ATS-6 Experimental Communications Satellite—Report on Early Orbital Results

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The primary purpose of the ATS-6 spacecraft is to evaluate a variety of new space communications concepts requiring the use of a geosynchronous spacecraft. The uniqueness of the ATS-6 is embodied in the use of a three-axis stabilization system of sufficient accuracy to utilize fully the narrow beamwidths of the high-gain antenna. On July 2, 1974, the ATS-6 was declared operational (launch date was May 30, 1974); since then, the spacecraft has successfully supported health and education telecommunications, aircraft ranging and communications, and UHF television broadcasts. The experiments have been performed at frequencies extending from 136 MHz up to 30 GHz and have utilized pointing accuracies of 0.04 deg.

Introduction

THE Applications Technology Satellite VI (ATS-6) is the latest and most ambitious of the NASA experimental communications satellites. After nearly ten years in design and development, it was launched on May 30, 1974, and has been operating successfully in orbit now for more than seven months. Although its experiments are scheduled to be carried on for at least two years, some early results are becomming available. It is the purpose of this paper to review the spacecraft design, describe the experiments, and present a brief treatment of those results that might be of interest to the communication community.

ATS-6 represents a major departure from earlier spacecraft in the NASA Applications Technology Satellite series. Unlike the earlier spin-stablilzed or gravity-gradient stabilized spacecraft of the first five experimental geosynchronous satellites, ATS-6 is a three-axis body stabilized vehicle with the capability of providing precision offset pointing. It is designed to usher in a new era in communication satellite technology where the traditional roles of small satellites and large earth terminals are reversed. A high gain 9.1-m (30-ft) diameter parabolic antenna is deployed on the spacecraft so that communications can be established with correspondingly small, austere, ground terminals. With rf gains of from 34 dB up to more than 50 dB over the range of uhf to C-band, relatively conventional satellite transponder performance parameters are able to achieve highly unconventional results. In fact, ATS-6 represents the first serious attempt to design a satellite capable of providing a direct broadcast relay of television to multiple low-cost receivers. Furthermore, it is designed to provide mulitple voice and data duplex relay links between both commerical aircraft and low orbit spacecraft and their respective ground terminals.

In addition to pioneering in direct TV broadcast, satellite air traffic control, and satellite tracking and data relay applications, ATS-6 also serves as a platform for many experiments in millimeter wave propagation, radio-frequency interference measurements, and meteorological and scientific measurements from synchronous altitude. Altogether, ATS-6 carries some 18 scientific, meteorolgical, and communications technology experiments. This paper will describe seven of these latter experiments and touch very briefly on their results to date. The experiments to be covered are:health, education, telecommunication experiment (HET); position location and aircraft communication experiment (PLACE); tracking and data relay experiment (T&DRE); television relay using small terminals (TRUST); millimeter wave propagation experiment (MMW); COMSAT propagation experiment (Propagation); radio-frequency interference experiment (RFI).

Each of these experiments imposes certain common and peculiar requirements on the performance objectives of the ATS-6 spacecraft. The primary objectives of ATS-6 can be summarized as follows: 1) To demonstrate deployment of a 9.1-m diameter parabolic reflector in space. 2) To provide 0.1-deg fine pointing at any offset angle within ± 10 deg of the local vertical. 3) To provide tracking of fixed and moving targets to less than 0.5-deg accuracy. 4) To provide an integrated transponder and feed system for the following experiments: HET; TRUST; PLACE; T&DRE, and RFI. 5) Provide an oriented stable platform in geostationary orbit for additional experiments.

To appreciate the experiments fully, it is advantageous to review the basic design configuration of the ATS-6 spacecraft.

Spacecraft Description

Designed to be launched atop an Air Force Titan IIIC booster, the configuration of ATS-6 is depicted in Fig. 1 (stowed) and Fig. 2 (deployed). The 9.1-m reflector is a furlable, 48-rib design with a copper-coated dacron mesh that can be coiled into a compact, torus-shaped package for launch. The truss to support the antenna elements at the focal plane of the reflector is an eight-element, A-frame design made of graphite-reinforced plastic. This material was chosen because of its excellent dimensional stability over wide temperature variations. The reflector is designed for an $F/D = 0.44$.

The solar arrays are locked around the main body of the satellite, the earth viewing module (EVM), during launch. Following separation from the third stage of the Titan launch vehicle (the Transtage) after injection into the final geosynchronous orbit, restraining cables for the booms/arrays are cut by pyrotechnics. Spring/damper mechanisms at the hub end of each boom provide a rate-controlled deployment to a high locked position. When the arrays are subsequently released, similar spring/damper mechanisms cause a 180° rotation of each semicylindrical array about a skewed hinge line to yield oppositely facing arrays. The reflector is then deployed by cutting a cable holding spring-loaded doors around the sides of the torus container. The strain energy resident in the coiled position of the reflector ribs causes deployment to occur as the restraining doors are opened. The booms are then lowered from their high position (chosen to insure safe reflector deployment, even under possible array

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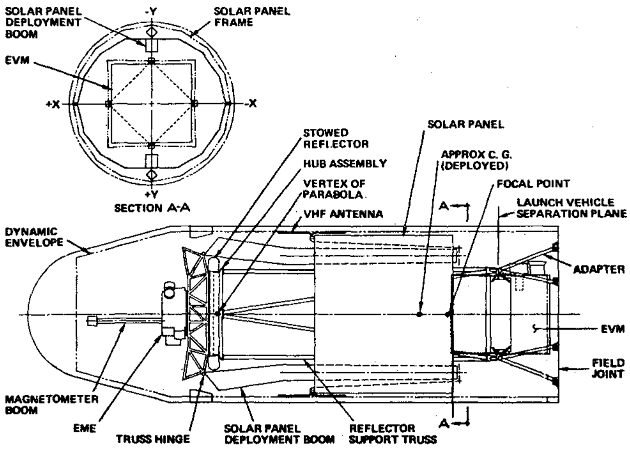

Fig. 1 ATS-6 launch (stowed) configuration.

