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FedSat Launch and Operations

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Abstract. Australia's first satellite in more than 30 years, FedSat, was successfully launched on a Japanese rocket on the 14th December 2002. Eleven hours later it was acquired by the ground station in Adelaide on its first pass, and operations began. Within four weeks the 2.5 metre long boom, holding the sensitive magnetometer of the University of Newcastle, was deployed, and immediately started recording scientific data. The GPS instrument operated successfully from the beginning, as did the Star Camera. By the end of February the system operations were refined, and all payloads officially commissioned. Scientific operations were begun on 3 March 2003, and have continued to the present.

This paper presents the story of the launch and early operations of FedSat - a significant achievement for Australian engineering.

Introduction

The FedSat satellite was built by the Cooperative Research Centre for Satellite Systems (CRCSS) – a consortium of universities, the Commonwealth Science and Industry Research Organisation (CSIRO) and industrial partners VIPAC Engineers & Scientists Ltd, and AUSPACE Ltd. Originally slated for launch in 2000, it was launched on 14 December 2002, as a donated piggy-back ride to the NASDA ADEOS 2 earth-resources satellite. The major goals of the FedSat mission were to demonstrate Australia's capability to design, build and operate a small satellite. These goals have been met beyond all hopes, and the project is a resounding success. Already FedSat has lasted longer than the previous two Australian satellites put together; it is the first micro-satellite with Ka-band capability; and the first to demonstrate the capabilities of a self-healing computer. A related goal, to grow the Australian space industry, is one we are still striving for.

Another major aim of the project was education, both with regards to scientific applications, and in training young engineers in the exciting high technology field of space engineering. During the course of the project up to 10 students were involved in engineering the satellite, and a further 60 postgraduate students were involved in academic research. Already 21 students who worked on FedSat have graduated, with 16 PhDs, 3 MEng's and 2 MSc's.

The other main goal of the project was scientific research. So far about 220 academic papers have been written based on FedSat, with still the major portion of the data to be acquired from the mission. The project has resulted in adoption of FedSat components on other satellites (the UHF communications packages, ADAM 2 and 3, will be flown on KITSAT4 and X-Sat, respectively), and there are real prospects for additional exploitation of FedSat space hardware as well as ground segment modules. The primary ground station is currently supporting the CHIPSAT mission as well as FedSat.

This paper concentrates on the operations of FedSat from launch up until June 2003.

The Satellite Design

Several of the technical team were experienced with building large satellites in Europe, so it was decided to follow the European conventions in designing the satellite, and later in assembly, integration and testing. The latter, however, were constrained by the requirements of the launch authority, NASDA. As a result of this process it was possible to address all criteria followed by larger satellites, and choose those that were important to a low budget small satellite like ours.

FedSat[1] (see Figure 1) is a 50cm cubic scientific experimental satellite, with a mass of 60kg. It uses S-band communications with data rates of 4kbits/sec uplink, and 250—1000kbits/sec downlink. Power is provided by solar cells mounted on four of the outer surfaces and a Nickel Cadmium battery in two separate packs. Three-axis attitude control is achieved using reaction-wheels, based on a magnetometer and a set of sun-sensors, with magnetorquers providing continuous desaturation to the wheels. Overall control is maintained using dual redundant ERC-32 processors. This redundancy was important for such a critical subsystem, but it was a rare exception to the rule that no redundancy could be afforded in terms of cost, mass, volume and complexity.

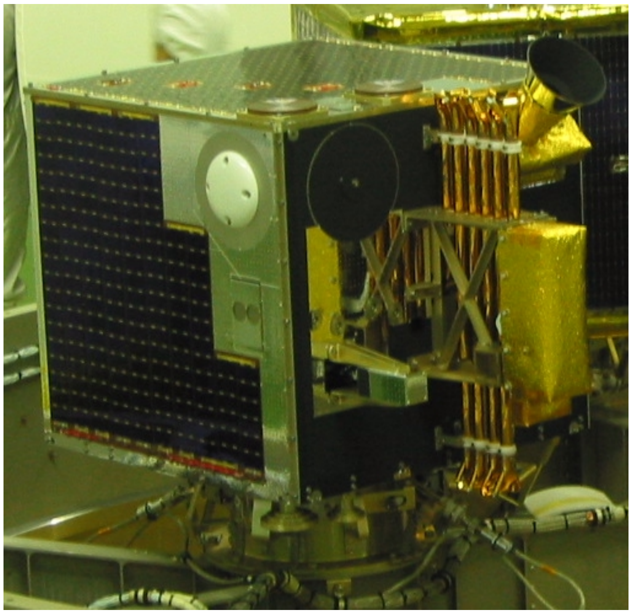


Figure 1 FedSat on Adapter Ring

(photo: A. Bish)

