The Technology Demonstration Objectives of the Orbital Test Bed Mission: Using the Hosted Payload Concept to Advance Small Satellite Technologies and Scientific Capabilities

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ABSTRACT

This paper discusses the technology objectives of SST-US's OTB mission and the relevance of Surrey's hosted payload approach for flying U.S. government sensors and commercial payloads to enable the commercialization of small satellite products and technologies and advance the capabilities of future small satellite systems.

SST-US's second ride-share mission, OTB-2, is scheduled for flight readiness in 2016. OTB-2's mission parameters and applicability to diverse payload, technology, and science requirements are presented and reviewed. Using the most recent mission OTB, which successfully passed critical design review in January 2014, the upcoming OTB-2 flight opportunity, and a selection of previous missions as specific current and past examples, this paper also describes how technology demonstration objectives were achieved.

The paper also discusses different mechanisms for creating and exploiting fast-turnaround hosted payload opportunities, the common programmatic and mission integration approach that characterizes Surrey's hosted payload missions and the critical factors that enable success from mission to mission.

INTRODUCTION

Surrey Satellite Technology US LLC (SST-US) is a satellite mission prime contractor, with satellite manufacture, assembly, integration, and test facilities; and a satellite control and operations center, located in Englewood, Colorado. The U.S.-incorporated company was established in 2008 to address the U.S. market and its customer base. SST-US and its parent company Surrey Satellite Technology Limited (SSTL), collectively referred to as "Surrey," are world-leading small satellite mission and solution providers. With a flight heritage stretching back to 1981, Surrey has a long, proven track record of successful hosted payload missions, many with a technology demonstration objective. Having manifested over 50 hosted payloads on 31 of the 41 satellites launched at the time of writing, Surrey has unrivalled capability and a high degree of mission integration experience. The paper leads with a discussion of the hosted payload concept and the applicability of the hosted payload approach to meeting technology demonstration objectives.

A discussion of four of Surrey's previous missions illustrates that there is not a "one-size-fits-all" solution for providing hosted payload solutions. A repertoire of different methods for creating hosting opportunities is an important enabler for hosted payload customers.

Surrey combines a rigorous technical approach and end-to-end solution with inherently adaptable, modular designs, a flexible mindset, and the desire to fully understand each stakeholder's motivations and its key organizational and mission drivers.

The ongoing OTB and OTB-2 missions will form the basis for examining the Surrey hosted payload and mission integration approach and will inform the conclusions and recommendations for successfully integrating technology demonstration packages as hosted payloads missions.

THE HOSTED PAYLOAD CONCEPT

The Surrey definition of a hosted payload is a payload, a subsystem, or equipment that is not part of the primary mission and is accommodated, flown, and operated as a system using a commercial satellite (also referred to as the "host spacecraft") and ground segment resources and capabilities.

Based on Surrey's own experiences of executing hosted payload missions, this is an empirical, and therefore, a wider and more inclusive definition than the traditional space industry interpretation. This empirical definition encompasses the provision of flight opportunities and tailoring mission-specific commercial, technical, and programmatic solutions for a diverse range of government and commercial hosted payload customers.

"Hosted payloads" is a relatively recent term adopted within the industry during the past five years, and such systems may also be referred to as "co-manifested," "ancillary," or "secondary" payloads.**1**

In many cases, hosted payloads remain attached to the host satellite for the mission duration; however, the increasing capabilities of small satellites and their separation and deployment systems are stimulating possibilities for hosted payload systems to be deployed as free-flyers once the larger host satellite has reached orbit.

The impacts of the hosted payload mission stretch across many different organizations, and the collaboration and cooperation of diverse stakeholders are required to ensure the successful implementation of successful hosted payload missions. The primary stakeholders are the following:

1. Mission prime contractor
2. Satellite manufacturer
3. Commercial satellite owner and operator
4. Primary mission customer
5. Hosted payload customer
6. Hosted payload manufacturer

In many instances, a distinct entity does not perform the role of each stakeholder. For example, the primary mission customer is often the satellite owner and operator, and the hosted payload customer may also be responsible for designing and manufacturing the payload.

No two of Surrey's hosted payload missions have been the same, due to the variables that have existed in the primary mission, the hosted payload capacity available, and the hosted payload requirements. The underlying approach to hosted payload missions, however, has been a constant factor throughout.

BENEFITS OF THE HOSTED PAYLOAD CONCEPT FOR TECHNOLOGY DEMONSTRATION MISSIONS

There is a growing need and demand for reliable cost-effective access to space for technology demonstration and science objectives. Surrey's own evidence of this – namely experience of its flight opportunities being over-subscribed – is borne out by news articles and opinions expressed in industry publications.**2**

Technology demonstration missions are an indispensible mechanism for transitioning ideas from research to real-life applications. These missions enable the demonstration, infusion, and commercialization of new concepts, systems, and technologies in a non-operational mission scenario, for a fraction of the overall mission costs, thereby overcoming the problem of a lack of in-orbit flight heritage that is often a major barrier to operational mission implementation and commercial success in the space industry.

Technology demonstration payloads may have a strong experimental focus, being "firsts" in their scientific and technological fields, or may be "proof-of-concept" payloads, often with the aim of changing existing paradigms or achieving order-of-magnitude improvements in cost, performance, or schedule. The desired end result of such technology demonstration missions is to rapidly improve Technology Readiness Levels (TRLs) to demonstrate the performance, feasibility, and endurance of technologies in the physical environment of space. This allows final system requirements and Concept of Operations (CONOPS) to be fine-tuned and finalized to reduce the risk of deploying such systems in operational missions.**3** Furthermore, as the cost of technology reduces and accessibility and utility increase, the number of possible uses and applications also tends to increase, thereby potentially accelerating the adoption and integration of new technology into more missions.

Surrey acknowledges and understands that technology demonstration payload customers may be cautious about the hosted payload approach and may have concerns that the hosted payload mission provider can help achieve their objectives outside the context of a dedicated mission. It is therefore essential that the customer and mission provider adopt a collaborative partnership approach to ensure that both parties understand the key driving requirements and prioritize and address the primary objectives. Open discussions to challenge the mission needs, as well as managing the customer's expectations, are critical success factors in hosted payload missions. As an example, the United States Air Force (USAF) accomplished 85 percent of its Commercially Hosted Infrared Payload (CHIRP) mission objectives at less that 15 percent of the cost of building and launching its own dedicated satellite. (Data for this mission are in the public domain). It is important to understand which requirements are essential to mission success and will provide the necessary level of confidence for a technology demonstration payload to be used in an operational setting and which requirements have a disproportionate impact on the cost of the mission.**4**

Cost is one of the key drivers for the growing acceptance of and demand for the hosted payload approach. A payload "hitching a ride" on a commercial mission is driven to align its development with the host satellite's fast-paced programmatic milestones. Signing up for a hosted payload flight opportunity offering faster access to space necessarily results in a more rigorous approach to rejecting scope and schedule creep – and therefore costs – leading to greater programmatic efficiency.

The total mission cost is an important consideration in a hosted payload mission. Costs associated with building the instrument and satellite and procuring a launch are near-term and significant; however, the additional cost of operating the satellite and its payloads may lead to missions ending or not being extended while the mission is still generating useful data. In the case of technology demonstration missions, there is value in being able to characterize the performance and endurance of the system over time, and for science missions, in building a catalog of longitudinal data. Implementation of low-cost ground infrastructure and simple in-orbit operations to maximize the return of in-orbit assets are becoming increasingly important.

Surrey has a long heritage in technology demonstration and test bed missions, both of which are proven means for achieving the flight experience necessary to enable the commercialization and technology transfer of technological developments into future missions and business opportunities.**5** Surrey originated as an academic department within the University of Surrey (UoS), U.K., and has strong continuing links with the Surrey Space Centre (SSC) at the UoS. With this academic beginning and a background in developing space know-how with many other organizations, Surrey has a natural affinity with research and development programs and an inherent ability to work with educational, academic, and research teams in the government and commercial sectors.

