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AFFORDABLE ACCESS TO SPACE – GETTING THERE

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ABSTRACT To realise the full potential of modern low cost mini-micro-nano-satellite missions, regular and affordable launch opportunities are required. It is simply not economic to launch satellites of 5-300kg on single dedicated launchers costing typically $10-20M per launch. Whilst there have been periodic 'piggy-back' launches of small satellites on US launchers, these have been infrequent and often experienced significant delays due the vagaries of the main (paying!) payload.

In 1988, Arianespace provided a critical catalyst to the microsatellite community when it developed the ASAP platform on Ariane-4 providing, for the first time, a standard interface with affordable commercial launch contracts for small payloads up to 50kg. Some 20 small satellites have since been launched on the Ariane-4 ASAP ring, however as most of these microsatellite missions seek low Earth orbit (especially sun-synchronous) the number of prime missions into these orbit has declined since 1996 and with it the useful low cost launch opportunities for microsatellites. Whilst Ariane-5 has an enhanced capacity ASAP, it has yet to be widely used due to the infrequent launches, higher costs, and the unpopularity of the GTO orbit required by the majority of customers. China, Japan and India have also provided occasional launches for small payloads, but not yet on a regular basis.

Fortunately, the growing interest and demand for microsatellites coincided with the emergence of regular, low cost launch opportunities from the former Soviet Union (FSU) - both as secondary 'piggy-back' missions or as multiple microsatellite payloads on converted military ICBMs. Indeed, the FSU now supplies the only affordable means of launching minisatellites (200-500kg) into LEO as dedicated missions on converted missiles as these larger 'small satellites' are often too big to be carried 'piggy-back'. The entrepreneurial effort of leading FSU rocket & missile organisations has taken over providing launches for the small satellite community with an excellent track record.

However, negotiating and completing a Launch Services Contract for a micro-minisatellite with any launcher organisation is a complex matter and risky territory for the unwary or inexperienced - who may fall prey to unexpected costs and delays. Whilst this warning should be heeded when dealing with European and US organisations, it is particularly relevant to negotiating launches from the FSU where there is a plethora of agencies and organisations providing a bewildering range of launch vehicles and options. Furthermore, the FSU has developed a very different technical and managerial philosophy towards launchers when compared with the West and this can be unnerving to 'first-time buyers'. Organisations experienced in dealing in the FSU will encounter an excellent service - once the launch service agreement has been thoroughly and fiercely negotiated in every detail. Inexperienced buyers have encountered delays, lost opportunities, unexpected taxes, additional cost for services or facilities not originally specified, and frustration at the different procedures used in the FSU. Fortunately, all this can be avoided and the FSU is the current mainstay for launching small satellites quickly, affordably and reliably.

SSTL has unique experience gathered over 22 years in handling launches for small satellites, ranging from a 6kg nanosatellite, 50-120kg microsatellites, and a 325kg minisatellite, using 7 different launchers from the USA, Russia, Ukraine, and Europe. This experience, and working closely with organisations in the FSU, has enabled SSTL to provide good value launches for its small satellite customers without delay and with an excellent launch success.

The paper will describe the experience gained by Surrey, across the various launch providers, in successfully launching 21 small satellites - affordably, reliably and quickly. It will highlight the key factors that are necessary to ensure a 'good experience'.

1 INTRODUCTION

Today, small satellites have developed to play a full part of space technology. They have grown from experimental activities to operational systems. One defining factor in the development has been the availability of launch opportunities at reasonable cost. In the 1970s and early 1980s, spacecraft were generally only getting bigger and heavier. The possibilities offered by the emergence of miniaturized electronics was recognised by researchers at the University of Surrey, who managed to build the first modern, microprocessor-controlled microsatellite UoSAT-1. This satellite was launched in 1981 by NASA as a secondary payload on a Delta-2 launcher, together with the Solar Mesosphere explorer.

