**Metal 3D Printer Commissioning**

**Initial Design Report**

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Fall 2024 - Spring 2025

A machine with a stand and a cart

Description automatically generated with medium confidence

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**Sponsor and Faculty Advisor: Constantin Ciocanel**

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# DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

# EXECUTIVE SUMMARY

Our project involved commissioning, testing, initial operation, and training development of a Concept Laser Mlab Cusing R metal 3D printer. This printer was donated by Honeywell to NAU’s Mechanical Engineering department and was stationed in the IDEA Lab in the engineering building. The goal was to have the printer fully functioning by the end of the 2024–2025 school year and ready for integration into the ME286L Manufacturing Lab curriculum, as well as available for work orders from the IDEA Lab.

The printer uses laser powder bed fusion (LPBF) technology, which fuses powdered metal together to form a part. Since this powder is often reactive with oxygen, it requires an inert environment – provided using argon gas. Unlike fused filament fabrication (FFF), which extrudes thermoplastics through a nozzle to create a shape, LPBF uses a laser to melt extremely thin layers of powdered metal onto the previous layer. Each layer is spread across the powder bed with a blade, melted into the cross-section of the part, and repeated until the print is complete. The finished part is surrounded and filled with loose metal powder, which must be carefully removed before it can be handled safely.

The project had several components that needed to be completed for success. First, we installed the printer and restored it to working conditions. The printer had been donated due to unresolved issues with build plate alignment and condensate leakage. Our first task was to connect it to power and argon supplies, then run test prints to identify the sources of those problems. We fixed issues ourselves when qualified and brought in a specialized technician when necessary. For example, if the alignment issue had involved the fiber laser system, we were not trained or authorized to service it.

Once the printer was operational, we printed cylindrical tensile test specimens and compared them to machined counterparts of the same material. This allowed us to analyze differences between printed and non-printed materials, as well as evaluate the surface finishes of both machined and non-machined printed parts.

We planned to print a final part to be implemented in a demonstration assembly. The purpose of this part is to showcase the capabilities of additive metal manufacturing by using topology optimization to create a geometry that would be impossible to fabricate using traditional subtractive methods. However, due to the timeline of the capstone report, this portion of the project has not yet been completed and is scheduled for finalization after submission.

Additionally, a simplified instruction manual and training program are in development. These are intended to walk a first-time user through their initial print, including software setup, machine operation, and safety procedures. While drafts of these materials are underway, the finalized versions will be completed after the report deadline and are intended for future use by the IDEA Lab to begin student training.

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# BACKGROUND

This section outlines the overall goals and objectives of the project. It includes a description of the project scope, the expected deliverables, and the criteria that defined a successful outcome.

## Project Description

The Metal 3D Printer Capstone, also known as the Metal 3D Printer Commission, was a project focused on setting up the IDEA Lab’s Concept Laser Mlab Cusing R. This included connecting the machine to utilities, verifying that it was operational (and troubleshooting if it was not), printing a variety of test parts to evaluate the printer’s capabilities, and developing instructions for use by IDEA Lab managers.

Metal 3D printing, or additive manufacturing, has transformed how industries approach production, enabling rapid prototyping, mass customization, and on-demand manufacturing of metal components. However, before a metal 3D printer can be used in any practical or industrial setting, it must undergo a commissioning process to confirm that it operates safely and reliably. This project was initiated to ensure that the new metal printer met key industrial standards for accuracy, mechanical performance, and cost-effectiveness. A successful commissioning process was essential to establishing confidence that the printer could consistently produce high-quality parts.

The project began with the physical installation of the printer, followed by calibration, testing, and optimization of its printing processes. The team printed a series of test parts to identify any quirks or recurring issues that arose during operation. The final steps of the commissioning process are outlined in the next section.

## Deliverables

* **Working printer:** Install and restore printer to proper functionality, which is measured by accurate parts and a reliable printing process.
* **Finished part with assembly:** Print a final part as part of assembly using topology optimization, whether this assembly belongs to another team or is a project exclusive design.
* **Test specimen:** Evaluate printed specimens against machined counterparts; this will be a tensile test comparing a traditionally machined dog bone specimen, printed stock machined to specification, and a fully printed specimen.
* **Instruction manual for IDEA Lab managers:** Create an instruction manual for training purposes in preparation for work orders and ME286L curriculum expansion. IDEA Lab managers should be able to easily operate the machine for work orders and keep a safe environment inside the lab.

## Success Metrics

The success of this project relied on several key technical requirements. The printer needed to produce parts with dimensional accuracy within ±0.1 mm, while maintaining rough surface values suitable for the intended applications. Additionally, the mechanical properties of the printed parts – such as tensile strength and density – were expected to match or exceed 95% of those produced by traditional manufacturing methods. The system also had to operate safely, meeting all relevant safety standards for handling metal powders. This included proper ventilation, inert gas usage, and functioning emergency stop mechanisms.

By the end of the project, the metal 3D printer had been fully commissioned and could produce high-quality metal parts with the precision and reliability required for a wide range of applications. This commissioning process not only ensured that the machine operated within the desired technical specifications but also laid a foundation for future use in capstone projects, undergraduate research, and broader work within the mechanical engineering department.

# REQUIREMENTS

The requirements of this project were determined through a need-based assessment of our customer and their desired outcomes. Our primary customer was the Mechanical Engineering Department, represented by Department Chair Dr. Constantin Ciocanel, as the goal was to commission a machine for long-term use within the department.

This section outlines the customer requirements for the project, the engineering requirements associated with commissioning the printer, and a House of Quality analysis illustrating how these requirements relate to one another.

## Customer Requirements (CRs)

The customer requirements represented the most important aspects of the project as defined by our primary stakeholder, Dr. Constantin Ciocanel. These requirements guided our decision-making throughout the commissioning process. Each requirement is listed below, along with a brief description of how it was evaluated:

