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Spaceflight's FORMOSAT-5/SHERPA Mission
How to Set a World Record for the Number of Satellites Deployed in a Single Launch

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ABSTRACT

In November 2016, Spaceflight, in partnership with SpaceX, is scheduled to set a new world record for the most number of free-flying spacecraft deployed from a single launch with eighty-nine spacecraft deployed during the FORMOSAT-5/SHERPA mission. This paper describes how this record was accomplished and key lessons learned.

Spaceflight is a world leader in the development of commercial rideshare opportunities for the small satellite industry. Success on this mission required both technical and business innovations to include design and development of SHERPA, a custom ESPA Grande ring with custom payload adapters and dispenser systems, designed for manifesting multiple secondary payloads and hosting secondary payloads. Adapter plates designed for SHERPA enable either one or two microsats, or up to seven Innovative Solutions in Space (ISIS) QuadPack dispensers to be deployed from a single port. SHERPA carries a deployment sequencer to send separation commands to separation systems, and a data recorder and UHF transmitter to capture and send deployment state information to a ground receiver at Wallops Island, VA. In addition to technical development, procedures developed ensure a "do no harm to others" philosophy is enforced on all payloads, regardless of size and complexity.

MISSION OVERVIEW

The record-setting FORMOSAT-5/SHERPA mission is made possible by an innovative space segment and ground segment operating together in a new operations construct. The space segment is composed of the SHERPA system launched on a SpaceX Falcon 9 Launch Vehicle (LV). SHERPA is a custom Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) Grande ring outfitted with custom payload adapters and dispenser systems, designed for manifesting multiple secondary payloads and hosted secondary payloads (see Figure 1). SHERPA enables greater access to space for small spacecraft and hosted payloads through launch services arranged by Spaceflight.

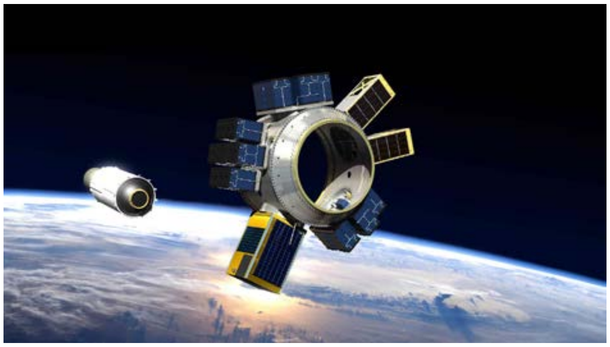


Figure 1: An Illustration of SHERPA Deployed On-orbit

SHERPA operates in one of three modes:

1. A non-propulsive free-flyer spacecraft, that functions independent of the launch vehicle, dispensing payloads at a pre-determined time after launch vehicle separation
2. As a propulsive free-flyer spacecraft, hosted payload platform, separating from the launch vehicle and operating as a spacecraft bus under its own power, propulsion and attitude control for several years
3. As a non-separating payload adapter dispensing payloads while connected to the launch vehicle

For the FORMOSAT-5/SHERPA mission, SHERPA operates in the first of the three modes. At launch, the SHERPA spacecraft is in a passive-state, with all functional circuits deactivated, prevented from powering-ON by inhibit circuitry. The system is armed for activation prior to launch. It continuously monitors the inhibit circuit for the LV separation, which triggers the SHERPA spacecraft's transition to operational state. In the operational state, a pre-programmed script controls the deployment of the multiple payloads. Telemetry is collected and stored during deployment, and downlinked upon command from a ground station.

MANAGING MULTIPLE INTERFACES

Spaceflight is a world leader in the development and coordination of rideshare missions. In the Spaceflight business model, Spaceflight is a single point of contact between its customers and the launch vehicle provider. The model allows the launch vehicle provider to focus on a minimum number of payload and customer interfaces, and gives rideshare customers the advantage of working with a single informed point of contact that is synchronized with all stakeholders in the mission. From the founding in 2010, Spaceflight has cultivated relationships with spacecraft developers, vendors, and launch vehicle providers. These relationships, along with our acquired payload integration experience over several launch campaigns, enables the company to envision and realize a complex mission such as the one carrying the SHERPA spacecraft.

In addition to the personal interfaces described above, the FORMOSAT-5/SHERPA mission encompasses dozens of mechanical and electrical interfaces to include the LV, adapters, separation systems, customer spacecraft, ground support systems, the ground segment, and the primary payload. Successful mission execution requires a solid technical foundation combined with seamless management of many customer, vendor, and regulatory interfaces.

Spaceflight has contracts resulting in manifesting over two dozen discrete customers/entities on the SHERPA system. Some of these customers come through Spaceflight's international launch partner Innovative Space Logistics (ISL), B.V., a subsidiary of Innovative Solutions in Space (ISIS), B.V. from the Netherlands. ISL brings thirteen unique spacecraft to the mission manifest representing international governmental, educational, and commercial projects from the Republic of Korea, Israel, Slovakia, Finland, Chile, Spain, France, Brazil, and the United Arab Emirates. In addition to these customers, Spaceflight has launch contracts with several US commercial, amateur, and government space organizations including but not limited to the Aerospace Corporation, NovaWurks, NASA Ames Research Center, and AMSAT.

Execution of a successful mission requires management of customer, SHERPA, vendor, launch vehicle, and regulatory interfaces.

