# LAUNCHERONE: VIRGIN ORBIT'S DEDICATED LAUNCH VEHICLE FOR SMALL SATELLITES & IMPACT TO THE SPACE ENTERPRISE VISION

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## ABSTRACT

Virgin Orbit is developing a space transportation service to provide an affordable, reliable, and responsive dedicated ride to orbit for smaller payloads. No longer will small satellite users be forced to make a choice between accepting the limitations of flight as a secondary payload, paying dramatically more for a dedicated launch vehicle, or dealing with the added complexity associated with export control requirements and international travel to distant launch sites.

Virgin Orbit has made significant progress towards first flight of a new vehicle that will give satellite developers and operators a better option for carrying their small satellites into orbit. This new service is called LauncherOne (See the figure below). LauncherOne is a two stage, air-launched liquid propulsion (LOX/RP) rocket. Air launched from a specially modified 747-400 carrier aircraft (named "Cosmic Girl"), this system is designed to conduct operations from a variety of locations, allowing customers to select various launch azimuths and increasing available orbital launch windows. This provides small satellite customers an affordable, flexible and dedicated option for access to space.

In addition to developing the LauncherOne vehicle, Virgin Orbit has worked with US government customers and across the new, emerging commercial sector to refine concepts for resiliency, constellation replenishment and responsive launch elements that can be key enables for the Space Enterprise Vision (SEV). This element of customer interaction is being led by their new subsidiary company, VOX Space.

This paper summarizes technical progress made on LauncherOne in the past year and extends the thinking of how commercial space, small satellites and this new emerging market can be brought to bear to enable true space system resiliency.

## 1. THE UNMET NEEDS OF RESPONSIVE LAUNCH

Historically, various US Government customers have had a long-standing desire to increase timely and responsive access to space through the use of small satellites. Finding launch opportunities for these small satellites has been challenging and cost prohibitive due to the high cost of launch. This has made it incredibly difficult for the US Government to fly payloads into orbit to test and demonstrate new technologies and enable capabilities that support both strategic and tactical space superiority.

VOX Space, and its parent company Virgin Orbit, were formed from the onset with the intent of transforming the launch industry. Virgin Orbit, realizing the tremendous potential of small satellites to provide capabilities such as global connectivity, remote sensing, security, and other visionary new capabilities that benefit our planet, has been developing the LauncherOne launch vehicle to get small satellites to orbit quickly, reliably, and affordably. This vehicle is ready to provide capable launch services to customers as early as 2018.

LauncherOne provides unparalleled flexibility due to its mobile launch platform, a modified 747-400 known as "Cosmic Girl", and design, which was designed from the onset to be simple, yet robust, reliable, and responsive. The carrier aircraft can fly to anywhere in the world, offering customers the ability to target a wide range of orbits without the need for a costly dogleg maneuver. Furthermore, air launch eliminates common cause of launch delays such as weather and logjams in the launch queue, ensuring timeliness of launch. From a launch integration perspective, satellites can be pre-encapsulated, placed into storage, called up on demand when needed and integrated with LauncherOne in a timeframe of days, enabling a truly responsive capability. Additionally, the large volume available in the fairing enables a diverse range of manifest capabilities.

Table 1 summarizes key LauncherOne technical elements and performance parameters.

**Table 1: LauncherOne Capabilities against Key Performance Criteria**

| Key Performance Criteria | LauncherOne Capability |
|---|---|
| **Launch spacecraft up to 450 kg to LEO** | LauncherOne delivers up to 500 kg to LEO. |
| **On demand** | LauncherOne can deliver payloads with minimal call-up time. |
| **With precision** | LauncherOne provides precise delivery of payloads; injection capabilities are as follows:<br>• Apogee/Perigee: +/- 15 km<br>• Inclination: +/- 0.15º<br>• RAAN: +/- 0.2º |
| **Accommodate timely and flexible launch of small payloads** | LauncherOne delivers small payloads from an air-launched platform that can be deployed anywhere in the world |

## 2. INTRODUCTION TO LAUNCHERONE

LauncherOne is a simple, expendable launch vehicle designed to place small satellites of up to 500 kg / 1100 lbm into a wide range of Low Earth Orbits (LEO) at an affordable price. Rather than launching from the ground, LauncherOne is carried to an altitude of approximately 35,000 feet by the 747-400 carrier aircraft, Cosmic Girl, as depicted in Figure 1.