The satellite was launched into near sun-synchronous orbit, with an altitude of 800kms, and an Adelaide ground-station pass time of around 10:30am local time. The successful launch was particularly satisfying for the Australian engineering team that built the satellite, as they had been charged with the difficult task of taking over from the English contractor, SIL (Space Innovations Limited), after they went into receivership half way through the programme. Lack of documentation and inconsistent workmanship made the task of the engineering team especially onerous. Only through dedication and long hours of work for weeks and months on end, was it possible for the small team to overcome all difficulties and satisfy launch schedule, budget constraints and interface requirements leading up to launch. In the end the cost for design, build and operating FedSat ran to AUD 22M.

The Payloads

FedSat carries on-board six major experimental payloads (see Figure 2):

- The UHF Communications Experiment was developed and built by ITR (Institute for Telecommunications Research) at the University of South Australia. It includes equipment to study store and forward, new coding methods, and several other applications.
- The Ka-band Communications Experiment was developed and built by CTIP (CSIRO Telecommunications & Industrial Physics). It includes equipment to study the transmission characteristics of Ka-band frequencies, and the operations of new hardware equipment under space conditions.
- The NewMag Experiment was developed by the University of Newcastle, in collaboration with UCLA (University of California Los Angeles). It comprises a three-axis fluxgate magnetometer mounted on the end of a 2.5m boom, and is intended for studying the dynamics of the Earth's magnetic field.
- The GPS (Global Positioning System) experiment was developed by the Queensland University of Technology, based on a BlackJack GPS receiver built by the American firm *Spectrum Astro* with NASA funding. There is a single aft-pointing GPS antenna. Experiments are designed for precise

navigation, timing and applications to atmospheric physics.

- The High Performance Computing Experiment (HPCE) was developed by the Queensland University of Technology, in conjunction with Johns Hopkins University, and with funding support from NASA. It is designed for studying computing performance and error correction in reconfigurable arrays in the space environment.
- The Star Camera was purchased from the University of Stellenbosch. The instrument allows retrieval of precise pointing information in support of the NewMag experimental programme.

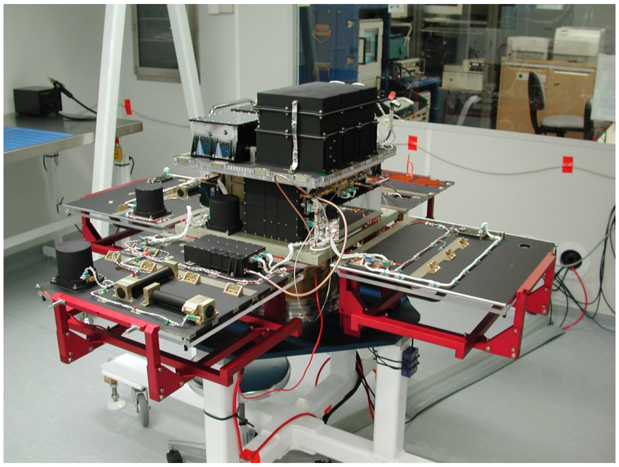


Figure 2 FedSat Internals *(photo: C. Todd)*

The Platform

The design of the satellite structure is based around six honeycomb outer panels, with an interior shelf dividing the platform equipment attached to the base-plate, from the payloads in the upper chamber (see Figure 2). The platform sub-elements are used as load bearing parts of the primary structure. This minimises the mass while efficiently utilising the available volume. The structural load is transmitted directly through the base-plate to the platform equipment, and on through the payload equipment, creating a very rigid structure. This rigidity led to problems later when launch vibrations were found to be larger than expected (see section on Assembly, Integration and Test).

The internal volume available to the payload electronics was generous, and imposed no significant constraints on their design. However, mounting constraints on the external faces of the satellite were more severe, and ruled out several higher performance antennae options for the payload experiments.

Two S-band patch antennas (receive and transmit), and the communications payload antennas (UHF quarter-wave bent-whip, and Ka-band isoflux horns) are mounted on the nadir face. Two other S-band antennas (for communicating with the satellite when upside-down) are accommodated on the zenith face.

