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

Space Cryogenics Workshop

June 25-26, 2015

Phoenix, AZ

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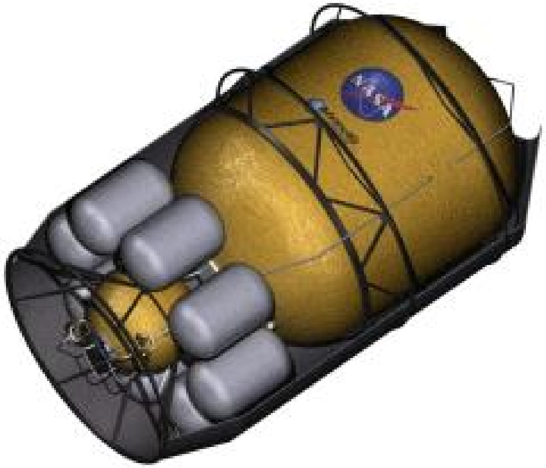
Introduction

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

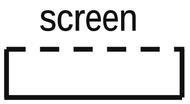
- CPST was being developed by NASA under the Space Technology Mission Directorate to demonstrate cryogenic fluid management technologies (storage, liquid acquisition, transfer, gauging) in space for up to 3 months
- An Engineering Development Unit (EDU) was built to provide a “Proof of Manufacturability” 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}

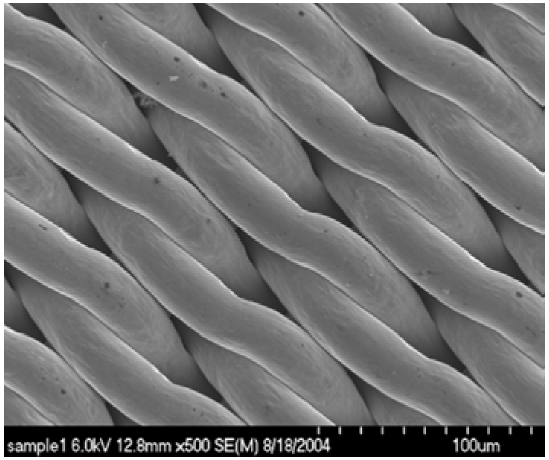


$$\Delta P_{BP} = \frac{4\gamma}{D_P}$$

γ, surface tension
D_P, effective pore diameter

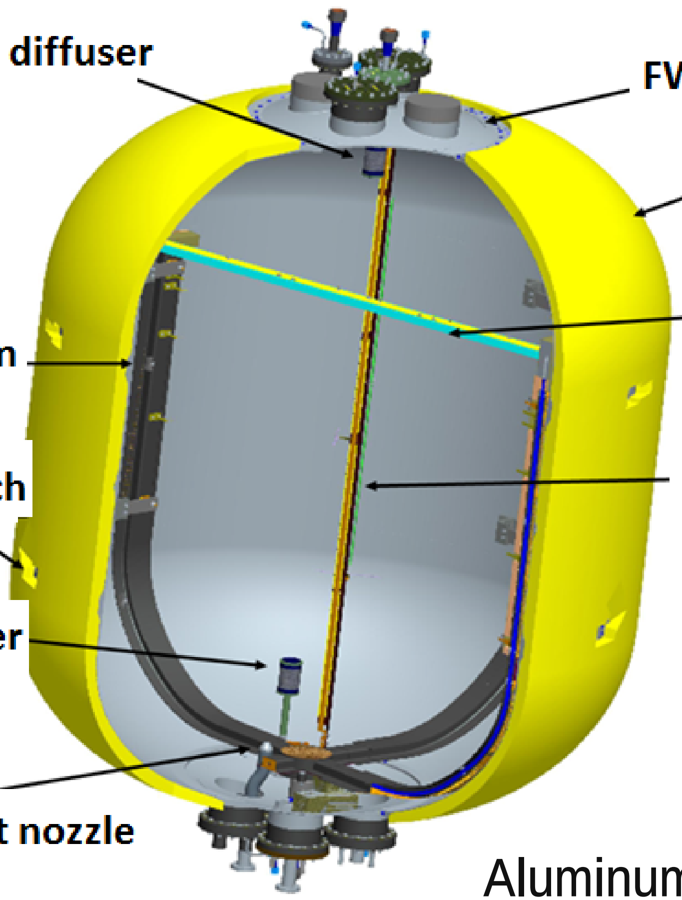
- Advantages
  - Screen channel LAD's support higher flow rates
  - More robust against adverse accelerations (spacecraft maneuvers)
  - Can be characterized to some degree in 1g

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

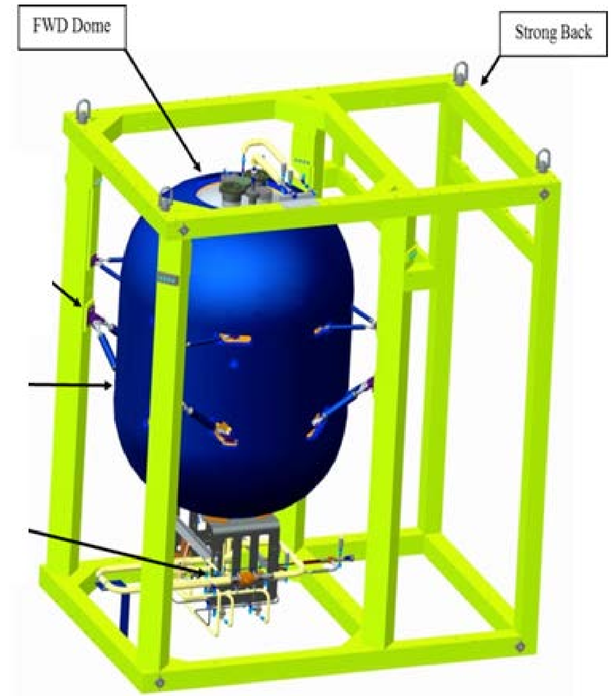


Dutch twill weave, 325 x 2300 weaves/inch

EDU test article



Aluminum tank
67" x 91"

