



Design of a station for inspecting and cleaning optics

Master Thesis

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Master Thesis Assignment Form

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The main objectives of the thesis are to design the station for inspecting and cleaning optics and design the laminar flow cabinet.

1. Getting acquainted with the issues and current solutions of the workplace.
2. Defining the required parameters for the proposed device.
3. Research available and possible solutions on the market.
4. Solution design according to defined requirements. 3D CAD model, production drawings.
5. Verify the structure by the calculations and simulations (e.g., flow inside the cabin).

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- [2] RIDER, Michael. *Designing with Creo Parametric 3.0*. CDC publication. 2015. ISBN 9781585039807.
- [3] labassociates. *Laminar flow cabinet: an important piece of equipment for a lab* [online] (cit. 24. 2. 2022), available: <https://labassociates.com/laminar-flow-cabinet>
- [4] Edmund Optics. Application Notes [online] (cit. 24. 2. 2022), available: <https://www.edmundoptics.com/resource-page/application-notes/optics/>

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B.Sc. Hoang Bao Nguyen

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THEME: DESIGN OF A STATION FOR INSPECTING AND CLEANING OPTICS

Abstract: The aims of the diploma thesis is to develop a cleaning optical fixture and the cabinet that occupies it. The optical lens is an essential component of the laser system. As a result, it's critical to keep the lens clean to avoid dust. These contaminants have the potential to cause irreversible damage to optical lenses. Considering inspecting and cleaning optics is a delicate process, the important aim of the fixture kit is to provide ease of use, friendliness, and lens safety. For the station, the design will be based on the laboratory hoods that are now available on the market, from which we will modify the cabinet to fit our needs. The cabinet's function is to ensure the operating chamber's objects and materials from external contamination and cross-contamination. The design of this thesis is accomplished with Autodesk Inventor software, and Ansys software is utilized to analyze the air flow inside the box.

Keywords: Optics, lens, cleaning, inspecting, contaminants, laboratory hoods, laminar flow, air flow, Ansys, optimize.

Abstrakt: Cílem této diplomové práce bylo vyvinout zařízení pro čištění optiky a skříň, ve které bude zařízení umístěné. Optická čočka je základní součástí laserového systému. Je proto důležité udržovat čočku v čistotě, aby se na ni neprášilo. Tyto nečistoty mohou způsobit nevratné poškození optických čoček. Vzhledem k tomu, že kontrola a čištění optiky je choulostivý proces, je důležitým cílem sady přípravků zajistit snadné použití, opatrnost při manipulaci a bezpečnost čoček. U stanice návrh vychází z laboratorních digestoří, které jsou nyní dostupné na trhu, dle kterých je skříň upravena podle požadavků. Funkcí skříně je chránit předměty a materiály provozní komory před vnější kontaminací a křížovou kontaminací. Pro návrh konstrukcí byl použit software Autodesk Inventor a pro analýzu proudění vzduchu uvnitř boxu byl použit software Ansys.

Klíčová slova: Optika, optická čočka, čištění, kontrola, kontaminanty, laboratorní digestoře, laminární proudění, proudění vzduchu, Ansys, optimalizace.

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CHAPTER 1

1 Introduction

1.1 Objective

Nowadays, laser technology in the sphere of industry is widely used and has had a significant economic and social impact. It has greatly contributed to the advancement of natural science and technology. It has a variety of applications in medicine, transmission of information, high energy lasers, research... The optical lens is an essential component of the laser system. As a result, it's critical to keep the lens clean to avoid dust. These contaminants have the potential to cause irreversible damage to optical lenses. The goal of this thesis is design and develop the station for inspecting and cleaning optics. It will be separated into two sections: part 1 will construct a cleaning fixture kit, and part 2 will build the station where we will work, examine, and clean. Considering inspecting and cleaning optics is a delicate process, the important aim of the fixture kit is to provide ease of use, friendliness, and lens safety. For the station, the design will be based on the laboratory hoods that are now available on the market, from which we will modify the cabinet to fit our needs. The cabinet's function is to ensure the operating chamber's objects and materials from external contamination and cross-contamination. The design of this thesis is accomplished with Autodesk Inventor software, and Ansys software is utilized to analyze the air flow inside the box.

1.2 Outcome

After learning about the cleaning process and examining the products available on the market. A new fixture kit has been devised to make this procedure easier and more efficient. It follows the product design process. Individual optical lenses impose particular design constraints. To boost speed and efficiency, commercial mechanical parts will be employed. Following the completion of the drawing, a simplified prototype was created utilizing 3D printing. The sample has passed the initial testing and has satisfied the standards.



Figure 1: The fixture kit

The Fixture kit will be placed inside the cabinet to eliminate the contamination from outside work environment during cleaning & inspecting process. The cabinet's design is inspired by laboratory hoods, with the purpose of creating laminar flow within the cabinet. This is a stream of pure air with no impurities in it. This thesis concentrates on the computation and selection of appropriate filters and blowers. Aluminum extrusion will be used for the frame, as it is easy to fabricate and assemble and has a low cost.

The first design was created. For this thesis design, the core functional demands were considered, and all of them were achieved, allowing the remaining needs to be addressed in future versions of the product.

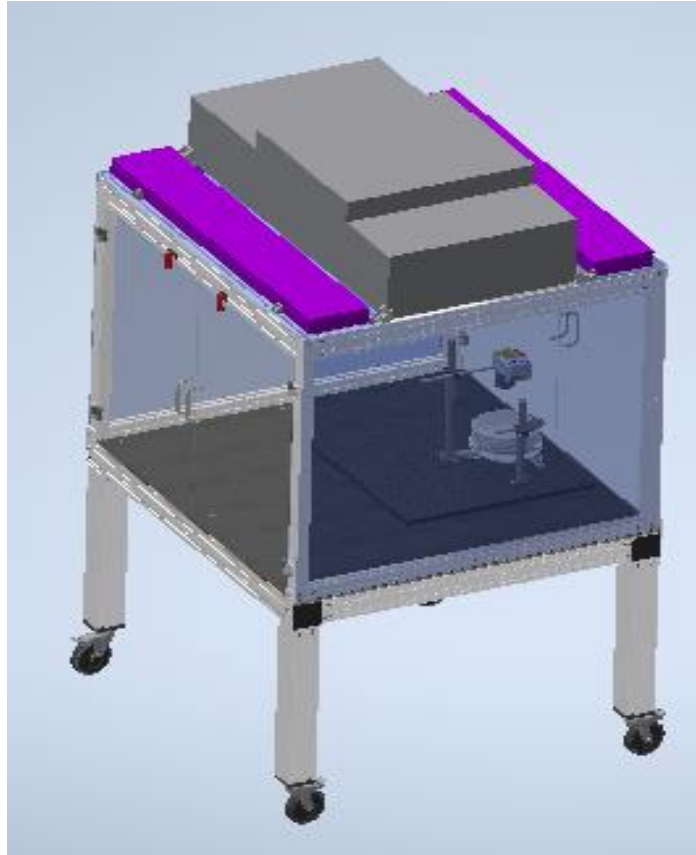


Figure 2: The assembly drawing of Laminar flow box

1.3 Structure of the thesis

The thesis is organized into four chapters. The importance of the thesis topic and the work done is demonstrated in Chapter 1. In chapter 2, talk about the structural properties of the optical lens, and the cleaning optic process. Also discuss and analyze the fixture kit design basic designs, as well as build drawings and prototypes. In Chapter 3, understand about laminar flow cabinets, calculate, design, analyze, modify, and choose the best solution. Chapter 4 provides a brief review of the thesis along with recommendations for further revisions.

CHAPTER 2

2 Optic inspection station design

2.1 Optical manufacturing specifications

2.1.1 Bevel

Considering glass borders are so vulnerable, it's crucial to secure them when manipulating or installing a component. The most frequent method of safeguarding these corners is to bevel the edges. Bevels act as protective chamfers, eliminating edge chipping. They are identified by their face width and angle.

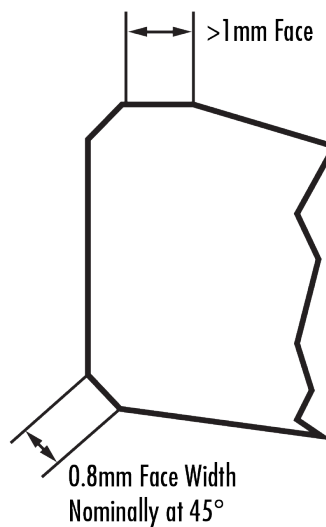


Figure 3: Bevel on an Optical Lens [1]

The most typical bevel angle is 45 degrees, and the face width is dictated by the optic's diameter. Because of the risk of developing edge chips, optics with diameters smaller than 3.00mm, such as micro-lenses or micro-prisms, are normally not beveled. Because of the high angle between the surface and the edge of the lens, no bevel is required for tiny radii of curvature, such as lenses with a diameter of 0.85 x radius of curvature. The maximum face widths for all other sizes are listed in Table 1.

Diameter	Maximum Face Width of Bevel
3.00mm – 5.00mm	0.1mm
5.01mm – 25.4mm	0.25mm
25.41mm – 50.00mm	0.3mm
50.01mm – 75.00mm	0.4mm

Table 1: Face width of bevel corresponding to diameter [1]

2.1.2 Clear aperture

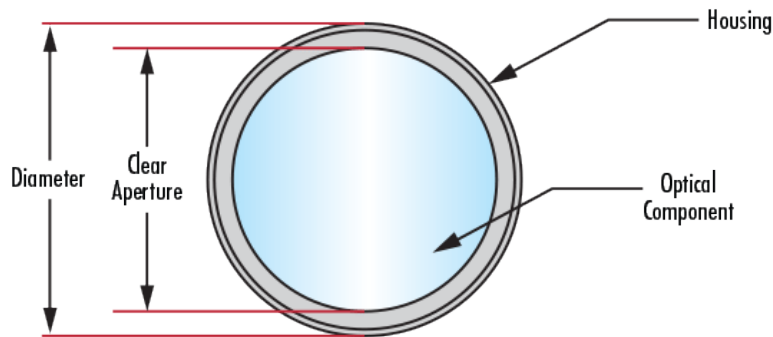


Figure 4: Graphic Indicating Clear Aperture and Diameter of a Filter [1]

The diameter or size of an optical component that does indeed ensure quality is known as the clear aperture. Manufacturers do not guarantee that the optic will satisfy the listed requirements outside of that. Due to manufacturing constraints, producing a transparent aperture that is exactly equal to the diameter, or length by breadth, of an optic is practically unachievable. Table 2 shows the most common clear apertures for lenses.

Diameter	Clear Aperture
3.00mm – 10.00mm	90% of Diameter
10.01mm - 50.00mm	Diameter – 1mm
≥ 50.01mm	Diameter – 1.5mm

Table 2: Clear aperture corresponding to diameter [1]

2.2 The cleaning optic process [2]

Because of the sensitive nature of optics, certain processes must be implemented to ensure that their functionality and durability are maximized. Optical components can get into encounter

with impurities such as debris, humidity, and skin oils throughout regular operation. These impurities cause scattering off the optical surface and absorb incident light, resulting in critical areas on the optical surface and lasting damage. Coated optical components are particularly vulnerable to this type of damage.

2.2.1 Handling



Figure 5: Handling the optic [2]

With using appropriate handling procedures, you can minimize the need to clean your optics and so extend their life. Always use a hygienic, temperature-controlled environment to unpack or open lenses. Never hold optics with bare hands, since skin oils can cause irreversible damage the optical surface properties. Therefore, utilize gloves; otherwise, optical or vacuum gripper may be useful for smaller optical components. If at all feasible, only hold the optic along non-optical surfaces, such as the ground edges of the optic, regardless of the method employed to hold it.



Figure 6: Storage the optic [2]

Any contamination on the optic or the surface will be crushed in if it is laid on a hard surface. Most optics should be enveloped in lens fabric and placed in an optic storage box made specifically for the optic. The box should typically be maintained in a low-humidity, low-contaminant, and temperature-controlled environment. Because optical components are easily damaged or polluted, and some optical coatings are hygroscopic, correct storage is critical for their safety.

2.2.2 Blowing off the surface of an optic

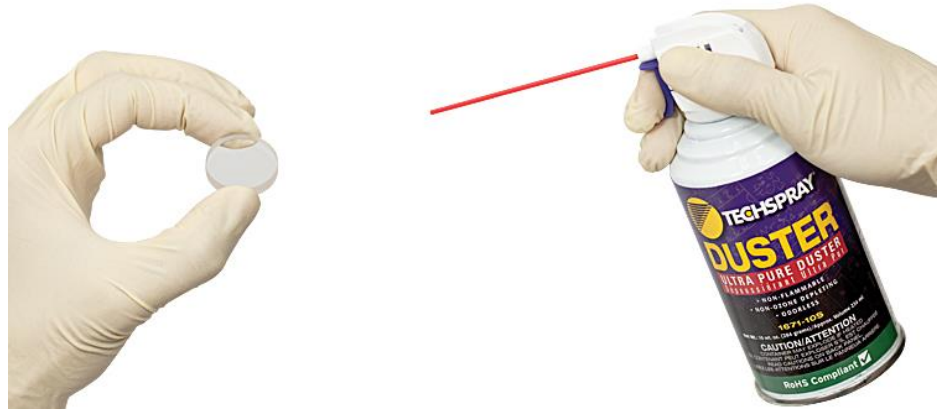


Figure 7: Blowing the surface of the optic [2]

Before using any other cleaning approach, dust and other loose particles should normally be blown away. This procedure requires an inert dusting gas canister or a blower bulb. If blowing on the surface with mouth, saliva droplets will most likely be coated on the optical surface.

Hold the can straight as well during the process if you're using inert dusting gas. Before or during usage, do not jiggle the can. Additionally, begin the gas flow with the nozzle directed away from the optic. These methods assist prevent the inert gas particle from settling on the optical surface. If you're using canned gas, keep it 6" (15 cm) away from the optic and use small blasts. With the nozzle of the inert gas can at a cutting angle to the optical surface, pass it over the optic. Create a figure-eight shape over the optical surface for wide surfaces.

Almost all varieties of optics may be cleaned with this procedure. However, for some optics that can be harmed by physical touch, such as holographic gratings, ruled gratings, unprotected metallic mirrors, calcite polarizers, this is the only permitted approach for cleaning. This cleaning procedure should be utilized as a first step in cleaning practically all optics because it is non-contact and solvent-free.

Caution: The polished escape face on calcite polarizers is extremely delicate and can be harmed if air is blown too directly at it.

2.2.3 Cleaning optics with a fixture kit

Step 1: Inspect the Optic.

To begin, inspect the optic to identify where the impurities are located. This allows the user to view the optic in the fixture so that the contaminant is removed off the optic's surface as soon as possible by being dragged across it.

Step 2: Place the Optic in the Fixture.

Insert the optic by pressing the actuator tabs on the self-centering lens mount. The drop and drag approach is suitable for flat optical surfaces like mirrors. Make sure the optic is properly positioned, with the underneath of the lens lying on the widest area of the fingers.

Step 3: Clean the Optic

Hold a new, clean piece of lens tissue above (not in touch with) the optic so that the lens tissue is pulled across the optical surface as you pull it. After that, apply one or two drops of an approved fast-drying solvent to the lens tissue that is being held above the optic. The lens tissue will come into touch with the optical surface due to the weight of the solvent. Drag the moist lens tissue across the optic slowly and steadily, being careful not to pull the lens tissue off the surface. Keep drawing the lens tissue away from the optical surface until it is completely free.

The right amount of solvent will preserve the lens tissue moist throughout the drag but won't leave any detectable solvent on the optical surface once it's over. Check the optic and repeat as required, but each sheet of lens tissue should only be used once. Many people like this form of cleaning because the lens tissue only comes into light touch with the optical surface. Small adhered particles and oils can be virtually eliminated from an optical surface using this method. Contaminant concentrations that are too high often necessitate multiple treatments.

