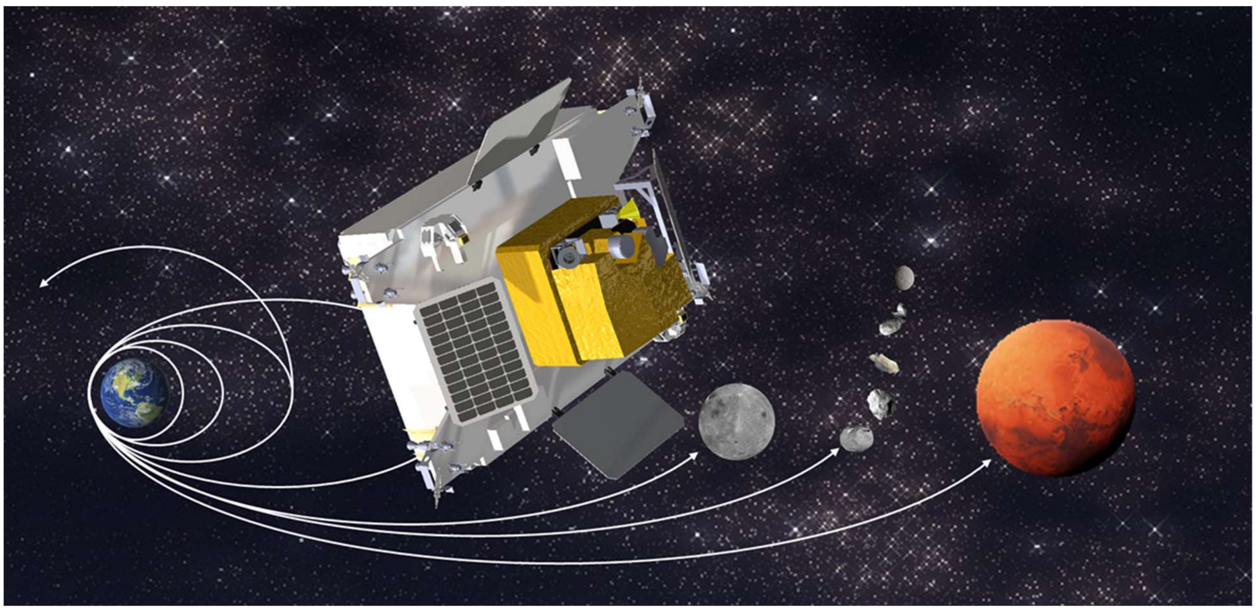
Bradford Space Logistics

Square Rocket Spacecraft

Payload User's Guide

v0.9, March 2021



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Payload User's Guide Overview

This document is presented as an introduction to the Bradford Space Logistics Services available using the Square Rocket spacecraft. It is provided for planning purposes only and is superseded by any mission specific documentation provided by us.

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Meet Square Rocket

Square Rocket is a non-toxic chemical-propellant rideshare-compatible spacecraft for space-to-space transport. Square Rocket is compatible with most affordable launch vehicles, giving the customer flexibility in reaching high orbits previously inaccessible without a dedicated launch, including and especially geostationary and deep space destinations. Operating in the deep space environment is somewhat different than in LEO, and there are corresponding departures from typical small spacecraft design. Contact us for more information and see Appendix 1 for deep space design guidelines.

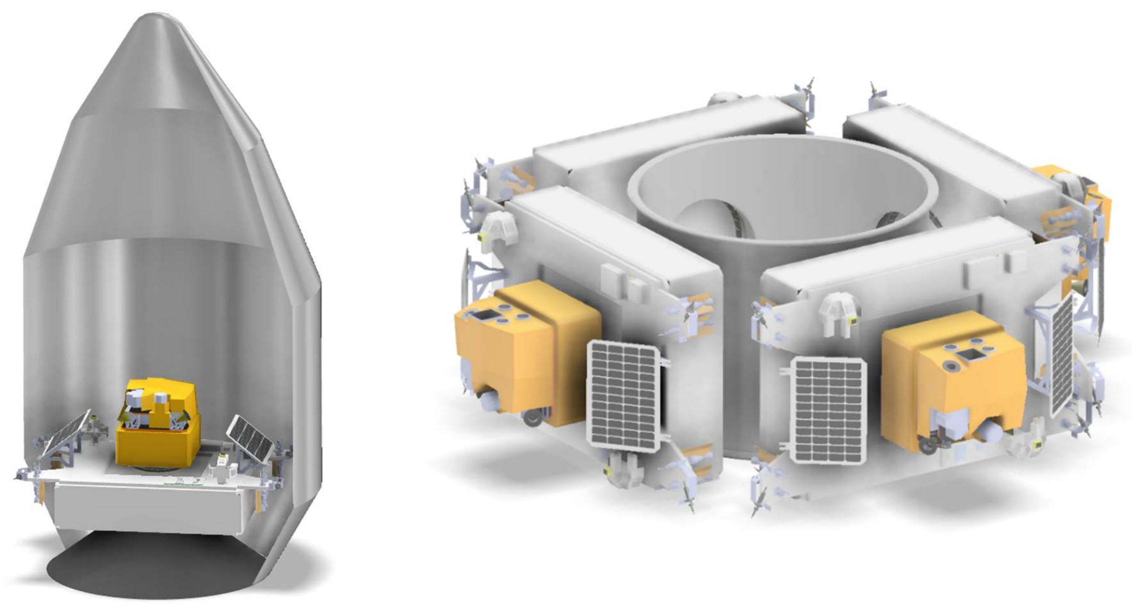

Figure 1: Square Rocket in rideshare configuration and with dedicated launch

Performance Overview

Mass to Orbit Capability

Square Rocket delivers payloads up to 300 kg to orbits previously inaccessible without a dedicated launch vehicle. Now, high-Earth orbit and deep space destinations become accessible to small satellites from a commercial launch to LEO or GTO.

