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BIOSATELLITE II OPERATIONS

By

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The BIOSATELLITE spacecraft was designed to be launched, flown, and recovered with services already operational. As the first flights approached, we learned that biological research had some modifying effect on everything associated with it, and contingency possibilities became more obvious. As a result, ~~Thus,~~ the scope of preparations around the world grew considerably over initial concepts. Thanks to this preparation ~~enthusiasm found everywhere, this~~ The new biological space laboratory ~~kind of scientific flight~~ was smoothly handled through major changes in flight plan.

The Spacecraft

The 950-pound spacecraft is 8-feet long and 56 inches in greatest diameter, where it mates with the two-stage DELTA launch vehicle. About half the spacecraft weight and bulk is in its reentry vehicle which separates and returns to earth at the end of the flight. For this 3 day mission it carries battery power supplies with main capacity of 330 ampere hours at 26 volts. Lacking the usual solar panels, its smooth external surface is designed to maintain moderate internal temperatures with a minimum of electrical heating.

The attitude-control system employs sensitive gyroscopes and compressed nitrogen gas to reduce the spacecraft rotatation rate to less than one revolution in twenty minutes so that acceleration forces on the biological specimens are acceptably small. Rotational accelerations are only 0.04 degrees/sec/sec. In its position control mode the system establishes orientation within six degrees of optimum for retro thrust at the end of the mission. Infrared horizon detectors and a magnetometer to sense the earth's magnetic field are used for position control.

The separation and recovery system are initiated by a timer which is set during flight, from the ground. The reentry vehicle is separated by explosively released springs and is immediately spun about its major axis by compressed gas jets to maintain orientation. The retro-rocket fires for ten seconds, slowing the reentry vehicle 600 feet/second from its previous orbital velocity. Shallow angle reentry occurs about 4,000 miles farther down range. After aerodynamic retardation, the parachute cover is ejected and the capsule is extracted from its ablative reentry shield which falls away. The 'chute is specially reinforced to allow for engagement of hooks from a turboprop retrieval aircraft during descent. A radio homing beacon is energized at separation, and a flashing light and dye marker are activated if the capsule should land in the ocean.

The 285-pound capsule itself contain~~ed~~s all experiments in BIOSATELLITE II. Details of the environmental control system and experiment mechanisms it ~~contains~~ carries are covered by others. The capsule and encasing heat shield have breach rings near the nose by which access is available for late installation of live biologicals.

Communications with the spacecraft during orbital flight were, planned with NASA's Space Tracking and Data Acquisition Network (STADAN). Position determination is made by tracking a 100 mw radio beacon carried by the spacecraft. Data ~~were~~ are received in the form of pulse code words frequency modulated on a 136-megacycle carrier. 256 words of 6-binary bits (plus 1 parity) each are transmited at one frame per second. They are arranged in 118 channels of information of which 62 are environment parameters and verifications of electro-mechanical acutations for experiments. The others are used for evaluation and operational control of the spacecraft.

Commands ~~were~~ are transmitted by pulse duration codes on a 148-mc carrier. 54 of the 70 available channels ~~were~~ are utilized, 9 for managing the radiation source holder and for fixing and feeding experiments. Orbital communications equipment is duplicated for reliability: Selection can be made from the ground between two tracking beacons and between two telemetry transmitters; either of two command decoders can be addressed; and two command receivers ~~operate~~ in parallel feeding both decoders.

When the reentry vehicle separates from the spacecraft, an FM/FM telemetry transmitter transmits engineering data related to the separation, spin, retrofire, etc. This transmitter also serves as a backup to the 240-mc radio beacon activated at the same time to guide aerial retrieval pilots to the descending parachute.

<u>Preparation of Support Facilities</u>

Hangar "S" at Cape Kennedy was refurbished with clean rooms and work areas for general spacecraft project use early in the BIOSATELLITE program. Adjustments were included to optimize it for BIOSATELLITE use. The one major development especially for BIOSATELLITE ~~was~~ is an 8,000 square foot biological laboratory made from the existing butler building attached to Hangar "S". It features single pass (non recirculating) air conditioning, extensive laboratory-type cabinetry and fixtures, and emergency power distribution to maintain environmental chambers during critical weeks of launch preparation. Large trailers also were accommodated for plant growth and for future animal colonies.

