Simulated Propellant Loading System (SPLS): Testbed for Cryogenic Component and Control Systems Research & Development

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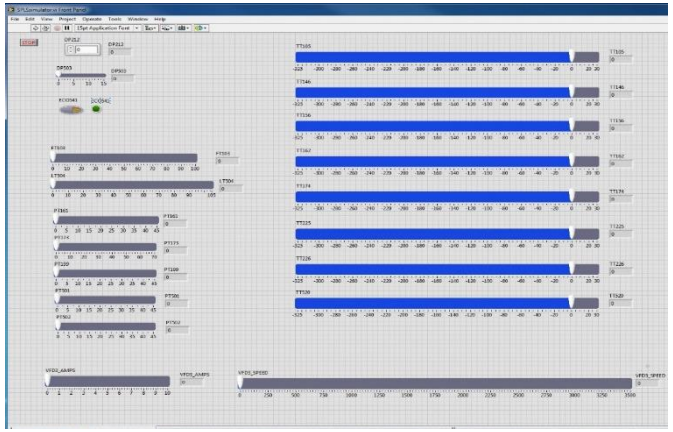
Cryogenics Test Laboratory

Introduction

- Simulated Propellant Loading System (SPLS)
  - Development of a simulated launch cryogenic propellant delivery system
  - Testing of a complete loading sequence for ground systems research and development
  - Validation and verification of a reliable repeatable sequence
  - Supporting testing of new technologies
    - Hardware and Software
  - Future capability improvements
  - Future technology testing

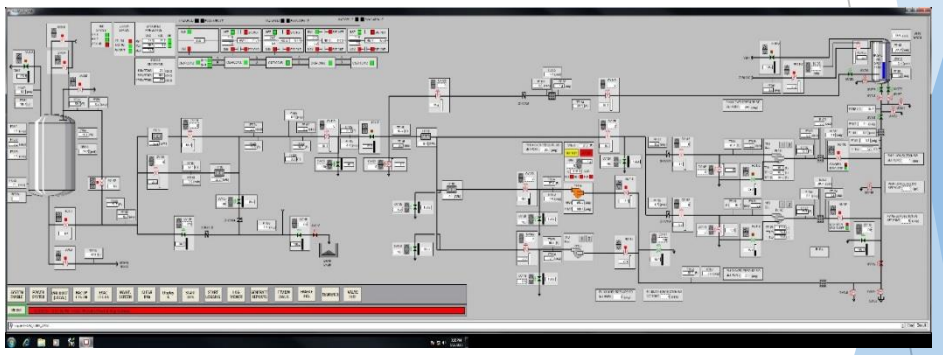
Experimental Setup

- Storage Tank
- Simulated Vehicle Tank
- Propellant Transfer Lines
- Instrumentation
- Data Acquisition, Command and Control System
- Monitoring and Real-Time Plotting
- SPLS Simulator

