ASUSat1: Low-Cost, Student-Designed Nanosatellite

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Abstract

On January 27, 2000 (UTC) ASUSat1 was launched into space onboard Orbital Sciences' Minotaur rocket. The launch was the culmination of six years of effort by over 400 students.

ASUSat1 is an innovative nanosatellite bringing new concepts for low-power, low-mass, highly constrained designs. Its primary mission was earth imaging, with several secondary missions including orbit determination, amateur-radio communications, passive stabilization techniques, attitude detection, and composite-material research.

Following the successful launch and deployment of ASUSat1, the satellite operated for 14 hours. In spite of this, the team collected useful data from the satellite, and verified many of the design concepts incorporated into the satellite. Following the on-orbit failure of ASUSat1, the team conducted an investigation to try and single out the problem. Even though no specific problem was identified, the team has noted several design and system-level issues to be taken as lessons learned from this project to future ASUSat satellite projects.

Introduction

The ASUSat Student Satellite Program is managed entirely by undergraduate and graduate students with oversight by a faculty advisor. Industry engineers and additional faculty are available for consultation and periodic evaluations of student progress. There are over half-a-dozen projects currently under way, ranging from soda-can-sized 'satellites' launched from amateur rockets to as high as 12 km before descending under parachute, to a constellation of three satellites performing stereoscopic imaging to be launched from the Space Shuttle in 2002.

ASUSat1 is the original project that has made it possible for the program to grow to its current state of multiple in-progress projects. Begun in October 1993, over 400 students (85% undergraduate) have participated in the numerous iterations of ASUSat1 from initial concept, through design and development, integration and testing, and flight and ground operations. These students have gained valuable hands-on experience in the design and application of nanosatellite technologies, and today many of them are practicing engineers in the space industry.

ASUSat1

Miniature satellites are considered to be those under 200 kg[1], microsatellites as between 10 and 50 kg, and a nanosatellite between 1 and 10 kg. Figure 1 shows ASUSat1 of mass 5.9 kg, easily being held by one person. This is a prime example that real capability can be achieved in a nanosatellite-size spacecraft.

Figure 1. 6-kg mass ASUSat1

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The original goal of the ASUSat1 project was to show capability in a 5-kg-class package and provide technology demonstration in flight to enable other nanosatellite missions. The strict mass, volume, and power constraints associated with nanosatellites eliminate the use of many common off-the-shelf components and require innovative rethinking of many commonly used techniques such as active attitude control, radiation shielding, large battery packs, structures, thermal control, and many complex mechanisms. Also with the minimal power that can be generated from the small surface areas, only the lowest power consuming devices could be used.

Satellite Overview

Earth Imaging

Two similar cameras were mounted inside the satellite to point nadir. The spectral range of one camera was visible blue, and the other visible red and near infra-red. The cameras were independent of each other. Working together, the cameras provided images useful for vegetation indexing. Would have used separately, the visible blue camera was to provide general earth observations. The field of view of both cameras was 18 degrees and the resolution was 496 x 365 pixels. From the planned orbit, the expected resolution was about 0.5km/pixel. The cameras did not have a specific mission and the students at ASU were prepared to entertain interesting challenges for scientific observations with the images made available for download via the Web.

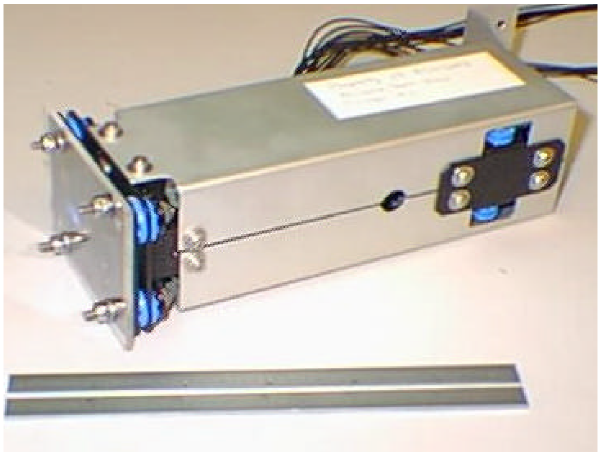

Figure 2. Camera assembly

Figure 3. Image with visible blue filter

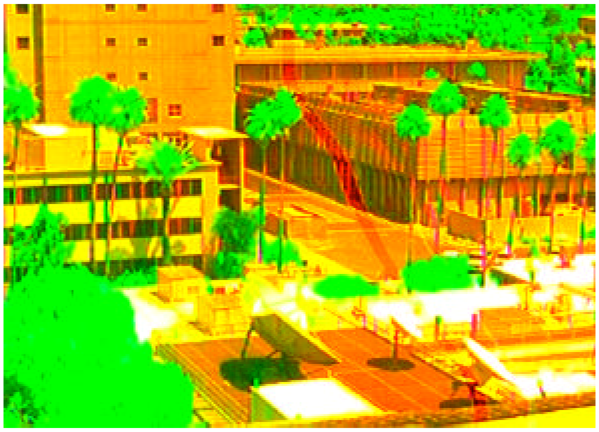

Figure 4. Image with IR / near-IR filter

Structure

To minimize mass, the team chose to construct the spacecraft bus entirely of composite material (M55J carbon fiber w/ 954-2A cyanate resin). The structure was designed to be 14 sided to maximize solar power, and was 25 cm tall and 32 cm in diameter with a wall thickness of 30 mils.