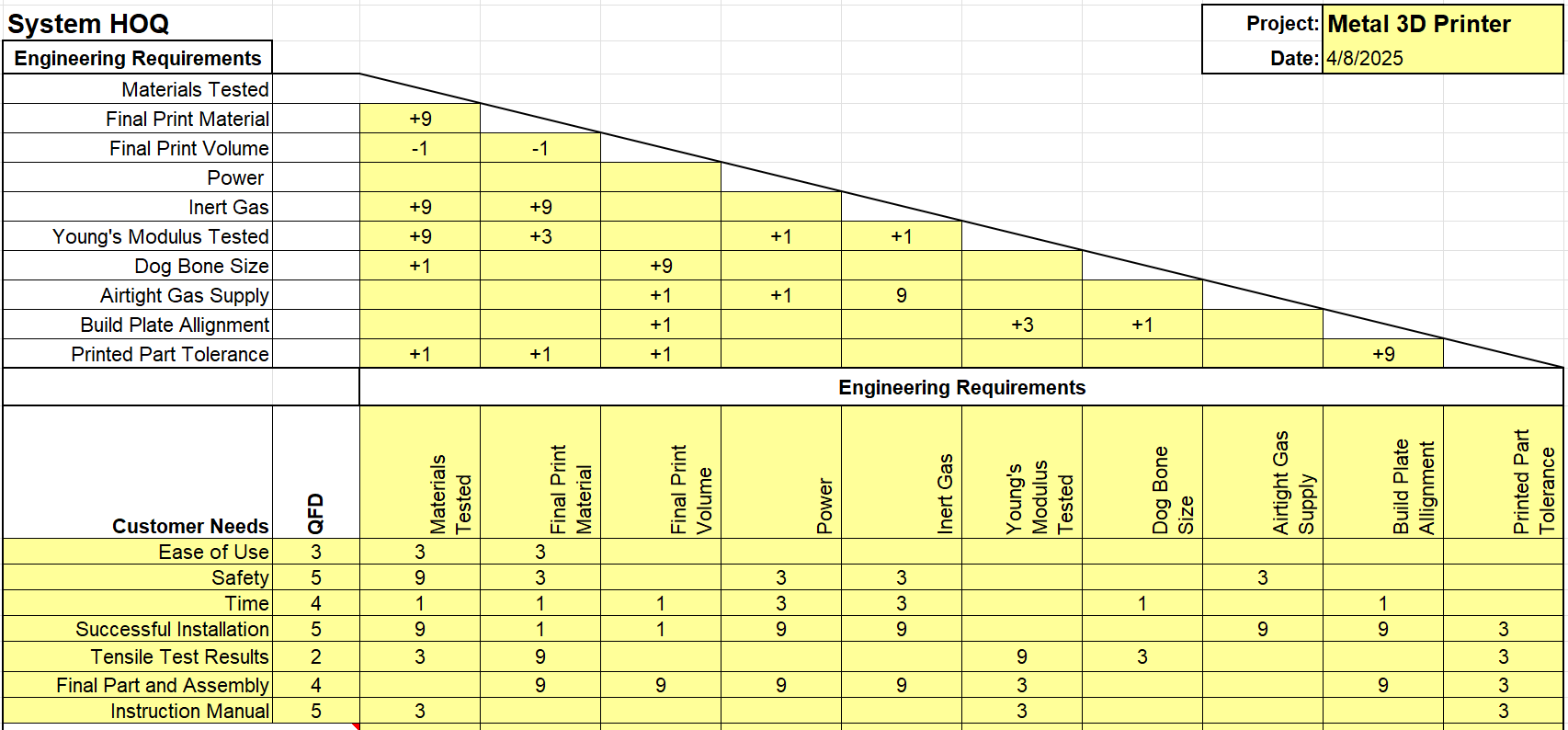
* **Ease of Use:** Integration of the machine’s operating procedures into the existing IDEA Lab workflow. This included the clarity and accessibility of our training program.
* **Safety:** Ensuring the safety of all users during and after machine operation. This involved strict adherence to safety protocols, visible signage for hazardous procedures or areas, and proper use of personal protective equipment (PPE).
* **Time:** Timely installation, troubleshooting, and repair of the printer. Deliverables, including the training program, were expected to be completed in a timeframe that would allow the printer to be fully operational and ready for use by summer 2025.
* **Successful Installation:** Verification that the printer was fully installed and operational, capable of producing prints reliably.
* **Tensile Test Results**: Comprehensive and accurate data evaluating the mechanical strength of printed materials, specifically in comparison to machined counterparts.
* **Final Part and Assembly:** A demonstration part designed using topology optimization to showcase the unique capabilities of metal additive manufacturing. The part was intended to have a geometry that could not be fabricated using subtractive methods. *(Note: this portion of the project is scheduled for completion following the final report submission.)*
* **Instruction Manual:** A simplified operating and safety manual, along with a step-by-step training program designed to guide future users through their first print. *(Note: this portion of the project is scheduled for completion following the final report submission.)*

## Engineering Requirements (ERs)

The engineering requirements of this project were based on printing constraints and the physical needs of the printer. These requirements are listed below, along with descriptions of how each was considered during the project:

* **Materials Tested:** The printer is capable of printing with a wide range of metals, including aluminum, stainless steel, titanium, and bronze. For initial testing, we used 316L stainless steel, as it is safer than more reactive metals such as aluminum and titanium and was generously donated to us by the University of Arizona.
* **Final Print Material:** The primary candidates for the final print material included 316L stainless steel, aluminum, and titanium. The choice depended on our capabilities at the time and the desired strength-to-weight ratio for the demonstration assembly. This decision directly influenced several customer requirements, including safety, ease of use, time, and the final part and assembly.
* **Final Print Volume:** The machine's maximum build volume was a limiting factor, restricted to 90 × 90 × 80 mm. This constraint guided our part design and testing strategy.
* **Power Requirements:** The printer required a 240V, 16A outlet for operation. Ensuring reliable power access was part of the initial setup process.
* **Inert Gas:** To create a safe inert environment for powder melting, the system could use either nitrogen or argon gas. We used argon, as it is more broadly compatible with various metals and more commonly used in LPBF systems.
* **Young’s Modulus Testing:** The mechanical performance of printed samples was evaluated through tensile testing, specifically by measuring Young’s modulus in gigapascals (GPa). For 316L stainless steel, a typical value is approximately 193 GPa.
* **Dog Bone Specimen Size:** The size of the tensile test specimens was determined based on the printer’s build volume, the dimensions supported by our testing apparatus, and the availability of comparable machined dog bones for baseline comparison.

## House of Quality (HoQ)



*Figure 1: House of Quality*

# RESEARCH WITHIN YOUR DESIGN SPACE

This section of the report covers benchmarking, a literature review, and mathematical modeling and simulation. Benchmarking examined the range of metal additive manufacturing processes used in industry, along with the advantages and disadvantages of each method. The literature review summarized key resources that helped us understand the fundamental aspects of the project and the broader field of additive manufacturing. Finally, the mathematical modeling included calculations and simulations related to the finalized part and tensile test specimens.

## Benchmarking

Additive metal manufacturing is an emerging branch of additive manufacturing (AM) that is still in its early stages. There are several different types of metal AM technologies, and our project utilized the most common among them: Laser Powder Bed Fusion (LPBF). LPBF uses a laser to selectively melt layers of powdered metal within a powder bed to build up a part layer by layer.

Within the industry, the current state-of-the-art in metal AM is often evaluated based on three key parameters: build volume, build rate, and resolution (precision). LPBF excels in print accuracy and design freedom but is limited by build volume. As the size of an LPBF system increases, it becomes more difficult to regulate inert gas flow and maintain print accuracy. The state-of-the-art LPBF system during our project was the GE Atlas 3D printer [1], which featured the largest known LPBF build volume of 1.1 × 1.1 × 0.3 meters.

Other metal AM methods are also widely used or under development and are evaluated using the same criteria. The second most common process is binder jetting, which also uses a metal powder bed but replaces the laser with a polymer binder. During printing, the binder is extruded across the powder in the cross-section of the part. Once the polymer dries, excess powder is removed, and the part is sintered – heated just below the metal’s melting point – to burn off the binder and fuse the powder into a solid object. Binder jetting is less hazardous than LPBF during printing but suffers from high shrinkage and reduced density after sintering. The leading system in this category is the ExOne X1 160Pro, with a build volume of 800 × 500 × 400 mm [2].

Another emerging metal AM technique is Directed Energy Deposition (DED), which resembles fused filament fabrication (FFF) used in plastic printing. In DED, powdered or wire metal is melted using a laser or electron beam as it exits a nozzle, and the molten material is deposited layer by layer to form a part. A key advantage of DED is its ability to support much larger build volumes since it does not require a sealed powder bed. However, DED suffers from lower resolution and less consistent precision, often producing parts that require high tolerances or post-processing. The state-of-the-art DED system at the time of our project was the EBAM® 300 Series [3], which used an electron beam to melt wire feedstock and had an enormous build volume of 6096 × 1397 × 1371.6 mm. It could print up to 20 pounds of material per hour – far exceeding LPBF’s print rates and build sizes, albeit at the cost of fine detail and precision.

## Literature Review

### Nolan Hann

**Operating Manual, Type: Mlab cusing R**

This manual from the Hofmann Innovation Group provides detailed operational guidelines for the Concept Laser Mlab Cusing R, a metal 3D printer that uses powder bed fusion (PBF) technology. The document covers essential aspects of machine operation, including setup, calibration, safety protocols, and maintenance procedures. It also provides instructions for optimizing printing parameters to achieve high-quality prints in various metal alloys. This manual is critical for technicians and operators working with the Mlab Cusing R, as it offers comprehensive instructions to ensure proper machine function and maximize part quality, making it an important resource in the practical deployment of metal additive manufacturing systems.

**“Powder characterization techniques and effects of powder characteristics on part properties in powder-bed fusion processes.”**

This paper provides an in-depth exploration of powder characterization techniques and their critical impact on part properties within powder bed fusion (PBF) processes. The authors examine the influence of various powder characteristics, such as particle size, shape, and distribution, on the final mechanical properties and dimensional accuracy of printed parts. The work is a valuable resource for understanding how powder properties affect performance in PBF and for developing strategies to improve print quality by optimizing powder materials. This study is particularly relevant for researchers and professionals working with metal additive manufacturing who are focused on improving part consistency and quality.