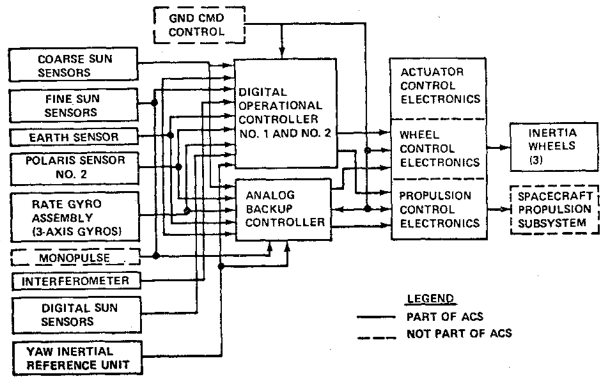

Fig. 3 Simplified block diagram of attitude control subsystem.

unfold failure conditions) to a lower, final orbital position to minimize solar pressure torques.

The deployed spacecraft measures 15.8 m (51.7 ft) from tip to tip of the solar arrays and 8.2 m (26.9 ft) from the bottom (earth viewing face) of the EVM to the top of the magnetometer boom. The gross launch weight of 1397.5 kg (3078.3 lb) includes a 48.2-kg (106.1-lb) adapter structure which remains with the Transtage.

The thermal control subsystem is designed to maintain a 20°C ± 15°C average temperature on all mounting surfaces within the EVM through use of superinsulation, thermal louvers, and heat pipes. Thermal coatings and thermostatically controlled heaters are used for certain external components. The tight temperature control maintained within the EVM is made possible by the use of some 1.6m^2 of self-actuating louvers on the north and south faces of the EVM, and by approximately 70 m of heat pipes bonded into the north and south honeycomb panels and into the transverse panels between them in the EVM.

The power subsystem of ATS-6 is designed to provide a well-regulated 30.5-v supply for the multimode subsystem and experiment loads. The two fixed hemicylindrical solar arrays, consisting of 16 flat panels each, together provide a near-constant power output (almost 600 w initially) as the sun rotates around the apparent-cylinder axis /north-south) once per day. Energy storage is provided by two 19-cell, 15 A-h, nickel cadmium batteries that provide housekeeping power during sun occult and also support peak load conditions when the spacecraft power demands exceed the solar array capability. The power subsystem has numerous automatic protective features, extensive redundancy, and operates in a shunt, charge, or boost mode to handle the large variations in required power for the various spacecraft operating modes (e.g., 260 w for the occult mode, up to 550 w for the PLACE mode).

The ATS-6 telemetry and command subsystem utilizes two pairs of vhf dipole antennas located at the edges of the solar arrays. These provide near-omni coverage in the stowed configuration during the launch, ascent, and final orbit injection phases, during the various stages of spacecraft deployment, and for the fully deployed operational configuration. Once the spacecraft is earth-oriented, command/telemetry data are transmitted via the 9.1-m reflector with about a 15° field-of-view and 14-dB gain. Commands are normally sent at vhf frequencies, but can also be uplinked at C-band. The telemetry and command subsystem has extensive cross-strapping features and is fully redundant.

The attitude control subsystem (ACS) serves to stabilize and orient the spacecraft after separation from the transtage. It also provides the necessary stabilization and accurate slewing control for the various ATS-6 experiments. The basic elements of the ACS are depicted in Fig. 3. The control reference signals are obtained from the following sensors. Two (redundant) three-axis rate gyro assemblies provide

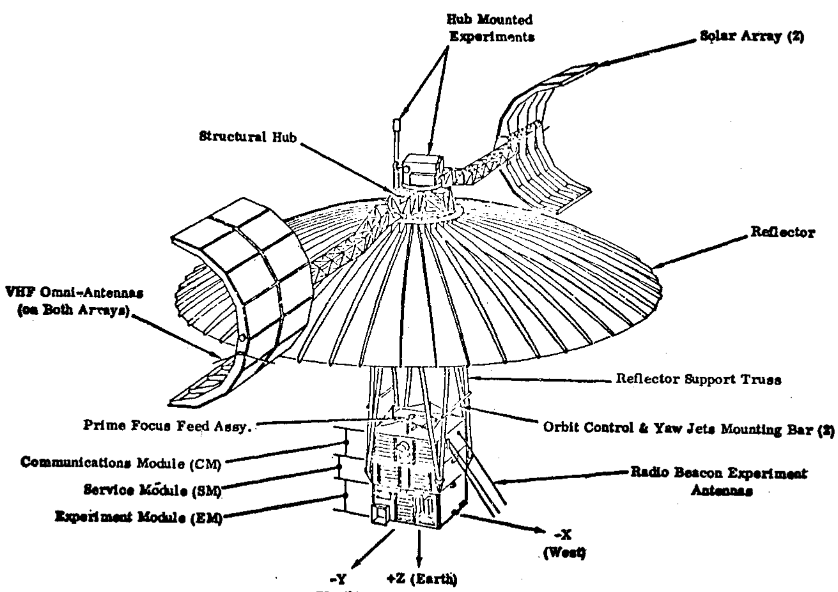

Fig. 2 ATS-6 orbital (deployed) configuration.

