Liquid Acquisition Device Hydrogen Outflow Testing on the Cryogenic Propellant Storage and Transfer Engineering Design Unit

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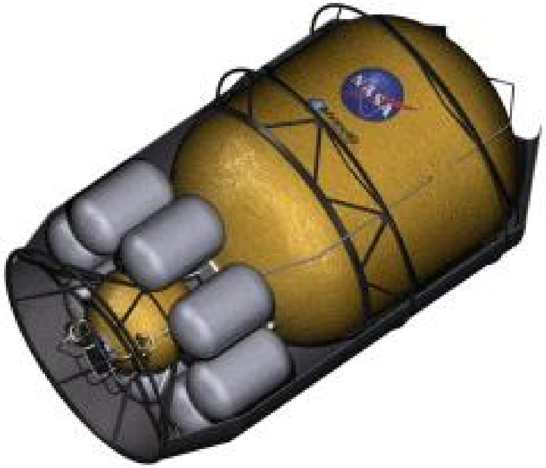
Introduction

Cryogenic Propellant Storage and Transfer (CPST) mission and the EDU

- CPST was being developed by NASA under the Space Technology Mission Directorate to demonstrate cryogenic fluid management technologies (storage, liquid acquisition, transfer, gauging) in space for up to 3 months
- An Engineering Development Unit (EDU) was built to provide a "Proof of Manufacturability" for the Flight Article.
- The Flight article was not built due to reformulation of the project at the direction of the STMD office.
- Ground based LH2 testing of the EDU was completed
- This talk focuses on the liquid acquisition device data



CPST concept

Screen channel Liquid Acquisition Device

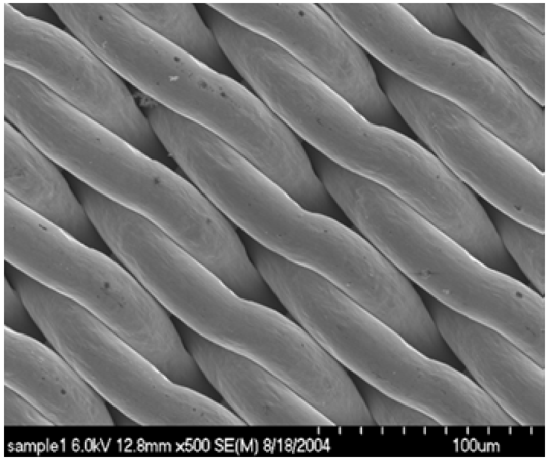
- Construction
  - U-shaped channel; open side is covered with stainless steel screen
  - Screen side faces tank wall
  - Wetted screen pores allow liquid to pass through, but prevent vapor ingestion up to the bubble point pressure, ΔP_{BP}

$$\Delta P_{BP} = \frac{4\gamma}{D_P}$$

γ, surface tension
D_P, effective pore diameter

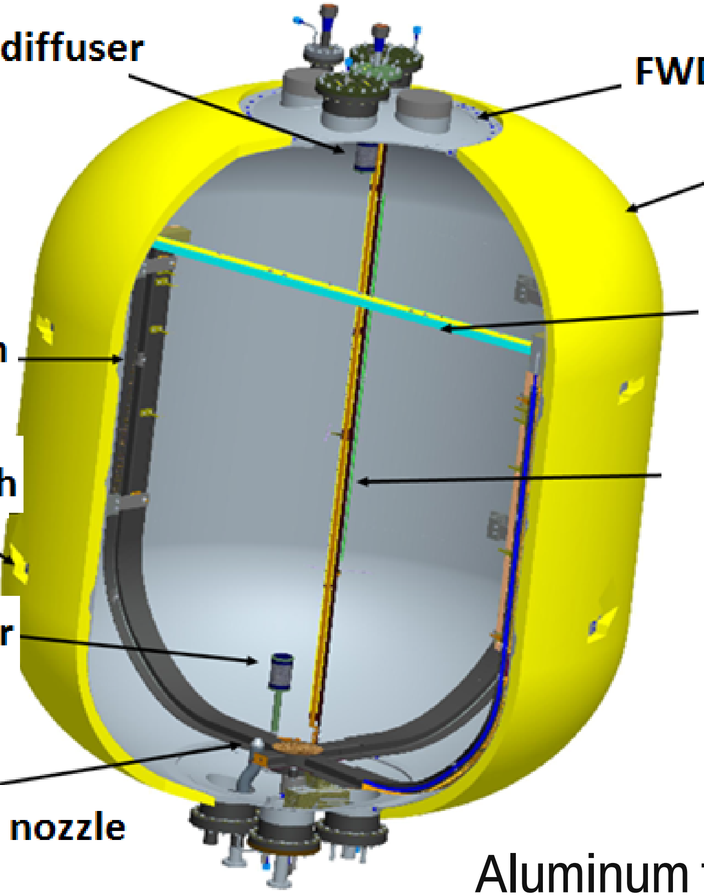
- Advantages
  - Screen channel LAD's support higher flow rates
  - More robust against adverse accelerations (spacecraft maneuvers)
  - Can be characterized to some degree in 1g

- Disadvantages
  - Complex construction
  - LAD channel not easily refilled in presence of non-condensable pressurant gas

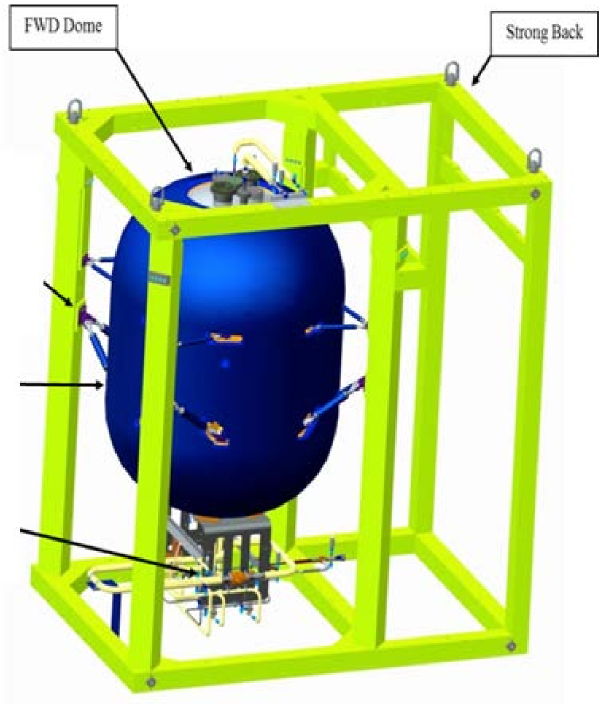


Dutch twill weave, 325 x 2300 weaves/inch

EDU test article



Aluminum tank
67" x 91"

