X-482-69-16

NASA TM X- 63461

NASA METEOROLOGICAL AND COMMUNICATIONS SATELLITE PROGRAMS

FEBRUARY 1969

GSFC

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

X-482-69-16

NASA METEOROLOGICAL

AND COMMUNICATIONS

SATELLITE PROGRAMS

Herbert I. Butler
Operational Satellites Office

Speech delivered to members of the National Council for the Social Studies at GSFC, November 26, 1968.

February 1969

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

PRECEDING PAGE BLANK NOT FILMED.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

NASA METEOROLOGICAL AND COMMUNICATIONS SATELLITE PROGRAMS

INTRODUCTION

This year the National Aeronautics and Space Administration (NASA is celebrating its tenth anniversary. Two of its oldest programs, frequently cited as contributing most to the benefit of mankind and to the peaceful uses of outer space, are the weather-satellite and the communications-satellite programs. What are these programs? What have they done for us? What will they do for us in the future? I hope to answer these questions and others in the next few pages. I plan to give you a brief description to help you understand what these programs are, how they work, and to give you some idea of why there are so many different types, sizes, shapes, orbits, etc. I also plan to describe the capabilities and limitations of these programs and how we hope to improve the programs in the future. Through all this, I hope to convey to you a better basis on which to judge the value and potential of these programs.

The first question we may ask is, "Why do we need weather and communications satellites?" One answer is that the breakthroughs in space technology present an unparalleled opportunity to alleviate some of the most pressing problems of our time. For example, in under-developed areas of the world, improved weather forecasts could contribute directly to improved agriculture and increased food production; satellite communications could be used for education in under-developed areas where conventional educational methods are not practical.

SUPPORTING SPACECRAFT

Figure 1 shows the three major spacecraft projects that support the two programs: TOS (TIROS Operational Satellite) and Nimbus devoted to meteorology and ATS (Applications Technology Satellite) devoted to meteorology and communications. The spacecraft on the right, is marked SMS, standing for Synchronous Meteorological Satellite, a part of our program for the near future. This satellite should also be marked ATS. The ATS satellites, two of which have been successfully launched, operate in an orbit concentric with the earth's equator, approximately 23,000 miles above the earth's surface. At this altitude,

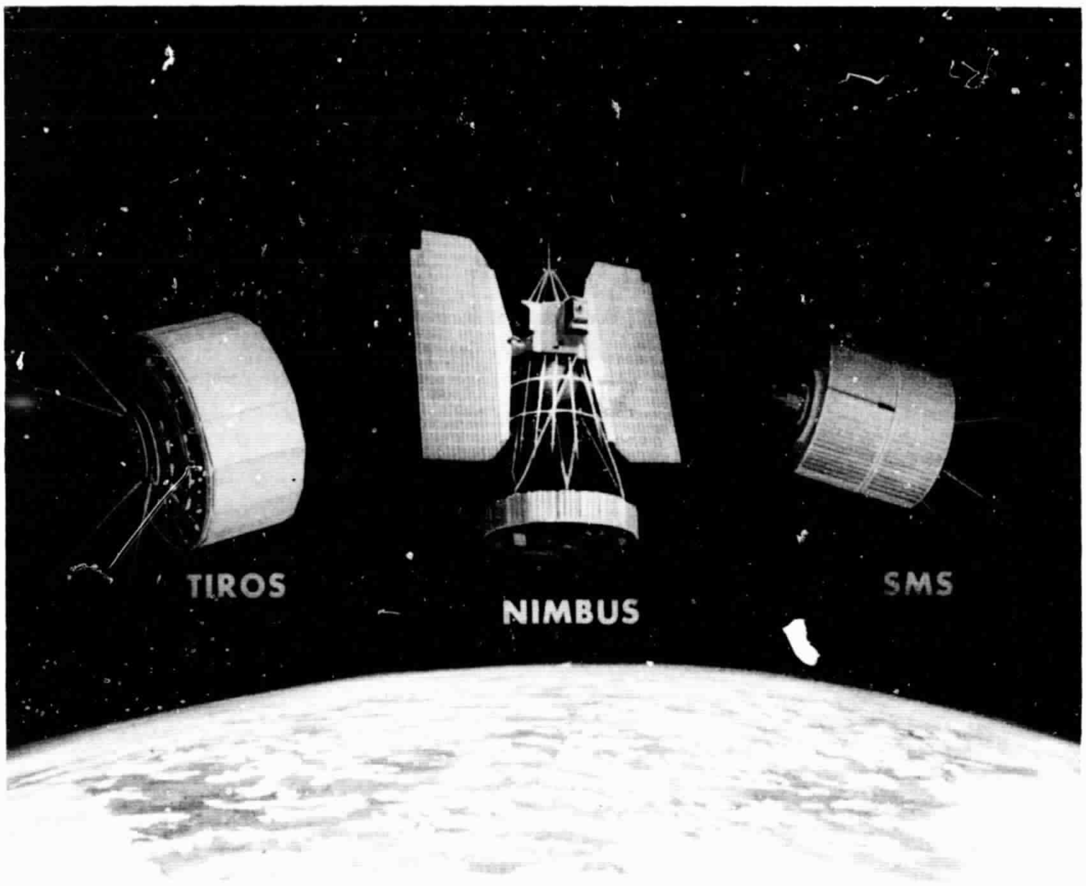


Figure 1. Meteorological Satellites

the rate of spacecraft rotation about the earth can be made to coincide precisely with the rate of the earth's rotation about its own axis. Thus, spacecraft in this orbit can hover above any given point on the earth's equator; they have been identified as earth-synchronous satellites. This synchronism makes the ATS an ideal platform to provide continuous observation of the earth's weather and also to serve as a communications-relay station. In this latter function, the ATS has been the real workhorse of the communications program. The ATS, an outgrowth of the early NASA Syncom satellites, is similar to the Intelsats (Early Bird, Lani Bird, etc.) which are currently used as part of the COMSAT network.

The TIROS system is older than the Nimbus. The first TIROS was launched in April 1960 and demonstrated effectively that a lot of very useful meteorological information could be obtained from a satellite in earth orbit. Originally only a few TIROS spacecraft were to be launched and the operational system was to be developed around a larger spacecraft represented by Nimbus. Very early in the search for meteorological information, two distinct approaches became necessary so we separated the job into two separate project efforts. The idea of simultaneously conducting an operational program and a research and development program was simply not feasible: it would have been like simultaneously running a scheduled railroad and a laboratory with the same personnel and facilities. The TIROS program developed into our TIROS Operational System (TOS) and the Nimbus program became our research and development program. To express it a bit differently, Nimbus represents our testbed for all of the advance sensors and the new types of devices with which we are experimenting. We have to prove their feasibility and utility before we can apply them in an operational sense.

The size of the spacecraft in Figure 1 is a little misleading. The TIROS is the smallest of the three, weighing only about 300 pounds compared to the approximately 700-pound Nimbus and the 700-pound ATS. The TIROS spacecraft is about 42 inches in diameter and about 22 inches high; Nimbus stands about 11 feet high. The solar-array paddles from which Nimbus derives its power are each approximately 8 feet high by 3 feet wide. The ATS spacecraft is approximately 56 inches in diameter and stands approximately 7 feet high. TIROS is spin-stabilized: it spins in space exactly like a gyroscope or top and the axis about which it spins is fixed in space and points to a fixed location in the sky. Nimbus is an earth-oriented spacecraft: the lower section of its sensory ring always points to the earth. The stabilization and control system in the upper section of Nimbus is very sophisticated and competent. This mechanism contains sensors which detect the horizon of the earth and the position of the sun and compute the attitude of the spacecraft. To correct any tilt, the computer then actuates counter-rotating flywheels and gas jets, adjusting the spacecraft attitude so that the lower face of the spacecraft is always pointing precisely toward the center of the earth. This precise pointing is extremely important for some of the more advanced sensors that require a longer observation time to make their measurements than television cameras require.

Figure 2, a picture of the cloudcover of the earth taken in the early days of TIROS, demonstrates the significance of looking at very large areas (roughly 2,000 by 2,000 miles) over the earth which were heretofore covered only sparsely by ships at sea or by aircraft flying the

Figure 2. Cloudcover, TIROS 1, April 1960

airways around the world. This picture can also show clearly that the viewer's observations differ according to where he is stationed and what path he is taking. For example, an observer in an aircraft flying along the broad path of clear area may report relatively clear skies. If he is flying a parallel path about 100 miles or so away, he may report cloudy skies or some other observation which is completely different and misleading. So from pictures like this one, we were first able to observe more completely and to a far greater degree of accuracy, the cloud coverage over a significant area of the earth. From these pictures, we can also determine to a certain extent, the nature of the cloudcover. We can tell from the shape and texture of the clouds a good deal about how the weather will move in the next time period. Although many other sensors are being developed, pictures of the cloudcover of the earth still form the primary mission of the operational meteorological satellites. Taking these pictures over the entire surface of the globe so that daily global coverage can be obtained is an important and difficult part of the job. Why do we need global coverage? Because as our studies and understanding of meteorology develop, it becomes more apparent that although local observations are reasonably adequate for short-term prediction, we must know what is happening in areas far removed from the local scene if we are to improve the accuracy of and lengthen the term of predictions.

Figure 3 shows how we go about achieving global coverage over the surface of the earth. The sun-synchronous orbit provides an almost ideal solution to the problem. In order to achieve this sun synchronism,

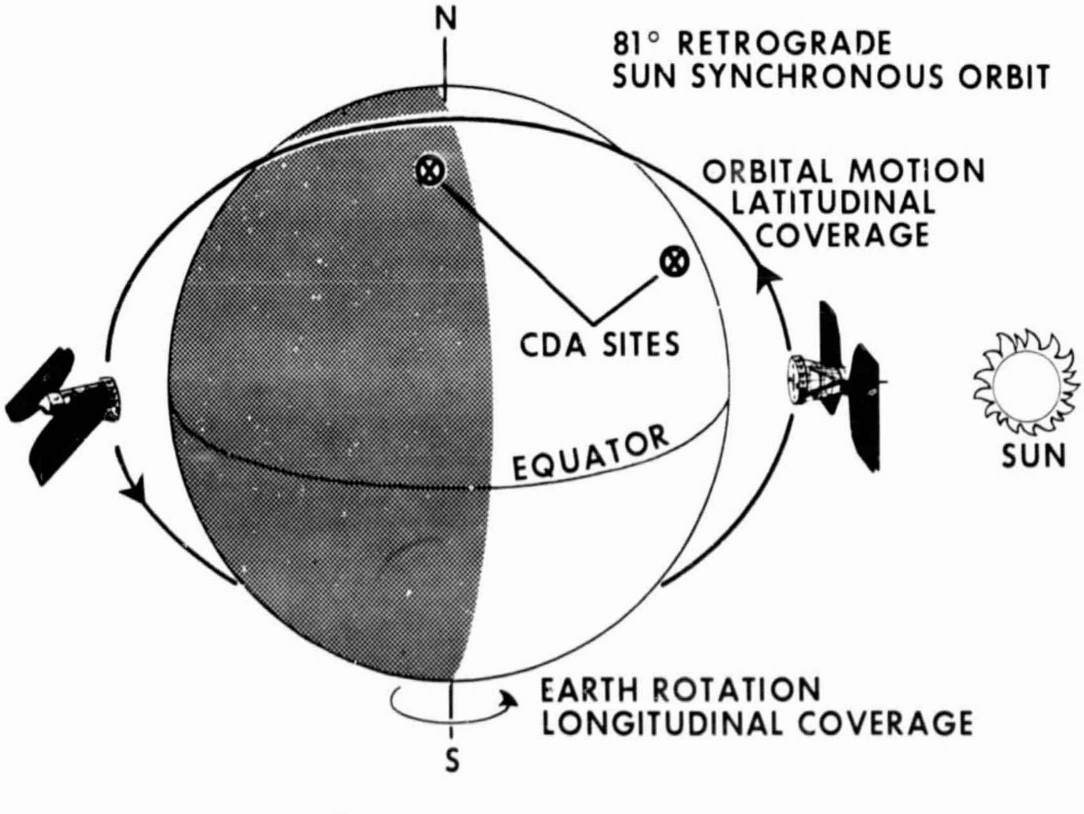


Figure 3. Sun-Synchronous Polar Orbit

the spacecraft is launched into a near-polar orbit, where the inclination of the orbit plane is approximately 80 degrees to the equator. This orbit, also called a retrograde orbit, permits the plane of the orbit to precess or rotate at approximately 1 degree per day, a rate equivalent to that of the rotation of the earth about the sun. Because the satellite can get the best view of the earth when the sun is over its shoulder, so to speak, it is launched at either local noon or local midnight. This launch then yields an orbit plane that contains the earth-sun line. Consequently, the spacecraft will always view the earth at near local noon on the sunlit side and near midnight on the dark side. Viewing time can be varied by reasonable amounts: it does not have to be precisely high noon. We have obtained very good illumination results with a 9 a.m. orbit to provide meteorological observations early in the day and with a 3 p.m. orbit to provide observations in the afternoon. Actually, the meteorologist would like to have the advantages of both periods. Weather satellites are launched into an orbit at an altitude of approximately 750 nautical miles (n.m.) above the earth's surface. From a practical point of view, this orbit is fixed in space and the earth rotates under it. The duration of the orbit, that is, the time to complete one full go-around about the earth, is just long enough so that the earth rotates or moves at the equator by a distance equal to the width of the picture swath. Thus, no gaps in picture coverage occur at the equator and the overlap between adjacent orbits increases toward the poles. Picture coverage of the entire earth takes approximately 12 to 14 orbits in 24 hours. The only gaps that occur result from lack of illumination. They occur at whichever pole happens to be in the winter season and is too dark for photography. Here we rely on other types of sensors to view the earth.