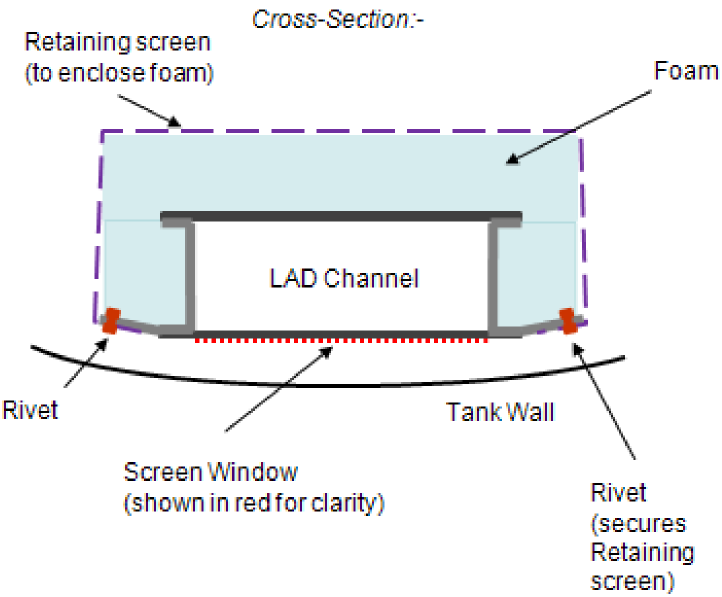


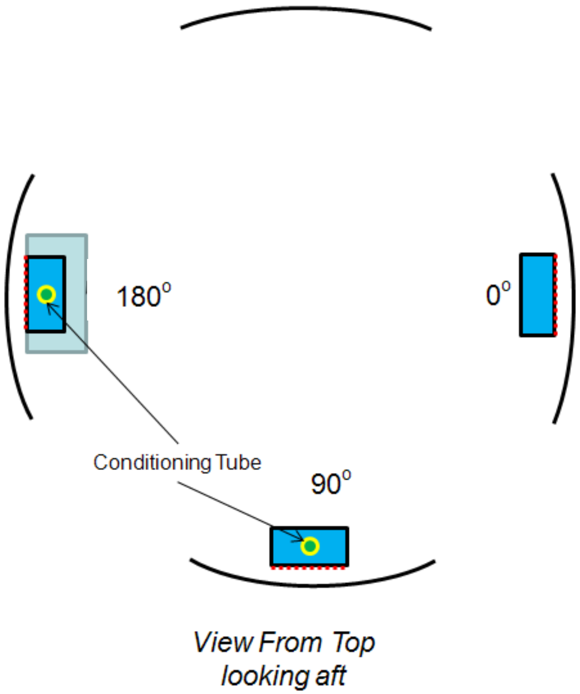
- LH2 testing conducted at MSFC TS-300
- 20 days of testing to quantify performance of various subsystems (6/12/14 – 7/1/14)

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

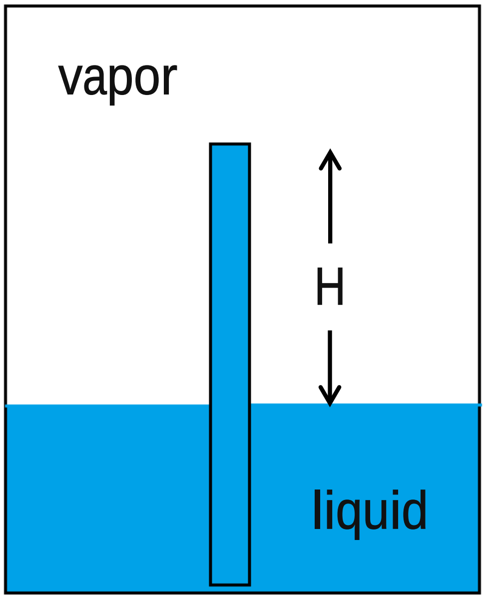
  - Bare LAD; +TVS conditioning (did not function); + Foam insulation





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

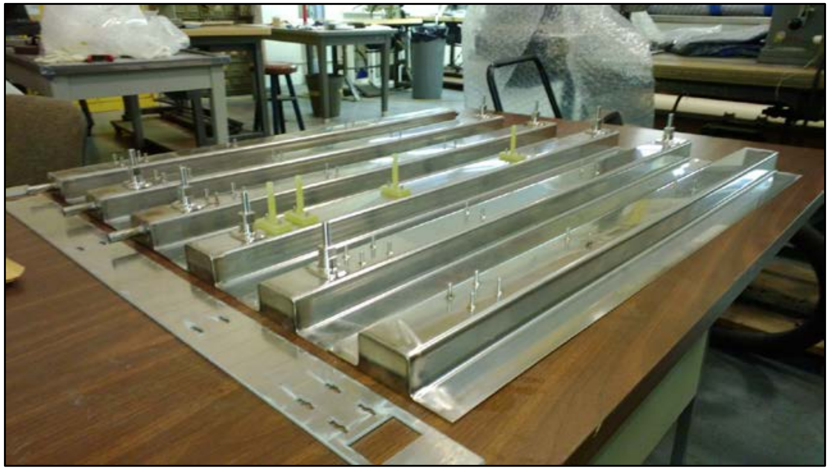
Fluid	γ/Δρ (m³/s²)	H_max (m)
Hydrogen	2.77 E-5	0.81
Oxygen	1.16 E-5	0.34
Methane	3.16 E-5	0.92