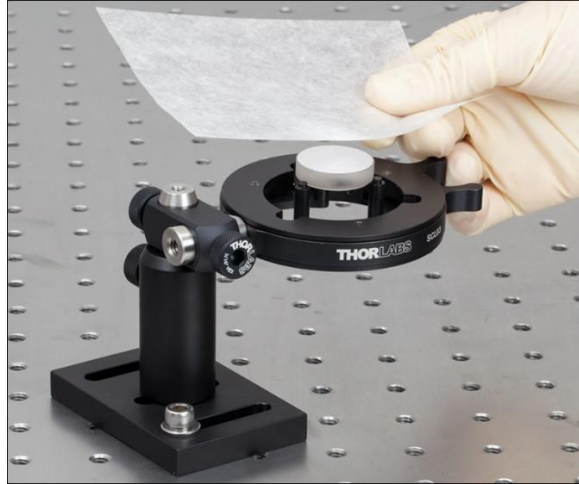


Figure 8: Insert the optic into the Fixture [2]

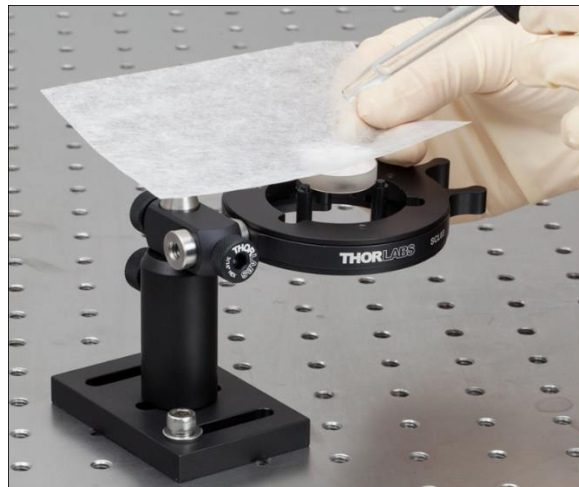


Figure 9: Place solvent drops on the tissue [2]



Figure 10: Drag the tissue across the optic [2]

2.3 Market research

2.3.1 Round optic mount

2.3.1.1 Self-Centering Lens Mount



Figure 11: Self-Centering Lens Mount SCL03 [3]

Features:

By pinching the actuator tabs between the thumb and forefinger, the lens mount fingers can be simply opened with one hand. As the actuator tabs are relaxed, the lens is basically held between the mounting fingers. The spring-loaded fingers clamp the optic tightly, while the nested ring design keeps it in place.

Disadvantages:

Limitations in terms of optical shapes and range. Alignment Grooves can only be utilized for round optics with a diameter ranging from 3.8 mm to 76.2 mm.

Inserting the optic necessitates the use of a careful, completely concentrated hand.

2.3.1.2 Universal Adjustable Lens



Figure 12: Universal Adjustable Lens [4]

Features:

To accommodate any spherical object, Universal Adjustable Mounts are employed. Three of the holder's support shafts are fitted with non-rotating V-groove aluminum universal detachable tips for lenses, mirrors, and other objects. For rough placement and diameter setting, each individual adjustable shaft of the holder has a threaded thumbscrew, sliding sleeve, and fixation tool. To provide fine adjustment travel, only a twist thumbscrew of the shaft is required.

Disadvantages:

Limitations in terms of optical shapes and range. There are two variants with differing holding diameters: 10-66 mm and 38-103 mm.

Inserting the optic necessitates the use of a careful, completely concentrated hand.

2.3.2 Rectangular Holder

2.3.2.1 Adjustable Kinematic Mounts for Rectangular Optics



Figure 13: Adjustable Kinematic Mounts 100C [5]

Features:

Clamping Arm with Adjustable Clamping Capacity for Optics Up to 1.3" (33.0 mm) Optics up to 65 mm wide are held securely in place by two rubber-padded arms that may be locked with a 0.05" hex key on tall mounts. The rubber pads are 0.79" in length (20.0 mm).

Disadvantages:

Limitations in terms of optical shapes and range are disadvantages.

2.3.2.2 Rectangular Optics Holders 830-0100 and 830-0110



Figure 14: Holders 830-0100 and 830-0110 [6]

Features:

They make mounting rectangular optics simple and safe.

Guiding pins ensure that optical components are positioned correctly and consistently.

Mounting may be done horizontally or vertically thanks to M6 holes on both sides.

Disadvantages:

Shapes and range of lenses are limited.

2.3.3 Conclusion

Summarizing the disadvantages of Fixture models available on the market for inspecting and cleaning optics, we have the following conclusions:

- The optics are difficult to install. Placing the optic in the proper position necessitates a high level of attention. It's conceivable that the lens will be damaged.
- From differing viewpoints, it's difficult to illuminate. When illuminating from various angles, we must either change the light source or remove the lens and reinstall it at a different angle after fixing the lens on the fixture. This takes time and doesn't ensure lens safety.
- These fixtures are unable to accommodate rectangular lenses or huge spherical optics.

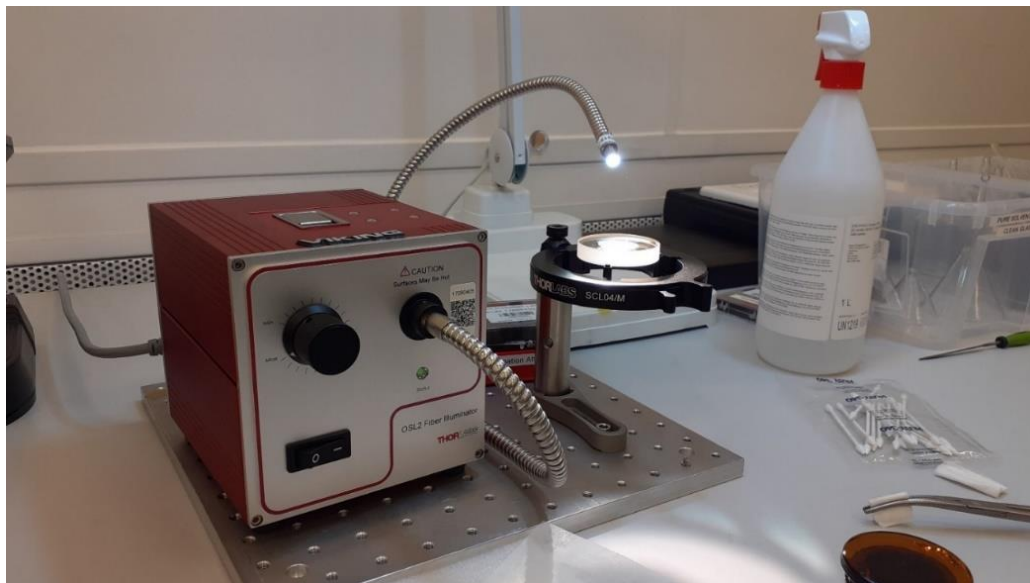


Figure 15: Self-centering lens SCL04 used in cleaning optics at Eli-beamlines

2.4 Design

The previous section provides us with an objective view, pros and disadvantages of each product relative to the reference information of the items accessible on the market. Following that, the most appropriate design based on the company's requirements, specifically at Eli (size and shape of each lens is given).

The goal is for different inserts to accept optics of various sizes and shapes. The ability to rotate the insert allows you to inspect and clean the optic from various angles. The insert should be constructed to reflect as little light back towards the camera as feasible. Inserts should be able to hold optics of various sizes firmly.

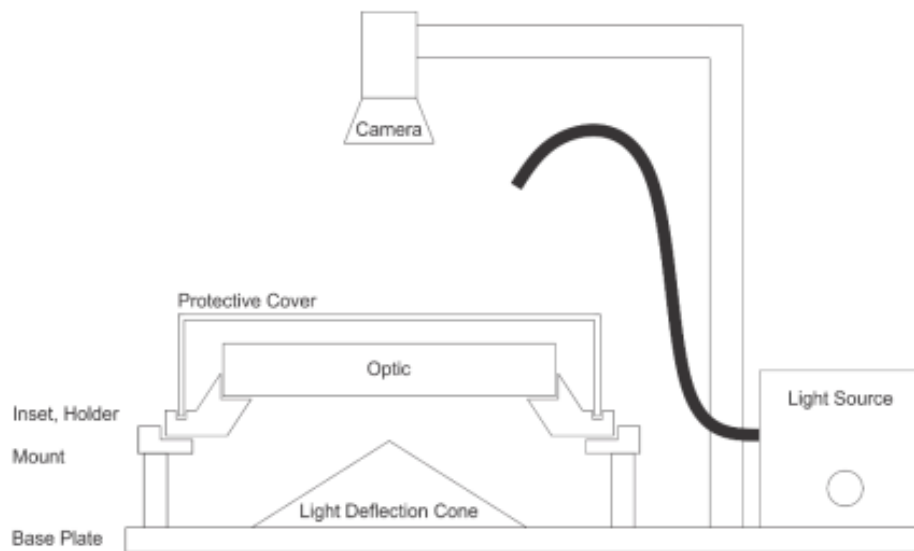


Figure 16: Schematic of optics inspection station

2.4.1 The insert

The insert is responsible for holding the lens in place; different inserts will be required for different lens sizes. We create appropriate inserts based on the given dimensions.

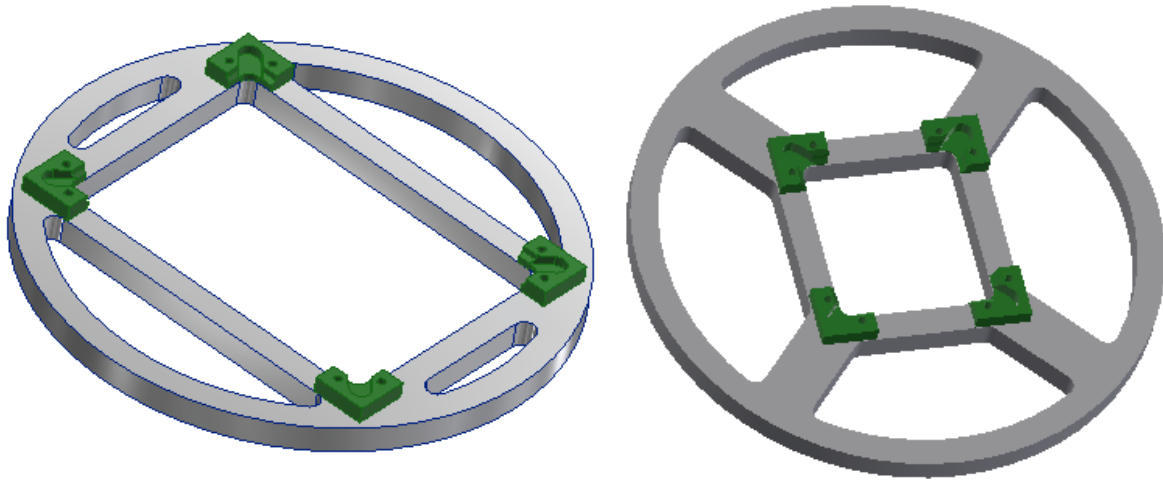


Figure 17: The inserts for the rectangular optics

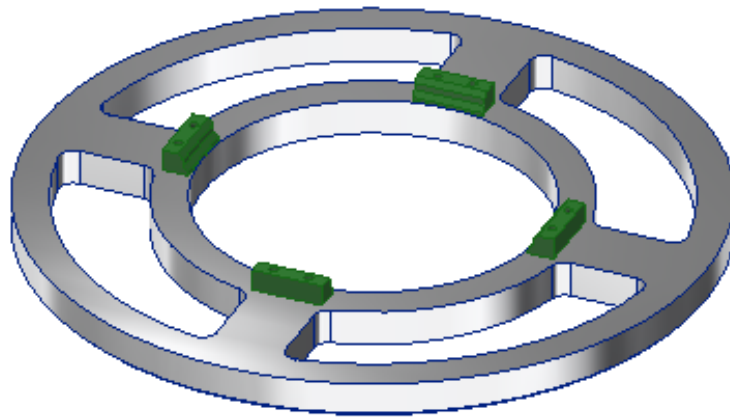


Figure 18: The inserts for the round optic 100 mm

The inserts are custom-made to fit each size and shape. They do, however, have the same height and exterior diameter to ensure that they'll be assembled on the same base. The insert is made up of four pads that are fixed to the turntable. Each Optic's size and shape require a separate turn table. For each optic's shape, the pads are the same.

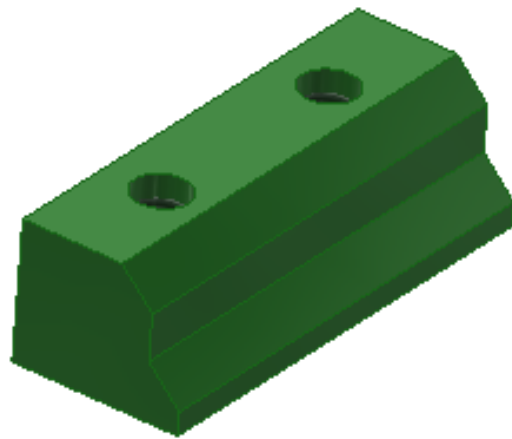


Figure 19: The holder pad for round optics

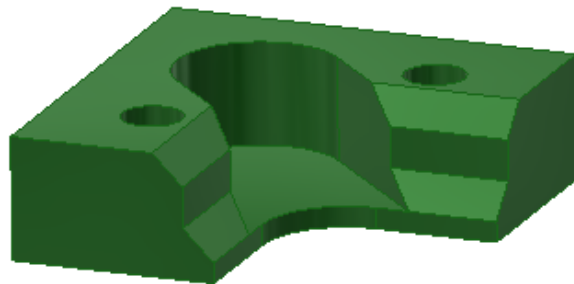


Figure 20: The holder pad for rectangular optics

Because the holding pad comes into direct contact with the optic, it must be carefully considered. Original Material "S" green® is the material utilized, and it is noted for having great slide qualities, good wear resistance, and a long lifespan. It is a product of the industrial plastics industry. With optic safety, it secures the contact.

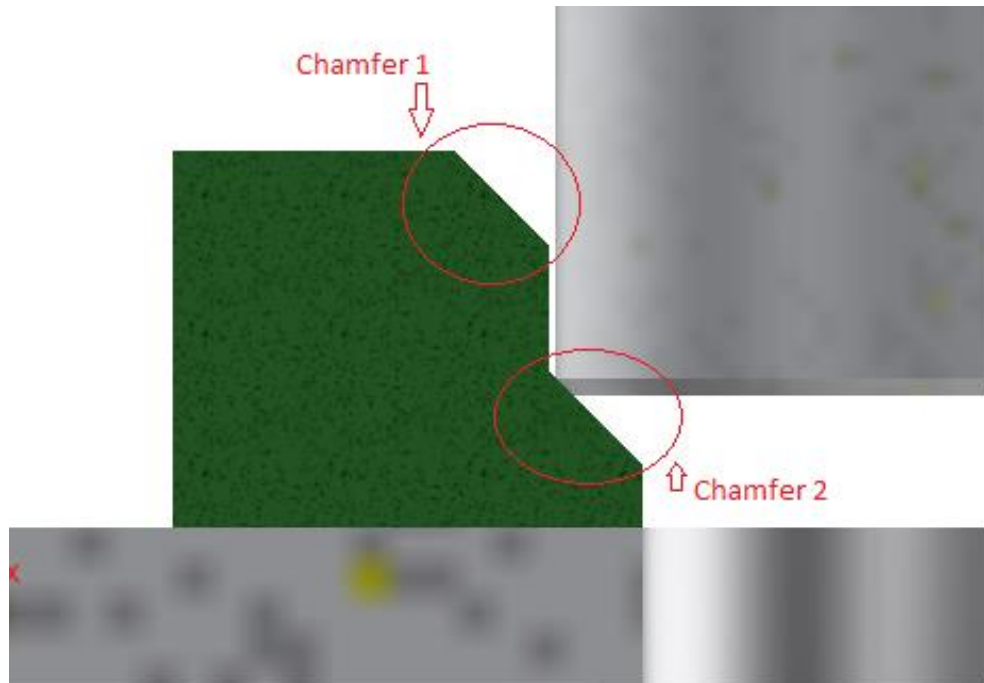


Figure 21: The insert's section cut

The pads for round and rectangular optics serve the same purpose: to make contact with the chamfer of the optic (instead of at optic surface as commercial products). The Chamfer 1 is used to make it easier to insert Optic.