Figure 4 shows the basic spacecraft used for the operational system. The side view shows how it spins just like a wheel in orbit about its axis, the axis lying perpendicular to the plane of the orbit. When the cameras are pointing toward the earth, a detector aboard the spacecraft recognizes the horizon of the earth and provides the indication or trigger pulse to the camera shutter. The shutter is opened for the next picture only after an interval of several revolutions. Each picture overlaps the preceding picture by a nominal amount. This sequence goes on for the full period that the satellite is in the daylight portion of the orbit. The cameras, of course, are shut off at the nighttime side.

Figure 5 is a top view of the satellite with the "top hat" removed. The hat carries the solar cells from which the spacecraft derives its power — approximately 30 watts. We removed the hat to show the layout

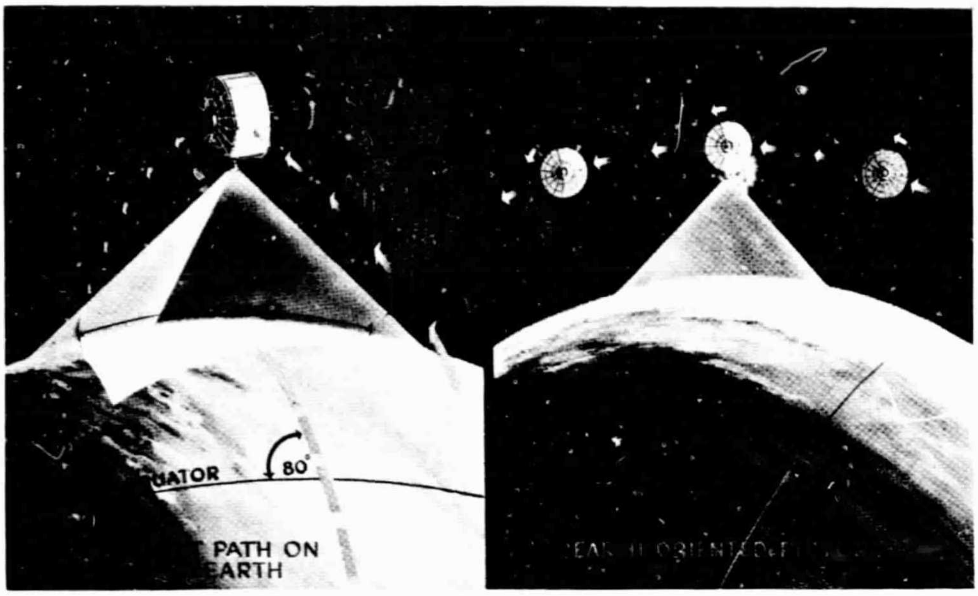


Figure 4. TIROS Operational Satellite (TOS)

of the components on the base plate. The symmetry of the layout results from redundancy or doubling of all major subsystems to provide reliability and long life. We have almost two complete satellites in one package: two cameras, two tape recorders, two sets of transmitters and receivers, and so forth. The two dome-like objects are tape recorders which are similar in principle to the tape recorders that you are probably familiar with; indeed, some of you may have used one when you visited Goddard Space Flight Center (GSFC) to record this talk. Of course, the recorders in the satellites are highly specialized with carefully designed mechanisms throughout. They use specially selected magnetic tape and are carefully tested and optimized for this particular task. The cameras are similar in principle to the cameras used in the TV studio. However, the cameras in the satellite use a vidicon picture tube, which has a "sticky" or retentive photo-sensitive faceplate. If you were using the vidicon to follow normal motion in the TV studio, the pictures would be smeared. However, the camera, at 750 n.m. away from earth, photographs a practically still earth during the short interval when the shutter is open. The sticky characteristic permits the signal to be read out from the camera at a very low rate, reducing the bandwidth requirement and permitting the electrical signal to be stored on the tape recorder. Many other mechanisms in the package are similar to everyday items. For example, the clock mechanisms on board are functionally similar to the clocks at home that get you started

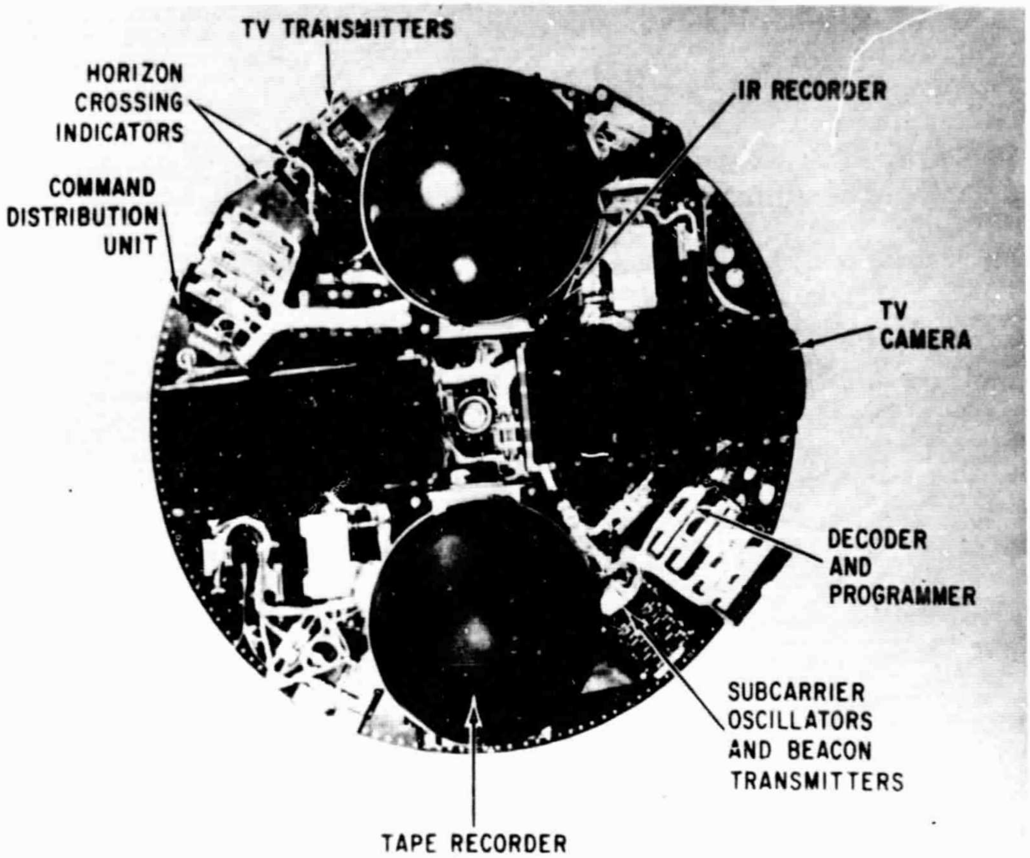


Figure 5. TOS, AVCS, Top Removed

in the morning. Ours happen to be all electronic but they work exactly the same as yours. Because we analyze orbit information and know when the spacecraft is going to pass over certain parts of the earth, we can set the clock mechanism the same way that you may set the alarm to go off at 6 in the morning. We set the clock to alert the cameras at a particular portion of the orbit. Precisely when the spacecraft is passing over the ground station, the clock is signaled to start and it begins to measure time and count out the interval set into it. Precisely when it is supposed to alarm, it triggers off a sequence of electrical events: one of the cameras warms up and starts to take pictures and one of the tape recorders starts up and records signals from the camera. This sequence continues until the spacecraft goes into darkness. The camera and tape recorder are shut down until the spacecraft comes within view of the ground station and the tape recorders are read out.

TRACKING

Figure 6 illustrates the tracking loop; I will use it to explain how we track and control the spacecraft. The crossed antenna array in the lower lefthand corner of Figure 6 is part of a STADAN tracking station.

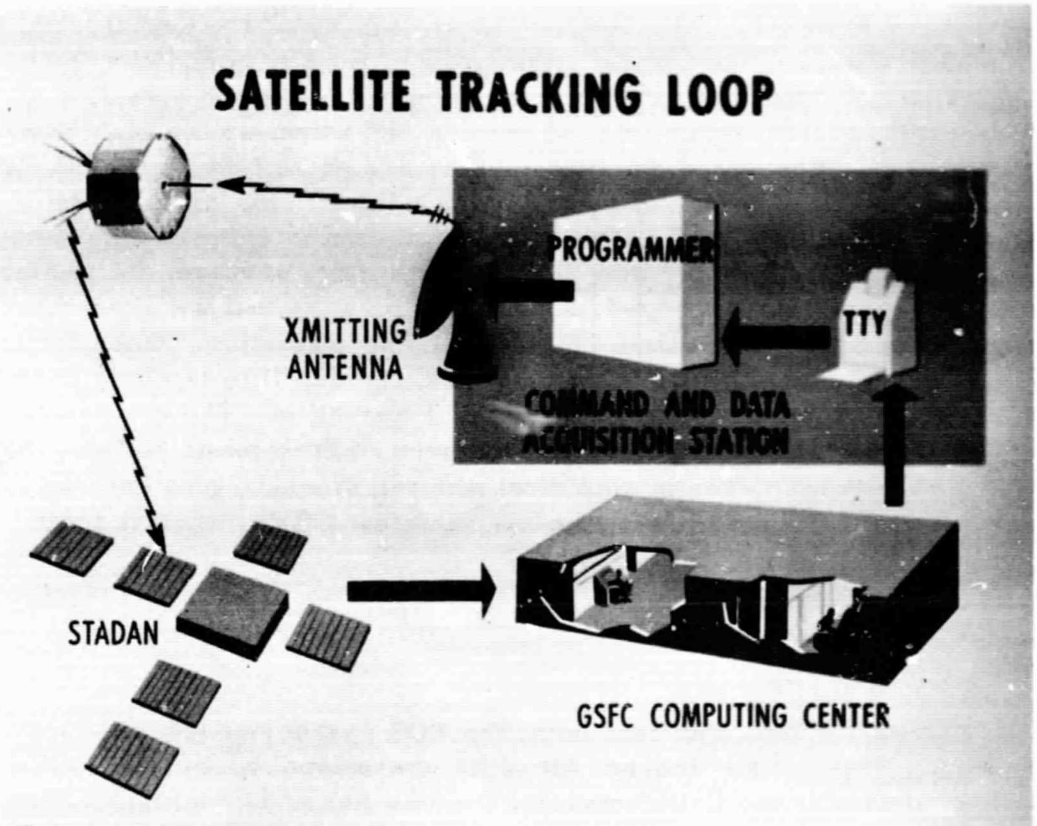


Figure 6. Satellite Tracking Loop

STADAN stations are located throughout the world. In its normal orbit around the earth, the satellite continuously transmits a beacon signal from a very low-power transmitter. The tracking stations observe the exact time and path of crossing and transmit this data to Goddard where they are fed into a computer. Exact orbit is determined: the path that the satellite is following has been defined in a three dimensional sens‹ the time measurement provides the vital fourth dimension. The time measurement is extremely important: we must know exactly where th spacecraft is at each instant of time so we can predict the time in the satellite orbit that will be optimum for picture taking and set the clocl accordingly, and so, later, when we examine the picture, we can determine the precise position of the satellite when the shutter was snappe‹ Most of the pictures are taken over water or over solid cloudcover. I these, because geographical features cannot be readily identified, we must know the exact location of the spacecraft at a certain time befor‹ we can identify the area photographed.

When the satellite comes within view of the Command and Data Acquisition Station, indicated by reception of the beacon signal, the spacecraft is first commanded to turn on and warm up the high-power transmitter. When good communications are established with the spa‹ craft, it is then commanded to play back a tape. This stage of the operation is critical because this recorded data is unique. The next time the satellite goes by that area of the earth's surface, the weather will, of course, have changed, so we must be sure that we always get nice, clean data with a minimum of noise and distortion. When the tap recorders have completed their playback, the satellite is commanded to set the clocks for the next sequence of operation. The clocks start, and as the satellite leaves the viewing area of the ground station, the high-power transmitter is shut down and the satellite continues on its way, carrying out its mission for the next few orbits, when it again comes in view of a ground station.