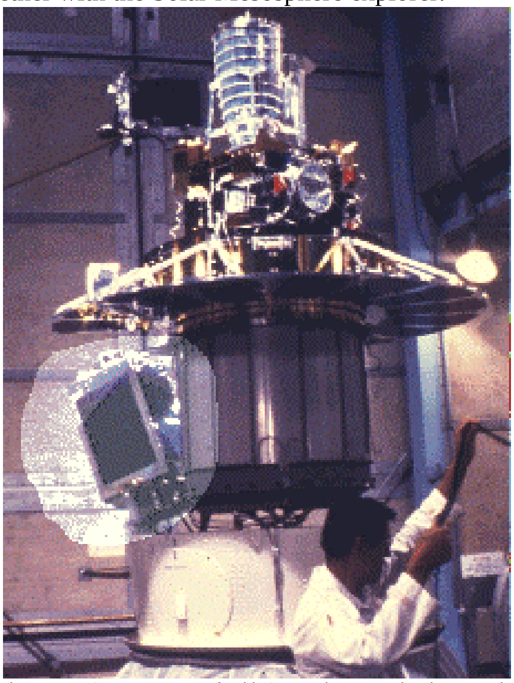

Figure 1 UoSAT-1 spacecraft with SME primary payload on a Delta launcher (Highlighted)

UoSAT-1 exceeded its orbital life expectancy by five years, and, when it finally re-entered after more than eight years in orbit, it was still functional. Based on this success a second satellite was built and UoSAT-2 was launched again as a piggy-back payload on Delta in 1984, together with the Landsat-5 primary payload. This satellite is still operational after more than 18 years in orbit.

SSTL has continued to launch spacecraft on a variety of launchers: as secondary payloads; shared launches; and one as primary (only) passenger [1].

Figure 2 UoSAT-2 spacecraft with LandSat-5 primary

Table 1 shows the launch vehicles and the number of SSTL spacecraft launched on them.

Launcher	Number of launchers	Number of spacecraft
Delta-2	2	2
Ariane-4	6	10
Tsiklon	1	1
Dnepr	2	2
Kosmos	2	3
Zenith	1	2
Athena	1	1
TOTAL	**14**	**21**

Table 1 SSTL launch history

2 SECONDARY LAUNCHES

Secondary launches have developed as a result of the increasing capability of launch vehicles. The available mass is not always being used completely by the primary payload, this is normally compensated for by the use of balancing weights. A typical Ariane-4 launch may have a 200 kg aluminium ring inserted between the launcher and the payload when launched into low Earth orbit.

The fairing diameter is also mostly fixed, and any unused space could be made available to secondary spacecraft.

Over the years NASA offered secondary launches into Low Earth Orbit for free to educational and amateur organisations like AMSAT. Twelve such spacecraft have been launched, starting with OSCAR-1 in 1961 to SUNSAT in 1999. This is a rate of about one every three years. The FSU has also launched some 19 of educational and amateur satellites over the years.

3 CHARACTERISTICS OF SECONDARY LAUNCHES

The defining characteristic of a secondary launch is that the mission must accept all constraints imposed by the primary payload:

- Launch date
- Launch date slips (or advancement!)
- Launch time
- Launch cancellations
- Available mass
- Available (often fixed) volume
- Target orbit
- EMC-RFI limitations
- Permitted materials used in the spacecraft

As an illustration, typically when a secondary passenger spacecraft is not ready in time, or the launch agency deems that the risk of launching it would be to great to the main passenger or the launch vehicle, they can decide to leave the satellite on the ground, and launch a mass dummy instead. Arianespace for instance makes the secondary passengers manufacture and deliver a mass dummy to the launch site at the start of the campaign for just such an eventuality.

Being a secondary passenger may impose additional difficulties

- Access to the launcher for integration may be restricted to certain periods
- Few or no telemetry lines available for launch phase information
- Working area may be restricted
- There may be no control over the attitude or the timing of the spacecraft separation in orbit.
- There may be a delay in being allowed to switch the spacecraft on once in orbit to allow for sufficient distance from the main payload

For all these difficulties, there is the one major advantage: the launch cost is only a fraction, less than 10% normally, of the cost of the complete launch.

The launch price is often based in the marginal cost i.e. the additional cost incurred by the launch agency in order to integrate and launch the secondary satellite, although now that the market for small satellites is maturing, some launch agencies are offering launch prices based on the launch mass of the satellite: figures of 10,000 to 15,000 US$/kg have been quoted.