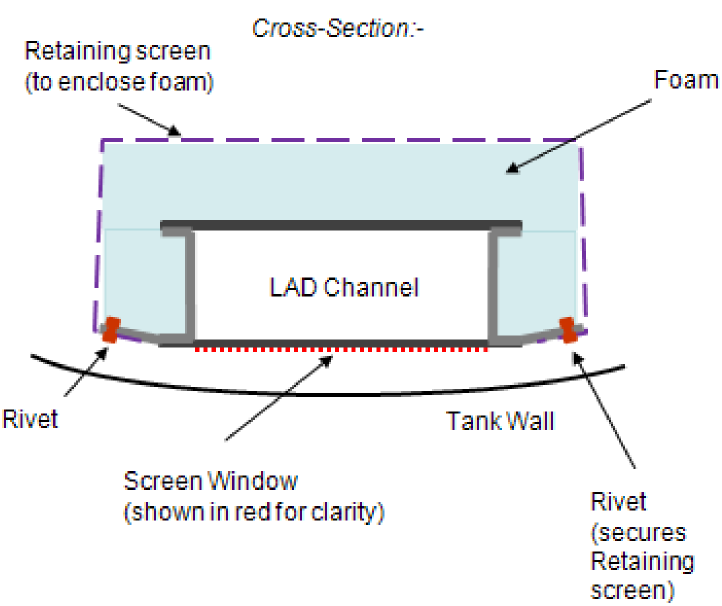


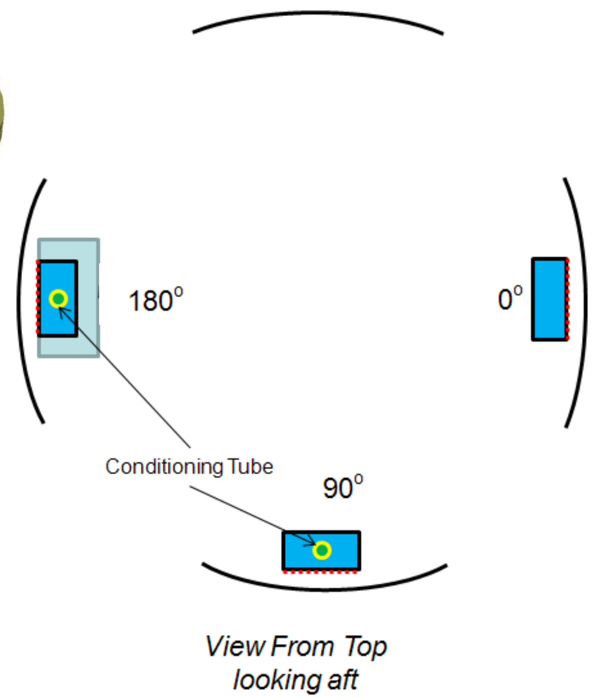
- LH2 testing conducted at MSFC TS-300
- 20 days of testing to quantify performance of various subsystems (6/12/14 – 7/1/14)

EDU liquid acquisition device (LAD) design

- 325 x 2300 screen channel gallery arms (based on seam welding capability)
- LAD arms extended only to the top of the storage tank barrel
- Three (3) different LAD configurations to determine the best method for mitigating heat transfer into LAD arms

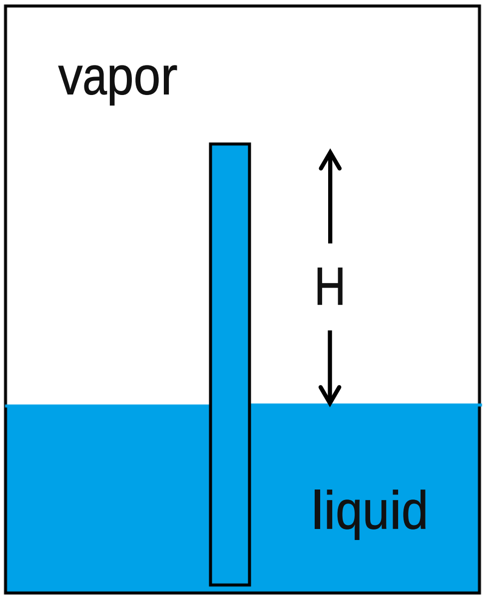
  - Bare LAD; +TVS conditioning (did not function); + Foam insulation





LAD breakdown

In 1g, the screen channel LAD can support a liquid filled vertical column up to some height, H_max



$$H\_\max = \frac{\Delta P_{BP}}{(\rho_L - \rho_V)g} = \frac{4\gamma}{(\rho_L - \rho_V)gD_P}$$

For the 325x2300 screen mesh used in these tests, D_P = 14.0 microns

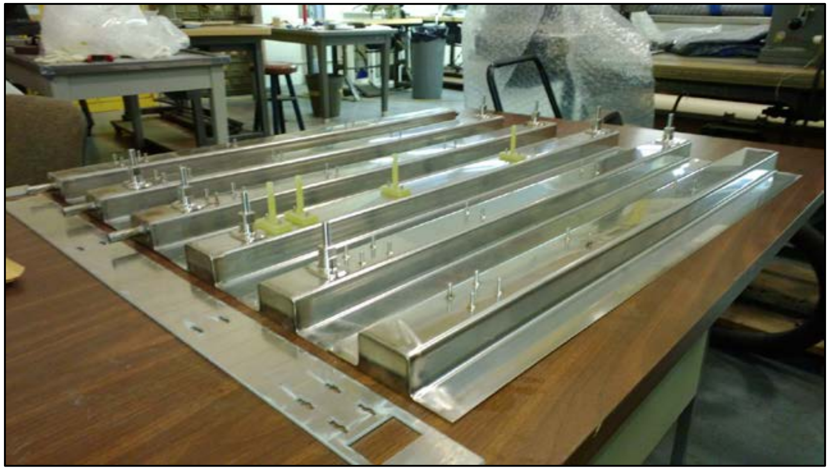
Fluid	γ/Δρ (m³/s²)	H_max (m)
Hydrogen	2.77 E-5	0.81
Oxygen	1.16 E-5	0.34
Methane	3.16 E-5	0.92