Dynamics and Control

Stabilizing a nanosatellite is not a trivial task. Due to the strict power, cost, and weight constraints, the dynamics team could not use standard devices such as off-the-shelf torque rods, magnetometers, thrusters, and sensors. However, for earth imaging and for communications optimization, a stable earth-pointing orientation was needed. The ASUSat1 team developed an innovative passive stabilization and damping collaboration incorporating many student-designed components. One of these components was a passive gravity-gradient fluid damper. This damper coupled with the gravity-gradient boom was to provide 3-axis stabilization.

The main stabilization system was the gravity-gradient boom, a cylindrical 2-meter beryllium copper element with a 135-gram tip mass. The boom was to be deployed from a student-designed release mechanism that is 3.8 x 3.8 x 6.6-cm and of mass less than 130 grams. The release mechanism was an offshoot of current industry designs, but was much smaller and lighter. One electrical signal was required from the launch vehicle at the beginning of the mission to release the element, stabilizing the satellite for the duration of the mission.

Figure 5 shows two students performing the final winding of the boom element into the deployment mechanism.

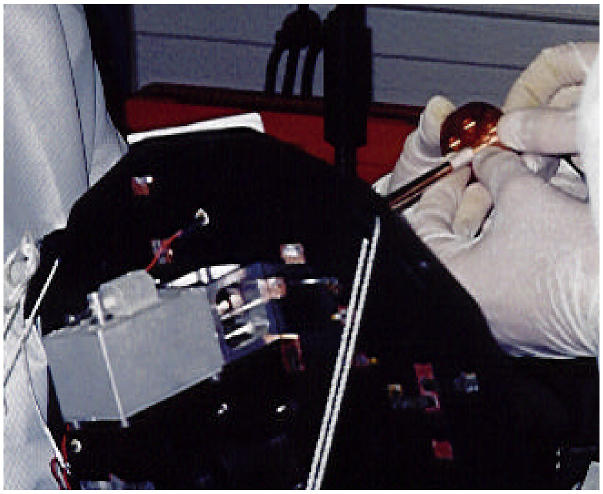

Figure 5. Final winding of boom element

Figure 6 is a close-up of the 135-gram tip mass, in its stowed configuration.

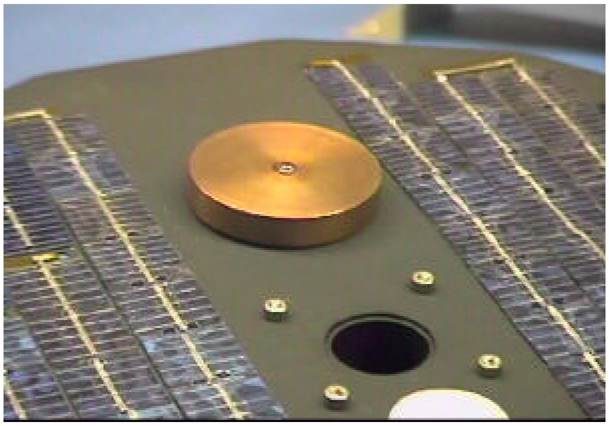

Figure 6. Tip mass and GG boom stowed

Figure 7 is a graphic of the spacecraft in its deployed configuration, showing the extended gravity-gradient boom and transmit and receive antennas. The extended tip mass provided the relative difference in principal moments of inertia that enabled a gravity-gradient stabilization scheme.

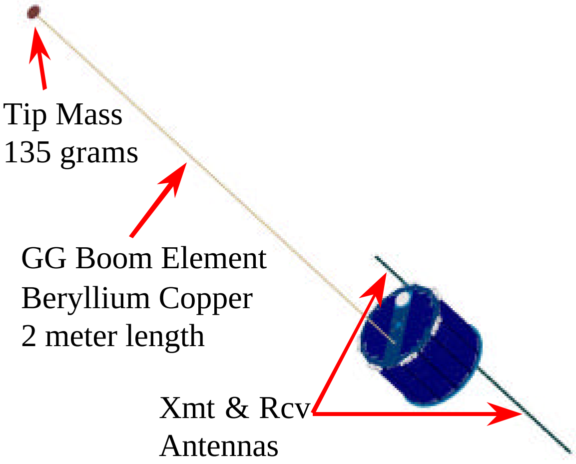

Figure 7. ASUSat1 deployed

By utilizing the pitch and roll/yaw decoupled equations of motion of a gravity-gradient stabilized spacecraft in low-earth orbit, the stability of the craft can be easily determined from the two parameters k_1 and k_3, functions of the principal moments of inertia. ASUSat1's principal MOI are [9.616, 9.438, 0.671] (N*m^2). These values give k_1 and k_3 parameters of 0.9 and 0.3, respectively. These parameters are plotted in Figure 8; ASUSat1 was clearly in the stable region of the plot.

One advantage of the extremely light-weight spacecraft is that to obtain the 0.9 parameter value, the required mass for the boom tip (an otherwise un-utilized cost to the mass budget) is only 135 grams. This is an example of the phenomenon that in spacecraft design, and especially in nanosatellite design, mass begets additional mass and the inverse is also true. That is, as component mass increases/decreases, so does structural mass to support it and attitude control hardware to control it.