The launch pad was rewired to provide sensing and control circuits needed for the BIOSATELLITE spacecraft which were not previously available on the DELTA facility. A special pull-away coolant fluid disconnect was developed for capsule thermal control to the moment of launch. Frog eggs were kept at $40^{\circ}F$ by ~~a separate~~ one of the loops through this disconnect. The ~~biggest~~ greatest launch complex improvement was air conditioning of the work room that surrounds the launch vehicle and spacecraft above the 90-foot level in the service gantry. Temperature, humidity, cleanliness, were thereby insured for the period when the capsule would be opened and biological experiment assemblies transferred from their transporters to the spacecraft. Some alterations also were designed to allow faster final preparation and rollback of the service tower after spacecraft work was completed.

The DELTA launch vehicle was used essentially in its normal two-stage configuration. Its "shroud", originally designed for the much larger NIMBUS spacecraft, protected BIOSATELLITE from aerodynamic heating during ascent. Minor changes that were made are related to the special BIOSATELLITE problem of quick final preparations and launch after experiment specimens were delivered to the spacecraft. The method of final arming of the booster's solid-rocket ignition circuits was changed and specially permitted by the Range Safety Officer because of its importance to the mission. Alignment fixtures for mating the two halves of the 550-pound shroud were extended to allow late access to the capsule and subsequent quick closure. Explosive bolts on the shroud closure bands were redesigned for faster final hookup and checkout. The countdown was to allow only four hours (instead of the typical sixteen hours for other spacecraft) from the time the capsule was sealed, and the reentry heat shield was assembled over it, until launch.

Initial ~~determination~~ computation of BIOSATELLITE II's orbital location was relatively routine, since tracking data interconnections between the Air Force Eastern Test Range and NASA's Goddard Space Flight Center were already well developed. Additional telemetry data transmission terminals were provided at Antigua and the Cape so that effect of separation from the booster could be monitored at the Flight-Control Center at Goddard.

A "Multipurpose Satellite Operations Control Center" was tailored to BIOSATELLITE needs at GSFC. It featured telemetry ground stations (primary and backup) to separate the data channels, and a computer. Digital and analog displays enabled the control team at Goddard to directly observe spacecraft reaction while instructing command station operators by voice links.

In addition to the ~~refinement of trajectory data and~~ prediction of tracking station contacts, the Orbital Computations Center at Goddard ~~assisted with~~ performed special computations to guide recovery commands. Catalogs of predicted BIOSATELLITE recovery opportunities were delivered to the Control Center every few hours as the orbit definition was improved by continued tracking measurements. A "Normal and Early Call-Down" catalog gave instructions for commanding the reentry vehicle to its point of closest approach to Hawaii, but safely away from the island and ~~[illegible]~~ foreign air lanes. Other catalogs designated commands for extreme emergency conditions which might dictate immediate calldown or the use of the backup fixed timer in the spacecraft.

Command control and telemetry data collection were required once each orbit, early after lift off, and at the latest opportunity before recovery. ~~As shown in figure —,~~ NASA's Satellite Tracking and Data Acquisition Network (STADAN) stations at Johannesburg, South Africa; Fort Myers, Florida; Quito, Ecuador; Lima, Peru ~~;~~ and Santiago, Chile~~; and Carnarvon, Australia~~ are ~~almost~~ ideally situated. ~~Only~~ Carnarvon, Australia ~~which is~~ a Manned Space Flight Network station, required some additional basic equipment. The existing antenna and receivers of the Range and Range-Rate measuring system there were connected into a temporarily-installed pulse ~~conde~~ code demodulation unit. A command transmission set with simple Yagi antenna and a tape recorder were added. And data transmission terminals were installed.