From the hosted payload customer point of view, the customer must be sure that the route to orbit it selects is low-risk from a design as well as an industrial and implementation perspective. The customer needs "peace of mind" that the mission provider will deliver its system to orbit on time and within budget and with the necessary operating resources and environment to execute the mission to acquire vital in-orbit data and heritage. The customer can address many of these concerns by starting the hosted payload "journey" with a hosted payload opportunity provider with a track record in satellite manufacture, mission integration, and operations, using low-risk satellite platform designs.

CREATING HOSTED PAYLOAD OPPORTUNITIES FOR TECHNOLOGY DEMONSTRATION MISSIONS

Several different approaches can be employed either in isolation or in combination to generate hosted payload accommodation capabilities and flight opportunities on board commercial satellite missions.

Use of Excess Satellite Capacity

Using excess satellite capacity is the simplest option for hosting payloads that can be readily accommodated within an existing mission's baseline technical and programmatic envelope. It is the most cost-effective and efficient approach for leveraging underutilized platform capabilities with the least additional risk and non-recurrent engineering (NRE).

Depending on the driving requirement, payloads suitable for using excess capacity typically require a relatively small proportion of the available payload mass and power and have simple accommodation, interfacing, and operational requirements. The mission provider can accommodate these payloads relatively late in the mission schedule as the primary and secondary mission designs mature and design margins are released. Surrey employed this approach on OTB – finalizing agreements for embarking several "last-minute" technology development packages in the weeks leading up to the OTB mission preliminary design review (PDR).

Enhancement of Baseline Satellite Capability

In some instances the mission provider can proactively create excess capacity or additional performance capability to support hosted payload mission needs. The provider can implement enhancements to the baseline primary mission solution to provide additional payload-supporting resources or CONOPS support by augmenting power generation with extra solar panels, improving satellite performance parameters through avionics changes, modifying data handling and transmission capabilities, or making mechanical modifications and repackaging to increase accommodation, footprint, and field of view (FOV) capabilities. Surrey implemented many of these strategies on OTB.

Spacecraft Growth

Satellite growth options, such as mechanical modifications, or "upgrading" to a different or larger platform size class can be investigated to provide additional payload capacity.

Technical changes can arise, such as adding additional avionics, adding interface electronics, or modifying the structure. Rather than attempting to reengineer an already-optimized solution, the provider can accommodate these changes rapidly, cost-effectively, and with low risk by considering a larger spacecraft platform, rather than attempting to re-engineer an already-optimized solution.

Payload Re-manifesting

Maximizing the benefits and returns of the whole mission is key to successfully hosting payloads. As such, the provider may adjust the total payload suite to suit the mission and orbit requirements. In some cases, the competing requirements of the primary and hosted payloads may be such that the provider can better meet the overall needs of the primary and hosted payload customers by iterating the payload combinations to be manifested on alternative upcoming flight opportunities.

Payload Aggregation

Uniting a group of discrete payloads and instruments from different providers that have complementary requirements to create a dedicated "test bed" mission to deliver all of them to orbit on one satellite is a successful approach – Surrey's TDS-1 being a good example.

Launch Scenario Flexibility

Rapid mission tempo and experience and visibility of the launcher market allow a wide range of different launch vehicle scenarios and orbit insertion options to be considered for hosted payload opportunities. Launcher diversity, combined with satellite compatibility with most launch vehicle envelopes and launch environments, allows launch vehicle selection to be tailored, based on the most commercially attractive option that meets the mission specific technical and timescale requirements.

The benefit of access to a wide range of international launch options means that there is a high likelihood of a flight opportunity being available within the required hosted payload mission timeframe. Acquiring additional launcher mass, to either increase the satellite payload carrying capabilities or to act as a satellite rideshare integrator, also serves as an enabler to providing the desired launch.

SURREY'S HOSTED PAYLOAD AND TECHNOLOGY DEMONSTRATION HERITAGE

Surrey calls on a long and successful history of flying technology demonstration missions as hosted payloads alongside its primary missions as illustrated by four recent missions: exactView-1 (eV-1), CFESat, GIOVA-A, and TDS-1.

exactView-1 (eV-1), Launched 2012

Primary Mission

exactView-1's primary mission is to provide the highest detection performance from a commercial provider in monitoring in near-real-time Automatic Identification system (AIS) data on the locations, speeds, and routes of vessels throughout the world's oceans.**6** The 100 kg-class exactView-1 was the highest detection performance commercial AIS satellite ever built at that time and the fifth deployed satellite in exactEarth's advanced vessel monitoring satellite constellation.

Surrey was responsible for the development, production, validation, and verification of the SSTL-100-based eV-1 spacecraft platform and upgrade of the customer's existing Surrey-built ground segment and for providing in-orbit commissioning and twelve months of operation services. Surrey adapted the baseline SSTL-100 platform design to accommodate several customer-supplied payload modules. The primary payloads comprised a two-channel AIS data receiver and a C-band downlink.

Figure 1: Launch Integration of exactView-1

Hosted Payloads and Technology Demonstration

Alongside the primary payload, Surrey also accommodated, flew, and operated a European Space Agency (ESA)-funded hosted payload suite.

One of the hosted payload elements was a Consultative Committee for Space Data Systems (CCSDS) translation node to demonstrate the capability of Surrey satellite platforms to interface with CCSDS-based systems and infrastructure, to leverage the investments in the existing installed base of CCSDS ground stations.

Some of the pathfinder technologies within the hosted payload suite that were developed, tested, successfully demonstrated, and gained flight heritage on the mission have since been developed as commercial products for use in upcoming missions.

The C-Band TTC and downlink will be flown again on the Canadian M3MSAT program and the S-Band TTC transponder on the twelve-spacecraft Formosat-7 weather and climate monitoring constellation, for which Surrey is the mission prime contractor. The Formosat-7 spacecraft are also flying updated versions of the RF Beacon and TriG instruments, which were originally flown on PICOSAT, an earlier Surrey–USAF technology demonstration mission, providing another example of the successful exploitation of instruments gaining in-orbit heritage.**7**, **8**, **9**, 10.

CFESat, Launched 2007

Primary Mission

Cibola Flight Experiment Satellite (CFESat) was a technology demonstration pathfinder mission, carrying eight new technologies for space flight validation, including a supercomputer equipped with field-programmable gate arrays (FPGAs), a new power supply, inflatable antennas, deployable booms, a new type of launch-vehicle separation system, and a high-density pack of AA lithium-ion batteries. Surrey's customer was Los Alamos National Laboratory (LANL), Los Alamos, New Mexico, a research lab of the U.S. Department of Energy (DOE).**11**

The primary objective was to survey portions of the VHF and UHF radio spectra. The experiment used networks of reprogrammable FPGAs to process on board the received signals for ionospheric and lightning studies. The mission also validated the on-orbit use of commercial, reconfigurable FPGA technology demonstrating several different schemes for the mitigation and correction of "single-event upsets" that would crash most computer systems in use at the time. CFESat was supported by the DoD's Space Test Program (STP) and was part of the STP-1 space flight mission. The highly configurable nature of the payloads meant that the CONOPS and resulting power thermal demands required close monitoring and control with payloads being switched on and off as necessary to balance the spacecraft resources.

Hosted Payloads and Technology Demonstration

LANL conducted over 20,000 experiments in the first two years of operations.**12**

Surrey was responsible for the development, production, validation, and verification of the SSTL-150-based spacecraft platform and ground segment and for providing in-orbit commissioning support services. Surrey implemented significant developments to accommodate, deploy, support, and operate the diverse science and technology demonstration payloads, including carbon fiber reinforced plastic (CFRP) solar arrays, deployable booms and hold-down-and-release mechanisms, as well as mechanical modifications to meet Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) launch environment and envelope requirements.

The CFESat industrial model demonstrated the successful approach for the accommodation of sensitive and classified payloads on a Surrey platform, with payload integration taking place at customer facilities. Surrey encrypted the payload data using a customer-provided COMSEC unit, integrated by the customer at LANL facilities after platform delivery.

