# Evolvable Cryogenics (eCryo) Project
# Technology Workshop with Industry

## Engineering Development Unit (EDU) Workshop

### Cryogenic Isolation Valves

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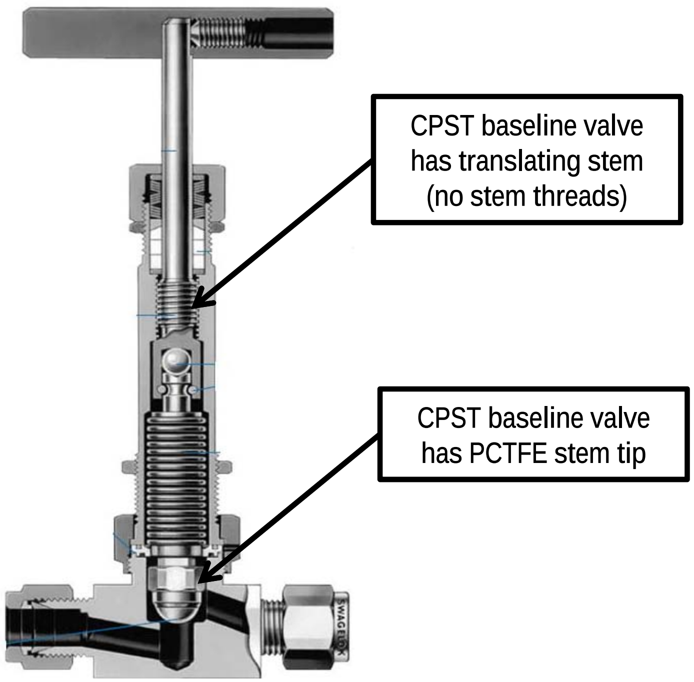
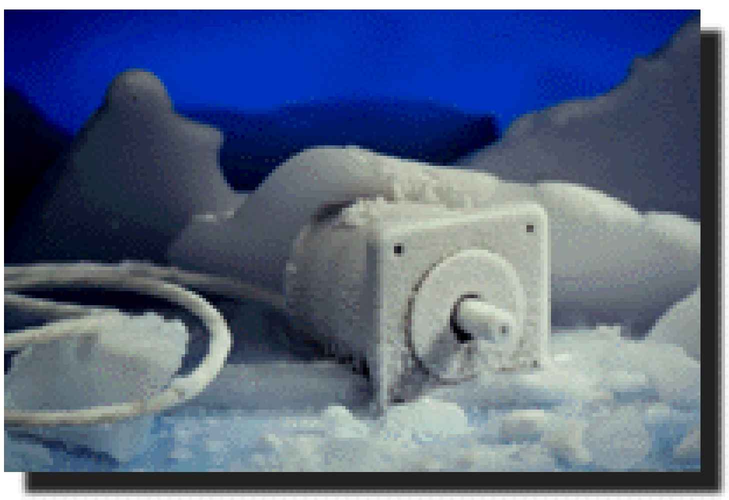
# Background – CPST Needs a Valve

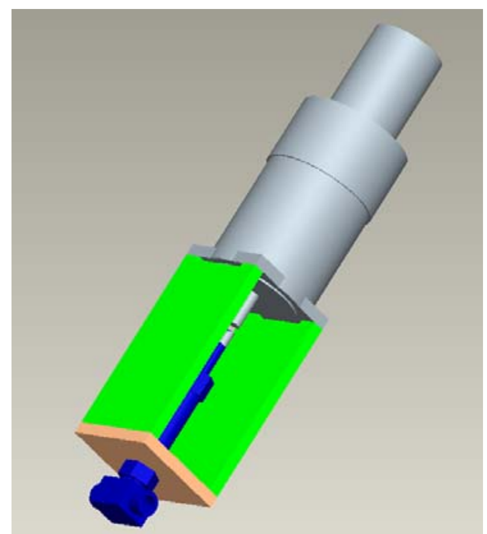
- CPST GTA needed a cryogenic isolation valve that met the following requirements:
  - Low Cost
  - Low Leakage
  - Low Heat Input
  - Operate in Vacuum Environment
  - Hydrogen Compatibility
- Initial valve trade study covered everything from a flight-like valve to an in-house valve design to COTS valves.
  - Most cost-effective option was to use a proven COTS valve.
  - A Swagelok® U-Series valve with a PCTFE Stem tip for use with LH2 was chosen. This valve has a welded bellows which in combination with the PCTFE stem tip provides lower risk of external and internal leakage.



# Background – CPST Needs a Valve

- Another trade study was conducted to select an actuator for the valve.
  - Stepper motors were considered but eliminated due to cost and complexity of control system.
  - A flight-like design was also considered, but eliminated due to low TRL level and cost.
  - An in-house pneumatic bellows actuator was chosen.
    - PRO: Lowest cost option.
    - PRO: No heater required, so low heat input option.
    - CON: Requires additional facility valve to control pneumatics (open/close valve).



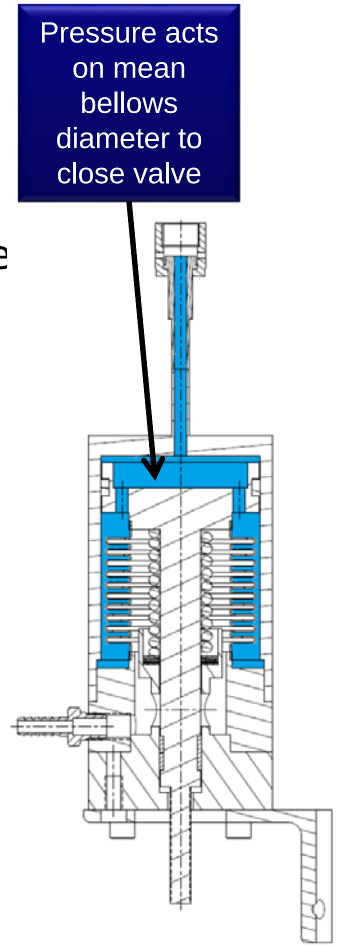


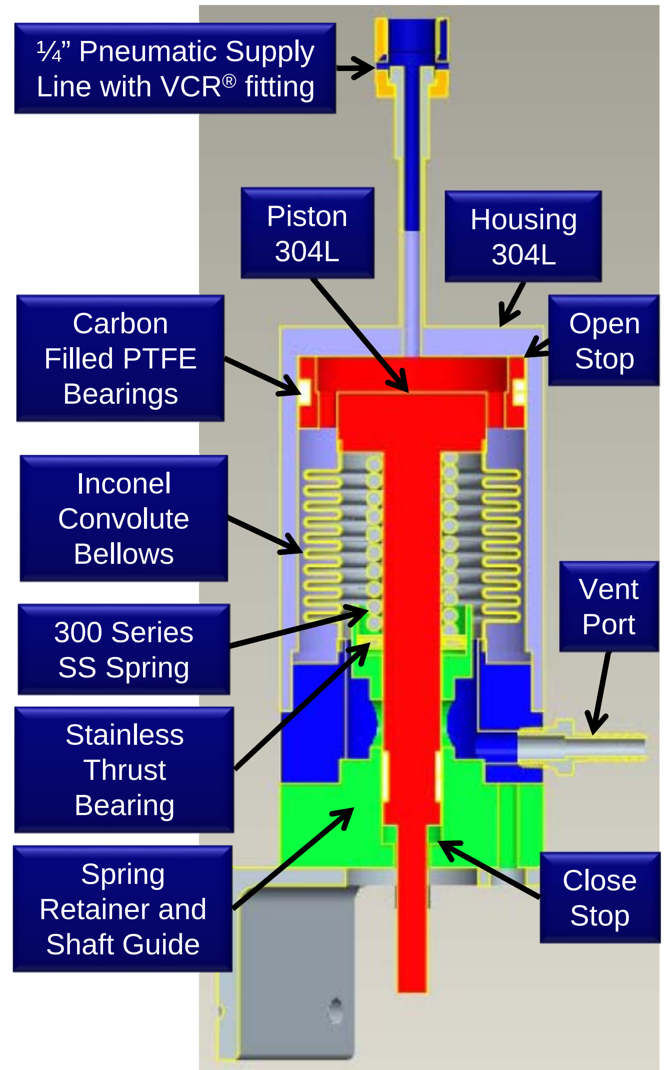
# Background – Actuator Design

- Key Actuator Design Parameters
  - Performance
    - Min. Stroke Length: 0.100 in.
    - Max. Stroke Time: 0.500 seconds
    - Minimum Stroke Time Limit: 0.250 seconds
    - Cycle Life: 2,000
  - Environments
    - Maximum Temperature: 100° F
    - Minimum Temperature: -400° F
    - Max. External Pressure: 15 psia
    - Min. External Pressure: 0 psia
  - Interfaces
    - Mounting Interface: 1/4”–20 UNC on 2” bolt circle
    - Valve to Actuator Shaft Interface: 5/8”–24 UNF
  - Safety
    - Pressure Boundary Burst Factor (excludes bellows): 4
    - Pressure Boundary Burst Factor, Bellows: 1.5
    - Pressure Boundary Proof Factor (excludes bellows): 1.5
    - Pressure Boundary Proof Factor, Bellows: 1.25

# Background – Actuator Design continued…

- Actuator Concept of Operation
  - Spring and bellows spring load provides opening force.
  - GHe provides closing force via external pressure on bellows.
  - Passive state is open, but can be made to “fail closed” on loss of power by using a solenoid that provides GHe pressure to actuator in unpowered state.
  - Actuator GHe fills and vents through supply tube on top of actuator.
  - Inner bellows open to external environment via vent port.