TOS

Figure 7 shows how data from the TOS spacecraft are handled. This part of the job — indeed, all of its operational aspects — is the responsibility of the Environmental Science Services Administration (ESSA). The AVCS (Advanced Vidicon Camera System) spacecraft is on the lefthand side of Figure 7. The system uses two Command and Data Acquisition (CDA) stations, one located near Fairbanks, Alaska, and one on Wallops Island, Virginia. The data is piped, without any delay, from both stations through wideband communications links to ESS data-processing analysis facility at the National Weather Satellite Center (NWSC) at Suitland, Maryland. The processed data goes out ov many different types of communications channels to domestic users throughout the United States and by radio and even, on occasion, by

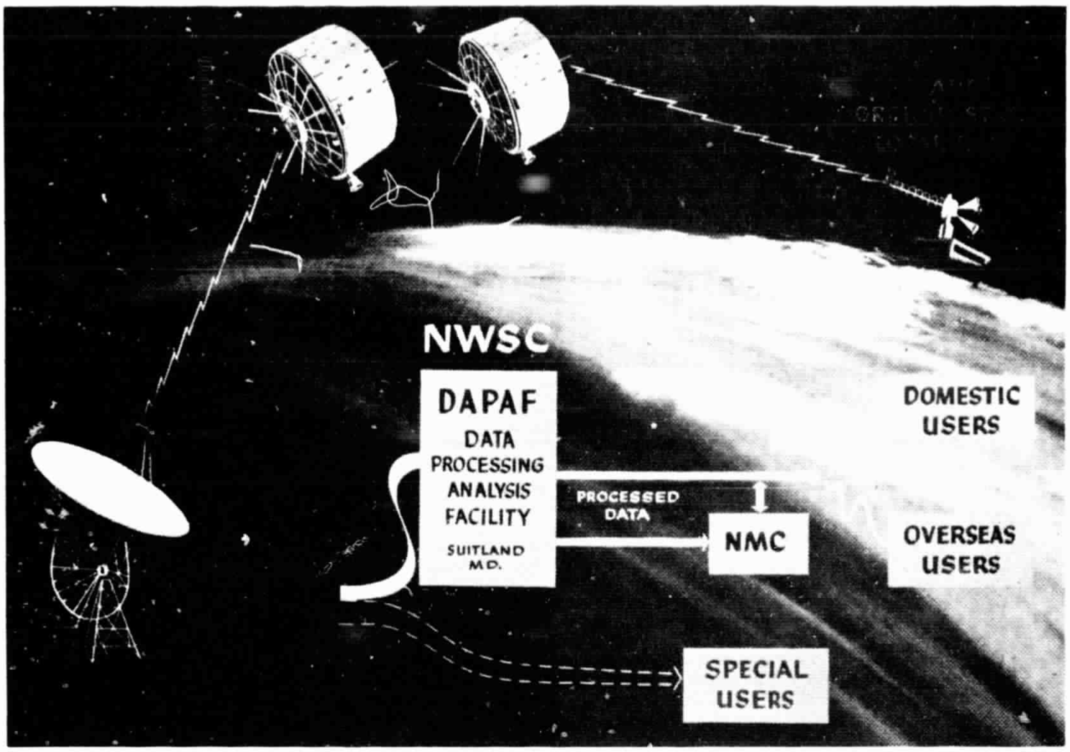


Figure 7. TOS Data Flow

cable to overseas users. The dotted lines on the bottom of Figure 7 show the special users. The most important one, of course, is the Department of Defense.

The TOS system requires two types of spacecraft. They look alike, but the one on the righthand side of Figure 7 is different. It is identified as the Automatic Picture Transmission (APT) spacecraft. Its outstanding function is the provision of almost instantaneous direct readout of the television pictures as the spacecraft camera takes them. Its cameras are similar to the AVCS cameras. (Both of these cameras, were developed under the Nimbus program.) It does not use tape recorders, however, and the data is not stored on the spacecraft. Instead, the signal is converted to a characteristic fully compatible with facsimile operation so, with very simple ground equipment, any interested user can receive the signal and reproduce the picture that the spacecraft takes as it flies overhead.

Many of the pictures that you see in your daily newspapers were taken at a remote location and transmitted to your newspaper by facsimile means. The big advantages of this equipment are its simplicity and its economy: the signal can be transmitted between locations over an ordinary telephone line instead of requiring expensive, high-quality TV circuits such as those used for transmitting television programs.

The APT ground station (Figure 7) is basically a simple facility. Its antenna may be only a little more complex and a little larger than the TV antenna on top of your own chimney. It has the required receiver and facsimile reproducer. In its most expensive form (fairly elaborate and ruggedized) this equipment cost approximately $30,000. Many professional and amateur users throughout the world used ingenuity and a little knowledge of electronics to build a complete station from surplus gear; they spent just a few hundred dollars. Today throughout the world approximately 300 to 350 stations are operating: these stations have boosted many smaller emerging nations by providing a means for rapidly augmenting their meteorological capability. Many of these countries depend strongly on their agricultural economy and improved weather information helps them solve the problem of feeding their hungry people.

We did not achieve our goal of obtaining daily global weather coverage until February 13, 1965, with TIROS 9. TIROS 9 was launched into a polar orbit and the mosaic of its pictures (Figure 8), which cover the globe, was completed only after the satellite orbited approximately 14 times. In Figure 8 we have taken a little artist's liberty to outline the continents more strongly, but the cloudcover of the earth is unretouched. In this mosaic for the first time we saw the full relationship of the cloudcover as it encircled the earth.

Figure 9 shows some of the processed data that the operational satellite system turns out every day. The earth is divided into three areas to provide necessary detail with the least amount of distortion. The two poles are illustrated separately as polar stereographic type projection and the center equatorial section is in the form of the more familiar Mercator projection. ESSA transmits these pictures daily to users throughout the United States and to member nations of the World Meteorological Organization (WMO). (This organization does not suffer from the problem of the iron curtain: it is made up of more than 100 member countries around the world.)

Many have claimed that weather programs have saved or will save much money for communities and key industries such as agriculture, shipping, and airlines. However, these claims are a bit difficult to pin down into actual dollars. I believe the weather program is equally or

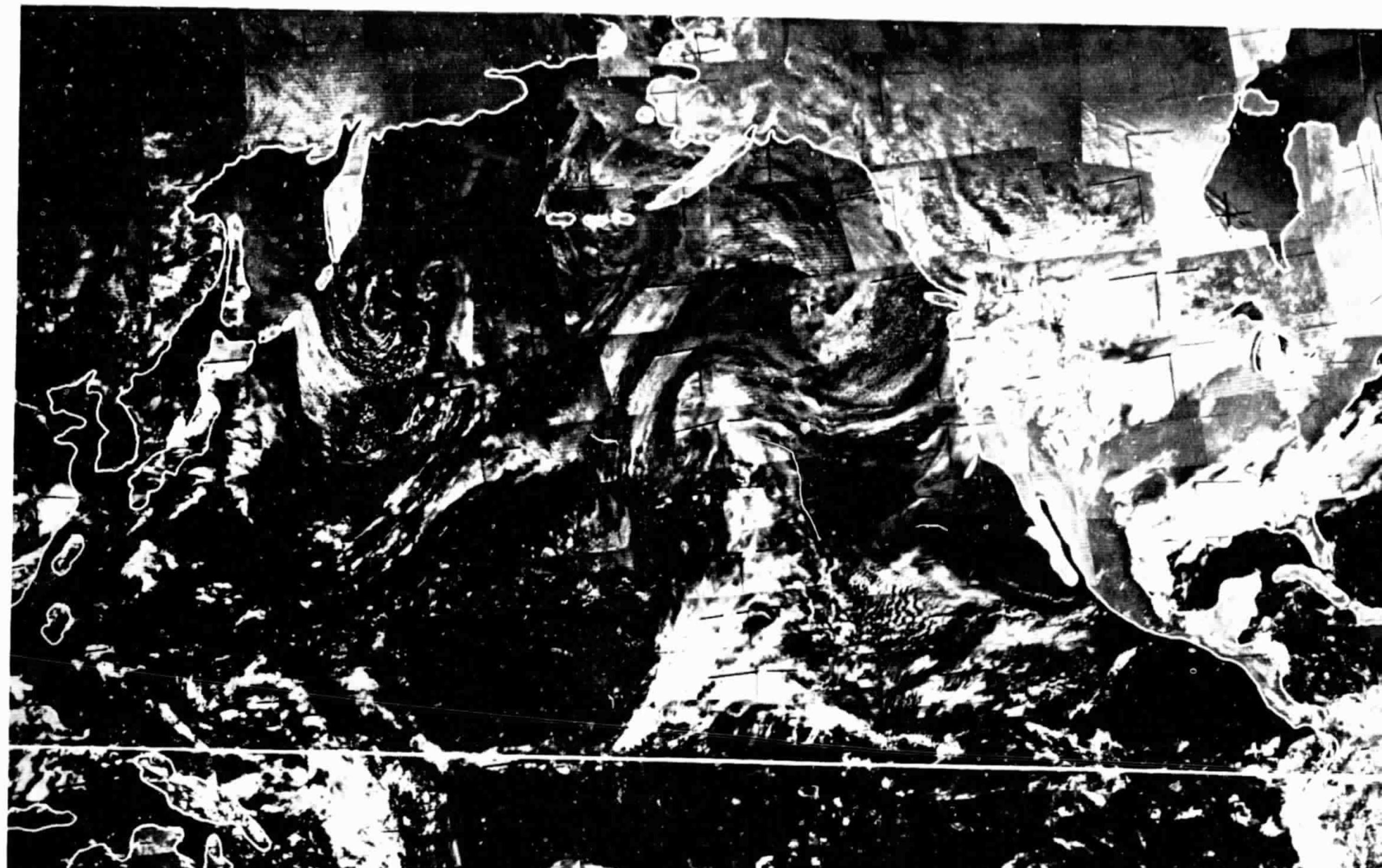
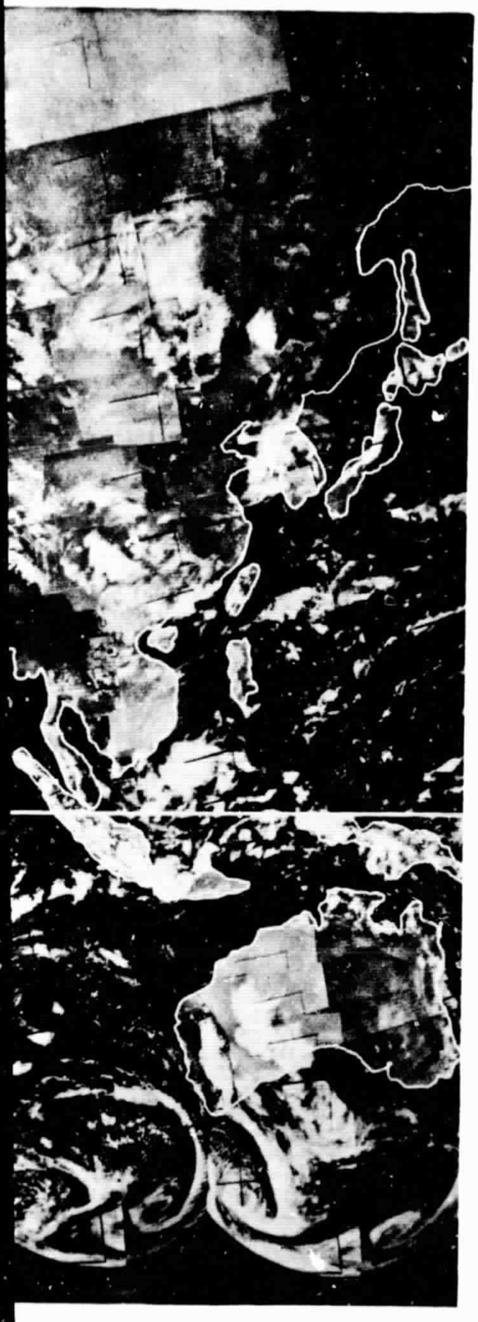


Fig 8. Fi

Figure 8.ß TIROS 9 Globa



9 Global Photomosaic

13 Fig 8. C

PRECEDING PAGE BLANK NOT FILMED.