Air launch has many benefits over ground launch. Air launch eliminates much of the compulsory overhead of ground launch systems, and provides unprecedented flexibility in launch operations. By operating independently from national launch ranges, LauncherOne avoids common causes of launch delays such as logjams in the launch queue, weather, unavailable radar tracking assets, and boats in the launch pad stay-out zone. The carrier aircraft serves as a mobile launch platform, offering custom launch solutions not traditionally available to small satellites, including tremendous flexibility in the spaceport of origin, orbital destination, and launch date.

The simple design of LauncherOne increases reliability while keeping costs low. In order to balance performance with commercially-competitive pricing, LauncherOne was designed through a "clean-sheet" design process, in which all potential vehicle configurations were traded against each other (different numbers of stages, various propulsion types, etc.). Throughout LauncherOne's design, the Virgin Orbit team actively rejected

complexity, favoring a straightforward and reliable design. This avoids the common trap of incurring significant cost increases for only a marginal increase in performance.

**Figure 1. Cosmic Girl 747-400 Carrier Aircraft**

The current configuration of LauncherOne has been in development since the early part of this decade and is rapidly nearing flight; a test flight and a transition to commercial services is expected in 2018.

The LauncherOne system consists of three major elements: the launch vehicle, carrier aircraft, and ground segment. The carrier aircraft is a modified 747-400 that carries the launch vehicle under the port (left) side wing between the fuselage and inboard engine. The carrier aircraft provides electrical power, purge gasses, health monitoring, and control of the launch vehicle by a launch engineer onboard the aircraft. The ground segment consists of equipment to load propellants on the launch vehicle, ground stations to gather and distribute telemetry, and a mission control center to monitor the launch operation.

LauncherOne is a two stage vehicle, with a 72” diameter first stage and a 59” diameter second stage and fairing, constructed primarily of composites to minimize weight and maximize propellant mass fraction. The first stage is powered by a Newton 3.1 turbopump-fed LOX/RP-1 booster engine that delivers 73,500 lbf of thrust the second stage is powered by a Newton 4 engine that delivers 5,000 lbf of thrust. The vehicle can deliver over 500 kg to a low inclination, low altitude orbit. A few of the high level specifications of LauncherOne are shown in Figure 2.

The LauncherOne payload assembly enables payloads to be mated with a payload adapter and encapsulated in the payload fairing independently of the first and second stage launch vehicle integration. This enables integration to happen in parallel, and allows for pre-encapsulation of payloads if desired by the customer.

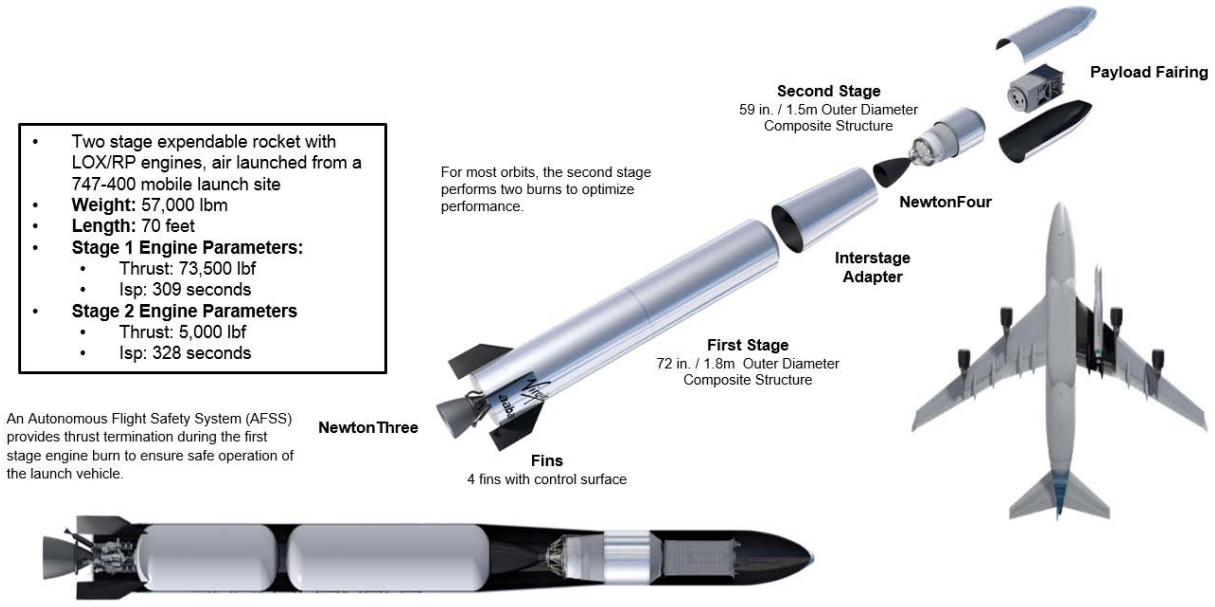


**Figure 2. LauncherOne Overview**

## 3. INTRODUCTION TO VOX SPACE

VOX Space, LLC is a US-incorporated, wholly-owned subsidiary of Virgin Orbit, LLC. VOX Space provides the national security community of the USA and allied nations with responsive, dedicated, and affordable launch services for small satellites bound for Low Earth Orbit. Headquartered in Manhattan Beach, California, VOX Space can provide study, analysis, integration, and launch services using Virgin Orbit's LauncherOne, while ensuring our customer's critical information is protected. An organizational structure showing the relationship between VOX Space and the Virgin Orbit is shown in Figure 3.

