Center for Space Exploration and Technology Research (cSETR)

NASA University Research Center
University of Texas El Paso

Cryogenic System Development for LOX/Hydrocarbon Propulsion Research

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Agenda

- **Introduction**
  - Background
  - Motivation
  - cSETR
- Cryogenic System
  - Methane Condensation System
  - Delivery System
  - Data Acquisition and Control
- Safety considerations
- Testing
- Conclusions and Future Work

Introduction: Background

Current Propulsion Systems

Used propellants:

- Liquid Oxygen (LOX)
- Liquid Hydrogen (LH_2)
- Monomethyl Hydrazine (MMH)
- Nitrogen Tetroxide (NTO)

Disadvantages

- Carcinogenic, toxic, corrosive and hypergolic (MMH and NTO)
- Leaks, High flammability limits, low ignition energy and boiling point 20K (LH_2)

Introduction: Motivation

Space systems safety

- Design to avoid hazards
- Stringent safety and energy programs
- Protect ground personnel and onboard astronauts

Consequences

- Design, operation and handling costs are elevated

Methane vs. Hydrogen

- Higher liquid density (425/70 [kg/m^3])
- Warmer storage temperature (~108K/20K)
- Smaller flammability limits (5.4-59.2/4.65-94 [mol%])

Advantages

- Less production energy
- Higher tank storage (V,T)
- Relatively lower safety precautions

