Cryogenic Liquid Level Measurements Using Fiber Optic Sensor System (FOSS) Technology

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Presented By

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Background

- NASA Dryden has developed a Fiber Optic Sensor System (FOSS) for in-flight strain measurements on aircraft
- The system measures strain & temperature as changes in reflected wavelength from a laser source.
- The system has successfully flown on several aircraft at DFRC.
- Launch Services Program (LSP) has sponsored testing of the DFRC FOSS at MSFC in LN_2 and LH_2 to examine applicability to cryogenic stage usage.
- LSP is funding FOSS redesign for launch vehicle application (w DFRC & MSFC)

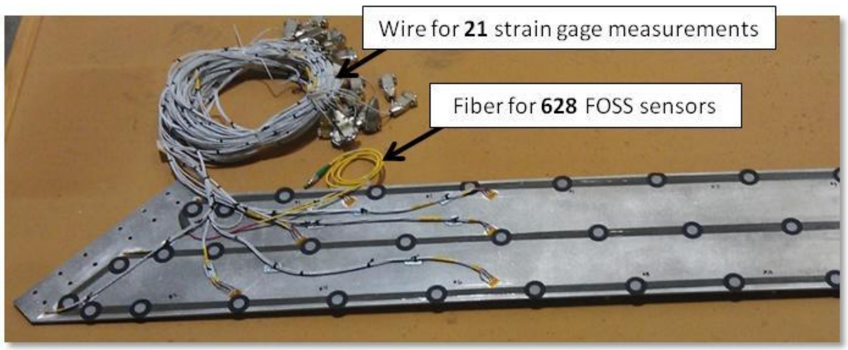
Flight System

Justification

- More accurate measurement of liquid propellant level (mass gauging/propellant utilization) in a launch vehicle increases the performance of the vehicle by minimizing the residual propellant needed for a mission.
- “Cryo-FOSS” could result in increased payload or, for missions that payload mass just exceeds the threshold for an additional solid rocket motor (Atlas V, Delta IV), the elimination of a solid motor. The latter case would result is a savings of $20-40M+.

Benefits - Technical

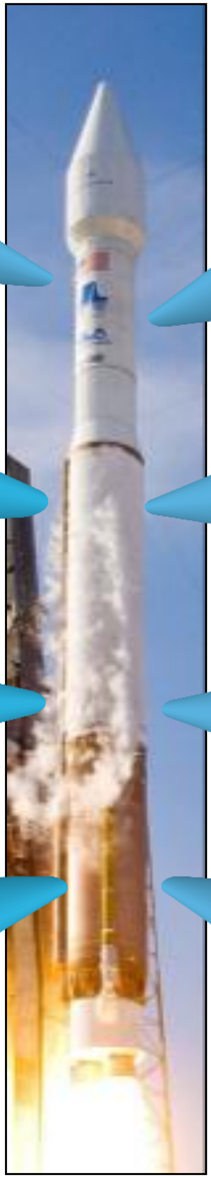
- FOSS can dramatically improve structural and system efficiency for space vehicle applications by …
  – Providing >100x the number measurements at 1/100 the sensor weight
  – Acquiring 16,000 measurements, each at 100 samples / sec at 0.25 in intervals.
  – Reducing data system integration time and cost by utilizing a single system for space / launch vehicles
  – Increasing capability of measuring multiple parameters in real time (strain, temperature, liquid level, shape, applied loads, stress, mode shapes, natural frequencies, buckling modes, etc.)
  – Providing validated structural design data that enables future launch systems to be lighter and more structurally efficient
  – Providing an unprecedented understanding about system/structural performance throughout space craft and mission life cycle

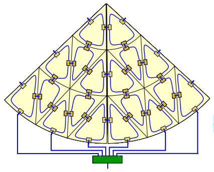


FOSS State of the Art Comparison

	Conventional strain gages	FOSS sensors
Weight	FOSS is 0.1 – 1% the weight of strain gages (based on past trade studies)	
No. of sensors / leadwire	1 / 3	2000 / 1
Space / LV TRL	8	3
Parameters Sensed	strain	strain, temp., shape, magnetic field…
Temperature correction	Nonlinear sensitivity; varies from lot to lot	Linear sensitivity; constant from lot to lot
Sensitivity to EMI / EMP	Yes	No
Embeddable?	No	Yes
Typical installation	4 hrs / 1 SG	2 man days for 40 ft fiber (2000 strain sensors); uses SG techniques

