STAR-LORD PAYLOAD USER'S GUIDE

29 March 2017

Contact Information

Please contact Christopher Craddock with enquiries regarding the suitability of our launch vehicle for your mission's requirements.

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Revision History

Version	Date	Prepared By	Notes
1	25 January 2017	RocketStar Team	Initial Release
2	29 March 2017	RocketStar Team	Clarifications

Table of Contents

1 Introduction

RocketStar was established in 2014 in New York City to be a producer of small launch vehicles that make space accessible for anyone who has a CubeSat and a credit card. RocketStar is developing a new generation of aerospike rocket engines that are cost-effective, reliable, and environmentally friendly. Our aerospike rocket engine will maintain its aerodynamic efficiency across a wide range of altitudes using an altitude compensating exhaust design instead of a traditional rocket nozzle. This will result in a vehicle that uses 25-30% less propellant at low altitudes. RocketStar's flagship Star-Lord launch vehicle is powered by pressure-fed, environmentally friendly liquid oxygen - liquid methane aerospike rocket engine technology. The RocketStar Star-Lord launch vehicle will deliver a 300kg total payload compliment to a 28-degree orbital inclination, 185km altitude Low Earth Orbit (LEO). A typical payload compliment is a 100kg smallsat and twenty 3U cubesats released approximately 30 seconds apart by our payload deployer system. Higher orbital inclinations and higher altitudes reduce this typical payload capacity. A single 3U cubesat is assumed to be 10kg. RocketStar's launch vehicle will provide low-cost, high-frequency launch capability for the rapidly growing and critically underserved small satellite industry. RocketStar's lean development approach delivers game changing launch costs, accessibility, and reliability for customers.

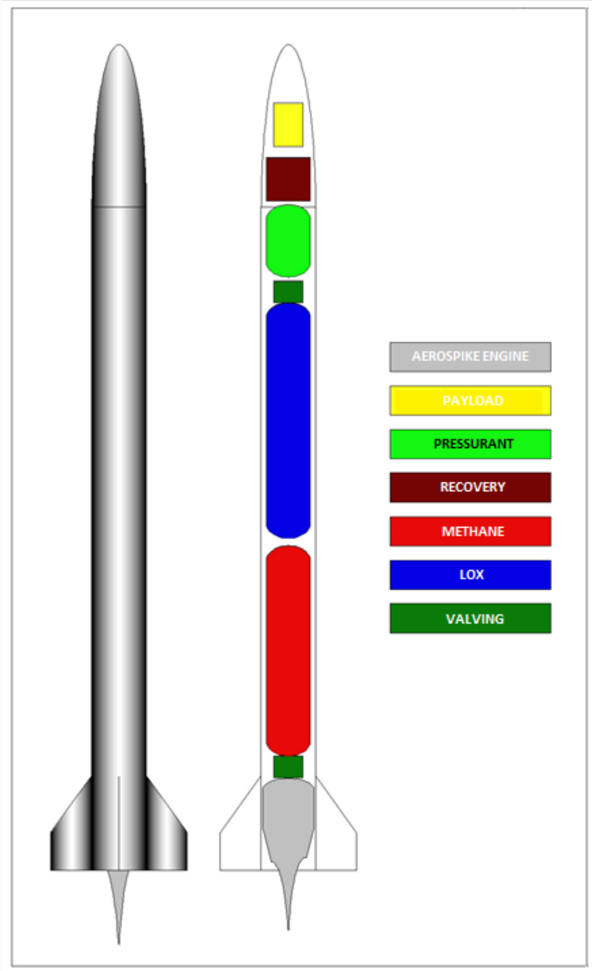


Figure 1: Star-Lord Launch Vehicle

RocketStar's seasoned engineering team is comprised of industry-proven leaders with experience in both building commercial launch vehicles as well as successful technology firms. Augmenting and rounding out this team are passionate young minds from the country's top engineering schools. Each vehicle is engineered with cross-industry design insights and leverages high Technology Readiness Level (TRL) design elements to reduce risk and guarantee reliability. The technologies employed in our flagship launch vehicle provide a clear pathway for future incremental improvements in vehicle capability. This unique development approach aims for monthly rocket launches within 3 years of initial launch. RocketStar's operations are highly streamlined, with design, testing, and production located in New York with launch and mission operations located in Florida.