Figure 2: CFESat integrated to the ESPA ring

LANL and Surrey have since exploited several of the payload technologies. Most notably are the variants of the FPGA architectures, which have been qualified for use on future missions; and the CFESat platform developments – in particular the successful demonstration of the ESPA-compatible mechanical configuration and deployable solar panel approach – have been pivotal in the successful realization of the OTB mission.

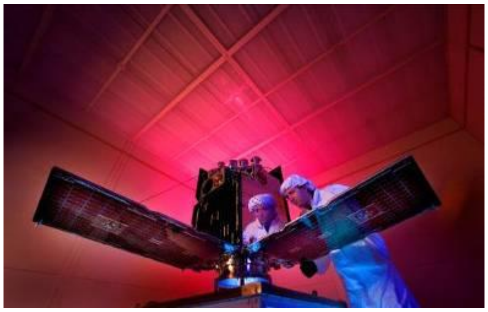

Figure 3: CFESat, ready for launch [Credit: Sanchez]

GIOVE-A, Launched 2005

Primary Mission

The GIOVE-A mission was an ESA program to develop, manufacture, and launch the first Galileo Satellite for Europe's Satellite Navigation System as well as secure the Galileo frequency filings at the International Telecommunications Union (ITU). GIOVE-A was a development satellite, required to act as a test bed to accommodate and fly the core Galileo technologies for first time. It was also Surrey's first mission as a prime contractor for ESA.**13**

Figure 4: GIOVE-A deployed in orbit [Credit: ESA]

Many of the Galileo payloads had very stringent accommodation requirements (thermal environment and stability in particular); Surrey successfully met these requirements using its standard satellite engineering practices and processes. Despite the extremely harsh and demanding radiation environment associated with the Galileo medium-Earth orbit (MEO), for which Surrey had not previously developed a spacecraft, Surrey successfully implemented the use of some commercial-off-the-shelf (COTS) components and technologies, all of which operated successfully for the mission's lifetime.

Surrey designed, built, and tested the satellite in a rapid thirty-month program and launched on schedule on December 28, 2005, allowing ESA to claim the frequency filings for the Galileo program three months before the license expired. ESA declared GIOVE-A a full mission success in 2008, and Surrey successfully demonstrated in this project that it can apply its low-cost rapid-response approach to a higher class of mission than had previously been thought possible.

Surrey successfully balanced the accommodation and operational requirements of the primary payload (including two redundant, small-sized rubidium atomic clocks, each with a stability of ten nanoseconds per day, and two signal generation units, an L-band phased-array antenna) and secondary payloads (comprising a Merlin space weather monitor, Cosmic-Ray Energy Deposition Experiment, a laser retroreflector, and a SGR-GEO GPS receiver) with the platform capabilities.

Hosted Payloads and Technology Demonstration

Although still operational, GIOVE-A was officially retired on June 30, 2012, having been successfully operating for much more than double its 27-month design life. Surrey took over operations of GIOVE-A and was able to operate and thoroughly demonstrate its SGR-GEO GPS receiver. The nature of this hosted payload meant only very short periods of operations during GIOVE-A's operational mission were possible. In April 2013 GIOVE-A was the first civilian satellite to perform GPS position fixes from above the GPS constellation.**14** This demonstrated that current satellite navigation signals could guide missions much further away in space, up to geostationary orbit or as far as the Moon. This successful demonstration and technology breakthrough has catalyzed the commercialization of the system for future MEO and geostationary missions for Surrey and other prime contractors and validated the platform designs which form the basis of Surrey's GMP-D and GMP-T geostationary spacecraft products.

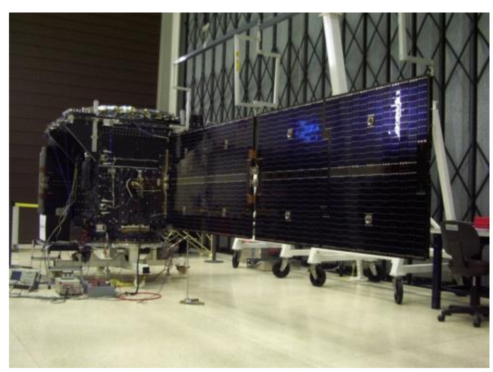

Figure 5: GIOVE-A during test

TDS-1

TechDemoSat-1 is an in-orbit technology demonstration mission for innovative U.K. spacecraft equipment and software. TechDemoSat-1 is based on the SSTL-150 platform and is part-funded by a grant from the U.K.'s Technology Strategy Board (TSB), and SEEDA (South East England Development Agency). The spacecraft is carrying eight separate payloads from U.K. academia and industry and over twenty product developments for Surrey, providing valuable in-orbit validation for new technologies in the form of physical payloads and software. Development of space technology is a key strategic objective for the U.K.**15**

Co-manifested payloads and technology demonstration

The payloads flying on TechDemoSat-1 are as follows:

- MuREM: a flexible miniature radiation and effects monitor from Surrey Space Centre, consisting of COTS devices that will be monitored while exposed to the space radiation environment.

- ChaPS: a prototype compact instrument to detect electrons and ions from the Mullard Space Science Laboratory that will demonstrate a payload design that combines the capabilities of multiple analyzers by using four miniaturized sensors to perform simultaneous electron-ion detection. Each of the sensors is optimized to carry out electrostatic analysis of the different space plasma populations expected in low-Earth orbit (LEO).

- HMRM: a lightweight, ultra-compact radiation monitor designed to measure total radiation dose, particle flux rate, and identify electrons, protons and ions from Rutherford Appleton Laboratory and Imperial College. The Highly Miniaturised Radiation Monitor is a disruptive new technology that is four orders of magnitude smaller in terms of volume than its predecessors, delivering energy spectrum information in the same way as its larger counterparts. The compact form and savings of scale make this a commercially attractive radiation monitor for widespread use on spacecraft, providing real-time and cumulative dose information about the radiation environment in orbit.

- LUCID: a device that makes use of detector technology developed at CERN, to measure characterization of the energy, type, intensity, and directionality of high-energy particles from the Langton Star Centre.

- Compact Modular Sounder system: a modular infrared remote sensing radiometer unit from Oxford University's Planetary Group and Rutherford Appleton Laboratory that will measure the composition and temperature of Earth's atmosphere as well as demonstrate that an instrument on a small satellite can deliver the same well calibrated products as an instrument on a larger spacecraft.

- A de-orbit sail from Cranfield University to increase aerodynamic drag at end of life and reduce time to orbital decay to mitigate debris proliferation in LEO.

- Cubesat ADCS: a three-axis attitude determination and control subsystem from SSBV.

- Sea State Payload: a device using an enhanced GPS receiver from Surrey and components from a synthetic aperture radar from Airbus Defence and Space to monitor reflected signals to determine ocean roughness.

Figure 6: TDS-1, ready for launch

At the time of writing, TDS-1 is scheduled for launch on June 28, 2014.

CURRENT HOSTED PAYLOAD TECHNOLOGY MISSIONS: OTB

OTB is an SST-US-owned-and-operated mission to fly a suite of experimental and technology development hosted payloads and equipment alongside SST-US's primary payloads.**16**

SST-US is developing, producing, validating, and verifying the spacecraft and ground segment; accommodating and integrating the payloads; and executing the launch campaign and launch and early operations phase (LEOP). SST-US will also operate the payloads and deliver the payload data to its hosted payload customers.

The OTB mission evolved out of what was going to be a dedicated SST-US mission to fly a Surrey payload suite addressing multiple strategic opportunities and objectives. During the preceding years, SST-US participated in dialogs with many government and commercial teams who had payloads to fly but very little funding to finance a dedicated mission. Many U.S.-origin (designed, manufactured, or funded) payloads have flown on Surrey's previous international missions; however, there is an enduring demand and a customer "value" associated with being hosted on U.S.-owned satellites and delivered to orbit on U.S. launchers.