2.4.2 The base

The insert is supported by the base. At the pads, the Insert can be rotated on the base.

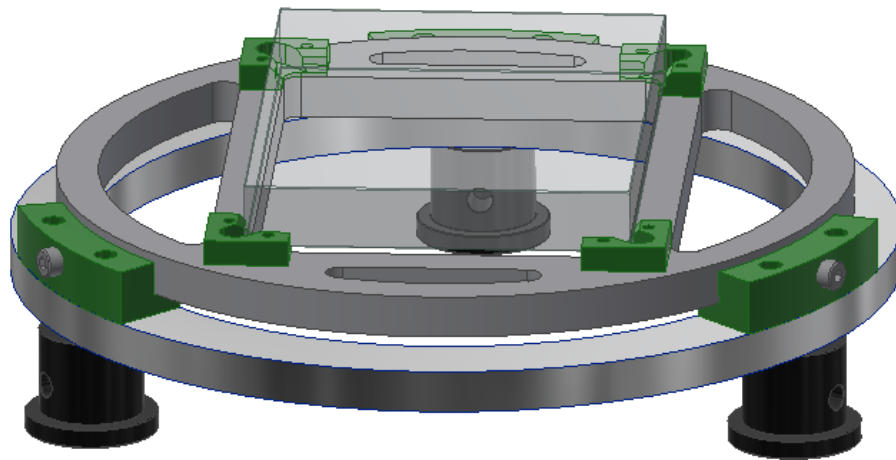


Figure 22: The inspection station

Three pads, one base ring, and three supports build up the base. The pads are also made of "S" green material, which has outstanding sliding properties. On the pads, the turn table can be readily rotated.

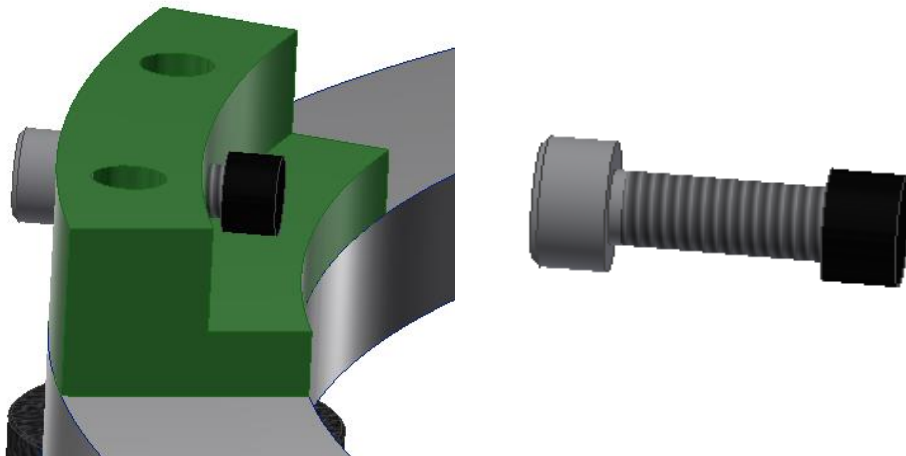


Figure 23: The base's pad

We can fix the turn table with three M4 screws and a rubber cover at the end once we've found the area that needs to be cleaned.



Figure 24: The support [7]

Thorlab Posts are utilized to support the entire device.

2.4.3 The protective cover



Figure 25: The protective cover

Polycarbonates will be used to construct the cover. It's a robust, optically transparent substance.

The range of motion of the cover is restricted by the inner diameter and the difference in height between the turntable and the pads.

2.4.4 Result

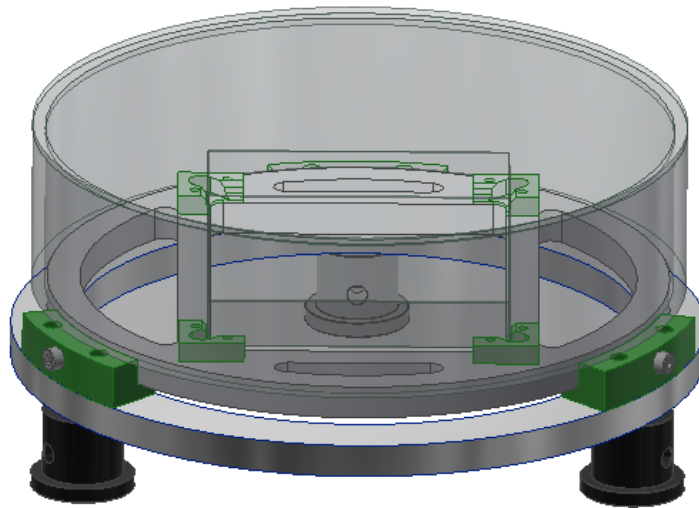


Figure 26: The station for inspecting and cleaning

The entire model is designed on Inventor. After having a final drawing to evaluate the function of each part, 3d printing is used. 3D printing is a technique that allows us to create the quickest prototype possible, allowing us to assess the model's accuracy.



Figure 27: The insert prototype made by 3D printing



Figure 28: The prototype of Inspection station

After getting the prototype, the test shows that the model has the following advantages:

- Simple design, easy to use for operator
- Ensure that the lens is safe by ensuring that no direct contact exists between the lens surface and the implant.
- Because the Insert can be rotated on the base, it's easy to inspect from various perspectives.

CHAPTER 3

3 Laminar flow cabinet design

This chapter will show how to build a laminar flow box, which is important when you have certain dimensions and can't find an equivalent device on the market. In this thesis the box will have dimensions W x D x H: 1152 x 1250 x 910 mm.

3.1 Introduction

In this project, we designed the laminar flow box with the purpose of preventing contaminants and dust from the surrounding environment from entering the workstation during inspection and cleaning.

3.1.1 Cabinet classification

Air travels through the cabinet in a laminar flow. It operates by circulating air inwards via one or more HEPA filters, resulting in a bacteria-free atmosphere. Dust-free air is created by laminar air flow. The air from the room is filtered and delivered into the working chamber via a HEPA filter. A workstation for laminar air flow consists of a chamber with a HEPA filter and a centrifugal blower assembly. It's commonly employed in microbiological manipulations, sterile testing, and some sub-toxic material operations, among other things.

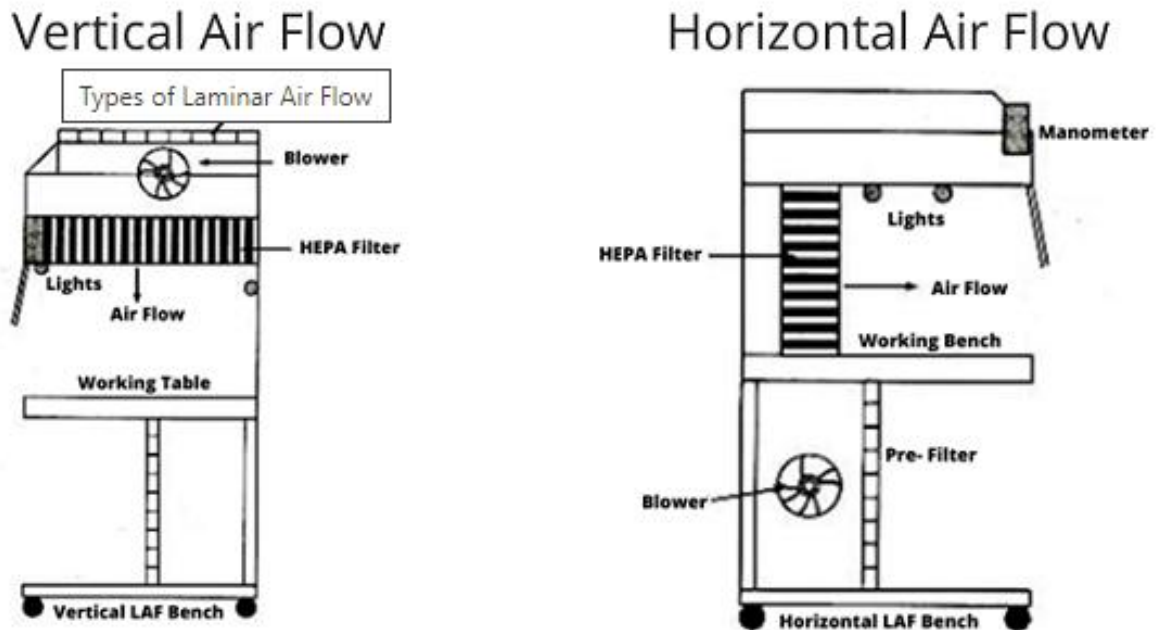


Figure 29: Vertical and horizontal airflow configurations [8]

Horizontal and vertical airflow layouts are offered for laminar flow hoods. A horizontal flow hood moves air from the back of the device to the front of the work area using HEPA or ULPA filters. A vertical flow hood moves air from the top of the device down to the work surface, passing through filters.

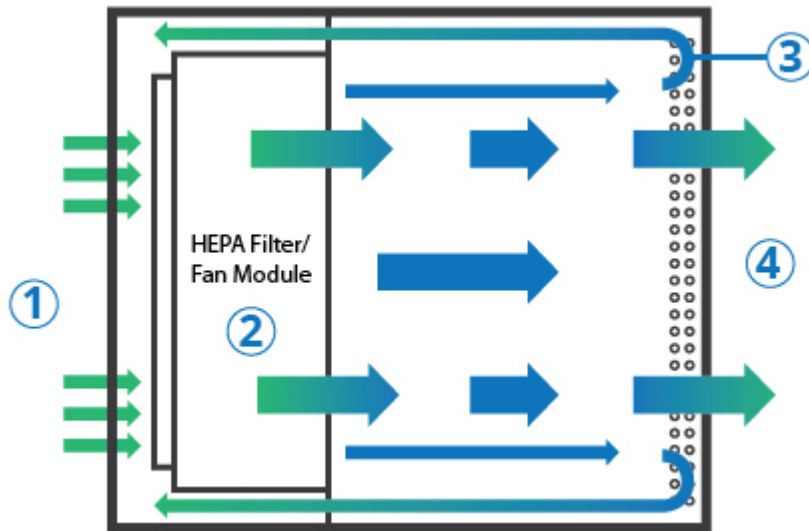


Figure 30: Horizontal laminar flow hood diagram [9]

Horizontal Laminar Air Flow:

The Pre-filter and Blower are located on the bottom of the cabinet in Horizontal Laminar Air Flow. The HEPA filter is situated directly in front of the operator. Filter HEPA Filtered air and exhaust are sent towards the front workstation. A horizontal flow design hood, unlike a vertical flow configuration hood, will demand extra backside space to allow air to enter the box. Due to the arrangement of the fan and filter, a larger workbench and floor area will be necessary.

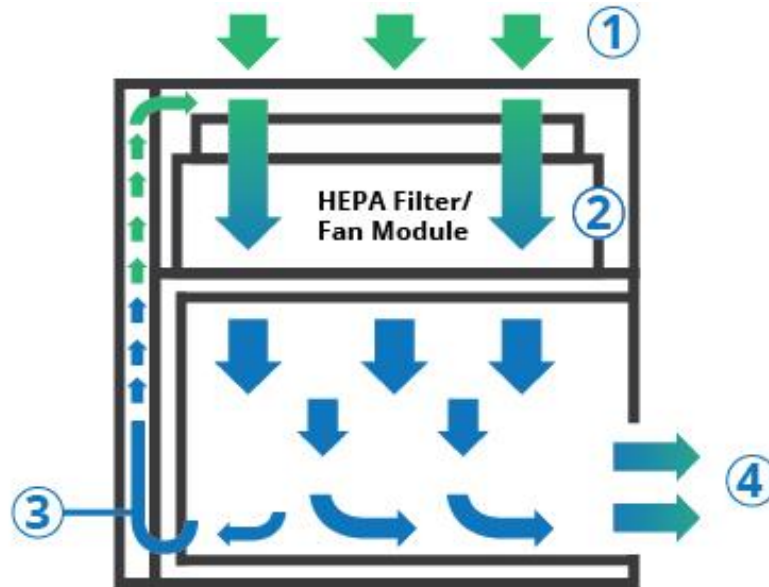


Figure 31: Vertical laminar flow hood diagram [9]

Vertical Laminar Air Flow:

The Pre-filter and Blower are installed on the top of the chamber in vertical laminar air flow. On the top of the working space, there is also a HEPA filter. Upon that working area, air flows vertically downward. It offers the worker more safety. A vertical design may be preferable for laboratories with limited floor space. The flow hood may be mounted on a conventional lab bench because the fan and filters are located at the top of the unit.

3.1.2 Market research

3.1.2.1 Benchtop Vertical Laminar Flow Hoods- Air Recirculation



Figure 32: Bench-top Vertical Laminar Flow Hood [9]

Dimensions W x D x H: 1905 x 762 x 1143 mm

Features:

- Back Plenum on bench-top models provides air recirculation that reduces the percentage of dirty air passed through the filter. Overall, it extends the life of the filter.
- Portable laminar flow work-stations provides a space-saving design that can be positioned on nearly any bench or work surface.
- Final Filters: HEPA: 99.99% efficient @ 0.3 μ m particles or ULPA: 99.999% efficient @ 0.12 μ m particles
- Average airflow velocity: 0.4572 m/s
- The price is \$3420.

3.1.2.2 Economic Vertical Laminar Flow Hoods Without Air Re-circulation



Figure 33: Economic Polypropylene Vertical Laminar Flow Hood [9]

Dimensions W x D x H: 1257.3 x 762 x 121.2 mm

Features:

- Air Recirculation: Not Available
- General Construction: Polypropylene
- Final Filters: HEPA: 99.99% efficient at removing 0.3 μ m particles or ULPA: 99.999% efficient at removing 0.12 μ m particles
- Fan Motor: Direct drive, forward curve, centrifugal-type with sealed bearings; rated for continuous duty; furnished with overload protection and a two-speed switch. Rated .25 HP @ low speed; .333 HP @ high speed (2' x 4' models)
- Average Airflow Velocity: 0.4572 m/s
- The price is around \$3000.

3.1.2.3 Free-Standing Horizontal Laminar Flow Hoods



Figure 35: Free Standing Horizontal Laminar Flow Hood [9]

Dimensions W x D x H: 1841.5 x 762 x 889 mm

Features:

- Airflow Direction: Horizontal
- Pre-Filter: Reusable Polyurethane Foam
- Final Filter: HEPA (99.99% efficient at capturing 0.3 μ m particles)
- Fan Motor: Direct drive, forward curve, centrifugal-type with sealed bearings; rated for continuous duty; furnished with overload protection and a two-speed switch.
- Average Airflow Velocity: 0.4572 m/s
- The price is \$4900.

3.1.2.4 Horizontal Laminar Flow Bench



Figure 36: Horizontal Laminar Flow Bench [9]

Dimensions W x D x H: 1930.4 x 914.4 x 1581.15 mm

Features:

- Pre-Filter: Washable Polyurethane Foam
- Final Filter: HEPA: 99.99% efficient at capturing 0.3 μ m particles
- Fan Motor: Direct drive, forward curve, centrifugal-type with sealed bearings; rated for continuous duty; furnished with overload protection and a two-speed switch.
- Average airflow velocity: 0.4572 m/s
- Air slots along the side edges minimize backwash and turbulence in the work area.
- The price is \$5100.