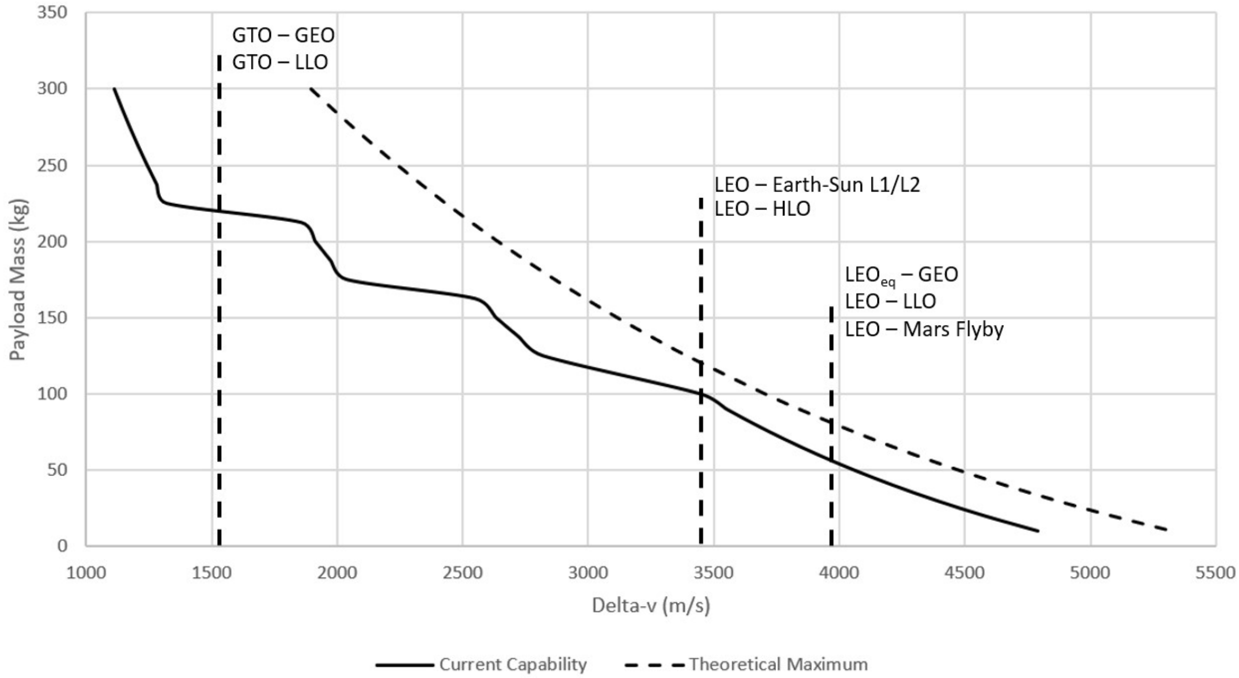

Figure 2 - Payload capacity and ΔV capability

Table 1: Square Rocket delivery of payloads to destinations of interest

Destination	Departure Point	Payload Capability
Cislunar space, escape velocity	Low Earth Orbit (LEO)	100 kg
Geostationary and Geosynchronous Orbit (GEO/GSO)	LEO$_{eq}$	50 kg
	GTO	200 kg
Mars intercept, Venus intercept, Low Lunar Orbit	LEO	75 kg
Molniya/Tundra Orbit	LEO (high inclination)	150 kg
Mid-Earth Orbit (GPS constellation location)	Low Earth Orbit	200 kg
Dispersed LEO and HEO locations (constellation setup)	Low Earth Orbit	300 kg

Square Rocket can reach geostationary orbit within days and lunar orbit within weeks.

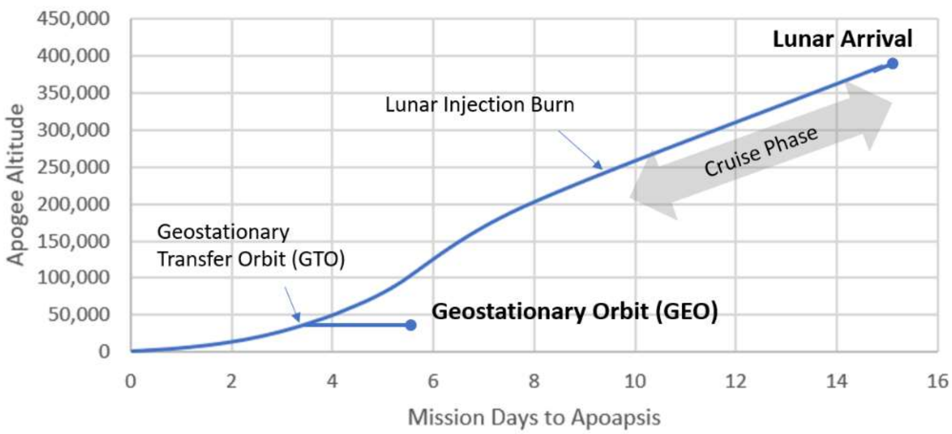

Figure 3: Square Rocket time of flight to GEO and Cislunar space

Multiple Payloads

Square Rocket is capable of multiple restarts to deliver multiple payloads to mixed trajectories. The payload adapter interface allows for both containerized and un-containerized satellites, though containerized satellites must include the mass of the dispenser system (I.e., for CubeSats) in their payload mass accommodation.

