SCOUT/CRRES

Patrick H. Cudmore
Flight Data Systems Branch
Applied Engineering Division
Goddard Space Flight Center
Greenbelt, Maryland 20771

ABSTRACT

This paper describes a Scout-launched chemical release satellite that the Goddard Space Flight Center (GSFC) will design, fabricate, integrate, test, and qualify. This will be done using off-the-shelf components assembled to a NASA/GSFC-supplied spacecraft structure as follows:

- Four chemical release modules from the CRRES satellite (BASD)
- Communications, data handling, and power systems from GLOMR (DSI)

This satellite will also include flight electronic instrumentation that will measure electric and magnetic fields and particles, and will be furnished by TBD.

INTRODUCTION

NASA's Get Away Special (GAS) program initiated broad utilization of the space environment through provision of low cost access to space. The GAS program has also spawned low cost freeflyer capability realized by the NUSAT and GLOMR satellites that were spring-ejected from the GAS can.

Fig. 1 shows the GLOMR satellite built by Defense Systems, Inc. (DSI) and operated for 14 months with their portable ground station. That GAS Cannister-launched satellite provided all the power, telemetry, command, memory, and housekeeping required to accommodate the payload for the entire mission which was terminated when the GLOMR reentered the atmosphere.

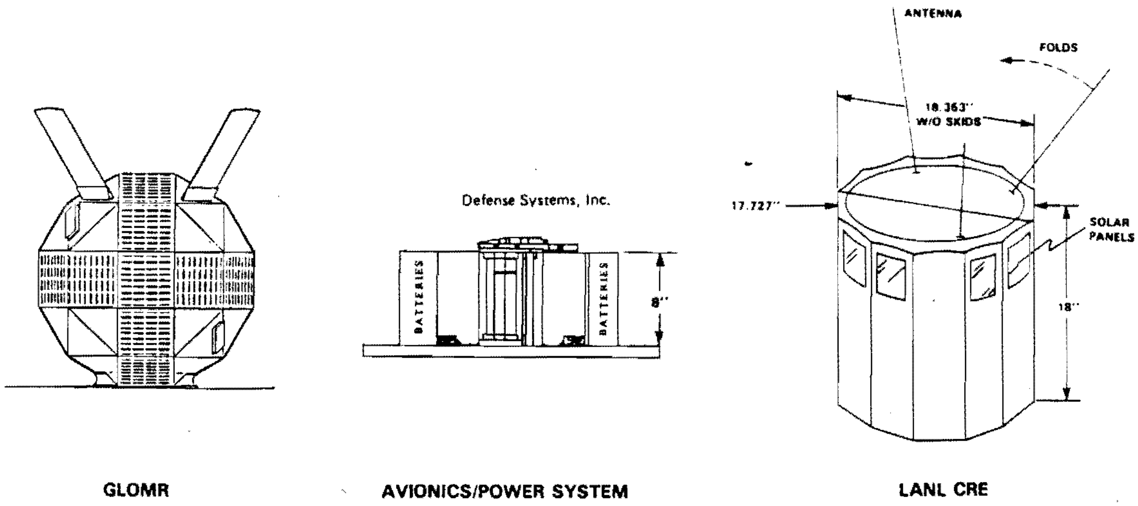


Fig. 1 CRRES/Scout Heritage

Fig. 1 also shows a CRE satellite (3 have been built) for Los Alamos National Laboratories. Also shown in Fig. 1 is the basic packaging of the avionics, power, and communications common to both this CRRES/Scout satellite and the three CRE satellites.

With the removal of the CRRES satellite from the STS manifest and the availability of space-proven DSI hardware on a limited production line basis, it became feasible and cost-effective to configure a Scout-launched spin-stabilized satellite with the basic DSI bus and four chemical release cannisters from the CRRES program. Figs. 2 and 3 show the design concept for this CRRES-derived satellite. GSFC will furnish the structure, mount the DSI solar arrays, power system, avionics and communications, as well as four chemical release cannisters supplied from the CRRES program. The satellite will also have a 3-axis vector magnetometer and electric field instrumentation mounted on boom, for scientific data collection. The magnetometer will serve another purpose, that of maintaining spin axis precession and nutation control in conjunction with a digital sun sensor, electromagnets, and a 80C86 microprocessor to close the control loop. The scientific community will furnish other instrumentation to be packaged radially outboard of the main bus electronic module.

