UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

DEPARTMENT OF CIVIL ENGINEERING

CIV4044S

Research Project

The design of a Rigsby Stage for the study of thin sea ice sections

Prepared for: Professor Sebastian Skatulla

Prepared by: Steven McEwen

Date: 23 November 2021

PLAGIARISM DECLARATION

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2. I have used the Harvard-UCT convention for citation and referencing. Each contribution to, and quotation in, this body of work, from the work(s) of other people has been attributed and has been cited and referenced.

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Acknowledgements:

I would like to acknowledge the following for their invaluable input in this research project:

- Professor Sebastian Skatulla
- Pierre Smith, of the UCT Mechanical Engineering Workshop
- A special thanks to co-supervisor Dr Keith MacHutchon for his mentorship and assistance through every step of the project.

Terms of reference:

On the 18th of June 2021 Professor Sebastian Skatulla, who is a lecturer at the University of Cape Town, presented and published the research topic on behalf of the department of Civil Engineering. The topic published being ‘Experimental and Computational Analysis of Physical and Mechanical Properties of Artificial Sea Ice’.

Co-supervisor Dr Keith MacHutchon then elaborated on a further topic section, namely ‘The design of a Rigsby Stage for the study of thin sea ice sections’. This project would help supply the University of Cape Town with an instrument that UCT does not currently have access to. The analysis that this instrument provides is critical in understanding microprocesses of ice and how they relate to the physical properties and characteristics of ice sheets.

The instructions upon submitting the research proposal are to include the following:

- Provide a working Rigsby Stage to UCT for future research.
- Provide reliable testing to prove a > 5° margin of error for the Rigsby Stage.
- A breakdown on how to operate the Rigsby Stage, with a design for future construction in the event of breakage.
- Submit a draft research project by the 5th of November 2021.
- Submit a draft poster summarising the research project by the 12th of November 2021.
- Submit a final research project by the 26th of November 2021.
- Submit a final poster summarising the research project by the 3rd of December 2021.

Abstract:

The University of Cape Town does not currently have access to a Rigsby Stage. This is a device that assists in the determination of physical material properties of sea ice by orienting crystals or crystal sections so that the position of the optic axes can be measured.

The objectives of this project are to design and construct this high grade Rigsby Stage and to make sure that it has a degree of error and useability that is of an acceptable standard for future research to be undertaken at UCT. To ensure this, an eight-step method was carried out. This method included each phase of the device's creation, from initial research to the testing of the final product. There are no existing testing protocols in the literature for a Rigsby Stage and thus a unique test was created to prove the reliability of the device.

The working Rigsby Stage was constructed by the UCT mechanical engineering workshop, with the assistance of Pierre Smith. This construction was based on the design that is produced in this report. Due to the high workload of the workshop, the construction process was delayed and therefore additional smaller constructions were unable to be added to the device. These requirements are, however, laid out in this report.

Once the additional constructions are complete the provided device will need to pass the initial phase of testing. This testing checklist is provided in the report and upon completion the device will be considered of adequate quality to be used for a reliable study of thin ice sections. It is important to note that the device has an estimated margin of error of 5 degrees and all results should allow for this when analysing testing results.

Once the device is considered to be usable in an experimental environment, future researchers are recommended to follow the thin ice analysis procedure that is provided in this report for the use of the Rigsby Stage.

The device is, however, only able to perform manual analysis of ice sections and it is therefore recommended that future research is conducted to upgrade the Rigsby Stage to conduct semi-automated analysis of the thin ice samples. This could be modelled off Langes' system.

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Glossary:

- UCT- University of Cape Town
- Dr – Doctor
- SIE – Sea ice extent
- km – kilometres
- cm - centimeters
- mm – millimetres
- LED – light emitting diode
- A1,2,4 and 5- Axis 1,2,4 and 5
- w - watts
- CFL - Compact fluorescent lamp
- IP67 - Ingress Protection Code 67
- Vac - Volts Alternating Current
- Vdc - Volts Direct Current

1. Introduction

1.1. Problem description

The orientation of the c–axis of individual ice grains provides fundamental insights into several basic ice properties. In particular, the distribution of c-axis orientations for a given thin section reveals information on the growth process and subsequent history of the sampled ice.

The ice crystals' c-axis orientations are often also related to other physical properties of an ice core and can be used as a predictive tool, provided a reliable correlation between c-axis orientation and the property under consideration has been defined. UCT doesn't have access to any instrument that gives the user the ability to determine (and thus record) the c-axis distributions in ice samples. Therefore, one of these instruments (a Rigsby Stage) is required by UCT for in depth testing and predictive trials of ice samples.

This research project describes the design, construction, and analysis of a Rigsby stage, with the intention of being used by UCT for future research.

1.2. Background to investigation

Society is becoming increasingly educated on the great effect that sea ice has on global processes, particularly on the climate. For this reason, The University of Cape Town (UCT) is at the forefront of Antarctic Sea ice research. The research aims to assist in determining physical material properties of sea ice such as its varying crystalline structure. However, UCT doesn't have access to a Rigsby Stage, which is an instrument that is used to orient crystals or crystal sections so that the position of the optic axes can be measured. This device will assist in the determination of these physical material properties of sea ice.

This thesis aims to provide an accurate, working and control tested Rigsby Stage, for the future analysis of ice sheets at the University of Cape Town. This thesis not only provides the device, but also will give any future researcher a holistic understanding of how best to utilise and potentially improve upon the device.

1.3. Objectives of the study

The following are the objectives of this report:

- Conduct a review of literature regarding c-axis and associated physical ice properties, operation and use of existing Rigsby devices
- Provide a detailed design, including drawings of proposed Rigsby device for construction and clear reasoning as to why each aspect of the device is made in a particular way.
- Construct a high grade Rigsby Stage device with the help of the mechanical engineering workshop.
- Complete a suitable final product analysis and control test of Rigsby device to determine whether the degree of error and useability is within an appropriate range for scientific experimentation.

1.4. Scope and limitations of the study

Through the investigation and construction of a Rigsby device, the proposed research aims to contribute to the future research of crystal structure. It also aims to add to the understanding of physical ice properties in any future UCT research projects. However, the investigation has the following limitations:

(i) There are no papers documenting control tests or procedures to perform on a newly made Rigsby device to compare with, thus control parameters may not be as reliable as those used for existing devices. This could affect the device's margin of error. The unique nature of ice surfaces also doesn’t provide an opportunity to compare our instrument using a uniform material.

(ii) This report will not conduct further in-depth analysis on the results acquired nor will any in depth physical assumptions be made when observing ice sheets with the constructed Rigsby Stage. All tests and observations are done purely as a control test to see the accuracy of the constructed Rigsby Stage.

(iii) The construction schedule relies entirely on the availability of the mechanical engineering department as they are constructing the main aspects of the device. Any delays on their end will cause inevitable delays for any further construction and possibly limit the ability to undertake any device stress testing, and thus not identify any unforeseen problems.

