Countdown to launch of the first microsatellites qualified for flight on Ariane-5 ASAP

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Abstract. In the fourth quarter of 2000, the first Ariane-5 to carry “piggy-back” payloads on the newly-designed ASAP ring is planned to be launched into a geo-synchronous orbit. The two 100kg spacecraft carried on the ring will be the second generation of microsatellites from the UK Defence Evaluation & Research Agency (DERA), called STRV-1c and –1d.

Between them, these spacecraft carry 25 separate experiments sponsored by a wide variety of national and international government agencies, academia and industry. The experiments cover a wide range of technical research areas including new lightweight RF hardware, Internet-type communications protocols experiments, the latest radiation detectors, GPS experiments and debris detectors.

The paper describes the process of assembly, integration and test of these small, but very challenging, spacecraft leading up to the launch campaign and initial operations phases. The management and technical lessons learned through the process of becoming the first microsatellites to be qualified for flight on the new Ariane-5 ASAP are also described.

Introduction

Following the success of the first pair of DERA Space Technology Research Vehicle microsatellites (STRV-1a and –1b), which were launched as auxiliary payloads on an Ariane-4 in 1994, the follow-on programme, STRV-1c & -1d, was initiated. During the feasibility study, Arianespace announced that an Ariane Structure for Auxiliary Payloads (ASAP) would be developed for Ariane-5. The “ASAP-5” would be capable of carrying larger microsatellites than the Ariane-4 version (100kg rather than 50kg each). The level of experiment sponsor interest was sufficiently high to warrant the larger microsatellites and the decision was made to proceed with an ASAP-5 compatible spacecraft design. In order to maintain a low-cost approach, and to capitalise on the success of the first mission, as many of the spacecraft subsystems that could be directly reused in STRV-1c/d. Clearly, the larger structure would be a new undertaking. However, the flat-panel, CFRP composite and aluminium honeycomb construction techniques were adopted from the basic STRV-1a/b design.

From 1997 to 1999 the design and construction of the two spacecraft, and their 25-experiment payload was completed. The spacecraft and ground segment test programme was completed over a six month period ending in early 2000.

As shown in Figure 1, a fit check of both flight spacecraft with the ASAP-5 was completed in March 2000 and the spacecraft are now awaiting launch later this year.

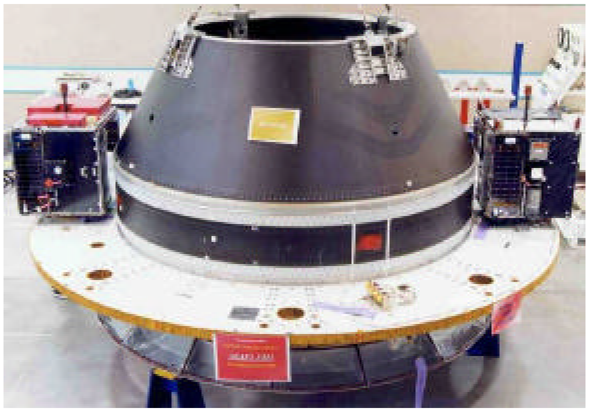


Figure 1: STRV-1c/d on the ASAP-5

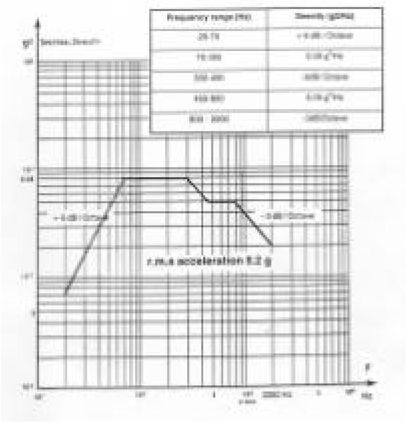
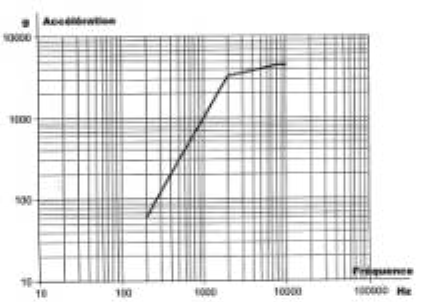
Arriving at this position has been an exercise in the management of parallel development programmes: the spacecraft, under DERA’s direct control, the ASAP-5, under that of the launch authority, and the experiments under the control of numerous payload sponsoring organisations. This paper recounts the challenges faced, how they were tackled and describes some of the lessons learned.

