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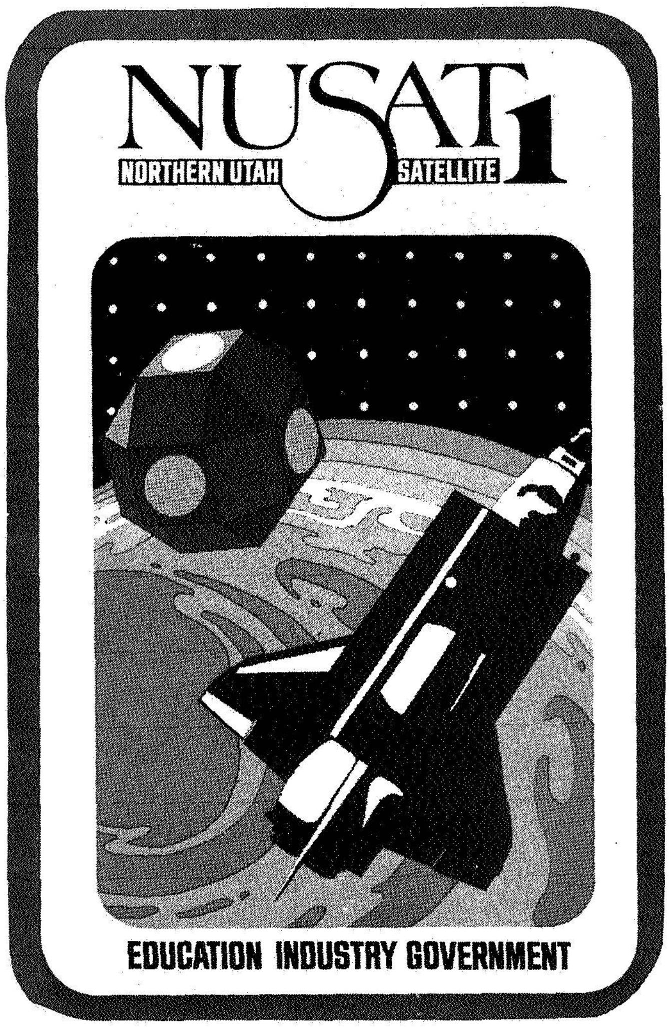

"NUSAT 1 - The First Ejectable Getaway Special"

by

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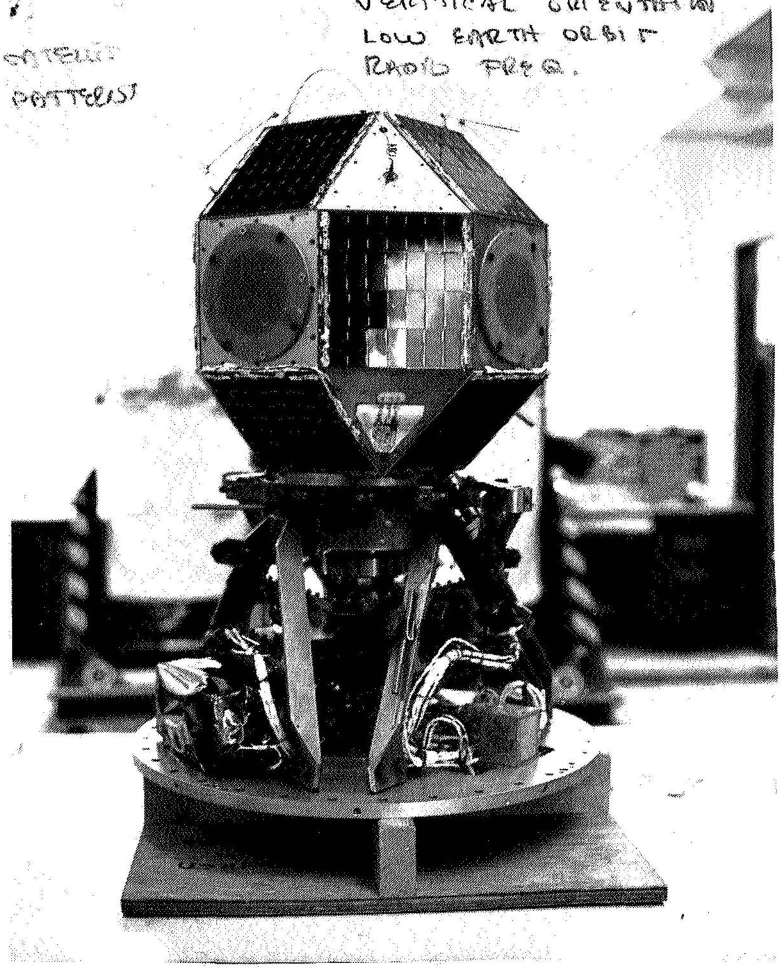
SPACECRAFT LAUNCHING
(1) [GROUND STATIONS] ✓
ORBITAL LAUNCHING ✓
COMMUNICATIONS SATELLITE
ATTENNA RADIATION PATTERNS

