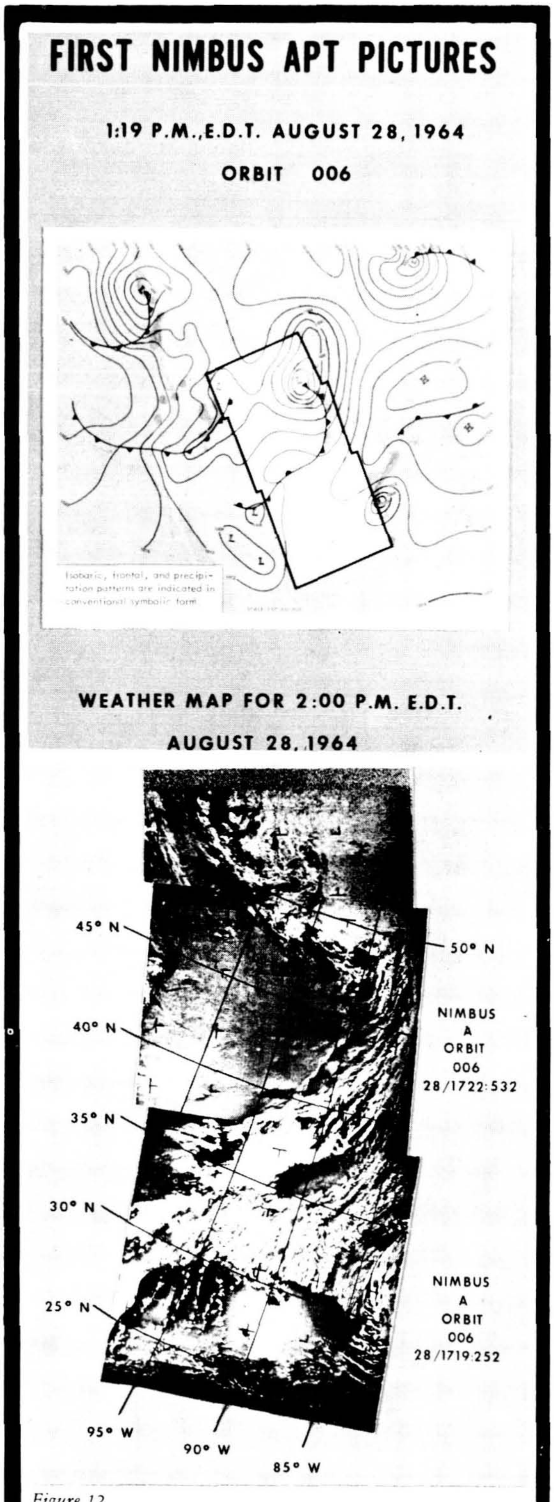


Figure 12

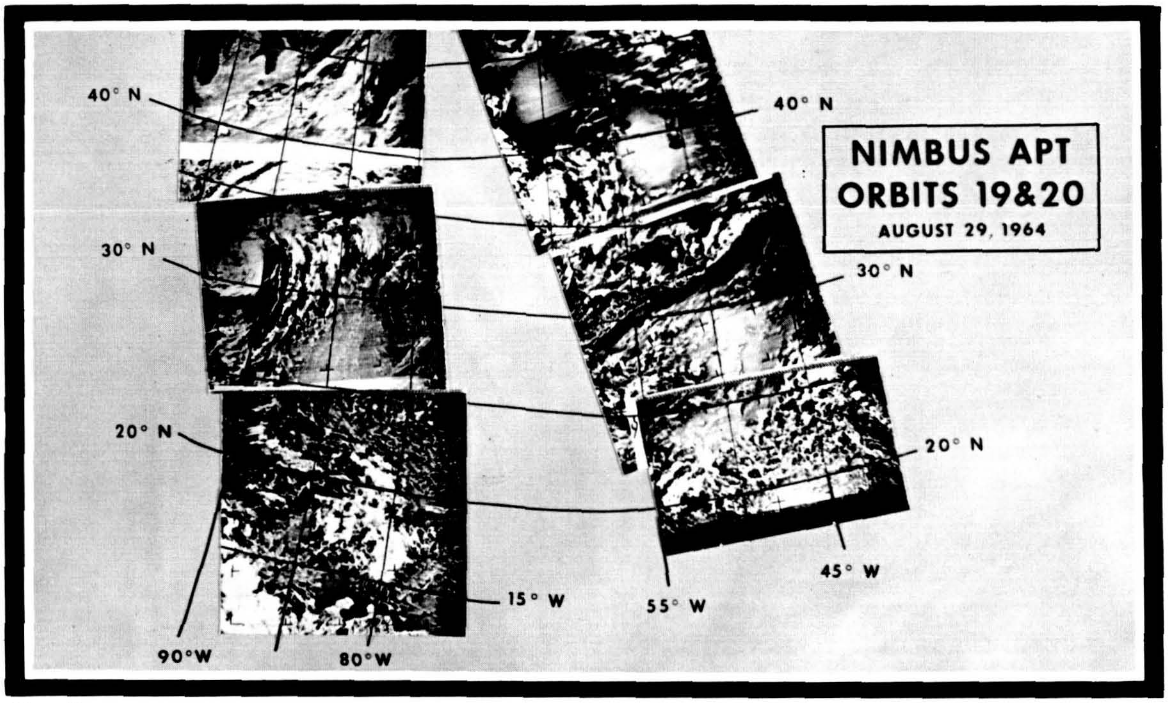


Figure 13

Figure 14

uous overlap of the pictures. The two passes together demonstrate the vast area which can be viewed—from the western part of the Atlantic to the middle of the continent. This represents a span of 45 degrees—one-eighth of the distance around the world. Such geographic features as Cuba, Florida, and the Great Lakes stand out clearly in this high resolution picture, as do Hurricane Cleo and cloud bands over the northeastern part of the United States.

Under optimum conditions, three passes can be acquired by any one station—one overhead and one to each side.

Data from the Vidicon Camera System

Figure 14 demonstrates some of the advances made with the Advanced Vidicon Camera System (AVCS). This picture covers the border area of Afganistan and the Soviet Union, along tributaries of the Amu-Dar'ya River, shown at upper left. Of special interest is the fact that the picture was received at Goddard Space Flight Center already gridded with latitude and longitude lines on it. This information is provided by a computer using the satellite's orbital and attitude information when the picture is taken. The consecutive black and white dots delineate the latitude and longitude. In the light areas of cloudiness in the lower part of the picture, the black dots stand out; in cloudless areas where the photograph is dark, the white dots appear. The computer also prints out the latitude and longitude of a specific intersection on the photograph, indicated by the arrowhead in the center of the photograph—in this case, 36 degrees north latitude and 66 degrees east longitude (upper left in picture).

The original objective of the AVCS, providing total global cloud cover, would have been achieved had the orbit been sufficiently close to the one intended. The extent to which it was achieved, particularly at apogee, is demonstrated by a group of AVCS pictures taken over Western Europe (See Figure 15). Each triplet of the group represents the pictures taken by the three cameras aboard the satellite, covering an area more than 1,400 miles wide and approximately 500 miles deep, along the orbital path.

Data from the High Resolution Infrared Radiometer

The high resolution infrared radiometer (HRIR) is a new system, first tested on Nimbus I. It was developed to provide pictorially, on a real time basis (instantaneously transmitted to the ground), cloud cover information from the dark side of the earth.