Customer Interfaces

Customer interfaces can be broken into several sections to include Spaceflight-to-customer personal interfaces and technical interfaces.

With respect to personal customer interfaces, a Spaceflight mission manger provides launch updates, manages the customer Interface Control Document (ICD), coordinates technical discussions and decisions, participates in reviews, and arranges for final launch integration. The mission manager is responsible for managing all technical interfaces between the customer hardware and Spaceflight hardware using and interface control document that contains requirements relating to mechanical interfaces, spacecraft design, spacecraft operations, contamination control, environmental testing, and range safety.

Customer hardware interfaces can include both mechanical and electrical interface points between spacecraft. On the FORMOSAT-5/SHERPA mission, there are no electrical interfaces with customer spacecraft. The mission does require dozens of customer mechanical interfaces, and to manage these Spaceflight relies on standardized interfaces and documentation. Spaceflight procures all separation systems featured on the mission; therefore, mechanical interfaces are given by the specific separation system specifications. Examples of procured separation systems include the Motorized Lightband and the QuadPack dispenser.

The SHERPA mission manifest features the following CubeSat form factors: nine 1U CubeSats, two 1.5U CubeSats, one tethered 1U and 2U CubeSat, seventy-one 3U CubeSats, one 6U CubeSat (340.5 mm in length), and three 6UXL CubeSats (365.9 mm in length). Despite the existence of CubeSat standards, CubeSats are hardly standardized. Each CubeSat developer spacecraft features intricacies, and they do not always adhere to the Cal Poly CubeSat Design Specification. Several spacecraft on the manifest require additional volume for protrusions beyond the plane formed by CubeSat rails. The QuadPack dispenser allows for these excursions giving Spaceflight's customers the flexibility required to be successful in their unique missions.

Examples of design, operational, and contamination control requirements include but are not limited to electrical system inhibit scheme, materials selection criteria, delayed radio frequency transmissions, thermal vacuum bake-out testing, and surface cleanliness verification. Spaceflight adheres to rideshare guiding principle of "do no harm to others" on the launch. As such, Spaceflight levies requirements on electrical system inhibit schemes, which depend primarily on hazards present. Where a catastrophic hazard is present, Spaceflight requires dual fault tolerance to prevent inadvertent activation of the rideshare spacecraft. In all cases integrated rideshare spacecraft are inhibited using at least one separation switch to prevent inadvertent activation prior to deployment on-orbit. The "do no harm to others" principle also dictates requirements for materials selection and contamination control. There are several contamination sensitive spacecraft on the manifest including the FORMOSAT-5 primary spacecraft itself. In an effort to provide mission assurance for all our customers and FORMOSAT-5, Spaceflight levied strict materials selection, thermal vacuum bake-out test, and surface cleanliness requirements. Every spacecraft is subjected to some level of bake-out where most used a Thermoelectric Quartz Crystal Microbalance (TQCM) to bake-out until a given rate is achieved.

Environmental test requirements were provided to the customers based on SHERPA environments transmitted through the SHERPA spacecraft interface to payload interfaces. Spaceflight conducted several analyses to determine SHERPA-to-payload environments resulting requirements levied in individual payload Interface Control Documents (ICDs) for quasi-static, sine vibration, random vibration environments. In particular, requirements for microsatellite- and CubeSat-level random vibration testing had to be derived via analysis from the input vibration spectrum at the SHERPA to Launch Vehicle interface. Onto these levels, a safety factor was added to ensure safety margins. To support the launch provider with Coupled Loads Analysis (CLA), Spaceflight assembled an integrated finite element models using customer, vendor, and internally produced models. Spaceflight used results from the CLA to validate environmental test requirements established from SHERPA-level requirements.

Finally, given that the SHERPA launch takes place from the US Western range the payload stack and all integrated rideshare spacecraft are subject to Air Force Space Command Manual (AFSPCMAN) 91-710 Range Safety User Requirements Manual. To support customers in compliance with AFSPCMAN 91-710, Spaceflight tailored AFSPCMAN 91-710 requirements and provided template Missile System Prelaunch Safety Packages (MSPSPs) to each spacecraft developer. Each spacecraft developer completed template MSPSPs and submitted them to Spaceflight for review. Spaceflight then forwarded the individual MSPSPs to the 30th Space Wing range representative for comment and/or acceptance.

SHERPA Interfaces

To support the integration of 89 spacecraft onto the SHERPA spacecraft, Spaceflight designed, built, and qualified three unique payload adapters, the QuadPack Plate (QPP), the Radial Port Adapter (RPA), and a Dual Port Adapter (DPA). Each payload adapter has a 36-bolt interface to mate with the ESPA Grande ring, and the external side features circular separation systems such as the Planetary Systems Motorized Lightband (MLB) or in the case of CubeSat dispensers, the ISIS QuadPack.

The adapter plates are 6061-T651 aluminum designed to support maximum mass spacecraft under maximum loading, and qualified by analysis using no-test safety factors of 2.0 on yield and 2.6 on ultimate. Figure 2 shows the SHERPA spacecraft integrated with port adapters and flight harnesses without CubeSat dispensers or microsatellite payloads.

