Modeling in the Stateflow® Environment to Support Launch Vehicle Verification Testing for Mission and Fault Management Algorithms in the NASA Space Launch System

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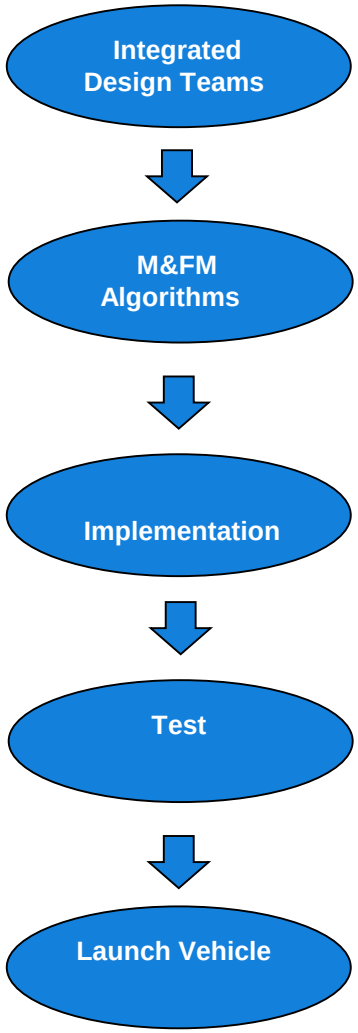
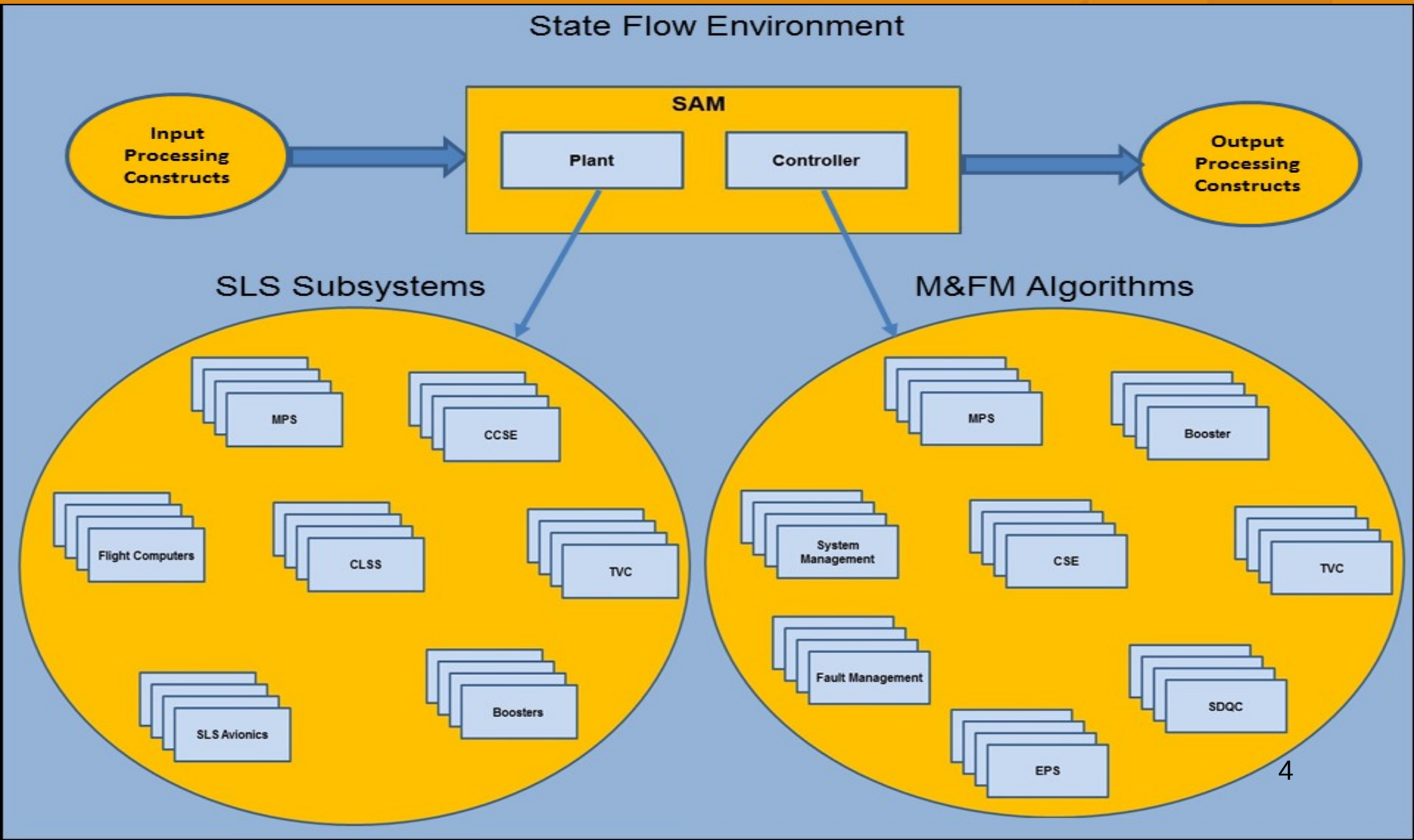
Mission & Fault Management - SLS

