Extreme Environments Test Capabilities at NASA GRC

for Parker Hannifin Visit

June 8, 2016

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Relevant Test Facilities

- Fuel Cell Testing Lab
- Structural Dynamics Lab
- Thermal Vacuum Test Facilities
- EMI Test Lab
- Creek Road Cryogenic Complex

Fuel Cell Testing Laboratory

Fuel Cell Testing Laboratory

- Test Cell 111 dedicated for fuel cell testing
  - Test capability for fuel cells at stack level through full system with balance of plant
  - Test Cell is designed for a variety of sizes and types of Fuel Cells
    - Can run FC's ranging from 1 kW up to 125 kW
    - Can run hydrogen/air Fuel Cells
    - Can run hydrogen/oxygen Fuel Cells
    - Other supply gases possible depending on demand
  - Test Cell has built in Safety Devices & Control
    - Combustible Gas (hydrogen) detectors, 2
    - High/Low O2 sensor
    - Heat Detection Cable (190 degrees F)
    - Tied into Dispatch which notifies first responders
    - Class 1, Division 2, Group B NEC rating
    - Cell operates via PLC, unattended operations allowable

Fuel Cell Testing Laboratory

- Hydrogen System
  - Set Up for 2 Tuber Trailers (up to 2,400 psig) and 1 K-Bottle Pack Station
  - Pressure Control
  - Nitrogen Purged
- Nitrogen System
  - Set Up for 1 Tuber Trailer (up to 2,400 psig) and 1 K-Bottle Pack Station
  - Pressure Control
  - Valve Actuation Back-up
- Oxygen System
  - Set Up for 1 Tuber Trailer (up to 2,400 psig) and 1 K-Bottle Pack Station
  - Pressure Control
  - Nitrogen Purged

Fuel Cell Testing Laboratory

- Compressed Air System
  - Research Air
    - 2 (10 HP Ingersoll Rand Unigy air compressors)
    - Air to Test Cell for fuel cell usage and/or cooling air
    - Ability to supply all test cells with 1 compressor
  - Shop Air
    - 1 (7.5 HP Ingersoll Rand Unigy air compressor)
    - Shop Tools
    - Valve Actuation
    - System Components

Fuel Cell Testing Laboratory

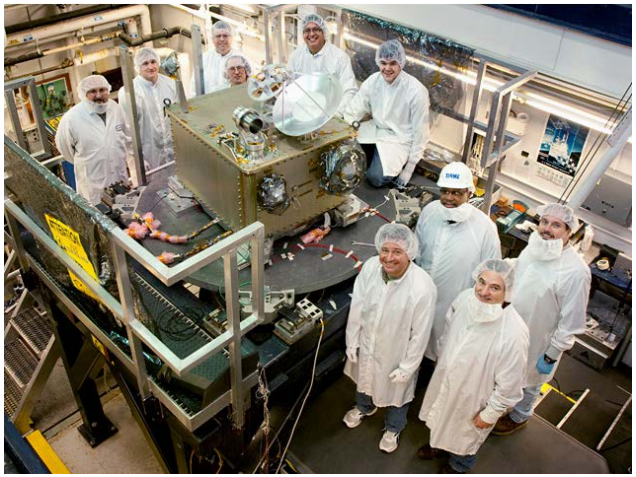
- Cooling Water
  - 35 kW thermal capacity, second unit available if required
  - Pump, 10 GPM at 60 psi
- Power
  - Available in building: 480 VAC, 277 VAC, 208 VAC, 120 VAC
  - Power cables run through test cell feed-thru
  - 2 circuits available
- Data Acquisition
  - 144 Analog input channels
  - 120 channels 0-1V isolated analog input
  - 24 channels that can be configured for various ranges between +/-30VDC
  - 24 Channels of Type T thermocouples

Structural Dynamics Lab (SDL)

- Performs tests to verify survivability of a component or assembly when exposed to vibration stress screening or a controlled simulation of the actual flight or service vibration environment
- Possible to test operating fuel cell assemblies under vibration conditions
- Future capability to test operating fuel cell assemblies under simulated thermal, altitude, and vibration conditions concurrently – see slides for Kinetic High Altitude Simulator (KHAS) under Thermal Vacuum section
- Vibration testing service can support all phases of hardware development process including engineering evaluation, design qualification, service hardware acceptance, verification and certification of flight hardware
- Services include requirements definition and planning, fixture design and fabrication, test operations, data acquisition, interpretation, and analysis, test documentation and reports

Structural Dynamics Lab (SDL)

- **Environmental Testing**
  - Sinusoidal Vibration
    - Sine Sweep
    - Sine Burst
    - Sine Chirp
  - Random Vibration
  - Classical Shock
  - Force Limiting



- **Modal Testing (Impact and MIMO)**
  - Boundary Conditions:
    - Fixed - base
    - Driven - base
    - Free - Free
  - 10’ X 10’ Modal Floor with a 4” X 4” mounting hole pattern
  - 50 and 100 Lbf MB portable shakers
  - Resonant frequency/mode shapes
  - Structural damping
  - Component interface environments

Structural Dynamics Lab (SDL)

Technical Capability Summary

- **Excitation**
  - Ling Electronics 4022:
    - Sine: 40,000 Lbf
    - Random: 35,000 Lbf
    - Stroke: 1.5 in. pk-pk
  - MB Dynamics C-220 (Converted C210):
    - Sine: 35,000 Lbf
    - Random: 35,000 Lbf
    - Stroke: 1.0 in. pk-pk
  - MB Dynamics C-60
    - Sine: 6,000 Lbf
    - Random: 4,500 Lbf
    - Stroke: 1.0 in. pk-pk.
- **Control**
  - Spectral Dynamics Jaguar:
    - 18 Input Channels
    - Sinusoidal vibration control and analysis software
    - Random vibration control and analysis software
    - Shock control and analysis software
  - Spectral Dynamics (GenRad) 2552B:
    - 12 Input Channels
    - Sinusoidal vibration control and analysis software
    - Random vibration control and analysis software
    - Shock control and analysis software