4 ARIANE-4 ASAP

As mentioned before, NASA has over the years provided on average one launch every three years suitable for secondary payloads, with no guarantee that this will continue. This meant that, when the University of Surrey decided to further develop its space activities, it was necessary to place this on a more commercial footing.

In 1985 a commercial company, called Surrey Satellite Technology was founded. The first satellite launch opportunity targeted by the new company was again one offered by NASA, but the primary satellite was delayed by several years, which meant that the launch opportunity was effectively lost.

At that time, around 1988, ArianeSpace developed the Ariane Structure for Auxiliary Payloads, or ASAP. This is a ring type structure, mounted on the third stage of the Ariane-4 launch vehicle. The aim of this structure was to provide regular access to space for small payloads by providing a simple dedicated interface [2].

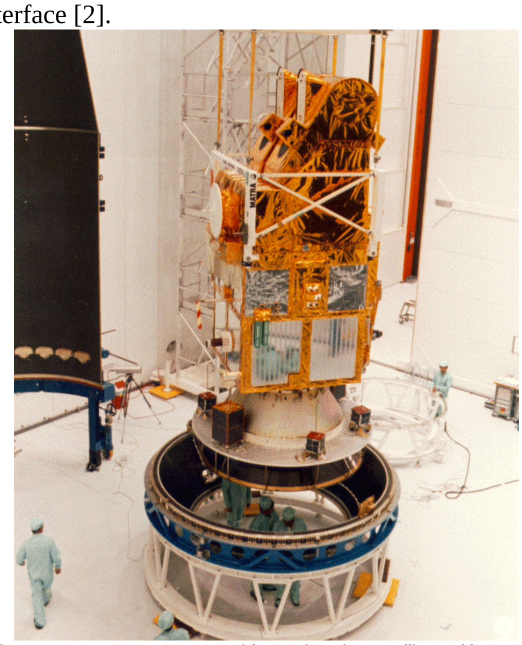

Figure 3 UoSAT-3, UoSAT-4 and four 10kg microsatellites with SPOT-2 primary on Ariane-4 ASAP no.1 (Vol. 35)

ArianeSpace had several reasons to develop this structure: [3]

- ArianeSpace wanted to develop the market for small satellites
- Arianespace wanted to offer this launch option as a trial to customers for main payloads, as a way to get teams trained in launch campaigns, essentially as a marketing exercise.
- There was spare capacity on most Ariane launches, especially those into Low Earth Orbits.

Developing a standard interface, and qualifying this with mass dummies, can reduce the analysis activity for each individual spacecraft, saving cost overall. The Ariane-4 ASAP system has been used on 7 occasions, once in GTO, all the others in LEO. SSTL has launched spacecraft on all the LEO ASAPs flown, and it provided a number of sub-systems including the separation system for the two spacecraft on the other ASAP into GTO.

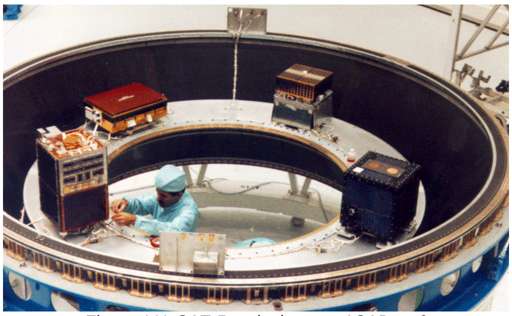

Figure 4 UoSAT-5 and others on ASAP no.2

5 LAUNCH AGENCY ACTIVITY

The launch agency has to perform a great number of activities in order to launch any satellite, almost independent of its mass, and even for a secondary satellite the list is quite extensive. It is based on the extent of these activities that the launch price is determined, rather than on the mass fraction of the secondary payload in relation to the overall launch mass. It is often the case that several secondary satellites sharing one launch pay the same price, even though their mass and volumes may differ widely.