1.5. Plan of development

This research project begins by laying out the literature that was used to improve the understanding of the study such as the ice, the ice properties and how the device will assist in understanding the material. The project report will then describe in detail each step of the design process that was followed for the construction of the Rigsby Stage. The report will then move on to describe the various forms of analysis of the device. This includes the analysis of the testing and analysis of the device properties. Finally, the report will end with the project's conclusions and recommendations.

2. Literature review

2.1) Introduction to literature review

The proceeding section provides a sequenced understanding of the research topic. The review will begin with an understanding of the material (sea ice) studied with the Rigsby Stage. This is followed by various methods used to study the material. The review will finish off with a study of existing instruments and the characteristics and operational understanding of them. The literature review will give the full understanding required to design a Rigsby Stage that will meet all its analytical objectives.

2.2) Sea ice and its significance

2.2.1) Sea ice and its continuing effect on the planet

Sea ice is one of the major climatic controllers due to its high reflective and strong insulating nature (Bintanja *et al.*, 2013*)*. Given that the density of sea ice is less than the sea water that it interacts with, the ice will float above the water. This floating property means that the ice resembles a thin blanket over much of the ocean surface, which controls, but is also controlled by, heat fluxes, moisture, and momentum across the interface of the ocean and atmosphere (Dieckmann and Hellmer, 2010). Sea ice formation and degradation operates on an annual cycle, and it plays an essential role on large scale systems. These systems include the global climate and the life cycles of almost all marine plants and animals. Sea ice is one of the largest biomes on earth. In winter it expands to an area of up to 7% of the earth's surface (Dieckmann and Hellmer, 2010). However, humans tend to adopt an out of sight, out of mind approach when it comes to our environment. Unfortunately for humans the effects aren't as out of sight as we might believe. The climatic effects of sea ice loss are not limited to the Arctic and Antarctica (England *et al*., 2020). The strong sea ice retreat is associated with global climate warming. Research has found that combined Arctic and Antarctic sea ice losses will account for 20–30% of the projected tropical warming and precipitation changes (England *et al*., 2020). However, sea ice does not respond passively to climate change. Sea ice retreat intensifies climate warming through the surface-albedo feedback (Bintanja et al., 2013). This is where global warming decreases the amount of ice cover and hence decreases the albedo. The albedo is responsible for much of the solar reflection and thus its decrease will lead to an increase in the amount of solar energy absorbed and lead to more warming. The balance and coexisting relationship between ice and water controls the habitability of the polar fractions of the globe and influences the entirety of the world's human and animal population in some way or another. The freezing of water to form ice is one of the most common phase transformations in the natural environment. However, a complete understanding of its microscopics and their influence on macroscopic phenomena still eludes us (Wettlaufer, 1999).

2.2.2) Why are researchers interested in the properties of sea ice?

Sea ice research spans numerous modern scientific disciplines. These include glaciology, geology, chemistry, oceanography, biogeochemistry, geophysics and numerous branches of biology (Dieckmann and Hellmer, 2010). The vast array of disciplines grants researchers knowledge of all the processes associated with sea ice. Figure 2-1 below portrays the range of research from molecular and microscopic level to satellite images.

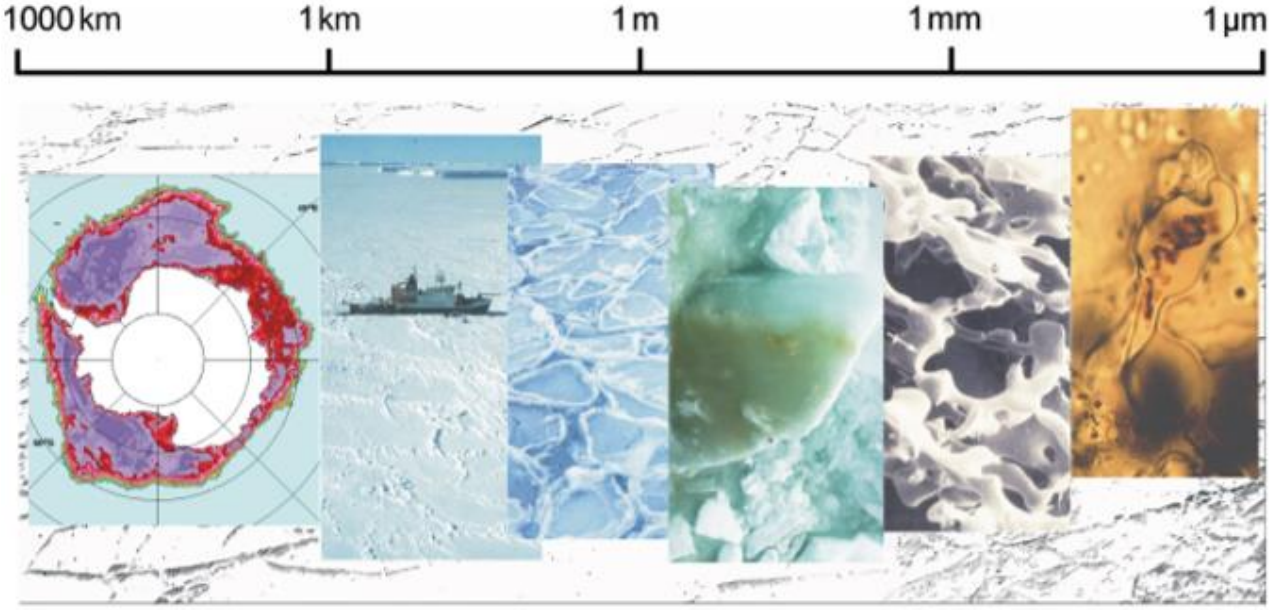


Figure 2-1: Research range in size from Satellite images to Diatoms in a brine pocket (Dieckmann and Hellmer, 2010)

This range of information is important to understand all possible links between the polar regions and global-scale climate (Dieckmann and Hellmer, 2010). As discussed in the section above, sea ice is a fundamental component of many of earth's major systems. We therefore cannot ignore it in the large-scale environmental discussions (Dieckmann and Hellmer, 2010). Researchers use various models to make climate predictions, ranging in magnitude of intensity. Under the high-emissions scenario, models predict that the Arctic will have an ice-free summer by the middle of the 21st century. These same models predict that Antarctica may lose one-half of its sea-ice cover by the end of the century (England *et al*., 2020).

The effects that these changes will have on the climate system are predictably severe, however researchers need to conduct more research to fully understand the impact of future Arctic and Antarctic sea ice losses (England *et al*., 2020). To do this, information is being compiled to validate numerical models that analyse the impact of sea ice regarding past and present climate change. These models aren't limited to climate change. Global positioning technology is being used to track birds and animals, to study their seasonal migrations associated with sea ice (Dieckmann and Hellmer, 2010). The energy balance in the Southern Hemisphere is, to a large extent, controlled by variations in the sea ice cover. Since the variations are products of the changes in the atmosphere (winds and temperatures) and in the ocean (ocean heat flux and currents), there is a strong interdependence in the system. One significant change (increase in global temperatures or ocean heat flux) will significantly alter the mass and energy flow between the components (Weeks and Ackley, 1986).

