

EG-498-10342/10351 Capstone Design I

Report: *Concept of Operations*

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Contents

1	Introduction.....	3
2	System Description	4
3	Physical Environment	4
4	Support Environment	5
5	Operating Modes.....	5
6	Use	6
7	Stakeholders.....	6
8	Impact Considerations.....	7
9	Risks.....	7

1 Introduction

A Concept of Operations (referred to as “ConOps”), is a complete, thorough, and technical description of a system—oftentimes including illustrations for a visual understanding. It clearly defines the system’s operation, environment, application, purpose, and associated risks. The information in the ConOps should be easily translatable into system and subsystem requirements that promotes effective analysis, a versatile, reliable, and optimized engineering design. The primary descriptive areas are as follows:

- System Description
- Physical Environment
- Support Environment
- Operating Modes
- Use
- Stakeholders
- Impact Considerations
- Risks

2 System Description

This proposed system is a *thermally-controlled Printed Circuit Board ("PCB") testing chamber*. It is a table-top system strategically designed for ease of use and versatility. The diverse array of mechanical, electrical, and software components work systematically to regulate and maintain precise internal thermal conditions, while electronic devices are tested for performance.

The PCB is inserted into the chamber, which houses the component during thermal changes and electronic testing; the chamber is designed to accommodate 12" x 12" electronic boards, and spans the commercial temperature range of 0°C to 70°C. Insulation minimizes undesired thermal loss across the internal refrigeration system and external seals/ports/doors. All system "entrances" allow for the insertion of the PCB and necessary power/data electronic cables, alongside maintenance purposes.

A user will then interface with the system (either locally or remotely) to set parameters and target values, and modify existing settings. Internal temperature data and control system performance are actively measured, logged, and stored in a text-based format for traceability, analysis, and maintaining a strict 3°C tolerance on the designated setpoint.

PCB testing procedures commence after the temperature setpoint has been reached and during its control. A successful product includes PCB functioning properly during temperature stabilization. This testing is used for verification and modification of electrical performance of PCBs and individual components.

Ultimately, this thermally-controlled PCB testing chamber enables engineers to simulate real-world settings, typical environmental conditions, and normal operating use-cases of electrical components. The performance results and analysis help to engineer improvements for more efficient, reliable, and capable systems.

3 Physical Environment

The physical environment consists of the necessary conditions for successful operation of the system.

The system will be operated indoors. It will not be designed for outdoor use where environmental factors are variable, such as extreme rain, wind, snow, or foreign debris; these may inhibit operation and performance characteristics of internal and external electronics, mechanical components, and other critical surfaces. External ports/openings/seals alongside the electromechanical devices will not be engineered specifically to withstand these conditions. Thus, the operation shall consist only in a predictable indoor environment. Access to ventilation is required for high quality performance, and meeting engineering codes. Laboratory ambient temperature conditions (approximately 20-25°C temperature and <50% humidity) are suggested for human safety, ease of maintenance, and long-lasting component performance, protection, and reliability.

Successful operation necessitates no specific lighting conditions, where the system can be used day or night.

Normal operation requires a consistent source of power for all sub-systems to successfully function, and a healthier system in the long-term.

A PC will be used for the collection of system information from the datalogger. The system will be designed for having one or more simultaneous operators with these controls. The user(s) can locally interface with the system through a built-in HMI device, or control the system remotely through the PC.

4 Support Environment

This section focuses on the additional resources, services, and conditions needed to operate, maintain for reliability, and support the system across its entire lifecycle. Individual parts and the whole system are designed and fabricated with replaceability, upgradability, and serviceability in mind.

For one, the system shall be designed with proper/clear maintenance access. This is important for faster/simpler routine inspections of electrical and mechanical sub-systems, cleaning procedures, calibration of components and systems, and replacements of materials and parts. Adequate space provides ease-of-access for personnel and materials during work.

Proper maintenance tooling and equipment are to be readily available within the indoor environment to ensure operation and testing are efficient and successful.

The required indoor electrical supply matching the system's requirements is to support the system's normal operation.

The mechanical design, electrical schematic, bill of materials, and other ancillary specifications are to be included with the chamber's use and to be referenced for future support.

All components, systems, and fabrication techniques are to conform with contemporary standards.