SPACE SHUTTLE MISSION 51-B
EJECTION
VERITICAL ORIENTATION
LOW EARTH ORBIT
RADIO FREQ.



Abstract:

Four hours, fourteen minutes and forty-two seconds after the space shuttle, Challenger, was launched on mission 51B, a small satellite was ejected into independent orbit from a Getaway Special canister. This event was an exciting milestone in a project conceived over seven years ago. It is hoped that the story of NUSAT (Northern Utah SATellite) will be an inspiration for other experimentors to exploit this new service of the Getaway Special program. This paper describes the purpose and history of the project, the NUSAT spacecraft, the ground station and its operation, and some future directions envisioned by the participants.

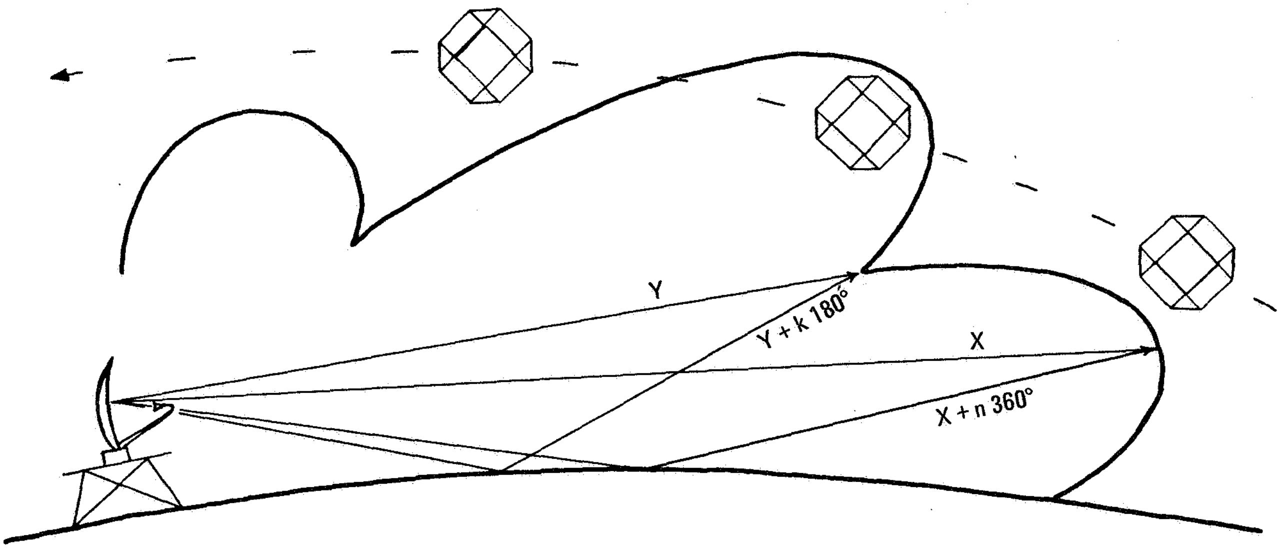
Purpose:

The project was organized with three stated goals:

- to provide an exciting real life educational experience for student participants;
- to demonstrate an efficient technique for optimizing coverage of FAA air traffic control radars; and
- to experiment with the GAS canister as a platform for ejecting small satellites into independent orbit.

Among implied goals also considered were:

- to test the effectiveness of an ad hoc, all volunteer organization made up of individuals from education, industry, and government;
- to enhance public and industry interest and support in Northern Utah as an environment conducive to aerospace activities;
- to facilitate networking of interested aerospace technologists.



k = ODD INTEGER
n = ANY INTEGER

The Problem:

The Air Traffic Control Radar Beacon Systems (ATCRBS), are the primary systems used by air traffic controllers to identify and locate aircraft in their control volume. These radars, an evolution of the old military Identification Friend or Foe (IFF) system, provide the controller with azimuth, distance, altitude and identity information for each target, making it possible for them to maintain a safe and efficient flow of air traffic. These radars, in excess of 2,000 stations around the globe, all operate at the same uplink frequency of 1030 MHz and downlink frequency of 1090 MHz.