- LAD screen "breakdown" happens when the pressure exceeds the bubble-point pressure (e.g., H > H_max) and vapor is ingested.
- Fluid flow creates additional pressure drop (decreasing H)

LAD Manufacturing

Curved Arm Perforated Plate/Screen Assembly

Back Side – LAD Straight Sections



Screen Side – LAD Straight Sections

LAD's were bubble-point tested to 0.8 psid in IPA prior to integration

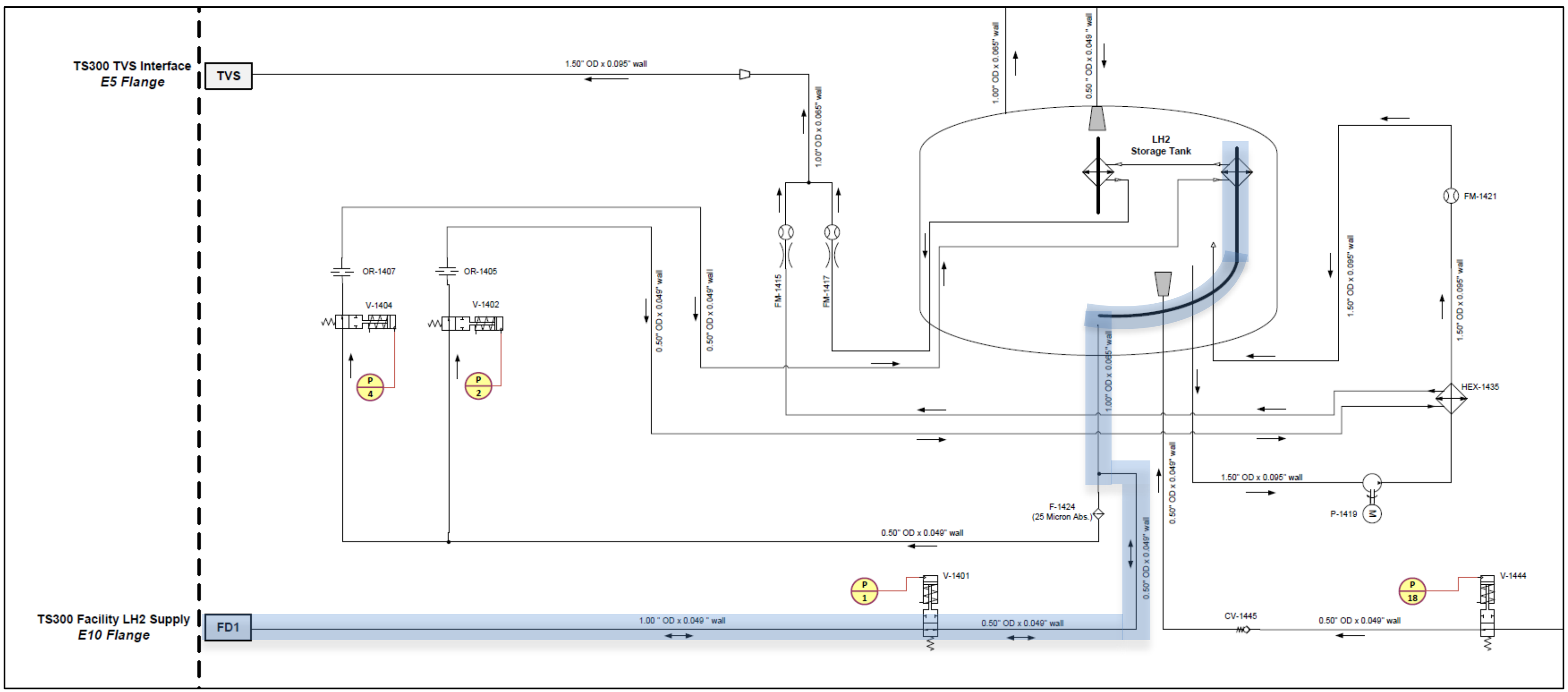
LAD assembly and installation

Connection to tank outlet

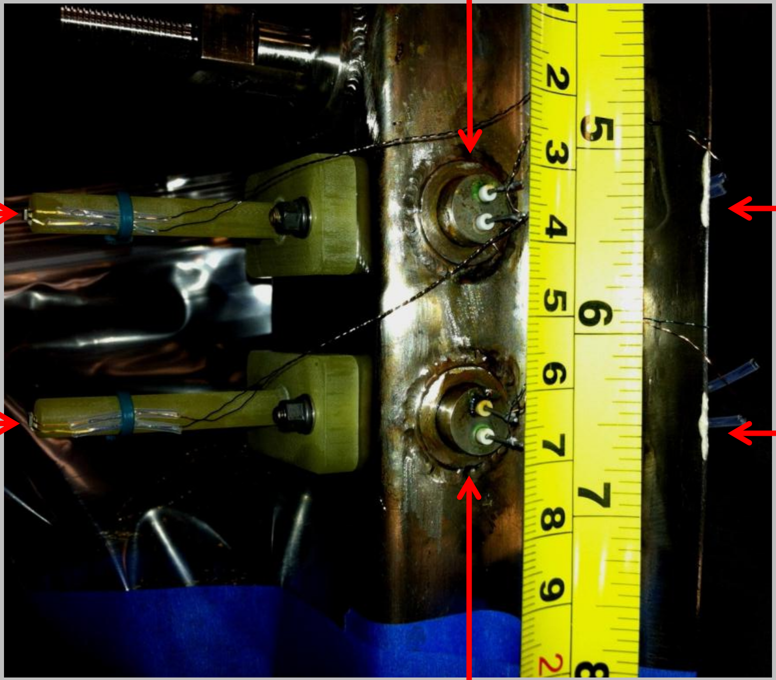
Integrated into tank shell

Tank fill/drain operation

- The excerpt from the CPST EDU Schematic Rev B below shows the fill/drain flow path.
- All storage tank fill and drain operations are through the LADs. There is not an alternate path for either fill or drain operations.



