Progress Towards FedSat 2001 A'stralian Space Odyssey

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Abstract. In mid-1997, the Australian Government approved the setting up of a Cooperative Research Centre for Satellite Systems (CRCSS) to promote Australian space research. A key outcome of the research activities is intended to be the launching of a research satellite - FedSat- by the year 2001, the centenary year of Australian Federation. This will be the first Australian built satellite since 1970, and vital a step towards Australia's re-entry into the satellite business. This talk describes the aims of the FedSat mission; the design of the overall system; and provides up-to-date details of progress towards project completion.

Introduction

The FedSat satellite is, like its earlier sisters WRESAT and OSCAR V, a micro-satellite. However, with a mass of only 58 kilograms, she is packed with a selection of scientific payloads that are unusually complex for a nation stepping lightly back into space, after a break of three decades. On the one hand, technology has advanced to such a degree that small nations, like Australia, and many others in the South East Asian region, can contribute to the world body of knowledge on satellite and space applications, cheaply and simply. On the other hand, the task of managing this particular enterprise is formidable.

Neither the options of a turn-key contract, nor of building the whole system from scratch, have been taken. Instead, the CRCSS has opted to take the middle road – buying a platform from an experienced provider, with accompanying technology transfer, and building, assembling and testing the system themselves.

The task is hard enough for one central institution to carry out, with the lack of infrastructure and experience that prevails at such an early stage of a new industry. The FedSat programme is carried out by a host of industrial and university partners with little experience in working together, and with a variety of ideas on project management.

Fortunately, the very technology that allows complex experiments to be packed into a satellite the size of your microwave-oven, also allows the possibility for distributed management. Video- and tele-conferencing; instant written communication through email; exchange of data via the Internet: all these advances mean the task of communication between groups of people spread across the face of Australia; and sub-contractors and providers scattered around the world… are at least feasible.

The coordination centre is located in Canberra, at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Telecommunications and Industrial Physics office (CTIP), with overall responsibility for managing the CRCSS, and the FedSat project. Responsibility for managing the development of the payloads and the platform, fall to the two prime industrial partners of the CRCSS: Auspace Ltd in Canberra; and Vipac Engineers and Scientists Ltd in Adelaide.

Aims and Objectives

Scientific Objectives

The overall scientific aims of the project are to:

- Obtain pure and applied knowledge in the field of space science by carrying out experiments in space.
- Disseminate the knowledge throughout the research community, and pass it on to the education curricula.
- Take advantage of the applied science results by commercialisation of the products.

Engineering Objectives

The overall business strategy is to reduce the cost of space missions by designing and building robust and innovative satellite systems in Australia.

The engineering aims of the FedSat project are to:

Gain knowledge of small satellite technology through:

- Designing
- Developing
- Assembling, Integrating and Testing
- Commissioning

a small, innovative research satellite by the year 2001, in support of the scientific aims of the project.

The FedSat Mission

The FedSat satellite was intended to be a cubic 50Kg micro-satellite, with a 50cm sides. It was to orbit at high inclination at an altitude of around 800kms, with one face pointing towards the Earth.

Payloads were initially to have included:

- Both Fluxgate and Induction Coil Magnetometers mounted on a 3 meter boom, and supported by a star camera.
- Global Positioning System (GPS) dual frequency receiver, with multiple antennae.
- Communications package, with:
  - UHF/VHF store & forward
  - Base-band processing
  - L-band inter-satellite link
  - Ka-band mobile terminals
- High Performance Computing package servicing high data-rate payloads
- High efficiency Solar Cells experiment

The aims of the experiments were the following:

Communications: Test satellite-to-satellite communication; gain experience operating multi-satellite Low Earth Orbit constellations; test Ka-band down-link; carry out digital signal processing experiments in multi-media data transmission, two way paging, and remote area personal safety communications.

Space Science: use magnetometers to measure electrical currents and perturbations in the Earth's magnetic field.

Remote Sensing: GPS occultation experiments for atmospheric sounding.

Engineering Research: Space qualification of a new solar panel; new on-board processors; and a GPS receiver.

The payloads are to be mounted on a platform, providing the satellite structure, power and control facilities. This includes Tracking, Telemetry & Control (TT&C), as well as satellite attitude control.