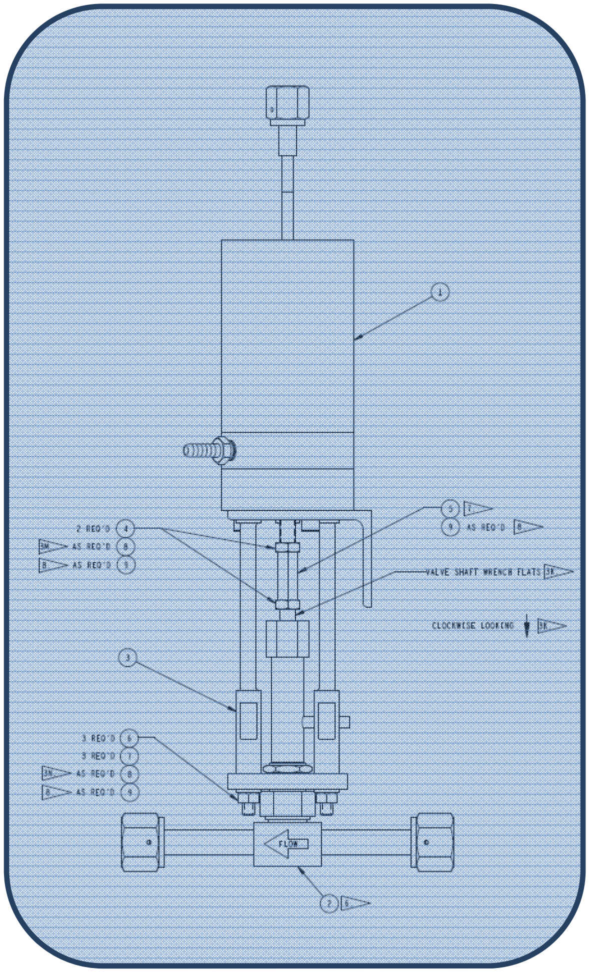



# Background – Actuator & Valve Testing

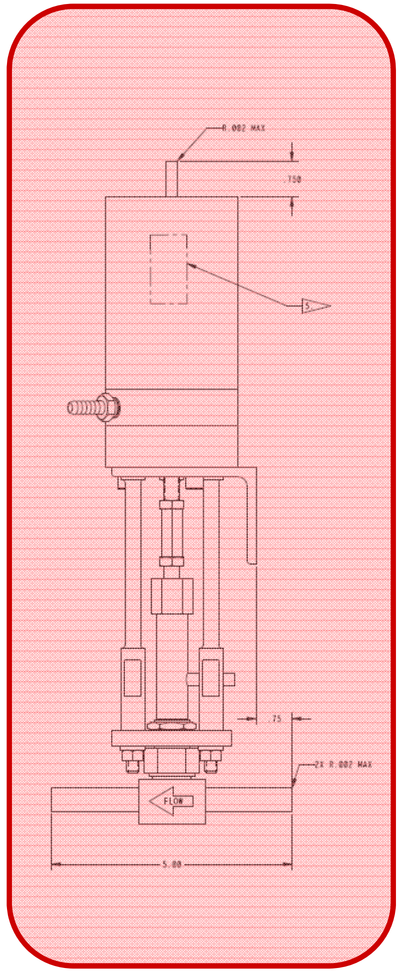
- Development Testing
  - Actuator Bellows
    - Pneumatic Proof Testing
    - Helium Leak Check
    - Burst Test
  - Actuator Housing
    - Pneumatic Proof Testing
    - Helium Leak Check
    - Burst Test
  - Stroke Length Test
  - Force Output Test
  - Confirm Actuator to Valve Interfaces
  - Cycle Life Testing
    - Actuator Bellows
    - Valve Internal Leakage
  - Valve Flow Coefficient Test
- Characterization Testing at Ambient Temperature
  - Flow Rate and Pressure Drop Test
  - Cycle Verification and Response Time Test
  - Internal Forward Leakage at Low Actuator Pressure
  - Force Balance Verification
  - Internal Forward Leakage at High Actuator Pressure
- Acceptance Testing at LH2 Temperature
  - Cycle Verification and Response Time Test
  - Internal Forward Leakage at Nominal Actuator Pressure
    - ≤ 492 sccm

# Background – Valve Assembly

**Acceptance Test and EDU Configuration**




**GTA Configuration**

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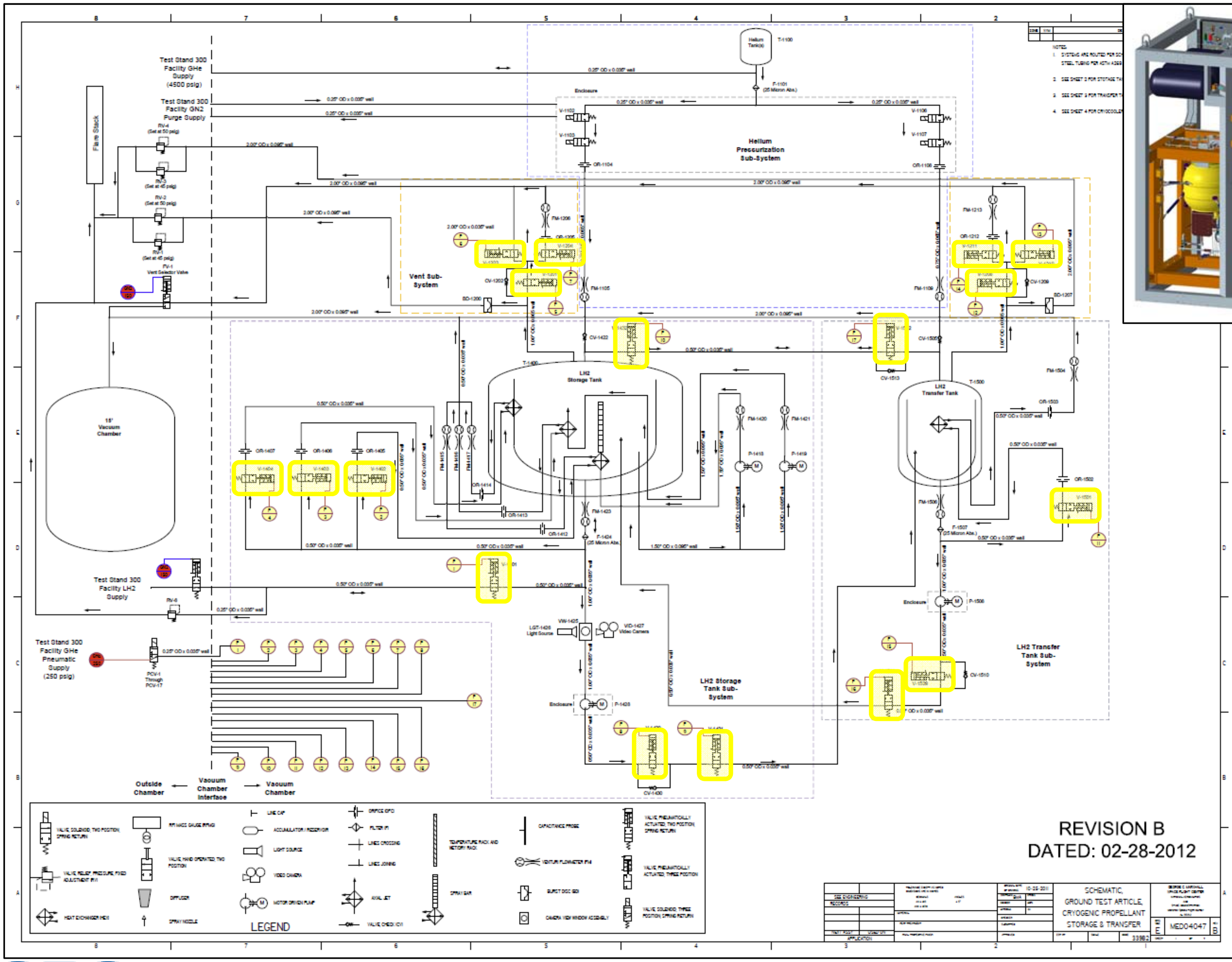
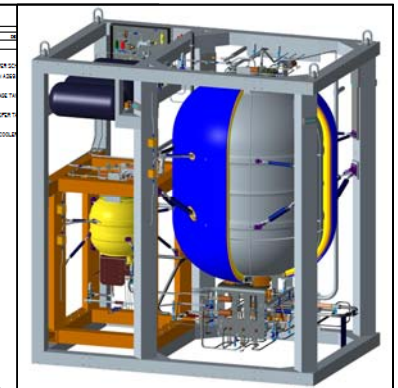
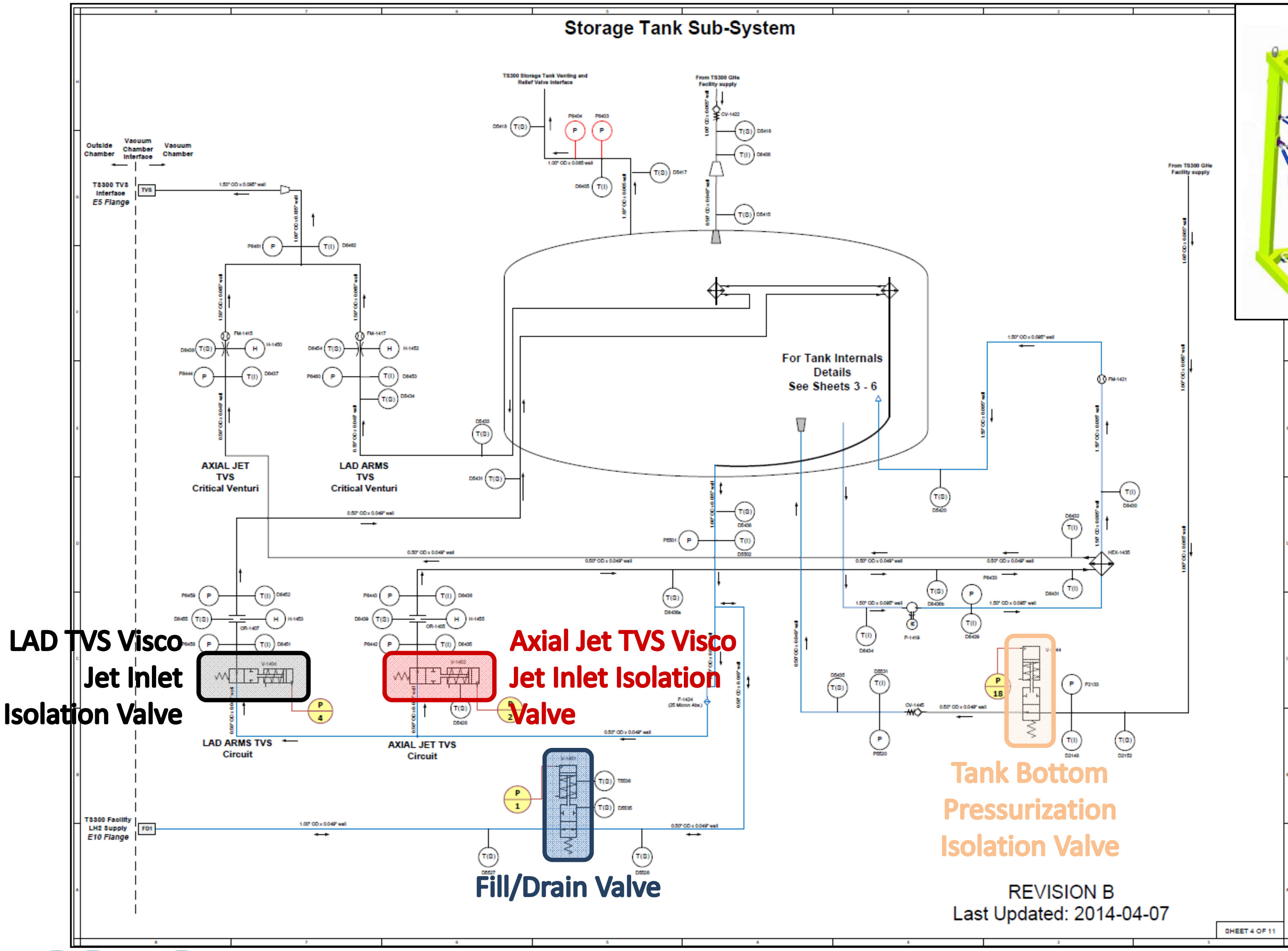
# Background – CPST GTA Schematic