LAD silicon diode sensors (Temperature, wet-dry)



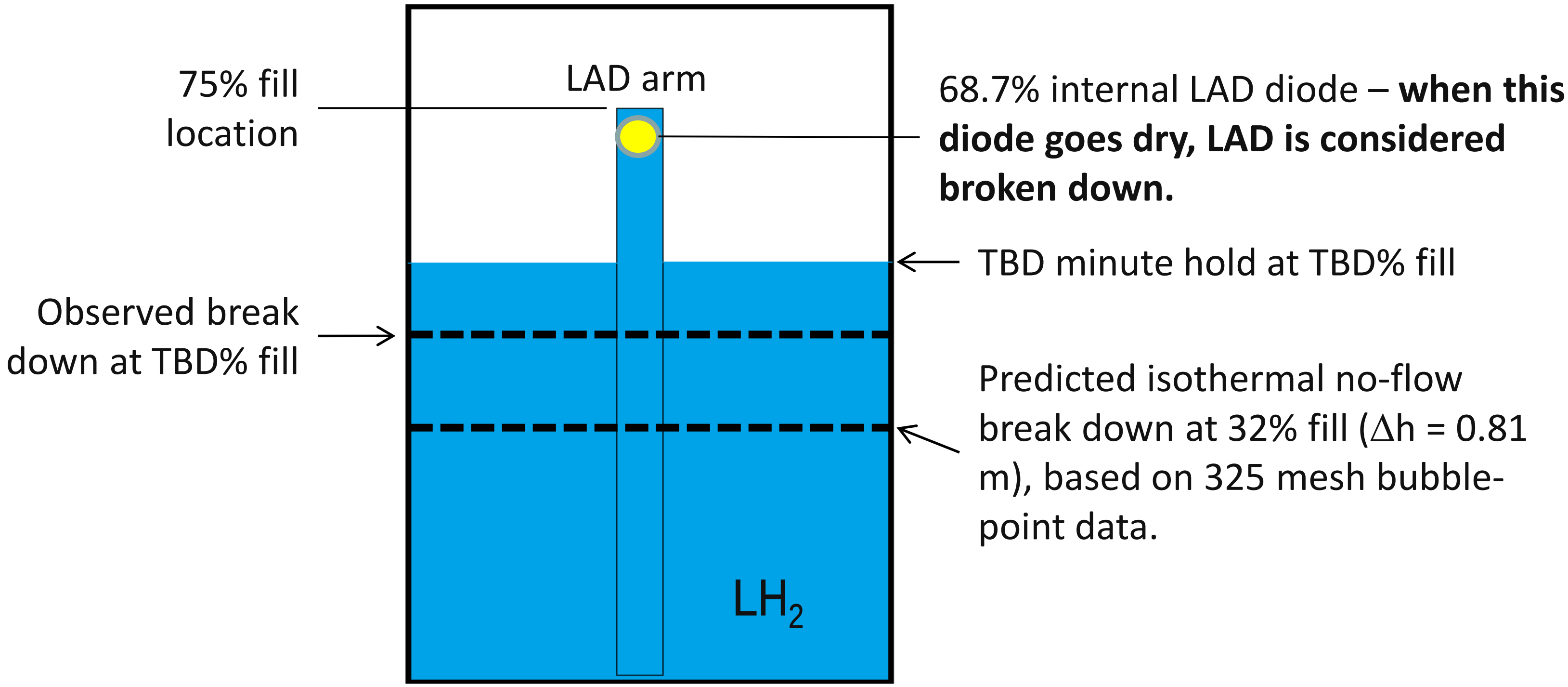
Diode Not Functional for LH2 Test (red)

Diodes Shown in Picture (yellow)

Station Level	Fill Level	Distance from Tank Bottom	LAD Arm 2: 180 Degree Arm			LAD Arm 3: 90 Degree Arm			LAD Arm 4: 0 Degree Arm		
			Screen	Internal	External	Screen	Internal	External	Screen	Internal	External
A	68.7%	85.2"	D4413	D4414	D4415	D4425	D4426	D4427	D4437	D4438	D4439
B	66.7%	80.2"	D4416	D4417	D4418	D4428	D4429	D4430	D4440	D4441	D4442
C	58.3%	77.3"	D4419	D4420	D4421	D4431	D4432	D4433	D4443	D4444	D4445
D	43.7%	76.4"	D4422	D4423	D4424	D4434	D4435	D4436	D4446	D4447	D4448

LAD testing and "breakdown"

