ASTROBOTIC

July 2024 | Version 1.0

Terrestrial Rocket Testbeds

Publicly available document, please contact Astrobotic for more details.

Xodiac Rocket Lander

Payload User's Guide

MAKING SPACE ACCESSIBLE TO THE WORLD

Table of Contents

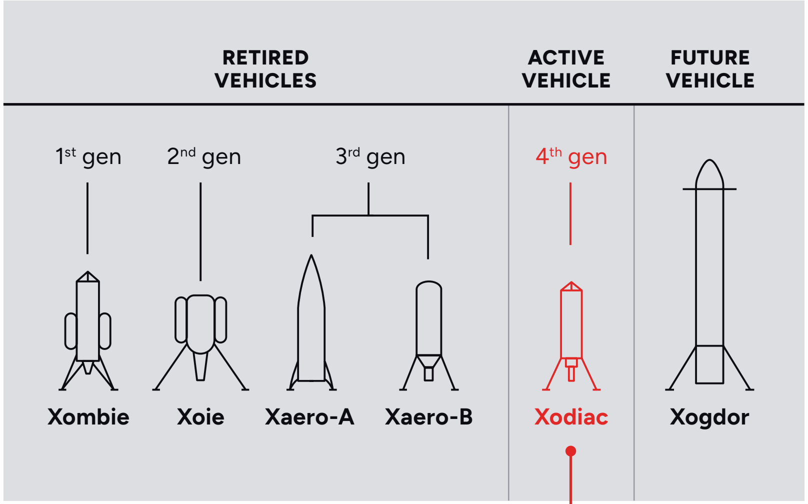
Astrobotic Rocket Landers

Astrobotic's rocket landers provide customers a low-cost way to test, mature, and validate payloads before they are sent to space.

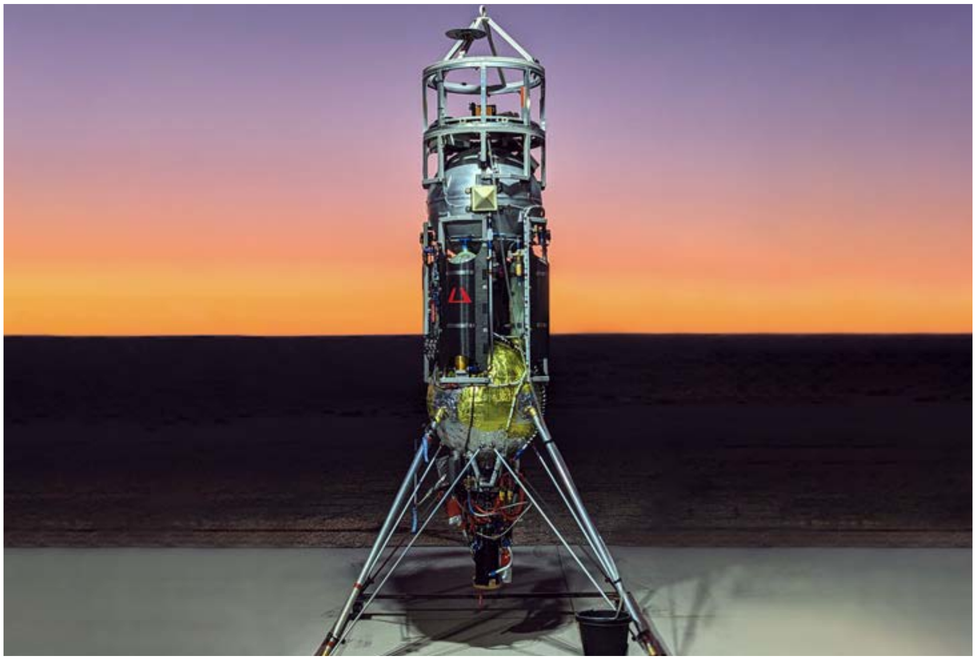
Overview of Vehicles

Astrobotic's rocket landers are vertical-takeoff, vertical-landing (VTVL) vehicles that simulate relevant mission environments through propulsively-controlled hovering, cross-range and downrange translations, and vertical landing maneuvers. Astrobotic has developed five terrestrial rockets to date that have successfully performed over 600 flights since 2009. Xodiac, the subject of this Payload User's Guide (PUG), is Astrobotic's active vehicle and is currently available for operations. Xombie is also maintained as a backup flight vehicle.

Astrobotic continues to develop new rocket landers to meet growing customer needs. Xogdor, Astrobotic's first rocket lander designed to fly to space, will be available for commercial flights starting in 2026. Xogdor is described in more detail on Page 29 below.



Astrobotic Rocket Landers

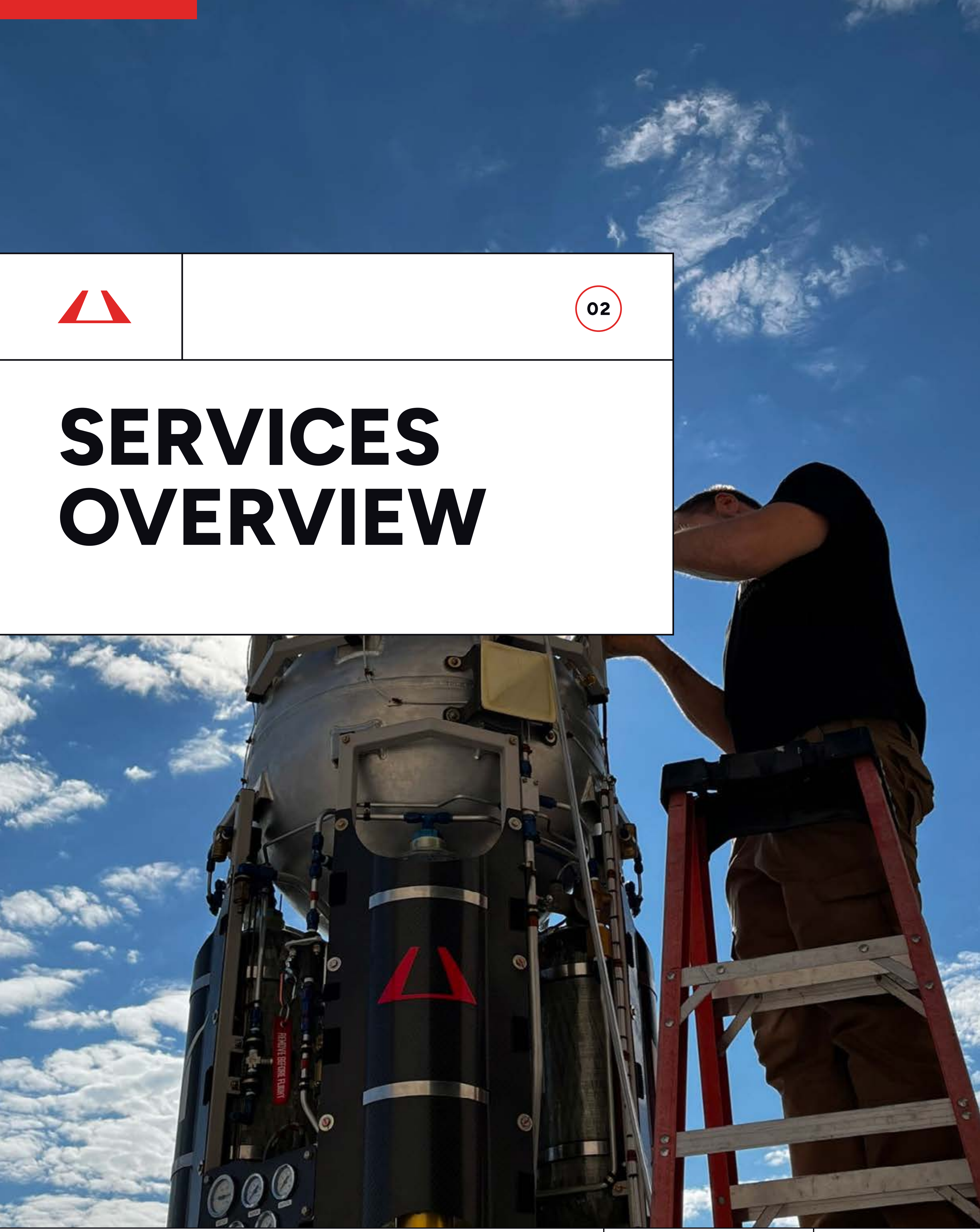


Xodiac

Xodiac at a Glance

This PUG focuses on Xodiac, Astrobotic's 4th generation rocket lander. Xodiac has flown more than 160 flights without a mishap, demonstrating unparalleled reliability, safety, and mission success.

Xodiac serves as a testing platform for customer payloads to reduce operational risk and provide data necessary to advance technology readiness levels. Xodiac can also meet unique customer needs, such as simulating diverse landing environments and supporting open- and closed-loop free flight options.



02

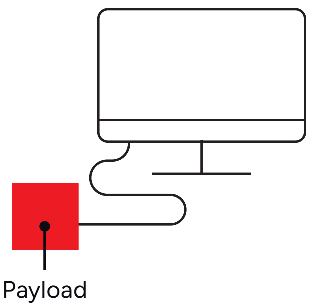
SERVICES OVERVIEW

Payload Terrestrial Flight Testing

Astrobotic is a spaceflight services company that provides terrestrial rocket flight testing for customer payloads.

01

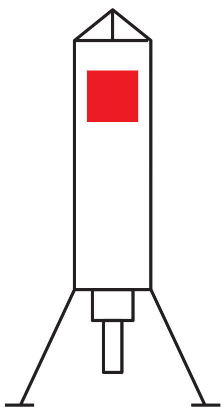
Payload Interface Testing and Flight Planning



On each mission, Astrobotic works with the payload customer to help them develop their payload and plan their flight test campaign on Xodiac.

02

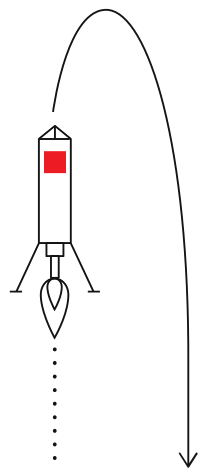
Payload Integration



Each payload undergoes mechanical fit and electrical interface checks. Following successful checks, Astrobotic integrates the payload to Xodiac at our Mojave, CA test site.

03

Flight Testing



Astrobotic conducts the payload flight test on Xodiac. After the flight, Astrobotic de-integrates and returns the payload to the customer, and provides a final flight report.

CONTACT US

Astrobotic's Payload Customer Service Program provides each customer with comprehensive support from contract signature to the test campaign's end. This program equips the customer with the latest information on the campaign and facilitates technical exchanges between the customer and Astrobotic engineers to ensure payload compatibility and overall flight test success.

Payload Accommodation

Xodiac can accommodate a wide range of payload types and unique testing needs.

Companies, government agencies, universities, nonprofit organizations, and individuals can flight test their payloads on Xodiac at affordable rates. Please contact Astrobotic for a flight campaign quote.

A standard Xodiac flight can carry up to 38 kg of payload mass and 104 L of payload volume. Nonstandard flights are also available to support payloads that require more mass or volume, in-flight power or comms services, or nonstandard flight trajectories.

Numerous Testing Applications

- ENTRY, DESCENT & LANDING TESTING
- SENSOR, COMPONENT & INSTRUMENT TESTING
- PLUME-SURFACE INTERACTION TESTING
- NIGHTTIME FLIGHT OPERATIONS TESTING

A Standard Xodiac Flight Accommodates up to:

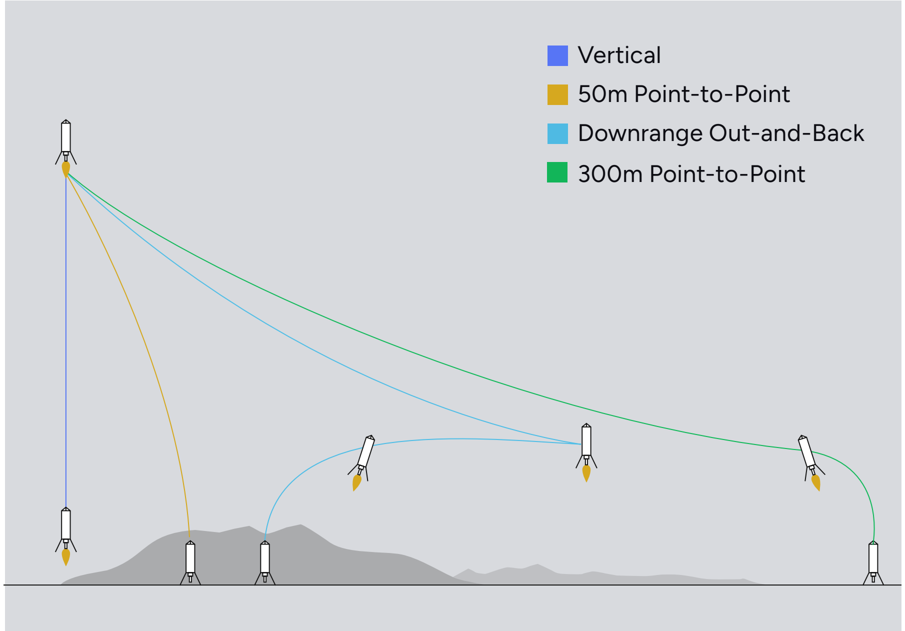
38 kg OF PAYLOAD MASS

104 L OF PAYLOAD VOLUME

Additional capabilities are available upon request. Please see page 5 and 10 for nonstandard specifications.

