

THE SPACE TECHNOLOGY RESEARCH VEHICLES : STRV-1A,B,C&D

Cdr Richard Blott RN
Mr Nigel Wells

Space Department
Defence Research Agency
Farnborough
Hampshire
GU14 6TD
United Kingdom

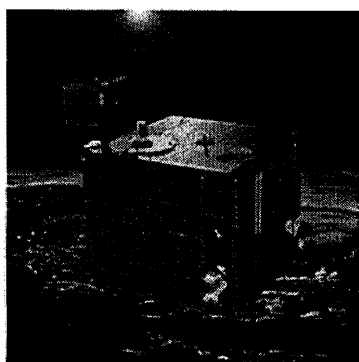


Fig 1 STRV 1a and b

Abstract

The paper presents an overview of the achievements of the Space Technology Research Vehicle (STRV) 1a&b microsatellite mission in geostationary transfer orbit (GTO). Launched in June 1994 as auxiliary passengers on an Ariane-4, the two satellites achieved their primary objectives of demonstrating new space technologies and techniques in a harsh radiation environment at low cost and in a short timescale. The follow-on mission : STRV 1c&d will also be designed and built by the UK Defence Research Agency at Farnborough and the mission is described in detail. The proposed science and technology payload, sponsored by the UK Ministry of Defence, the UK Particle Physics and

Astronomy Research Council, the US Ballistic Missile Defense Organisation, the US Air Force, the US Naval Research Laboratory, the European Space Agency, the Canadian Defence Research Establishment and the Canadian Space Agency, is also discussed. STRV 1c&d are currently scheduled to launch into GTO aboard an Ariane-5 towards the end of 1998 for a nominal one year mission.

1. Introduction

STRV 1a&b were designed with the principal aim of providing the technology community with affordable access to earth orbit to allow an in-orbit evaluation of new technologies. The spacecraft were designed built and tested by the UK Defence Research Agency (DRA) and their subcontractors at Farnborough and have been operated from the one of the Agency's ground stations at Lasham in southern England. Although the original planned mission was 12 months, the experimental data gained was of such value that operations continued for 2 years from June 1994 to June 1996. One of the main reasons for this success was the short duration of the project, progressing from design to operations in 3 years. Both satellites are still fully operational and are in the process of being leased to the University of Colorado.

This is to enable the University to prove compatibility with the international Consultative Committee for Space Data Systems (CCSDS) packetised Telemetry, Telecommand and Control (TT&C) design within their own ground segment.

Details of the STRV 1a&b mission were presented to the Conference this time last year and are available in Reference 6. However, it is worth re-iterating that the design was largely experimental with the majority of the platforms and subsystems incorporating new features or techniques. Although each spacecraft mass was less than 55Kg, 14 different experiments were on board at launch and, as described later in the paper, a fifteenth was added during the second year in orbit.

The majority of technologies flown as experiments were associated with ongoing research programmes sponsored by the UK Ministry of Defence (MOD), the Ballistic Missile Defence Organisation (BMDO) of the US Department of Defence (DoD) and the European Space Agency (ESA). In addition to experiments, the BMDO negotiated the use of the NASA Deep Space Network (DSN) as back up to the Lasham ground station. ESA provided design effort and solar panels and the USAF Phillips Laboratory at Albuquerque also provided solar panels. The results of the experiments have been shared between the different sponsors to their mutual benefit. The international collaborative aspects of the project have proved extremely successful. As a result, all the original organisations are participating in the follow-on mission and Canada has also decided to contribute 3 experiments to STRV 1c&d.

STRV 1c&d will also exploit the characteristics of the geotransfer orbit (GTO), particularly the environmental effects shown in figure 2. However, a number of changes

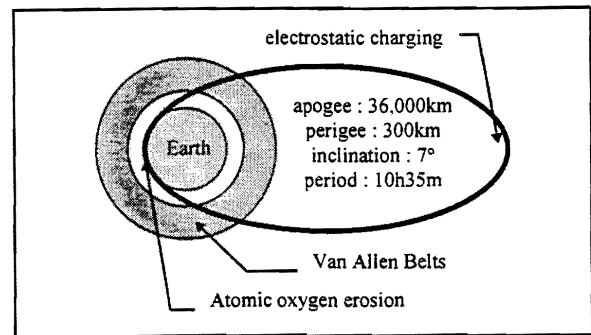


Fig 2 STRV in GTO Schematic

are being made to the design to reflect the demands of the new experimental payload and to modify some aspects of sub-system performance in the light of the STRV 1a&b experience. This paper addresses the STRV 1a&b performance during the second year in orbit, with particular focus on the Space Communications Protocol Standard (SCPS) experiment conducted during the first 6 months of 1996. Plans for the STRV 1c&d mission are then described with an explanation of the new experimental payload and the associated design modifications.