# Background – CPST EDU Schematic




# CPST EDU Testing

- The valves experienced some cycles during characterization and acceptance testing prior to being installed into the CPST EDU test configuration.
- Since their installation into the CPST EDU test configuration, two rounds of testing have occurred.
  - LN2 Testing: 1 day
  - LH2 Testing: 20 days
- Valve Cycle Count
  - The valve cycle life is governed by the actuator cycle life limit of 2,000 cycles.

| Valve | Cumulative Cycles prior to LH2 Test | Cycles Accumulated During LH2 Test | Cumulative Cycle Count | Cycle Life Remaining |
|---|---|---|---|---|
| V-1401 Fill/Drain | 108 | 32 | 140 | 1860 |
| V-1444 Bottom Press | 107 | 14 | 121 | 1879 |
| V-1402 AJ TVS VJ | 109 | 53 | 162 | 1838 |
| V-1404 LAD TVS VJ | 109 | 25 | 134 | 1866 |

  - The remaining valve cycles are adequate on all four valves to allow further testing with the EDU hardware.

# CPST EDU Testing continued…

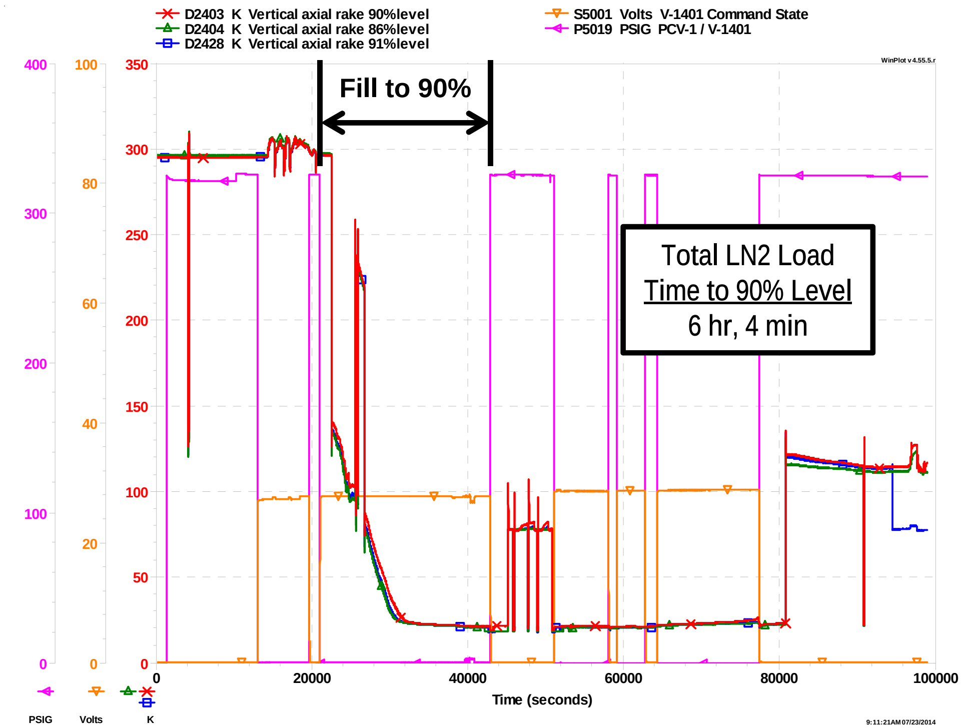
- Actuation Pressure During LH2 Testing
  - All actuators are fed from the same supply, so they should not differ from each other greatly (variation due to pressure drop along different line lengths and calibration).
  - Nominal Actuation Pressure: 325 psig
    - Should not exceed 350 psig

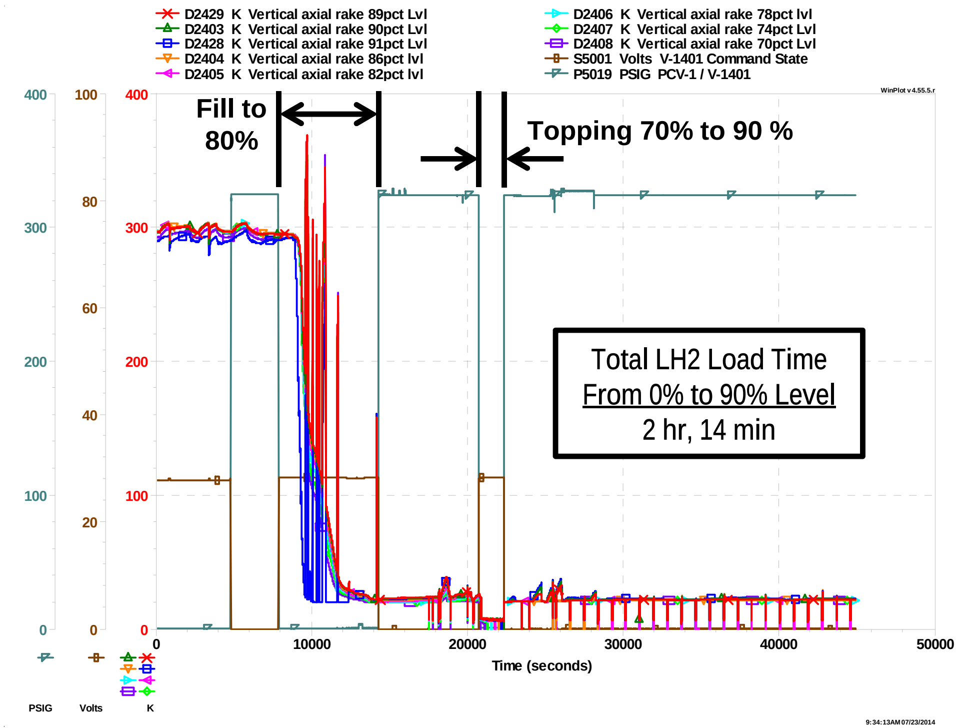
| Valve | Maximum Actuator Pressure | Date / Test Day / GMT Day |
|---|---|---|
| V-1401 Fill/Drain | 331.723 psig (P5019) | 19 June / Test Day 8 / GMT Day 170 |
| V-1444 Bottom Press | 327.139 psig (P5036) | 19 June / Test Day 8 / GMT Day 170 |
| V-1402 AJ TVS VJ | 328.759 psig (P5020) | 12 June / Test Day 1 / GMT Day 163 |
| V-1404 LAD TVS VJ | 325.345 psig (P5022) | 11 June / Pre-Test / GMT Day 162 |

  - None of the cryogenic isolation valve actuators were exposed to excess pressure.

# CPST EDU LH2 Testing Data Observations
# Fill/Drain Valve Performance During Tank Loading

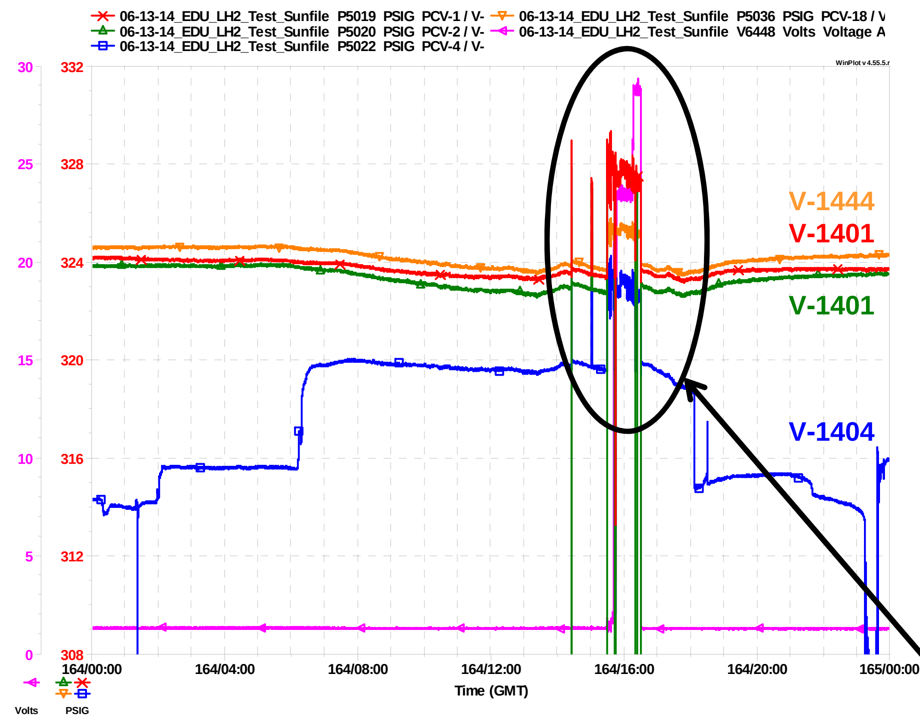
- Fill/Drain Valve Performance During Tank Loading
  - LN2 load time to 90% level on the vertical temperature rake was 6 hours, 4 minutes.
  - Removal of the Fill/Drain Valve was evaluated; decided to leave the valve in place.
  - LH2 load time from empty to 80% level on the vertical temperature rake was 1 hour, 47 minutes.
  - LH2 topping time from 70% to 90% was 27 minutes.
  - A cold helium purge was used prior to initial fill, but effect was minimal on bulk tank temperature.
  - Full size data plots are included in Backup.



