

## A Vehicle Management End-to-End Testing and Analysis Platform for Validation of Mission and Fault Management Algorithms to Reduce Risk for NASA's Space Launch System

The engineering development of the new Space Launch System (SLS) launch vehicle requires cross discipline teams with extensive knowledge of launch vehicle subsystems, information theory, and autonomous algorithms dealing with all operations from pre-launch through on orbit operations. The characteristics of these spacecraft systems must be matched with the autonomous algorithm monitoring and mitigation capabilities for accurate control and response to abnormal conditions throughout all vehicle mission flight phases, including precipitating safing actions and crew aborts. This presents a large and complex system engineering challenge, which is being addressed in part by focusing on the specific subsystems involved in the handling of off-nominal mission and fault tolerance with response management. Using traditional model based system and software engineering design principles from the Unified Modeling Language (UML) and Systems Modeling Language (SysML), the Mission and Fault Management (M&FM) algorithms for the vehicle are crafted and vetted in specialized Integrated Development Teams (IDTs) composed of multiple development disciplines such as Systems Engineering (SE), Flight Software (FSW), Safety and Mission Assurance (S&MA) and the major subsystems and vehicle elements such as Main Propulsion Systems (MPS), boosters, avionics, Guidance, Navigation, and Control (GNC), Thrust Vector Control (TVC), and liquid engines. These model based algorithms and their development lifecycle from inception through Flight Software certification are an important focus of this development effort to further insure reliable detection and response to off-nominal vehicle states during all phases of vehicle operation from pre-launch through end of flight.

NASA formed a dedicated M&FM team for addressing fault management early in the development lifecycle for the SLS initiative. As part of the development of the M&FM capabilities, this team has developed a dedicated testbed that integrates specific M&FM algorithms, specialized nominal and off-nominal test cases, and vendor-supplied physics-based launch vehicle subsystem models. Additionally, the team has developed processes for implementing and validating these algorithms for concept validation and risk reduction for the SLS program. The flexibility of the Vehicle Management End-to-end Testbed (VMET) enables thorough testing of the M&FM algorithms by providing configurable suites of both nominal and off-nominal test cases to validate the developed algorithms utilizing actual subsystem models such as MPS. The intent of VMET is to validate the M&FM algorithms and substantiate them with performance baselines for each of the target vehicle subsystems in an independent platform exterior to the flight software development infrastructure and its related testing entities.

In any software development process there is inherent risk in the interpretation and implementation of concepts into software through requirements and test cases into flight software compounded with potential human errors throughout the development lifecycle. Risk reduction is addressed by the M&FM analysis group working with other organizations such as S&MA, Structures and Environments, GNC, Orion, the Crew Office, Flight Operations, and Ground Operations by assessing performance of the M&FM algorithms in terms of their ability to reduce Loss of Mission and Loss of Crew probabilities. In addition, through state machine and diagnostic modeling, analysis efforts investigate a broader suite of failure effects and associated detection and responses that can be tested in VMET to ensure that failures can be detected, and confirm that responses do not create additional risks or cause undesired states through interactive dynamic effects with other algorithms and systems. VMET further contributes to risk reduction by prototyping and exercising

the M&FM algorithms early in their implementation and without any inherent hindrances such as meeting FSW processor scheduling constraints due to their target platform - ARINC 653 partitioned OS, resource limitations, and other factors related to integration with other subsystems not directly involved with M&FM such as telemetry packing and processing. The baseline plan for use of VMET encompasses testing the original M&FM algorithms coded in the same C++ language and state machine architectural concepts as that used by Flight Software. This enables the development of performance standards and test cases to characterize the M&FM algorithms and sets a benchmark from which to measure the effectiveness of M&FM algorithms performance in the FSW development and test processes.