2. STRV 1a&b - Second Year in Orbit

During the second year in orbit the spacecraft and ground station performed well. No major sub-system failures were experienced and the environmental effects, particularly radiation degradation of the Ga As solar arrays, were less than predicted. Some experiments ceased operating but the performance of others was improved. The experimental data provided by those that did cease operating still well exceeded the experimenters' initial requirements. Of particular interest was the satellite performance during the long eclipse period and then without eclipse, see figure 3.

At maximum, some 140 minutes of the 10.5 hour orbit was spent out of sight of the sun. Despite this, the spacecraft continued to perform satisfactorily, although payload

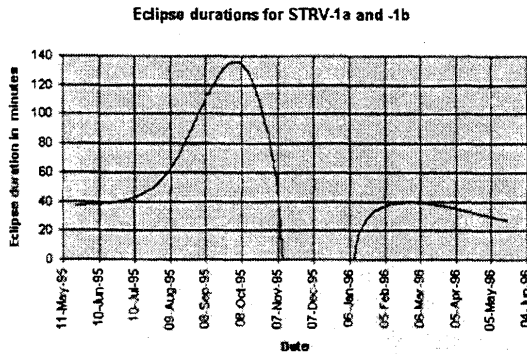


Fig 3 GTO Eclipse Duration

operations were reduced to conserve power.

During the long eclipse the STRV 1a&b battery anomaly, described in Reference 6, appeared to self-correct. The battery had been operating at 5% below full capacity since launch and prevented the successful operation of the Charge Alleviation Experiment (CAE). However, the apparent reconditioning of the battery has allowed numerous successful plasma discharges from the CAE.

3. The SCPS Experiment

The National Aeronautics and Space Administration (NASA), the DoD and DRA have jointly started a standardisation initiative to develop a new space communications system, known as the Space Communications Protocol Standards (SCPS) initiative. When complete, the SCPS standards will complement and expand the current CCSDS TT&C standards. The objective is to provide a more comprehensive set of spacecraft control and monitor data handling services based on and compatible with commercial Internet protocols but adapted to the specific needs of space communications links. These will serve a wide range of civil and military space missions for the foreseeable future. The applications of SCPS to space based communications links, supporting Internet type data transfers, particularly those involving longer time delays, is also being investigated.

Although the CCSDS packetised standards provide the underpinning for the automated, error-free exchange of data between space and ground stations, it is limited to basic data transfer. SCPS will provide the additional capability to aggregate both telecommand and telemetry data into recognisable files and transport them end-to-end through the data networks containing space links in a reliable and secure manner. To do this, a 'skinny stack' of upper layer space data protocols are being developed which will eliminate the need for "project uniqueness" and provide:

- an efficient file handling protocols based on FTP,
- a retransmission control protocol based on TCP with various modes of operation and for use over networks with one or more unreliable space data transmission paths,
- an optional data protection mechanism which can assure end-to-end security and integrity of message exchange,
- a scalable networking protocol to support both connectionless and connection oriented message routing through networks with space data transmission paths.

The CCSDS working group accepted the four specifications as a new work item in November 1995 to be developed to full international standards over the next two years.

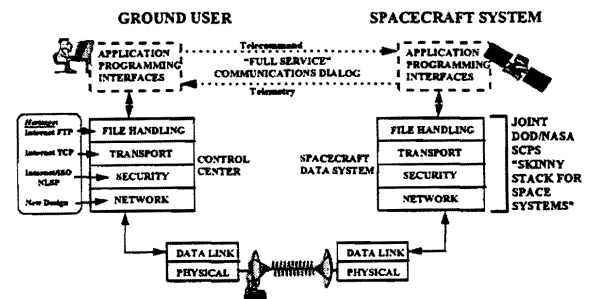


Fig 4 Scope of the SCPS System

More details of the four SCPS protocols are given in Reference 7. The scope is shown in figure 4, illustrating how the 'skinny stack'

for space systems interfaces with the application programmes and the physical data links.