3.1.3 Conclusion

	Horizontal Laminar Air Flow	Vertical Laminar Air Flow
Advantages	<ul style="list-style-type: none"> • Less rooftop capacity is required • Reduced turbulence on the work surface • Greater depth of worksurface 	<ul style="list-style-type: none"> • Less floor area is needed. • It is possible to install it on a normal workbench. • A rooftop filter provides convenient access.
Disadvantages	<ul style="list-style-type: none"> • Worksurface depth is restricted. • Larger equipment might create more turbulence. • Contaminants may be blasted directly into the operator's body. 	<ul style="list-style-type: none"> • Worksurface depth is restricted. • When changing filters, you may need to use a step ladder. • Stacking items is not permitted since it obstructs ventilation.

3.2 Design

When the benefits and drawbacks of each style of hood are considered, the vertical flow hood is the best option. Vertical laminar flow hoods have the advantage of saving space, and when constructed with a clear back panel in addition to clear side panels, they enable 360° visibility and let extra ambient light onto the work area.

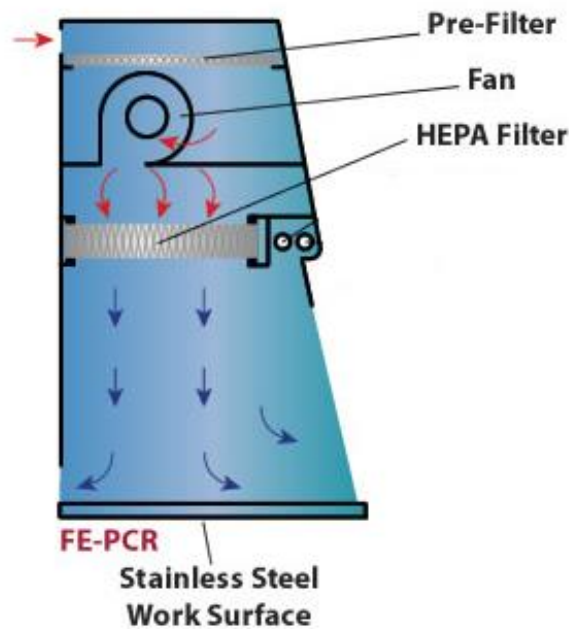


Figure 37: Schematic of vertical laminar flow cabinet [10]

A standard laminar flow cabinet is made up of three components:

- A pre-filter and a High Efficiency Particulate Air filter.
- A blower fan of the appropriate size.
- A plenum for laminar flow, as well as a box to hold everything together.

The objective is to provide a constant and smooth flow of clean air over a workbench. In the following sections, we'll learn about each part and how to compute the best option.

3.2.1 Pre-filter selection

In the first stage, room air is pushed through the top of the container via a preliminary filter. Larger particles are filtered out, extending the durability of the main filter. According on the load, this preliminary filter is usually a low-cost choice with a service life of roughly six months. In the second stage, the pre-filtered air is adequately forced through a HEPA filter with an efficiency of >99.9%. The generated air flow is uniform and clean, and it is spread vertically throughout the workspace. In the final stage, the purified air escapes the cabinet through the open front.

As a pre-filter, Luftfilterbau recommends using the filter pad HS-E/360.

	Typ	HS-E/360
Efficiency (synthetic dust)	[%]	>97
Efficiency (atmospheric dust)	[%]	55
Class according to EN 779		F5
Nominal airflow	[m ³ /h*m ²]	2520
Nominal initial velocity	[m/s]	0,7
Nominal pressure drop with nominal airflow	[Pa]	60
Recommendet final pressure drop	[Pa]	400
Temperature-resistance	[°C]	130
Thickness	[mm]	25

Table 3: The filter pad HS-E/360 properties [11]

3.2.2 HEPA filter

3.2.2.1 Introduction of HEPA filter

The acronym HEPA stands for high-efficiency particulate air. It is critical for any air purifier to function properly. The HEPA filter is really effective. It is capable of killing 99.9% of hazardous airborne particles. Particles with a diameter of 0.3 microns or less are the most common. These microns are extremely microscopic and are typically invisible to the naked eye [12].

HEPA filters are typically constructed of fiberglass, are a system for keeping volatile particles in the atmosphere. These extremely small, randomly organized fibers form a mesh-like lattice that traps contaminating substances [13].

The figure 39 shows the HEPA's operation. The thick brown/tan lines in the filter medium are fibers. Air flow is represented by the blue lines. A particle is represented by the dark circle (dust, bacteria, spore, etc.). The dotted red line depicts the particle's trajectory; take into account that when a particle gets within one radius of a fiber, it clings to it. Because to collisions with gas molecules, the particle (typically 0.1 m or less) has such a trajectory in diffusion [14].

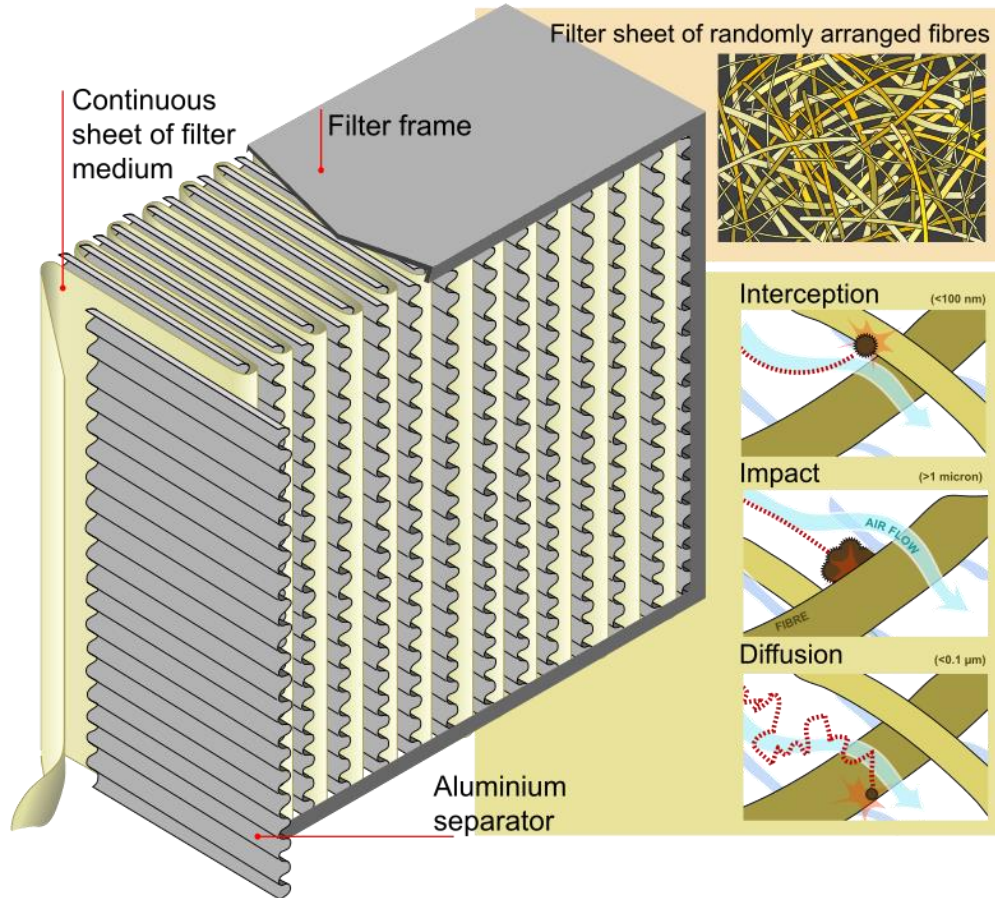


Figure 38: The main parts of a HEPA filter and its function [14]

It's beneficial to think of air as a viscous liquid like honey on the 100 nm to 1-micron scales, which are the most problematic for filters. For the most part, particles can travel around the fibers of the filter medium when the fluid runs through the filters. Inertial impaction: As the flow is diverted around a fiber, larger particles (>1 micron) may be heavy enough to keep on moving in a virtually straight line (Newton's Law). Interception: Smaller particles are not impacted by inertia as much as larger particles are, but if they are brought within one particle radius of the fiber, they will be intercepted. Diffusion: As smaller particles (100 nm) are buffeted by molecular collisions they travel randomly among streamlines. A particle traveling along a streamline that is very close to a fiber may be smashed against the fiber by such a collision [14].

There are a variety of HEPA filter standards. ISO 29463 is built from EN 1822, which specifies the EPA, HEPA, and ULPA filter classes typically used in industrial applications, and is designed to bring clarity in this tangle of regulations.

Efficiency	EN 1822	ISO 29463	Retention (averaged)	Retention (spot)
EPA	E10	—	≥ 85%	—
	E11	ISO 15 E ISO 20 E	≥ 95% ≥ 99%	—
	E12	ISO 25 E ISO 30 E	≥ 99.5% ≥ 99.9%	—
HEPA	H13	ISO 35 H ISO 40 H	≥ 99.95% ≥ 99.99%	≥ 99.75% ≥ 99.95%
	H14	ISO 45 H ISO 50 H	≥ 99.995% ≥ 99.999%	≥ 99.975% ≥ 99.995%
ULPA	U15	ISO 55 U	≥ 99.9995%	≥ 99.9975%
		ISO 60 U	≥ 99.9999%	≥ 99.9995%
	U16	ISO 65 U	≥ 99.99995%	≥ 99.99975%
ISO 70 U		≥ 99.99999%	≥ 99.9999%	
U17	ISO 75 U	≥ 99.999995%	≥ 99.9999%	

Table 4: Filter comparisons in terms of efficiency [14]

In basic terms (and permitting for some effect on factors such as air-flow rate, physical properties of the particles being filtered, and engineering specifics of the entire filtration-system configuration, not only the filter-media characteristics), HEPA filters have the most difficulty capturing particles in the 0.15 to 0.2 μm size range. Unlike ionic and ozone treatment systems, which use negative ions and ozone gas, HEPA filtration operates through mechanical means. As a result, the chance of pulmonary adverse effects such as asthma and allergies being triggered is substantially lower when using HEPA purifiers [15].

In commercial settings, HEPA filters must be checked and replaced at least every six months to verify that they are performing properly. These filters should be changed every two to three years in household applications, relying on the average ambient air quality. If you don't change your HEPA filter on time, it will impose strain on your equipment or system and won't be able to remove particles from the air effectively. A blocked HEPA filter can also result in substantial bypassing of airflow over the filter, depending on the gasketing materials used in the system's design [16].

3.2.2.2 HEPA type selection

Not all High Efficiency Particulate Air filters are suited for laminar flow applications. HEPA filters are utilized in a wide range of applications such as furnace air filtering, hospitals, and laboratories. According to the Luftfilterbau company's recommendation, use HEPA HS-Mikro SF.

HS-Mikro SF are utilized in a wide range of applications, including sterile and clean rooms, as well as industrial and technological operations. Viruses, bacteria, hazardous dusts, and other suspended debris are safely filtered. Typical fields of application include medical spaces rated DIN 1946, operating rooms, intensive care, labs, precision engineering, and oil fog and smoke filtering, among others. The filter has a significantly bigger filtration surface than a HEPA-Filter with metal spacers due to its pleated design and thermoplastic separators. They can be made totally metal-free and hence completely flammable, making it easier to dispose of problematic filtrates. The filter can be used for both supply air filtration and exhaust air filtration. The filter can be customized to meet the unique needs of various processes and operating environments thanks to a variety of options. Special heat resistant thermoplastic spacers for temperature ranges up to 120°C can be added to this filter type as an option. These filters are identified by the model name HS-Mikro SF-T [17].

Type:	HS-Mikro RF	HS-Mikro SF	
Class EN 1822	E11	H13	H14
Efficiency EN 1822 @ MPPS [%]	> 95 %	> 99,95 %	> 99,995 %
Initial-ΔP [Pa] at nominal air flow	125	250	260
Max. temp. [°C]	65° / opt.120°	65° / opt.120°	65° / opt.120°

Table 5: The properties of several forms of Hepa [17].

The HEPA filter class H14, as defined by EN 1822, is used in this study. For 0.3 micron particles, this filter has a 99.995 percent efficiency rating. Choose HEPA with a width of 550 mm, a height of 1150 mm, and a depth of 150 mm based on the cabinet's dimensions. According to the supplier, the Nominal Air Flow for this size of filter is $Q_n = 1990 \text{ m}^3/\text{h}$.

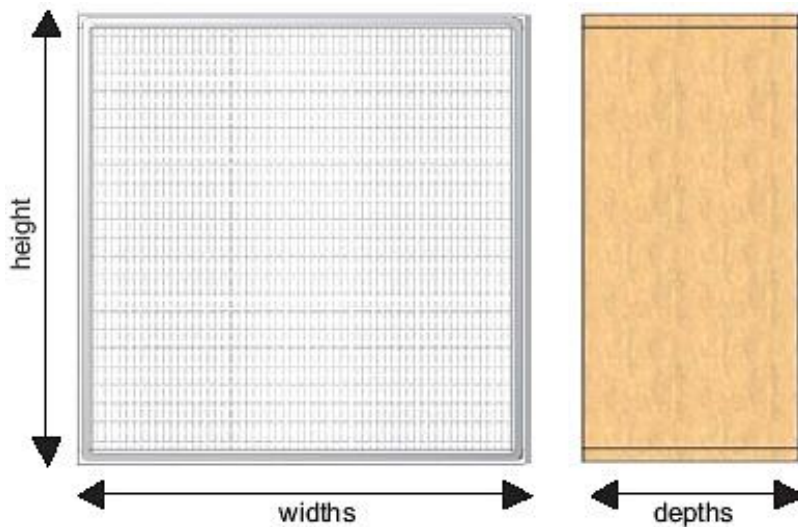


Figure 39: Schematic of Hepa filter.

3.2.3 Blower selection

The selection of a blower is an important stage in the construction of a laminar flow box. Not all blowers can produce adequate flow. This issue will be clarified in the following section.

3.2.3.1 Theory of fluid flow

3.2.3.1.1 Fluid regime

A system's fluid flow can be either laminar or turbulent. Each flow type has its own characteristics, which must be understood before the fluid system can be designed. When it comes to the design and simulation of fluid-dependent systems, understanding fluid flow behavior is crucial. Engineers and designers need a deeper grasp of flow pathways and velocities within systems for effective fluid modeling in computational fluid dynamics (CFD).

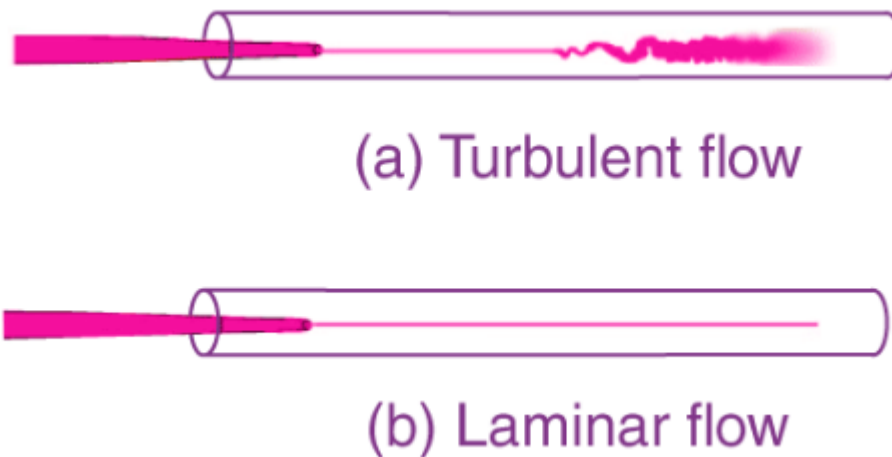


Figure 40: Types of flow [18].