A full understanding of this process and how it operates and regulates the system is complex and not yet fully understood by research. It is clear though that it is crucial to the explanation of the role of the Polar heat sink in global climate.

2.2.3) Similarities and differences between Arctic and Antarctic Sea ice.

Global climate change causes a different response of sea ice in the Arctic to that in the Antarctic. One of the most vivid examples of this is the Antarctic sea ice area, which has been growing at a rate of $1.9 \pm 1.3\%$ per decade since 1985 (Bintanja et al., 2013). This contrasts greatly with Arctic sea ice extent (SIE) which has decreased, as shown below in figure 2-2, which compares the SIE in the Arctic in September 1997 and 2007. September SIE has nearly halved since 1979, with an estimated 8,000 km3 of sea-ice volume lost over that period (England *et al*., 2020).

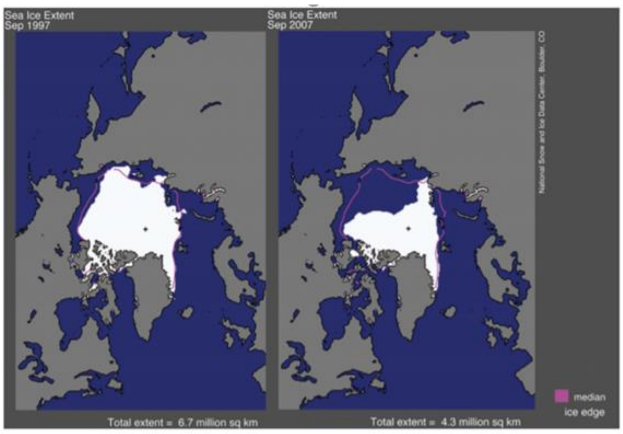


Figure 2-2: Difference in sea ice extent in Arctic from 1997 (left) to 2007 (right) (Dieckmann and Hellmer, 2010)

Antarctic sea ice extent increased gradually over much of the satellite record (1979 to present), reaching successive record highs in 2012-14. Yet, 2016 saw the beginning of the most pronounced fall in sea ice cover ever observed. 2017 and 2018 set new records for minimum SIE in the Antarctic since satellite observations began in 1979, and a considerable decline in the sea ice cover in both the Arctic and Antarctic is expected by the end of this century (Eayrs, C. et al. 2021). Over the three years that followed, the precipitous drop in Antarctic sea ice was equivalent to 30 years of sea ice loss in the Arctic. This drastic drop can be seen below in figure 2-3.

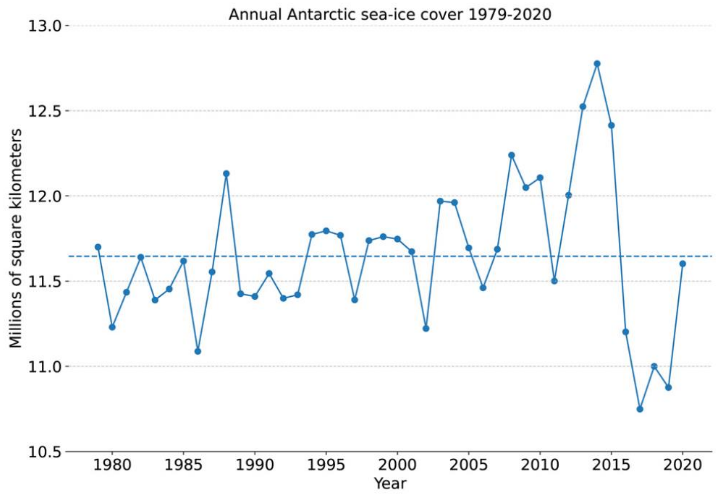


Figure 2-3: Annual Antarctic sea ice extent from 1979 through to 2020 (average for the period is shown by dotted blue line), based on data from the National Snow and Ice Data Center (NSIDC). Eayrs, C. et al. (2021)

Ice growth and melting in both polar regions are governed by the same energy fluxes. However, there are several factors that differentiate the processes that occur in the different hemispheres. A characteristic of general circulation models (GCMs) of the atmosphere is their incompetent representation of these features. If the models' constants are set to give a better representation to the Southern Hemisphere conditions and parameters, the Northern Hemisphere circulation becomes less realistic (Weeks and Ackley, 1986). This shows us that inadequately represented Southern Hemisphere processes have been created by reliance on Northern Hemisphere models (Weeks and Ackley, 1986). It is believed that a better understanding of the exchange processes in the Southern Hemisphere by field studies and experiments would probably improve simulations, and thus better predictions of the global climate system as it undergoes the inevitable changes that climate change presents (Weeks and Ackley, 1986).

Sea ice extent is only part of the story. For now, researchers only have reliable information on sea ice cover from satellites. Alternatively, accurately measuring Antarctic Sea ice thickness is an active area of research and is essential if we are to fully understand how the ice is changing (Eayrs, C. et al. 2021). The processes that influence Antarctic sea ice act on a wide range of time and space scales.

Under certain conditions, Antarctic sea ice can be susceptible to rapid change. Sea ice plays a significant role in global climate, and it is important that we narrow the knowledge gaps to be able to make future projections. It is for this exact reason that new techniques are urgently needed as researchers can no longer rely on linear techniques and zonally averaged metrics to study sea ice variability (Eayrs, C. et al. 2021).

2.3) Understanding the ice

2.3.1) Ice crystal structure and c-axis.

Ice is built up from many individual ice crystals that are packed closely together. At the top of an ice sheet the crystals have an unpredictable orientation. This is because the snowflakes have settled randomly at the top. However, as you travel further into the lower layers of the ice the direction of the crystals become more uniform. Inside these ice crystals the water molecules are arranged in layers of hexagonal rings as displayed in figure 2-4 below. (University of Copenhagen, 2009)

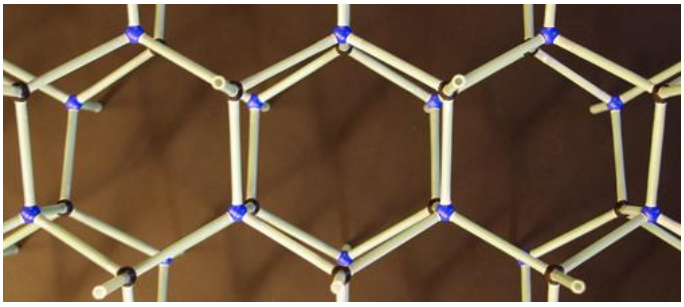


Figure 2-4: The hexagonal ring structure of an ice crystal (the blue and black spheres represent the oxygen atoms from the H_2O). (University of Copenhagen, 2009)

The hexagonal ring layers are known as the basal planes of the crystal. The axis that is perpendicular to these basal planes is known as the c-axis of the crystal (Iliescu, Baker and Chang, 2004). The bonds between molecules in the same basal plane (the hexagonal connections displayed in figure 2-3) are up to 100 times stronger than the bonds between molecules located in the different basal planes above or below it. This means that when an ice crystal deforms then it is gliding on its basal planes (University of Copenhagen, 2009). Figure 2-5 below shows how this deformation occurs, we can imagine this gliding by comparing it to a deck of cards. Pushing from the top won't break the structure, however pushing from the side will cause the cards to topple over.