The ideal radar would provide uniform coverage of a cylindrical volume of air space to a distance and altitude of interest to the air traffic controller. However, low angle reflections in the environment of the radar interrogator cause interference patterns in space, creating nulls and lobes. To combat this problem the FAA began installing radar antennas which reduced low-angle radiation and, therefore, reduced the blind spots in the coverage volume.

Because of their vertical radiation pattern geometry the tilt adjustment of these new antennas is critical. The only way to determine the existence and magnitude of this interference pattern is the use of flight check aircraft at a cost now in excess of $1,700 per hour. A technique called the "solar" uses the sun as a source of incoherent radio frequency energy to determine antenna tilt angle, but has many drawbacks and cannot determine the interference pattern.

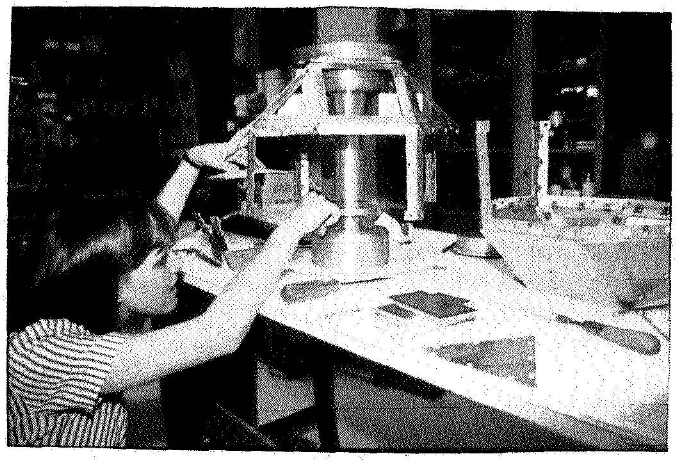
It was proposed that a device in low earth orbit could be used to measure the vertical radiation pattern of these antennas, and that this could be done more completely and at lower cost than any other technique.

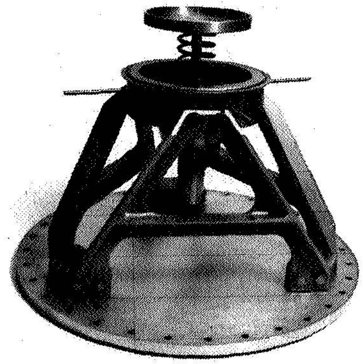
Evolution:

The original idea was to have a 1090 MHz orbiting transmitter continuously transmitting a unique RF pulse code at a predetermined duty cycle. Although this would have been a very simple device, there were several problems. Since all airborne transceivers use this same frequency, there was the nagging worry that some failure mode could result in interference with the global air traffic control system. The peak RF power required exceeded the state of the art available at the time. And, finally, the power possible from solar cells on a craft small enough to launch from a Getaway Special canister could not support the orbiting transmitter envisioned.

After several iterations, a concensus was reached to build a receiver that could be remotely programmed to come on at a future time, recognize a particular radar and store the received data (amplitude and time) for later transmission to the ground station.

Another consideration was the effect of the satellite's antenna pattern upon the signals received. Either the antenna system should be isotropic and circularly polarized, or else the spacecraft would have to be stabilized. Several stabilization schemes were considered then rejected, including spin stabilization, gravity gradient stabilization, aerodynamic stabilization and photon pressure stabilization. It was finally decided to build an antenna system as nearly isotropic as possible. This was achieved with six orthogonally mounted L-Band receiver antennas. Each antenna was a circularly polarized, double Archimedean spiral, backloaded cavity, designed so that the half-power points coincided with the same points of adjacent antennas.





Mechanical structure of the spacecraft (contributed by John Boyer, Weber State College):

The decision to eject an isotropic receiving system from a Getaway Special Canister also constrained the size and shape of NUSAT 1. It would have to be nearly spherical and no greater than 20" in diameter. It was decided to construct a 26-sided polygon with 18 square sides and 8 triangular panels. Six of the 8" square sides would support the L-band radar antennas and the remaining 12 would support solar cell arrays. Four of the triangular panels would support the VHF and UHF communications antennas, two would support Xenon flash bulbs, one a Langmuir probe experiment and one a power connector for ground testing and battery charging.