Separation and retrofire were to have been observed and recorded by two instrumented World War-II Constallation airplanes operated by the Navy's Pacific Missile Range from Point Mugu, California. A 136-mc telemetry receiver and antenna were installed in one to record data on attitude control, electrical, and thermal systems through separation and retrofire. The planes were to stage from Guam to cover any call-down to ~~in~~ the Hawaiian area. When higher priority commitments made their availability to BIOSATELLITE doubtful, the Eastern Test Range Ship "USNS Coastal Victory" was requested from Fremantle, Australia where it was stationed between assignments. A telemetry receiving kit for the 136-mc spacecraft data was rushed to Perth, Australia from Cape Kennedy and installed just before sailing.

An existing Air Force Tracking Station at Kaena Point, Oahu was readied to pass data directly to Goddard for trajectory computation in case of overshoot of the Hawaiian area. This interconnection required only minor computer programming at both sites, but was the first such NASA cooperation from Kaena Point.

Recovery tests proved compatibility of the BIOSATELLITE configuration with Air Force equipment. Training films were made defining the handling of the recovered capsule. Protection against radiation exposure of personnel, the logs and photographic records to be made of ~~its~~ the capsule's environment enroute to the laboratory, and delivery to the disassembly site without exceeding thermal and shock tolerances were emphasized.

Because of the highly perishable ~~payload~~ contents, special attention was devoted to ~~the problem of~~ quick recovery in case of water impact. Helicopter ranges being very limited from their ship, a new system for surface-to-air pickup was developed for BIOSATELLITE with Air Force cooperation. It was designed to be dropped into the water near the capsule with para-divers who would erect it. The pickup aircraft could proceed to the laboratory within the hour of finding the capsule. The kits were carried aboard an Aerospace Rescue and Retrieval Service aircraft stationed in Hawaii which flew with the regular recovery force.

Six trailers were placed at a specially-prepared dock on the edge of Hickam Air Field near Honolulu. They served as laboratory and office spaces for experimenters and capsule disassembly teams. Emergency power service was established to insure controlled environment through the critical post-flight period.

All of the above facilities were interconnected by the NASA's Communications System managed by GSFC. Several new links were leased, and assignments of circuits were scheduled for the launch, flight, ~~and~~ deorbit, and recovery phases of flight as needed. ~~Figure indicates the extent of circuits involved~~.

Preparation of Procedures

Experiment specimen preparation, loading and unloading were planned and practiced in conjunction with spacecraft systems tests at the General Electric Company Plant in Philadelphia. In this way, three months before first flight, compatibility of the spacecraft with the living organisms was conclusively and formally established to the satisfaction of the investigators.

At Cape Kennedy, the nearly one hundred persons associated with the experiments met and participated in a dress rehearsal that went right to the hangar door with complete assemblies and live specimens on prescribed schedule. It was a necessary preparation to achieve fully-coordinated flow, even though it had been done three times before at the Cape for BIOSATELLITE I (for which experiment preparation was also flawless).

The spacecraft preparation procedure was similarly repeated. Minor changes had been made with special Safety Office approval to ascertain the integrity of the previously-failed retrorocket firing circuit. [illegible]

All handling and preparation of flight material was witnessed by inspectors from an independent Air-Force managed office, to insure objective adherence to the assembly and checking procedures established. Formal records and disposition of every observed anomaly were thereby initiated until the capsule was sealed for flight.

A different launch pad was used for this second BIOSATELLITE, slightly complicating the transfer of experiment assemblies because of the lower roof in the air-conditioned room atop the gantry. The only other change from previous procedure was placement of insulation on the frog egg coolant connector to prevent dehydration of the capsule air ~~for~~ during the first part of the flight.

Critical launch vehicle and shroud preparation, in the final four hours after the spacecraft was readied, had been demonstrated for BIOSATELLITE I and on several flights with other spacecraft.

STADAN Stations in Florida, South America, and South Africa were visited by project representatives who explained the methods of operation with BIOSATELLITE. Particular attention was given to handling of commands and to contingency procedures in case of voice communications failure. Each station was provded with one or more "Immediate Calldown" command tapes containing the thirty-seven commands that would place the reentry capsule within reach of emergency retrieval forces in the event of catastrophic loss of electrical or compressed gas energy. (This tape was to be specially controlled by the senior team member at the site and was to be updated by the teletype transmission from the Control Center when the actual orbit was measured.)