Current DFRC FOSS R&D





TPS Health Monitoring

Strain

Embedded Strain

Temperature and *Cryogenic* Liquid Level

Magnetic Field

2D Shape

Applied Loads

3D Shape

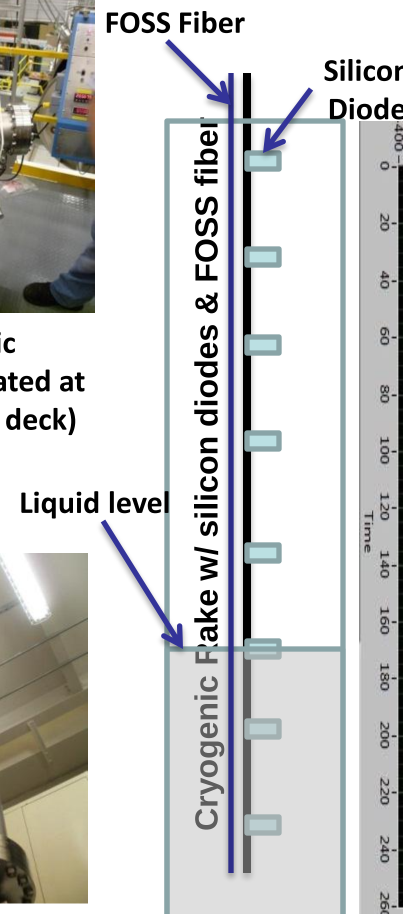
Cryo-FOSS

- The Challenge
  - The liquid / gas transitional phase is difficult to discriminate
  - Discrete temperature diodes spaced along a rake yields course spatial resolution along with high wire count

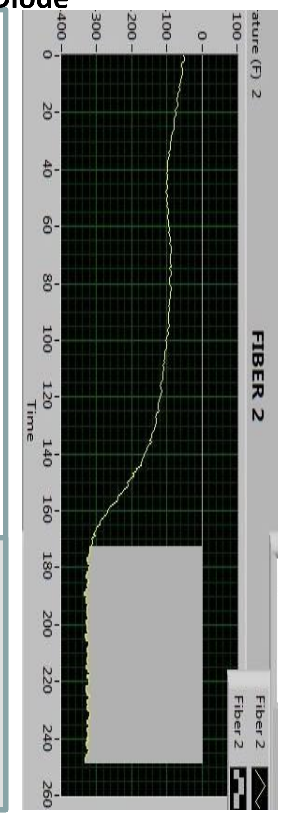
- FOSS Approach
  - Using a single fiber Bragg grating sensing cable and anemometry methods the transitional phase can be mapped better
  - Using a single continuous grating fiber high spatial resolution can be achieve as low as 1/16”
  - Along with the single fiber optic cable a heater wire is used to accomplish the anemometry measurement

Cryogenic Container located at MSFC (above deck)

Cryogenic Container located at MSFC (below deck)



Cryogenic Container

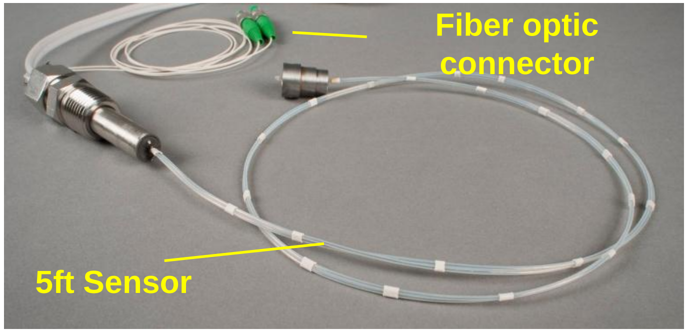


1st Gen CryoFOSS Test Results

A NASA New Technology Report (NTR) has been filed for the cryogenic liquid level measurement method described in this technical paper (or presentation) and are therefore protected. Those interested in using the method should contact the NASA Innovative Partnership Program Office at NASA Dryden Flight Research Center for more information

Cryo-FOSS

- Novel Technical Features
  - Capable of resolving high degree of spatial resolution as fine as 1/16” (typically set for ¼”)
  - Up to 2048 discrete levels are serially multiplexed onto a single hair like fiber
  - Up to 8 fibers can be stacked for a total of 320 sensing feet
  - A single interrogation system can be used for measuring temperature, strain, shape and liquid level, making for a complete health monitoring unit
  - Significantly lower bulkhead pass-through requirements for a single 40 ft long sensor
  - Small, lightweight form factor