Laminar flow is a type of fluid (gas or liquid) flow in which the fluid flows smoothly and in regular patterns. The velocity, pressure, and other flow parameters at each point in the fluid stay constant in laminar flow, also known as streamline flow. Laminar flow over a horizontal surface is made up of thin layers, or laminae, that are all parallel to one another. Laminar flow occurs only when the flow channel is tiny, the fluid moves slowly, and the viscosity of the fluid is generally high. Laminar flow is the passage of oil through a narrow tube or blood via capillaries. Except near solid boundaries, where the flow is generally laminar, particularly in a thin layer just next to the surface, most other types of fluid flow are turbulent [19].

Turbulent flow is a type of fluid (gas or liquid) flow in which the fluid fluctuates or mixes irregularly, as opposed to laminar flow, in which the fluid moves in uniform channels or layers. The speed of the fluid at a given position in a turbulent flow is constantly changing in speed and phase [20].

In this design the influence of each type of flow is understood as follows. while laminar flow is ordered and parallel which helps to reduce turbulence, the unintentional entry of pollutants

into the workplace. On the other hand, turbulent flow is chaotic and non-linear. The work environment will be contaminated by turbulent.

A dimensionless parameter called Reynolds number was discovered to predict fluid behavior under a wide variety of flow circumstances. The Reynolds number is expressed by the ratio between inertial and viscous forces.

$$R_e = \frac{\rho \cdot u \cdot d}{\mu} = \frac{u \cdot d}{\nu} \quad [10]$$

where:

- ρ is the density of the fluid
- u is the macroscopic velocity of the fluid
- d is the characteristic length (or hydraulic diameter)
- μ is the dynamic viscosity of the fluid
- ν is the kinematic viscosity of the fluid

If the fluids are Newtonian, the Reynolds number also predicts the viscous behavior of the flow. As a result, it's vital to understand the physical situation in order to avoid making incorrect assumptions. Internal and external flows, as well as transition regimes, are the primary subjects of study for the Reynolds number. Fluids with a constant viscosity are known as Newtonian fluids. The Reynolds number's applicability varies based on the fluid flow's characteristics, such as velocity, density variation, viscosity variation, internal or exterior flow, and so on.

3.2.3.1.2 Volumetric flow rate

The volumetric flow rate (also known as volume flow rate, rate of fluid flow, or volume velocity) is the volume of fluid that passes per unit time, particularly fluid dynamics; it is commonly symbolized by the sign Q (occasionally V). Cubic meters per second (m^3/s) is the SI unit.

Volumetric flow rate is determined by the limit:

$$Q = \lim_{\Delta t \rightarrow 0} \frac{\Delta V}{\Delta t} = \frac{dV}{dt} \quad [21]$$

That is, the flow of a volume of fluid V per unit time t through a surface.

The volumetric flow rate is likewise a scalar quantity because it is merely the time derivative of volume, which is a scalar quantity. The change in volume is the amount that flows after crossing the boundary for some time duration, not simply the initial amount of volume at the boundary minus the final amount at the boundary, since the change in volume flowing through the area would be zero for steady flow [22].

The following formulas can be used to calculate the volumetric flow rate:

$$Q = \int \int_A v dA \quad [11]$$

v : flow velocity vector field

A : cross-sectional vector area/surface

In practice, this is the definition that is utilized. The area used to determine the volumetric flow rate might be real or imaginary, flat or curved, and represented as a cross-sectional area or a surface. The vector area is made up of the magnitude of the area through which the volume flows and a unit vector normal to the area.

In the simplest example, that formula can be simplified as follows:

$$Q = v \cdot A$$

The equation provided is only valid for flat, plane cross-sections.

3.2.3.1.3 Continuity equation

The transfer of various quantities, such as fluid or gas, is described by the continuity equation. The equation shows how a fluid in motion conserves mass. The continuity equations maintain numerous physical phenomena such as energy, mass, momentum, natural numbers, and electric charge.

The continuity equation is useful for determining the flow of fluids and their behavior as they pass through a pipe or hose. Tubes, pipes, rivers, ducts with moving fluids or gases, and many more things are all affected by the Continuity Equation. The continuity equation can be stated in either an integral form for use in a limited region or a differential form for use at a single point.

The continuity equation in fluid dynamics states that the rate at which mass leaves a system equals the rate at which mass enters a system in any steady state process.

The following is the differential form of the continuity equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0 \quad [23]$$

Where,

t : time

ρ : fluid density

u : flow velocity vector field

The following are the continuity equation's assumptions:

- The tube is having a single entry and single exit
- The fluid flowing in the tube is non-viscous
- The flow is incompressible
- The fluid flow is steady.

The equation is simplified as follows:

$$Q = A_1 v_1 = A_2 v_2 = \dots = \text{constant} [14].$$

3.2.3.2 Calculation

The acceptable air flow speed limits in Laminar Flow systems are defined by ISO 14644. To achieve correct Laminar Flow, the air flow speed must be 0.45 m/s within a 20 cm distance of the HEPA Filter's surface (with a 20% tolerance, this is a minimum flow of 0.36 m/s and a maximum flow of 0.54 m/s). When air has a flow speed of 0.54 m/s (the highest allowable speed according to the ISO 14644 standard), it will travel in a laminar regime over a distance of 2.9 m. The flow will be in a transition zone after 2.9 m, which will not be harmful or dangerous to the process. This length will be raised to 4.3 m when air flows at 0.36 m/s [24].

The goal is to find a blower that can provide airflow with a speed of 0.36 to 0.54 m/s after passing through the HEPA filter. Choose the required air speed is $u = 0.5$ m/s.

To select the suitable blower, the required flow rate and static pressure must be determined.

a) Required flow rate

The flow rate/ air flow in this case is known as the volume of air passing through the Hepa filter in a given time. It also refers to the amount of air produced by the fan over time.

$$Q_r = \frac{V}{t} = v \cdot A [11]$$

- Q_r : Flow rate
- V: Volume of air passed
- t: Elapsed time
- A: Cross sectional Area
- v: The average velocity

$$Q_r = A \cdot u = \text{width of the Hepa} \times \text{height of the Hepa} \times \text{air speed}$$

$$Q_r = \frac{550}{1000} \times \frac{1150}{1000} \times 0.5 = 0.316 \frac{m^3}{s} = 1138.5 m^3/h = 670 \text{ CFM}$$

b) Static pressure

Static pressure (pressure drop) is considered the resistance of the filters to flow. When the blower pushes the air across the filter, the friction between the air and filter will cause the pressure drop.

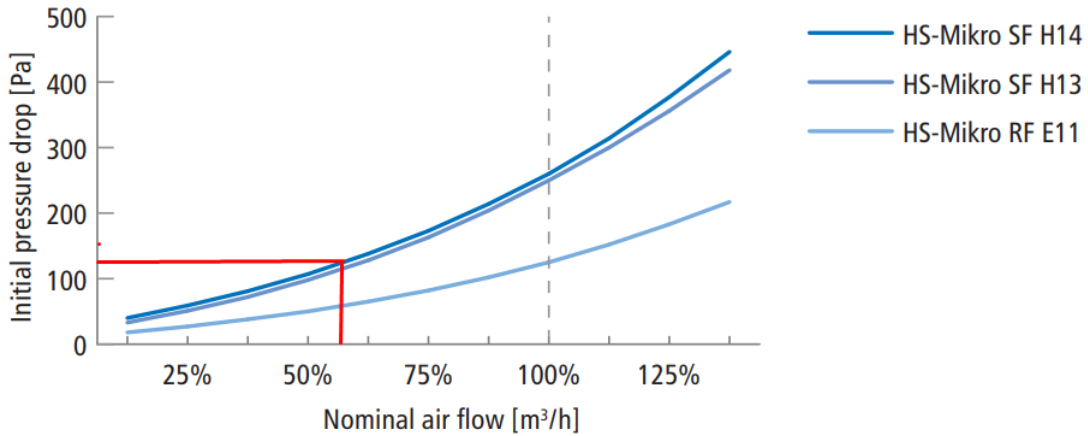


Figure 41: The rated air flow respect with initial pressure drop SF H14 [17]

Air resistance rises directly proportional to air flow. The graph above depicts the relationship between the filter's static pressure and the air flow produced by the blower. Determine the value of static pressure by following the curve of filter H14 and basing it on the difference between actual and nominal air flow

$$\frac{Q_r}{Q_n} = \frac{1138.5}{1990} = 57.21\%$$

The pressure drop obtained by HEPA filter is $P_{Hepa} \approx 125$ Pa.

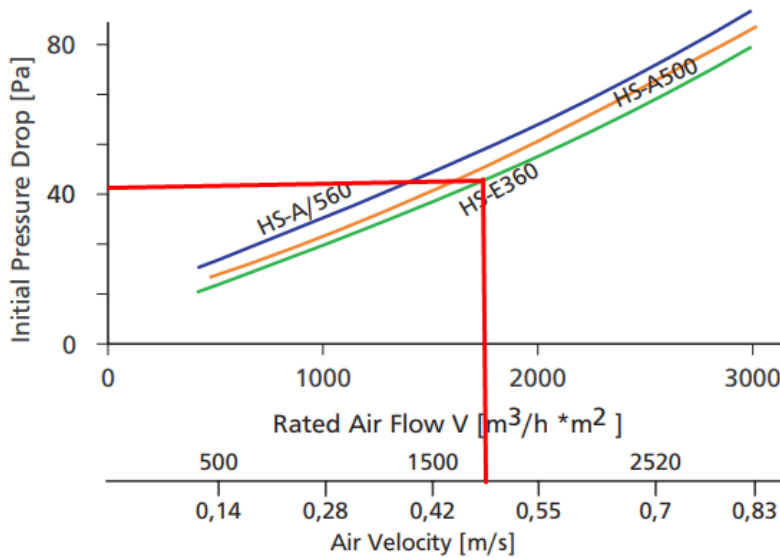


Figure 42: The rated air flow respect with initial pressure drop of HS-E360 [11]

The pre-filter, like the Hepa filter, creates pressure drop. Determine the value of static pressure by following the curve of filter HS- E360 and basing on air velocity produced by blower. The air speed for the blower has been set to $v=0.5$ m/s. The pressure drop obtained by Pre-filter is $P_{pre} \approx 42$ Pa.

The sum of the pressures created by the Pre-filter and Hepa filters is regarded the total pressure drop of the system. Total static pressure:

$$P_{static} = P_{Hepa} + P_{pre} = 125 + 42 = 167 \text{ Pa} = 0.67 \text{ wg}$$

c) Choose blower

Acquiring the information necessary to select an appropriate blower the required flow rate and static pressure:

$$Q_r = 670 \text{ CFM}$$

$$P_{static} = 0.67 \text{ wg}$$

Choose Dayton 1TDU1 Blower

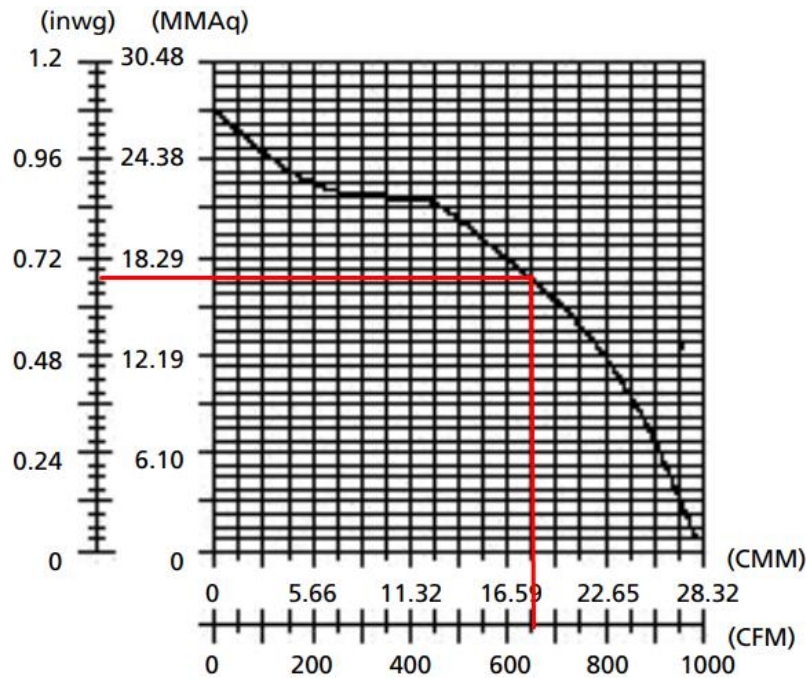


Figure 43: Dayton 1TDU1 performance curve [24]

According to the performance curve this fan can provide:

$$Q = 652 \text{ CFM} = 1107.75 \text{ m}^3/\text{h} = 0.308 \text{ m}^3/\text{s}$$

The actual air speed through the Filter:

$$u = \frac{Q}{A} = \frac{0.308}{0.55 \times 1.15} = 0.486 \text{ m/s}$$

Compare this to the standard speed range required for Laminar flow:

$$0.36 \text{ m/s} < u < 0.54 \text{ m/s}$$

It's acceptable.

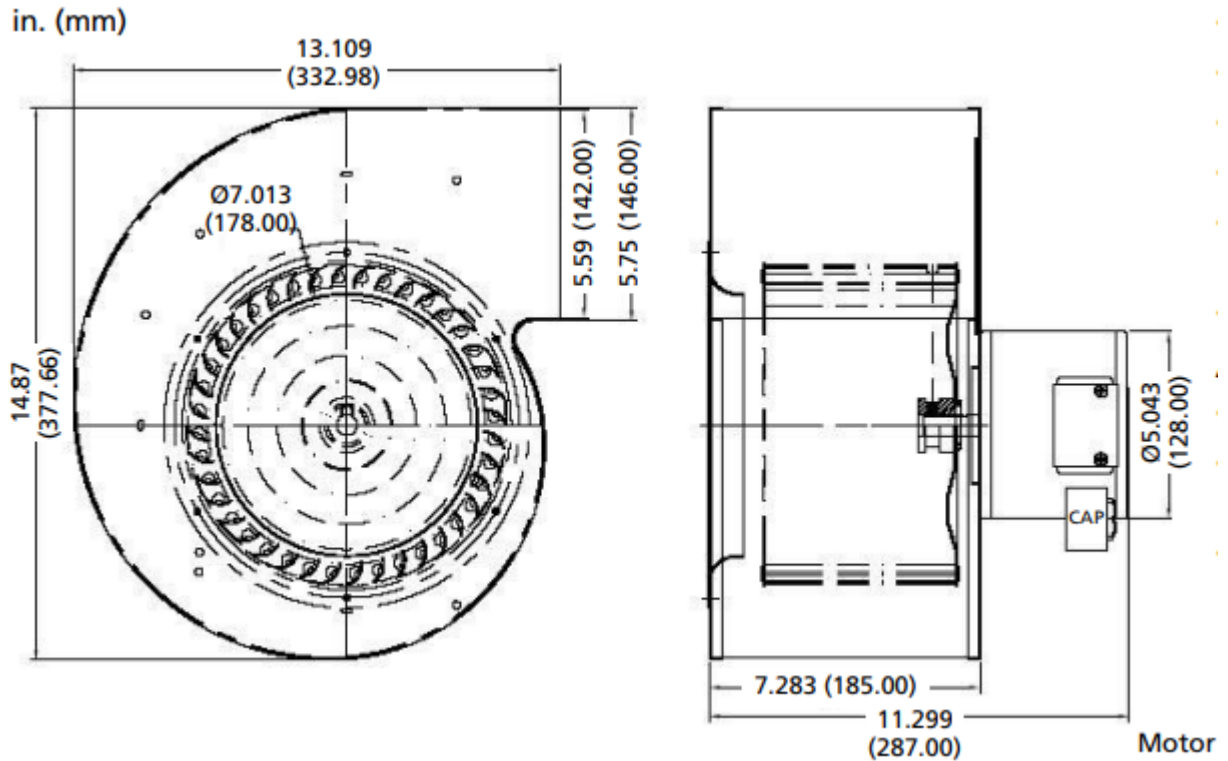


Figure 44: Dayton 1TDU1 dimensions [24]

Features:

- PSC motor
- Baked enamel Gray finish
- Heavy gauge steel housing
- All position Mounting
- Maximum Ambient Temperature 104°F
- Suitable for 50Hz operation

Additional Benefits:

- Permanently Lubricated Ball-Bearings
- Extruded Aluminum Blower Frame for Increased Rigidity [24]

3.2.4 Plenum evaluation

This chapter came from a desire to learn more about the cabinet's air flow distribution. For the current selection of blower and filter in the cabinet, the air flow in a typical laminar cabinet is uniform. The air flow distribution inside the cabinet is also affected by the location of outlets in the cabinet. As a result, a Computational Fluid Dynamics (CFD) study is required to evaluate the air flow pattern and distribution, which will aid in determining which places are suitable for outlet placement.