Air-Force Aerospace Rescue and Retrieval Service Forces in the Azores, Burmuda, Guam, and Japan were instructed and equipped to retrieve the capsule in case of extreme emergency call down.

Specially prepared packages of weather data were hand carried from the Environmental Science Services Administration office in Washington daily beginning a week before launch.

Regularly available weather information was supplemented by the ATS satellite whose neighboring Control Center delivered pictures of the recovery area to the BIOSATELLITE Recovery Controller several times daily.

Launch and Flight-Control Teams were organized to include experimenters' representation. Report of experiment acceptability was ~~made~~ received from the launch tower to the Mission Director's Center before launch, and the Flight-Control Center was attended by an Experiments Controller twenty-four hours per day. Data flow from the spacecraft were directly minitored by these experimenter representatives from prelaunch on, and were utilized for operation of ground-control tests.

Familization exercises were held using magnetic tapes from spacecraft system tests at each STADAN supporting site. Ten days before launch a world-wide telemetry data-handling and command control dress rehearsal was held over a twenty-three hour period to demonstrate that all facilities and personnel were prepared. Simulated trajectory and telemetry data transfer from Cape Kennedy were processed, and communications with deorbit monitoring and recovery forces were exercised.

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Travel reservations were made for the forty-two persons to be transferred to Hawaii after launch. Commercial airlines cooperation was arranged to provide for contingency launch dates at two-day intervals. A NASA plane was ordered to rush part of the Control Team to Goddard from the Cape immediately after lift off.

Preparation was ~~made~~ completed for ground-control tests at the Cape simultaneous with the flight. The prototype spacecraft capsule was instrumented to be held at controlled environment and for its completely assembled experiment mechanisms (including radiation source holder) to be operated in synchronism with flight events. Other controls without radiation were developed to maintain temperatures the same as flight. Biological specimens for control were loaded from the same stock

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Operational commitment to the appointed launch time began with scheduling BIOSATELLITE II only three weeks ahead of INTELSAT IIC from the only DELTA launch complex at Cape Kennedy. Further commitment was made with the preparation six weeks before flight of radiation sources with 60 day half lives. Three pairs (for flight and ground control) were ordered for September 5, 10, and 15. The commitment grew with deployment of the deorbit monitoring ship to the New Zealand coast and of aircraft to Guam. At minus one day, hypergolic fuel was loaded into the DELTA second stage, limiting its operational life to 15 days. At minus 5 seconds an explosive line cutter inside the spacecraft reduced our tolerance for further delay to 1/2 hour.

as for flight during the countdown sequence.

The Flight

The countdown began at 1:00 a.m., Cape Kennedy time, September 7, 1967, with the assembly of amoeba modules. The count was designed for latest possible preparation of frog eggs, wheat seedlings and lysogenic bacteria for which time before orbital injection was most critical.

Primary and backup flight hardware were loaded, with the second set used for ground controls. Assembly went perfectly with readiness for delivery to the launch pad at 8:10 a.m., twenty minutes ahead of schedule. Stripped threads on two screws of one backup package was the only recorded anomaly!

Launch was delayed by spacecraft and launch-vehicle problems after the capsule was first closed. When readiness was established for launch at 6:04 p.m., three hours and four minutes late, recheck of previous experimenter estimates showed more than ninety-five percent expectable return of scientific objectives still available from the flight. Launch preparations had been good, world-wide support was fully available, and launch and recovery weather was promising; so the launch decision was made.

When the launch had been delayed beyond the first hour, the flight plan was reduced to forty-six orbits instead of forty-seven to keep deorbit in darkness where ~~attitude control~~ alignment with respect to the horizon would be optimum. The two telemetry aircraft had been made available to ~~the project~~ BIOSATELLITE in the final days before launch, but engine failure had prevented one from reaching Guam. The operative plane was directed to move to Townsville, Australia to be better prepared for Orbit 46 recovery. (Diplomatic clearance had previously been arranged there against such a contingency.)

(see 2) The ship was asked to move as far south as possible along the New Guinea coast.