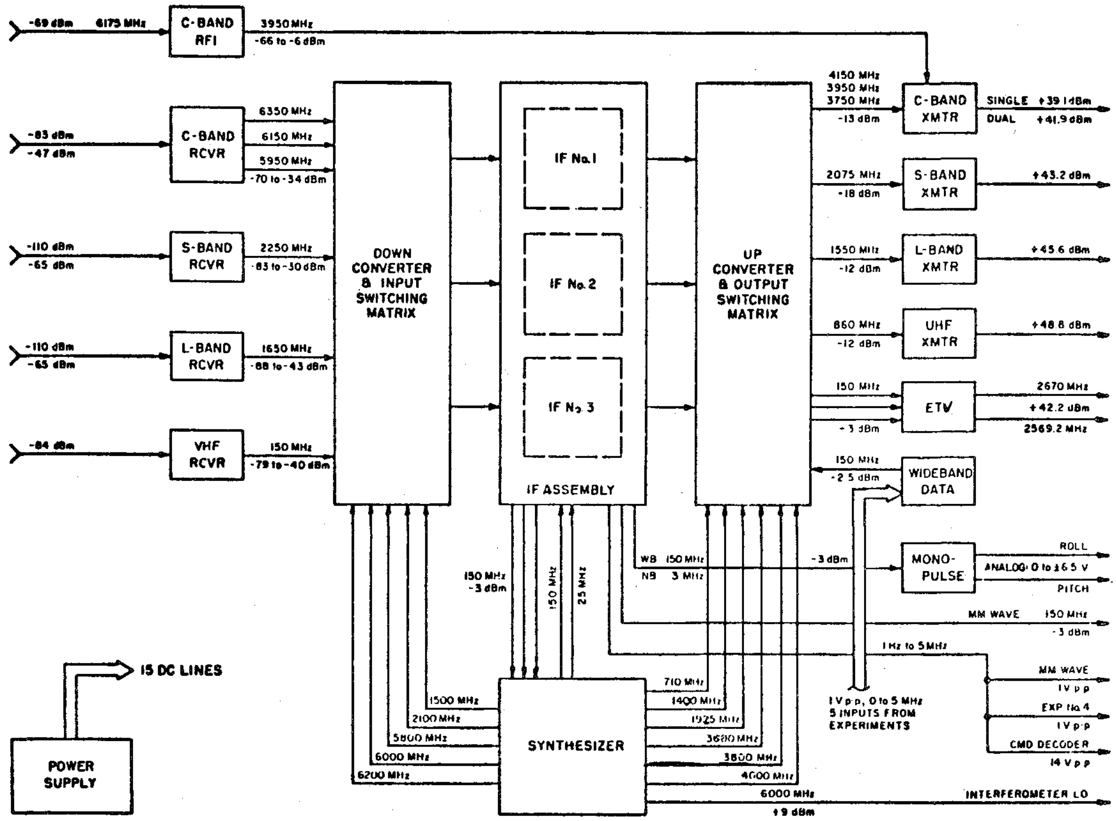

Fig. 4 Simplified block diagram of communication subsystem.

angular rate data for rate damping and rate compensation during the acquisition modes. Analog and digital sun sensors provide all-attitude pitch/yaw sun angle data for use during the initial sun and earth acquisition modes. The earth sensor assembly is used for measuring roll/pitch angles of the spacecraft Z-axis off the local vertical (up to $\pm 14°$) during the initial earth acquisition mode and subsequent operational modes. The yaw inertial reference unit and the Polaris sensor are used for measuring angular motions around the spacecraft Z-(yaw) axis.

A C-band interferometer, when illuminated by rf energy from a ground transmitter, measures the spacecraft roll and pitch angles (over a primary angle range of $\pm 17.5°$) relative to a line-of-sight vector from the spacecraft to the transmitter. A monopulse mode in the communication subsystem also provides roll/pitch error signals which enable the ACS to boresight the 9.1-m reflector to a ground station emanating a vhf, S-band or C-band signal. The S-band monopulse mode can also be used for a closed-loop satellite track mode based on S-band transmissions from the target satellite.

The ACS features two redundant digital operational controllers (DOC's). The basic control laws for the various acquisition and operational modes are programmed into the DOC memory, which can be reprogrammed by ground command. The DOC accepts mode/pointing commands from the ground, as well as orbit ephemeris data for the purposes of holding a fixed ground aim point (by compensating for nongeostationary orbit effects) or of tracking a low-orbiting satellite in an open-loop programmed track mode. The analog backup controller (ABC) is a simple, low-power analog controller that serves as a backup to the DOC's for the acquisition modes and for the local vertical and station point (monopulse) operational modes.

The actuator control electronics (ACE) includes the wheel drive electronics, the wheel unload logic, and the spacecraft propulsion subsystem (SPS) control electronics and associated power supplies. The ACE drives the inertia wheels or the SPS thruster valves in response to attitude error signals from either one of the DOC's the ABC, or by ground command. The three inertia wheels serve as the prime torquers for all modes of operation except acquisition, orbit control, and jet-only control.

The spacecraft propulsion subsystem provides fully redundant thrusters for orbit control and three-axis attitude control, including inertia wheel momentum unloading. It utilizes 16 catalytic hydrazine thrusters fed from two propellant tanks with positive expulsion bladder control operating in a single blowdown mode. Thrust levels for all thrusters average about 0.46 N (0.10 lbf). The total propellent load is 49.9 kg (110.6 lb) plus 0.82 kg (1.8 lb) of pressurant.

The communication subsystem is an integrated multifrequency double conversion transponder capable of receiving up to three signals in any of four frequency bands (C, S, L, and vhf), and amplifying, processing, and retransmitting them on any commanded frequency in four frequency bands (C, S, L, and uhf). As shown in the simplified block diagram of Fig. 4, the communication subsystem consists of a transponder and antenna feeds. The transponder is itself an essential part of most of the communication experiments.

The transponder can be divided into four major functional elements: the receivers, the if amplifier assembly, the frequency synthesizer, and the transmitters. Supporting these major elements are the rf input-output circuitry, wideband data unit, monopulse detector, command decoders, and dc-dc converters. With certain exceptions, all active components are redundant. This includes the synthesizer, transmitters, receivers (except L-band), monopulse, wideband data unit and transponder, command decoder. The if is triply redundant.

The communication subsystem operates in various commandable modes to fulfill the requirements of the ATS-6 experiments. In the coherent mode, all local oscillator signals are synthesized from a single oscillator phase-locked to the C-band signal carrier transmitted from the ground to the spacecraft. In the noncoherent mode, the local oscillator

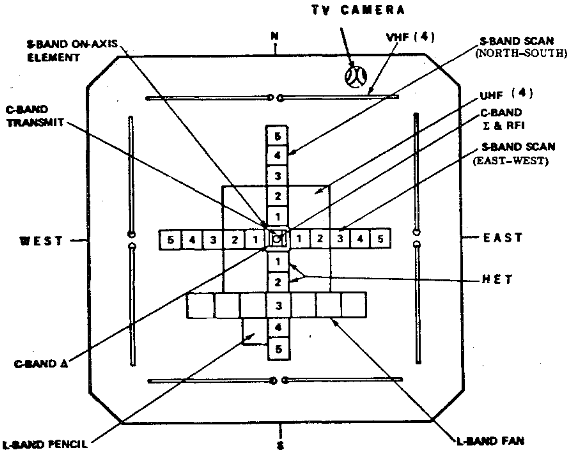

Fig. 5 Diagram of prime focus feed.