- 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

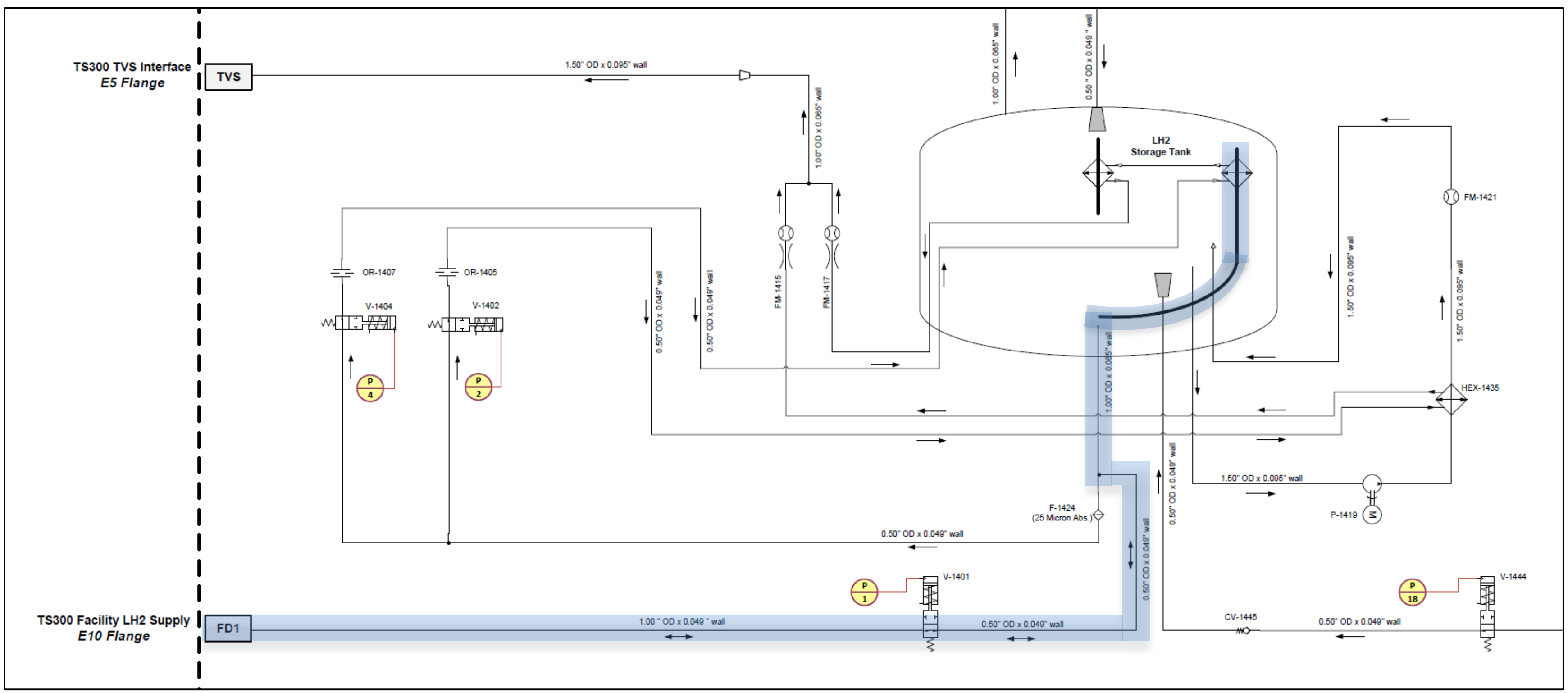
LAD assembly and installation

← 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)