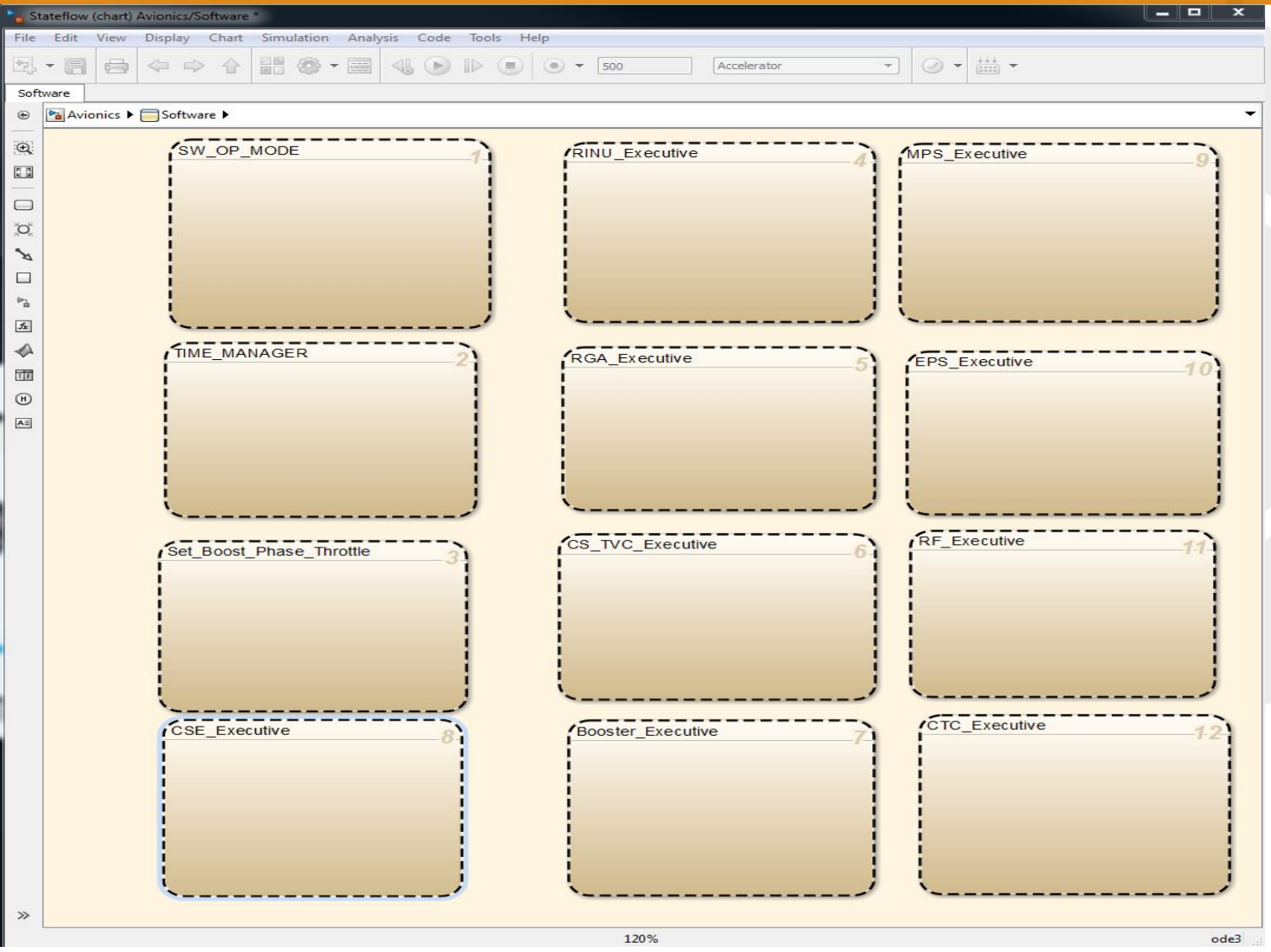


- Fault Management Software
  - Error Prone
  - Requirements and Design Phase
  - Other Factors
- Model Based Systems Engineering
  - Rich graphical constructs
  - Deterministic
  - Standards
- Previous NASA Stateflow ® Applications
  - LADEE
  - Ares – Orion Command Abort
  - NESC – Toyota, Commercial Spacecraft

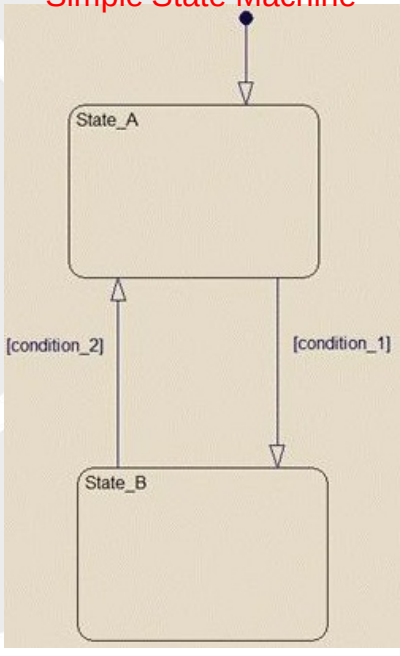
State Analysis Model (SAM)



