Inverted Outflow Ground Testing of Cryogenic Propellant Liquid Acquisition Devices

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Introduction

Needs and Goals

- NASA is developing propulsion system concepts for human exploration.
- Propulsion concepts will require the vapor free acquisition and delivery stored cryogenic propellants during periods of microgravity
- Screen channel capillary liquid acquisition devices (LAD's) used for earth storable propellants in the Space Shuttle Orbiter and other spacecraft propulsion systems, but only very limited capability currently exists for cryogenic propellants.
- System concept studies established screen channel LADs as an important component of PMD design.
- Experiments are required in cryogenic propellants for LAD channel assemblies at flow rates representative of actual engine service to both quantify performance parameters and validate design models

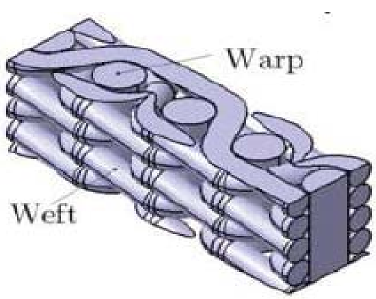
High Flow Rate LAD Test Objectives

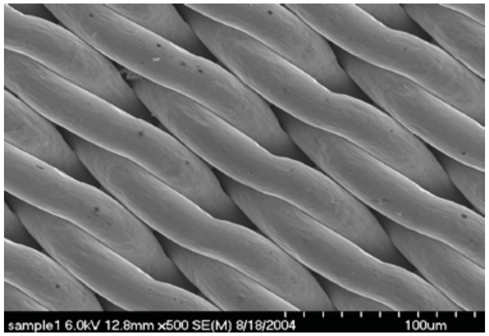
Objective: Provide Exploratory Benchmark Data For Representative Flow Conditions Of LOX Through A Prototypical LADs Channel.

- Representative flow conditions:
  - Varied flow rate (0.2-0.4 lbm/s), pressure (50-240 psia) and temperature of LOX (163-195°R)
  - As close as possible to the usage conditions predicted by mission studies yet still within capabilities of the test facility
- Data will be used to develop and refine predictive models for LAD design
- Three major test series planned:
  - a pressure drop through screen to measure the pressure loss across the screen material itself
  - horizontal LAD outflow to determine the flow loss down the channel
  - vertical LAD inverted outflow to measure the actual bubble point itself under flow conditions.
- Results of the pressure drop and horizontal outflow testing have been reported previously this report will focus on the vertical outflow testing

Screen Channel Liquid Acquisition Devices

- Screen channel LADs are best in multi-directional, multi-g environments
- LADs well characterized and used for storable propellants (propellants that are liquids at room temperature)
- System trades show usefulness LADs even for cryogenic applications
- Multiple screen mesh styles – square, Dutch Twill (tortuous flow path)
- Warp/Weft wires characterize the mesh, 325 warp wires per inch and 2300 weft wires (325x2300) typical
- LADs rely on capillary flow, and wicking and surface tension forces for barrier to vapor ingestion
- No optimized LAD configuration yet; fine mesh screens = good wicking & screen retention vs. high pressure drop and potential for clogging





PMD Overview – The Bubble Point

- Definition: differential pressure across a screen pore that overcomes the surface tension of the liquid at that pore
- Measurable quantity (derived from Young-LaPlace equation)

$$\Delta P_{BP} = \frac{4\sigma \cos\theta_C}{d}$$

- Liquid oxygen on stainless steel contact angle zero = cosine term one
- Smaller pore diameters are favorable for cryogenic systems to counteract low surface tension
- Estimated pore size for 325x2300 screen of 0.000567 inches from prior tests