Xodiac Testing Capabilities

Xodiac can fly a variety of flight profiles to meet the specific needs of customers' payloads.



Representative flight trajectories of Xodiac

Xodiac provides several flight options to customers, including: vertical ascent and descent, point-to-point, and down-range out-and-back. Representative flight trajectories are shown in the figure to the left. For each of these trajectories, Xodiac vehicles take off and land vertically at one or more of Astrobotic's established launch and landing sites. Standard flight profiles consist of a vertical launch, a propulsive climb to a predetermined altitude, downrange translation (if desired), a propulsively controlled descent, a deceleration and approach burn, and finally a controlled vertical landing.

Flight profiles may be customized to meet payload-specific needs and are designed by Astrobotic engineers based on customer input. Contact Astrobotic for more details.

	STANDARD PAYLOAD SERVICE	NONSTANDARD SERVICE
PAYLOAD MASS	≤ 38 kg	< 50 kg
FLIGHT ALTITUDE	450 m	500 m
FLIGHT DISTANCE DOWN RANGE	50 m	300 m
MAX FLIGHT SPEED	27 m/s	27 m/s
MAX OFF-VERTICAL POINTING	20°	20°
LANDING PRECISION	2 cm	2 cm
MAX FLIGHT TIME	≤ = 120s	≤ = 180s
ROLL CONTROL TOLERANCE	> ± 3˚	± 3˚
FLIGHT CADENCE	2 flights per week	> 2 flights per week

Xodiac Flight Options

OPTION 1

Tethered Flight Test

Tethered flight tests provide a low-risk first step toward flight qualifying an integrated payload system by connecting Xodiac to Astrobotic's boom lift via a tether. The tether protects the vehicle and payload from major damage if an off-nominal event occurs.

- OPTION 1A **FUNCTIONAL ANALYSIS TETHERED FLIGHT TEST**

  Functional analysis flight tests are designed to verify vehicle-payload compatibility in a low-risk flight environment to prepare for a campaign flight.

  To ensure safe operations and maximize the chances of success, Astrobotic conducts at least two functional analysis tethered tests before proceeding to campaign tethered flights or any free flights.

- OPTION 1B **CAMPAIGN TETHERED FLIGHT TEST**

  Campaign flights are used to collect flight test data for payloads that do not require a higher-altitude free flight. Static hover flight profiles are available for campaign tethered flight tests.

OPTION 2

Free Flight

Free flights fly without a tether, allowing for higher altitudes, downrange translation, and more sophisticated trajectories.

- OPTION 2A **OPEN-LOOP**

  Passive Open-loop: A "passive open-loop" campaign involves a payload with all command and data handling (C&DH) activities isolated entirely from Xodiac. A "level one" passive open-loop payload requires a minimum level of payload integration. A "level two" passive open-loop payload is one that requires significant integration activities (e.g., payloads that require an off-nominal or non-standard mounting structure).

  Participating Open-loop: A "participating open-loop" campaign involves a payload that requires active real time communication between Xodiac and the payload. A "level one" participating open-loop payload is one that receives communications from the vehicle during flight operations. A "level two" participating open-loop payload sends and receives communications with the vehicle, but information received by the vehicle from the payload is not integrated into vehicle system controls.

- OPTION 2B **CLOSED-LOOP**

  A "closed-loop" campaign allows the payload and flight computer to engage in active real-time two-way communication that is integrated into the vehicle system controls. In these flights, Xodiac's Sensei™ hypervisor system allows the payload to effectively fly the vehicle. If the payload deviates from the approved flight area or sends commands beyond a permitted limit, the hypervisor will take control and execute commands to land the vehicle safely.

Payload Customer Support

Astrobotic is committed to ensuring customers complete their flight test successfully and acquire meaningful data. To achieve this, Astrobotic provides a comprehensive payload customer service program to support customers through the development, integration, and testing of their unique payloads.

01

Services Agreement

Following contract signature, the payload customer is connected with an Astrobotic payload manager to begin developing a schedule, Interface Control Document (ICD), and flight test plan.

02

Technical Support

Throughout the contract, Astrobotic supports the payload customer by hosting regular integration working group meetings, participating in payload design cycle reviews, facilitating payload interface tests with Xodiac, and refining the flight test plan.

03

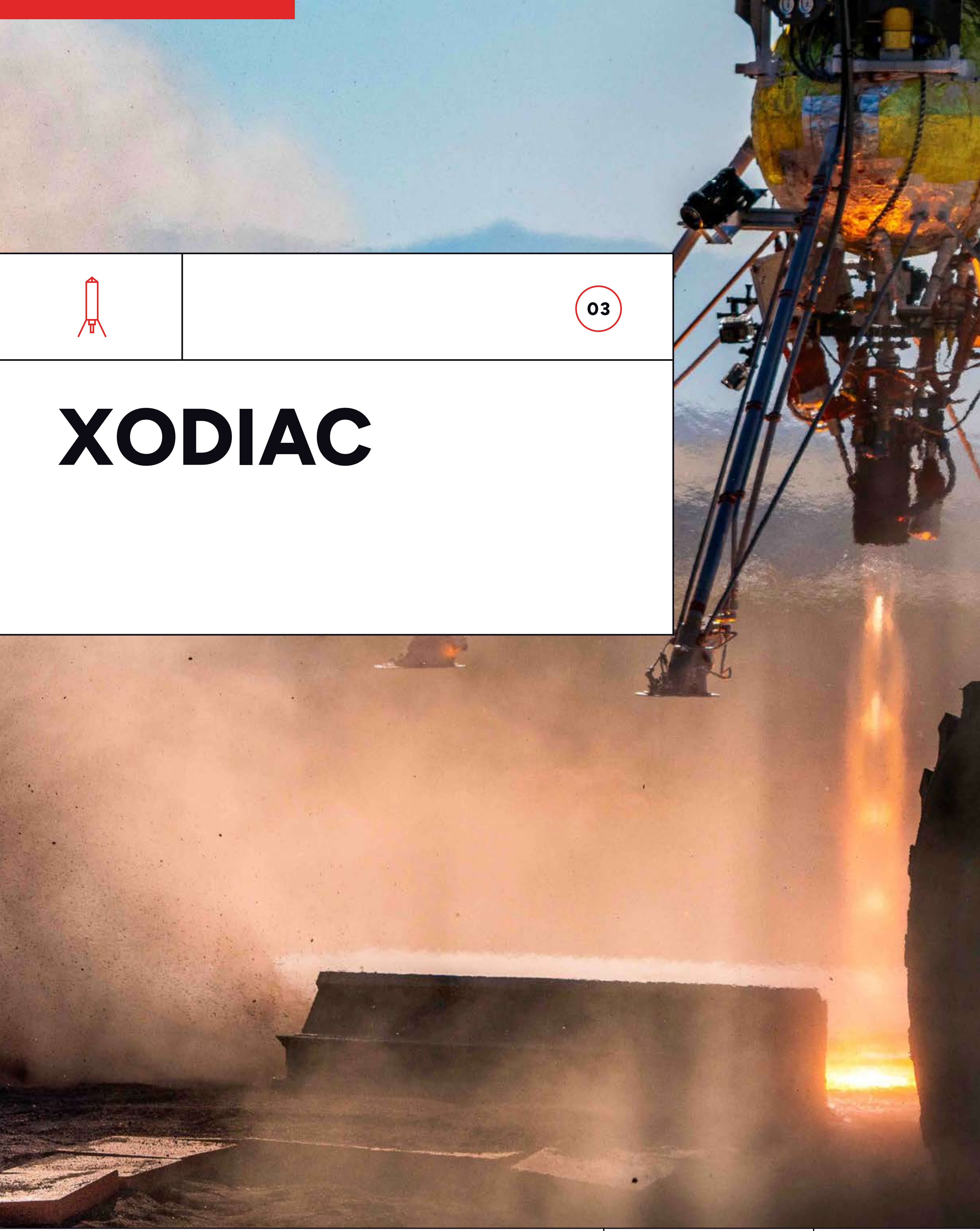
Integration

The payload is delivered to Astrobotic's Mojave, CA test facility, where Astrobotic accepts the payload and integrates it to Xodiac. Astrobotic also conducts pre- and post-integration payload checkout testing before and after integration, respectively.

04

Flight Testing

Astrobotic conducts two or more tethered flight tests of the payload to qualify the system, followed by the tethered or free campaign flights. After all flights are complete, Astrobotic safely de-integrates the payload and returns it to the customer, followed by a final flight report.



03

XODIAC

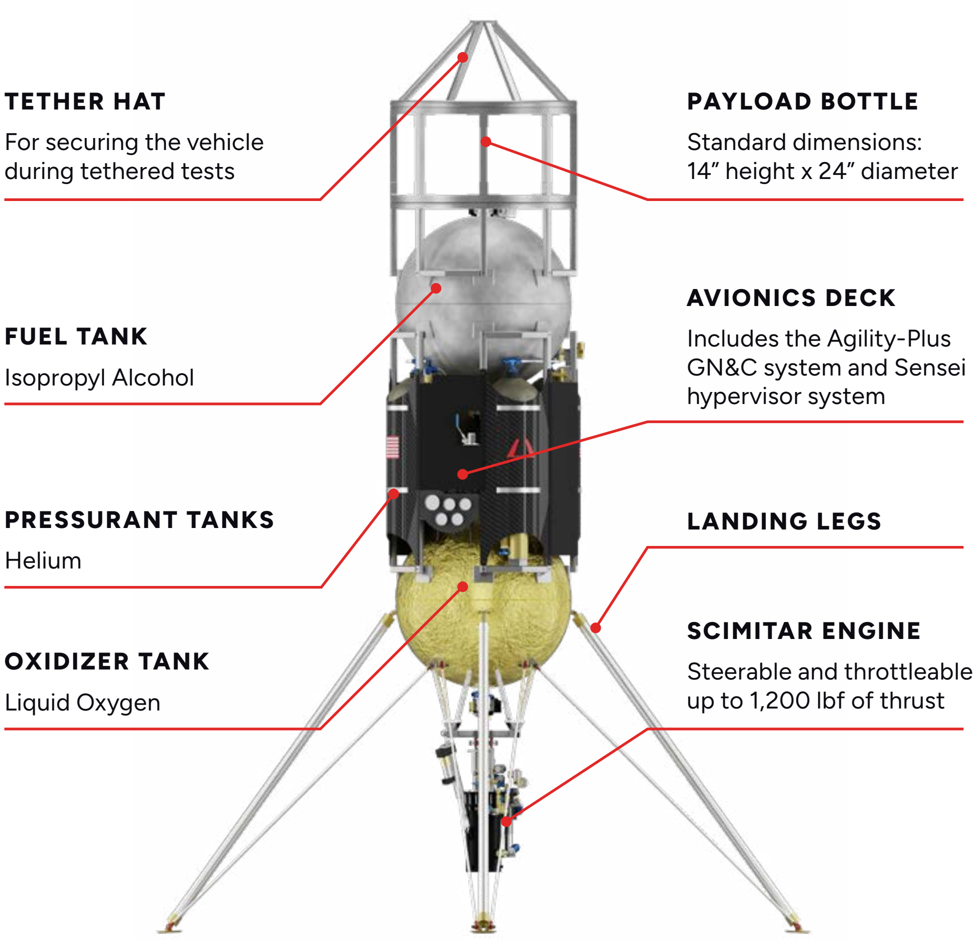
Xodiac Overview

Astrobotic's 4th generation rocket lander has flown more than 160 successful flights with 100% mission success.

Astrobotic's Xodiac rocket lander is a versatile platform that can be used as a testbed for customer payloads and concepts of operation.

Xodiac stands 11 feet tall and can accommodate up to 50 kg of payload (38 kg in its standard payload configuration). Its Scimitar engine is a throttleable liquid oxygen and isopropyl alcohol engine that produces up to 1,200 lbf of thrust. The ability to throttle and gimbal Scimitar provides outstanding control of the vehicle, including extended hover capabilities and highly precise landings—within 2 cm of its target.

Xodiac incorporates Astrobotic's Agility-Plus™ guidance, navigation, and control (GN&C) system, enabling complete control over vehicle flight trajectories and pinpoint landings. Xodiac also features Astrobotic's proprietary Sensei™ hypervisor system, an industry-unique closed-loop testing capability that allows a payload to effectively fly the vehicle (within acceptable flight parameters).



