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Military Communication Satellites

JANUARY 1968

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AEROSPACE CORPORATION

Prepared for SPACE AND MISSILE SYSTEMS ORGANIZATION
AIR FORCE SYSTEMS COMMAND
LOS ANGELES AIR FORCE STATION
Los Angeles, California

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FOREWORD

This report is published by the Aerospace Corporation, El Segundo, California, under Air Force Contract No. F04695-67-C-0158.

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Approved

Carlton W. Miller
Associate General Manager
Satellite Systems Division

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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ABSTRACT

Earth-orbiting satellites are a flexible and rapid means of communications, and as such, are extremely valuable to the military. The paper discusses the Initial Defense Communication Satellite Program (IDCSP). In IDSCP, several satellites are launched one at a time into a near-synchronous equatorial orbit with a single launch. IDSCP has demonstrated the feasibility of point-to-point communication via satellite between semi-fixed ground terminals. It is the intent of the satellites to implement a world-wide military communication system.

The paper describes additions to IDSCP which allow it to be used as a special-purpose satellite by the United Kingdom. A tactical communication satellite, which uses small, moving terminals, is also described.

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I. INTRODUCTION

The idea of using an earth-orbiting satellite as a microwave relay point between two earth terminals is an old one. However, only during the last decade has the science of space technology advanced to the point where such a proposal could be given serious consideration. Such communication satellites have obvious advantages in handling unique and vital military communications. The flexibility of a system that can implement military command between ground terminals 9000 miles apart and simultaneously permit communications over the next hill has much to recommend it. An additional advantage to a satellite communication system is the fact that ground terminal equipment may be located near the area in which communications are required, thus obviating the need for long land circuit "tails." By the use of ground terminals that are transportable or even mobile, a flexible configuration may be retained. This flexibility is especially important in "contingency situations" where a critical situation in a foreign country may vastly increase the need for reliable communications for an undefined period of time. Conventional communication methods in such situations, in addition to taking a long time to establish, require that much fixed equipment be left behind should the situation change. In the case of communication links established via satellite, ground terminals may be removed and the satellite itself may be repositioned to cover a different part of the earth.

It has become convenient to discuss military communication satellite systems in terms of whether they are for strategic or tactical communications. Such terms serve chiefly as descriptive designators, since most satellites can be used for either type of system.

Strategic systems have come to mean an orbiting system of satellites (either stationary or in random orbits) associated with a number of earth terminals in such a way that communications can be established over any link in which a satellite is mutually visible to two or more ground stations. A tactical system, on the other hand, is generally considered to be one employed especially for localized tactical communications. In general, the satellite itself may differ from a strategic system in that it is especially designed to work with highly portable or even mobile ground stations. Such terminals might be aboard aircraft, carried on mobile land vehicles, or, as has been demonstrated, carried by a two-man "back-pack" team.

Early experiments in establishing a military communication satellite system included the Courier program which led toward a very ambitious program to establish a synchronous communication satellite. This program, known as Advent, was to develop a completely synchronous station-kept satellite. Because of the early state of space technology and the incomplete knowledge of satellite design, many difficulties occurred in the Advent program. Also, because electronic technology had not reached the state required to provide a lightweight transponder, the satellite's weight rapidly approached the limit that could be boosted into orbit by the Centaur launch vehicle. Difficulties with the Centaur program resulted in a final launch capability less than that originally envisioned. These problems within the Advent program became apparent in 1961, and in May 1962 the Secretary of Defense canceled the program and directed that a revised communication satellite program be initiated to carry unique and vital military traffic.

In the original planning two communication satellite systems were considered: the first, which used the Atlas-Agena, was to place a number of satellites into approximately 6000 n mi random polar orbits; the second, which was to come somewhat later, was for a few synchronous altitude equatorial satellites.

After a long series of studies conducted by the Air Force with the help of industry and nonprofit corporations such as the Aerospace Corporation, RAND Corporation, and MITRE Corporation, program authorization was granted in October 1964.

II. THE INITIAL DEFENSE COMMUNICATION SATELLITE PROJECT

In accordance with recommendations of the study groups, this Initial Defense Communication Satellite Program (IDCSP) was to utilize satellites weighing approximately 100 lb and carrying a solar cell array designed to operate in polar orbits. The satellites were to employ an X-band transponder that operated in the exclusive satellite communication frequency band. The original plan was to establish the system by launching seven or eight satellites on each Atlas-Agena booster.

An important consideration in establishing the system was the concept of multiply launched satellites. It was apparent from the first cost studies that to attempt to deploy a system, especially a random system that required 15 to 20 satellites for reasonable coverage between ground terminals, with a single satellite per launch vehicle, was economically unfeasible. Using the capabilities of the Atlas-Agena and designing the satellites to be carried in a dispenser that could release seven of them one at a time into orbit allowed a much more cost-effective program plan. For the second system being planned, with synchronous altitude satellites, it was expected that the satellites would be heavier and would have to be launched only two at a time by Titan IIIC.

In late 1964, the use of the Titan IIIC for launching the IDCSP appeared feasible and was so directed, with the Atlas-Agena capability maintained as a back-up. Although the Titan program was concerned primarily with research and development of the booster itself, a quick review of the capabilities of the IDCSP satellites to operate in near-synchronous equatorial orbits