Typical direct mission related activities performed by or on behalf of the launch agency include:
- Mass and volume analysis
- Interface definition
- Interface validation tests (fit-check meeting)
- Orbital separation analysis
- Launch campaign support
- Cleanroom space provision
- Launch
- Orbital debris analysis
- Orbital elements generation

The launch agency must also negotiate with the primary customer, as there is normally no financial benefit for main passenger in having secondary spacecraft on the same launch. Issues to be negotiated are for instance:
- Risk analysis
- Insurance
- Timescales for launch campaign activities
- Separation analysis
- EMC/RFI between main and secondary passengers

The following hardware is typically supplied by or through the launch agency as part of the contract:
- Spacecraft mechanical interface
- Spacecraft electrical interface
- Ordnance firing lines
- Telemetry lines through the launcher
- Separation system hardware (pyros)
- Specialised tools to enable integration
- Space on the fairing for a mission logo

Additional services normally supplied by or through the launch agency:
- Safety and security at the launch site
- Customs support for import of the spacecraft and associated support equipment, and return of the support equipment.
- Local transport
- Import and export licence application support

All these services are normally subject to negotiation, and are usually captured in the launch services contract. The actual details are specified in the various appendices, of which the main one is the Interface Control Document

6 INTERFACE CONTROL DOCUMENT

The Interface Control Document (or ICD) is a collection of specifications of all technical and non-technical issues relating to the launch of a satellite. Subjects covered range from detailed mechanical and electrical interface drawings between the spacecraft and the launcher, to requirements for tests to be performed on the spacecraft before integration, and e.g. what medical and transport facilities are available at the launch site, what mains voltage is available and what plugs to bring for this.

The ICD is a 'living' document, which is under controlled release, and various updates are published during the course of the contract to keep track of information as it develops. It is the main technical document between launch provider and customer, and all and any information relating to the launch and associated activities must be recorded either in it, or referred to in it.

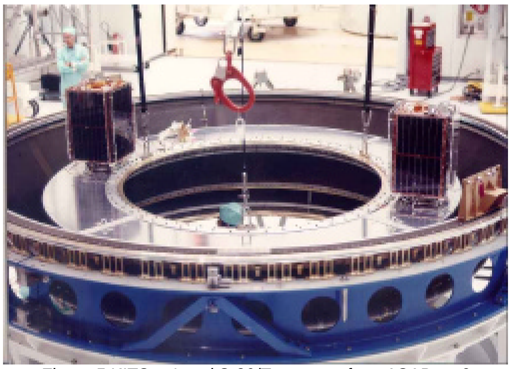

Figure 5 KITSat-1 and S-80/T spacecraft on ASAP no.3

Launch agencies like ArianeSpace, who have a long history of dealing with commercial customers, have a standard document, in which the details are completed as the activities progress. Other launch suppliers will negotiate a new ICD for every launch, and this is often a learning process for both sides. FSU launch providers for instance may have a different understanding of what constitutes a clean room compared to western launch ranges, but on the other hand most facilities are quite adequate and SSTL has provided its own portable cleanroom to be set up in any assembly building on site. This way expensive refits of the launch facilities can be avoided.

7 THE LAST ARIANE-4 ASAP LAUNCHES

SSTL has launched ten satellites using the Ariane-4 ASAP, with a yearly launch between 1990 and 1993, but after that only a few of them have been available for launch into Low Earth Orbit. Only two such ASAP's have flown since 1993, both with military primary payloads. This restricted the access for secondary customers to military spacecraft. SSTL launched the Cerise and Clementine military spacecraft on these launches, in 1995 and 1999 respectively.

As Ariane-4 is no longer produced, and the last ones are not planned to go into LEO, this launch availability has now ceased.

8 FSU LAUNCHES

Launch vehicles of the Former Soviet Union (FSU) tend to be manufactured in large batches, with little possibility of modification. The main spacecraft however come in a wide variety. These spacecraft tend to use a few standard busses that often have large margins available, both in terms of mass and volume. This allows small satellites to be carried on 'piggy-back' on the main satellite itself.

