Next-Generation Suborbital Researchers Conference

18 – 20 February 2010

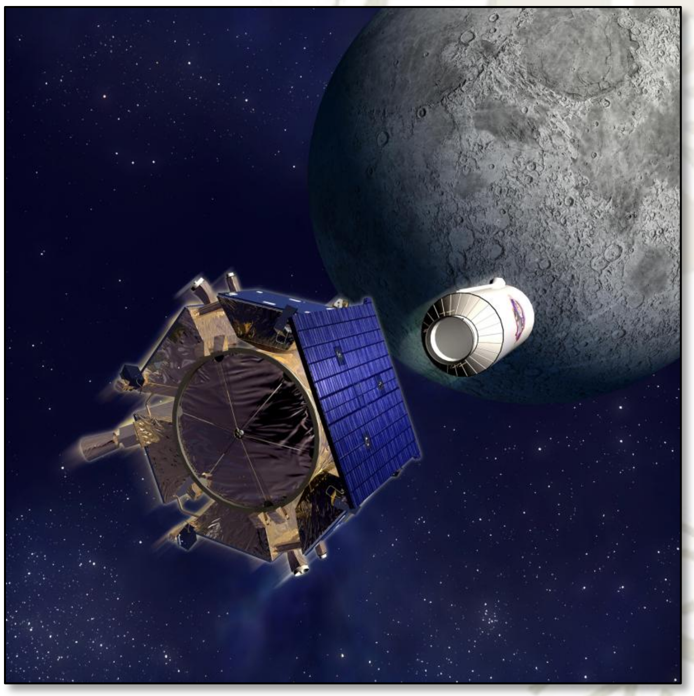
Boulder, CO

If given the opportunity to conduct an experiment in microgravity,

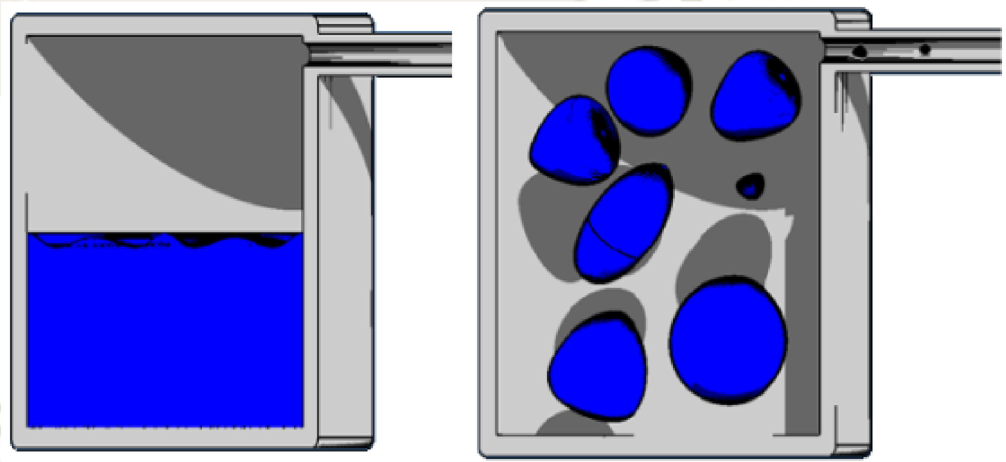
WHAT WOULD WE DO?

The Problem and Proposed Solution

No current, acceptable solution exists to determine liquid volume in a tank exposed to microgravity, without some form of stratification, tank stirring or spacecraft acceleration



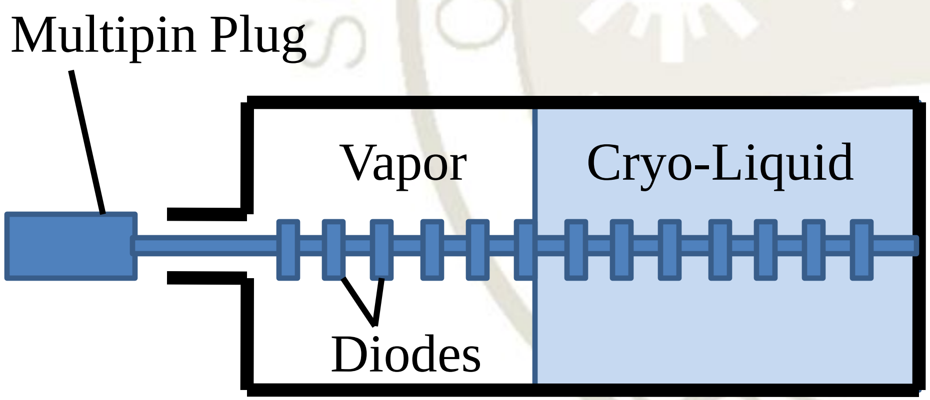
An *optical mass gauge* is a viable option