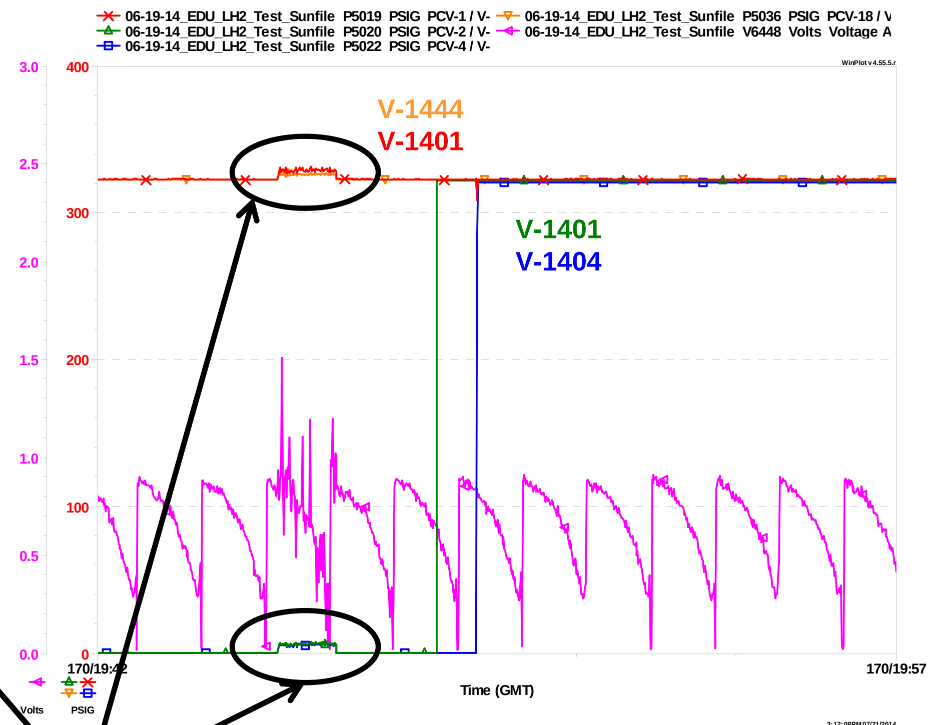



# CPST EDU LH2 Testing Data Observations
# Valve Actuation Pressure

## Data Plot: 6/13 Valve Actuator Pressures and AJ Mixer Pump Voltage




## Data Plot: 6/19 Valve Actuator Pressures and AJ Mixer Pump Voltage



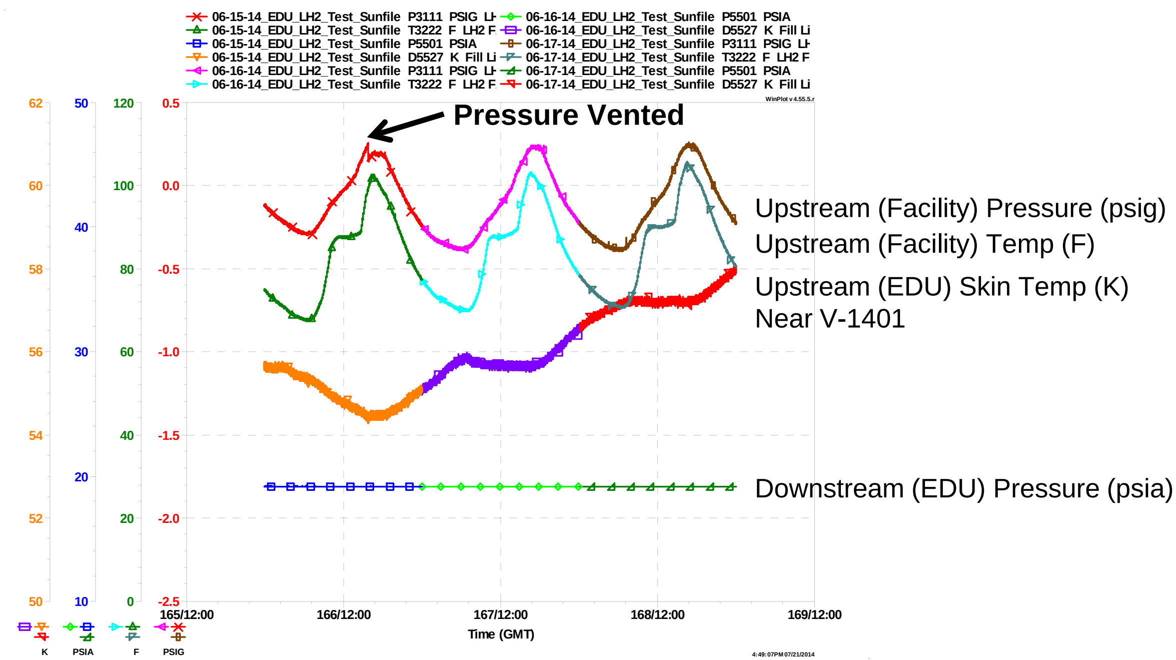

Noticeable shift in all actuator pressure data when AJ Mixer Pump is running, not a real pressure change.

This instance coincides with the AJ Mixer Pump being run at 40 Hz when it had a voltage cutoff.

# CPST EDU LH2 Testing Data Observations
# Valve Internal Leakage

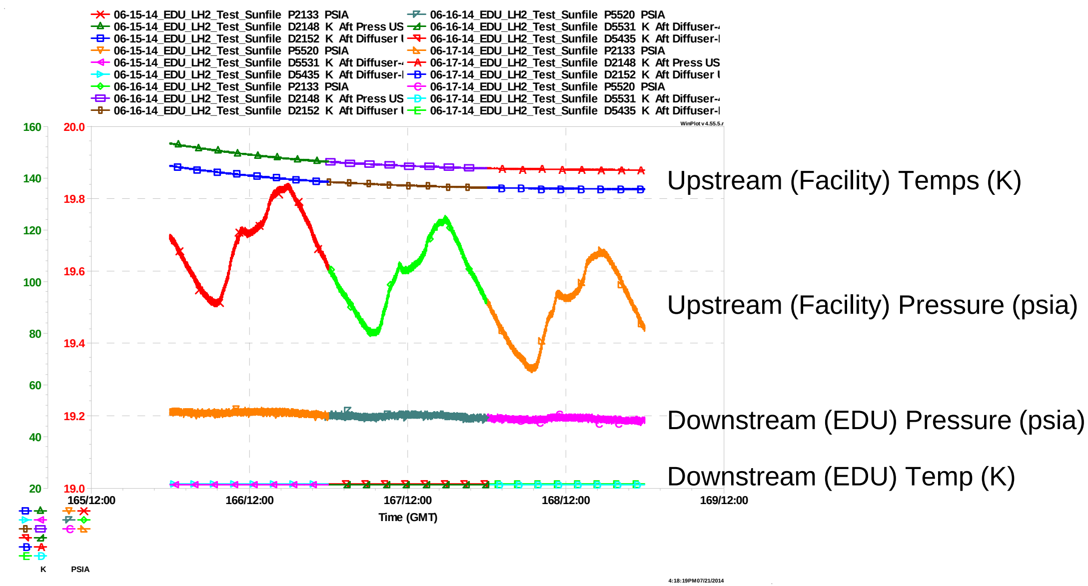
- Valve Internal Leakage
  - V-1401: Fill/Drain Valve
    - There was suspicion of leakage noted in the 15 June Daily Activity Log. Pressure was vented between V-1401 and facility valve ROV-20-618, or dropped from 0.24 to 0.14 psig. The facility pressure measurement (P3111) then rose to about 0.2 psig.
    - The data plot below includes data for three days starting on 15 June and shows that the facility pressure and temperature (T3222) measurements cycle with the temperature of the day. The pressure values range from +0.24 to -0.38 psig daily.
    - If there is a leak, it is very small and self-limiting. Further evaluation in work.

Pressure fluctuations follow daily temperature cycle. Downstream side of valve interfaces with outside of chamber.



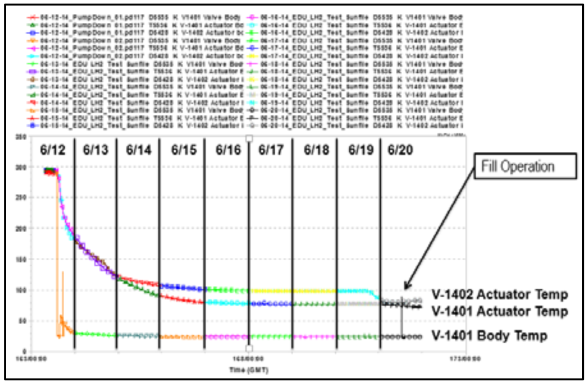
- Valve Internal Leakage
  - V-1444: Tank Bottom Pressurization Isolation Valve
    - The data plot below includes data for three days starting on 15 June and shows that the EDU pressure measurement cycles with the temperature of the day. Although not shown, the facility pressure (P3272) and temperature (T3271) measurements also show this behavior.
    - There is no indication of a substantial leak. Further evaluation in work.
  - V-1402: Axial Jet TVS Visco Jet Inlet Isolation Valve
    V-1404: LAD TVS Visco Jet Inlet Isolation Valve
    - The downstream side of these valves are exposed to the 15-ft vacuum chamber. There was no pressure build-up in the 15-ft vacuum chamber suggesting these valves did not leak.