Progress

Funding

The Australian Cooperative Research Centre (CRC) programme was designed to bring industry, government research agencies and academia together in joint projects of national significance. The level of funding contributed by the Commonwealth government is at a level of about one dollar, for every two dollars contributed by the partners. This makes it challenging to achieve the objectives of the programme, while staying within budget.

Launch

Another critical factor in any satellite project is the launch. In the case of FedSat this had far reaching consequences in respect of costs and schedule. The CRCSS, through CSIRO, is currently examining with the National Space Development Agency (NASDA) of Japan the prospects of launching FedSat as a piggy-back payload on an H-IIA launch from Tanegashima Space Center in southern Japan.

NASDA has reported to the Japanese Space Activities Commission on a proposal to supply a piggyback launch in exchange for scientific data from the mission. A final decision is expected in April 2000.

The proposed launch is scheduled for November 2000, with a sun-synchronous orbit, at an altitude of 800 kilometres, with an ascending node crossing time of 10:30 am.

The Platform

An executive decision was made early on to reduce the overall risk of the project by going to an external supplier for the satellite platform. After an open tendering process, the CRCSS chose a proposal from Space Innovations Limited (SIL), the UK subsidiary of San Diego-based SpaceDev, Inc. SIL's response to the request for proposal was judged to have the best technical fit with the requirements, as well as the best business case for future collaborative opportunities with the CRCSS. By this means it was hoped there would be greater degree of technology transfer, and a greater chance of achieving the major aims of the project.

Communications are secured using S-band receivers and transmitters – one antenna for each, on both top and bottom. These antennae feed their signals into, and take their signals out from the central Data Handling System (DHS). At the core of the DHS is an ERC-32 processor. This is responsible for all Tracking, Telemetry and Control (TT&C) of the spacecraft.

Attitude control is implemented by 3 precision reaction wheels, provided by the Canadian company Dynacon. These wheels were designed for astrometric quality pointing, greatly in excess of the requirements for the FedSat experiments. Desaturation of the wheels is achieved using 3 magnetotorquers.

Attitude knowledge, accurate to $\pm 2°$, is derived from a series of Sun-sensors, as well as a small 3-axis magnetometer. Indeed, at the last minute, before design was frozen, a star camera from the University of Stellenbosch was included. Unfortunately, at such a late stage, it was not possible to acquire the software necessary to use the star camera data in real time for determination of attitude. Instead, the data will be downloaded with the payload data, and precise attitude determined at the post-processing stage.

Power is derived from 19 strings of Gallium-Arsenide solar cells on Germanium substrates, distributed across the four faces of the cube that see the sun. These provide a maximum power of around 50W.

Backup power for eclipse operation is derived from dual redundant strings of Nickel-Cadmium rechargeable batteries. Power from the solar cells, in excess to operational requirements, is used to recharge the batteries in sunlight. Power in excess to these requirements is radiated away as heat.

The Payloads

As the project design advanced, different factors, in particular schedule and funding, but also the volume, power and mass budgets, contributed to significant descoping, and alterations from the original mission concepts. These included:

- Omission of the Induction Coil Magnetometer and the Star Camera on the end of the boom, and a reduction in length of the boom to 2.5 meters.
- The GPS receiver update rate was reduced from a maximum of 50Hz, down to 1Hz. The number of GPS antennae also had to be reduced from four or more, down to just one single antenna.
- UHF/VHF store and forward was changed to just a UHF capability.
- The L-band intersatellite link was dropped altogether.
- Ka-band experiment dropped the capability to transmit a beacon signal during routine receive and transmit operations.
- The High Performance Computer dropped its capability to interact directly with other payloads.
- The High Efficiency Solar Cells experiment was dropped altogether.

Even with these savings, the mass target had to be increased from 50 Kg up to 58 Kg, the volume allowance had to be increased to accommodate the boom (as discussed in the next section), and the power generating capability had to increased as much as possible.

NewMag

The magnetometer experiment, called NewMag, is led by the University of Newcastle, and is being built in conjunction with the University of California, Los Angeles (UCLA) in the USA.

The main purpose of the experiment was to improve modelling of the ionosphere and exosphere through satellite based magnetic field observations. It was originally meant to be a balanced experiment with complementary capabilities from both Induction Coil and Fluxgate magnetometers. The former is capable of detecting oscillations (ELF waves:- Extreme Low Frequency waves) in the Earth's magnetic field from 1Hz up to 1KHz. While the Fluxgate magnetometer is able to detect oscillations down to the lowest possible frequencies (ULF waves:- Ultra Low Frequency waves), as well as the DC main field vector.