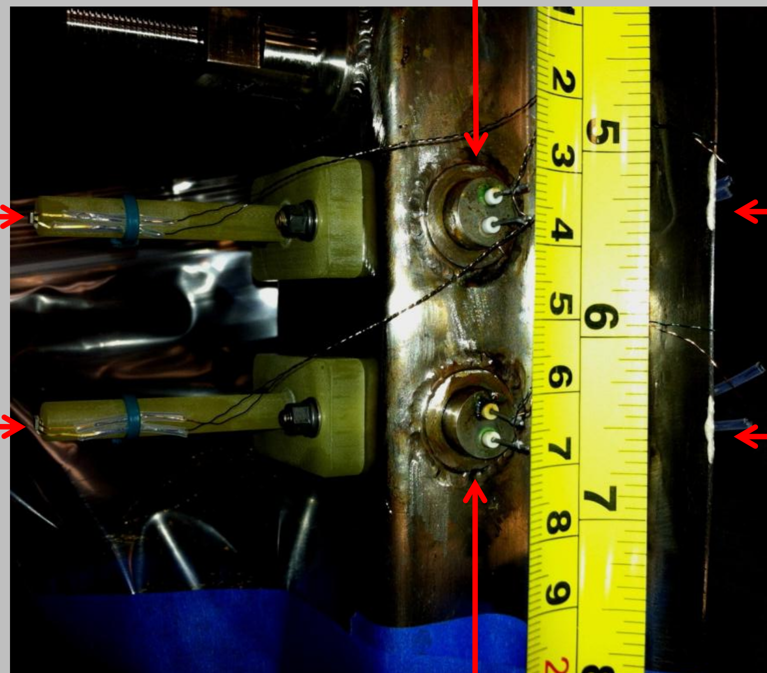
Internal Diode
D4438

External Diode
D4439

Screen Diode
D4437

External Diode
D4442

Screen Diode
D4440



Internal Diode
D4441

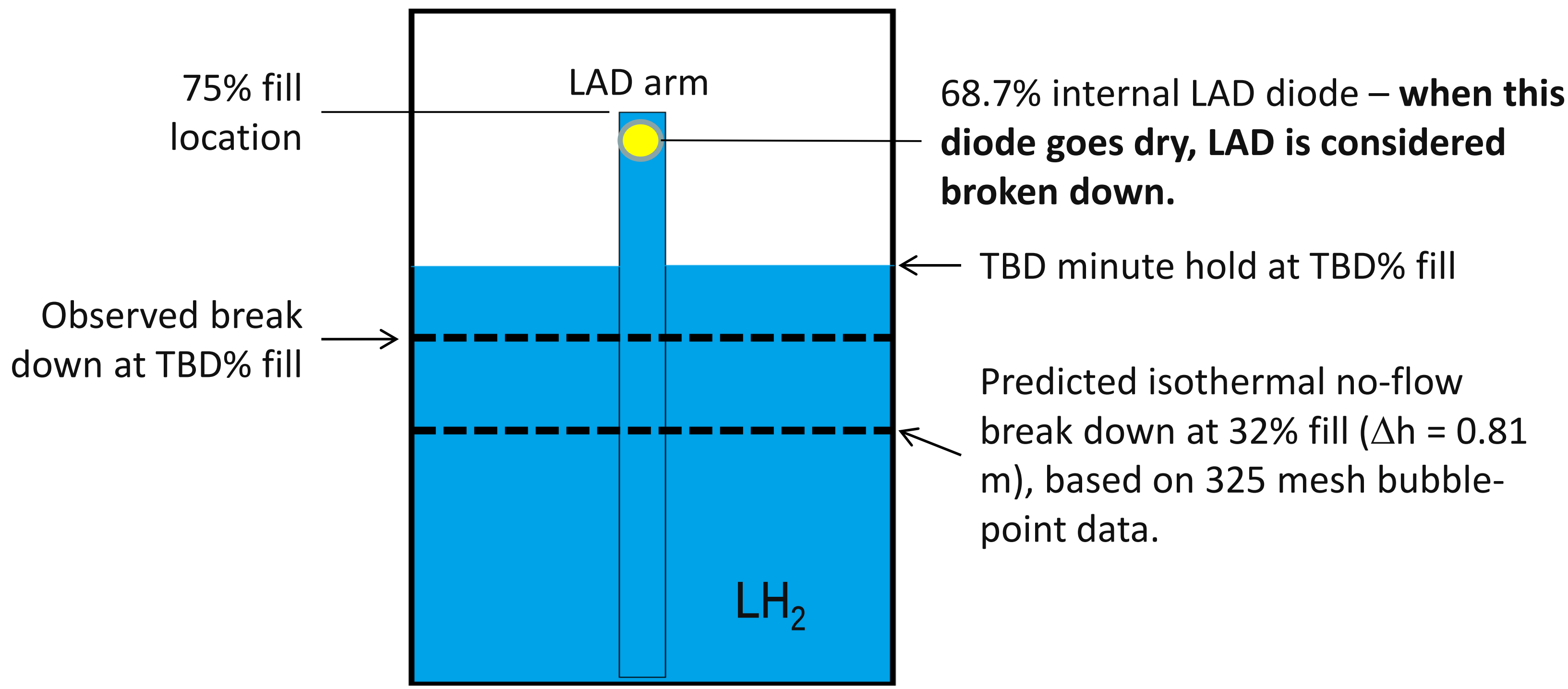
Diode Not Functional for LH2 Test

Diodes Shown in Picture

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"

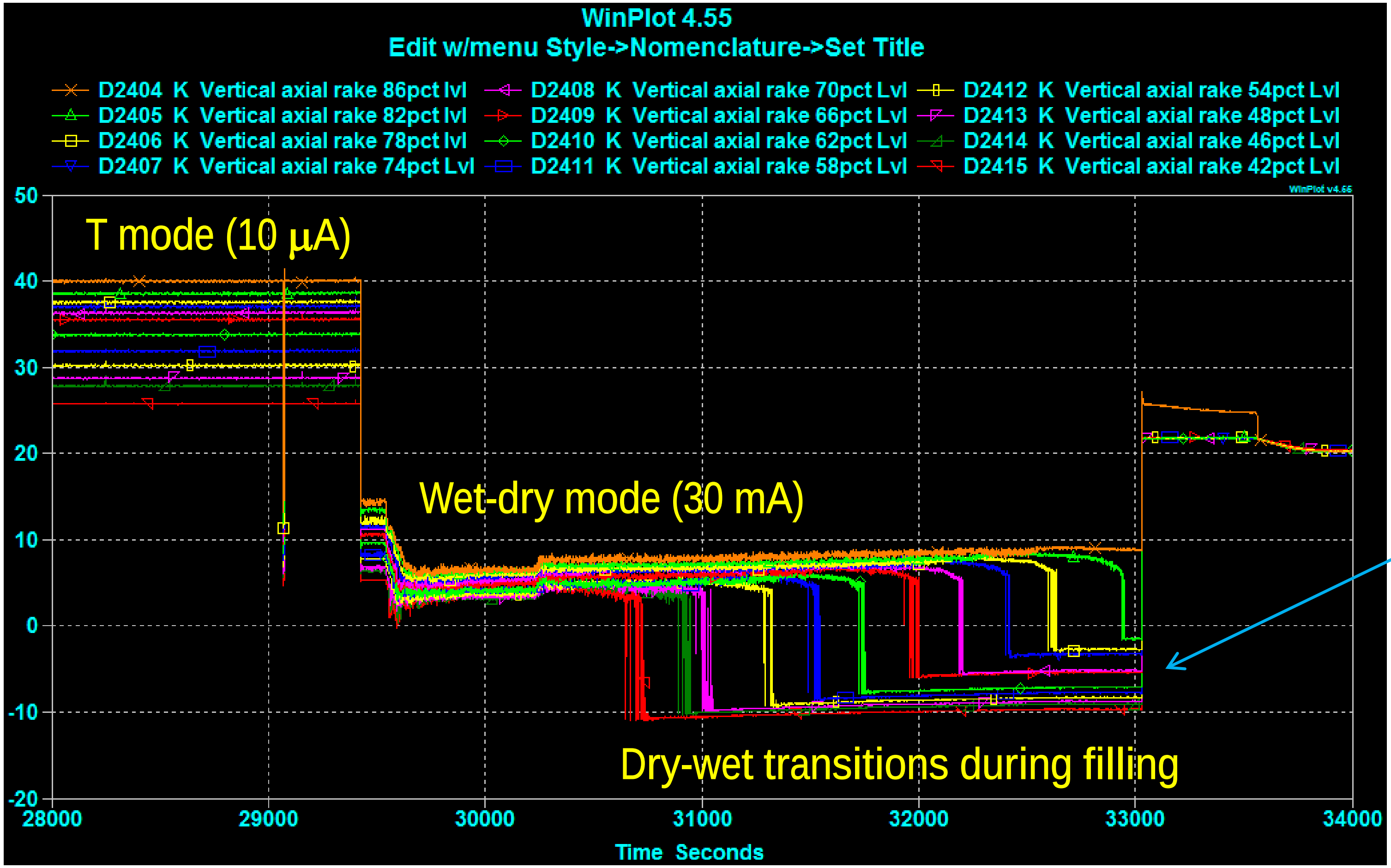
- Tank is initially filled above 75% fill, completely submerging the LAD
- Tank level decreases due to boil-off and outflow tests
- LAD diodes are monitored to determine when gas has been ingested ("breakdown")
- Tank is refilled to conduct more tests