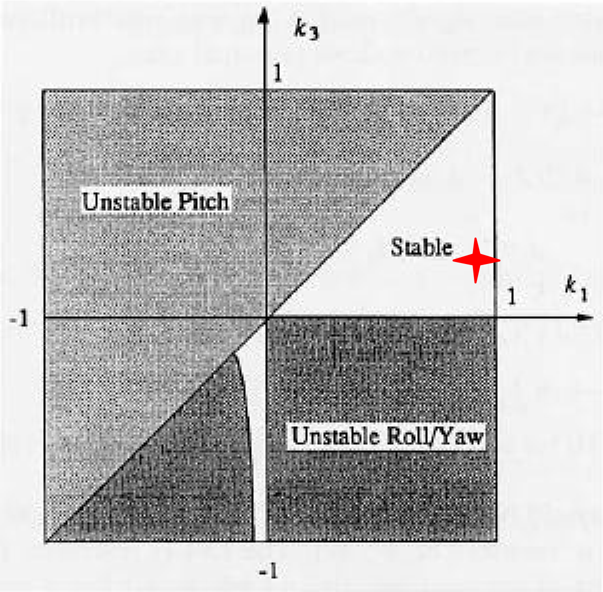

Figure 8. Gravity gradient stability plot, showing stability for ASUSat1[2]

A gravity-gradient boom (about +/-5 degrees[3]) cannot provide fine stabilization as the satellite is expected to wobble around its equilibrium point. This could cause the images to miss the targeted areas of interest so a finer stabilizing system was added.

The fine attitude control was also a passive system, called the gravity-gradient fluid damper. The system was built around a ball with four different mass concentrations that floated in a viscous liquid inside a larger shell attached to the satellite body. The physical principle behind it was that the inner ball should be aligned with both the earth's gravity vector and with the velocity vector of the satellite's orbital motion. Since the satellite would wobble around its equilibrium point, the wobble energy should be dissipated with time in the viscous liquid between the inner ball and the outer shell. This method was based on a new concept, and had not been space proven. If successful, it was expected that the satellite would reach a steady state in about 600 orbits. Both of the methods (gravity-gradient boom and gravity-gradient fluid damper) were completely passive, thus being an ideal solution for a satellite with a low power budget. Figure 9 is an image of the damper housing and the interior ball. The holes in the ball accommodated tungsten caps to provide the different moments of inertia.[45]

Figure 9. Gravity-gradient fluid damper

Gravity-gradient stabilization schemes have two stable orientations; one pointing nadir and one pointing zenith. If an uncontrollable event caused the satellite to flip or if the satellite was deployed in the wrong direction from the launch vehicle, many of the satellite's functions would cease to work. The only active means of attitude control added on the satellite was one small, lightweight, student-designed Z-axis magnetorquer. This z-coil was to be used to flip the satellite over in case of an upside-down orientation. Because of the large current draw of the coil, it was limited to emergency situations only. Figure 10 is a close-up view of the coil.

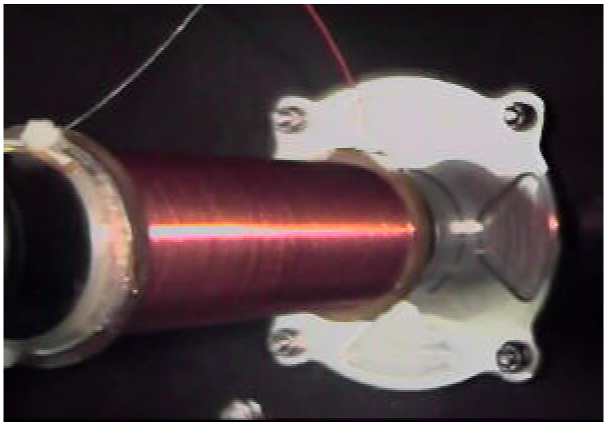

Figure 10. Z-axis magnetorquer

For attitude determination, various commercial sun/earth horizon sensors were evaluated, but due to the large cost of these units the students reverted to designing their own sun/earth sensors. The emphasis in the design was to build a low-weight, low-cost sensor array for determining the satellite's orientation to within +/-10 degrees. The sensor array was built using twenty-three photosensors mounted on the circumference of the satellite and sampling at three different angles. Such an array reduced costs to under $1000 and minimized required internal volume. The data gathered from the sensors coupled with the camera images was to provide the information to refine the attitude determination algorithm. Figure 11 is a close-up of the sensor blocks; the long blocks were mounted on the side of the spacecraft, with the short blocks mounted on the top and bottom bulkheads.