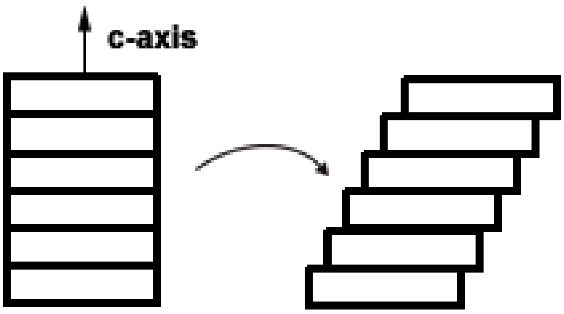


Figure 2-5: Deformation occurs when basal planes glide past each other. (University of Copenhagen, 2009)

This "gliding" is the individual crystals rotating on the basal plane. Researchers have established that the c-axes of the crystals rotate towards an axis of compression and away from an axis of extension (University of Copenhagen, 2009). The effect gives researchers a way to track the patterns of compression or extension. Deep down in the ice sheet the crystals are no longer randomly oriented but have a preferred direction. Thus, knowing the orientations of the ice crystals deep inside the ice sheets gives us a way to model the flow of naturally occurring ice (Iliescu, Baker and Chang, 2004). This information can be used for a host of scientific research that requires knowledge of the previous direction and flow of the ice sheets.

2.3.2) Relationship between the crystal structure of ice and its associated mechanical properties.

Researchers have improved their understanding of how the microscopic interfacial structure of ice controls important physical pattern formation during ice-crystal growth (Wettlaufer, 1999). Several basic ice properties were found to be related to this pattern formation and c-axis coordinaton. These parameters contain information on the prior thermal and flow history of the ice (Chan *et al*., 2014). This means that the crystal orientation and grain size of ice are of great interest to glaciologists.

What interests researchers particularly is that the distribution of c-axis orientations for a given thin affects its softness for further deformation (Alley, Gow and Meese, 1995). This means that it could not only be used to track the history of the ice, but it could also be used as a predictive tool (Lange, 1988).

The orientations of ice crystals in an ice sheet both reflect and affect its flow and are an indication of whether they underwent one of the following three processes:

1. polygonisation, in which the grains split into two separated by a sub-boundary of a few degrees of misorientation.

2. recrystallisation involving nucleation, in which new random orientations appear.

3. either strain-induced boundary migration or grain growth, in which grains grow, but no new orientations appear.

To accurately model the plastic flow of ice in different forms it is necessary to get a full understanding of the ice crystals present and classify what process the ice underwent to be the final product that is now observed in nature (Iliescu, Baker and Chang, 2004).

Understanding the mechanical processes associated with these growth conditions could also allow us to identify the best conditions to possibly artificially create ice formations to adapt to harsher surroundings or environmental challenges. This is an interesting avenue to pursue when climate change and its inevitable resulting environmental change is considered.

2.4) Determining the Crystal structure of ice

2.4.1) Ice Birefringence

Birefringence is a unique property of some transparent solid materials. These transparent solids have a refractive index that depends on the distortion and polarisation of the original light source. When light travels through a medium it will travel at a slower speed than it would if it were to simply pass through a vacuum. To represent this concept, scientists refer to the refractive index of a material. The refractive index (n) can be calculated using n = c/v where c is the speed of light in a vacuum and thus the fastest speed and v is the slower speed of light in the medium (Abramowitz and Davidson, 2021).

The most well-known birefringent effect is that of calcite. This is because it has been observed for thousands of years that light transmitted through calcite takes two very distinguishable paths that we can see even to the naked eye. Although our early ancestors had no idea why this was occurring, this was the first observable effect of birefringence. Further study into this effect led scientists to quantify this phenomenon (Abramowitz and Davidson, 2021). To compare the levels of birefringence of different solid materials, the maximum difference between refractive indices exhibited by the materials is compared. The structures within the solid materials have been examined to show that crystals with non-cubic crystal structures are often birefringent.

Birefringence can also be thought of as doubly refractive as it seems to split light into two rays, as observed when looking through a slab of calcite. These two rays are defined as the ordinary ray and the extraordinary ray (Elert, 2019). As the name implies, the o-ray behaves in an “ordinary” way, following Snell’s law without a problem. The e-ray gets its name because it does not obey snells rule. The index of refraction for the e ray is a continuous function of direction, whereas the one for the ordinary ray is independent of direction. The measure of birefringence (δ) [delta] is the difference between the indices of refraction of the two rays. δ = ne – no (Elert, 2019). Figure 2-6 below shows the values of some of the common solid birefringent materials. Note the values for ice as this is the material that is observed in the project. The delta value is so miniscule it is almost neutral.

Material	Crystal system	n_o	n_e	Δn
barium borate BaB_2O_4	Trigonal	1.6776	1.5534	−0.1242
beryl $Be_3Al_2(SiO_3)_6$	Hexagonal	1.602	1.557	−0.045
calcite $CaCO_3$	Trigonal	1.658	1.486	−0.172
ice H_2O	Hexagonal	1.3090	1.3104	+0.0014
lithium niobate $LiNbO_3$	Trigonal	2.272	2.187	−0.085
magnesium fluoride MgF_2	Tetragonal	1.380	1.385	+0.006
quartz SiO_2	Trigonal	1.544	1.553	+0.009
ruby Al_2O_3	Trigonal	1.770	1.762	−0.008
rutile TiO_2	Tetragonal	2.616	2.903	+0.287

Figure 2-6: Commonly used Birefringence values (Elert, 2019).

All these concepts are background to explain the point that is particularly useful to the observations undertaken within this report. The crucial effect of birefringence is that when the incident angle of the light source is observed just right, the o and e rays will follow the same path and the birefringence cannot be seen geometrically (Elert, 2019). The reason of importance of this point will be described at the end of this section once further relevant and required concepts are described.

Birefringence can be used for many scientific experimentations and real-world applications. For that reason, the quantification of the colors seen in birefringent samples is commonly studied by means of the Michel-Levy chart illustrated in Figure 2-7 below. Using this chart, the polarisation colours seen in the microscope can be correlated with the actual retardation, thickness, and birefringence of the sample. The chart is simple to use with birefringent samples if you know two of the three variables (Abramowitz and Davidson, 2021).