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

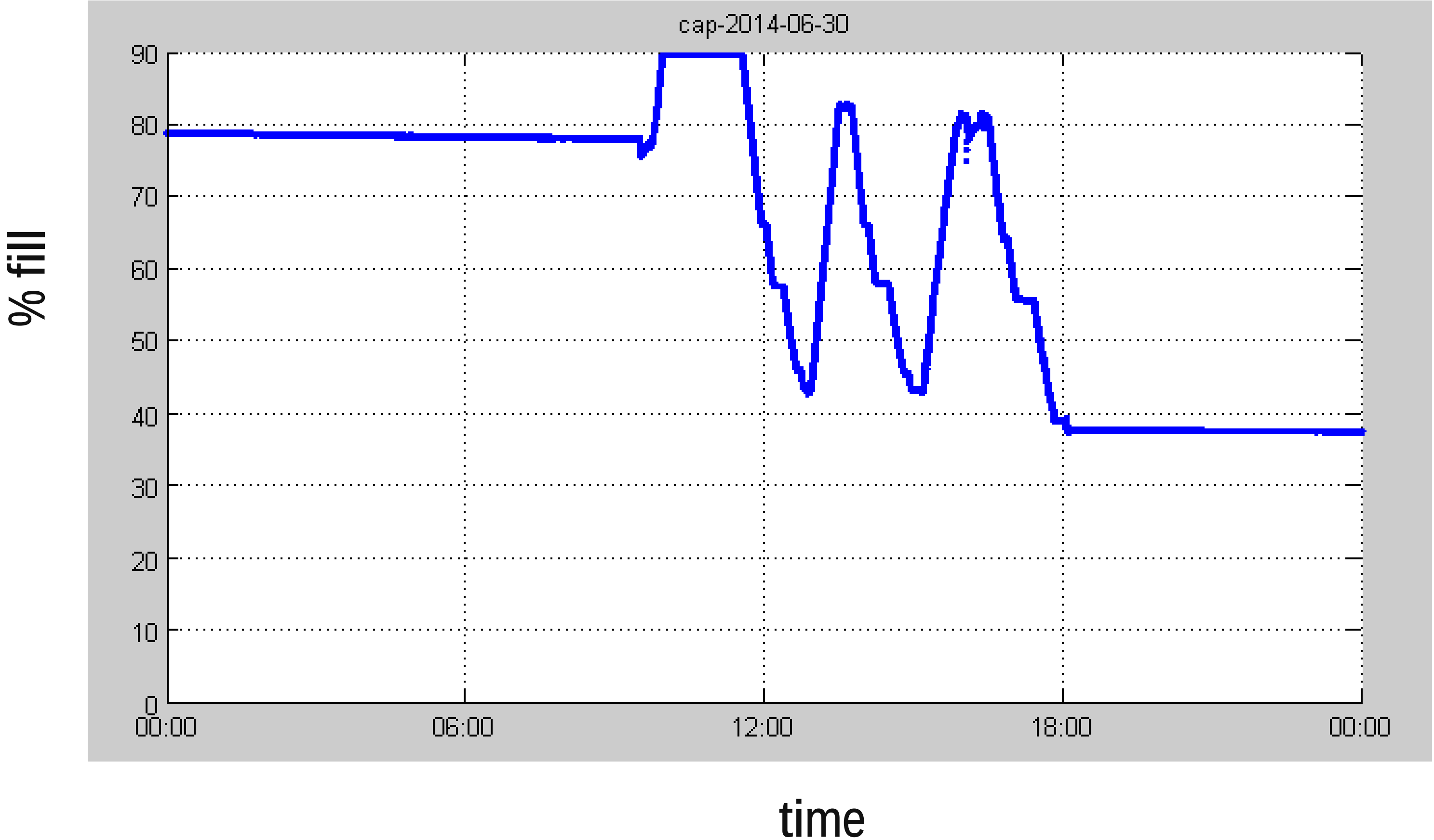


- Different offsets in the transition value are due to lead resistance
- This did not affect the analysis, which was done manually