HRIR measures the intensity of infrared radiation from the cloud tops;

Figure 15

NIMBUS AVCS PICTURES

1. IRELAND
2. BREST
3. BAY OF BISCAY
4. PYRENEES MTS.
5. GIBRALTAR
6. ORAN
7. SAHARA
8. SCOTLAND
9. LONDON
10. CHERBOURG
11. I DE MALLORCA
12. SARDINIA
13. TUNIS

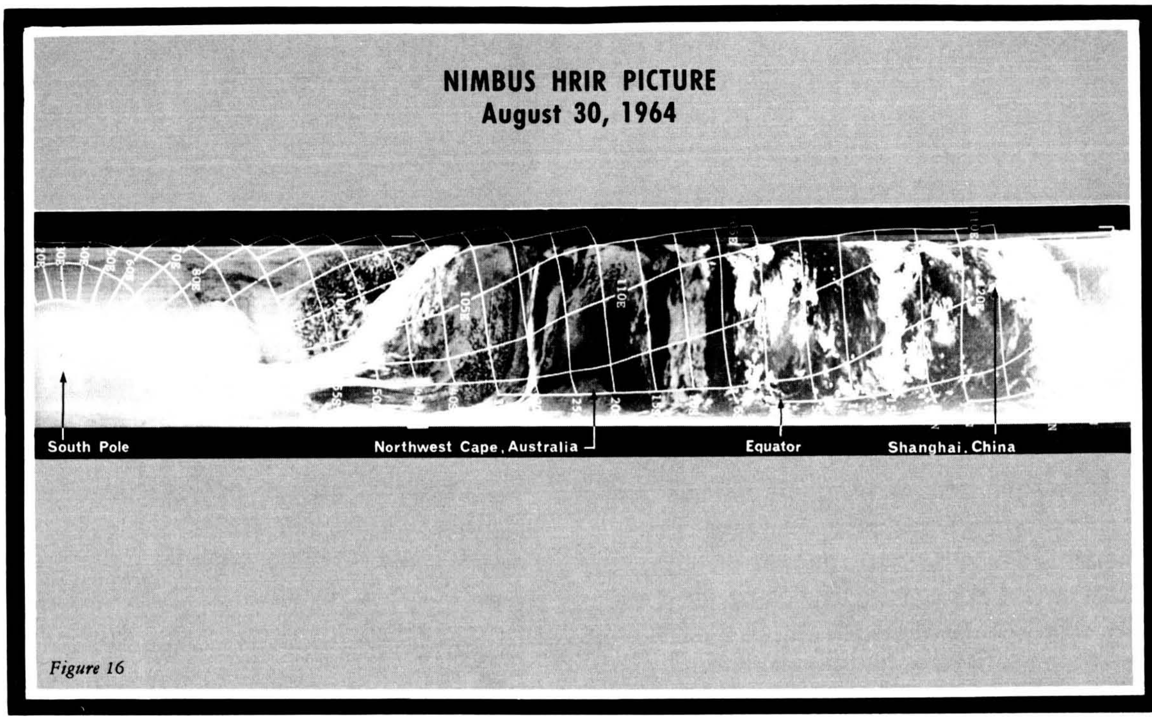


Figure 16

in effect it takes temperature readings at the different levels. The rate at which the temperature changes with increase in altitude can be approximated, hence, the differing levels of infrared radiation provide a basis for estimating the height of the clouds.

It is necessary not only to have the information as to where clouds are located and how high they are, but to have this information displayed quickly, in usable form. The procedure is this: Different intensities of radiation are expressed in shades of gray on a map so that higher levels of radiation emitted by warmer surfaces (e.g., the surface of the earth), appear as dark grays, and the lower levels of radiation coming from colder surfaces (e.g., cloud tops) appear as lighter shades. In this manner, the clouds appear white over a dark background, and higher clouds appear whiter than lower clouds.

Figure 16 shows a pass recorded by the HRIR from the South Pole to the area of the Yellow Sea. The quality of these pictures is equivalent to the quality of the TIROS vidicon pictures. Since each pass appears as a strip, HRIR provides a continuous scan as the satellite moves forward. This pass, reading from south on the left to north on the right, shows a cold front coming out of the storm center of Antarctica. The western tip of Australia, the tropical clouds in the mid-Pacific, and the Shanghai area of China are visible.

Future Nimbus Components

The value of the Nimbus has been proved by the satellite's successful launch and operation. A number of new elements probably will be included in subsequent Nimbus spacecraft (see Figure

17). Nimbus B (which will be the third Nimbus to be launched) for instance will carry a number of new devices to explore further the composition of the earth's atmosphere and various meterological phenomena.