The Bubble Point

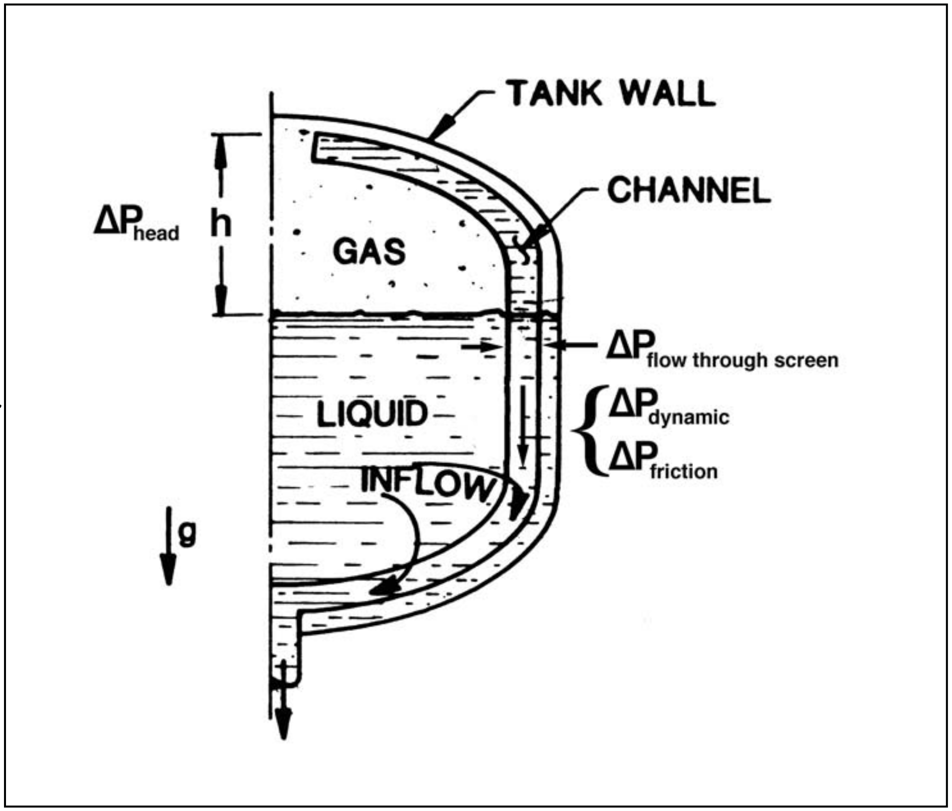
- Screen channel LADs fail when vapor is ingested across the screen during liquid outflow

- For dynamic flow systems,

$$\Delta P_{total} = \Delta P_{hydrostatic} + \Delta P_{FTS} + \Delta P_{frictional} + \Delta P_{dynamic} + \Delta P_{other}$$

where $\Delta P_{total} < \Delta P_{BP}$

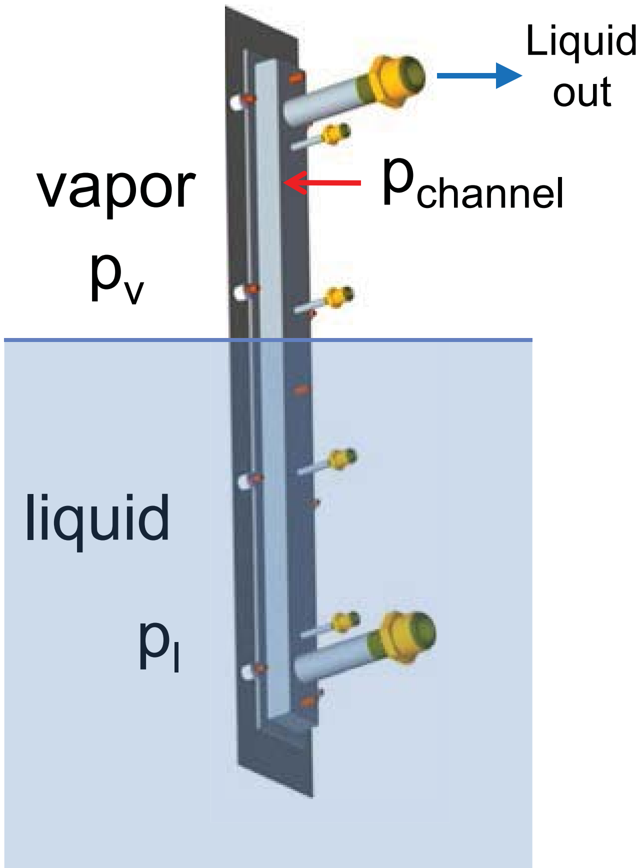
to prevent vapor ingestion into the channel