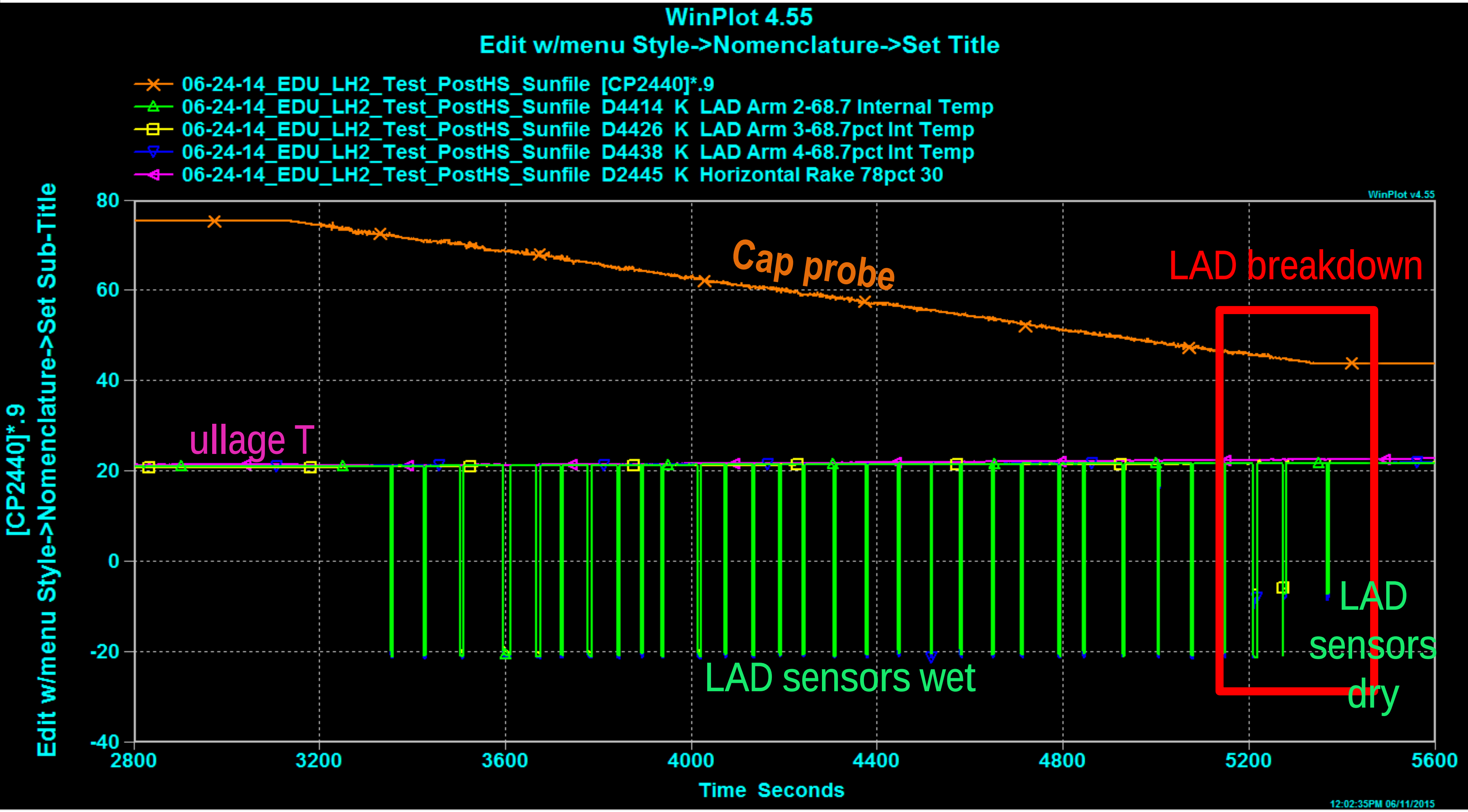
LAD test events

- 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

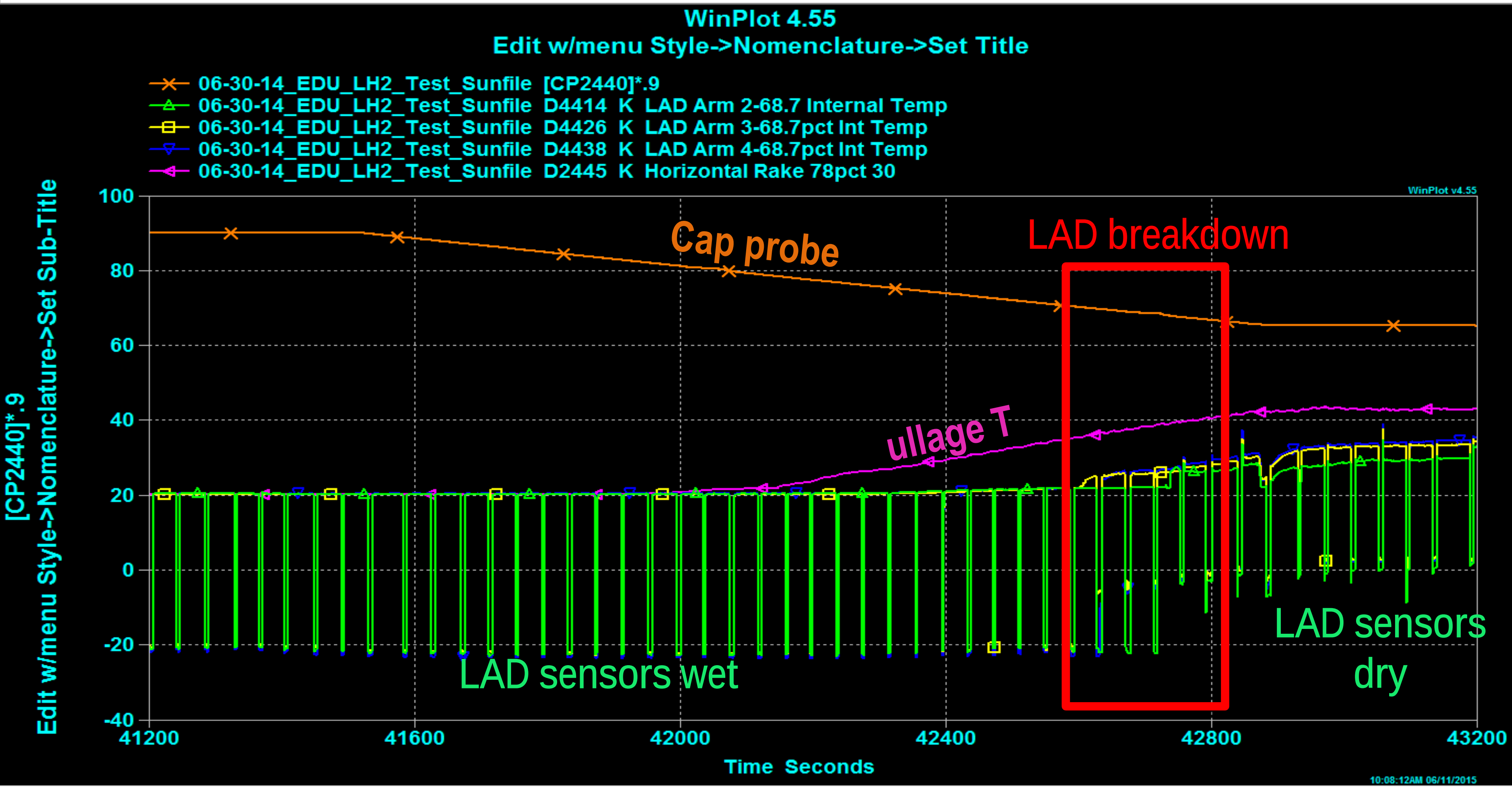


LAD outflow #1, cold helium (AFT diffuser)