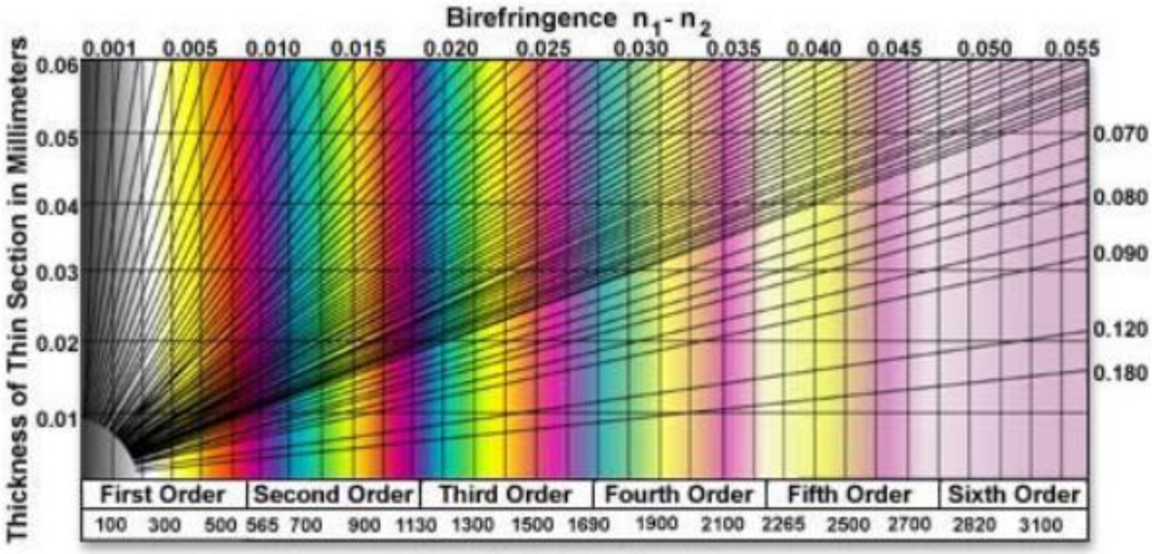


Figure 2-7: Michel-Levy Birefringence chart (Abramowitz and Davidson, 2021)

A particular application that is of great importance to this study is the fact that when double polarised light is perpendicular to the face of a crystal surface the o and e rays will follow the same path and the birefringence cannot be seen geometrically (Elert, 2019). The light will therefore pass directly through the crystal without any refraction taking place. When observing a surface that is made from many different crystals (each with different orientations) such as ice, there will be some crystals that are in the same plane as the light and others that are not. Due to the refractive process, any white light that enters the sample without being perpendicular to the surface will exit the sample as a different refracted color. Observing the surface of an ice sample on the opposite side of the incoming light will therefore reveal many different crystals of different colours. The crystals that have no colour must therefore have allowed the light to pass through without refraction and therefore must be perpendicular to the incoming light. The application of this knowledge is used to map the c-axis fabrics of ice, as explained in the section 2.4.2 that follows.

2.4.2) Mapping c-axis fabrics.

Ice in its natural form resides as a polycrystalline aggregate. This aggregate's structure is governed both by the conditions under which it was created and its later thermomechanical history. As was depicted in the section 2.3.2, the strength of a single crystal of ice depends strongly on its orientation (Iliescu, Baker and Chang, 2004). The strength and resistance to deformation of an Arctic ice floe depend on the fabric, texture, and loading direction. These are the basic mechanical properties that can be measured and predicted by observing and plotting the c-axis orientation. Therefore, to prove and predict the mechanical properties of ice we rely on the ability to accurately map the orientations of the c-axis fabrics.

Orientation, indicated by the direction of the c-axis of a grain, is often used collectively over all grains to interpret the direction of ice flows, or the thermal history that the crystals have experienced (Chan *et al*., 2014). The crystal orientation is determined by studying 0.5mm thick slabs of ice. When this slab of ice is placed between two crossed polarisation filters, the individual ice crystals can be seen.

The colour of the crystal depends on its orientation (University of Copenhagen, 2009). The reason for this comes back to the refraction and birefringence of ice that was described in section 2.4.1 above. Figure 2-6 below shows two examples of what can be seen when examining the thin ice slabs.

Figure 2-6: showing two different thin ice slab observations (Chan *et al*., 2014)

Notice the difference in colour uniformity between the two ice samples shown in figure 2-6. The crystals at the top of an ice formation have a random distribution as can be seen by the thin section to the left having many different colours. Deeper down, the deformation of the ice has led to the crystals having a preferred direction. Therefore, most of the crystals in the thin section to the right have similar colours – blue. The size of the individual crystals also changes with depth. In the Greenland ice sheet these crystals are between 1 mm and 10 cm in diameter (the typical size of the crystals in glacier ice is 1 – 5 mm). In the top layers the crystals are generally small, but with time the smallest crystals are 'absorbed' by larger neighbouring crystals causing the size of the crystals to increase with depth. This means that when the glaciers are close to bedrock the crystals can grow large, because the geothermal heat released from the bedrock increases the absorption and therefore the growth rate of the crystals (University of Copenhagen, 2009).

The crystal size also depends on the impurity content of the ice. When there is a high impurity content the crystals tend to be smaller because the impurities inhibit the growth of the crystals. This colour is associated with a c-axis direction and from there the flow history of this ice sample can be determined (University of Copenhagen, 2009).

2.4.3) Instrument used to determine crystal structure of ice.

A Rigsby Stage is an instrument used for orienting crystals so that the direction of the c-axis can be recorded. The device relies on the fact that ice is optically uniaxial and shows extinction between cross-polarisers when the c-axis lies in the polarisation plane of either polarising filter. (Langway, 1958). Figure 2-7 below shows the layout of a semi-automated Rigsby Stage designed by Lange in 1988. Apart from the monitor, triggering device and interface box, this is an optimal device for the research needed at UCT.

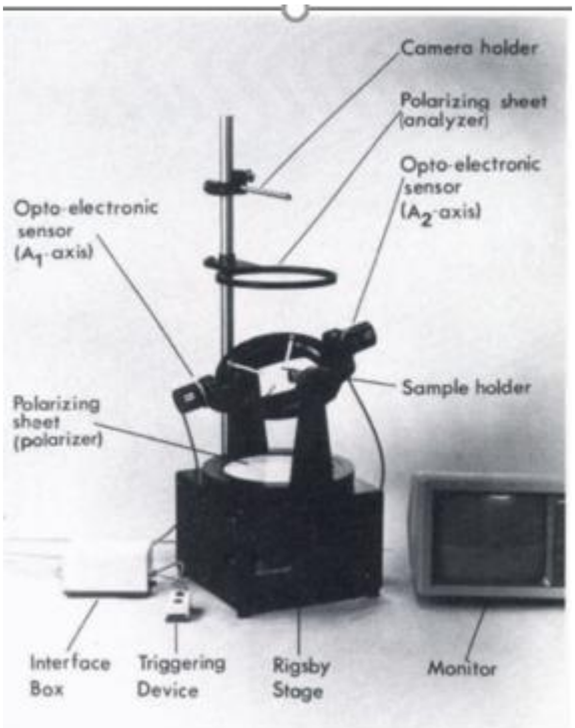


Figure 2-7: Lange's Rigsby Stage (Lange, 1988)

2.5) The Rigsby Stage

2.5.1) Sectioning of thin ice for analysis and required testing conditions.

The preparation of thin sections requires a cold area of about minus 10 degrees Celsius. The methods used to prepare the thin section of ice depend upon the equipment that is available and the purpose of the study (Langway, 1958). Any technique will reduce the section to an optimum thickness (0.5mm in the case of this study). Because of the low birefringence (0.0014) of ice, a section of ice with a large latitude will be needed for the thin sections used. However, when the grains are so fine that the thickness of the thin section is greater than the diameter of the grains being measured, orientation is not possible (Langway, 1958). The technique that will be used in this research project will make use of a microtome that is shown in figure 2-8 below.