Bus Characteristics

Fig. 4 is the spacecraft block diagram for the power, data, and communications systems. These systems, as well as the mechanical systems, are described below.

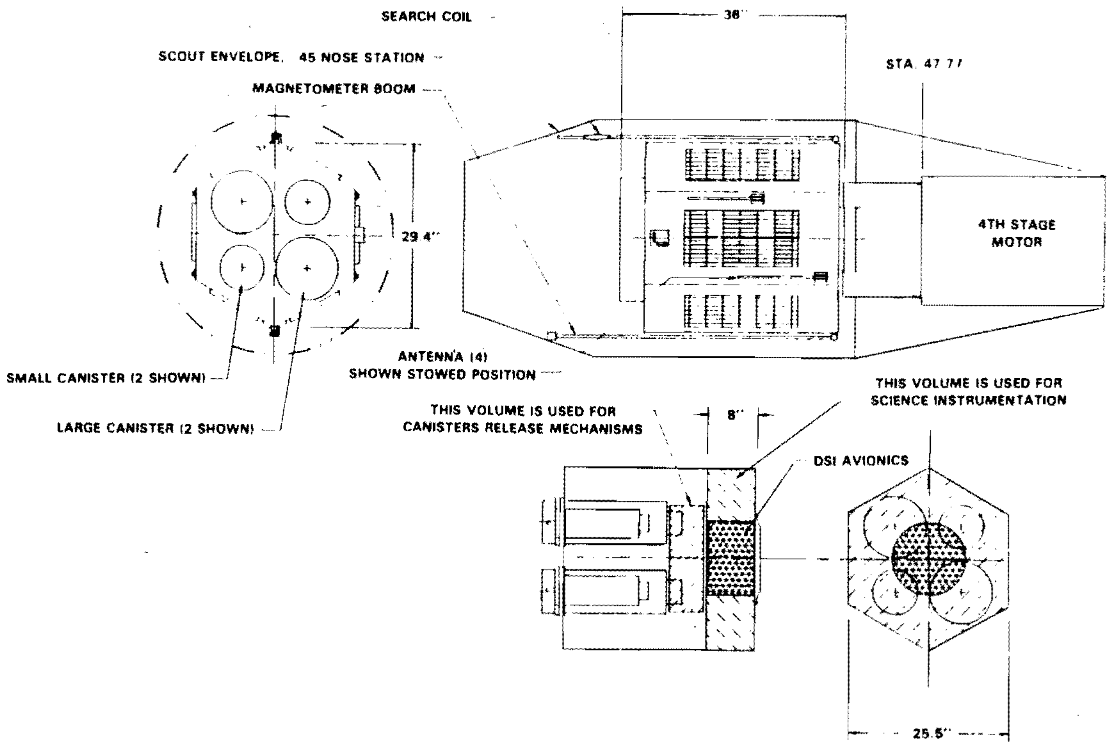


Fig. 2 CRRES/Scout Configuration

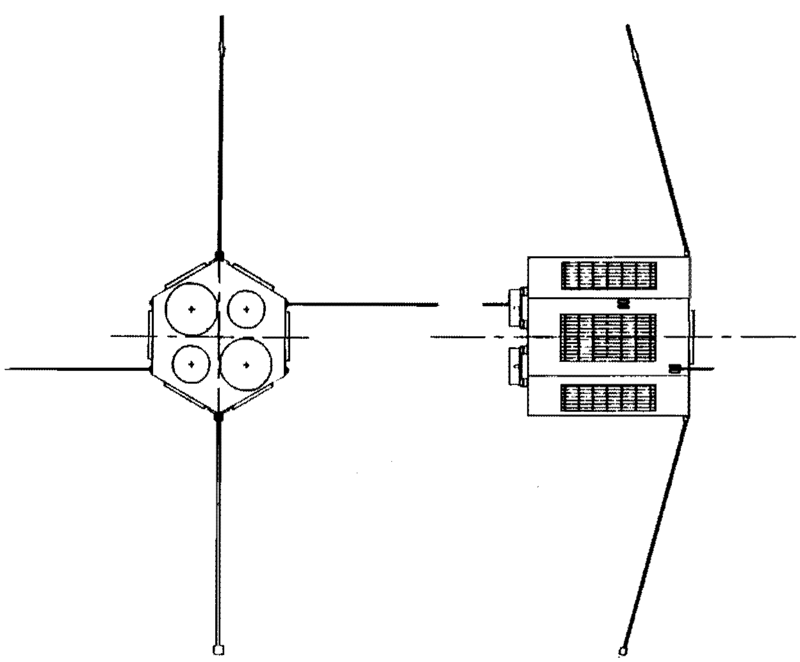


Fig. 3 CRRES/Scout Orbit Configuration

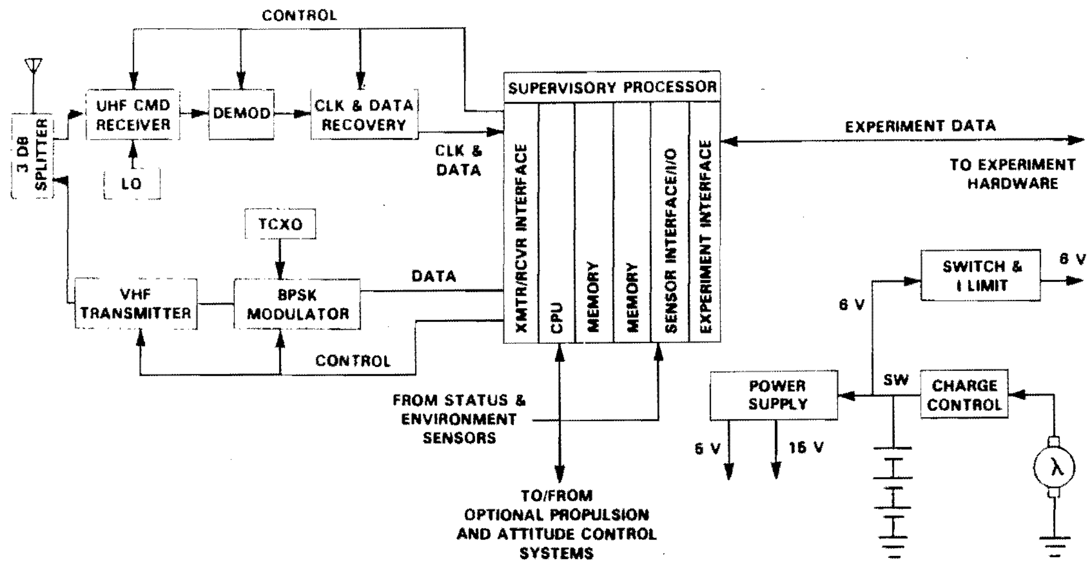


Fig. 4 Spacecraft Bus Block Diagram

SATELLITE BUS CHARACTERISTICS

Mechanical

The structure and mechanical systems will be relatively simple and lightweight, and use fixed solar arrays attached to the sides of the structure and spin-deployed booms and antennas.

The primary structure will be a six-sided box as shown in Fig. 2, with bulkheads as required to support the sides, CRRES cannisters, and subsystems. It will be attached at the base to the Payload Support Ring of a standard Payload Adapter Section, which incorporates the payload separation mechanism. The structure will be built up from aluminum alloy sheet metal and/or honeycomb panels joined and stiffened with extrusions and/or bent up shapes to minimize weight.

The magnetometer boom, search coil boom, and the four antennas will be spin-deployed. A simple latch mechanism will maintain this in the extended attitude. A yoyo despin system will be used to reduce spin rate to the desired value.

Power System