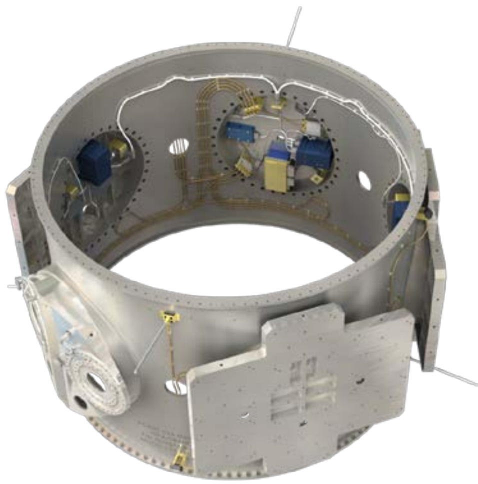


Figure 2: An Illustration of the SHERPA spacecraft shown with Port Adapters

The RPA is shown in Figure 3. Under maximum flight loading, the RPA is designed to carry a 150 kg payload with its center of gravity offset 40 cm from the interface plane.

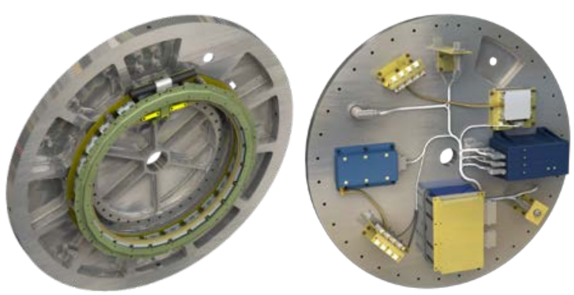


Figure 3: An Illustration of the Internal and External faces of the RPA

The internal side of the RPA has bolted interfaces for the Master CORTEX avionics, battery and battery isolation, CADET U UHF transceiver assembly, GPS assembly, as well as the bolted interface for the ESPA Grande ring. The external face has bolt patterns for an 11.732-inch and a 15.000-inch MLBs. There is one RPA on SHERPA

The QPP, shown in Figure 4, is designed to carry seven ISIS QuadPack dispensers loaded with maximum mass CubeSat payloads, 24 kg payload in total for each QuadPack.

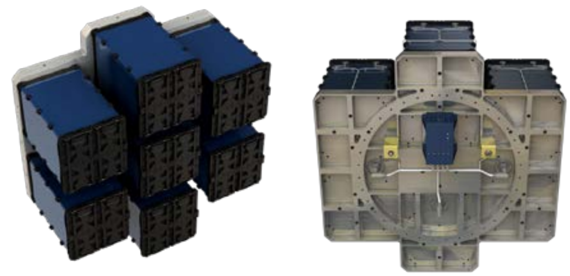


Figure 4: An Illustration of the QuadPack Plate shown with Seven ISIS QuadPacks

The QPP internal face features bolt patterns for CORTEX secondary controllers, which are SHERPA valve drivers, the avionics stacks that direct power to each separation system. There are three QPPs with secondary controllers on SHERPA.

Finally, the DPA, shown in Figure 5, is designed to carry two 85 kg payloads with their center of gravity 40 cm from the interface plane under maximum flight loading.

Figure 5: An illustration of the DPA

The DPA has bolt patterns for 8.000-inch MLBs and 11.732-inch MLBs.

In addition to port adapters, Spaceflight also designed the flight harness from the SHERPA avionics to each of the five ports and the integrated separation systems. Figure 6 shows an illustration of the SHERPA flight harness.

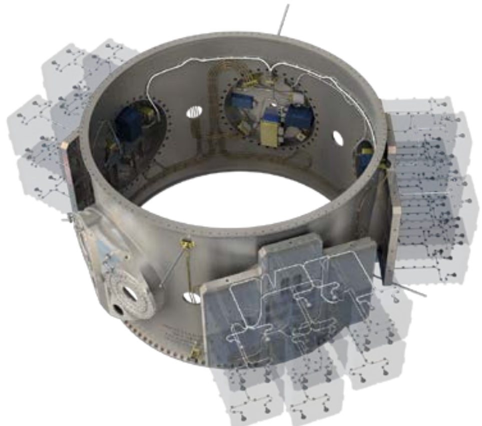


Figure 6: Illustration of SHERPA Flight Harness

Vendor Interfaces

A large part of the SHERPA mission is management of hardware that is designed and built by vendors. Spaceflight utilized several vendors in support of the SHERPA mission such as LoadPath, Moog CSA, RUAG, and Innovative Solutions in Space.

For example, all Ground Support Equipment, such as a payload breakover fixture, payload handling and lifting hardware, ESPA integration cart, ESPA lift ring, and SHERPA shipping container were procured through vendors as mentioned above.

The Auxiliary Payload Handling Cart and lift systems, shown in Figure 7 and Figure 8 were designed and built under Spaceflight direction by LoadPath. Spaceflight uses the cart for QPP, RPA, and DPA plate payload integration.