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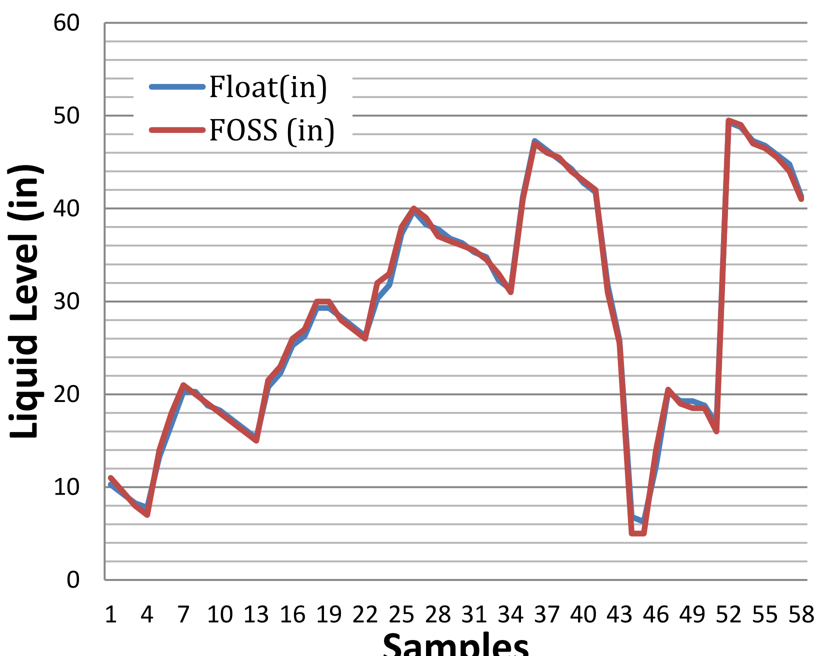
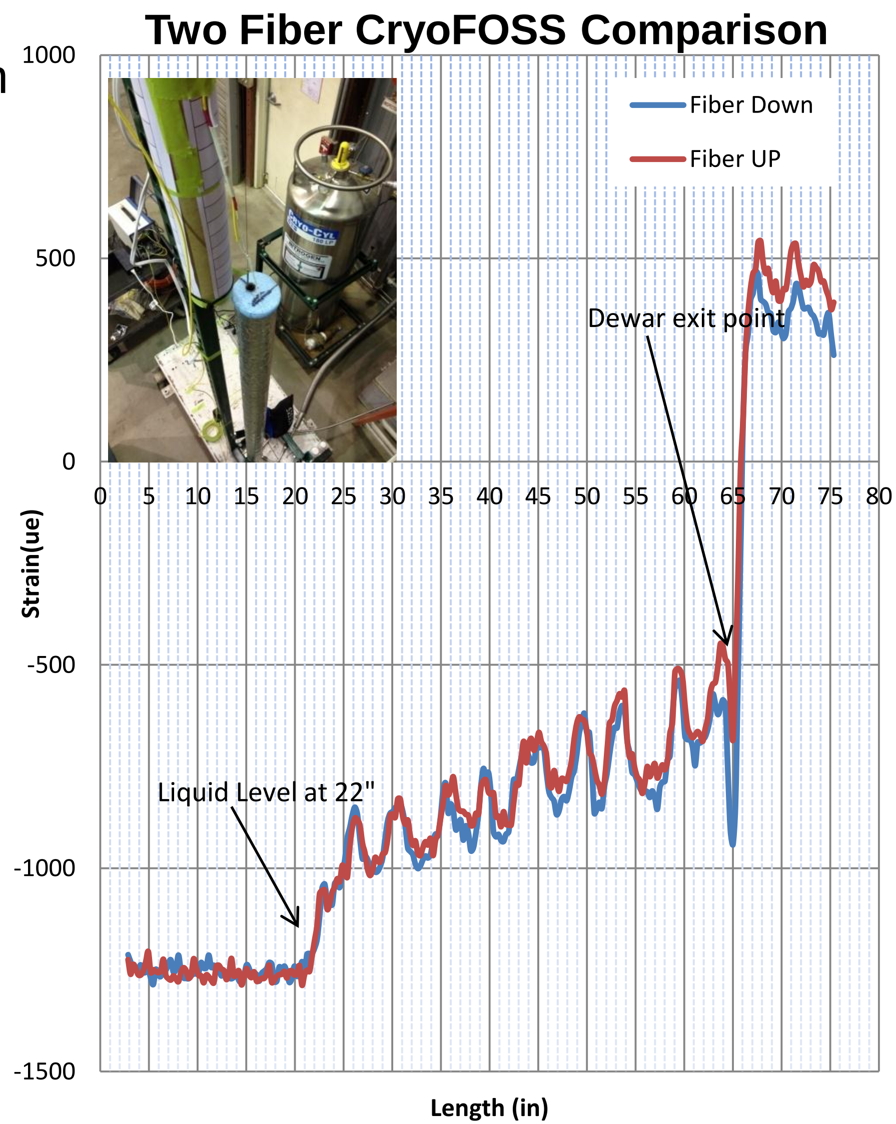
CryoFOSS LN_2 Testing at DFRC