Xodiac Specifications

PAYLOAD REQUIREMENTS	STANDARD	NONSTANDARD	EXCLUDED
MASS*	≤ 38 kg	< 50 kg	≥ 50 kg
VOLUME	104 L (14” h x 24”Ø)	> 104 L (> 14” h and/or > 24”Ø)	Dependent on form factor and CG changes
CG LOCATION	< 1% from center of payload bottle	> 1% from center of payload bottle	> 1% overall vehicle CG shift at vehicle dry mass
ENVIRONMENTAL CONTAINMENT	None	Environmental control available	N/A
COMPONENTS EXTERNAL TO PAYLOAD BOTTLE	None	External accommodations available, subject to CG changes	External components that cause > 1° overall vehicle CG shift at vehicle dry mass
EXTERNAL ANTENNA	None	Dependent on EMI	Dependent on EMI
PAYLOAD-EMITTED EMI/RFI	No significant EMI/RFI	No significant EMI/RFI	Significant EMI/RFI

** Unique mass requirements will be evaluated on a case-by-case basis and may require modification to or removal of the standard payload mounting plate.*

PAYLOAD INTERFACES	STANDARD	NONSTANDARD	EXCLUDED
VEHICLE TELEMETRY	No	Yes	N/A
POWER SOURCE	Payload-provided	Vehicle-provided	N/A
SHORE POWER	No	Yes	N/A
DRY SWITCH	1	> 1	N/A
DATA STORAGE	None	Data storage options available	N/A
FIELDS OF VIEW	Radial and upward	Angled and nadir	N/A

Payload Interfaces

Astrobotic works closely with customers to ensure proper, safe, and efficient integration of their payload onto Xodiac.

Payload Qualifications

Payloads are required to meet the following requirements before they can be flown. All payloads are subject to an Astrobotic technical review and are accepted on a case-by-case basis.

MOUNTING

Payload customers are required to provide an Astrobotic-approved payload mounting interface for attaching their payloads to Xodiac. Astrobotic will work with customers to define the vehicle interface and approve mounting plate designs. Astrobotic can also provide mounting plate design and fabrication services, as well as consultation on nonstandard mountings and nonstandard payload services.

Payloads are mounted inside the "payload bottle," which is located at the top of Xodiac and is open to the environment in its standard configuration.

Alternative mounting arrangements may be possible depending on the payload's form factor and requirements. For example, it may be possible to add adapters to mount payloads at the base of the vehicle or on the side of the fuselage. Such custom integrations, which incur non-recurring engineering (NRE) and may require additional payload integration facilities, are available as a nonstandard service.

ENVIRONMENTAL CONTAINMENT

Payloads must provide containment for any liquids or gases used or generated by the payload. The containment system must remain intact at all times during testing and flight operations. Any payload that does not provide its own liquid or gas containment will be considered nonstandard and may require additional costs and fees for Astrobotic to fabricate a containment unit or structure.

SAFETY REQUIREMENTS

All payload components must conform to applicable aerospace safety standards. Astrobotic will work with payload customers to identify applicable safety requirements and verify compliance before proceeding to testing.

RFI/EMI

Payloads must not interfere with Xodiac's electrical or communications systems. Astrobotic's test team will conduct an on-vehicle test of the integrated payload to verify non-interference. Additionally, all payloads should meet MIL-STD-461 requirements. Payload customers may be required to provide test documentation showing MIL-STD-461 compliance. If no such documentation is provided, Astrobotic may determine that the payload is nonstandard and requires additional testing, which may incur additional costs and fees.

Xodiac Reference Frames

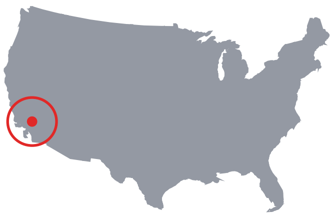
For payloads receiving data from Xodiac, the reference frame definitions provided in Appendix A below will apply.

04

ASTROBOTIC FACILITIES

Astrobotic Facilities

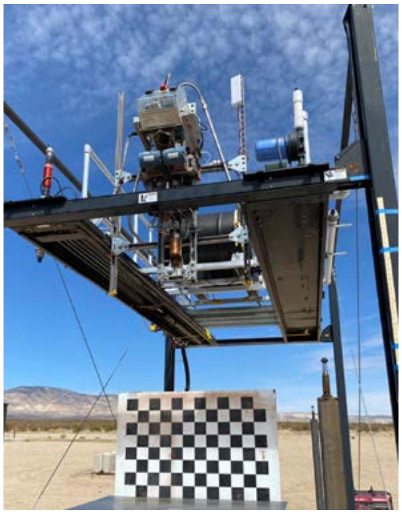
Astrobotic operates two primary facilities: a rocket test facility in Mojave and a headquarters in Pittsburgh.



Mojave, CA

The Mojave campus is Astrobotic's primary site for rocket lander development and testing. This site hosts Astrobotic's rocket lander fleet, hot fire test stands, and flight test area at the Mojave Air & Space Port (MASP). The Mojave campus includes approximately seven acres of outdoor space for engine and vehicle testing and 20,000 square feet of indoor space across several buildings.

Astrobotic's Mojave Assembly Building (MAB) (pictured below) is a new, 10,000 square foot building designed for fabrication and assembly of VTVL vehicles, integration of landers and spacecraft, and integration of payloads onto Astrobotic's rocket landers, lunar landers, and other vehicles. The MAB also serves as the primary facility for cleanroom operations and avionics testing in Mojave. A machine shop is located directly across from the MAB and can provide custom payload bottle and mounting solutions for Xodiac flight testing.



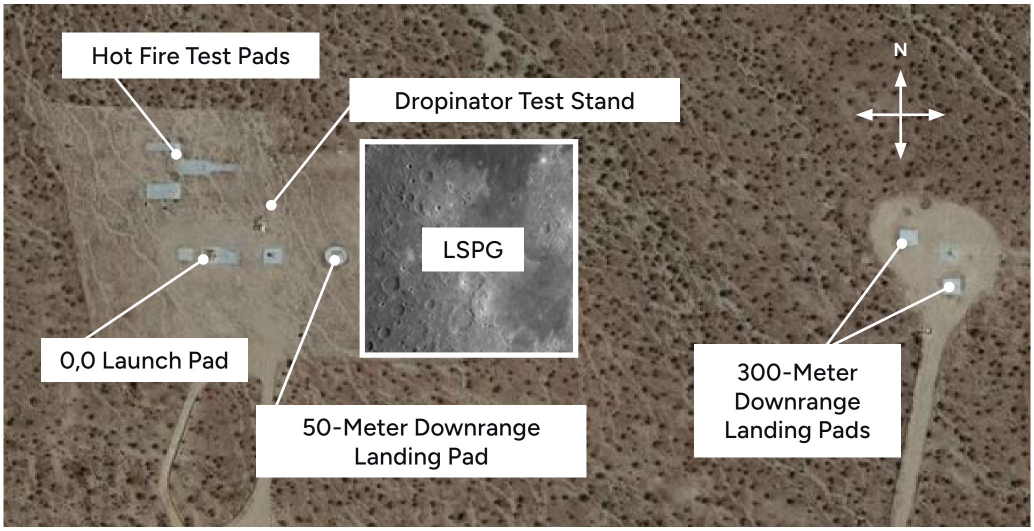
"Dropinator" dynamic test stand

Mojave Assembly Building (MAB) (left) and "Burninator" test stand (right)

Flight vehicle maintenance and storage is conducted primarily in Astrobotic's main hangar, known as "the Aviary". This 5,000+ square foot facility also provides on-site office space for payload customers during their test campaigns.

The "Aviary" Hangar

MOJAVE TEST SITE 5



Map of Test Site 5 at the Astrobotic Mojave Campus

Flights are conducted from Test Site 5, a seven-acre test range north of MASP's runways. Astrobotic's flight and engine test infrastructure at Test Site 5 consists of two command bunkers, six VTVL launch and landing pads, and three dedicated engine test pads. The primary launch pad (referred to as the 0,0 pad) is a 24 ft x 24 ft reinforced concrete slab. The test site is accessible via a dirt road and is a 20 minute drive from the MAB.

Test Site 5 also includes Astrobotic's 2.5 acre Lunar Surface Proving Ground (LSPG), which is directly to the east of Astrobotic's 50 m downrange landing pad. A photo of the LSPG is shown below. The LSPG is approximately 100 m x 100 m plot of simulated lunar terrain for testing lunar flyovers and surface operations. The design is based on real lunar topography at the south pole of the Moon.

Xodiac on the launch pad at Test Site 5 (left) and the real lunar LSPG (right)

Pittsburgh, PA

Astrobotic's headquarters, located in Pittsburgh, PA, is a 50,000 square foot state-of-the-art lunar logistics facility. It includes a high bay cleanroom for primary spacecraft AI&T activities and the Astrobotic Mission Control Center (AMCC), from where lunar lander missions are operated. Astrobotic's facilities also include a fabrication shop with extensive tooling and test equipment for prototype hardware development, including tools and machinery for metalworking, 3D printing, and general fabrication. These fabrication and testing capabilities are available as a nonstandard service to Xodiac customers for payload development.

Facilities at Astrobotic's Pittsburgh, PA headquarters: Exterior (top), AMCC (bottom left), thermal vacuum and vibration table test facilities (bottom right)

Peregrine lunar lander in the cleanroom at Astrobotic's Headquarters

05

PAYLOAD ENVIRONMENTS

Payload Environments

Payloads will experience a variety of environments during a Xodiac flight campaign.

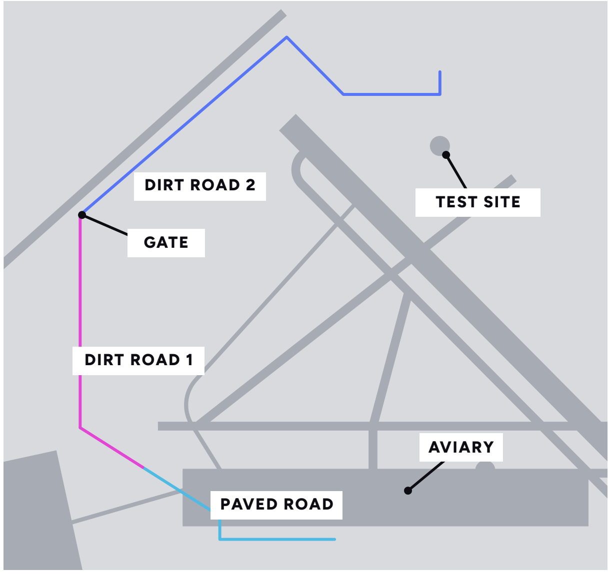
Pressure and Temperature Environments

Payloads are exposed to external atmospheric conditions in Xodiac's standard open payload bottle. Subject to payload size, requirements, and other constraints, Astrobotic may be able to provide an environmental control canister to protect the payload from the environment. A control canister allows Astrobotic and the payload customer to exercise greater control over the temperature and pressure within the payload bottle. Fabrication, installation, and use of a payload canister involves NRE and is considered a nonstandard service.

Mechanical Environments

Payloads will be exposed to a variety of mechanical loads during a Xodiac test campaign that can be attributed to two main phases: ground transportation and flight. During the ground transportation phase, Xodiac is transported between the payload integration facility and launch pad using a trailer. The route (shown in the figure below) is 2.5 miles long and takes approximately 20 minute each way. The route has multiple terrain types, with the majority being a dirt road that sees heavy truck traffic and can be deeply rutted. During the ground transportation phase, Xodiac will be secured to the transport trailer with a clamp at each foot and stabilized with two straps connecting the top of the landing gear to the trailer deck. This phase will subject Xodiac and the payload to the longest duration loads during the test campaign. Payloads will experience a second set of mechanical loads during flight. The accelerations during this flight phase will be the largest in magnitude, but will be significantly shorter in duration than the transportation phase.

Xodiac being prepared for transport from the Aviary to Test Site 5

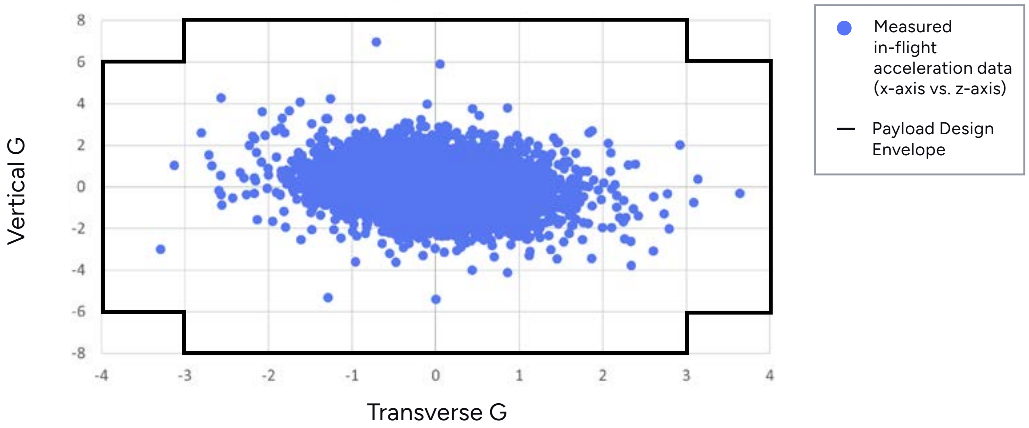


Route to test site from the Aviary

Mechanical Loads Summary

The mechanical loads experienced by a payload on Xodiac are plotted at right and summarized in the tables below. This data is based on the measured acceleration time series and shock response spectra shown on the following pages. The black outline in the plot to the right represents the maximum load envelope that payloads should design to. More specific payload requirements will be provided during pre-integration technical interchanges to ensure payloads will survive all environments during a Xodiac test campaign.