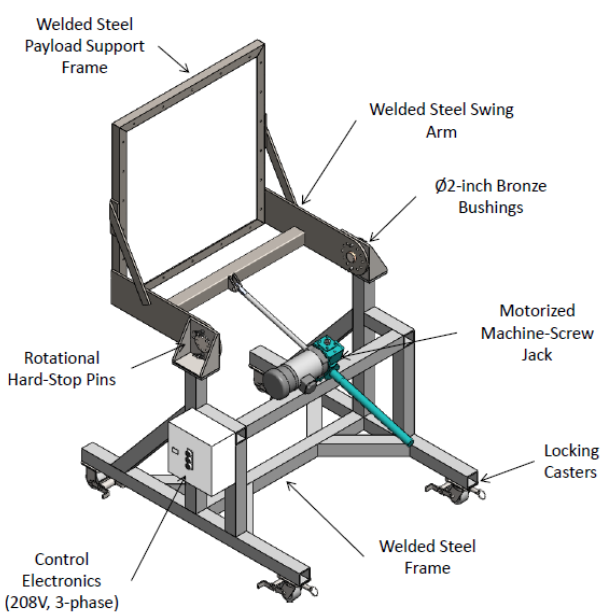


Figure 7: Auxiliary Payload Handling Cart (Image Credit: LoadPath)

The Auxiliary Payload Handling Cart is capable of a controlled breakover by means of a motorized machine-screw jack, which facilitates both vertical and horizontal integration of spacecraft and payloads onto adapter plates. In addition to the Auxiliary Payload Handling Cart, Spaceflight procured lift systems to interface with existing GSE attachment points on the QPP, RPA, and DPA plates.

Figure 8 shows the three types of lift systems designed to be used with the loaded QPP, RPA, and DPA plates and the Auxiliary Payload Handling Cart. This series of GSE enables payload integration without the need to interface directly with customer hardware.

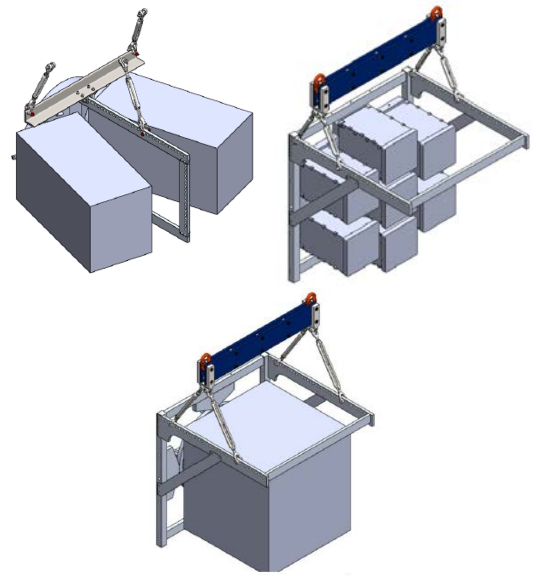


Figure 8: Auxiliary Payload Handling Hardware (Image Credit: LoadPath)

The SHERPA Handling Cart, also designed and built by LoadPath, is shown in Figure 9.

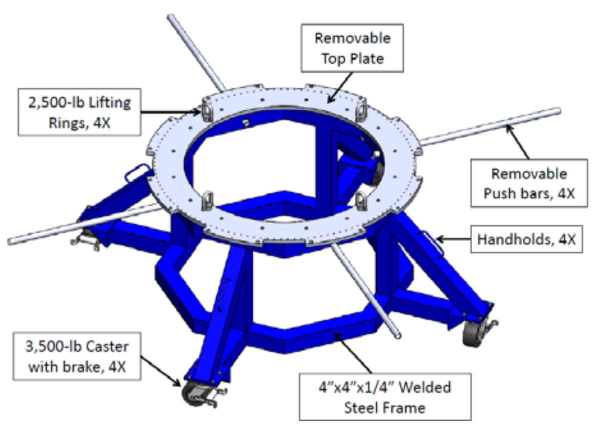


Figure 9: SHERPA Handling Cart (Image Credit: LoadPath)

The SHERPA Handling Cart is designed and tested to show compliance with SHERPA requirements, and AFSPCMAN 91-710 safety requirements. Spaceflight will use this cart in support of SHERPA integration activities at the Spaceflight Payload Processing Facility (PPF) in Tukwila, Washington, and at Vandenberg Air Force Base (VAFB) in the SpaceX PPF.

Figure 10 shows an illustration of the ESPA Lift Ring, which is procured from Moog CSA Engineering. The ESPA Lift Ring, A36 steel, features four 15,000 lb capacity hoist rings and a 116-bolt EELV interface to mate with the ESPA forward interface, designed and tested to show compliance with AFSPCMAN 91-710 safety requirements.

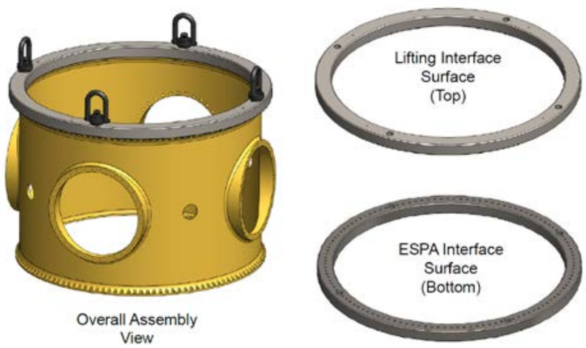


Figure 10: Moog CSA ESPA Lift Ring (Image Credit: Moog CSA Engineering)

The ESPA Lift Ring is used to lift SHERPA when it is lifted for integration. The ring design minimizes deformation of the lower bolted interface that occurs when lifting the fully integrated SHERPA spacecraft.

Figure 11 shows an image of the custom-made SHERPA shipping container.