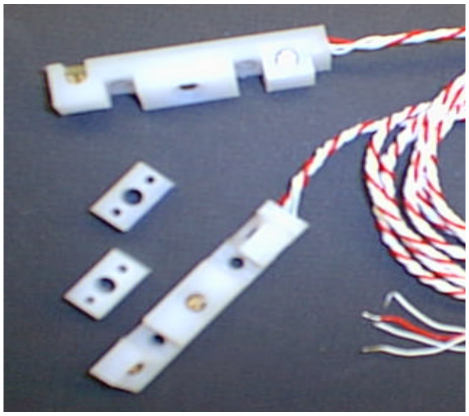

Figure 11. Attitude-determination sensors

Ephemeris determination was by GPS. GPS has been introduced to satellites only during the past several years, but is rapidly becoming a standard in spacecraft design. ASUSat1 used a Trimble SVee-Six GPS receiver. The unit consumed only 1.5 watts and was to be used to periodically collect orbital data points that would be stored in the satellite's computer and transmitted to the ground station for analysis. On-board ephemeris determination was not expected at this point due to the fact that the spacecraft computer did not have floating-point capability. This was a terrestrial (non-space-rated) unit that was conditioned for space by the use of epoxies and shielding and was expected to give position accuracy within 150m and similar accuracy for velocity measurements. Imagery of the GPS board, EMI box, and patch antenna are provided in Figure 12.

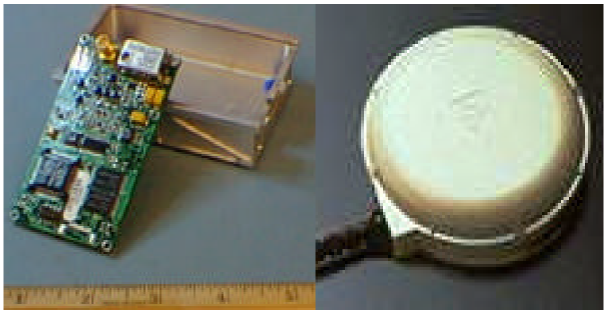

Figure 12. ASUSat1's GPS components

Using the techniques described above, it was expected that the entire attitude/orbital determination and control system would have a mean power consumption of less then 0.75 watts.

Communications

ASUSat1 was to demonstrate that it could carry onboard a low-power transmitter, modem, and 2 receivers along with transmit and receive antenna, and have useful contact with the ground. The ASUSat1 team wished to demonstrate the ability to send up new commands and receive new data. Amateur radio operators around world would also be able to use the satellite as an analog voice repeater as well as to download telemetry. Antennae were simple tape measure segments. The ground station was set up at ASU.

To enable the amateur radio community to participate in satellite operation, the communication system was fully compatible with amateur radio standards. The communications system was a common VHF uplink, UHF downlink (mode B) system. The digital system was to use 9600 Baud FSK, which was compatible with UO22/KO25 and similar satellites. AX25 was to be the main communications protocol, making use of a KISS TNC possible.

While being similar in modulation technique to UO22/KO25, the downlink would not be active continuously. This was needed in order to conserve power and enable data/audio multiplexing on the same downlink. Telemetry beacons would use standard formats which were supported by WISP. Telemetry configuration files would be made available to the public shortly before launch.

FM Repeater

One of the most important contributions of ASUSat1 to the amateur radio community would be the addition of another easy-sat to the fleet. The satellite would have a mode B FM repeater similar to the popular AO-27. It was estimated that the repeater mode would be enabled only when the satellite was in sunlight. This was again to maximize the time that the transmitter could be driven at full power. The repeater would be PL-tone activated. In addition, the downlink was to be shared between both the digital and analog payloads. The digital payload always had priority over the FM repeater. If a QSO was taking place while the satellite needed to send a beacon, the downlink would be captured before the transmission and released back to the repeater after the transmission was over. All-in-all the performance of the FM repeater was expected to be slightly better than that of the AO-27, with 6dB more power and less spin modulation.

A repeater would enable ham-radio experimenters to make use of the satellite to bounce their signals to a footprint over 6000km in diameter. This would enable them to make radio contacts well beyond the line of sight capability of VHF/UHF FM communications.

Electrical Power System (EPS)

Power availability was the primary factor in determining the mission profile. Due to the small size of the satellite, the available power from the solar array was limited. GaAs solar panels were mounted on all 14 sides and the top bulkhead of the satellite. Power from the solar array was transferred directly to the battery pack. The battery pack was a six-cell Sanyo NiCd pack with a capacity of 5AHr and a nominal voltage of 7.2V. From the battery, power was transferred to a high-efficiency DC/DC 5V voltage regulator. The last part of the power system was the switching network, which fed all the subsystems. Since power management was so important, all payloads had power switches - except the OBC. Calculations estimated that the system should have 6W average available for mission operations.

Thermal

Limiting temperatures (as determined from the operating temperatures of internal components) ranged from 0°C to +50°C. A total of 25 transducers were placed on the composite structure and on various components to take temperature measurements. Passive control was accomplished through various paints and coatings.

Command and Data Handling (C&DH)

The commands subsystem consisted of the command control board built around the Intel 80C188EC embedded processor. The controller board design consisted of 128k EPROM, 1M of RAM w/ EDAC, HDLC SCC, relay drivers, A/D converter, reset circuit, and associated circuitry.

The spacecraft software was designed around the BekTek Spacecraft Operating System (SCOS). The SCOS offered services of a real-time multi-tasking kernel, a message passing facility, AX.25 protocol drivers, and a set of DMA/Interrupt based I/O drivers designed for 80C188 microprocessor. The SCOS had Application Program Interface which made the job of interfacing each spacecraft task code easy.

ASUSat1 was designed to be operating-system agile. This meant that operators would have the capability to change the software on-board the satellite on the fly. The implications of this were that the mission profile could be changed at any time and the hardware resources on board the satellite used in many ways. This gave the satellite a large degree of mission flexibility and opened the door to in-orbit experimentation.