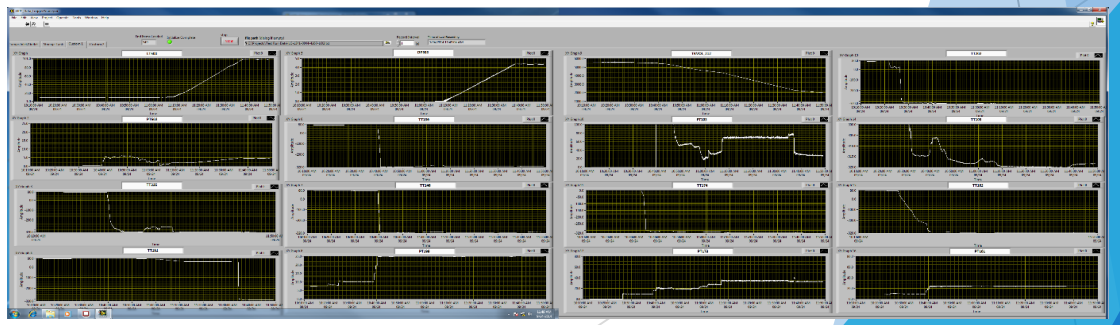


SPLS Simulator

SPLS Full Configuration



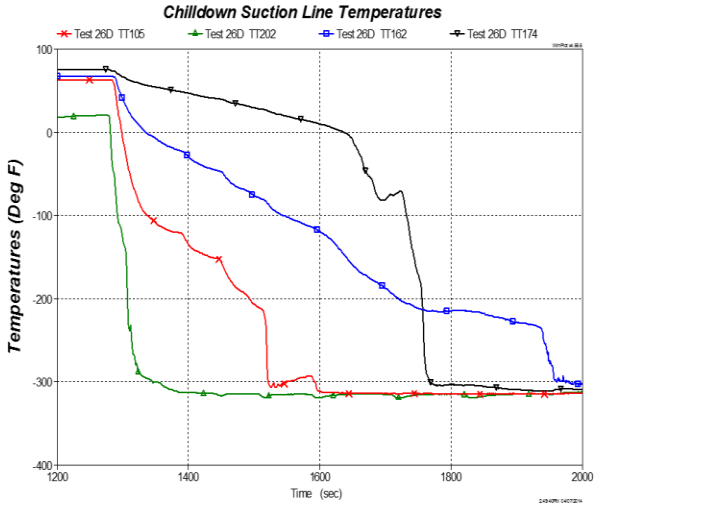
PLC DAC, Command, and Control System



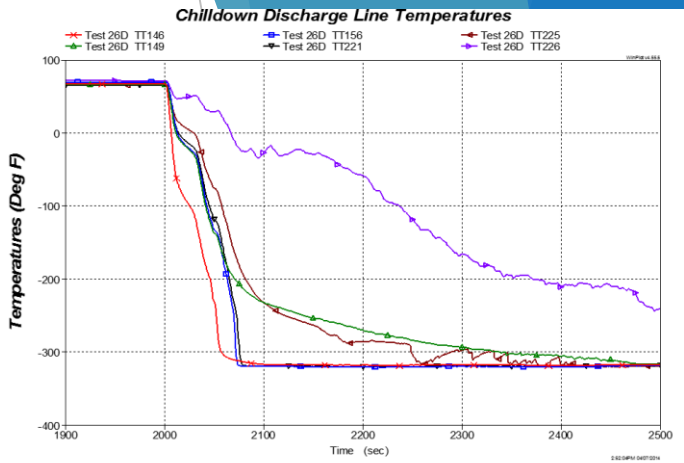
Real-time Plotting Monitoring Tool

Sequence Testing

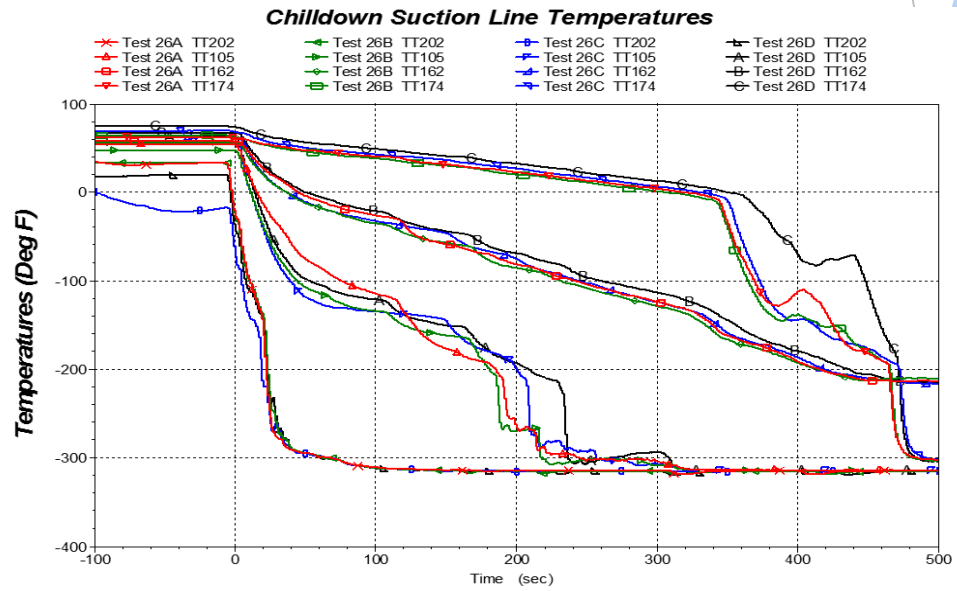
- Iteration process on an automated sequence
  - Configurations
    - Main Valve and Bleed Valves
  - Trigger Points
    - Temperatures, Pressures, Flow
  - Automation
    - Automated Sequencer
  - Redlines
    - Activation: Storage Tank
- Simulated Propellant Transfer Phases
  - Chilldown
    - Suction Line
    - Discharge Line
    - Vehicle Inlet Valve
    - Ullage Pressure
    - Pump Chilldown
  - Repeatable test shows consistency
    - Small variation due to initial atmospheric temperature conditions.