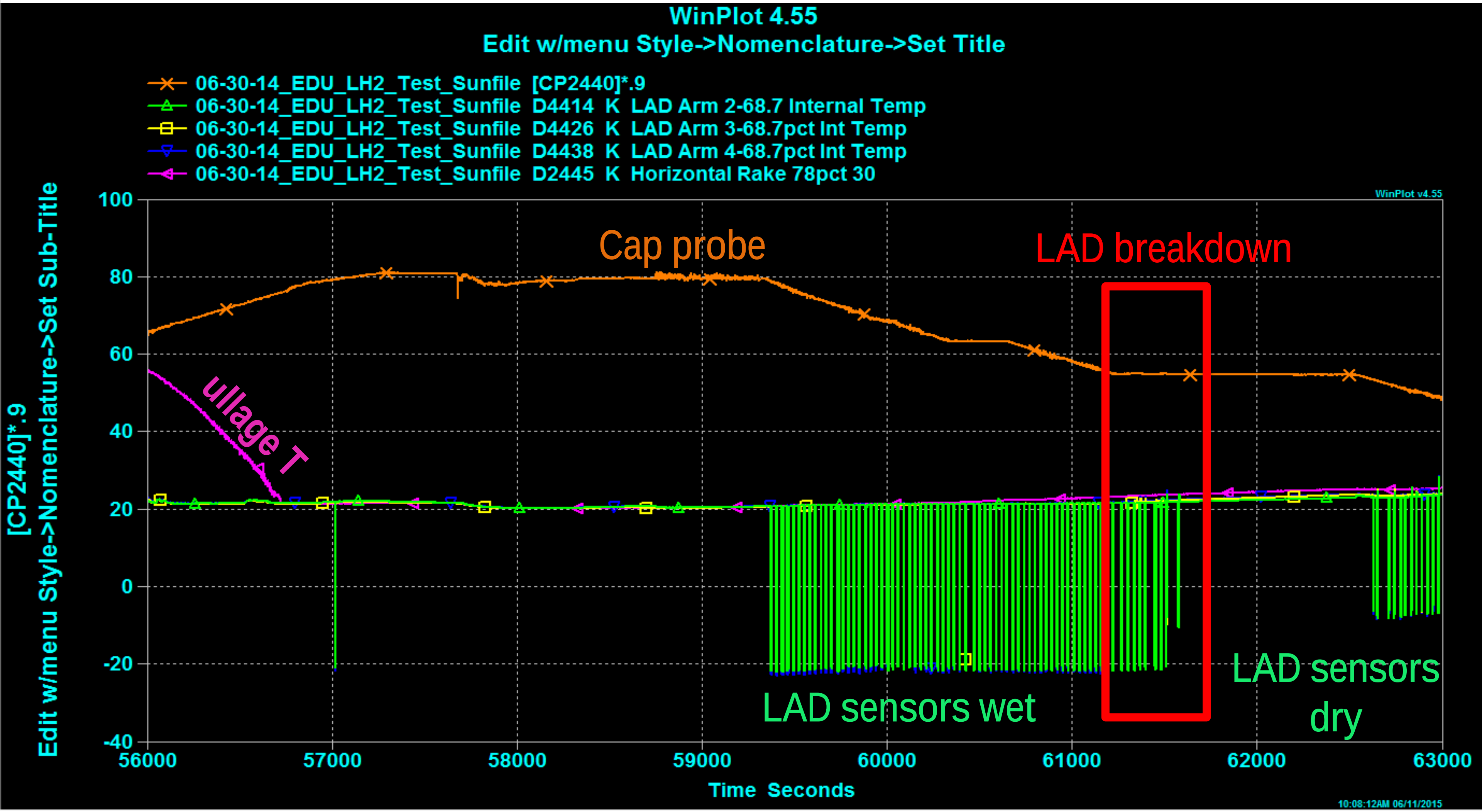
All three LAD arms break down between 44% - 46% fill level
Ullage temperature near LAD is 22.4K
(Top of LAD is at 75%; predicted isothermal, static breakdown is at 32% fill)

