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Path to the First Flight of the SL-OMV

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ABSTRACT

The growing number of dedicated small launch vehicles will lower the cost of space access in the coming years but many challenges remain in utilizing these for small payloads particularly CubeSat missions. Cubesats still have a similar number of concerns and obstacles as a secondary payload on a larger rocket as they do on a small rocket such as desired orbital location. Constellation phasing creates another challenge without using on-board propulsion or time consuming differential drag strategies. All of these create additional challenges for the mass/cost constrained CubeSat developer.

Many of these challenges can be met through the use of a propulsive rideshare adapter or Small Launch Orbital Maneuvering Vehicle (SL-OMV). The SL-OMV is a low mass and low cost propulsive adapter that can be used to distribute CubeSat payloads (1U, 3U, 6U, 12U, and non-standard sizes) with different orbital parameters than the primary payload or each CubeSat with a different orbital destination. This is important for both Rideshare launches but single mission dedicated cluster launches. The SL-OMV can remain on orbit for a longer duration allowing for constellation phasing for payloads without propulsion. This can be used for "on demand" deployments that are useful across commercial, civil, and military space applications.

The SL-OMV is designed with the future small launch vehicle systems in mind including using low cost platform avionics and composites, composites for low mass structures, modular payload accommodations, and green propellant for spaceport operations and especially for European launches where REACH legislation may limit traditional propellants like Hydrazine. The SL-OMV can reduce costs for space access using rideshare and enable low cost missions that previously could only be achieved through the expense of a dedicated launch vehicle and propulsive spacecraft.

The development and first flight unit of the SL-OMV is being funded jointly by Moog and the United Kingdom Satellite & Launch Program (UKSLP) and is scheduled for launch in the early 2020's from a new launch site on the north coast of Scotland. This will be the first UK vertical launch site and be used by multiple launch vehicle providers. In addition to the SL-OMV, this launch will carry multiple CubeSats for a variety of missions including an advanced low-latency weather data satellite. The SL-OMV will deploy CubeSats from multiple missions at different altitudes and be used to place spacecraft in a precise formation orbit.

INTRODUCTION

The Moog Small Launch Orbital Maneuvering Vehicle (SL-OMV) is a propulsive small satellite launch adapter designed for use on small launch vehicles, particularly those of the 300 kg to LEO class. The SL-OMV provides the ability to deploy payloads at different orbits which is critical for payloads from different customers (i.e. rideshare) or payloads from the same customer that require constellation phasing or even a combination of the two. This furthers the investment made in the small launch vehicles themselves and allows for mixed manifest with a variety of customers or end users.

The SL-OMV is a turnkey solution that can be leveraged on several different launch vehicles, both existing, and in development. The system is designed to be mass and cost efficient and includes a Green Propulsion system enabling launches from Spaceports and other facilities that do not have hazardous payload processing capabilities. Moog has been developing the

SL-OMV based on market input from across the global space community while leveraging hardware and technologies that are being developed for this market as well. The design reflects this market input in performance, capabilities, modularity, and cost.

Moog sees the SL-OMV as a complimentary technology to the Small Launch Vehicle (SLV) market and greatly enhances the utility of low cost access to LEO. The SL-OMV and potential future variants can allow for easier space access beyond LEO.

Recent funding from the UK Space Agency (UKSA) Spaceflight Programme initiative provides an opportunity for multiple launch vehicles and launch sites to be developed reading the UK for domestic launch beginning in the 2020's. This is seen as a key compliment to the existing market and capabilities within the UK and provides the last step to having an "end to end" space economy in the UK.

HOW SLV'S ARE CHANGING THE LAUNCH MARKET

With smaller launch vehicles in development, it is finally an option for a small satellite, or constellation of CubeSats, to purchase the majority of a launch vehicle's capacity and benefit from greater influence over the schedule, drop-off location, and even the orbit parameters as compared to a "hitchhiker" payload.

Many of the new, commercial spacecraft companies require anywhere from one to hundreds of spacecraft to meet their data collection goals and often require constellation refreshes at a regular rate. Unlike rideshare opportunities, which are sporadic and vary widely in cost per kilogram, a small launch vehicle can offer dedicated launch at a regular cadence.