The STRV spacecraft were the first in Europe to fully implement the CCSDS compatible ESA TT&C standards in an operational mission and are expected to have widespread international application in the space industry. Together with the reprogrammable onboard computers, the spacecraft therefore provided an excellent vehicle to prove the SCPS protocols over a live space link. New SCPS software was hosted on one of the STRV 1b spacecraft Mil Std 1750A, (dual-redundant) computers with 128Kbyte SOS RAM. The SCPS development team produced a 'lightweight' version of the Transport, File Transfer and Security protocols which were compiled into 1750 assembler code and debugged using an STRV engineering model. After debugging, the software was uploaded to STRV 1b with the assistance of an operating system (Kernal), developed by the Mitre Corporation to provide the interface to the onboard computer, taking up 120Kbytes of the available RAM.

Modifications to the ground station were also necessary. Two 486 PCs were added to the original configuration: one for secondary CCSDS processing and one, the SCPS Workstation, to host the SCPS ground protocol software. The general arrangement is shown in Figure 5 which shows the alternative links through Lasham or the DSN to the spacecraft and the NASCOM link between Lasham and Goldstone. Additionally, an Internet link with Mitre in Reston Va enabled the trials to be supervised remotely from the USA. The SCPS software runs as an application on the SCPS workstation. It receives instructions from the Internet and forwards them, using the SCPS protocols, to a telecommand workstation which transmits them as STRV CCSDS packets to the spacecraft. Software in the

spacecraft monitors the received instructions and provides performance feedback through the telemetry downlink. As a part of this experiment, STRV 1b was given its own Internet Protocol (IP) address. We believe that it is the first spacecraft to do so, and to demonstrate that instructions could be sent by Internet from remote sites to an operational spacecraft.

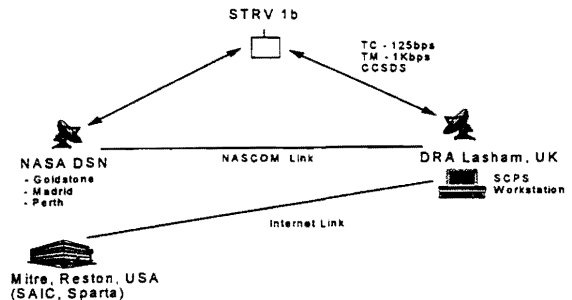


Fig 5 SCPS

Trials were conducted in a suitably stressful environment provided by low data rates (125 bps uplink and high error rates). The data from the trials is still being analysed but the interim results have been encouraging. Laboratory predictions had indicated that the SCPS Transport protocol was 8 to 30 times more efficient than the commercial Internet TCP over stressed links with high error rates. In figure 6 below the laboratory predictions are indicated by diamonds and the first measured results by crosses. These indicate quite reasonable correlation between laboratory and live results. In addition the functionality of the File Transfer and Security protocols have been successfully demonstrated. The command to open a SCPS File Transfer connection, transfer a file from space to ground, read a file record and edit a file proved very reliable.

The experiment has provided a very useful checkout of basic elements of the SCPS protocols over a live space link. Full data analysis will take until the end of 1996 but the initial results are already providing a useful input to the development of the full

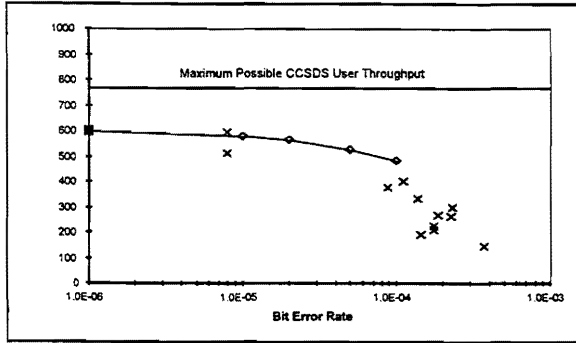


Fig 6 Preliminary SCPS data link comparison

standards. It also demonstrated the benefits of the capability to re-programme an in-orbit computer to change mission characteristics at short notice and low cost. The limited capability of the 1750A computer and the 128Kbyte RAM did limit the scope of the trial. It was not possible to demonstrate the networking protocol and some of the more demanding aspects of the Transport protocol. We plan to address these in follow-on missions.