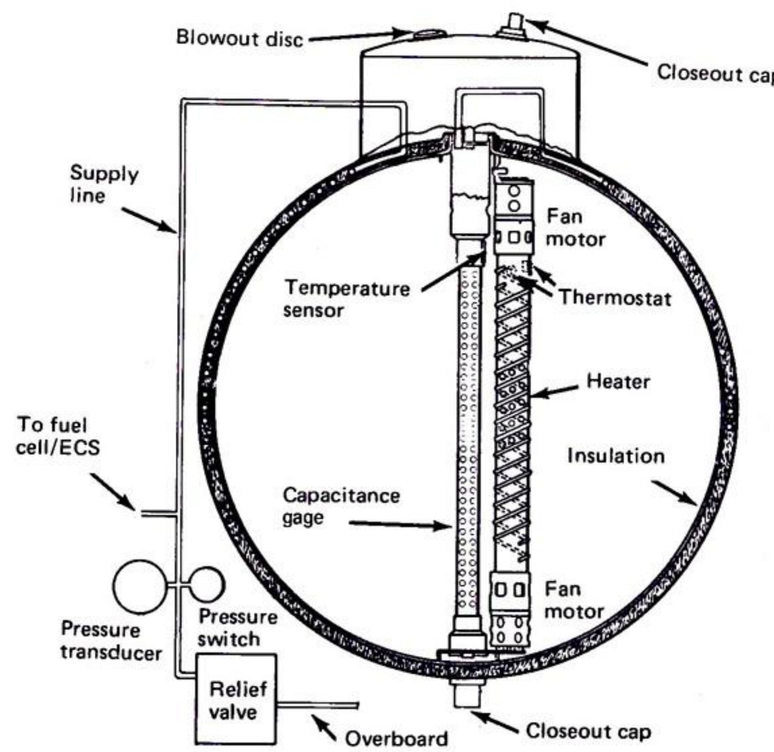
Normal Gravity **Microgravity**

Alternative Methods

Alternative Method	Basics	Requirement
Capacitive Sensor	Permittivity of the cryogenic fluid is related to the volume within the tank.	Settling / Stratification
Liquid-Level Diode Sensor	A strip of silicone diodes are brought to a certain temperature. Time constants allow for fluid volume measurement.	Settling / Stratification



Optical mass gauge will not require settlement or acceleration of spacecraft



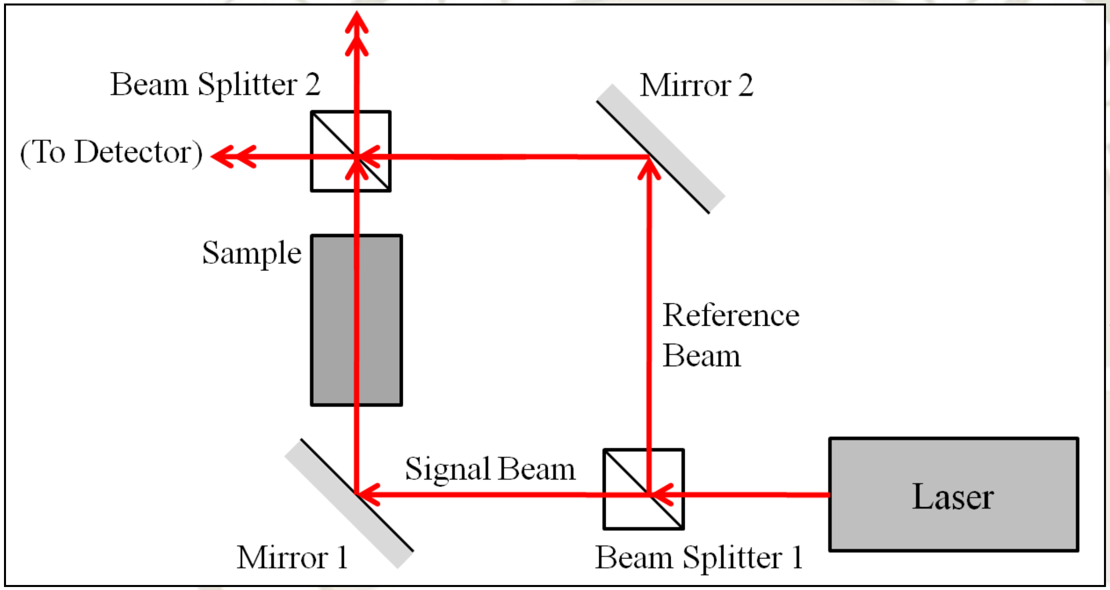
CSU's Microgravity Experiment

Objective:

Design, fabricate, and successfully flight-test an optical mass gauge sensor capable of accurately determining liquid volumes contained within a tank exposed to any gravitational environment.

We are currently working in cooperation with NASA's Marshall Space Flight Center to produce a rugged and miniaturized optical mass gauging platform for launching on a sounding rocket.

