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XEUS: A POWERFUL PATH TO BEYOND LEO ACTIVITY

Melissa Sampson, Ph.D.
United Launch Alliance, Melissa.sampson@ulalaunch.com

Luke Farrell
Masten Space Systems, lfarrell@masten.aero

Khaki Rodway
Masten Space Systems, krodway@masten.aero

ABSTRACT

XEUS, the eXperimental Enhanced Upper Stage, fulfills a need for an affordable, large commercial lunar lander vital to creating a cis-lunar economy and developing recurring activities beyond LEO. XEUS enhances the Advanced Cryogenic Evolved Stage (ACES) with a mission kit to enable the stage to reach destinations beyond Low Earth Orbit (LEO) and function as a lander upon arrival. Several elements of the XEUS system are already under development. ACES provides a high mass fraction structural backbone, powerful avionics package, reliable main propulsion system, and other subsystems necessary to travel to the moon. A Masten Space Systems mission kit provides entry, descent, and landing (EDL) flight software, landing sensors, and distributed landing propulsion to achieve precision landings in challenging terrain. Most mission kit technologies build upon Masten's XL-1 lunar lander, which features extensible GNC flight software and 6 DOF simulator applicable to systems using multiple engines, different sensors, and different environments. This unique combination of hardware and technologies yields lower development cost, risk, and schedule. Additionally, the XEUS design infuses lessons learned from previous, conventional lander designs to provide an optimized lander system built to deliver large payload and cargo masses to the lunar surface, such as base infrastructure, large rovers, scientific payloads, and in-situ resource utilization production equipment. This means fewer launches from Earth are required to deliver payloads to lunar destinations, opening the door more quickly and at reduced cost to help build a self-sustaining cislunar economy. XEUS is an innovative solution to the ongoing challenge of creating affordable and reliable access beyond LEO.

INTRODUCTION

Moving beyond LEO in a sustainable manner is an important step to a self-sustaining space economy and has been a challenge for many years. Masten Space Systems and United Launch Alliance are developing XEUS, which will enable large cargo capacity to the Earth Moon L1 and lunar surface and cargo deliveries from the lunar surface back to L1 or GEO. XEUS is a mission kit, which complements ULA's ACES vehicle. The robust ACES subsystems will provide transport to the lunar vicinity and XEUS takes over from there. XEUS will rely on technology from Masten's XL-1 technologies for EDL, GNC and landing propulsion. Building on lessons learned from previous landers, previous technologies and previous hardware, XEUS will deliver large, commercial payloads to the Moon at a lower cost, jumpstarting the cislunar economy.

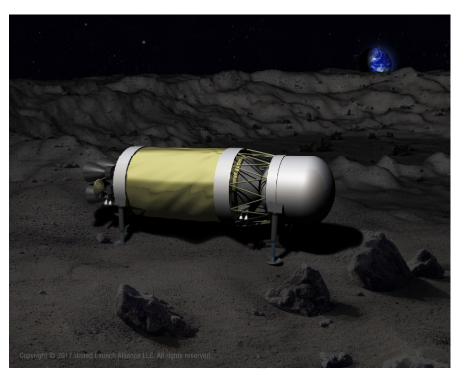

Exhibit 1. XEUS Concept

ULA ACES

ULA is developing the Advanced Cryogenic Evolved Stage (ACES) as the next step of launch vehicle evolution. ACES is a second stage based on Centaur, a high performance second stage. Centaur has an extensive flight history, successfully delivering commercial, NASA, government and national security payloads safely to space. ULA has delivered 117 missions, with 100% mission success, over the last ten years. ACES will continue the record of reliable and regular transportation, while increasing performance and decreasing cost.

XEUS attaches to ACES as a mission kit. ACES provides the structure and subsystems for the trip to EML1 or lunar landing. Main engine propulsion, avionics, cryogenic propellant management, and additional subsystems support the ACES/XEUS vehicle as it travels from Earth to the Moon. Compared to Centaur, ACES offers significant performance increases while keeping recurring cost low. With increased thrust and increased propellant capacity, ACES can perform longer duration missions, with multiple engine burns, enabling lunar missions. Long duration missions, such as XEUS, will require multi-layer insulation (MLI), advanced subsystems including Integrated Vehicle Fluids (IVF), and cryogenic propellant management. ACES has the potential to be refueled in space, allowing for even greater payloads to be delivered to the Moon. ULA is actively developing these technologies as part of ACES development, which will also benefit XEUS.