Upon launch, the OBC was loaded with a bootloader only. The bootloader maintained the satellite in a power-safe mode, and awaited commands from the ground station. During the operations phases, the Bektek multi-tasking operating system would be uploaded to the satellite. Once operational, the operating system would enable operators to take full advantage of all the resources on the satellite.

Satellite Deployment

Figure 13 shows a flight-version of the deployment system, which consisted of the guide rod running through the center guide tube on the satellite, the separation spring mounted to the guide rod, the Marmon clamp band for holding the satellite in place during launch, the pyrotechnic bolt cutter, and the base plate for mounting the system into launch vehicle. This hardware supported the payload during ascent, and then deployed it safely away from the launch vehicle. The plate was 0.95-cm aluminum that was pocketed out from the backside to reduce weight. The deployment system, including cabling and ordnance, had a mass of only 2.3 kg.

Figure 13. Marmon-clamp deployment system

Integration

Figure 14 shows the final assembly of the ASUSat1 spacecraft. In the first picture can be seen the boom-deployer housing, the camera housing, the shrink-wrapped z-coil, and the attitude-sensor blocks. The second picture shows the insertion of the commands and communication panel; the visible side is the comm system (receivers, modem, transmitter, and GPS), the commands and dynamics data acquisition boards are on the other side.

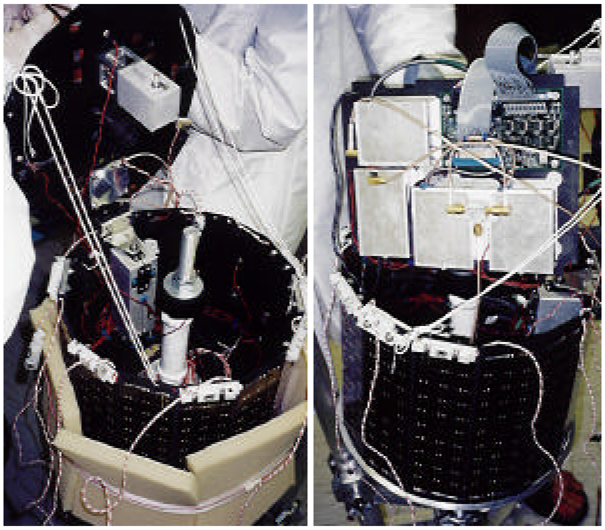

Figure 14. ASUSat1 during final assembly

Figure 15 is a picture of ASUSat1 taken on June 23, 1999, after the satellite passed acceptance and functionality tests and was integrated to the JAWSAT Multiple Payload Adapter.

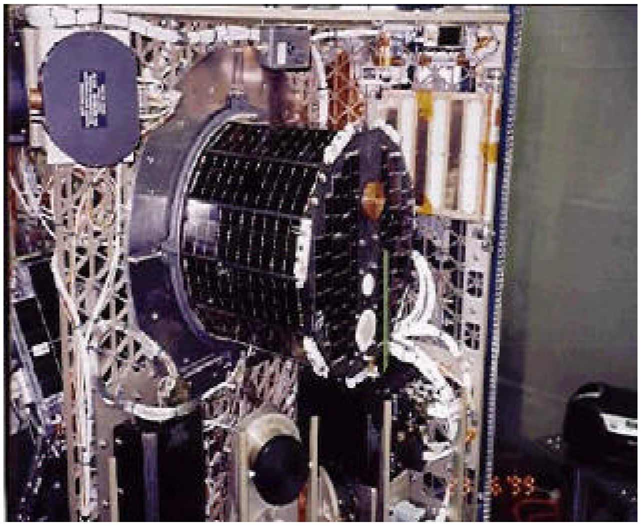

Figure 15. Integration of fully functional ASUSat1 to JAWSAT MPA

Mission Sequence of Events

Following the successful liftoff of the OSP at 2000-01-27 03:03:06 UTC, the 12.9-pound nanosatellite ASUSat1 was the first of five payloads to be deployed. The Air Force requested that each of the payloads immediately inform them of initial signal acquisition, to confirm successful deployment from the fourth stage.

Since ASUSat1 was an amateur-radio satellite, several stations world-wide volunteered to monitor for signs of life. The station that played the most important role in this was that of the South African SunSat team. The launch profile out of Vandenberg sent the payloads south, over Antarctica, and then north right over South Africa. About 45 minutes after lift-off, ASUSat1 was heard by radio amateurs in South Africa. Over the next several hours telemetry was collected from several stations worldwide. At first, telemetry indicated that all systems were nominal except battery charging. After an evaluation by the operations team, it was decided that the problem could be either a real charging problem, or sensor malfunction. As a precaution, the team decided to command the satellite to reduce power consumption. Nine hours into the mission the team had the first opportunity to command the satellite, and commissioning began. In later passes it was confirmed that in fact a critical failure in the power system was preventing the solar arrays from supplying power to the batteries. The last contact with ASUSat1 was made 14 hours into the flight. Power budget calculations suggested that the satellite had about 15 hours of operational time on battery power alone.

The following is the log of events as recorded by the ASUSat team:

Jan 27 2000, 03:03:06 UTC:

Launch from VAFB 10 minutes ahead of schedule. The launch is visible from ASU. The rocket goes out of range by the time the third stage fires. Due to the time delay in obtaining rocket telemetry from the Air-Force's remote tracking station, all payloads are requested to report any sighting of the satellites.

