

# Autonomy of NASA Missions

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## Abstract

*NASA increasingly relies on autonomous systems concepts, not only in the mission control centers on the ground, but also on spacecraft, on rovers and other assets on extraterrestrial bodies. Space missions lacking autonomy will be unable to achieve the full range of advanced mission objectives, given that human control under dynamic environmental conditions will not be feasible, due in part, to the unavoidably high signal propagation latency and constrained data rates of mission communications links. While autonomy cost-effectively supports mission goals, autonomy supports survivability of remote missions, especially when human tending is not feasible. As such, not only are Autonomous concepts but also Autonomy concepts required to be brought to bear on future space missions – self-governance and self-management.*

## 1. Introduction

With NASA's renewed commitment to outer space exploration, greater emphasis is being placed on both human and robotic exploration. Indeed, NASA has a new (as of 2004) initiative with that title – Human & Robotic. In reality, even when humans are involved in the exploration, human tending of assets becomes cost-prohibitive or is not feasible, and therefore increasingly in future missions, remote mission assets will need to work autonomously.

Moreover, much of the mission control on Earth will be performed with little or no human intervention. In addition, certain exploration missions will require spacecraft that will be capable of venturing where humans cannot be sent. Spacecraft that cannot be tended at all times by humans will be required to work autonomously.

Though autonomy will be critical for future missions, it will be necessary that these missions have autonomy properties. Autonomy alone, absent autonomy, will leave the spacecraft vulnerable to the harsh environment in which they have to work and most likely performance will degrade, or the spacecraft will be destroyed or will not be able to recover from faults. Ensuring that

exploration spacecraft have autonomy properties will increase the survivability and therefore the likelihood of success of these missions.

## 2. Autonomy and Autonomy in NASA Missions

**Autonomy:** Until the mid-1980s, all space missions were operated manually from ground control centers. The high costs of satellite operations prompted NASA and others to begin automating as many functions as possible. In our context, a system is autonomous if it can achieve its goals without human intervention (self-governance). A number of more-or-less automated ground systems exist today, but work continues towards the goal of reducing operations costs to even lower levels. Cost reductions can be achieved in a number of areas. Greater autonomy of satellite ground control and spacecraft operations are two such areas.

The goals of greater autonomy have been further complicated by NASA's plans to use constellations and swarms of nanosatellites for future science-data gathering, which are much more complicated, if not impossible, to manually operate compared to traditional single spacecraft missions. Spacecraft in swarms and constellations must communicate to coordinate and cooperate with each other. Radio or laser communications of constellation elements with each other or with ground control may suffer large propagation delays or complete outage (e.g., due to signal blockage) for extended periods of time.

**Autonomy:** NASA requires autonomy in its missions to ensure they can operate on their own to the maximum extent possible without human intervention or guidance. A case can be made that all of NASA's systems should be autonomous, and exhibit the four key properties of autonomy systems: self-configuring, self-optimizing, self-healing and self-protecting [1][2][3][4].

Self-configuration is needed in NASA missions because the nature of the mission may change as time goes on. New or different science may need to be analyzed based on data collected or if one science instrument fails or deteriorates, another onboard instrument may need to be used instead of or to help

adjust for the first's condition. Reconfiguring the spacecraft may also be necessary when batteries or solar cells are deteriorating.

Self-optimization is needed because the spacecraft, science instruments, and the science being collected may change during the mission, and the instruments may need to be adjusted or recalibrated. Also, the spacecraft could optimize its operations by learning more about the phenomenon it is observing and how or where to best view it. For constellations or swarms, vehicles will have to constantly adjust their positions due to drift, or optimize themselves when members are lost.

Self-healing is needed when a spacecraft is damaged, its software is corrupted, or a member of a swarm or constellation is lost. Examples of software self-healing would be when a spacecraft is hit by a large amount of radiation and the memory is damaged or altered. The spacecraft would have to recognize this and then request a new version from other spacecraft or mission operations. Self-healing in a swarm or constellation could include moving another spacecraft into the place of a lost one or requesting a replacement from Earth.

Self-protection is needed to keep the spacecraft out of harm's way. An example is when solar flares erupt. Solar flares release charged particles that can cause damage to electronics. In cases such as these, if a solar flare can be detected, the spacecraft can put itself into a sleep mode until it passes. Another example would be a rover on Mars. Large dust storms can cause damage to many systems. When a dust storm is sensed, the rover could cover itself or go to a better protected area, such as a rock outcropping or other sheltered area.

**The need for both::** The best possible situation for NASA would be to launch a spacecraft with its mission specified in terms of high level policies and then simply receive science data from it with no low-level in-flight directions, corrections or recoding - a utopian vision. To reach for this vision of operations, NASA needs its missions to be both autonomous and autonomic. Autonomy alone does not guarantee autonomic properties. Autonomous systems can operate independently but do not necessarily have self-configuring, optimizing, healing and protecting properties of autonomic systems.

Combining autonomy with autonomicity will require a new set of requirements and verification procedures above and beyond what is currently available. NASA currently has no truly autonomous or autonomic missions. Requirements will have to be developed that reflect these types of missions. This would also be true for verification of autonomous and autonomic systems [5]. New verification procedures need to be developed, either through direct verification, or through simulation if direct verification would damage the system. Since these systems will be intelligent, new methods will have to be developed that can guarantee correct operation.

### 3. Conclusion

The research briefly summarized here investigates the need for autonomy and autonomicity in future NASA missions. Further reading may be found on, for instance, the autonomic properties of two multi-agent systems developed at NASA Goddard Space Flight Center (GSFC) and a concept mission that is currently planned to launch in the 2020 to 2030 time frame in [6][7][8].

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