Figure 11: Custom-made SHERPA Shipping Container

The shipping container, constructed from hardwood and plywood, encapsulates SHERPA and the integrated spacecraft during transit from Tukwila, Washington to VAFB. It has an attachment point for a HEPA-filter air handler, and it features a floating floor to mitigate against vibration loading and shock events caused by over-the-road travel.

For its primary structure the SHERPA spacecraft utilizes an ESPA Grande ring procured from Moog CSA in the "5-42-24" configuration. The nomenclature "5-42-24" means an ESPA ring that is 42-inches in height with five 24-inch ports.

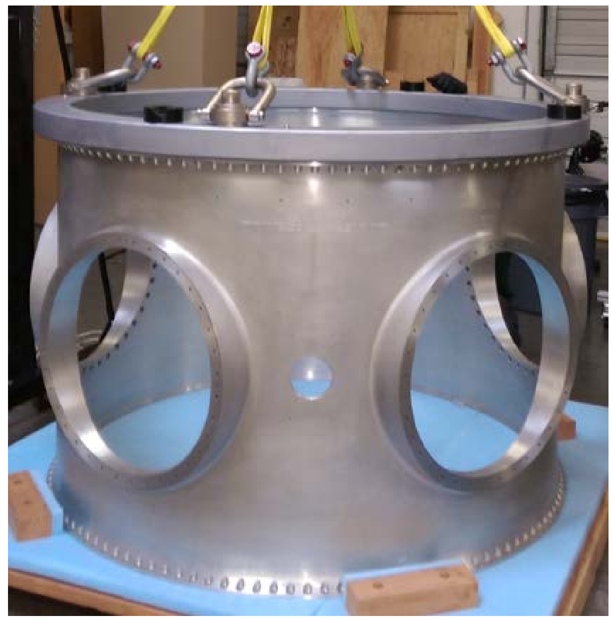


Figure 12: 5-port ESPA Grande Ring

SHERPA spacecraft separation from the Falcon 9 second stage is enabled by a RUAG Payload Adapter System (PAS) 1575S ESPA Separation System. Spaceflight worked with both SpaceX and RUAG to ensure the separation system met all launch and mission requirements to include umbilical and pyro connector brackets to pass electrical signals between the Falcon 9 and FORMOSAT-5 vehicles across the SHERPA separation plane.

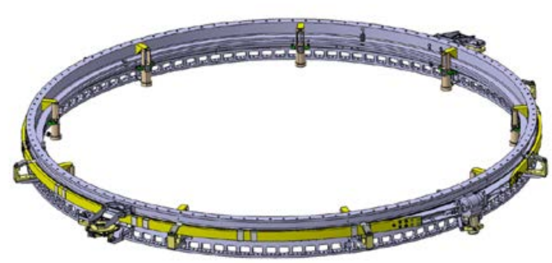


Figure 13: RUAG PAS 1575S ESPA Separation System (Image Credit: RUAG)

The QuadPack, shown in Figure 14, is a deployment system for CubeSats, which Spaceflight uses to integrate customer CubeSats with the SHERPA spacecraft. The QuadPack is designed and manufactured by Innovative Solutions in Space of the Netherlands, and it is capable of carrying one or more CubeSats in interior canisters.

Figure 14: Innovative Solutions in Space QuadPack Dispenser (Image Credit: Innovative Solutions in Space)

To integrate customer microsatellites with SHERPA, Spaceflight procured Motorized Lightbands from Planetary Systems Corporation (see Figure 15), specifically an 11.732-inch and 15.000-inch MLB,

Figure 15: Planetary Systems Corporation Motorized Lightband (Image Credit: Planetary Systems)

Each dispenser and MLB was tested under the vendor standard test programs, which included random vibration, thermal vacuum, and reliability testing.

Launch Vehicle Interfaces

The interfaces between SHERPA, the Primary Payload and the Launch Vehicle are controlled and managed through a SHERPA-to-LV ICD. Figure 16 shows the Integrated Payload Stack (IPS), which comprises the LV Payload Attach Fitting (PAF), the SHERPA separation system (a RUAG PAS 1575S), the SHERPA spacecraft, the Primary Payload payload adapter (a RUAG PAS 1194VS), and the Primary Payload, FORMOSAT-5.

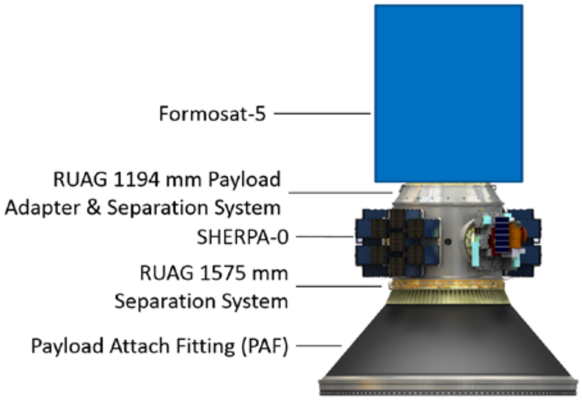


Figure 16: Integrated Payload Stack

Regulatory Interfaces

There are several regulatory interfaces that must be managed to launch a rideshare mission. To name a few, Spaceflight must coordinate with the Federal Communication Commission and the Department of Transportation.