By discarding the Induction Coil, the experiment loses the capability to track oscillations up to the higher frequencies, thereby losing part of the total picture. Similarly, by discarding the star camera from the end of the boom, the precision of position knowledge could not be guaranteed high enough to make significant contributions to Geomagnetic mapping of the Australian region, for geophysical and mining exploration.

Nevertheless, with a guarantee of continuous operation, even through eclipse, the extremely sensitive Fluxgate magnetometer is capable of contributing much high quality information on the dynamics of the magnetosphere. In particular:

- boundary-layer processes, or wave-particle interactions, associated with magnetosphere-ionosphere coupling, through observations of ELF and ULF waves.
- interactions of electrons cascading down geomagnetic field lines near the poles, and how these transfer energy into the ionosphere, causing auroral activity.
- little studied Equatorial Electrojet currents.
- contributions to the world space weather forecasting activities, with warnings of impending magnetic storms.

The Fluxgate magnetometer is based on a UCLA proven design from the FAST mission, and consists of a three-axis orthogonal magnetometer with associated electronics. The sensors have a dynamic range of 65536 nT, with 16 bit precision, and a bandwidth of 10Hz.

The boom for the magnetometer was a major design item for the platform. The final choice was a 2.5 metre articulated boom from the University of Stellenbosch in South Africa. This boom has already operated successfully on the SUNSAT mission. However, the mounting for the boom was located on one of the side faces of the satellite. This resulted in a significant excursion from the nominal 50 centimetre cube of the satellite.

GPS

The GPS receiver payload is led by the Queensland University of Technology (QUT), and is being built in the USA according to a design from the Jet Propulsion Laboratory (JPL). The hardware is being funded by NASA, with whom the CRCSS, through CSIRO, is developing a cooperative research agreement under which scientific data will be supplied to USA researchers.

There are two independent groups of experiments to be carried out using the GPS receiver. The first, led by QUT, is concerned with precise timing, and position and attitude determinations of the spacecraft itself. While the second, led by La Trobe University, uses the timing data and known positions of the GPS satellites to determine electron content of the atmosphere.

Initially it was hoped to place 4 GPS antennae on the zenith face of the satellite to accurately determine attitude from the phase information derived from the antennae. This would have demonstrated a cheap method of attitude determination suitable for microsatellites. With only one antenna, derivation of attitude is more of a challenge. However, attitude can still be derived using a sequence of measurements to simulate a multi-antennae phased array. This will have important applications in new generations of Low Earth Orbit spacecraft.

Precise position information is derived by observing between 4 and 8 GPS satellites simultaneously, and solving the three-dimensional triangulation equations, while taking proper account of multipath (due to on-board reflections). This can either be done in real time, or more accurately, after post-processing. Modelling shows that there is greater than a 95% chance that sufficient satellites will be visible at any one time to ensure an accurate position fix.

One problem with current GPS satellites is the deliberate inclusion of errors in the timing signals – resulting in position errors for ground applications on the order of hundreds of meters. FedSat would be able to calculate the time errors, and transmit them back to ground, augmenting the so called *wide area global positioning systems*. In effect this would improve position estimates on the ground to the order of a meter or better.

The GPS receiver is also to provide precise timing for the UHF experiment to measure positions of mobile terminals, and in particular marine buoys in the ARGO project, through Doppler measurements. This would result in position measurements that are essentially independent of the GPS system.

One of the meteorology experiments was originally intended to examine the vertical density profile of the atmosphere, by observing the effects of refraction of GPS satellites as they set. This, however, required a 50Hz update, which has since been dropped.

Researchers at La Trobe University intend performing a similar experiment, by observing setting satellites to determine the electron density profile of the ionosphere, since it is electrons in the ionosphere that result in timing errors of GPS signals. Another experiment measures satellites flying directly overhead as FedSat simultaneously flies over a GPS ground station, resulting in a measure of the total electron content for the atmosphere. The combined data from these two experiments allows the derivation of superior ionospheric models, which in turn can be used by other GPS users for corrections to their position-location and timing determinations.

Communications

All the communications payloads and ground-based hardware are being built in Australia.

The UHF and Base-Band Processing experiments are led by UniSA (University of South Australia). The dropping of the VHF option for the UHF/VHF experiment had no significant impact on the outcomes from the experiment.