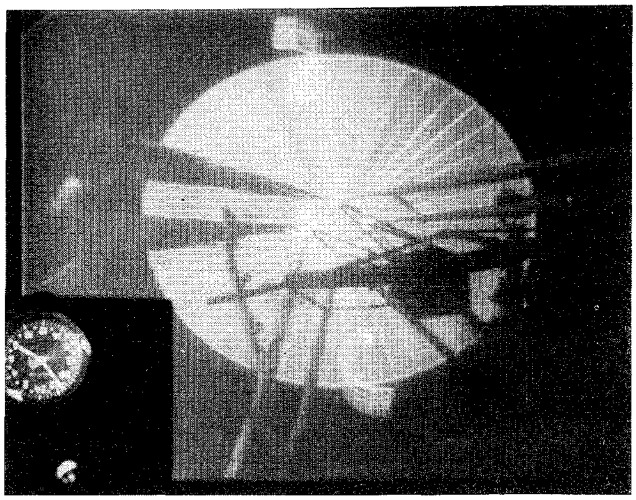

Fig. 6 TV self-portrait.

frequencies are generated within the spacecraft by a highly stable fixed-frequency oscillator with an initial frequency tolerance of ± 10 ppm and a long-term stability of better than ± 3 ppm in three months. The primary mode of transponder operation is frequency translation with hard limiting in the if section. This mode can be used with any combination of receivers and transmitters. A second mode of frequency translation with AGC-controlled linear amplification is available via the 3950 MHz channel of the C-band transmitter only.

The antenna feed assemblies provide radiating and receiving elements for the communication subsystem. The prime focus feed (Fig. 5) is located on the top surface of the communication module at the focal plane of the 9.1-m parabolic reflector. Multiple feeds are used to accommodate the various spacecraft rf frequencies and to permit beam shaping and scanning. In addition to the prime focus feeds, Earth viewing horns are located on the bottom surface of the EVM to transmit and receive wide beam C-band signals directly to and from the Earth acting as the data link for experiments.

Spacecraft Launch and Orbital Performance

Exactly three years and four months from the date the hardware development phase was initiated, ATS-6 was successfully launched from Cape Canaveral at 0900 EDT on May 30, 1974, aboard a Titan IIIC. Final injection into a near-perfect geosynchronous orbit occurred at 1531 EDT.

The launch/ascent/injection sequence was a nominal one for the Titan. It involved injecting into the transfer orbit at the second equatorial crossing of the initial low-altitude parking orbit, and injecting into final geosynchronous orbit at first apogee of the transfer orbit. Spacecraft separation was excellent, with the subsequent tipoff rates below 0.15 deg/sec (compared to a spec limit of 1 deg/sec).

The final geosynchronous orbit was characterized by an inclination of 1.8 deg, as planned, an eccentricity of 0.0008, a subsatellite position of about 95 deg W longitude and a westward longitude drift of 0.27 deg/day. Because of the very small period and eccentricity errors realized by the Titan, some 8.2 kg of spacecraft hydrazine propellant budgeted for correcting 3-sigma period/eccentricity errors was saved (out of a total of 49.9 kg). This saving, in conjunction with lower-than-budgeted propellant expenditures for attitude control, indicate a projected propellant capacity well in excess of that required for the design goal of a 5-yr mission lifetime.

Following ATS-6 separation from the Transtage, the onboard automatic deployment sequencer performed flawlessly (as did all the associated 36 microswitches and pyrotechnic elements) in sequential control of the spacecraft deployment. All of the deployment motions themselves occurred within approximately 35 min of separation. Less than 6 hr later, the spacecraft had completed sun acquisition, earth acquisition, pitch and roll control to local vertical, and yaw orientation.

Some three days into the mission, established in advance as a suitable period for completion of spacecraft outgassing activities, the Polaris star tracker, some of the high-powered transmitters, and an on-board television camera were activated. This wide-angle camera is located in the top (space side) of the earth viewing module and oriented so as to view the deployed reflector and solar booms/arrays. On the midnight side of the ATS-6 orbit (to prevent direct sun illumination and damage to the camera) a series of self-portraits were commanded to be taken by the camera and were telementered to the ground. These pictures provided an early confirmation of proper deployment of the reflector and of the booms/arrays. Later, antenna gain and pattern measurements provided further confirmation that the reflector is maintaining a proper contour. Figure 6 shows one of the TV self portraits.

For the first 30 days in orbit, the spacecraft was subjected to an extensive checkout routine to establish system and subsystem performance in space. The results have been most satisfactory. All spacecraft subsystems were shown to meet and, in most cases, exceed their design objectives. Of particular interest are the attitude control subsystem and the communications subsystem. Both of these subsystems were tested thoroughly in all of their modes for both primary and backup systems. This covered pointing, slewing, and tracking a commanded ephemeris, making antenna pattern measurements, measuring gain at and off boresight, and monopulsing at vhf, S-band and C-band.

Table 1 compares the actual measured in-orbit performance of the ACS against its specification requirements. In every parameter the measured performance exceeds its specified requirement by a factor of two or better. Pointing stability has been particularly effective with the C-band interferometer as the sensor. The interferometer has been demonstrated to sense an angle change of less than 0.0014 deg. In this case, the control system is limited only by the 0.005-deg programmed resolution of the digital controllers.

Table 2 provides a similar comparison for the communication subsystem. G/T and EIRP measurements were made as near beam center as could be determined, and with calibrated ground terminal instrumentation. Except for the L-band fan beam, which has no single peak value, all measured peak valves equaled or exceeded their specified values.