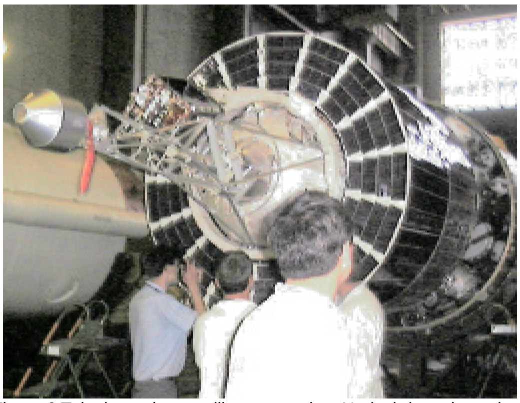

Figure 6 Tsinghua microsatellite mounted on Nadezhda main payload

Mounting spacecraft onto another spacecraft has both advantages and disadvantages:

- There is no standard interface, this must be negotiated every time
- The mass and volume may have tight restrictions, but there often is room to negotiate specific extensions
- There is no interface to the launch vehicle, technical negotiations can happen directly with the main passenger. This is often simpler than having to go through a third party.

With any launch it is important to have clear specifications in the launch agreement on all aspects of the launch and associated activities, but with launches from the FSU this is all the more true, as typically there are organisations from various nations involved, and the activities are also often spread over several countries. Some of the types of organisations that SSTL has dealt with are the following:

- Launch agreements with the Russian Space Agency
- Technical agreements with various Russian main satellite providers
- Launch and technical agreements with a Ukrainian main satellite provider
- Launch campaign activity with a Ukrainian rocket manufacturer
- General coordination with the Russian Space forces

Figure 7 Cosmos launcher for Tshingua and SNAP-1

In order to ensure that all agreements and permissions are in place it is important to have good insight in which organisation is concerned with what part of the activity: not only are there many organisations to deal with, but responsibilities of these organisations tend to change over the years.

There are many western agents who are marketing FSU launchers, but SSTL has always found it most beneficial dealing with the launch providers direct. For this SSTL employs Commercial Space Technology (CST) as its agent in Moscow. CST keeps SSTL up to date with the latest developments in availability of launches and facilitates the negotiation and execution of the Launch Services Agreement.

SSTL has launched eight spacecraft using FSU launches since 1995, and has signed up for two more launches for another seven spacecraft

9 FIT-CHECK MEETING

One of the first meetings after signing the contract for launch, and following the ICD meeting is a Fit-Check meeting. This is where the mechanical and electrical interfaces between the launcher and the spacecraft are physically checked against the ICD. This is done by bringing those parts of the flight separation system together with a size and mass representative model of the spacecraft to the launcher manufacturing facility and performing a full integration, as would be carried out at launch site.

This normally happens about six months before launch, before the launcher is shipped to the launch base. It allows for any problems that arise to be sorted before arriving at the launch site. Not only would there be little time available, but also the technical facilities at the launch site may not be suitable to manufacture or modify any equipment.

The entire launch vehicle integration procedure is normally performed, often concluding with an actual firing of the separation pyros to ensure correct operation of all mechanical systems and electrical connections. This also ensures that there is appropriate access for tool access for the activities. This meeting is also a good forum to discuss any additional issues for the actual launch campaign.

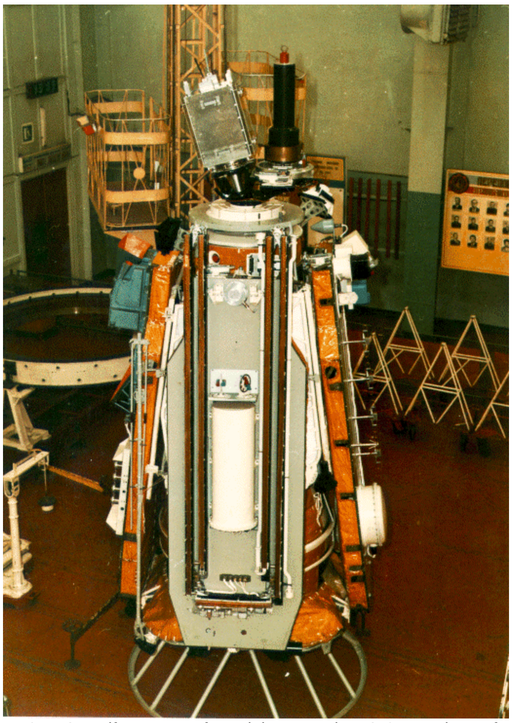

Figure 8 FASat-Alfa spacecraft model mounted on SICH-1 primary for the Fit-check meeting

The ICD is updated with any particulars of note, ensuring that the launch campaign details can be finalised.