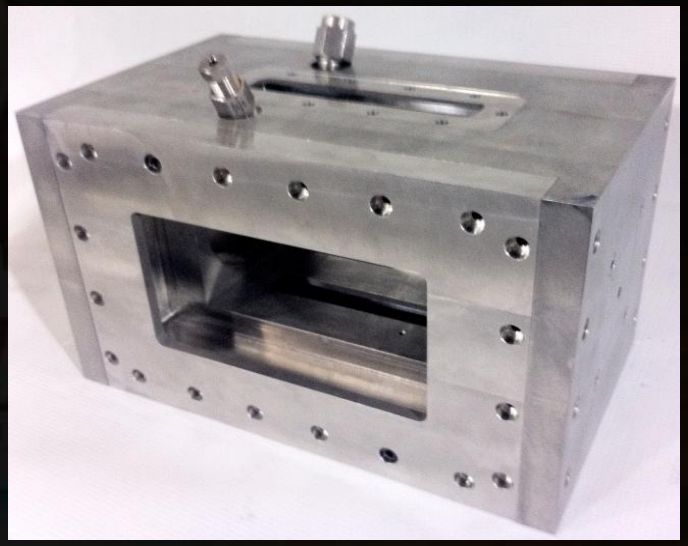
Introduction: cSETR

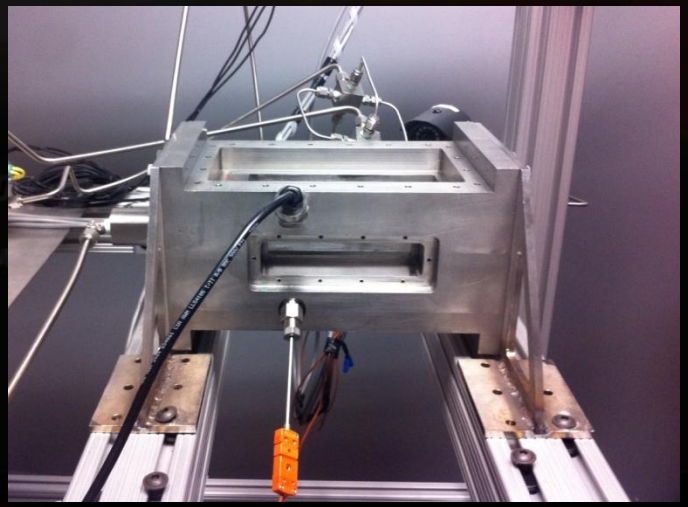
Liquid Methane Research

- Ignition physics
- Heat transfer thrust chambers
- Injector dynamics

Potential applications

- NASA Lunar ascent engine
- Mars in-situ resource utilizations

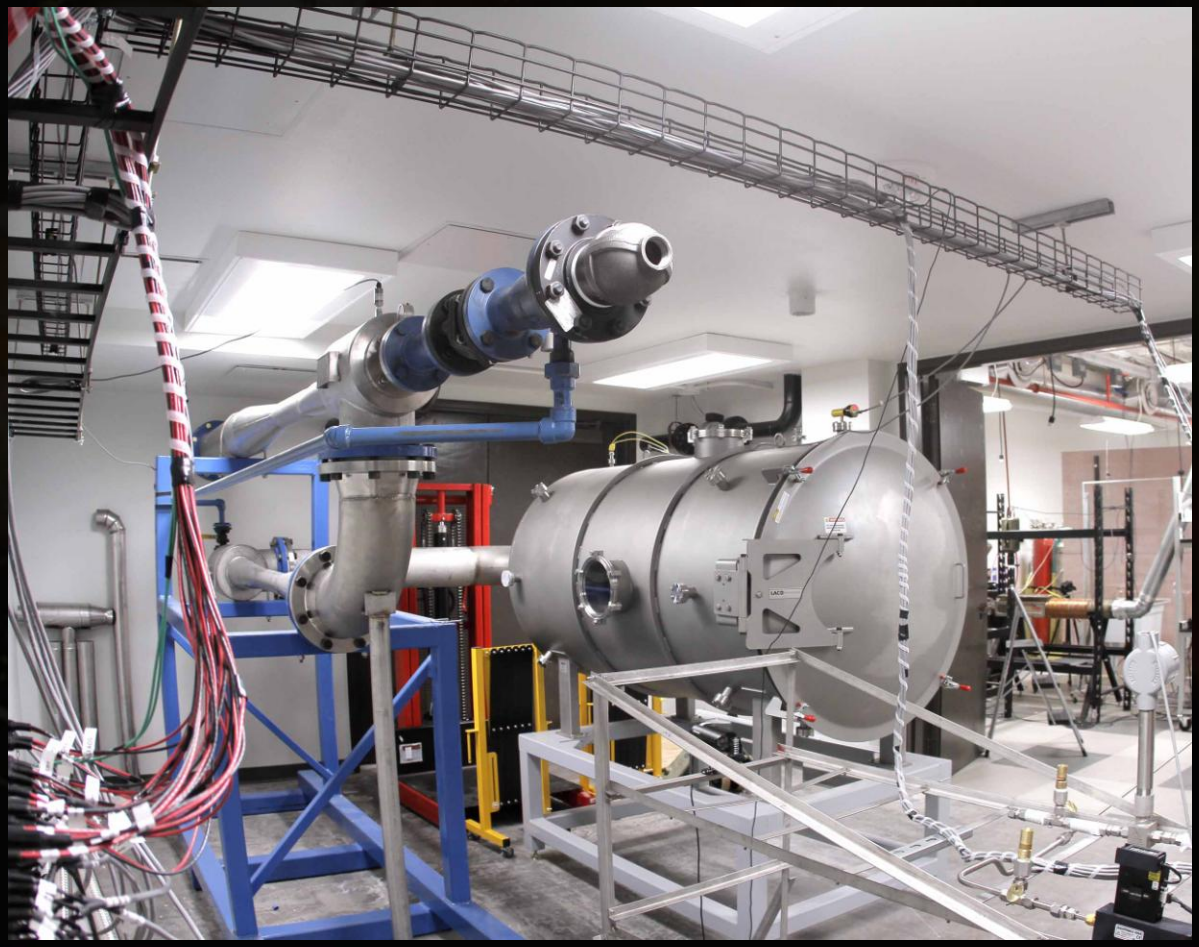




Introduction: cSETR

Opportunity areas

- Reliable Ignition
- High heat load management
- Fast response
- Associate components life



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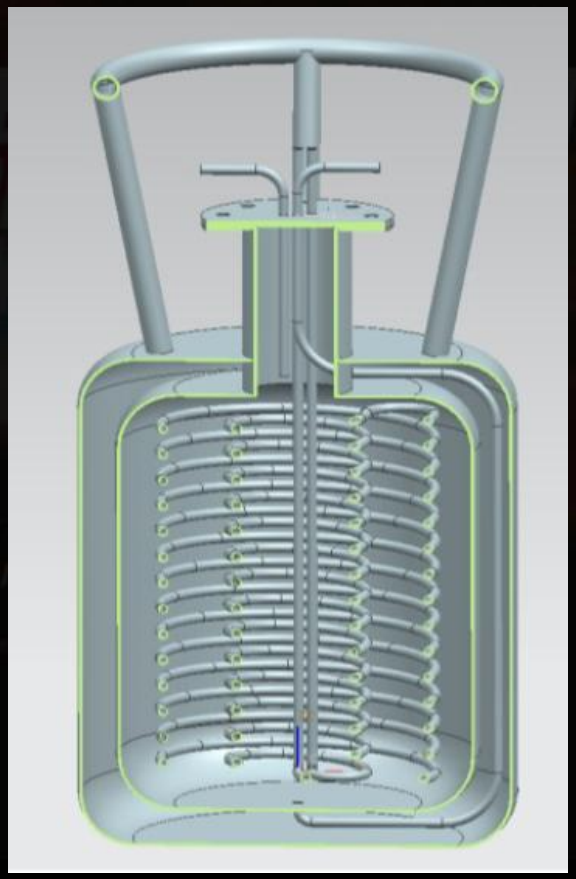
Cryogenic system