Software

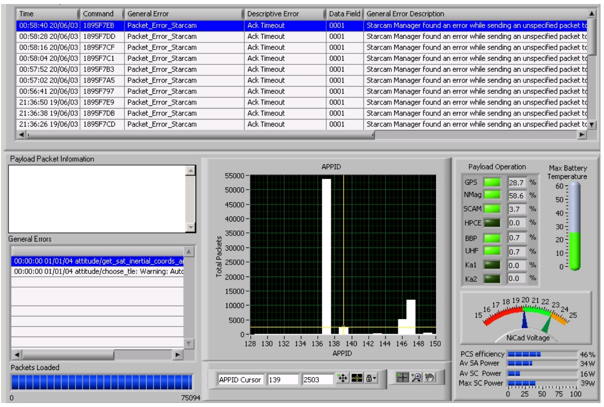
Control software for the satellite was based on the language ADA (named after Lady Ada Lovelace, daughter of Lord Byron and the world's first programmer). This is a structured language, providing a strict framework for writing code, and incorporating user-friendly comments. Work on the code was shared between CRCSS engineers, and staff from the Canberra based company *Software Improvements*. The conventions for communicating with the satellite were based on the European Space Agency PUS (Packet Utilisation Standard) Database.

The Ground Station

The Ground Station for FedSat was set up at ITR (Institute for Telecommunications Research) at the University of South Australia in Adelaide. The 3-metre dish purchased from the CSIRO was mounted on the roof of the facility. The telemetry down-converter and variable rate demodulator were supplied by SIL, and an AVTEC provides the packetiser / de-packetiser function.

Operations Control Centre (OCC) software was originally intended to be based on an *Integral* turn-key system, purchased from the US, but this turned out to be inappropriate to the system design. In the end we wrote the software from scratch. Visual Basic, as the only language that students were all familiar with, was chosen for writing the software. The task was a little more difficult than first thought, but basic functionality was achieved before launch.

A separate programme was written to acquire telemetry, and display it. This package, called Telemon (see Figure 3), was based on LabView. After launch Telemon was improved and took over several functions of the OCC software.



Time	Command	General Error	Descriptive Error	Data Field	General Error Description
00:58:40 20/06/03	1895F7EB	Packet_Error_Starcam	Ack Timeout	0001	Starcam Manager found an error while sending an unspecified packet t
00:58:28 20/06/03	1895F7DD	Packet_Error_Starcam	Ack Timeout	0001	Starcam Manager found an error while sending an unspecified packet t
00:58:16 20/06/03	1895F7CF	Packet_Error_Starcam	Ack Timeout	0001	Starcam Manager found an error while sending an unspecified packet t
00:58:04 20/06/03	1895F7C1	Packet_Error_Starcam	Ack Timeout	0001	Starcam Manager found an error while sending an unspecified packet t
00:57:52 20/06/03	1895F7B3	Packet_Error_Starcam	Ack Timeout	0001	Starcam Manager found an error while sending an unspecified packet t
00:57:02 20/06/03	1895F7A5	Packet_Error_Starcam	Ack Timeout	0001	Starcam Manager found an error while sending an unspecified packet t
00:56:41 20/06/03	1895F797	Packet_Error_Starcam	Ack Timeout	0001	Starcam Manager found an error while sending an unspecified packet t
21:36:50 19/06/03	1895F7E9	Packet_Error_Starcam	Ack Timeout	0001	Starcam Manager found an error while sending an unspecified packet t
21:36:38 19/06/03	1895F7DB	Packet_Error_Starcam	Ack Timeout	0001	Starcam Manager found an error while sending an unspecified packet t
21:36:26 19/06/03	1895F7CD	Packet_Error_Starcam	Ack Timeout	0001	Starcam Manager found an error while sending an unspecified packet t

General Errors

```
00:00:00 01/01/04 attitude/get_sat_inertial_coords_a
00:00:00 01/01/04 attitude/choose_tle: Warning: Aut
```

Payload Operation		
GPS	28.7	%
NMag	58.6	%
SCAM	3.7	%
HPCE	0.0	%
BBP	0.7	%
UHF	0.7	%
Ka1	0.0	%
Ka2	0.0	%

APPID Cursor 139 2503

PCS efficiency	46 %
Av SA Power	34 W
Av SC Power	16 W
Max SC Power	39 W

Figure 3 Telemon status display. Top panel shows error packets; middle panel is a bar chart of the number of packets received from different stores; green lights show which payloads operated; the thermometer to the right shows maximum battery temperature; and the gauge at bottom right shows the limits of battery voltage.

Assembly Integration and Test

The satellite was assembled in the clean-room at Auspace in Canberra. The core team included about six people for much of the time, with the help of several students. However, after some postponements of the launch date, the number of core personnel dropped to about four up until packaging for transport, with three engineers following the satellite to Japan for the launch campaign.