For example, a typical 100 kg Square Rocket Payload could feasibly support the deployment of 3x "heavy" 12U satellites or 4x "light" 12U satellites.

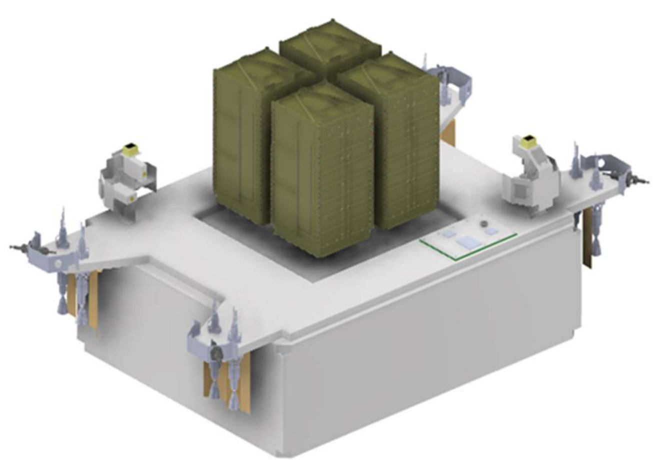

Figure 4: Square Rocket caries containerized payloads in separate dispensers.

Orbit Determination & Injection Accuracy

Square Rocket payloads experience a maximum of 0.2 *g* acceleration powered by thrusters designed for high-precision maneuvers, compared with traditional upper stages that have accelerations upwards of 15 *g* as they approach the end of their injection maneuver. While the vehicle is designed primarily for high ΔV, it is also capable of precise injection to a desired altitude, approaching +/- 60 meters altitude knowledge reaching apogee at GTO.

Square Rocket autonomously confirms its trajectory with GPS in low-Earth orbit, and on high-Earth and hyperbolic orbits, Square Rocket confirms its trajectory using pseudo-noise ranging and a network of partner ground stations. The vehicle is capable of orbital impulse adjustments of approximately 1 N-s, implying a 5 mm/s course correction resolution capability when carrying a 100 kg payload. Square Rocket precision injection capabilities are more akin to a high ΔV satellite than a high-thrust rocket.

Orbit Determination Accuracy	
Minimum ΔV impulse	5 mm/s
Instantaneous position knowledge at LEO [1σ]	+/- 15 meters along orbit +/- 5 meters along plane
Instantaneous velocity knowledge at LEO [1σ]	< 25 cm/s[1]
Time-integrated best position knowledge	0.3 m (3D RMS)[2]
Time-integrated best velocity knowledge	< 1 mm/s
High orbit apogee prediction	+/- 0.06 km (LEO velocity to GTO apogee)

Mars Orbit Package Add-On

Square Rocket in its baseline configuration is designed for near-Earth and cislunar operations. However, it contains sufficient ΔV to inject payloads on Mars-crossing and Venus-crossing trajectories. A Mars Orbit Package is added to the baseline vehicle to make it Mars-orbit capable while decreasing the deliverable payload. Customers seeking Mars transport should contact us for additional information regarding this service.

Parameter	**Square Rocket (Baseline)**	**Square Rocket with Mars Orbit Package**
Dry Mass	91 kg	109 kg
Power at 1 AU	250 Watts	650 Watts steerable
Data Rates	1 Mbps at 600 km	~50 kbps from Mars at 1.6 AU
Pointing	Coarse, spin-stabilized	Fine, 3-axis control
Mars Payload from LEO	75 kg Mars-intercept	15 kg to Low Mars Orbit

[1] Example GPS receiver
[2] For example, comparable to PROBA-2

Separation Attitude & Deployment Velocity

Square Rocket offers 3-axis attitude control or spin-stabilized separation as a standard service. For inertial separation, the vehicle will point the payload to the desired LVLH attitude and minimize attitude rates. For spin-stabilized separation, the launch vehicle will point the second stage and payload to the desired LVLH attitude and initiate a spin about the launch vehicle X-axis at a customer-specified rate dependent upon payload mass properties. Standard pre-separation attitude and rate accuracies are developed as a mission-specific standard service. More information about separation attitude and rate accuracy is available from us upon request. Separation tip-off and deployment velocity are determined by the customer-specific mechanical interface between Square Rocket and its payload.

Logistics Operations

Transport to Launch Site

Square Rocket is designed for compatibility with multiple launch vehicles and, because the propellant is rated as a 1.4S explosive when in a proper container, is intended to be shipped by road after propellant loading. While payload integration occurs in a facility within a one day drive of both Cape Canaveral and Wallops, Square Rocket can be alternatively transported to international and other US launch sites at an increase in processing time.