2 Launch Vehicle Overview

RocketStar's flagship Star-Lord launch vehicle is a Two Stage To Orbit (TSTO) small launch vehicle powered by powered by a pressure-fed, environmentally friendly liquid oxygen - liquid methane aerospike rocket engine for the first stage and elements of it for the second stage. The Star-Lord launch vehicle stands 27.4 m (90 ft) tall and is 2 m (6.6 ft) diameter. The first stage will have a cluster of eight 22 N (5,000 lbf thrust) engines. The upper stage will have a single 22 N (5,000 lbf thrust) engine. The RocketStar Star-Lord launch vehicle will deliver a 300kg total payload compliment to a 28-degree orbital inclination, 185km altitude Low Earth Orbit (LEO) utilizing efficient technologies such as composite tanks, a plug cluster first stage aerospike, and a traditional bell nozzle engine 2nd stage. Higher orbital inclinations and higher altitudes reduce this typical payload capacity. We place heavy reliance on 3D printed parts, using the latest in materials science that will allow us to manufacture complex parts with integrated cooling channels, heat resistance, and structural elements that are modular and can be used to build multiple configurations of the greatest strength and durability. Our aerospike engine will maintain its aerodynamic efficiency across a wide range of altitudes using an altitude compensating exhaust design instead of a traditional rocket nozzle. This will result in a vehicle that uses 25-30% less propellant at low altitudes.

RocketStar's operations are highly streamlined, with design, testing, and production located in New York with launch and mission operations located in Florida. Our New York facilities are located in Brooklyn, NY; a short drive from Lower Manhattan Island via the Brooklyn Bridge. We employ a modular design approach in which the rocket is a build-up of structural "tuna cans" that are easily transported to the launch site.

Our aerospike engine has four major engine modules. ***Fuel and oxidizer pintles*** - The liquid rocket engine injector is one of the most sensitive and complex components of the engine. Performance data for rocket engines are practically always lower than the theoretically attainable values because of imperfections in the mixing, combustion, and expansion of the propellants. The most significant improvements in injector nozzle performance can be achieved through the adaptation of nozzle exit pressures to the variations in ambient pressure during the vehicle's ascent through the atmosphere. The pintle design allows a continuous variation of the injector and, thus, optimum expansion area ratios throughout a mission. One highly desirable feature of the pintle injector is its inherent combustion stability. Even at power levels as low as 10%, the pintle injector has never exhibited acoustic instability. Considering the depth of throttling required for the reference mission, a multi-stage/multiple pintle system may be required. ***Ignitor*** – Stable, even propagation,