Between two and two and one-half hours delay, potential conflicts for utilization of a key STADAN station at Santiago, Chile, on the second flight day was passed. This conflict would have been with the Orbiting Geophysical Observatory spacecraft, then accorded high priority because of control problems with an oscillating boom. (BIOSATELLITE was to have otherwise unequalled priority for STADAN operational support.)

"Immediate" emergency calldown command preparations had to be revised, since opportunities for retrieval near Air Force Bases in the Northern hemisphere (Burmuda, Azores, Guam, and Japan) with deorbit in darkness was no longer practical. The 165° west meridian was chosen.

The recovery-support ship carrying two helicopters was ordered south by the Air Force.

Four minutes after launch, extension of the 10-minute telemetry timer was commanded from Fort Myers to permit spacecraft data recording and observation at booster separation from the Eastern Test Range's Antigua Tracking Station. The spacecraft did not respond, but launch-vehicle instrumentation indicated proper separation with   deg/sec initial rotation.

Thirty minutes after launch, telemetry was turned on from Johannesburg indicating the attitude rates to be in good control and confirming the several functions actuated by the booster separation switch. The attitude-control system was turned off as planned, to conserve power and avoid any possibility of control failure. It was reactivated at Carnarvon where rotation near 2 deg/sec was observed, apparently resulting from outgassing of insulating plastic surrounding the capsule. This effect was more persistent than in the BIOSATELLITE I flight, requiring nearly ten orbits for complete decay.

At the end of the first complete orbit, programmed source holder had opened one hour after launch. Photographs of the pepper plant were being made every ten minutes, the frog egg assembly had been heated, various amoebae modules were fixed or fed, and a frog egg module had been injected with fixative.

Contacts with the spacecraft every orbit provided temperature information for ground controls; confirmed satisfactory environmental control; verified programmed fixing, feeding, and photography in experiment modules; and confirmed the health of the spacecraft for continued flight.

Typically, a teletype message was sent after conference in the Control Center to each STADAN station thirty minutes before contact. Voice circuit was established in the final ten minutes, and telemetry was commanded on as the spacecraft reached 5 to 10 degrees above the horizon. "Rate sense" mode was commanded to activate gyro output amplifiers showing rotational rates. After thirty seconds of examination by the Control Team, "rate control" was commanded, except when no significant buildup had occurred. A few seconds later all axes would be inside the 0.3 degree/sec control dead band, and the control system commanded off. Telemetry was turned off as the spacecraft approach the horizon, usually after five or six minutes. After twenty-four hours, ~~all~~ fixations and feedings of experiment modules ~~were commanded~~ by ground controllers were scheduled during such contacts. These procedures continued every ninety minutes through Orbit twenty-three, but were made difficult by the frequent refusal of the spacecraft to accept commands. Many repetitions were required: Rate control was not achieved in one instance; and telemetry could not be started in another.

During Orbit 16, the weather agency identified tropical storm Sarah southeast of Hawaii moving westward. The recovery-support ship was halted during Orbit 22 because of adverse weather prediction.

Photographs of the Hawaiian area weather were received from the ATS Control Center about four hours after exposure, confirming the problem.

After consideration of risks, and review with experimenter representatives of the estimated high proportion of possible results achieved at that point, it was decided to begin the series of commands to effect recovery on Orbit 30. A recovery opportunity reachable from Hawaii with deorbit in darkness presented itself then. The recovery pilots and crewmen had just been released from their daily alert status for BIOSATELLITE, and were recalled during the twenty-fourth orbit. In their briefing, acceptable recovery weather was predicted after a rough flight south for the rendezvous.

Because of the many commands to be actuated and the persistent balkiness of the command receiver, the STADAN station at Orroral, Australia and the augmented Manned Space Flight Net Station at Carnarvon were brought to fully active status with the project. The telemetry was turned on and its timer bypassed from Lima on Orbit 24. Two contacts per orbit were made thereafter.