One group of experiments will be designed to determine how temperature and density of the air vary with altitude under differing conditions such as changes in seasons, the position of the sun and many similar factors.

Another group of experiments is designed to explore the capabilities of satellites to collect data from sensor platforms (such as balloons or buoys).

Still another group of devices will explore further the ability to correlate readings obtained from satellites with all of the atmospheric conditions which might affect those readings. Measurements have no value unless it is known what conditions pertained when the readings were taken—that is, what effect the sun, wind, cosmic rays, and other phenomena were having upon the sensing devices. When known effects of those factors are correlated with the satellite readings, reliable information will result.

Finally, Nimbus B will contain still more advanced instruments to experiment further with the tracking and identification of storms.

Figure 18 shows one of the components—the interrogation, recording and location subsystem (IRLS). While the spectrometers and interferometers on the satellite will measure the temperature structure of the atmosphere from a distance, this system will collect similar information from instrumented platforms in the atmosphere and on the earth; the satellite in turn would relay the informa-

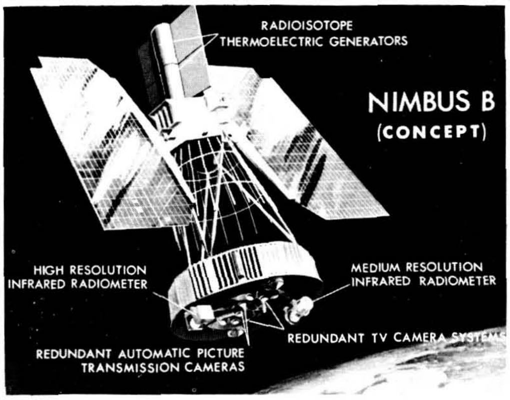


Figure 17

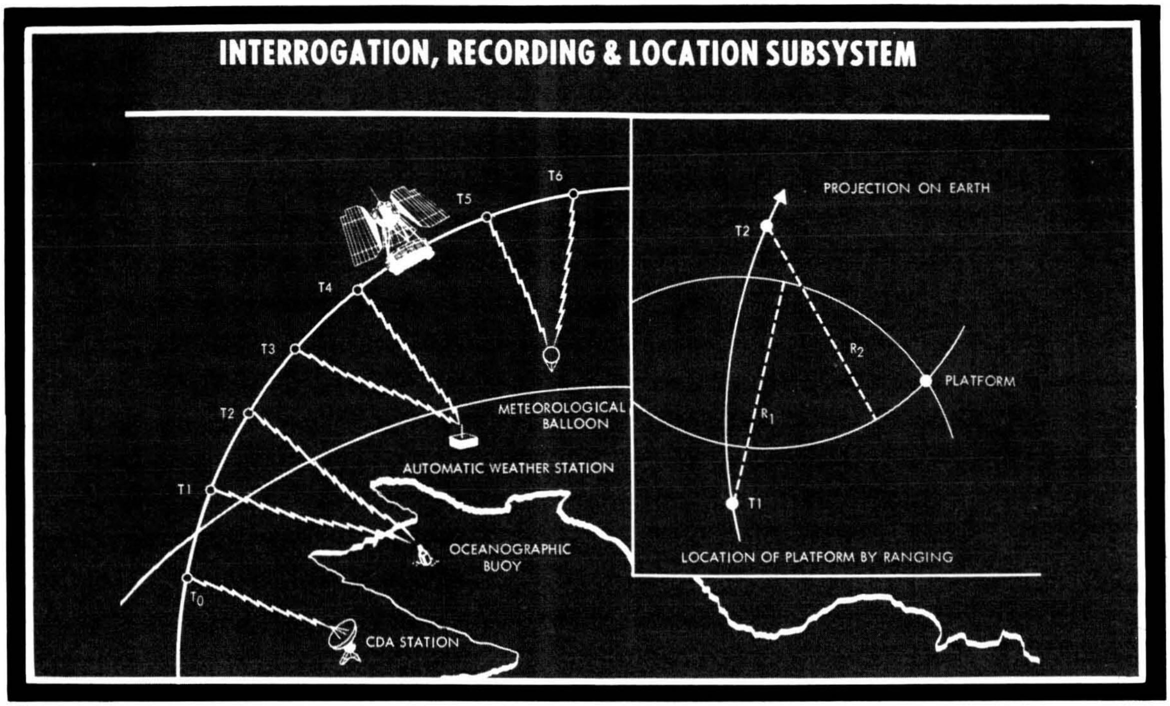


Figure 18

tion to the command and data acquisition stations as it travels within their range during each orbit.

The location of the platform is determined as illustrated in the inset of Figure 18. The satellite would interrogate a platform, such as a balloon, weather station or ocean buoy; the delay in response would determine the platform's distance from the satellite's position. This distance is represented as the radius of an arc around the satellite. Then a second interrogation is made, another arc projected, and the location of the platform will be at the intersection of the two arcs.

METEORO-LOGICAL SOUNDING ROCKETS