**“Powder bed fusion processes: An overview.”**

This chapter offers a comprehensive overview of powder bed fusion (PBF) processes, explaining the different variants, such as selective laser melting (SLM) and electron beam melting (EBM), while highlighting the technological challenges and opportunities presented by these techniques. The authors cover topics such as the influence of process parameters on build quality, thermal management, and potential applications of PBF technologies in various industries. This source is essential for anyone seeking a broad understanding of PBF processes and their application in metal 3D printing, making it a foundational reference for students, researchers, and practitioners.

**“An overview of residual stresses in metal powder bed fusion.”**

This article provides a thorough review of residual stresses in metal powder bed fusion, a key issue that affects the dimensional accuracy and structural integrity of 3D printed metal parts. Bartlett and Li discuss the formation mechanisms of residual stresses, their impact on part quality, and various methods for mitigating these stresses, such as post-processing heat treatments. The paper is especially useful for researchers focused on enhancing the mechanical performance of metal parts produced through additive manufacturing by addressing stress-related issues. It also offers insight into future research directions aimed at reducing residual stress through process optimization and material development.

**"Surface Finish for 3D Printed Tooling: Advancing PBF Technology as a Production Tool | Blog."**

This blog post by AddUp focuses on advancements in powder bed fusion (PBF) technology, particularly in improving surface finish for 3D-printed tooling. It discusses the importance of achieving fine surface finishes for production-grade tools and the techniques available to improve surface quality post-printing, including surface polishing and chemical treatments. The article is relevant for professionals in manufacturing seeking to implement PBF in production environments, as it provides practical insights into how surface finish affects tooling performance and how to overcome common challenges in metal 3D printing.

**“Stress-Strain Concepts: Why They Matter in Materials Testing.”**

This blog post from Materion explains the fundamental concepts of stress and strain in materials testing, emphasizing their importance in understanding the mechanical behavior of materials under load. The article discusses how stress-strain curves can reveal critical information about material strength, elasticity, and ductility, which is crucial in determining the performance of materials used in industrial applications. This resource is useful for engineers and researchers involved in materials testing and quality control, as it offers clear explanations of key mechanical testing concepts relevant to additive manufacturing and metalworking.

**“All About Tensile Testing: How to Set Up Your Samples for Accurate Results.”**

This article from Materion provides an in-depth guide to tensile testing, covering how to properly set up and prepare samples to ensure accurate test results. It highlights the importance of sample geometry, gripping methods, and the alignment of testing machines in obtaining reliable tensile strength data. The article serves as a practical guide for engineers and technicians involved in testing materials, particularly those working with 3D-printed metal parts, where accurate tensile testing is essential for validating mechanical properties and ensuring product quality.

### Nathan Krikawa

**“Selective Laser Melting: Materials and Applications”**

This book by P. Konda Gokuldoss goes in depth on the selective laser melting (SLM) process which our machine uses. This was a good introduction to the industry and made the machine far simpler and more accessible in the early stages of the project. The book covers all different materials used by the industry in this process and the major applications of SLM on a commercial scale.

**“Introduction to Finite Element Analysis & Design, Second edition”**

This book by N. H. Kim, A. V. Kumar, and B.V. Sankar explains finite element analysis through both hand calculations and simulations. It goes from the very basics of what finite element analysis is and is used for, all the way into the most complicated application cases. This was a huge help when becoming familiar with finite element analysis in preparation for topology optimization.

**“Research of 316L Metallic Powder for Use in SLM 3D Printing”**

This paper contains detailed analysis of the material properties of 316L metallic powder before and after SLM printing and goes into very fine detail about how the laser melting process affects the molecular structure of the material and what this means for final prints. Once we decided to use this material, this source was a goldmine of what to expect and why when it comes to tensile testing and final print properties.

**“Multiscale Analysis of Surface Texture Quality of Models Manufactured by Laser Powder-Bed Fusion Technology and Machining from 316L Steel”**

This paper by D. Gogolewski, T. Barkowiak, T. Kozior, and P. Zmarzly covers much of what we plan to test regarding tensile testing and printed vs. machined print surfaces and will be very useful to reference as we do our tensile testing. Surface quality is a big part of final part production and this paper studies the exact material we plan to use.

**“Topology Optimization in Engineering Structure Design”**

This paper by W. Zhang, J. Zhu, and T. Gao, is an in-depth explanation of topology optimization, specifically for structural design in engineering. This is extremely useful as we dive into topology optimization. This covers how and when to use topology optimization, common use cases and misconceptions, and methods for producing optimal designs with topology optimization.

**“Topology Optimization 101: How to Use Algorithmic Models to Create Lighweight Design”**

This article by Formlabs contains a detailed guide to using topology optimization to reduce the weight of designs while retaining structural integrity. This is a very top-level guide but is useful in understanding the use of topology optimization and planning how it would best be applied to a final part.

**“Powder Bed Fusion | Additive Manufacturing Research Group”**

This article from Loughborough University covers their projects related to LPBF and what they have encountered and put research efforts into. This served as a good representation of the current university state-of-the-art system and helped plan research and design topics that we want to focus on at NAU.

**“Metal 3D Printer Precision System | Objective 3D”**

This article contains all the manufacturer specifications of our Concept Laser Mlab Cusing R metal 3D printer in brochure format and is a very useful reference material when looking at its power and gas requirements as well as its build plate, material, and resolution specifications.

**“F3184 Standard Specification for Additive Manufacturing Stainless Steel Alloy (UNS S31603) with Powder Bed Fusion”**

This standard for the usage of 316L steel in powder bed fusion from 2023 is a great up-to-date resource that we will be referencing often throughout this project. It covers everything we need to know about the material, how it prints, and how best to utilize it for good results.

## Mathematical Modeling

### Nolan Hann

**Finite Element Analysis Simulation – Tensile Testing**

Shown below are two dog bone samples simulated using SolidWorks [20]. The first followed a traditional ASTM D638 design, while the second used a cylindrical geometry. Both specimens were simulated using 316L stainless steel as the material and subjected to 40 kN of tensile force, with 20 kN applied to both the top and bottom ends of each part. These simulations were relevant to the specimens we planned to print and machine for comparative testing. Understanding where the material was most likely to fail provided insight into the expected behavior of printed parts and highlighted potential structural weaknesses. This, in turn, informed decisions about part orientation during printing, particularly in mitigating layer-based shear failures.

A 3d model of a tall object

Description automatically generated

*Figure 2: Finite Element Analysis - Squared Dog Bone*

A diagram of a cylindrical object

Description automatically generated*Figure 3: Finite Element Analysis Simulation - Round Dog Bone*

### Nathan Krikawa

**Finite Element Analysis - Hand Calculations:**

A diagram of mathematical equations

Description automatically generated

*Figure 4: FEA Hand Calculations*

I performed basic finite element analysis (FEA) hand calculations on a single element to better understand the internal mechanics at play. This exercise proved especially useful when running full-object simulations in SolidWorks, as it gave me a clear understanding of what was happening and why throughout the simulation process.

**Finite Element Analysis Simulation - Simple Bracket Analysis:**

Text BoxText BoxPictured below is a full simulation of the effect of a static 300lb load on a simple 316L steel bracket I made in SolidWorks [20]. The bracket is fully supported on one side with a distributed load on the other. The next step will be to use topology optimization to decrease the weight of the bracket while maintaining the stress zones of this structure.

A computer screen shot of a blue object

Description automatically generatedA computer screen shot of a computer generated image

Description automatically generated

# DESIGN CONCEPTS

This section of the report covers the functional decomposition of the printer’s components and their roles, as well as the generation and selection of concepts for the final printed part.

## Functional Decomposition

*A diagram of a computer system

Description automatically generatedFigure 7: Physical Decomposition of Mlab Cusing R 3D Printer*

The printer could be broken down into four key systems: the laser, the build module, the computer system, and the airflow system.

The **laser system** consisted of two main components: a Yb:YAG fiber laser and a series of mirrors. The fiber laser generated a high-powered beam that was transmitted through transport fibers and focused through a lens. This beam was then directed onto the build plate using adjustable mirrors, which controlled the position of the focused laser during printing.