Basic Interferometry

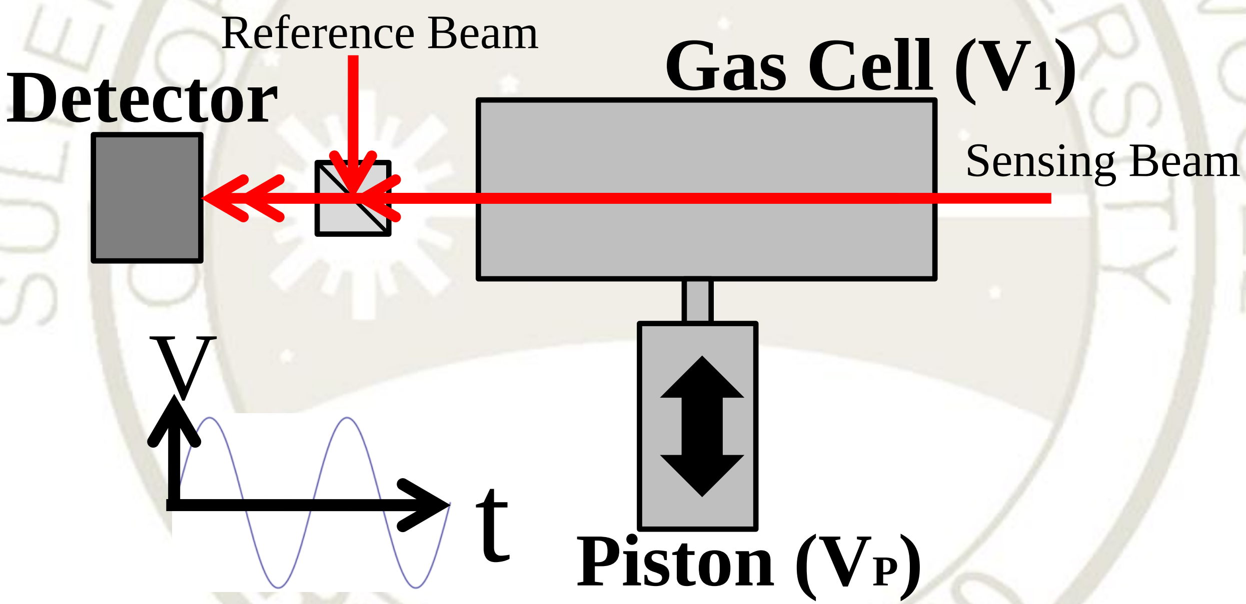


Mach-Zehnder Interferometer

The amount of space occupied by a fluid inside a tank is determined by measuring the index of refraction of a gas within the system. This is done by using an interferometer which operates by analyzing the interference pattern generated by two or more optical signals

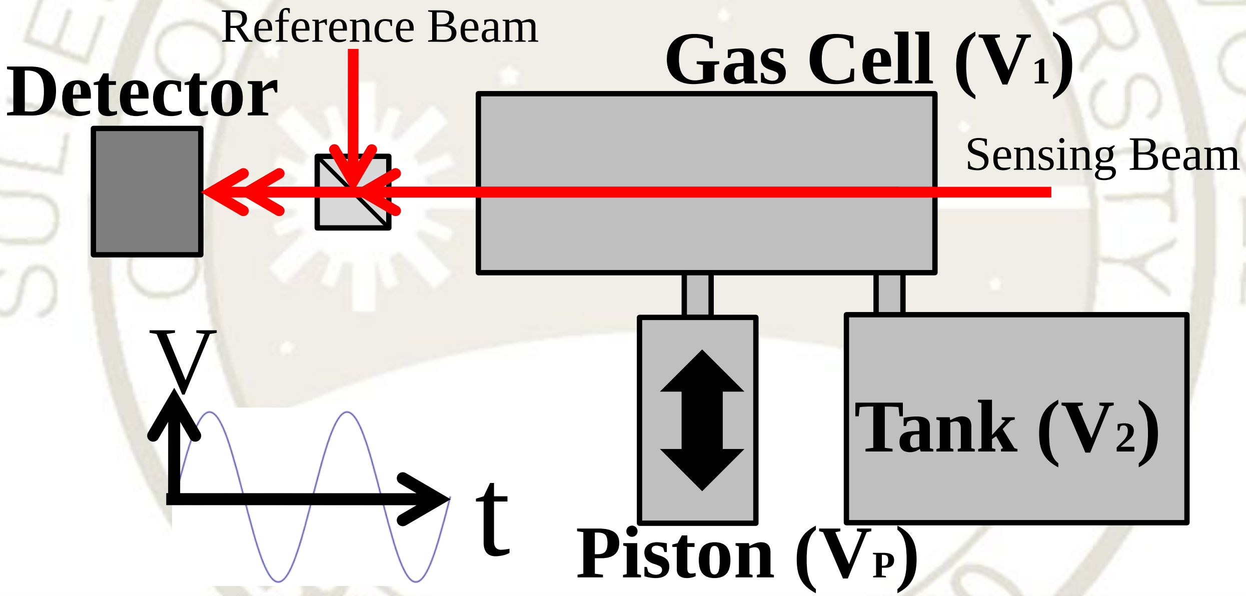
Theory of Operation

At first, a piston pressurizes the gas cell, producing a reference fringe count Δm_1



Theory of Operation

A tank is then exposed to the measurement system, and a second piston cycle produces corresponding fringe count Δm_2