3.2.4.1 Numerical methodology

Numerical method is an approximate method for solving mathematical problems, taking into account the extent of possible errors. The method is needed as many mathematical problems do not lead to an exact solution; for example, solving a general polynomial of degree five or higher and most of the non-linear differential equations.

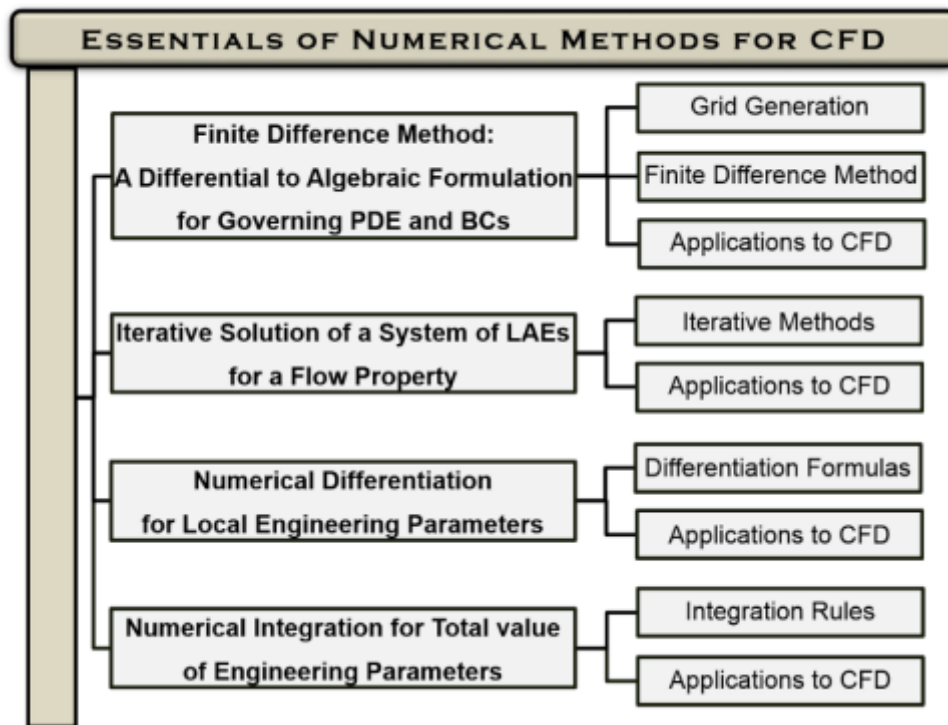


Figure 45:Essentials of numerical methods for CFD [25]

Numerical method results in a discretization error, during a discretization procedure (FDM or FVM) to convert a differential equation to a system of linear algebraic equations. The discretization error corresponds to a difference between the exact solution of the differential equation and the exact solution of the LAEs. An algorithm is numerically stable if an error, once it is generated, does not grow too much during the computation. An art of a numerical method is to find a stable (or well-conditioned) algorithm for solving a mathematical problem. [25]

The numerical model is based on the finite volume approach, and Ansys Fluent is used to simulate flow mechanics of airflow. The equations that regulate flow physics contain continuity, momentum, and energy, and they all follow the conservation principle. Navier-Stokes equations are the governing equations of Computational Fluid Dynamics. It is based on the conservation law of physical properties of fluid. The principle of conservational law is the change of properties, for example mass, energy, and momentum, in an object is decided by the input and output [26].

Continuity equation:

$$\frac{D\rho}{Dt} + \rho \frac{\partial U_i}{\partial x_i} = 0 \quad [26]$$

Momentum equation:

$$\underbrace{\rho \frac{\partial U_j}{\partial t}}_I + \underbrace{\rho U_i \frac{\partial U_j}{\partial x_i}}_{II} = - \underbrace{\frac{\partial P}{\partial x_j}}_{III} - \underbrace{\frac{\partial \tau_{ij}}{\partial x_i}}_{IV} + \underbrace{\rho g_j}_V \quad [26]$$

- I: Local change with time
- II: Momentum convection
- III: Surface force
- IV: Molecular-dependent momentum exchange (diffusion)
- V: Mass force.

Energy equation:

$$\underbrace{\rho c_\mu \frac{\partial T}{\partial t}}_I + \underbrace{\rho c_\mu U_i \frac{\partial T}{\partial x_i}}_{II} = - \underbrace{P \frac{\partial U_i}{\partial x_i}}_{III} + \underbrace{\lambda \frac{\partial^2 T}{\partial x_i^2}}_{IV} - \underbrace{\tau_{ij} \frac{\partial U_j}{\partial x_i}}_V \quad [26]$$

- I: Local energy change with time
- II: Convective term
- III: Pressure work
- IV: Heat flux (diffusion)
- V: Irreversible transfer of mechanical energy into heat

3.2.4.2 Simulation using ANSYS

Geometry modeling

Inventor version 2020 was used to construct the 3D view schematic diagram of the cabinet, which measures 1.152 m in length, 1.250 m in width, and 0.91 m in height.

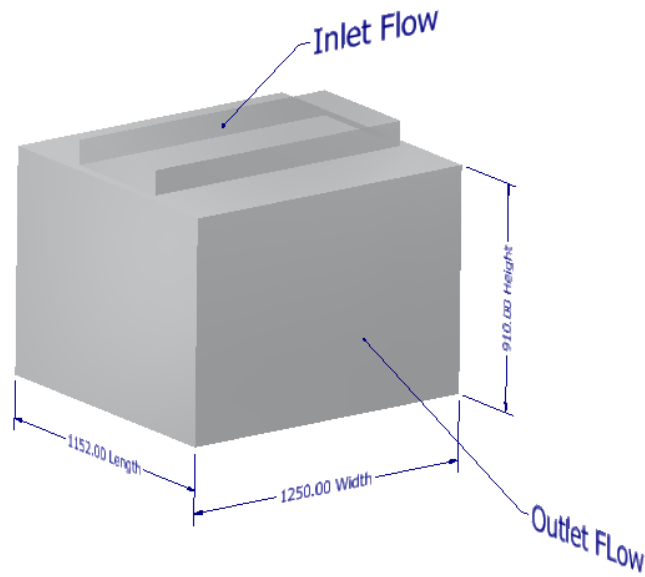
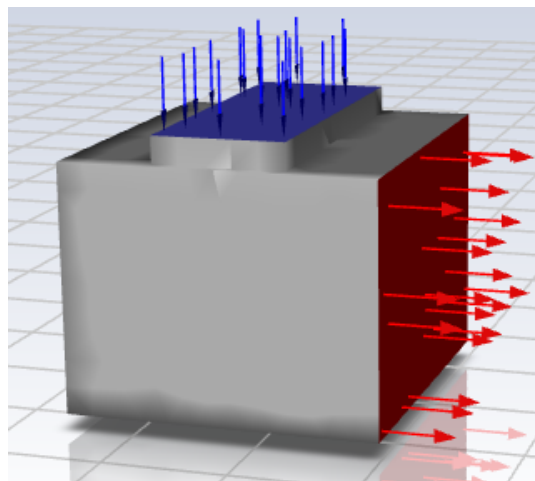


Figure 46: The 3D view of the cabinet

The air flow enter to the cabinet through Hepa filter and diffusers was indicated at the middle part of the cabinet. The single outlet is located in front of the cabinet, and this side is completely open for operator processing.

We'll look at three scenarios to analyze the flow properties inside the box: single outlet, double outlets, quadruple outlets



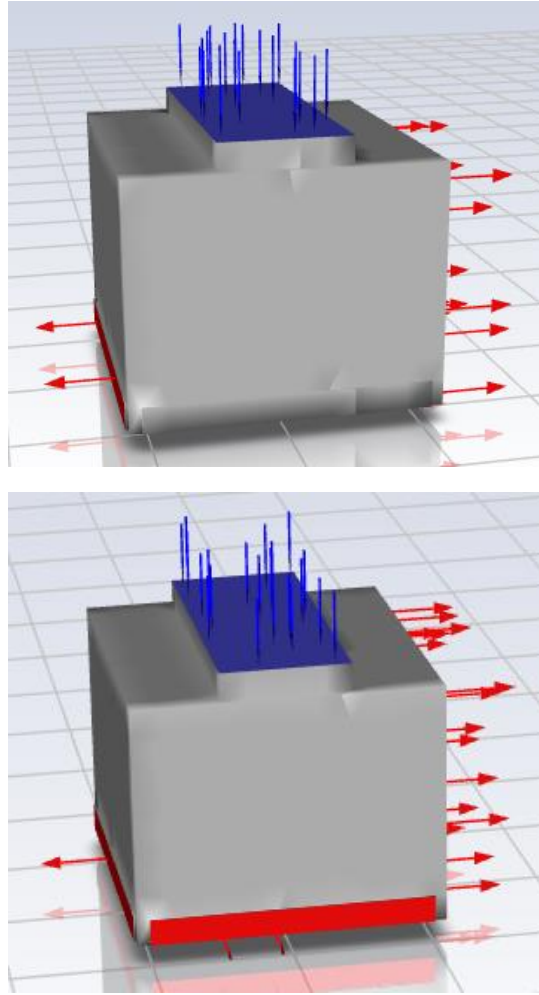


Figure 47: Cabinet design in Ansys with various outlet positions

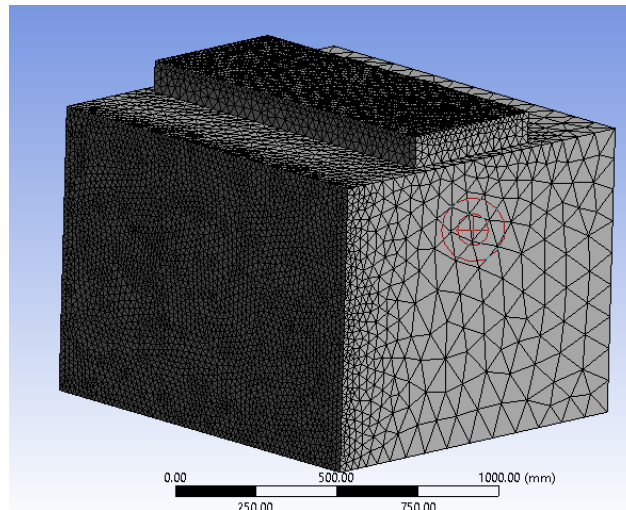


Figure 48: Mesh generated for single outlet

The meshing process was performed on generating volume of geometry modelling of air diffuser in room. The mesh sizing was assigned to inlet and outlets is 20mm.

The solution setup was established in ANSYS FLUENT solver configuration, where the laminar model was defined. The project's working fluid was defined as air, the properties of which are shown in Figure 49.

The screenshot displays the ANSYS FLUENT material properties dialog for 'air'. The 'Name' field contains 'air'. The 'Material Type' is set to 'fluid'. The 'Chemical Formula' field is empty. The 'Fluent Fluid Materials' dropdown is set to 'air'. The 'Mixture' dropdown is set to 'none'. The 'Order Materials by' section has 'Name' selected. There are three buttons for database selection: 'Fluent Database...', 'GRANTA MDS Database...', and 'User-Defined Database...'. The 'Properties' section shows 'Density [kg/m³]' set to 'constant' with a value of 1.225, and 'Viscosity [kg/(m s)]' set to 'constant' with a value of 1.7894e-05. At the bottom, there are buttons for 'Change/Create', 'Delete', 'Close', and 'Help'.

Figure 49: The fluid material properties setting

Boundary conditions:

- Velocity inlet $v = 0.486$ m/s
- Pressure outlet (gauge pressure) = 0
- Gravity $g = 9.8$ m/s²

The boundary conditions were set with inlet velocity at 0.486 m/s as calculating velocity for laminar air flow, while air flow was defined in a direction normal to the inlet. Following 200 iterations, the iteration procedure was carried out.

Any iterative solution process can provide converged solution which is relative to some criteria, i.e., when all discretize transport equations have complied with the specified tolerance defined by ANSYS FLUENT residuals or the solution will not vary further with subsequent iterations. However, convergence may not have similar accuracy if it does not match with any similar simulation data (Stamou & Katsiris, 2006). [27]

The iterations computation is used to plot the scaled residuals until the solution has converged. Figure 50 depicts the continuity and velocity residuals with solution convergence from this project's simulations. When nearing the 75th iteration, the residuals were found to be relatively stable.

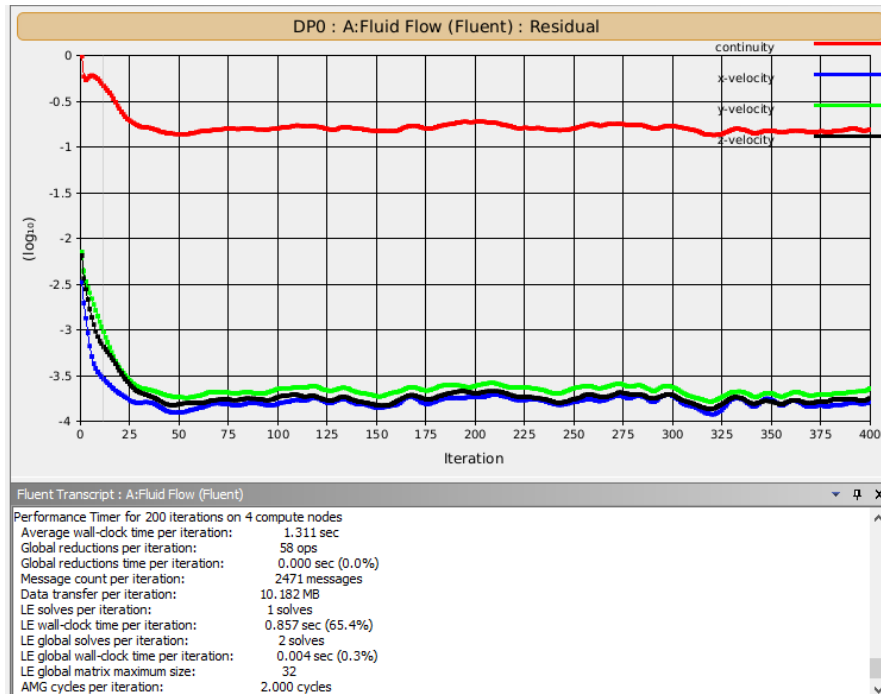
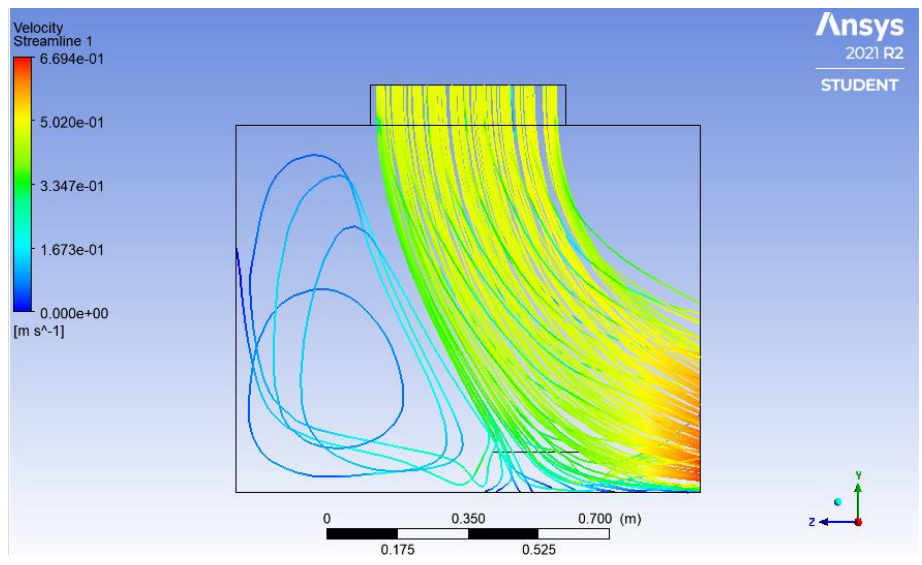