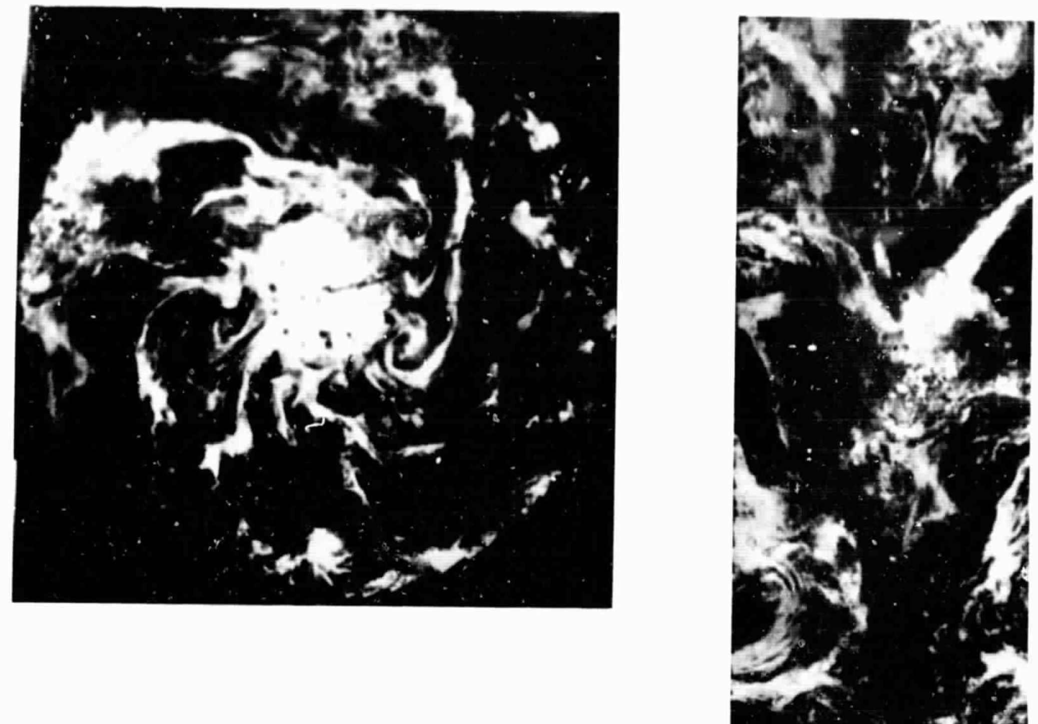


Figure 9. Processed Data, Operational Satellite System

more important to the saving of lives than to the saving of money. Figure 10 shows a picture of hurricane Beulah taken in 1967 by an AVCS satellite. This picture enabled us to give early warning to the people in Beulah's path. As you remember, Beulah was a destructive storm and, even with the warning, caused considerable loss of property and some loss of life. We like to feel that our warning saved many more lives.

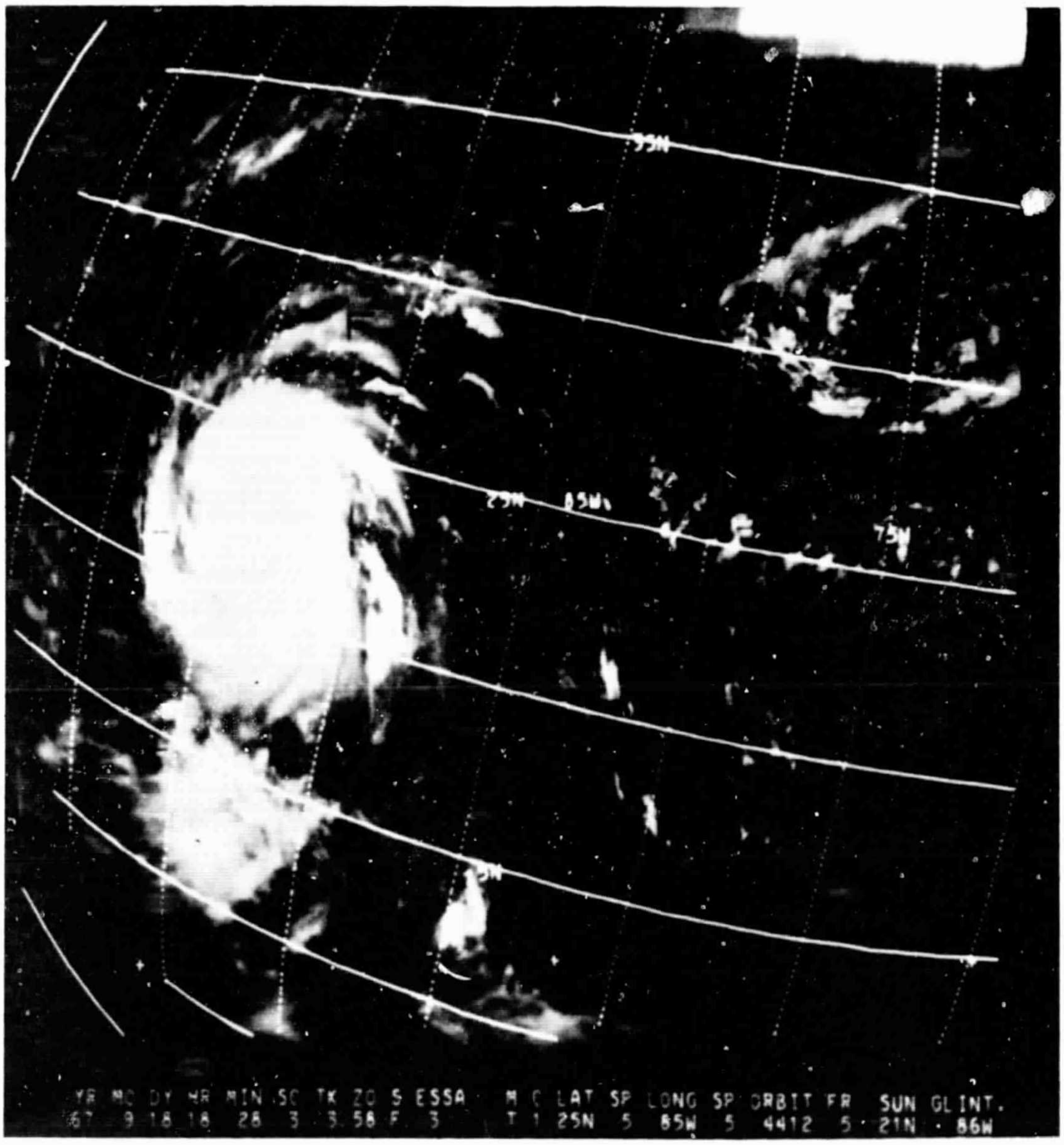


Figure 10. Hurricane Beulah, September 18, 1967

Figure 11 is a picture taken over western Europe. You may be able to identify the outline of the north European coast, particularly Denmark and Sweden. An APT ground station in Berlin which the Germans designed and built recorded the photograph. (In the photograph, this station is near the central cross-hair mark.) Of course, the Germans used information that we supplied to them but they also used some of their own ingenuity and precise engineering to turn out one of the best APT stations that we know of. This is not too surprising: their technical competency is quite advanced. We have, however, had

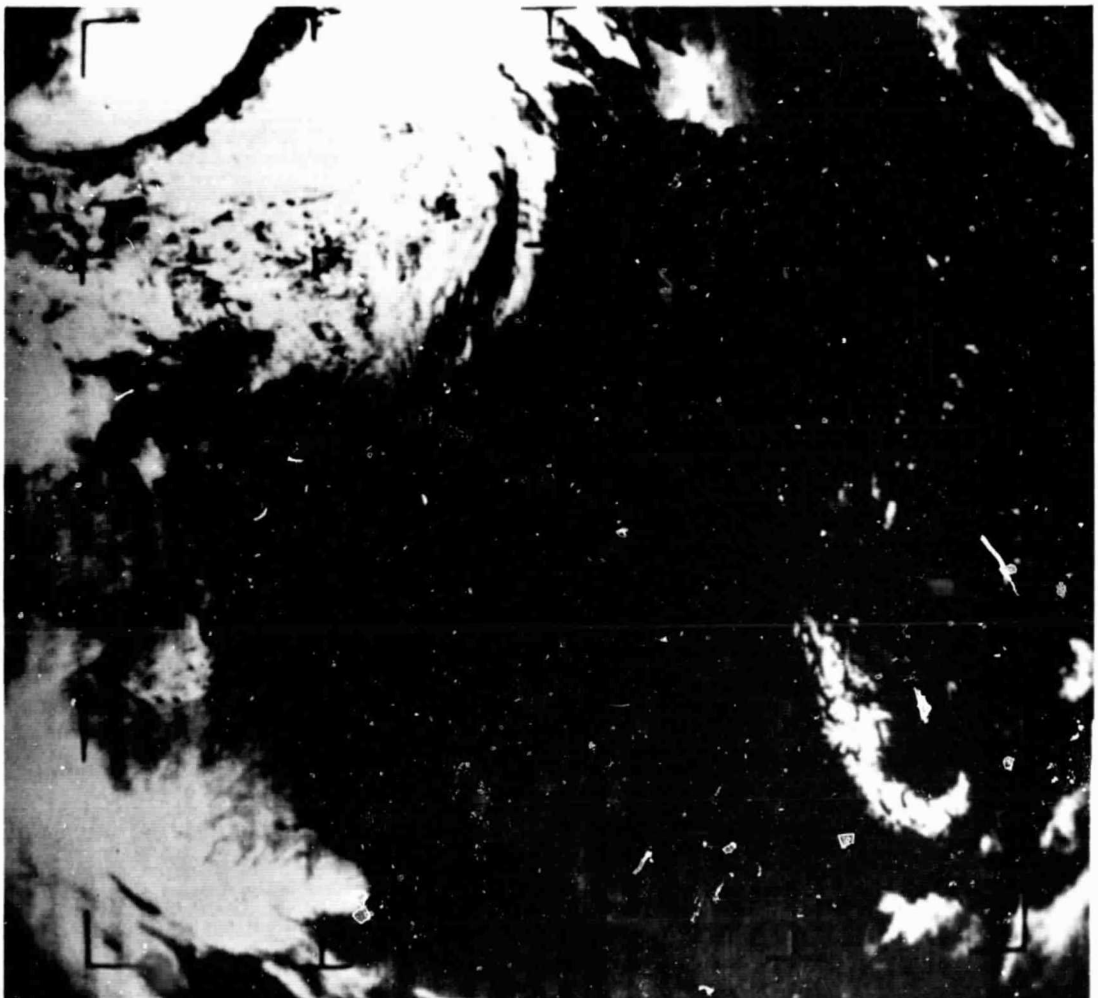


Figure 11. Photograph Taken Over Western Europe

pictures of almost equal quality from many amateurs and users at Universities. The key to this quality picture taking is that the APT system is basically simple and does not require an elaborate set of ground equipment. The white area in the lower left center portion of Figure 11 is not cloudcover but snow on the Alps. Photos of snowcover may become valuable in determining water runoff and the possibilities of flood conditions.

NIMBUS

Figure 12 shows Nimbus B, which we expect to launch in March or April of 1969. It will carry a number of advanced experiments that show tremendous promise for the operational system. Figure 13 shows one of these, the Interrogation Recording and Location System (IRLS). With the IRLS, the spacecraft can interrogate sensors located on the ground in remote high mountain areas or in rough territory such as portions of the Arctic or Antarctic, or perhaps, as these experiments develop, at various levels in the atmosphere or out at sea. These sensor platforms can carry sensors to measure such parameters as temperature, pressure, humidity, sea state, ocean currents, and wind velocities and thereby provide considerable input to the meteorological network.

Nimbus B will carry a number of infrared sensors to be used for various purposes: the most important is that of observing the earth's cloudcover at night. The infrared sensor does this by detecting the radiant-heat energy emitted by the earth and its cloudcover. Because the amount of energy emitted is a function of temperature, the clouds with temperatures lower than those of earth, stand out against earth. By selecting different parts of the infrared spectrum, we can observe water vapor and carbon dioxide, to name just two atmospheric constituents important to meteorology.