Design & Test Requirements

Spacecraft-level requirements

Table 1 summarises the design and test requirements for the spacecraft, as specified in the first release of the ASAP-5 User's Manual. [1] The STRV-1c/d development programme was occurring in parallel with that of the ASAP-5 and hence these initial requirements were subject to alteration with time.

Table 1: ASAP-5 design & acceptance test requirements (per spacecraft)

Design requirements	
Parameter	**Initial specification**
Mass	<100kg
Centre of Mass position	<450mm above separation system interface plane & <5mm from the geometrical x,y centre
Volume	600x600x800mm
Quasi-static load	9g (lateral) & 16.5g (longitudinal)
Fundamental frequencies	>50Hz (lateral) & >100Hz (longitudinal)
Separation system	Multi-spring, ring-fracture device supplied by Arianespace
Test Requirements	
Test	**Initial specifications**
Random Vibration	
Sine Vibration	2.0g (lateral) & 3.0g (longitudinal) from 0-100Hz
Shock	

During the structure design phase, the most demanding requirement to be met was the lateral fundamental frequency of >50Hz. This was particularly challenging due to a relatively high centre of mass position of the spacecraft combined with a relatively small diameter of the separation system mechanical interface to the ASAP.

Figure 2: STRV-1c under vibration test

The initial design concept favoured the use of "support jacks" mounted on the ASAP surface directly beneath each of the four corners of the spacecraft (see Figure 3).

This system was previously used on STRV-1a/b, however, they were not considered suitable for ASAP-5 by the launch authority and another solution had to be found.

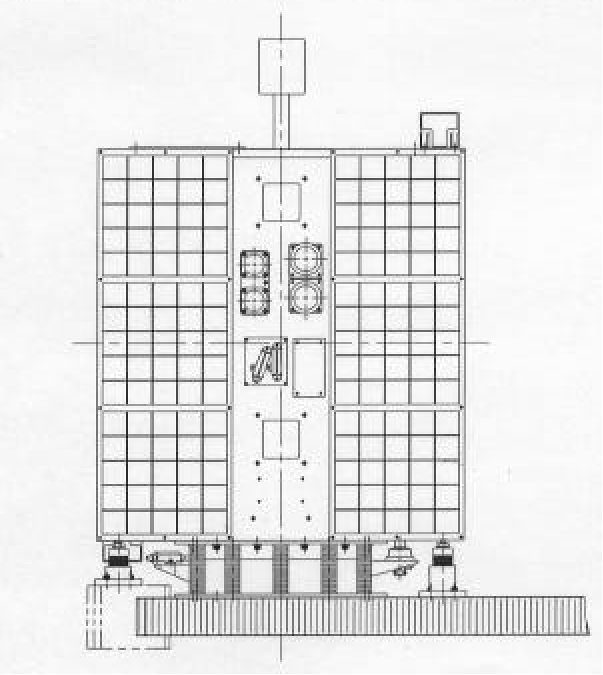


Figure 3 Support jacks concept

The basic design of the structure is a flat panel base with two bonded side walls. The other closing walls and two internal shear walls are then bolted to this basic frame. Horizontal shelves are mounted within the two spaces either side of the shear walls, as shown schematically in Figure 4.

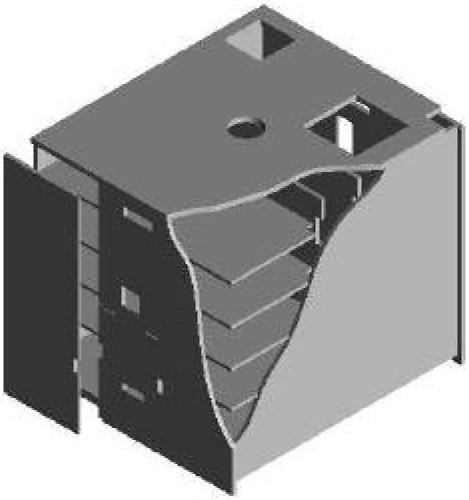


Figure 4 Overall structure design

The bonded joint between the base and two opposing side panels, shown in Figure 5, is a novel, DERA-patent design which offers high stiffness and excellent load transfer. However, the overall stiffness of the spacecraft is dominated by the baseplate stiffness and therefore this area of the design required further attention.

