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# Humans in the Loop

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## Editorial

Ever since Luna 1 rocketed out of Earth orbit for a planned encounter with the Moon in January 1959, the human race has sent a fleet of robotic spacecraft out to deep space on missions of exploration and discovery. For example, several precursor robotic spacecraft were sent by the USA to explore the Moon and help in the selection of suitable landing sites for the planned manned exploration of the moon by the Apollo Program. First deployed were the hard-impact Ranger probes that sent back images of the surface until their impact; next the Lunar Orbiter spacecraft provided detailed images to produce global lunar maps; finally, the soft-landing surveyor spacecraft investigated potential Apollo sites from the surface. It was only after these robotic missions were completed that the manned Apollo missions commenced, which successfully put several astronauts in lunar orbit and on the lunar surface. Although the outstanding accomplishment of the Apollo missions resulted in extraordinary returns in terms of scientific discoveries, no human has ventured beyond low earth orbit (LEO) since the program ended in 1972. All subsequent missions of science and exploration beyond the relative safety of LEO have been performed solely by robotic spacecraft. For decades, even before the Apollo program, there has been an ongoing debate about whether humans should venture into deep space or whether robots should only perform all such voyages. I believe that we will only be able to fully explore the solar system using both a human and a robotic presence. An examination of some recent robotic missions supports this belief.

In the early days of space exploration, nearly all spacecraft control, except the most basic housekeeping and state of health functions, was largely done using humans in mission control on the ground. Basic monitoring and the ability to go into preplanned "safe modes" were done automatically onboard the spacecraft, which was a necessity as the spacecraft ventured father away, and the communication lag times increased from seconds to hours. However, data analysis was still performed on the ground in mission control, and command loads were generated and sent to the spacecraft to tell it what it should do in the future. If an anomaly occurred that prevented the normal sequence of commands, it could cause a serious problem for the spacecraft and even jeopardize the mission. It was thus desirable to make the spacecraft as "smart" as possible, allowing it to perform most functions autonomously. This was facilitated by the incredible growth of computing power and miniaturization of electronics since the 1950s. Autonomous operations, where the routine operations were planned onboard the spacecraft instead of on the ground has been gaining ground since the 1990s. The first autonomous operations experiment was performed by the Clementine spacecraft when it did an autonomous mapping orbit of the Moon in 1994. This was followed shortly by the TAOS (Technology for Autonomous Operational Survivability) spacecraft the same year that did even more autonomous operations, and in 1998 by the Deep Space 1 mission, which did not only autonomous science operations, but also autonomous navigation and maneuvering. These achievements and many others since have led to the belief by some that we will soon have fully autonomous robotic spacecraft exploring the solar system and sending their analyzed data results and images back to Earth. There will not have to be a mission control monitoring and controlling these vehicles. In fact, they will provide a virtual presence that will preclude the necessity of humans to follow them out in space with the attending cost and danger. However, I believe that a couple recent missions have shown that we are a long way off from achieving fully autonomous space exploration.

Launched in 2007, Dawn orbited and imaged the minor-planet Vesta in 2011-2012. It then left Vesta on a three-year journey to the dwarf planet Ceres, which it began orbiting in March, 2015. The Dawn operations team overcame many formidable challenges to accomplish mission success. In particular, they rescued the spacecraft, which was single-fault tolerant, from a double fault in the attitude control system-the loss of two of four reaction wheels, after it left Vesta. This should have meant the failure of the mission to Ceres. However, the flight team undertook the most intensive engineering campaign of the mission to redesign the operations architecture for the remainder of the mission to save the Ceres science goals. Ultimately their plan accomplished all of the original mission objectives while not requiring further use of the reaction wheels. The Ceres mission was originally considered unachievable without reaction wheels, but the human element of this system was able to think outside of the box and come up with an unlikely, but successful new plan.

The other recent mission of space exploration that was saved by the human element was the spectacular flyby of Pluto by the New Horizons spacecraft in July, 2015. After the flyby of Jupiter in 2007, the spacecraft spent the majority of the next eight years in hibernation mode, during which it sent weekly beacon signals and monthly state-of-health checks. Once a year, New Horizons was awakened for a comprehensive checkout before being returned to hibernation. During this cruise period, the flight team planned for the one-shot flyby encounter with Pluto. This routine was rudely interrupted when just 10 days before the flyby, the flight team was presented with the time-critical challenge of a major spacecraft anomaly, which caused a loss of communication. This anomaly would have meant the failure of the mission. However, the flight and engineering teams could reestablish contact, determine the cause of the problem, and reconfigure the spacecraft flight system for the encounter. This complex response was designed and executed in less than three days, restoring the spacecraft’s ability to fully execute the encounter command load on schedule, with only four hours to spare. A small amount of pre-encounter science was lost because of the failure, but the flyby and post-flyby encounters were completely successful, and all of the science objectives were achieved. For their exceptional performance in saving this mission at the last moment, the New Horizons flight team was awarded the International Space Ops Organization’s Award for Outstanding Achievement in May, 2016.

Although we are making huge advances in artificial intelligence and autonomy, the human element is still essential to successful robotic space exploration. Onboard computers cannot for the foreseeable future replace the innovation, imagination, and insights of the human mind. This is especially true when a team of brilliant engineers, scientists, and technicians work together to overcome the complications created by completely unexpected anomalies and problems. Sometimes the spacecraft can or must rely on its own capabilities, but the direst situations usually require human creativity back on Earth to find a solution. Our true potential in space exploration will not be achieved unless these creative minds get out there and apply their abilities in person. Yes, there is a need for both humans and robots in space exploration.