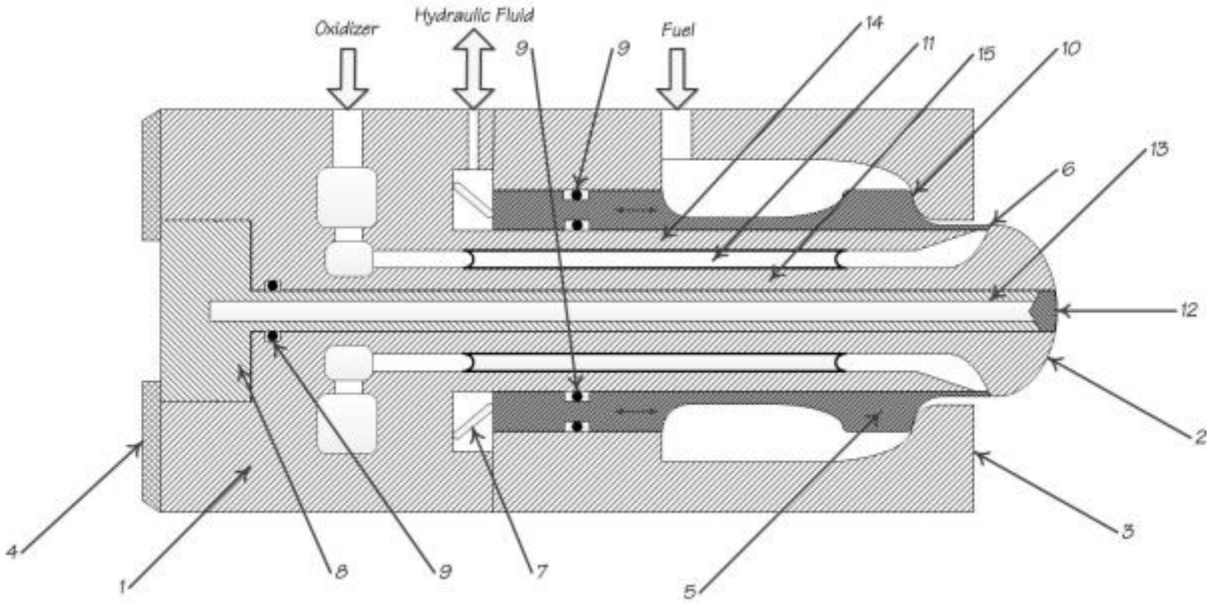


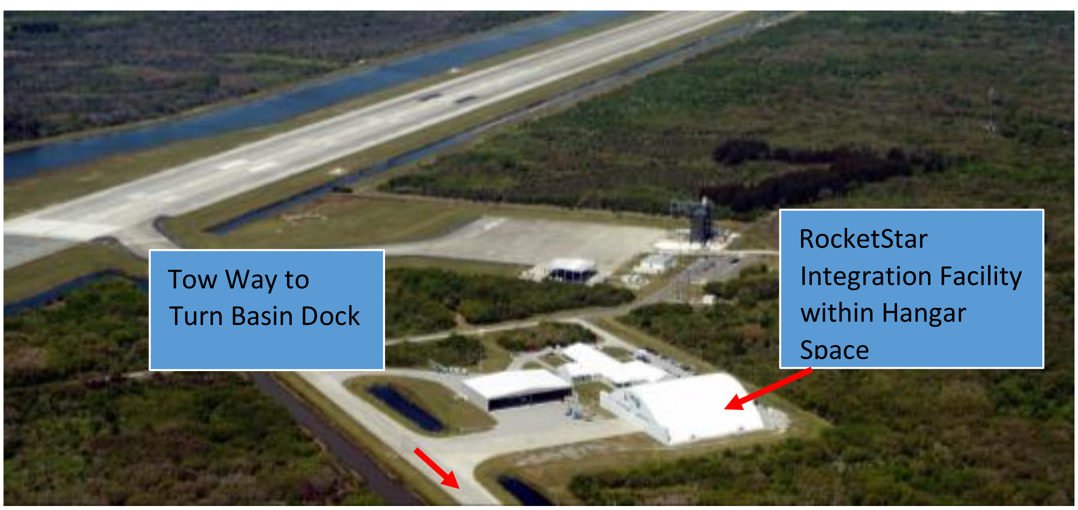
Figure 2: Liquid Oxygen – Liquid Methane Injector Pintle for Aerospike Rocket Engine

and timely combustion of the oxidizer-fuel mixture is necessary to provide continued stable thrust and avoid detonative explosion and catastrophic damage. Given the necessity for shutdown and restart there are four choices for ignition: catalytic, hypergolic, electrical, or LASER. In most cases, the ignitor will be a central part of the fuel and oxidizer injection nozzle. A spark torch ignitor can burn many times, is ideal for re-startable engines, and can be easily integrated into the fuel/oxidizer injector nozzle. Gaseous propellants burn cleanly and will produce limited to no particles into the combustion gases. ***Combustion Chamber*** - The combustion chamber consists of the volume between the injector faceplate and the throat of the aerospike where the combustion process takes place. In order to ensure that combustion stability is achieved, the combustion chamber must be long enough to ensure proper mixing and combustion of the propellants. If the length is too short and the propellants exit the chamber without mixing and combusting, performance is lost. ***Aerospike Nozzle*** – The key features of the aerospike nozzle will be the approach used to secure the center body, the optimum geometry of the aerospike, and the additive manufacturing of the appropriate materials needed to withstand the heat and pressure during firing.

3 Ground and Flight Operations Overview

Our launch and mission operations are located in Florida. The integration facilty is in hangar space located at the former Shuttle Landing Facility at Kennedy Space Center. The Shuttle Landing Facility covers 200 ha (500 acres), has indoor and outdoor processing areas, equipment storage areas, hazardous operations areas, a control tower, and a single runway:

15 / 33. The Shuttle Landing Facility is now managed by Space Florida, the aerospace economic development agency of the State of Florida. The runway is still active, but low volume. RocketStar activities will be in coordination with Space Florida and other Shuttle Landing Facility residents. The integration facility is air conditioned and meets MIL-STD-1246-C specifications for Visibly Clean. The payload integration area within the integration facility will meet ISO Class 8 (Federal Standard 129-e Class 100,000) with personnel attired in clean room garments (provided). The RocketStar launch and mission control center is also located at the former Shuttle Landing Facility. It serves as the technical team location for launch preparations, launch operations, launch, and mission operations. Once payloads are integrated into the launch vehicle, a clean air trickle purge will be applied at all times other than vehicle rollout and just prior to launch. The launch vehicle is built-up in a horizontal orientation. Our launch platform barge is based outside the gates of Kennedy Space Center along the Barge Canal on the Banana River. For launch campaigns, 3 days before launch it is towed to the Turn Basin Dock near the Vehicle Assembly Building at Kennedy Space Center. Two days before launch, the launch vehicle is towed over to this dock from the integration facility. One day before launch, the launch platform is towed to the launch location in international waters 20km offshore, the vehicle is raised to the vertical position, serviced with the required quantities of liquid oxygen and liquid methane propellants, and prepared for launch. During final launch countdown, all ground and flight systems will be veried as ready, the Range and Weather will be verified as within limits, and final launch sequence will occur. For a nominal mission, at an altitude of approximately 185km and the upper stage has achieved a 28-degree inclination orbit, the payload release sequence will begin. Approximately every 30 seconds, the primary 100kg smallsat and the twenty 3U cubesats are released one by one.