The SHERPA spacecraft is a spacecraft with a transceiver, so it is necessary to coordinate with the FCC to operate on orbit. As a part of the FCC authorization, Spaceflight must demonstrate compliance with orbital debris requirements. As a good steward of our industry, Spaceflight assumes a proactive stance to minimize generation of orbital debris. In the preliminary stages of the mission, the orbit, which has a high apogee at 720 km, was thoroughly vetted to ensure compliance with the 25-year deorbit requirement. Spaceflight analyzed configurations from a heavy 1U CubeSat without solar arrays to the fully integrated SHERPA to ensure all equipment reenters the atmosphere within 25-years.

Department of Transportation Code of Federal Regulations (CFR) Title 49 requirements also are applicable because the integrated SHERPA spacecraft is shipped via highway from the Spaceflight payload integration facility to VAFB. The primary item of concern involved in the SHERPA transport is individual lithium-ion cells and batteries integrated within each spacecraft and the SHERPA spacecraft itself. Spaceflight has developed a screening process to determine individual spacecraft compliance with CFR 49 requirements. In areas where compliance cannot be verified, Spaceflight has filed for and received a special permit to transport.

It is worth mentioning Spaceflight also follows established internal processes and procedures for export of controlled information to our foreign national customers and vendors. These processes and procedures are considered proprietary by Spaceflight, so they are not discussed in this paper.

INTEGRATION OF 89 SATELLITES

Operations during launch campaign at VAFB are limited to SHERPA integration with the LV and FORMOSAT-5 integration with SHERPA, so all payload integration must be completed prior to arrival. Spaceflight will arrive at the payload integration facility at L-15 days. Customer spacecraft start arriving at the Spaceflight payload processing facility at L-60 days. The majority of customer spacecraft arrive for payload integration at L-45 days. These constraints leave less than 45 days for payload integration, final checkout, encapsulation, and transit to the launch site.

Payload Processing Facility

At the start of the mission, Spaceflight did not have a cleanroom for payload integration, so one had to be built. The 100,000-class cleanroom is now operational with an area of 800 ft^2 (74 m^2) and a 20-ft (6 m) high ceiling. A gantry crane spans the room with a maximum hook-height of 12.5-ft (3.8 m) and 4,000 lbm (1,814 kg) lift capacity. For all integration activities involving suspended flight hardware, Spaceflight uses the gantry crane with a MSI Challenger crane-scale in the lift train allowing high-fidelity weight measurements of each port adapter and the integrated SHERPA spacecraft itself.

SHERPA Spacecraft Testing

Prior to integrating customer spacecraft with SHERPA, the vehicle is subjected to several day-in-the-life tests. Spaceflight refers to a day-in-the-life test a Mission Simulation Test (MST). An MST commences with a simulated separation from the launch vehicle, given by disengaging the separation switches, which initializes the SHERPA flight computer and the thirty-minute countdown timer. A successful MST is given by all payload deployment events are captured in telemetry and visually on emulator or test hardware. Test configurations have progressed from all test hardware on a bench, known as the SHERPA flatsat, to integrated test hardware on the ESPA ring with support hardware such as the emulator board shown in Figure 17, to flight hardware in the loop. This has been a gradual progression to reach the pinnacle “test as you fly” configuration.

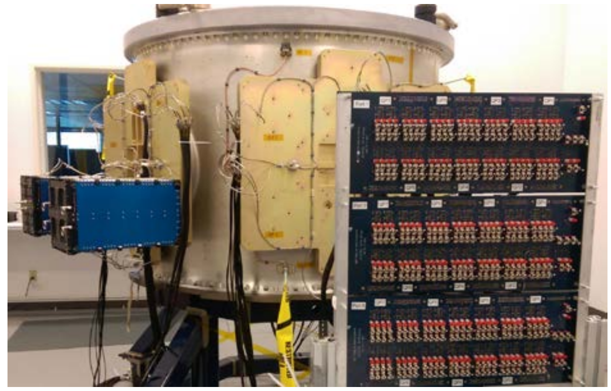


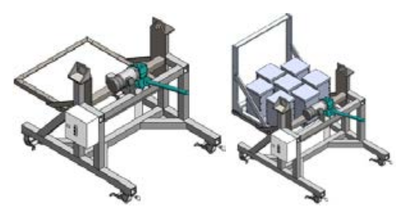
Figure 17: SHERPA in the Mission Simulation Test Configuration

To date Spaceflight has conducted eleven MSTs with the hardware on the ESPA ring, in the SHERPA configuration. Over fifty MSTs have been completed between the SHERPA flatsat and the flight hardware. The final configuration is SHERPA with flight avionics, flight battery, two to twenty-one flight QuadPacks, two MLBs, and GSE termination cap installed. In this configuration, mission telemetry is transmitted over-the-air after deployments from the SHERPA communication suite to the Spaceflight Networks antenna on the roof of the integration facility.

Rideshare Payload Integration

In support of spacecraft integration to SHERPA, Spaceflight has identified and drafted dozens of procedures. Unless necessary, Spaceflight does not physically perform customer spacecraft integration to adapter or dispenser. This limits Spaceflight procedures to QuadPack and QPP to SHERPA, Payload and RPA to SHERPA, and Payload and DPA to SHERPA integration. For microsatellites, the Spaceflight procedure takes over vehicle integration once the customer hardware interface is within a set distance from the adapter/separation system interface, usually a fraction of an inch.

Figure 18 shows steps to integrate the QuadPacks with the QuadPack plate, breakover, and attachment of the QPP Lift System.