SST-US's market analysis indicated that teams with sufficiently mature business cases had definite interest in using available excess satellite capacity. SST-US decided to further stimulate this latent market by oversizing the original OTB satellite and to evolve the mission to provide capacity for such payloads, then offer the excess capacity to all U.S. market sectors on a commercial basis.[17]

The SSTL-150 ESPA configuration, proven on the CFESat mission and capable of meeting higher mass and power demands, provided additional payload capacity, growing the available payload carrying capability and permitting Surrey to solicit and accommodate additional hosted payloads for the flight.

The SSTL-150 ESPA platform flexibility made it possible for SST-US to accommodate a diverse range of payloads and equipment on a heritage platform with proven flight success. Surrey used the SSTL-150 ESPA for the CFESat mission for the U.S. Air Force on the first ESPA launch on the Department of Defense STP-1 Atlas 5 rocket – a program with similarly challenging accommodation and operational requirements and demands on platform resources.

Table 1: OTB Mission Parameters

Parameter	Value
Mission name	OTB
Baseline satellite platform	SSTL-150 ESPA configuration
Flight Readiness	Q3 2015
Launch Vehicle	Falcon Heavy
Orbit	Altitude: 720 km +/- 18.5 km Inclination: 24 degrees +/- 0.2 degrees
Mission Constraints	180 kg maximum mass for ESPA launch
Spacecraft Mass at CDR*	164.9 kg (15.1 kg below ESPA limit)
Spacecraft Power at CDR*	120 W OAP
***Including system margins**	

The SSTL-150 ESPA satellite platform flexibility made it possible for SST-US to accommodate a diverse range of payloads and equipment for the OTB mission on a proven, heritage platform. It was capable of meeting higher mass and power demands and provided additional payload capacity, which permitted Surrey to solicit and accommodate additional hosted payloads for the flight.

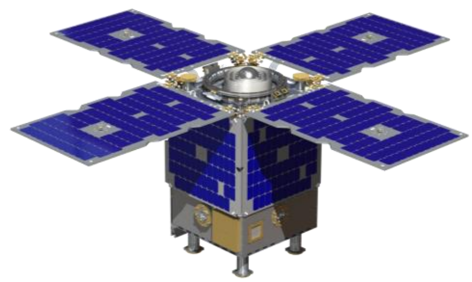

Figure 7: OTB, in deployed configuration

OTB PAYLOAD MANIFEST

The OTB mission is demonstrating and hosting a wide range of new platform and payload technologies and science instruments from a diverse government and commercial customer base. SST-US recently publicly announced the flight manifest and launch provider.[18]

OTB Primary Payload: SST-US Primary Payload Suite

OTB's primary payload is SST-US's Primary Payload Suite, comprising the Electronics Test Bed, the FlexRX receiver, the RadMon sensor, the CUSP instrument and the high-efficiency solar cell experiment.

The Electronic Test Bed seeks to evaluate and demonstrate a number of new electronic components, processors, and memory devices, enabling in-orbit heritage to be gained on components that may be incorporated into future Surrey designs.

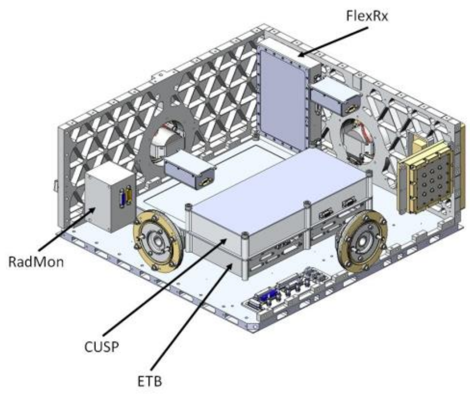

Figure 8: CAD image showing OTB's primary payload suite

FlexRX, Surrey's next-generation programmable receiver equipment is being flown to allow the in-orbit test, demonstration, and qualification of a new unit that will be used on future Surrey missions and sold as a commercial product for integration into third-party missions.

The RadMon is Surrey's latest generation radiation effects monitor that will collect data on the radiation environment in space for correlation with other OTB sensors and for applications in future Surrey missions.

Colorado University Surrey Project (CUSP) is a joint project between Surrey and the University of Colorado, Boulder. CUSP is a data collection and storage electronic test bed experiment built by students using off-the-shelf components, intended to test the low-cost development approach as much as the low-cost component technologies themselves.

Solar cells designed by EMCORE Corp. are being incorporated into the satellite power system. These EMCORE cells are more efficient than those flown on previous Surrey missions, consistent with Surrey's "fly new with old" philosophy. Gaining in-orbit heritage and performance characterization of these cells will be an important step in validating them for wider use on Surrey platforms and other missions.

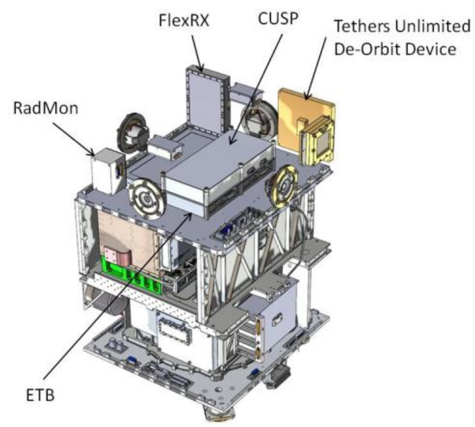

Figure 9: Accommodation of OTB's primary payload suite

OTB's Hosted Payloads

Deep Space Atomic Clock (DSAC)

The DSAC payload is a miniaturized, ultra-precise mercury-ion atomic clock that is orders of magnitude more stable than current space-based navigation clocks, DSAC is being developed by the California Institute of Technology's (Caltech's) NASA's Jet Propulsion Laboratory (JPL) for NASA's Space Technology Mission Directorate's Technology Demonstration Missions Program. DSAC will demonstrate the precise timing and navigation capabilities that will be required for NASA's pursuit of deep space exploration.**19**, **20**.

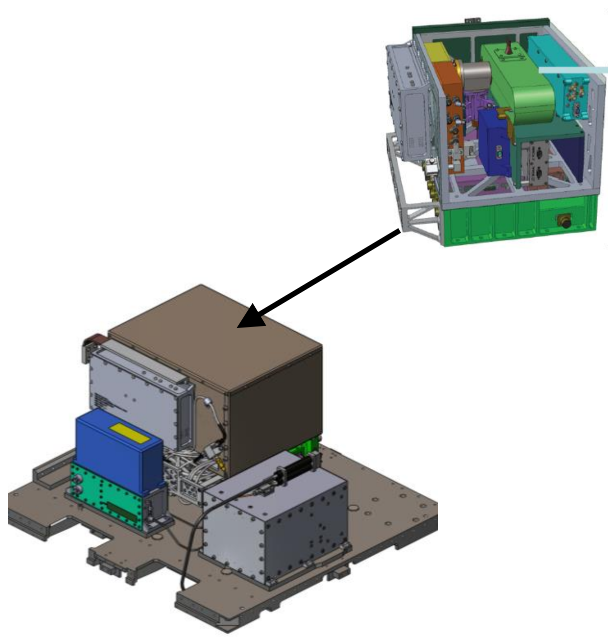

Figure 10: CAD model of the preliminary configuration of the DSAC Demonstration Unit [Credit NASA/JPL] and its accommodation on OTB

Modular Solar Array (MSA)

Developed by Vanguard Space Technologies for the U.S. Air Force Research Laboratory, the MSA will demonstrate flight readiness of a standardized modular approach to solar panels, with the ability of modules to be quickly replaced during final satellite testing prior to launch. Space-qualifying a system with this degree of interchangeability and change-out capability has the potential to reduce schedule delays (and therefore cost) before launch, when there is typically very little remaining schedule margin.