The satellite was assembled with five major components:

- The central post is a single dumbell-shaped piece of 7075-T73 aluminum. The top is a cylindrical cup large enough to allow mounting of the top L-Band antenna and rigid enough so that lifting screws can be attached for manipulation in 1 g. The bar of the dumbell provides the major structural strength and support for the module shelves. The bottom is another cylindrical cup similar to the top, but with the addition of a beveled ring to be held by the V-band clamp.

- The two octagonal shelves of ½" thick 7075-T73 aluminum provide rigid support for the electronic circuit modules, the battery pack and the outer shell.

- The outer shell of the satellite was fabricated in two pieces from 14 gauge 2024-T6 sheet aluminum, formed into a 26-sided polygon. Each seam and joint is fastened by aircraft type backing plates and nut plates. This outer shell provides support for the solar cell arrays, antennas, strobe lights, Langmuir probe and connector.

Although this structure is exceptionally strong and a good thermal conductor, a major flaw is the lack of accessibility to internal components. Students are now designing a structure that will retain the advantages of NUSAT 1's mechanical design, but provide greater accessibility to all internal areas.

Ejection Mechanism (contributed by John Boyer, Weber State College):

The dimensions of this mechanism were constrained by the volume of the satellite, the canister and the space needed for the ejection control system.

The three "A" frame supports were machined from 7075-T73 aluminum. They support a single-piece, multicavity aluminum structure that houses the ejection spring and plunger, and provides the bevel ring that matches the satellite ring and to which it is held by the Y-band clamp. They were designed to withstand the cantilever stress of supporting the satellite during shipping and launch accelerations.

The spring characteristics and plunger length were designed to allow full spring compression by the weight of a 150 pound satellite in 1 g and to provide an ejection velocity of about 3.5 ft/sec. at 0 g.

Four small, steel radial rods were installed below the beveled ring to limit motion of the V-band clamp towards the base by springs after ejection.

The V-band clamp, which has been used before on other launch systems, held the beveled rings together until released by pyrotechnic bolt cutters.

Power System (contributed by Robert Twiggs, Weber State College):

The source of electrical power for the spacecraft is a system of solar cells, twelve panels of 28 cells each, which charge a battery pack via isolation diodes. The 10.5 v, 5 ampere-hour battery pack is made up of five 2.1 v Gates X-cells.

Several weeks before launch the batteries were charged and then isolated from both the solar cell arrays and the satellite electrical systems by microswitches on the base ring. Upon ejection the microswitches closed, connecting the solar cell arrays to both the battery pack and the satellite electrical systems.

Since these systems require ± 15 volts, +5 volts, and the +10.5 volts of the battery, a +5 volt switching regulator and three ±15 volt DC converters were needed. These voltages are distributed to the various circuit groups via electronic switches under control of the microcomputer. These groups provide the following modes of operation:

- Mode 0: the default, or "sleep", mode, in which only the microcomputer and the uplink communications receiver are powered.
- Mode 1: the RAM or, program loading mode.
- Mode 2: the L-Band data collection mode, in which all radar receivers and associated processing circuits are powered.
- Mode 3: the down link transmit mode.
- Mode 4: the on board sensor monitor mode, in which all light sensors, Langmuir probe and voltage monitors are on.

Although some of these modes, or combinations of them, require much more power than the solar cell arrays can provide (0.6 ampere/array), the duty cycle of these modes is low enough to allow satisfactory operation of the satellite.

Control System (contributed by Chris Williams, Hill Air Force Base):

On-board management of the satellite is under the control of an NSC 800 National Semiconductor microcomputer. This is an eight-bit, Z80 comparable, microprocessor system. On-board memory includes 2K of ROM and 2K of RAM with the microcomputer, and 48K of RAM which are turned on under software control.

The operating system is characterized by exceptional flexibility, with very little program in ROM and most software loaded into RAM from the ground station when needed. This allows the ground system operators to change procedures and variables and to experiment in ways not even considered before launch.