- A float device was used as reference
- Two fill drain cycles were performed with holds in the fill process at multiple levels
- Two 75 inch continuous grating fibers were used with spatial resolution set for ¼”
- CryoFOSS tracked within 1.5% of float
- Good fiber-to-fiber matching achieved





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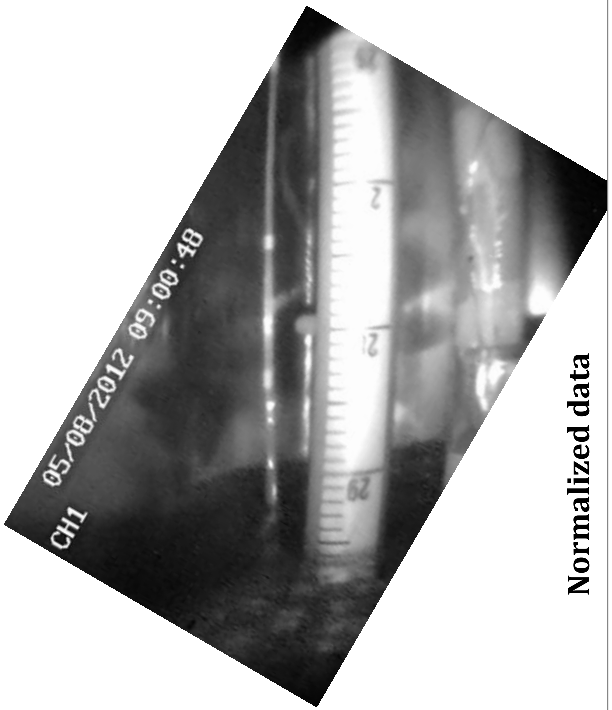
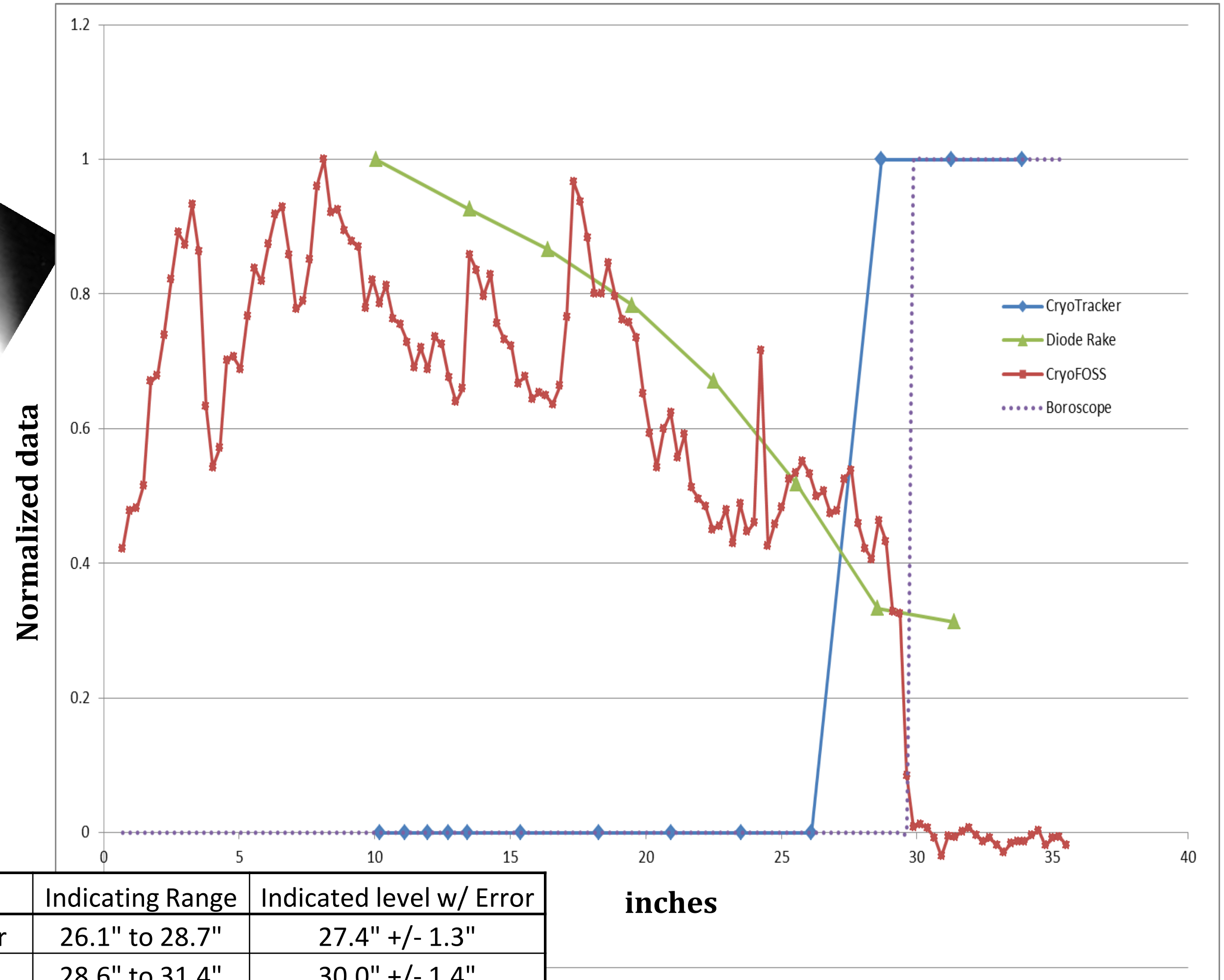
CryoFOSS LH_2 Testing at MSFC