Forty-eight solar panels (each 4.25" x 4.25") of the kind used on GLOMR will generate 1.170 watts, each when facing the Sun, for a total of 56.16 watts. Assuming 40% umbra and recognizing that the maximum projected area is 1/3.14 times the total cell area, these 48 panels will produce 10.7 watts average power when the cylinder is spinning normal to the Sun.

The overall efficiency of the GLOMR electric power system is 90% (90% of solar panel power is available as battery output power). Using the same efficiency for the power system of this satellite, the average available power from the batteries is 9.63 watts. Allowing 3 watts for internal housekeeping and ACS purposes, then approximately 6.6 watts average are available for science instrumentation. To maintain the 25% DOD requirement, higher power instrumentation could be used on a duty-cycled basis. For example: A period of 1 hour per day could be made available for an instrument drawing 105 watts.

$$\frac{\text{420 watt-hour battery pack}}{\text{25\% depth of discharge}} = \text{105 watt hours}$$

To recharge the batteries:

$\frac{105}{0.9}$ = 117 watt-hours would have to be put back. At 7.7 watt hours available to the batteries each orbit (assuming 40% umbra), it would take about 15 orbits to recharge the battery pack. To summarize, the science instruments could draw 6.6 watts continuously or about 100 watts for an hour each day.