Structural Dynamics Lab (SDL)

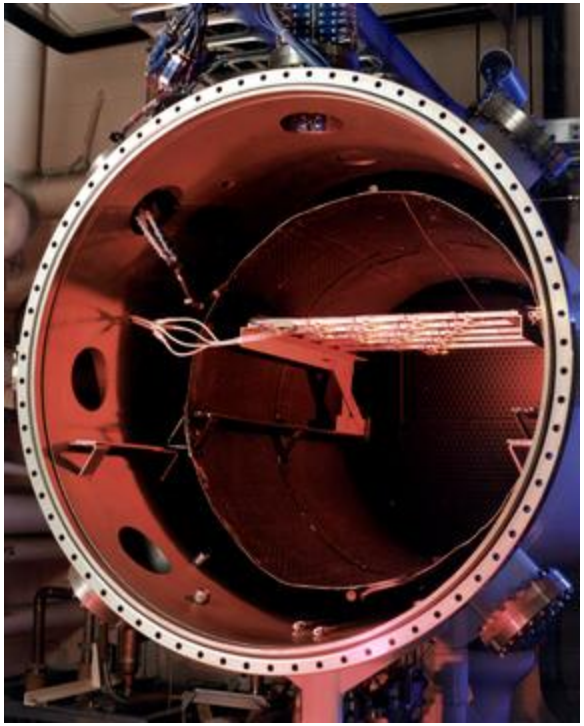
- **Data Acquisition**
  - 100 Channels of Piezoelectric Accelerometer Signal Conditioning
  - 60 Channels of Analog Signal Recording (DAT format)
  - MTS IDEAS Test Acquisition and Analysis Software
    - 92 Channel VXI 1432 Cards Voltage/ICP Accelerometer Digital Acquisition System
  - Two Independent (or combined) 48 Channel HP VXI based Digital Acquisition Systems
  - Portable Data Acquisition capability

Thermal Vacuum Test Facilities

- NASA GRC at Lewis Field has six thermal vacuum chambers (VF-6, VF-10, VF-13, VF-17, VF-20 and VF-67) ranging from approximately 3 to 25 ft diameter by 5 to 70 ft long, that operate with a base pressure on the 10-6 to 10-7 torr scale, using full or partial liquid nitrogen cold shrouds

Thermal Vacuum Test Facilities

- TVAC facilities have been used to prove hardware capabilities in lunar or Martian environments for ISRU application, LEO and GEO environments for solar array testing and CubeSat applications, and altitude testing



Thermal Vacuum Test Facilities

Kinetic High Altitude Simulator (KHAS) Description

- KHAS is slated to be a flexible, world-class environmental simulation facility. KHAS will be capable of simultaneous temperature, altitude, and vibration testing of operational test articles per RTCA DO-160F.

Industry Problem

- Currently, the majority of airborne equipment testing per RTCA DO-160F is performed using a multitude of test facilities. This can require the customer to modify the test articles or even develop test-specific articles in order to accommodate specific tests and facilities. All of this leads to prolonged test schedules, complex logistics management, and process inefficiencies leading to increased overall test costs.

Our Solution

- KHAS will enable simultaneous testing within a single facility. Unlike other test apparatuses, KHAS will enable test articles to be operational during testing within a desired environmental condition, thereby providing a more realistic test.

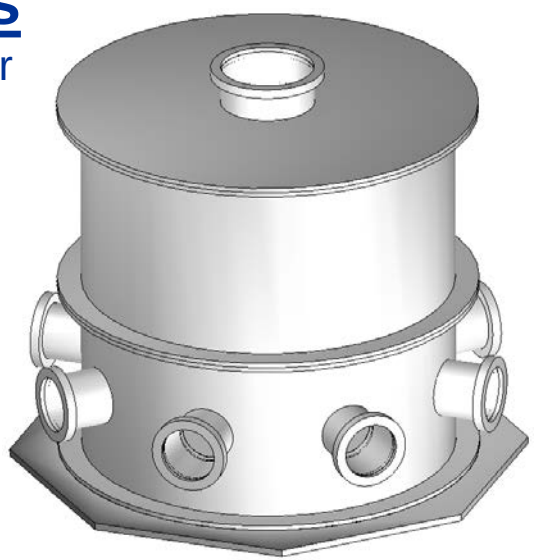
Current Status

- Phase 1 feasibility analysis complete, preliminary parts list generated

Thermal Vacuum Test Facilities

KHAS High-Level Capabilities

- Enables simultaneous operational testing per RTCA DO-160F, Sections:
  - 4.0 – Temperature and Altitude
  - 5.0 – Temperature Variation
  - 8.0 – Vibration
  - Future Extensibility may add other effects, based on market demand (e.g. humidity, electrical/signal effects, etc.)
- ***Portability***: Entire system will be portable
- ***Test Article Weight***: Up to 550 lbs
- ***Simulated Altitude***: Up to 65,000 ft.
- ***Temperature Range***: -100°F (-60°C) to 180°F (85°C)
  - Temperature Variability Rate: Up to 60°C/min
- ***Test Duration***: 4+ hrs
  - Current concept design has been optimized to minimize operating costs
- ***Frequency Range***: 10 – 2000 Hz
  - Integration and Operations in collaboration with world-class vibrations experts at NASA GRC SDL