Actually, infrared measurements can be made both day and night, although infrared is the only practical method we have devised for viewing or imaging cloudcover at night. This method has been demonstrated very effectively in what is probably the most important new sensor system to come out of the Nimbus program, the High-Resolution Infrared Radiometer (HRIR). Figure 14 combines two illustrations concerning the HRIR. The upper half is a picture of hurricane Gladys taken at "high midnight" in 1964. It was taken with the infrared detector which operates differently from the conventional camera. The picture is not snap-action; instead, it consists of a sequence of scan lines and

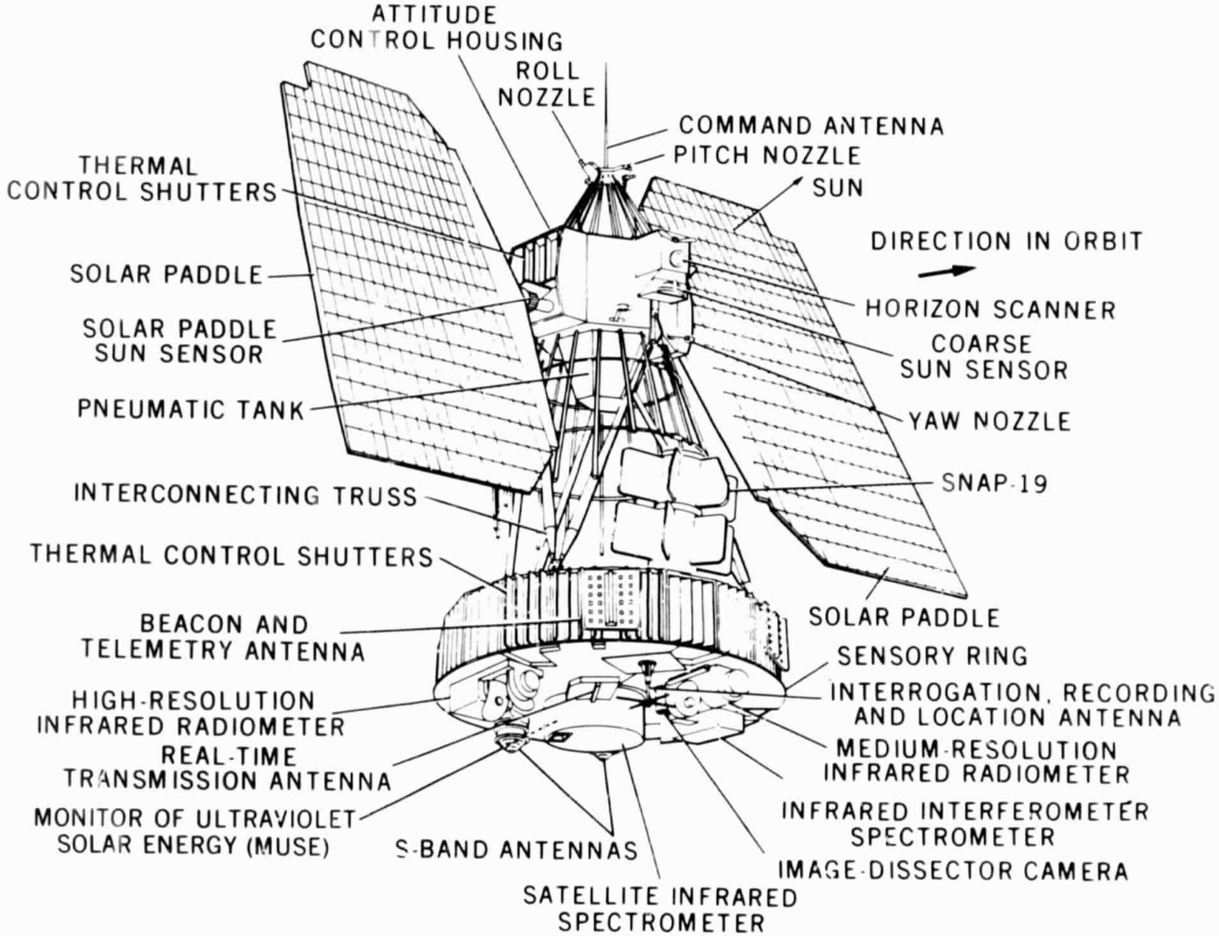


Figure 12. Nimbus B

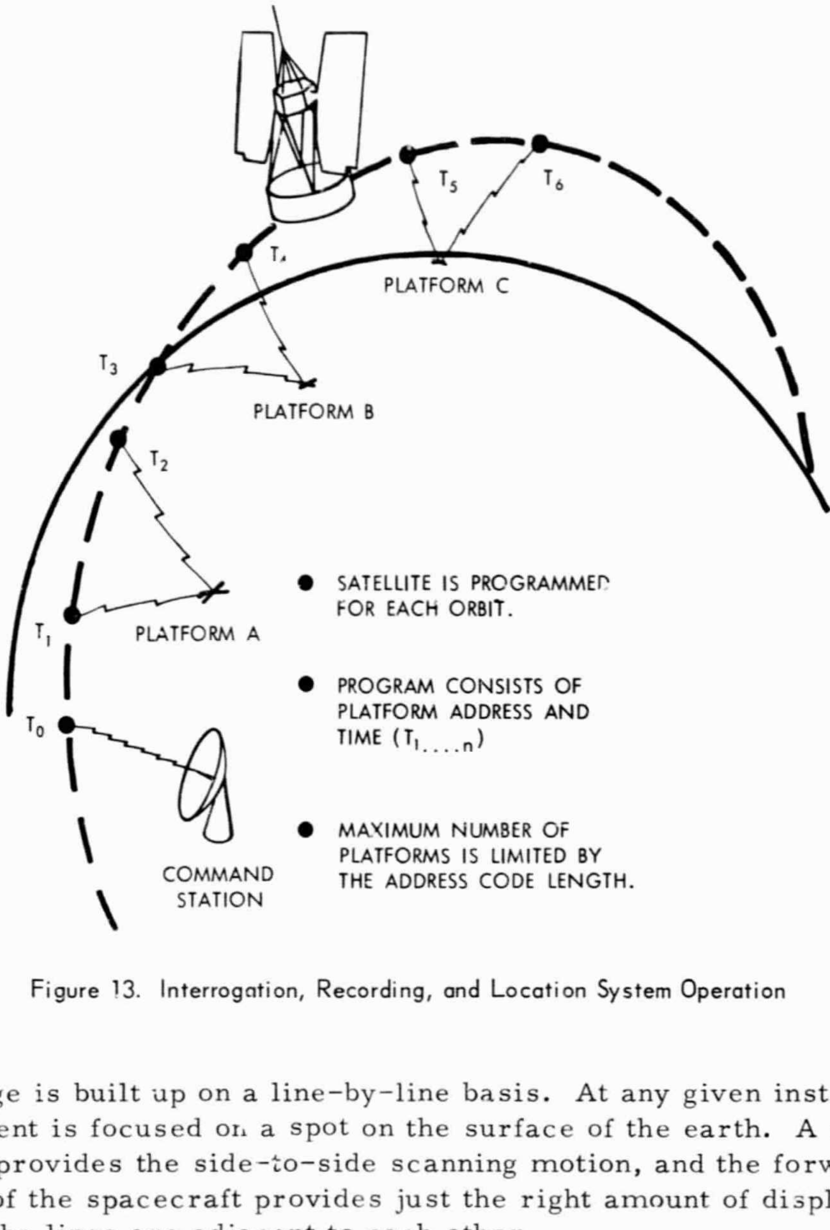


Figure 13. Interrogation, Recording, and Location System Operation

the image is built up on a line-by-line basis. At any given instant, the instrument is focused on a spot on the surface of the earth. A rotating mirror provides the side-to-side scanning motion, and the forward motion of the spacecraft provides just the right amount of displacement so that the lines are adjacent to each other.

The lower part of Figure 14 shows a single trace or scan line taken right through the eye of the hurricane. The signal varied as a function of the intensity of energy radiated from the surfaces below the satellite as the sensor scanned across. The black areas, which represent the higher temperatures, indicate higher on the scale, running about 290° K. Then, as we cut across the high, cold clouds, we get lower temperatures running about 230°K. As the scanner cut right through the eye of the

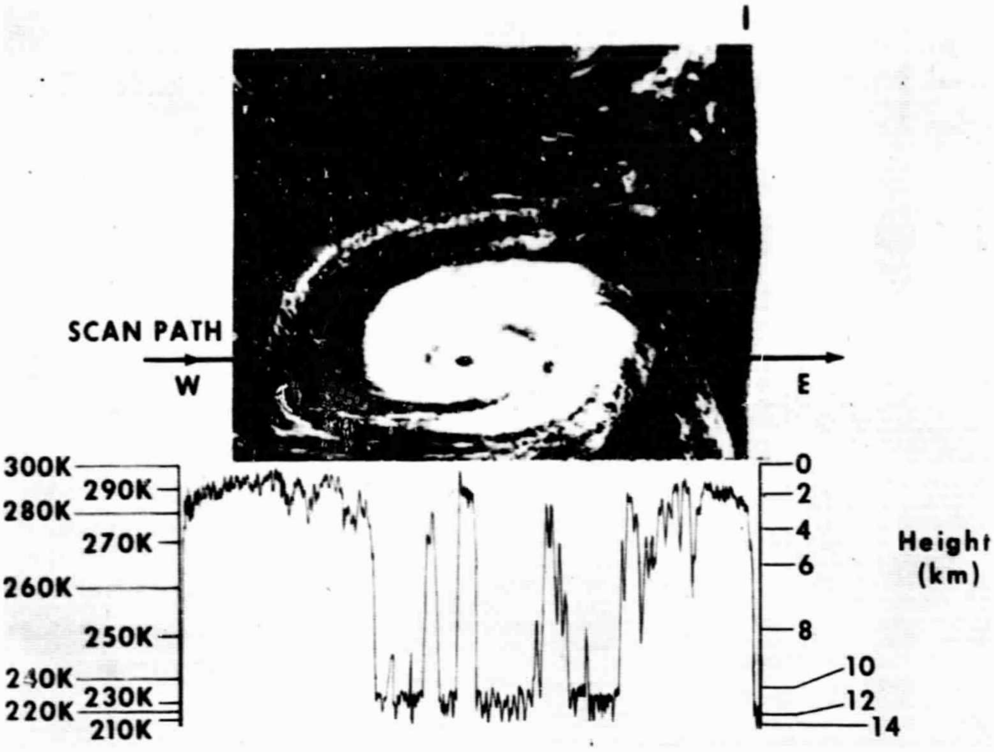


Figure 14. Analog Trace of a Single Nimbus 1 HRIR Scan Through Hurricane Gladys (Orbit 305, September 18, 1964)

storm, it was looking almost down to the surface of the water or at least to a much warmer area that was in the eye of the storm. On the righthand side the temperature measurement is translated into a measurement of height; the warm clouds are quite low, running down to 1 and 2 kilometers above the surface of the earth and in some cases a little bit lower. The lowest temperatures correspond to a height of about 13 or 14 kilometers, representing, in more common terms of measurement, about 37,000 feet. This system represents a real breakthrough. It was thoroughly demonstrated on Nimbus I and for the first time provided the meteorologist with a complete view of the earth on its nighttime side. Now outputs of the two major systems (the camera in the daytime and the infrared sensor at nighttime) can be combined to provide twice the amount of viewing over the surface of the earth.

The infrared system on Nimbus 2 photographed at night the full section of an orbit that took place over the east coast of the United States (Figure 15). The Great Lakes are quite clear and Maine, Cape

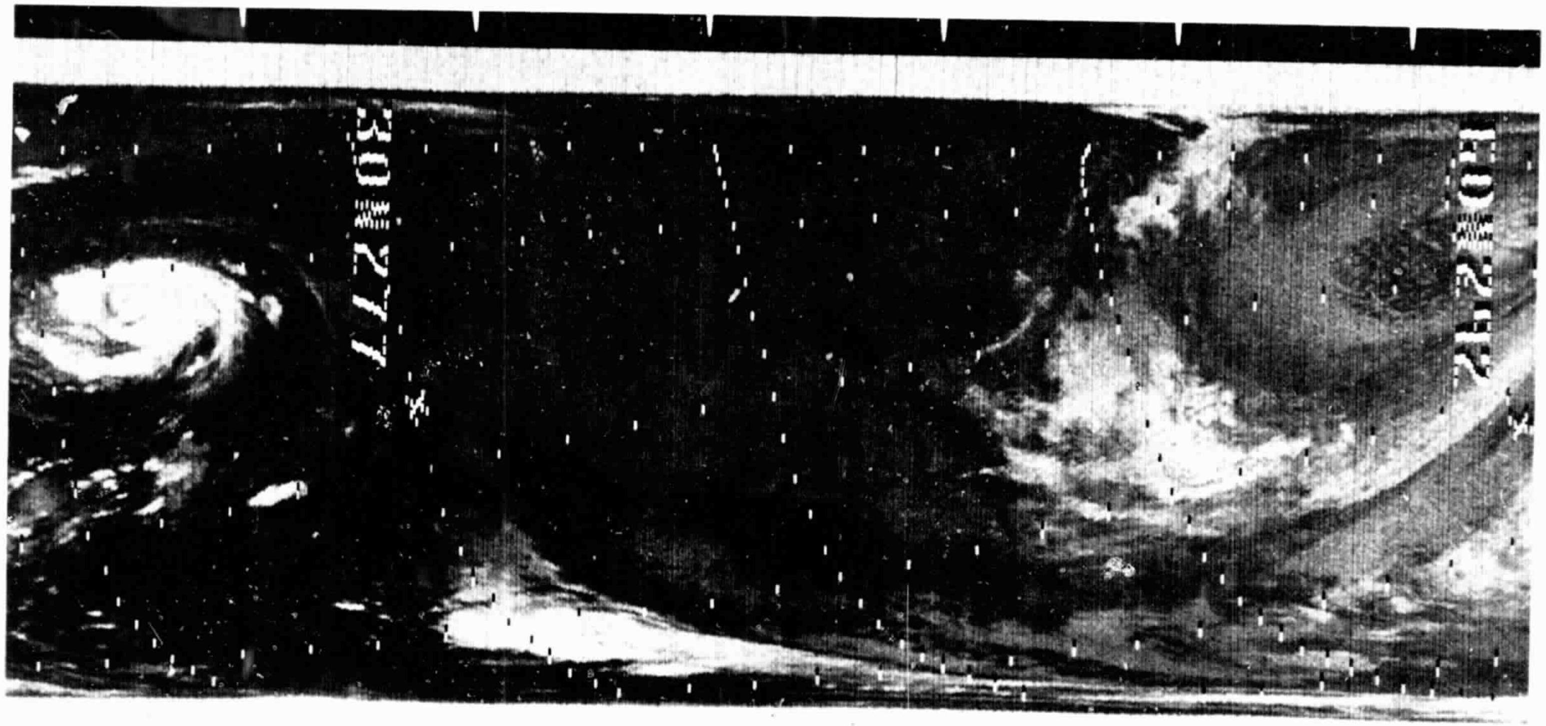


Figure 15. East Coast of the United States, HRIR, September 1964

Cod, the Chesapeake Bay area, and Washington are recognizable. Hurricane Inez is in the lower portion of the picture. Notice the relationship between the storm and the cloud system which extends offshore over the Atlantic Ocean. The dark band off the continental shore is of even greater interest, not only to the meteorologist, but also to the oceanographer. If you look carefully, you can distinguish between the light-gray land, the darker gray ocean current right near the land, and the slightly darker warm Gulf Stream, which can be traced up to Newfoundland. This type of picture which reveals ocean-current location, promises to be valuable to oceanographers and other scientists, including social scientists, interested in potential resources from the sea.