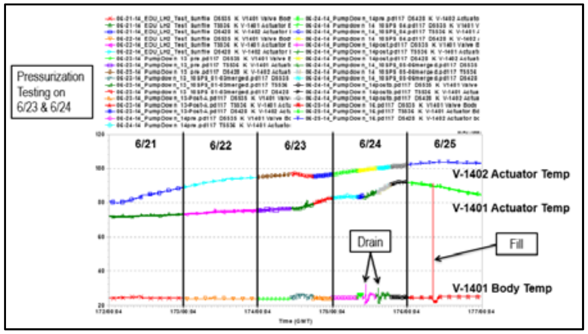
Pressure fluctuations follow daily temperature cycle. Upstream side of valve interfaces with outside of chamber.

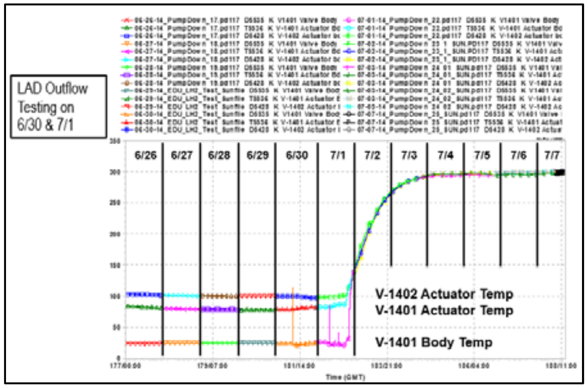


# CPST EDU LH2 Testing Data Observations
# Valve Temperature Measurements

- Valve Body and Actuator Temperature Measurements
  - V-1401: Fill/Drain Valve
    - Body Temperature Measurement:  D5535
    - Actuator Temperature Measurement:  T5536
  - V-1402: Axial Jet TVS Visco Jet Inlet Isolation Valve
    - Actuator Temperature Measurement:  D5428
  - Plots of the data for the duration of the test are included in Backup.
  - There was a thermal model created of the valve to assist in determining an appropriate purge rate.  This data could be compared to that model.
  - No conclusions can be drawn from this data at this time.



# Conclusions

- The cryogenic isolation valves operated as expected, allowing the related Test Objectives and Success Criteria to be met.
  - Valves opened/closed when commanded.
  - The pressure supplied to the actuators was nominal.
  - The valves retained LH2 in the storage tank with acceptable internal leakage levels.
  - The remaining valve cycles are adequate on all four valves to allow further testing with the EDU hardware.
    - Allowable cycles based on actuator design: 2,000

| Valve | Cumulative Cycle Count | Cycle Life Remaining |
|---|---|---|
| V-1401 Fill/Drain | 140 | 1860 |
| V-1444 Bottom Press | 121 | 1879 |
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# Cryogenic Isolation Valves Back-up Charts

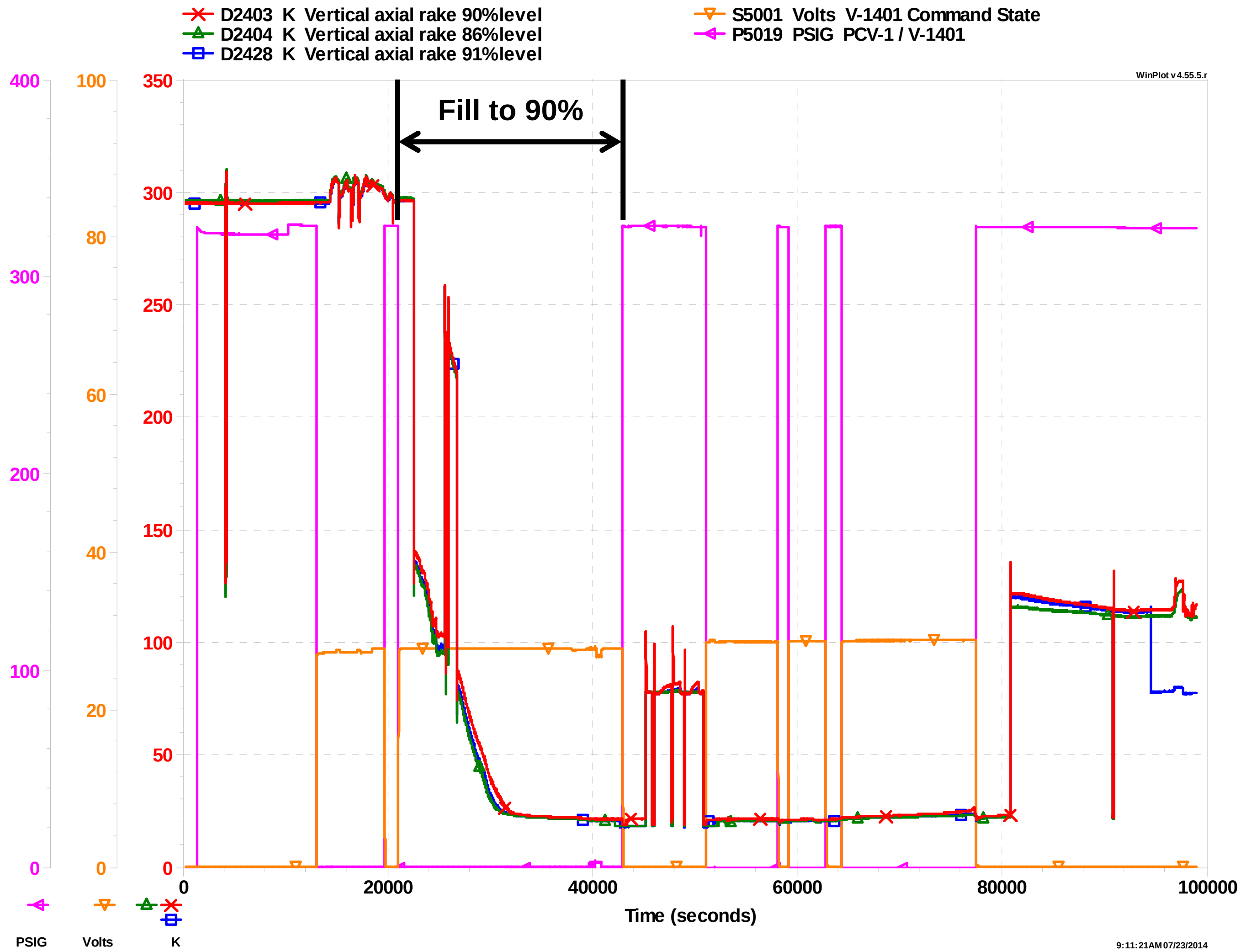
# Acronyms & Abbreviations

| | |
|---|---|
| ° | Degree |
| AJ | Axial Jet |
| COTS | Commercial Off The Shelf |
| CPST | Cryogenic Propellant Storage and Transfer |
| eCryo | Evolvable Cryogenics |
| EDU | Engineering Development Unit |
| F | Fahrenheit |
| GHe | Gaseous Helium |
| GMT | Greenwich Mean Time |
| GTA | Ground Test Article |
| Hz | Hertz |
| in. | Inch |
| K | Kelvin |

| | |
|---|---|
| LAD | Liquid Acquisition Device |
| LH2 | Liquid Hydrogen |
| LN2 | Liquid Nitrogen |
| PCTFE | Polychlorotrifluoroethylene |
| psia | Pounds Per Square Inch Absolute |
| psig | Pounds Per Square Inch Gauge |
| PTFE | Polytetrafluoroethylene |
| sccm | Standard Cubic Centimeters per Minute |
| SS | Stainless Steel |
| TRL | Technology Readiness Level |
| TVS | Thermal Venting System |
| UNC | Unified National Standard Coarse Thread |
| UNF | Unified National Standard Fine Thread |
| VJ | Visco Jet |

# CPST EDU LH2 Testing Data Observations
# Fill/Drain Valve Performance During Tank Loading

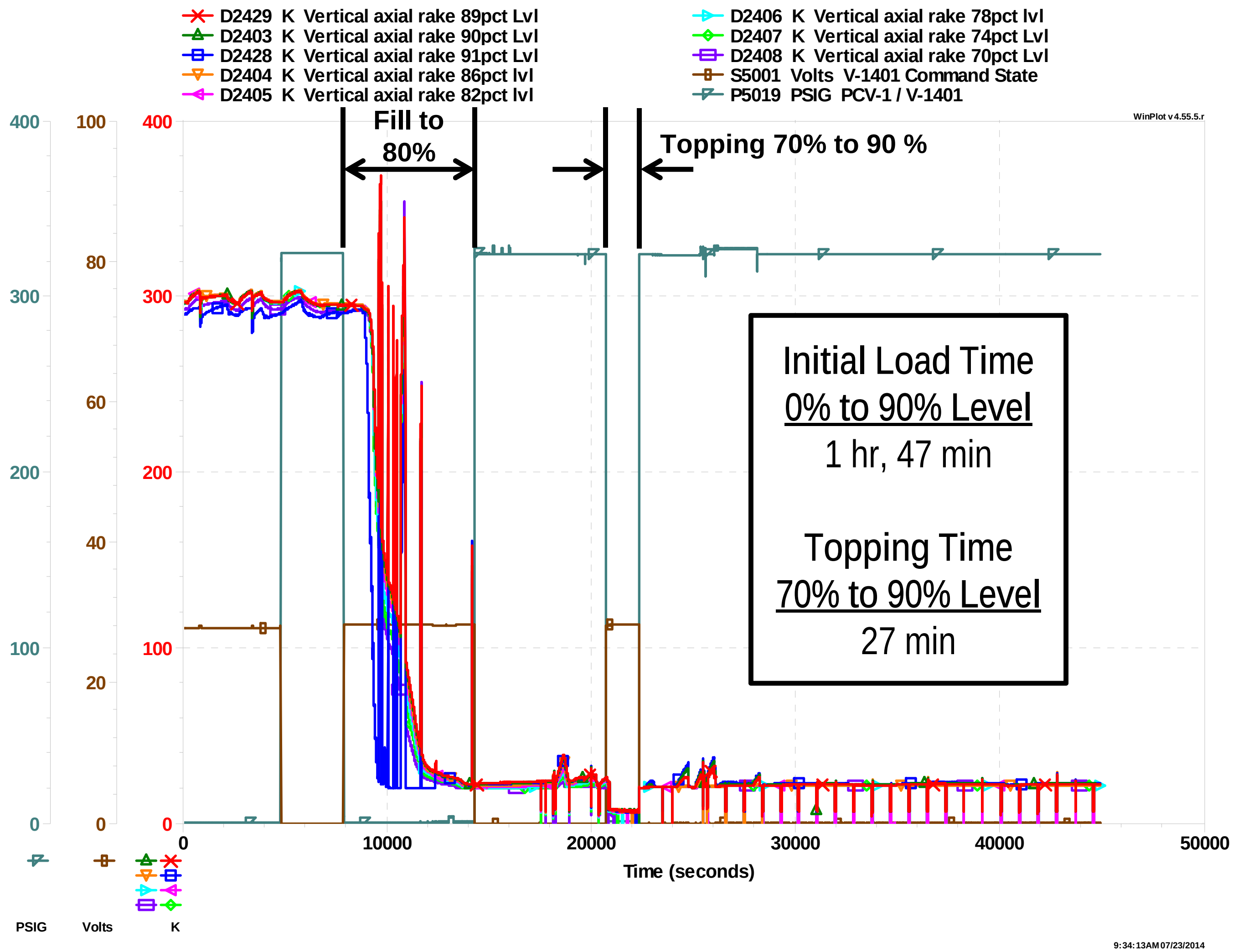
Data Plot: 5/29 LN2 Cold Shock V-1401 and Vertical Temp Rake