10 LAUNCH CAMPAIGN

It is important to check every detail of the ICD carefully, as technical facilities at a launch site may not be anywhere near to what one normally expects to have available at home. Launch sites tend to also be in remote places like Kourou in South America, or Plesetsk in Northern Russia. It may well take several days to travel to one of these sites, and as flights may not be available every day it could cause considerable delays if proceedings have to stop to get some more tools.

To limit this risk SSTL takes complete toolsets and support equipment to the launch site. The mass of the support equipment is typically about 1000 kg, for a 50-100 kg spacecraft, with a comparably large volume of shipping crates. For small organisations, like Universities, this may come as a shock, and the cost of a typical launch campaign may well be equal to what they budgeted to spend for the entire mission.

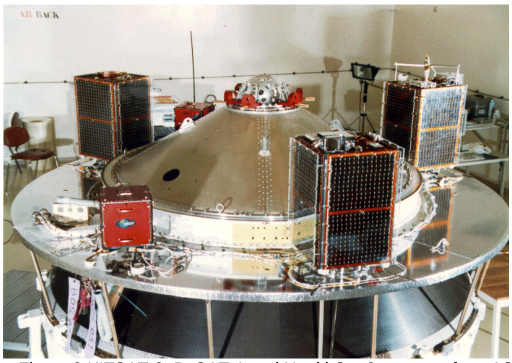

Figure 9 KITSAT-2, PoSAT-1 and HealthSat-2 spacecraft on ASAP no.4

A launch campaign can take anything from two weeks to over a month, but typically the spacecraft must arrive at the launch base about three weeks before the scheduled launch date to allow all preparations and tests to be completed. About one week before launch the spacecraft is integrated to the launcher, after which no access to the satellite is typically allowed. This means that the spacecraft design must be such that operationally there is no requirement to access the spacecraft during this time. Sometimes it is possible to charge to batteries shortly before launch, but that is the only activity normally allowed. SSTL always specifically negotiates battery charging and maximum periods without charging (e.g. in the case of a launch delay).

The launch campaign is used to perform those activities on the spacecraft that cannot be completed before arrival at the launch site:

- Final preparation of thermal surfaces
- Battery charging
- Removal of lens caps and other non-flight items like solar array protectors
- Insertion of flight arming plugs for the batteries and pyros
- Mounting of the spacecraft on the launcher
- Connecting of the pyrotechnics to the launcher
- Filling of propulsion systems

This time is typically also used to perform a final operational check of the spacecraft; this to show that there has been no electrical damage to the systems during shipping.

As small satellites typically have short development cycles, the time at the launch campaign is also used to further training of the operators, and to perform additional software tests.

With most launches, the spacecraft mounts onto an interface structure between the launcher (or main passenger) and in some cases it is possible to remove this interface from the launcher, and mount it on a separate stand. This is shown clearly in the case of the Ariane-4 ASAP. This entire ASAP is positioned in a separate building, where the secondary spacecraft can be integrated to it at relative leisure. Only at a late stage is the complete integrated structure then moved to the launch vehicle to be integrated as one complete unit.

Figure 10 TiungSat spacecraft being mounted onto its interface

For some FSU launches the spacecraft were mounted onto their individual supports, then the integrated secondary spacecraft with the support are moved to and mounted onto the main spacecraft

This has the major advantage that any operation near or on the main passenger or the launch vehicle is performed solely by the main spacecraft operators or the launch agency, involving only interfaces between units supplied by themselves. This means that is it very unlikely that there would be any problems with the integration at this point, which is important, as this mostly happens very shortly before launch.

11 SHARED LAUNCHES

Where there is no primary payload paying the bulk of the launch cost, the cost must be shared between the passengers on a different basis. Unlike the secondary launch, where a charge is made either on a fixed amount per kilo or on a marginal cost basis, here the entire launch price must be distributed.