The separation timer was loaded by a series of eighteen ones and zeros transmitted in proper sequence by Carnarvon on Orbit 26. Repetitions were necessary before some digits could be verified, so the timer could not be started until thirty seconds late. The Air Force was advised of the resultant 120 nautical miles relocation of predicted recovery point. The magnetotmeter bias register was successfully loaded from punched tape with eight binary digits transmitted one second apart on Orbit 27 from Carnarvon. This bias value controlled current in a magnetometer coil to compensate for the strength and direction of the earth's magnetic field at the selected deorbit such that alignment of the retrorocket was in the orbital plane. The BIOSATELLITE recovery control computer program at Goddard was exercised at this time to determine what compromise values would be acceptable in case of difficulty in the command sequence and what relocation of the recovery forces might be so necessitated.

Under the guidance of experimenter representatives (who conferred with colleagues assembled in Hawaii), all the remaining experiment actuation commands were rescheduled and accomplished in the final five orbits.

The radiation source holder was closed on Orbit 28 and the separation ignition circuits were armed.

Because of launch delay, Australia's Weapons Research Establishment Tracking Station at Woomera had been asked early in the flight to assist with deorbit telemetry data recording. The ship's effectiveness had been reduced by planned Orbit 46 recovery, and the single aircraft at Townsville had lost an engine enroute from Guam. After the early calldown decision, telemetry operators were called from their homes at 1:00 Sunday morning in Australia to be on duty two hours later. They had typically sixty desert miles to drive. Their first technical briefing on BIOSATELLITE was in progress when it appeared above the horizon. The deorbit telemetry transmitter turned on as programmed, and a complete clear recording was made.

Meanwhile, the Australian Air Force was most cooperative in closing the Townsville Airfield to potentially interferring traffic and in providing communications relay for the instrumented aircraft. The trained crew was able to get a sufficiently clear record from the air strip to report a perfect separation and retrofire sequence before atmospheric interference blanked communications. Due to the relocated deorbit point, Orroral could record environment conditions through separation. The 136-mc telemetry receiving gear on the grounded aircraft and the ship provided records of engineering value on attitude control and thermal responses of the spacecraft pushed by retrorocket exhaust gas.

Recovery was exactly as planned, an estimated ~~about~~ sixteen miles from the predicted point. The aircraft interior was maintained at $60^{\circ}F$ on the flight to the laboratory. Disassembly was begun in the air-conditioned trailer lab at Hickam Air Force Base three and one-half hours after retrieval.

Complete photographic records were made of the disassembly and of specimens according to plan. Ground controls, too, at Cape Kennedy were disassembled in a coordinated sequence.

At Goddard and all tracking stations, operations continued as data for engineering analysis of spacecraft subsystems was accumulated. Several functional tests were completed before failure of the battery power early on the fourth day of flight. the attitude-control system was subjected to numerous tests. A cold test was made by reducing power usage to almost nothing, and the low voltage operating characteristics of many components were observed as the battery decayed on the fourth flight day. A theory was advanced to explain the command anomaly and was successfully tested. Later proven from manufacturing records, the two command receivers had been connected opposite in phase to their output coupling transformer. Operation succeeded when received signal strength was low or the frequency was off such that their phase-shift characteristics differed enough that they did not cancel each other.

After a launch has been performed and tracked with the well-established ~~known~~ expertize of DELTA launch ~~crews~~ and Air Force Eastern Test Range ~~Teams~~ crews, the flight was treated with keen interest all around the world. Tracking station personnel, who are typically citizens ~~nationals~~ of -- and sometimes government employees of, -- countries in which they are located, responded to our Control Team as if no other project were as important. (And they continue anxious to receive reports by the investigators about BIOSATELLITE II.) Navy flight crews willingly planned duty schedules on Guam to cover every contingency we could describe. The crew of the ship, "Coastal Sentry" made it clear to us that they would rather serve than wait in port between assignments, and they worked diligently to make up for the hurried operation planning via teletype.

Woomera is an Australian (not United States) owned and operated Station, and their reaction to off-hours call was exemplary. The Air-Force officers and men, with their own projects to support, welcomed ~~our~~ NASA's requirements for prima donna treatment of a bioscience capsule and delivered it with great satisfaction.

Aerospace Rescue and Retrieval Service Officers expressed disappointment in our modified emergency plan after the delayed launch and have asked how they might better assist future flights.

We gratefully acknowledge the individual effort and sacrifices made by so many to manage the BIOSATELLITE II flight.

Illustrations

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2. Exploded view of S/C
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