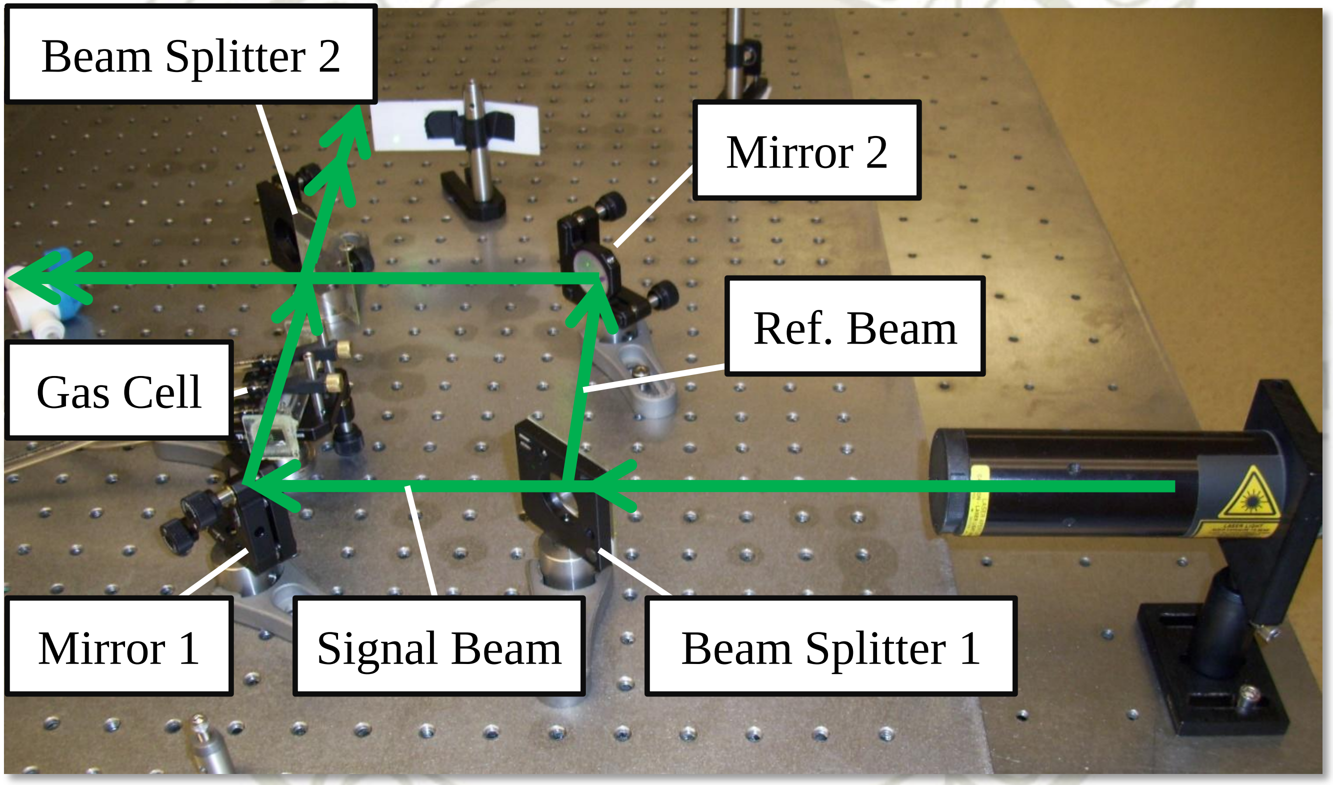


The fringe counts can then be related to volumes using the mathematical relationship:

$$\frac{\Delta m_1}{\Delta m_2} = \frac{(V_1 + V_2 + V_p)}{(V_1 + V_p)} = 1 + \frac{V_2}{V_1 + V_P}$$

where V_1 is the volume of the gas cell, V_P is the volume of the piston, **and V_2 is the ullage volume of the tank**

Initial Mach-Zehnder Interferometer



Interferometer was constructed at the CSU Engineering Research Center (ERC) using a Helium-Neon Laser at 543.5 nm (Green Light)