TT105: Tank-Pump Suction	TT202: Tank Discharge	TT162: Pump Suction	TT174: Pump Discharge



TT146: Common Pump Discharge	TT149: Country Cross Line	TT156: Skid Outlet
TT221: Prop Conditioner In	TT225: Prop Conditioner In	TT226: Vehicle Tank In

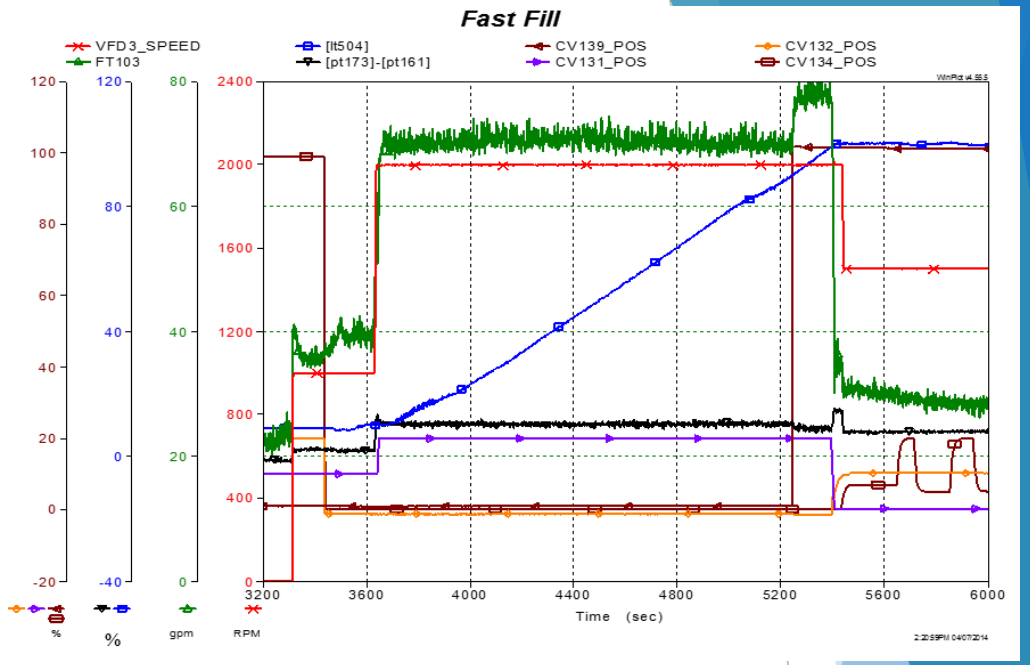


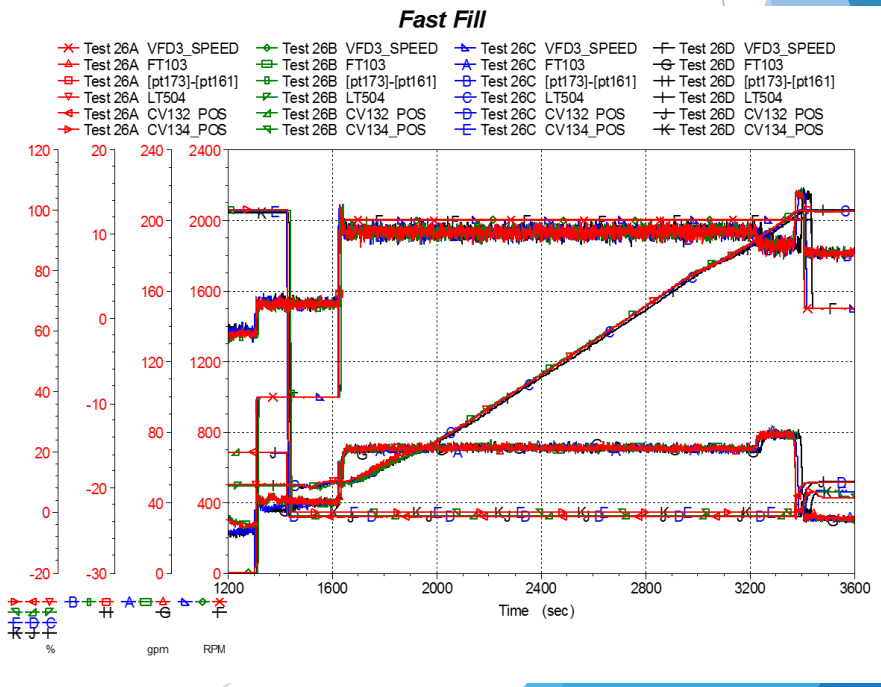
Time Alignment Reference	
Test 26A	1337
Test 26B	1303
Test 26C	1527
Test 26D	1285