4. STRV 1c&d

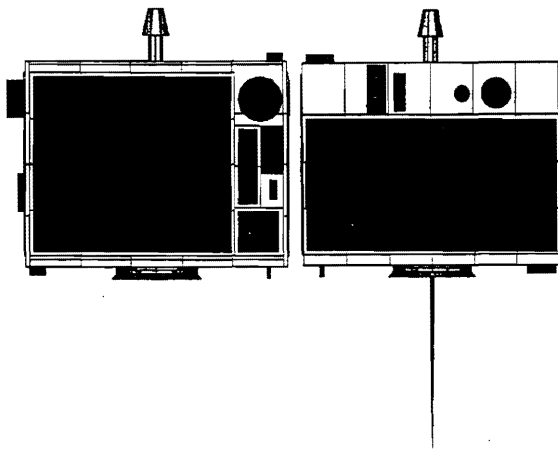


Fig 7 STRV 1c and d

The STRV 1c&d mission is now defined. It will have the same orbit as STRV 1a&b. The spacecraft and ground station will incorporate the same design features but a number of

modifications are being made to improve performance. The most significant of these are driven by a larger experiment payload of some twenty three experiments. Together these require significant increases in power and data handling capability. As a result, the beginning of life (BOL) solar panel generating power has been increased from 33 to 55 watts and the on board computers and memory have been updated. The increased power has been achieved by maintaining the same cuboid shape but enlarging the structure from a 460mm to a 700mm length of side. As a result the spacecraft mass has grown from 55 Kg to 75 Kg. This is too large for the Ariane 4 auxiliary payload launch capability but well within the constraints for the Ariane 5 Ariane Structure for Auxiliary Payloads (ASAP).

The experiments have a range of objectives. Some are aimed at flight proving new components, sub-assemblies or technology. Others exploit the unique exposure to the space environment in the GTO for accelerated life testing, particularly of radiation sensitive components. The enhanced on board computing capacity will permit the prototyping of new software. At the same time, a comprehensive suite of environmental monitors will continue to provide data about the space environment and record the environmental background for the other experiments. This information will be of particular interest in the approach to solar maximum at the end of this century.

The first objective of the STRV programme is demonstrate the application of emerging technologies which will enhance current capabilities and reduce cost and risk in future procurement. As a result, the majority of the experiments have direct applications to both civil and military production spacecraft. The second objective is to characterise the space environment more accurately to enable more efficient design in future equipment. The third objective is to make this research very

affordable through international collaboration, bringing together a wide range of interests from the USA, Canada and Europe in a complex but compact low cost mission.

One group of experiments is aimed at enhancing aspects of platform technology. They include:

- Mapping the signal from the Global Positioning System (GPS) constellation throughout the GTO.
- Accelerated life testing a wide range of advanced solar panels and measuring their radiation tolerance.
- Flight testing a new Sparc processor OBC design and associated fault tolerant memory.
- Flight testing a new Lithium Ion battery and power conditioning and control system.
- Flight testing advanced multifunction structures designed to achieve major mass and volume savings in comparison to conventional design.
- Demonstrating a new low cost, compact earth sensor.
- Flight testing a new lightweight, highly stable oscillator.
- An electronic test bed for the flight testing of advanced COTS components.
- A secure CCSDS TT&C experiment.

The unique characteristics of the GTO will also be used to investigate techniques for more accurate geo-location of terrestrial emitters. Although originally developed for military purposes, these techniques are of increasing interest to civil users whose services are interfered with or whose facilities are used illegally. Also, following the success of the STRV 1b SCPS experiment, advantage will be taken of the enhanced on board computing capability for a follow-on SCPS experiment. At the same time, there are plans to exploit the computing and reprogramming resources to investigate aspects of some of the onboard communications processing techniques which

are of increasing interest to communications providers.