The microcomputer is capable of monitoring and controlling many functions and parameters of the spacecraft. These include monitoring of: battery bus voltage (1), temperature sensors (12), light sensors, for attitude determination (8), Langmuir probe voltage (1) and L-band receiver outputs (6). And the control of: antenna release (1), Xenon strobe lights on/off (1), 48K RAM on/off (1), power group switching on/off (6), radar pulse pair spacing (1), start converstion command (1), as well as analog outputs for setting the radar receiver noise threshold and determining the sun direction.

Upon ejection, the microcomputer was turned on and went through an initialization sequence which included deployment of the communications antennas 18 seconds after ejection and resetting of software clocks. The operating system then entered an "IDLE" program loop which keeps the system in mode 0, polls the communications receiver system for incoming messages (the "COMM" routine) and does an unconditional battery check every 10 minutes.

If upon polling the uplink communications system a valid query message, "WSC return", is present, the control changes to mode 3 and replies to the ground station "NUSAT TO WEBER STATE GROUND". It then enters mode 1 and awaits a program upload for up to 10 minutes. If it receives a valid program it responds "SUCCESSFUL UPLOAD" and then executes the program. If it receives an invalid program, such as one with check sum data errors, it responds "UNSUCCESSFUL UPLOAD" and returns to the IDLE routine.

Every 16 milliseconds a non-maskable interrupt is received from a crystal-controlled clock circuit. The interrupt processing routine then updates the software clock, checks if an uploaded program is being executed and if the COMM routine has been called in the last 10 minutes. If an uploaded program is being executed and it has been less than 10 minutes since COMM was called, control returns to the executing program. But if no RAM-based program is executing or 10 minutes have elapsed, the interrupt processing routine returns the satellite to IDLE.

There are at least three levels of protection against hardware or software failures which would result in loss of control of the on board system. These include:

- the non-maskable interrupt routine described above which automatically returns the system to its IDLE mode if 10 minutes have elapsed since the last call of COMM.
- an eighteen minute hardware reset timer that is reset to zero whenever the COMM routine is executed. In other words, the system would reinitialize from a hardware reset if COMM had not been called within eighteen minutes.
- a battery bus voltage check every 10 minutes which executes a software reset if the voltage falls below 9.75 volts.

Of course, long duration programs such as these which call up L-Band collection during future orbits can remain in RAM and operate for many hours as long as they periodically call up "COMM" to reset the software clocks.

Communications System (contributed by Lee Barrett, Computer Science Corp):

Another paper, "The Northern Utah Satellite (NUSAT) Communications Link" by Lee Barrett, will present a detailed description of the design and evolution of the NUSAT communications system. In the present paper the reader will find a general description of the system used to send control and data messages between the ground station and the satellite. The antenna tracking control system is included as part of the communications system.

The ground station employs two Apple IIE computers. One computer controls the orientation of the antennas by driving elevation and azimuth control rotors according to a predicted plan for each pass of NUSAT over the ground station. The other computer handles the communications duties of uploading programs and downloading data.

The first Apple IIE contains a table of predicted azimuths, elevations and times for the period NUSAT will be in sight of the ground station. This table is generated by another computer from orbital parameters provided by NORAD. When commanded to start tracking by an operator, this computer outputs signals to rotors which control the elevation and azimuth of an antenna array. This array includes a KLM model 435-18C/CS-2 UHF antenna with 12dbC gain and 33° beamwidth, and a KLM model 2M-14C cut for 137.9 MHz with 11dBd gain and 38° beamwidth. Both cross-polarized multiple-element yagi antennas are mounted side by side on a fiberglass crossbar.

The second computer is connected via an RS232 interface to an audio frequency shift keying (AFSK) encoder/decoder. Although designed for a 2400 baud rate, the system usually is operated at 600 baud. The encoder and decoder circuits are connected to the 450 MHz transmitter and 137.9 MHz receiver, respectively. The operator selects the message or program to be uploaded to the satellite from a disc-loaded menu.

The VHF and UHF antenna systems on the satellite are similar in design. Two vertical antennas are mounted at right angles to each other, resulting in no cross coupling. The two antennas are then fed with another 90° phase shift to create a circularly polarized antenna system. The antennas are all flexible whip-type elements that are tied down to Nichrome wire retainers by nylon lines while in the GAS canister. Eighteen seconds after ejection a large current pulse vaporizes the wire and releases the antennas.

The microcomputer is interfaced to the UHF receiver and the VHF transmitter on the satellite via another AFSK encoder/decoder circuit. The spacecraft radios are standard commercial models modified for this application.