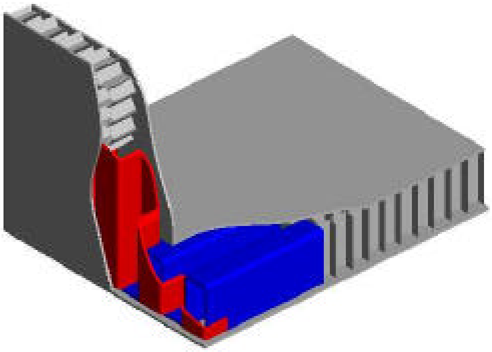


Figure 5 Corrugated composite joint design

Without the use of the corner jacks, the stiffness of the base panel was increased by incorporating a solid ring of CFRP within the panel lay-up, located at the bolted interface to the separation system. This added significantly to the mass of the structure (now at 20kg for the complete design) and although the lateral fundamental frequency was increased to around 40Hz, this was not sufficient to meet the specification. Another problem was associated with the increasing stiffness of the lateral modes: the longitudinal fundamental mode frequency was also increasing to well in excess of the required 100Hz. This mode was beginning to couple with the modes of the internal shelves which meant that the individual equipments within the spacecraft were being exposed to amplified levels of vibration. Analysis indicated that in some cases this was in excess of their unit-level qualification test levels. As discussed later in the paper, this represented a serious potential threat to the programme. Therefore, in parallel with the base stiffening exercise, the shelves required their fundamental frequencies to be increased by additional stiffening. Again, this had a mass penalty.

The prospect of meeting both the mass limit and the fundamental frequency requirement, but at the same time ensuring that the vibration environment at the internal units was acceptable, proved to be very challenging. However, good progress was being made on the design and qualification of both the ASAP-5 and the separation system, and Arianespace were able to modify both the mass and frequency constraints in the light of test and analysis data. This was sufficient to allow DERA to freeze the design and proceed with the construction of a qualification model structure without further strengthening. Following the successful completion of the qualification tests, the two flight model structures were then built.

Unit-level requirements

The programme imposed qualification and acceptance test level requirements on all units and experiments to fly on the spacecraft. In summary, the mandatory environmental tests were:

- 5 cycles of thermal vacuum (+60ºC to –40ºC)
- random vibration (16g rms)

The thermal vacuum tests were based on standard practices and comfortably encompassed the predicted temperature excursions. The random vibration specification was a factored version of the spacecraft-level test, to take account of the expected transfer function of the structure. In many cases, the qualification vibration testing of the payload occurred comparatively early in the programme and therefore a high degree of pressure was on the structural design to deliver the appropriate vibration environment. The difficulties with the attainment of fundamental modes was thus central to the viability of the entire design.

Once the experiments had passed these tests, they were accepted for bench-level functional testing against engineering model platform systems. Only after satisfactorily meeting these test requirements were the experiments offered for integration into the flight spacecraft.

One of the major management issues during this period was the co-ordination of the 25 separate experiments to ensure that they arrived for testing on time and then rescheduling activities in the light of test difficulties. The process adopted to manage the unit-level functional testing is described in the following section.

Unit-level Test Philosophy

The test philosophy applied to all equipments was an incremental series of functional tests, each building on the success of the previous tests. This so called "loop testing", shown in Figure 6, was an effective means of uncovering issues early in the programme and hence reduced the risk of "last minute" difficulties later on.