Kennedy Space Center's Shuttle Landing Facility – site of RocketStar's
Ground Operations Facilities

Kennedy Space Center's Turn Basin Dock (note Shuttle Landing Facility at top)

4 Payload Accommodations

The payloads are protected from aerodynamic buffeting and heating by the payload fairing consisting of a carbon fiber composite structure. The payload area above the recovery system will be approximately 2 cubic meters (71 cubic feet) in volume. To optimize use of the available payload volume; 1U, 2U, 3U cubesats and a single smallsat will be integrated into a single payload deployment device offline with the entire assembly installed into the launch vehicle at the launch site. This device can accommodate mechanical actuation of a cubesat's activation switch. This device has standard attach bolt patterns that will be provided at initial discussions approximately 18 months before launch. Customers with larger smallsats or clusters of cubesats will be provided with other deployment accommodations. Cubesat and smallsat customers will have the opportunity to perform final battery charging and checks up to 1 week before launch. Customers can expect up to 4 weeks of not having access to batteries prior to launch. Charging or other diagnostic checks will not be available once the deployment device is mated to the vehicle and payload fairing is installed. All payloads will be in power-off mode from installation to on-orbit deployment. After closeout for flight, the payload fairing will have a continuous clean air trickle purge of 0.1 psig less outages for vehicle rollout for installation on the launch platform. The purge will be re-established on the launch platform. The purge will be disconnected one day before launch. On ascent, the payload fairing will vent pressure to ambient all the way to vacuum conditions at its on-orbit arrival.

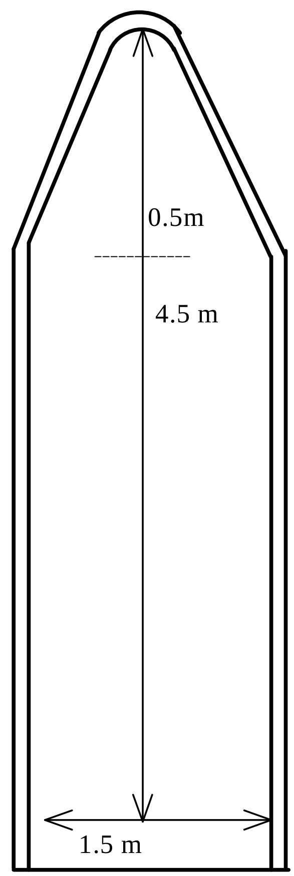


Figure 3: RocketStar's Star-Lord Payload Fairing

5 Payload Environments

This section describes the environment and loads that payloads will be subjected to during launch on RocketStar's launch vehicle. All cases are considered worst case until actual values are measured during the first 1-3 developmental flights. Certain requirements may be reduced at that time.

Flight Loads – Quasi-Static

Table 1 shows the maximum quasi-static loads to be expected at the payload/launch vehicle interface during flight. The z-axis is along the length of the launch vehicle with z-0 at the launch platform-to-launch vehicle interface. Follow the right-hand rule for x and y axes.

Event	Axial Load (x), g	Lateral Load (y,z), g
Liftoff	1.3	±0.3
Max qα	1.8	±0.3
Engine Cutoff (MECO)	6.0	± 0.3

TABLE 1: QUASI-STATIC FLIGHT LOADS AT SPACECRAFT/LAUNCH VEHICLE INTERFACE

Flight Loads – Random Vibration

During launch, payloads will be subjected to a random vibration environment due to a combination of engine vibrations, vehicle structural modes, and aerodynamic buffeting. The intensity of these vibrations is highly dependent on payload mass and the interface between the payload and the launch vehicle.

Spacecraft with masses above 91 kg (200 lbs) shall design to the blue curve presented in Figure 4, with detailed values provided in Table 2. Spacecraft with masses below 23 kg (50 lbs) shall design to the red curve presented in Figure 4, with detailed values provided in Table 2. These levels are subject to change. Please contact RocketStar for custom requirements if your spacecraft has sensitive equipment.