The **build module** relied on four major components: the powder chamber, the build plate, the overflow chamber, and the coater. Powder stock was first loaded into the powder chamber, where it was stored and gradually fed into the build process. A motorized plate raised the powder to a set level, allowing the coater blade to sweep along the X-axis and evenly distribute powder across the build plate. The build plate itself was a detachable component made of the same material as the part being printed to ensure proper weld adhesion. As printing progressed, the build plate gradually lowered to accommodate the increasing height of the part. Any excess powder was swept into the overflow chamber, which funneled the material into reusable storage containers.

The **computer system** included two distinct components: a front-end Windows desktop and a G-code processor. The desktop computer served as the user interface, where print files were stored, accessed, and configured. It also allowed users to adjust machine parameters. Once a file was selected and sliced, the desktop communicated the print job to the second computer, which translated the sliced model into machine instructions for execution by the printer’s mechanical systems.

The **airflow system** was managed primarily through the printer’s internal ventilation setup. This system received a supply of inert gas (either argon or nitrogen) and directed it across the build chamber to maintain a safe, oxygen-free environment. The airflow was then routed through filters that removed condensation and excess powder particles dislodged during the build process.

## Concept Generation

As a commissioning project, our concept generation was limited to three specific areas of design that were used in later phases of the project. For each area, we developed several basic design options from which final selections were made. These design areas included the final part, test parts, and tensile test dog bone specimens.

### Final Part

For our final part, we needed a design that would demonstrate the capabilities of the metal 3D printer by creating a geometry that could not be manufactured using traditional subtractive methods. We approached this by replacing previously solid regions of a part with optimized geometries – removing material through topology optimization. This process reduced the weight of the part without compromising its structural integrity, ultimately improving the performance of the overall assembly.

We developed three concepts for the final part: a fastener (such as a bolt or screw), a structural bracket, and a scaled-down version of a larger component – for example, a skateboard truck.

The fastener concept involved hollowing out a standard bolt or screw in CAD and filling the interior with a lattice structure to minimize weight. This approach could significantly reduce the total weight of an assembly when multiple fasteners are used. It also had the advantage of being easily mass-producible, as several fasteners could be printed simultaneously within the machine’s build volume.

The bracket concept represented a more conventional structural part that would be straightforward to implement in an assembly. By applying topology optimization, we could reduce the weight of the bracket and introduce complex internal geometries—ideal for showcasing the design freedom enabled by additive manufacturing. The final concept was a scaled-down larger component, which offered more flexibility in design. We selected a skateboard truck as an example. This design could be topology optimized and potentially include lattice regions to further reduce weight. Visually, it would be the most striking of the Text BoxA diagram of a metal rod

Description automatically generated with medium confidenceA black and white drawing of a bracket

Description automatically generatedA black and white drawing of a skateboard

Description automatically generatedthree and could be incorporated into a small, assembled model for demonstration purposes.

Text BoxText Box

### Test Part

The purpose of our test parts was to help identify and diagnose the alignment issue present in the printer by tracing it back to its source. The most effective prints for this purpose featured steady curves, complex geometries, and clear visual reference points relative to the surface axes.

We developed three design concepts for test parts: a Benchy, a miniature figurine, and a bevel gear.

The Benchy is a widely used test print that comes pre-installed on many plastic 3D printers. It is commonly used to evaluate printer calibration and alignment. Its design includes a variety of geometries—angled, curved, and flat surfaces—as well as overhangs and internal features, making it ideal for identifying inconsistencies or misalignment.

The miniature figurine was selected to test the printer’s resolution and ability to handle fine detail and overhangs. Its complex surfaces provided multiple points of reference to detect subtle misalignments during the printing process.

The bevel gear offered a simpler geometry with low tolerance requirements. Its uniform teeth and broad flat surfaces made it easy to spot misalignment issues visually, particularly along the gear’s edges and pitch lines.

Text BoxA close-up of a gear

Description automatically generatedA grey robot with a grey background

Description automatically generated with medium confidenceA blue toy boat on a surface

Description automatically generatedText BoxText Box

### Test Specimen

The concept generation for the test specimen was straightforward. We identified two possible specimen types: a rounded dog bone and a flat dog bone. The final choice depended entirely on the capabilities of the testing apparatus we were granted access to. The size of the printed specimen was determined by the dimensions of the machined specimen we either purchased or had manufactured and had to fit within the constraints of our build volume.



*Figure 14: Dog Bone Specimens*

## Selection Criteria

The selection criteria for our concepts varied slightly across each design category. For the final part, the key criteria were that the design could not be manufactured using subtractive methods, incorporated topology optimization, was visually appealing, and could be integrated into a larger assembly. For the test part, the selected design needed to include both flat and curved surfaces, along with some level of intricate geometry to help identify potential alignment issues. In this case, selection was less critical, as we anticipated using multiple test parts throughout the machine evaluation process. Lastly, the choice between dog bone specimen designs depended entirely on the testing apparatus available to us. The selected specimen had to be compatible with the testing equipment and fit within the printer’s build volume.

## Concept Selection

Based on the selection criteria outlined for each design area, we selected the skateboard truck as the final part, the Benchy as the test print, and the cylindrical dog bone as the tensile test specimen.

The skateboard truck was chosen for the final part because it allowed significant design freedom within the constraints of our build volume. It was well-suited for topology optimization and could incorporate internal lattice structures, making it an excellent demonstration of the capabilities of additive manufacturing. Additionally, its unique geometry and potential for visual appeal made it ideal for use in a compact assembly model.

The Benchy was selected as the test print due to its widespread use as a calibration tool in the 3D printing community. It offered a variety of flat and curved surfaces, internal features, and overhangs, making it highly effective for identifying printer alignment issues.

Finally, the cylindrical dog bone specimen was selected for tensile testing. This design was compatible with the available testing apparatus and allowed for direct comparison to standardized machined counterparts while remaining within the printer’s build volume.

## Commissioning Evaluation

Because this project focused on commissioning rather than design, we structured our entire process as a detailed list to track progress and clearly identify remaining tasks. Each major step in the list was broken down into sub-sections with corresponding explanations and details to guide our workflow.

At the time of this report, we had finished Section Five: Testing and had just begun work on Sections Six through Eight.

1. Needs Assessment:

* Requirements
  + *Equipment:* Wet-separating vacuum, argon tank holder, PPE, wire EDM/bandsaw, etc.
  + *Software:* Magics, Autodesk Netfabb
  + *Lab:* 240V, 16A outlet, chemical disposal protocol
* Consultation with Stakeholders
  + *Mike Downey:* Industry expert and donation involvement.
  + *Dr. Constantin Ciocanel:* ME Department Chair and project sponsor
  + *Honeywell and University of Arizona:* Industry standards and prior installation knowledge

2. Vendor Selection and Procurement

* Vendor Research
  + Identified potential vendors for equipment, electrical work, and Colibrium Additive health check/upgrade
* Request for Proposals
  + Collected and reviewed quotes from selected vendors
* Proposal Evaluation
  + Compared quotes for cost, lead time, and support
* Contract Finalization
  + Ordered equipment and submitted necessary work orders

3. Pre-Installation Planning

* Site Preparation
  + Met with EHS chemical safety representative in IDEA Lab to discuss ventilation, machine and gas placement, and safety procedures
* Infrastructure Checks
  + Planned and scheduled 240V outlet installation
  + Identified safe disposal areas for materials and chemicals

4. Installation and Setup

* Installation
  + Followed the manufacturer’s installation guide for setup
* Software Setup
  + Installed Autodesk Netfabb on a dedicated computer
  + Verified that the printer’s onboard software was operational

5. Testing

* Initial Calibration and Configuration
  + Used built-in software to calibrate and configure the printer
* Safety Testing
  + Tested emergency stop functionality, ventilation flow, and inert gas system
* Functional Testing
  + Performed test runs without material, then with material
  + Began with small prints to identify any immediate issues
* Troubleshooting
  + Diagnosed alignment issues and traced the root cause
* Machine Repair
  + Determined whether external technician support was necessary
  + Repaired issues within our scope and arranged additional support as needed

6. Training (In Progress)

* User Training
  + Developing a first-print tutorial with an accompanying instruction manual
  + Covers slicing in Autodesk Netfabb, uploading to the printer, and executing a print
* Maintenance Training
  + Preparing training for IDEA Lab employees to maintain and operate the printer safely

7. Ongoing Maintenance and Support *(In Progress)*

* Regular Maintenance
  + Drafting a recommended maintenance schedule and procedures
* Vendor Support
  + Maintaining contact with Colibrium Additive for future technical support and repair needs.