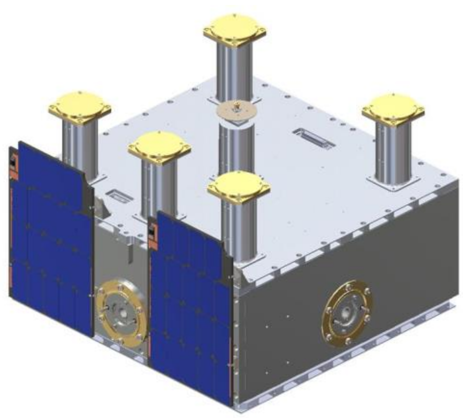

Figure 11: MSA panels accommodation on OTB

Integrated Miniaturized Electostatic Analyzer (iMESA-R)

Developed by cadets at the U.S. Air Force Academy in Colorado Springs, Colorado, the iMESA-R is a sensor that will sample the electrostatic field and electron density of the space environment to find plasma irregularities that may forecast outages in space weather models.

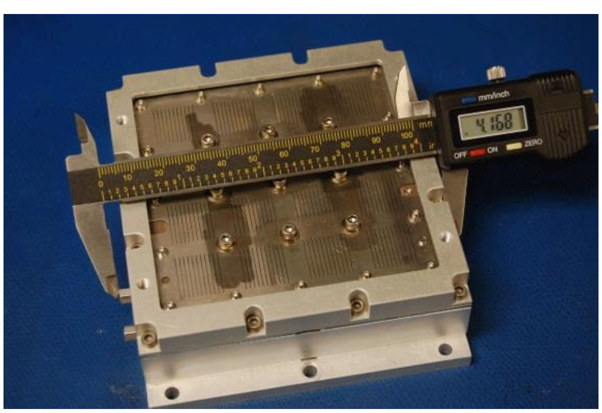

Figure 12: Precursor to the iMESA-R variant being flown on OTB [Credit R.Kiziah]

While iMESA instruments have flown on previous USAF missions, the variant flying on OTB features a new miniaturized dosimeter design.**21**

Terminator Tape Deorbit Module

OTB will test a Terminator Tape Deorbit Module**—**a device developed by TUI (Tethers Unlimited Inc.) of Bothell, Washington, to deorbit the OTB satellite at the end of its planned mission. TUI used their Cubesat tether design as the basis for this new, larger Small Satellite tether. The OTB mission will be the first Surrey spacecraft to fly a tether-based deorbit system. This passive de-orbit device is an ideal mass, power, volume, and cost-efficient solution to complement the business case closing objectives of the OTB mission; any typical fluid or solid-based propulsion device would impact the payload carrying capabilities of the satellite platform, in addition to requiring active control at end of life and additional redundancy and safety mechanisms.**22**

Figure 13: Terminator Tape Deorbit Module prototype

OTB'S HOSTED PAYLOAD FLEXIBILITY

The OTB payload manifest illustrates the broad variety of technologies and payloads that Surrey has successfully integrated into the mission, each with distinct and differing accommodation and operational requirements. The OTB system block diagram, presented in Figure 14, highlights why Surrey has the flexibility to fly a wide range of hosted payloads.

As owner of the mission and systems requirements, Surrey is able to reconfigure the mission solution by trading off and substituting compatible, proven Surrey units for the baseline systems as necessary to support the hosted payloads' aggregated operational requirements. All of the platform subsystems are Surrey-designed and built to allow a high degree of interface "tuning" and optimizing from the unit level up to the subsystem, system, and mission-level. This approach is at the opposite end of the spectrum from a typical industry "black-box integrator" – designing and building a platform and mission solution from bought-in units; managing ongoing inflexible interfacing, operation, and compatibility requirements at the platform level; and reducing the opportunities to adapt the primary mission for other hosted payloads.

Surrey's standard system architecture allows the interface between the hosted payload and the platform to be created at any point, for example:

1. Via a payload-specific PIU (Payload Interface Unit);

2. Via a platform-level PIU which performs the interface function for all of the hosted payloads; or

3. Directly into the spacecraft platform via the CAN bus, RS422, LVDS or other interface standards.

For the OTB mission, Surrey is implementing two of these scenarios: option 1 for the DSAC payload and option 3 for all other payloads.

OTB LOW-COST GROUND SEGMENT AND OPERATIONS

Surrey's existing ground segment infrastructure is capable of all mission operations for more than twenty satellites, simultaneously. Surrey will use the infrastructure for pre-launch system validation during system end-to-end tests (SEETs) and other verification checks, launch campaign, LEOP, and spacecraft and payload checkout tasks. Surrey will also use the infrastructure for executing all satellite, primary payload, and hosted payload in-orbit operations. The orbit and inclination of the OTB mission require the incremental inclusion of additional ground station capability. These capabilities will be interfaced into the existing Surrey ground segment architecture through a standard low-cost approach of installing of Surrey mini-racks on tertiary sites.

The SST-US Spacecraft Operations Center (SOC) will serve as the primary operations center for coordinating spacecraft and payload tasking, mission monitoring, and managing and providing payload mission and health data to all of OTB's payload customers. The SSTL SOC will act as the secondary operations center.

Surrey will encrypt payload mission and TTC data on the uplink and downlink for all OTB payloads and make available mission data to each customer via

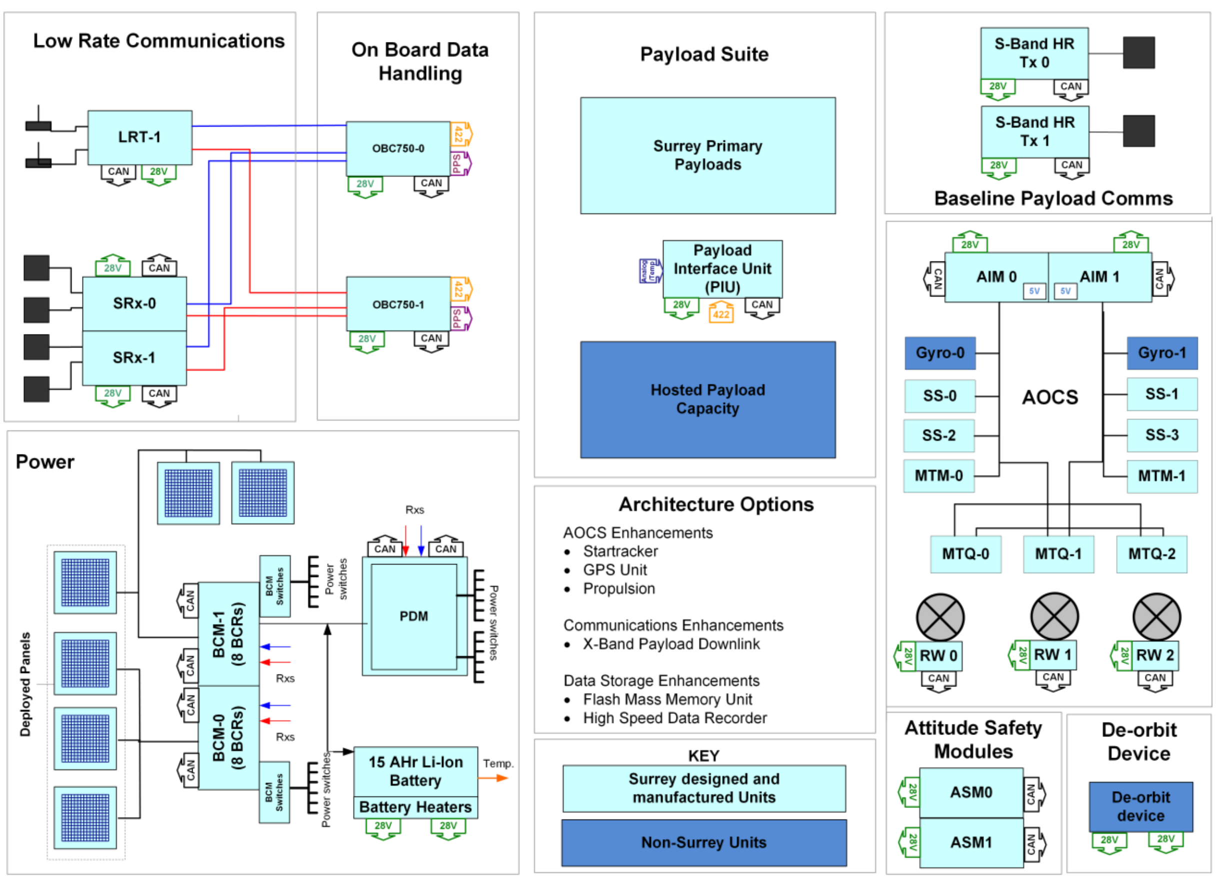

Figure 14: OTB system block diagram

dedicated FTP sites.