MATLAB Stateflow

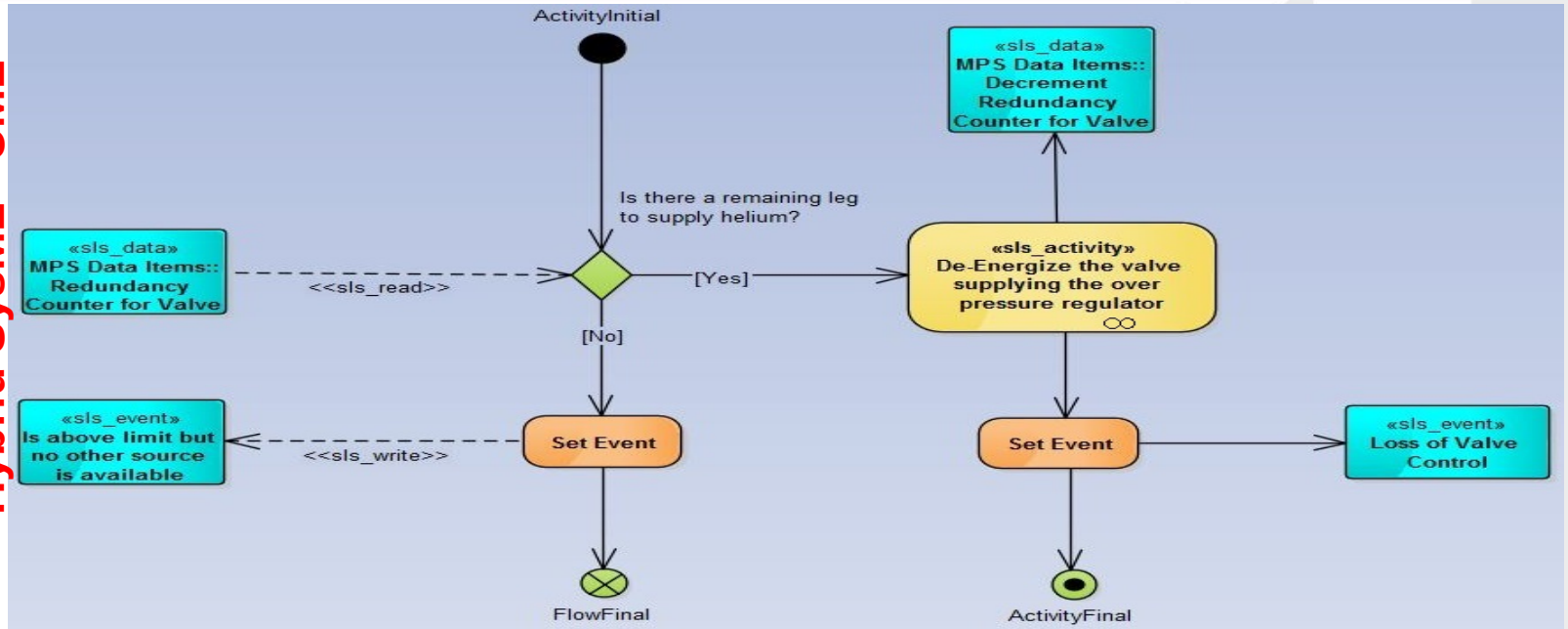


Simple State Machine

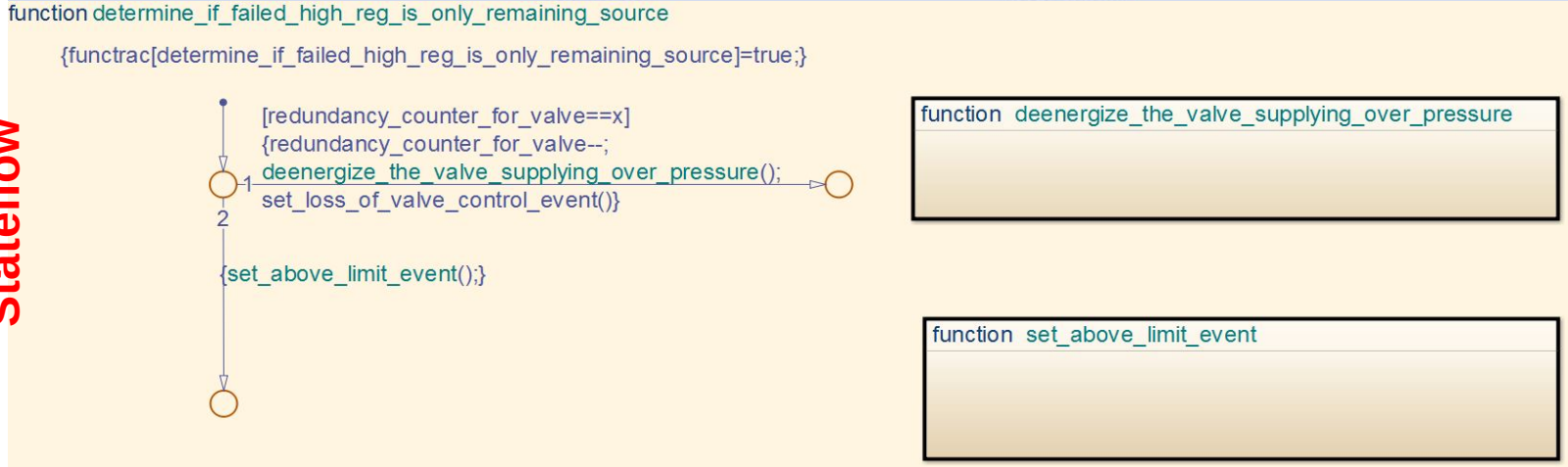


UML Modeling and Stateflow for M&FM

Hybrid SysML - UML



Stateflow



SAM Testing

- Script Driven → Ground Operations Timeline →
- Nominal Sequence Generator → Fault Generator
- Rule Checker → Analysis Report Generator → Timeline & State Report scripts → SAM Test Report

State Flow Env.