TT105: Tank-Pump Suction	TT202: Tank Discharge	TT162: Pump Suction	TT174: Pump Discharge

Cont.

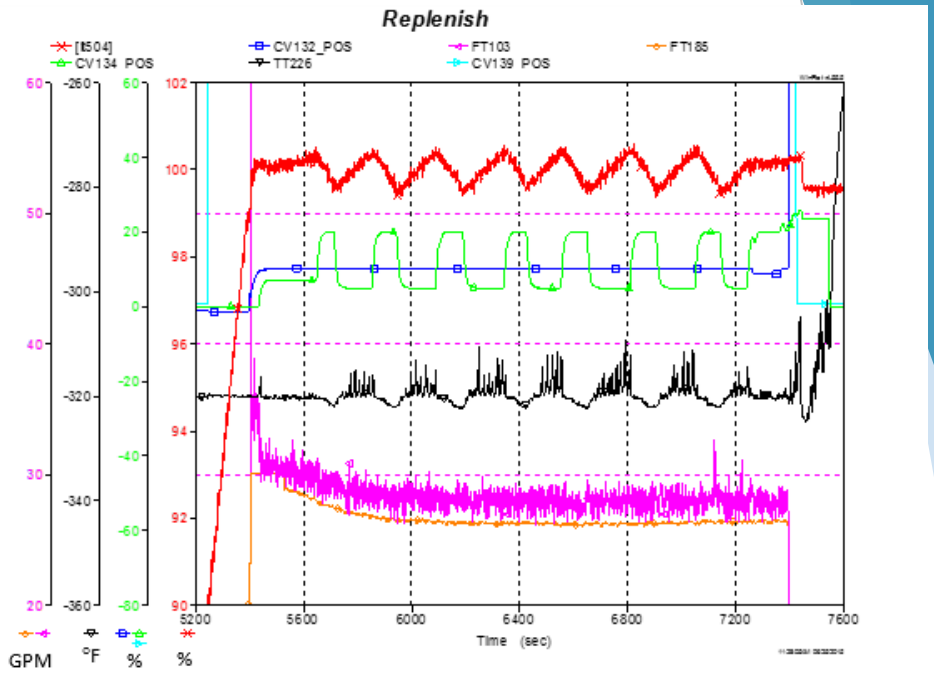
- Slow-Fast Fill
  - Gradual increase in suction pressure
  - Pump speed step increase
  - Closing exhaust valves (“bleed” valves).
  - Reduce flow to vehicle tank
    - 30 min of fill to max liquid level
    - Application placeholder
- Repeatability
  - Test 26A, Test 26B, Test 26C and Test 26D