Methane condensation system

- cSETR needs of Liquid Methane: 1 to 25 L
- Make in-house Liquid Methane with a heat exchanger
- Liquid nitrogen as cooling fluid (77K boiling point)
- Operating pressure of 1MPa
- Vertical thermocouple array as level gauge



Cryogenic system

Methane condensation system

Heat transfer-energy model:

- Condense 10 L (4.3 kg) Methane
- 3800 kJ (17 kg liquid nitrogen)

$$Q = \mathring{m} \cdot \int_{T_1}^{T_2} C_v dT$$

Multi-resistive heat transfer model:

- Log mean temperature difference
- 18 m coil (1/4" diameter)
- 2.5 L/hr condensation rate

$$Q = U \cdot A \cdot \Delta T$$

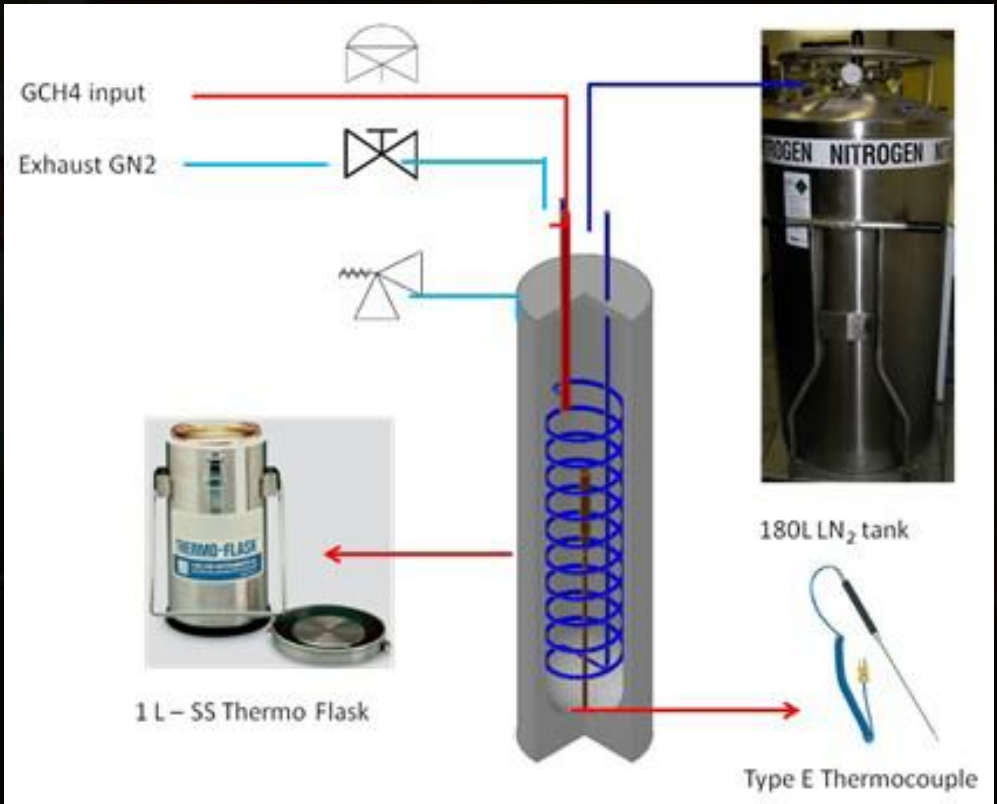
$$Where: U = \frac{1}{\frac{1}{h_{Natural}} + \frac{\ln\left(\frac{D_0}{D_i}\right)}{2\pi k l} + \frac{1}{h_{Forced}}}$$

Cryogenic system

Methane condensation system

Proof of concept

- 1L cryogenic Dewar
- 1m Stainless Steel (1/8” diameter) coil
- Weight change over time