PAYLOAD RECEIVING (1 DAY)

We recommend all payloads to be packaged for shipping using a ruggedized outer shell, and a nitrogen filled inner shell or bag appropriate for an ISO 6 clean room. Upon receiving your payload, the outer shell will be removed, and the inner package moved to the anteroom of our ISO 6 payload processing area. The payload will be cleaned with vacuum and/or nitrogen to remove any shipping contaminants, and then moved into the ISO 6 processing area. Please budget one day for payload receiving.

PAYLOAD INTEGRATION WITH SQUARE ROCKET (2 DAYS)

During payload integration, the payload will be lifted onto the Square Rocket and mated with fasteners. After mechanical mating, the electrical harnesses will be attached to the Square Rocket payload interface. Customers are encouraged to participate in payload integration either on-site or virtually. After integration, we allow up to two days for payload checkouts; during which time we will provide support for any testing required by the customer.

PROPELLANT LOADING AND VEHICLE PACKAGING (1 DAY)

After payload checkouts are complete, the Square Rocket stack is moved into our propellant loading station and then our packaging and shipment area. The loading and packaging for shipment is allocated one day for processing.

Customer payloads that require low risk propellants such as refrigerants, inert gas, or LMP-103s may be fueled at our factory with prior coordination and safety review. Toxic or high hazard propellants such as hydrazine are discouraged and shall only be fueled at the launch site.

Shipping to Launch Site (1 day)

We ship to the launch site using standard ground transport. Please allow one business day for shipping to the launch site.

Launch Site Operations (30 to 90 days)

After arrival at the launch site, we coordinate all launch vehicle integration activities with the launch provider. Because the spacecraft is pre-fueled and checkouts are completed at the factory, we need only maintain battery charge levels and perform minimal checkouts to ensure Square Rocket and its payload are functioning. In the event a customer payload is found to be non-functioning, we coordinate return of the Square Rocket and payload to the factory for troubleshooting. Standard checks include routine verification of leak integrity, battery charge state, flight computer basic communication and function, and payload heartbeat and health monitoring. We budget support for up to 90 days of launch site processing to allow for high uncertainty in launch schedules.

Launch & Spaceflight Operations

Flight operations are budgeted for twenty calendar days from launch including all phases of the Square Rocket mission. For customers desiring longer missions (for example, missions to map the Van Allen Belts or perform GEO surveys) our team can perform analysis specific to unique missions as an additional service offering.

On-Orbit Checkout (1 day)

After release from the launcher, Square Rocket automatically deploys solar arrays, charges the batteries, orients for communications, and establishes communications with the ground station. Our team then performs vehicle and payload checkouts, which are budgeted to take one business day. Low Earth Orbit collision deconfliction is coordinated with JSPOC through electronic messaging. However, with only one day required for checkout, we expect minimal likelihood of needing to perform collision avoidance during the checkout phase.

Orbit Raising (up to 15 days)

Once Square Rocket and payload are verified ready for orbit raising, we set the vehicle to autonomously orbit raise. Because the Low Earth Orbit satellite population is growing exponentially, Square Rocket raises both apogee and perigee to 600 km to de-conflict with the emerging LEO communications constellations prior to continuing to higher orbits. Once clear of the high traffic orbits, Square Rocket performs apogee burns to reach target orbit followed by perigee burns to circularize (if needed). We expect that most transfers between Low Earth Orbit and Low Lunar Orbit will take ten to fifteen days.

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PAYLOAD SEPARATION (2 DAYS)

Upon reaching the target orbit, we coordinate with the payload customer to deploy the payload. We budget two days for payload deployment operations to ensure a clean separation and smooth handoff to the customer operations team.

POST-SEPARATION DISPOSAL (1 DAY)

After a successful payload separation, we command Square Rocket to move to a pre-determined disposal orbit to ensure zero risk of re-connection with the deployed payload.

Payload Accommodation

Payload Envelope & Center of Gravity

Square Rocket payloads are accommodated on the forward spacecraft deck within a rectilinear prismatic volume as depicted below:

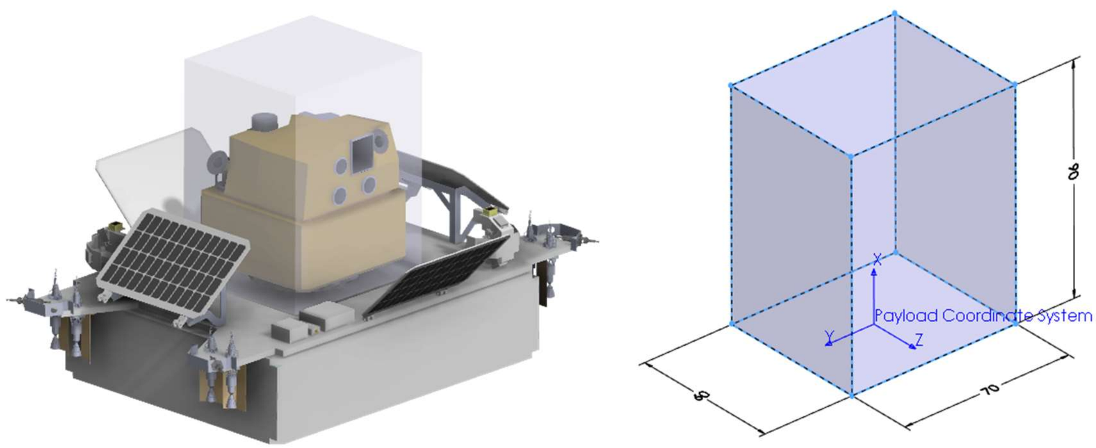

Figure 5 – Example small satellite payload onboard Square Rocket. Linear dimensions in centimeters.