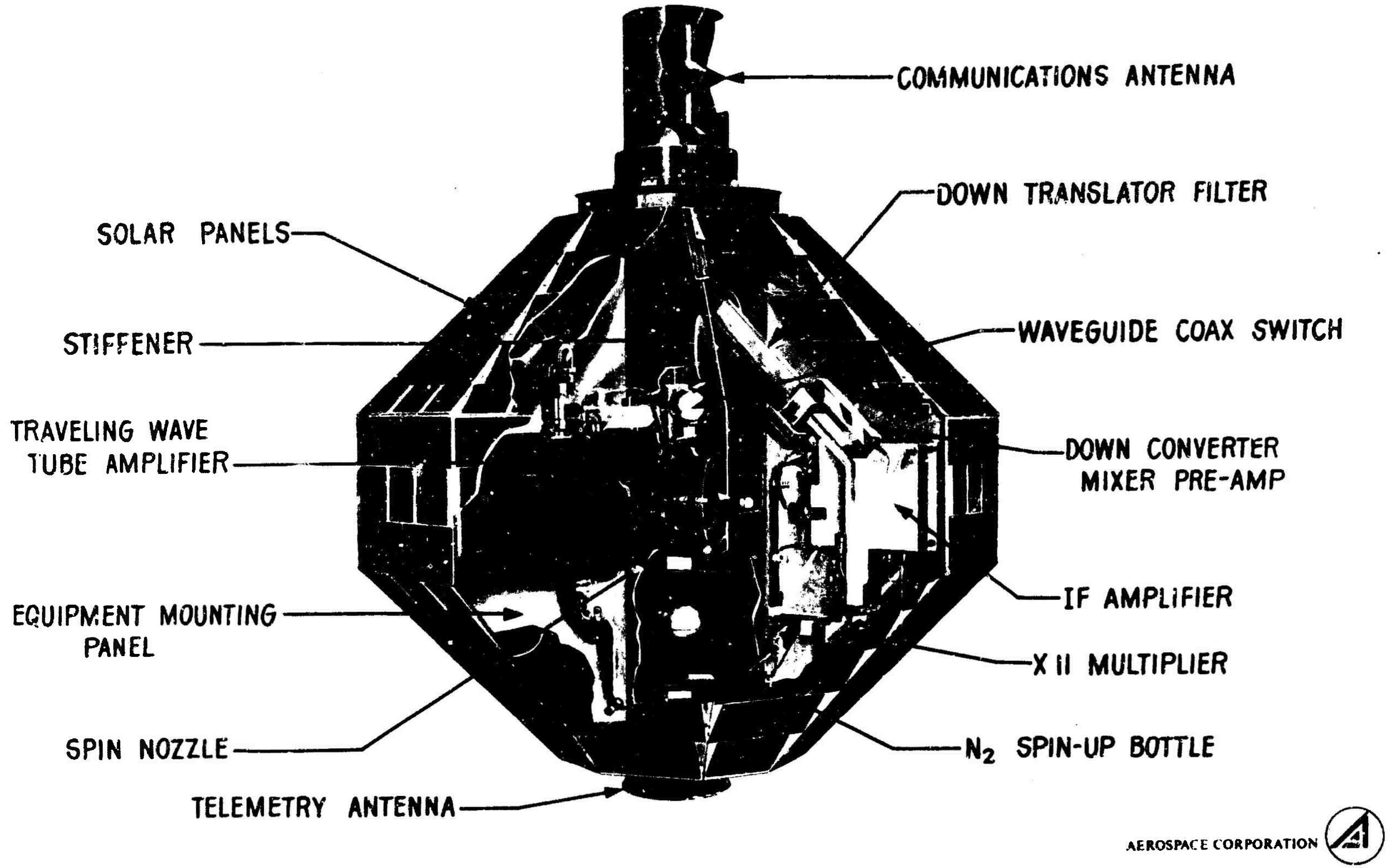

Fig. 1. Cutaway of spin-stabilized communications satellite.

and the capabilities of the booster revealed that with minor revision such operation was entirely feasible. Accordingly, in June 1965, with the first Titan IIIC launch a success, the Atlas-Agena back-up was dropped, and the Titan IIIC was used to launch eight IDCSP satellites at a time.

Figure : is a cutaway view of the IDCSP satellite. It is powered by approximately 8000 solar cell placed on 24 aluminum substrate panels. No batteries are included, and the satellite does not operate during eclipse periods. The satellite is spun about its principal axis of inertia, thus gyroscopically stabilizing the communication antenna. The spin-up is achieved by means of a cold gas nitrogen system which energizes two small nozzles on the equator of the satellite. The microwave transponder is an all solid state, hard limiting frequency translator using a 3-W traveling wave tube amplifier (TWTA) power output tube. A redundant TWTA is provided which is automatically switched on in case of failure of the first tube.

Since a command system is not required, the satellites can operate properly and fulfill their primary communication mission without the use of telemetry. It was decided that for a research and development slanted program, the availability of performance characteristics via telemetry would be most useful. A simple pulse-code modulation (PCM) telemetry generator and a 400-MHz transmitter is included in each satellite. In addition to sending performance data and operating temperatures from each satellite, the telemetry generator provides a unique satellite identification code. Also, each satellite in a payload transmits its telemetry data on a slightly different frequency. Information about the spin axis orientation of each satellite is provided by a sun sensor.

