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Making Space on Orbit: Responsible Orbital Deployment in the Era of High-Volume Launch

Peter Beck
Rocket Lab
14520 Delta Lane, Suite 101, Huntington Beach, CA 92647; +1 (714) 465 5737
media@rocketlabusa.com

ABSTRACT

The long-awaited era of dedicated small satellite launches has arrived, and with it, new challenges and responsibilities for launch providers. For decades the focus has been on providing a frequent, reliable and affordable service to space for small satellites. With this now a reality, the question on the industry's mind is how to cope with the growing challenge of orbital debris from high-volume launch. Following Rocket Lab's recent successful orbital launches, a growing number of commercial launch players are looking to provide a service to orbit for the burgeoning market. Given space's significance as a global resource, the safe and sustainable management of the domain must be a global priority. Significant responsibility for this rests with launch providers.

This paper looks at the orbital debris challenges associated with high-volume launch and the enabling characteristics of innovative deployment technology for both functional spacecraft benefit and sustainable debris management.

INTRODUCTION

On May 25th, 2017, Rocket Lab successfully launched its first Electron launch vehicle to space. The mission represented a number of world firsts and marked the beginning of a new era of rapid, reliable and cost-effective space access for small satellites. The mission, named 'It's A Test,' saw the launch of the world's first fully carbon-composite launch vehicle and the first 3D printed engines flown to space. That same Rutherford engine became the first battery powered electric pump-fed engine flown to space. 'It's a Test' also lifted off from the world's first private orbital launch site, Rocket Lab Launch Complex 1, located on New Zealand's Māhia Peninsula. In the two years from that inaugural launch to the time of submitting this paper in June 2019, Rocket Lab has successfully launched an additional five Electron missions, deploying a total of 28 satellites to orbit for customers including NASA, DARPA and the U.S. Air Force Space Test Program, as well as several commercial satellite operators. It's a mission cadence that will rapidly increase to an Electron launch every two weeks by the end of 2020, with a second launch pad under construction at the Mid-Atlantic Regional Spaceport in Wallops Island, Virginia, USA, to support this rapidly increasing cadence. Rocket Lab will continue to increase this cadence to a launch every week in the coming years, with launch facilities and Electron production processes already streamlined to support this.

High-volume launch of this nature has finally liberated the small satellite industry from the challenges associated with traditional rideshare arrangements on large launch vehicles, where small satellites often face delays and less than ideal orbital placements. However, this volume of launch also presents a challenge to the growing number of commercial launch players looking to enter the market in coming years. High-volume launch means the potential for a rapid rise in orbital debris left behind by spent launch vehicle stages used to deploy satellites to orbit. Given space's significance as a global resource, the safe and sustainable management of the domain must be a global priority. Significant responsibility for this rests with launch providers. The key to ensuring this responsible management is the Rocket Lab Kick Stage.

THE ELECTRON LAUNCH VEHICLE AND KICK STAGE

The Electron launch vehicle is a privately developed orbital launch vehicle (Fig. 1) servicing the small satellite market. It is currently the only fully commercial launch vehicle in operation dedicated solely to small satellites.

Figure 1: Electron Launch Vehicle Lifts-Off For The 'Still Testing' Mission, Rocket Lab's Second Launch, On 21 January 2018.

Electron has been designed for rapid manufacture and launch to meet the rapidly evolving needs of the growing small satellite market. Capable of launching payloads of up to 225 kg (496 lbs.), nominal Electron missions lift 150 kg to a 500 km sun-synchronous orbit from Rocket Lab Launch Complex 1 in New Zealand. By late 2019, Rocket Lab will also launch Electron from Launch Complex 2 at the Mid-Atlantic Regional Spaceport at Wallops Flight Facility in Virginia, USA.

All flight systems and launch vehicle components are designed, built and tested in-house at Rocket Lab (Fig. 2).

Figure 2: Rocket Lab Production Complex.

Electron's design incorporates a fusion of both conventional and advanced liquid rocket engine technology coupled with 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

SPECIFICATION	VALUE
Length	17m
Diameter	1.2m
Stages	2 + Kick Stage
Vehicle Mass (Lift-off)	13,000 kg
Nominal Payload Mass	150 kg (Sun-Synchronous Orbit)
Payload Diameter	1.08m
Standard Orbit	500km (Sun-Synchronous Orbit)
Propulsion - Stage 1	9x Rutherford Engines (Lox/Kerosene)
Propulsion - Stage 2	1x Rutherford Engines (Lox/Kerosene)
Material/Structure	Carbon Fiber Composite
Standard Launch Site	Mahia, New Zealand

ELECTRON KICK STAGE

The Electron Launch Vehicle has been designed to deploy small satellite payloads by precise and innovative means, leaving no part of the launch vehicle in orbit following payload deployment.

Electron is a two-stage to orbit vehicle, with an additional Kick Stage (Fig. 3) designed to carry out the final payload deployment phase of launch. On lift-off, Electron's first stage is powered by nine of Rocket Lab's in-house designed and manufactured engine, Rutherford. An electric turbo-pumped LOx/RP-1 engine specifically designed for the Electron Launch Vehicle, Rutherford adopts an entirely new electric propulsion cycle, making use of brushless DC electric motors and high-performance lithium polymer batteries to drive its turbo-pumps.