PAYLOAD DESIGN LIMIT LOADS



Ground Transport Data

	X-AXIS (TRANSVERSE)	Y-AXIS (TRANSVERSE)	Z-AXIS (VERTICAL)
FREQUENCY RANGE	1 – 150 Hz	1 – 150 Hz	1 – 150 Hz
MAX ACCELERATION	14.09 m/s² (1.44 g)	8.42 m/s² (0.86 g)	36.99 m/s² (3.77 g)
3-SIGMA ACCELERATION	1.69 m/s² (0.17 g)	1.26 m/s² (0.13 g)	1.12 m/s² (0.11 g)

In-Flight Data

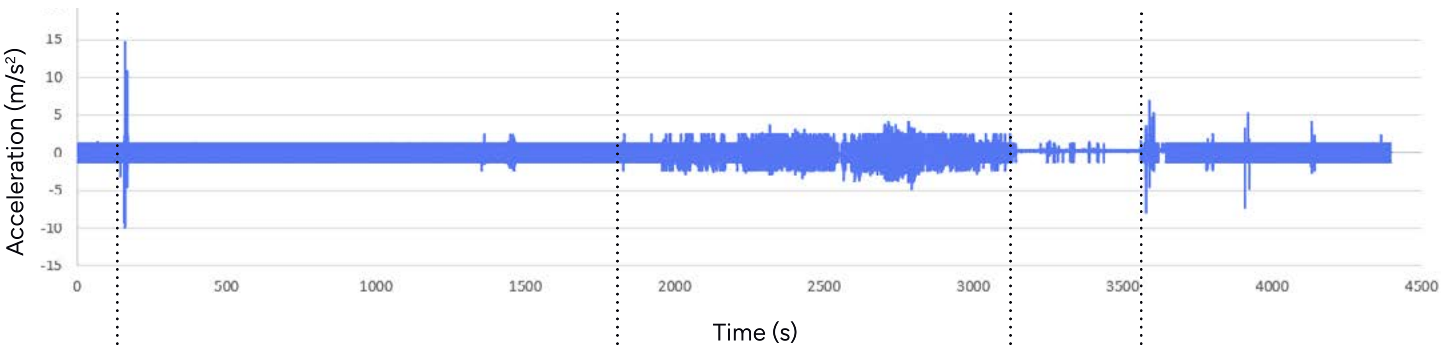
	X-AXIS (TRANSVERSE)	Y-AXIS (TRANSVERSE)	Z-AXIS (VERTICAL)
FREQUENCY RANGE	1 – 150 Hz	1 – 150 Hz	1 – 150 Hz
MAX ACCELERATION	35.68 m/s² (3.64 g)	35.49 m/s² (3.62 g)	68.38 m/s² (6.97 g)
3-SIGMA ACCELERATION	17.67 m/s² (1.80 g)	15.73 m/s² (0.1.60 g)	26.73 m/s² (2.73 g)

Z-axis values have been calibrated to Earth surface gravity (1 G)

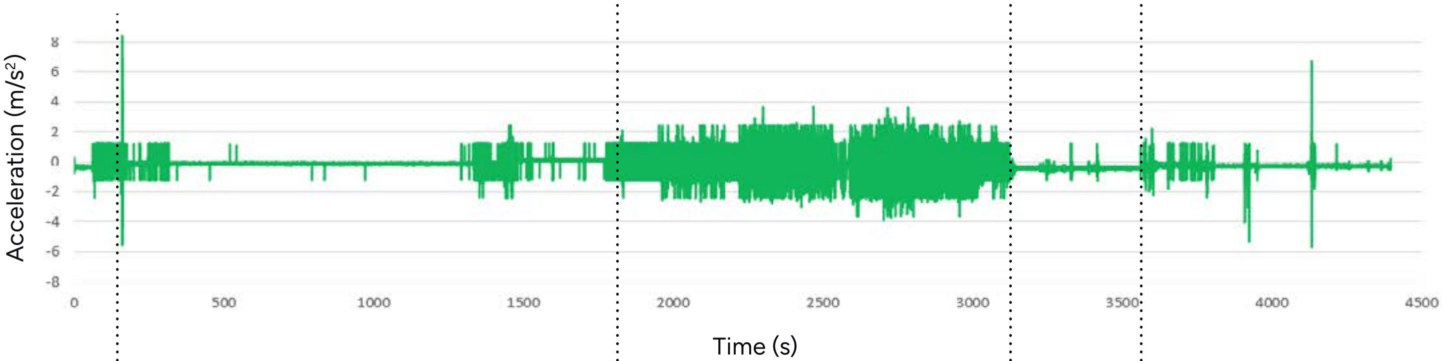
Ground Transportation Loads

The plots below show the accelerations that payloads can expect to experience during a one-way ground transport. The data provided below was measured during transportation from the Aviary to the launch pad by an IMU mounted inside Xodiac's payload bottle.

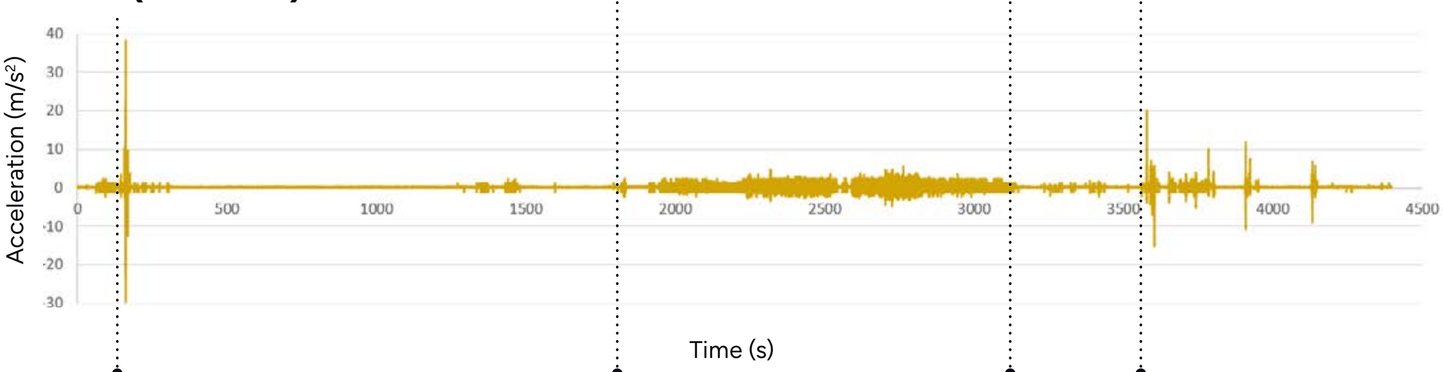
X-Axis (Transverse)



Y-Axis (Transverse)



Z-Axis (Vertical)



01 Vehicle Loading Onto Trailer

02 Transport Begins

03 Transport Ends

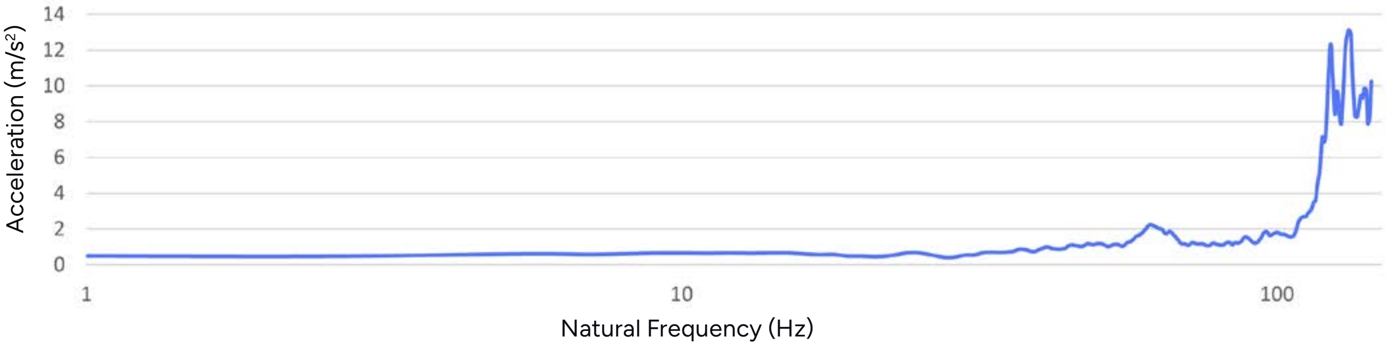
04 Vehicle Unloading Onto Pad

Z-axis values are relative to Earth surface gravity (1 G)

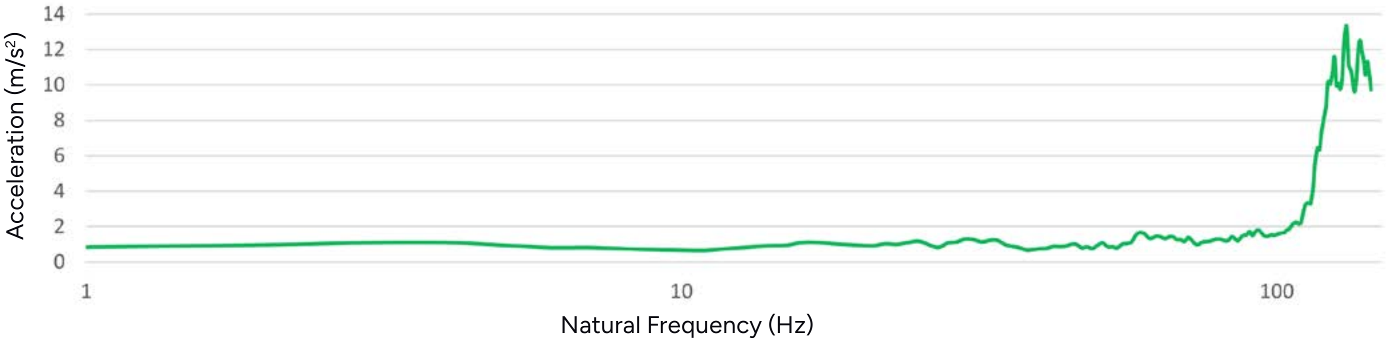
Ground Transportation Shock Response Spectra

The plots below are the shock response spectra for the ground transportation phase. These plots were derived from the measured acceleration data provided on the previous page.

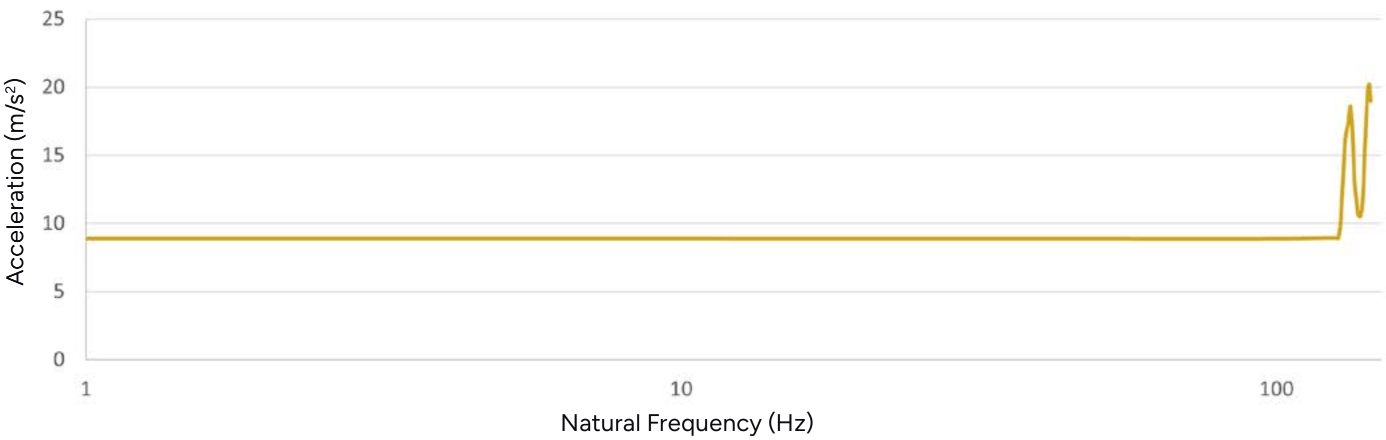
X-Axis (Transverse)



Y-Axis (Transverse)



Z-Axis (Vertical)

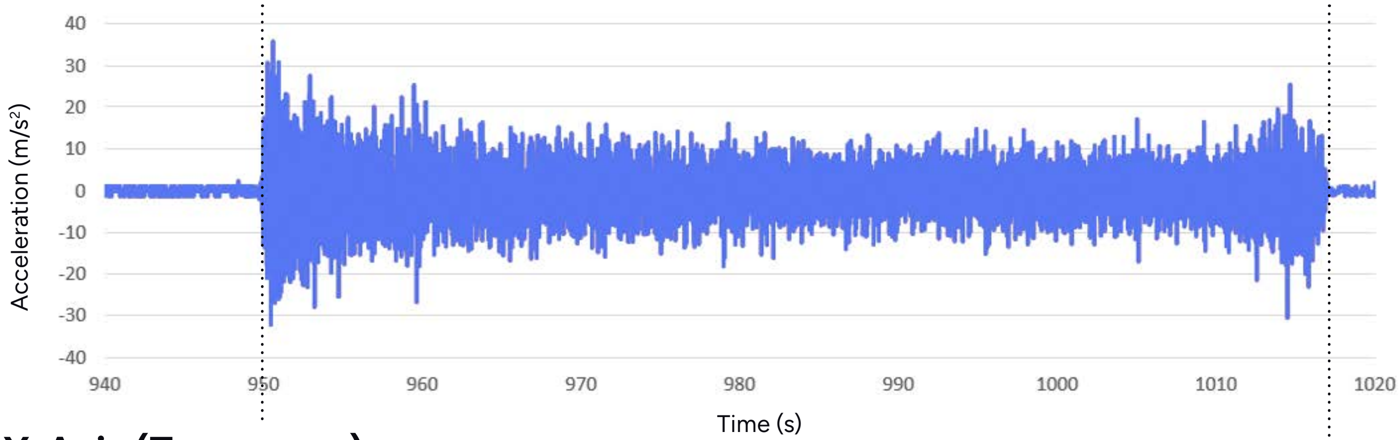


Z-axis values are relative to Earth surface gravity (1 G)