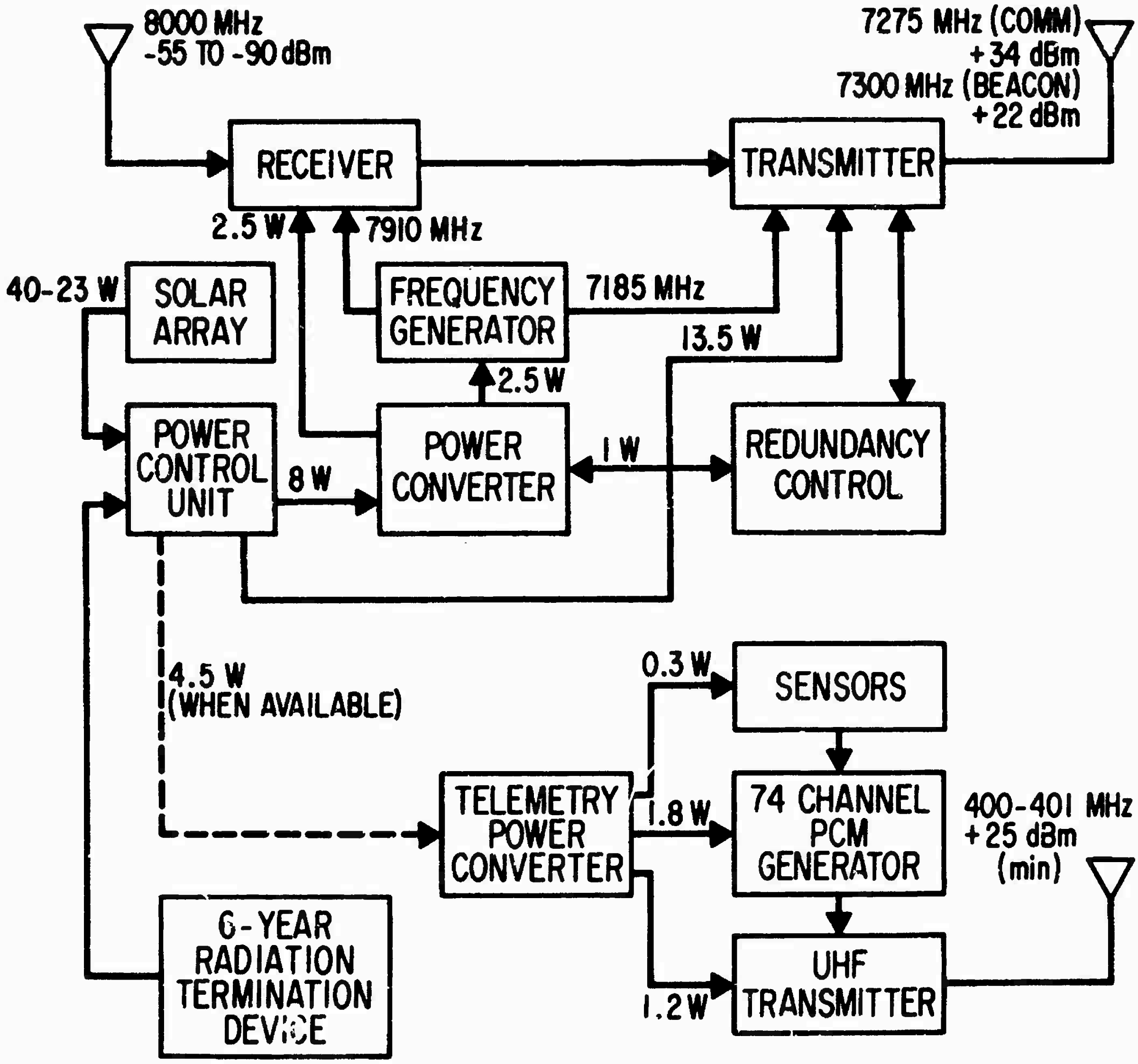

Fig. 2. IDCSP satellite electronics.

Figure 2 is a block diagram of the IDCSP electronics. It consists of three subsystems: The first is the X-band microwave transponder itself, consisting of a repeater, a transmitter, and a common frequency generator. The second subsystem includes the solar array which provides primary power at approximately 40 W initial orbit value, the power control unit, and the power converter. The third subsystem is the telemetry, consisting of the sensors, the PCM generator, and uhf transmitter. In addition, each satellite is provided with a redundancy control to switch TWTAs in the event of failure of the first tube. A six-year radiation termination device removes all primary power from the satellite after a period of six years.

Figure 3 shows a number of IDCSP satellites in the process of assembly at Philco-Ford, the satellite prime contractor. A unique feature of this program was the fact that for the first time, satellites of any type were being built on a production line basis. By the use of much automated aerospace ground equipment and by evolving special production techniques, Philco was able to produce satellites at the rate of two per month.

Figure 4 shows eight satellites in their dispenser mounted on top the transtage of the Titan IIIC. This picture was taken in the environmental shelter at the launching pad at Cape Kennedy just prior to the lowering of the payload protection fairing.

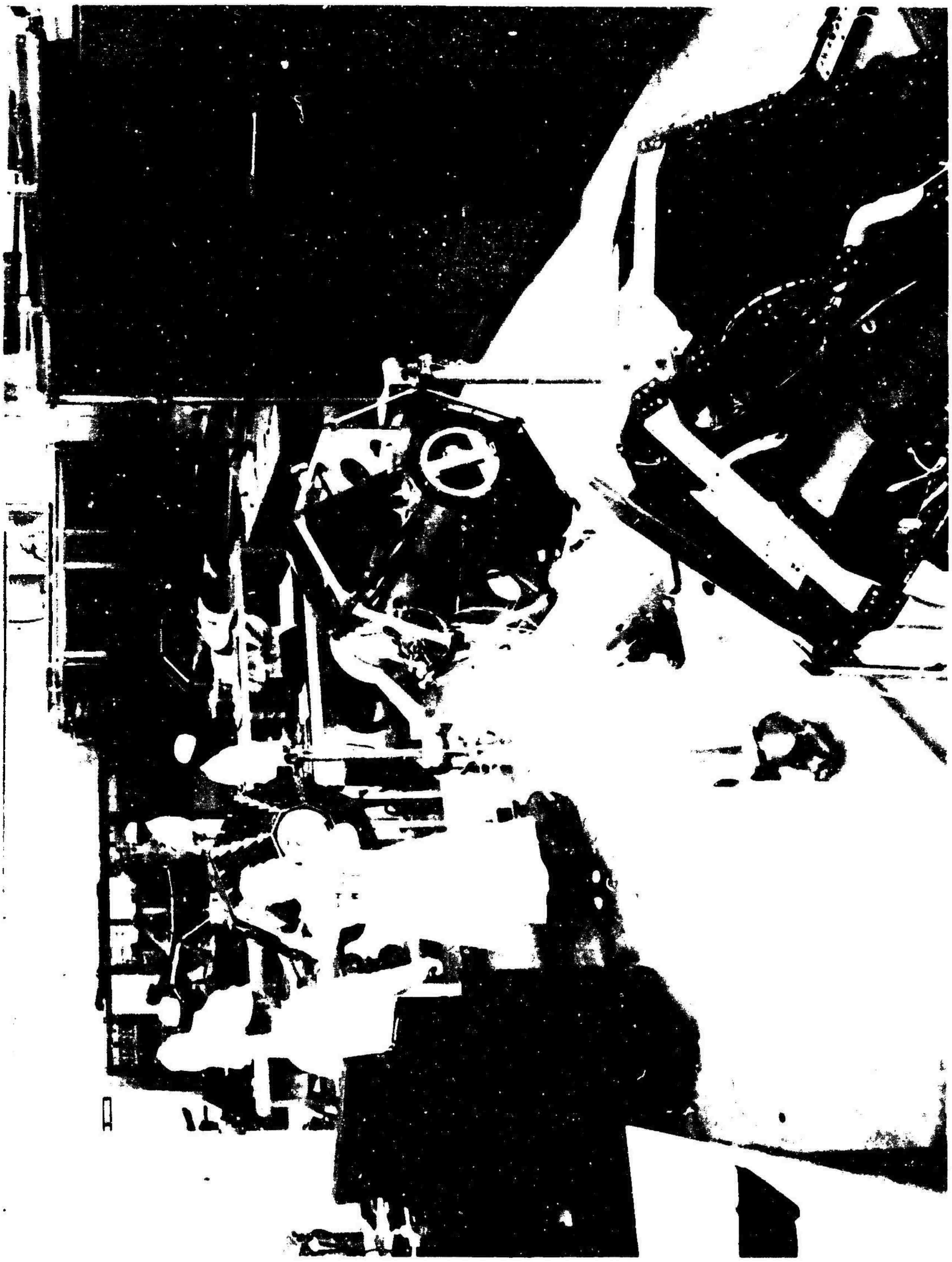

Fig. 3. IDCSP satellites in assembly line.