A major experiment is a new technology infra-red camera designed to detect cold objects against a cold background. Associated with this is an investigation of data compression techniques to provide timely, high quality images over limited capacity communication links. The environmental measurement suite includes an update of the Radiation Environment Monitor flown on STRV 1b complemented by devices to measure both high and low energy particle densities. Two experiments are being flown as prototypes of devices to provide environmental monitoring on future military and civil communications satellites. Additionally, there are experiments to measure ionospheric tomography, atomic oxygen and debris and micro-meteoroid effects.

In addition to enlarging the spacecraft structure a number of other modifications are being incorporated. Although retaining the 1750A computer technology in the form of its big brother, the 31750, for basic spacecraft bus control, the addition of the Sparc, with a further 8Mbytes of RAM, and a Digital Signal Processor for intensive analogue computation, provides exceptional in-orbit processing power to support the exploitation of techniques to give greater spacecraft autonomy and onboard payload data processing. Associated with this, the uplink data rate is being increased from 125bps to 1Kbits and the downlink data rate from 1 Kbits to 10Kbits. This can be achieved with minor modification to the spacecraft on board data handling and communications design. Similarly, little modification is required to the ground station apart from upgrading of some of the PCs, some additional equipment associated with the CCSDS experiment and the head amplifier for the main tracking dish.

Other improvements include a new design of nutation damper and a different type of Earth Sensor. Both underperformed in STRV 1a&b and although this did not impact on the experiment results it introduced complications in mission control which can be designed out with components giving the required performance. We are also investigating aspects of the thermal design to reduce the sensitivity to solar aspect angle experienced on STRV 1a&b. Finally, there are a range of components which are no longer available and for which suitable replacements have to be found. This includes the replacement of the Carbon Peek material used in the structure with a Carbon Polycyanate and a range of ACTEL electronic devices.

A 2 year programme for the assembly, integration and test of the STRV 1c&d spacecraft and experiment payload starts in December this year. The necessary modifications to the ground station will be made during this period. The spacecraft will be available for launch from December 1998 and we expect there to be several launch opportunities in the 6 months up until June 1999. Currently a mission of one year of operations is planned during which the data objectives of all the experiments can be readily achieved. However, the lessons learned from STRV 1a&b indicate that there may well be a requirement to extend the mission and that will be an option if it is required.

5. Conclusions

The STRV 1a&b mission has proved much more successful than originally anticipated. The flexibility and robustness of the design was well demonstrated by the addition of the SCPS experiment during the second year of operations and the extension of the spacecraft life into a third year of utilisation. The lessons learned have been incorporated into the early design of the follow on STRV 1c&d

mission. It is also most encouraging that all the experimenters who participated in STRV 1a&b are flying experiments on STRV 1c&d and that a number of new participants, particularly from Canada, have joined the programme.

Having proved the concept and the value of a space technology research vehicle with STRV 1a&b it is possible to focus follow-on activity more directly on emerging technologies with space applications. As a result we are able to see a fast, inexpensive route from research to production application with associated cost and risk reduction unachievable through alternative strategies. The 3 years from design to operations, achieved with STRV 1a&b, is being reduced to 2 years for STRV 1c&d. Although there have been considerable benefits from the re-use of much of the original design, there is a significant increase in the effort required to incorporate the higher number of experiments and the trend to increasing experiment sophistication.

6. Acknowledgements

The paper is derived from the gratefully received contributions of the STRV 1a&b and c&d project teams. The assistance of the team which designed and implemented the SCPS experiment has been particularly helpful.

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in the United States. He has an honours degree in electrical engineering, is a member of the Institution of Electrical Engineers and is a chartered Engineer.

8. Biography

Mr. Wells is the STRV-1a/b Mission Manager in the Space Technology Division of the DRA's Command & Information Systems Sector at Farnborough. Mr. Wells is also the Spacecraft Manager for STRV-1b and is responsible for the day-to-day operations of the STRV-1b spacecraft. Prior to launch, Mr. Wells and was responsible for the design and development of the STRV-1b and has been a member of the scientific staff at the DRA since graduating from the University of Bristol, England with an honours degree in Physics in 1987.

Commander Richard Blott BSc MIEE CEng is the STRV 1c&d Project Manager. He joined the programme in the Summer of 1995 from the NATO Communications and Information Systems Operating and Support Agency (NACOSA) where he was responsible for implementing improvements to NATO strategic communications of which satellite communications form a major part. Previous experience in a wide variety of technical and project management appointments includes a 3 year appointment