The 450 MHz transmitter is a Spectrum Communications model SCT410, with the 7 watt output boosted to 100 watts by an external linear power amplifier.

The 450 MHz receiver is an ICOM model IC-4AT transceiver, with the transmitter section removed. This receiver has a sensitivity of 0.35 uv for 20 dB noise quieting. The amount of doppler shift either the ground or satellite system will tolerate depends upon the level of signal received.

The 137.9 MHz transmitter is a modified Spectrum Communications model SCT110, with an output power of 10 watts.

The 137.9 MHz receiver is a Spectrum Communications model SCR-200.

L-Band System:

This system consists of the circuits needed to receive, recognize and measure the signals from a particular air traffic control radar. There are six separate, identical RF channels, each associated with one of the six orthogonally oriented antennas.

The output of each antenna is amplified approximately 60 db by a broadly tuned amplifier before passing through a 1030 ± 1 MHz multicavity filter. The output of this filter is amplified 30 dB more prior to detection. The detected signal, a 0.7 microsecond rectangular pulse, is compared to a noise threshold level generated under software control and sent to a peak-and-hold circuit if the signal exceeds the threshold.

This signal is sent to a coincidence circuit, along with output signals from the other five channels, where it is applied to a pulse pair discriminator circuit. The purpose of this circuit is to determine when radar pulses of a unique time interval have been received. This interval is determined by control software. When radar pulse pairs of the correct interval and sufficient amplitude have been received, the microcomputer then commands the analog-to-digital converter to measure the amplitude of the receiver output signal in the peak-and-hold circuit of each channel at a future time. This time is the predicted time of the next radar pulse, based upon the known pulse repetition frequency of the radar under test.

The microcomputer then processes the six received signals, rejecting those from antennas aimed at the sun and determining the actual pulse amplitude, based upon the signal component seen by each receiver. The calculated pulse amplitude along with the time of the measurement is stored in RAM for transmission to the ground station upon demand.

Auxiliary Experiments:

There are two auxiliary experiments included on NUSAT. The Langmuir probe is designed to measure ambient electron density in orbit. The result is a voltage included in the sensor readings. The two Xenon flash lamps can be commanded on to facilitate optical tracking of the spacecraft.

Operation:

The planned operational strategy is to progress slowly from shorter to longer program operations. The first operation after launch was to send the "WSC return" query at the zero doppler location in the pass over the ground station and receive the reply message. The second operation was to upload a program called "Beddy-bye" which simply returned the satellite to the IDLE mode. This operation was to be repeated a number of times per pass to determine the length of time and doppler range within which the system can reliably operate. After reliable operation of two minutes or more was achieved, then the sensor monitor and data down load were to be executed. However, this last step has not been tried as of June 6, 1985, due to cyclical variations in the reliability of system communications. The next operation will be a test to discriminate one radar signal successfully. When this has been achieved, full radar antenna pattern measurements will be scheduled.

A fully successful operation will follow this scenario: On a pass over the ground station, a program will be uploaded which will command NUSAT to start the L-Band data collection process one or two minutes before appearing on the local horizon of the radar to be tested. For example, to test the FAA radar at Pico del Este, Puerto Rico, the program will start execution while NUSAT was still southwest of Bogota, Colombia. At this time, technicians at the radar will start transmitting a unique test signal interlaced with the normal radar signals.

NUSAT will measure and store the peak amplitude and time of the strongest signal received during each scan of the radar antenna. Five to nine minutes later, after the satellite has descended over the radar horizon, the data collection routine will stop and the data will be held in RAM until commanded to down load on a subsequent pass over the ground station at Weber State College.

It is hoped that the vertical radiation patterns of several radars can be measured during the lifetime of the satellite.

History:

In 1978 the authors presented a proposal to carry a 1090 MHz transmitter into low earth orbit in a Getaway Special canister

In 1982 a group was formed at Weber State College in Ogden including representatives from Weber State College, Utah State University, New Mexico State University, the Federal Aviation Administration, the United States Air Force and several aerospace and electronics companies.

In January of 1983 the concept was still that of a transmitter in orbit. In March of 1983 it was modified to be a transponder replying to radar interrogations. By September of 1983 the final design concept was agreed upon, and system design and fabrication was started.