final assembly and payload integration, spacecraft-level testing, and flight readiness activities. OTB will be

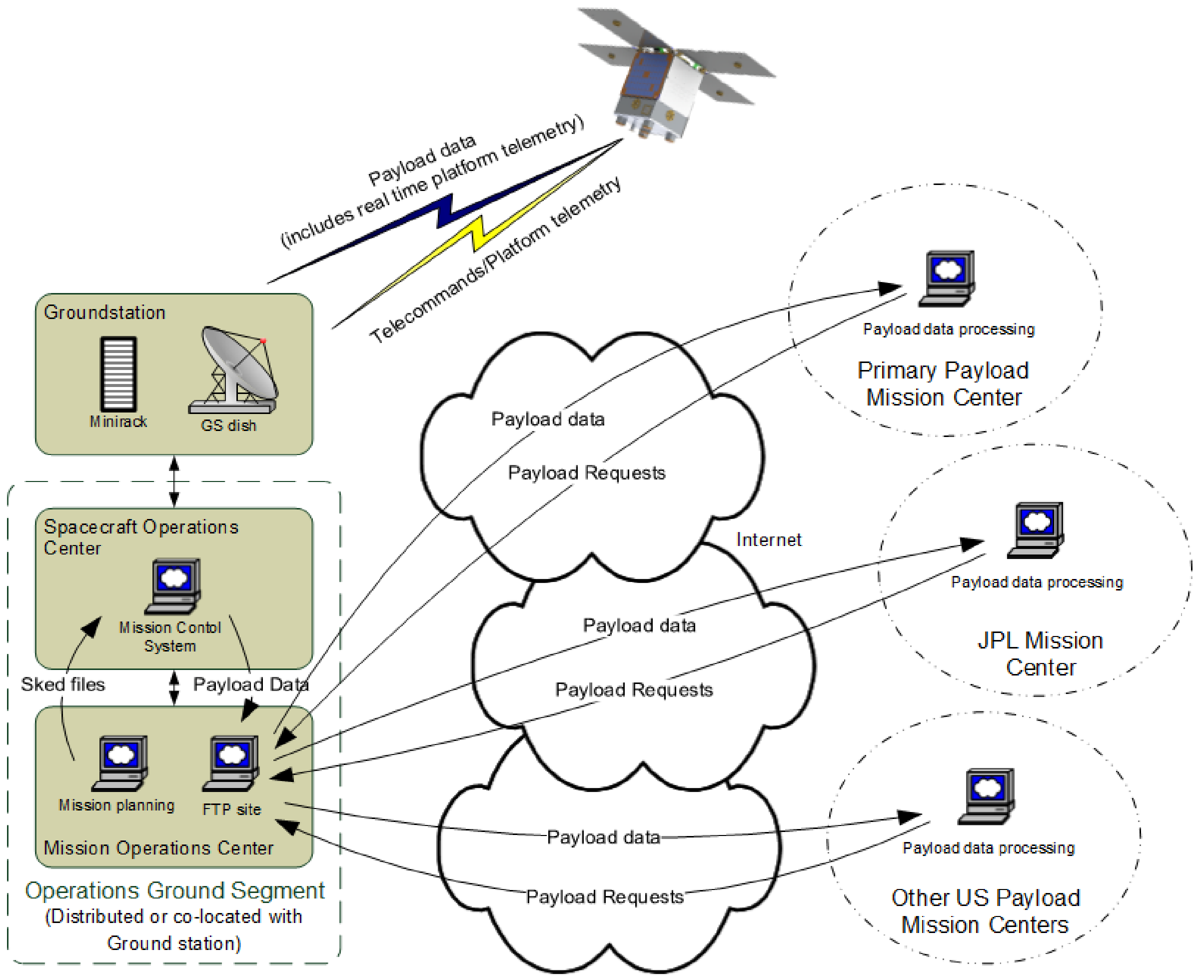

Figure 15: OTB Mission Architecture

Surrey's spacecraft operations are designed to support a highly autonomous, "lights-out" concept during routine operations. This highly-automated space and ground segment approach reduces operations costs and maximizes operational flexibility and reliability. The "lights-out" concept is supported by operator notification in the event of anomalies and full manual control via telemetry and telecommand systems. This is achieved through distribution of system functionality in both ground and space segments.

OTB PROGRAM STATUS

At the time of writing, the OTB program is in post-CDR phase and preparations are underway for assembly of the spacecraft prior to platform testing. SSTL is manufacturing and assembling the platform modules. SSTL will ship the platform to SST-US for launched on the Falcon Heavy as part of the STP-2 launch manifest with the assistance of the DoD.

THE OTB-2 MISSION

SST-US recently announced plans for a second Orbital Test Bed (OTB-2) ride-share mission dedicated to flying technology demonstration payloads, subsystems, and equipment. OTB-2 is scheduled for launch into low-Earth orbit in the 2016–2017 timeframe.**18**

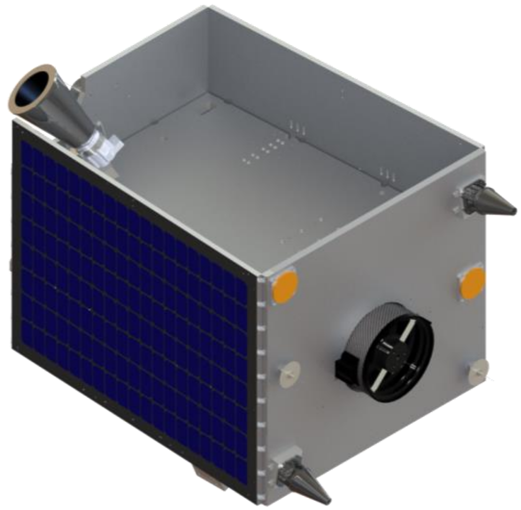

Figure 17: The flexible hosted payload deck of the OTB-2 satellite

physical accommodation and environmental envelopes – maximizing the likelihood of a launch in the required timeframe.

The straightforward interfacing of the SSTL-150 supports ease of integration and adaptability of the platform for payload accommodation. Figure 17 illustrates the SSTL-150's capability to accommodate many different payloads. Surrey originally baselined the "RapidEye" configuration for the OTB mission for the same reasons; however, the mission-specific drivers for OTB resulted in the evolution to the SSTL-150 ESPA configuration.**25**

 TOPSat October 2005	 DMC+4 October 2005	 CFESAT March 2007	 RapidEye x 5 August 2008
 Sapphire February 2013	 TDS-1 Q2 2014	 KazMRES Q2 2014	KAZSTSAT

Figure 16: The SSTL-150 platform has been baselined for 12 previous and current missions

OTB-2 Spacecraft and mission overview

The OTB-2 baseline satellite platform is the SSTL-150, a heritage platform used for twelve spacecraft in the Surrey mission fleet, including KazEOSat-2 and TDS-1 satellites.**23**

Surrey has always maintained that launch vehicle flexibility is a key mission enabler.**24** Surrey has baselined the SSTL-150 "RapidEye" platform for OTB-2 because of its compatibility with a wide range of international launch vehicles and their associated

At the time of writing the top-level OTB-2 mission parameters that Surrey has released into the public domain are as follows:

Table 2: OTB-2 Mission Parameters

Parameter	Value
Mission name	OTB-2
Baseline satellite platform	SSTL-150
Flight readiness	2016 (launch window not publicly announced)
Orbit range	700 km +/-50 km
Hosted payload mass carrying capability	50 kg
Available hosted payload power	85 W orbit average power (OAP)
Hosted payload volume dimensions (dims), depicted in green in Figure 18	External dims: 735 x 870 x 250 mm Star Tracker subtracts corner volume of 308 x 105 x 250 mm 250 mm external payload height may increase depending on launch vehicle Internal dims: 268 x 299 x 115 mm
Mission lifetime	5–7 years, depending on final payload manifest and CONOPS requirements
Published *baseline* values. These are non-mission-limiting values before implementation of any satellite enhancements and launch manifest confirmation	