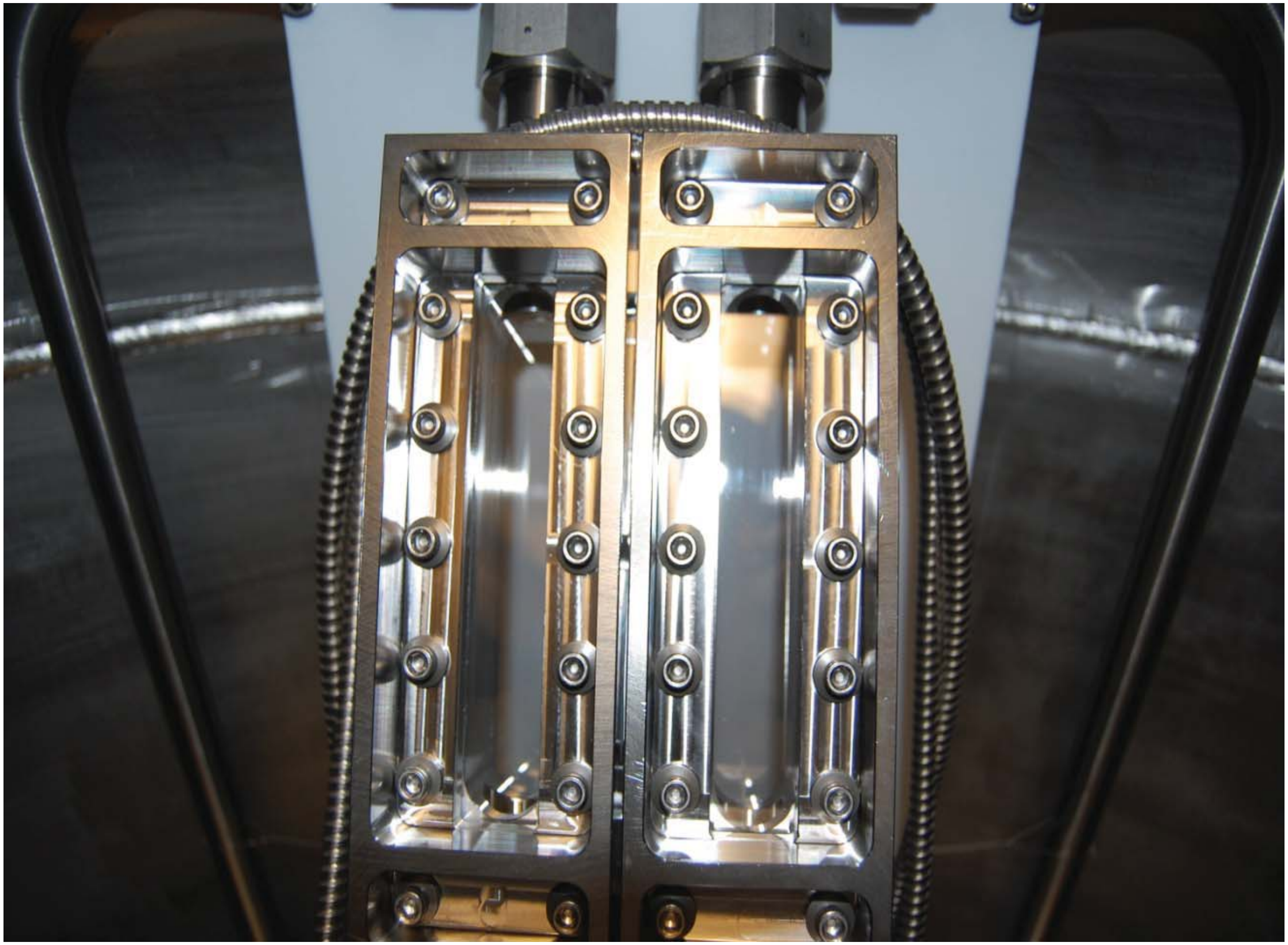
Description of Experimental Setup

Determination of Bubble Breakthrough

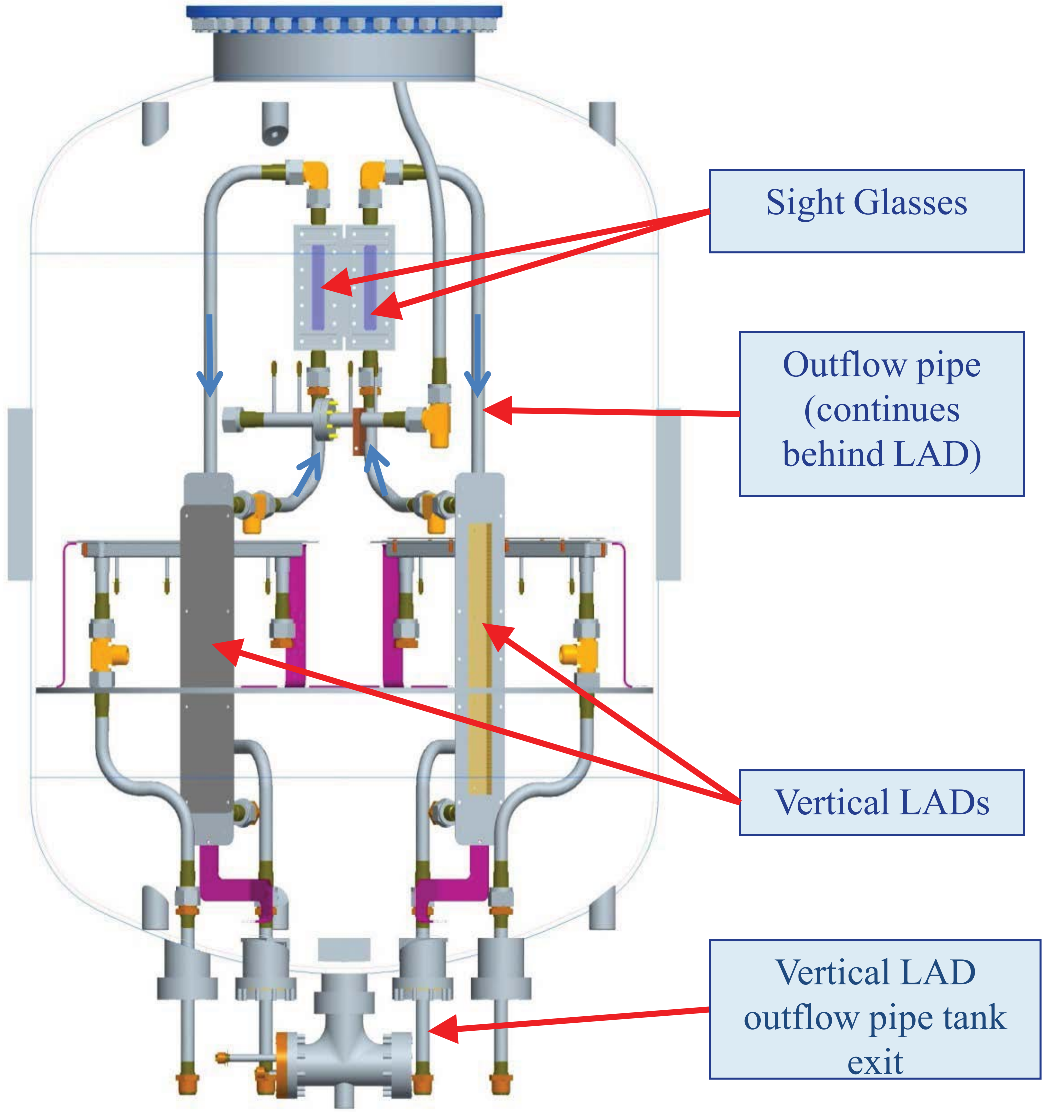
- Two Vertical LADs
  - Rectangular 2” wide by 1” deep by 24” long channel
  - Sealed with a metal frame containing an opening 2” wide by 19” long covered with fine mesh screen (325 warp and 2300 weft wires per inch in a tight Dutch twill weave)
  - Screen served as a “window” to allow flow.
  - Identical except LAD 3 had its screen window welded in place with a series of overlapping spot welds rather than the diffusion bond used to attach LAD 4
  - One inch diameter outlet tubes either end of the channel, Two outlet tubes were provided to allow for flushing, only one outlet used in test the other capped
  - Tubes for pressure taps installed at four locations, two middle pressure taps capped, after estimates showed little pressure signal