Figure 2-8: Ice sectioning microtome

The microtome will use a slab of ice cut from an ice core and slice it down to a thin section, only 0.5 mm thick. The upper part of the machine with the microtome knife moves back and forth, each time removing a thin layer of ice. A glass slide with the thin ice sheet is then removed from the cutting machine and placed onto the Rigsby Stage for analysis.

2.5.2) Operation of a Rigsby stage.

To fully understand the manipulation of the Rigsby Stage, it is desirable to be familiar with the optical symmetry of crystals. However, ice, being a uniaxial substance, is relatively simple to orient and it is possible to master the mechanics involved without a thorough knowledge of crystal optics (Langway, 1958). Using a Rigsby Stage, rotations about four separate axes are necessary to fully determine the c-axis of a grain to an estimated error of roughly 5° (Langway, 1958). Figure 2-9 below shows a simple sketch of the proposed Rigsby Stage to be created in this project. Five different axes of rotation are shown. These axes are used to orient the ice sheet in different directions to identify what direction the crystals are oriented.

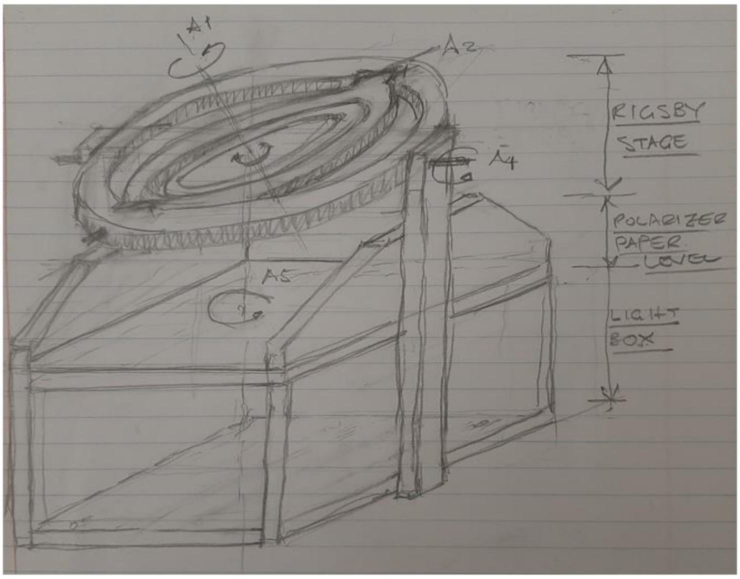


Figure 2-9: Proposed Rigsby stage

No standard procedure is used to orient a crystal when using the Rigsby Stage nor should there be, for each investigation involves different considerations. Figure 2-10 below shows a plan view of the rotation axes of a Rigsby Stage at the rest position.

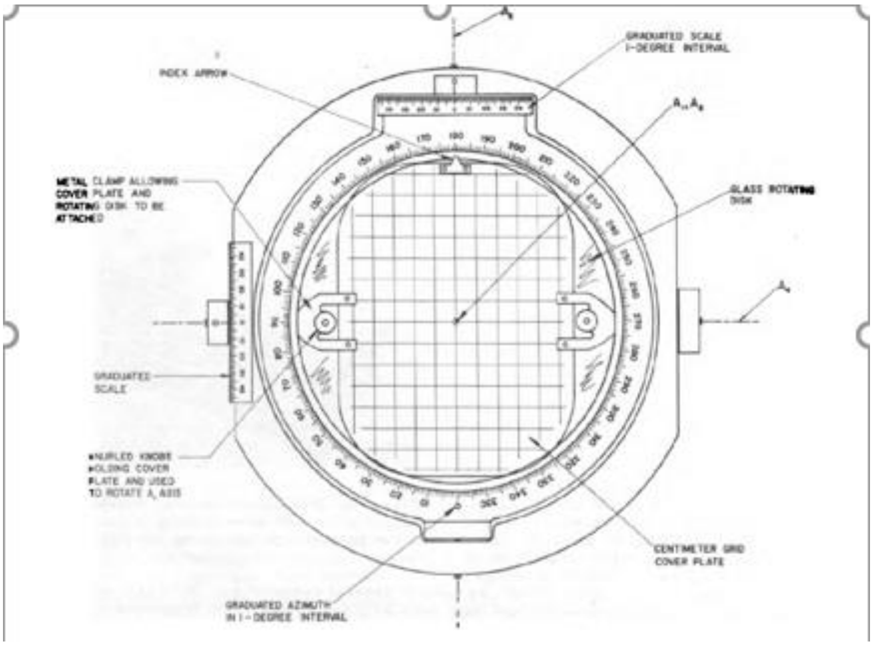


Figure 2-10: Rotation axes of universal stage at rest position (Langway, 1958).

In figure 2-10 a grid can be seen on the face of the ice plate. This grid is used to measure the thickness of the crystals on the ice sheet. It can also be seen that there are degree measurements on each axis of rotation to help record the orientation of the crystals.

2.5.3) Data collection and analysis.

To get an accurate reading for the orientation of a thin ice sheet it is necessary to use the Rigsby Universal Stage to measure the orientations of c axes of ≈ 100 grains or more. This data is then recorded and presented as a scatter plot or contour plot on a Schmidt equal-area projection as shown in figure 2-11 below. (Alley, Gow and Meese, 1995). It is also possible to produce plots of a c-axis distribution for different orientations, by computing the rotated angles of c-axes (Lange, 1988).

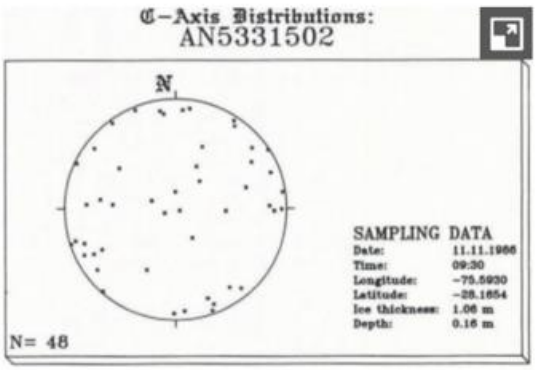


Figure 2-11: Sample Schmidt diagram of a sea ice thin section (Lange, 1988)

These spatial distribution maps of c-axis scatter plots can reveal additional information about processes responsible for the observed fabric and texture of the ice.

3. Methodology and design process

This section will walk the reader through the full 8 step design process that was undertaken to produce the final Rigsby Stage.

3.1. Defining the problem and requirements

The orientation of the c–axis of individual ice grains provides fundamental insights into several basic ice properties. In particular, the distribution of c-axis orientations for a given thin section reveals information on the growth process and subsequent history of the sampled ice. UCT doesn't have access to any instrument that gives the user the ability to determine (and thus record) the c-axis distributions in ice samples.