- Objective
  - Experimentally-validate Cryo-FOSS in LH2
- Test Details
  - Dewar dimensions: 13-in ID x 37.25-in
  - Fill levels of ~20%, 43%, and 60%
  - Instrumentation systems
    - Video boroscope (validating standard)
    - Cyrotracker (ribbon of 1-in spaced silicon diodes)
    - MSFC Silicon diode rake
    - Fiber optic LH2 liquid level sensor
- Results
  - Cryo-FOSS sensor discerned LH2 level to approx. ¼-in in every case
  - Excellent agreement achieved between cryo-FOSS, boroscope, and silicon diode cryotracker

Cryo-FOSS

LH_2 20% Fill Level (29.6")





device	Indicating Range	Indicated level w/ Error
CryoTracker	26.1" to 28.7"	27.4" +/- 1.3"
Diode Rake	28.6" to 31.4"	30.0" +/- 1.4"
CryoFOSS	29.4" to 29.6"	29.5" +/- 0.13"
Boroscope	29.6"	29.6"

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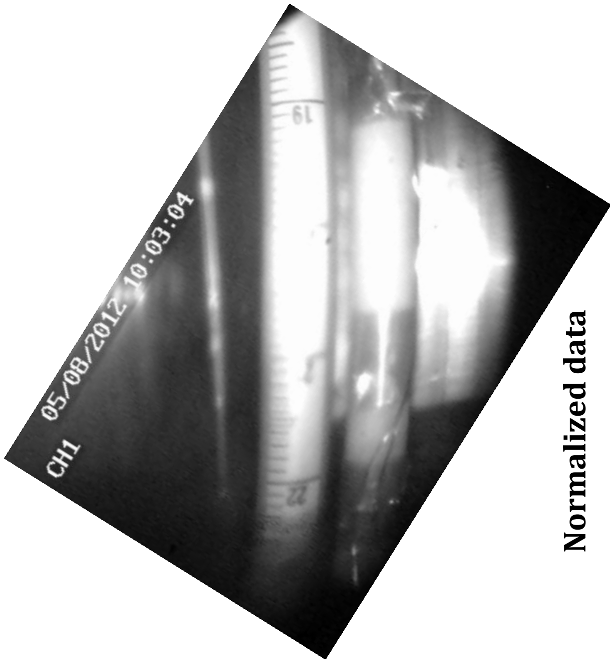
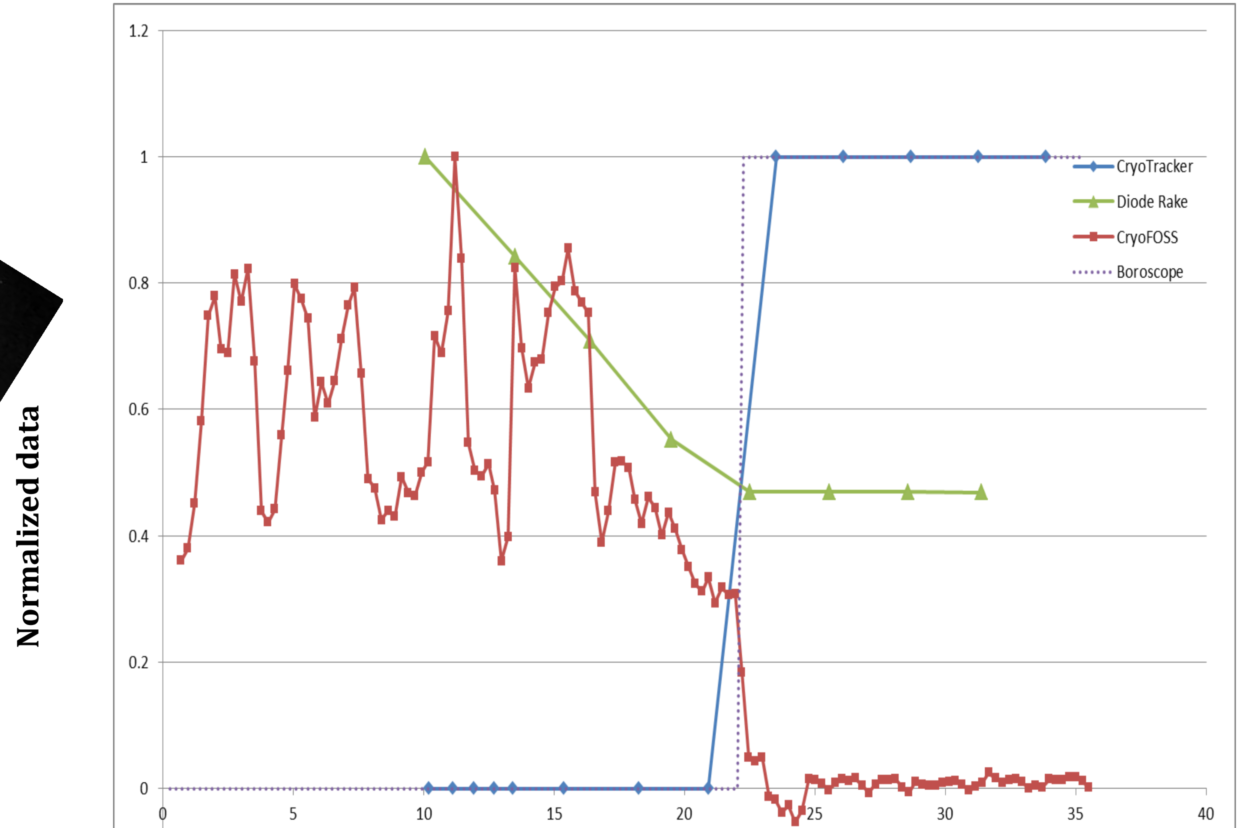
LH_2 40% Fill Level (22.3")