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



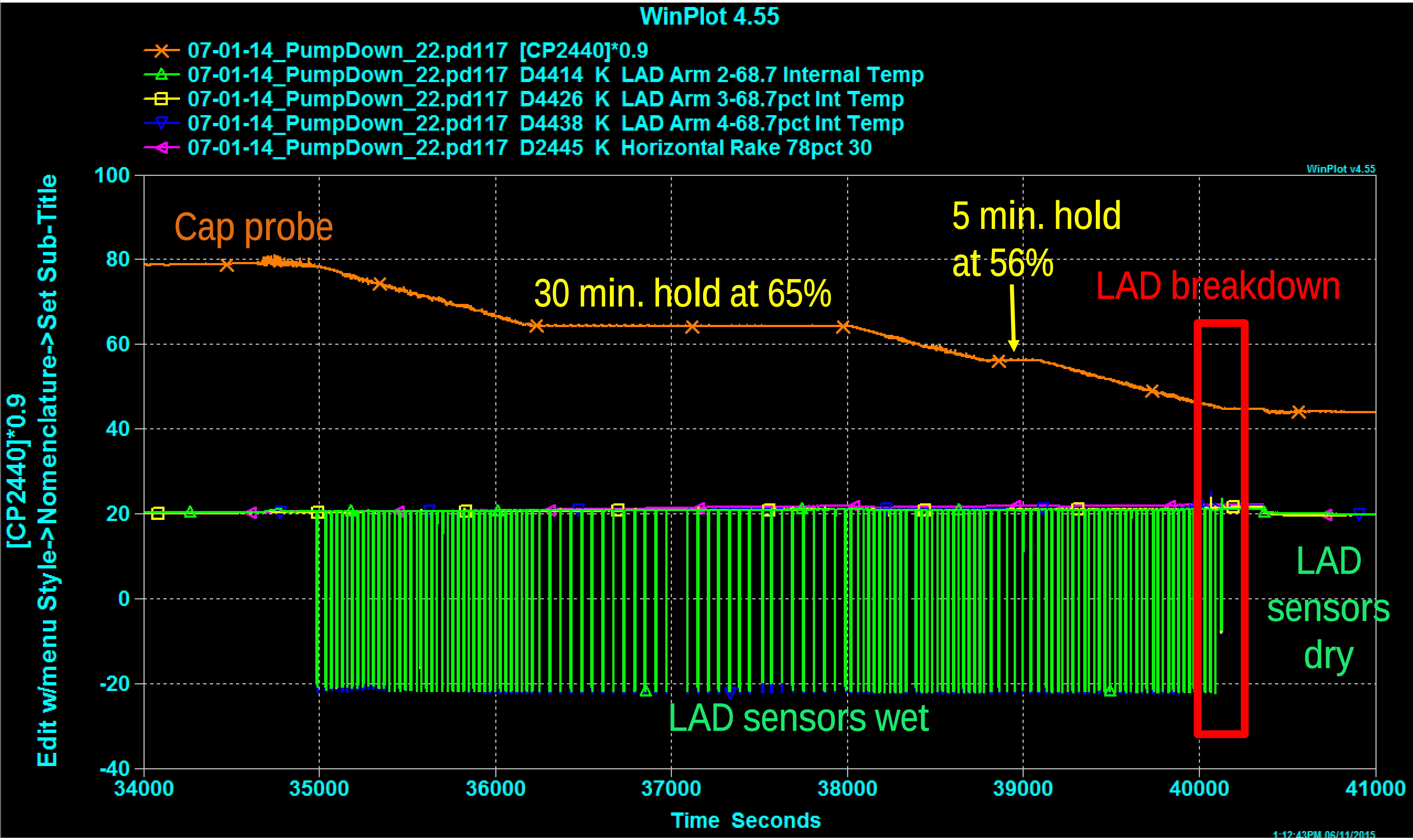
All three LAD arms break down between 67% - 70% fill level (foam-insulated LAD is last to breakdown)
Ullage temperature near LAD is 35 – 40 K
(Top of LAD is at 75%; predicted isothermal breakdown is at 32% fill)
LAD outflow tests #3 and #6, warm helium, shows similar result

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

Acknowledgements

This work was supported by NASA's Space Technology Mission Directorate, through the CPST and eCryo programs.

Many people contributed to the EDU: Special thanks to…

Rafiq Ahmed
Marius Asipauskas
Denny Bartlett
Dr. Jim Blackmon
Leo Bolshinsky
Shane Carpenter
Dave Chato
Melanie Dervan
Andy Hissam
Kim Holt
Frankie Jernigan
Maureen Kudlac
Jim Martin
Michael Middlemas
Rob Minor
Jeff Oliver
Lila Paseur
Dawn Phillips
Chris Popp
Matthew Pruitt
Mike Reynolds
Joey Scarfo
Andrew Schnell
David Sharp
Richard Sheller
Myron Tapscott
Steve Tucker
Alicia Turpin
Ron Unger
Norris Vaughn
Arthur Werkheiser
Hunter Williams
Rob Wingate
Craig Wood