Total LN2 Load Time to 90% Level 6 hr, 4 min

# CPST EDU LH2 Testing Data Observations
# Fill/Drain Valve Performance During Tank Loading

## Data Plot: 6/12 LH2 Test V-1401 and Vertical Temp Rake



# CPST EDU LH2 Testing Data Observations
# Valve Actuation Pressure

Data Plot: 6/13 Valve Actuator Pressures and AJ Mixer Pump Voltage

Noticeable shift in all actuator pressure data when AJ Mixer Pump is running, not a real pressure change.

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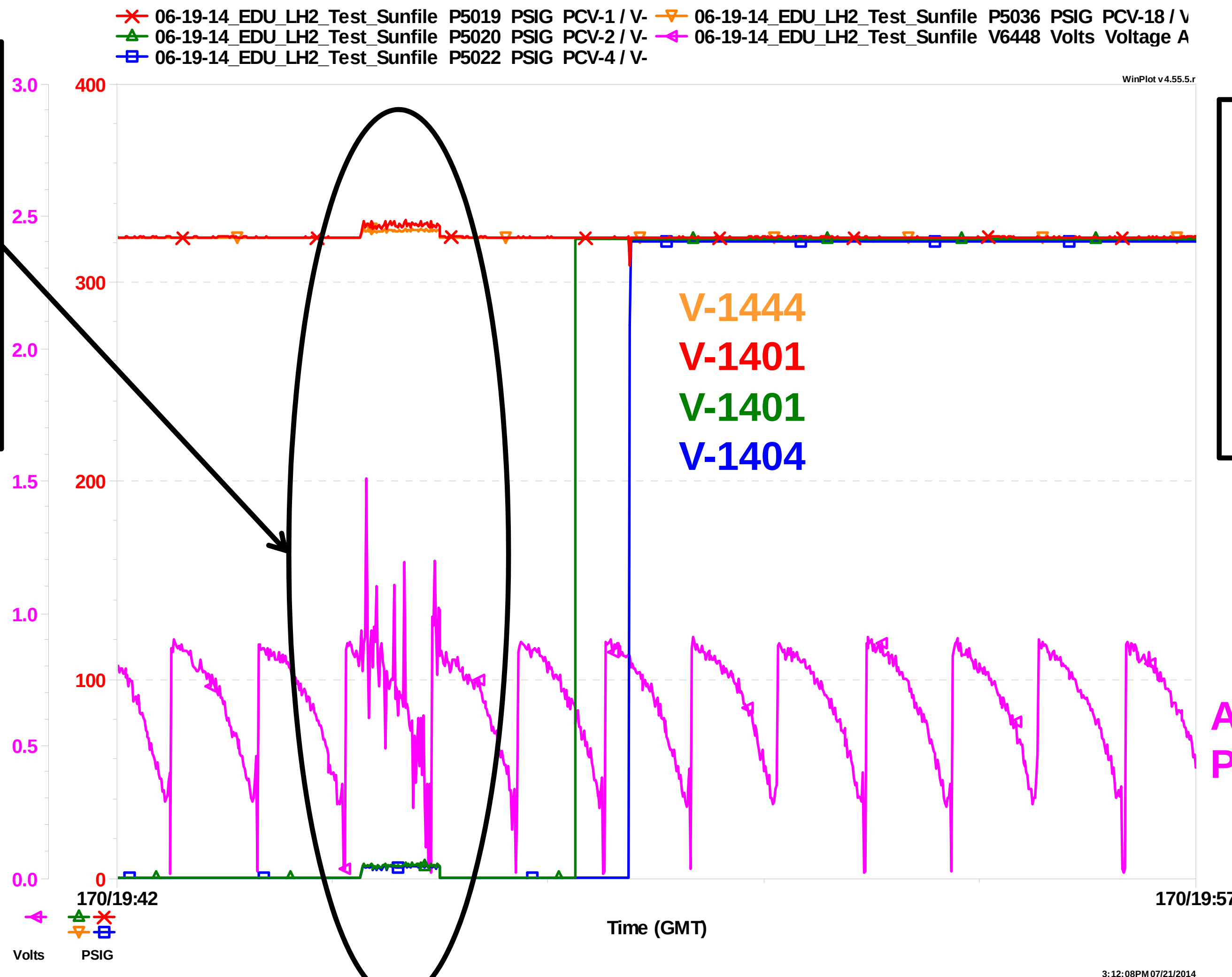


This instance coincides with the AJ Mixer Pump being run at 40 Hz when it had a voltage cutoff.

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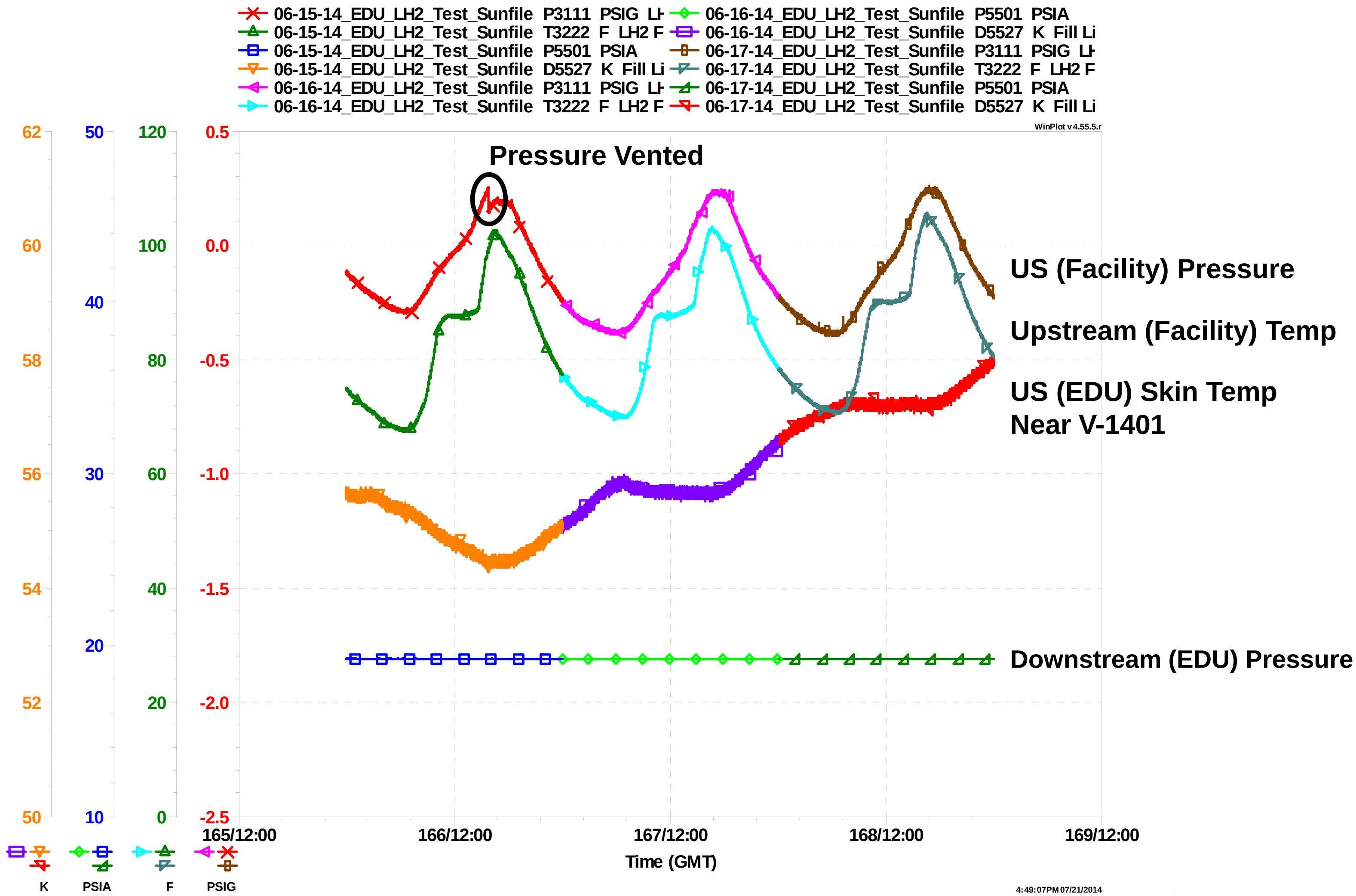
# CPST EDU LH2 Testing Data Observations
# Valve Internal Leakage – Fill/Drain Valve