More Options for Small Satellites

The rapid growth of small satellite industry has led to an equally rapid growth in the Small Launch Vehicle market. SLV systems in development range from 4-5 kg capacity up to 500 kg capacity. There are over 100 systems in development, with at least 34 of them still active in the last 2 years, in addition to existing systems like Pegasus XL and Minotaur[1,2,9,12]. The lower capacity SLV are aimed towards CubeSat-class payloads where one launch may carry only one or two payloads. Many of the vehicles have a 200 kg to 400 kg throw mass and even with an "ESPA Class" payload of 180 kg there is additional capacity for small payloads such as CubeSats. This capacity also allows for a cluster of small payloads which enables an entire constellation to be launched at once. Some of these launch vehicles are planning for launch rates of 20-30 per year with Virgin Orbit's LauncherOne[3] or even up to once a week with Rocket Lab's Electron[4].

This capability is important as estimates show up to 2000 small payloads between 1-50 kg will be launched from 2019-2023[5]. CubeSats are transitioning from technology demonstration platforms to critical assets as part of commercial business models and even military applications. From 2014-2018 37% of the launched small payloads were for scientific or technology purposes whereas the forecast from 2019-2023 is showing 68% will be for Earth Observation, Remote Sensing, and Communications. The largest class of these payloads will be in the 3U or 6U range[5].

Role of the SL-OMV

Although the luxury of being the primary customer on a launch affords many privileges, small launch customers competing in the new space market cannot afford to waste launch capacity. New ways to optimize the capability of an SLV is required. The SL-OMV can serve several different mission types as shown in Figure 1. In some cases multiple mission types can be performed in a single launch providing flexibility.

For this reason, the SL-OMV has been designed to be compatible with the new class of Small Launchers and existing small launch systems such as the Pegasus and the Minotaur family. Only the diameter of the adapter and propulsion tank attachments need to change in order to interface with LVs from 24" to 38.8".

For SLVs such as Rocket Lab's Electron, the SL-OMV would be the primary passenger. Whereas on vehicles, such as Virgin Orbit LauncherOne, Orbex Prime, Firefly Alpha, Northrop Grumman Innovation Systems Pegasus XL or a Minotaur vehicle the SL-OMV could be placed under a primary passenger in a similar fashion to the ESPA ring on the EELV-class rockets. A stacked configuration is also possible within larger fairings such as the LauncherOne or Alpha.

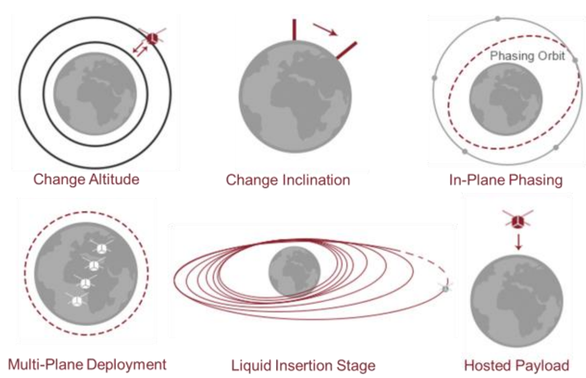

Figure 1: SL-OMV Use Cases

SL-OMV CAPABILITY SUMMARY

The key characteristics of the SL-OMV system are a lightweight, composite cylinder adapter, a green propulsion system, a fixed solar array, and the flexibility to mount multiple kinds of payload adapters. Figure 2 shows the SL OMV block diagram. The key vehicle properties are highlighted here, with further detail on the vehicle's subsystems and mission scenarios presented later in the paper.

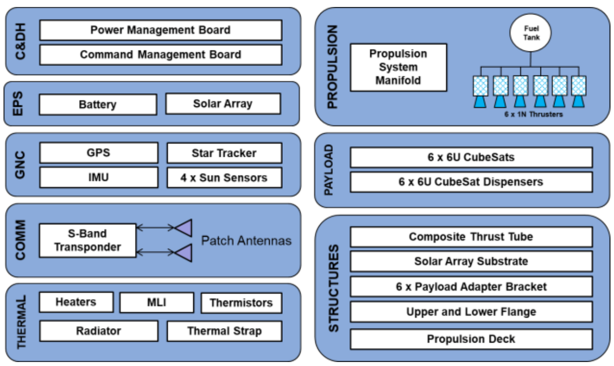

Figure 2: SL-OMV Block Diagram

Dimensions and Mass

The SL-OMV structure has a nominal height of 24" and a diameter of 24". With six (6) payload dispensers attached, the vehicle measures 40" across. The nominal diameter can be expanded to 38.8" to accommodate a variety of vehicles and standard separation systems.