- User GUI
- Test Cases: Nominal, Off-Nominal, VMET, MCaRT, SIL
- TRAC Trouble Ticket System Summaries

User GUI

SAM_execute

Scenario | Scenario Builder | History

Command

failure_bus[redacted]_HIGH_CURRENT=true[[redacted]]

v ^

Selected Scenario

failure_bus[redacted]_HIGH_CURRENT=true[[redacted]2]

Halt/No Halt

LAUNCH HALT

M&FM EVENTS

EVT_[redacted]_GoFor[redacted]_CMD_Received At time MET =
[redacted]_AUTO_LAUNCH_SEQUENCE At time MET = -[redacted]
EVT_EPS_[redacted]_1553_COMM At time MET =
EVT_[redacted]_1553_COMM At time MET =
EVT_[redacted]_1553_COMM At time MET =
EVT_EPS_[redacted]_1553_COMM At time MET =
EVT_MPS_[redacted]_1_LOSS_OF_FUNCTION At time MET = -[redacted]
EVT_MPS_[redacted]_LOSS_OF_FUNCTION At time MET = -[redacted]
EVT_[redacted]_Engine_Fail At time MET = -[redacted]
EVT_[redacted]_Launch_Halt At time MET = -[redacted]4
EVT_[redacted]_Launch_Halt At time MET = -[redacted]
EVT_[redacted]_Launch_Halt At time MET = -[redacted]
EVT_[redacted]_Launch_Halt At time MET = -[redacted]
[redacted]_PAD_SAFING At time MET = -[redacted]
EVT_[redacted]_Loss_of_[redacted] At time MET = -[redacted]
EVT_[redacted]_Launch_Halt At time MET = -[redacted]
EVT_[redacted]_LOSS_OF_COMM_[redacted] At time MET = -[redacted]
EVT_[redacted]_Loss_of_Comm At time MET = [redacted]
EVT_[redacted]_LOSS_OF_COMM_WITH_[redacted] At time MET = -[redacted]
EVT_[redacted]_LOSS_OF_COMM_WITH_[redacted] At time MET = -[redacted]
EVT_[redacted]_Pad_Safing_Complete At time MET = -[redacted]
EVT_[redacted]_CMD_Received At time MET =

MISSING NOMINAL EVENTS

EVT_[redacted]_Start_Enable_Command_Sent
EVT_[redacted]_Overboard_Bleed_Valve_is_closed
EVT_[redacted]_Overboard_Bleed_Valve_is_closed
EVT_[redacted]_Overboard_Bleed_Valve_is_closed
EVT_[redacted]_Overboard_Bleed_Valve_is_closed
EVT_[redacted]_Overboard_Bleed_Valve_is_closed
EVT_[redacted]_[redacted]_COMMANDED
[redacted]_CORE_STAGE_BOOSTER_FLIGHT
EVT_[redacted]_CSE_THROTTLE_[redacted]
EVT_[redacted]_CSE_THROTTLE_[redacted]
[redacted]_CORE_STAGE_FLIGHT
EVT_[redacted]_STAGE3_[redacted]
EVT_[redacted]_Shutdown_Sequence_[redacted]
[redacted]CORE_STAGE_[redacted]
EVT_[redacted]_All_Shutdown
EVT_[redacted]_Shutdown
EVT_[redacted]_Prevalve_Close_Indicating_Closed
EVT_[redacted]_Prevalve_Close_Indicating_Closed
EVT_[redacted]_Prevalve_Close_Indicating_Closed
EVT_[redacted]_Prevalve_Close_Indicating_Closed
EVT_[redacted]_Prevalve_Close_Indicating_Closed
EVT_[redacted]_Prevalve_Close_Indicating_Closed