We intend to put the IR system into operation on TIROS M, which is scheduled to be launched in May 1969 and will carry not only the cameras but the infrared detectors as well. Figure 16 shows that TIROS M combines not only the advanced sensors tested on Nimbus, but also a number of other valuable features. We have increased considerably the solar-array area on the paddles, which now yields almost 400 watts to operate additional equipment. We will put a three-axis stabilization system in TIROS M so that, as in Nimbus, the lower face will continue to look toward the earth at all times and will not depend on a timing mechanism like the one on the spinning spacecraft. This will enable us to use sensors which require a longer look at the earth to make a proper measurement. The follow-on spacecraft to TIROS M will be the ITOS (Improved TOS) which, making unnecessary the simultaneous orbiting of two types of spacecraft (one devoted to AVCS and one devoted to APT) will provide quite a savings.

ATS

Figure 17 shows the ATS, which is a spinner, in principle similar to the other spinners like TIROS. ATS, too, serves as a test-bed for both the meteorological and the communications experiments. I believe that in the United States we tend to take for granted the communications satellites. The subtitle on our TV screen "via satellite" has become quite common. The fact that the picture originated in a far-off place is interesting but not "cosmic". Up to the present time and for the near future the communications satellites have really served to augment our long-distance cable facilities and provide a better, but not radically different, service. However, the technology being developed promises many new and exciting applications. For example, on one of the upcoming ATS launches we plan to experiment with a portion of the

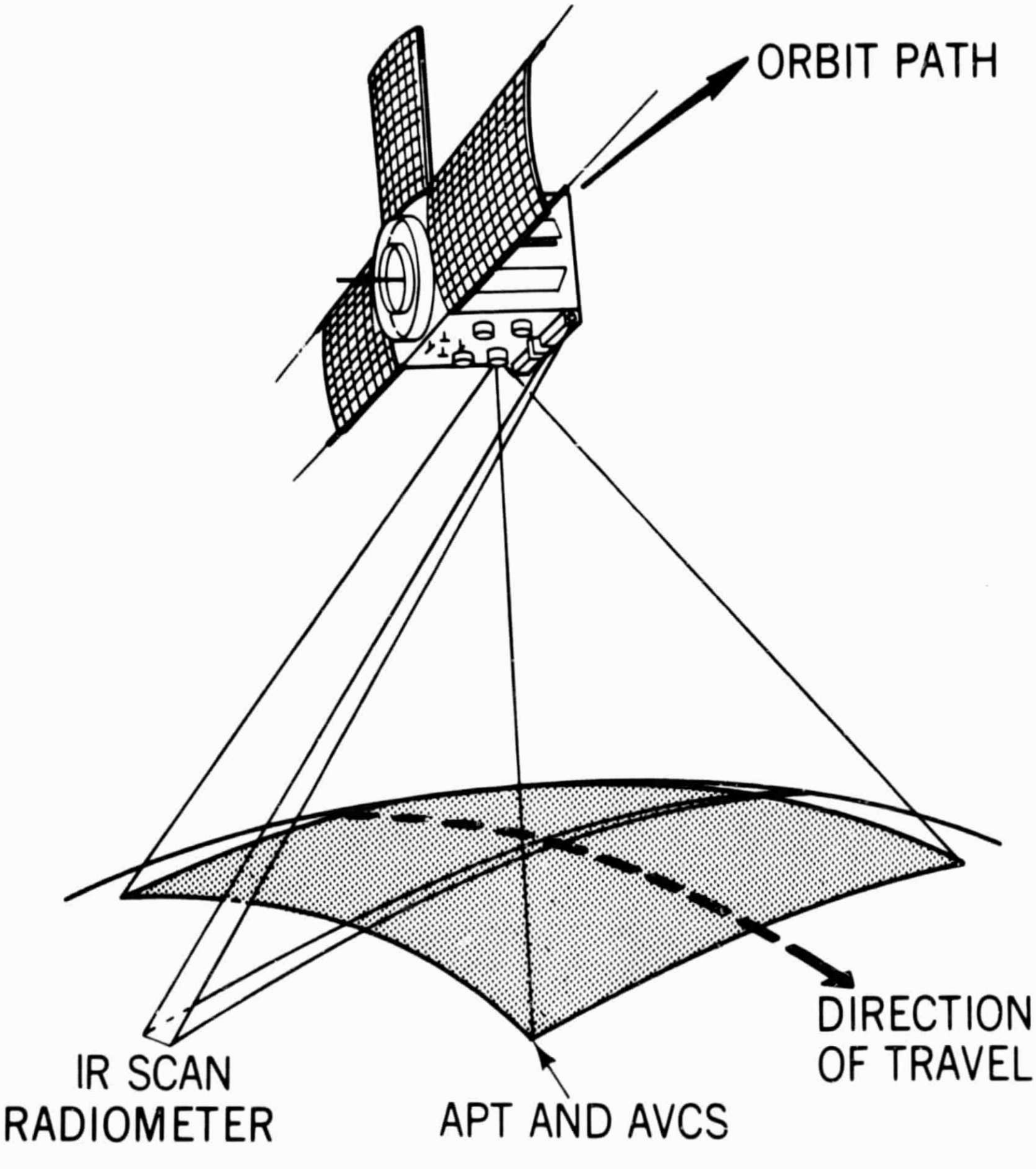


Figure 16. TIROS M Sensor Field of View

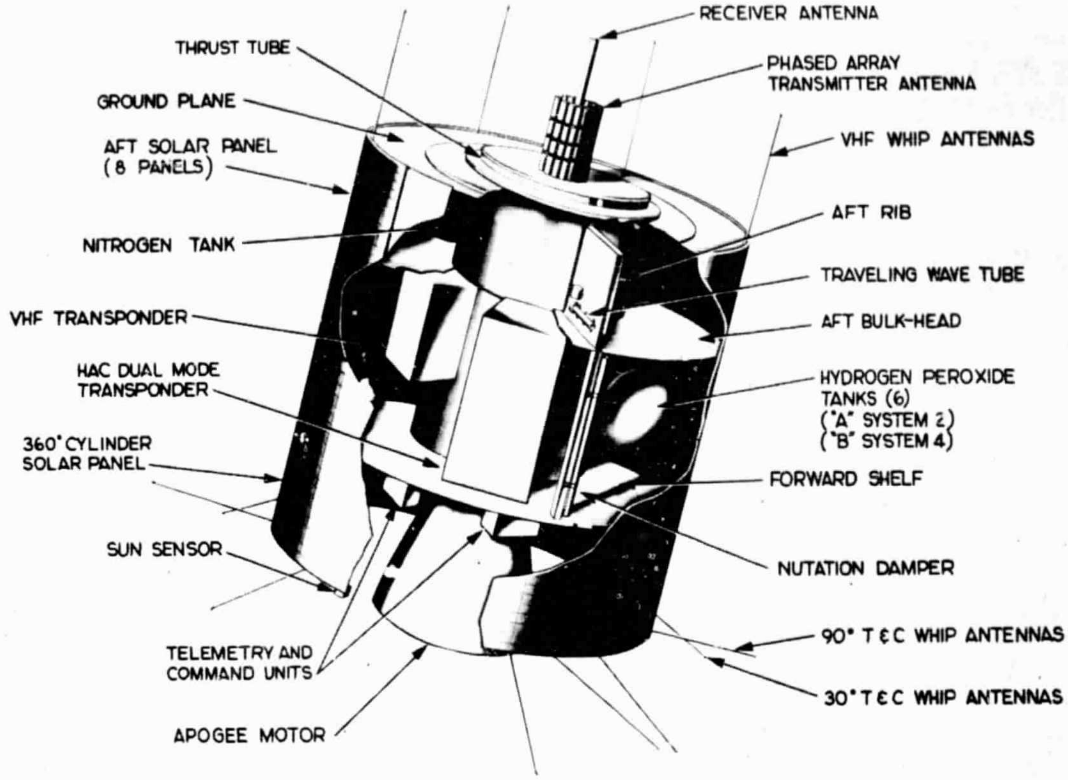


Figure 17. ATS

radio-frequency spectrum known as millimeter waves. These extremely short-wave transmissions have not yet been successfully exploited on a commercial basis. Some of the advanced techniques now under experiment may open new avenues for expanding the usable part of the spectrum and enable us to carry out projects needing additional frequency allocations.

We have tested on the ATS continuous communications with trans-ocean aircraft. As commercial planes cross the Atlantic or Pacific Ocean, for long periods the aircraft are not in radio communication with either coast, neither the point of origin nor the destination. An oversimplified explanation of this communications gap is that equipment, size, weight, power, and antenna size make it necessary for aircraft to operate at high frequencies. Radio transmission at these frequencies is satisfactory only for line-of-sight operation and, as a result, when the distance becomes great enough, the receiver drops below line-of-sight to the transmitter; reception fades and soon becomes nil. However, the synchronous (stationary with respect to the earth) satellite, which is in line-of-sight to the aircraft and the distant shore, can provide a radio-relay point and thus maintain communications. For example, a synchronous satellite positioned over the Pacific Ocean can see both the United States and Asia and retransmit messages from an aircraft to either or both continents. I witnessed a demonstration of this capability in a test with a JAL plane flying from Japan to the United States. When it reached the region where it was out of radio contact with Japan and was, of course, not yet in contact with the United States, it transmitted its signal to the ATS. The satellite relayed the signal to the NASA station in the Mojave Desert, which relayed the signal by landline to Goddard. We talked directly to the pilot and the transmission was as clear as, I trust, you were able to hear my voice when you visited the Goddard Space Flight Center. Several implementation problems remain to be solved, but this project could greatly increase air-travel safety.

The synchronous satellite also promises to be valuable in the field of meteorology. Tests conducted on two ATS launches indicate that this promise can be fulfilled. For example, Figure 18 shows a picture of approximately one-fourth of the earth's surface taken from ATS III positioned over Brazil. The mouth of the Amazon River is close to the center of the picture. The continuous weather observation breakthrough has provided potential for early detection of severe storms and continuous storm observation to determine the storm's path. This observation has enhanced our ability to predict the path and severity of the storms. Dr. Fujita of the University of Chicago assembled a sequential series of spin-scan pictures into a time-lapse moving picture. In this movie, he correlated the cloud motions with actual tornado tracks as determined by radar and visual observations. These observations provide strong evidence that it will be possible to improve the accuracy and timeliness of the tornado warning system. Admittedly, these improvements are still experimental and uncertain at this time, and the synchronous satellite may not turn out to be superior or more economical for this purpose than, say, an expanded network of ground-radar sets. However, the possibility of continuous viewing of larger storms, hurricanes and typhoons, and particularly the possibility of early storm detection, make the synchronous satellite very promising. Certainly these observations will provide a better basis for our understanding of the complex atmospheric process. We hope that some day we will be able to ameliorate directly the effects of severe storms.