Fig. 4. Satellites mounted on Titan IIIC transtage.

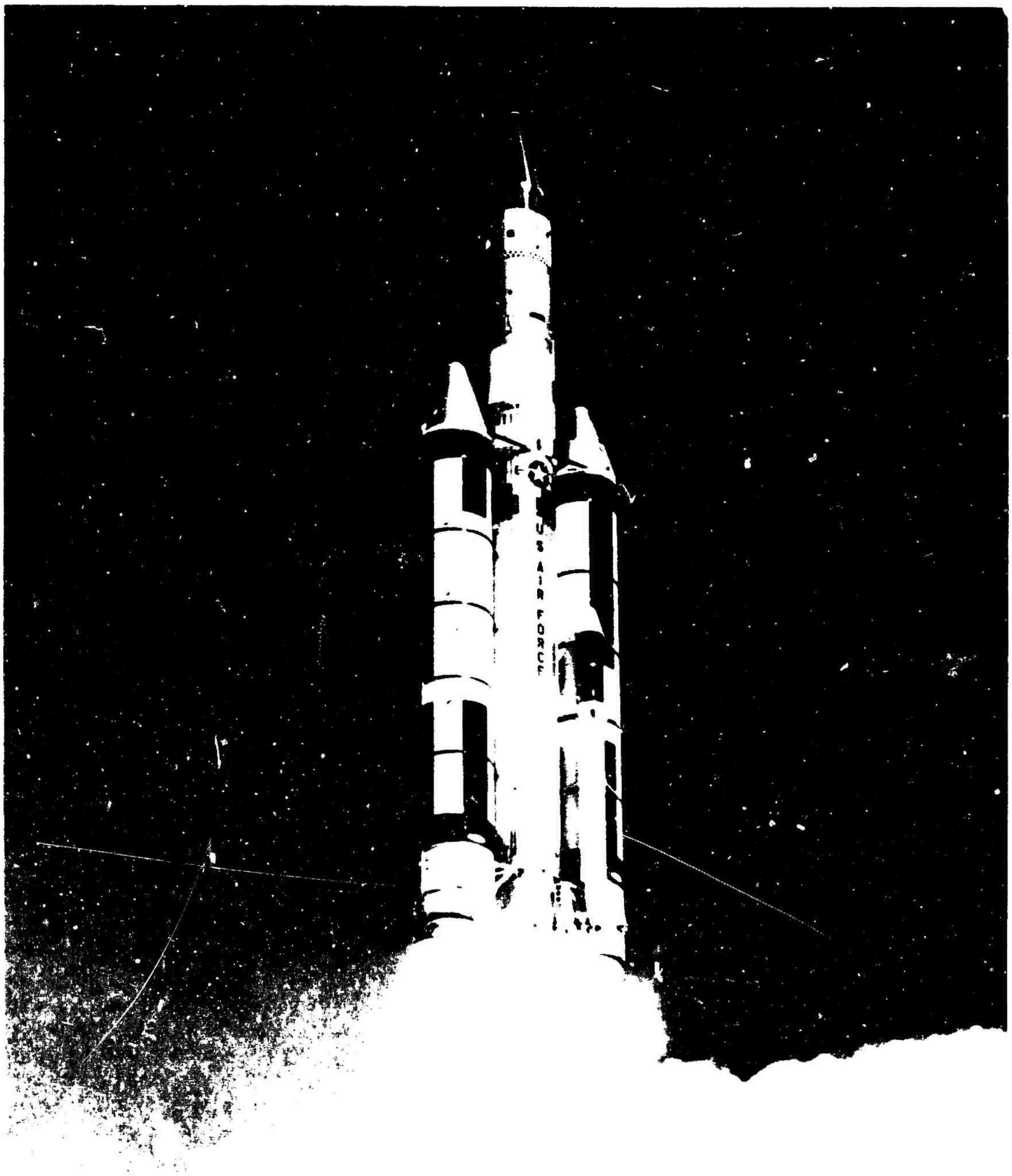

Fig. 5. First IDCSP launch aboard Titan IIIC.

III. IDCSP LAUNCHES

Figure 5 is a photograph of the first successful IDCSP launch, which occurred on June 16, 1966. This launch involved one of the most complicated orbital injection sequences attempted by any space launch vehicle.

Figure 6 is a sketch of the principal maneuvers required to inject satellites into the desired ~18,000 n mi equatorial orbit. In addition to maintaining the accuracy of the on-board inertial system during the 5.5-hr transfer orbit, the Titan IIIC transtage was called upon to perform a number of maneuvers during this transfer ellipse. So that the sun side of the satellite payload would not become too hot, the transtage was yawed back and forth several times during the transfer coast. In addition, the transtage was rolled several times to position its own telemetry antennas properly for telemetry readouts. When apogee at ~18,000 n mi was achieved, a final transtage burn was initiated to circularize the orbit. Thereafter, the transtage was yawed to the left to position the axis of the satellites on board the dispenser perpendicular to the equatorial plane. Next, the transtage attitude control system initiated an incremental velocity program as it ejected satellites one at a time. The velocity differential was added after each satellite was ejected, causing the last satellite ejected to be traveling 35 fps faster than the first. This differential velocity between the satellites caused them to spread out in orbit and to assume a random distribution. Figure 7 is an artist's concept of this ejection process.