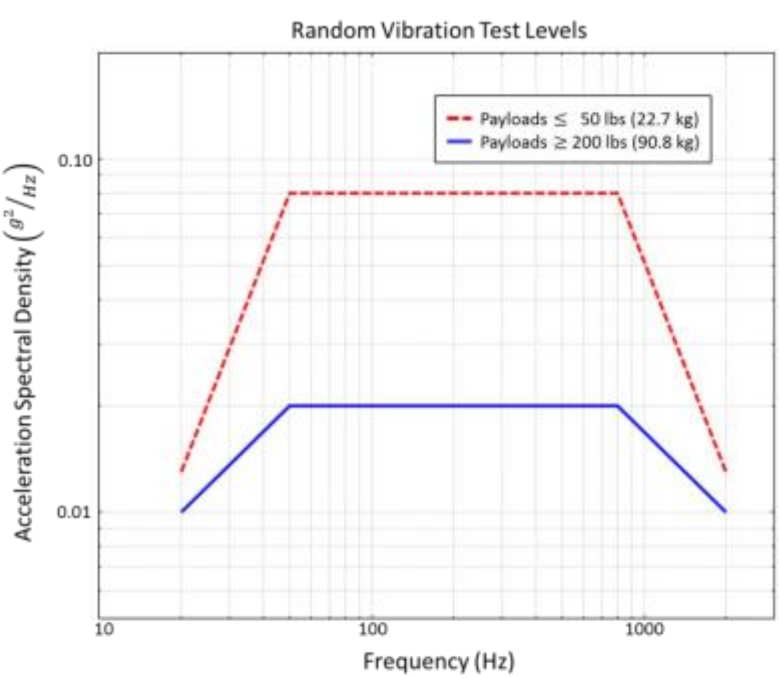


FIGURE 4: RANDOM VIBRATION TEST LEVELS

TABLE 2: RANDOM VIBRATION LOADS FOR PAYLOADS 200 LBS (91 KG) AND LARGER

Frequency	**ASD Level (g^2/Hz)**
20 Hz	0.01
20-50 Hz	+2.28 dB/octave
50-800 Hz	0.02
800-2000 Hz	-2.28 dB/octave
2000 Hz	0.01
Overall	**4.86 G_{RMS}**

TABLE 3: RANDOM VIBRATION LOADS FOR PAYLOADS 50 LBS (23 KG) AND SMALLER

Frequency	**ASD Level (g^2/Hz)**
20 Hz	0.013
20-50 Hz	+6 dB/octave
50-800 Hz	0.08
800-2000 Hz	-6 dB/octave
2000 Hz	0.013
Overall	**10.0 G_{RMS}**

Flight Loads – Acoustic

The maximum acoustic environment the payload sees is at liftoff and through transonic flight. It is expected to meet an Overall Sound Pressure Level (OASPL) of <135 dB.

Shock Loads

The maximum shock environment at the payload interface occurs during Payload separation from the vehicle and is dependent on the specific mission configuration of payloads. Shock levels at the payload separation interface due to other flight events such as stage separation and engine ignition/shutdown – are not significant compared to the shock caused by payload separation. Figure 9 illustrates the maximum expected shock environment. Detailed values are presented in Table 4.

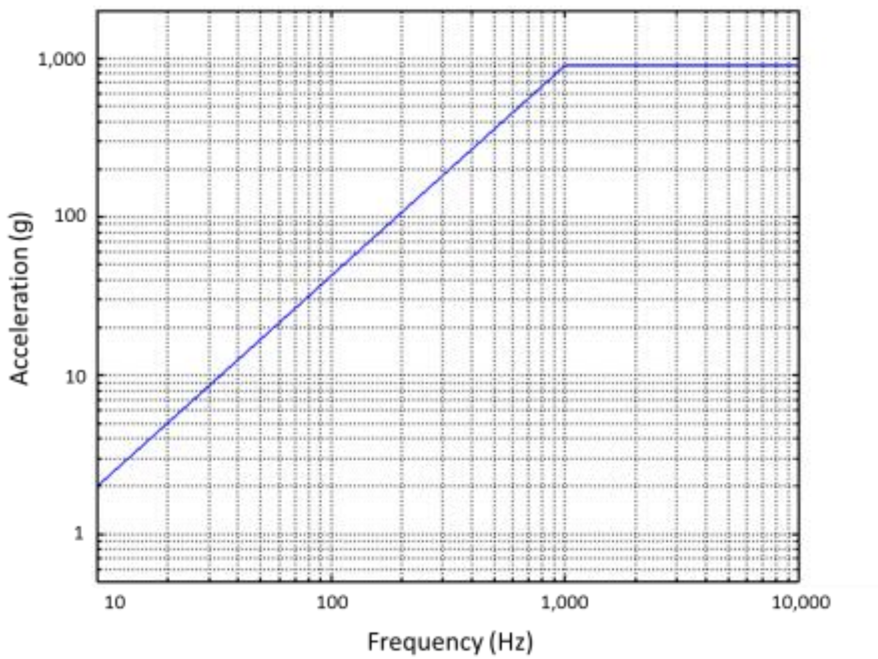


FIGURE 5: EXPECTED SHOCK LEVELS DURING PAYLOAD SEPARATION

TABLE 4: EXPECTED SHOCK VALUES

Maximum Expected Shock Loads During Flight	
Frequency	**SRS (g-peak)**
10 Hz	2
10-1,000 Hz	+3.99 dB/octave
1,000-10,000 Hz	900