Stringent vibration tests were carried out at VIPAC's Melbourne facilities, ensuring compliance with the launch authority safety criteria. When the vibration loads of the new NASDA HIIA rocket were characterised properly, it was found that the levels were beyond those acceptable for the equipment designs we had chosen. This necessitated a quick redesign of the launcher junction ring to incorporate an effective anti-vibration system.

Plans were made to carry out thermal vacuum testing in a refurbished vacuum chamber at Auspace. However, it was at a lower priority to solving the engineering problems that occurred up to the last minute, and to testing the system. In the event there was not sufficient time left at the end to carry out thermal vacuum testing.

The Launch

The engineering team were given every assistance in Japan by NASDA staff, and their friendliness made the experience one to remember. The launch went ahead on schedule (see Figure 4).

Figure 4 The Launch of FedSat aboard NASDA's HII-A F4[2]

In Japan the engineering team, NASDA officials and dignitaries monitored the events from ground-based cameras as well as telemetry from the second stage. Video footage of the separation of FedSat was acquired in Japan, and passed on to Australia as soon as possible (see Figure 5). The key observation was the timing of the rotation rate at 4 degrees per second. This was excellent news since we had expected some 12 degrees per second, with an upper limit of up to 35 degrees per second (feared to be beyond the attitude control system's capabilities).

Figure 5 FedSat separation[2]

In Australia a cocktail party was called to watch the launch on a projected Internet feed at ITR. TV crews, engineers and families milled around enjoying the atmosphere. Each major event—launch; first stage cut-out; first stage separation etc—was ticked off, until separation of FedSat was confirmed. At that point a separation switch activated itself and turned on power to essential satellite equipment – the Power Conditioning System (PCS) itself; the Data Handling System (DHS) and the S-band receiver.

The next major event for Australia was the first pass of the Adelaide ground station 11 hours after launch — in the middle of the night. For many months the engineering team had been sweating over whether the orbit parameters would be accurate enough to pick up FedSat with the 3-degree beam width of the ground antenna. We worried whether there would be sufficient power for FedSat while it was tumbling; whether the tumble rate would be too great for us to contain; what we would do if we couldn't contact FedSat; whether we should set up a second ground station to try and pick up FedSat earlier. Initial orbital parameters were given to us by NASDA soon after launch, but they were unable to follow it after the first orbit. We had great help from the North American Aerospace Defence Command – NORAD, who supplied us with urgent updates of the orbital parameters as they became available. Also the laser-tracking group – EOS (Electro Optic Systems Pty Ltd) – gave us their utmost assistance.

When the time came for the first pass we were armed with the latest NORAD Two Line Elements (TLEs) and bottles of champagne (just in case). TV crews recorded every detail as we searched for FedSat. Conversation faded to nothing, and all we could hear was '*Elevation 10 degrees*' or '*Two minutes into pass*'. No response. We started searching around the most probable position – '*moving 5 degrees ahead*'; '*moving 5 degrees behind*'. Still nothing, and we were half way through the pass with the elevation was starting to decline. One of the team noticed that the RF transmitter was switched off. It had been on at the beginning, but for some strange reason had switched itself off during the pass. We switched it on and returned to the most probable position. Within seconds we made contact with FedSat – with just three minutes of the pass left to go. A cheer went up, and we started sending up stacks of commands to download housekeeping data of FedSat's exploits up to that time. It was tumbling by half a turn every 45 seconds, and we had to switch the transmitter from top to bottom antenna, and back again.

By the time the pass ended we had confirmed the tumble rate, and had a fair idea of the condition of the satellite. The telemetry was working correctly (see Figure 6), power in the battery was good, and it was running hot. The battery really was hot, up in the high thirties, when we had expected something in the twenties. This represented a threat to the mission since the batteries would degrade at high temperatures, and it was one of the first things we needed to correct. Interestingly, and inexplicably, the battery temperature increased as the battery discharged, and decreased as it charged.

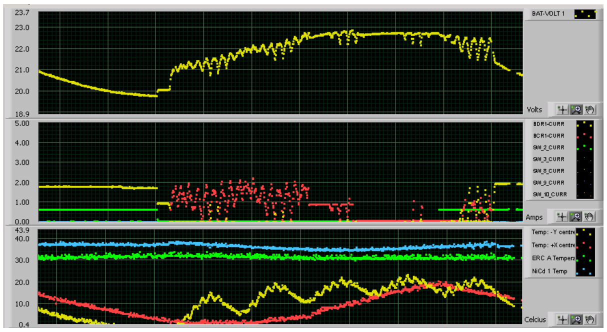


Figure 6 Telemetry from the first pass. Top panel shows battery voltage, and the top trace of the bottom panel shows battery temperature.