Data Plot: 6/15 – 6/17 Pressure & Temperature Data for V-1401

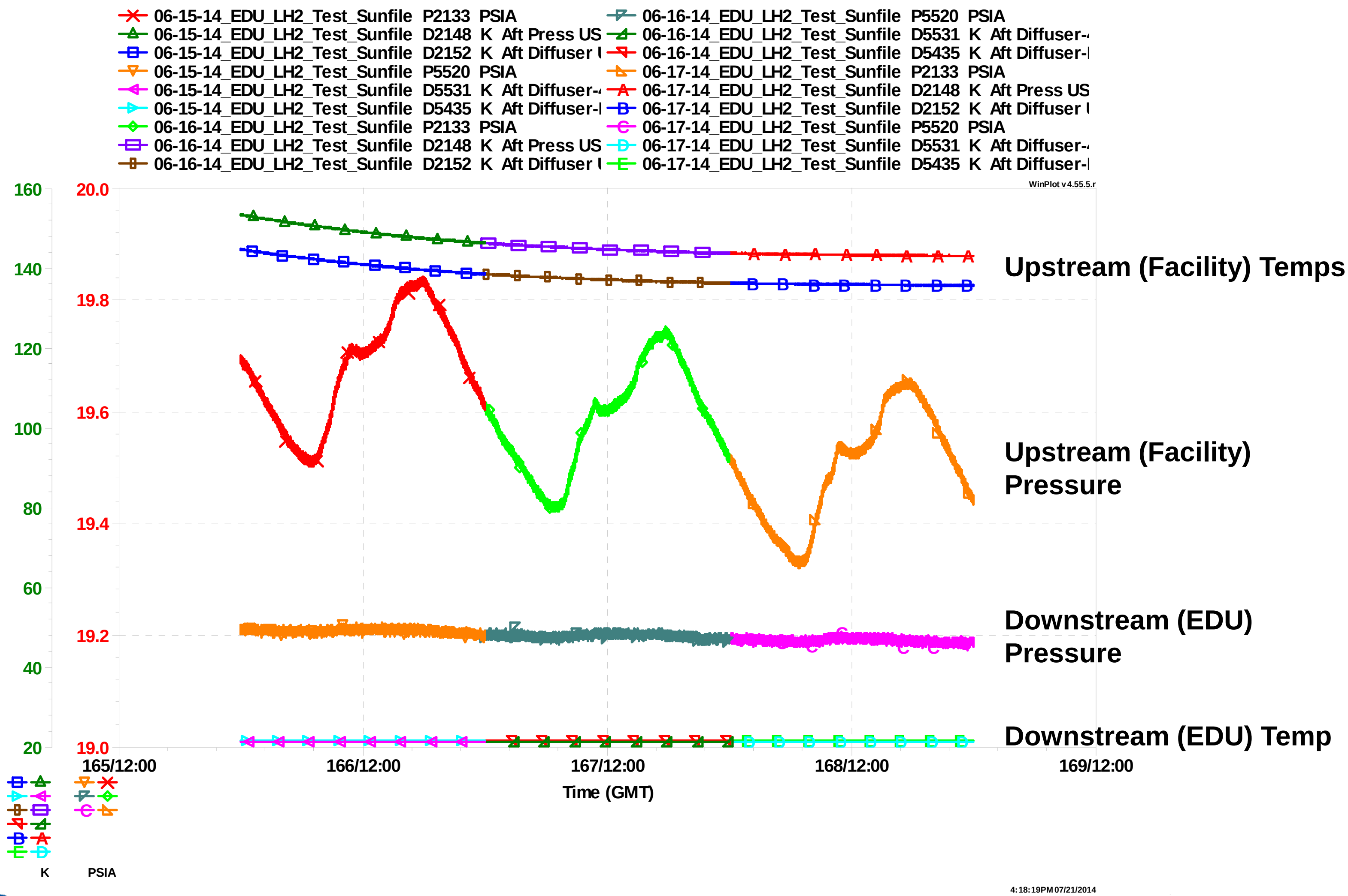
Pressure fluctuations follow daily temperature cycle. Downstream side of valve interfaces with outside of chamber.



# CPST EDU LH2 Testing Data Observations
# Valve Internal Leakage – Tank Bottom Press Iso Valve

## Data Plot: 6/15 – 6/17 Pressure & Temperature Data for V-1444

Pressure fluctuations follow daily temperature cycle. Downstream side of valve interfaces with outside of chamber.



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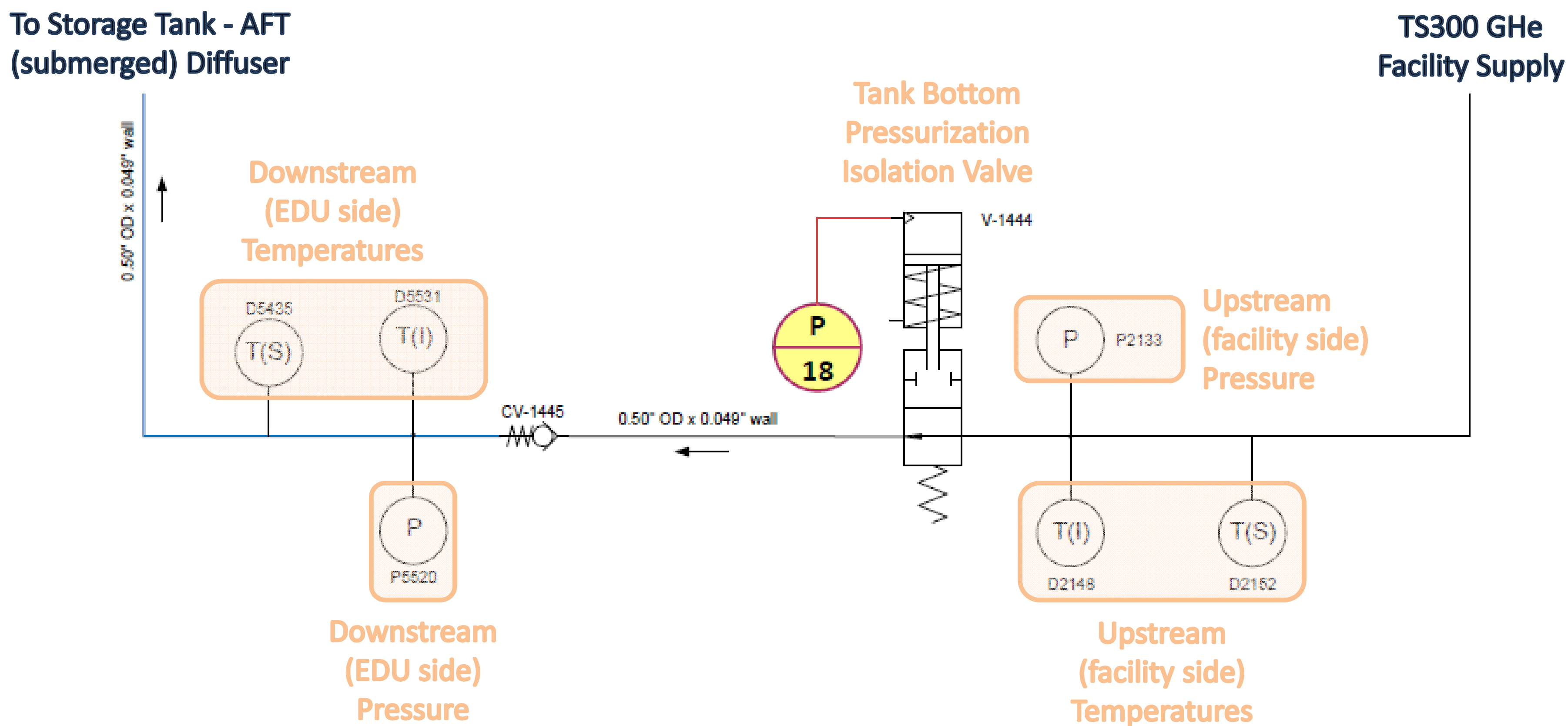
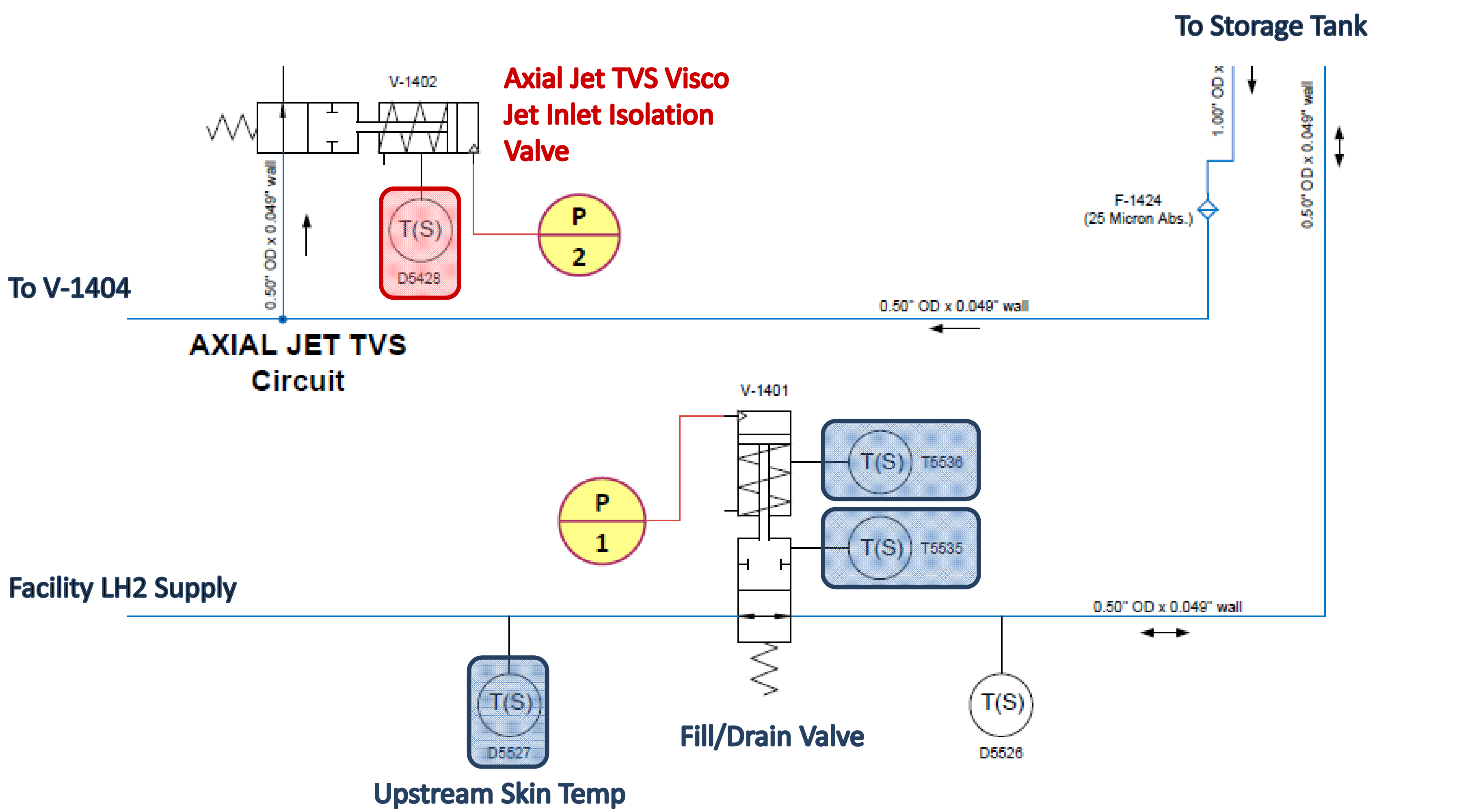
# CPST EDU LH2 Testing Data Observations
# Valve Internal Leakage – Instrumentation Location

