AUTONOMOUS OPERATIONS MISSION DEVELOPMENT SUITE

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• Motivation
• ISHM-AC: Development and Applications
• AOS: Development and Application
• AO MDS
  • Development
  • Application
  • Class B Safety Critical Certification Path
• Potential Use
• Conclusions
INTEGRATED SYSTEM FOR HEALTH MANAGEMENT AND AUTONOMOUS CONTROL (ISHM-AC)
APPLICATION:
SIMULATED PROPELLANT LOADING SYSTEM (SPLS)

- Propellant Transfer Lines
- Storage Tank
- Simulated Vehicle
- Instrumentation
- Data Acquisition
- Command and Control System
- Simulator
- Verification and Validation
- Certified
- Technology Testing Platform
SOFTWARE ARCHITECTURE

- Application
- Knowledge Base
- Modeling
- Automated Control
- Monitoring
- User Interface
- External I/O
- Autonomous Control
- External Simulator
APPLICATION DEVELOPMENT SYSTEM – CONTROL MAP
APPLICATION DEVELOPMENT SYSTEM – OPERATOR USER INTERFACE

- Plan Execution
- Redline Monitoring
- Console Message
- Timers
AUTONOMOUS OPERATIONS - NOMINAL

• Nominal scripted plan executed
• Redline monitoring evaluation
• Sensor Model Determining Health
• Domain Map contains application knowledge
• Autonomous Engine identifying sensors
AUTONOMOUS – OFF-NOMINAL

- Autonomous Engine
  - Executes mitigation actions
- Nominal scripted plan executed = Mitigated or Aborted
- Redline monitoring evaluation = Mitigated or Aborted
- Sensor Model Determining Health
TEST RESULTS

ISHM – AC vs. SPLS Baseline
NOMINAL: CHILLDOWN PHASE – SIMULATED GSE

**Chart: Childdown Suction Line Temperatures**

- **Legend:**
  - ISHM-AC
  - Test 26A

- **Graph Details:**
  - Time (sec)
  - Temperature (Deg F)

- **Time Alignment Reference Table:**
  - Test 26A: 1337
  - ISHM-AC: 0

**Table:**

NOMINAL: REPLENISH PHASE – SIMULATED FLIGHT VEHICLE
OFF-NOMINAL: AUTONOMOUS ENGINE

- Plan Execution
- Failure Insertion
- Alternate Sensor Model
- Mitigation Telemetry
- Plan Execution Continuation
OFF-NOMINAL: AUTONOMOUS ENGINE

- Redline Monitoring
- Failure Insertion
- Alternate Sensor Model
- Mitigation Telemetry
- Redline Monitoring Continues
CONCLUSION

• ISHM-AC: Verification and Validation of Autonomous Operations
• Application supports real-time laboratory operations with cryogenic commodity
• Support mitigation procedures that allows safe continuation of operations
• NASA Technology Readiness Level (TRL) from an analytical and experimental proof-of-concept (Level 3) to validation in laboratory environments (Level 4)
WHAT’S NEXT?

• Increase to higher TRL 4 → 5
• Use the software in Ground Support Equipment (GSE)
• Real cryogenic propellant
• Expand capabilities
• Improve models
• Failure scenarios similar to real GSE.
• GSE Space Shuttle similar failure cases
• Support more complex concept of operations.
AUTONOMOUS OPERATIONS SYSTEM (AOS)
APPLICATION – UPSS AND IRON ROCKET
SOFTWARE ARCHITECTURE

• ISHM-AC
• AOS
  • Different Communication Protocols
  • New Bridge and Gateway
  • Expanded Application Layer
  • Standardized Database
  • Modular Domain and Displays
  • Application engine and generic engine
  • Library expansion
SOFTWARE ARCHITECTURE – CONT.

- AOS
  - Redundancy modifications and modeling
  - Physics Model and Simulator
  - Multi-source telemetry support
  - Several PLC interactions
UPSS AND IRON ROCKET CONTROL MAPS
PHYSICS MODEL

DTS Vehicle Simulator

UPSS and DTS Physics Model
AUTONOMOUS OPERATIONS - NOMINAL

• Application Software Components
  • Telemetry/Command
  • Domain Model
  • Data Processing
• Nominal scripted plan executed
• Redline monitoring evaluation
• ISHM executes models and evaluates health
AUTONOMOUS – OFF-NOMINAL

- Models Determines Off-Nominal Conditions
- Redline monitoring executes mitigation actions
- Nominal plan execution is aborted
- Safing plan executes
TEST RESULTS

AOS on UPSS and DTS
NOMINAL OPERATIONS

• Chilldown operations
  • UPSS Chilldown
  • Main Inlet Block Valve
  • Simulated Vehicle Inlet
  • Parallel chilldown operation

• Serial Loading
  • Slow-Fast Fill Stage 1
  • Replenish Stage 1
  • Load Stage 2
  • Continue with Stage 3
OFF-NOMINAL OPERATIONS

