Implementing Responsive and Reliable Access to Space for Small Satellites

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ABSTRACT

Rocket Lab is a space technology company and the global leader in dedicated small satellite launch. Founded in 2006 by CEO Peter Beck, Rocket Lab's mission is to make space accessible by offering frequent, reliable, and affordable small satellite launch services. With a record of 11 launches since May 2017 and as at 06 June 2020, the company has delivered 48 satellites to orbit with 100% mission success for government customers including NASA, DARPA, the NRO and the United States Air Force, as well as many commercial small satellite providers. With regular and reliable dedicated launch opportunities now operating on Rocket Lab's Electron launch vehicle, no longer are small satellites forced to fly as secondary payloads with little control over orbit and launch schedule.

While Electron's launch success to date represents significantly improved space access for small satellites, Rocket Lab is developing new systems and infrastructure to further increase launch cadence, provide more launch opportunities, and ensure resiliency in orbit for small satellites. With the growth and increasing reliance on small satellite constellations, the ability to deploy new satellites to precise orbits in a matter of hours, not months or years, is critical to small satellite operators.

Rocket Lab already operates Launch Complex-1 in New Zealand, the only privately-owned and operated orbital launch site in the world, licensed by the FAA for 120 launches per year. The company also recently completed development of a U.S. launch site, Launch Complex-2, located at NASA Wallops, that can support 12 launches per year, with the first mission from the site to occur in 2020. Construction is now underway on a third launch pad, located at Launch Complex 1, that will reduce turnaround time between launches and enable Rocket Lab to conduct parallel launch campaigns simultaneously from the one launch complex.

In addition to launch sites that enable frequent launch opportunities, Rocket Lab has made significant progress towards making Electron a reusable launch vehicle, a development that will further increase launch frequency by eliminating the need to build a new Electron first stage for every mission.

Because access to space is more than just launch vehicles and pads, Electron is also introducing an all-inclusive spacecraft build and launch service that enables small satellite customers to focus on delivering their service from orbit and generating revenue, rather than building their own satellite hardware.

This paper summarizes Rocket Lab's launch successes and technical achievements of the past year and examines the developments underway to further improve space accessibility through an increased launch cadence and streamlined small spacecraft hardware development.

INTRODUCTION

Small satellite operators have traditionally been forced to choose between flying on a large vehicle as a secondary payload with little control over launch timing and orbit or paying significantly more for a dedicated launch vehicle.

Since 2017, U.S. space systems company Rocket Lab has operated a frequent and cost-effective dedicated launch service to orbit for small satellites, freeing them from the traditional constraints of launching as rideshare payloads on larger launch vehicles.

Between Rocket Lab's inaugural launch in 2017 and the submission of this paper on 06 June, 2020, Rocket Lab has delivered 48 satellites to orbit with 100% mission success heritage for customers across 11 Electron launches. Government small satellite customers include NASA, DARPA, the NRO and the United States Air Force, as well as many commercial and educational small satellite providers. Rocket Lab's launch cadence has doubled each year since Electron launches began. The company continues to work towards its goal of weekly launches with the introduction of streamlined production processes, including factory automation, to produce a full Electron launch vehicle once every 18 days, and Rocket Lab holds a full manifest of launches for government, national security, and commercial small satellite operators for the remainder for 2020 and into 2021.

This paper summarizes Rocket Lab's progress towards truly responsive space since that first launch, including efforts towards reusability, the construction of additional launch pads, and the development of Rocket

Lab's own satellite program to offer a streamlined launch-plus-spacecraft offering as a bundled service.

AN OPERATIONALLY RESPONSIVE LAUNCH VEHICLE: ELECTRON

The Electron launch vehicle is a privately developed orbital launch vehicle (Fig. 1) optimized to meet the needs of the small satellite market. As of the date this paper was submitted on 06 June, 2020, Electron remains the only fully commercial small launch vehicle in operation dedicated to small satellite launch.

Figure 1: The Electron Launch Vehicle Lifts-Off For The Dedicated Launch 'Birds Of A Feather' For the National Reconnaissance Office, On 31 January 2020.

Electron has been designed for rapid manufacture and launch to meet the evolving needs of the growing small satellite market. Capable of launching payloads of up to 225 kg (496 lbs.), nominal Electron missions lift 200 kg to a 500 km sun-synchronous orbit. All Electron launches to date have flown from Rocket Lab's privately-owned Rocket Lab Launch Complex 1 in New Zealand. By late 2019, Rocket Lab also launches Electron from Rocket Lab Launch Complex 2 at the Mid-Atlantic Regional Spaceport at Wallops Flight Facility in Virginia, USA.