Cryogenic system

Methane condensation system

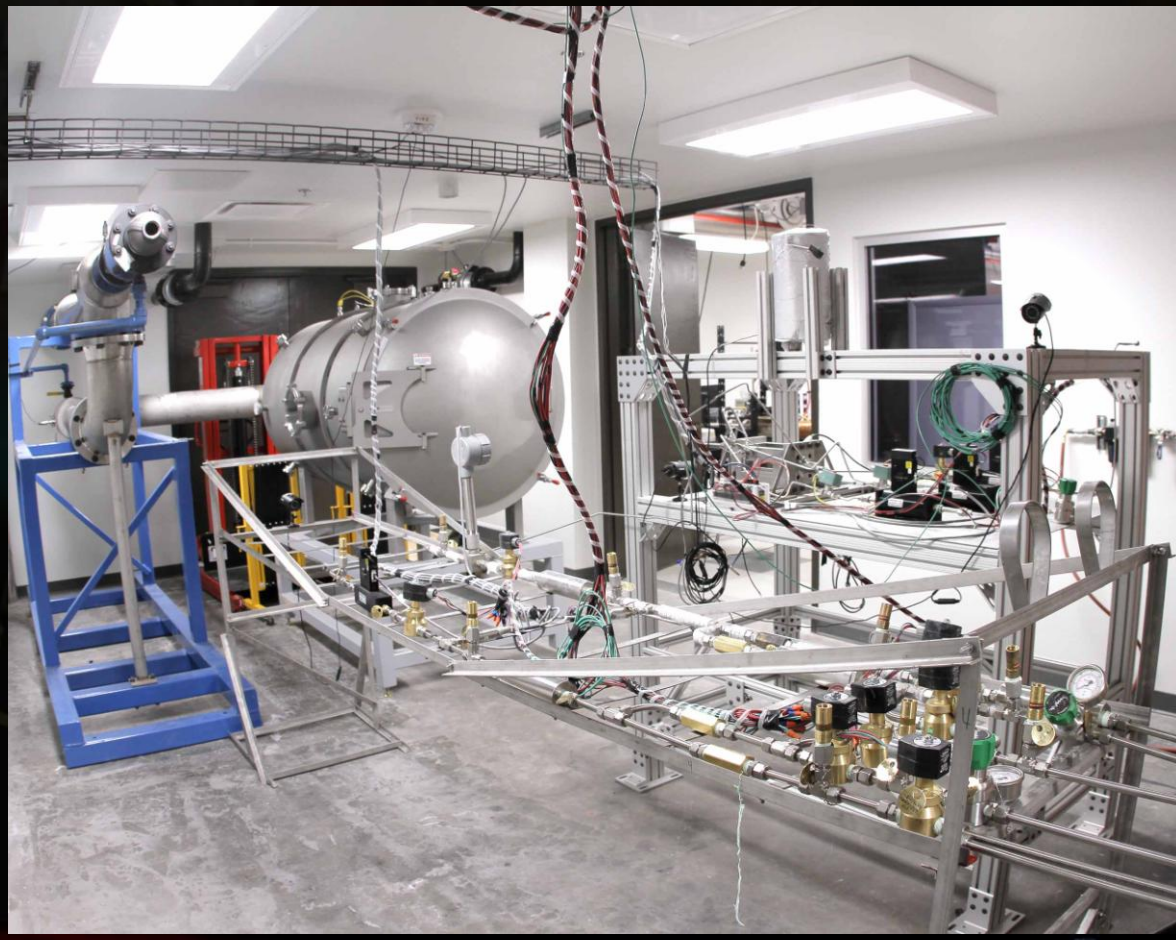
Second generation condenser

- 2.5 m (1/4” diameter) coil
- 2L condenser
- Third generation condenser in development

