Advancing Autonomous Flight Management Capabilities for Spaceflight Vehicles

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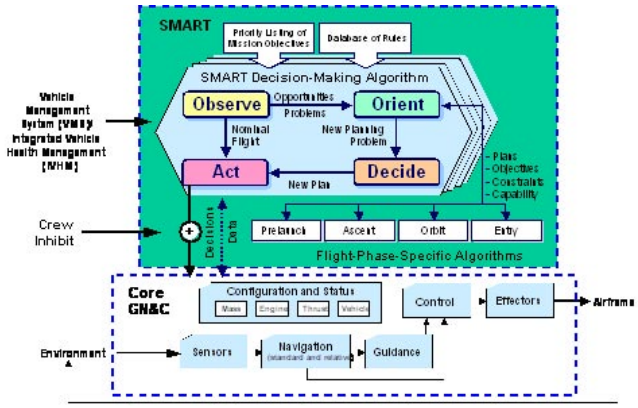
Successful execution of the exploration missions will require extensive use of autonomous systems for critical functions that are traditionally the responsibility of ground-based flight controllers. Increased time delay and potential loss of signal in communications with Mars or lunar spacecraft make the current flight management model anachronistic for the Constellation Program. In addition, NASA's current vehicles rely on guidance, navigation, and control (GN&C) flight software that lacks self-reconfiguration capability and is heavily dependent on prelaunch configuration and processing. As a result, the prelaunch flight products and limited onboard algorithms bound the real-time performance capability of the vehicle. NASA is trying to address these issues by evolving functions such as real-time monitoring, option evaluation, and decision making from the ground-based flight management model to an approach that balances both ground vs. onboard authority and human vs. computer authority.

An onboard autonomous flight management (AFM) system is comprised of flight mechanics functions that execute the autonomous and automated decision-making process and command the vehicle GN&C system to perform the appropriate actions. For example, the AFM system will monitor a docking at Mars and execute an abort if it determines that a failure has occurred that is beyond the GN&C system's ability to resolve. The system is also designed to perform its functions independent of, or in conjunction with, the ground-based flight controllers or onboard crew.



Flowchart shows the functioning of SMART.

We initiated the Spacecraft Mission Assessment and Replanning Tool (SMART) Project to develop a cost-effective real-time AFM system that reduces the reliance on prelaunch configuration and processing, increases vehicle performance, and improves safety for future human-rated spaceflight vehicles. The SMART Project followed a methodical development process of defining a set of attainable AFM system requirements, determining the design-to level of automation and autonomy using the function-specific level of automation and autonomy tool, and then developing a prototype as a capability demonstration testbed and cost/benefit assessment tool. The team of engineers from the Engineering Directorate and the Mission Operations Directorate developed the SMART AFM concept shown in the figure below. The separation between the SMART domain and the core GN&C domain is clearly delineated. The GN&C system continues to perform its primary functions; namely, determining current state, executing the mission plan, and controlling the vehicle to account for dispersions. SMART serves as the decision-making layer for the flight management aspects of the vehicle. The crew and the ground-based flight controllers can inhibit and/or override certain commands that SMART generates, and, if necessary, will provide the system with new data or decision alternatives.

The SMART Project was successful in developing a concept-based Phase 1 prototype as shown in the figure. This SMART prototype demonstrated the capability to monitor, predict, and evaluate the ascent trajectory, including abort options, of

the expendable launch vehicle (ELV) with an Apollo-based capsule. It was also able to show that an AFM system can retarget the guidance due to a catastrophic ELV failure and provide the predicted range/crossrange capability for the capsule after the abort. The initial prototyping effort has proven that a hierarchical decision-making architecture with predictive algorithms can provide significant benefit for time-critical decisions such as ascent aborts.

The SMART Project has provided an important first step towards the development of an AFM system for future spaceflight vehicles. The prototype was successful in demonstrating the capabilities and benefits of an AFM system, thereby providing an infrastructure to evaluate additional AFM capabilities and a means by which to test proposed requirements.