device	Indicating Range	Indicated level w/ Error
CryoTracker	20.9" to 23.5"	22.2" +/- 1.3"
Diode Rake	19.5" to 22.5"	21.0" +/- 1.5"
CryoFOSS	22.2" to 22.5"	22.3" +/- 0.13"
Boroscope	22.3"	22.3"

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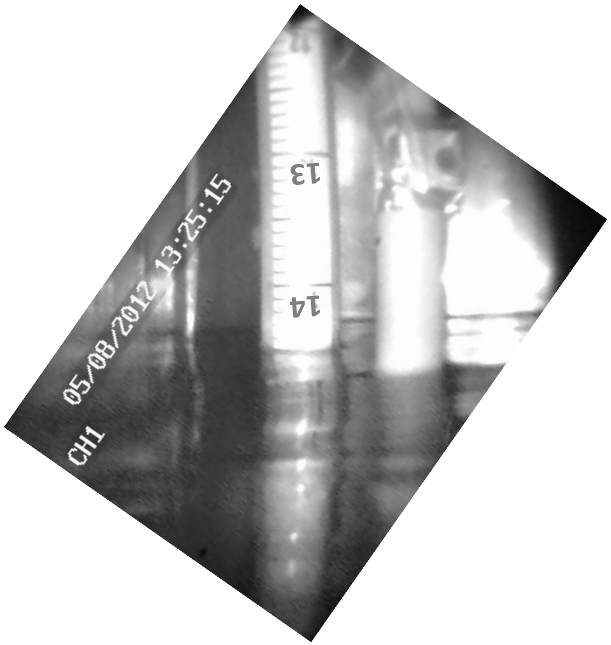
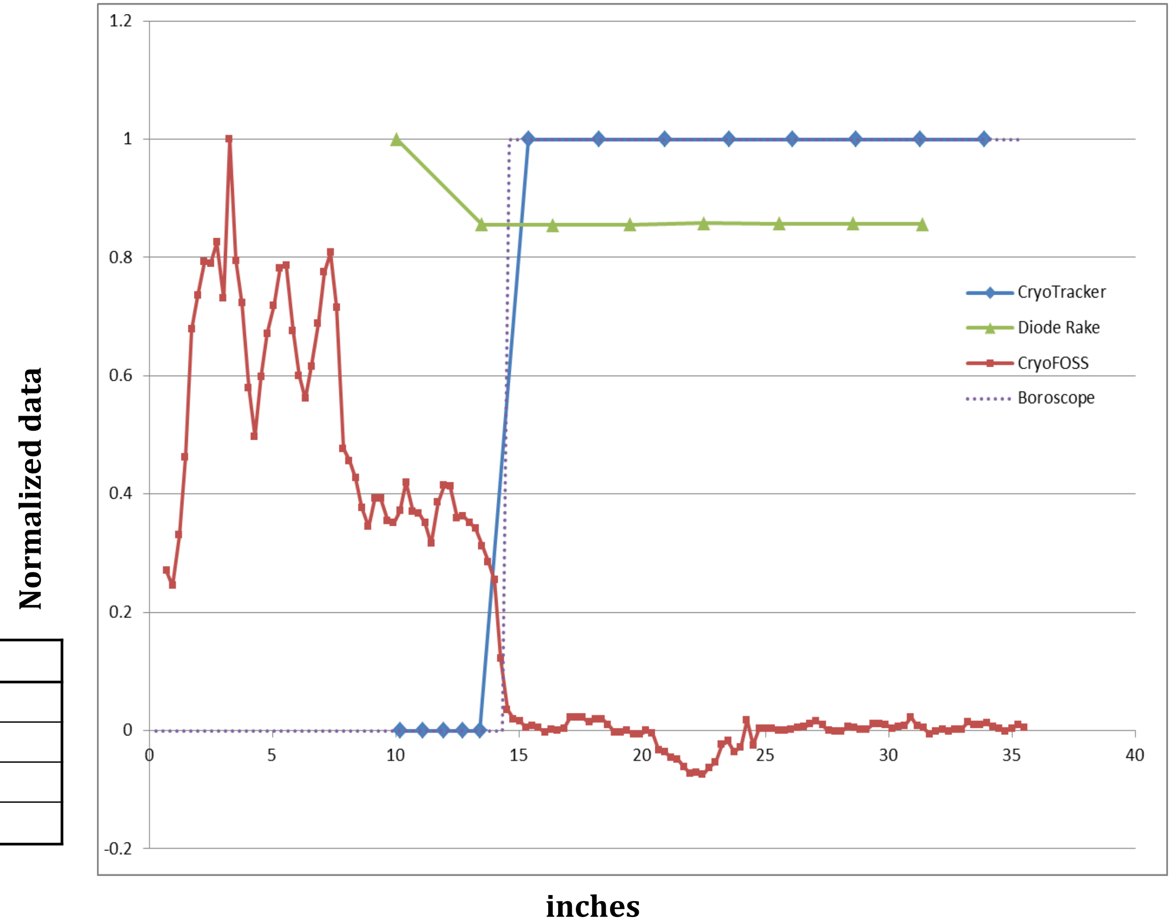
LH_2 61% Fill Level (14.5”)





device	Indicating Range	Indicated level
CryoTracker	13.4" to 15.4"	14.4" +/- 1.0"
Diode Rake	10.1" to 13.5"	11.9" +/- 1.8"
CryoFOSS	14.3" to 14.5"	14.4" +/- 0.13"
Boroscope	14.5"	14.5"