KHAS Concept – Full Capability

- Inner Diameter = 39”
- Inner Height = 39”
- 8 feedthru ports
  - Power
  - I&C
  - LO_2/GO_2 (fuel port #1)
  - LH_2/GH_2 (fuel port #2)
  - LN_2/GN_2 (atmosphere)
  - Spares (3)
- Lid port is used by facility

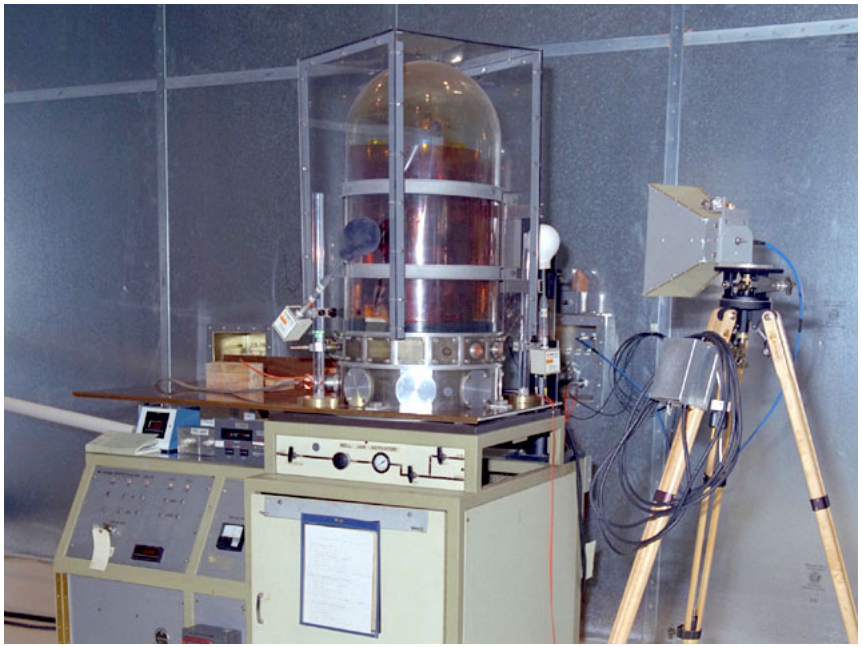
KHAS Concept - COTS

- Alternatively, We could develop a COTS option (includes temp & altitude, excludes vibration from simultaneous testing). Later, the full–capability option could be developed.

Electromagnetics Interference (EMI) Lab

The EMI Lab has successfully verified every piece of flight hardware to leave GRC since its completion in circa 1995.

Planned upgrades to the facility including anechoic chamber treatment for small test articles, mode-tune reverberation chamber characterization for large test articles, and high frequency test equipment.



Electromagnetics Interference (EMI) Lab

The Electromagnetic Interference (EMI) Laboratory offers several Electromagnetic Compatibility (EMC) services like EMC hardware design to meet the desired requirement, specification comparisons, consultation during design development, and prefabrication analyses. The EMI Lab provides intermediate testing as the design progresses, testing for shielding effectiveness, filtering, and grounding, final qualification testing of experiments in flight configuration, and testing at customer locations for items too large to fit in the EMI Laboratory shielded room.

This facility consists of three shielded rooms, two test chambers, and a control room. All walls, ceiling, and floors are constructed of 26-gauge galvanized steel sheets laminated to both sides of a structure core. The rooms meet the electromagnetic wave attenuation requirements used by the National Security Agency (NSA). They prevent transmission of electromagnetic waves into, or out of, the enclosure, which provides low electric and magnetic field ambient conditions. Electrical power is provided through filtered AC lines to eliminate transfer of interfering signals such as radio, TV, and RADAR.

The large shielded enclosure is a fully functional package with support for stirred and tuned mode operation with Statistical Mode Averaged Reverberation test. This methodology of test is good for Immunity test or shielding effectiveness test.

Electromagnetics Interference (EMI) Lab

Emissions	Method
CE01	Automated
CE03	Automated
CE07	Manual
RE02	Automated
RE04, RE101	Automated
Magnetic	Automated/Manual (H-Field)

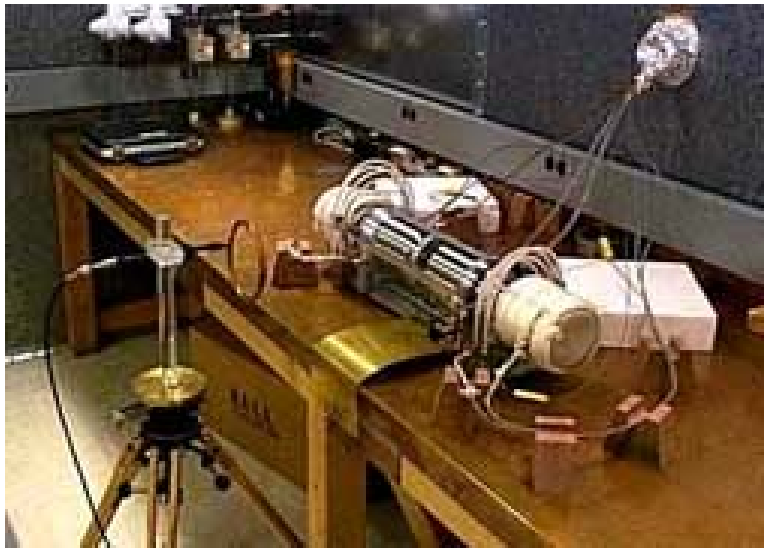
Susceptability	Method
CS01	Automated
CS02	Automated
CS06	Manual
RS02	Manual
RS03	Automated
RE03-PL	Automated