The limited mass of the new small launch vehicles requires that the SL-OMV be as light as possible. In total, the wet mass of the vehicle is approximately 70 kg, including approximately 17 kg of green propellant. With a full complement of 6x6U CubeSats and dispensers (~90 kg), the vehicle is approximately 155 kg (varies based on payload and dispenser masses). Each component has a mass contingency based on its maturity level. The overall system has a mass margin of 15% that will be reduced as the design matures. The maximum propellant mass of 17 kg can be reduced as needed by the mission and launch vehicle capacity. Table 1 shows how these values breakdown over the whole system.

Table 1: SL-OMV Mass Breakdown

Subsystem	Mass + Cont (kg) + System Margin
ADCS	0.6
Avionics	3.9
Comms/TT&C	1.5
Power	5.9
Propulsion	8.6
Separation System	4.1
Structure	21.2
Thermal	4.3
Harness	2.3
Vehicle Dry Mass	52.5
System Margin (15%)	7.9
Max Propellant	17.0
Vehicle Wet Mass	77.4
Payload	88.3
TOTAL	165.65

Capabilities

The SL-OMV is capable of on-orbit operations nominally up to 12 months (but can be more), allowing the vehicle to deploy satellites over longer periods of time than a typical upper stage of just a few hours or stay on-orbit to act as a hosted payload platform once payloads have been deployed.

The propulsive capability of the SL-OMV varies based on the satellite and dispenser mass, total amount of propellant, and sequence payloads are deployed. The system has >250 m/s capability but can be greater based on the payload deployment sequence.

Payload Interface Options

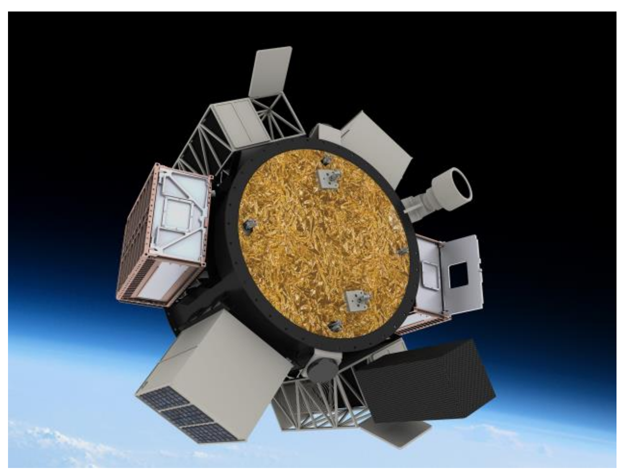

Figure 3: SL-OMV with 3U, 6U, and 12U Payloads

Many different payload configurations can be achieved by swapping dispensers. The overall structure has been designed to allow for various dispensers and separation systems without changing the core structure (see Figure 3). This includes the Planetary Systems Corp. (PSC) 6U dispenser[6] or 'skeletonized' designs like the Tyvak RailPods with extremely lightweight materials are used to optimize the payload carrying capability[8]. The system can accommodate other dispenser designs including circular or multi-point mounting systems.

The composite structure is capable of mounting a range of small satellite dispensers and adapters on top as well. On top of the ring, a payload can mount directly to the 24" diameter SL-OMV, or an adapter cone or plate can be used to mount a 11.8" or 15" Motorized Light Band (MLB).

SL-OMV SYSTEM DETAILS

The SL-OMV system is very similar to a small satellite, but with a much greater emphasis on low cost and low mass hardware, often derived from the growing expertise within the CubeSat community. The overall system must be cost competitive enough relative to the cost of dedicated launch vehicles and mass efficient due to the 200-400 kg to LEO capacity of the target launch vehicles all while being as reliable as the launch vehicle or more so.

C&DH and EPS Systems

The core technology to for this vehicle is based on Moog's extensive spacecraft avionics experience. A system typically used on larger and higher reliability spacecraft has been scaled to meet the mission requirements. This allows a solution with extensive heritage but to be in a form factor and cost range appropriate for this type of mission. Figure 4 shows a block diagram of the Integrated Avionics Unit (IAU) I/O. The IAU contains the Electric Power System (EPS) controls that performs all power conditioning and switching in addition to hosting the flight computer that performs all Command and Data Handling (C&DH) and Guidance Navigation and Control (GNC) aspects.