MASTEN HERITAGE VEHICLES

Masten's corporate inception began by winning the $1M Northrop Grumman NASA Centennial Lunar Lander Challenge XPrize with a vehicle and engines that demonstrated takeoff and landing flight, 180 second hover, translation, precision landing, and rapid turnaround with two flights in under two hours. Over the course of Masten's 13 year history, the company has designed, built, and flown 5 reusable vertical takeoff vertical lander vehicles with over 450 FAA-approved flights. Masten has transferred this knowledge and expertise into a Space Act Agreement with the NASA Lunar CATALYST project to design a next generation commercial robotic lunar lander called XL-1.

Masten's core concept leverages rapid testing and iterative design to advance the state of the art in precision landing, frequent ascent and descent, and EDL testbed technologies. Two fundamental principles drive the reliability and economy of Masten vehicle designs to date and have informed Masten's XL and XEUS vehicle family designs:

1. Design for multi-mission compatibility – Masten focuses on the development of core capabilities to maximize multi-mission compatibility and to broaden the appeal of its platforms and thereby establish and maintain commercial viability. Configuration optimization may be achieved on a mission-by-mission basis within defined parameters, but the fundamental lunar lander performance capabilities are driven by the philosophy that new and/or more capable technologies are available faster every day, and leveraging existing capabilities effectively can lower cost and decrease development time of a new vehicle.
2. Design for reusability – Masten recognizes that the reusability of lander spacecraft is not presently a market-driving concern. However, Masten's experience and emerging trends in the development of reusable launch vehicles have shown that price sensitivity is likely to ultimately lead to increased demand for reusability. By designing for ultimate reusability, Masten is positioned to take advantage of the simplicity, economy and reliability that are hallmarks of Masten lander designs and lay the foundation for future reusable lander operations.