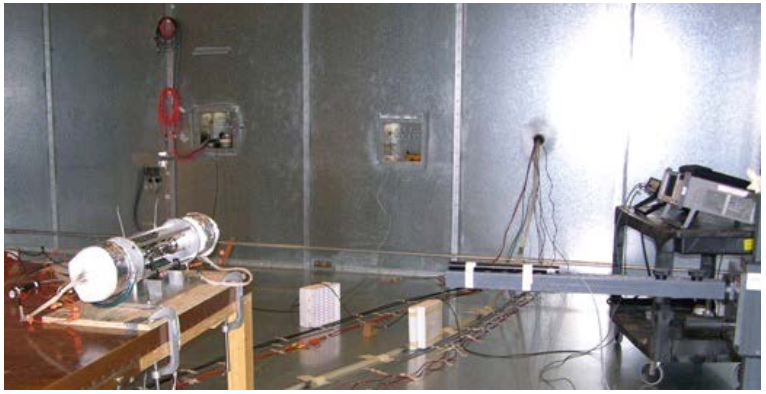
Electromagnetics Interference (EMI) Lab

Located in Building 332, Contains:
1 large mode-tuned reverb chamber,
- 32 by 24 by 16 ft
- Door: 10 by 14 ft

1 small reverb chamber
- 12 by 16 by 8 ft
- Door: 6 by 7 ft

Shielded Test Control Room
- 10 by 12 by 8 ft





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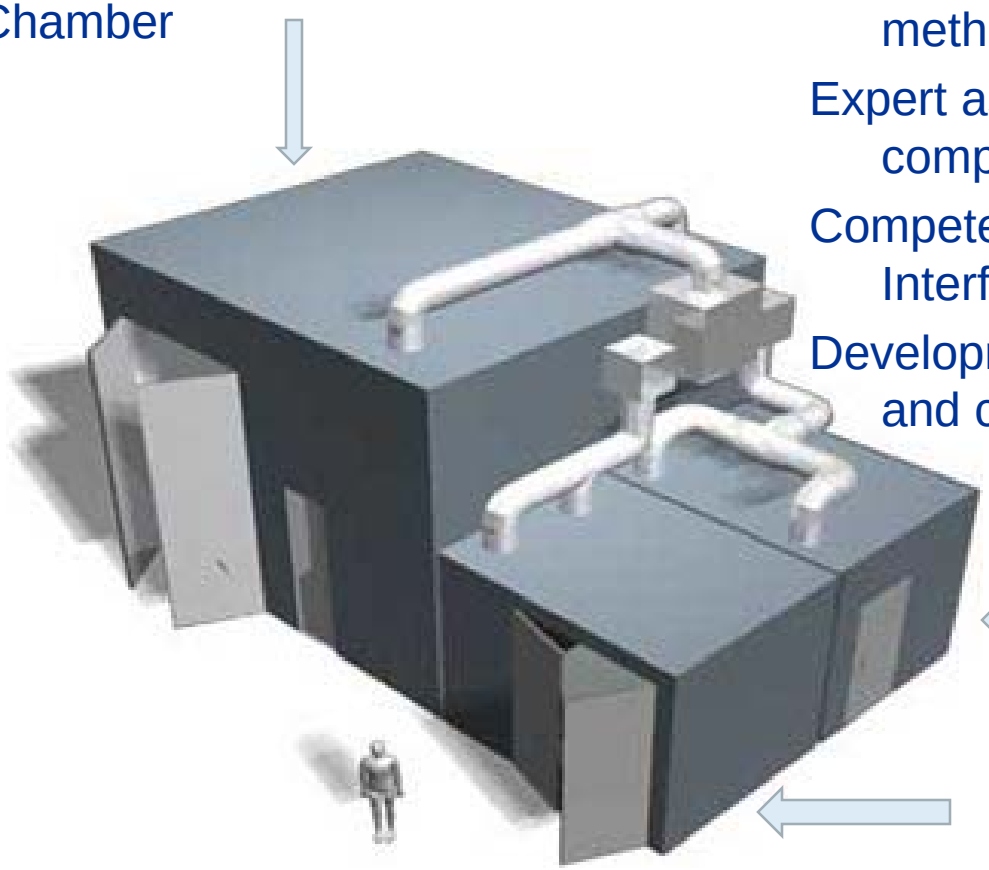
Electromagnetics Interference (EMI) Lab

- Two fully trained EMI test engineers
  - Lead test engineer has over 17 years experience
- Skilled interpretation of specifications and test methods
- Expert assistance in troubleshooting non-compliances
- Competent support in obtaining Tailoring Interface Agreements (TIA) or waivers
- Developmental testing of components, boxes, and cables

Mode Tuned Reverberation Chamber



Shielded Control Room

Anechoic Chamber

Electromagnetics Interference (EMI) Lab

- Large Chamber
  - Reverberation chamber simulates cavity environments
  - Fields are made statistically uniform by rotating the two stirring paddles
  - This is becoming the “gold standard” for a robust susceptibility test, because energy impinges on the system under test from all directions and polarities
  - Size of test article (ft.)can be 17 ½ L x 8 ½ W x 7 H
- Anechoic Chamber
  - Reverberation chamber simulates free space
  - Walls are covered by ferrite tiles to absorb lower frequencies and carbon impregnated composite cones to absorb higher frequencies
  - Size of test article (ft.) can be 7 ¾ L x 2 ¼ W x 2 ½ H