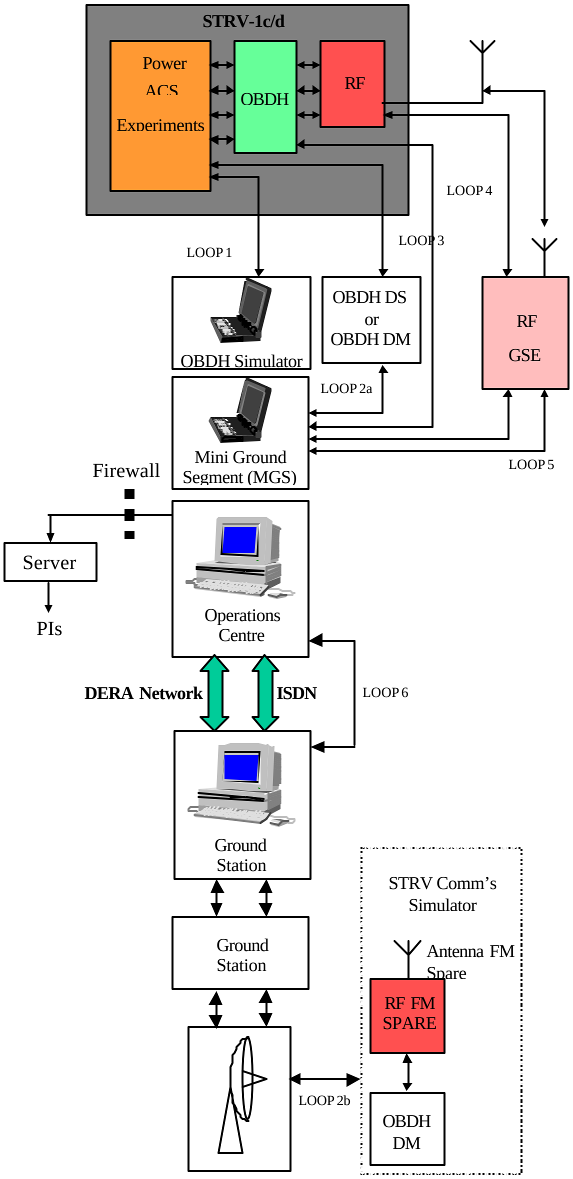


Figure 6 "Loop Test" arrangement

The first loop, was a basic test of the equipment against a PC-based simulator of the OnBoard Data Handling System (OBDH). This allowed testing of the first iteration of the application software and to confirm hardware interfaces. Loop 2a introduces a breadboard version of the OBDH (a "demonstration model" or "DM"). In parallel, Loop 2b tests the DM interfaces, over RF, to the ground station. Loop3 introduces the flight OBDH and hence any interface timing issues can be resolved. Loop 4 is the same series of equipment tests, but this time conducted through the flight RF equipment, and Loop 5 then introduces the flight antennas into the chain. The final "system test", Loop 6, demonstrates full functionality over the LAN and back-up ISDN links between the Operations Centre at DERA Farnborough and the DERA station in Scotland.

Spacecraft Environmental Test Philosophy

The majority of the STRV-1c/d test programme was conducted on site using the wide range of DERA test facilities ideally suited to micro/minisatellite programmes, including vibration, moments of inertia, spin-balance, thermal vacuum and solar simulation.

Both spacecraft were subjected to acceptance-level vibration (sinusoidal and random) and shock tests. In addition, 6 days (approximately 12 orbits) in the solar simulation facility was scheduled in order to validate the thermal design and prove on-orbit operations from the ground segment.

Vibration

In each axis of vibration, accelerometers were mounted at the locations on the spacecraft shown in Figure 7, and these recorded the frequency responses in three axes. The test arrangement is shown in Figure 2.

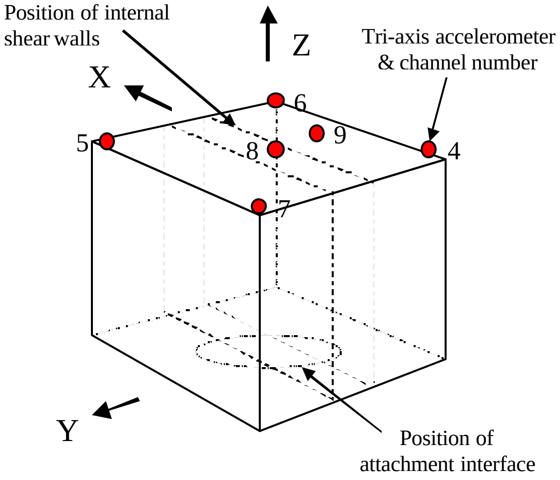


Figure 7 Vibration accelerometer locations

Before and after each of the full level tests, low level (at 0.2g, from 5 to 2000Hz) sine sweeps were conducted to provide a modal characterisation of the spacecraft. Comparison of the pre- and post-test results provides evidence that the spacecraft has survived the environment without damage. These responses also accurately determined the fundamental frequencies of the main modes.

Shock

As shown in Figure 8, the spacecraft were suspended from an overhead crane and the shock system (a ring containing pyrotechnic shock generators, supplied by Arianespace) was mounted to the base interface plate. The spacecraft was covered in a protective anti-static sheet to prevent the impingement of the chemical products of the shock generators.

Figure 8 Shock test arrangement

Shock accelerometers were located in the positions shown in Figure 9, and as was the case for the vibration test, pre- and post- test low-level sine sweeps were performed to demonstrate that the spacecraft had survived the test without damage.