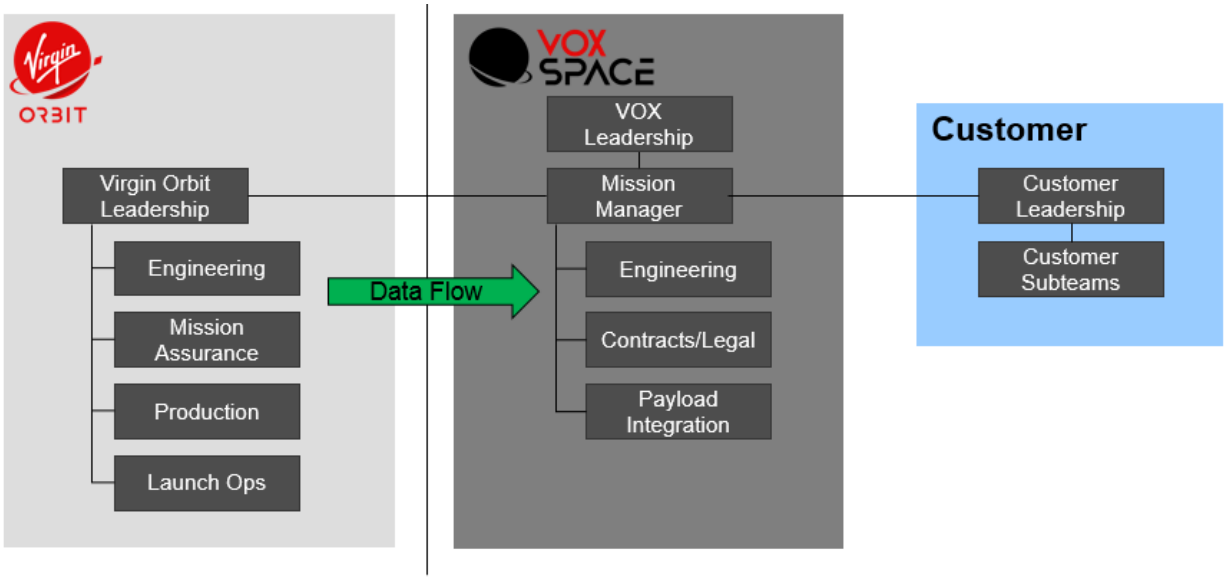


**Figure 3: Organizational Structure between Virgin Orbit and VOX Space**

## 4. RESPONSIVE LAUNCH DEMONSTRATION

One area that is gaining significant traction in the small satellite community is shortening the timeline to launch and truly enabling a responsive capability. Despite existing launch and payload integration timelines that are already fairly short in nature, there remains a level of optimization for reducing all of the associated timelines related to launch – everything from reducing the timeline for payload integration to loading ops on the tarmac just prior to launch. There is also the mission planning element (running trajectories and Monte Carlos, generating gains) as well that can significantly increase the amount of time required for launch preparation. VOX Space and Virgin Orbit are prepared to study the requirements for enabling a truly responsive capability should the customer demonstrate interest in this area. This study would investigate all the improvements in launch preparation that would be required that would minimize launch timelines and increase flexibility/resiliency without significantly increasing technical complexity or cost.

On top of a study to refine the requirements for responsive launch, one potential demo that may be of significant interest to the Government customer is a tech demo that will demonstrate a surge capability (see Figure 4). For this demonstration, an actual rapid call up and launch concept of operations would be demonstrated. The specific mission that will be performed will not be defined in detail ahead of time – rather, the government will provide a general idea of what will have to occur during the tech demo. A wide variety of scenarios are possible, considering the flexible responsiveness built into the architecture. For example, the scenario might be launching a satellite on a 14 day timeline from initial call up to operational capability (or some other determined time frame). During the actual exercise, the details of the actual mission will be outlined, and the countdown will commence. An example scenario might be delivering an imaging satellite to a 500x500 km Sun-Synchronous Orbit. When the clock starts, the VOX Space team will be responsible for performing all aspects of the payload and launch vehicle integration on a much reduced timeline from a standard launch. Concurrently, during this time standard mission planning activities will occur, which will include such tasks as generating trajectories, running Monte Carlo sets, and generating gains. Once the vehicle launches and enters orbit, a second phase will take place in which the software interfaces between the VOX Space team and the military's BMC3 system are demonstrated.