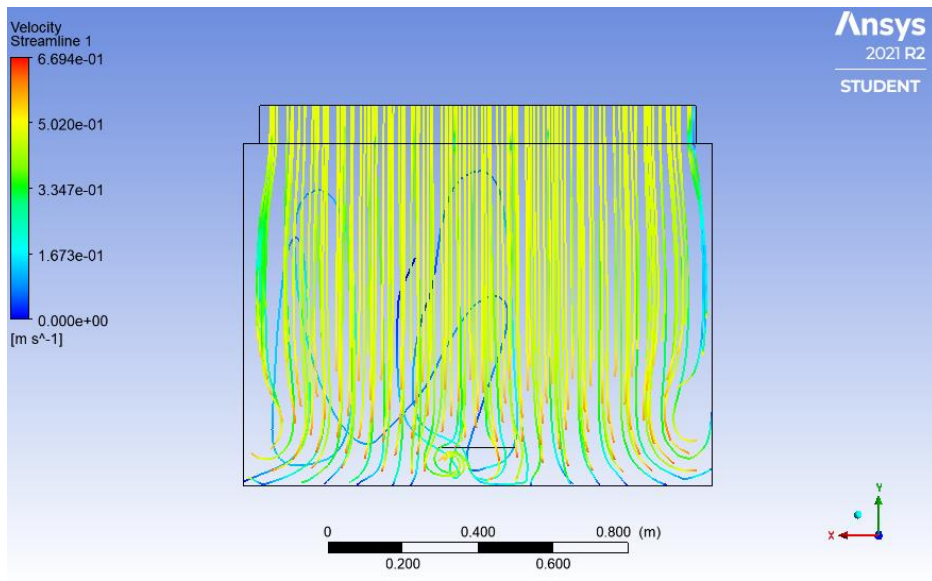
Figure 50: Residual plot of single outlet

Result

The boundary outcomes will be visible when viewing the inside result because the geometry model was created in 3D. To display the graphical effects of velocity in the cabinet, streamline views within the room were established.

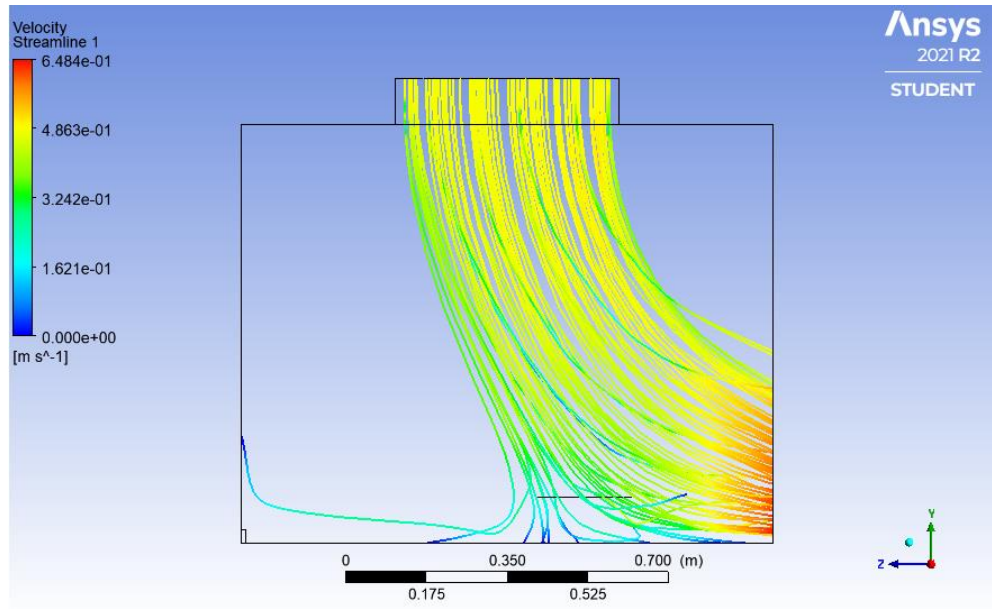


a. Side view

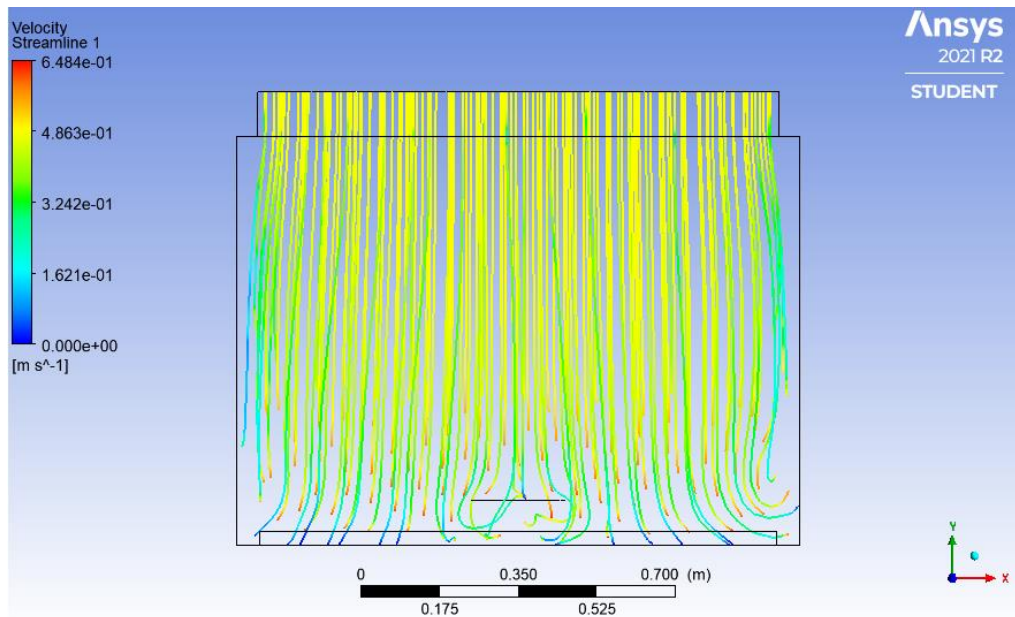


b. Front view

Figure 51: Streamlines velocity of 150 particles for single outlet cabinet

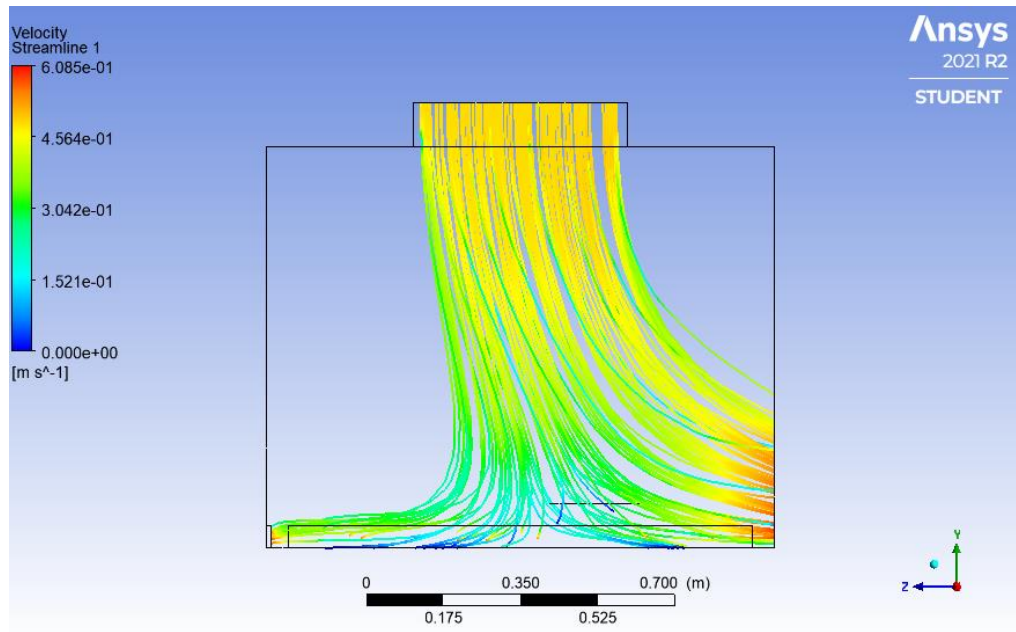


a. Side view

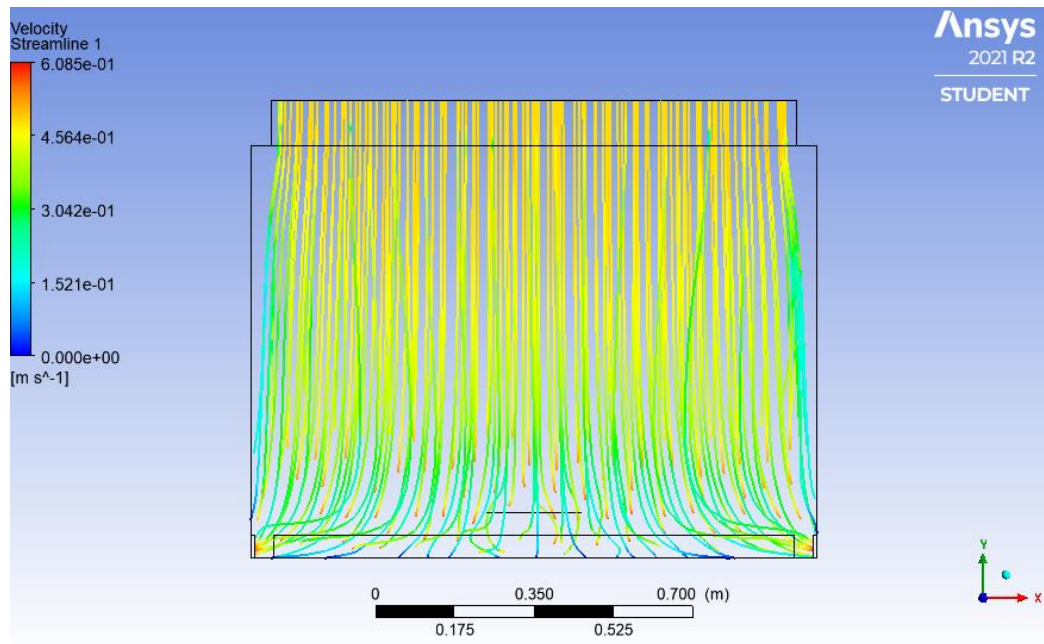


b. Front view

Figure 52: Streamlines velocity of 150 particles for double outlets cabinet



a. Side view



b. Front view

Figure 53: Streamlines velocity of 150 particles for quadruple outlets cabinet

The impacts of the outlets on the air contribution inside the cabinet are shown in the figures above. Three types of cabinet design case studies in which outlets are placed in various locations.

Case 1: Single outlet

The air forced through the filter tends to exhaust at half the cabinet height, causing air contribution to concentrate in the front of the cabinet and a lack of air flow in the middle. Some flows become trapped behind the cabinet, potentially cause turbulence inside.

Case 2: Double outlets

After noticing turbulence in the back of the cabinet, an exit was built on the back side to provide ventilation. The second outlet's dimensions are 1150*30 mm.

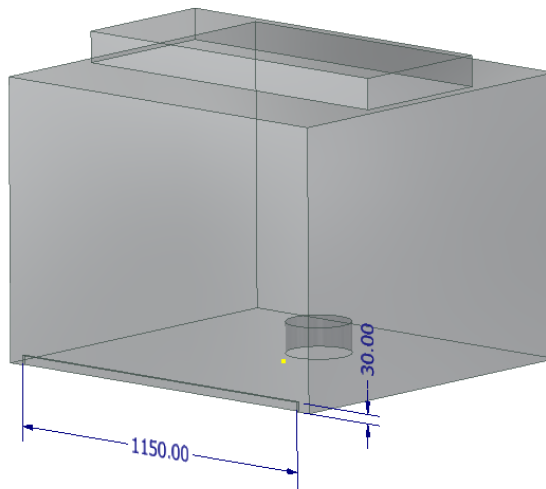


Figure 54: Dimension and location of the second outlet

Figure 51 demonstrates the effect, which shows some streamlines blowing to the back exit, reducing turbulence inside.

Case 3: Quadruple outlets

Raising the outlet height and adding two extra exits on both sides of the cabinet.

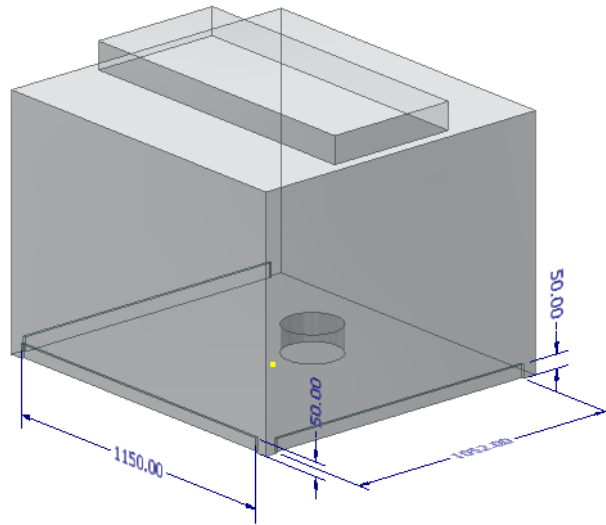


Figure 55: Dimension and location of the quadruple outlets

Figure 53 indicates that when two outlets are present on both sides of the cabinet, the flow is more equally spread than in the previous two situations. Compare all three fields of data to determine case 3 is the most optimal.

The CFD technique was utilized to examine the cabinet's steady state conditions in this chapter. Various inferences and ideas for design optimization can be drawn by plotting velocity contours. With only one outlet, the air contribution is not evenly distributed across the space. The impact of the outlet on air contribution is considerable. Compare the data from all three fields to establish that case 3 is the most ideal, with air equally distributed around the room.

CHAPTER 4

4 Conclusion

The target of the diploma thesis is to develop a cleaning optical fixture and the cabinet that occupies it. As a result, the content is divided into two main tasks.

Because of the unique nature of the project, some particular sized lenses (not very common) are required for the fixture, and there are no commercially available fixtures for these optics. Chapter 2 discusses the relevance of optic qualities and cleaning procedures, as well as a comparison of commercial fixtures. Understanding them is critical for the subsequent design processes. Improvements have been made. After determining the function of the fixture, a schematic is created. The next stage is to construct each component individually. For optic insertion and mounting, parts that come into direct touch with the optic are developed with safe geometry and materials. After having a final drawing to evaluate the function of each part, 3d printing is used. The model was assessed, and the results met the requirements.

The goal of chapter 3 is to propose a design concept for laminar flow cabinets. In laboratories, contamination-sensitive activities such as plant tissue culture are performed inside laminar flow cabinets. In the pharmaceutical industry, drug manufacturing techniques and operations of particle-sensitive electronic devices are also performed inside the cabinet.