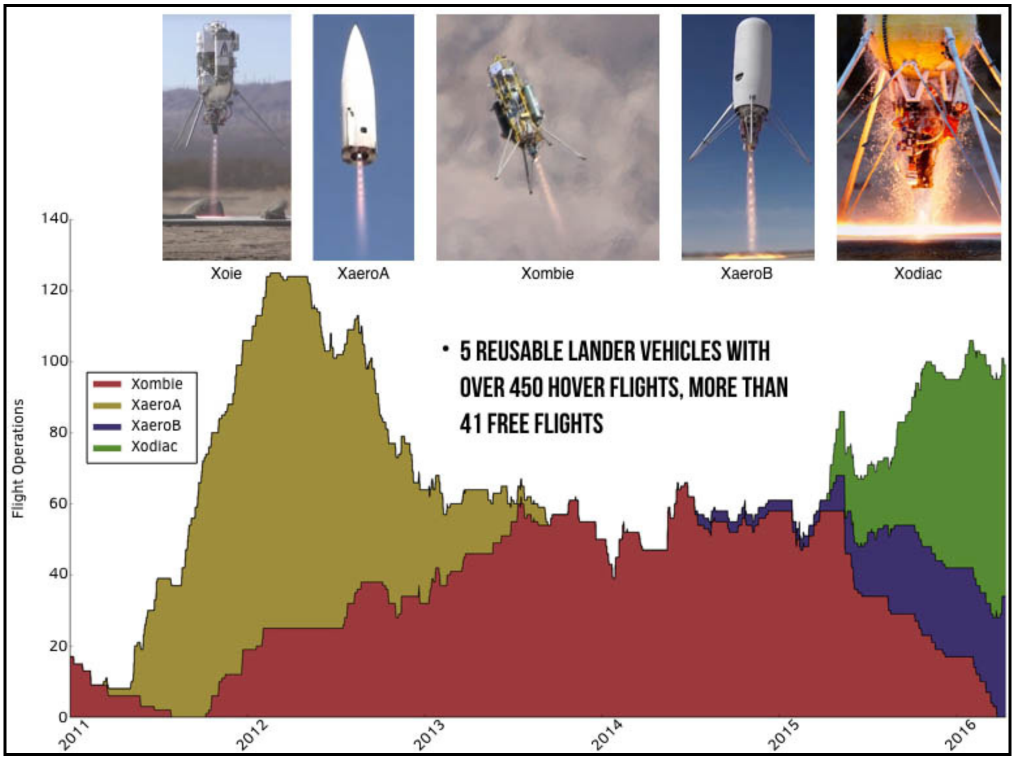

Exhibit 2. Frequency of Masten Rocket Operations Over Past 5 Years

METHODS

Masten has adopted a capability-driven methodology to vehicle design that enables broad mission profiles. This contrasts traditional mission-centered approaches where space vehicles are built from the ground up to perform specific tasks. The root of the Masten's approach is not a single mission a vehicle performs, but an envelope of capabilities. This has similarities to aircraft development--wherein an operational envelope is defined during design. This approach, when combined with Masten's long-standing rapid test philosophy, allows low-fidelity, low-complexity predictions to be qualified by actual flight data, rather than extensive analysis effort. Although not explicitly applied, this approach is also attributed to launch vehicles that are designed at their outset to provide a range of launch capabilities.

To further facilitate maturation of XEUS, Concept Maturity Levels (CML) have been integrated into Masten's design process--a construct for rapid maturation of vehicle concepts used by JPL's Innovation Foundry. This approach is meant to give better form to the pre-Phase A design process, i.e. prior to reaching preliminary design (PDR). Additionally it avoids advancing premature designs to inappropriate levels of detail, and provides a construct for understanding a system design space.

GNC & FLIGHT SOFTWARE

Masten has expanded its reusable launch vehicle GNC systems and software to enable multi-mission planetary landing capability. A model based development approach allows for rapid, low cost design while maintaining a rigorous systems engineering process, and is scalable to the design of spacecraft and lunar landers. Efforts are underway to port Masten legacy flight software to NASA's cFS architecture, enabling a high degree of modularity and portability between different hardware architectures and different missions. By reusing software components developed and maintained by NASA, Masten is leveraging the benefits of resource intensive, high reliability software development, while still maintaining low cost and short development timescales for specific vehicles and missions. This new architecture is being implemented for use on the XL-1 terrestrial demonstrator, and will be extended and reused on XEUS.

PAYLOAD, SCIENCE AND TRANSPORTATION OPPORTUNITIES

Future lunar exploration is open to multiple opportunities. Potential mission plans are looking at sample return, human habitation, and robotic excursions. One certain aspect of space transportation is the desire for humans to live and work in space. Customers will include governments, the science and research community, energy and mining industry, tourists, and in-space manufacturers. Anticipated XEUS payloads include surface instrumentation, human habitation modules, rovers and other surface lunar transports, in-situ resource extraction and infrastructure assembly equipment, and materials and supplies.

CONCLUSIONS

In conclusion, the XEUS concept delivers large, commercial, affordable, lunar payload capability. XEUS is designed for a low recurring cost by building on prior technologies at Masten and ULA. Creating a lunar lander with high payload capacity will enable lunar infrastructure and research to be created quicker. The sooner lunar access is regular, the sooner the cislunar economy will begin to thrive and move towards self-sustainment. The cislunar economy is not solely about lunar access, although the Moon is an important factor for propellant extraction and technology testing. XEUS will continue to be refined and the technologies matured. XEUS is a powerful path beyond LEO activity and development is moving quickly forward.

REFERENCES

[1]Carpenter, J.D., *et al.* "Scientific Preparations for Lunar Exploration with the European Lunar Lander," Planet.Space Sci. 74 (2012) 208 arXiv:1207.4965

[2]National Research Council, Division on Engineering and Physical Sciences, Space Studies Board, Committee on the Scientific Context for Exploration of the Moon, "The Scientific Context for Exploration of the Moon: Final Report," National Academies Press, Jul 3, 2007

[3]Zegler, F.; "Development Status of an Integrated Propulsion and Power System for Long Duration Cryogenic Flight", Space 2012, Pasadena, CA, AIAA-2012-5302, September 2012

NOMENCLATURE

ACES	=	Advanced Cryogenic Evolved Stage
CML	=	Concept Maturity Level
EDL	=	Entry, Descent and Landing
EML1	=	Earth/Moon Lagrange Points #1
GEO	=	Geosynchronous Orbit
GNC	=	Guidance, Navigation, Control
LEO	=	Low Earth Orbit
XEUS	=	eXperimental Enhanced Upper Stage
ULA	=	United Launch Alliance
6 DOF	=	Six Degree of Freedom