The distribution of the launch costs over the satellites can depend on a number of factors:

- The mass of each spacecraft
- The volume of each spacecraft
- Any special requirements of individual spacecraft like orbit, launch date etc.
- Multiple launch deals

The advantage of a shared launch is that there is the possibility for any of the passengers to influence aspects of the launch, and if there are specific problems the launch could be delayed. This is unlike a secondary launch, were if the satellite is not ready in time the launch will go ahead with a mass dummy.

Figure 11 TiungSat-1 and others on DNEPR launch platform

With a shared launch the entire mass capability and the complete available volume inside the fairing can be used. It can be divided up between the passengers in the most optimum way. This in itself may require joint negotiation between the individual payloads

The Malaysian TiungSat spacecraft was launched together with a group of other small satellites on a shared Dnepr vehicle, and SSTL has signed up several Cosmos launchers to launch the eight Disaster Monitoring Constellation (DMC) spacecraft. This is a group of spacecraft working as a single constellation providing daily imaging of any place on Earth. These are owned by different customers, and they are built on different timescales, therefore the launches must be coordinated to ensure that all spacecraft end up in the same orbit.

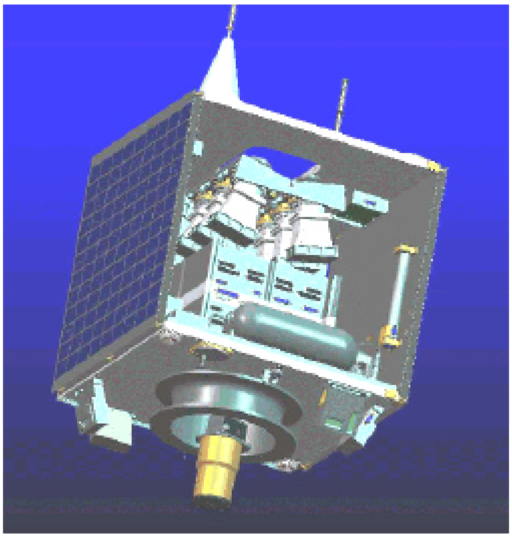

Figure 12 DMC-1 spacecraft

As there are enough spacecraft to fill up the launchers it was possible to sign up several rockets at once, and fill them up with a selection of spacecraft.

12 PRIMARY LAUNCHES

The development of small launchers, especially those based on ex ICBMs has made it feasible to consider launching a small satellite as primary customer in an affordable manner. SSTLs 325 kg UoSAT-12 experimental minisatellite was launched in 1999 as the primary and only customer on the first Dnepr orbital flight.

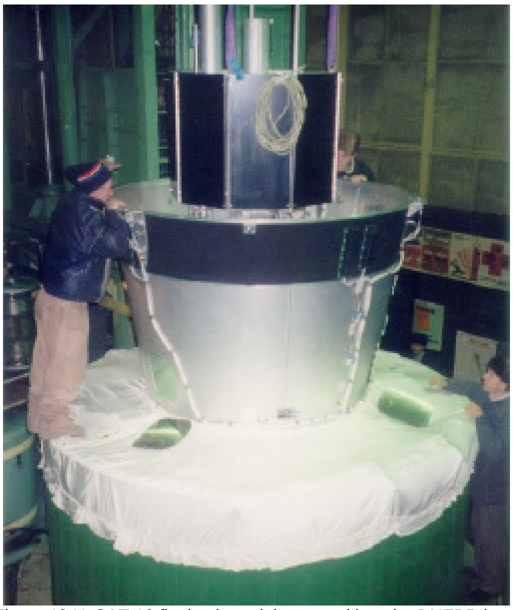

Figure 13 UoSAT-12 fit-check model mounted into the DNEPR head adapter

The primary customer typically has full control over the final orbit and the launch time and date, allowing full mission flexibility. In the case of the UoSAT-12 launch the launch provider decided the launch time and orbit, as it was a joint experimental activity between SSTL and Kosmotras, the latter demonstrating the full availability of the launch service, including ground facilities and support.

Figure 14 DNEPR launching the UoSAT-12 spacecraft

SSTL used UoSAT-12 to demonstrate several new platform and payload capabilities, including attitude agility, orbital control and high-resolution Earth observation.