Cryogenic system

Delivery system

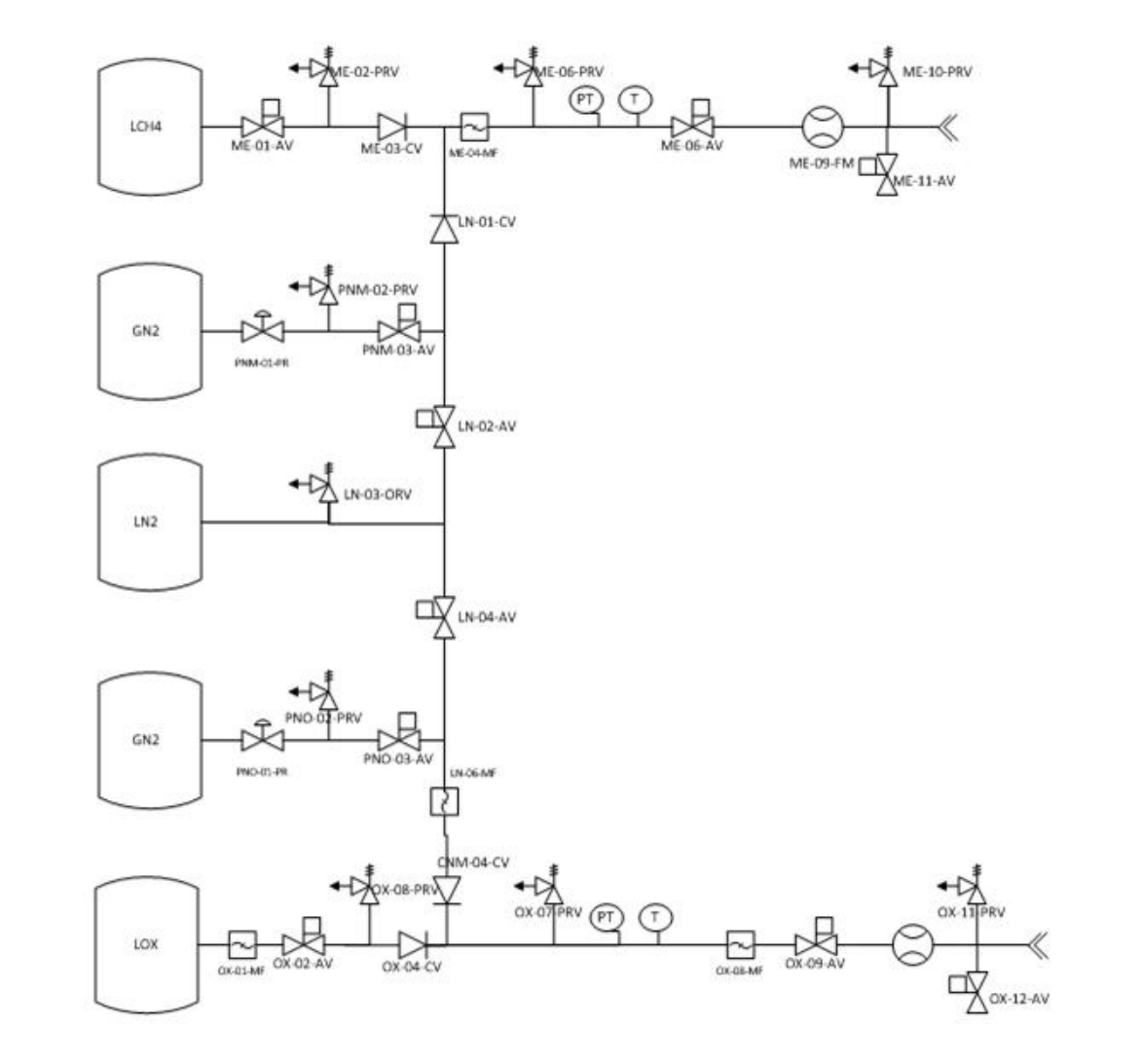
- Deliver cryogenic LOX and Methane to test articles
- Powers up to 100N LOX/CH4 thrusters with 368 ISP
- Maximum pressure 1310 KPa (190 PSI)
- LOX compatible materials



Cryogenic system

Delivery system

- Liquid nitrogen chill down system
- Gas nitrogen purge system
- 25µ filter for LOX and 40 µ for LN2 and LCH4



Cryogenic system

Delivery system

- Actuated valves, flow meters, pressure transducers and temperature diodes
- Pressure relief valves and ventilation system

Cryogenic system

Controls system

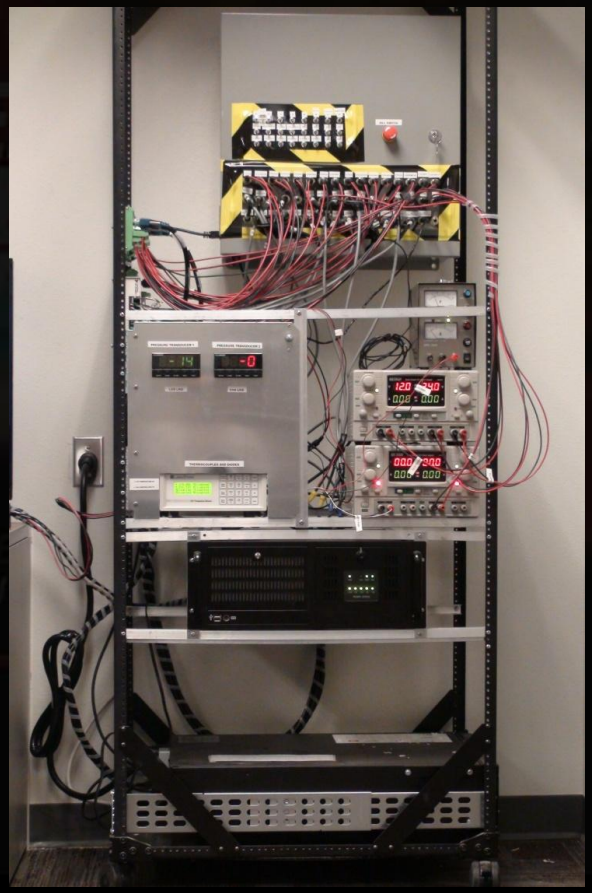
- Allow for remote operation and monitor the delivery system
- Redundant capacity for diagnostics of critical parameters (temperature and pressure)
- Incorporate an auxiliary mode capable of controlling the feed system components without an electronic controller
- Incorporate an emergency procedure to abort any experimentation if the test article becomes a hazard
- Record all the data generated by the sensors and the transducers