The CRRES/Scout battery pack consists of 84 gates-sealed lead acid D cells, each producing 2 volts and 2.5 A-H (5 W-H). These are connected in 28 parallel strings of 3 series cells producing a bus that is expected to vary from 5.2 to 7.5 volts. A series regulator provides 5.00 V to the onboard equipment. A step-up DC/DC converter provides 15 V for the onboard transmitter.

At 15 charge cycles per day (5400 per year), conservation of batteries requires limiting the depth of discharge. For one-year-long missions with very high peak-to-average energy usage ratios, a maximum DOD of 25% is recommended (battery never discharges below 75%).

For the mission, the nominal DOD (for an average power drain of 9.6 watts) is 1.5%, assuring long life for the battery pack.

Data System

An INTEL 80C86 microprocessor is used with 10E7 bits of RAM memory for command and telemetry data storage and to control the interface with the attitude control, instrument, and communication system.

The uplink and downlink protocol used is a partial implementation of the IBM Synchronous Data Link Control (SDLC) described in Fig. 5.

It should be noted that the ending FLAG of one frame may also serve as the beginning FLAG of the following frame. The only control field function that is implemented is the POLL/FRAME bit (bit 4). The ADDRESS field must always contain the correct value which is the destination device address for that frame. The INFORMATION field is either empty (0 bits in length) or contains a message packet as described in Table 1. Standard transmission events used with GLOMR begin with 60 empty frames.

For housekeeping purposes, the data system inputs temperatures, voltages, etc. and computes and stores maximum, minimum, average, and current values in a 10E7 memory for downlink. The data system provides TBD services to the instrumentation package.

For command memory, 1024 EDACed locations are provided with 1 second execution accuracy for mission operations.

FLAG 01111110 8 BITS	ADDRESS FIELD 8 BITS	CONTROL FIELD 0 BITS	INFORMATION FIELD N BITS	FRAME CHECK (CRC-CCITT) 16 BITS	FLAG 01111110 8 BITS

Fig. 5 Data System Protocol

Table 1
INFORMATION FIELD MESSAGE PACKET

FIELD	LENGTH	TYPE	CONTENT
TYPE-ID	1	8 BIT INT	ALWAYS 01H
ODAC	1	8 BIT INT	ORIGINATING DEVICE ADDRESS
DDAC	1	8 BIT INT	DESTINATION DEVICE ADDRESS
MSG-ID	2	16 BIT INT	SERIAL NUMBER OF MESSAGE
MSG-COUNT	2	16 BIT INT	BYTE COUNT OF MESSAGE TEXT
MSG-TEXT	N	STRING	MESSAGE TEXT

NOTE: LENGTH IN BYTES

Communications

The GLOMR omnidirectional communications system (UHF up and VHF down) will be used for this mission except that narrower band turnstile antennas will be used for a net gain of 3 dB. Both the uplink and downlink use Binary Phase Shift Key (BPSK) modulation due to the link margin possible with the narrow bandwidth required, the simple modulators,, and the simple transmitters.

The disadvantage is that for the satellite uplink, the satellite demodulator draws a lot of power. This is by-passed by turning on the demodulator only when an uplink carrier is detected. The UHF command receiver uses a 20 kHz bandwidth in order to minimize doppler effects. The receiver sensitivity is TBD DBM for 10E-5. A 10-watt VHF transmitter is used for downlink on all available orbits to recover data stored in the solid state memory.

There are two innovations in the communications system for this satellite made available by the microprocessor in the flight and ground equipment:

1. The downlink rate will vary between the GLOMR 1200 bps and 128 kbps, depending on the range, as measured by the ground station and uplinked back to the satellite continuously (the range difference varies about 25 dB from horizon to zenith). This allows 10E7 bits of data (a full day at 100 bps) to be recovered in a few minutes.

2. GSFC developed Reed-Solomon and Convolutional Coder Chips that enable a 7 dB improvement in downlink data rate and will be command configurable in or out of the downlink.