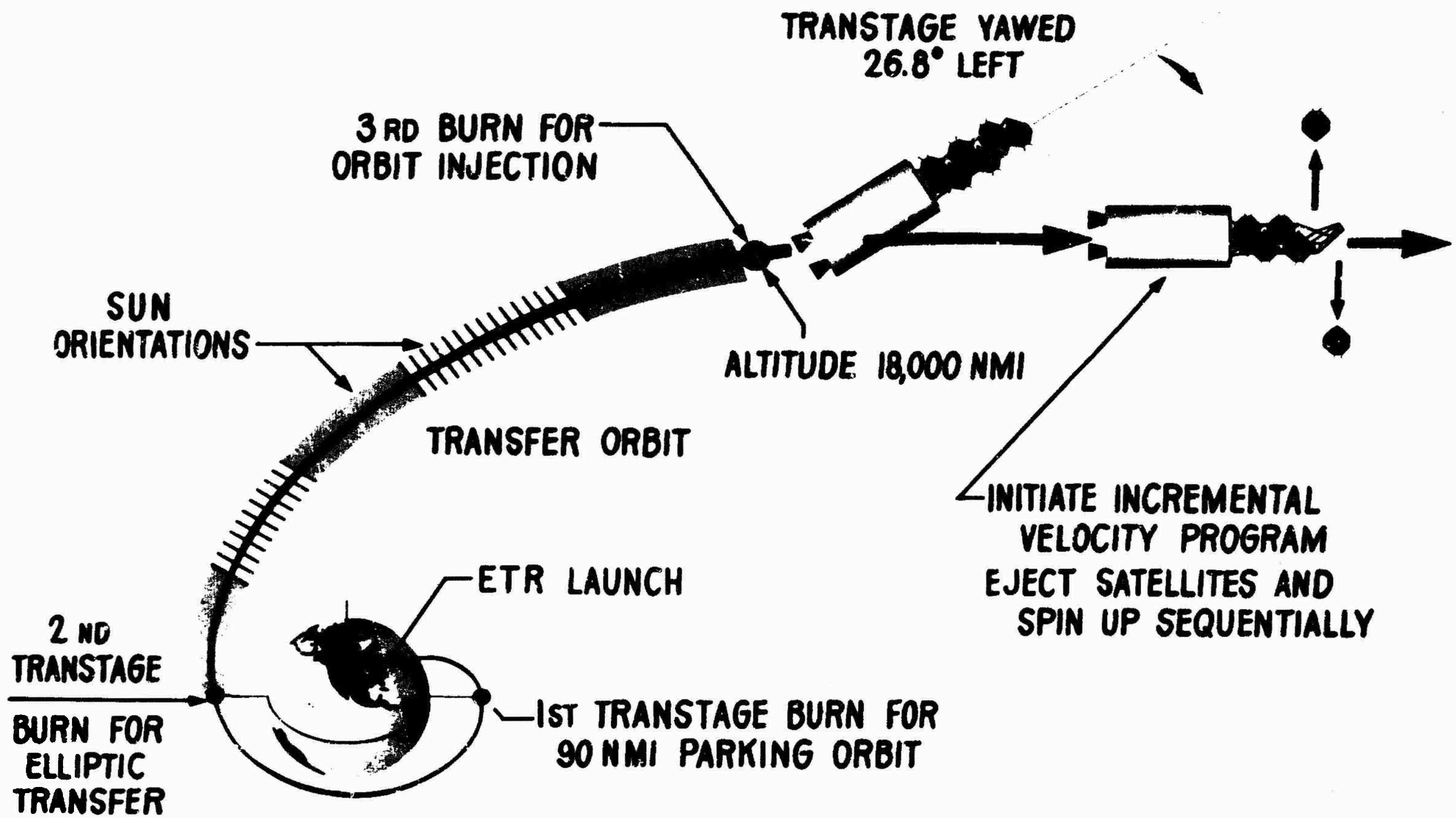

Fig. 6. Ascent trajectory.