Payloads shall be compatible with the following dynamic envelope:

Table 2 – Payload dynamic envelope dimensions

Axis	Dimension [cm]
x	90
y	70
z	60

Square Rocket is a rideshare payload subject to launch vehicle center of gravity requirements. It offers flexibility to the customer to accommodate a wide range of payload masses while still maximizing ΔV for the given configuration.

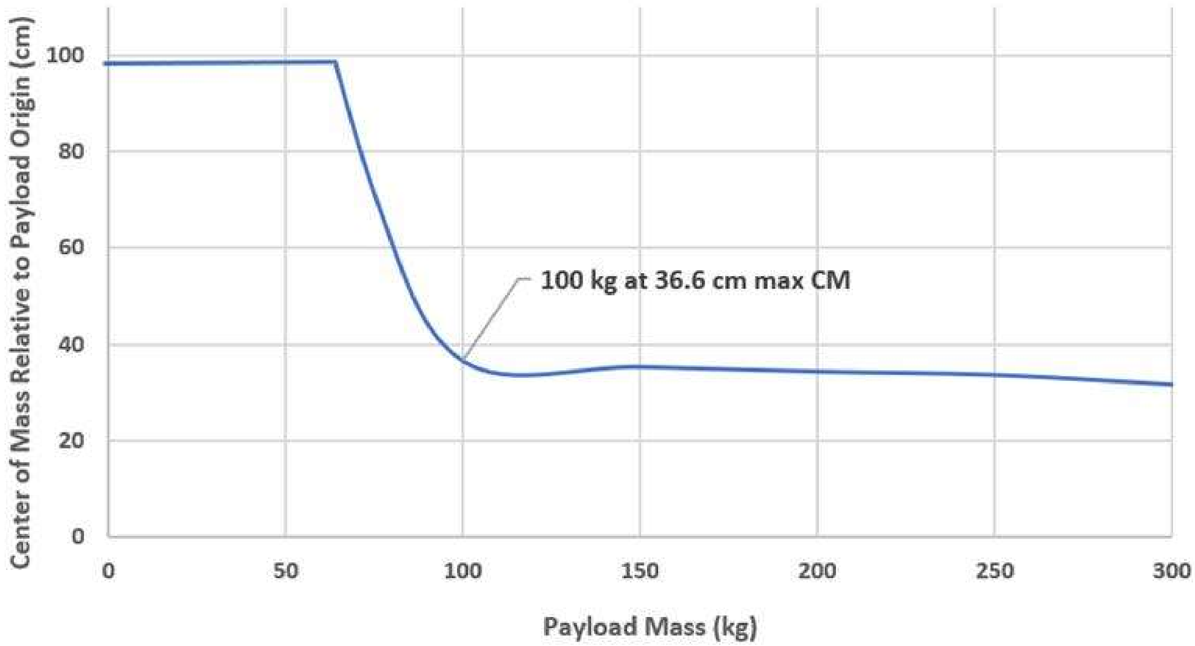

Figure 6 - Mass - CG constraints for Square Rocket

Payload Mechanical Interface

The following COTS separation systems are currently supported:

- 1x PSC MLB-15 separation system
- 4x PSC MLB-8 separation system
- PSC 12-U & 6-U CSD dispensers in various arrangements
- Maverick Space Systems Mercury & NLAS CubeSat dispensers
- Other separation systems, as negotiated.

Please reference the documentation for PSC Motorized Lightbands and Canisterized Satellite Dispensers where applicable. Specification of readily available COTS separation systems improves price and lead time. See examples below:

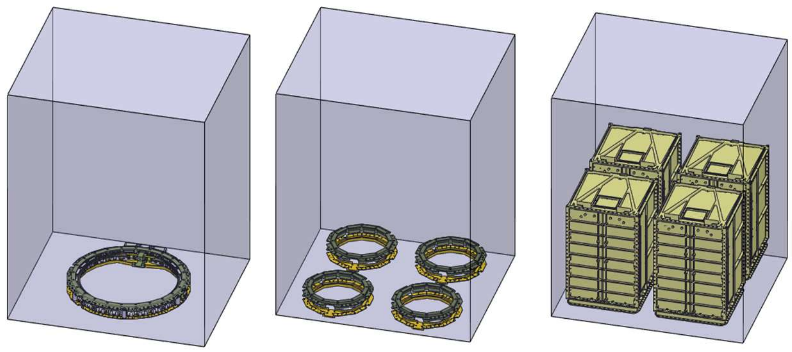

Figure 7 – Example separation system arrangements. Containerized payloads can be arranged in multiple configurations.