It may also be possible to vary the uplink rate by as much as 32 dB (25 + 7) above the 1200 bps GLOMR using the same techniques as for the downlink. The system implementation and implications of this will be studied and resolved in the near future.

It is anticipated that a center frequency between 136 and 138 MHz will be used for downlink and one between 148 and 150 MHz will be used for uplink.

The CRRES/Scout mission will use coherent uplink/downlink transmissions in order to allow standalone versus standby NORAD orbit determination via doppler information from the recovered carrier of the downlink.

Attitude Control System

Attitude Stabilization Concept

The Scout CRRES spacecraft will be spin-stabilized, rotating about the launch spin axis. It will be passively stable--that is, with the spin moment of inertia greater than the transverse moments--and passively damped. Two magnetic torquers, parallel and normal to the spin axis, a magnetometer, a 4-pi steradian sun sensor, and a microprocessor complete the attitude control equipment complement. Fig. 6 is a block diagram of the spin control system.

At injection, CRRES will be spinning at 140-180 rpm, with the spin axis parallel to the Scout velocity vector. A yoyo will despin the CRRES to a much lower rate. Because of the highly stable spin configuration, CRRES will be precessed to the orbit normal by gravity gradient torque. However, a magnetic torquer will probably be used to accelerate the reorientation, as well as to adjust spin rate.

The chemical release cannisters are clustered around the nominal center of mass and will be deployed parallel to the spin axis. Because each cannister is off center, there will

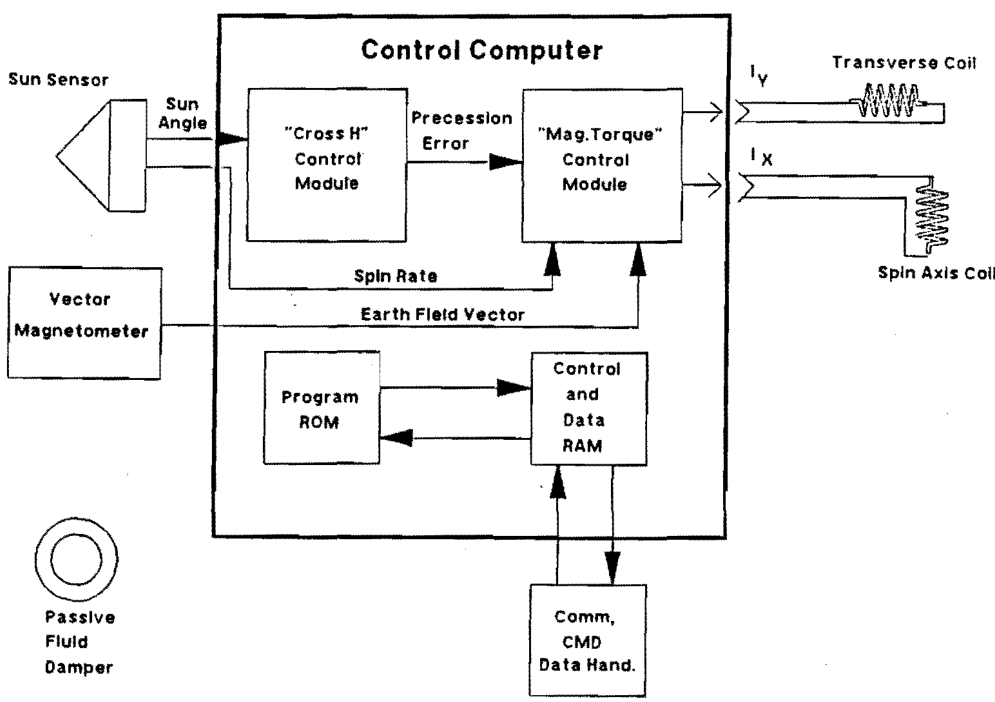


Fig. 6 Spacecraft Attitude Control System

be a dynamic perturbation at every deployment. But because attitude is not critical, the disturbance is acceptable and will be damped by the passive damper. Dynamic analyses and simulations during the development phase will verify attitude stabilization.

GROUND STATION

The ground station antenna is also omnidirectional. It uses a ground antenna similar to that of the satellite to provide the omni pattern, except that a QUADRIFILAR or a DISCONE antenna provides patterns (omni in azimuth and nearly hemispherical in elevation) that are "sucked in" a little at the zenith to provide more low-elevation angle gain. DSI has achieved +2.5 dB gain at the horizon with these antennas.