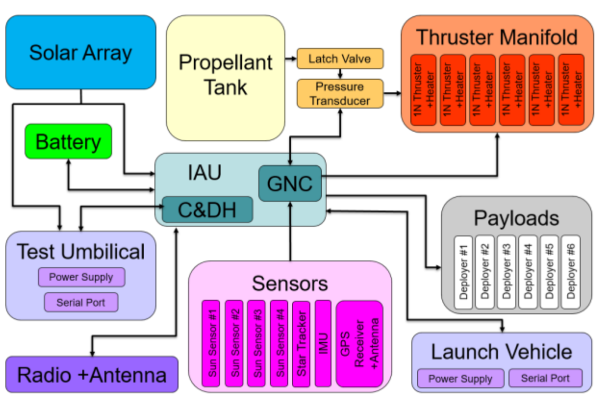

Figure 4: IAU I/O Block Diagram

Power

A further advantage of utilized small spacecraft avionics and sensors is the low power draw of the components. This feeds directly into the sizing of the solar array and the ability to fit it within the small area available on the top of the SL OMV. This fixed array simplifies the overall power system design by eliminating the need for deployment systems or actuators (see Figure 5). In the event a fixed array is not enough power for the required mission a deployable array option based on deployable CubeSat solar arrays is available.

The SL-OMV includes a battery that is sized to accommodate the operation of the SL-OMV and a small amount of heater power used to maintain the CubeSat temperatures. The battery is sized to provide enough energy to perform a typical transfer maneuver on battery power alone (e.g. 100 km orbit change). Upon completion of the burn, the SL OMV would orient itself sun-pointing and recharge the battery. This process can be repeated as needed for subsequent burns and maneuvers.

The avionics are designed to have very low power draw and the largest power draw during operation is that of the thrusters during the pre-heat and firing. This provides the largest power draw on the system and is accounted for as part of the burn planning to include recharge orbits as necessary

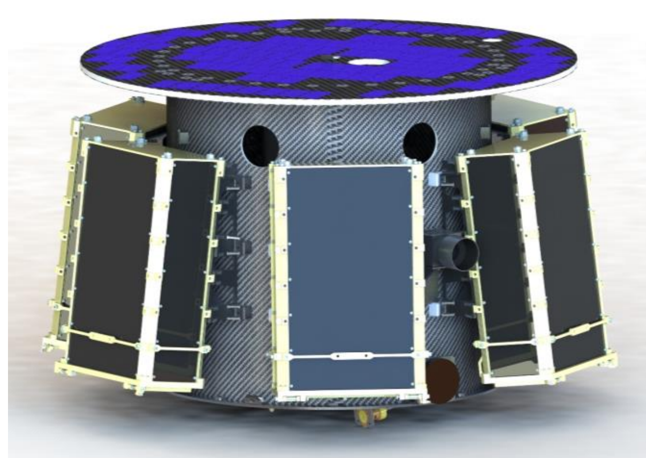

Figure 5: View of SL-OMV

Guidance, Navigation, and Control

The baseline SL-OMV GNC subsystem is designed for on-orbit maneuvering and payload deployments. The basic missions of this CubeSat tug can be completed with a minimally complex system consisting of thrusters, a star tracker, sun sensors, and an Inertial Measurement Unit (IMU).

For extended missions with fine pointing requirements, reaction wheels can be added and a second star tracker may be included depending on the agility required.

Structure

Moog is developing the composite cylinder structure that will support the SL-OMV payload elements and any additional payloads located on top of the adapter as required. The composite structure will leverage a previous Moog program which developed a composite dual-launch adapter for the Minotaur IV launch vehicles called CASPAR. Moog has also assessed using Additive Manufacturing as an option for rapid configuration changes.

Moog has engaged with various SLV providers and satellite users to understand the range of potential primary payload masses and launch vehicle environments. The structure will use traditional carbon fiber elements and manufacturing techniques, reducing development risk and costs. These structures are commonplace in space applications including many launch vehicle structures being made from similar materials. This reduces both the mass and perceived risk to SLV providers.

An additively manufactured variant using Titanium was developed and analyzed and was approximately 30%-40% heavier than the carbon fiber variant, but in absolute terms this was ~3 kg. The carbon fiber composite system provides other advantages such as a more stable thermal environment and micrometeorite protection and is manufactured more easily from existing capabilities. The additively manufactured variant may be applicable for passive adapter applications (similar to ESPA).

Propulsion

A major element of the SL-OMV is its on-board propulsion system. Moog is leveraging a flexible propulsion system designed to be compatible with Hydrazine but baselining the green propellant LMP-103S that has been successfully deployed on the Planet Skysat-C constellation. The ability to use a green propellant as part of the baseline design is a critical enabler to this particular system as many of the target launch vehicles will not include Hydrazine processing as part of their standard service. A simple blowdown system with six 1N engines are used to provide 3 Degrees of Freedom (3DOF) control (see Figure 6 and Figure 7).