On July 2, approximately one month after launch, spacecraft checkout was complete and ATS-6 was declared operational. The spacecraft was turned over to the experimenters and since then over 4000 hr of experiments have been performed to date (February 1975). ATS-6 has per-

Table 1 ACS in-orbit performance compliance

Mode	Parameter[a]	Spec	Actual
ABC sun acquisition	Time to acquire (min)	30	10
	Pointing accuracy (deg)	4.5	2
ABC Earth acquisition	Time to acquire (min)	80	50
	Pointing accuracy (deg)	1.0	0.35
ABC local vertical	Pointing accuracy (deg)	1.0	0.35
DOC vhf monopulse	Pointing stability (deg)	1.0	0.5
DOC S-band monopulse	Pointing stability (deg)	0.3	0.01
DOC C-band monopulse	Pointing stability (deg)	0.1	0.002
DOC offset point ground[b]	Pointing accuracy (deg)	0.1	0.049
	Pointing stability (deg)	0.1	0.01
DOC low jitter[b]	Pointing accuracy (deg)	0.5	<0.1
	Pointing stability (deg)	0.01	0.005
	Rate stability (low frequency) (deg/sec)	0.001	0.0003
DOC satellite track	Tracking accuracy (deg)	0.5	<0.2
DOC offset point slew	Rate (deg/min)	≥0.5	1.2
	Settling time (min)	≤10	<3
DOC operational modes (above)	Yaw accuracy using PSA (deg)	0.15	<0.1

[a]Indicated parameters pertain to roll and pitch, except for the first mode, which pertains to pitch and yaw and the last mode, which pertains to yaw. [b]Using either the Earth sensor or the interferometer.

formed properly through one equinox (occult) period and two solstice periods without exhibiting any anaomalies. Even more impressive, however, has been the success of the major communications experiments which utilize this satellite.

Experiment Results to Date

Health, Education and Telecommunications Experiment (HET)

The single experiment on ATS-6 that has received the widest acclaim in the public press has been the HET experiment. This cooperative venture between NASA and the Department of Health, Education, and Welfare is intended to evaluate the effectiveness of satellite TV relay as a means for delivering educational programming and health care to remote areas within the United States. This experiment has provided the first opportunity to use satellite communications for the transmission of television and multiple voice channels to low-cost Earth stations.

Most of the HET programs originate in color at Denver and are transmitted at 6 GHz to ATS-6, where they are received in the Earth-coverage horn located in the bottom of the EVM. The FM signal is downconverted to a 150-MHz if, amplified, and upconverted to either or both of two frequencies: 2566 MHz and 2667 MHz. The two upconverted frequencies are routed to two 15-w solid-state rf amplifiers, which in turn drive two separate S-band feed antennas. This results in the transmission of two adjacent spot beams, each with slightly less than 1-deg beam width and an effective radiated power of nearly 50 dBW over the field of view. When pointed at CONUS, the combined coverage of the two beams is about 1600 km N-S and 550 km E-W.

The color TV transmissions are received on small (3-m diameter) antennas with an equally austere receiver-converter.

Table 2 Communication subsystem in-orbit performance compliance (receive operations)

Receive frequency (MHz)	30-ft antenna near-peak gain[a] (dB)	Field of view (FOV) (deg)	Required peak G/T (dB/K)	in-orbit near-peak G/T[a] (dB/K)
6350	48.4	0.4	13.5	16
6350	18.4 (ECH)	20	−17	−14
2250	40.6	1.0	9.5	10.4
1650	28.5	7.5×1.0	−5.0 (FOV)	−2.6 (FOV)

(Transmit operations)

Transmit frequency (MHz)	30-ft antenna near-peak gain (dB)	Field of view (FOV) (deg)	Required peak EIRP (dBW)	In-orbit near-peak EIRP[a] (dBW)
3950	40.1	0.6	48.2	48.7
3950	17.1 (ECH)	20×13	25.4	25.7
2075	40.0	1.0	51	52.5
2570	40.7	0.85	52.3	52.7
1550	26.8	7.5×1.0	42 (FOV)	42.1 (FOV)
860	33.3	2.8	51	52.6

[a]Calculated values based on in-orbit measurements and measured ground station characteristics.

The total cost for the terminal (antenna and electronics) is less than $5000. With the nominal receiver G/T of approximately 7 dB/K, the predetection C/N has been averaging about +17 dB and the resultant post-detection S/N about +47 dB peak to rms weighted noise. This corresponds to something between a TASO grade 1 and grade 2 quality picture.

Since July 2, 1974, when ATS-6 was declared operational, programming has occupied between 30 and 40 hr of satellite time per week. Nearly 120 recive-only terminals have been deployed throughout selected regions of the continential United States and Alaska. The regions covered are, Appalachia, Veteran's Administration, Rocky Mountains (2 regions, East and West), and Washington-Alaska. Routinely, the satellite is commanded to point its HET beams precisely to the selected areas at different times throughout the day. This is done entirely using the inertia wheels, so that no fuel is expended. In addition to direct TV broadcast, the Indiam Health Service in Alaska has four 3-m antenna terminals configured to generate and transmit black and white TV from remote medical aid stations. These transmissions are uplinked to the ATS-6 at S-band (2250 MHz) where they are received in the 9.1-m antenna, cross-strapped through the if to one of the HET S-band transmitters, and rebroadcast for reception at regional medical centers, sometimes just a few hundred miles away. These transmissions are being effectively used for remote medical diagnosis.

Picture quality and system reliability have been exceptionally high throughout all aspects of the experiment to date. Precise daily broadcast schedules have been maintained with almost no exceptions since the July 2, 1974, start of programming. In general, system performance and operation have been so good that any remaining evaluation of the experiment will be based solely on program content and viewer acceptance.