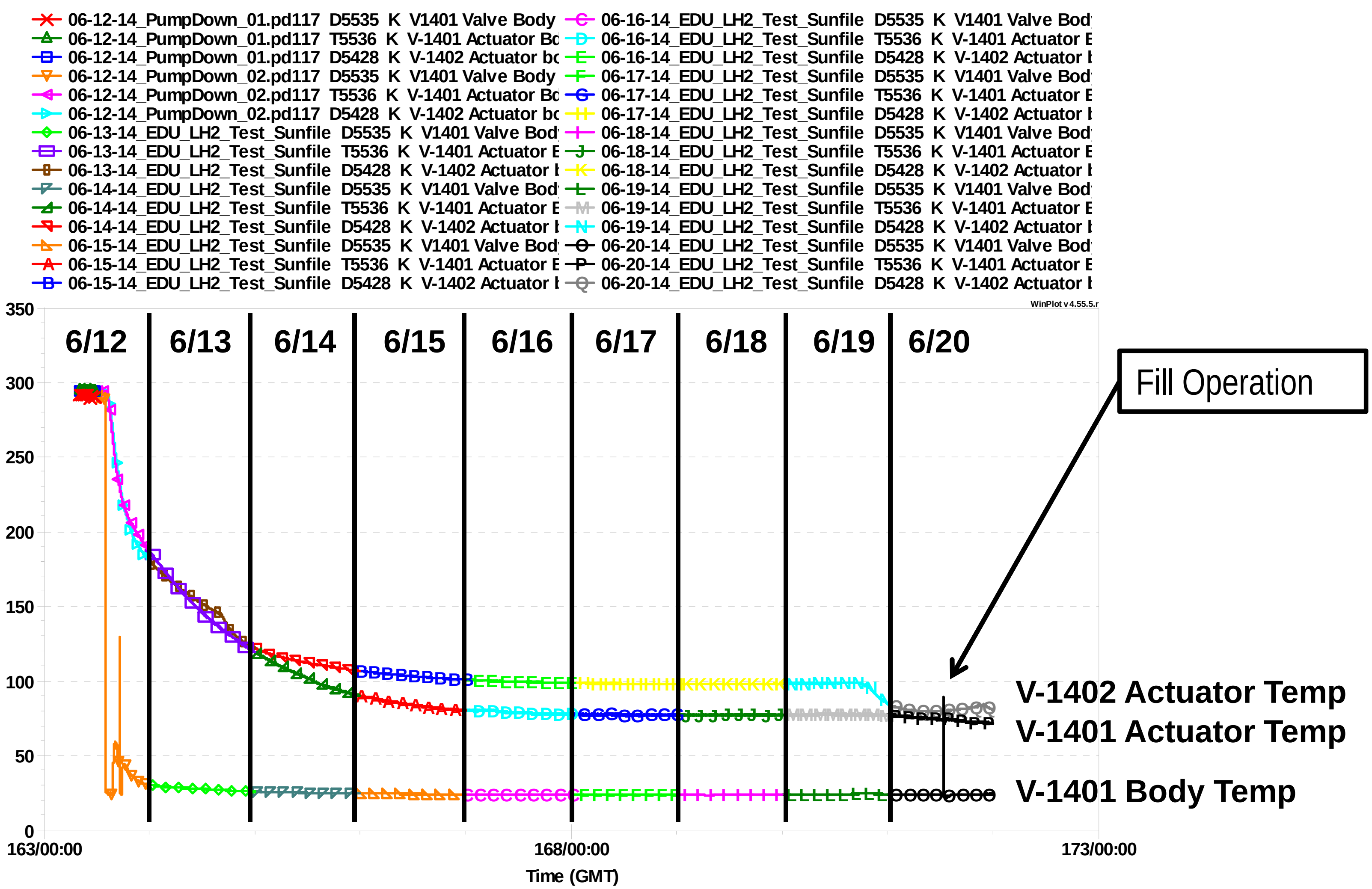


# CPST EDU LH2 Testing Data Observations
# Valve Temperature Measurements



# CPST EDU LH2 Testing Data Observations
# Valve Temperature Measurements

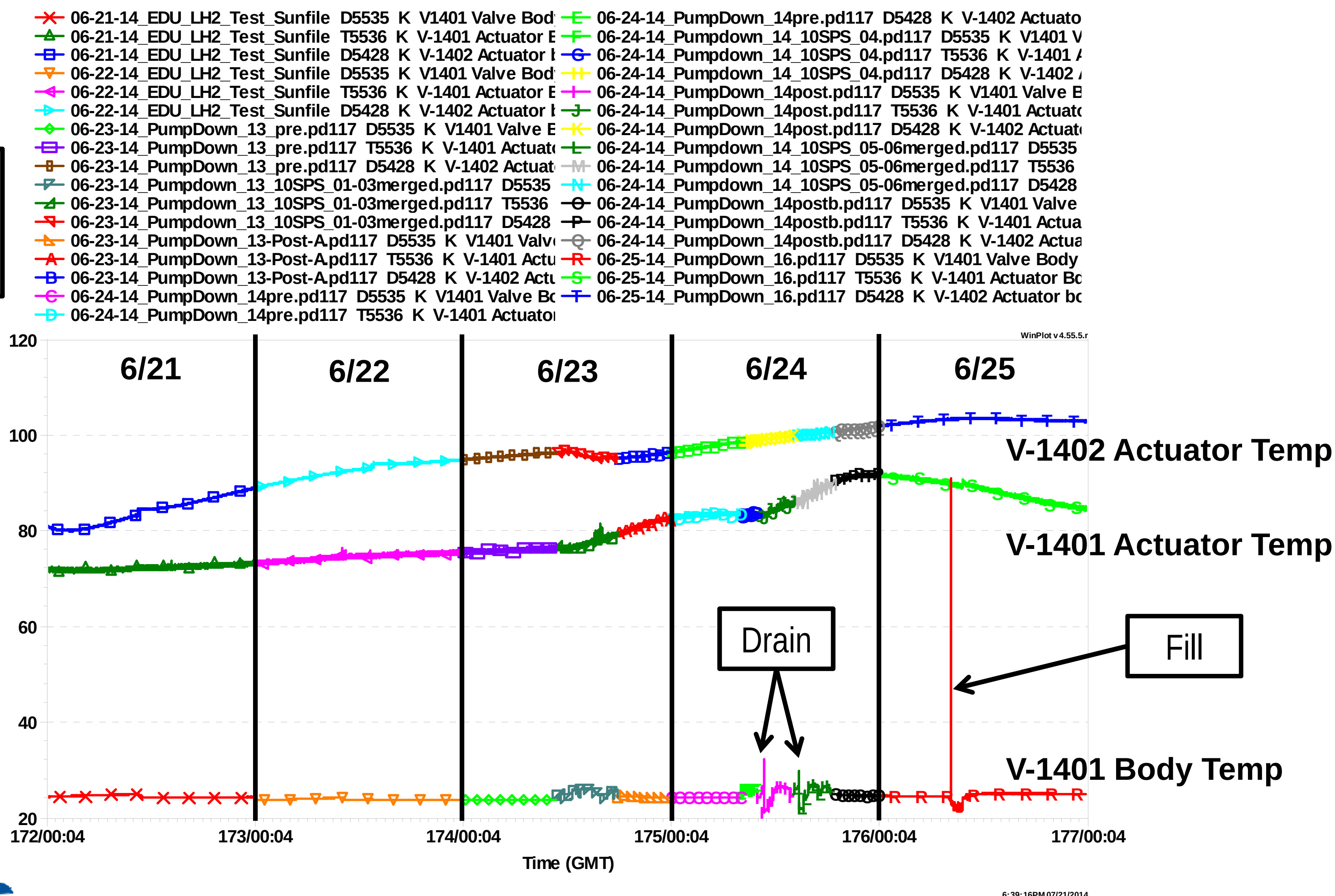
Data Plot: 6/12 – 6/20 V-1401 & V-1402 Valve Body/Actuator Temperatures



# CPST EDU LH2 Testing Data Observations
# Valve Temperature Measurements continued…

## Data Plot: 6/21 – 6/25 V-1401 & V-1402 Valve Body/Actuator Temperatures

Pressurization Testing on 6/23 & 6/24

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# CPST EDU LH2 Testing Data Observations
# Valve Temperature Measurements continued…

## Data Plot: 6/26 – 7/7 V-1401 & V-1402 Valve Body/Actuator Temperatures

LAD Outflow Testing on 6/30 & 7/1