Electromagnetics Interference (EMI) Lab

- Control Room
  - Shielded control room keeps noise from infecting the test chambers
  - Stand-alone computers control the test equipment
  - Shielded feed-throughs allow customers' support equipment to interface with article under test
  - Equipment available on-site to support a wide variety of EMI testing:

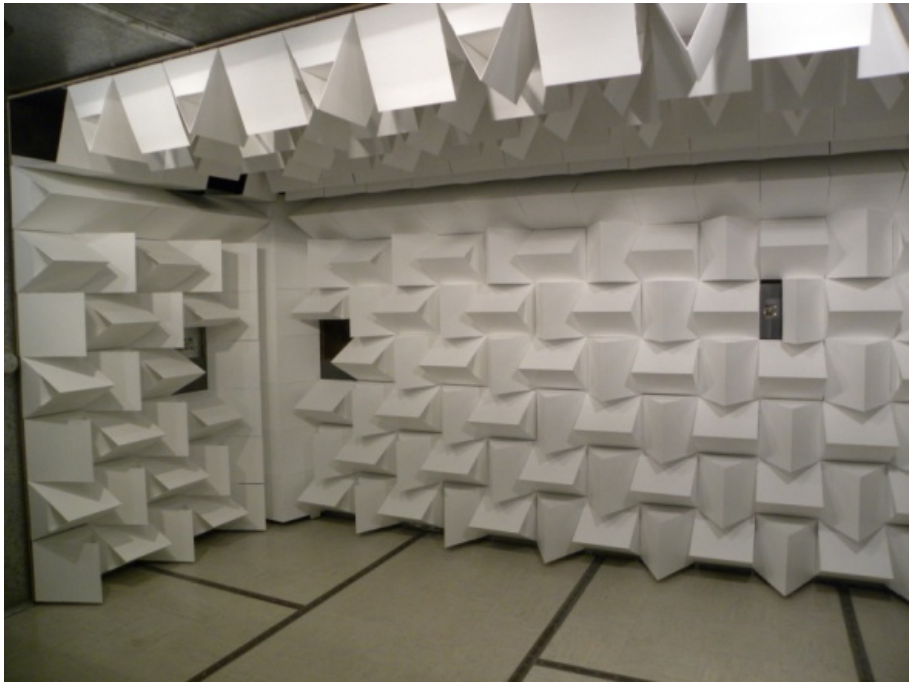
    MIL-STD-461F

    Indirect Lightning

    IEC 61000-4-21

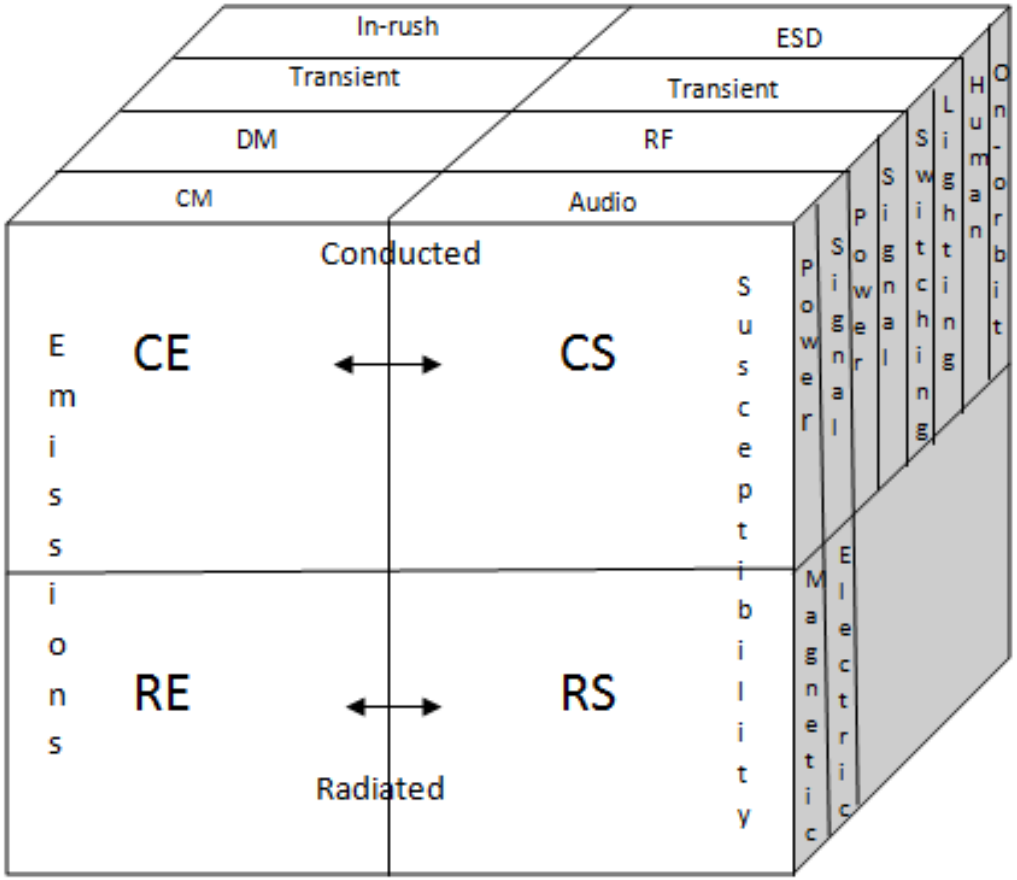
    RTCA/DO-160

Electromagnetics Interference (EMI) Lab

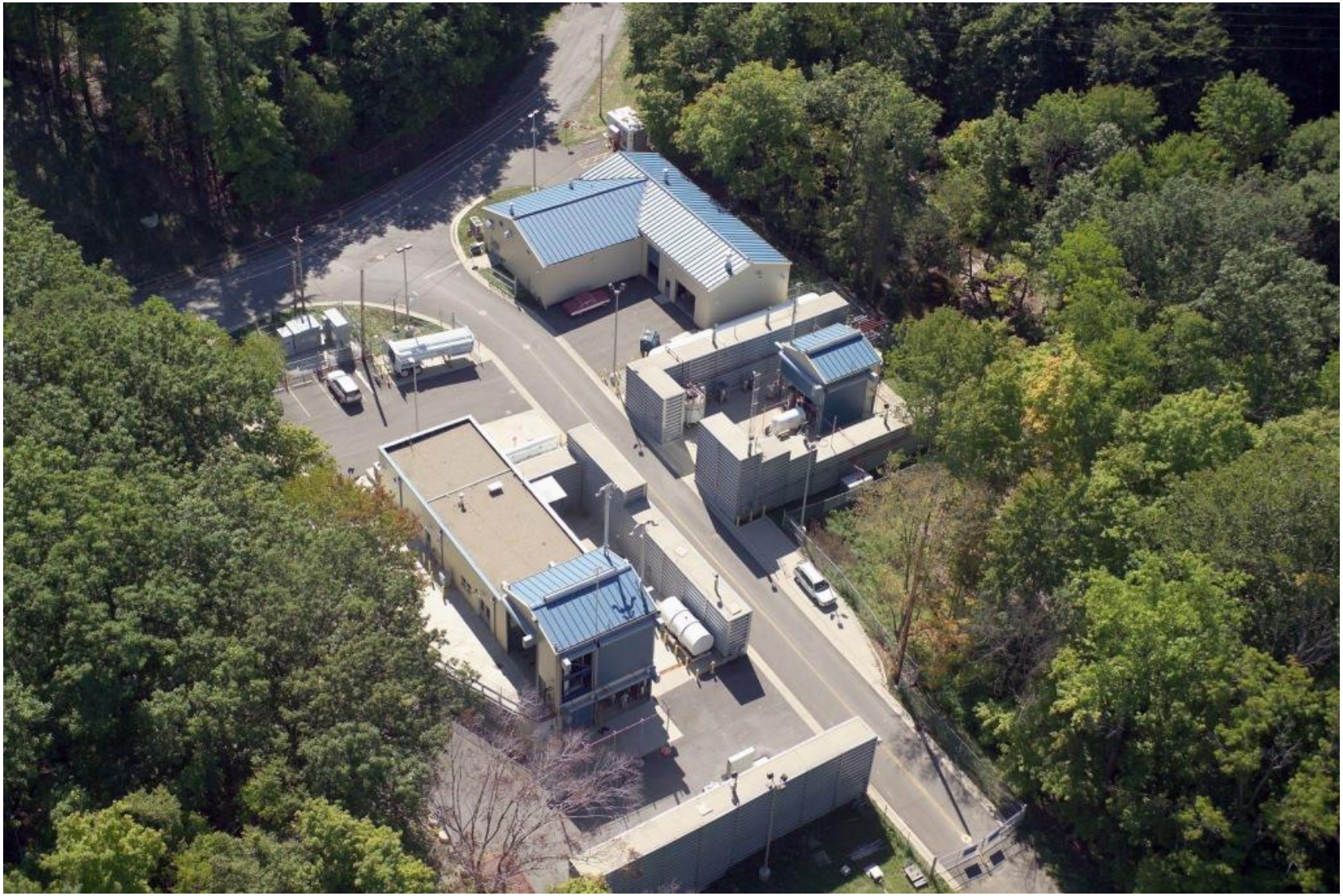


Electromagnetics Interference (EMI) Lab

EMI Test Categories



Creek Road Cryogenic Complex



Creek Road Cryogenic Complex

- Construction completed Fall 2003, state-of-art facility and data acquisition
- Space simulation, launch profiles and high altitude
- Creek Road Cryogenic Complex (CRCC) consists of 4 separate test cells: Small Multi-purpose Research Facility (SMiRF), Cryogenics Component Lab 7 (CCL-7), Cryomotor Pad*, and 20K – 90K Calorimeter Test Bed*

*Information available upon request

Creek Road Cryogenic Complex

SMIRF: provides the ability to simulate space, high altitude, & launch pressure environments; conduct calorimetry tests on prototype insulation systems; and handle hazardous gaseous and cryogenic flammable fluids without compromising on personal safety; specializes as a small scale screening facility for concept and component testing; supports Cryogenic Fluid Management (CFM) technology development (thermal control, liquid supply, low gravity mass gauging), planetary simulation, and any test requiring a hazardous commodity in a thermal vacuum chamber

Capabilities

Test Fluids: LH2 - 4500 gal (17,000 l), LN2 - 6000 gal (22,700 l), LO2 - 3600 gal (13,600 l), LHe (500 liters), LCH4 - 6000 gal (22,700 l)

Vacuum Environment:

- Continuous: 5 x 10-6 torr
- Ascent Profile: 760 to 1 x 10-2 torr in 2 min.