8. Documentation Handover *(In Progress)*

* Documentation
  + Compiling user manuals, safety procedures, and training materials in a format that is easy to access and use

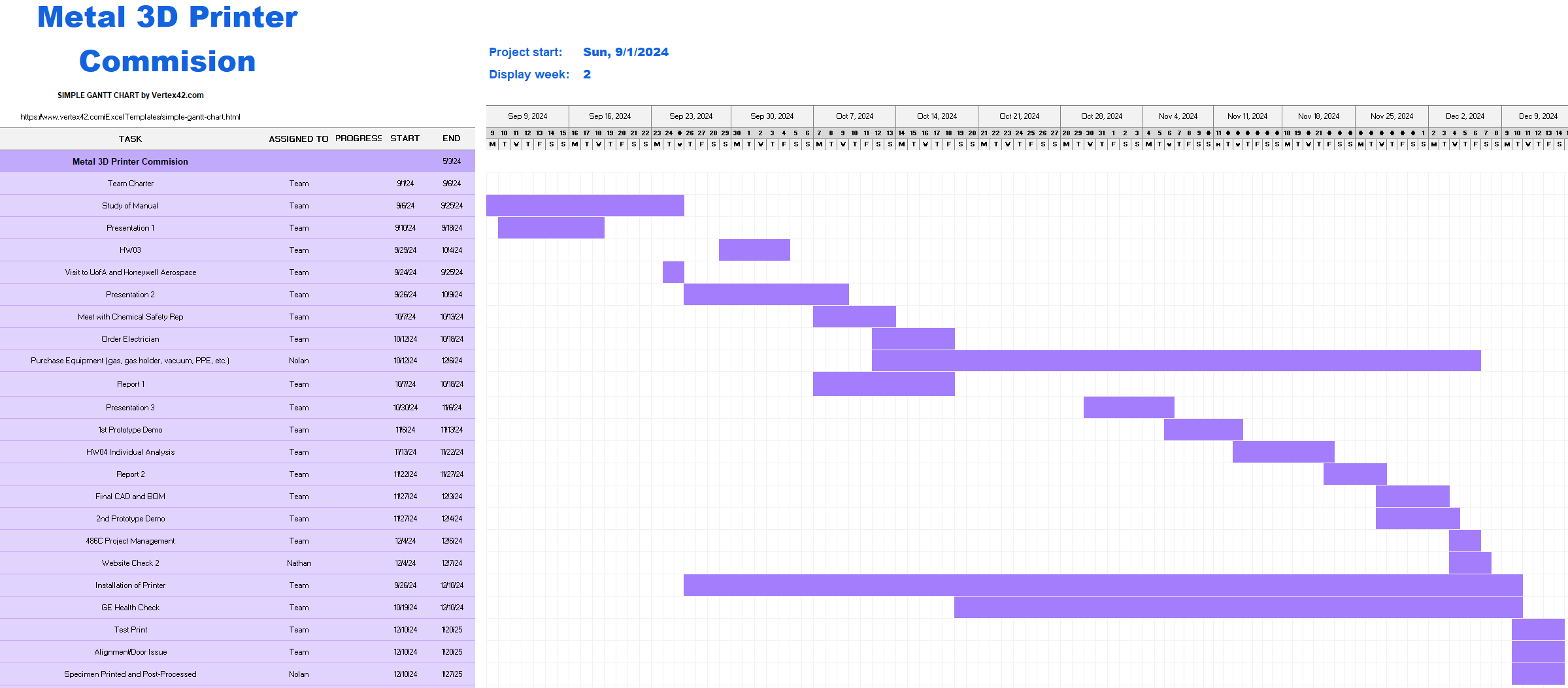
Successful commissioning was defined as achieving a fully operational printer with a safe, consistent, and repeatable printing procedure – ready to be taught to IDEA Lab employees and incorporated into the ME 286L curriculum.

# SCHEDULE AND BUDGET

As a commissioning project, both timeline and budget were planned around key milestones such as installation, testing, and training development. This section summarizes the projected and actual timelines, along with the costs associated with equipment, setup, and vendor services.

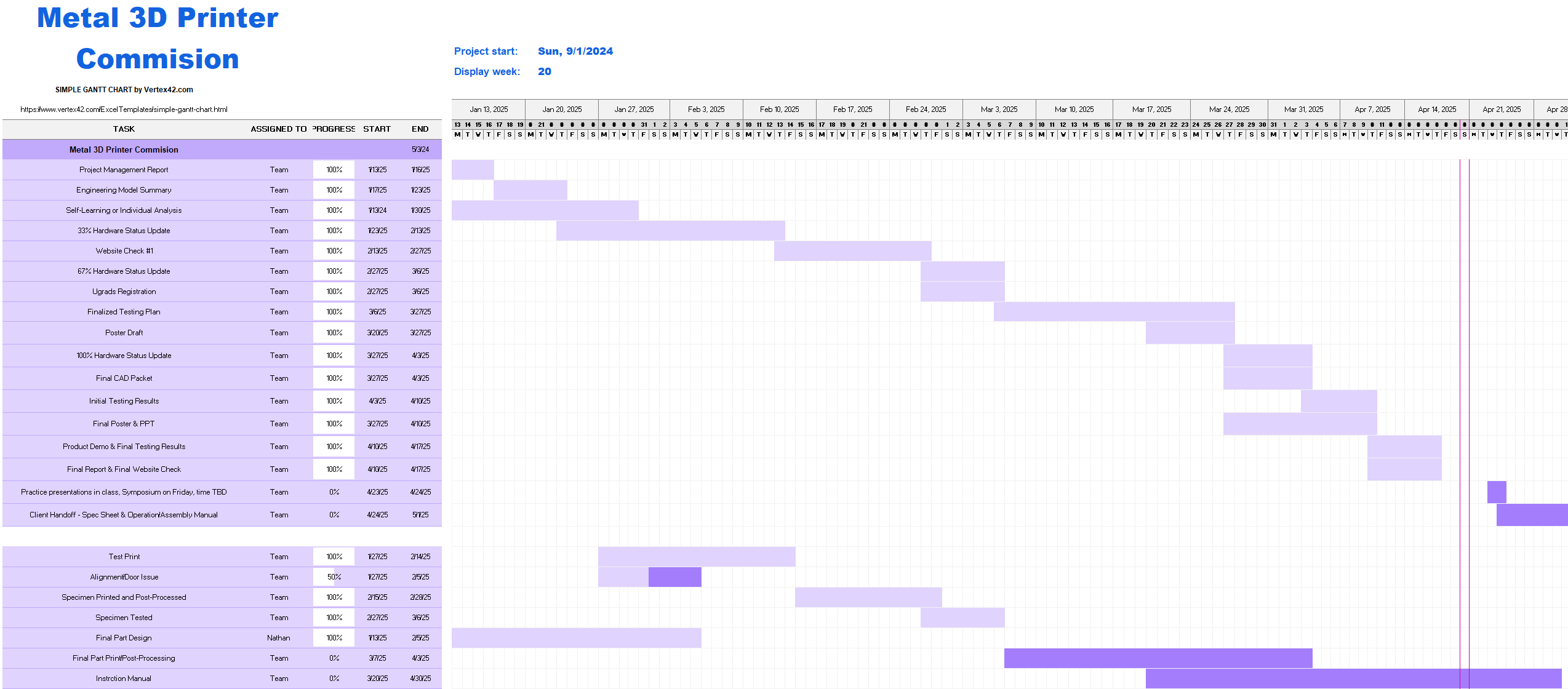
## Schedule

### Fall 2024 Gantt Chart:



*Figure 15: Fall 2024 Gantt Chart*

### Spring 2025 Gantt Chart:



*Figure 16: Spring 2024 Gantt Chart*

## Budget and Bill of Materials (BOM)

### Purchasing Plan

As part of the purchasing plan, we ensured the team was equipped with all necessary personal protective equipment (PPE) before beginning any work with the printer. A wet-separating vacuum was also acquired to safely remove and dispose of residual metal powder from both the machine and the glovebox trolley.