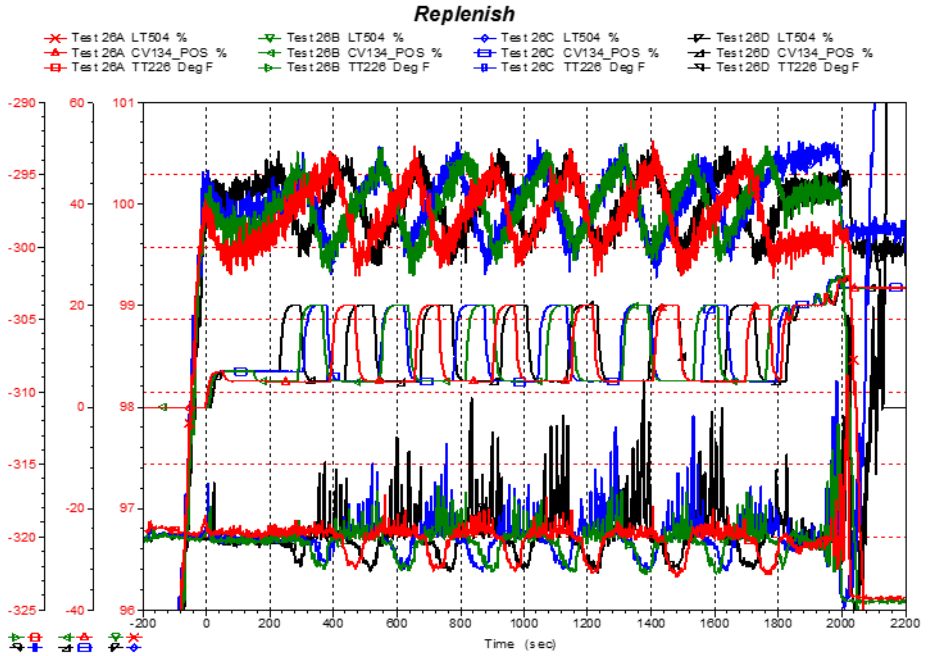




Cont.

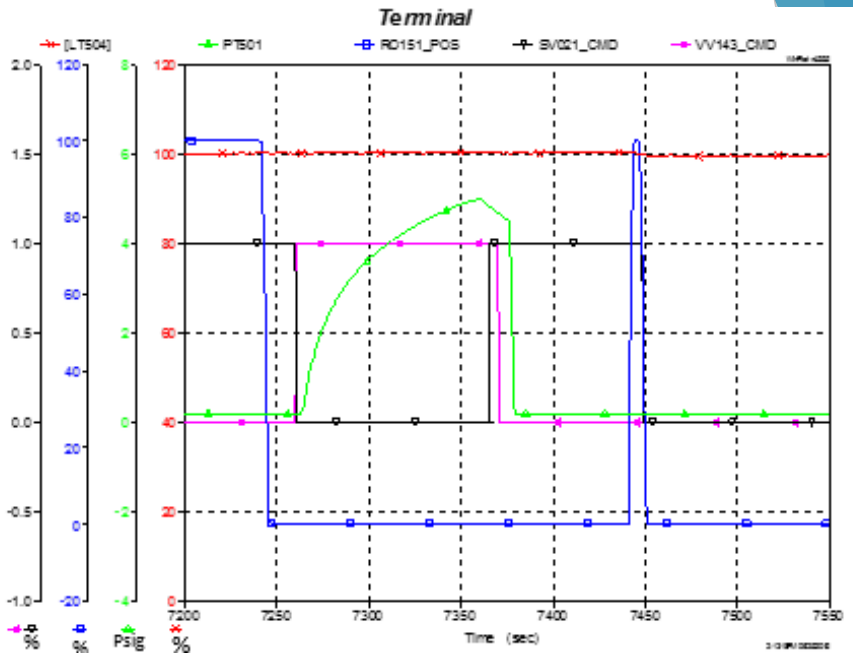
- Replenish
  - Max level threshold = 99.5% – 100.5%
    - Exhaust valve and liquid level oscillations
  - Exhaust valve management
  - Replenish valve fixed
  - Flow conditioning
    - Prevent temperature increase
    - Removes warm liquid
      - Fill line up to replenish valve
      - Open % exhaust valve on fill line
  - Temperature Oscillations
    - Exhaust flow increase/decrease -> temperature oscillations (10 degrees)
  - Repeatability
    - Small variation due to atmospheric conditions