The single ground station will be like the GLOMR ground station shown in Fig. 7. It contains an IBM PC with a printer, transmitter for command link transmissions, a receiver for telemetry reception and an onmidirectional antenna. It can be placed on a desk, or a transportable package can be developed. The ground station software capabilities are extensive and highly automated. The following describes the capabilities of this menu-driven, user-friendly program:

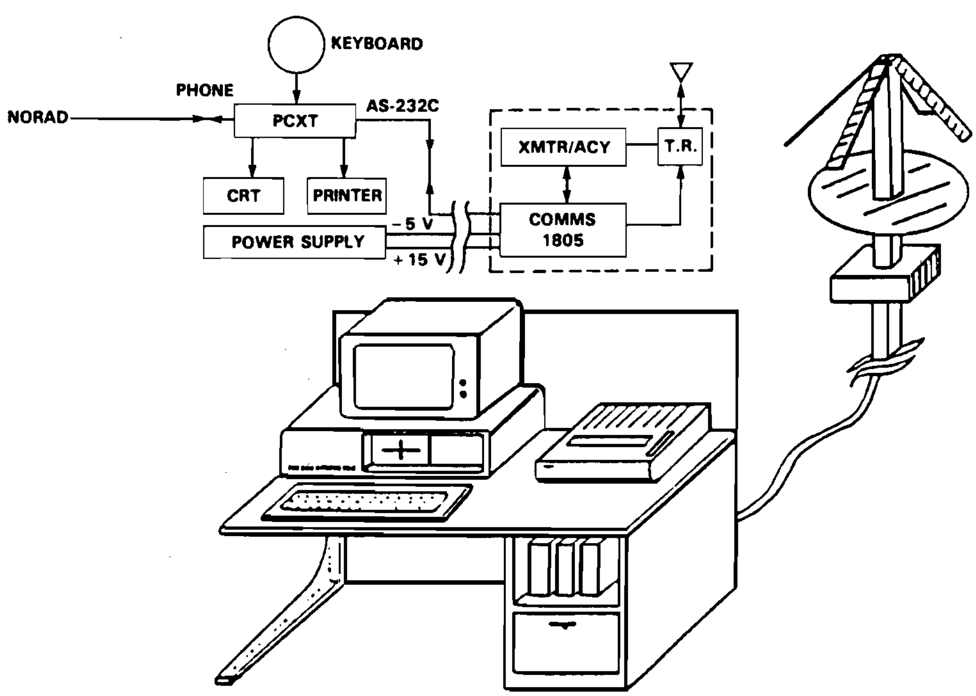


Fig. 7 Ground Station

Prepass Preparation

1. Input orbital parameters in any set of coordinates (the program actually uses NAVSPASUR Charlie elements, but it will accept any).

2. Compute the visibility schedule (the Rise and Fall times, peak elevation and corresponding azimuth angles of each pass for any specified number of days, and the recommended uplink and telemetry schedules. All times are computed to the nearest second.

3. Schedule review and edit to permit interactions and changes.

4. Real- and fast-time CRT map display of the satellite track, identifying times and places when it will be visible from any number of designated points.

5. Preparation of uplink commands. This permits the user to enter in a high-level, menu-driven manner the operations he wants the spacecraft to execute. The commands can be reviewed before approving them.

Autonomous Operations

6. The ground station is dormant and awaiting the scheduled time when it is to contact the satellite and uplink commands and receive telemetry. Data is automatically stored on disk for later review and processing. The ground station CRT also displays in real time the housekeeping telemetry portion of the downlinked data so immediate commands could be sent to the spacecraft to correct problems.

7. To assist the user to keep track of events, the CRT display is shown with the satellite moving in real time to indicate its present location. Two minutes before the scheduled contact, an audio alarm alerts the user to pay attention (if this is an attended pass).

Post-Pass Operations

8. After the pass, the user can look at the full telemetry and data dump.

MISSION OPERATIONS

General

After release from the Scout, microswitches turn on the battery system and power up the main computer. A real-time clock has already been powered up prior to integration with the Scout.

When the spacecraft is over the ground station, the ground uplinks a schedule, a set of numbered events to be executed on schedule, a priority sequence and housekeeping commands to the command memory for subsequent execution over the next 24 hours to 1-second accuracy.