Throughout the commissioning process, additional unanticipated items were identified and procured. These included a replacement pressure latch, a steel alignment bar, and a new build chamber door seal—each critical to resolving mechanical and gas containment issues that arose during testing.

### Manufacturing Plan

The manufacturing phase began with preparing the build plates for use. This involved consulting with the NAU machine shop to develop a process for removing printed parts and cleaning the plates for reuse.

Once this procedure was established, we moved forward with slicing our first part using Autodesk NetFabb and conducting our first print using stainless steel (316L) powder. During this phase, we encountered and resolved several hardware issues, such as gas leakage from the door latch and a faulty door seal.

Following these initial trials and after verifying the print workflow, we planned to machine additional specimens in the shop and continue printing additional parts using the finalized setup.

### Bill of Materials

The following table outlines the materials and equipment purchased or used throughout the project:

*Table 1: Bill of Materials*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Items needed | Cost ($) | Amount | Total ($) | Supplier |
| Uline Industrial Nitrile Gloves | 13 | 2 | 26 | Uline |
| Dewalt Concealer Safety | 12.24 | 2 | 24.48 | Amazon |
| N95 Mask w/ air valve | 9.98 | 2 | 19.96 | Home Depot |
| ECLIPSE Static Control Wrist Strap | 6.43 | 1 | 6.43 | Amazon |
| Ruwac Wet Seperator MX200 | 9109 | 1 | 9109 | Ruwac USA |
| Gas Tank Holder | 69.99 | 1 | 69.99 | Amazon |
| Class D Fire Extinguisher | 1100 | 1 | 1100 | Uline |
| Peripherals | 800 | 1 | 800 | ITS |
| Computer | 2200 | 1 | 2200 |  |
| Build Plates | 220 | 4 | 880 | Colibrium |
| Industrial Grade Argon Gas Tanks | 350 | 2 | 700 | Airgas |
| Electrician Visit | 10000 | 1 | 10000 | NAU |
| Disk Drive | 14.58 | 1 | 14.58 | Amazon |
| Mineral Oil | 12.88 | 3 | 38.64 | DK Hardware |
| Disposal Drums | 135 | 1 | 135 | EHS |
| Stainless Steel Bar | 45.95 | 1 | 45.95 | OnlineMetals |
| Door Seal | 16.5 | 1 | 16.5 | GE |
| Pressure Latch | 130 | 1 | 130 | GE |
| 3D Printed Prototypes | 20 | 1 | 20 | ELEGOO |
| SS 316L Powder and Inconel 718 Powder | 0 | 1 | 0 |  |
| Mlab Powder Shaker | 0 | 1 | 0 | Honeywell |
| Overall Total |  |  | **25336.53** |  |
| Remaining |  |  | 1309 |  |

# DESIGN VALIDATION AND FINAL HARDWARE

This section details the validation procedures used to confirm that the printer met functional and safety expectations. Testing included evaluations of gas system integrity, build plate alignment, tensile test specimens, and sample print quality. Together, these tests ensured the printer operated safely, produced reliable parts within specification, and was ready for integration into academic and research workflows.

## Topology Optimization Validation

This section outlines the basic process used to topology optimize our final part, a scaled-down skateboard truck. The goal was to reduce weight while maintaining structural performance, using software tools to remove unnecessary material based on simulated loading conditions. This approach highlights the design freedom enabled by metal additive manufacturing.

### Skateboard Truck Load Case Calculations

This section contains the assumptions used to calculate the loads which our skateboard truck (described later) was subjected to in the topology optimization simulations.

The assumptions of this optimization regard the load conditions with which we performed the simulations. There are three separate loads we included: a vertical impact load on the ends of the truck (wheels), a horizontal impact load on the ends of the truck, and a vertical impact load along the truck. In both vertical load cases, horizontal momentum is not accounted for to consider the worst-case scenario. It should be noted that while each of these load cases are for different scenarios, the topology optimization must be performed with all potential worst-case loads applied to the model at the same time to account for all situations in the result of the simulation.

**Vertical impact load on ends of truck (1):**

This load was calculated with the conditions of a 250lb person and 5.5lb skateboard falling 5 feet onto a single truck with an impact time of 0.1 seconds. The load calculated is split between both ends of the truck, as the truck would tilt and intersect with the board if the load was only applied to one.

**Horizontal impact load on ends of truck (2):**

This load was calculated with the conditions of a 250lb person and 5.5lb skateboard hitting an obstacle while traveling at 10mph with an impact time of 0.1 seconds. The load calculated is applied to both ends of the truck to simulate hitting a rock or similar object and is applied to both ends of the truck separately. This is to simulate a worst-case scenario where the skateboard and person are stopped completely by a rock hitting one wheel. It is applied to both sides of the truck for symmetry in the topology optimization simulation.

**Vertical impact load along the truck (3):**

This load was calculated with the conditions of a 250lb person and 5.5lb skateboard falling 3ft onto a hard surface with an impact time of 0.1 seconds. This is to simulate a person attempting to grind along a ledge, rail, or other surface in which all the force is directed along the truck and bypasses the wheels.

**Equations and Solutions:**

**Vertical impact load on ends of truck (1):**

Impact velocity:

Total mass:

Change in momentum:

Impact load:

**Horizontal impact load on ends of truck (2):**

Impact velocity (m/s):

Total mass:

Change in momentum:

Impact load:

**Vertical impact load along the truck (3):**

Impact velocity (m/s):

Total mass:

Change in momentum:

Impact load:

These load case calculations provided a realistic foundation for the topology optimization process. By identifying where and how the part would be loaded, we were able to define meaningful constraints and ensure that the final design maintained structural integrity while minimizing material usage.

### Optimization Simulation Conditions

Before running the topology optimization simulation, several conditions and constraints needed to be defined to guide the solver and produce a viable design. These inputs ensured the simulation remained realistic and aligned with the part’s functional requirements. The following bullet points outline the specific parameters used in our optimization setup, including symmetry, mass reduction targets, and fixed geometry regions.

**Loads:**

* Hanger:
  + Vertical impact load on ends of truck: 1269N
  + Horizontal impact load on ends of truck: 1037.2N
  + Vertical impact load along the truck: 985.2N
* Base:
  + Impact load separately on both kingpin hole and pivot socket: 1269N
  + This load was chosen as it was the highest load on the truck, and therefore the worst-case scenario for the baseplate.

**Conditions and constraints:**

* Both:
  + 316L stainless steel
  + Symmetry across x-z plane
  + 60% weight reduction
* Hanger:
  + Fixed at pivot rod and bushing hole
* Base:
  + Fixed at bolt holes in corners

### Final Optimization

This section outlines the final stages of topology optimization, where multiple iterations were performed to minimize mass while achieving a factor of safety above 2. The process began with a 60% mass reduction target, followed by analysis of simulation results to identify weak points. Both initial models failed under the original load case at this reduction level, so additional iterations were completed with material added in areas where failure occurred. The original 60% reduction models are shown below alongside their corresponding baseline geometries.

A silver object with a handle

AI-generated content may be incorrect.A blue and yellow object with holes

Description automatically generated

*Figure 17: Optimized Hanger (60%)*

*Figure 18: Original Hanger*

A blue and yellow object with holes

Description automatically generatedA grey object with a hole

Description automatically generated

*Figure 19: Optimized Baseplate (60%)*

*Figure 20: Original Baseplate*

After many rounds of simulation and adjustment, we finalized our designs at 59.7% weight reduction for the hanger and 52.4% for the baseplate – both achieving minimum factor of safety values above 2. Reaching these results required multiple iterations, as early versions often failed under load or introduced new weak points with each change. Each simulation took considerable time to set up and process, making the iterative optimization both time-intensive and computationally demanding. The final optimized models are shown below, alongside the original geometries and their factor of safety calculations.

A blue and green object

AI-generated content may be incorrect.A blue object with white text

AI-generated content may be incorrect.