System	Classification	Hardware	Electrical Requirements
Cryogenic Feed System	Control	10 Solenoid valves	Excitation: 120 V AC
	Measurement	2 Pressure transducers	Excitation: 10 VDC
			Output: 0-30 mV
		2 Cryogenic Temperature sensors	Excitation: 10 µA
			Output: 0-1500 mV
		2 Cryogenic Flow meters	Excitation: 8 VDC
			Output: 4-20 mA
Multipurpose Optically Accessible Combustor	Measurement	1 Pressure transducer	Excitation: 10 VDC
			Output: 0-30 mV
		2 Thermocouples	Thermocouple data acquisition channel
		2 Gas Flow meters	Excitation: 12 VDC
			Output: 0-5 V
Multipurpose Altitude Simulation System	Measurement	2 Pressure transducers	Excitation: 10 VDC
			Output: 0-5 V
		1 Pirani Vacuum Gage	Excitation: 12 VDC
			Output: 1-8 V
Torch Igniter	Control	2 Solenoid valves	Excitation: 24 V DC
	Measurement	2 Gas Flow meters	Excitation: 12 VDC
Spark Exciter	Control	1 Voltage Transformer	Power: 12 VDC
			Output Control: 5 VDC

Cryogenic system

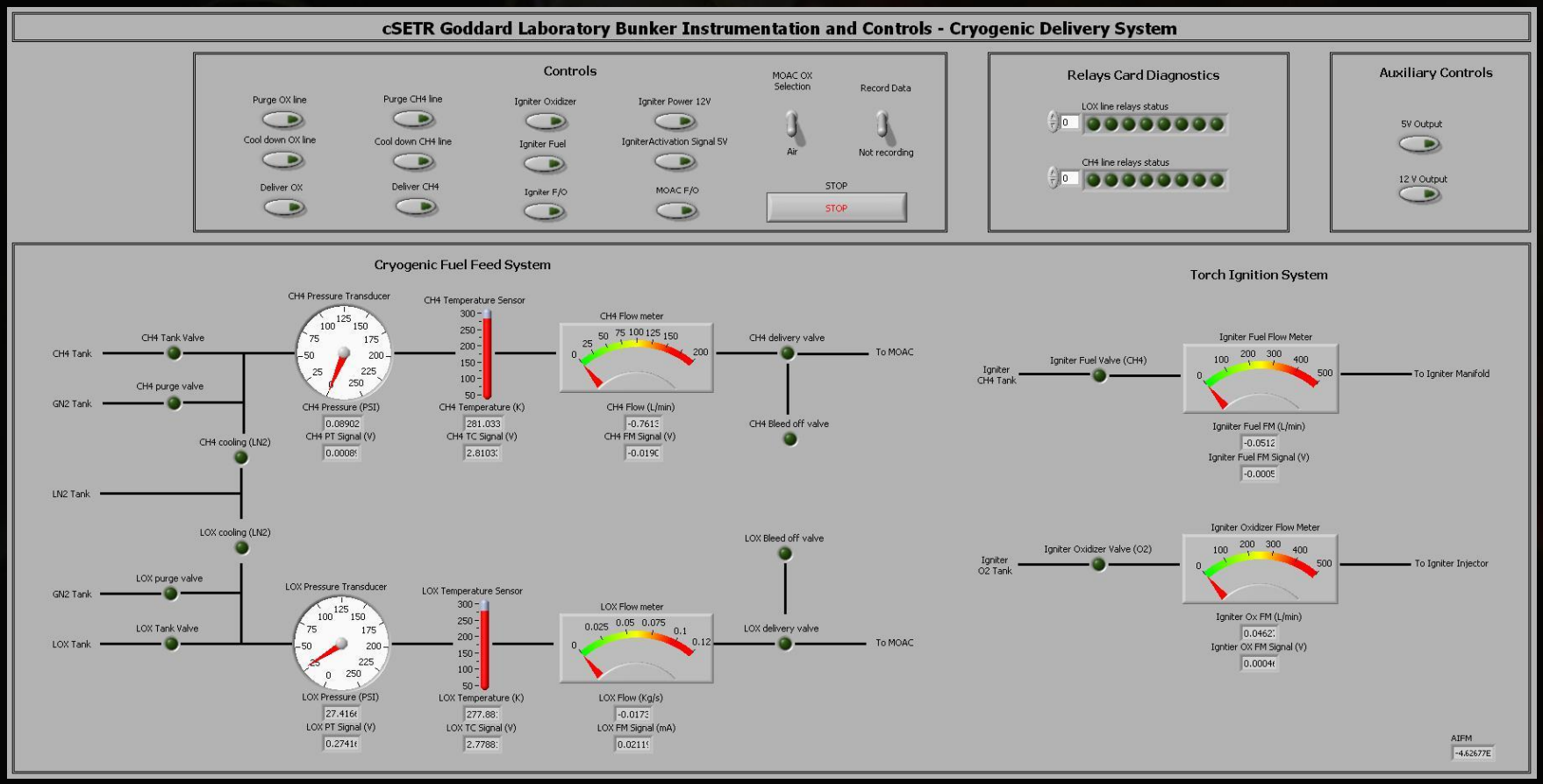
Controls system

- Back Up power supply (30 minutes)
- Industrial computer with 2 hard drives of 500 GB
- 16 relay output channels
- 24 analog input channels
- Expandable to 12 PCI cards
- Modular patch panels
- Controlled via LabVIEW GUI



