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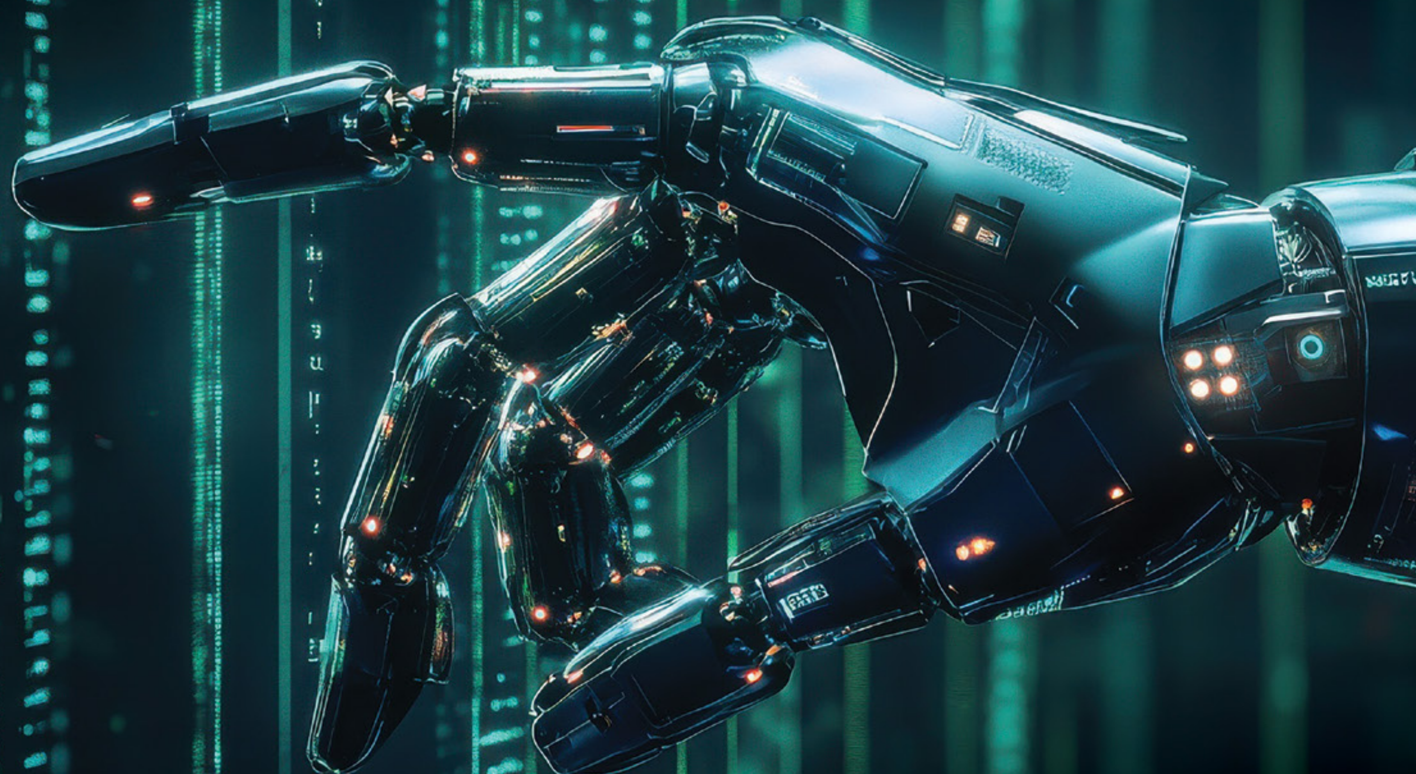

Storable Propellants Unlock Cislunar Success

Channeling Wave Energy for Advanced Ocean Monitoring

The cislunar domain offers unprecedented opportunities across science, commerce, and defense. It not only provides a gateway to deep space exploration, but also offers strategic defense value, supports advancements in science and technology, and paves the way for international collaboration.

Cislunar Space Exploration: Next Frontier for Propulsion Advancements

The race is on for leadership in cislunar space, considered a gateway to the future of space exploration. Yet operating in this domain introduces unique challenges for propulsion systems. In contrast to low Earth orbit (LEO), the cislunar environment requires higher precision propulsion solutions; these are necessary to enable rapid and accurate maneuvering of spacecraft and long-term sustainability. Propellants like hydrazine and nitrogen tetroxide offer the high energy density required for cislunar missions, but they must be handled very differently from the inert, non-reactive gases at play in LEO systems.

The good news is the space industry is hard at work on cislunar advancements. Focusing resources on compatible fluids and advanced valve systems, engineers are designing new ways to safely handle the unique demands of cislunar fuel storage, handling, and in-space refueling. As these technologies mature, missions in this domain of space between the Earth and Moon become more feasible, creating opportunities to harness its vast potential.

Cislunar Significance

Cislunar space is the region between Earth and the Moon. Here, an object's trajectory is affected by the gravity of both. This area has emerged as a hub for scientific discovery, commercial opportunities, and national security imperatives. The region offers a strategic vantage point for Earth observation, deep-space communication, and lunar exploration. Countries such as the United States, China, and India, alongside private space firms, are investing heavily in infrastructure to maintain a competitive edge.