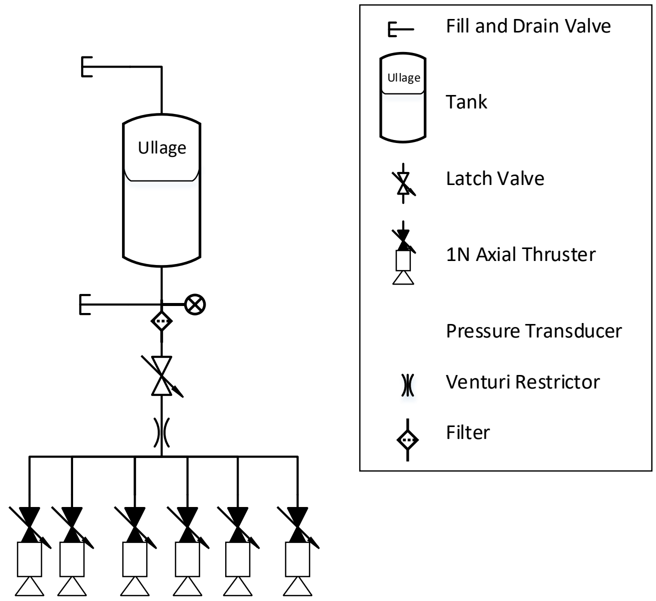

Figure 6. SL-OMV Propulsion System Schematic

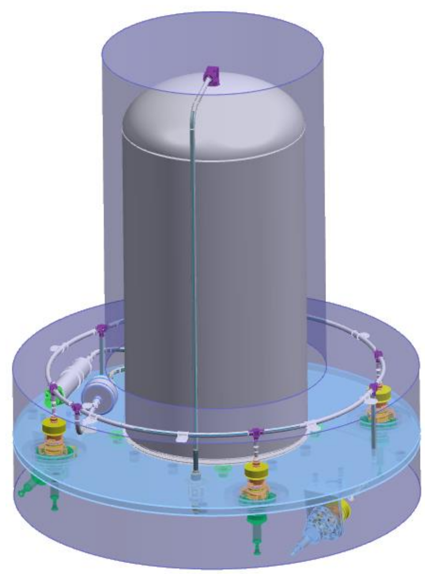

Figure 7. SL-OMV Propulsion System

Launch vehicle and spacecraft propulsion system containing hydrazine or other hazardous propellants require additional design, test, qualification, and operational considerations to ensure hardware and personnel safety. In many cases this drives costlier system designs. Green propellants allow for a "single-fault tolerant" designs that can reduce overall life cycle costs including reduced component count9, system testing, and lower cost manufacturing techniques such as flared tubing and mechanical fittings instead of all-welded systems that have 100% radiographic (X-Ray) inspection requirements for hypergolic systems[7].

System Integration and Test

The SL-OMV is designed to be modular to both aide in easy of assembly but also to accommodate module assembly at different locations. Due to the specialized nature of propulsion that module will be assembled and tested at a site that specializes in propulsion. The structure will be fabricated by a composite manufacturing site and shipped for integration and test. Avionics, GNC, separation system, CubeSat deployers, and power elements will be procured from existing sites and shipped separately. All of these will be integrated and tested in the final SL-OMV system (see Figure 8).