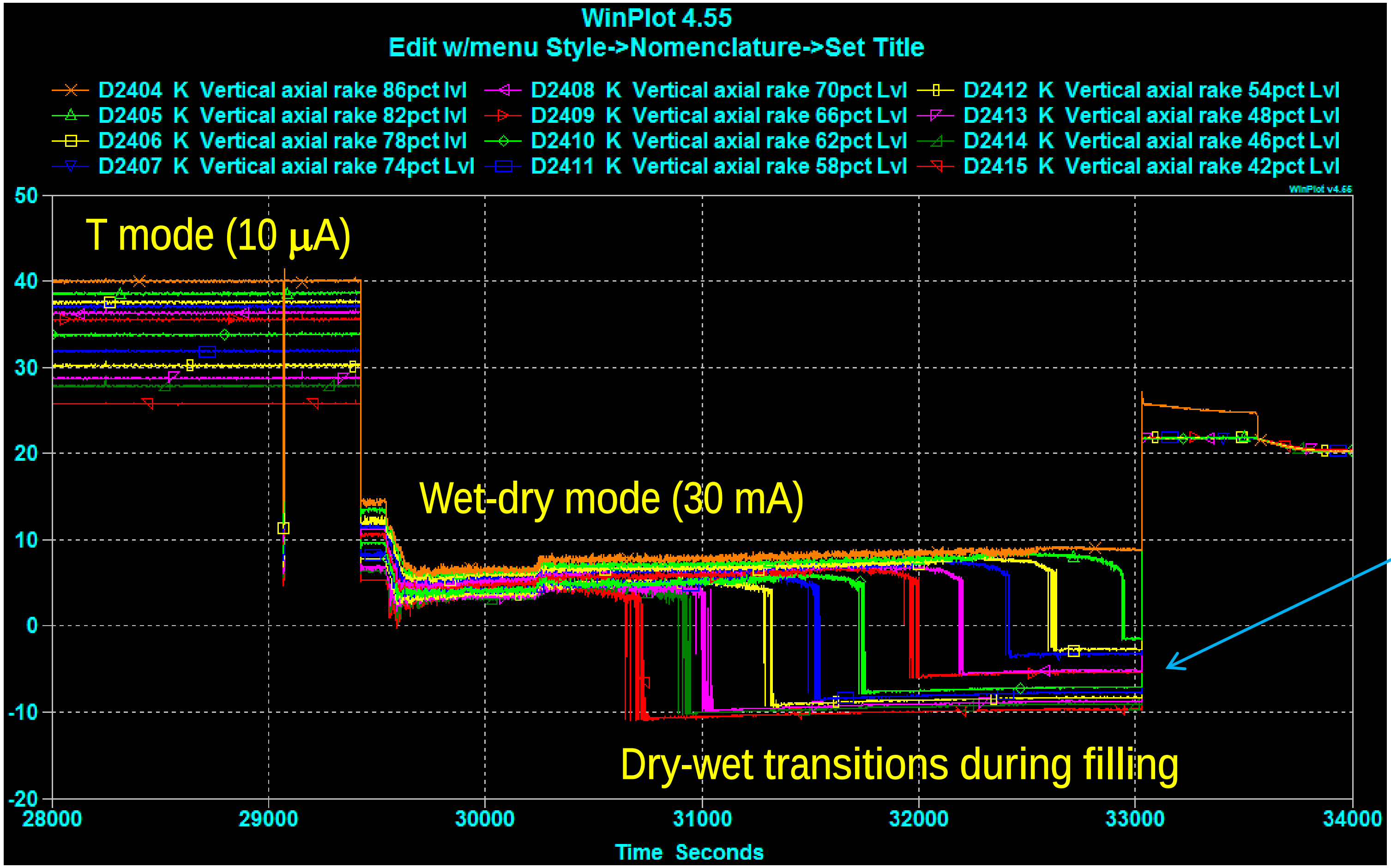
- Tank is initially filled above 75% fill, completely submerging the LAD
- Tank level decreases due to boil-off and outflow tests
- LAD diodes are monitored to determine when gas has been ingested ("breakdown")
- Tank is refilled to conduct more tests



Silicon diode data

Silicon diodes are run "hot" (30 mA) when in wet-dry mode.

- The T reading during wet-dry mode is obviously not accurate. It is based on an DT- 670 voltage vs T table (valid for 10 μA) extrapolated to negative temperatures

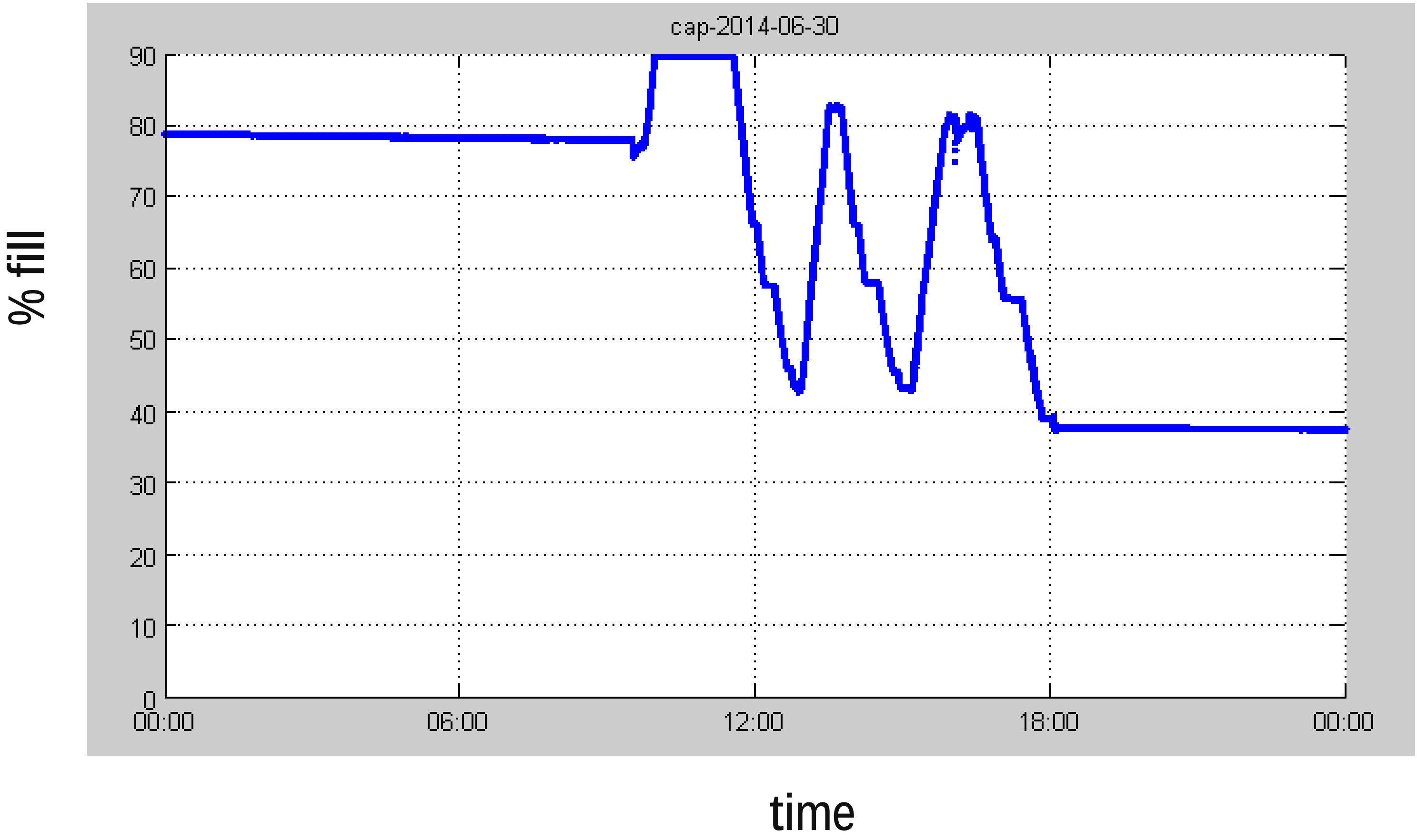


- Different offsets in the transition value are due to lead resistance
- This did not affect the analysis, which was done manually