Payload Fairing Conditioning

Upon payload fairing installation, a continuous supply of clean air is provided at a typical environment range as stated in Table 5. The air is supplied to the payload area through the air-distribution access door. A trickle nitrogen (MIL-PRF-27401F, Type 1, Grade B purge) can be provided for specific bagged sensors while inside the integration facility prior to final payload fairing installation. This trickle purge will be controlled by customer supplied equipment. Source nitrogen can be provided by facility systems or K-bottles. For roll-out from the integration facility for installation on the launch platform, all purges will be discontinued. After installation onto the launch platform is complete, the air purge will be re-established. All purges are discontinued one day before launch.

TABLE 5: PAYLOAD BAY ENVIRONMENTAL CONDITIONING

Location		Temperature	Relative Humidity	Flow Rate	Filtration	Hydrocarbons
RocketStar Integration Facility	Payload Integration Area	75F ± 5F 23.89C ± 2.8C	50% maximum	900-1500 CFM 25.5-42.5 m^3/min	Class 100,000	15ppm max
RocketStar Integration Facility	Vehicle Integration Area	75F ± 5F 23.89C ± 2.8C	50% maximum	180-240 CFM 5.1-6.8 m^3/min	Class 100,000	15ppm max
Turn Basin/Launch Site	Launch Platform	75F ± 5F 23.89C ± 2.8C	50% maximum	180-240 CFM 5.1-6.8 m^3/min	Class 100,000	15ppm max

Payload Fairing Thermal Environment During Launch

The launch vehicle's payload fairing is exposed to aero heating during ascent. The ascent heating is analyzed by using computational fluid dynamics (CFD and is a function of time, wall temperature, and the spatial locations. The worst case thermal environment inside the fairing is calculated as (TBD).

On-Orbit Thermal Environment

RocketStar missions are expected to be of short durations for delivery of payloads into Low Earth Orbit. Smallsat(s) and cubesat(s) will be released within a few minutes of achieving orbit. Active thermal control or heating of payloads is not provided. If during the first 1-3 developmental flights actual thermal data indicates that actions are required to improved thermal environment, during coast periods, the launch vehicle can be oriented to meet specific sun angles.

Payload Fairing Internal Pressure

As the launch vehicle ascends through the atmosphere, the payload area will be vented through one way vents at the aft end. The maximum expected pressure decay rate inside the payload bay is -0.24 psi/second. The internal pressure and depressurization rates are illustrated as functions of time in Figure 6.

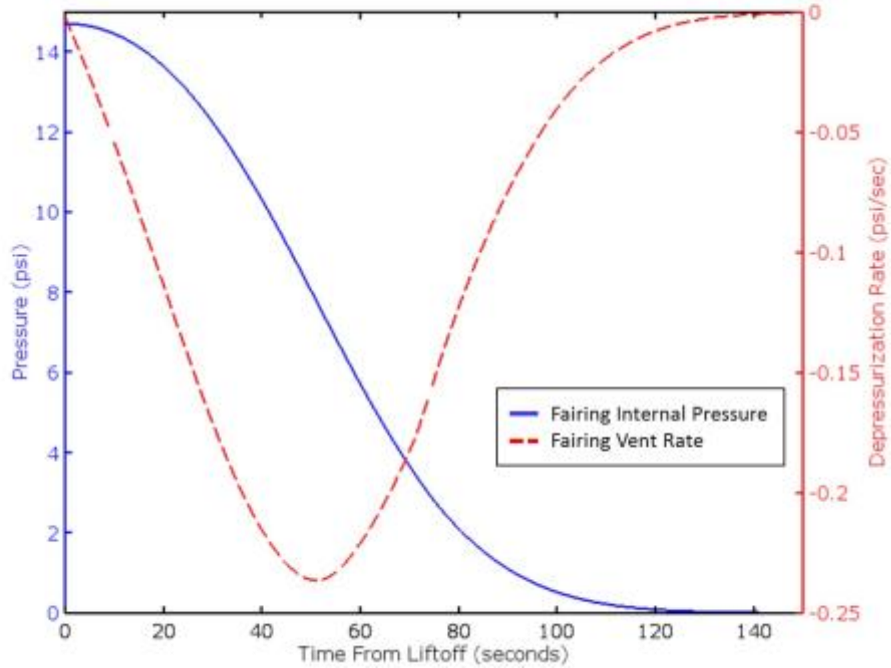


FIGURE 6: PAYLOAD FAIRING INTERNAL PRESSURE PROFILE

Payload Radio Frequency Environment

The launch vehicle's RF system characteristics are TBD. All payloads are expected to pass testing to MILSTD-461 for radiated emissions and susceptibility. The launch vehicle's RF system is particularly sensitive to payload RF emissions. Payloads are powered off during launch to reduce the risk of damage caused by RF interference. RF transmissions by payloads are not to occur until 20 minutes has elapsed after deployment. Additionally, customers must ensure that any payload component or material constituents that are sensitive to RF transmissions are compatible with the electromagnetic environment to be provided.