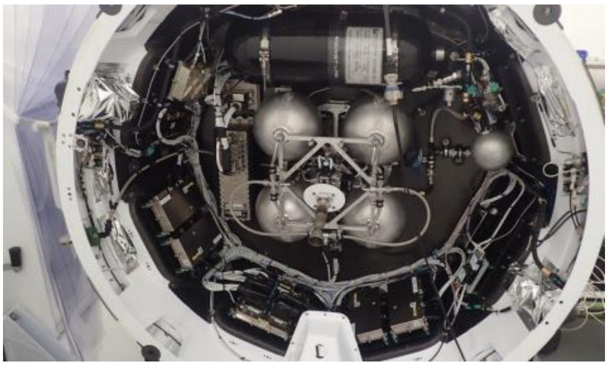

Figure 3: Electron's Kick Stage, including Curie Engine.

Rutherford is the first oxygen/hydrocarbon engine to use additive manufacturing for all primary components, including the regeneratively cooled thrust chamber, injector pumps, and main propellant valves. Additive manufacturing of engine components allows for ultimate manufacturability and control.

Following fuel depletion, Electron's first stage is jettisoned approximately 163 seconds following lift-off. Several seconds after this, a single vacuum optimized Rutherford engine ignites and continues to orbit carrying the Kick Stage and payloads (Fig. 4). Approximately 540 seconds after lift-off, the Kick Stage and second stage separate. The Kick Stage's engine, a 3D printed, bi-propellant engine name Curie, ignites and circularizes the orbit of the Kick Stage and its payloads. At precise, pre-defined intervals, payloads are then deployed to their specified orbits.

Figure 4: Payloads mounted on Electron's Kick Stage prior to deployment,11/11/2018.

Following the deployment of all payloads, the Curie engine is capable of reigniting and maneuvering the Kick Stage into a highly elliptical orbit where it is experiences significant atmospheric drag at perigee and is pulled back into the Earth's atmosphere where it is destroyed completely on re-entry. Because Electron's second stage is also left in a highly elliptical orbit, it too experiences significant drag and is destroyed on reentry. The deorbiting process for Electron's second stage can take as few as 12 days from launch. The deorbit time for the Kick Stage can be less than two hours after lift-off.

This complete process means Rocket Lab is capable of deploying customer satellites, then leaving no part of the Electron launch vehicle in orbit to add to orbital debris risk. This is crucial to ensuring the safe, responsible and sustainable use of space as a global domain as we enter an era of high-volume launch. The Kick Stage has flown on all five of Rocket Lab's orbital launches to date.

Photon

Since Rocket Lab's founding in 2006, the Kick Stage was always designed to be only the first step in Rocket Lab's plans for a complete spacecraft platform. In April 2019, Rocket Lab announced the Photon spacecraft. Photon takes the existing Kick Stage and incorporates high power generation, high-accuracy attitude determination and control, and radiation-tolerant avionics to provide a bundled launch-plus-satellite offering to small satellite operators. Essentially, Rocket Lab is now a single-stop mission provider, delivering a spacecraft build and launch service together. This lets small satellite operators focus on their core purpose - their payload applications - without the needless distraction of developing or procuring a spacecraft platform. By using Photon's flight-proven technology as their payload bus, small satellite operators can negate the need to scale teams of spacecraft engineers and commit capital to developing the satellite infrastructure to support their payload. This rapidly accelerates the timeframe to orbit for commercial and government small satellite customers alike, but it will also drastically reduce risk. A small percentage of small satellites are never contacted by the satellite operator following launch. In addition to the wasted time and capital of this failure phenomenon, this also adds non-functioning mass to orbit, further adding to orbital debris risks. By providing small satellite operators with a flexible, cost-effective and tailored spacecraft bus solution that is flight-proven, this risk can be reduced.

Photon is designed for a wide range of applications. At its most fundamental level, the platform serves as the Kick Stage, whereas advanced versions of Photon are enabled by augmenting the Kick Stage with high (kW-class) power generation and precise attitude control capability. In its full performance configuration, Photon is an approximately 60 kg wet mass satellite platform that can carry up to 170 kg of useful payload, depending on orbit. Whereas in conventional launches, 30-60% of this payload capacity would be consumed by a satellite bus, the Photon platform makes the entire payload capacity of Electron useful for the customer. Photon specifications are outlined in Table 2.

Table 2: Photon Spacecraft Platform Specifications

Specification	Kick Stage	Standard Photon	Performance Photon
Payload mass	Up to 200kg	Up to 170kg	Up to 160kg
Payload volume	Electron payload fairing		
Payload power (peak)	N/A	100 W	TBS Variant(s) 1000W
Payload energy	N/A	TBS	TBS Variant(s) 300 Wh
System voltage	N/A	28 V unregulated; regulated options available	
Poiting accuracy	N/A	5 degrees	50 arcsec
Pointing stability	N/A	1 deg/s	2 arcsec/s
Slew rate	N/A	5 deg/s	
Specific impulse	220s		290s
Payload data interfaces	LVDS, ethernet, CAN RS422 / 485 Space Wire		
Payload data storage	N/A	8 GB	32 GB
Communications	N/A	S-band space / groun	Space-ground via GEO
Telemetry & command data rate	N/A	Up to 512 kbps	S-band: up to 512 kbps GEO relay: up to 200 kbps
Payload data rate	N/A	Application-dependent	
Design lifetime	Hours	LEO > 5 years	
Navigation accuracy	5 - 10 m		

Conclusion

To meet the growing launch demand of the small satellite industry, Rocket Lab is scaling its operations to become the most prolific launch provider in the world.

More than 100[1] small satellite launch companies in various stages of development hope to provide a service to orbit too, and the risks this poses to the longevity and safety of low Earth orbit as a useful domain are great. Through the Kick Stage, and now Photon program, Rocket Lab is addressing this immediate industry challenge in a unique and sustainable way, while continuing to provide the most frequent, reliable and cost-effective dedicated access to orbit for small satellites.

References

1. Werner, Debra. "An embarrassment of rockets?" Space News, 22 May 2019: Web