*Figure 22: Final Optimized Hanger FOS (59.7% weight reduction)*

*Figure 21: Original Hanger FOS*

A blue object with a hole

AI-generated content may be incorrect.A blue object with a hole

AI-generated content may be incorrect.

*Figure 23: Original Baseplate FOS*

*Figure 24: Final Optimized Hanger FOS (52.4% weight reduction)*

The final optimized hanger and baseplate designs demonstrated significant weight reduction while maintaining structural integrity, highlighting the potential of topology optimization in real-world applications. In the context of a skateboard assembly, these parts would contribute to a lighter setup, improving maneuverability, reducing rider fatigue, and allowing for quicker response during tricks and turns. Unfortunately, due to time and material constraints, we were unable to print the optimized parts in metal. However, the completed models remain a strong demonstration of the capabilities of additive manufacturing when paired with advanced design techniques

## Failure Modes and Effects Analysis (FMEA)

The table below presents the Failure Modes and Effects Analysis (FMEA) for the printer, outlining the primary issues encountered during testing and operation, along with their potential causes, effects, and mitigation strategies.

*Table 2: Printer FMEA*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Part # and Functions | Potential Failure Mode | Potential Effect(s) of Failure | Potential Causes and Mechanisms of Failure | RPN | Recommended Action |
| Laser System |  |  |  |  |  |
| Laser - Melt powdered metal | Temperature Fatigue | Build Failure, Neccessary visit from technician | Overuse | 24 | Call Technician |
| Mirrors - Reflect laser onto build plate | Wear | Build Failure, Necessary visit from technician | Overuse, wear over time | 18 | Call Technician |
|  |  |  |  |  |  |
| Build Module |  |  |  |  |  |
| Powder Chamber - Holds powder for dispensing across build plate | Corrosion | Contamination of material stock, replacement of build module | Condensate buildup | 48 | Check for any signs of rust or oxidation |
| Build Plate - Supports melted powder | Wear, Temp Deformation, Corrosion | Build Failure | Improper cleaning/removal procedure | 32 | Check for any signs of rust or oxidation, machine often |
| Overflow Chamber - Holds excess powder | Corrosion | Contamination of material stock, replacement of build module | Condensate buildup, improper cleaning procedure. | 36 | Check for any signs of rust or oxidation |
| Coater - Dispenses powder across build plate | Wear | Lines in prints, could cause build failure | Not checking for defects in coater blade, not replacing blade. | 16 | Check coater for wear, defects in surface |
|  |  |  |  |  |  |
| Air Flow |  |  |  |  |  |
| Air Supply - Maintains inert argon atmosphere | Wear | Gas Leak | Cut in gas line, leaky valve | 72 | Replace parts |
| Ventilation System - Captures fumes and condensate into filter | Corrosion, Wear | Build Failures, potential fires | Failure to maintain/ replace filters | 90 | Regularly change filters |
|  |  |  |  |  |  |
| Computer |  |  |  |  |  |
| Magics - Slices models for printing | Computer Error | Lost Files, Program Crashes | Large, complex part is entered into program | 24 | Restart program, account for time lost |

## Testing Plans

Part of our project involved testing the printer after successful installation, which included running several test prints and conducting a tensile test using printed samples. The two experiments conducted are outlined below, along with the specific project requirements they addressed.

*Table 3: Testing Plans*

|  |  |  |  |
| --- | --- | --- | --- |
| Experiment/Test​ | Relevant DRs​ | Testing Equipment Needed​ | Other Resources​ |
| EXP1 - Test Print​ | ER2 - Final Print Material (SS 316L)​ ER4 - Power​ ER5 - Inert Gas​ ER8 - Airtight Gas Supply​ ER9 - Build Plate Alignment​ ER10 - Printed Part Tolerance (±0.2mm)​ CR2 - Safety​ CR4 - Successful Installation​ CR6 - Final Part and Assembly​  CR3 - Time​ | Small tube​ Dial gauge indicator​ Shim​ Calipers​ | Rail system to slide dial gauge indicator along build module​ |
| EXP2 - Tensile Test​ | ER2 - Final Print Material (SS 316L)​ ER6 - Young's Modulus Tested​ ER7 - Dog Bone Size​ CR5 - Tensile Test Results​  CR3 - Time​ | Tensile test equipment​ Calipers​ | ​ |

### EXP1 – Test Print

**EXP1.1 – Gas Leak Test**  
This test was conducted to verify that the printer’s inert gas system was sealed and functioning properly. Using a copper tube to detect audible leaks, the team checked all critical gas flow components, including the build chamber, tubing, and internal connections. Ensuring a leak-free system was essential for both safety and material efficiency, especially during long prints that displace oxygen in the lab environment.

**EXP1.2 – Build Module Trials**  
Each of the three remaining build modules was tested to determine if its z-axis elevator provided a level build plate. This was evaluated by observing the evenness of the first powder coating layer. One module had already been confirmed to be misaligned during a prior print, so the goal was to identify a functional module that would allow printing to continue without modification.

**EXP1.3 – Shim Alignment Procedure**  
Since none of the available build modules were properly aligned, a manual alignment process was performed using shim stock. Shims were cut and inserted beneath the build plate to compensate for low areas, and adjustments were made until the surface was as level as possible. The levelness was tested visually by applying thin layers of powder. This alignment was necessary to prevent print defects caused by uneven powder distribution.

**EXP1.4 – Test Print and Tolerance Check**  
A test part was printed and measured to determine whether the printer met dimensional accuracy requirements. Calipers were used to compare printed dimensions to the original CAD model, with a target tolerance of ±0.2 mm. Achieving this tolerance confirmed that the printer was properly aligned and configured, completing the installation and fulfilling a key customer requirement.

### **EXP2 – Tensile Testing**

This test measured the mechanical properties of 316L stainless steel specimens produced by both machining and additive manufacturing. Three samples from each method were tested using a tensile tester capable of applying up to 60,000 lbf, with data recorded through a connected DAQ system. Each specimen was pulled to failure while recording stress, strain, and deformation behavior. The results were used to compare ultimate tensile strength, yield strength, ductility, and Young’s modulus between the two manufacturing methods, fulfilling several key engineering requirements related to material validation.

## Testing Results

### Test Print Results

**EXP1.1 – Gas Leak Test Results**  
The gas leak test identified a leak at the build chamber door latch. A temporary fix using duct tape resolved the issue, eliminating audible leakage. Although a permanent replacement latch is still pending, this test confirmed that the system could safely hold inert gas in the short term, enabling continued testing and part printing.

**EXP1.2 – Build Module Trials Results**  
All four build modules were tested for functionality and alignment. Only one out of the three build modules worked properly. This confirmed the need for manual adjustment and ruled out relying on manufacturer calibration, directly informing the next phase of testing.

**EXP1.3 – Shim Alignment Results**  
The build plate was successfully leveled using a shim-based adjustment method. This ensured a flat printing surface and allowed the team to move forward with accurate printing. However, due to build plate variation, the alignment must be rechecked before each print. A permanent fix would require a field service to repair the z-axis elevator of the build module

A small metal object on a table

AI-generated content may be incorrect.**EXP1.4 – Test Print and Tolerance Results**  
A scaled-down Benchy model was printed and measured within the target tolerance of ±0.2 mm, confirming the printer’s ability to produce dimensionally accurate parts after manual alignment. This result validated the commissioning process and met key project requirements. Pictured below are the printed Benchy and a table of the measured dimensions. While the print was within tolerance, visible warping on the roof and surface discoloration indicated insufficient heat dissipation during unsupported overhangs. This aspect of the print was also valuable, as it demonstrated the printer’s current limitations when printing unsupported geometry.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Part | Dimension | Expected (mm) | Actual (mm) | Difference (mm) |
| Overall | Width | 19.22 | 19.04 | 0.18 |
|  | Length | 37.2 | 37.24 | -0.04 |
| Roof | Length | 14.26 | 14.13 | 0.13 |
| Cargo | Width | 7.44 | 7.27 | 0.17 |

*Table 4: Tolerance Testing*

*Figure 25: Benchy Test Print*

### Tensile Test Results

When it comes to tensile testing, the team was able to successfully machine and print a total of six cylindrical samples, however different orientations for the printed samples were not achieved due to time constraints, material shortage, and concern for failure due to steep overhangs on the part.