13 LAUNCH CAMPAIGN PROBLEMS

No two launch campaigns are the same, and there are always lessons to be learned from problems that occurred during the execution of all activities. Problems have occurred with both western and FSU launch campaigns, but by having experience, being fully prepared and by having planned sufficient contingency time SSTL has always managed to make the launch in time, and successfully complete the launch campaign activities.

Small satellites on tight budgets can only allow short launch campaigns. There is little time between arrival at the launch site and launch. This means that it may be difficult to make up for any lost time, and it would be very costly to simply ship the spacecraft and support staff over early, as this would substantially increase the cost of the launch campaign.

Some examples of the actual problems that had to be dealt with during previous SSTL launch campaigns are the following:

- Shipping delay: two spacecraft stayed behind in transit in Paris, whilst the support staff was already in Kourou, it took another week before cargo space was found on a flight, as there are not many flights to French Guyana. Most large spacecraft travel by privately chartered aircraft to avoid such occurrences, but this is not possible on a small satellite budget,

- Customs delay: Two spacecraft spent several months in Moscow customs, as there was some disagreement over the details of the shipping list: whereas in Kourou a description of 'box of hand tools' would suffice, here an individual description of every screwdriver and spanner was required. This is easy enough when known in advance, but with no access to the boxes it is difficult to regenerate a list with that level of detail.
- Tax issues: For space launches mostly all items are deemed temporary imports: the support equipment because it will be shipped back to the UK; and the spacecraft because it will be launched into space. For one spacecraft the local customs officers thought otherwise, and demanded a 100% tax on the value of the spacecraft. This was sorted by getting the ambassador of the satellite customer's country to quickly negotiate an 'agreement of technical cooperation' between the countries, which then removed the tax liability.

14 SPACECRAFT DESIGN FOR SHARED LAUNCH

SSTL spacecraft have always been designed to be launched as secondary or shared passengers. This has meant simple and unchanging mechanical and electrical interfaces, and for instance launching the spacecraft 'dead' only switching on when separated from the launcher in orbit. This has made it simpler to negotiate launch services agreements, as there are few safety issues to deal with, and for a second launch with the same provider only a few updates are required.

15 PRESENT LAUNCHES

SSTL has signed a single launch services agreement essentially procuring three Kosmos launch vehicles under one contract for eight satellites including five for the DMC.

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Figure 16 Cosmos launcher with ALSat being raised for launch

The first of these launches was successfully completed in November 2002, launching the ALSat satellite for Algeria from the Plesetsk Cosmodrome in Northern Russia. As this paper is being produced we are in the middle of preparing for the second of the three Kosmos launches

This one will launch three SSTL satellites together with two Russian and one Korean craft into Sun Synchronous Orbit at the end of July 2003.

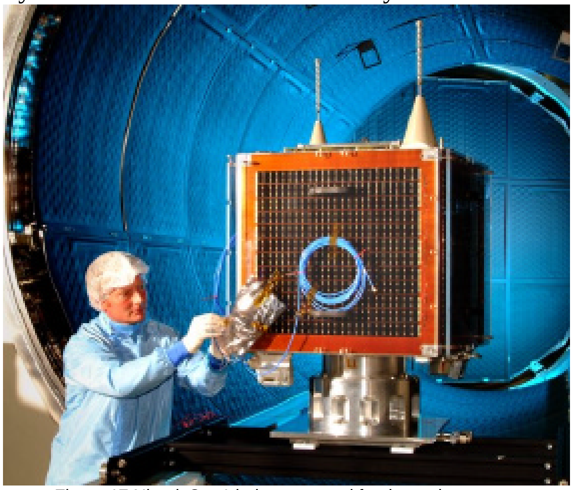

Figure 17 NigeriaSat-1 being prepared for thermal vacuum test

16 CONCLUSION

SSTL's experience of launching twenty-one spacecraft in twenty-two years has been described, detailing the specific attributes of launching a small satellite as either secondary or shared passenger with a main payload on a launcher. Specific problems that can occur and have actually occurred over the years have been described. This experience may well help preventing others from suffering the same difficulties, and make it easier and less daunting to embark on a launch activity for a small satellite.

"Prepare for Any Eventuality"

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