Jan 27 2000, 04:00:00 UTC, Orbit 1:

Paul Roos (ZS6HQ) from South Africa hears two 9600 baud bursts at exactly 2 minute intervals. Even though nothing was decoded, it matched the transmission pattern of ASUSat1. The Air Force was notified of the sighting.

Jan 27 2000, 04:46:00 UTC, Orbit 2:

The first pass at ASU was only 1 degree above the horizon. The team did not expect to receive anything but aimed the antennas towards the expected AOS anyway. After about 5 minutes, the team heard two strong squelch breaks, and a weak eye pattern appeared on the oscilloscope. Again, nothing was decoded, but the eye pattern gave everyone a good feeling. The team knew it was ASUSat1.

Jan 27 2000, 05:40:00 UTC, Orbit 2:

Niki Steenkamp and Dirk van der Merwe from the Sunsat team heard ASUSat1 over South Africa and decoded the first message. The message reported a satellite uptime of 02:20:39 and that receiver switching sequence has started. This confirmed that the satellite is up, running and awaiting command from the ground-station.

Jan 27 2000, 07:19:00 UTC, Orbit 3:

The SunSat team heard ASUSat1 for the second time and decoded several more frames. This time three frames were captured. The first is an uptime identification frame. The satellite reported an uptime of 03:56:09 with an "Arizona State University Satellite". The second frame was a telemetry frame. The third frame was a text beacon announcing that the satellite is using WISP compatible telemetry. This reception was great. The sequence of frames was as expected.

Upon analysis of the telemetry frame, a concerning discovery was made. The telemetry byte showing charge level was indicating the solar array is not charging. A quick observation of battery voltage indicated it was a bit on the low side. A quick discussion amongst the team came up with the following assumption.

The charging current sensors suffered from some problems during integration. A blow out of the sensor was possible. Since battery voltage was not critically low, it wasn't possible to assume lack of charge at a high confidence level. Just in case, the team decided to reduce beacon rate upon AOS in order to enable the satellite to charge better.

Jan 27 2000, 08:25:00 UTC, Orbit 4:

Ian Ashley (ZL1AOX) from New-Zealand received and decoded an uptime message. The uptime message reported an uptime of 05:10:57 and indicated the start of the receiver switching sequence. The satellite was working as expected.

Jan 27 2000, 12:33:54 UTC, Orbit 7:

First pass at ASU – a 17 degree pass. A strong carrier was heard right on AOS – no modulation detected. An uplink was established within a few minutes on the ASUSat command frequency. The unmodulated downlink was a surprise. All reports up to this point indicated a 9600-baud signal was heard. At this point we could not estimate what was the cause of this. After quick consultation the command team decided to try to warm up the transmitter. The PTT-Hold command was sent and the transmitter was keyed for 5 minutes. The warm-up procedure did not have any affect on the transmitter. Just before LOS a command was sent to decrease all beacons to once every 10 minutes.

Jan 27 2000, 12:40:00 UTC, Orbit 7:

Concurrently, Randy Kohwley (N7SFI) reported monitoring an unmodulated carrier from ASUSat1. Randy was monitoring from Lompoc, California.

Jan 27 2000, 12:42:00 UTC, Orbit 7:

Steve Diggs (W4EPI) heard a strong carrier, with no modulation over Atlanta, GA. Steve was listening to our attempts to communicate with ASUSat1. Steve reported the carrier to be strong S5 and also reported some slow cyclic fading.

Jan 27 2000, 14:12:52 UTC, Orbit 8:

Second pass at ASU – a 25 degree pass. The satellite showed up as expected on AOS. The carrier was still unmodulated. At this point, the command team decided to perform a system reset in order to try and resolve the anomaly. The reset code was sent, and the satellite was reset as expected. Just before LOS, a clean eye pattern appeared on the scope. The 2W downlink was received very well.

Jan 27 2000, 16:48:52 UTC, Orbit 9:

A third frame was received and decoded by the SunSat team. The frame reports an uptime of 02:39:19, which is a confirmation that the system was reset properly. An additional telemetry frame indicated that the battery voltage was lower than before. At this point the team began to fear that the initial concern regarding no charge has come true. Calculations show that with a full battery charge, the satellite should be able to operate on batteries only for about 15 hours. At this point, the satellite has been in orbit for almost 14 hours. Following this pass, ASUSat1 was not heard by any ground-station around the world.

Results

Even though the mission lifetime was much shorter than the team expected, the data obtained provided a lot of insight into the operation of the satellite.

Deployment

The deployment of ASUSat1 was controlled entirely by the launcher. The deployment occurred in three steps. In the first step, the rocket maneuvered to bring ASUSat1 to a nadir-pointing orientation. Once this was achieved, a signal was sent to initiate the deployment of the satellite's gravity-gradient boom and downlink antenna. Shortly after that, the main bolt-cutter was fired and the Marmon clamp holding the satellite securely in place pulled away and the satellite was deployed. The satellite was turned on by two microswitches, which activated upon physical separation from the deployment mechanism.