A group of metal tools on a wood surface

AI-generated content may be incorrect.A group of metal objects on a wood surface

AI-generated content may be incorrect.

*Figure 27: Machined Test Specimen*

*Figure 26: Printed Test Specimen*

The samples were then placed inside an Instron tensile tester and broken in tension, resulting in the graph below, where the additive samples are warmer colors and subtractive samples in cooler colors.

*Graph 1: Tensile Testing Results*

The additive samples tended to perform more similarly to one another, while the subtractive samples had a noticeable variation in the test. Ultimately, the additive samples tended to have higher maximum stress and yield strength compared to their machined counterparts, however their Young’s modulus were lower on average. This may require further testing to properly conclude when comparing machined versus printed parts, however we can say that printed parts a very similar to machined parts in performance.

### Iterative Print Validation

The printing process was refined through a series of iterative test prints, each revealing specific challenges that informed improvements in print setup, file preparation, and overall machine configuration.

The first print was cancelled several hours in after it became clear that the build plate was not properly leveled. Powder was unevenly distributed, especially at the corners, causing incomplete layer fusion and localized overheating.

In the second print, we revised our support strategy, choosing to only support the bottom of the part. However, the interior of the part failed to sinter, while only the exterior contours printed correctly. This was traced back to an improperly exported slice file, which caused the printer to misread internal geometry and generate ineffective toolpaths.

The third print was a success. The part sintered together as intended, thanks to corrected file exports and the addition of a solid baseplate for support. Minor issues were still present: the coater blade sustained damage from a sharp edge early in the print, leading to a slight bulge in one section, and the roof of the part showed heat-related warping due to unsupported overhangs.

The fourth print was of our three tensile testing specimens, which went off without a hitch.

Despite these setbacks, each print iteration played a critical role in refining our workflow, improving file preparation, and deepening our understanding of the printer’s behavior. These tests allowed us to identify and address key issues related to build plate leveling, file exporting, and support strategies. The iterative process not only improved our printing reliability but also provided valuable experience that will inform future users. Images of each print stage are shown below to illustrate the progression.

A close-up of several wooden objects

AI-generated content may be incorrect.

A small metal object on a table

AI-generated content may be incorrect.A silver object on a metal surface

AI-generated content may be incorrect.A metal object on a table

AI-generated content may be incorrect.

*Figure 31: 4th Print*

*Figure 30: 3rd Print*

*Figure 29: 2nd Print*

*Figure 28: 1st Print*

## Future Testing Potential

Looking ahead, we plan to conduct additional tensile testing to further investigate and validate the mechanical properties of metal parts produced through additive manufacturing. One key area of interest involves comparing post-processed additive parts – those that have undergone heat treatment, surface finishing, or hot isostatic pressing (HIP) – to conventionally machined counterparts made from the same base material. This comparison would provide more realistic insight into the performance of additively manufactured parts when finished to industry standards, particularly in terms of strength, ductility, and surface quality.

Another promising direction involves analyzing the effects of build orientation on mechanical performance. Given adequate time and resources, we would like to print tensile specimens at various angles relative to the build plate (e.g., 0°, 45°, and 90°) to study how anisotropy from the layer-by-layer process impacts structural integrity. These results would help identify optimal build orientations for different load cases and offer valuable design guidance for future capstone projects and research applications.

Additionally, expanding our testing to include a broader range of printable metals—such as bronze, aluminum, and titanium—holds significant educational and research potential. Each material brings unique mechanical and thermal properties that could serve diverse applications. For example, titanium’s high strength-to-weight ratio is ideal for aerospace applications, while bronze’s wear resistance makes it suitable for art, tooling, and marine environments. However, introducing new powders would require careful logistical planning. This includes sourcing appropriate materials, verifying compatibility with printer parameters, and implementing updated cleaning and safety protocols to prevent cross-contamination and mitigate reactivity risks—particularly with reactive metals like aluminum and titanium.

Pursuing these expanded testing and material capabilities would significantly enhance the research and instructional value of the IDEA Lab’s metal 3D printer and provide a strong foundation for future projects in additive manufacturing.

## Final Hardware

The final hardware setup marks the end of our commissioning efforts and the beginning of the printer’s usability within the IDEA Lab. Shown below are two key images: one of the final printer setup and another of the machine mid-print during a successful run – something that took a long time to reach. Getting to this point required a combination of troubleshooting, repair, and iteration across both hardware and software systems.

The commissioning process came with several challenges. We had to address alignment issues in our only working build module, fix a leaking build chamber door latch, and learn how to properly use and configure the machine's software and Autodesk Netfabb. Through testing, we were able to patch the leak, manually level the build plate using shims, and develop a reliable startup and print procedure. Each step helped us better understand the machine and move closer to a working system.

Print iteration was just as important. Our first print failed due to poor leveling and powder coverage. The second print failed because of an improperly exported slice file that caused the interior of the part to be skipped entirely. The third print was mostly successful, but we still saw minor issues like coater blade damage and roof warping due to unsupported overhangs. Our fourth print went well without any issues. Every print helped refine our workflow, from file preparation to part orientation to support design.

A close-up of a laser cutting

AI-generated content may be incorrect.By the end, we had a working printer capable of producing consistent, dimensionally accurate metal parts. The build plate was fully leveled, the gas seal verified, the slicing workflow tested, and the printer behavior predictable.

*Figure 33: Benchy Test Print Mid-Print*

*Figure 32: Final Printer Setup*

A machine in a room

AI-generated content may be incorrect.

# LOOKING FORWARD

Moving forward, additions to the project can be implemented in several meaningful ways to enhance the capabilities and reliability of the Mlab Cusing R system. One key objective is to bring in certified field technicians from Colibrium Additive to perform a comprehensive health check on the machine. This evaluation would ensure that all subsystems operate within their optimal parameters and could help identify potential issues before they become critical. During this visit, technicians could also install an upgraded build plate z-axis elevator, which would improve print reliability, reduce mechanical wear, and reduce the chance of a critical malfunction that could render the build module unusable.

In addition to hardware upgrades, expanding the range of printable materials would significantly increase the machine’s versatility and utility within the IDEA Lab. Currently, the machine is primarily set up for stainless steel; however, exploring alternative metals such as aluminum, titanium, or cobalt-chrome could allow for a broader scope of capstone projects and research opportunities. These materials, commonly used in aerospace, automotive, and biomedical industries, would provide students with hands-on experience using industry-relevant materials and processes.

However, incorporating these new materials would require implementing more stringent safety protocols and operational procedures. Aluminum and titanium powders are highly reactive with oxygen and present a greater fire and explosion hazard compared to less reactive metals. Therefore, increased safety measures – such as more frequent and thorough cleaning of the build chamber, stricter inert gas monitoring, and enhanced personal protective equipment (PPE) requirements – would be necessary to mitigate risk. It may also be beneficial to invest in additional training for lab staff and users, focused on safe handling and maintenance practices specific to reactive metal powders.

Overall, these future additions would not only improve the reliability and performance of the printer but also position the IDEA Lab as a more advanced facility capable of supporting cutting-edge student work, interdisciplinary research, and industrial partnerships.

# CONCLUSIONS

The Metal 3D Printer Capstone project successfully commissioned the IDEA Lab's Concept Laser Mlab Cusing R printer, transforming it from an unused donation into a valuable resource for future academic and research use. The team completed installation, calibration, and functional testing, resolving key issues such as gas leaks and build plate misalignment. Test prints and tensile specimens were produced to evaluate performance, and drafts of a training program and instructional manual were initiated to support future users.

While some deliverables – such as the final optimized part and training documentation – remain in progress, the printer is now operational and on track to be fully integrated into the ME 286L Manufacturing Lab and available for IDEA Lab work orders. Looking forward, continued material testing, expanded metal powder capabilities, and further investigation into build orientation effects will broaden the printer’s educational and research impact. This project not only restored a valuable piece of equipment but also laid the foundation for its sustained use in advancing metal additive manufacturing at NAU.

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