To effectively perform its job for the laboratory the device needs to effectively fulfil all the following requirements:

- High performance in a sub-zero environment:

  The device will contain and examine a 0.5 mm thick sample of ice. To maintain the structure of this sample the device will perform its analysis at the UCT polar laboratory. This analysis will be performed under sub zero conditions (-10 degrees Celsius). The device needs to maintain its shape, and structural integrity in this environment. The shape retention is especially important for any connecting parts as cold shrinkage could affect rigidity and measurement accuracy.

- Relatively high level of durability:

The device will be used for multiple generations of students and researchers to follow. For this reason, it should not be brittle or fragile. Due to the unique requirements that a device like this one fulfils; it is not in high demand. For that reason, there is limited availability to purchase a device of this nature. If the device were to break it would be a tricky endeavor to replace.

- Cost effective:

The device will be manufactured and financed by UCT. For this reason, it needs to be in line with a suitable budget. The device also serves a very niche purpose and will therefore not entice as great an incentive for funding as a more generic research tool.

- Accurate axis movement and measurements:

The fundamental outcome of the device is to provide a measurement of the orientation of the c–axis of individual ice grains within the test sample. For this reason, both the operation and measurement of the device needs to allow for the highest level of accuracy.

If the margin for error is too large the results of any experiment performed with the device will be unreliable and therefore pointless. Langway (1958) states that using a Rigsby Stage, rotations about four separate axes are necessary to fully determine the c-axis of a grain to an estimated error of roughly 5°.

- Efficient and coherent:

To get an accurate reading for the orientation of a thin ice sheet it is necessary to use the Rigsby Universal Stage to measure the orientations of c axes of ≈ 100 grains or more (Alley, Gow and Meese, 1995). The device must therefore be efficient in its operation to minimize the length of time required for operation in a sub-zero lab. As stated previously, the device will be used by many future students and researchers, therefore it must be coherent and easy to understand and operate. This will reduce the regularity of mistakes and need for intervention by future supervisors.

3.2. Research and preparation

3.2.1. Analysis of existing instruments

The device that is being built already exists and therefore doesn't have to be reinvented. For this reason, the device will be able to draw on existing instruments for design ideas and combine the best elements of existing iterations (within the budget and requirements of the project). The two devices that will be examined and used as inspiration are Langway's traditional Rigsby device, and Lange's more modern automated device. They are outlined below.

Langway's device:

Langway's Universal Stage uses the same basic principles as the Rigsby Stage that was first introduced by Fedorow, which is used on a polarising petrographic microscope. The same principles apply in that it allows the angular rotation of multiple axes of the Rigsby Stage to optically orient a crystal. This stage, however, has four axes of rotation (A1,2,4 and 5) compared to the three axes of a rotating microscope stage (Langway, 1958).

The stage is mounted between two polaroid discs and can accommodate a thin section of ice with a diameter of up to 130mm. The frame of the stage is made of anodised aluminium and has three of its axes of rotation graduated (Langway, 1958). One axis serves as an azimuth control; the other two permit the angle of inclination to be recorded. The fourth axis allows the entire stage to be rotated on a vertical axis without disturbing the oriented specimen and serves as a check.

The circular rotating disc that supports the thin section (the sample holder) is made of glass. Two knurled knobs allow for azimuth rotation of the section and to clamp the cover plate over the thin section (so as not to fall whilst rotating). The cover plate (clear plastic) is etched with a centimeter grid for exact measurement of the grain widths. A copper pointer is attached to the cover plate for an index in obtaining azimuth positions. The stage is mounted on a wooden base that doubles as a carrying case. This allows the Rigsby Stage to be transported and thus used in a field setting. The base has a hinged opening which permits storage of the component parts of the stage. A polished, stainless-steel sheet is attached to the bottom hinged door of the base. This sheet is used to reflect light and transmit it through the instrument during field use. This is due to the lack of available power source in a field operation. If, however, a power source is available, an ordinary extension cord and bulb (150 w) is used as a light source. A heat absorption plate is inserted in a slot provided under the polariser. This defuses the light, reduces the heat, which in turn maintains the molecular structure of the ice sheet and reduces the glare (Langway, 1958).

Given the device's relative simplicity and lack of electrical and sophisticated components, this will likely be the device that the most inspiration will be drawn from for this project's design. Figure 3-1 is a picture of Langway's initial Rigsby Stage rings.

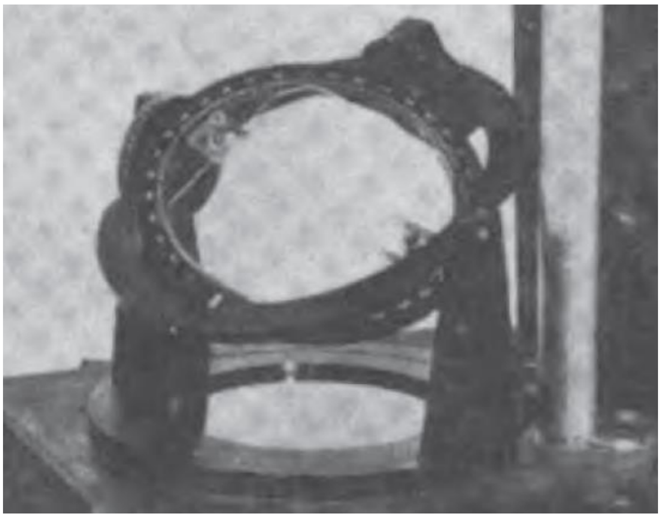


Figure 3-1: Langways Rigsby Stage

Lange’s Device:

The basic component of Lange’s system is the same conventional Rigsby universal Stage that Langway developed, which is described above. The stage similarly has four axes of rotation which are used to determine the grain orientation. The Rigsby stage, the monitor and the triggering device can all be operated in a cold-room, in temperatures as low as –30°C. To ensure proper operation of the television screen at these temperatures, it is housed in an insulated box which is fitted with a plexi-glass window for proper viewing of the screen (Lange, 1988).

Lange’s device is a more integrated system for ice-fabric analysis on a Rigsby Stage. The system is fitted with two opto-electronic sensors for assessment of azimuth and the tilt angle of each individual grain. The signals from the opto-electronic sensors are then sent to a computer terminal via an interface box, which facilitates transformation of Gray-coded data to ASCII data records (Lange, 1988).

The terminal is connected to a main-frame computer, where the recorded and digitised angles of the c-axis orientations of individual thin sections are stored in separate data files (Lange, 1988). These files are compatible with other already existing files containing additional ice-core data and thus become part of and add to an extensive data bank (Lange, 1988). Lange also developed software to produce, among other things, plots of c-axis orientations in a Schmidt net, which is a tedious process to do by hand.

This semi-automatic equipment, consisting of electronic components which link directly with a computer, or a data logger, is an ideal tool if multiple research projects will have to be performed using these Rigsby Stage outcomes on a daily or weekly basis. Apart from the obvious time reduction benefits, another major advantage of such a system lies in the fact that it frees the operator from writing down numbers by simultaneously inputting the data into a computer (or into a computer-compatible data-storage medium) for further analysis (Lange, 1988).