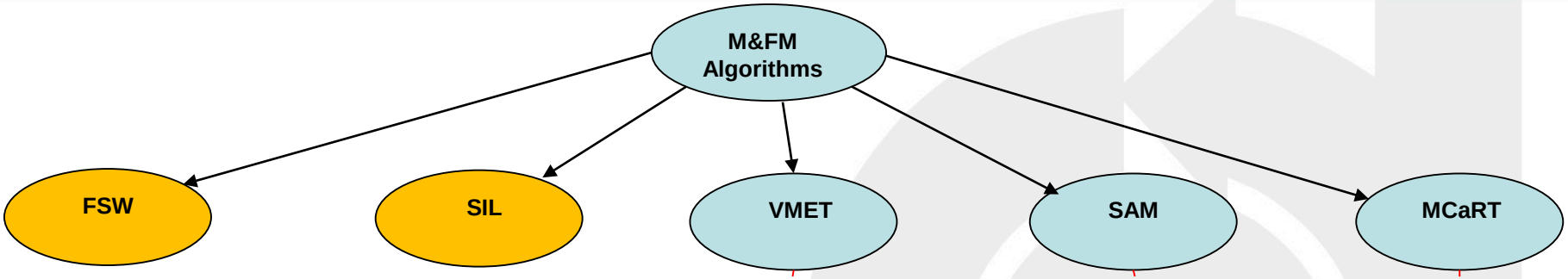
RULE VIOLATIONS

OPS: Engine [redacted] Commanded Open without failsafe [redacted] will no

UNEXPECTED EVENTS

EVT_[redacted]_LOSS_OF_FUNCTION
EVT_[redacted]_LOSS_OF_FUNCTION
EVT_[redacted]_Engine_Fail
EVT_[redacted]_Launch_Halt
EVT_[redacted]_Launch_Halt
EVT_[redacted]_Launch_Halt
EVT_[redacted]_Launch_Halt
[redacted]_PAD_SAFING
EVT_[redacted]_Loss_of_[redacted]
EVT_[redacted]_Launch_Halt
EVT_[redacted]_LOSS_OF_COMM_[redacted]
EVT_[redacted]_Loss_of_Comm
EVT_[redacted]_LOSS_OF_COMM_WITH_[redacted]
EVT_[redacted]_LOSS_OF_COMM_WITH_[redacted]
EVT_[redacted]_Pad_Safing_Complete