Proper deployment of the boom cannot be verified by means of telemetry, yet the downlink signal played an important role in constituting that the satellite was stable. The downlink signal was strong, stable with low cyclic fading. This fact suggested that the satellite wasn't tumbling, but gravity-gradient locked, with a very low wobble around the stable point. In addition, a strong downlink could not have been possible if the downlink antenna wouldn't have been deployed. It is therefore a safe assumption that all the elements of deployment took place successfully as expected.

Telemetry

The operation of ASUSat1 after power-up was in safe mode, and controlled by the bootloader. In safe mode, the satellite turned off all non-critical subsystems of the satellite, and awaited command from the ground station. Periodically, it transmitted telemetry and status beacons to help with tracking and analysis. This mode proved to be of extreme importance in this mission. The ability to have multiple ground stations collect data in a non-intrusive mode was a great mode of operation.

System Mode Switches

The system mode switches gave the operators a quick summary of the power settings of all payloads, and the communications system. The power settings were all set to safe mode. Later, this was verified by actual voltage and current readings. The two receivers were constantly switched into one modem. Again, the switching pattern indicated that the computer was behaving as expected.

Thermal

One of the challenges on ASUSat1 was thermal management with the carbon composite structure. In order to verify the thermal models, 22 thermal sensors were mounted in various locations. The telemetry suggested that the initial temperatures were within the design limits. The maximum external temperature was 30C, and the internal temperature was a minimum of 10C. This suggested a nominal environment for satellite operation. Even though the team did not get to monitor the steady-state conditions, this was satisfactory.

Sun Earth sensors

The Sun/Earth sensors required extensive offline analysis, and a special operations mode was required in order to sample them properly. The telemetry data included samples that were well below the ideal sampling rate. This was designed to enable operators to do a simple test of the sensors.

The data received from the sensors was not enough to make any firm conclusions as to the exact orientation of the satellite. With that, the top and bottom sensors appeared to give values which were consistent with proper satellite orientation (nadir pointing).

Power Consumption

Five monitoring points gave a picture of current consumption by the various subsystems. The first four indicated current consumption, which was verified during integration. All the subsystems were operating nominally. The last telemetry channel was the battery-charging indicator. The indicator read zero charging in all the telemetry frames. This is the channel that initially got the operators' attention, and signaled that something was wrong. Later this would be verified with the battery voltage.

In addition to the current monitors, the system had 11 voltage monitors. The voltages were verified with the system mode switches and found to match.

The operation of the DC/DC converters which power the regulated 5V bus met the tight design tolerance. The battery voltage was used to monitor and verify the charging problem. Between the first and last telemetry frames the battery voltage dropped from 7.36V to 7.02V. The nominal battery voltage of the pack was 7.2V.

Communications

The digital communications system was the key to communications with the satellite. The downlink signal was reported to be strong and clear during the lifetime of the satellite. Several stations world-wide reported hearing the periodic beacon of the satellite. The ASUSat ground-station established command and control over the satellite. Some anomaly occurred in the downlink, yet it was quickly resolved by the team. Down the line, a more in depth investigation would have been conducted in order to determine the cause of the anomaly. With that, the problem resolution indicated that it was not a critical issue.

Flight Computer

The flight computer was the heart of ASUSat1. The computer controlled all of the functions of the satellite. Throughout the mission lifetime the data suggested that all of the components of the computer operated flawlessly.

Dynamics Board

All of the sensors sampling took place by the dynamics board. The board included a sophisticated software controlled variable gain, variable bias 128 channel analog to digital conversion system. The system performed as expected, with no apparent problems.

GPS, Cameras, Fluid Damper & Ham Radio Repeater

Unfortunately, all of the experiments on the satellite never got a chance to be tested. All of the experiments required a multitasking operating system to be uploaded to the satellite. The commissioning of the experiments was expected to take place in the second and third phase of satellite operation, in the month after launch.

Failure Analysis

Following the on-orbit failure of ASUSat1, a formal investigation was done. The possible failure modes were recognized and plausible causes were considered.

Launch Environment

The first big question concerned the launch environment and whether it was within the specifications provided by the launch provider (Orbital Sciences). ASUSat1 was designed and tested to withstand the Minotaur launch to acceptable industry standards. Using data provided post launch, the launch environment was determined to be within the envelope specified by Orbital Sciences. This ruled out any damage to the satellite by the launcher.

Fault Analysis Tree

The fault analysis tree is shown in Figure 16. The starting point for the analysis was the fact that the satellite failed about 14 hours after launch. Supporting evidence included the facts that the charge indication was reading zero current, and battery voltage was dropping. Payload failure was ruled out since the telemetry indicated that all the payloads were operating within the design envelope. Two main faults were identified. The first was that the current sensor failed and essentially cut-off power to the system. This is not likely, due to the fact that the sensor read zero. In the case of sensor failure, it is most likely that the reading would have been saturated.

The more likely answer is in the tree branch from the "no-charge from array" box. All of the possible scenarios that could have led to no charge from the array are indicated. Due to the little amount of telemetry available, non-of the failure modes can be pointed to as a "smoking gun", and the real reason will never be known.

During the fault analysis process, the team did stumble upon a systems failure in the integration process. Throughout the integration and qualification process, the satellite was run through tests which verified all the critical components of the satellite. Due to the lack of a mobile test fixture, the team was not able to do a full illumination test on the solar array after it was integrated onto the satellite. Even though the arrays were tested before final integration, and just prior to final closeout, after the array was plugged in, a functional test was not performed.