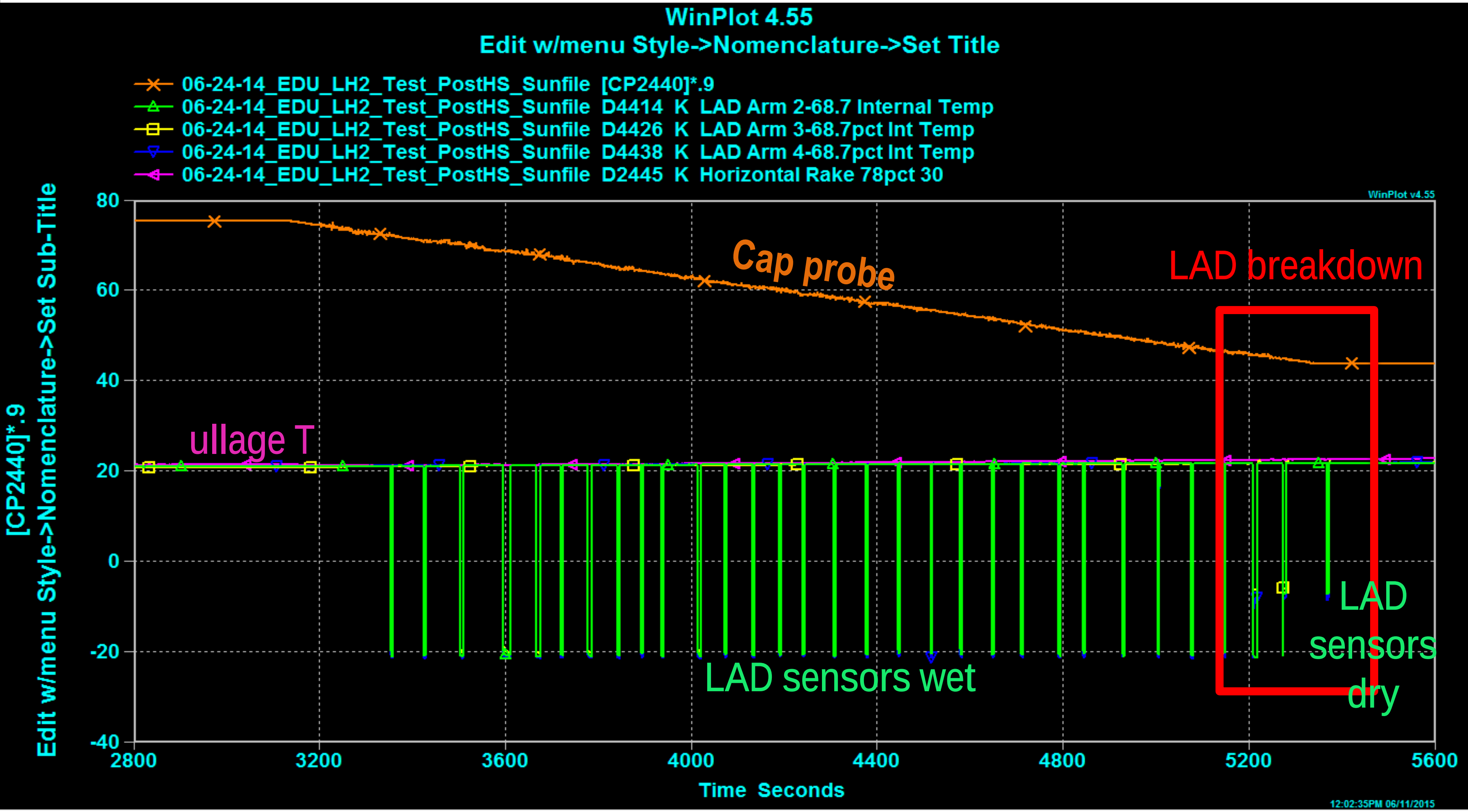
LAD test events

- Data was analyzed from the following test events:
  - Day 13, LAD outflow #1
  - Day 19, LAD outflow #2-4
  - Day 20, LAD outflow #5, 6

Day 19; Outflow tests 2-4



LAD outflow #1, cold helium (AFT diffuser)

