Design and Fabrication of an Environmental Testing Chamber for Simulating Space-like Vacuum and Thermal Conditions

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***Abstract*—This proposal describes a project to build a controlled thermal vacuum chamber, called an Environmental Test Chamber or ETC, as well as associated test automation software, and documentation describing its safe operation and use by other SPEX teams. Low-cost pumps and off the shelf hardware enable useful vacuum to be generated. Vacuum pumps under $200 have been shown to achieve up to -28 inHG. While this is not an accurate representation of the space environment, these vacuum conditions are suitable for High Altitude Balloon component testing, and other flight hardware. [1]**

I. Introduction

Space provides a unique and challenging engineering environment. Hardware designed to operate in this environment needs to be validated in realistic testing conditions before flight. An Environmental Test Chamber (ETC) provides a controlled test bed for simulating the atmospheric and thermal environment of space and near-space environments that can be repeated at low cost. RIT does not have readily available and suitable ETCs for student use. Some laboratories have expensive vacuum pumps but are unwilling to allow unsupervised use by students or testing of unproven engineering designs. For example, space-qualified thermal vacuum chambers built by other universities can cost over $5,000 for the vacuum pump alone.[2] Low cost, commercial vacuum pumps provide the opportunity to achieve relatively low pressures in a small testing volume for dramatically lower cost. DIY vacuum chambers are a relatively popular project for amateurs on Youtube and other online forums.[3]

II. Primary Objective

The goal of this project is to design, build, and verify a functioning ETC that enables testing of flight components and flight systems in a controllable thermal and low pressure environment. Students will research the expected environmental conditions of high altitude flight and the on-orbit environment. Using low cost components, students will construct an ETC that can replicate those environments within a reasonable degree. Accuracy in simulation will be traded for reduced cost. The final ETC should have a usable testing volume for hardware SPEX expects to fly in the near term. Sensor and computers should be included in the system to enable monitoring the environmental conditions within the chamber, as well as enabling long-duration test cycles across a range of conditions.

III. Benefit to SPEX

Proper and thorough testing is a critical component of mission success. Many SPEX projects are unable to test their designs in proper environmental conditions, meaning flight tests assume additional risk. An ETC would enable risk reduction on projects like HAB and IREC, as well as provide opportunities to replicate industry-standard testing on space-like designs.

Some examples of near-term testing benefits include HAB camera shutdown investigation. HAB-CV camera performance, IREC desert heat validation, and $50Sat orbital thermal cycling. Sensors and electronics have performance curves related to environmental conditions. An ETC would enable fine characterization of these sensors before flight, increasing confidence in the data collected.

An ETC would have reduced mission risk for each of those projects and will be useful for future iterations of those types of projects. An ETC would likely prove useful to many other applications in the near to medium future.

IV. Implementation

At the end of the project, a working Environmental Test Chamber should be delivered. It should be capable of maintaining a near-vacuum for extended periods of time, as well as cycling between 0 and > -25 inHG at reasonable rates (< 1 hour duty-cycle).

A. Deliverables

The chamber should also be able to subject the test article to thermal variations between -20 C and 50 C. Cooling is considered an advanced feature due to the difficulty of removing thermal energy from the ETC compared to adding thermal energy.

An additional feature would be the ability to direct the applied thermal energy to simulate satellite tumbling or orbital cycles. Another metric to consider is the ability to apply the average solar radiation (1,368 W/m2) to the working surface of the test article to simulate on-orbit thermal conditions.

Along with the ETC hardware, there should be a control system allowing for software control of pressure and temperature, as well as data recording and real-time monitoring of the current environment. Users should be able to define preset environmental conditions that the ETC should attempt to maintain within reasonable bounds. Also users should be able to define a test sequence, which may consist of a number of environmental conditions varying over time, as well as the ability to cycle between high and low values for controlled environmental conditions. These should be repeatable N times or for a preset time period. A stretch goal should be to determine the temperature and pressure rates of change for the system, and if possible, determine ways to adjust these rates.

Finally, detailed operating instructions should be written and validated, to provide a safe way for other members to utilize the ETC. Instructions on setup, operation, maintenance, as well as detailed safety procedures in case of an accident or malfunction should be written and tested with the final hardware.

B. Milestones

This list is preliminary and should be considered a placeholder to be refined during the review process. Times are approximate.

TABLE I
NOTIONAL TIMELINE OF PROJECT MILESTONES

Phase	Task
1	Students research the particular variables of the near-space and space environment. The requirements for test article dimensions and usability are determined.
2	Mechanisms for controlling temperature and pressure and researched and proposed.
3	Initial design work begins on the mechanical system. Students research materials and component selection, including unorthodox sources like craigslist, to meet requirements.
4	Initial Assembly begins. Software and sensors are introduced to begin characterizing the responsiveness of the chamber.
5	Students work to automate control of ETC temperature and pressure.
6	Dry(empty) testing occurs to validate ETC meets minimum performance requirements.
7	First component test occurs while software automation continues to be refined. Procedure writing begins.
8	Full procedure writing finishes alongside completion of automation software. Long duration automated tests are attempted to verify the design.
9	Remaining time can be dispersed across real testing of flight components, improvements to hardware, software, and procedures as more tests are conducted, as well as completion of the final Technical Report

V. EXTERNALITIES

A. Prerequisite Skills

This project does not require advanced machining or analysis skills on the engineering side. Commercial Off the Shelf (COTS) components should be sought out for the pump, electronics, and ETC chamber volume. Knowledge and desire of coding will be required to write basic control software. If advanced CS skills are available, more complex control algorithms like PID can be implemented to the automation software. Upperclassmen engineers should be available to provide guidance and mentorship on the space environment, safety best practices, and the thermodynamics involved in the ETC.

B. Funding Requirements

Precision in simulating the space environment should be traded whenever possible to maintain reasonable costs. There are many examples of basic vacuum chambers and ETCs being constructed for low cost using COTS components. The estimated cost of the project should not exceed $400. Commercial vacuum pumps suitable for this project can be found for under $100. Similiar vacuum pump projects had total Bill of Material costs including pumps, pressure vessels, and fittings for less than $250. [1] The use of repurposed components may enable increased functionality while staying under the cost cap.

C. Faculty Support

No faculty have signed on to support this project at this time. It would be wonderful if a faculty member had interest in using the finished product for their own non-critical testing and could offer mentorship and advisement. It is not required for project success.

The project team should meet or exceed any safety requirements imposed by RIT Environmental Health and Safety

D. Long-Term Vision

The ETC enables better testing and validation of SPEX projects. As these projects increase in cost and complexity, accepting the risk of no environmental testing becomes increasingly unadvisable. A fully functional and safe ETC would increase project success and provide data to aid in engineering analysis and validation.

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