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# Toward a CisLunar Marketplace

**In the progression of the human economy, only one domain remains undeveloped: outer space. The high cost of reaching orbit has been an obvious hurdle, but another challenge is that goods and people must move efficiently from place to place once they are in space. United Launch Alliance, the joint venture of Boeing and Lockheed Martin, is addressing both problems through its CisLunar-1000 initiative. Michael Holguin of ULA shares an insider's account about progress to date.**

Creating an economy in the space between Earth and the moon's surface, called cis-lunar space, has always posed a chicken and egg dilemma. The cost of launching, building and operating orbiting facilities makes the business case difficult to close, but without being in business, it's difficult to lower costs and prove the business case. As a result, the great potential of space has sat idle on terra firma, despite the intriguing results of years of experiments aboard the International Space Station.

What's needed to set the space economy in motion is a basic commercial infrastructure, especially the ability to affordably launch and transport cargo among various locations. If this lynchpin can be created, the possibilities are myriad. Here are a few examples:

- Solar power might be beamed from space to remote locations on Earth to transform the energy industry with substantial benefits for humanity.

United Launch Alliance

▲ An artist's rendering depicts United Launch Alliance's Advanced Cryogenic Evolved Stage, ACES, transporting a module to a new orbit.

- Fiber optic cables and computer chips could be manufactured with properties better than anything reproducible here on Earth.
- Water in the form of ice could be harvested from the moon or asteroids to make it unnecessary to resupply propellants from Earth's deep gravity well, making the economy nearly self-sustaining. It's estimated that the lunar poles hold more than 90 billion metric tons of ice.

## Steady progress

It was with this in mind that in 2015 United Launch Alliance announced an initiative called CisLunar-1000 that envisions 1,000 men and women working and living in space in just 30 years, part of a self-sustaining space economy benefiting those on Earth. February was an important month for ULA and others involved in this effort. ULA hosted a workshop with participants from several sectors of the space, manufacturing and mining industries. This workshop established the construct of the CisLunar Marketplace, a forum in which contributors to current and future space development can discuss strategies to overcome the obstacles of expanding the space economy and sphere of human influence. We worked together to create the broad outlines of a road map for creating the necessary infrastructure. For example, the key milestones enabled by the development of reusable in-space transportation technology will pave the way for the following major CisLunar Marketplace epochs:

- Today to 2022: Foundations — Improved access to space and the first commercial habitat in low Earth orbit. Surveys of near Earth objects and exploration of the lunar poles.
- 2022 to 2027: The Tipping Point — Infrastructure development for a cislunar outpost to host orbital manufacturing facilities. Demonstration of orbital propellant refueling technology.
- 2027 to 2032: Space Industrial Revolution — Creation of space-based power generation infrastructure. Commercial crops on orbit. In-space resource utilization and space tourism beyond LEO.
- 2032 to 2037: Safeguarding Our World — Generation of clean, affordable energy via space solar power beyond 2 gigawatt capability. Large-scale in-space manufacturing.
- 2037 and Beyond: New Era of Exploration — Cislunar space as a stepping stone for propellant staging for Mars missions. Greater than 10 gigawatt space solar powered infrastructure. Mars mission staging node established in cislunar space.

This timeline was among the accomplishments at the Feb. 14 workshop attended by more than 60 entrepreneurs, investment bankers and others interested in building the infrastructure, which will include asteroid and lunar mining equipment, space habitats, space solar power systems and in-space transportation vehicles. NASA and U.S. Air Force participants described how the national interests would benefit from and become an anchor tenant for some of the CisLunar Marketplace, much like the current transition to commercial providers for secure communications and Earth observation. We divided up into cross-functional teams that addressed transportation, resources, habitats, space energy and manufacturing. These teams developed intercompany dependencies, such as the space habitats and manufacturing facilities that will be required in order to house crew and machines for on-orbit production of goods. The workshop also demonstrated a burgeoning need to get these business interests working together as a marketplace to overcome the technical and financial hurdles. The business case for the technology will need to be demonstrated, as well as the infrastructure for supporting the ongoing manufacture and return of goods from space. Much like the major industrial titans did in the days of the American industrial age, these entrepreneurs are determined to make the CisLunar Marketplace a reality. (Also: "Strategizing about Mars," Page 40.)