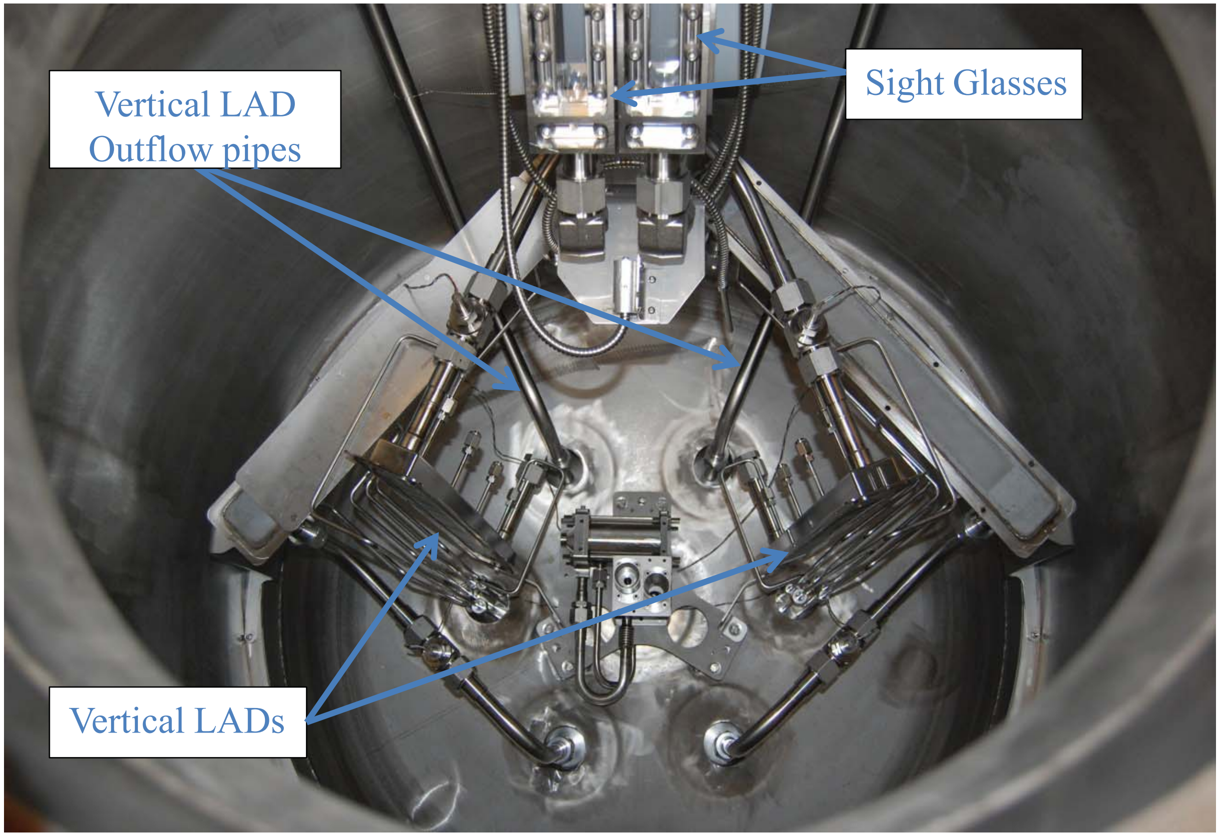
Outflow Sight Glasses



CAD Layout of Test Tank

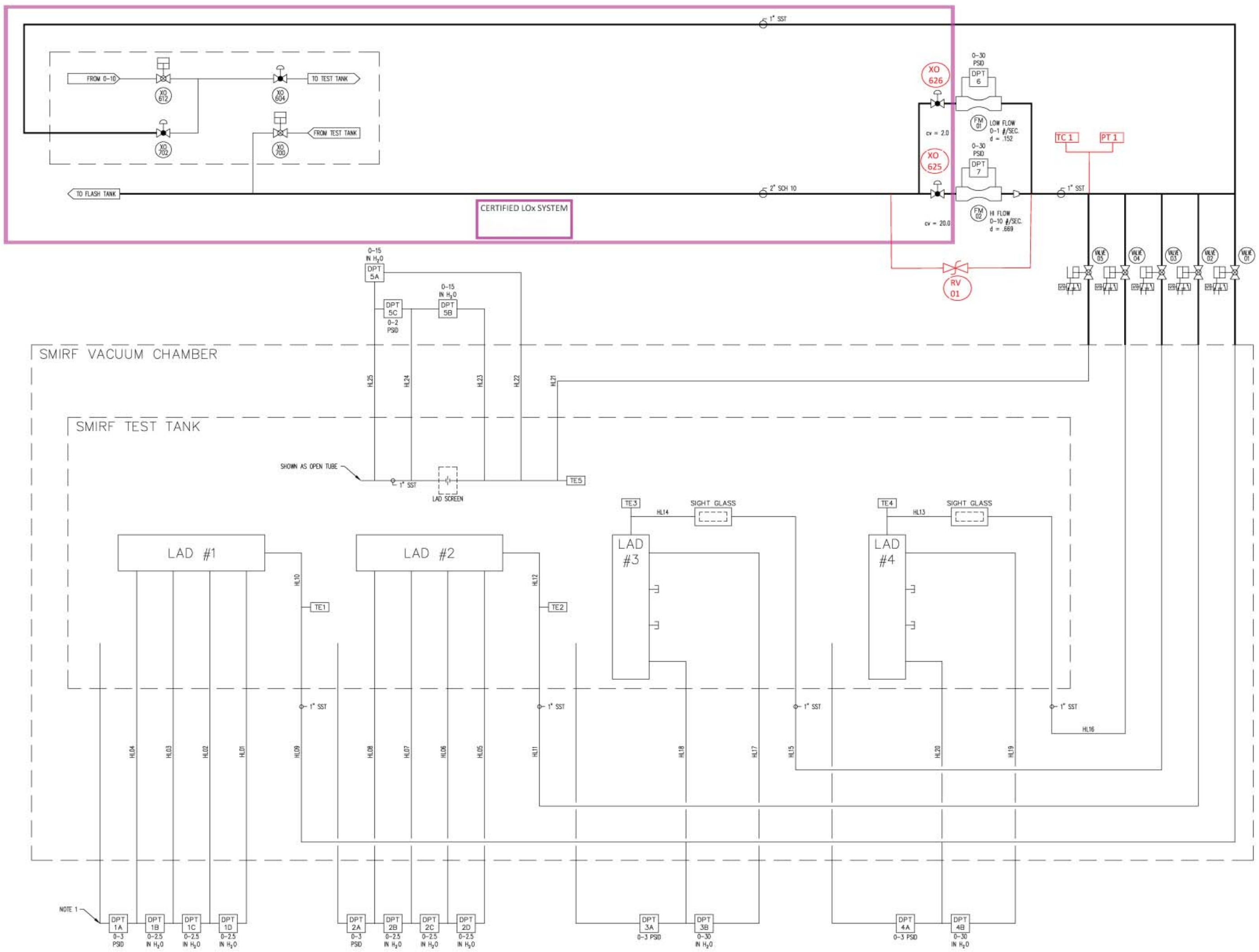


Test Hardware Continued



Test Tank Being Installed in Chamber

Schematic of Outflow Manifold



Results

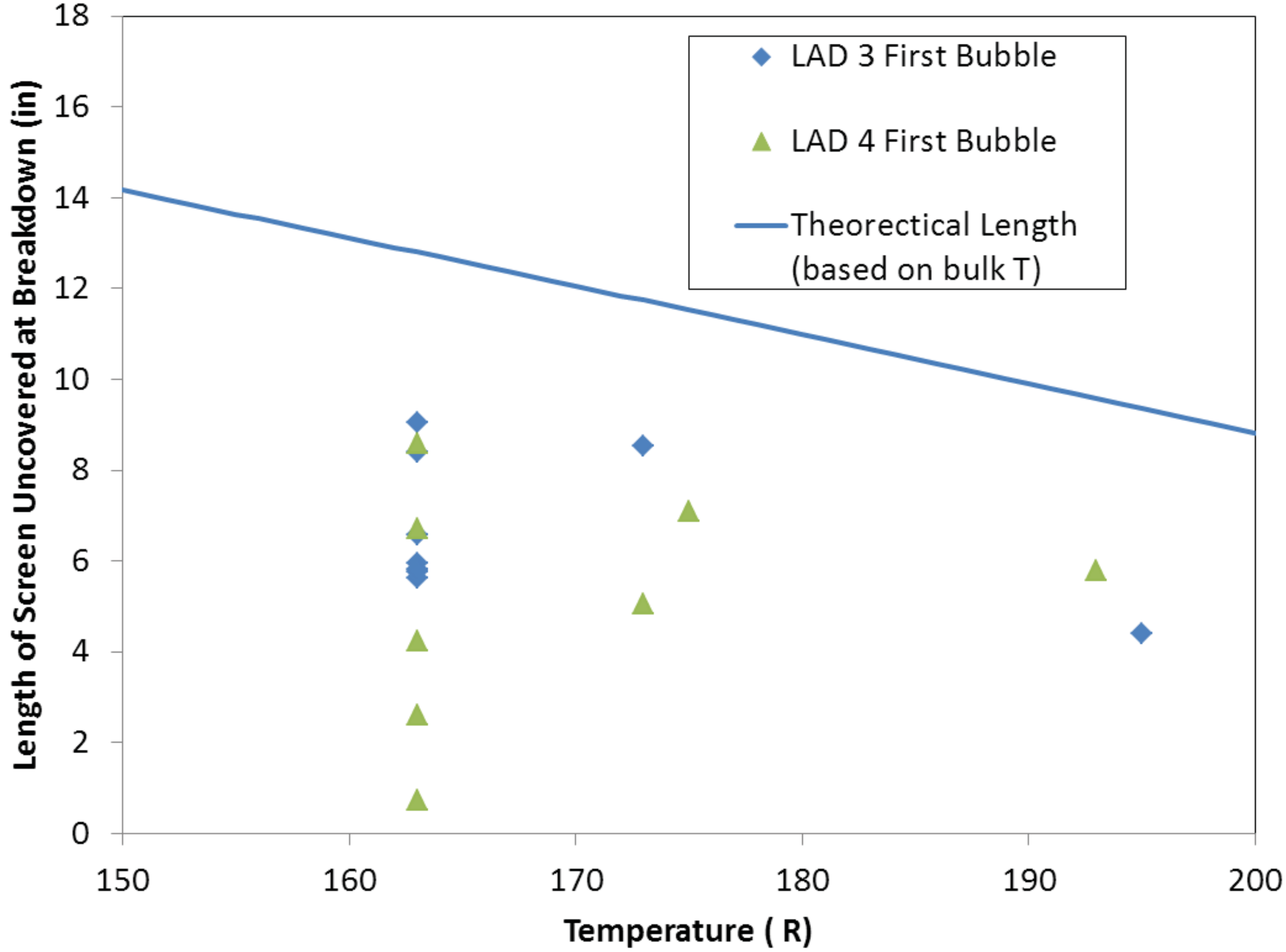
LAD 3 Test Results

Date	P (psia)	T (R)	LAD No.	Uncovered Screen Length 1st Bubble (in)	Uncovered Screen Length All Bubble (in)	Flow rate(s) (lb/s)
Feb. 24	50	163	3	5.96	6.16	0.3
Mar. 12	50	163	3	9.05	9.08	0.2
Mar. 5	150	163	3	5.83	6.28	0.3
Mar. 5	150	163	3	5.61	not observed	0.3
Feb. 26	240	163	3	5.76	6.21	0.3
Mar. 11	240	163	3	6.56	6.82	0.2
Mar. 16	240	163	3	8.39	8.53	0.4
Mar. 2	50	173	3	8.53	not observed	0.3
Mar. 11	240	195	3	4.41	6.06	0.3