Electron's design incorporates a fusion of both conventional and advanced liquid rocket engine technology coupled with the innovative use of electrical systems and carbon composite materials. Electron launch vehicle dimensions and specifications are outlined in Table 1.

Table 1: Electron Launch Vehicle Dimensions and Specifications

Length	17m
Diameter	1.2m
Stages	2+ Kick Stage
Vehicle Mass (Lift-off)	13,000 kg
Nominal Payload Mass	200 kg (Sun-Synchronous Orbit)
Payload Diameter	1.08 m
Propulsion – Stage 1	9x Rutherford Engines (Lox/Kerosene)
Propulsion – Stage 2	1x Rutherford Engine (Lox/Kerosene)
Material/Structure	Carbon Fiber Composite
Launch Site Locations	Mahia, New Zealand Wallops Island, Virginia

In March 2020 the Electron launch vehicle was awarded a Category 1 certification by NASA, providing confidence for NASA's low cost scientific, educational, and technology demonstration small satellites. NASA is now considering Rocket Lab and the Electron launch vehicle for Category 2 Certification, a classification that enables higher value payloads to be integrated for launch.

Electron Launch Vehicle Reusability

Significant developments and iterations have also been made to Electron as part of the company's launch vehicle reusability program. The program's end goal is to enable an Electron first stage, or booster, to be recoverable first from the ocean then secondly from mid-air with the use of a helicopter, before being refurbished and flown again on multiple missions.

A mid-air recovery test as part of the program was successfully completed in early March, 2020. The test was conducted by dropping an Electron first stage test article from a helicopter over open ocean. A parachute was then deployed from the stage, before a second helicopter closed in on the descending stage and captured it mid-air at around 5,000 ft, using a specially-designed grappling hook to snag the parachute's drogue line (Fig 2). After capturing the stage on the first attempt, the helicopter safely carried the suspended stage back to land. Rocket Lab is currently targeting its 17th Electron launch for its first recovery demonstration.

Figure 2: An Electron Test Article Is Captured By A Helicopter During A Mid-Air Recovery Test As Part Of The Electron Launch Vehicle Reusability Program.

By eliminating the need to build a new first stage for every mission, Rocket Lab's launch vehicle production rate will increase significantly and thus further iterate the company's launch frequency.

OPERATIONALLY RESPONSIVE LAUNCH PADS

To further support the company's rapid call-up capability for operationally responsive space launch, Rocket Lab operates two launch pads for the Electron launch vehicle, with a third pad currently under construction. Combined, the FAA-licensed pads offer Rocket Lab customers more than 130 launch opportunities every year.

Rocket Lab Launch Complex 1

Rocket Lab Launch Complex 1 (Fig 3), located on the Mahia Peninsula in New Zealand, remains the world's only privately-owned and operated orbital launch site in the world. Rocket Lab Launch Complex 1 offers small satellite customers unmatched control over their schedule and orbit, with orbital inclinations available from sun-synchronous through to 39 degrees, and 120 launch opportunities available from the site every year.

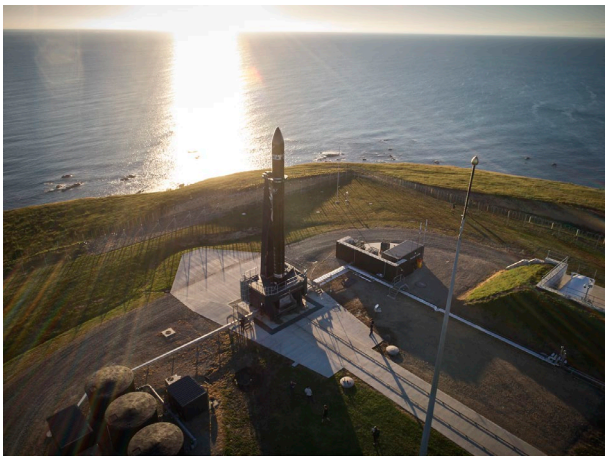

Figure 3: Rocket Lab Launch Complex 1, Located At Mahia Peninsula, New Zealand.

Initially opened in 2016 with a single pad and vehicle hangar, Launch Complex 1 has grown to include extensive range control operations and vehicle integration facilities equipped to process two Electron vehicles simultaneously. The site is also home to two 100K class cleanrooms for payload processing on site, each with dedicated and private customer facilities. Work has also begun on the construction of a second launch pad within Rocket Lab Launch Complex 1 (Fig 4). By replicating the layout and systems of the current launch pad onsite, maintaining and operating two privately-controlled launch pads from the same site will reduce pad turnaround time and enable parallel launch campaigns. The second launch pad is expected to be completed by the end of the 2020.