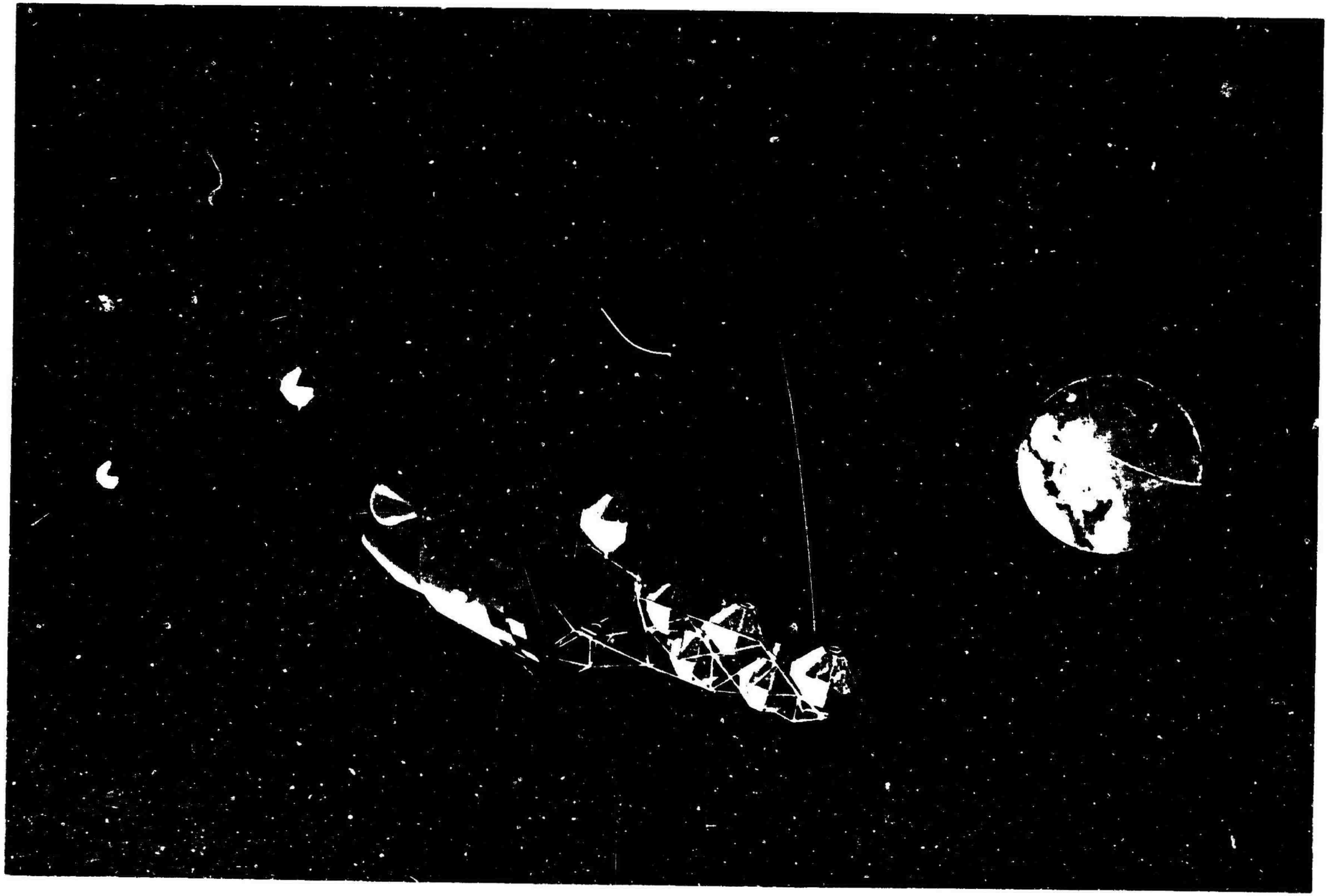

Fig. 7. Artist's conception of IDCSP satellite ejection.

A second launch attempt, made in August 1966, was planned to place eight additional satellites in orbit. Due to a failure of the Titan IIIC payload fairing, the booster separation destruct mechanism was activated and the Titan IIIC launch vehicle was destroyed about 80 sec into the flight. An intensive investigation into the fairing failure led to the recommendation that an aluminum fairing be substituted for the fiber-glass honeycomb then being used. An aluminum fairing was procured, and a third launch in January 1967 with an eight-satellite payload was completely successful.

IV. MULTIPLE PAYLOAD LAUNCH

A fourth launch was planned to carry three additional IDCSP satellites, an experimental uhf satellite built by Lincoln Laboratories, and a gravity gradient experiment built by Applied Physics Laboratory of Johns Hopkins University. Additionally, a fourth IDCSP satellite was to be modified to include an electronically phased array to "despin" the antenna beam so that it always faced the earth. This satellite was called the despun antenna test satellite (DATS). Electronical despinning of the antenna yielded approximately 10 dB of additional effective radiated power. Although only an experiment, this satellite has been used to prove conclusively the effectiveness of higher power satellites in improving communications between smaller earth terminals. To support the above six satellites, the Martin Company designed a dispenser to fit on the Titan IIIC transtage.

Figure 8 is a photograph of the six satellites in the multiple payload dispenser just prior to launch. This launch, which occurred on July 1, 1967, was a complete success, and all satellites were delivered to their planned orbits. This launch resulted in a total of 18 IDCSP satellites -- all in their planned random orbits. All 18 are operating as planned and are providing communications between earth terminals within their field of view. Of the 18 satellites, four have switched TWTAs. It is believed that this does not necessarily imply a failure of the TWTA itself, but rather indicates difficulties in the redundancy control circuits associated with temperature extremes and turn-on transients encountered during the eclipse season.

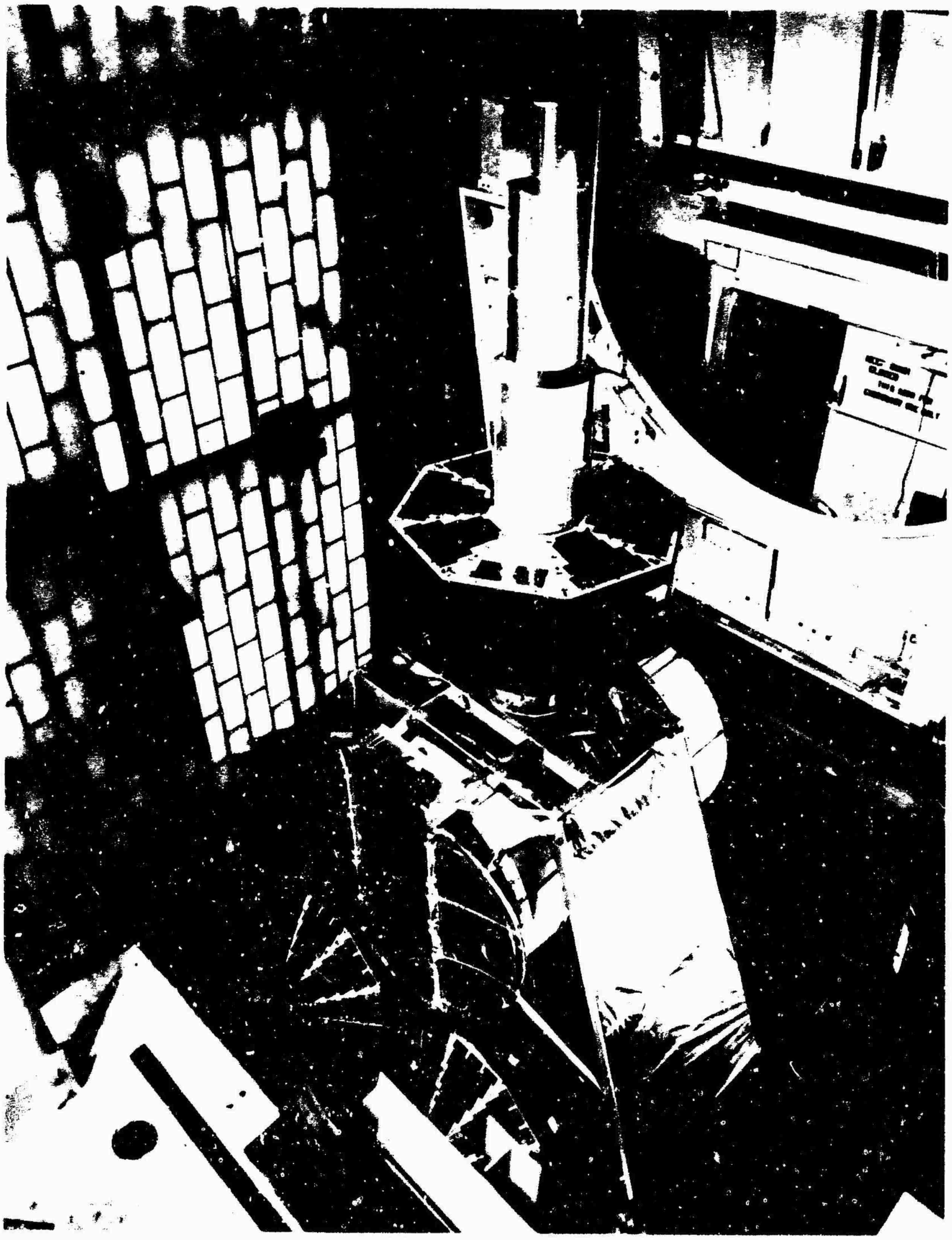

Fig. 8. Multiple payload dispenser containing six satellites.