Cryogenic system

Controls system



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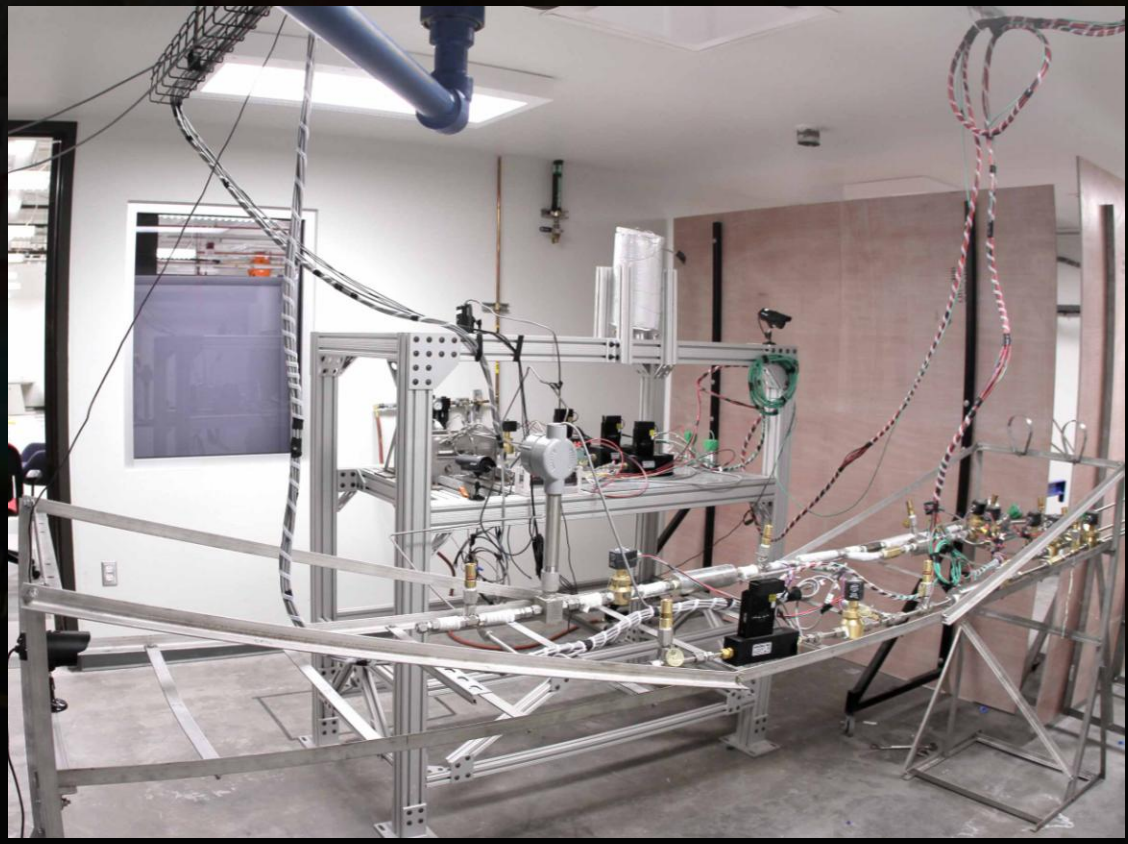
Safety Considerations

Cryogenics' Potential hazards

- Physiological
  - Frostbite, asphyxiation, hypothermia, death
- Over pressure
- Materials and components damage
- Fire and Explosions
  - LOX systems



Safety Considerations

Safe operation

- Remote testing
- Projectile-proof bunker
- Cryogenics training
- PPE
- Written procedures and hazards analysis
- Dry runs
- Testing with supervision

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Testing

- All testing is performed remotely from a control room
- A minimum of 3 personnel is required, a test director, a test operator and a safety operator
- Pre-test is conducted in three major phases. Functional testing, pressure testing, propellant line fill
- Operability and delivery are in expected performance
- The system has been pressure tested at a maximum pressure of 344 kPa (50PSI) using gas Nitrogen and 206 kPa (30 PSI) on a gas Oxygen/Methane test