5 Operating Modes

- The system will include a “Shutdown” state, where it's fully disconnected and consumes no power. This will contribute to energy savings, while promoting longevity of components and materials.
- The system will have a “Standby” mode. Herein shall the system be powered on but performing no function. It will wait for user-input and configuration for safety purposes and ensuring the system operates as intended.
- The system will have a “Start” mode. The various sensors, devices, mechanisms, electronic components, and software shall operate according to the temperature setpoint as specified by the user. This is the normal operation for testing the PCBs.



- The system shall include a “Safe” state. With this, all mechanisms become manual allowing operators to safely investigate system errors, mechanical or electrical faults, or other issues pertaining to the system’s function and performance.



6 Use

The system will be used indoors in a laboratory setting to test PCBs under controlled thermal conditions.

A user(s) will insert a PCB (up to 12” x 12”) inside the chamber, connect the necessary electrical stimulus/measurement cables through the designated ports, and interface with the system to ensure conditions match the testing needing to be done. The target temperature setpoints via the HMI or remote PC control will be set. The internal chamber’s temperature and other data will be monitored real-time, and the user(s) will make the necessary adjustments as needed. Temperature information and the system’s status is logged to a PC. The effects on the PCB are to be observed.

The user(s) is responsible for loading/unloading the PCBs safely, initiating tests, setting the designated parameters, reviewing logged data, analyzing system performance, and making modifications as needed.

7 Stakeholders

Based on the system’s various use cases and engineering design lifecycle, it’s important to recognize all associated users and stakeholders. It will be designed for a variety of personnel that rely on it for testing, analysis, and engineering improvements, all who interact with the system in different ways.

- Primarily, “engineers” are responsible for the system’s outline, requirements, design, schematics, materials/resources, fabrication process, testing, analysis, and final product implementation. They are also the users who manage the actual operation of the system in regards to setup, software interfacing, and PCB performance verification. They ensure the entire design is up to specifications and meets the customer’s defined requirements.
- Some overlap with these stakeholders are “maintenance personnel”, who are responsible for maintaining the integrity of the system, sufficient resources, necessary tooling/equipment, appropriate electrical/mechanical/software inspections, and ensuring the system’s long-lasting performance. Oftentimes the engineers are the same ones responsible for maintaining the system.
- We are also stakeholders in our own project, completing our own project takes our own time to design, test, develop. And failure to meet the project’s milestones will reflect poorly on us as a team as well as individually, academically.
- Other primary stakeholders include the faculty and sponsor who play a direct role in providing project guidance, customer-driven requirements, while ensuring the correct resources are available and the project schedule is met.

- Some secondary stakeholders include possible faculty, students, electronic or thermal-based product manufacturing companies, society, and other personnel who use this system for personal engineering tests or project/product inspiration.
- Other companies that supply materials or fabrication tools are also stakeholders in this project. These, while having no hands-on application with the product in regard to control or designing the system, still play a critical role. They ensure proper lead-times, correct resources are shipped, materials are of high-quality, and thus the system's design meets standards and specifications, which all help the project timeline to be accurately and efficiently followed.

Collectively, all of these stakeholders ensure that the thermally-controlled PCB testing chamber is efficiently developed, functions correctly and produces reliable data, and ultimately helping to accurately test/improve PCB performance.

8 Impact Considerations

The following impact considerations illustrate the possible situations the system can be subject to.

- Surfaces (primarily external) may extend beyond the safe-touch limits concerning extreme temperatures, having risk of accidental human injuries during or post-operation.
- Failure to implement proper electrical wiring and safety measures could increase the risk of electrical shock, human injury, fire hazards, and damage to internal electro-mechanical components.
- With inadequate ventilation, system may cause overheating to components or surroundings.
- Excessive system usage may cause high power consumption.
- Operating mechanical equipment may generate noise that can affect surrounding personnel or equipment.
- Insufficient table space or clearance could limit proper operation, restrict maintenance access, and increase the likelihood of accidental damage or safety hazards.
- The system may require extra personnel for regular calibration, cleaning, or inspection.
- Data collection may require constant management of storage space.
- System may need a user present for a safety measure prior to operation.
- Non-compliance with electrical safety or mechanical design codes or using improper materials for the system's application could result in safety hazards, equipment failure, or unsafe operating conditions.

9 Risks

The risks associated with the system's engineering design process, fabrication timeline, and normal operation are often identified as situations where the system doesn't meet the predefined requirements.