In August of 1984 the mechanical design and construction was complete and a thermal analysis was performed. This was done by computer model and indicated that in-orbit temperature extremes would be between 44°F and 88°F (excluding the antennas).

An initial vibration test was performed on satellite and support structure components only in the summer of 1984.

Later in the fall, the entire satellite, mounted upon the ejection mechanism in its launch configuration, was vibration tested. In both of these test series three procedures were performed: a resonance search from 0 to 50 hertz, which was negative; a transportation test to simulate the stresses experienced during shipment and launch; and a random high frequency noise vibration test. Based upon the second series of tests, three modifications were performed; installation of foam backing on the circuit board enclosure cover of the computer to prevent boards from shaking loose from their sockets, removal of the brass spheres from the ends of the antennas and moving of the antenna tie-down locations. The latter two modifications were performed to avoid damage to the solar panels by motion of the antenna tips.

Thorough testing and debugging of the electronic systems continued through the winter of 1985 until delivery to the Goddard Space Flight Center in March, at which time the satellite was integrated with the Getaway Special canister and tested by NUSAT and NASA personnel.

In early April the final charge was applied to the batteries and the package was installed in the orbiter cargo bay at the Kennedy Space Flight Center.

The Future:

The success of the NUSAT project was due to the intense dedication and vision of a handful of skilled volunteers, the support of many cooporations, academic institutions, students, government groups, the press and families. Looking back upon the project to date, it is obvious that there were numerous errors, oversights and inefficiencies. Some efforts were duplicated and some things forgotten.

The NUSAT team is now in the delicate process of forming a new organization that, it is hoped, will assure greater efficiency and opportunity to all, while continuing to promote the spirit of volunteerism and camaraderie that marked this project from its birth. This organization is called the Center for Aero-Space Technology (CAST) and is really just a formal coalescing of most of the original participants.

Its Statement of Purpose and Goals is:

"The Center for Aero-Space Technology is a non-profit organization of individuals from industry, education, and government in association with Weber State College. The purpose of the Center is to propose, solicit, design and manufacture useful aero-space experiments, devices or systems, or to support similar enterprises in other Utah schools and organizations.

The goals of the Center are:

- to generate significant, practical and realistic technical experiences for students;
- to provide a local center in which aero-space technologists can connect with others of similar interests, share their expertise with students and associates, and achieve other personal goals;
- to create an environment in Northern Utah which will support aero-space industries;
- and to facilitate public aero-space education in Utah.

It is envisioned that future projects will be modeled after the NUSAT 1 project, in which its goals were achieved through a combination of student and volunteer efforts, donated resources, and contracts from other organizations."

It soon became apparent that organizations can budget donations to projects like NUSAT on an annual basis, but it is difficult to obtain one-time donations on short notice to an informal group. Therefore, it is hoped that CAST can more readily solicit donations for sponsored projects. Also, such projects need the logistics support made possible by association with an educational institution, its physical facilities and contract office.

CAST is already considering at least three proposals to launch satellites into independent orbit, and several projects involving non-ejectable Getaway Special payloads. These include: a standard ejectable vehicle with a reliable communications control and sensor system for carrying other experiements; a NUSAT 2 satellite for the purpose of checking FAA radars; assisting a high school experiment germinating seeds in an artifically created 1 g environment; and an experiment concerning the broadcast of high frequency (27 MHz) signals from a satellite.

Humanity is on the threshold of developing an infrastructure that will allow exploration, commerce and recreation throughout the solar system and eventually to the stars. The NUSAT participants are enthusiastically doing their small part to develop the technologies and technologists to exploit this infrastructure, and they thank NASA and its Getaway Special program for making this possible.

The following corporations made donations of money, material or time to the NUSAT 1 project:

Morton Thiokol, Inc.
TRW, Inc.
Rockwell International Corp.
National Semiconductor Corp.
Apple Computer, Inc.
Sperry Corp.
Boeing, Inc.
Microtech Research, Inc.
Globesat, Inc.
McDonnell Douglas Astronautics Co.
Spectrum Communications
Consolidated Air Freight
United Technology
Maggione Electronics
ICOM, Inc.

Weber State College
Utah State University
New Mexico State University
Federal Aviation Administration
NASA Goddard Space Flight Center
Hill Air Force Base
AMSAT, Inc.
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Applied Solar Energy Corp.
Pacific Chromalox
South Western Data Systems
Flamenco Engineering, Inc.
Computer Science Corp.
Wall Industries