OTB-2 Primary Payload: SST-US Imaging Payload

Surrey is flying its next-generation 1-meter imaging system. OTB-2 will be the first flight of this new imager, and being under full SST-US control and management, Surrey will be able to fully characterize and optimize its performance to drive improved performance on subsequent missions. In addition to the growing reliance on imaging data for environmental monitoring and rapid response to natural disasters, there has been a surge of interest in the commercialization of satellite imagery in the sub-1 m GSD (ground sampling distance) range, stimulated by the increasing demand for and use of business intelligence across a wide range of industries from agriculture to consumer goods.**26**

In many cases it is clear that image data business ideas do not progress through to funding and implementation because of the immaturity of the satellite and data provision infrastructure providers or because the total mission costs are too high or not sufficiently defined; however, Surrey has already demonstrated the necessary degree of end-to-end space and ground architecture capabilities and financial controls essential to close business cases for its customers through delivery of fixed-price, schedule-efficient programs for either customer ownership or data delivery business models.

OTB-2 Hosted Payload Accommodation Flexibility

As depicted in Figure 18, OTB-2's nadir-pointing primary imaging payload is accommodated internally, leaving the top deck free to accommodate many different payloads and instruments and support a wide range of physical orientation and FOV requirements. There is also scope to accommodate smaller payloads internally.

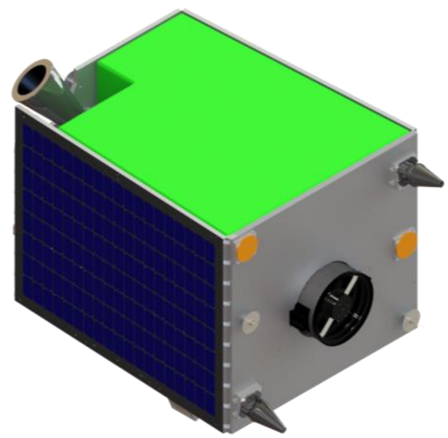

Figure 18: OTB-2 hosted payload accommodation capability (depicted in green)

This flexibility allows a wide range of missions to be supported, such as Earth and space sciences, remote sensing, technology demonstration, space situational awareness, communications, and navigation. New satellite platform technologies such as batteries, processors, AOCS units, and solar panel systems, may be incorporated into the baseline solution or flown alongside the primary spacecraft systems according to their technology readiness levels, technology demonstration objectives, and overall mission risk profile.

The OTB-2 baseline platform architecture is the same implemented for the OTB mission, thereby providing the high degree of mission and and payload flexibility necessary to accommodate and operate many different payload and mission requirements.

OTB -2 Programmatic Flexibility

Surrey has baselined a standard 24-month mission development schedule for the OTB-2 mission from program kick-off to flight readiness.

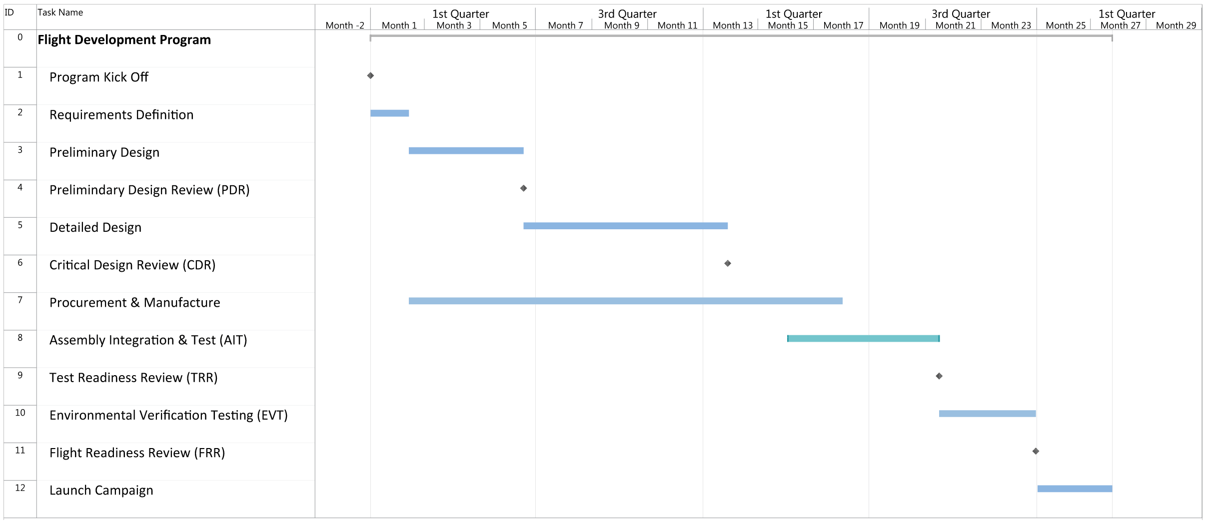

Figure 19: Standard Surrey 24-month SSTL-150 mission project schedule

Surrey has been successful at supporting the progress of customers' relatively early-stage concepts and designs, in parallel with maturing the overall mission and platform solution, primarily because of the accommodation and interfacing flexibility that is a mainstay of the Surrey platform design and implementation approach.

Typically, the larger the proportion of available resources required for a hosted payload, the earlier in the program a contractual commitment will be required, in order to secure the hosted payload flight opportunity. Formal contractual authorization for hosted payload flights is baselined to occur by OTB-2 platform CDR or approximately 18 to 24 months before flight readiness for complex payloads. However this could occur as late as 9 to 12 months before flight readiness for simple payloads. A similar flexibility is provided during physical integration: due to the stability of the structure design, as well as the platform assembly and integration process, payloads with a well-defined interface could be delivered as late as flight readiness minus four months, thereby maximizing the time that the hosted payload customer has to ensure flight readiness.

Several of Surrey's previous programs have accommodated changes in payload mechanical, electrical, and physical accommodation, sometimes late in the program, and in some cases even during the spacecraft environmental test campaign. The responsive and flexible approach used by Surrey in those instances was instrumental to the success of the mission.

MEETING THE CHALLENGES OF HOSTED PAYLOAD PROGRAMS

The vast majority of Surrey's missions have flown secondary payloads; therefore, Surrey fully understands the challenges associated with the hosted payload concept, and how best to address them.

The technical and programmatic requirements of hosted payload missions are not to be underestimated; however, the practice of managing and aligning mission integration and schedule requirements is a well understood and proven part of the standard flexible and pragmatic Surrey business approach.

Surrey's experience is that it is typically the commercial and contractual issues that take the most time and effort to resolve, in addition to setting expectations about the degree of insight into and influence on the primary mission that hosted payload customers can reasonably expect, in the context of their participation as a "passenger on the bus."

A flexible and proven approach based on a strong commercial mindset allows the support of customer-specific accommodation, programmatic, and operational requirements, without introducing any significant additional technical, programmatic, operational, and financial risks in the process. Some of the challenges which need to be managed in order to ensure programmatic success, include:

Management of the Primary Mission Schedule

Manufacture of some spacecraft elements often needs to be initiated before all of the hosted payload interfaces have been fully defined, in order to maintain the primary mission milestones. This is a typical approach for Surrey and is undertaken in accordance with the organization's risk management methodology. Reliance on a heritage flexible satellite solution that allows the early procurement and manufacture of "legacy" design elements and a rigorous change management philosophy are essential in order to facilitate this approach.