Incidentally, the camera that took these wonderful pictures is not conventional. It is an elementary device designed around a telescope

Figure 18. ATS Photograph

(Figure 19). The telescope focuses on a point about 2 miles in diameter on the earth's surface. All of the visible energy or light which the telescope picks up from that point is focused on the surface of the photomultiplier tube. This tube measures the intensity of this energy. As the spacecraft rotates, the telescope sweeps across the surface of the earth from horizon to horizon. As the intensity of the light varies across the surface, the energy on the photomultiplier varies accordingly and the voltage output delivered is proportional to the energy that the photomultiplier detects. Thus, this scanner functions similarly to the infrared scanner. The whole telescope, mounted on a pair of trunnions, is tilted a small amount betwee· each revolution of the spacecraft, creating a raster scan. Figure 18, made up of approximately 2,000 of these scans, was taken in about 20 minutes.

A Synchronous Operational Meteorological Satellite system, now in the planning stage, will be based on the technology demonstrated by ATS. It will incorporate the spin-scan camera and infrared detectors for night

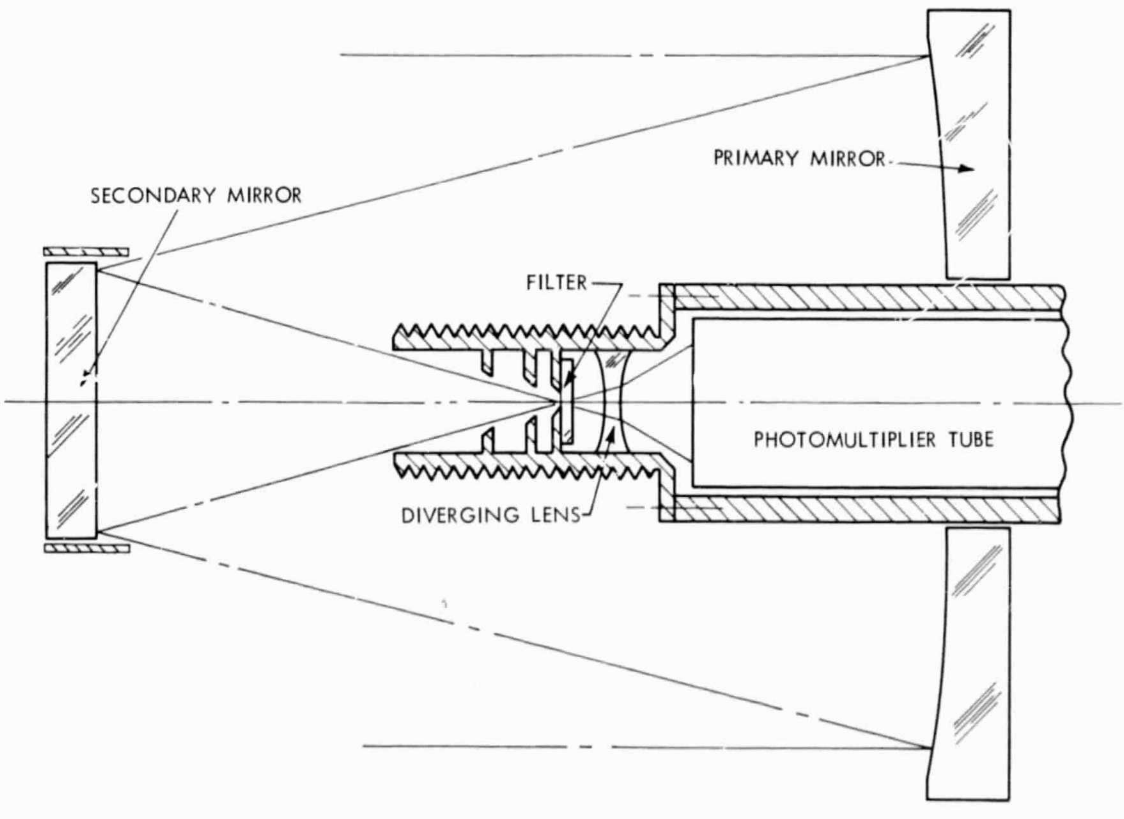


Figure 19. Spin-Scan Camera Optics

viewing and a number of data-relay features. Figure 20 shows the earth coverage that we expect to get with the proposed system. The system will initially use only two spacecraft. Their positions are marked on the map: one will be located over the Atlantic Ocean and one over the Pacific Ocean. The outlined areas in Figure 20 indicate the coverage that will be provided by the visual and infrared scanners for day and night viewing of the weather. The larger areas, marked "acquisition circle," indicate the communications region: areas that will be within communications range of each other. Thus, we will be able to make the observations; process the data; combine it where desirable with data obtained from other meteorological sources; and transmit the information to stations located within range of the spacecraft, ranging from Melbourne at the lower left, Tokyo at the upper left, and Offenbach and Nairobi on the right.

Under the heading of data relay, the first system tested on ATS was WEFAX (weather facsimile). In the WEFAX system, satellite photos and other weather data are processed at a central station. They can be enlarged, gridded, annotated, or reduced to a symbolic map form called nephanalysis. These processed data are then facsimile-scanned and transmitted to the synchronous satellite. This satellite acts as a relay station for rebroadcast in a format which simple ground stations can pick up and use locally. Figure 21 shows two photomosaics prepared by ESSA from TIROS Operational Satellites (TOS), pictures showing how the cloud pattern changed in 3 days. WEFAX retransmitted these pictures and a ground station designed primarily to receive APT pictures received them at Toronto, Canada. Application is still experimental, but the system shows tremendous potential as a means for delivering the data expeditiously and economically to the users.

ATS F and G (Figure 22), a brand-new spacecraft, will be used in a project to devise a means for increasing the amount of radio power transmitted toward the earth. The main feature of this spacecraft is the large parabolic antenna structure, or "dish." This 30-foot-diameter dish acts as a reflector to focus the energy of the satellite transmitter toward the earth and substantially increase transmitter efficiency. Figure 23 shows a possible application of the satellite in educational TV broadcast directly to schools or community centers for local retransmission by closed circuit TV. With only 40 watts of radio-frequency power in the spacecraft, we can now get sufficient energy so that fairly simple receiving equipment can receive the signal on the ground.

An even more dramatic application of this technology is the use of this spacecraft in a proposed direct-broadcast educational-TV system

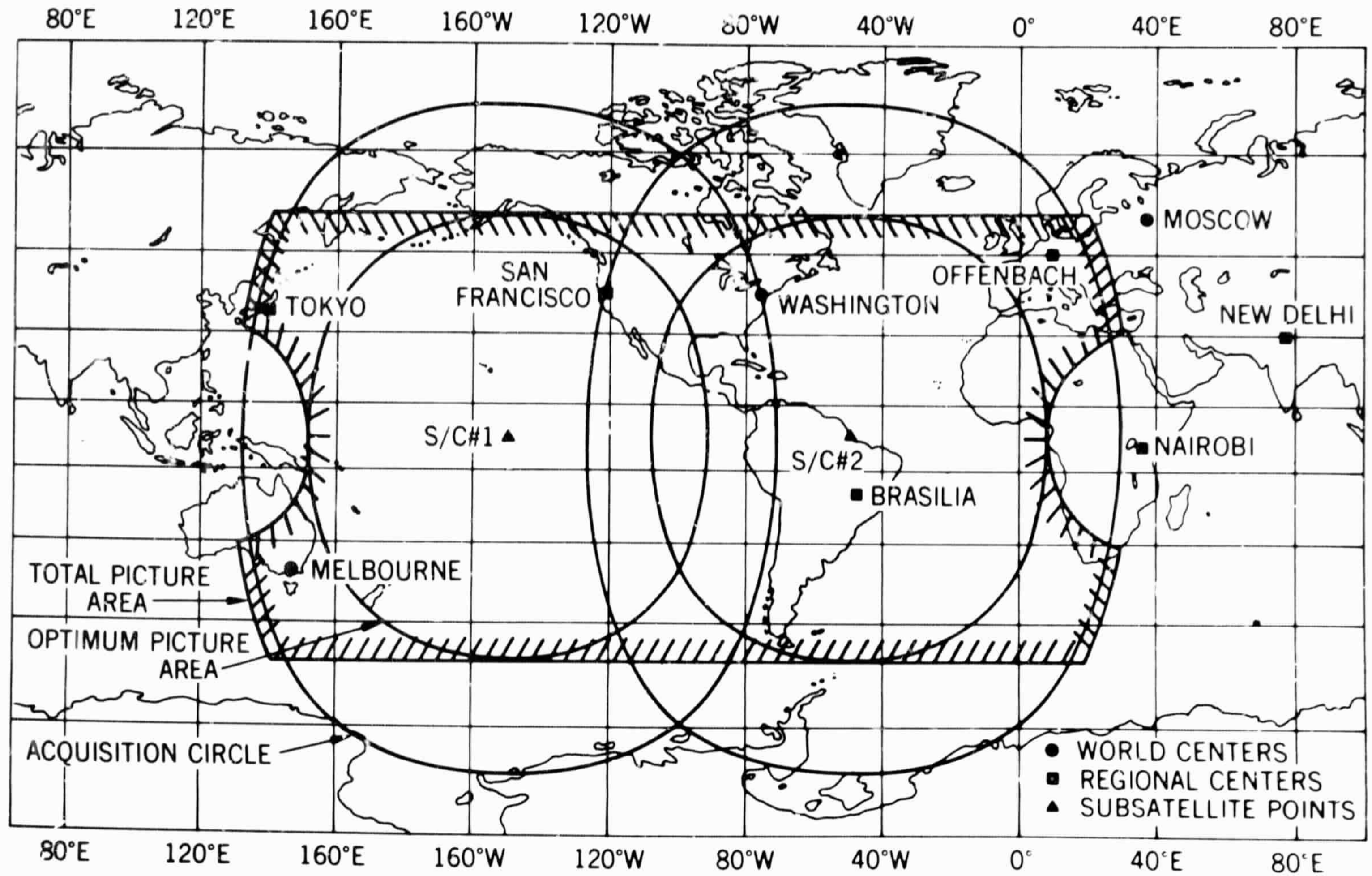


Figure 20. Synchronous Meteorological Satellite Program Picture Coverage and Acquisition Circles