Nevertheless, at the end of the pass, the champagne flowed, and silly chatter followed the release of tension. After that it was down to a routine – two morning passes, and two night passes.

Early Operations

A temporary solution to the hot battery problem was to switch on NewMag, somewhat in advance of our intended commissioning of the payload. This drew about 4 Watts, and helped to keep the temperature down. It also showed that NewMag was operating correctly. A more lasting solution to the hot battery problem was to lower the final charge level of the batteries.

Tests of the attitude magnetometer and the magnetorquers proved that these were also working correctly, and we could go ahead and test the detumble mode (see Figure 7). This involved commanding the use of autonomous software to actuate the magnetorquers at the appropriate times to slow down the rotation rate, based on feedback from the magnetometer. In order to guard against the possibility of a malfunction in the detumble mode; commands were backed up with counter commands to switch off the mode at a later time. Once the mode was fully checked out, detumble was left on to reduce the tumble rate down to less than 1 degree per second.

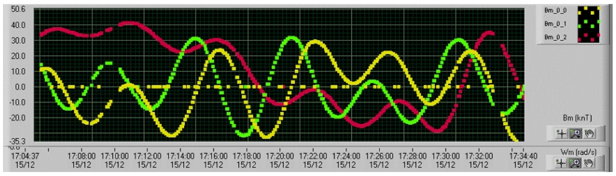


Figure 7 Magnetic field measurements (in kilo-nano-Tesla) in 3-axes over 30 minutes during first tests of Detumble

The next step was to test all aspects of the attitude control system. This involved functional tests of the digital sun-sensors, reaction wheels and rate sensors. The digital sun-sensors were simply switched on, and we observed a response depending on which ones were facing the sun. The reaction wheels were tested at ±10 radians per second, and the response observed on the rate sensors. Finally we switched into 3-axis pointing mode for a limited time to check correct operation. We learned that the time to acquire stable acquisition of pointing from a tumbling situation was up to two orbits, or about 3 hours. On the other hand, simply slewing from one pointing position to another took about 12 minutes.

Permanent Pointing Mode was initiated on 30 December 2002, two weeks after launch. By this time we were convinced that the satellite was safe, and we could relax the demanding schedule of attending both night and day passes. From that point night passes were only attended when there was an urgent need.

As can be seen from Figure 8, the typical pointing error displays excursions of ±10 degrees in each axis once every orbit. These were modelled by CRCSS engineers before launch and it was sincerely hoped that they were just a glitch in the model, rather than the pointing algorithm. As it turned out the glitches were real, and were related to the lining up of the sun-vector with the magnetic-vector. As a consequence of this the NewMag measurements were somewhat upset.

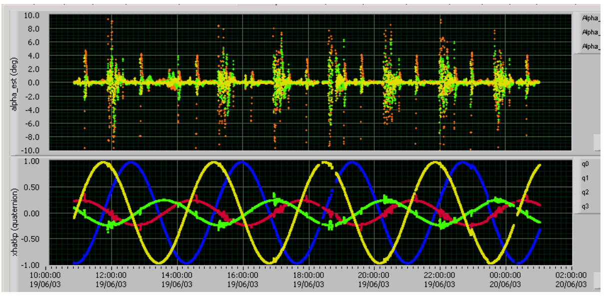


Figure 8 Typical pointing response. The top panel shows the estimated error in pointing over nearly 14 hours, and ±10 degrees in each axis. The bottom panel shows the quaternions for that period.

Once pointing was initiated, the engineering team in collaboration with Dynacon in Canada tried to characterise the pointing algorithm and fix the pointing excursions before the extra complication of boom deployment. For the next two weeks work progressed on testing control software, subsystems, and each of the payloads to prove their functionality. This was necessary for two reasons: firstly to check out the system while key members of the engineering team were still present; and secondly to prove functionality in case the satellite was lost prematurely.

During this period the large-file upload and download functions were tested using configuration files for the HPCE payload. These functions included packet checking, and capabilities to resend missing packets.

All downlink rates: 250; 500 and 1000 kbits per second; were tested routinely. The most appropriate rate was selected depending on volume of data to download, and the quality of data downloaded. At the higher data-rates, the link-margin was lower, and the number packet losses was higher. For normal downloads there is no facility for retrieving lost packets besides requesting the packets a second time. This was critical for NewMag data since each packet held critical scientific data, so NewMag data was routinely requested twice per pass, and the 500 kbit/sec data rate was settled on for routine operations.