When he was pioneering in rocketry shortly after World War I, Dr. Robert H. Goddard suggested that high-altitude rockets would play an important role in upper-atmospheric research. After the end of World War II, when surplus V–2's and other large rockets became available, it was in such research that rockets made their first scientific contributions.

NASA's role in using rockets to explore the upper atmosphere is not the kind of trail-blazing achieved by TIROS. Rather, the program is directed toward refining the techniques for such exploration, and for investigating the structure and characteristics of the upper atmosphere—from an altitude of 20 to 60 miles and above. It concentrates on improving the reliability and economy of the rockets and eliminating the need for special launching facilities such as elaborately-equipped pads.

The term "sounding rocket" is an analogy derived from the traditional soundings made by sea vessels in uncertain waters. The meteorological sounding rocket program is divided into two areas—small rocket vehicles like ARCAS or LOKI (see Figure 19) and large rockets like the NIKE-CAJUN. The program calls for development of a small meteoro-

Figure 19

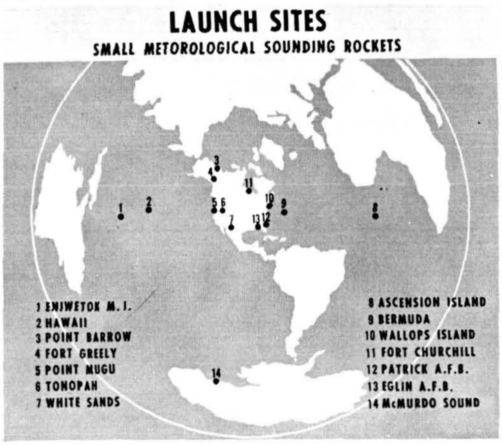


Figure 20

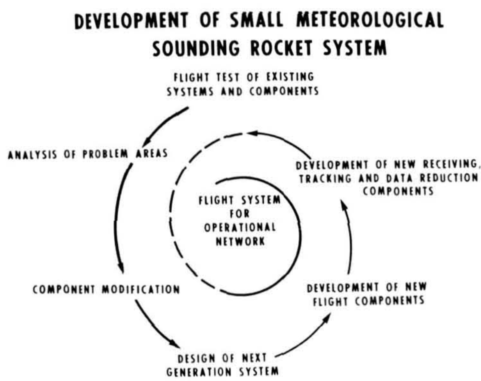


Figure 21

logical sounding rocket system, including sensors and associated ground equipment for smaller rockets, and development of techniques for upper atmospheric exploration by larger rockets.

Small Meteorological Sounding Rocket Development

Small meteorological sounding rockets such as those launched by NASA and other U.S. agencies in recent years (see Figure 20) perform varied functions. Some release "atmospheric indicators" such as spherical radar reflectors or chaff (metal needles which will show up on radar screens) so that tracking radar can observe how upper altitude winds affect the indicators as they fall. Others may parachute instruments which measure wind, temperature and pressure; as these instruments float down, miniature transmitters telemeter their findings to ground stations.