Figure 4: Construction Underway Of The Second Operational Launch Pad, Located At Rocket Lab Launch Complex 1.

Rocket Lab Launch Complex 2

On home soil in the United States, Rocket Lab Launch Complex 2 - located at the Mid-Atlantic Regional Spaceport within the NASA Wallops Flight Facility in Virginia – has been tailored specifically to provide responsive launch opportunities to U.S. government small satellite missions (Fig 5).

Figure 5: Rocket Lab Launch Complex 2, Located At Wallops Island, Virginia.

In addition to the pad itself, Launch Complex 2 will also be home to an Integration and Control Facility (ICF) located within the Wallops Research Park for processing payloads and Electron launch vehicles prior to lift-off. The ICF will house Range Control operations, payload integrations cleanrooms, and administrative offices. The site is also able to process multiple payloads and Electron launch vehicles prior to lift-off in support of rapid and responsive launch capability for the national security, military, and commercial sectors.

OPERATIONALLY RESPONSIVE SPACECRAFT: PHOTON

The Electron launch vehicle was developed to solve the bottleneck caused by traditional launch solutions for small satellites. However, launch is not the only challenge for reaching orbit for space users. With regular and reliable small satellite launch now a reality on the Electron launch vehicle, the next step in making space easy is satellites. In 2019, Rocket Lab established its Photon small spacecraft platform division to meet this demand.

Photon is a family of customizable small spacecraft with a common bus architecture (Fig 6) to accommodate a variety of payloads, instruments, mission designs, and objectives. By incorporating Electron's heritage third stage – known as the Kick Stage – within Photon's design, small satellite operators can fully utilize Electron's lift capacity and payload volume within the vehicle's fairing.

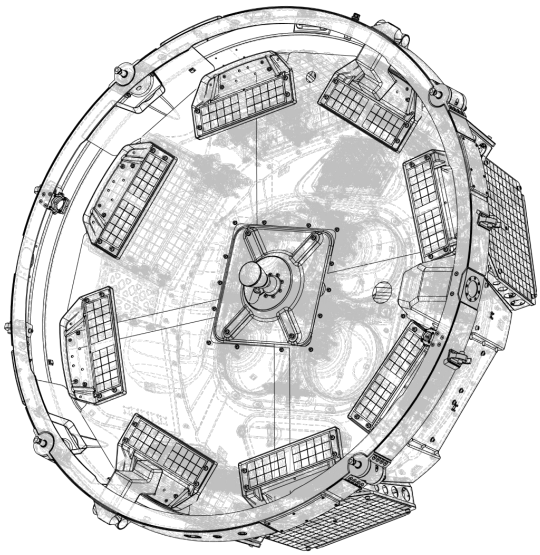

Figure 6: The Low Earth Orbit Configuration of the Photon Small Spacecraft Platform

Photon is available in low Earth orbit (LEO) configurations through to interplanetary exploration models.

LEO configurations of Photon operate the flight-proven Curie bi-propellant propulsion system capable of multiple burns in space. In addition to the ten successful orbital flights of the Kick Stage, more than 1,650 Curie engine tests have been conducted on the ground.

Interplanetary Photon models operate a higher-performance version of the Curie propulsion system called HyperCurie (Fig 7) and include larger propellant tanks and a precision orbit determination system within its architecture.

All Photon configurations are equipped with a high-power generation, high-accuracy attitude determination and control system and radiation-tolerant avionics.

Figure 7: Photon HyperCurie Propulsion System Undergoes Testing, May 2020.

Photon's incorporated payload mass can include >130 kilograms to 500km Sun Synchronous Orbit; >180 kilograms to a 40-degree 500km orbital destination, or; >40 kilograms for beyond low Earth Orbit and interplanetary missions.

With Rocket Lab's recent acquisition of leading satellite components provider Sinclair Interplanetary, several flight-proven spacecraft hardware components can be incorporated in Photon's design to meet specific mission needs. These include Sinclair Interplanetary reaction wheels, optical communications hardware, and star trackers - components which have been used in more than 100 satellites launched to orbit to date.

By creating a satellite bus platform that both incorporates flight-proven heritage and is simple to customize and iterate, Photon provides the type of reliability and flexibility inherent in a truly responsive spacecraft system.

End-To-End Mission Services

The challenges of procuring launch, building a spacecraft, and coordinating ground communications can be slow and cost prohibitive for many small satellite customers.

With Photon, Rocket Lab offers a complete, end-to-end mission service that provides the spacecraft bus, mission design, launch, and ground station support. With the spacecraft and launch taken care of, Photon customers are better able to dedicate time and resources to their core purpose – their product, service, or research.