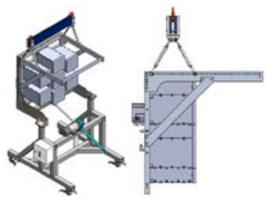


Figure 18: QuadPack and QuadPack Plate to SHERPA Integration Steps (Image Credit: LoadPath)

For each QuadPack, electrical continuity is checked through the flight harness to verify successful electrical mate with each QuadPack. Once the QPP is suspended, it is mechanically mated with SHERPA. Finally, the main SHERPA harness connectors are mated with connector bulkheads on the adapter assembly to complete electrical integration with SHERPA.

The Spacecraft to RPA and RPA to SHERPA integration procedure is largely the same as for the QPP, because the ground support equipment is the same.

The DPA to SHERPA has more steps due to the angle offset between the spacecraft positions on the adapter (see Figure 19).

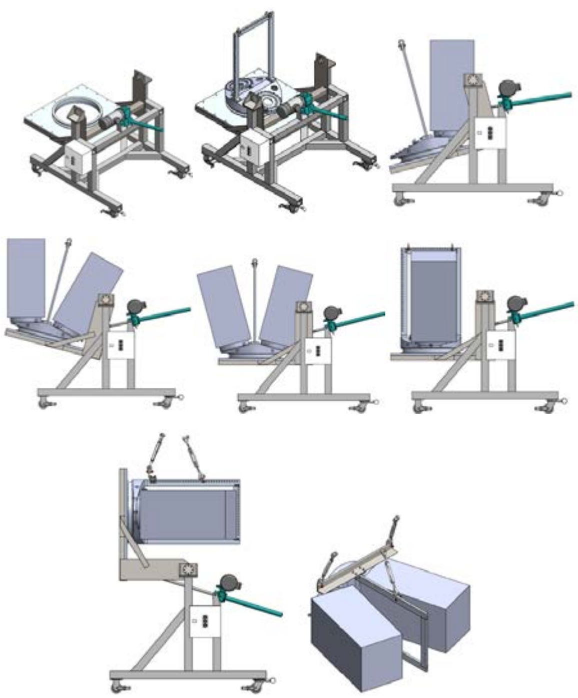


Figure 19: Payload and DPA to SHERPA Integration Steps (Image Credit: LoadPath)

After completion of payload integration, the Spaceflight integration team conducts a SHERPA aliveness check and UHF commanded transmission to ensure the master and secondary controllers are interconnected and the communication suite is healthy.

SHERPA Encapsulation for Transit

Post payload integration, SHERPA is encapsulated for transit within the SHERPA shipping container. The container features an over box that can be lifted exposing the SHERPA mounting interface. When ready for encapsulation SHERPA is lifted off the SHERPA Handling Cart along with the SHERPA Handling Cart top plate (see Figure 9), which forms the mating interface with the shipping container. After the SHERPA Handling Cart is removed from the work area, the shipping container base is rolled into the cleanroom. A large sheet of anti-static plastic is laid onto the shipping container base and fitted onto the bolted interface. SHERPA is then lowered onto the mounting bolts and secured for shipment. Another large sheet of anti-static plastic is laid out over SHERPA and the edges are heat-sealed to form a bag. The bag is then backfilled with nitrogen, and then the crate is rolled out of the cleanroom, so the over box can be lowered and bolted into place. Prior to encapsulation, the vehicle is instrumented with battery-powered sensors to detect vibration, shock, temperature, humidity, light, and sound. The sensors are also equipped with GPS to allow Spaceflight to track the shipment.

SHERPA transport to VAFB

Spaceflight has contracted with a major shipper to perform the shipment of SHERPA with its integrated spacecraft and support equipment to VAFB for LV integration. Given the size of the SHERPA shipping container, the transport is limited to driving during daylight hours with escorts; therefore, it will take up to three days to move SHERPA from Tukwila, Washington to VAFB, CA.

SHERPA LV Integration Campaign

Upon arrival at VAFB around L-15 days, the SHERPA spacecraft and support hardware containers are offloaded from the truck and moved into the SpaceX Payload Processing Facility airlock for cleaning prior to entering the cleanroom. Once the containers are in the cleanroom they are uncrated, and the hardware within is cleaned and certified. SHERPA is put through another aliveness check to verify vehicle health after transportation. In the following two days, SHERPA is integrated with the PAS 1575S, and the batteries are topped off for flight. At L-10 days, the SHERPA spacecraft must be ready for integration with the Falcon 9 payload attach fitting to support the SpaceX-driven launch integration flow.

MISSION DEPLOYMENT SEQUENCE

SHERPA is located between the SpaceX launch vehicle upper stage and the primary FORMOSAT-5 (F-5) payload (see Figure 16).

Figure 20 shows the nominal mission timeline. SpaceX first separates the primary F-5 payload from SHERPA at T+11 minutes. At T+70 minutes, SHERPA is separated from the LV second stage. This event triggers the SHERPA onboard master controller to power on, initialize and start a 30-minute countdown.