Even though some of the techniques are still experimental, research by sounding rocket indicates that the dynamic region from 20 to 60 miles up may act as a link between the sun's energy and the weather of the lower atmosphere. Consequently, development is underway on an inexpensive but reliable rocket system, usable either operationally or for research, to measure and furnish weather data, such as wind, temperature, density and pressure, first from 20 to 40 miles up, and eventually up to 60 miles.

Development of the system can be visualized as a spiral feedback process (Figure 21), beginning with existing components and systems. After these are flight-tested and studied, the problems

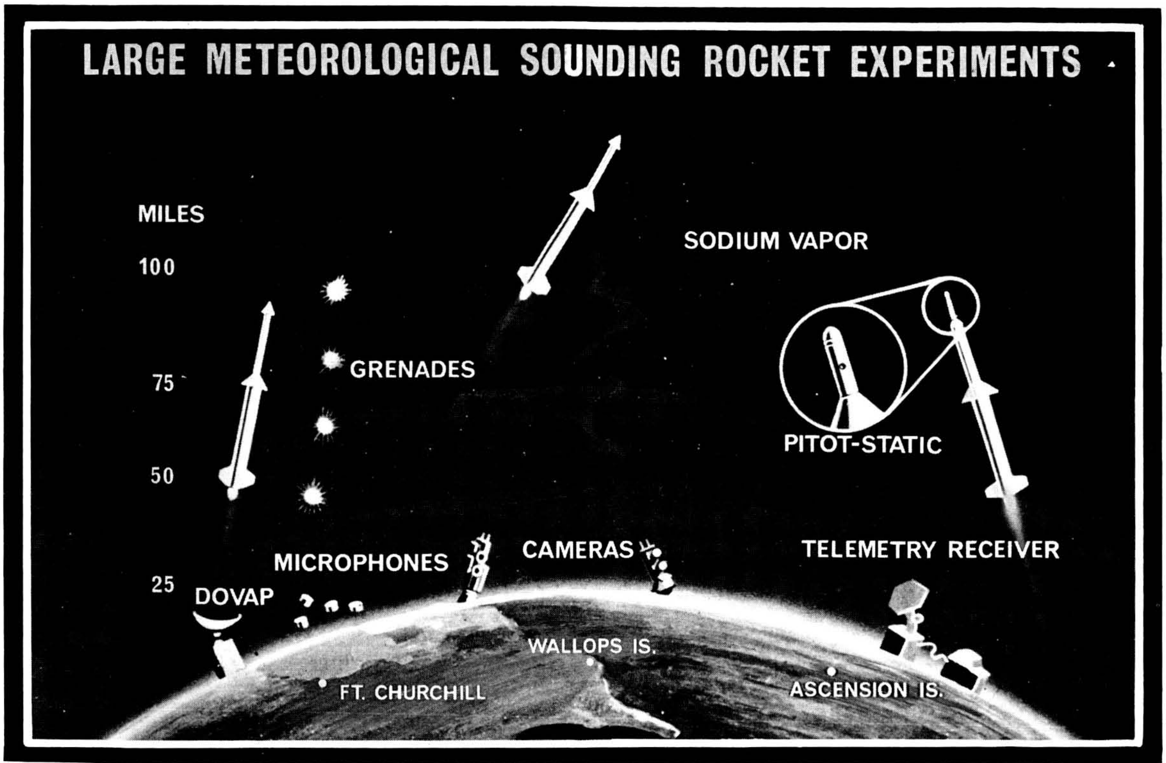


Figure 22

are identified, the solutions determined and the components modified as required. The flight-evaluation-modification cycle is repeated until an operational system is evolved.

Large Meteorological Sounding Rocket Experiments

Unlike the small meteorological sounding rocket program, which is primarily concerned with development of rocket systems, the large rocket program is devoted to improvement of experimental techniques and to actual scientific exploration of the upper air.