Rocket Lab is also partnered with Kongsberg Satellite Services (KSAT), the world's largest provider of ground station services, to further offer ground segment support in a complete mission solution for small satellite operators.

The partnership provides Photon customers downlink and uplink capabilities in UHF, S-band, X-band, and Ka-band across a global ground station network of over 200 antennas that supports 50,000 contacts per month. KSAT's ground network is designed and optimized for small satellite systems and scalable to meet individual mission needs, starting with support on a per-pass basis and options to move to full antennas as required.

Small Satellite Launch Beyond LEO

In response to increased global focus on lunar scientific and economic development, demand is increasing for cost-effective and reliable small launch solutions to test technology concepts, find and retire risk, and build infrastructure to support human spaceflight and interplanetary exploration.

In particular, the United States commitment to land the first woman and next man on the Moon by 2024 as part of NASA's Artemis program will first require pathfinding missions, spacecraft, and satellites to determine the stability of orbits around the Moon targeted for human spaceflight.

Rocket Lab will provide such a service for NASA in early 2021, when Electron will launch a CubeSat integrated with Photon into lunar orbit as part of NASA's Artemis program.

Rocket Lab will deploy the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) CubeSat to a near rectilinear halo orbit around the Moon, the same orbit planned for the Lunar Gateway. The Gateway is a planned small space station that will provide astronauts with access to the lunar surface. It will feature living quarters for astronauts, a lab for science and research, and ports for visiting spacecraft. CAPSTONE will also test a navigation system that will measure its position relative to NASA's Lunar Reconnaissance Orbiter (LRO) without relying on ground stations.

The mission will be launched from Rocket Lab Launch Complex 2 in early 2021.

While structurally the Electron launch vehicle maintains its full carbon-composite structure and Rutherford propulsion system, iterative improvements to the vehicle's performance and design are being made to increase its capability beyond low-Earth orbit into

both lunar orbit and further beyond into deep space. The CAPSTONE mission concept will also see Electron deliver a high delta-V variant of Photon (Fig 8) to a circular parking orbit before a series of phasing maneuvers establish Photon and the integrated payload in elliptical orbits of Earth over nine days to build up velocity for a Trans Lunar Injection to deploy CAPSTONE into an orbit around the Moon. Following CAPSTONE deployment, Photon's secondary mission objective will be to perform a trajectory correction maneuver to set it on a course for a lunar flyby, then interplanetary space.

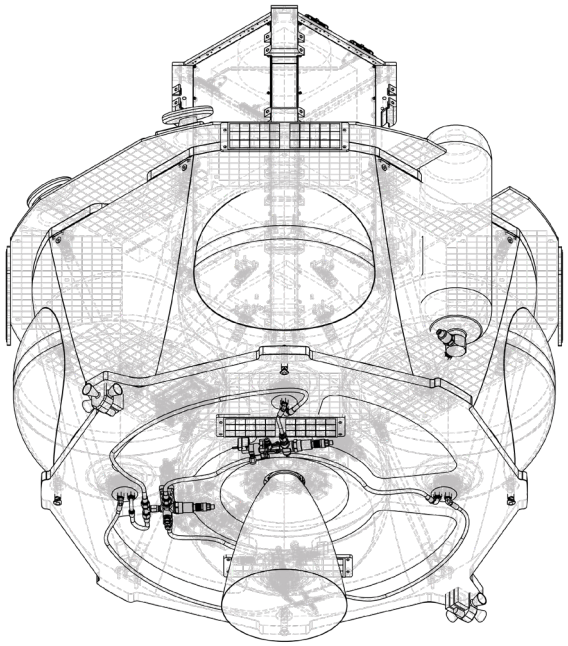

Figure 8: The Interplanetary Configuration of the Photon Small Spacecraft Platform.

This mission architecture coupled with interplanetary configurations of Photon enables precise targeting for small spacecraft missions beyond LEO with instrument/payload masses up to ~50 kg without the need for a medium or heavy lift launch vehicle, greatly expanding the potential for planetary exploration.

CONCLUSION

Rocket Lab's end-to-end mission solutions incorporating responsive launch vehicles, responsive spacecraft, and responsive launch sites is unmatched across the small launch industry and uniquely placed to serve the demands of government and commercial small satellite operators needing to respond quickly and cost-effectively to technical failures or deliberate actions against their infrastructure in space. With the ongoing success and development of its Electron launch vehicle reusability program, Rocket Lab has dedicated significant resource towards sustainably meeting its mission cadence goal of weekly launches to be able to provide unmatched scheduling opportunities and dedicated access to space for small satellites.