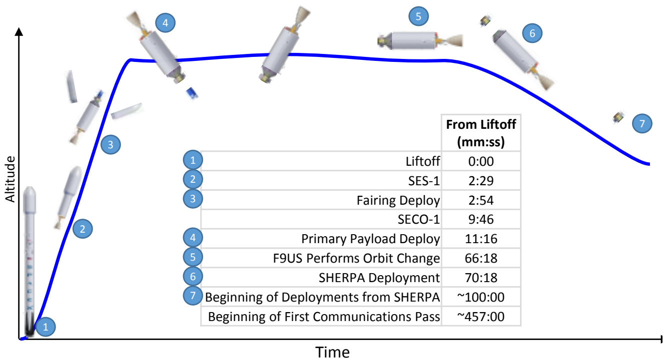


Figure 20: FORMOSAT-5/SHERPA Mission Timeline

Figure 21 shows the arrangement of the payloads on the ESPA Grande ring. Ports 1, 3 and 5 each have seven QuadPack dispensers containing eighty-seven CubeSats. Port 2 contains the eXCITe payload conglomerate (deployed as a single entity). Port 4 contains the Pathfinder 2 spacecraft and a mass replica.

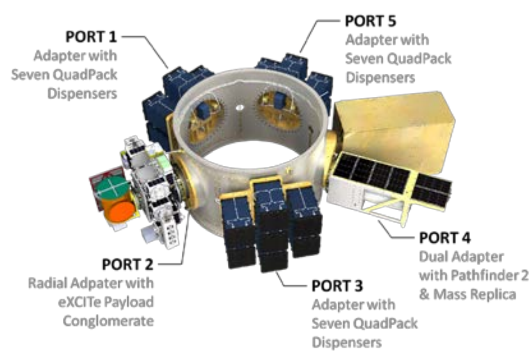


Figure 21: SHERPA Payload Arrangement

Microsatellites are deployed first (via Motorized Lightbands) followed by CubeSats (via QuadPacks). The eXCITe payload is deployed from Port 2 at T+100 minutes and the Pathfinder 2 payload from Port 4 30 seconds later. The mass replica is not deployed and remains on the ESPA ring. CubeSats are deployed at 30-second cadence in a round-robin sequence from Ports 1, 3 and 5 to minimize attitude changes to SHERPA. Analysis performed by Spaceflight determined that the deployment cadence provides sufficient orbital separation between the microsatellites and the CubeSats.

Twelve seconds after the deployment cycle is completed, the master controller reinitiates the deployment sequence again except at a faster 10-second

The 30-minute wait provides separation distance between SHERPA and the LV. At T+100 minutes, the secondary controllers are powered up and the deployment sequence is executed according to the SHERPA on-board mission script.

cadence. The entire deployment cycle is repeated to provide redundancy ensuring all payloads are deployed.

TELEMETRY

Deployment confirmation signals are queried and logged at 1 Hz. The master controller builds up the telemetry log file and stores it in the CADET U radio memory. Upon completion of the deployment sequences, the file is ready for downlink to the ground station via the onboard UHF transmitter.

For the SHERPA mission, the ground station is set up at Wallops Island, VA. As shown in Figure 22, the first communications pass over Wallops Island occurs 6.5 hours after separation from the LV. A second communications pass occurs just over 8 hours after separation. During these passes, the SHERPA spacecraft is commanded to send the telemetry file in its buffer.

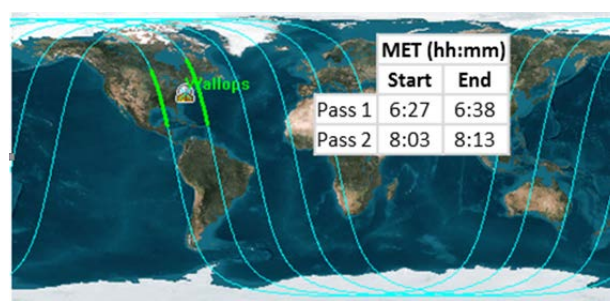


Figure 22: Ground Station Passes

The telemetry downlinked from SHERPA provides confirmation of payload deployment from the master controller and the time of each actuation. Spaceflight will use these data to provide customers with positive confirmation of deployment.

The telemetry in the downlink also includes response signals from the dispenser systems (i.e. Motorized Lightbands and QuadPacks).

FINAL RESULTS & STATUS

This mission is still ongoing with a tentative launch date of November 2016. As of the writing of this paper, the SHERPA integration team is completing flight-testing which includes two to three more mission simulation tests. Working from launch in November payload integration is scheduled to begin in September.

All rideshare spacecraft on the manifest are through test ready for payload integration or are in the final stages of vehicle testing.

KEY LESSONS LEARNED

The major lessons learned throughout this mission relates to navigating the logistical and engineering challenges of putting together and executing a mission as complex as a SHERPA platform filled with customer spacecraft. On typical rideshare missions, auxiliary spacecraft are simply integrated with launch vehicle adapters rather than a free-flying spacecraft, such as the SHERPA spacecraft. Throughout the design and integration process, every discipline of engineering must be exercised and standard aerospace practices followed. These standard practices are in place, because they are proven to work.

The SHERPA mission has enabled Spaceflight to evolve and standardize its approach to large-scale rideshare missions and vastly increase the worth of the Spaceflight offering to small satellite developers. This mission has also helped to prove the modularity, which is key for SHERPA and Spaceflight dedicated rideshare missions. The modular design of SHERPA, using RPA, DPA and QPP plates, improves the flexibility to accommodate different dispenser systems. This design approach and flexibility makes it possible to manifest multiple discrete payloads accommodating the needs of a wide range of customer spacecraft from the smallest pico-satellite to larger class microsatellites, even entire launch vehicles filled with small spacecraft.