## A space superhighway

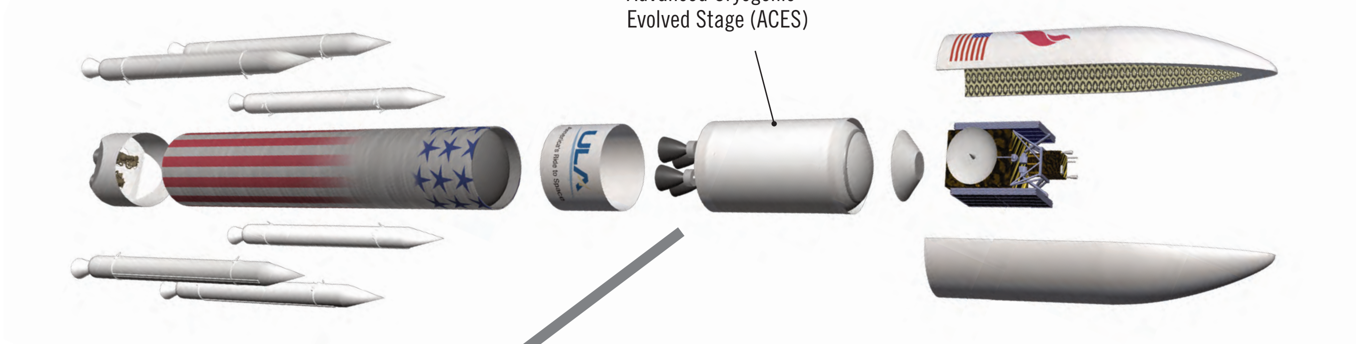
In the early 2000s, my colleagues and I, whose careers took us from the early Atlas and Titan programs at General Dynamics Space Systems to the Lockheed Martin Atlas 3 and 5 programs, and now ULA, began looking at the factors that were holding back space entrepreneurs. One was the lack of a reusable in-space, long-duration rocket stage that could move goods and people between orbits. There are numerous possible applications. Propellant could be carried from the lunar surface to a refueling location at a Lagrange point, one of the places in space where a spacecraft can remain while expending little fuel. Propellant could be carried to Earth orbit to refuel another stage that would boost a satellite to a new location. Resources could be brought to a manufacturing facility or goods could be moved to a staging location for return to Earth. To do those things, an ACES upper stage would need to remain ready for action over a span of weeks, months or years.

The long-duration requirement seemed like an unreachable goal when we looked at existing technologies. When delivering a satellite to orbit, an upper stage might need to operate for at most one to eight hours and conduct up to three main engine burns. Upper stage propellants, battery power and maneuvering capability, after all, are finite resources. Enter the ever-creative genius Frank Zegler, who patented an idea based on his experience with the Atlas rockets and their Centaur upper stages

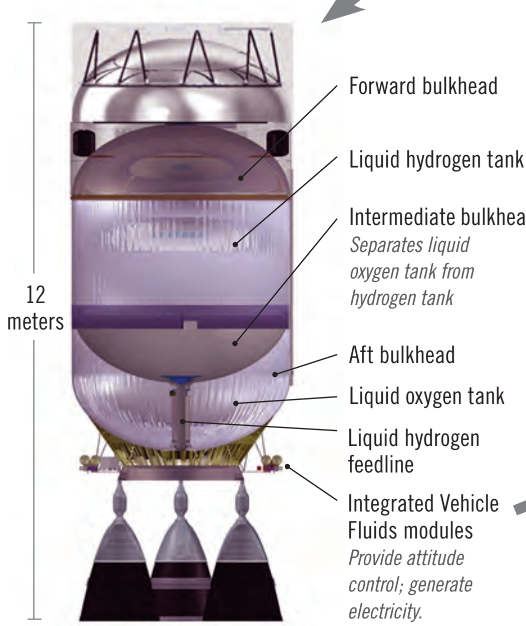
# Transportation for the space superhighway

Creating an economy in space will require transporting raw materials and finished products among orbits. United Launch Alliance wants its Advanced Cryogenic Evolved Stage, or ACES, to fill the role when it debuts in the 2020s.

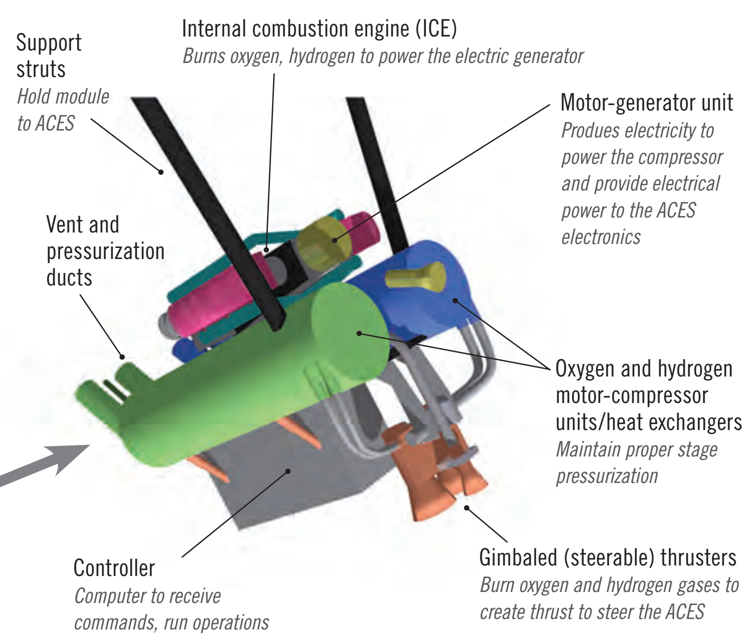
## VULCAN LAUNCH VEHICLE




## ADVANCED CRYOGENIC EVOLVED STAGE




## INTEGRATED VEHICLE FLUIDS MODULES




## Advanced Cryogenic Evolved Stage at a Glance

**Propellant capacity** 68,000 kilograms

**Engine Thrust** 222,000 to 534,000 newtons

**Engine options** One BE-3U; two or four RL10s; or two or three XCOR 8H21

**Notable** Three times greater propellant capacity than today's Centaurs. Tanks and intermediate bulkhead are stainless steel. External shell (not shown) relies almost exclusively on cylindrical shape and internal pressure to handle loads.