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Conclusions and Future Work

Conclusions

- A propulsion research system has been built and developed at the cSETR facilities at UTEP
- Produces up to 2L Liquid Methane
- Remotely tested gaseous fuels (Oxygen/Methane)
- Ambient and altitude testing (up to 85000 ft) capabilities
- Steady State and pulsing operation of 100 N class thrusters
- Strict safety policies to ensure personal wellness and facilities integrity

Conclusions and Future Work

Future Work

- Future testing includes chilled methane/Gas Oxygen, gas methane/LOX and finally LCH4/LOX
- Future condenser to operate at high pressures (1 Mpa – 145 PSI), produce 25L and collect the generated data
- Perform a non dimensional analysis to compare condensers' design and performance, characterizing the process with a non dimensional parameter

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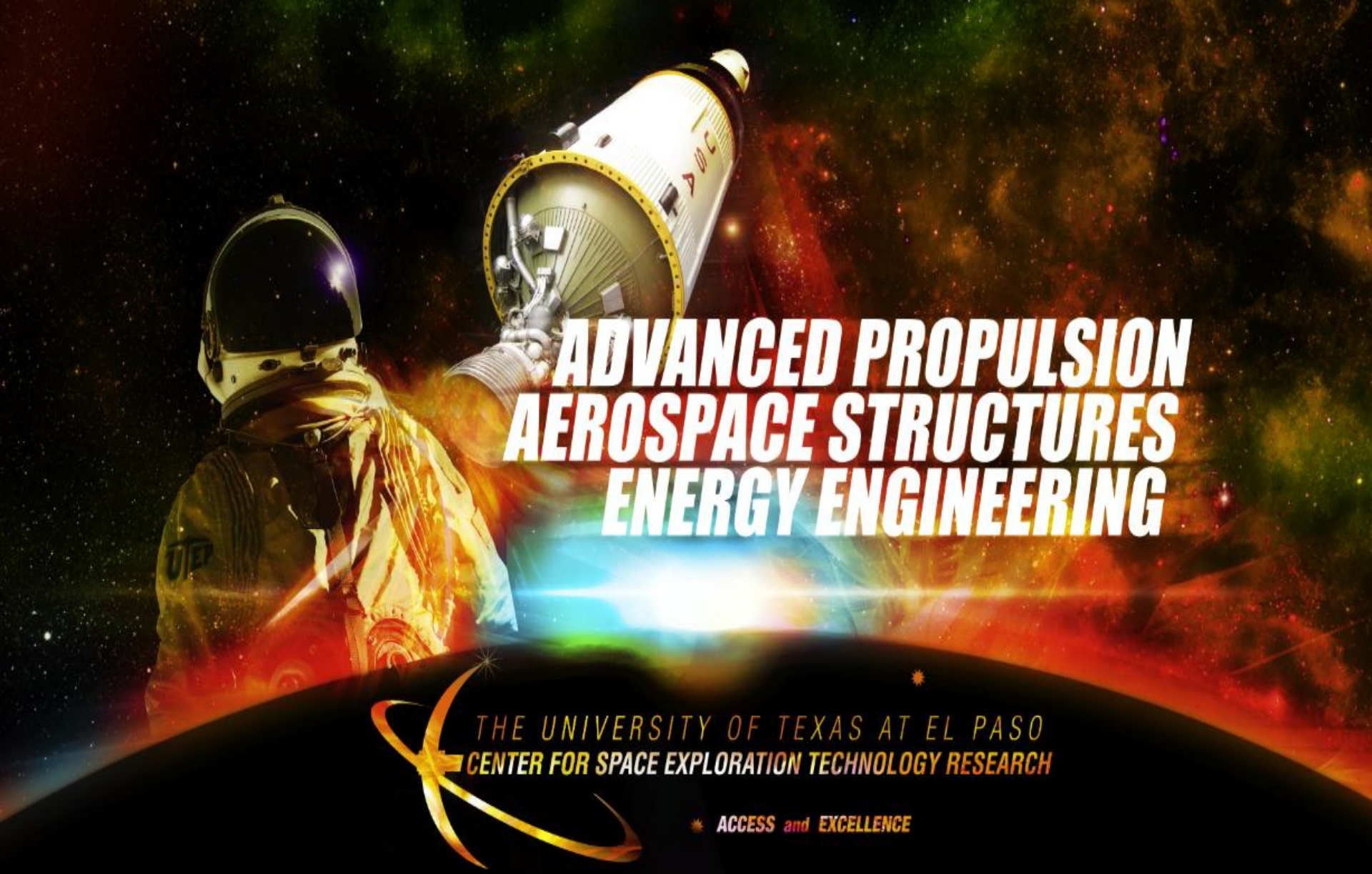
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Questions?