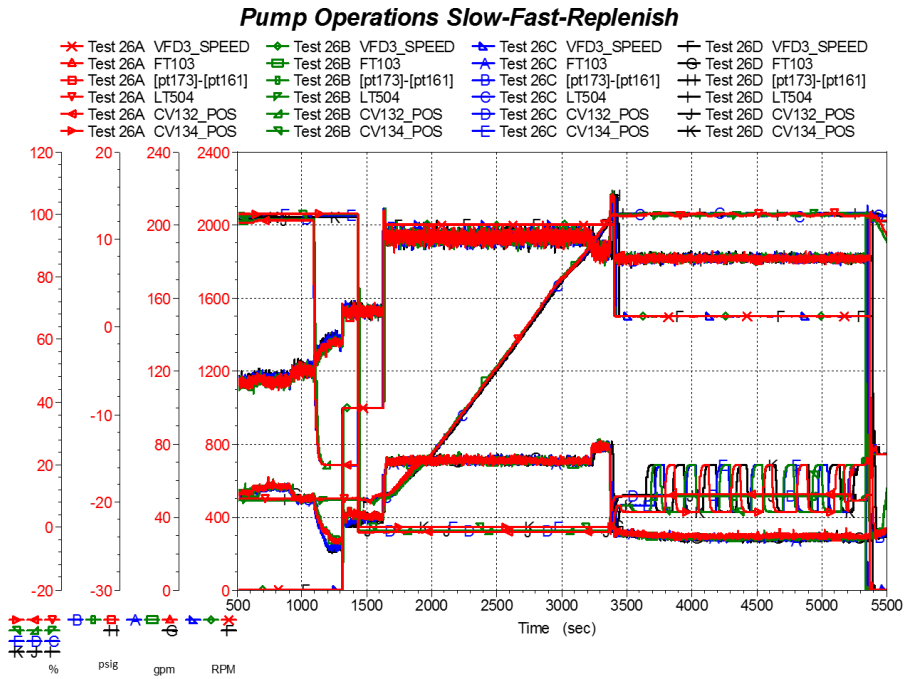




Cont.

- Terminal
  - Vehicle isolation
  - Ullage pressurization
  - Launch Commit Criteria
    - Pressure
    - Liquid level
  - Engine Valve analogy
- Securing
  - Storage tank isolation
  - Drainage
    - Fill lines
    - Vehicle tank
    - Boil-off
- Repeatability