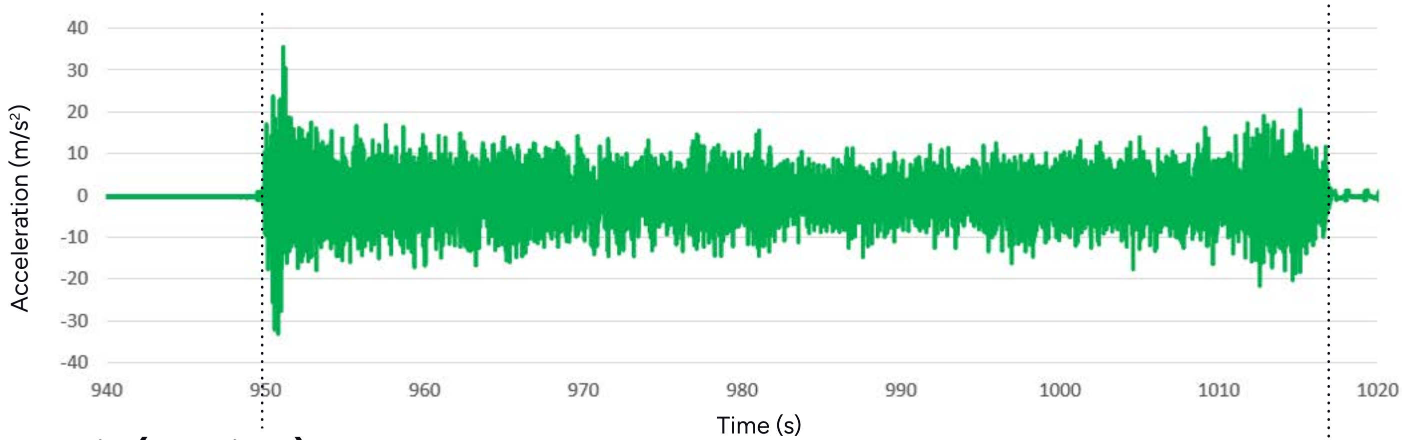
In-Flight Loads

The plots below show the accelerations that payloads can expect to experience during a standard Xodiac flight. The data provided below was measured during flight by an IMU mounted inside of Xodiac's payload bottle.

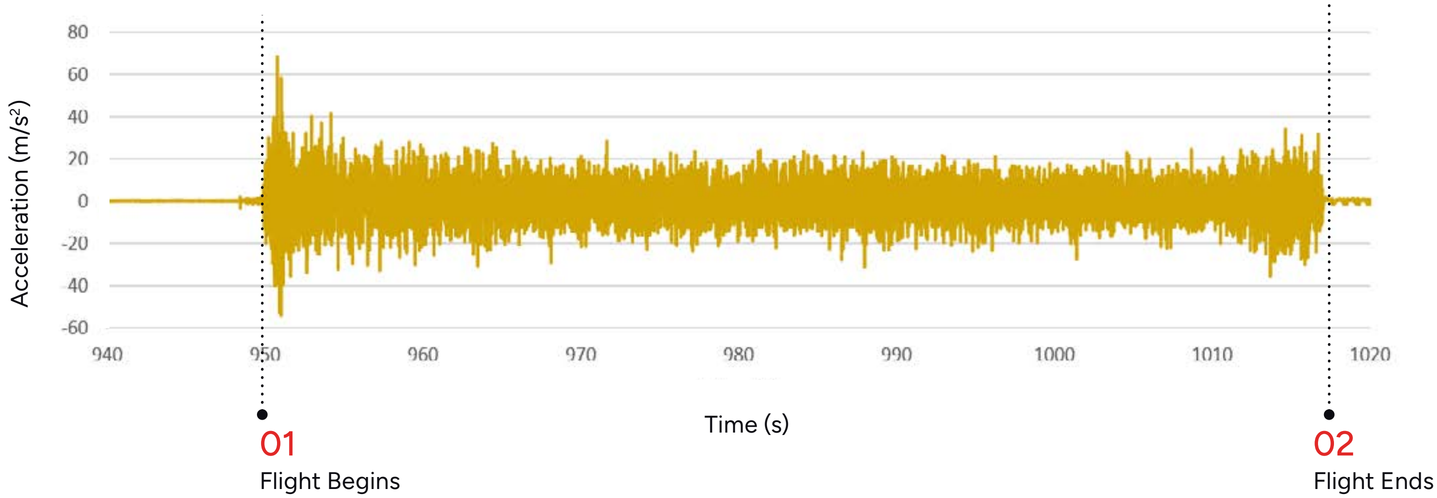
X-Axis (Transverse)



Y-Axis (Transverse)



Z-Axis (Vertical)

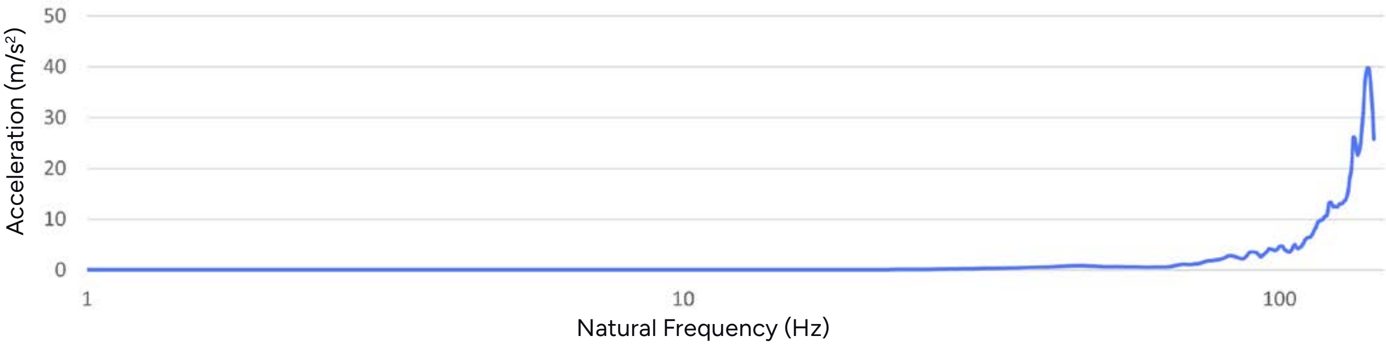


Z-axis values are relative to Earth surface gravity (1 G)

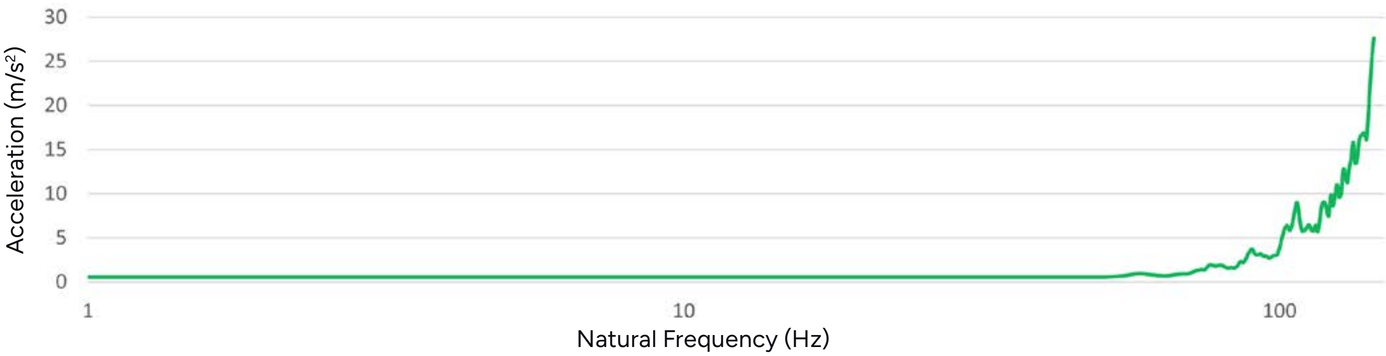
In-Flight Shock Response Spectra

The plots below are the shock response spectra for the in-flight phase. These plots were derived from the measured acceleration data provided on the previous page.

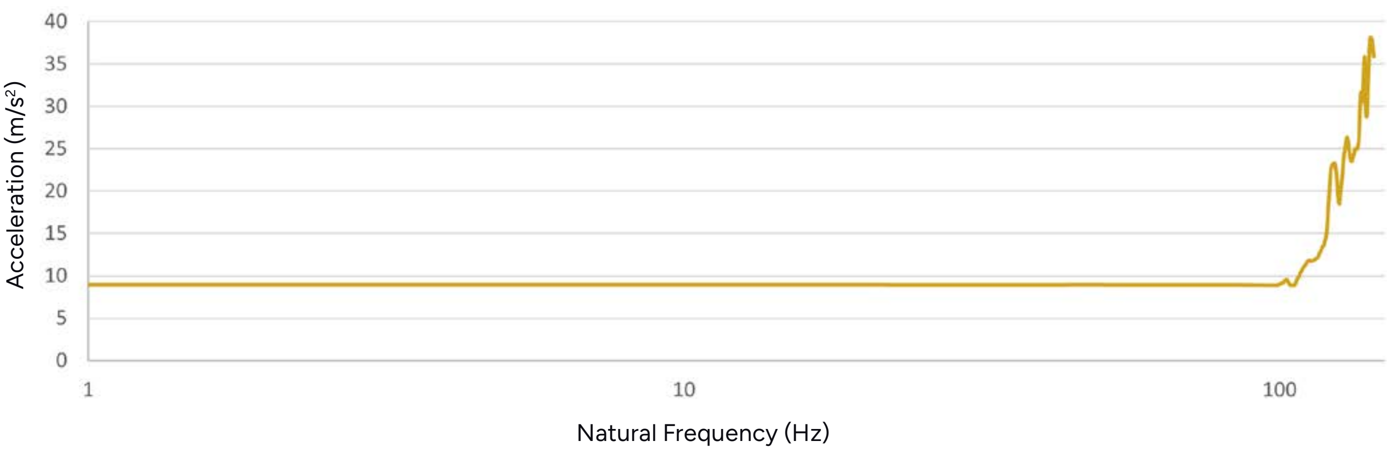
X-Axis (Transverse)



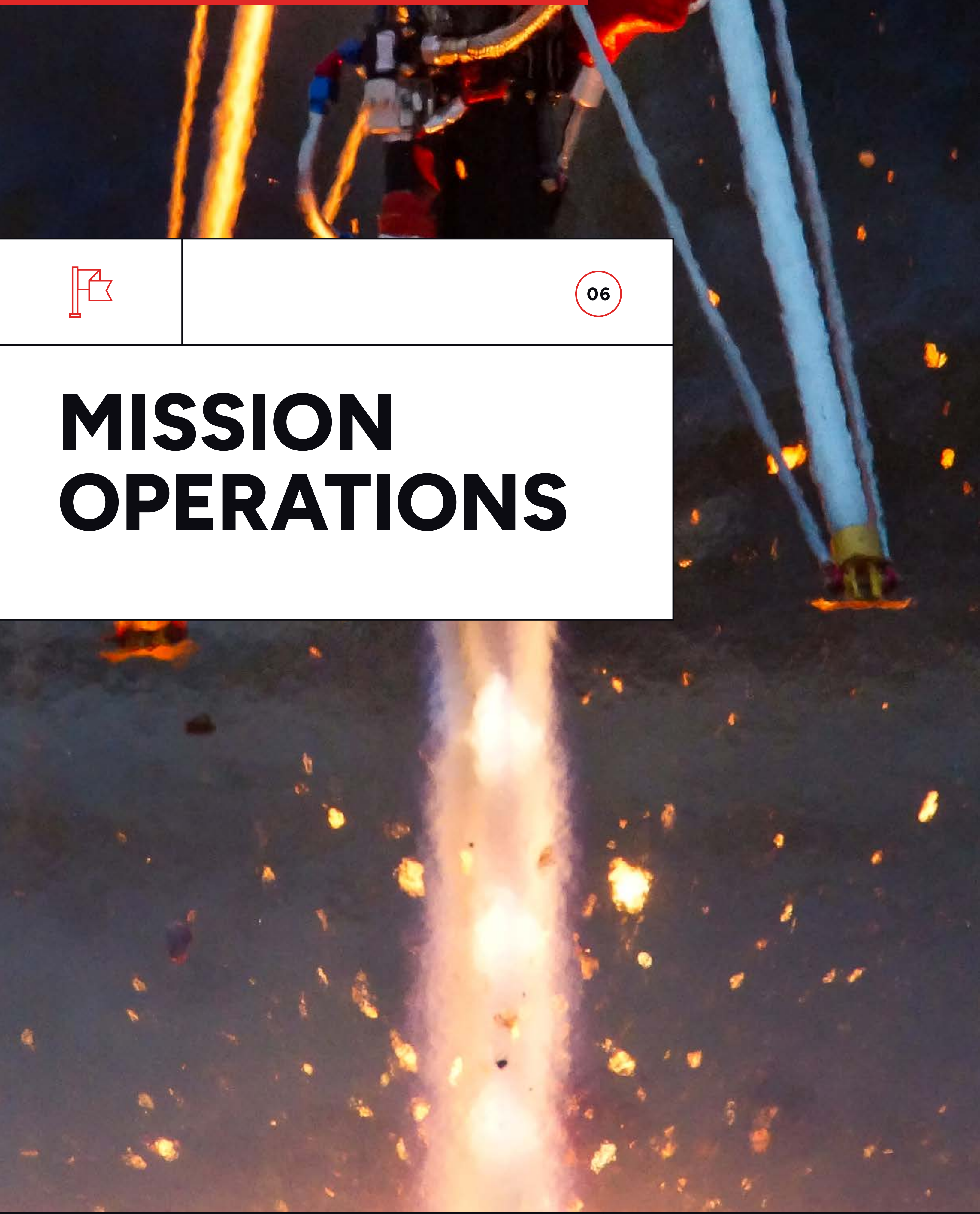
Y-Axis (Transverse)