The GPS payload functioned correctly, and started returning position data some twelve minutes after switch-on. In order to gain sufficient data in a pass for calculating orbital position, the GPS was switched on for 30 minutes once per orbit, rather than for two 20 minute periods per orbit as originally planned.

Star Camera was tested out, and after some adjustments to the operating parameters, it returned good images of star fields, as well as centroiding of star positions. Once on-board centroiding was shown to work, it was possible to download accurate pointing data from just a few packets each orbit.

The UHF communications package was turned on successfully, and a signal was detected at the UHF-ground station at ITR in Adelaide.

At last, after a dummy run of the command stack, the boom was deployed on 13 January 2003. The boom, purchased from the University of Stellenbosch, was the same model as they had deployed on SunSat in 1999.

In order to characterise the performance of NewMag, the payload was switched on over the critical period of boom deployment. Just before extension of the boom, commands were sent to exercise the magnetorquers at full power in both directions for each axis. Figure 9 shows how the measurements of the magnetic field varied in step with the magnetorquers excursions prior to boom extension. The chaotic region of the trace covers the extension of the boom over a period of just 10 seconds, finishing off with a decaying wave response reflecting resonant mechanical vibrations after extension.

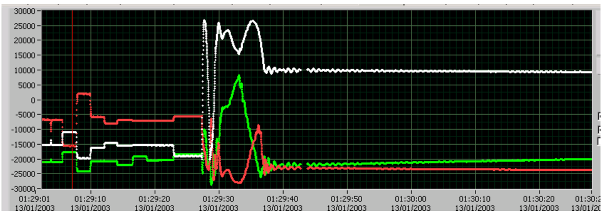


Figure 9 Magnetic field measurements during boom deployment, over a period of one minute

Immediately after boom extension the variations in power to the magnetorquers were repeated, and no trace of their fields were seen from NewMag measurements. This conclusively proved that boom extension had been carried out successfully. Later measurements showed that the magnetorquer fields did affect NewMag measurements at the tens of nano-tesla level, and desaturation of the wheels was switched off in the scientifically important regions over the Earth's Poles.

The extension of the boom represented for us the completion of the first stage of operations.

Payload Commissioning Operations

Operations continued over the next five months using some payloads on a routine basis, while others were gradually commissioned. Commissioning was officially completed on 3 March 2003, when all payloads had been operated with some level of success. However, progress was still being made with several payloads as this paper went to press in June 2003.

NewMag

After boom extension put NewMag out of range of most on-board magnetic interference, the data returned from the payload became scientifically valuable. This was just in time for a collaborative experiment with Davis Station in Antarctica. For this reason, special attention was given to NewMag to ensure as much data as possible was gathered during the critical time period.

Typical NewMag data is shown in Figure 10, where each axis is displayed separately over a period of about 100 seconds. Structure on the scale of 100s nano-tesla, are due to variations in the field aligned currents at the Pole.

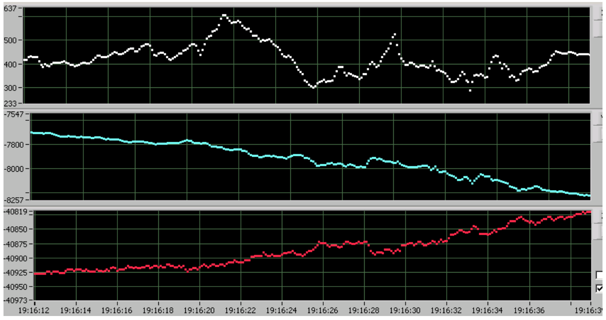
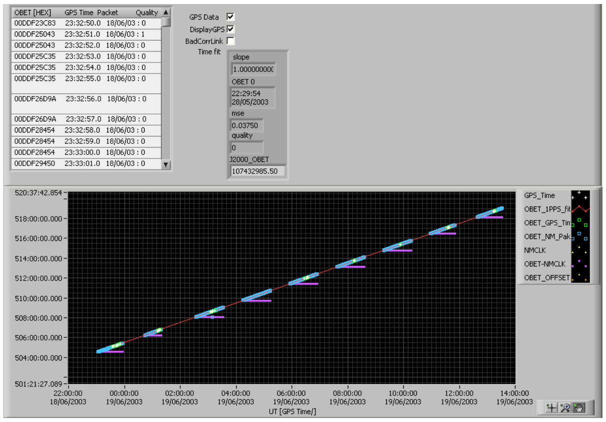


Figure 10 NewMag data

GPS

Figure 11 shows typical time correlation data derived from GPS. These are used to update the synchronisation of the on-board clock with UTC. Drift in the on-board clock was determined to be of order 2 seconds per week. Occasionally the on-board clock would reset back to zero, and a rough time-update had to be determined based on the time stamps on housekeeping packets. This was good enough for pointing purposes, and usually correct to within about 20 seconds.