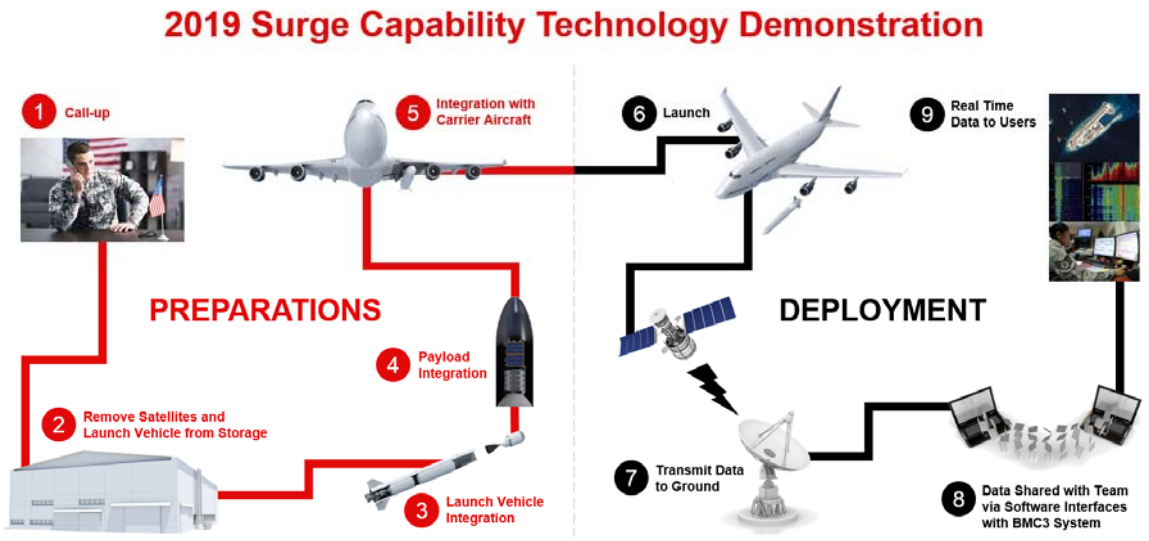


**Figure 4. Responsive Launch Technology Demonstration**

## 5. LAUNCHERONE AND IMPACT TO THE SPACE ENTERPRISE VISION

For many years, the United States military has been relatively unchallenged in the space domain. Today, there is a realizable threat from space forces from other countries, as evident by the Chinese anti-satellite missile test in 2007. Understanding the threat from our adversaries, General John Hyten, then commander of Air Force Space Command, announced the command's Space Enterprise Vision (SEV) in 2016. This Space Enterprise Vision will enable the Air Force to account for the increasing threat to space systems, and provides a long term vision for how the Air Force should build a force that is responsive to the threat.

We think LauncherOne and commercial basis for approaching space resiliency offers a different approach to enable a resilient Space Enterprise Vision. There is a diverse range of LEO small satellite constellations, ground analytics and small launch capabilities being commercially developed. We propose that this combination of systems can be the basis FOR the Space Enterprise Vision architecture including the "on call" or "surge" capability that each of the systems could individually provide.

This new ecosystem of companies and capabilities can bring forth a different perspective, energy, and approach to current space development. We envision a Space Enterprise that is robust, affordable, rapidly evolving and which demonstrates seamless interaction between government and commercial entities. To capture this spirit and resolve, we have drafted the following vision statement:

We propose providing an extensive capability in LEO for a variety of missions. Augmenting commercially developed architectures with additional or "surge" capability will be an affordable, new, and different way to start building a significant part of the SEV.

## 6. CONCLUSION

VOX Space intends to bring agile, innovative, and affordable solutions to next generation launch and space platforms for our government customers. Near-term and commercially available satellites and launch vehicles could provide a low-cost, rapid-response "surge" capability to maintain US Air Force Space Superiority during contested, degraded, and operationally-limited environments under tactically relevant timelines. We believe that this could be a different way to define an integrated and resilient space enterprise architecture concept that provides a holistic solution to the government, leverages the strengths and synergies of the commercial team to minimize gaps, and makes use of the space domain mission assurance attributes of distribution, diversification, disaggregation, deception, protection, and proliferation to ensure that the enterprise concept is aligned with the Commander's intent for SEV.