In this project, the laminar flow cabinet is employed to create a fresh work environment for cleaning and inspecting optics. Understanding the cabinet's principle of functioning, as well as the functions and standards of the HEPA filter, is critical. The cabinet's flow velocity is set according to ISO 14644. After gathering and calculating all of the essential parameters, the blower is chosen. CFD simulation is used in addition to evaluating the influence of air outlets on air distribution inside the cabinet. The low computation time and comprehensible display of the results are two advantages of numerical simulation. The thesis focused on the three distinct outlet design scenarios and concluded that the cabinet with quadruple outlets has the optimal flow dispersion.

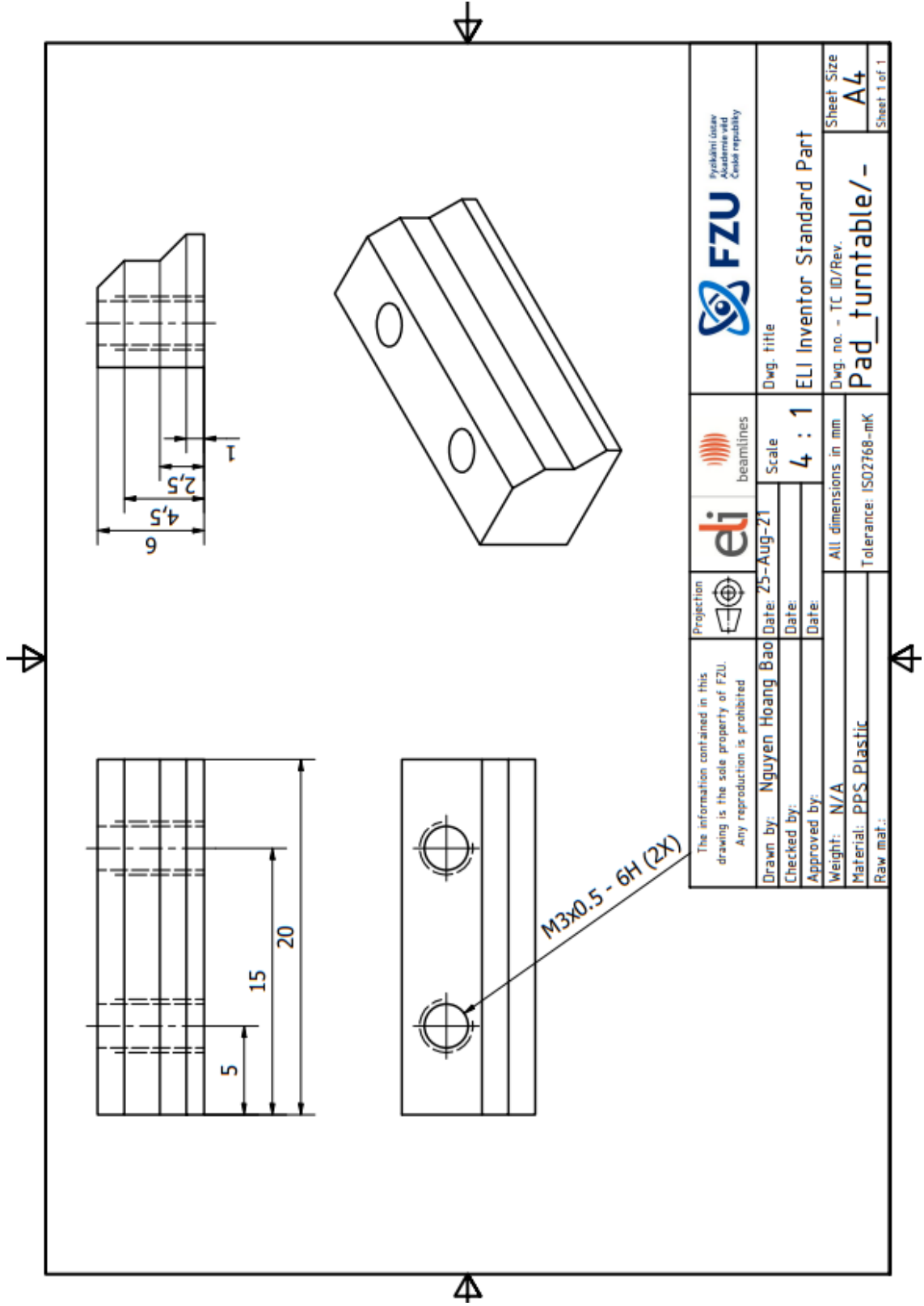
The design of the laminar cabinet as depicted in this paper is unfinished. Such as the plenum's thorough design for convenient replacement and repair, the sensor system, the electrical system, the display screen... It might all be the subject of continuing bachelor's or diploma theses.

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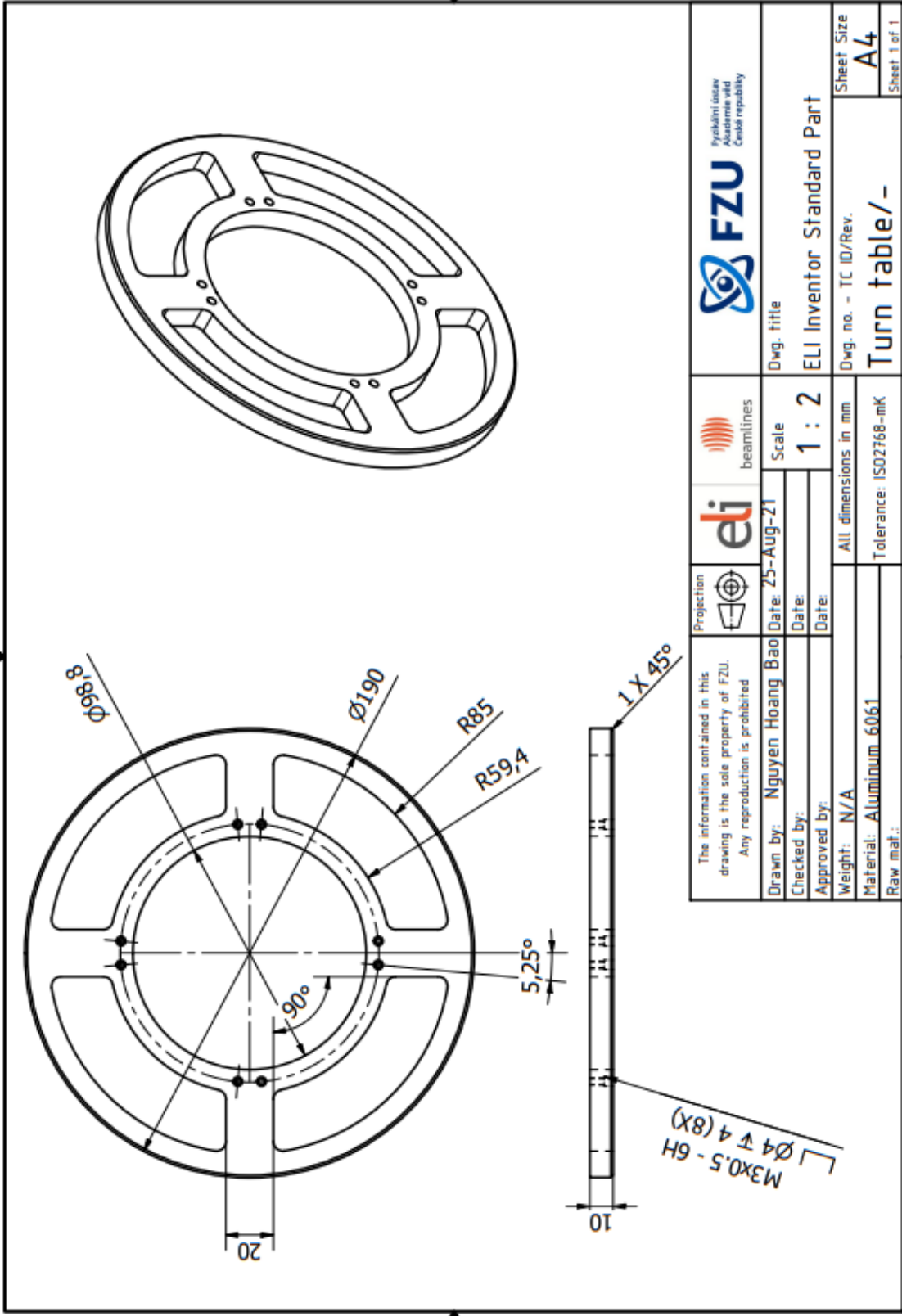
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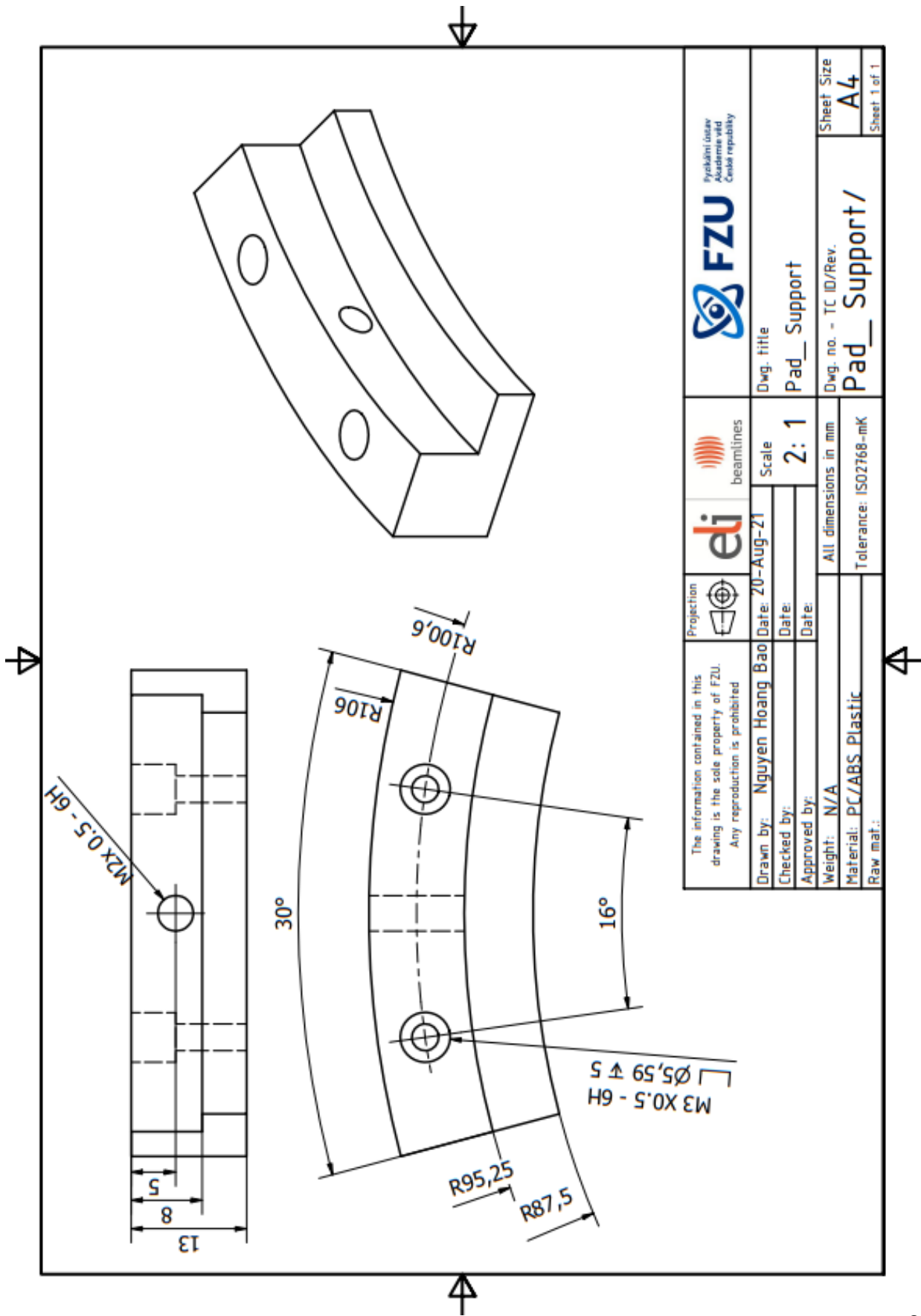
APPENDIX



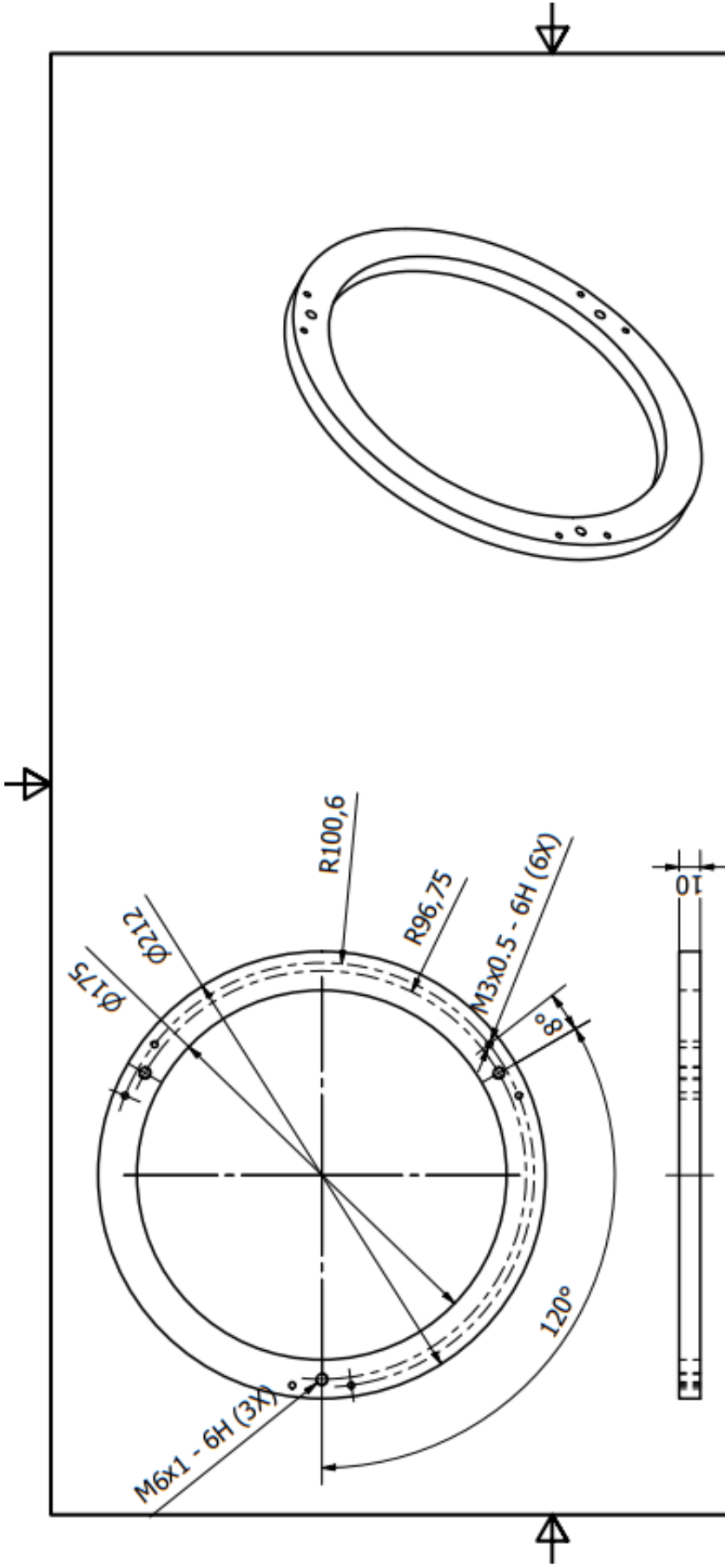
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