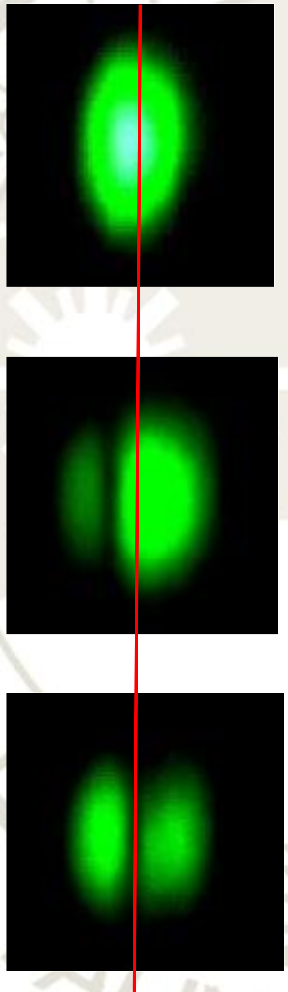
Demonstrative Fringe Shift

Interference

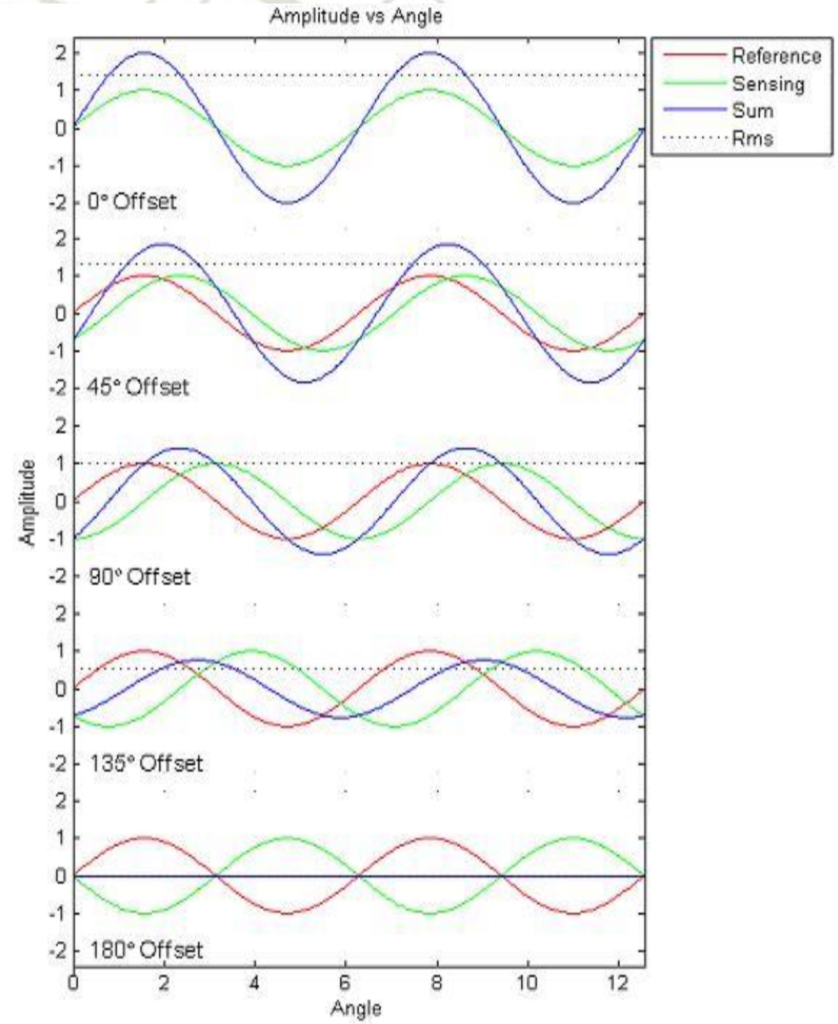
Constructive

Shift

Destructive



Point of Reference



Fringe Shift of Mach-Zehnder Interferometer

$$\Delta m = \frac{\Delta\emptyset}{2\pi} = \frac{l\Delta n}{\lambda}$$

$$PV = nRT$$

$$\frac{\partial P}{\partial m} \approx \frac{2RT\lambda}{3Al}$$

For The Initial prototype setup:

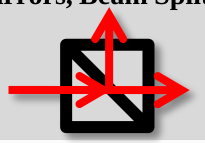
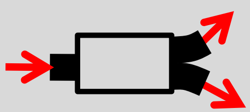
λ	543.5 nm
A	4.606 x 10^{-6} (m^3/mol)
R	8.314 (J/K*mol)
l	0.0762 m
T	297 K
P	84 kPa

= 33 fringes theoretical

Visually counted 36 5 fringes with lab setup

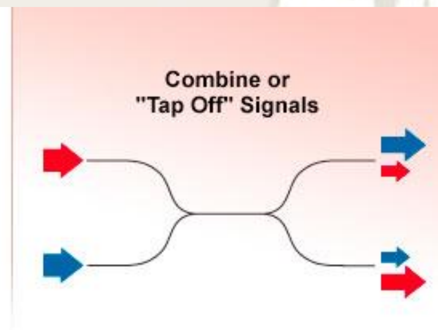
Good agreement between initial experiment and calculation