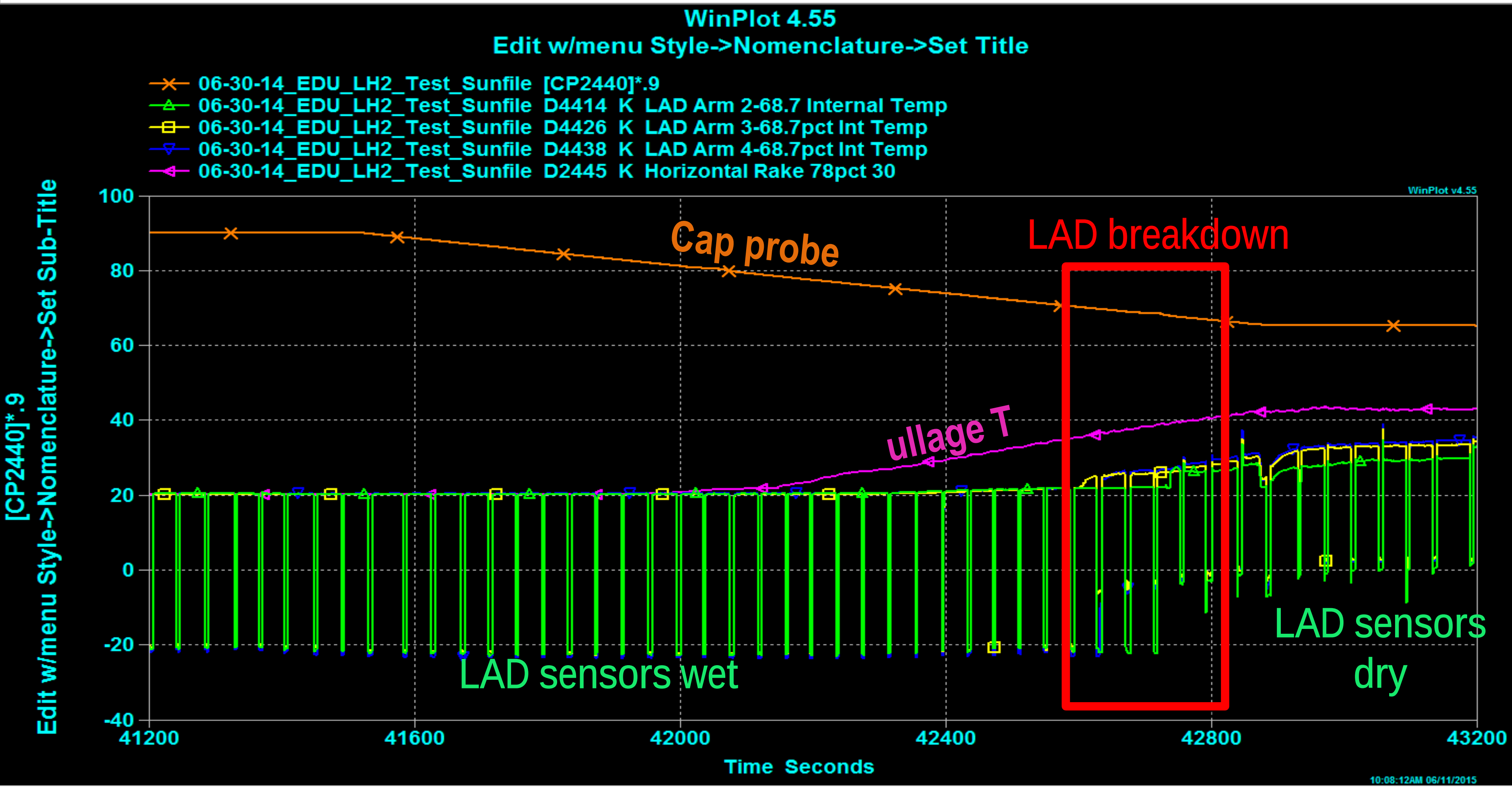


All three LAD arms break down between 44% - 46% fill level

Ullage temperature near LAD is 22.4K

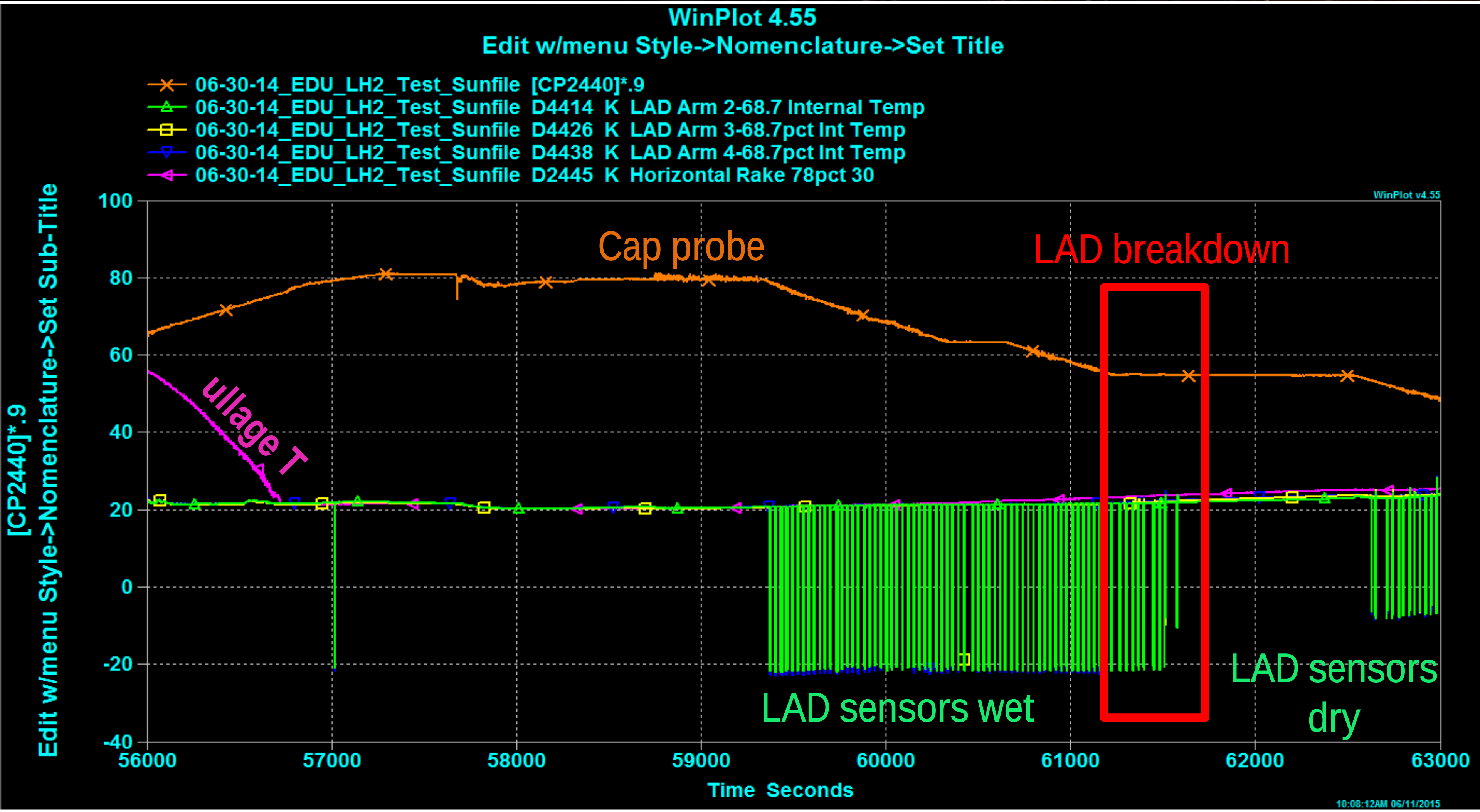
(Top of LAD is at 75%; predicted isothermal, static breakdown is at 32% fill)