The spacecraft is dormant until first schedule time. When that arrives, the computer executes the scheduled event (turn on experiment, telemeter collected data, change telemetry bit rate, turn on stabilization system, etc.).

In between scheduled operations, the computer performs routine functions, since otherwise it would be idling. Collection of housekeeping sensor measurements and computation of statistics of those measurements is an example of what the computer does when it has nothing else to do.

Specific

The Operational Scenario is designed to achieve the four releases in the shortest interval of time, and to coincide with the GTO releases. The GTO release times are governed by the mission parameters of that flight and are considered to be inflexible for the purpose of this scenario.

The operational control ground station is assumed to be at Pago-Pago in the Samoan Islands. This site can contact the spacecraft about 10 minutes before each Arecibo release is deployed.

The minimum time for the four releases is probably 60 days, based on 2 weeks checkout after launch and two releases 45 days apart, with the other two interspersed. The maximum operational period could be considerably longer if cloud cover over Arecibo or other circumstances interfere with releases. The discussion to follow is based on the minimum time. It also assumes, arbitrarily, that A-2 and A-4 are dawn releases.

Launch	Launch window is selected to: (1) provide a reasonable sun angle for the solar array, and (2) control the number

of days until first Arecibo release. Both of these affect the time of day of launch, but neither is critical, and no significant constraint is likely.

Checkout — Two weeks minimum are allowed to check out the spacecraft and ground system, determine the orbit, allow the attitude to stabilize, generate the detailed release sequence, and set up the first release at Arecibo.

A-2 Release — [Launch plus 2 weeks] The first release (barium) is made when the orbit plane precesses to the dawn side of the sun terminator. The time of release is established a few days beforehand by using doppler tracking to refine the orbit knowledge. The release command is issued to the spacecraft one third of an orbit before Arecibo, which is about ten minutes before cannister ejection. Upon notice of successful contact, the Arecibo campaigners commence operations.

A-1 Release — This is a night release of sulfur hexafluoride over Arecibo. Following a dawn release, the high latitude portion of the orbit will precess into the night half of the Earth. The Moon also revolves around the Earth, about six times as fast as the Sun. The A-1 release can be made any time that the high latitude of the orbit is in the Moon shadow (and the Sun shadow).

A-3 Release — Depending on time of year, the dusk release of another barium container will be set up about 3 weeks after A-2 release, when the orbit has precessed to the opposite side of the terminator. The process is essentially identical to the A-2 release described above.

A-4 Release — This is a repeat of the A-2 release. It can be done 45 days after A-2.

Post-Release — The in situ instrumentation onboard the spacecraft may be used for other measurements until the spacecraft reenters because of atmospheric drag. Daily contacts with the spacecraft provide data dumps to the ground station.

Detailed Release Procedure - All Arecibo releases are managed in the same general way: Orbit determination indicates a coming release opportunity; the time of cannister deployment is determined; Arecibo instrumentation is set up; the delayed command to deploy is issued during the orbit revolution before release; deployment and release occur to initiate the cloud experiment.

Orbit Determination - During the intervals between releases, the spacecraft is tracked by radar and one-way doppler from the spacecraft transmitter. Daily contacts from the ground station verify health of the spacecraft and, if required, return data from the in situ instruments on board. As a release opportunity approaches, orbit determination is refined to establish the precise time and location of the release opportunity.

Time of Deployment - As the time of deployment is established, a decision will be made whether to accept the opportunity, depending on ground conditions at Arecibo as well as release circumstances. In some cases there will be two opportunities, one day apart; the choice can then be based on the more favorable conditions. If the decision is to proceed, the Arecibo instrumentation will prepare for release and the spacecraft command sequence will be generated.

Deployment Command - The chemicals are released after a very precise delay that is initiated by cannister deployment. The cannister, then, must be deployed at precisely that time interval before release. The geographic release point is about a quarter of an orbit before Arecibo, which is a point on the Equator, near the Samoan Islands. The ground station may be located anywhere along the orbit path prior to this point. While there are no ideal locations, the possibilities include Darwin (Australia), Samoa, and some other islands, such as Guadalcanal. Wherever. Assuming that the actual point of deployment is not visible to the ground station, a delayed command to deploy is issued and verified. At the commanded instant, the cannister is deployed and begins to diverge from the spacecraft orbit at about two meters per second.