It was initially intended to use the UHF to interact with mobile terminals, and test store-and-forward capabilities. Early in the programme, however, an additional experimental focus was provided by ARGO (Array for Real-time Geostrophic Oceanography). This programme involves uploading data from a large number of floating buoys in the Southern Ocean, and forwarding the information to ground during the twice daily overpass of the ground station. The buoys, called PALACE floats (Profiling Autonomous LAgrangian Circulation Explorer), are intended to float submerged at some 1500 metres, for a week or two. They would then rise to the surface, recording temperature, pressure and salinity as they go, and remain on the surface for

24 hours, so they are able to transmit the data to satellite. The intention of the programme is to understand sub-surface expressions of surface effects, and contribute towards modelling a dynamically complete system for understanding climate.

With the ARGO experiment as a major objective for the experiment, the design of the hardware was driven by the need to communicate with very small, low power, terminals on the floats, using two-way messaging. The two-way capabilities allow control of the floats from the satellite, and greatly increase the efficiency of data up-link, since it is only be carried out once when FedSat is listening. Implementation of Turbo-coding results in much larger messages per packet, and further savings in power for mobile terminals.

The design will have highly desirable outcomes for communications with small hand-held terminals in remote areas, such as the outback of Australia.

The Base-band processor takes signals received either by UHF or Ka-band receivers, and modifies them, before regenerating the information and re-transmitting it. In particular, several different coding methods, including the previously mentioned cutting edge Turbo-Coding techniques, will be attempted.

The Ka-band payload is being built by CTIP in Sydney. The experiment is intended to demonstrate the properties and capabilities of this new and untested domain in frequency space. Other channels are over-full with users, and there is enormous pressure to utilise new bands. The Ka-band is at high enough frequencies to accommodate large data-rates. However, much work needs to be done to understand the atmospheric attenuation associated with variation in water-vapour content, clouds and precipitation.

TT&C Backup – In the original call for tenders there was intended to be dual redundant TT&C transceivers. However, it proved to be more efficient to provide just one transponder with the platform, and rely on the communications payload for backup TT&C. This was possible only through the versatility of having a Base-Band processor in the communications package. In the event of failure of the S-band transceiver, all payloads and unnecessary platform systems would be shut down, leaving only the UHF receiver switched on. This is a relatively low power instrument, and could be left switched on continuously, without running the batteries down. When the receiver picks up signals from ground, it passes the packets of information on to the DHS for interpreting. Data could then be downloaded via the Ka-band down-link. This incurs a high power drain, but has a high enough data-rate to ensure the objectives of the mission could still be met. With ground passes lasting no longer than 10 to 15 minutes, twice daily, the power drain is sustainable.

High Performance Computer Experiment (HPCE)

The HPCE is being developed by the Queensland University of Technology. The Prototype model of the HPCE is being built by Johns Hopkins University in USA, and the flight model is to be built in Australia.

The computer is built around modular reconfigurable logic chips (FPGAs - Field Programmable Gate Arrays). These devices each contain an array of several hundred logic blocks, with configurable inter-connecting wires. The hardware configurations of these wires are determined by downloading from memory a stream of configuration bits. These configurations can be loaded before launch, or up-linked during the mission. Each FPGA is capable of reconfiguration in a matter of seconds. This is a far superior method of configuring hardware interfaces for different instruments, than alternative options. Currently the only other possibilities are to use software reprogramming, which operates more slowly than reconfiguration by some 3 orders of magnitude; or physical configuration, which is cumbersome and expensive to do for each new mission, and impossible to alter after launch.

Space mission managers are currently reluctant to depend on FPGA chips due to their sensitivity to ionising radiation. This experiment will investigate the frequency and types of errors that occur for these chips in space, and experiment with ways and means of overcoming them.

Ground Stations

Ground stations are an integral part of any space mission. Most countries have the capabilities to receive signals from spacecraft already.

However, it is quite another matter to provide transmission capabilities; and also to progress into new frequency domains like Ka-band.

At the very start of development of satellite capabilities, there is much to be done to develop the necessary ground station facilities. The good thing is, that once these are in place, they are available for future missions, and less effort and resources need to be expended on their provision. The opposite side of the same coin is, that there must be investment in future missions for the initial outlays to become worthwhile.

The TT&C ground station is based in Adelaide, and run by the University of South Australia. The primary S-band antenna is a 2.5 metre dish located on the roof of the building. There is also a 6.8 metre dish available for backup TT&C, and a backup 10 metre dish in Canberra capable of receiving down-linked data.