Payload Electrical Interface

Power Supply

Payload electrical interface is a nominally 28V bus presented on a single switched LCL circuit. Up to 1A can be drawn continuously from this supply during most mission phases, with up to 6 hour interruptions before and during critical phases (usually, during orbit-raising thrusts). This power will be shut off during launch and during critical phases and can be used to reset the payload on customer request.

Mated Behavior

While mated to the Square Rocket, the payload must not activate, in any way:

- any torque actuator, reaction wheel or thruster.
- any radio transmitter of any kind
- any deployable mechanisms

In addition, the payload should tolerate radiated power from Square Rocket's own TT&C S-Band antennas.

All other payload systems, including avionics and heaters, may be operated at all times when power supply is provided.

Identification of the mated state should occur via the separation system's separation switches and/or the connector's loopback.

Payload Connector

Electrical and data exchange with the payload are conducted via the interface provided by the selected separation system. Once mated, customer access to this interface for GSE is provided by an Amphenol MIL-DTL-D38999 series TV III 15-18 socket on Square Rocket, with the following preliminary pinout:

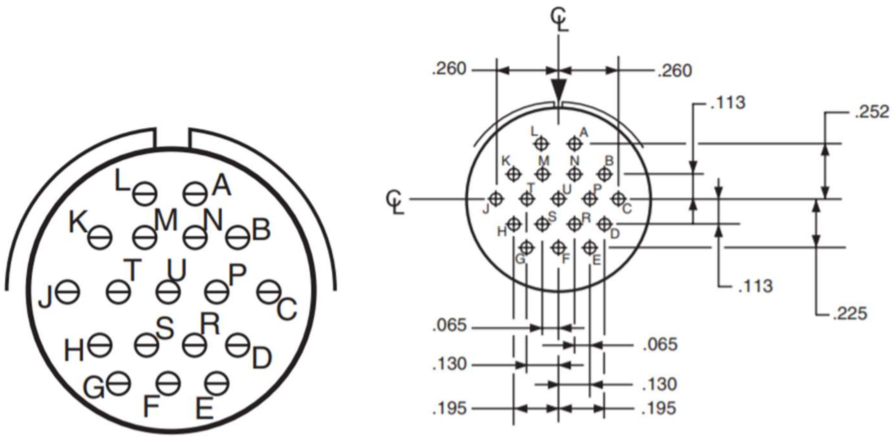

Figure 8 – GSE connector dimensions [in]

Table 3 –GSE connector pinout (preliminary)

Pin	Function
A	Loopback in
B	Loopback out
C	Payload Power in (from Square Rocket, 1A @ 28V)
D	Payload Power return
E	Payload data interface 1
F	Payload data interface 2
G	Payload data interface 3
H	Payload data interface 4

Pin	Function
J	Payload data interface ground
K	Payload Power Return (optional)
L	Spacecraft chassis ground
M	Pass-through
N	Pass-through
P	Pass-through
R	Pass-through
S,T,U	Unused
shell	Spacecraft chassis ground

Payload Data Interface

Protocol

The Square Rocket payload interface protocol is Ethernet. Communications are performed with a REST API interface, typical of most ethernet equipped devices. Mission time and position information is available through this API. The API interface document is provided to customers after agreement on logistics services.

Other electronic data protocols may be supported at additional cost and development time.

Downlink to Earth

Square Rocket can downlink data at rates of up to 10 kb/s from the payload. 1 GiB of long-term data volume in Square Rocket computer is available to the payload user, which can be downlinked once per orbit (in a package equivalent to approximately 1 kb/s of data collected continuously over the longest orbit). A forward channel is available for low-data rate uplink from Earth to the payload throughout. The terrestrial client interface to the forward and return data channels will be through a provided IP link, which will offer both the raw data from the payload as well as certain contextual parameters from Square Rocket (timestamp, position, radiation dose estimation, payload temperature, voltages, and current draws).

Payload Environments

Factory Integration

Customers may participate in integration operations or have integration handled by our staff. Payloads are initially received at a shipping dock then moved and unpacked in an ISO 6 cleanroom. Payload integration occurs in an adjacent ISO 6 cleanroom with Square Rocket. Payload functional testing (if needed) occurs prior to propellant loading. Square Rocket is eventually shipped to the launch site via ground, with batteries topped-off prior to loading in the truck and again at the launch site.

Launch-Site Integration

Integrated Square Rocket & Payload assemblies are transported by ground to the launch site. Payloads will be subject to the same ground handling loads and environments as launch vehicle rideshares. Integration processing is unique to each launch vehicle company and will be coordinated with customers prior to shipping.

Launch Environment

Launch environments generally derive from launch vehicle rideshare environments. Contact us for more information. The following sections describe the characteristics of the launch environment.