The team recognizes that on the system level this possibly could have mitigated the satellite's on-orbit failure.

Summary

ASUSat1 was all about engineering challenges. The initial design requirements were considered by many to be next to impossible. In 1993, nanosatellites were not considered to be viable spacecraft for any serious mission. ASUSat1 proved that even nanosatellites can be prospective candidates for science and communications missions.

ASUSat1 integrated a never-seen-before number of experiments into a 6-kg package. As a matter of fact, the team is not aware of any satellite that has achieved so much per unit mass.

The short on-orbit lifetime was a great disappointment to the team, but by no means is this project a failure. The experience gained from the design, construction, integration, operation, and failure is enormous. This experience is the baseline of the ASUSat program's ongoing and future projects.

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ASUSat1 has been granted the designation AO-37 (ASUSat OSCAR-37) by AMSAT-NA. OSCAR numbers are issued by AMSAT-NA, and is a long lasting tradition recognizing the achievement of various amateur-satellite groups since the first Amateur Radio Satellite beginning with OSCAR-1 in 1961. In order to qualify for an OSCAR designation, certain specified criteria must be met, including the provision of communication resources for the general amateur radio community and/or the conduct of technical investigations in all respects consistent with the Radio Regulations.

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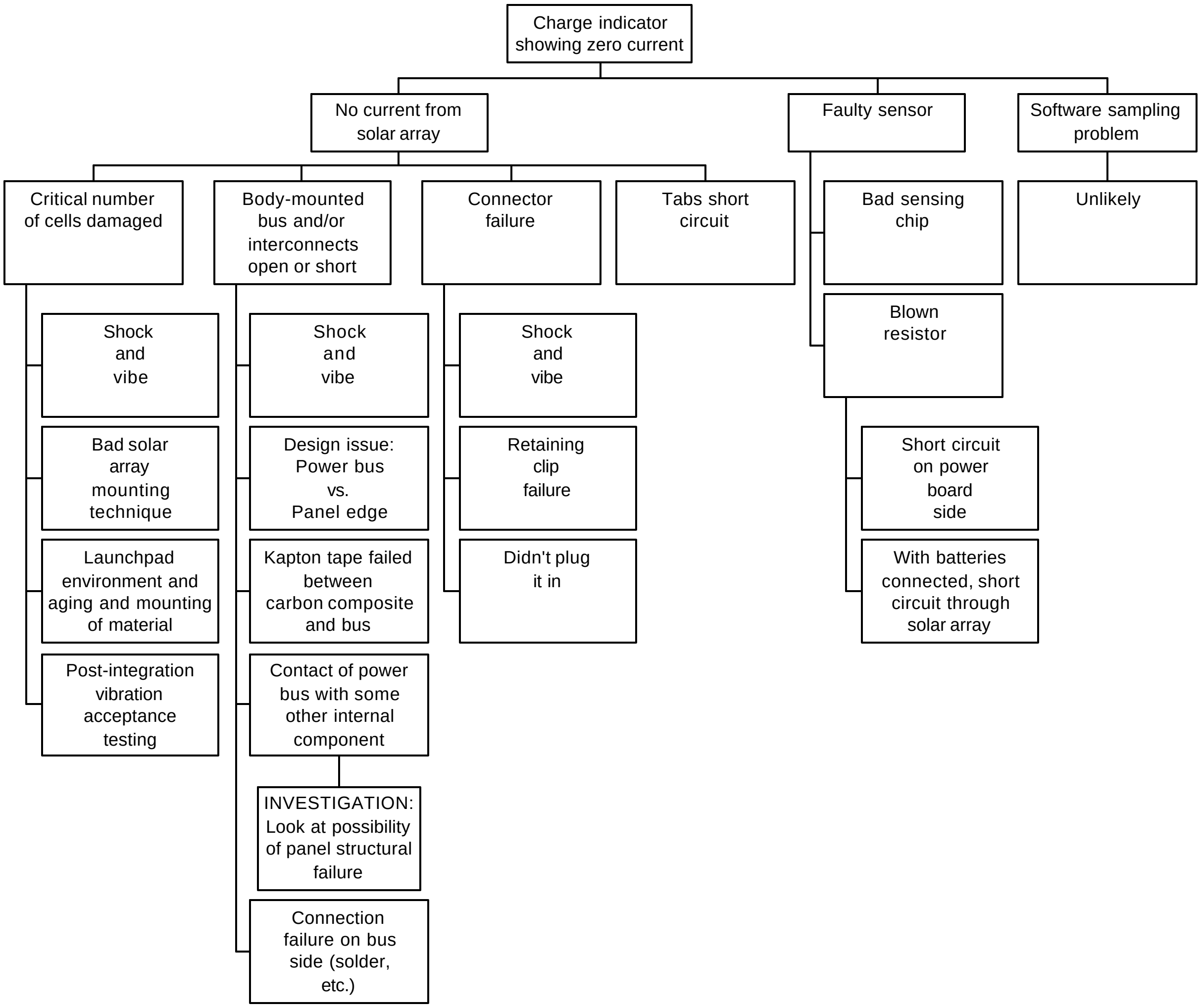

Figure 16. Fault tree analysis

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