These risks help describe failure possibilities of the system, sub-components, materials, or other project facets.

On top of this, a thorough analysis of the system helps to foresee other issues that may not be evident from solely observing the requirements. Obtaining “sufficient analysis” is vitally important in ensuring an effective product design, efficiency in building, good resourcefulness, and a healthy system in the long-run.

To reach a “sufficient” amount of analysis, it should consider the product’s design, application, general function, and systematic integration – though this process may be time, cost, and resource intensive. This helps ensure a strategically designed product that not only satisfies the defined requirements but is inclusive enough to also consider situational variables – which are other factors that influence daily operation.

That is to say, sophisticated and profitable analysis that provides insights into the system’s risks, covers the “obvious” requirements (*what* the final system includes), while also providing design implications which concern the methods of engineering the final product (*how* the system is built, operated, and maintained).

With that being said, the proposed system was strategically analyzed to identify numerous diverse risks. These risks are grouped by categories that outline the entire system. They also are individually ranked by both likelihood (probability of occurrence) and consequence (severity of impact on the product or stakeholders). It’s important to note that the likelihood is not based on probability within the pool, and how likely a scenario is to occur *compared to* the other risks, but on an individual scale; there is a linear scale translating percentage (0-100% likelihood) to score (1-5). The final ranked score considering likelihood and consequence is categorized by severity using the 3 M’s (minor, moderate, major). From this, the higher-ranked risks are prioritized to redirect resources and effort, and the other risks – while still meaningful to the project and important for the system’s function and product success – are simply considered with less priority. Mitigation steps are initiated and tracked to reduce the risk score through design changes, preventative measures, or control plans.

The following figures highlight this system’s defined risks in the engineering processes of design, fabrication, analysis, redesign / optimization, final product development, installation, operation, and maintenance:

Risk List

Letter	Consequence	Description
A	Asset	Mechanical Failure of Components (worn, broken)
B	Asset	Insufficient Dimensions for PCB testing (internal, external, cable port, chamber door)
C	Asset, Human Safety	Internal System is <u>Over</u> Temperature Range (fire, melting components)
D	Asset, Human Safety	Internal System is <u>Under</u> Temperature Range (frozen components)
E	Asset, Performance	System's Safety Measure Fails If Outside Temperature Range
F	Asset, Performance	Internal Heating/Cooling System <u>Can't Reach</u> upper/lower boundaries (poor components, inefficient controller)
G	Asset, Performance	Inconsistent Temperature Control (poorly designed microcontroller or interface)
H	Asset, Performance	Failure to Maintain Toleranced Setpoint ($\pm 3^{\circ}\text{C}$) (ineffective control system, poor insulation - internal & external)
I	Asset, Performance	Lack of Electronic Protection (excessive moisture buildup)
J	Cost	Spending Past Designated Budget for Equipment & Materials
K	Human Safety	Lack of Human Protection at Critical Temperature Ranges (burns)
L	Human Safety	System Fails to Meet Environmental/Engineering Codes
M	Human Safety	System Fails to Prohibit Temperature Control During Manual User Usage.
N	Human Safety, Performance	Chemical Leaking
O	Human Safety, Performance	Electrical Hazards (short circuits, improper connections)
P	Human Safety, Performance	System Fails to Operate Safely Under Normal Conditions
Q	Performance	Software/HMI Failure
R	Performance	Lack of Refrigerant Fluid in System
S	Performance	Controller not User Friendly (poor HMI design)
T	Performance	Sensor Reading Failure (miscalibration, component issue)
U	Performance	Improper Ventilation (pressure changes, fumes buildup)
V	Performance	Ineffective Insulation (poor materials or design)
W	Performance	Data Measuring, Collecting, and Logging Fail to Work Systematically
X	Performance	System Mode(s) Failures
Y	Schedule	Poor Scheduling for Fabricated Parts or Sourced Materials
Z	Schedule, Cost	Rework of Product (ineffective design from failed systems/components/materials)

Risk Matrix

Consequence

5	B, L	A, E, P	K, M, O	Z	
4		Y	N	I	Q, W
3		F, G	T, U, X	V	
2	R	J		C, D	H
1	S				
	1	2	3	4	5

Combined Risk Scores

- 0-9 Minor
- 10-19 Moderate
- 20-29 Major

Likelihood