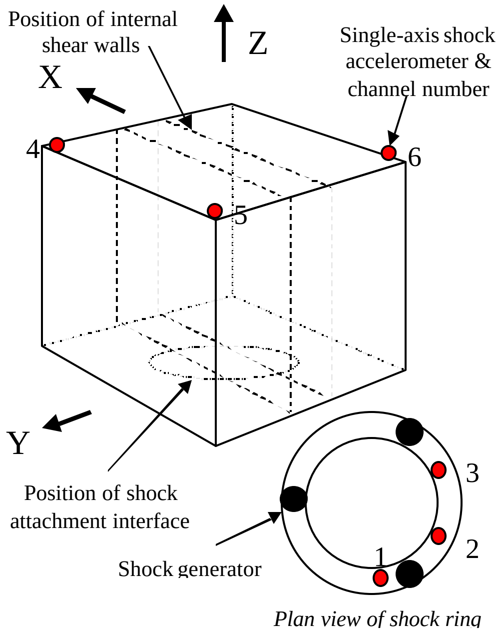


Figure 9 Shock accelerometer locations

Solar Simulation

In orbit, the spacecraft are spin-stabilised about the Z axis, and therefore to representatively simulate this in the solar simulation test, the spacecraft were mounted on a rotation rig, as shown in Figure 10.

Figure 10 Solar simulation test

The rig can control the speed of the spacecraft rotation and the timed activation of xenon lamps at the rear of the chamber bathes the spacecraft in sunlight as required. During eclipses, the liquid nitrogen filled shroud around the walls of the chamber provide an approximation of the deep space thermal background.

The purpose of this test was primarily to validate the thermal modelling of both spacecraft, and hence periods of hot and cold steady-state "soak" were planned. In addition, the test was an excellent opportunity to control the spacecraft as they would be on orbit. The test was therefore also planned to include nominal operational orbits to prove all spacecraft operating modes and to provide an end-to-end system test of the ground segment.

Spacecraft Environmental Test Results

Extensive results were recorded for both spacecraft in all the environmental tests and it is not practical or useful to present all the data here. Also, since both spacecraft behaved in an almost identical manner, only STRV-1c data is considered.

Vibration

Early in the programme, finite element analysis revealed that the X-axis random vibration was the most stressful test for the spacecraft. This data, from channel 4 in Figure 7, is presented below.

Figure 11 shows the responses recorded by the control and channel 4 accelerometers during the X-axis random vibration test of STRV-1c. The dominant fundamental mode at around 70Hz is clearly evident.

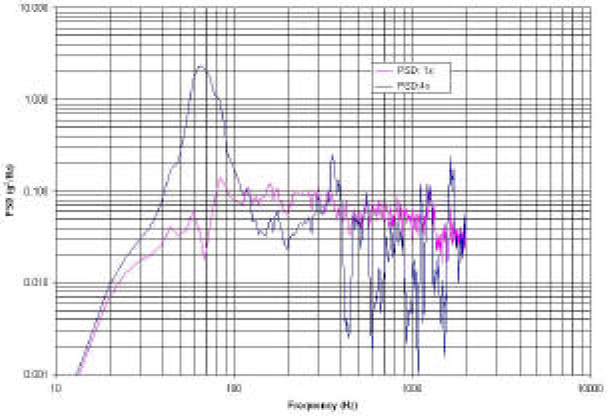


Figure 11 Acceptance-level X-axis random vibration

The low-level sine responses, recorded before and after this test are shown in Figure 12. The high correlation between these traces indicates that the dynamic response of the spacecraft has not been changed by the test environment.

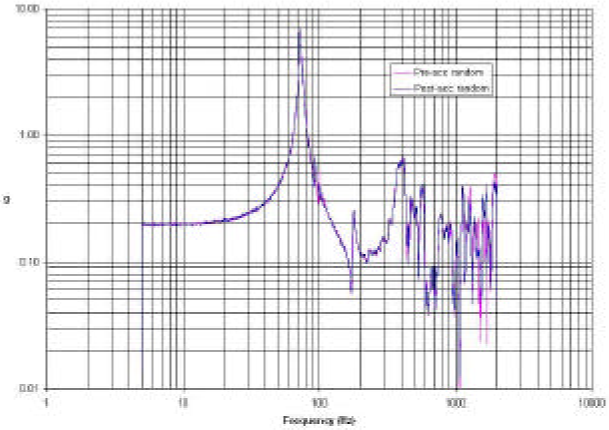


Figure 12 Low-level sine response (pre- & post-X)

Shock

The input shock, as recorded by one of the accelerometers mounted directly on the shock ring (see Figure 10), is shown in Figure 14. Also shown is the equivalent shock response spectrum (SRS).