Figure 22 shows three experiments performed with the NIKE-CAJUN, one of the large meteorological rockets. In the first experiment, a series of acoustic grenades is ejected along the trajectory of the rocket. As the grenades explode, microphones on the ground record the instant of the sound waves' arrival. The rocket's flight is tracked by radar, and the times of the explosions are recorded by the radar and by cameras on the ground. With the time of the explosion and the time the sound waves reach the ground, it is possible to compute the wind and temperature of the intervening air, since wind and temperature affect the transmission of sound. In 1963 this technique measured the lowest temperature ever recorded in the earth's atmosphere—a reading of minus 220 degrees, 50 miles over Sweden.

In the second experiment the rocket releases a trail of sodium vapor similar to a smoke trail during the upper portion of its flight. This trail moves with the wind and the movement is recorded by cameras on the ground. The speed and direction of the wind can be measured from the photographs.

The third experiment uses pitot-static tube methods to measure ram and ambient pressures of the atmosphere. The tubes, which have long been used to measure air speeds for aircraft, operate in this way: as the rocket (or aircraft) moves forward, air is collected ("rammed") under pressure into an aperture which points forward. The amount of pressure depends upon air density and air speed. Apertures on the sides permit simultaneous measurement of ambient pressure—i.e., pressure of the surrounding atmosphere without reference to the "ram" effect. In the meteorological rocket, the instruments' indications are converted into electrical signals which are telemetered to the ground, where they are used to compute air density and pressure.

Specific problems to which these large-rocket techniques are being applied include:

1. Detection of the existence and size of meteorological circulation systems in the upper atmosphere.
2. The relation between general atmospheric circulation and sudden increases in temperature.
3. The influence of tidal forces on the atmosphere.
4. Geographical and seasonal variations in the atmospheric structure (wind, temperature, pressure, etc.).
5. Causes of unusual temperatures and rate of temperature changes at altitudes over 20 miles in the winter atmosphere.

These problems are being studied through simultaneous launches at Point Barrow, Alaska, Fort Churchill, Canada, Wallops Island, Virginia, and Ascension

MEASURING AND SENSING INSTRUMENTS

Island, and in a cooperative program with Sweden. Shipboard launches are being made in the South Pacific Ocean off the west coast of South America.

Supporting Research and Technology

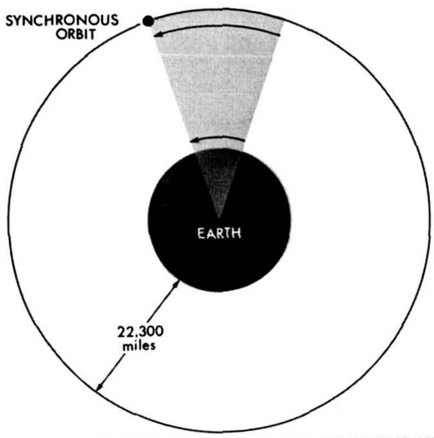
Supporting research and technology include the development of new systems to improve flight programs, as well as analysis of flight data which may help in future planning. These activities are a principal source of improvements in techniques and apparatus. A few of them are:

The Synchronous Meteorological Satellite

The closer an earth satellite's orbit is to the earth, the faster the satellite moves in its orbit. Thus, the moon, at a distance of 240,000 miles, orbits the earth in 29-and-a-half days, while astronauts, at a distance of about 100 miles, complete the trip in about 90 minutes.

At some distance between these extremes, a satellite could orbit the earth in 24 hours. If the orbit were equatorial (that is, in the plane of the earth's equator), the satellite would keep pace in its orbit with the earth's own rotation, as in Figure 23. To an observer on the earth's surface, the satellite would appear to be stationary; an observer on the satellite likewise would always see the same area of the earth's surface.