Design Loads

Launch loads consist of dynamic loads combined with quasi-static loads. For design purposes, payloads should use the load factors specified below:

Table 4 –Design load factors

Mass [kg]	**Design load factor** [*g*]
30	13
100	12
200	11
400	10

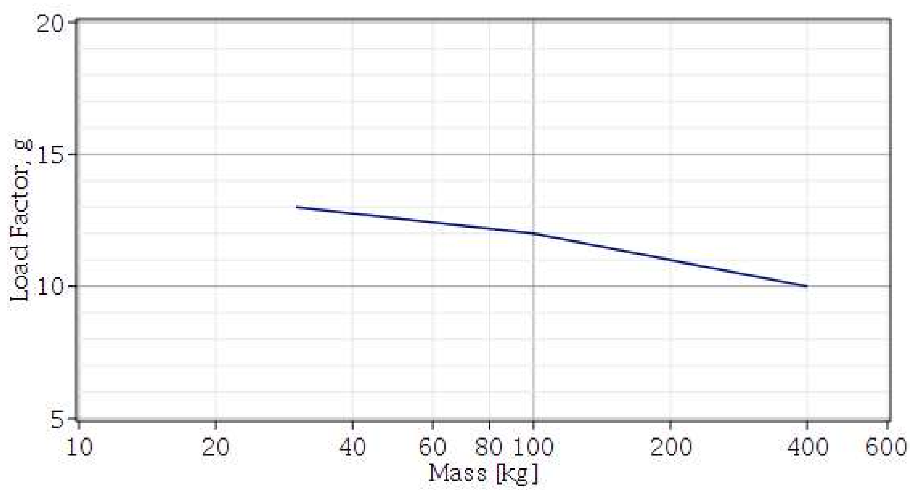

Figure 9 – Design load factors

Random Loads

Payloads shall have no significant modes of vibration below 60 Hz, and shall be compatible with 10 g_{RMS} random vibration per GSFC-STD-7000A (GEVS), summarized below:

Table 5 – Random vibration levels

Frequency [Hz]	PSD [g^2/Hz]
20	0.01
20-50	+6 dB/octave
50-800	0.1
800-2000	-6 dB/octave
2000	0.01

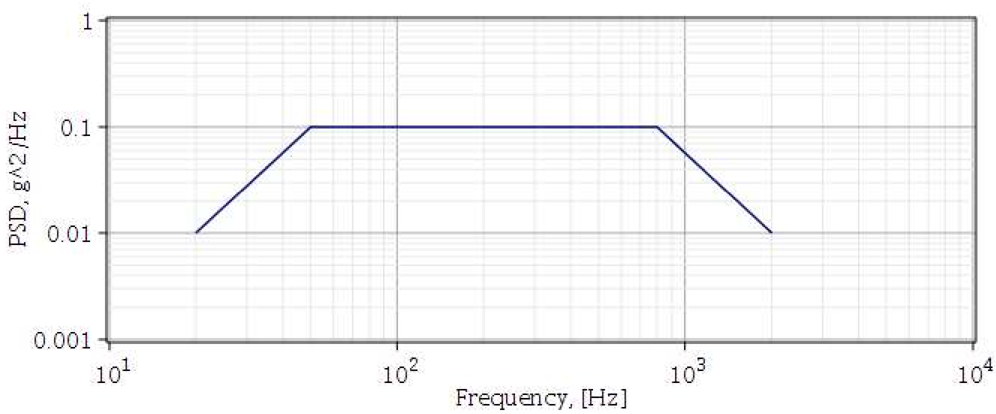

Figure 10 – Random Vibration Levels, 10 g_{RMS}

Shock & Acoustic Loads

For most payloads, shock loads are generally attenuated by various mechanical interfaces, and acoustic loads are typically enveloped by mechanically transmitted loads. For design and qualification, customers may use the shock and acoustic environments specified below.

Table 6 – Shock response spectrum

Frequency [Hz]	**SRS** [Q = 10 g_pk]
100	30
1000	1000
10000	1000

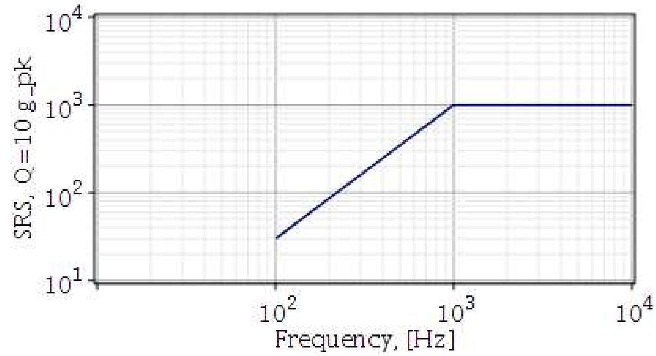

Figure 11 – Shock Response Spectrum

Payloads shall be compatible with the following acoustic environment:

Table 7 – Acoustic Environment

Frequency [Hz]	**SPL** [dB rel 20 µPa]
20	120
100	126
200	130
1000	122
10000	112

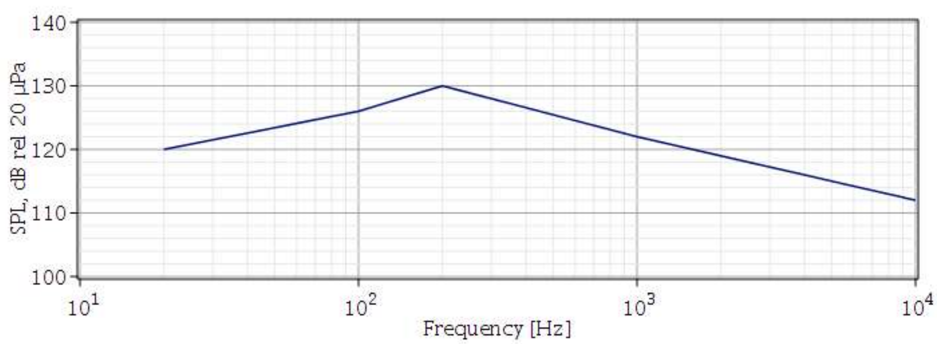

Figure 12 - Acoustic environment.