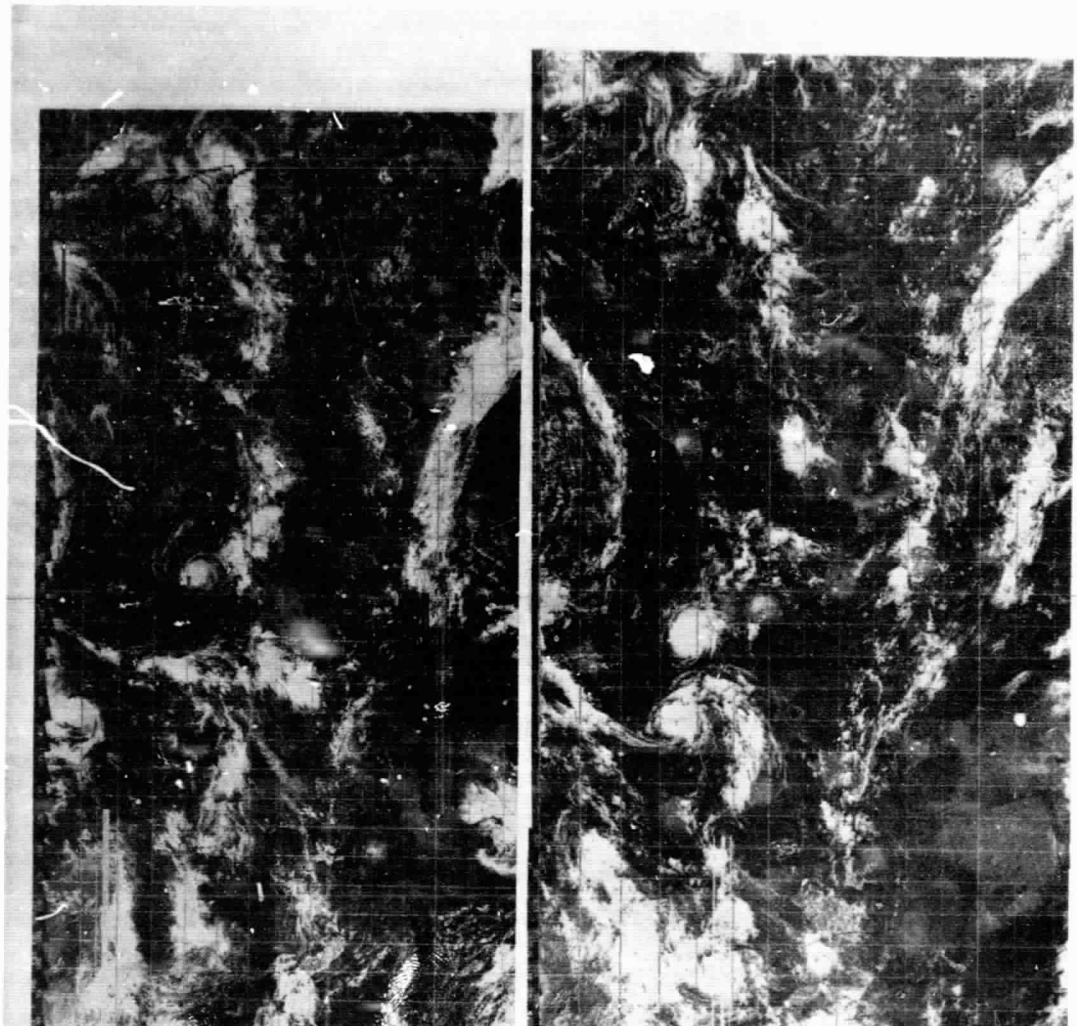


Figure 21. WEFAX Mosaics

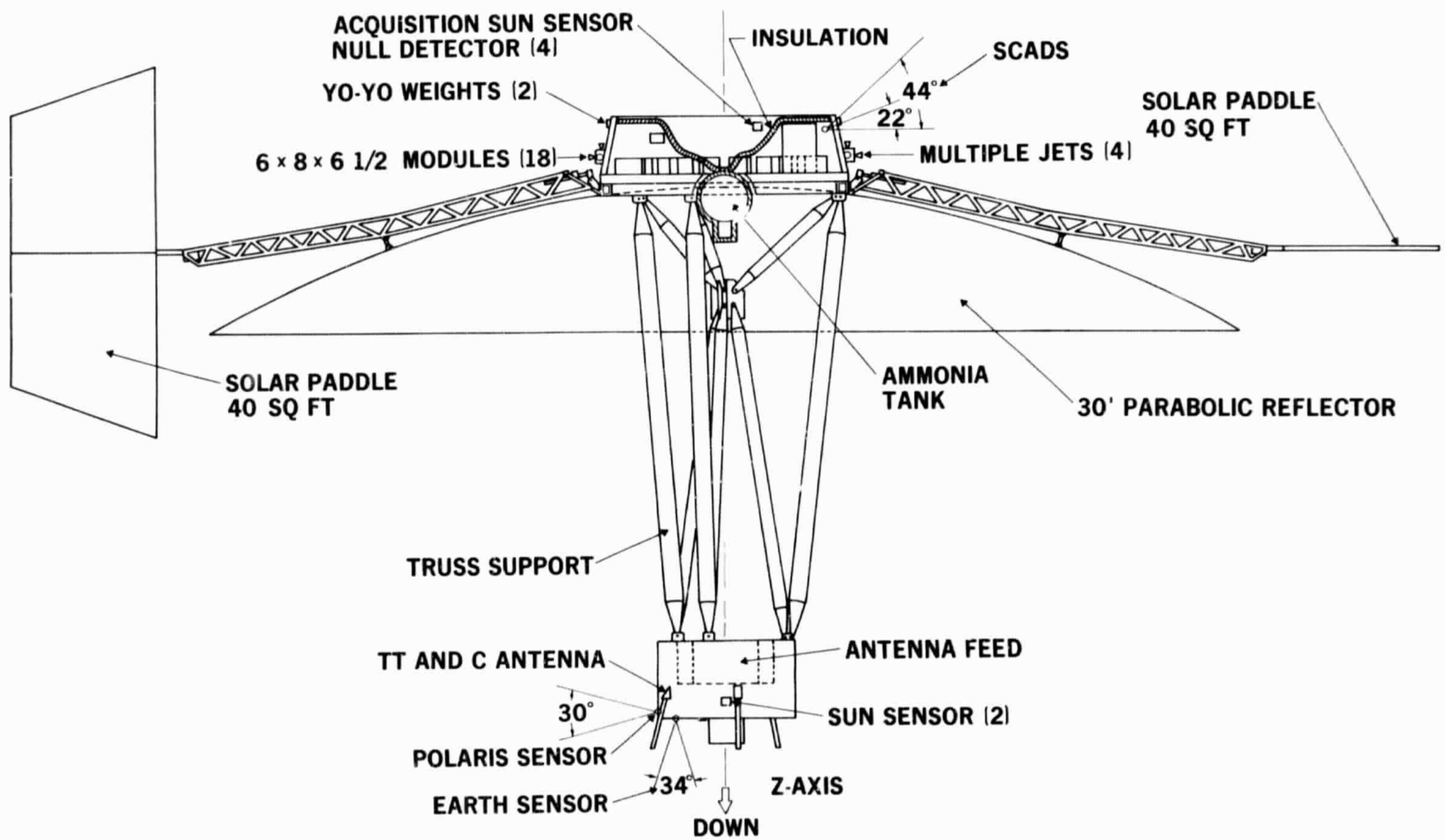


Figure 22. ATS F and G

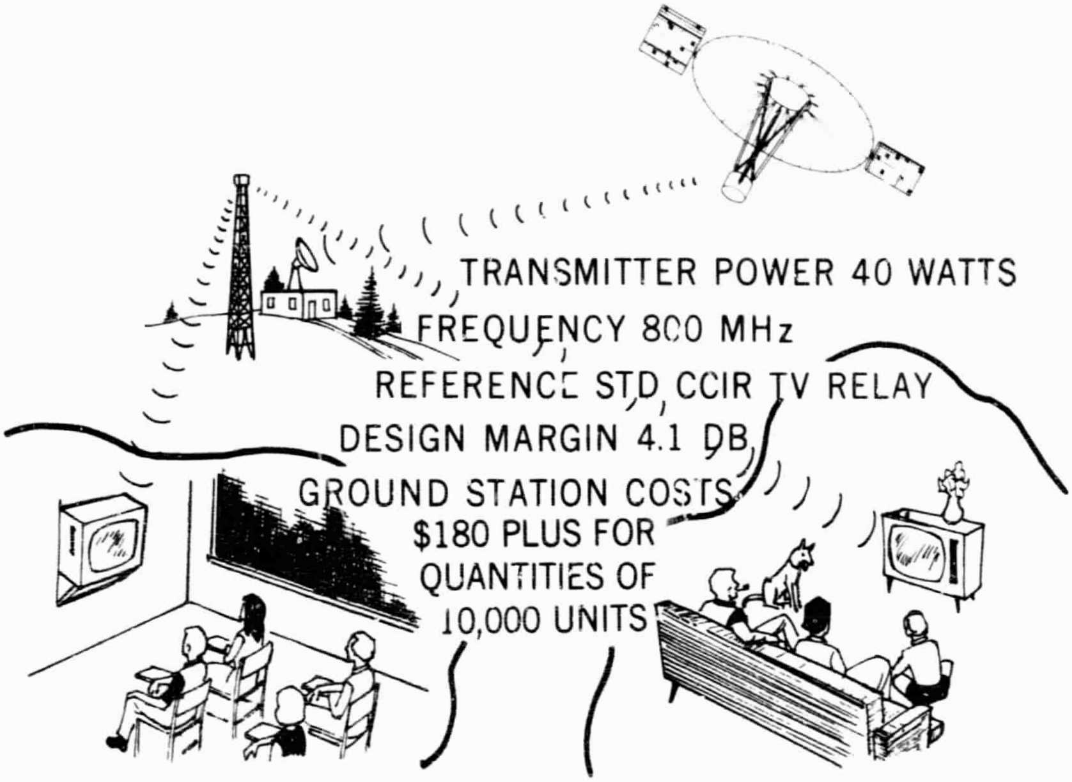


Figure 23. Direct Educational TV Broadcast to School and Community

to India (Figure 24). India is carefully considering this intriguing possibility. This system takes advantage of an advanced technology, leap-frogging over older and slower methods, and in one step, develops the means for teaching millions of people in underdeveloped areas of the world. The system would present the real fundamentals in education — not the common three R's for Reading, 'Riting, and 'Rithmetic, but matters even more fundamental such as hygiene, farming, and birth control. The system will first be used as an aid in improving basic conditions; only when these are improved will it be used to provide the more common forms of education. However, here I am transgressing on your territory as social scientists, and it is more appropriate for me to outline some of the problems rather than propose possible answers.

India has many languages and dialects. It is technically feasible to transmit to India the video signal along with a number of different audio channels, and letting the individual ground station choose the

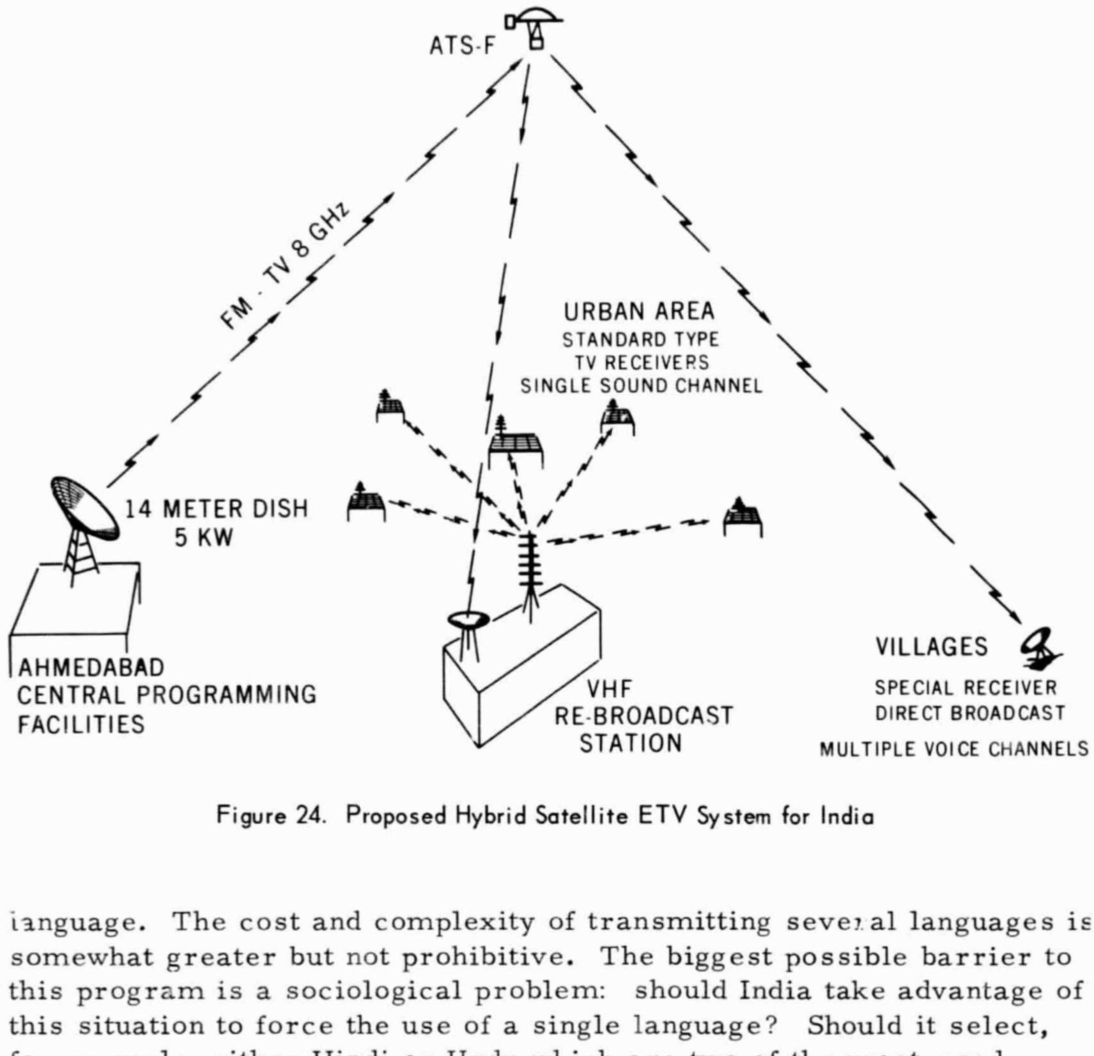


Figure 24. Proposed Hybrid Satellite ETV System for India

language. The cost and complexity of transmitting several languages is somewhat greater but not prohibitive. The biggest possible barrier to this program is a sociological problem: should India take advantage of this situation to force the use of a single language? Should it select, for example, either Hindi or Urdu which are two of the most-used languages?

The cost of the proposed system also raises serious sociological problems, not too different from some of the problems we face here in the United States. Where should the money, which is always limited, be spent: in direct support for food, health, housing, etc., or for advanced technology, which could ultimately provide far greater profit? Cost considerations should include not only the expenses of a satellite and ground stations, but also those of manpower. A program such as satellite educational TV is a huge undertaking, requiring a considerable investment in organization, program planning, training, and implementation.

A final, more subtle problem exists. India, as you know, is very concerned and proud of her neutrality. Would being committed to participate with the United States in an experiment with ATS F have a serious effect on India's position in world affairs?

These are challenging problems. They are as much of a problem to the social scientist as to the technologist. I hope that I leave you with some things to think about as well as a good basis on which to judge the value of this part of the space program.