Z-Axis (Vertical)



Z-axis values are relative to Earth surface gravity (1 G)



06

MISSION OPERATIONS

Pre-Flight

Proposal Development and Support

Astrobotic has years of experience developing suborbital flight test proposals and is a contracted flight provider for NASA's Flight Opportunities program. Astrobotic can provide insights on how to secure funding for flight tests and work closely with payload developers to refine their proposals. Please contact Astrobotic for more information.

Pre-Integration Technical Interchange

Astrobotic will begin working with customers immediately after contract execution to optimize the test campaign for the customer's needs and maximize the likelihood of success. This process, which typically begins 12 months prior to flight, involves project meetings, bilateral requirements definition, launch scheduling, and trajectory development.

PROJECT MEETINGS

Project meetings will begin with a kickoff shortly after contract execution. At the kickoff, Astrobotic and the customer will review the customer's test objectives and priorities, discuss payload requirements, establish a preliminary concept of operations, define basic integration requirements, and agree on a schedule for future technical interchange meetings (TIMs).

After kickoff, Astrobotic and the customer will hold regular TIMs to prepare for integration and flight operations. These TIMs typically begin six months before integration and are initially held monthly, increasing to weekly closer to integration. During TIMs, Astrobotic will work with the customer to define payload and trajectory requirements, develop the ICD, and plan the concept of operations to ensure the flight profile meets payload needs and maximizes the opportunity to collect the customer's desired data.

REQUIREMENTS DEFINITION

Astrobotic and the customer will cooperatively define requirements that inform the resulting payload development and trajectory development. Customers will develop documentation demonstrating their compliance with the defined requirements.

TECHNICAL DOCUMENTATION

Prior to integration, the payload customer is required to provide documentation indicating the center of gravity (CG) in three dimensions, payload mass in a flight-ready condition, a list of liquids and or gases to be used or generated, and a concept of operations. Astrobotic can help payload customers ascertain and document the required data as a nonstandard service.

REGULATORY DOCUMENTATION

Customers with payloads that are subject to regulatory requirements must present the appropriate documentation of regulatory compliance and approvals. Certain regulated payloads may be considered nonstandard.

SCHEDULING LAUNCH

Following contract signature, Astrobotic will work with the customer to schedule the best launch date and time. Standard service includes flights on any weekday from approximately 9 AM to 5 PM local time. For multi-flight campaigns, the standard turn-around time between flights is 2 days, excluding payload changes. Non-standard turn-around times may be reduced to 4 hours or less, excluding payload changes. If the customer requires access to the payload for data downloads between flights, additional time may be required. The exact turnaround time will be determined on a case-by-case basis depending on the exact customer services required. Note that limitations to flight availability and cadence may also arise due to weather, crew work time regulations, and air space and launch site availability from the MASP.

TRAJECTORY DEVELOPMENT

In parallel with the pre-integration meetings, Astrobotic will use customer input to either identify an appropriate preexisting flight trajectory or, if needed, develop a custom trajectory to meet payload needs. The flight trajectory will be reviewed with the customer during TIMs. Astrobotic will ensure that any custom trajectories are safe and meet payload needs by performing qualification tests with a mass simulator prior to payload integration.

Payload Integration

FIT CHECK (OPTIONAL BUT RECOMMENDED)

Astrobotic recommends that the customer participate in a fit check 3 to 4 months before integration to ensure that the payload can be properly integrated onto the vehicle. If the fit check is not successful, Astrobotic will advise the customer on modifications required for integration.

PAYLOAD READINESS REVIEW

Before the payload is delivered to the integration facility, Astrobotic and the customer will perform a Payload Readiness Review (PRR) to confirm the payload is ready for integration. The PRR will verify that the payload is compatible with both Xodiac and any co-manifested payloads, and assess system safety to ensure that the payload can be properly integrated. The PRR includes a comprehensive cooperative evaluation of mechanical and software interfaces and the identification of any sources of potential EMI/RFI interference.

PRE-INTEGRATION CHECKOUT TESTING (OPTIONAL BUT RECOMMENDED)

Astrobotic recommends that the customer participate in pre-integration checkout testing 1 to 3 months prior to the scheduled campaign flights. This checkout testing typically takes 1 to 5 days, depending on payload complexity. This step is optional, but has been shown to improve both the process flow and probability of success during the final integration and flight campaign. It validates the notional integration designs, supports an efficient concept of operations development, allows for initial EMI/RFI testing, and facilitates cooperative interaction between the teams. If any issues arise, the pre-integration checkout testing gives the team adequate time to solve them before integration.

PAYLOAD INTEGRATION

Upon receipt of the payload, Astrobotic will follow its proven integration process. During primary integration, an Astrobotic Payload Specialist and Launch Coordinator will work closely with the customer to integrate the payload into Xodiac's payload bottle and mount the system on the vehicle. Astrobotic will then test any EMI/RFI with the inertial measurement unit (IMU) data and/or GPS solution. Astrobotic will work with the customer to outline payload powering and checkouts during integration to meet test requirements while also maintaining necessary risk mitigation processes.

After payload integration, the payload is typically not removed until after the flight campaign is completed. If the payload is subsequently removed for any reason, additional tethered tests must be completed to requalify the integrated payload-Xodiac system prior to conducting any free flights.

POST-INTEGRATION TESTING

Once the payload has been integrated to Xodiac, Astrobotic will begin pre-flight preparations and testing to ensure a safe and successful campaign. All checkout testing will be performed at Astrobotic's "Aviary" hangar at the MASP.

FLIGHT READINESS REVIEW

After payload integration and testing is complete, Astrobotic and the payload customer will conduct a Flight Readiness Review (FRR). This review ensures that both the payload and flight vehicle are ready to perform a safe and successful flight campaign. An FRR is required before each flight for both tethered and free flights.

CUSTOMER SUPPORT PERSONNEL

A customer representative that is familiar with the payload must be present during the integration, testing, and flight of the payload. The representative should have the technical knowledge to answer specific questions about the payload and the authority to make decisions regarding any modifications to the integration, testing, or flight plan of the payload.

Flight Operations

PRE-LAUNCH PAYLOAD ACCESS

Customer personnel will have access to the payload up until two hours before the close of business the day prior to the scheduled flight. Payload access on the day of the flight or on-pad servicing of the payload can be included in the contract as a nonstandard service.

DAY OF THE FLIGHT

On the morning of the flight, a mandatory safety briefing will be held for all Astrobotic and customer personnel working within the flight test area. The integrated Xodiac vehicle will then be transported from the Aviary to the launch site. When Xodiac has arrived and the launch site and operations center are ready, the vehicle will be taken through a pre-launch checkout routine.

Immediately before liquid oxygen loading, the launch site will be cleared of all nonessential personnel. Once liquid oxygen loading commences, the test site will be considered to be in 'hazardous operations,' and all personnel must maintain a safe hazard radius from the vehicle.

FLIGHT

After liquid oxygen loading, flight operations will commence. Launches are typically conducted from the 0,0 Pad at MASP Test Site 5, with landings at either the 0,0 Pad, 50 m downrange landing pad, or 300 m downrange landing pad.

The customer's payload team will be invited to observe the flight with Astrobotic's test team. Tethered flights may be observed from Astrobotic's low-altitude bunker, providing a safe front-row seat. Free flights must be observed from the control center at Astrobotic's high-altitude bunker, located 380 m from the launch site.

POST-FLIGHT PAYLOAD ACCESS

Customer personnel will again have access to the payload after the vehicle has been returned to the Aviary. Access to the payload for on-pad servicing may also be available as a nonstandard service. Customers should expect to wait a minimum of one hour after landing if the vehicle is returned to the Aviary — or, for on-pad servicing, a minimum of 30 minutes after the vehicle has landed — before being able to access their payload.

FLIGHT DATA REPORT

Astrobotic will provide customers with a preliminary Flight Data Report within three business days after each flight. Astrobotic will provide the customer with a final Flight Data Report detailing the entire flight campaign within 30 business days of the final campaign flight.

Example Flight Day Schedule

	ACTIVITY
06:00 AM	Ground crew arrival and pre-ramp checks
07:00 AM	Ramp checks and vehicle loading for ground transportation
08:00 AM	Safety briefing
08:20 AM	Ground transportation of the vehicle and payload to the launch site
09:00 AM	Test site preparation
09:45 AM	Propellant loading
10:00 AM	Vehicle preparation for flight
10:10 AM	VEHICLE FLIGHT
10:15 AM	Post-flight safety
10:40 AM	Vehicle and payload shutdown
10:45 AM	Load vehicle and payload for ground transport
10:50 AM	Ground transportation of the vehicle and payload back to the Aviary
11:10 AM	Vehicle unloading
11:15 AM	Payload checkouts and post-flight activities

Xodiac Campaign Schedule

Example 12-Month Flight Schedule

MONTHS 1-6

#	TASK DESCRIPTION	MONTH 1	2	3	4	5	6
1	Project Meetings						
2	Requirements Definition						
3	Trajectory Development						
4	Payload Preparation and Integration Design						
5	Payload Interface Mechanical and Electrical Fabrication						
6	Fit Check (Optional)						
7	Payload Readiness Review (PRR)						

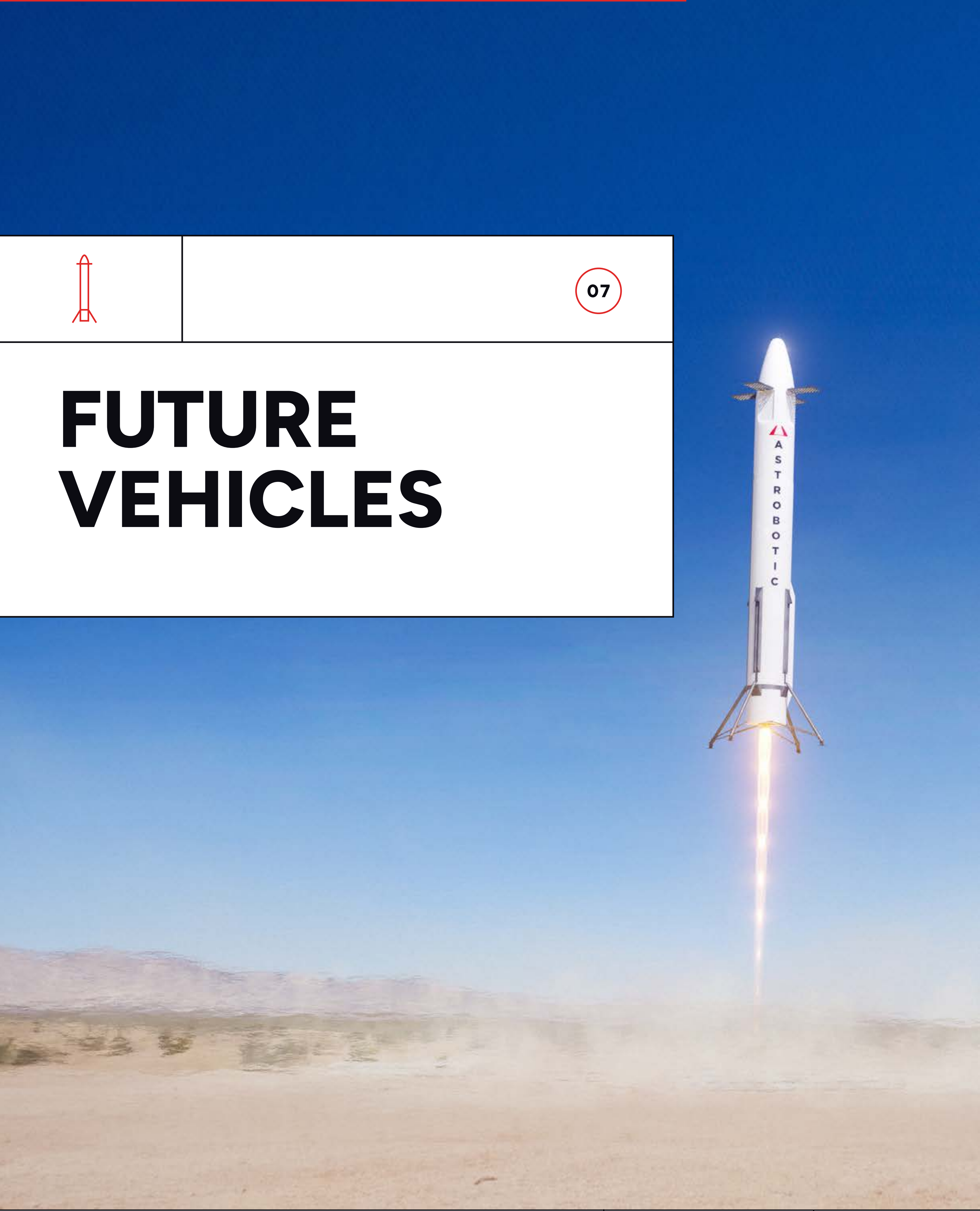
MONTHS 7-12

#	TASK DESCRIPTION	MONTH 7	8	9	10	11	12
8	Project Meetings (Continued)						
9	Trajectory Development (Continued)						
10	Trajectory Qualification Testing with Mass Simulator						
11	Pre-Integration Checkout Testing (Optional)						
12	Payload Integration						
13	Post-Integration Checkout Testing						
14	Flight Readiness Review (FRR)						
15	Flight Operations						
16	Final Data Report						

Payload & Astrobotic
Payload
Astrobotic

07

FUTURE VEHICLES



Xogdor

Xogdor, Astrobotic's first suborbital rocket lander, is expected to be available for commercial flights in 2026.