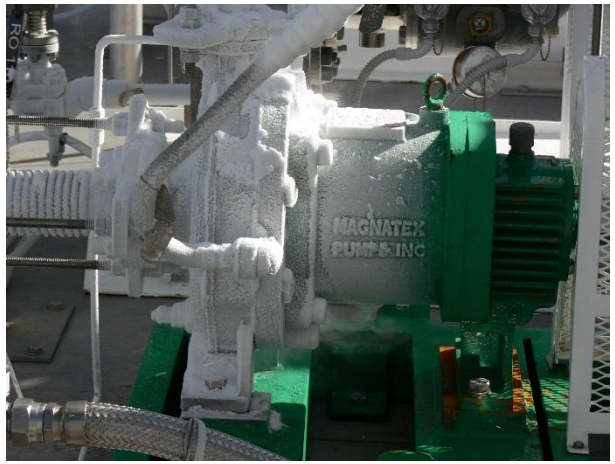


Testing

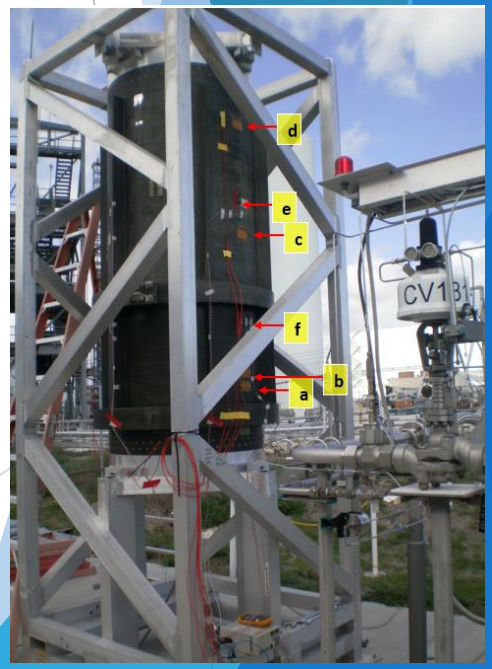
- Test Articles
  - Layered Composite Insulation for Extreme Conditions (LCX)
    - Thermal Insulation system currently being implemented
  - Wireless Surface-Acoustic-Wave (SAW) Sensor
    - Passive wireless liquid level sensor
  - AFRL Composite Tank
    - Simulate an all composite flight vehicle tank
  - Hydrostat Strain and Vibration Mode Testing
    - PTZ health monitoring technologies
  - Magnetic Coupled Cryogenic Pump
    - Enhance reliability and reduce maintenance cost
  - Neural Network Piezoelectric (PZT) Based Cryogenic Fluid Phase / State detection
    - Neural network creation and validation for fluid state detection.

LCX on a simulated vehicle tank (left) and piping flange assembly (right) on the SPLS

Wireless Surface Acoustic-Wave (SAW) Sensor



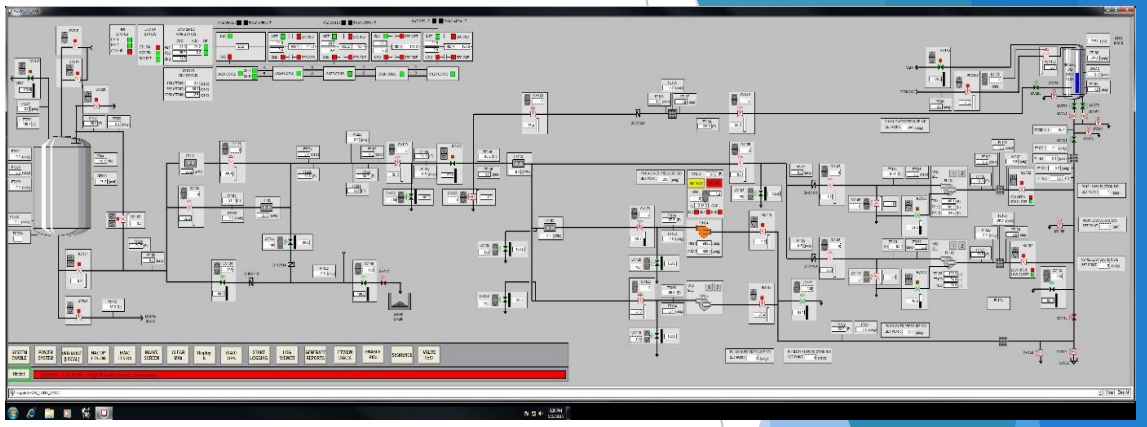
Magnetic Coupled Cryogenic Pump



Hydrostat Strain and Vibration Mode Testing

Health Monitoring, Management and System Safing

- Programmable Logic Controller (PLC)
  - DAC, Command & Control, Simulator
- Modeling of fault diagnostics and optimization (NASA AMES)
  - Physics-based models for chilldown, loading operations and health management
  - Two-phase flow modeling for cryogenic operations
- High level intelligent system
  - G2 ISHM NASA Toolkit & Knowledge-Based Autonomous Test Engineer (KATE)
    - Autonomous Sequence Command and Control
    - Health Management and Redline Monitoring
    - Failure Detection, Mitigation, and Recovery



