

ICESIP: Internal Combustion Engine Solar Independent Propulsion for Lunar Polar Exploration Rovers

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Abstract: The very idea that internal combustion engines (ICEs) could play a role in outer space exploration seems absurd. After all, there is no air available for combustion in outer space, and the thermal efficiency of ICEs is usually considered to be low. Nevertheless, United Launch Alliance (ULA) has recently announced the development of a 6 cylinder, “flathead” ICE to be used in its Centaur 3rd Stage. Its function is 3-fold: (1) rotary power will drive an electrical generator; (2) “waste” heat will be used to pressurize the liquid hydrogen (LH2) and liquid oxygen tanks (LO2); (3) the exhaust will be vented out a rocket nozzle to provide settling of the LH2/LO2 tanks. The total efficiency of the system is expected to approach 100%, and the mass savings is expected to be on the order of 1 tonne.

Another potential application of ICEs in outer space could be providing power for lunar polar exploration rovers (LPERs) designed to operate in permanently shadowed regions (PSRs) of the Moon. The Lunar PSRs are potentially the most resource-rich areas of the Moon. Evidence from the LCROSS mission estimated potential gold and silver electrostatic placer ores with concentrations measured in parts per thousand—if these results pan out, they could possibly close an economic case for commercial mining. In addition, many so-called anomalous craters have been identified by the Chandrayaan and LRO orbiters: these craters have high radar circular polarization ratios (CPRs) on their inside, but low CPRs outside of their crater rims. This pattern has been interpreted as representing relatively pure ice sheets with a minimum 2 meter thickness; such craters would have much higher water contents than the few percent reported by LCROSS.

However, exploring these craters represents a huge engineering challenge. For example, Whipple Crater (notable because it borders a relatively large plateau of permanent illumination) has 30° slopes. Such a crater could not be explored by a Resource Prospector Mission (RPM) LPER because such rovers can only handle slopes of 15° to 20°. Thus, to explore Whipple Crater, the LPER would have to land within the interior of the crater. Assuming this could be done, any solar panels would be useless. Therefore, a LPER would be required to carry with it all energy required for the mission. A plutonium powered LPER would be highly desirable, but such rovers are expensive, with costs measured in billions of USD. Hence the desirability of an affordable LPER that would not require a nuclear power plant.

To explore this possibility, we undertook preliminary engineering calculations based on the clean-sheet SonicFlow™ 2-cycle engine being developed by American Performance Technology. The advantages of this unique design are several: (1) zero oil consumption; (2) three times the power of similarly sized 4-stroke engines; (3) high power density (~170 W/cm³); (4) best in class torque output; (5) internal noise attenuation to reduce vibration; (6) 40% thermal efficiency. Our model assumed an RPM sized rover with a 30 kg mass budget for an ICE-electrical hybrid power plant, and an average 200 W power. Assuming 20% margin, after accounting for tankage, 12% boiloff of LH2, ~21 kg of LH2/LO2 could potentially power the LPER for up 6 days. In contrast, a battery-only LPER equipped with Tesla Roadster batteries would last perhaps 18-19 hours. Even if equipped with batteries having 2 MJ/kg specific energy, the battery-only LPER would last ~2.6 days. The ICESIP LPER also compared well to fuel-cell powered rovers.