Such an orbit is circular, 22,300 miles in radius. It is called a "synchronous orbit" because it synchronizes with the length of our terrestrial day. The SYNCOM satellite, a communications



SATELLITE MOVES IN ORBIT EXACTLY AS MANY DEGREES PER HOUR AS EARTH TURNS

Figure 23

Figure 24

spacecraft, is designed to operate in such an orbit. A meteorological satellite in such an orbit would, unlike most of the satellites described earlier, be able to monitor continuously the atmosphere within its field of view.

A study already has confirmed the feasibility of using TIROS K to demonstrate the value of such a satellite.

Another study has demonstrated the feasibility of including an existing advance vidicon system aboard a SYNCOM spacecraft. The "hitchhiker" could perform some of the functions of synchronous meteorological satellites and help confirm its feasibility. Results of such an experiment could be applied in the development of meteorological flight equipment to be incorporated into the NASA Applications Technology Satellite, which will be tested at a medium altitude and in synchronous orbit.

Development of a Day-Night Vidicon

For full effectiveness, the satellite's camera must deal with variations in image brightness of a million to one—the difference between day and night. Photography of infrared radiation makes it possible to have nighttime TV pictures, but with present techniques, resolution of such pictures is inferior to that of daytime TV cameras. Day-night versatility will require tubes capable of adjusting to the million-to-one range of brightness. Such units are possible for ground operation, but no vidicon camera which can be flown is currently capable of operating unattended and obtaining satisfactory detail in both dark and light—especially if it is scanning a half-illuminated earth.

Calibration of Infrared Sensors

Infrared sensors (radiometers) were described earlier as the instruments which report temperature of clouds and the earth's surface. It is more accurate to say that these instruments measure radiation emitted by the earth and the atmosphere, and this radiation may be used to determine the temperature of clouds and the earth.

Figure 24 is a map based on radiation measurements taken during the day and night of July 16, 1961 by TIROS III.

A TIROS III photograph in the chart makes it possible to correlate the TV picture and the temperature map derived from radiation measurements. The bright isolated cloud mass in the northeastern part of the Gulf of Mexico appears on the radiation map as an isolated patch. Since the meteorologist recognizes this correlation, it is possible to infer the weather picture from radiation maps even in areas too dark to provide adequate TV pictures. Such interpretation is part of the supporting research in weather science now being developed.

IN CONCLUSION

The meteorological satellites and sounding rockets, scanning the earth from their unique vantage point, have already provided data of practical value—even though they are still in the developmental stage. Information now being obtained is proving useful as a supplement to conventional types of weather observations, as well as a basis for studies which will advance meteorological science. As more sophisticated elements are incorporated into the design of future satellites and rockets, their value will become still more apparent to the nation and the world.

Because it is global in scope, the U.S. meteorological satellite program has as one of its primary objectives the establishment of a cooperative international weather program.

An initial step in this direction occurred in November 1961, when representatives of 30 nations gathered in Washington to attend the first International Meteorological Workshop, jointly sponsored by NASA and the Weather Bureau.

The three-fold objective of the workshop was to:

1. Aquaint weather scientists of other nations with meteorological satel-

lites and the data derived from them for use in future analysis programs national observation support efforts.

2. Familiarize the world meteorology community with the TIROS program.

3. Put current achievements in proper perspective for future operational programs.

As Hugh L. Dryden, Deputy Administrator of NASA, recently said:
"There is no doubt that our meteorological programs have enhanced our national standing in the eyes of the peoples of the world. Undoubtedly in the area of meteorology, the United States is the leader in space. In the field of international cooperation, our Automatic Picture Transmission System (APT) and our cooperative sounding rocket program have been building good-will, particularly in the underdeveloped countries.

Thirteen countries have used APT sets successfully and at least 29 have expressed interest. Among others, TV stations in the U.S., a Peace Corps mission, and a technological institute in India, have indicated intent to build their own APT sets based on our designs. Cooperative meteorological sounding rocket projects are underway with Argentina, Australia, Brazil, England, India, and Pakistan. Weather data from our research and development satellites are being used regularly by our military services as well as the Weather Bureau. Soon the operational system, funded by the Weather Bureau, based on TIROS and Nimbus-developed technology, will be inaugurated."

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