Fiber-Optic System

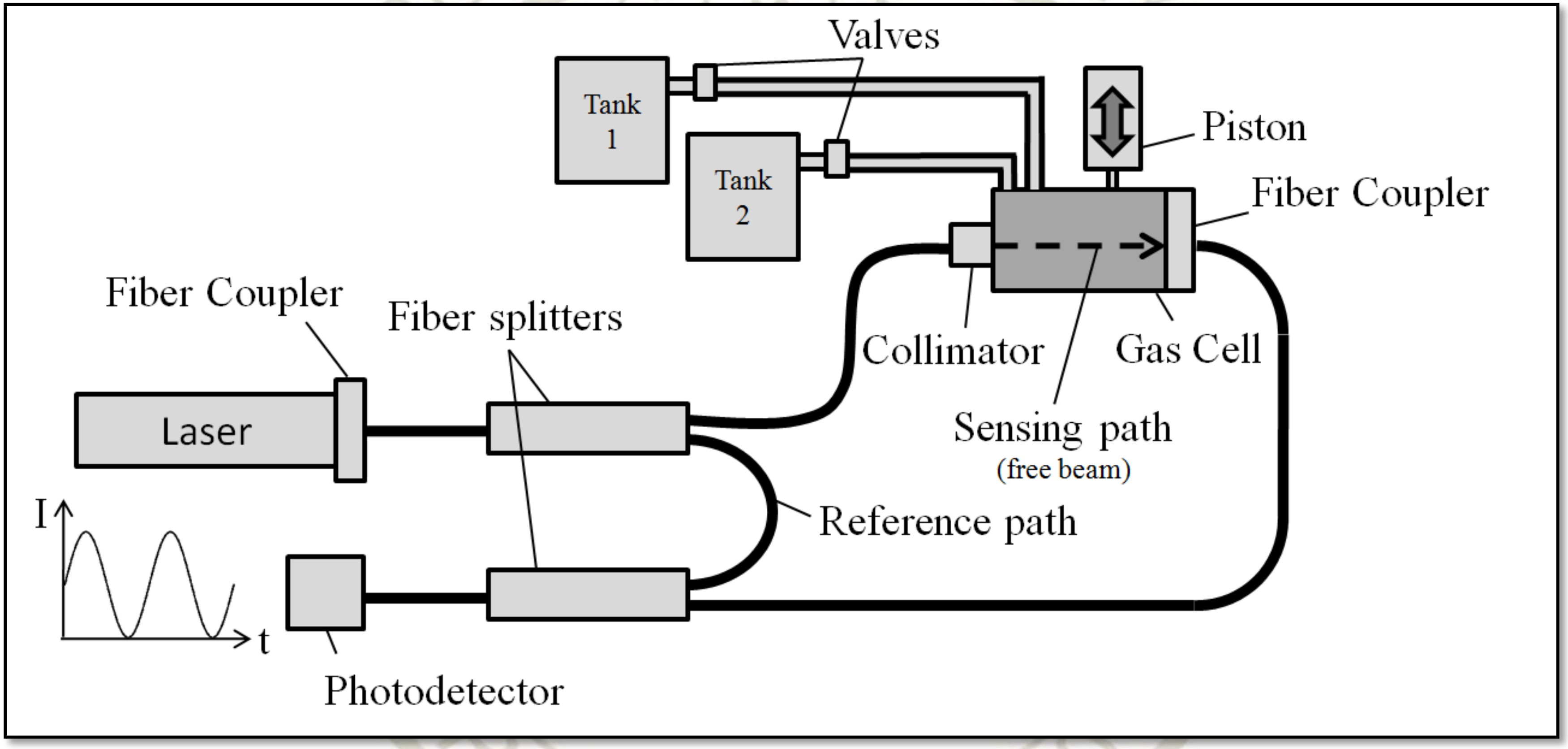
Concept Type	Weight	Size	Vibration Resistance	C.O.G. Conformity	Cost	Complexity	Manufacturing Ease	Total
Traditional Optics (Mirrors, Beam Splitters) 	1	1	1	2	3	2	1	11
Fiber Optics 	3	3	3	2	1	1	3	16

- Center Wavelengths from 632 nm to 1550 nm
- 50:50, 91:10, and 99:1 Coupling Ratios
- OCT Proven Couplers at 850 nm and 1310 nm

FC632-90B



System Layout



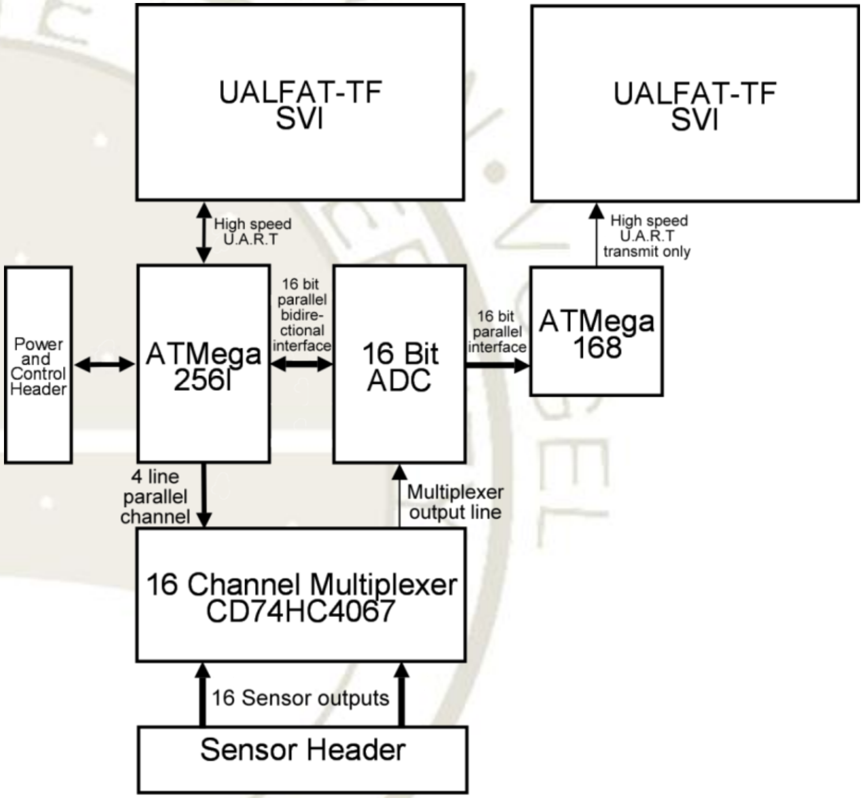
- Two tanks w/ different volumes of liquid are independently exposed to Gas Cell
- Amount of liquid in each can be determined
- The two tanks represent fuel/fluid levels at different periods during a mission