Thermal Environment: Shroud (110K to 390K) Programmable to simulate diurnal cycles

Test Article Size (width x height)

- With Shroud: 44” x 65” (1.1 m x 1.6 m)
- W/ Out Shroud: 71” x 101” (1.8 m x 2.3 m)

Data System:

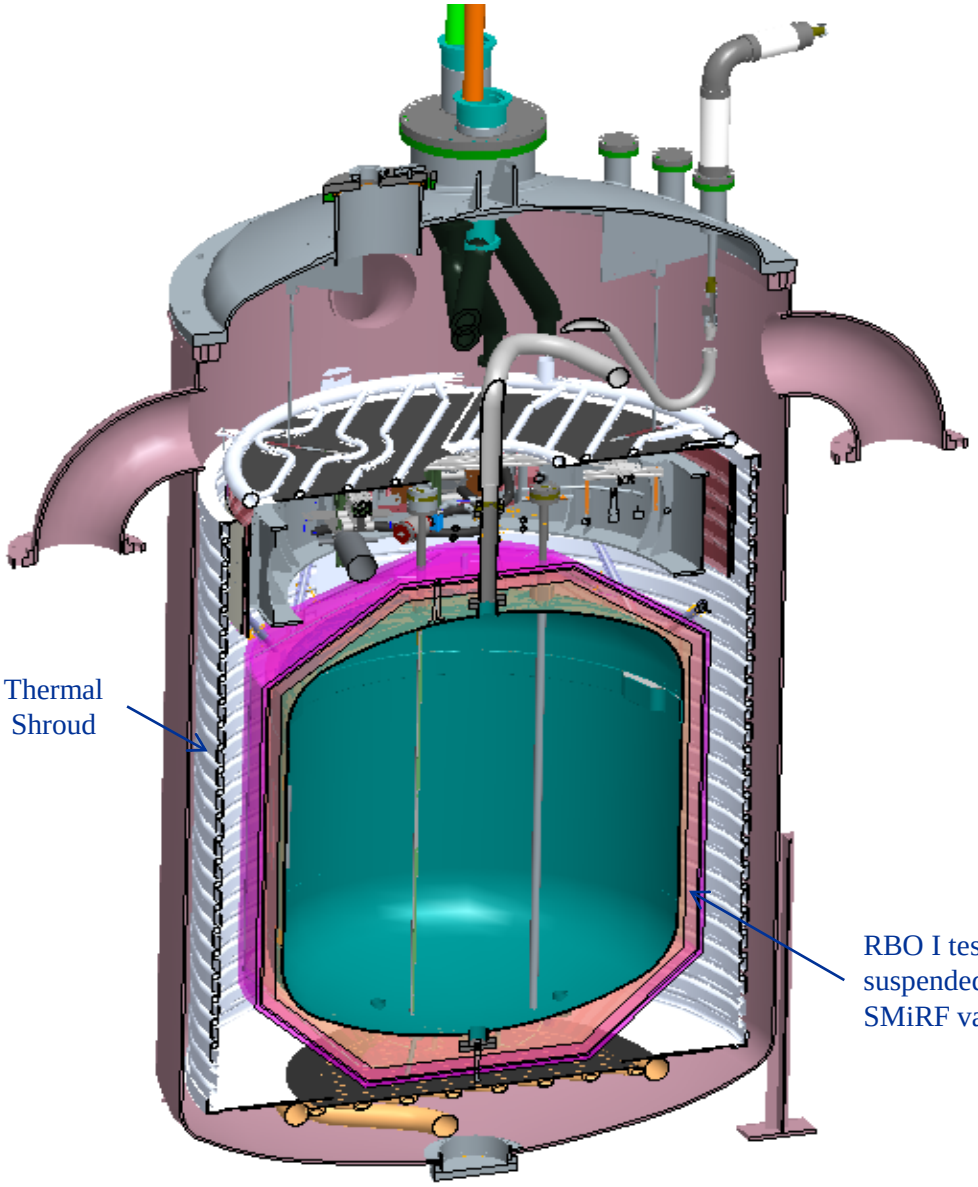
- 424 Recordable channels at speeds up to 1 Hz
- 64 Recordable channels at speed up to 0.1 Hz

Creek Road Cryogenic Complex

SMiRF:

- Highly configurable test cell
- Cryogens (LH_2, LCH_4, LO_2, LN_2)
- Gases (H_2, CH_4, He, N_2, O_2, CO_2)
- 1st floor Vac. Chamber (7400 L)
- 2nd floor piping & VC lid access
- Separate oxygen & flammable propellant systems
- Test articles up to 1.8 m x 2.3 m
- Safety handled w/ rollup doors, explosion proof equipment, gas detection, exclusion zone based on appropriate quantity-distance calculations
- Remotely operated for safety

Creek Road Cryogenic Complex



SMiRF Capabilities – cont'd

- Steady State ullage pressure control - 0.025 psi (1.7 mBar)
- Programmable thermal shroud (cold wall) boundary temperatures from -260F to 240F (110K to 390K)
- Data System – ~500 recordable channels at speeds of 1 Hz to 0.1 Hz
- Vacuum Chamber diameter ~ 6 ft (1.8 m)
- Multi-Layer Insulation (MLI) custom onsite fabrication and installation
- Vacuum levels as low as 3e-6 torr
- Controlled launch ascent pressure profile capability – Match current ELV fleet
- Residual Gas Analyzer on chamber

Creek Road Cryogenic Complex

SMiRF – Numerous pressure vessels

Volume = 58 ft^3 (1.6 m^3)
MAWP = LN2 - 250 psi (17.2 Bar)
LH2 - 150 psi (10.3 Bar)

Creek Road Cryogenic Complex

Volume = 6 ft^3 (0.17 m^3)
MAWP = LN2 - 250 psi (17.2 Bar)

SMiRF – Numerous pressure vessels cont.