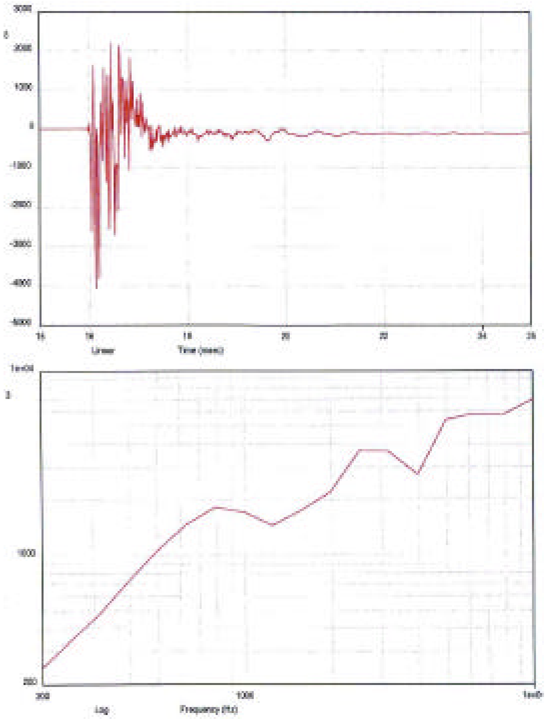


Figure 13 Input shock and SRS

This relatively high shock level (peak at around 4000g) is rapidly attenuated in the spacecraft structure, such that the effect at unit locations is much more benign. Figure 14 shows the same input shock as recorded at the top of the structure. Here, the peak is only 400g.

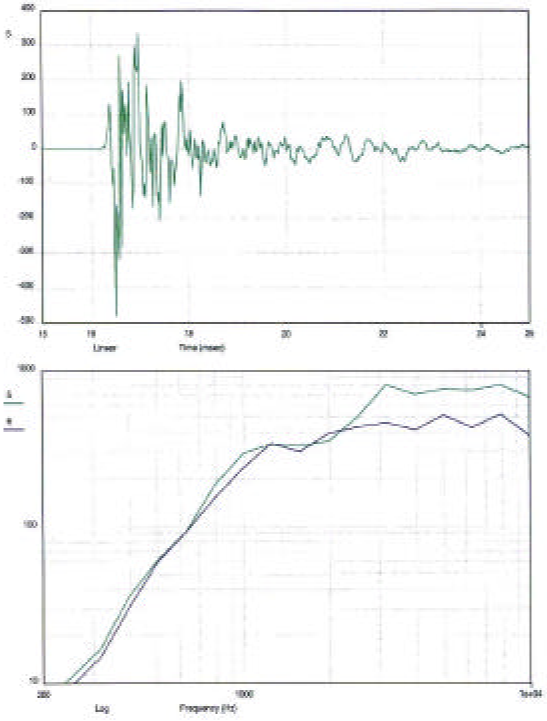


Figure 14 Response to input shock and SRS

The low-level sine sweeps performed before and after the shock test again indicated that the structure had not suffered any degradation as a result of this test.

Solar Simulation

The thermal models of both spacecraft were successfully validated by the solar simulation tests and only minor adjustments to the blankets and optical surface reflectors were needed to ensure adequate performance in orbit.

Both spacecraft were operated in all normal modes during the tests. The tests also proved to be a useful tool for debugging new ground segment software.

Conclusions & The Future

The STRV-1c & -1d spacecraft have successfully completed all environmental tests required by the launch authority and by the mission requirements.

A large payload compliment has been received from a variety of sponsors, tested in a low-cost but thorough manner and integrated onto the spacecraft. Both spacecraft now await a launch later in the year.

A number of lessons have been learned as a result of the experience:

- The development of a spacecraft in parallel with that of the launch platform naturally leads to evolving requirements during the course of the programme. This can be effectively managed by ensuring a larger design margin at the outset and by maintaining a flexible design.
- Requirement growth in a many-experiment payload has to be rigorously controlled.
- Reducing risk “up front” in the programme, by implementing as many interface and software tests as are practicable, is an important tool in overall risk reduction on the programme.
- Maintaining a regular dialogue, and developing a close and open relationship, with the launch authority is the only way in which a programme of this nature can succeed.

As the launch of STRV-1c & -1d is awaited, plans are already underway for STRV-1e & -1f. With the basic design of an ASAP-5 compatible spacecraft established, and the process of qualification for flight complete, DERA is well-placed to embark on the next STRV programme.

References

1. Arianespace, ASAP-5 User’s Manual, Evry, May 1997.