Position Location and Aircraft Communication Experiment (PLACE)

The objectives of the PLACE experiment are to 1) demonstrate feasibility of a communication link (data and/or voice) between a ground control center and a large number of aircraft and 2) to support the location of these aircraft via precise ranging. It is intended to obtain engineering data and practical experience for determining the operational feasibility of air traffic control and maritime satellite systems operating in the 1550 and 1650 aeronautical L-band. The experiment is international in scope, with participation from NASA, Department of Commerce/Maritime Administration, Department of Transportation, European Space Research

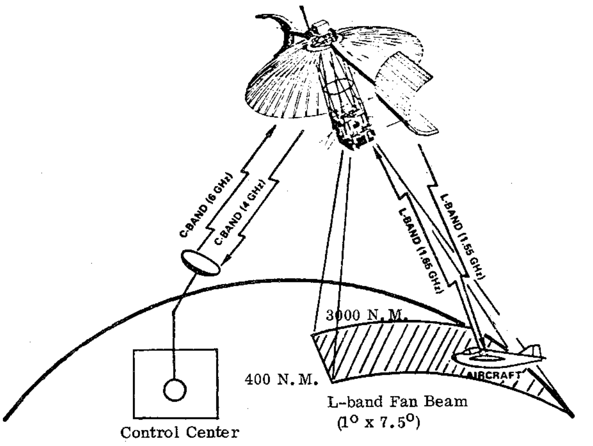

Fig. 7 Position location and aircraft communication experiment.

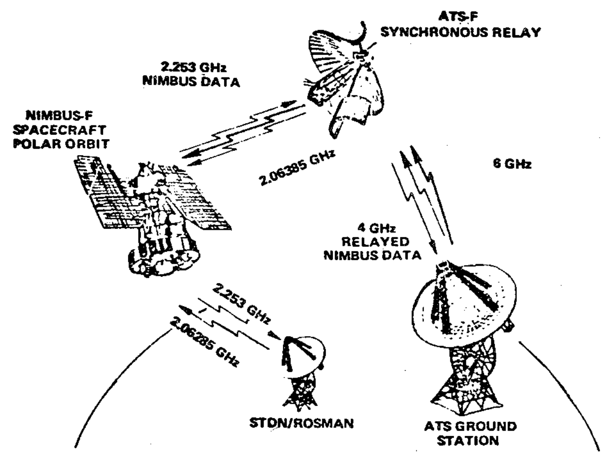

Fig. 8 Tracking and data relay experiment.

Organization, and the Canadian Department of Communications, and Ministry of Transport.

The PLACE system (shown pictorially in Fig. 7) consists of the ATS-6 with its 9.1-m antenna and transponder, one (or more) aircraft with its antenna and transponder, and a primary control center. The two-way simultaneous communication capability of the ATS-6 transponder is achieved by phase-locking the spacecraft synthesizer to a C-band signal from the ground station. This is accomplished by downconverting the C-band signal to one of the 150 MHz if amplifiers whose bandwidth is 40 MHz and then using the output to lock up the synthesizer. The coherent signal is then upconverted to L-band at 1550 MHz and relayed to the aircraft via a 40-w rf solid-state transmitter and a wide 1×7.5-deg "fan" beam. Information on the return link from the aircraft is transmitted in the form of a single sideband (SSB) modulated signal at L-band (1650 MHz) via a 100-w rf transmitter and selectable antennas with gains from 4 up to 12 dB. When multiple carriers are received at ATS-6, they are either translated to baseband and then remodulated onto a single C-band carrier or merely frequency translated into a linear transmitter. For the remodulated mode, the phase modulation index is held by automatic gain control at 0.85 rad rms independent of the number of carriers.

Since September 1974, PLACE experiment operations have averaged 10-15 hr of of ATS-6 operating time per week. Voice, data, and ranging links have been established routinely between NASA, FAA, and Maritime control centers and U.S., U.K., Norwegian, and Canadian aircraft and ships. Tests have been conducted to obtain system performance parameters related to signal power sharing (multiple carriers) and voice and data C/N in both the foreward and return links, as well as data channel bit error rates.

The voice and data channel bandwidth now being used is 12.5 kHz with channel separations of 25 kHz on centers. The 5 MHz transponder bandwidth provides capacity for up to 200 simultaneous users; although, to date no more than three users have accessed the transponder at any one time. Results so far have been quite satisfactory with measured values of carrier to noise density generally a few dB better than expected.

Tracking and Data Relay Experiment (T&DRE)

The objective of the T&DRE is to use a geosynchronous satellite as a repeater for two-way data transmission and tracking of a low orbiting spacecraft. The purpose of the experiment is to provide experience and information which can be used in designing future tracking and data relay systems.

The T&DRE system (shown pictorially in Fig. 8) consists of the ATS-6 with its antenna and transponder, and a primary control center. The two low orbiting spacecraft selected to conduct experiments with ATS-6 are the GEOS-C spacecraft launched in March 1975, and the NIMBUS-F spacecraft launched in May 1975. In addition, the ATS-6 spacecraft will be configured in this mode to support the Apollo/Soyuz rendezvous and docking mission launched in July 1975.

Communication between the ATS-6 spacecraft and the ground control center is at C-band using the Earth coverage horn at ATS-6, and between ATS-6 and the user satellite at S-band using the 9.1-m antenna on ATS-6. ATS-6 provides the coherent frequency conversion necessary for the precision tracking of the user spacecraft by phase-locking its transponder to a C-band reference signal from the ground. This is accomplished by downconverting the C-band signal to one of the 150-MHz if amplifiers whose bandwidth is selected to either 12 or 40 MHz and then using the output to lock up the synthesizer. The coherent signal is then upconverted to S-band at a nominal frequency of 2075 MHz and relayed to the user spacecraft via a 20-w solid-state rf transmitter and a narrow 1-deg wide spot beam developed from the 9.1-m antenna on ATS-6. Information on the return link from the user spacecraft is transmittted at S-band (nominally 2253 MHz) and received through the same spot beam from the ATS-6 9.1-m antenna. Table 3 presents some of the pertinent operating parameters for the forward and return links.

The NIMBUS-F ranging transponder is crystal controlled and the return ranging signals modulate a subcarrier. The GEOS-C ranging transponder includes a phaselock loop (PLL), which turns around the ranging signals directly. The ATS-6 spacecraft will track the low orbiting spacecraft by a program track mode through the on-board digital operational controller (DOC) which uses stored ephemeris data to generate the precise pointing angles as a function of time. ATS-6 can also be configured to monopulse track the S-band signal transmitted from the user satellite.

The T&DRE experiment is being exercised approximately 5-10 hr per week using the ATS-6 spacecraft, ATS ground station at Rosman, N. C., and the network test and training facility (NTTF) at Goddard Space Flight Center (GSFC) in Greenbelt, Md.