The signal to and from a dish is passed through to the decoding facility (depacketiser), and thence to a database. The database can be accessed through a user interface, and displayed, acted upon, or archived. All commands to the spacecraft are first passed through a command verifier, to check semantics, syntax and that the commands are not potentially hazardous.

Tracking of the spacecraft is open-loop, depending on precise orbit determination from other sources (e.g. on-board GPS; Ka-band determinations; NORAD – North American Aerospace Defence Command). The S-band beam-width is quite large, so there is some degree of leniency in the pointing precision. This will be most useful during the early mission phase, when the orbit is not yet well determined.

The Ka-band ground stations development are led by UTS (University of Technology Sydney). There are two Ka-band ground stations, the prime station at UTS, and one in Adelaide, at UniSA. These use two identical mechanically steered 1.2 m antennae, developed and provided by CTIP. Both antennae are transportable, but still heavy enough to ensure a tight control on pointing. The link margins are not high, so there is a real danger that the signal will be lost, or not acquired in the first place.

Indeed the margins are so small that precise modelling is required to determine the refraction of Ka-band frequency emissions through the ionosphere, and so determine the apparent position of the spacecraft as seen from the ground. Similarly, fast algorithms have been developed to determine the Doppler frequency offset due to the relative motion of the spacecraft. These algorithms are so efficient that they correspond to the maximum efficiency theoretically possible, and a considerable improvement over anything previously considered.

Power

The initial tender called for 18 strings of solar cells and 4 amp-hour batteries. Detailed modelling of the different modes of operation indicated that there was a severe power problem. Ideally both the number of strings of solar cells needed to be increased, and the capacity of the batteries increased for operations during eclipse. It turned out that it was only practical to increase the number of solar cell strings up to 19. Even so, this was sufficient to give some reasonable assurance of meeting all or most of the aims of the experiments. However, it was necessary to ensure that the power consumption for each of the payloads was reduced to the very minimum, and the operational duty cycles will have to be carefully controlled so each experiment achieves its objectives during a campaign, without compromising the battery charge limitations. Operations outside an experiment’s own campaign are desirable, but only at secondary priority.

Volume

The internal configuration of the satellite is basically a cubic box divided into two compartments, separated by a double panel. The platform equipment (most of it) resides in the bottom compartment, with the equipment itself providing the load carrying path directly from the bottom of the satellite to the bottom member of the double panel. Although this is a very efficient use of space, and minimises mass, it is rather inflexible. This is the main reason why larger batteries could not easily be incorporated without major structural redesign.

The top compartment carries all the payloads, as well as equipment that would not fit in the platform compartment. All the payload electronics boxes are fixed to the top member of the double panel, and nowhere else. Each panel is a honeycomb matrix, so it is important, especially for the payloads, to ensure that no inserts will be so overloaded, that they pull out during launch.

Mass

As was predicted from the start, any initial estimates of mass, volume and power, would only go up as the design of hardware developed. Again as predicted, the main mass increase came from proper considerations of harness, connectors, and tie-downs, as well as extra componentry necessary for power conditioning. Fortunately, the proposed launch vehicle can accommodate the small increase in mass that resulted.

Education

There are currently 34 graduate students involved in the FedSat research programme.

The objectives of the education programme is to qualify higher degree students at participating universities in space science and engineering; and to carry out continuing education for those already in the industry. It is estimated that the CRCSS will graduate one hundred PhD graduates by the year 2005. Current emphasis is in:

- satellite communications
- space science
- computing systems
- navigation.

In addition, continuing education courses are being developed for:

- satellite engineering
- space technology
- space applications

In the process it is intended to lift the national skills base to facilitate a satellite industry after the first term of the CRCSS.

Some Challenges

- The platform provided clock only has limited precision, and drifts relatively fast for applications where high positional accuracy is demanded. In these cases it would be advantageous, in future missions, to include a high accuracy clock as part of the payload.
- Test facilities in Australia are limited, with no thermal/vacuum or de-gaussing chambers large enough to take the complete satellite. This means the tests must be carried out off-shore, and at a time when alterations to design can not be implemented.
- The level of documentation achieved is a compromise between cost and preference.

The Future

The CRCSS anticipates a continuing role in conducting missions involving small satellites, and in developing payloads, niche products and services for the developing global small satellite market.

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