V. UNITED KINGDOM SATELLITE

As a result of the success achieved by the U.S. Air Force in establishing a communication satellite system, the government of the United Kingdom asked if the United States would be willing to establish for them a synchronous communication satellite that would provide unique and vital military communications. This request resulted in a Memorandum of Understanding being signed by Secretary of Defense McNamara and the U.K. representative of the Ministry of Defence, Lord Shackelton, on September 19, 1966. In this Memorandum the U.S. Government agreed to have the U.S. Air Force procure for Her Majesty's Government a synchronous station-kept satellite. The Air Force will launch this satellite for the United Kingdom and establish it on-orbit before turning the command and control function over to a telemetry and control station to be built in the United Kingdom near London.

Unlike satellites of the IDCSP, this U.K. satellite is to be launched on a Thor-Delta vehicle and thus requires its own apogee kick motor to circularize its final orbit. In addition, it is to be completely synchronous, which requires that station-keeping facilities be provided on board the satellite. Because the satellite must be kept on station, commands from the ground will be used to fire small, 5-lb-thrust reaction engines fueled with hydrazine.

Launch of the first United Kingdom satellite is planned for the latter part of 1968.

VI. TACTICAL COMMUNICATION SATELLITES

All of the satellites described thus far have been intended to implement a world-wide military communication system. This means that relatively large, complicated ground terminals may be used. In addition, such a system must operate in the defense communication system in a manner similar to other trunking circuits making use of cable or radio and, therefore, is subject to overall network control.

In contrast, the communication circuits that can be provided by a tactical communication satellite need ground stations that are simple, lightweight, and capable of operating from vehicles in motion, including modern high-speed aircraft.

There is one problem in using X-band microwave transmissions through a satellite from a moving vehicle. An antenna whose size is adequate to give the necessary gain must have a small beam width. There must then be a method for keeping the antenna trained on the satellite during the course of communications. Although the satellite itself may be station-kept, and hence its line of sight to the ground station fixed, the maneuvers of a moving platform such as an aircraft require the antenna constantly to be repositioned.

One way to avoid this difficulty is to use a frequency in the uhf band rather than in the super-high frequency (shf). Thus, a simple, nonsteerable antenna can be used. In addition to having essentially omnidirectional coverage, such an antenna has an effective aperture large enough to provide the necessary antenna gain.

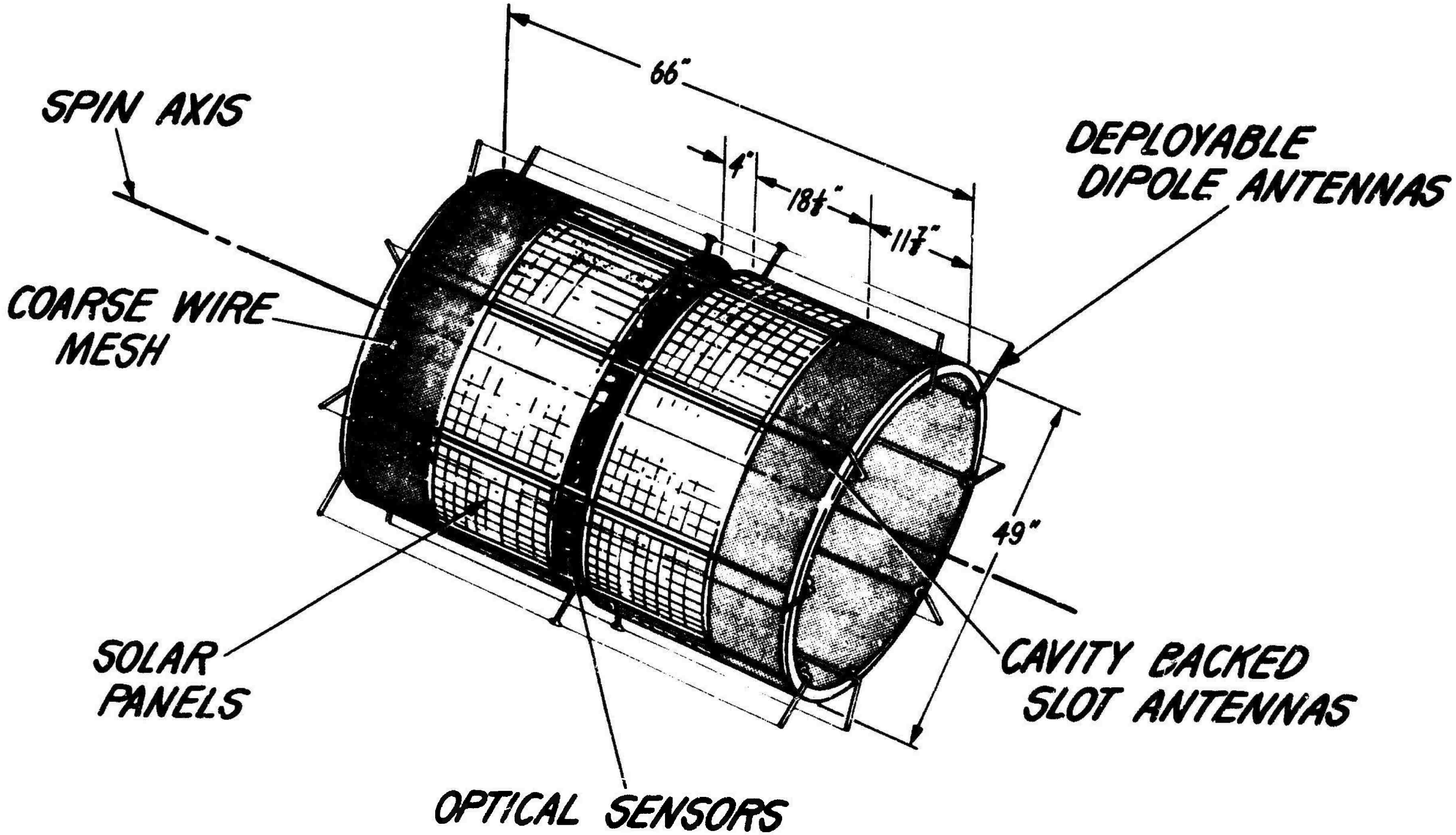

Fig. 9. The LES-5 satellite.