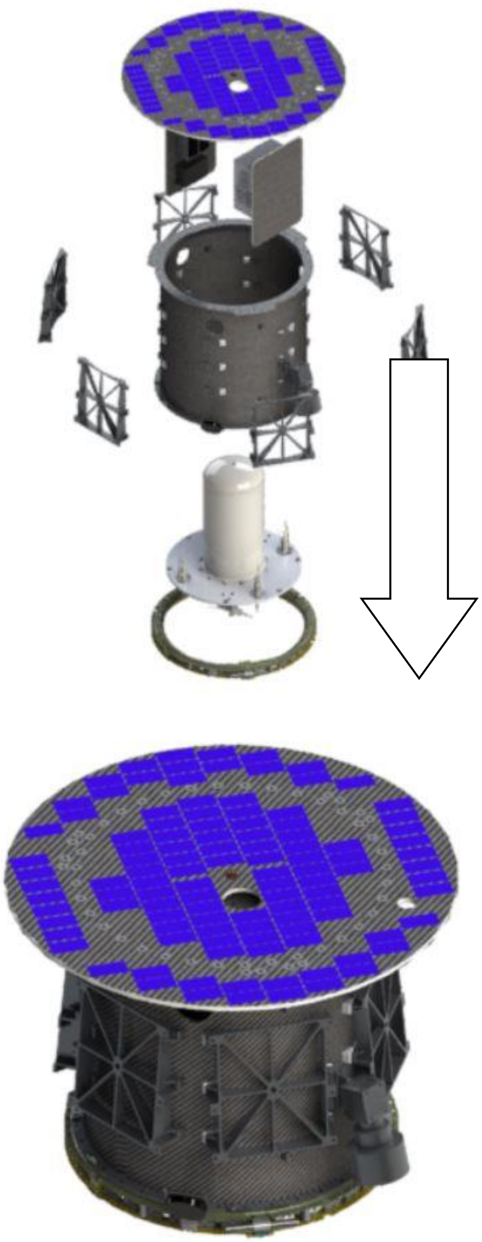

Figure 8. SL-OMV Integration Flow

SL-OMV AND FIRST LAUNCH FROM THE UK

Moog in partnership with Lockheed Martin and the UKSA, announced the first scheduled launch of its SL-OMV on July 17, 2018 as part of the UK Spaceflight Programme[10]. The SL-OMV's maiden voyage will launch in the early 2020s from the UK's first commercial spaceport at the Sutherland site in Melness, Scotland. Lockheed Martin, the prime contractor for UKSA's Spaceflight Programme, is the launch provider responsible for payload integration and launch service. The Moog operation in Reading, UK will perform final integration and test of the SL-OMV while leveraging the local supply chain. Figure 9 shows all of the Moog sites supporting this program.

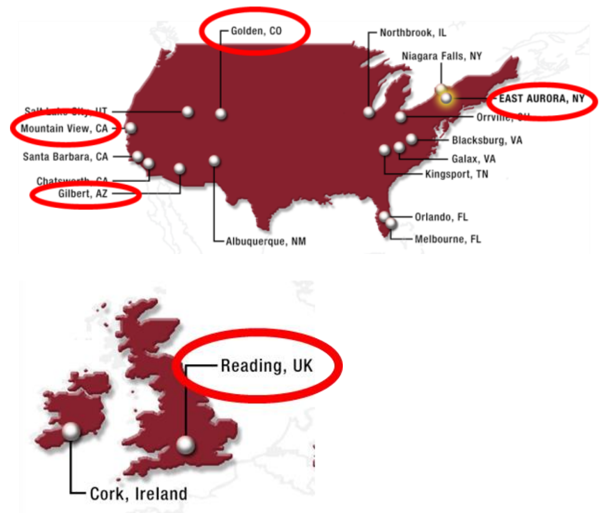

Figure 9. Moog Sites Supporting SL-OMV Program

The UKSA announced several other grants and initiatives related to launch including multiple other launch sites and launch vehicles[11]. The SL-OMV is designed to compatible with several launch vehicles including both horizontal and vertical launch. Currently the SL-OMV is capable of being launched on each of the options as part of this grant funding ensuring maximum utility of the SL-OMV.

Additionally the SL-OMV design is being assessed to maximize the supply chain and domestic capabilities from within the UK making this a truly indigenous capability that can support both UK and commercial missions. Several UK vendors have been selected to support this program including propulsion system integration and test at Nammo's Westcott propulsion facility; solar panel production from AAC Clyde Space in Glasgow, Scotland; battery production from ABSL in Abingdon; final integrated system level testing will be performed leveraging facilities in Harwell; and systems engineering support from KISPE located in

Farnborough. Additional vendors are currently being assessed and selected with a goal of an overall >50% program level support from the UK. Moog is currently nearly one year into the program schedule with a Critical Design Review (CDR) occurring in Summer 2019 and a flight readiness in Fall 2020.

CONCLUSIONS

The launch vehicle industry is slowly catching up to the evolving market of small satellites. SLVs are on the verge of providing regular access to space for spacecraft in the 200-400 kg class of vehicle. Rather than take a breath and wait years or even decades for the launch market to meet the specific needs of CubeSats, an interim solution can be created in parallel with the emerging SLV market. Moog's proposed solution, the SL-OMV, can enable on-orbit placement of large commercial and government constellations that have recently become financially viable due to the small satellite revolution.

The recent UKSA Spaceflight Programme grant funding will further accelerate this and make it possible for the SL OMV to be demonstrated in orbit having been launched from the UK. As the SL-OMV is compatible with multiple launch options that could originate from the UK there are several opportunities to leverage this innovative technology.

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