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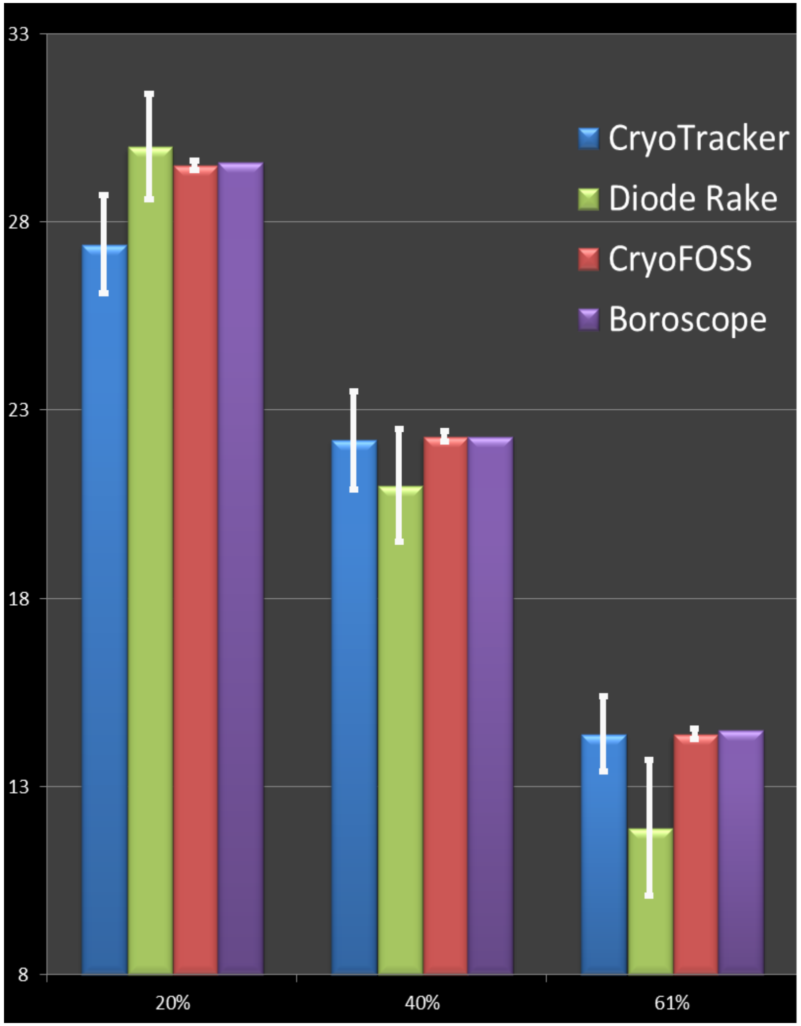
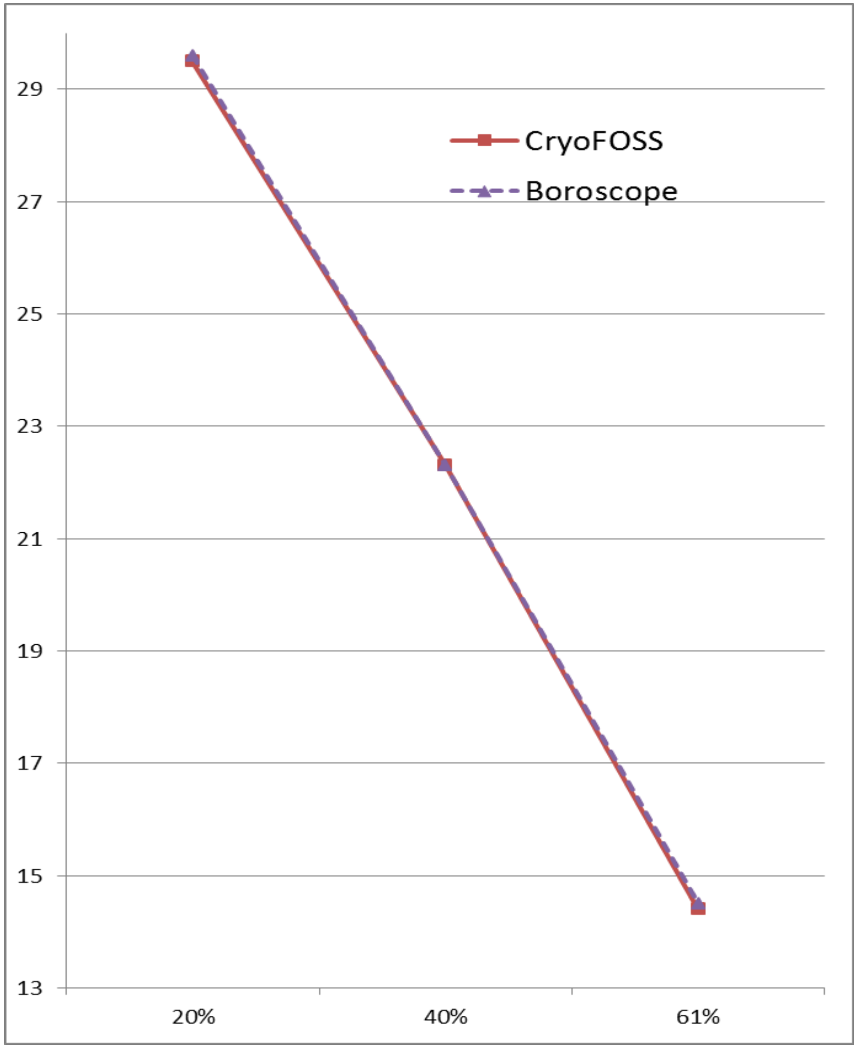
LH$_2$ Overall Results





Combined Results | **CryoFOSS compared to Boroscope**

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Concluding Remarks

- A cryogenic liquid level sensor, based on FOSS technology was developed and demonstrated in both LN_2 and LH_2
- The "Cryo-FOSS" sensor was able to discern LH_2 levels to within approx. 0.25 inch in every fill case.
- Agreement between Cryo-FOSS, video boroscope, and the Cryo-Tracker® was excellent, thus proving the concept for a lightweight, accurate, spatially precise, and practical solution to a challenging problem for ground and in-flight cryogenic fluid management of future launch applications.