LAD outflow test #2, warm Helium (FWD diffuser)



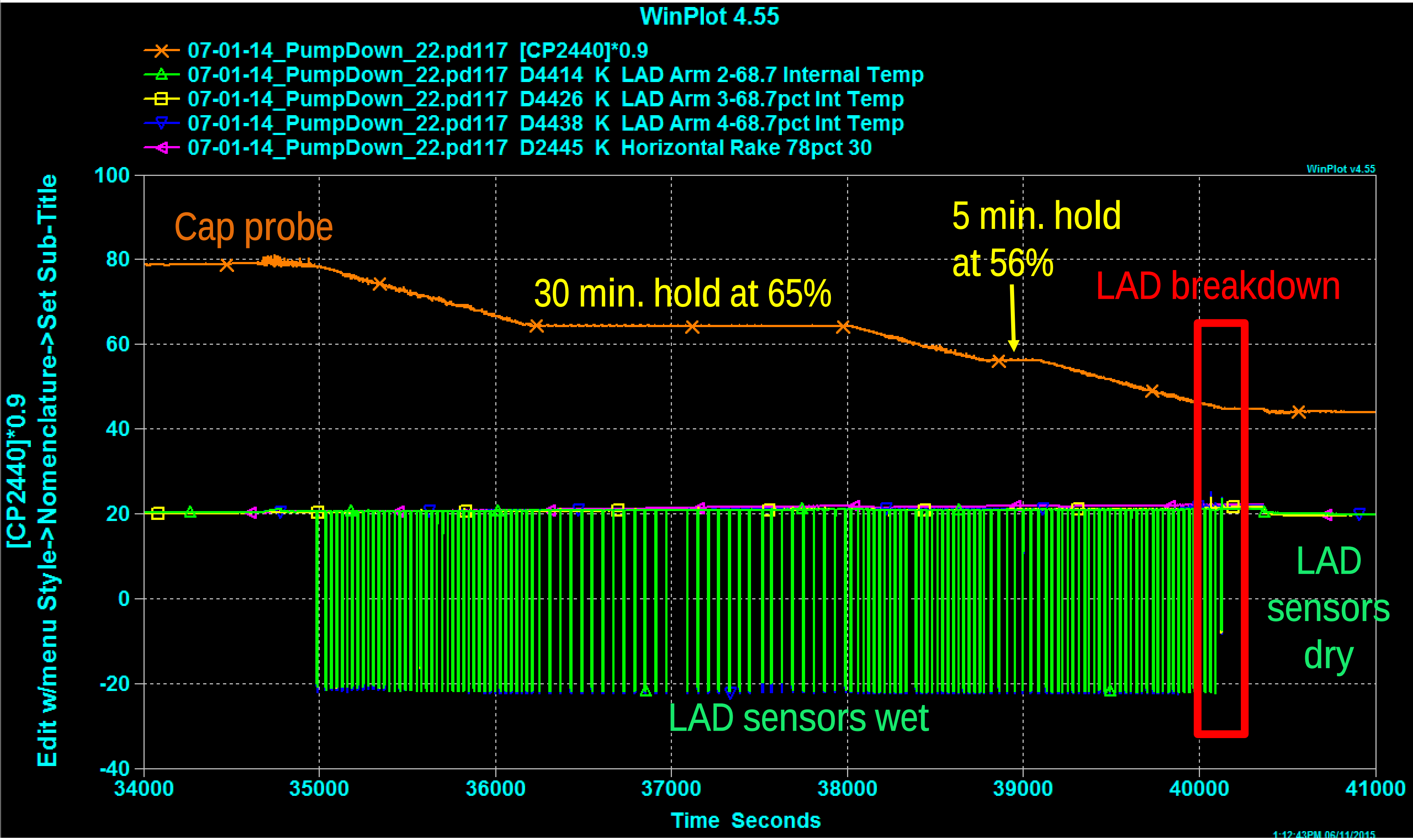
All three LAD arms break down between 67% - 70% fill level (foam-insulated LAD is last to breakdown)
Ullage temperature near LAD is 35 – 40 K
(Top of LAD is at 75%; predicted isothermal breakdown is at 32% fill)
LAD outflow tests #3 and #6, warm helium, shows similar result

LAD outflow #4; cold helium (AFT diffuser)



All three LAD arms break down between 55% - 56% fill level (approaching and during the no-flow hold)
Ullage temperature near LAD is 23.5 K
(Top of LAD is at 75%; predicted isothermal, static breakdown is at 32% fill)

Lad outflow #5; cold helium (AFT diffuser)



All three LAD arms break down between 45% - 47% fill level

Ullage temperature near LAD is 22.0K

LAD outflow summary

Test Day	Event	Liquid Level (%)	Holds	Pressure Source	Ullage Temp (K)	Ullage Pressure (psia)	Flow rate (GPM)	Column height at breakdown (cm)
13	LAD Outflow #1	45	N/A	AFT	22	32	9.7	57
19	LAD Outflow #2	68	N/A	FWD	35-40	32	12.4	13
19	LAD Outflow #3	67	N/A	FWD	35-40	32	12.5	15
19	LAD Outflow #4	55	5m @63% 5m@55%	AFT	24	32	9.8 to 0	38
20	LAD Outflow #5	45	30m@65% 5m@56%	AFT	22	23	7.3	57
20	LAD Outflow #6	68	N/A	FWD	32	23	7.9	13

- Warmer ullage temperature has adverse effect on breakdown height
- Warmer fluid at screen affects local surface tension

$$H\_\max = \frac{\Delta P_{BP}}{(\rho_L - \rho_V)g} = \frac{4\gamma}{(\rho_L - \rho_V)gD_P}$$

- Flow through the screen also creates a pressure drop, which would further decrease the column height at breakdown (forward work)
- Warm pressurant may be OK if accompanied by a large reduction in g

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