AUTONOMOUS OPERATIONS
MISSION DEVELOPMENT SUITE

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AGENDA

• 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 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

**Childdown Suction Line Temperatures**

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<th>Temperature (Deg F)</th>
<th>Time (sec)</th>
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<tbody>
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<tr>
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**Time Alignment Reference**

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<th>ISHM-AC</th>
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**Legend**

- Test 26A
- ISHM-AC

**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
• AOS
  • Redundancy modifications and modeling
  • Physics Model and Simulator
  • Multi-source telemetry support
  • Several PLC interactions
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

[Graph showing valve command and response over time]
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
NASA SAFETY, PROCESSES AND STANDARDS

• 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 - 1st, 2nd, 3rd 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)
1\textsuperscript{st} Stage is 3000 gallons, 2\textsuperscript{nd}/3\textsuperscript{rd} 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)
ACKNOWLEDGMENTS

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• NASA Headquarters: NASA Advanced Exploration Systems under the leadership of Jason Crusan and Richard McGuinnis.
BACKUP SLIDES
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