Management of the Hosted Payload Schedules

The programmatic milestones prescribed by Surrey for each hosted payload is influenced by each payload's maturity, the proportion of payload resources required, and the payload's complexity. Technology demonstration payloads are typically new developments wherein the designs are normally frozen relatively late from a commercial program perspective. Surrey's ability to maintain mission flexibility a long way into the commercial mission schedule enables such systems being manifested. In the case of the OTB DSAC payload – a technology development program carrying high design margins, consuming a high proportion of satellite resources, and having complex accommodation and operational needs – SST-US began evaluating its accommodation nine months before the other hosted payloads. By contrast, iMESA-R is a newer variant of a payload that already has flight heritage and is being flown to augment existing in-orbit coverage and generate more flight data. SST-US began factoring the iMESA-R into the OTB design trades only three months before PDR.

Program De-risking

It is essential that the hosted payload mission is able to meet the schedule requirements of the commercial mission. The approach that Surrey follows to de-risk both technical and schedule factors is an important aspect of ensuring that the project stays on scope, within budget, and on schedule. Surrey defines a timetable of design dependencies and data and simulator deliverables for each payload to ensure that all elements of the space and ground solution are implemented, tested, and verified. In the case of DSAC, SST-US delivered an engineering model and payload interface unit to JPL for the team to use for software development and pre-flight operations simulation.

Optimization of Integration Flow

The physical location of candidate hosted payloads payloads dictates the optimal integration flow and the payload delivery schedules to some extent, as does the payload complexity and associated validation and verification activities. In the case of the SSTL-150 "RapidEye" and SSTL-150 ESPA designs, the spacecraft avionics elements are efficiently stacked within the interior of the spacecraft volume. This enables payload units to be located and accommodated within the upper volumes of the spacecraft envelope, and allows all of the payloads to be integrated after platform integration, which affords integration sequencing within the constraints of the assembly, integration and test (AIT) and environmental test (EVT) schedule segment.

Commercial and Contracting Challenges

Cost is only one factor in the business case analyses that hosted payload customers and stakeholders perform when developing their mission plan. A combination of financial, commercial, programmatic, risk, and other metrics are taken into consideration in the hosted payload decision-making process.

Surrey bases its commercial contracts on a firm-fixed-price (FFP) basis for a fixed scope, based on the prevailing understanding of the mission requirements. Surrey carefully examines any need for changes to the agreed scope, as such changes can significantly impacts of such changes to the cost or, schedule, and risk can significantly impact the mission be significant directly and indirectly.

Payload development contracts and timescales have typically driven mission schedules, which has led to the current government procurement and funding methodologies. The slower pace for approval and release of government funding is a challenge to reconcile with the faster pace of commercial missions and may discourage potential customers considering a hosted payload approach. However, this is not an insurmountable problem. The commercially-based contracting approach that SST-US has agreed with JPL for flying DSAC as a government hosted payload is a "first." SST-US and JPL worked closely together to agree on the terms of the commercial flight services agreement to address the development, production, accommodation, integration, launch, and operational aspects of the DSAC mission. SST-US successfully overcame the pricing and commercial challenges associated with structuring a commercial deal for a government payload flight. The agreement was derived from Surrey's standard commercial terms and conditions.

CONCLUSIONS

The hosted payload approach can achieve a wide range of technology demonstration mission objectives and allows a broad range of customers to mature their in-orbit capabilities. The benefits of sharing the "cost to orbit," flying on a low-risk and cost-effective bus design, coupled with efficient processes that provide mission reliability and low-cost "lights out" operations, yield a low total mission cost concept and customer peace of mind.

A hosted payload concept is not a solution for all missions; particularly for systems with unique requirements that may not be straightforward. Surrey has acquired tens of decades and hundreds of orbit-years of hands-on experience and understanding of the challenges and risks, and has developed a common-sense approach to managing inherent uncertainties. Surrey accepts that risks cannot be reduced to zero. For missions that are difficult to fly as hosted payloads due to constraints associated with spacecraft accommodation, available resources, launch vehicle availability, operational requirements, or programmatic demands, Surrey provides low-cost dedicated missions as an alternative approach to reaching orbit.**18**

There are several critical factors for successfully managing the many competing requirements of the primary mission and the secondary payloads. The mission provider must provide the primary mission customer with the confidence that the cost-sharing benefits associated with flying hosted payloads are not outweighed by the potential introduction of additional risks, schedule impacts, or mission performance degradation. The provider needs a well-established successful technical, programmatic, operational and commercial framework for delivery, and a broad depth of mission experience and customer support know-how.

The more control the hosted payload opportunity provider has over the solution and its subordinate elements, the more flexibility it can provide. In Surrey's experience, integrated organizational capabilities and integrated core equipment, plus the capability to design and manufacture the majority of its spacecraft avionics, mechanics, and software, allow precise control over schedule, cost, and risk through careful tailoring and design iteration. This approach permits the development of a robust space system even in case of late-breaking changes in scope, and provides commercial and institutional customers more mission return for their budget.

Underpinning the mission flexibility there needs to be a solid and comprehensive understanding and appreciation for the key mission drivers, and reduction of derived requirements and "nice-to-haves." Surrey addresses this by going beyond meeting stated requirements to carry out detailed and informed investigations in order to establish the driving requirements at a payload and mission level. This maximizes the opportunities to aggregate as many complementary systems on one flight opportunity for greater mission efficiency. A provider with a collaborative approach to working with payload customers and a flexible approach to eliminating unnecessary requirements will maximize the number of opportunities available for hosting payloads, as well as give the stakeholder group a high degree of confidence that its objectives can be achieved. Surrey's regular mission tempo allows for optimization of payload manifests across multiple missions.

The key reason that technology demonstration customers consider a hosted payload approach is financial constraints. Being able to provide a cost-effective solution to getting to orbit under an FFP mechanism is a key enabler to provide such customers with confidence that their payloads will be flown on time and within budget. It is therefore essential that the hosted payload mission opportunity provider has the capability to knowledgeably and accurately define, scope, and price mission requirements and the associated programmatic. In tandem with this, the financial and contractual framework for manifesting government payloads needs to be better aligned and easier for commercial providers to use. Commercial providers are able to engage and facilitate the dialog with customers to adapt to and accept change and to become comfortable and familiar with a different approach.

RECOMMENDATIONS

There are several recommendations for technology demonstration customers and stakeholders who are considering flying a payload as a hosted mission.

If a hosted payload approach is one of the options in the mission trade space, the hosted payload customer should start the dialog with a range of hosted payload mission providers early. There are three key reasons for doing this: first, to understand the specific approach each opportunity provider applies to accommodating hosted payloads to determine whether this would be compatible with the hosted payload mission; second, to gauge suitability of satellite accommodation and operational capability; and third, to assess which providers may have a potential slot in the right timeframe to achieve the desired technology demonstration objectives.

The customer should progress the development of the technology demonstration payload as a parallel activity to finding a hosting opportunity. Typically, technology demonstration schedules will be longer than commercial mission schedules. In Surrey's experience, the sooner the provider is aware of potential hosting capacity requirements, the greater the likelihood is for offering a suitable option in the timeframe required, particularly if the hosted payload is large, has integration or operational constraints, or has sensitivities or restrictions.

The hosted payload customer should be open to accepting that it takes time to become comfortable with the tension between mission flexibility and requirements rigor; acknowledging that accomplishment of cost, schedule, and timely mission return objectives as a hosted payload requires flexibility about what the key mission objectives are, which requirements can be forgone, and maintaining astrong resistance against "requirements creep."

Hosted payload opportunity providers have a responsibility to manage the expectations of the hosted payload customer and provide clarity about the technical and programmatic process from the outset. This is especially true with for government customers who may be accustomed to owning the mission and driving the solution. The objective is a "win–win" for all parties.

The hurdles associated with government procurement processes and funding frameworks are disincentives for both hosted payload customers and opportunity providers. The example of OTB demonstrates that there are some relatively straightforward steps that could be taken to adapt the existing mission acquisition approach to accelerate the process of securing a flight as well as enable competitiveness.

Interest in, and support for hosted payloads is starting to build momentum in some program offices, but this is still a relatively new model for many. The more the industry can demonstrate the benefits and successes of the hosted payload approach and a commercially based contractual and financial model, the more interest there will be from the technology demonstration and science community to shape missions for a hosted payload solution.

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