6 Payload Integration

This section details the requirements to be satisfied for any payload on RocketStar's Star-Lord launch vehicle. The Interface Control Document (ICD) documents all mission requirements and verifications. RocketStar's philosophy is to keep documentation to a minimum and limited to that which is absolutely required in order to execute a mission successfully and safely.

The requirements for a payload's **Qualification/Acceptance Package** can be classified as follows:

- Demonstration through test or analysis, compatibility with the loads and environments generated by RocketStar's launch vehicle

- Demonstration through test or analysis, compatibility with RocketStar's launch vehicle's electrical and communications systems
- Documentary evidence of compatibility of mechanical and electrical interfaces

Resonances & First Natural Frequency

Provide evidence of the **1st lateral resonant frequency** being above **50Hz (TBD)**

Provide evidence of the **1st axial resonant frequency** being above **100 Hz (TBD)**

Quasi-static and/or Sine Vibration Loading

Provide evidence that the payload is robust and will not suffer mechanical failure under the loadings specified in Table 6, with positive margin.

TABLE 6: QUASI-STATIC LOADING FOR AUXILIARY AND SECONDARY PAYLOADS

Parameter	**Axial Load (x), g**	**Lateral Load (y,z), g**
Quasi-Static Loads	10	±2

Random Vibration

Provide evidence that the payload is robust and will not suffer mechanical failure under the loadings specified per Tables 2 and 3, with +3 dB margin. Test duration shall be 2 minutes.

Notching

Reduction of the vibration input amplitude at certain resonance frequencies (i.e. notching) may be possible, but not guaranteed.

Mass Properties

Payloads must adhere to the following requirements. Notify RocketStar as early as possible if actuals are higher. RocketStar may be able to accommodate within planned overall weight margin.

- 1U CubeSats shall not exceed a mass of 1.33 kg
- 3U CubeSats shall not exceed a mass of 10.0 kg

- 6U CubeSats shall not exceed a mass of 20.0 kg
- Actuation of all deployment mechanisms such as booms, antennas, and solar panels shall wait a minimum of 30 minutes after the CubeSat is deployed from the vehicle

For individual CubeSats, RocketStar will provide the dispenser. Larger CubeSat masses may be evaluated on a mission by mission basis. Customers planning to supply their own deployment canisters should contact RocketStar as early as possible in the mission planning process.

There are no strict requirements for Center of Gravity (CoG) positioning on the secondary payloads, as they are expected to be arranged as a whole within the payload space by RocketStar to achieve optimal mass distribution. Measured mass properties of all payloads must be communicated to RocketStar in accordance with the mission timelines identified in Section 7. A dummy mass representative of each payload shall be provided by each payload customer approximately 6 months before launch.

Grounding, EMC & RF Transmissions

It is assumed that all payloads will be powered off during launch and therefore will not be emitting any signals or radio frequency noise during the launch phase.

Numerical & Computer Models

In order for RocketStar to carry out its mission analysis and design, the following numerical and/or computer models of payloads will be required:

- A computer aided design (CAD) model, in STEP (*.stp or *.step) or Parasolid (*.x_t) format. The CAD model supplied should include accurate representations of the external characteristics and features of the spacecraft, including all appendages, and the separation system.

For the timing of model delivery requirements within the mission schedule, please refer to Section 7 of this user guide.

The requirements for a payload's **Ground/Flight Safety Package** are:

General Safety

Ground facility, systems, equipment and their operations shall meet the intent of KSC-DE-512, Facility, Systems, and Equipment General Design Requirements, and KHB-1710.2 KSC Safety Practices Handbook. RocketStar will assist customers in determining if their current designs and operations meet the intent of these requirements.

Spacecraft Batteries

Batteries and their systems must be inherently safe through the selection of appropriate design features or the use of appropriate safety devices, as fail operational/fail safe combinations to eliminate the hazard potential. An acceptable battery design includes controls for potential battery hazards. Battery design considerations must be given to the structural integrity of the cell and battery housings, the possibility of gas generation, pressure, and/or electrolyte leakage, the prevention of short circuits and circulating currents, the possibility for high battery temperatures, battery rupture and fire, over-discharging; and assurance of proper charging techniques. Examples of battery safety devices include: vent disks, current interrupt devices, positive temperature coefficient devices, fuses, and switches, relays, and diodes. Customers must ensure these devices are also evaluated for failure modes and reliabilities since they increase the overall number of failure scenarios.