Venting

Payloads shall be designed to venting requirements as required by the launch vehicle rideshare. For example, a typical depressurization rate is less than 3000 Pa/second (0.4 psi/second) from liftoff through fairing separation.

Outgassing

Payloads are not subject to stringent outgassing requirements unless otherwise indicated.

Thrust & Cruise Environment

Customers must design their spacecraft for compatibility with the spaceflight environment during cruise and thrust. Deep space is somewhat different than the LEO regime, and correspondingly there are consequences for successful design. See Appendix 1 for more information.

Loads

Payloads designed to withstand launch will readily withstand cruise loads. Payloads are not subjected to quasi-static accelerations any greater than 0.2 *g* in the longitudinal direction. There are no appreciable shock loads encountered during cruise and thrust.

Radiation

Delivery to interesting locations in cislunar space involves traversal of radiation environments more intense than those encountered in typical LEO operations. Payloads must be prepared to withstand the radiation environment associated with delivery to their destinations. For example, a LEO to GTO trajectory on Square Rocket involves exposure to 3 krad over 2.5 days through 2 mm of aluminum as shielding. Contact us for more information on radiation modeling.

It is recommended to power down all subsystems during transit of the radiation belts for additional SEE protection during cruise.

Thermal

Thermal requirements are driven by attitude and solar flux, which may vary extensively during cruise for adequate power and communications performance of Square Rocket. Payloads should be prepared to withstand periods of sun-pointing or anti-sun pointing. Some general guidelines are given below. Contact us for guidance with thermal modeling and simulation or to discuss your mission-specific pointing requirements.

Broadly speaking, thermal design for successful deep space missions involves decoupling the bus from its environment through the use of radiative insulation (typically multi-layer insulation), and proactively managing the remaining heat transfer to keep units within their required temperature range. Cooling is accomplished by means of radiators. Passive thermostatic control using variable-conduction components increases the flexibility of a thermal design, at the expense of increased system parts count.

Electromagnetic

For reliable delivery, payloads must not emit EMI that may affect the operation of Square Rocket or the launch vehicle. See MSFC-SPEC-521C, or contact us for detailed requirements on electromagnetic compatibility.

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Meet the Team

Bradford Space has provided reliable space systems for over 35 years through its facilities in Sweden, the Netherlands, and Luxembourg. The team responsible for logistics services and vehicle engineering is in the United States.

References

GSFC-STD-7000A
MSFC-SPEC-521C

Note to Readers

This is a working document, and as such is revised and updated periodically. We encourage readers to ensure they have the latest revision. Specifications and requirements may change without notice. This document represents our best prediction of system performance and is not necessarily representative of present-day capability or capacity. Contact us for clarification and updates.

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Appendix 1: Design Guidelines for Deep Space Small Spacecraft

Bradford Space has inherited knowledge of deep space component and mission design from ESA missions and asteroid mining spacecraft concepts. The company has accumulated a collection of lessons learned which may be useful to prospective customers and designers of deep space small satellite missions.

A condensed list of our design guidelines is presented below:

1. Radiation, both total ionizing dose (TID) and single event effects (SEE), can substantially impact mission operations. Shielding will help protect against TID damage, but it will not prevent SEE. Plan to be able to power cycle your vehicle from any state to recover from SEE, especially single event latch ups.
2. The most intense radiation between Jupiter and the sun exists in the Van Allen Inner Belt between 1,000 km and 12,000 km altitude above Earth. It is desirable to pass through this region as quickly as possible.
3. In deep space, the thermal environment is different from LEO, and this strongly impacts the overall design of the spacecraft. Thermal design should be considered during the earliest concept stages of mission planning.
4. Micrometeorite and Orbital Debris (MMOD) damage can be a significant concern if the target destination passes through denser debris fields. Whipple shields may be needed if you plan to fly though these regions.
5. Power system reliability is a key design driver. Ensure rigorous testing of all elements of the power system (batteries, solar panels and actuators, power processing, etc.) including full environmental range testing prior to shipping your payload for integration.
6. Many successful deep space missions have been performed without using reaction wheels for pointing. Propulsive spin-up, spin-down, and RCS pointing consume a relatively small amount of propellant for many missions and are worth considering in your design trades.
7. While Ka-band and optical communication is high performance, S and X-band ground stations are far more widespread and resilient to weather. We recommend considering S and X and their impact on ground station availability when trading communications options.
8. Remember— without Earth nearby:
    a. Solar wind and cosmic ray flux changes. Peak radiation events are sharper (CMEs, flares)
    b. There is no magnetic field to torque against
    c. There is no Earth-shine (thermal)
    d. Navigation in deep space conventionally relies upon the Deep Space Network or equivalent ranging systems. There is no GPS, NORAD, etc.
    e. Communications will be delayed by seconds to minutes.
    f. Omni antenna function is not guaranteed to work. Loss of pointing could lead to loss of mission.

The above list is not exhaustive. Contact us for application-specific mission design consultation, or to share a difference of opinion.

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