OBET [HEX]	GPS Time Packet	Quality
00DDF23C83	23:32:50.0 18/06/03 : 0	
00DDF25043	23:32:51.0 18/06/03 : 1	
00DDF25043	23:32:52.0 18/06/03 : 0	
00DDF25C35	23:32:53.0 18/06/03 : 0	
00DDF25C35	23:32:54.0 18/06/03 : 0	
00DDF25C35	23:32:55.0 18/06/03 : 0	
00DDF26D9A	23:32:56.0 18/06/03 : 0	
00DDF26D9A	23:32:57.0 18/06/03 : 0	
00DDF28454	23:32:58.0 18/06/03 : 0	
00DDF28454	23:32:59.0 18/06/03 : 0	
00DDF28454	23:33:00.0 18/06/03 : 0	
00DDF29450	23:33:01.0 18/06/03 : 0	

GPS Data ☑
DisplayGPS ☑
BadCorrLink ☐
Time fit
slope: 1.00000000C
OBET 0: 22:29:54 28/05/2003
mse: 0.03750
quality: 0
J2000_OBET: 107432985.50

Figure 11 Time correlation for the GPS data over 9 orbits

Analysis of GPS data show that the rms ranging errors for FedSat can be as low as 0.60m, but are typically about 50% greater than for other satellites having similar GPS receivers. This is believed to be due to FedSat using an aft-looking antenna, while the others (CHAMP, SAC-C and TOPEX/Poseidon) use upwards-pointing antennas.[3]

Star Camera

During routine operations Star Camera was scheduled each orbit to switch on and supply accurate pointing information for NewMag. The power-on command didn't always work correctly, so only about a third of the commands were successful. This phenomenon is still being investigated.

HPCE

The High Performance Computing Experiment (HPCE) was handicapped at first by initial difficulties with completing large file uploads before a DHS reset wiped the mass memory clean. When files were uploaded, another difficulty was ensuring long enough delays were programmed into the command stacks to ensure operations followed the proper sequence. Eventually we decided to move each uploaded file over from the mass memory to the payload FLASH memory as soon as possible. Once all four files belonging to one configuration were uploaded to FLASH, the experimental programme ran successfully.

Communications - UHF

After initial experiments showed that the UHF payload powered on correctly and could transmit beacon signals, it was found that the mode control did not always work according to plan. The logic was worked out over several weeks, but little more could be done until issues with the UHF ground station were solved. Once the ground station was fully operational the UHF beacon mode was commissioned successfully, and parts of the store and forward mode were tested.

One problem still outstanding with this payload is the random failure of some commands to execute, and this is still being investigated. Meanwhile, multiple versions of critical commands are sent up routinely.

We were, however, happy with the power capabilities of FedSat. Figure 12 shows typical power cycling. This was something we could not test on the ground, so it was of highest importance to see that all payloads, including the relatively power hungry communications packages, could operate without draining the battery too much.

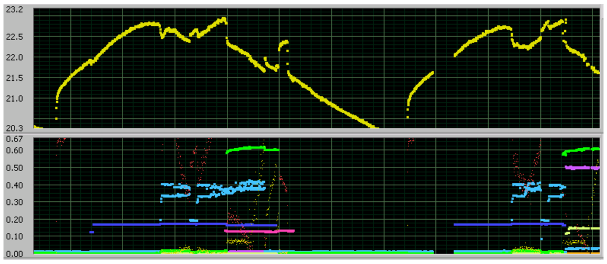


Figure 12 Typical power cycling including UHF payload switch on. The top panel shows battery voltage, and the bottom panel shows currents of various subsystems - GPS (light blue); NewMag (dark blue), Star Camera (pink); S-band Transmitter (green); and the UHF communications payload (purple and yellow).

Communications – Ka-Band

Initial command stacks to test the Ka-band caused havoc with the command system. This was due to two commands that weren't properly implemented in the flight software. As these commands were non-essential they were simply deleted from the standard set of commands.

Once payload telemetry indicated that all payload functions were operating correctly, nothing more could be done until commissioning of the Ka-band ground stations. The secondary ground station based at DSTO in Adelaide was the first to confirm reception of the Ka-band beacon signal. This was a major triumph, since the link-margin was low, and the beam width of the ground antenna small. DSTO relied on TLEs derived from the NORAD Internet site, so accuracy was an issue.