Astrobotic is currently developing its next-generation vehicle, Xogdor, under a NASA Tipping Point contract. The Block 1 vehicle will enter service in 2026 and represent a major leap forward for Astrobotic's VTVL testbed capabilities. Block 1 will fly higher, faster, and farther than Xodiac. Xogdor will be able to carry significantly higher payload masses, achieve supersonic speeds, and climb to suborbital altitudes, all while maintaining Xodiac's control, precision landing, and hover capabilities.

Artist's rendering of Xogdor in flight over the Mojave Desert

Key Features

VTVL FLIGHT HERITAGE

Leverages systems and institutional knowledge developed and demonstrated through 600+ past rocket lander flights

HIGHER, FASTER, FARTHER

Designed for flights above the Kármán Line, supersonic speeds, and long-range point-to-point missions

GREATER PAYLOAD CAPACITY

Can accommodate a payload mass of 200 kg in a 280 L payload bay, significantly more than Xodiac

CLOSED-LOOP TESTING

Equipped with Astrobotic's proprietary SENSEI™ system, allowing payloads to effectively steer the vehicle within permissible bounds

PRECISION FLIGHT AND LANDING

Flight-proven avionics and controls systems provide precision flight profiles and landings within centimeters of a target

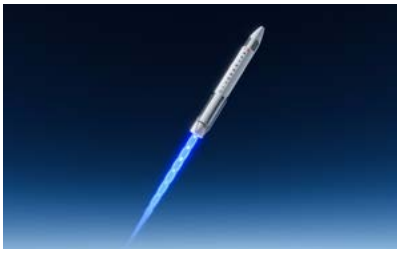
Xogdor Applications

Xogdor's unique set of capabilities will enable a wide range of applications.

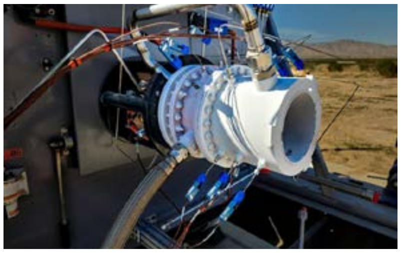
01 **SUBORBITAL TESTBED FOR SPACE TECHNOLOGY**

02 **HIGH-ALTITUDE ATMOSPHERIC RESEARCH**

03 **POINT-TO-POINT CARGO DELIVERY**



04 **MICROGRAVITY TESTING**



05 **NOVEL PROPULSION SYSTEM TESTING**

Xogdor Timeline

Payload reservations are currently being accepted for Block 1 flights, which will start in Q1 2026. More detailed payload user information will be made available prior to the commencement of commercial testing services in 2026.

Subsequent Xogdor blocks will improve upon the Block 1 design and introduce capabilities such as spaceflight beyond the Kármán Line, microgravity testing, hypersonic flight speeds, and suborbital payload deployment.

Artist's rendering of Xogdor in flight

08

GLOSSARY

Glossary

0,0 PAD: Astrobotic's primary launch/landing pad at Test Site 5.

50-METER PAD: A downrange launch/landing pad at Test Site 5, located 50 meters east of the 0,0 Pad.

300-METER PAD: A downrange launch/landing pad at Test Site 5, located 300 meters east of the 0,0 Pad.

AI&T: Assembly, integration, and test.

AMCC: Astrobotic Mission Control Center, located at Astrobotic's headquarters in Pittsburgh, PA.

APOGEE: The highest altitude point of a rocket's flight trajectory.

THE AVIARY: Astrobotic's primary VTVL rocket lander hangar and workspace for vehicle maintenance, storage, and repair.

CENTER OF GRAVITY (CG): The average location of the weight of the rocket.

C&DH: Command and data handling.

EMI: Electromagnetic interference.

FOV: Field of view.

FRR: Flight readiness review.

HYPERSONIC: Flight speed greater than Mach 5.

ICD: Interface control document.

IMU: Inertial measurement unit.

LSPG: Lunar Surface Proving Ground, a 10,000 m^2 simulated lunar surface located adjacent to Astrobotic's launch and landing pads at the Mojave Air and Space Port.

MAB: Astrobotic's Mojave Assembly Building.

MASP: The Mojave Air and Space Port.

NRE: Non-recurring engineering.

PRR: Payload readiness review.

RFI: Radio Frequency Interference.

SCIMITAR: The vehicle's 1,200-lbf LOX-IPA throttleable rocket engine.

SUPERSONIC: A flight speed greater than Mach 1.

TIM: Technical interchange meetings.

VTVL: Vertical-takeoff, vertical-landing.

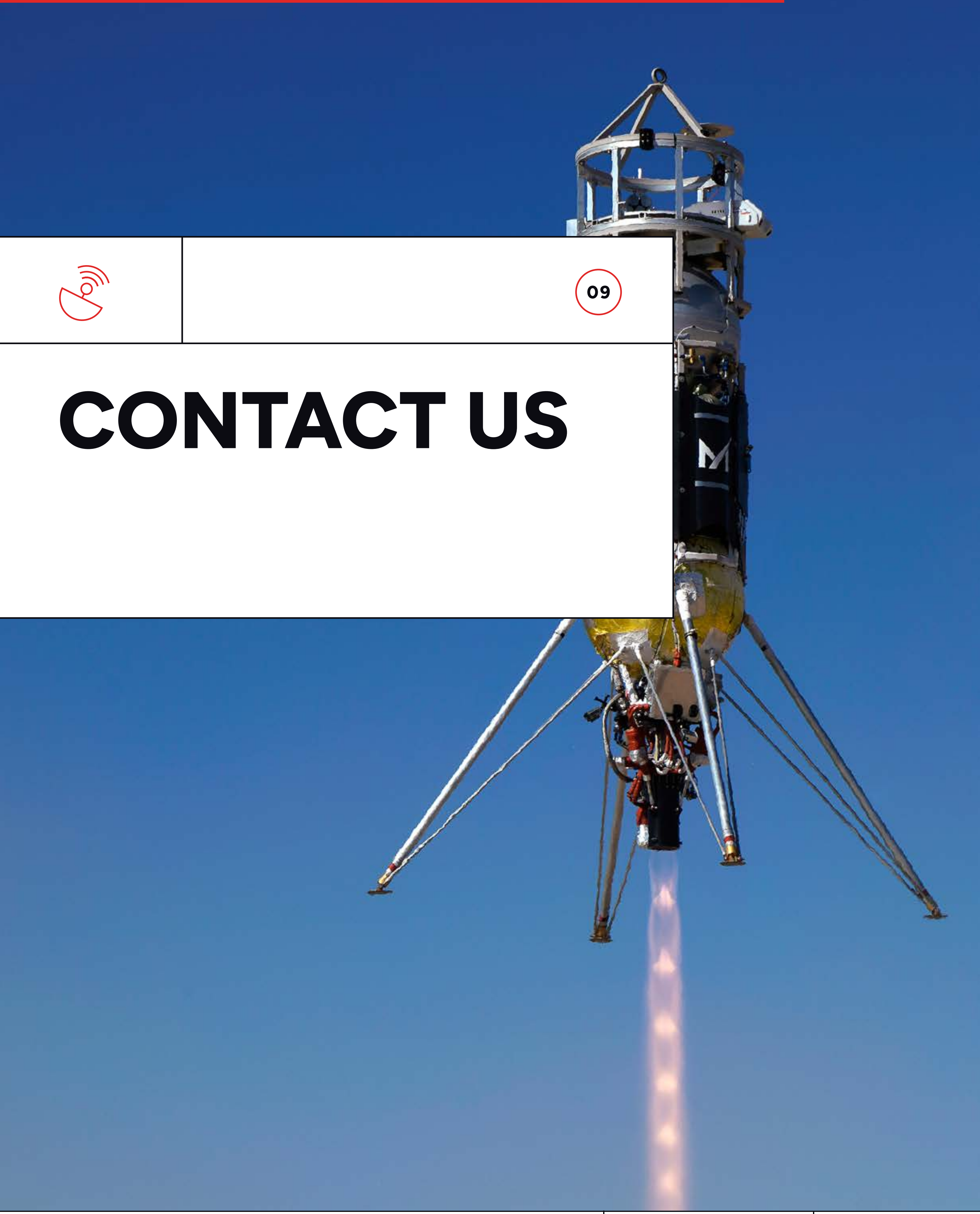
XOMBIE: Astrobotic's first-generation rocket lander, which has completed 227 successful VTVL flights.

XOIE: Astrobotic's second-generation rocket lander design, which completed 25 successful VTVL flights.

XAERO: Astrobotic's third-generation rocket lander design, which has completed 191 successful VTVL flights between the two variants, Xaero-A and Xaero-B.

XODIAC: Astrobotic's fourth-generation and currently operational VTVL, which has completed over 160 successful flights and counting.

XOGDOR: Astrobotic's fifth-generation VTVL rocket vehicle, scheduled to make its first launch in 2026. Xogdor will be able to carry significantly more payload mass, achieve supersonic speeds, fly to suborbital altitudes, and execute point-to-point delivery.



09

CONTACT US

Contact Us

Please contact us to discuss your payload and flight testing needs.

Business Development

The Business Development Team is available to current and potential customers for inquiries regarding all of Astrobotic's propulsive testing services.

HOTFIRE@ASTROBOTIC.COM
(352) 226-5708

Payload Management

The Payload Management Team is available to signed customers for mission-specific and technical inquiries.

VTVL@ASTROBOTIC.COM
(303) 242-0137

General

For all other inquiries, please use our general contact information:

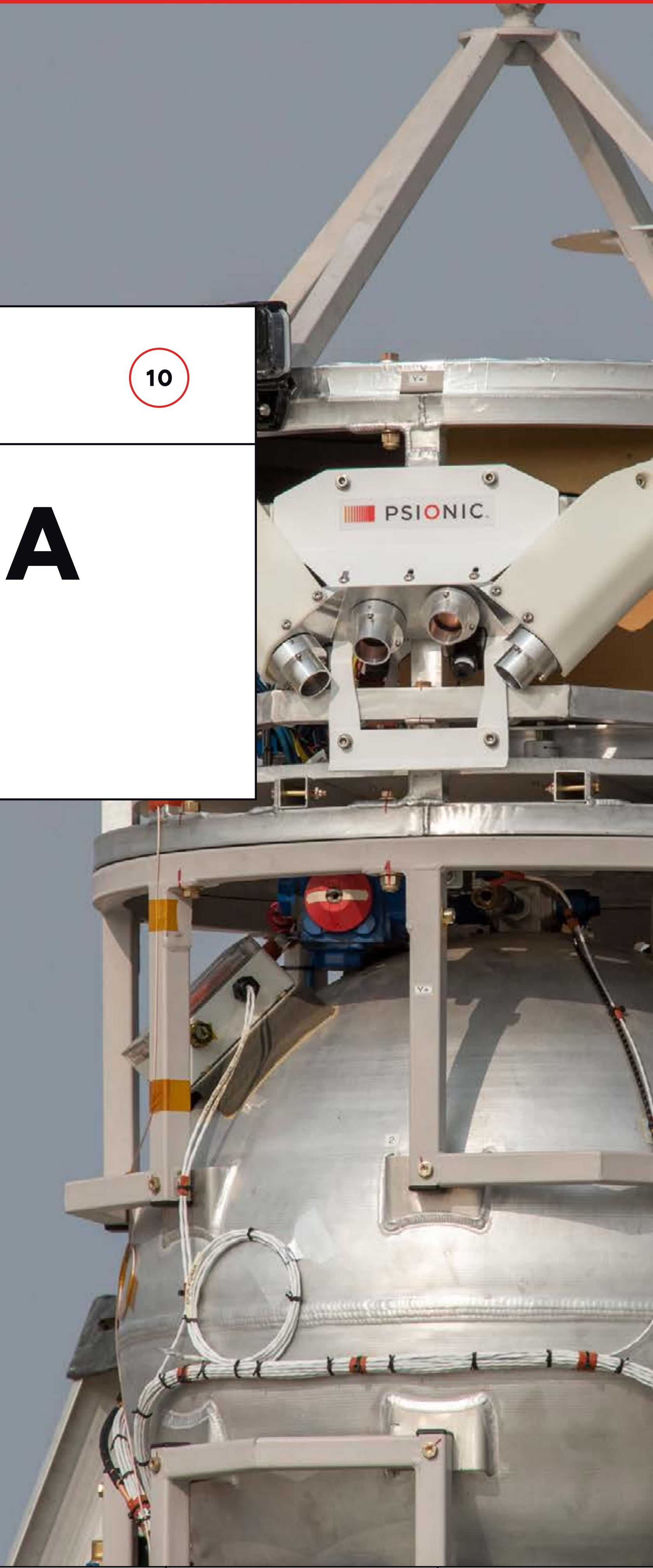
WWW.ASTROBOTIC.COM
CONTACT@ASTROBOTIC.COM
(412) 682-3282

ASTROBOTIC PROPULSION & TEST DEPARTMENT
1572 SABOVICH STREET
MOJAVE, CA 93501

ASTROBOTIC HEADQUARTERS
1016 N. LINCOLN AVENUE
PITTSBURGH, PA 15233

10

APPENDIX A



Xodiac Reference Frames

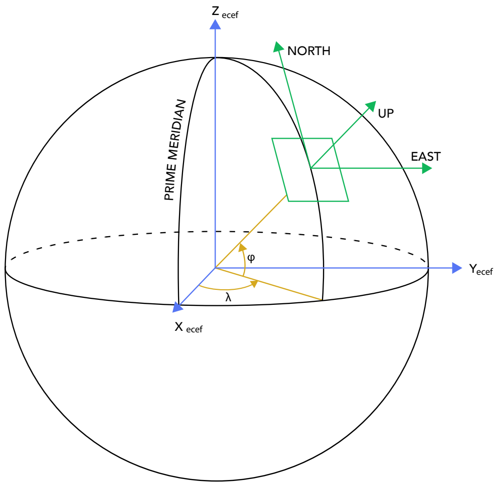
ECEF Frame

ORIGIN

- Center of mass of Earth

AXES

- X - Intersects 0° Latitude and 0° Longitude
- Y - Completes right-handed triad
- Z - Along spin axis of Earth, out of North Pole



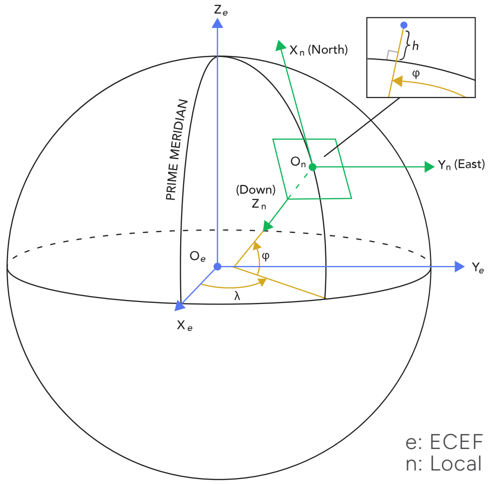
Geodedic Frame

ORIGIN

- Center of mass of Earth

AXES

- X - Latitude
- Y - Longitude
- Z - Height above the WGS84 ellipsoid



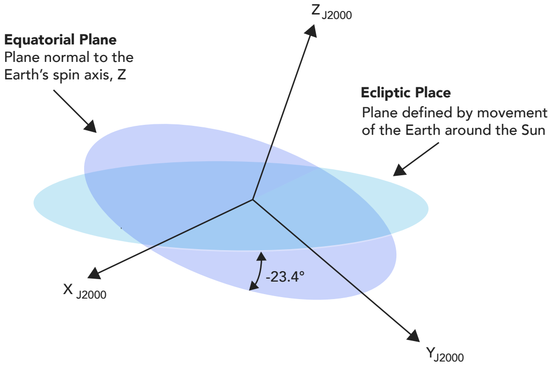
ECI Frame (J2000)

ORIGIN

- Center of mass of Earth

AXES

- X - Pointing along intersection of equatorial and ecliptic planes (vernal equinox)
- Y - Completes right-handed triad
- Z - Along spin axis of Earth at J2000 epoch

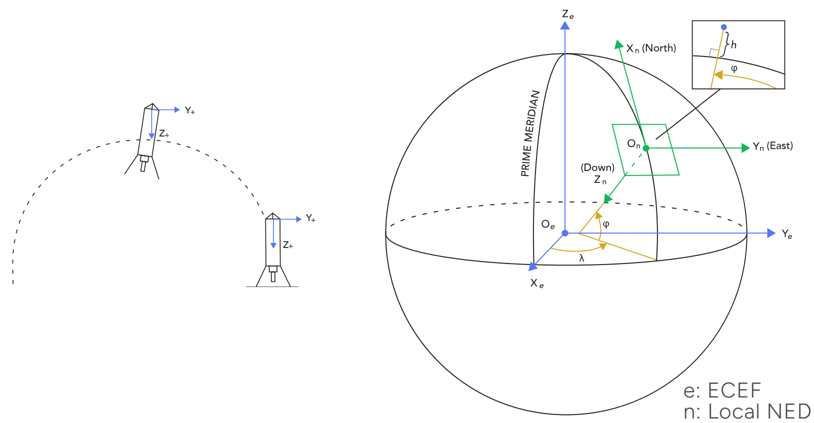


Local Frame (NED)

ORIGIN
- Nav center of IMU

AXES
- X - North (locally level to WGS84 ellipsoid)
- Y - East (locally level to WGS84 ellipsoid)
- Z - Down

LOOKING NORTH

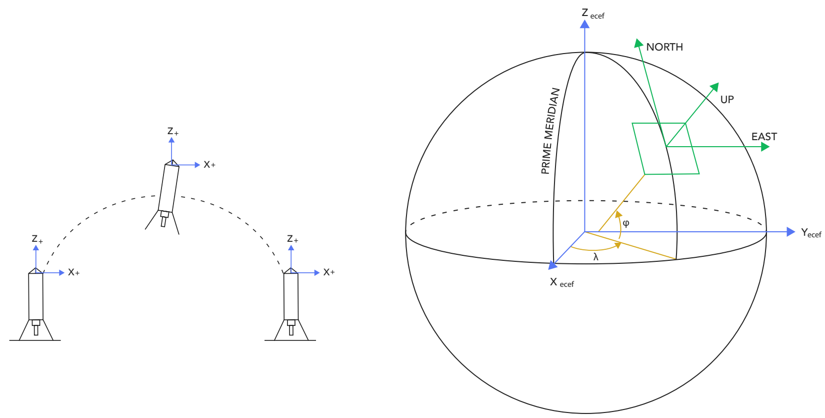


Nav Frame (ENU)

ORIGIN
- Nav center of IMU

AXES
- X - North (locally level to WGS84 ellipsoid)
- Y - East (locally level to WGS84 ellipsoid)
- Z - Up

LOOKING NORTH

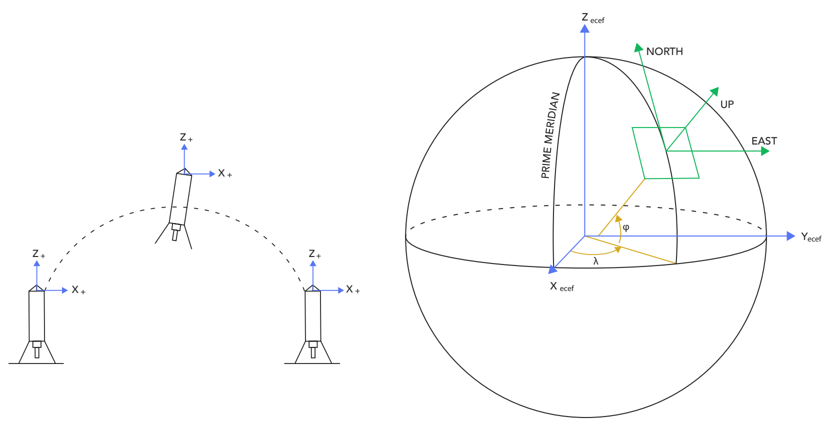


Nav0 Frame (ENU)

ORIGIN
- Nav center of IMU at time of initialization

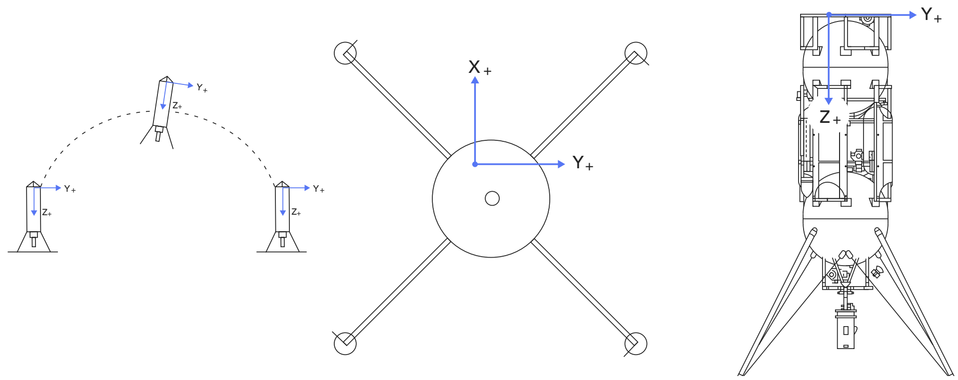
AXES
- X - North (locally level to WGS84 ellipsoid)
- Y - East (locally level to WGS84 ellipsoid)
- Z - Up

LOOKING NORTH



Body Frame

LOOKING NORTH | **TOP** | **FRONT**



ORIGIN

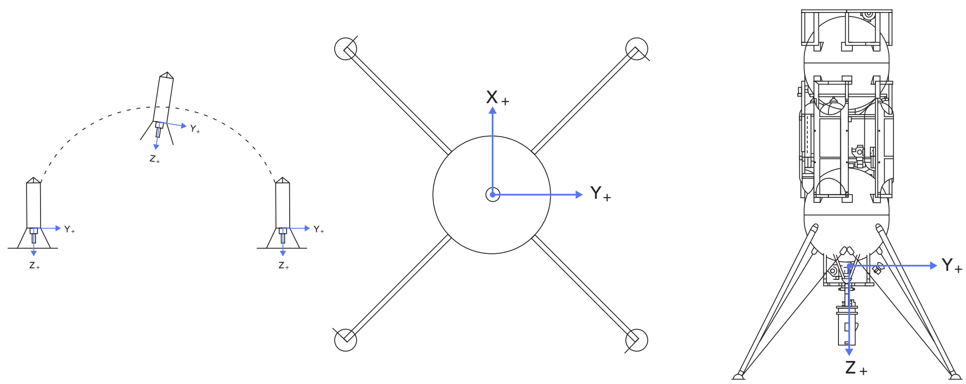
- Nav Center of IMU

AXES

- XY - Pointing out of the gimbal actuators
- Z - Pointing down, out of the engine

Mechanical Frame

LOOKING NORTH | **TOP** | **FRONT**



ORIGIN

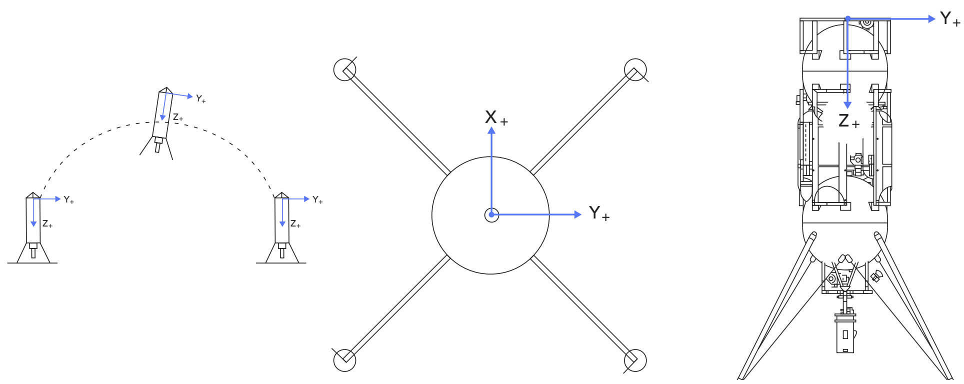
- Centerline of vehicle at top of engine cross

AXES

- XY - Pointing out of the gimbal actuators
- Z - Pointing down, out of the engine

Payload Frame

LOOKING NORTH | **TOP** | **FRONT**



ORIGIN

- Centerline of vehicle at payload mounting surface

AXES

- XY - Pointing out of the gimbal actuators
- Z - Pointing down, out of the engine

ASTROBOTIC