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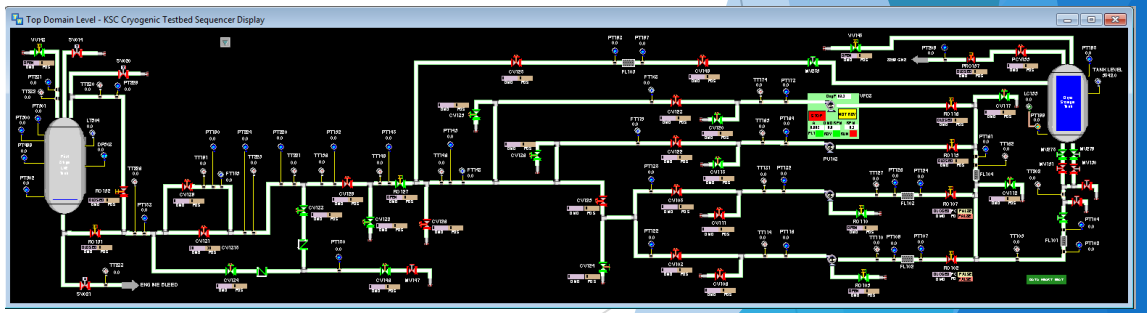
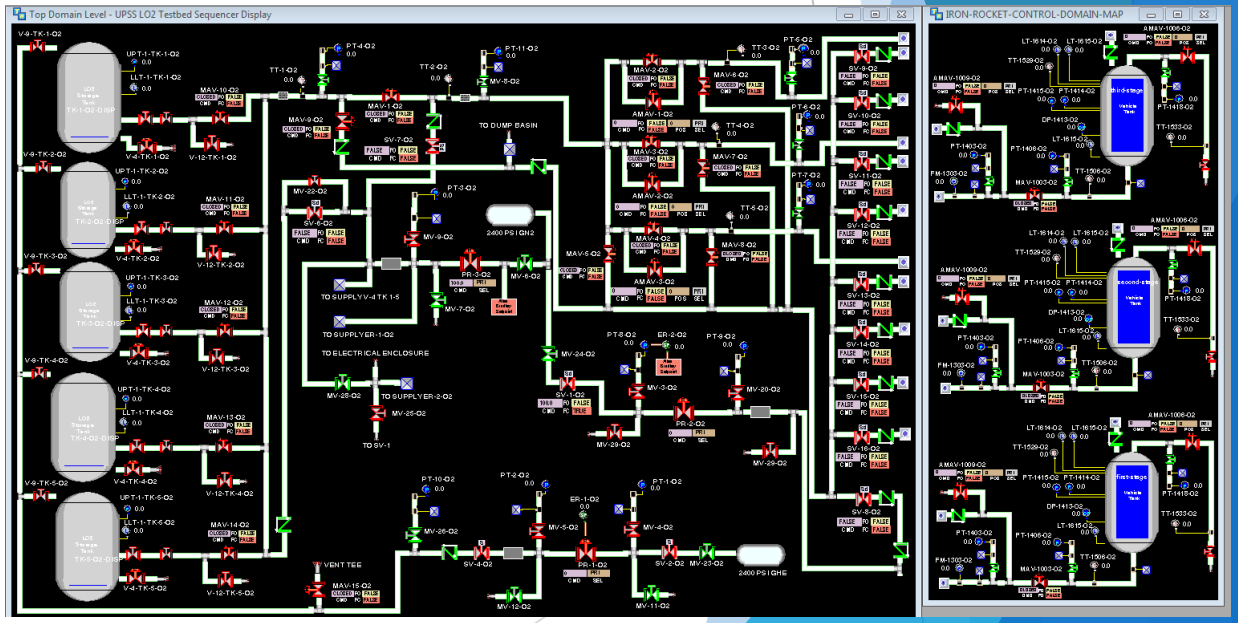


G2 ISHM NASA Toolkit

Future Implementation

- Commodity Conservation Technologies
  - In-Situ Evaporator Propellant Conditioning
    - External skid Cryogenic Densifier to improve commodity without increasing cost or heat gain.
  - Push back design modifications
    - Commodity reuse
- Modeling and Optimization
  - Physics Model Group and KATE
    - Use models to optimize chilldown and loading phases for commodity conservation
- Health Monitoring, Management and System Safing
  - Autonomous Operations System (AOS)
    - Increase capabilities for parallel cryogenic loading operation with liquid oxygen and liquid methane for a different cryogenic piping system

Propellant Conditioner



Autonomous Operations System (AOS)

Conclusions

- Complete system that simulates a launch cryogenic propellant delivery system
- Reliable repeatable cryogenic sequence has been demonstrated
- Applications: Testbed for support of new technology development
  - Cryogenic propellant transfer environment
  - Support on maturation processes
  - Modeling and physics testbed article
  - Supported technology demonstration for high level intelligent systems
- Future Implementation
  - Improving cryogenic commodity management and utilization
  - Testbed for software of more complicated systems

Questions