Volume = 6 ft^3 (0.17 m^3)
MAWP = LN2 - 250 psi (17.2 Bar)

Volume = 49 ft^3 (1.39 m^3)
MAWP = LH2 - 50 psi (3.45 Bar)
Aluminum construction

Creek Road Cryogenic Complex

Cryogenic Components Lab (CCL-7)

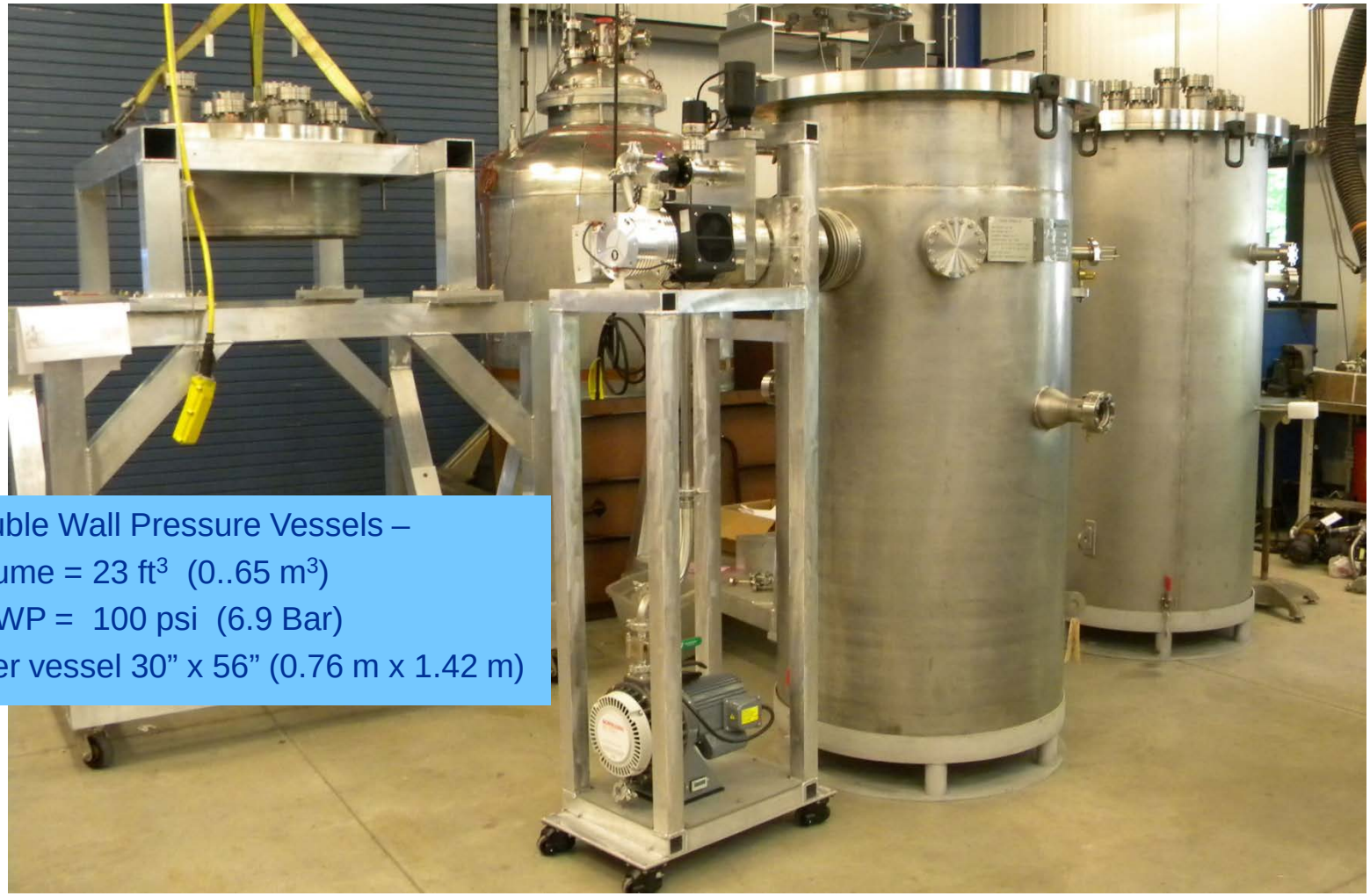
CCL-7 is a smaller version of SMiRF with similar capabilities. It is a highly configurable test cell providing the ability to simulate space, conduct highly accurate calorimetry tests (20K to 90K or -423F to -297F) on prototype insulation systems, and handle hazardous gaseous and cryogenic flammable fluids without compromising on personal safety.

Capabilities

- Cryogenic Test Fluids: LHe, LH_2, LN_2, LAr, LO_2, LCH_4 or other as required
- Gases: He, H_2, N_2, Ar, O_2, CH_4 or other as required
- Vacuum Environment: Continuous 1 x 10-6 torr
- Test Article Size (width x height): 30” x 56” (0.76 m x 1.42 m)
- Data System:
  - 320 Recordable channels at nominal speed of 1 Hz
  - 6 Recordable channels at speed up to 6250 Hz
- Numerous pressure vessels ranging from 0.2 ft^3 (0.006 m^3) to 23 ft^3 (0.65 m^3) with pressures up to 100 psig (6.9 bar)
- Residual Gas Analyzer
- Ejector system to sub-cool cryogens

Creek Road Cryogenic Complex

CCL-7 – Numerous pressure vessels



Double Wall Pressure Vessels –
Volume = 23 ft^3 (0..65 m^3)
MAWP = 100 psi (6.9 Bar)
Inner vessel 30” x 56” (0.76 m x 1.42 m)

Creek Road Cryogenic Complex

CCL-7 – Numerous pressure vessels cont.

Single Wall Vacuum Vessel –
Volume = 37 ft^3 (1.1 m^3)
MAWP = 10 psi (0.69 Bar)
Vessel ID 34” x 71” (0.86 m x 1.80 m)
Multiple ports in lid and vessel wall