Defense considerations extend the importance of the cislunar domain. In published discussions on national space strategy, the U.S. recognizes the need for robust infrastructure to maintain space superiority and protect vital assets. With cislunar space acting as the "First Island Off the Coast of Earth," as some defense analysts suggest, technological dominance in this region is critical. Notably, NASA's Artemis program and its associated payloads have accelerated interest in developing cislunar technologies, with initiatives like the Tipping Point program funding advancements in fluid storage and propulsion systems.

Storable Propellants Unlock Cislunar Success

In addressing the cislunar challenge, engineers face difficulties in handling "exotic" propellants like hydrazine and nitrogen tetroxide (compared to fluids used in LEO applications). These offer the high energy density required for cislunar missions but demand specialized materials and storage solutions to ensure safety and performance.

Cislunar space, encompassing the Moon and its surrounding region, has become pivotal to geopolitical, economic, and scientific competition among global powers, particularly the United States and China. This region's importance is driven by national interests, the discovery of lunar ice, and the economic potential of rare-earth minerals.

Cryogenic storage and material compatibility are also significant concerns. Components must withstand extreme temperatures and resist corrosion over extended periods. Traditional materials like aluminum and stainless steel are often insufficient for such applications, prompting the adoption of advanced alloys like Inconel, Monel, and ToughMet. Fluids must also remain stable for prolonged timeframes, ultimately without reliance on complex cryogenic cooling systems. These values enable spacecraft to handle longer missions anticipated for cislunar environments, where they may spend months or even years in orbit or on the lunar surface.

Creating a Safe, Sustainable Cislunar Infrastructure

Storable propellants used in cislunar applications are well-suited for integration with in-situ resource utilization (ISRU) technologies, where fuel can be manufactured from lunar or asteroid resources. This reduces dependence on Earth-based resupply, advancing the goal of sustainable and autonomous space exploration.

Missions involving lunar orbit, surface exploration, and gateway operations require the flexibility offered by storable propellants. These missions rely on in-space refueling, landers, and transfer vehicles. Missions involving crewed spacecraft also benefit; space vehicles can perform multiple burns or maneuvers without risk of fuel boil-off, which can occur with cryogenic propellants. Overall fuel stability and predictability minimizes risks associated with rapid cooling failures in cryogenic systems, ensuring safer operations during long-duration missions. Operations are more reliable for the long-term, better supporting orbit adjustments, descent, ascent, or abort scenarios. Propellant storage and handling infrastructure is simplified for a multitude of missions, reducing complexity and costs by avoiding reliance on cryogenic tanks, insulation, or active cooling systems.

Solving Cislunar Propulsion Design Challenges

An optimized approach to propulsion system development capitalizes on proven geometries, for example, applying them to new materials compatible with cislunar requirements. Ideally, existing designs made from traditional materials like aluminum and stainless steel can be adapted to alloys including Monel, Hastelloy, titanium, and Inconel. These materials are required for compatibility with the highly reactive storable propellants that power cislunar missions.

Extensive testing ensures these materials can withstand prolonged exposure to extreme conditions. This includes cryogenic testing, high-temperature simulations, and chemical compatibility experiments with reactive propellants. Partnering with organizations like NASA and universities to run empirical tests is essential for validating performance over time.

Computer simulations effectively model the behavior of materials and components under extreme temperatures, such as -420 °F. This provides the opportunity to evaluate changes in dimensions, sealing performance, and mechanical integrity due to thermal expansion or contraction.

Cislunar Strategy

Cislunar space is more than a stepping stone to the Moon; it is a proving ground for technologies that will shape the future of space exploration and defense. Combining legacy expertise and generational knowledge with forward-looking innovation, the engineering community is paving the way for reliable, sustainable operations in space. We've done it before — and today draw on the lessons of the 1960s space programs while integrating cutting-edge engineering and material science.

Both empirical and analytical validation play roles in cislunar success. Solutions must balance analytical simulations with real-world testing to validate material and system performance. For instance, storing components in harsh environments for extended periods helps assess corrosion, degradation, and long-term functionality.

Overall, engineers must recognize that deeper space applications, including cislunar missions, require higher propulsion efficiency. This is elevating the need to work with advanced propellants and develop robust engineering solutions to store and handle them safely and effectively.

Every mission brings unique challenges due to variations in fluids, storage times, and operational environments. Cislunar applications present a critical opportunity to refine designs and innovate in response to new and increasingly challenging mission-specific demands. As propulsion technologies evolve to meet these demands, they are unlocking opportunities that will define the future of space exploration.

Simultaneously, the resurgence of space as a strategic domain underscores the urgency of securing leadership in this new frontier. As countries vie for dominance in this new "space race," maintaining secure and sustainable access to cislunar space is essential for both economic prosperity and national security. For engineers, this requires a mindset on the future of rocket science, best served with heritage expertise at its core.

Storable propellants improve efficiency and scalability, enabling spacecraft and landers can remain on standby for future missions. For instance, vehicles can be pre-deployed to cislunar space or the lunar surface and remain operational when humans or cargo arrive later. Lunar ascent vehicles and landers can stay on the lunar surface for extended periods while waiting for the return journey. This capability is vital for sustained lunar exploration and for staging missions to deeper space destinations like Mars.

This article was written by Brian Ippolitto, Senior Director, Business Development of Space Business Unit, Marotta Controls, Inc. (Montville, NJ). **For more information, visit www.marotta.com.**