Although none of the user spacecraft are currently in orbit,† some measurements have been made with a ground (fixed) transponder acting as a simulated user spacecraft. The NIMBUS-F engineering model transponder with its gimbaled antenna and the GEOS-C engineering model hardware have both been checked out with ATS-6 in orbit. The Apollo–Soyuz engineering model transponder and gimbaled antenna, which are part of the command service module (CSM), have ben checked out with the ATS-6 spacecraft while the CSM was at the Johnson Space Center in Houston.

†Since this paper was originally published, Nimbus-F, GEOS-C, and the Apollo-Soyuz missions have been flown, with all T&DRE experiments being completely successful. ATS-6 relayed TV and data from over 130 revolutions of Apollo.

Table 3 T&DRE operating parameters

ATS-6 to satellite link	NIMBUS-F	GEOS-C	Apollo/Soyuz	
User antenna type	Gimbaled quad helix	Fixed-cavity backed spiral	Fixed	Gimbaled
User antenna gain (dB)	15	5	8	23
Forward link:				
Frequency (MHz)	2062.85, 2075	2075		2077.4
ATS-6 EIRP (dBw)	52.5	52.5		52.5
User G/T (dB/K)	-18	-28		-19.6
Measured link margin (dB)	8	N/A[a]	Voice Command	8-11 7.5
Return link:				
Frequency (MHz)	2253	2253		2256
User EIRP (dBW)	17, 20, 23	9		39.2
User power (Wa)	2, 4, 8	5		40
Data rate (kpbs)	4, 50	1.562, 15.62	Voice Telemetry TV	2.4 51.2 2000
Measured link margin (dB)			Voice Telemetry TV	$0.5-17$ 8-13 0.5

[a] Not available.

Results of the test conducted on the NIMBUS-F, GEOS-C, and Apollo Soyuz hardware in conjunction with ATS-6 are shown in Table 3. For the NIMBUS-F and GEOS-C tests, a bit error rate (BER) of 10^{-5} for transfer of telemetry was achieved. For the Apollo/Soyuz tests, a BER of 10^{-6} was achieved. The Apollo sequential color TV picture quality was rated as acceptable for both realtime and playback operation.

Television Relay Using Small Terminals (TRUST)

The TRUST experiment, being conducted while ATS-6 is in view of the United States, acts as a precursor experiment to the SITE (satellite instructional television experiment), which will be initiated this summer (1975) when ATS-6 is moved into view of India. Both experiments utilize the satellite C-band-to-uhf relay capability for TV transmission.

The objective of TRUST is to obtain technical and propagation data on an experimental system for FM relay of standard TV signals (black and white and color with associated sound) at uhf using the ATS-6 spacecraft. The high EIRP of the satellite enables reception on small (3-m antenna) terminals. An additional objective of TRUST is to provide interested developing countries an opportunity to participate in denonstrations of the ATS-6 as a pilot for a national educational TV system using inexpensive receivers.

Technically, both the TRUST and SITE experiments are quite similar. A frequency-modulated TV carrier (mod index of 1.2) at 6 GHz is transmitted from Rosman, N. C. to the ATS-6, where it is received in the Earth coverage horn antenna of the EVM. The signal is downconverted to if, amplified in a 40-MHz bandwidth, and upconverted to 860 MHz, where it is transmitted via a 100-w solid-state rf amplifier. The output of the amplifier drives a concentric four-element uhf primary feed to the 9.1-antenna producing a 2.8-deg broadcast beam with an EIRP in excess of 49 dBW throughout the field of view. The small terminal receiver with its 3-m "chicken-wire" antenna and a 1000°K noise temperature yields a G/T of -5 dB/K.

Based upon approximately 30 hr of experiment operation during 1974, using both TRUST and SITE ground terminals, the results to date appear quite satisfactory. Picture quality, sound quality, carrier to noise ratios, and cross talk levels are all within expected values. Measurements taken of the uhf carrier power level received at various off-axis positions within the broadcast beam have been compared with predicted values and found to agree with ± 1.5 dB. Tests conducted at Goddard Space Flight Center with the SITE terminal (prototype of the terminals for India) have measured the link

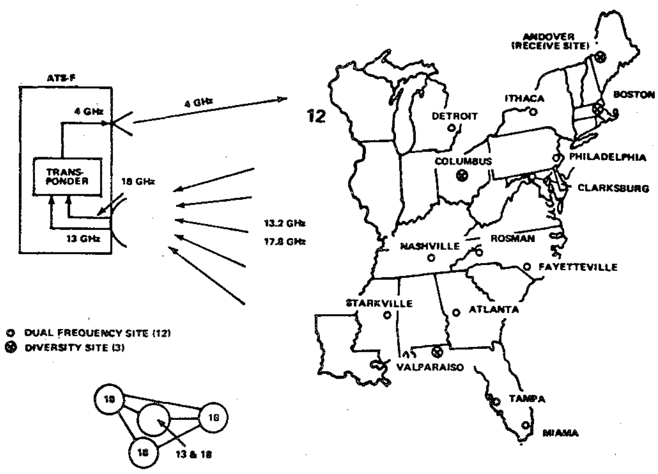

Fig. 9 COMSAT propagation experiment.

margins relative to an acceptable picture quality that exists for various positions within the beam relative to the boresight axis. The results show that at beam center an 8-dB margin exists. Thus, even over the entire field of view, the margin measures a comfortable 5 dB.

The above measurements provide a high level of confidence that the forthcoming SITE experiments over India will be technically satisfactory.‡ In preparation for the transfer of ATS-6 to 35 deg E longitude in May 1975, the government of India is completing the manufacture and installation of about 2400 of the small direct reception terminals in groups of 400 villages in each of six states throughout the subcontinent. Program material will be developed by India and transmitted to ATS-6 from one of two Indian Earth stations at Ahmedabad or Delhi. ATS-6 is scheduled to spend one year over India, transmitting at least 4 hr of television daily.