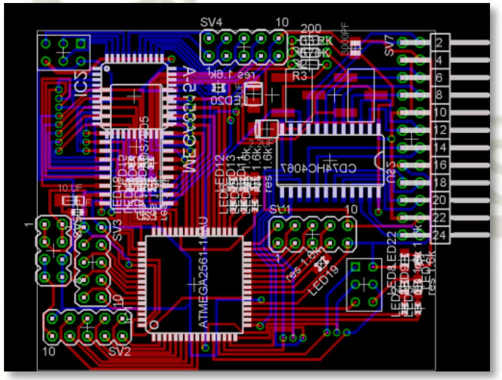
Data Handling and Control

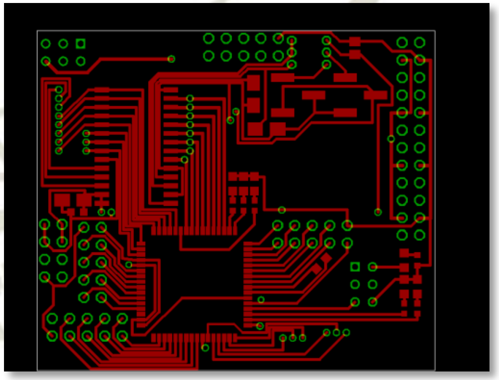
Voltage readout from Photodiode sent to custom-made electronics board

Utilizes Atmega 2561 and Atmega 8515, 16bit Analog to Digital Converter

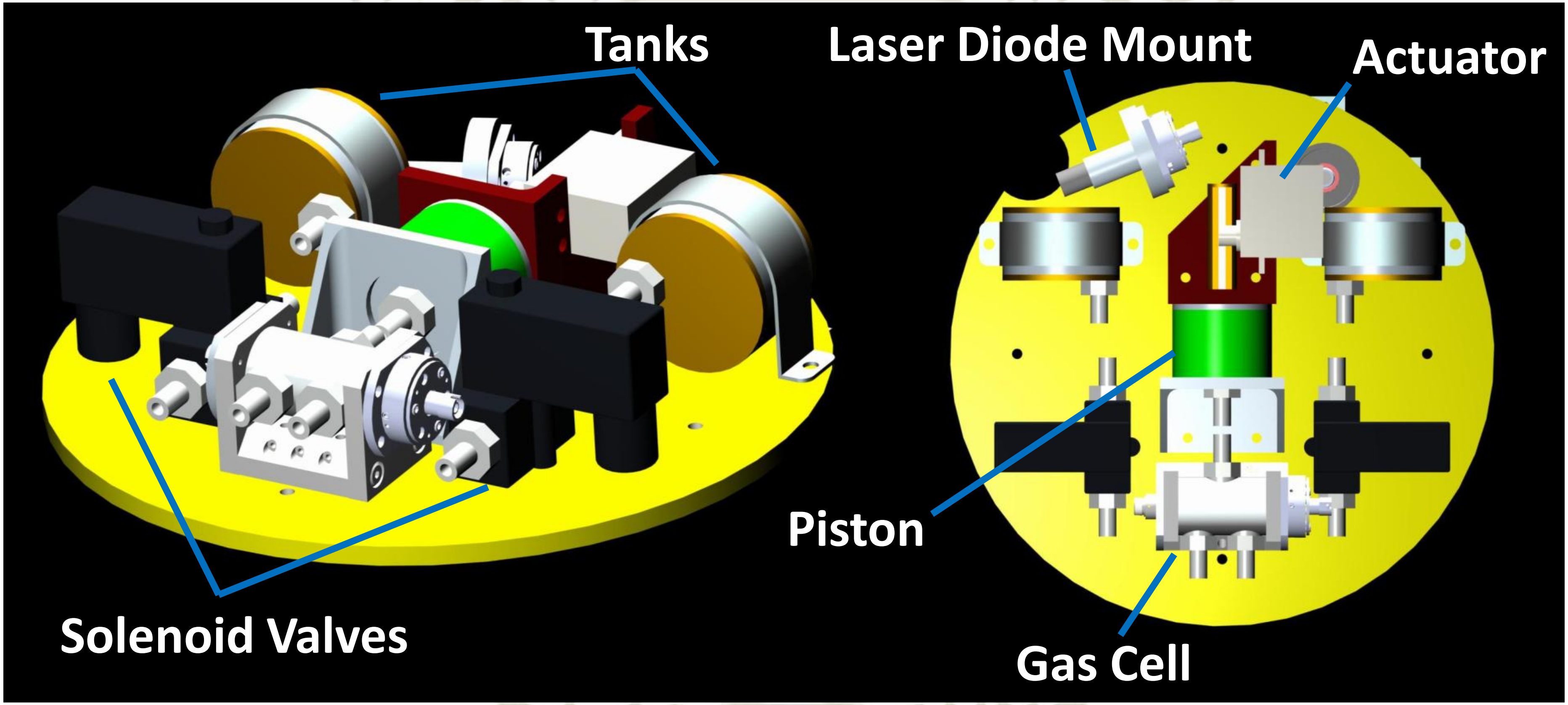
All electronics duplicated, data recorded to 4x 4GB uSD flash mem (redundant in case of failure)