The primary Ka-band ground station erected at the University of Technology Sydney Kuringai campus used orbit predictions by QUT from GPS payload measurements. Unfortunately the process for deriving orbit predictions at QUT was not fully automated, so there was a significant effort required on their part to predict orbits in time for Ka-band ground passes in Sydney. Again, it was a significant triumph when the Ka-band beacon was picked up in Sydney, about a week after success in Adelaide.

Operations

Structure

The operations structure for FedSat is illustrated in Figure 13. At the top of the organisational structure are the CRCSS executive with responsibility for the whole programme, and the Research Panel with responsibility for the research priorities. Payload groups interact with the Research Panel to gain approval for the scientific aims. It is then up to the Mission Operations Manager to implement the research goals in the most efficient manner possible.

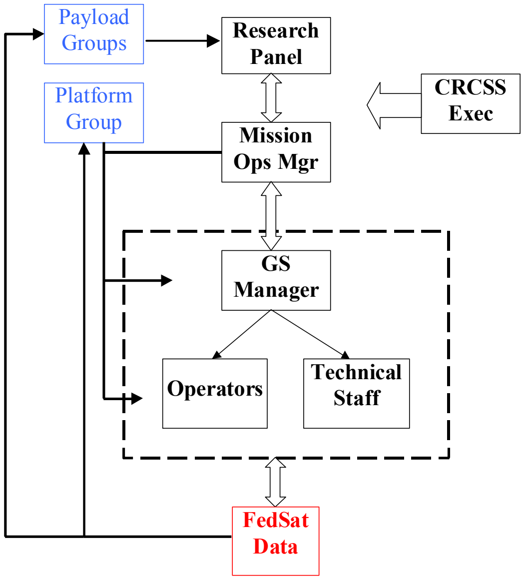


Figure 13 Operations structure

With no scheduling software, event optimisation software or automatic command checking software, most actions need to be carried out manually. This makes it important for all new stacks, and non-standard schedules to be signed off by the Mission Operations Manager personally. Normally a great reliance is placed on routine repeat operations of tested command stacks. Due to limited resources only a very small number of new developments or trouble-shooting can be carried out in a single week.

Once the stacks and schedule are approved for the pass, day or week, these are passed on to the Ground Station Manager and the operators. They have the responsibility to ensure the ground station operates correctly, with the help of technical backup, and send the appropriate commands to FedSat.

Feedback

Happy Things

- Although we sent all manner of bad commands to FedSat over the course of operations, and the satellite went through every conceivable malfunction, it always recovered robustly. One time an uplink error caused a reboot to fail and we were without control for several passes, and brown-outs occurred several times. When we regained control the power system operated better than ever. Another time we had the satellite spinning at 40 deg/sec or more, and were still able to recover pointing using the wheels, and the boom did not wrap itself around the satellite.
- On-board software worked with little requirement for modification. However, the few code uploads that were required went ahead faultlessly.
- The boom deployed faultlessly.
- Time-outs operated on all non-essential equipment to ensure they switched off even if their power-down command failed to operate.
- All payloads functioned correctly when valid commands were sent to them.
- The Ground Station command interface was more user friendly than initially feared, and became more so as further development took place.
- Staff and students performed selflessly, tirelessly, and worked wonders.
- The engineering team learned a lot from NASDA ground staff.
- The engineering and academic education outcomes were fantastic.

Things to Learn From

- Ground station hardware was not all made in-house, so it was difficult to modify equipment later when units malfunctioned during manufacture and test.
- Platform structure was not made in-house, so it was a hard to fix up later. Next time only specialist equipment will be procured over-seas.
- The platform structure was too rigid. Next time electronic component boards will be mounted vertically to the base-plate where possible.
- Although there were no bad consequences from missing out on thermal-vacuum tests, next time we would make sure the tests were carried out.
- Complete system testing at the end was all too brief. Many operations problems would have been picked up with a full three months of testing.
- Newly acquired engineering expertise needs to be retained with a follow-up programme.
- Management of the programme would have been easier if Requirements preceded Design.
- Brown-out consequences for all sub-systems need to be specified, rather than relying on independent voltage levels.

Conclusions

Over the past five years the CRCSS has shown that Australia does have the capabilities to build advanced technological equipment of space quality. Perhaps the hardest test was managing a project that was distributed across the length and breadth of Australia.

In order to benefit fully from the experience it is necessary to follow on from FedSat with a new initiative, with advanced capabilities and bringing new learning experiences. Steps are in hand to retain some of the expertise, and to go ahead with new ideas. Only the future will tell how successful we will be.

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