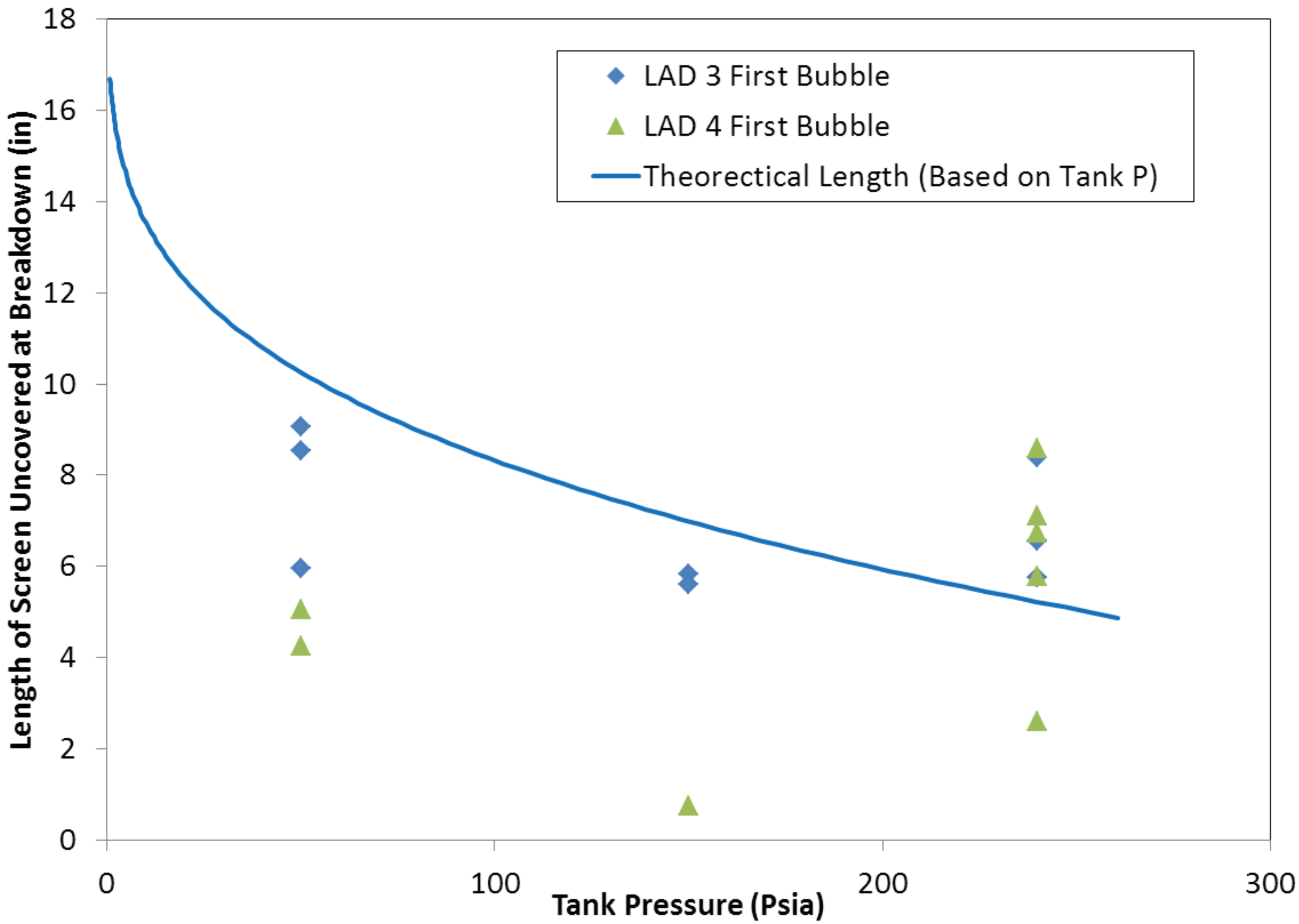
LAD 4 Test Results

Date	P (psia)	T (R)	LAD No.	Uncovered Screen Length 1st Bubble (in)	Uncovered Screen Length All Bubble (in)	Flow rate(s) (lb/s)
Feb. 24	50	163	4	4.24	4.55	0.3
	150	163	4	0.73	2.00	0.3
Feb. 26	240	163	4	2.60	2.86	0.3
Mar. 16	240	163	4	6.72	7.39	0.4
Mar. 17	240	163	4	8.59	9.97	0.2
Mar. 3	50	173	4	5.06	6.72	0.3
Mar. 18	240	175	4	7.10	not observed	0.3
Mar. 17	240	193	4	5.79	6.19	0.3