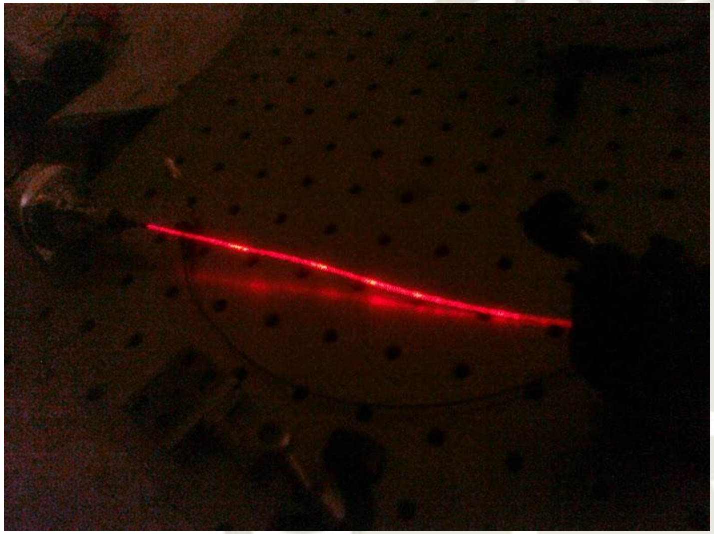


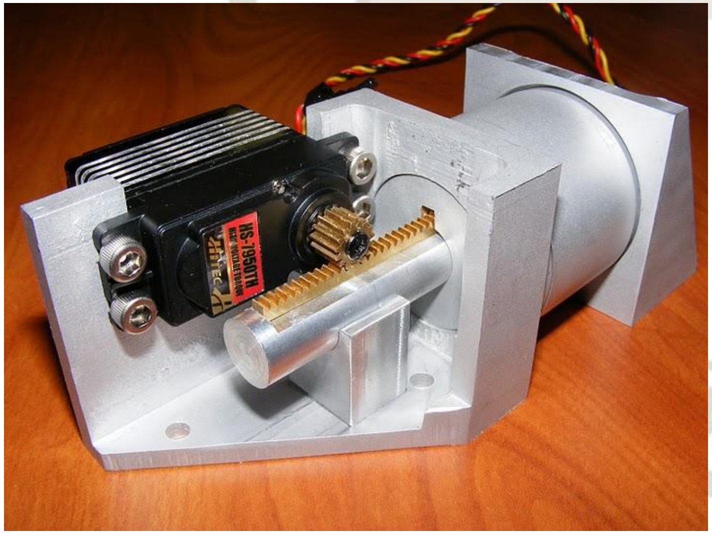


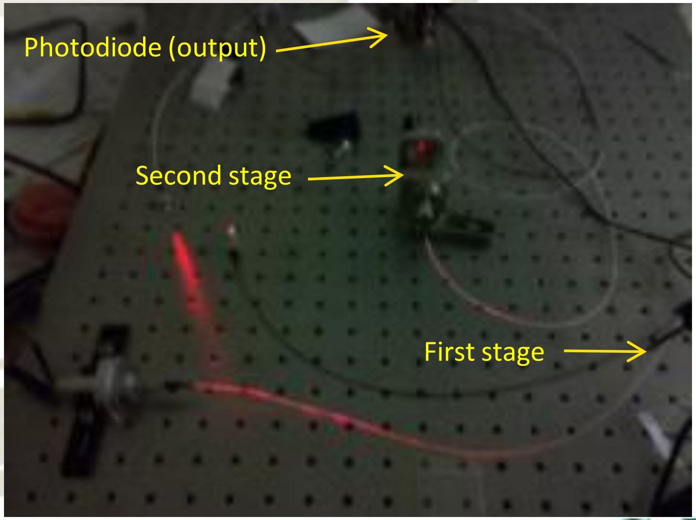
Solid Model of Flight-Ready Prototype



Construction of Prototype







Testing

- Comprehensive Leak Testing
  Pressurize the Tanks, Piston Chamber, Gas Cell, Lines to 40psi

- Vibration and Acceleration Testing (Sierra Nevada Corp.)
  20 minute run with payload placed vibration table in all 3 axes.

- Full Mission Simulation
  Including Compete Data Collection and Analysis

Summary

Introduced problems with measuring liquids in zero-g, alternative methods currently in use, theory of optical mass gauging

Team Status

Nearing end of prototype manufacturing, beginning testing phase

Overall Goal

Mature an existing technology for fuel measurement through a flight test

Acknowledgments

- Tim Schneider, Colorado State University (electronics)
- Dr. Valentine Korman, K-Science
- Dr. Kurt Polzin, NASA's Marshall Space Flight Center
- Jason Priebe and Lad Kurtis, Sierra Nevada Corp.
- Omnis Inc.
- Colorado Space Grant Consortium
- Colorado University RocketSat Program
- Colorado State University Senior Design

Questions?