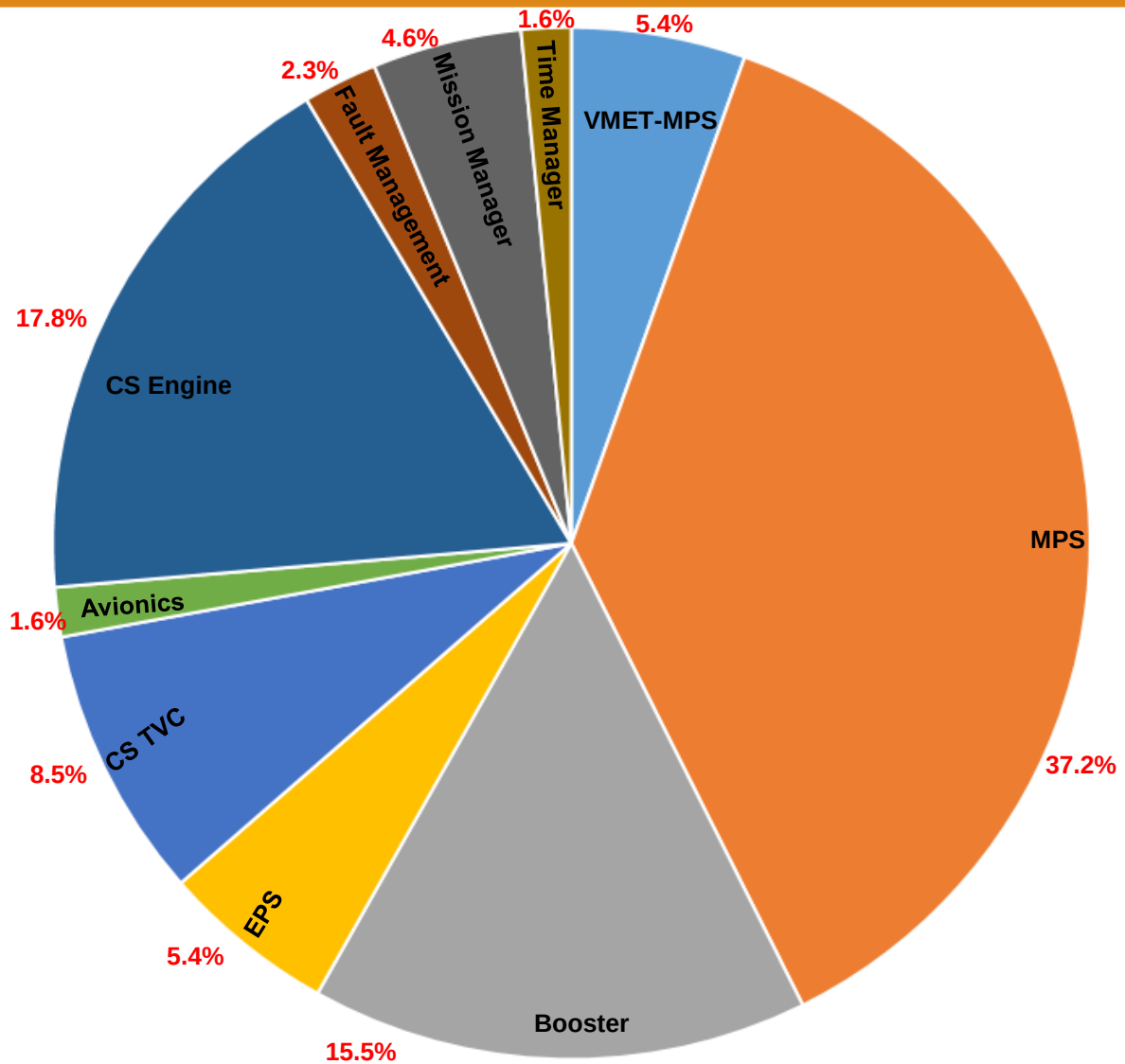
VMET, MCaRT, SIL Test Cases for the SAM



Test Case ID	Test Objective	Success Criteria	Duration / Fault Injection
MPS_Helium[redacted]	Test failure of helium isolation valve[redacted]	"EVT_[redacted]_HeliumValve[redacted]_Redundancy_Reduced" becomes "True" at Mission_Elapsed_Time = -[redacted] sec "EVT_[redacted]_Halt" becomes "True at Mission_Elapsed_Time = -[redacted] sec	Test duration is from Mission Elapsed Time = -[redacted] sec to -[redacted] sec Fault injected at Mission Elapsed Time = -[redacted] sec by setting Helium[redacted]_Energy =[redacted] & detected[redacted] cycles later at -[redacted] sec and [redacted] Halt set at Autonomous_Launch_Sequence at -[redacted] sec

Element	System	Response	Monitored Condition Name	Monitored Condition Description	Start Monitoring	Stop Monitoring	Units	Lower Trigger Limit (TBD)	Upper Trigger Limit (TBD)	Number of Indicators Needed to Generate Response
Booster	Igniter	Safing	Dual Boosters Ignition Failure	Both Boosters fail to ignite after T-[redacted] is reached	T+[redacted] msec	T+[redacted] msec	psia	[redacted]	[redacted]	2 of 2

Findings: VMET & SAM



MCaRT & SIL

19% of MCaRT entries tested
85.5% passed

45% of SIL test cases executed
27% passed

Finding Types

Logic Interpretation	30%
Editorials	55%
Logic Update	15%

SAM Forward Directions / Summaries

- Interactive Failures
- Prelaunch procedures → OMRs → LCCs → Rule Checker
- Hazardous State Identification
- Post Flight Analysis
- Other: EUS, crew habitat, payloads, proximity ops, rovers, robotic deep space missions, EDL ops
- MBE → M&FM Algorithms → FSW → Testing
- Challenges
- Questions

AIAA

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