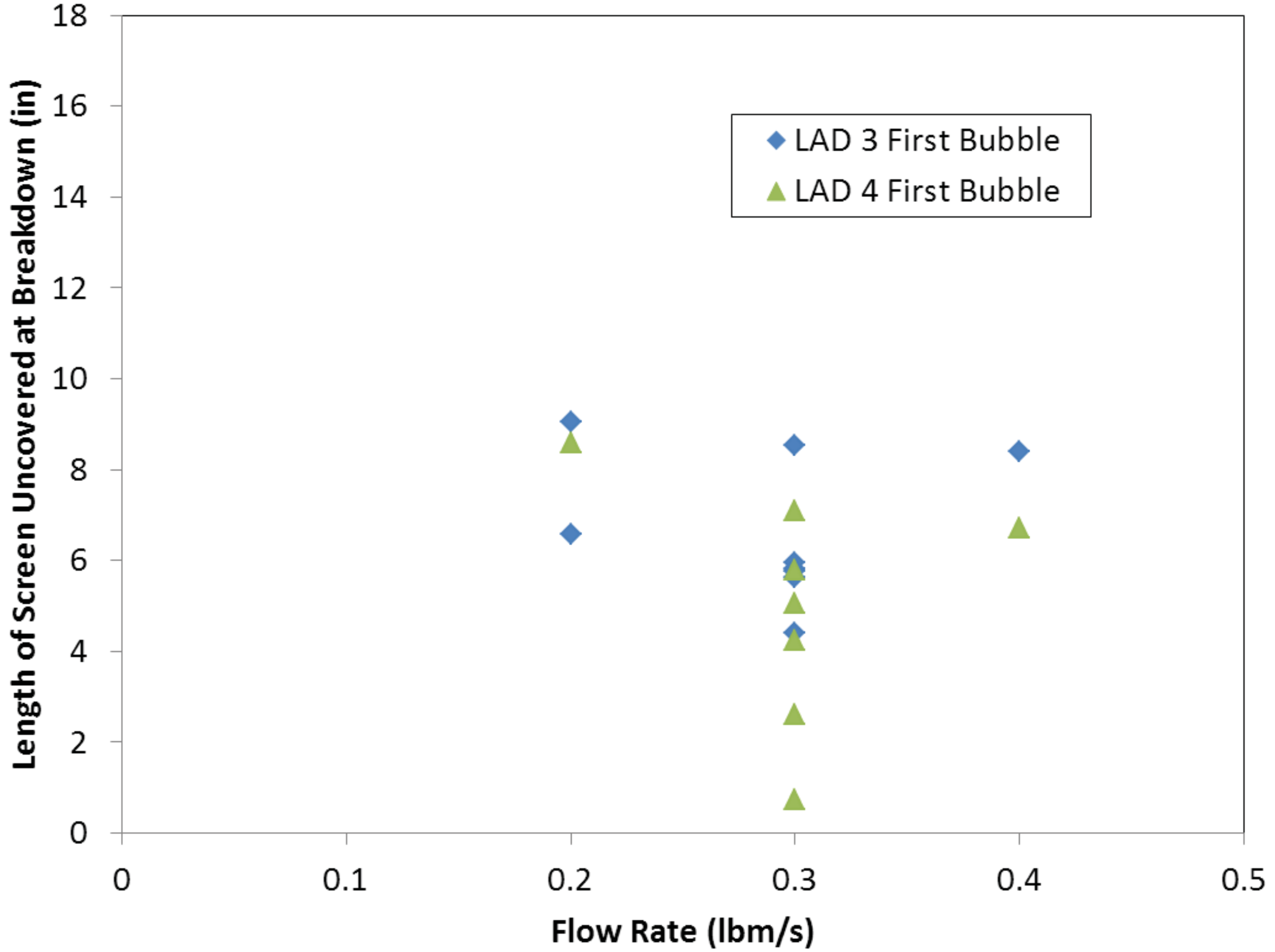
Uncovered Screen Versus Bulk T



Uncovered Screen Versus Tank P



Uncovered Screen Versus Flow Rate



Concluding Remarks

- Successes
  - Demonstrated an ability to acquire liquid oxygen and maintain a substantial flow rate without causing LAD breakdown
  - Shown an ability to do this over a wide range of pressures and temperatures, while determining the screen breakdown by visual observation of bubbles in the sight glass.
  - Initial breakdown is followed quite closely by a screen-wide breakdown in most tests, showing no unusually weak spots in either LAD.
  - No degradation in performance was found with time, in fact some of the highest uncovered screen lengths were observed in some of the last tests.
- Challenges:
  - Challenging to obtain a consistent measurement of uncovered screen lengths during the tests.
  - Although LAD 3 seemed to slightly outperform LAD 4, the results were not conclusive.