Millimeter Wave Experiment (MMW)

The objectives of the MMW experiment are 1) to determine the propagation characteristics and derive engineering data on a 20 GHz and 30 GHz space-to-earth communication link

‡The SITE experiment was initiated on August 1, 1975 and has been serving nearly 5000 television receivers throughout India. Programs are conducted for six hours a day, seven days a week. Picture quality has been excellent and audience reaction has exceeded all expectations.

operating under various meteorological conditions, and 2) to investigate techniques for predicting millimeter wave progagation effects from indirect means, such as radiometer sky temperature and radar backscatter.

The MMW experiment has two primary operating modes: 1) propagation and 2) communication. In the propagation mode, either a carrier frequency or multitones consisting of a comb of nine tones equally spaced out to 720 MHz from the carrier are transmitted at 20 GHz and/or 30 GHz via 2-w rf transmitters and either a wide 6×9-deg beam horn antenna or a 2-deg spot beam from a 0.45-m parabolic antenna. Both MMW antennas are located in the lower section of the EVM. The ground station located at Rosman, N. C. reveives the signals via a 4.5-m parabolic antenna and performs some initial data processing on site. Further data processing is conducted at Goddard Space Flight Center.

In the communication mode, modulated data, such as a color TV picture transmitted from Rosman at 6 GHz, is received at the spacecraft via the C-band Earth coverage horn, cross-strapped in the 150 MHz if amplifiers, and transmitted back down to Rosman at 4 GHz, and 20 GHz or 30 GHz or both. This mode provides a direct correlation of communication link quality at three frequencies experiencing the same weather effects.

The MMW experiment is being exercised approximately 16 hr per week. Although brief but intense fades as deep as 11.5 dB at 20 GHZ and 23 dB at 30 GHZ have been observed during a number of summer storms at Rosman, to date insufficient data have been compiled to enable any significant conclusions to be drawn regarding millimeter wave propagation statistics.

COMSAT Propagation Experiment

The objective of the Propagation experiment is to collect sufficient long-term data on propagation attenuation at the 13-GHz and 18-GHz bands over a large number of locations in the U.S. It is intended to permit determination of minimum power margins needed in future spacecraft communications systems designed for operation in the Ku-bands.

The experiment (illustrated in Figure 9) consists of a number of unattended transmitting Earth stations, the ATS-6 spacecraft with its Propagation transponder receiving on a special parabolic antenna with a 4×8.5-deg beam, and retransmitting the signals back down to the ground at C-band over the Earth coverage horn.

The unattended transmitting terminals consist of 1) fifteen small Earth stations separated by at least 100 miles with each station transmitting a unique cw signal at both 13.2 GHz and 17.8 GHz, and 2) three groups of three 17.8-GHz only Earth stations clustered around a dual terminal and separated by less than 25 miles. The Propagation transponder in ATS-6 receives the 13-GHz and 18-GHz signals from the trnsmitting Earth terminals and retransmits these signals as a composite signal at 4 GHz over the ATS-6 Earth coverage horn. The C-band Propagation experiment signal is orthogonally polarized to the normal ATS-6 C-band transponder signal. Thus, both signals are fed to the same antenna sinultaneously.

The C-band Earth terminal located at Andover, Me. receives all 39-cw signals simultaneously as transmitted by ATS-6 at 4.1 GHz. The composite signal is received and separated by a set of 39 phase-locked loops. The level of each carrier is then stored on magnetic tapes for statistical processing.

The Propagation experiment has been operated continuously since June 1974. Processing of the data is now in progress.

Radio Frequency Interference Experiment (RFI)

The objective of the RFI experiment is to provide data on mutual rf interference in the C-band spectrum shared between satellite and terrestrial telecommunication systems. The data will be used in the design and implementation of advanced communication satellite systems operating in the 5925-6425-MHz common carrier C-band.

The RFI experiment system consists of the NASA ground station terminal located at Rosman, and the ATS-6 spacecraft with its 9.1-m antenna and wide band (500-MHz) RFI transponder. A 30-dBw cw calibration tone is transmitted from a 1.8-m ground antenna and received by a 0.4-deg spot beam formed by the 9.1-m ATS-6 antenna. The signal is received in the RFI transponder where it is translated down to the 3700-4200-MHz band, amplified (with five selectable gains), and transmitted via the 12-w C-band transmitter and the wide beam Earth coverage horn. The signal is received on a 26-m antenna at Rosman and passed through a tunable receiver with a 10-kHz resolution. After calibration, the ATS-6 spot beam is then precisely pointed to selected geographic spots covering about 200 km in diameter while the ground receiver scans the 500-MHz rf spectrum in 10-kHz steps. The intensity of the received signals as a function of frequency is correlated with the AT-6 spot beam pointing location (spacecraft attitude) for subsequent computer data processing and analysis.

The RFI experiment has accumulated 500 hr of operation on the ATS-6 spacecraft using approximately 20 hr per week. A complete RFI scan of 30 geographic areas in the United States has been completed. The EIRP levels obtained during each survey represent the integrated rf power measured in the 10-kHz frequency slots across the 5925-MHz to 6425-MHz spectrum. The location of carrier frequencies measured across the 500-MHz bandwidth appears to be randomly distributed. An analysis of the data obtained from each geographic area surveyed indicates that the total number of C-band sources appears to decrease exponentially as the measured EIRP level increases. Typically, it varies from 100 or more 10-w sources down to less than 10 sources with power levels above 25 w.

Conclusions

Within a few days after its launch it became clear that the sixth NASA Applications Technology Satellite would be a complete success in terms of meeting all of its technology objectives. Separation, deployment of the antenna, acquisition of the earth, and operation of the attitude control, power, telemetry and command, propulsion, thermal control, structure, and communication subsystems have all been flawless. The book is not closed, however, on the applications objectives. Years of data reduction and evaluation lie ahead before the final chapter can be written on ATS-6. To date the response from the users has been highly enthusiastic and all indications are that the results will be positive. Typical of its supporters is the Honorable Casper W. Weinberger, Secretary of HEW, who, in a speech to the AIAA referring to the HET experiment, said, "Judging from six months of its pioneering work for our own people, I am convinced that ATS-6 will mark an historic advance in human communication and human progress."