Other problems arise, however, because of the use of these lower frequencies. Since the antenna can receive signals over a wide angle, transmissions from the satellite may arrive from more than one path, particularly when this path includes the surface of the ocean. Under such multipath conditions, signals arrive at the satellite both directly and from reflections. These signals arrive with differing amount of propagation delay, and require the use of specialized modulation and demodulation techniques.

The Air Force has been interested in the use of uhf transmissions from satellites for a number of years. A recent program resulted in the launch of a Lincoln Experimental Satellite (LES-4). This satellite contains a uhf beacon to permit associated ground stations to analyze the problems connected with multipath transmission.

As a part of the multiple payload launch described earlier, LES-5 (Fig. 9) was launched. A number of tests with various types of ground stations have been under way since the launch last July. These tests have included communications to highly portable ground equipment as well as to aircraft in flight -- all have been successful.

In addition to the Lincoln Laboratories' series of satellites, the Air Force is in the process of developing at Hughes Aircraft Company a tactical satellite to further experiments in the area of tactical satellite communication. Figure 10 is an artist's conception of such a satellite.

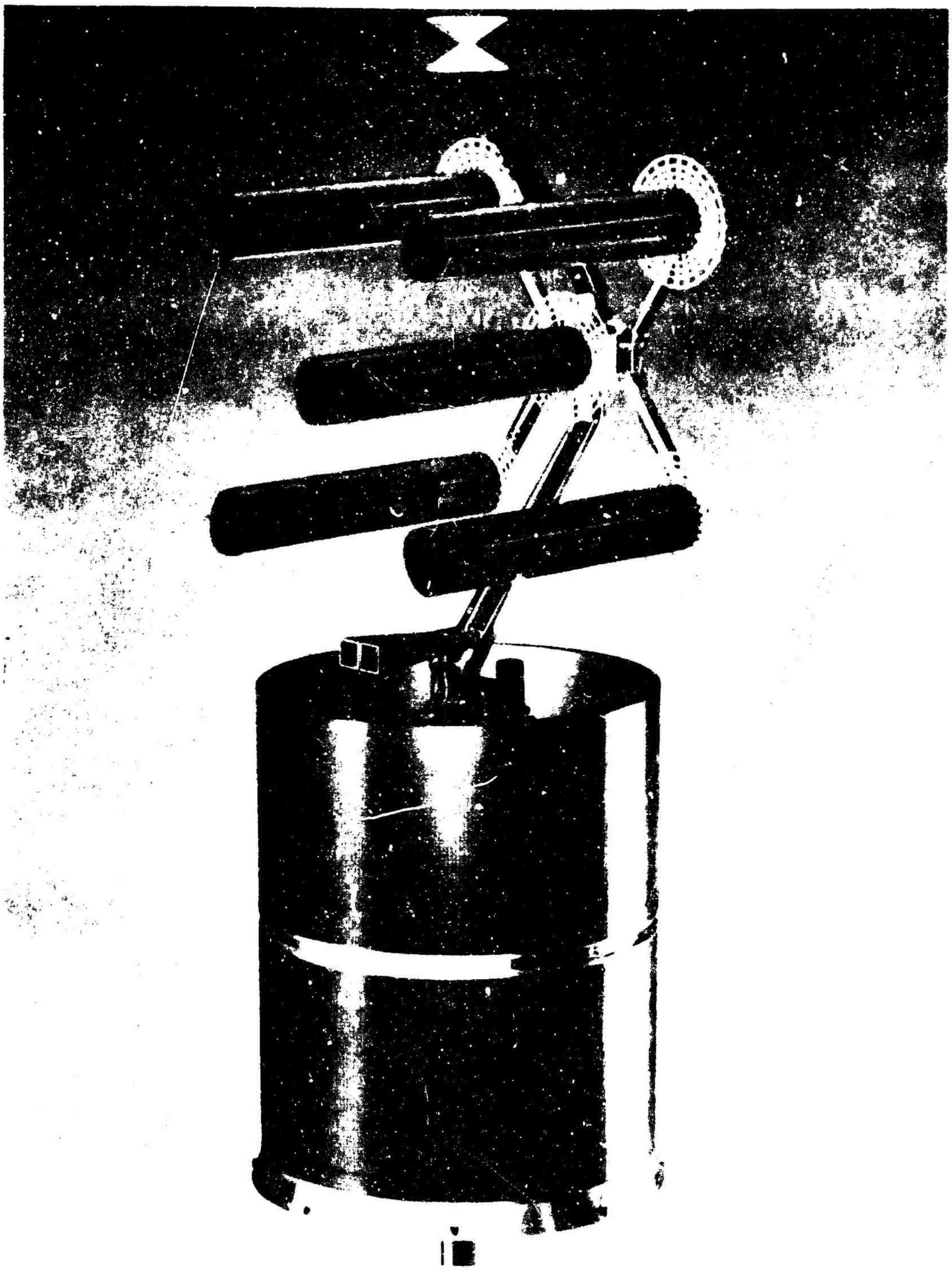

Fig. 10. Artist's conception of tactical satellite.

VII. CONCLUDING STATEMENT

The Initial Defense Communication Satellite Program now provides a limited operational capability between widely separated fixed terminals. The LES-5 and DATS have demonstrated advances in technology that will allow communication between aircraft, ships, mobile ground terminals, and the large, fixed installations. The technology that will allow a field unit based anywhere in the world immediately to contact other units in the theater or even the Continental United States has been achieved! Initial implementation of a system based on this technology is under way.

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Abstract (Continued)