Source: ULA

In the future, dozens of these and other reusable stages could move goods and crew back and forth through cislunar space to enable the marketplace and serve as a potential staging point for expansion of commercial space beyond.

that propel massive satellites into orbit. If we could find a way to produce electricity from the propellants carried in the Centaur, we could devote that electricity to pressurizing the tanks, powering the stage's electronics and providing attitude control for maneuvering. His idea was to run an internal combustion engine off the hydrogen and oxygen gases in the ullage, or empty portion, of the Centaur's cryogenic tanks and use that to power a generator. This way, the stage could produce enough electricity to power itself, eliminating the need for batteries, along with other benefits. Power could be supplied to recirculate the ullage gases through a compressor and heat exchanger to add heat and energy to maintain the proper pressure in the stage. This would eliminate heavy and expensive helium bottles and plumbing. In addition, those same ullage gases could fuel small hydrogen/oxygen thrusters mounted on a steerable gimbal to eliminate the need for toxic hydrazine fuel and the required bottles and plumbing.

We decided to call this combination of components the Integrated Vehicle Fluids system, or IVF. Today, this technology is at the heart of our Advanced Cryogenic Evolved Stage, or ACES, now in development, and will be a successor to Centaur. Another key innovation for ACES was developed by my colleague Bernard Kutter through his years as a thermodynamics engineer. He worked to find passive insulation and other technological breakthroughs that would keep propellant boil-off inside the tanks to just enough for the internal combustion engine. Cryogenic propellants would last inside ACES for weeks.

ACES will open the door to creation of a space superhighway. Once in space, an ACES stage would be ready to move cargo among orbits and the moon's surface as long as propellant remained available. It could be refueled by tankers launched from Earth or propellant derived from water mined from asteroids or the moon. Dozens of these and other reusable stages could move goods and crew through cislunar space to enable the marketplace and serve as a potential staging point for expansion of commercial space beyond. Also, IVF's capacity to generate several thousand watts of power creates other opportunities. Habitats or on-orbit factories could depend on the upper stage for power generation, life support, experiments, production or other uses.

## Access to space

Just as important as the in-space operations will be the impact of ACES and IVF on space launch. Today, each of our Centaur stages requires a complex set of power, reaction control and pressurization subsystems to deliver satellites to orbit. Each of these subsystems is independent of the other and requires plumbing, control systems and power. By combining those functions in a single IVF module, the weight and complexity of the stage will be reduced and the aft end will be much cleaner. IVF brings the added benefit of reducing propellant boil-off by maintaining optimal pressurization of the cryogenic tanks. This boil-off would otherwise shorten upper stage life. IVF also will be modular, meaning it can be built and tested offline and integrated as a component onto the vehicle, simplifying stage build and test operations at the factory and launch site.

IVF will be a key enabling technology for our line of Vulcan ACES launch vehicles in development. During launch, ACES will fire high above the atmosphere, just as Centaur does. Because the IVF performs the function of the helium pressurization and reaction control and electrical power systems, the bottles, plumbing and associated hardware can be eliminated, allowing more performance to be allocated to lifting payload rather than upper stage support systems. We calculate Vulcan ACES will increase the performance capability of a single stick configuration launch vehicle with six solid strap-on motors significantly beyond our most powerful launcher, the Delta 4 Heavy, with its three side-by-side Common Booster Cores. A Vulcan ACES launch will cost a fraction of that for a Delta 4 Heavy launch. ACES will have three times the propellant capacity of Centaur and be able to fly up to four RL10s (or equivalent alternative engines) with the goal of producing ACES for roughly the cost of today's Centaur.

Vulcan ACES with IVF will exceed the requirements defined by the U.S. Air Force in the Evolved Expendable Launch Vehicle program that created today's versions of the Delta 4, Atlas 5 and Centaur. Early testing of the IVF combustion engine and compressor components show great potential for this technology infusion.

By bringing new launch and in-orbit transportation capabilities to bear, space entrepreneurs and others have greater access to space and infrastructure to extend the reaches of humankind in space and increase the security of our planet and population. ★


Michael Holguin
is United Launch Alliance's program manager for development of the Integrated Vehicle Fluids module and a member of the company's Advanced Programs team. Michael began his career at General Dynamics in the 1980s as a flight operations engineer for the Space Shuttle/Centaur program, and later managed 17 successful Atlas Centaur launches. He recently served as the Commercial Crew Program manager at ULA. He earned a Bachelor of Science degree in mechanical engineering from New Mexico State University in 1983, a Master of Business Administration from University of Phoenix in1996 and a telecommunications degree from University of Denver in 2001.