Pressure Vessels

Spacecraft containing pressure vessels shall comply with the safety standards specified in ATR-2005(5128)-1, Operational Guidelines for Spaceflight Pressure Vessels.

Pyrotechnic and Explosive Devices

The standard baseline launch and launch services offering assumes that no pyrotechnic devices are present on the payload(s). Customers planning to include pyrotechnic devices should contact RocketStar as early as possible in the mission planning process.

Ground Support Equipment

All Ground Support Equipment (GSE) shall be safety tested with test reports available for review upon request. Electrical GSE must include safety measures which allow spacecraft power to be cut in case of emergency, and to prevent overcharging of spacecraft batteries. Lifting fixtures must be clearly marked with proof load limits. Propulsion system GSE must include relief valves that automatically actuate to prevent over pressurization. Propulsion system GSE designs must ensure any relief valve flow paths are directed away from personnel and clearly labeled.

Payload customers will also provide information for RocketStar to include in the master Launch Vehicle to Spacecraft **Interface Control Document (ICD)**. This information will include details of all interfaces (mechanical, electrical and other) and capture all information needed to describe the mission, interfaces and interactions between launch vehicle and payloads.

7 Timeline of Activities

A typical mission campaign timeline with key activities and milestones are included in Table 7. All timings are either before (-) or after (+) the launch date. These dates should be considered as guideline and not as firm constraints. Depending on the level of complexity of the payload and other special circumstances, these dates could shift to being necessary earlier or later than shown.

TABLE 7: TYPICAL MISSION TIMELINE

Event	Typical Timing	Comments
Initial customer contact	L-18 months*	TBC
Signing of Launch Agreement	L-12 months	TBC
Delivery of initial CAD model(s) & satellite information	L-9 months	TBC
Planning meeting 1	L-8 months	TBC
Fit check (with mass simulator)	L-6 months	TBC
Planning meeting 2	L-3 months	TBC
Delivery of final/confirmed payload numerical models	L-3 months	TBC
Commencement of launch campaign	L-6 weeks	TBC
Delivery of all payloads to launch site	< L-4 weeks	TBC
Launch Readiness Review	L-2 Days	TBC
Launch	L-0	TBC
Confirmation of launch performance & parameters	L+3 hours	TBC

Completion of mission & delivery of all data	L+1 week	TBC
Return of all customer launch site equipment	L+2 months	TBC

** Some payloads may be able to be accommodated at later notice than outlined, depending on level of complexity.*

Following approval of the Qualification/Acceptance Package, Ground/Flight Safety Package, inputs to the Interface Control Document, and fit checks of the dummy mass; the payload is delivered to the launch site 3-4 weeks before launch. During this period, all payloads are received, processed, and integrated into the launch vehicle. Also occurring during this period are launch vehicle systems test, checkout, and servicing. A Flight Readiness Review is conducted two days before launch where all data packages and procedures are reviewed in summary form by the entire team including payload customers, pilots, Range & Weather support personnel, and safety & security personnel. Following several days of integration and ground and flight systems check out at the integration facility at the Shuttle Landing Facility, the launch vehicle will be towed to the Turning Basin Dock and integrated on the launch platform. The platform is then towed to the launch site 20km offshore. On launch day, the vehicle will be serviced with the required quantities of liquid oxygen and liquid methane, the Range and Weather will be verified as within limits, and launch will occur.

The processing facility/hangar is a maintained as a visibly clean, climate controlled space at all times. It contains a payload processing clean room area maintained at Class 100K FED-STD209E. Gaseous helium and nitrogen fluid panels will be available in the processing facility. Nitrogen will be 99.99% pure per MIL-PRF-27401F, Grade B. Helium will be 99.995% pure per MIL-PRF-27407D, Grade A. Customer teams will be provided with one desk and one chair for each payload and access to a shared small meeting table having four chairs as well as a larger shared conference room. IT equipment will not be provided other than Wi-Fi access. Additional office space and other amenities can be provided as an option. Standard 110V/220V, 60 Hz AC power will be available in all areas. Other power needs can be provided as an option. Access to the launch vehicle during active processing will be limited to essential work only. When possible, pre-arranged tours for customers and other stakeholders will be conducted. All non-US citizens will require escorts at all times and trained in ITAR protocols. Customers and other stakeholders will be invited to view the launch from an official viewing point (i.e. grandstand) which will be a safe distance from the launch area. A limited number of customer representatives may be allowed to be present in the RocketStar Operations Control Room. RocketStar will provide all customers and other stakeholders with the final mission and orbit details as soon as feasible following payload deliveries.