Release - When the cannister reaches the release point, near Arecibo, the chemical payload is ejected and the cloud begins to expand and to drift over the instrumentation site. At this point, the cannister is approximately two kilometers from the spacecraft. The cloud expands rapidly, causing the spacecraft to pass through the outer shell. The separation distance is sufficient to protect the spacecraft from excessive chemical deposition, yet allows the onboard instrumentation to measure the electromagnetic fields within the cloud.

Ground Station Location

The ground station should be located on the orbit ground path that precedes Arecibo, and it should be at least one quarter orbit ahead of Arecibo. This constraint allows the station to issue cannister deployment commands with minimum lead time. Although the earliest reasonable station location is not clearly defined, a maximum of one orbit revolution is desirable.

The orbit path preceding Arecibo leaves 20 degrees N in mid-Atlantic, crosses the Equator over Kenya, passes over Northwest Australia, and crosses the Equator again southeast of Hawaii. The cannisters will be deployed from the spacecraft about 2000 km due south of Hawaii. Fig. 8 summarizes this geometry.

The orbit path lies 900 km north of American Samoa, giving a contact interval of about six minutes. The spacecraft will pass Samoa about 10 minutes before the time of release.

Samoa is the best choice for ground station location for the following reasons:

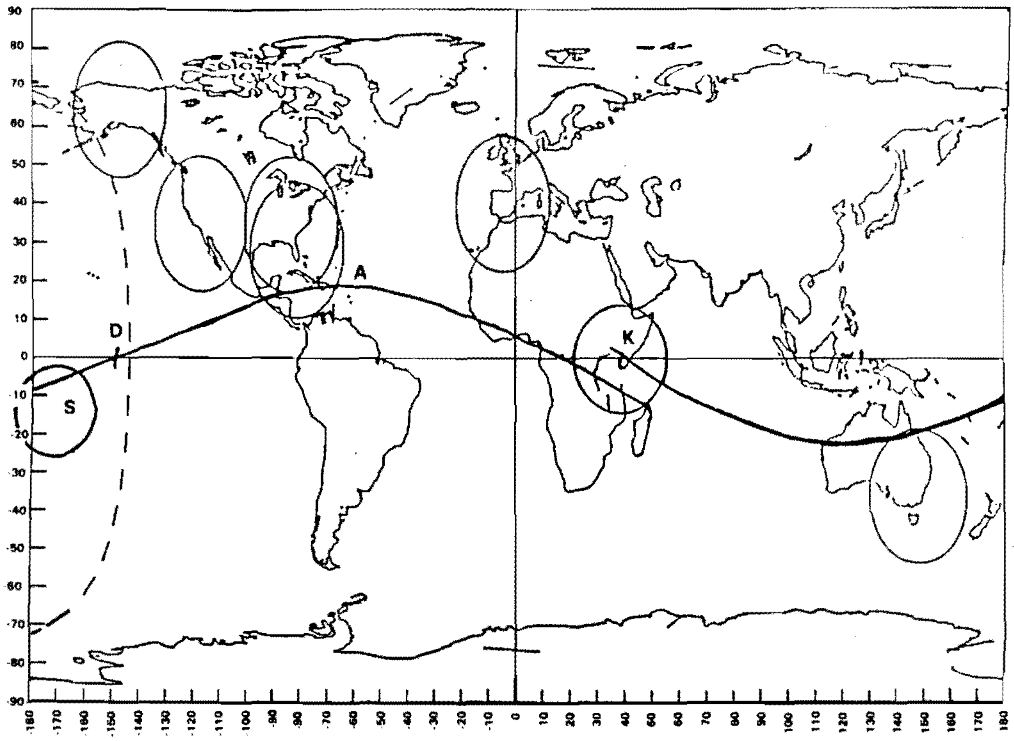
1. The location, 10 minutes before deployment, is almost ideal.

2. Contact duration of 6 minutes is adequate for data dumps, etc.

3. Samoa is an American territory, eliminating international complications.

4. Samoa has direct commercial air service from the United States with a single stop in Honolulu. Pago-Pago also has an excellent harbor.

5. Support facilities in Samoa should be good. (cf. Jim Gray, NASA/GSFC Code 820).



D — DEPLOYMENT POSITION
S — SAMOA GROUND STATION
A — ARECIBO, PR
K — SAN MARCO (KENYA) GROUND STATION

Fig. 8 CRRES/Scout Release Orbit

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