• Non-Safety Critical
  • Stage 1 inlet valve primary position indication failure
  • Secondary sensor continues operations

• Mitigation Actions
  • Operator Notification
  • Continue Operations
  • Liquid level keeps increasing
OFF-NOMINAL OPERATIONS

• Safety Critical
  • Valve fails to respond command
  • Overfill operation might occur

• Mitigation Actions
  • Operator Notification
  • Automated abort of nominal plan
  • Executes safing plan

Safety Critical Failure: MAV-4-02 Valve Fails to Respond

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CONCLUSIONS

• AOS: Verification and Validation for Autonomous Operations by using physics models and simulator
• Application development supports real-time ground support equipment (GSE) for cryogenic propellant commodity (LO2 and LCH4)
• Support mitigation procedures that allows safe continuation of operations
• NASA Technology Readiness Level (TRL) from validation in laboratory environments (Level 4) to validation in relevant environments (Level 5)
WHAT’S NEXT?

• Increase to higher TRL 5 → 6
• Test in Real Ground Support Equipment (GSE)
• Real cryogenic propellant: LO2 and LCH4
• Generalize code to support many applications
• Improve models by redesign and/or modifications
• Unit and Regression Testing
• Pursue Class B Safety Critical Classification
• Meet NASA Safety Standards for and Software Design Processes for Operations (Fielded Use)
AUTONOMOUS OPERATIONS MISSION DEVELOPMENT SUITE (AO MDS)
SOFTWARE ARCHITECTURE

• Tier 0: System level functionalities that are fundamental to the overall capabilities of the AO MDS.

• Tier 1: Primary capabilities of the AO MDS.

• Tier 2: Component that correspond to the primary capabilities on the AO MDS.
SOFTWARE ARCHITECTURE

• Application Layer
• I/O Management and Processing
• Mission Plan Management
• Mission Model
• Unit and Regression Testing
• System Synch.
• IDE
• User Interaction
• Included in the AO MDS is the ability to
  
  • Develop applications using the Integrated Development Environment (IDE)
  
  • The AO STU provides unit and regression testing of all application and AO MDS
  
  • Execute Missions Using the AO Run Time Environment (RTE)
    • Development version
    • Deployable version
  
  • Libraries will grow with each new mission (currently – primarily fluid/cryogenic)

The AO MDS is designed to make application software component development fast and affordable for safety critical applications which is why focus is on NPR 7150.2B compliance
• Acquired and configured the CollabNet TeamForge Application Lifecycle Management (ALM) tool to manage our requirements, project planning, and software configuration management.

• Working toward meeting the NPR 7150.2B Class B Safety Critical compliance.

• Established coding standards for the AO-MDS/G2 development.

• Established project specific desk instructions that align to the KDPs (Key Decision Points - Life Cycle)

• Developed an organizational training plan

• Updated the Software Assurance Plan
APPLICATION – UPSS AND IRON ROCKET
CRYOGENIC PROPELLANT LOADING OPERATIONS

LOX UPSS at Pad B – Up Close View of ISO Container and Storage Skid

LOX UPSS at Pad B – Up Close View of Vehicle Skid - 1st, 2nd, 3rd Stage Supply and Drain I/F
LOX UPSS at Pad B – Up Close View of Vehicle Skid - 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> Stage Supply and Drain I/F
LOX UPSS at Pad B
ISO Container and Storage Skid on Left Hand Side
DTS LOX – Iron Rocket (Vehicle Propellant Tank Simulator)
1st Stage is 3000 gallons, 2nd/3rd Stages are 500 gallons
AIMING FOR SMALL PAYLOAD VEHICLES
AO MDS POTENTIAL

In-Situ Resource Utilization

ORION: On Orbit Operations

Habitation Modules Operations
CONCLUSION

• AO MDS provides generic capability to develop/execute mission specific application software for several space applications
• AO MDS is designed to make application software component development fast and affordable for safety critical applications
• Increase in modeling and testing capabilities
• Follows NASA Processes and certified to be Class B Safety Critical
• Potential to increase TRL Level from 6 (prototype demonstration in relevant environment (ground/space)) to 7 (system prototype demonstration in space environment)
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QUESTION AND ANSWERS
HEALTH MONITORING

- Nominal
  - Phase Detection
  - Flow Subsystem

- Off-Nominal
  - Leak Detection
  - Valve Consistency
Integrated Functionality
(Includes Task Execution)

- Application Infrastructure
  (Required to Build Application Software Components)
- Mission Execution
  (Includes Creating/Executing Plans and Redlines)
- Mission Insight
  (Integrated System Health Monitoring)

Data Object Infrastructure

- Data Processing Engine
  (Includes Plot, Log, and Data Distribution From External Sources)
- Application Integrated Development Environment
  (Apps IDE)

User Support