The major advantages of this system are twofold. It greatly reduces the time the operator must spend in the cold-room, as they are freed from taking notes and writing down numbers during the measurements. Although the absolute accuracy of each measurement, which is limited by the intrinsic mechanical accuracy of the Rigsby Stage and by the observational accuracy (not better than ±1-2° for each angular reading), cannot be improved by the system, the risk of operator-induced errors is reduced (Lange, 1988). Figure 3-2 below shows Lange’s automated Rigsby Stage.

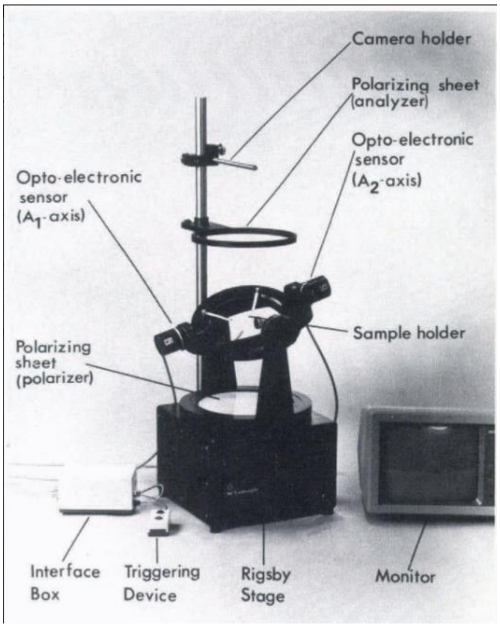


Figure 3-2: Langes automated Rigsby Stage

3.2.2. Mechanical design process

As stated previously, the final Rigsby Stage would be constructed by the UCT mechanical engineering department. Given the limited experience of the designer of the requirements of a mechanical engineering design, assistance was provided by Pierre Smith, of the UCT mechanical engineering workshop.

Initial meetings were scheduled with Pierre Smith and Dr Keith MacHutchon during the pre-design phase and ideas were exchanged on the best way forward. A schedule that worked for the mechanical engineering workshop was decided upon to allow for early construction. This was beneficial for all parties as it allowed for testing time after construction and limited schedule interruption for Pierre. The decided project schedule is shown below in table 3-1. Note the days to complete allowance for the device construction.

Task	Start Date	Days to complete
Gather Research	17-Jul	16
Write Research Proposal	26-Jul	12
Design Drawings	02-Aug	12
4035C design Project	10-Aug	51
Rigsby Stage Construction (by mech eng dept)	15-Aug	46
Research Ethics application	24-Jul	5
Reliability testing of Rigsby Stage	01-Oct	14
Thin ice sheet experiment with Rigsby Stage	15-Oct	7
Write Draft Abstract and Research project report	22-Oct	14
Make Draft poster outline	05-Nov	7
Write Final Abstract and Research Project	13-Nov	13
Make Research Poster	27-Nov	6

Table 3-1: Schedule of thesis

The design drawing requirements were expected to be completed on a software called Solidworks. This software required a week to learn and after that the design drawings were completed. These drawings were 3D modelled drawings and are attached in appendix 1. This is a requirement for the workshop as it gives a full picture of each individual part that required construction.

A second meeting was arranged with Pierre Smith and Dr Keith MacHutchon after the design drawings were completed. Input was provided by Pierre Smith given his extensive experience and a design was finalised for the construction phase.

3.2.3. Materials:

The material used in the construction of the Rigsby Stage plays a large role in the device's ability to meet the requirements laid out in section 3.1. To aid in the material selection process the designer reached out to Dr. Sarah George from UCT's center for materials engineering in the mechanical engineering department. Together, a shortlist was drawn up with plausible options for the material use. This shortlist will be compared in table form below, with regards to meeting the project's requirements.

These materials included both polymer and metal and are described below:

1. Acetal

Acetal plastic, also called polyacetal and polyoxymethylene (POM), is a general purpose, semi-crystalline, engineered thermoplastic. Acetal is commonly used for parts that need to be very stiff, have low surface friction and good dimensional stability. Dimensional stability is the ability of a plastic part to maintain its original dimensions when it is exposed to changes in temperature and humidity.

Here's an overview of the characteristics that make acetal a good option as a material for the Rigsby Stage:

- High tensile strength
- Natural rigidity
- Excellent dimensional stability
- Low water absorption
- Low thermal expansion
- Excellent abrasion resistance
- Laser cuts well
- Excellent wear in both wet and dry environments

Figure 3-3 below shows uncoloured Acetal material.

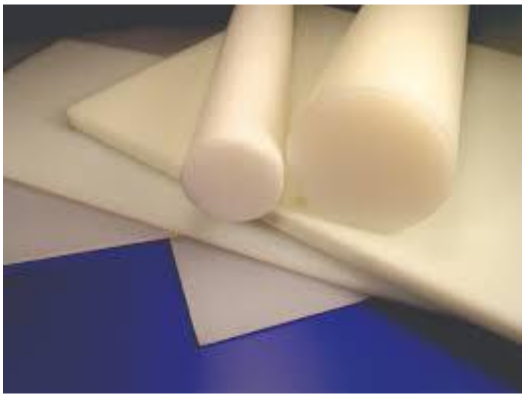


Figure 3-3: Acetal polymer material

2. Vesconite

A specialised hard-wearing thermopolymer designed for challenging operating conditions, Vesconite gives up to 10 times the life of traditional bronze or nylon bushings. Combining internal lubrication, a low friction coefficient and low wear rates, Vesconite does not require external lubrication, even where conditions are dry and dirty (Vesconite, 2021).

Some positive characteristics include:

- low friction
- low wear
- self-lubrication
- good dimensional stability
- very low water absorption
- suitability for both dry and immersed application
- good load carrying ability
- easy machinability
- greater cost effectiveness than traditional bearing metals.

Figure 3-4 below shows the raw Vesconite polymer material

Figure 3-4: Vesconite polymer material

3. Unplasticised (Rigid) PVC:

Polyvinyl Chloride (PVC) is one of the most widely used polymers in the world. Due to its versatile nature, PVC is used extensively across a broad range of industrial, technical, and everyday applications including widespread use in building, transport, packaging, electrical/electronic and healthcare applications. Some of the promising characteristics of the PVC material include (SpecialChem, 2017):

- durable and long-lasting material which can be used in a variety of applications, either rigid or flexible.
- Its good impact strength and weatherproof attributes make it ideal for construction products.
- PVC is easy to process, long lasting, tough, and light.

- PVC consumes less primary energy during production than any of the other commodity plastics.
- Minimum continuous service temperature of -10 degrees Celsius.

4. Aluminium T series

Aluminium is lightweight, durable, malleable and corrosion resistant. This metal is widely used for components in the aerospace, transportation, and construction industries.

The main characteristics of aluminium include:

- Non-corrosive: Aluminium naturally generates a protective thin oxide coating which keeps the metal from making further contact with the environment.
- Lightweight yet durable: about a third of the specific weight of steel. This cuts the costs of manufacturing with aluminium.
- Non-magnetic and non-sparking.
- Good heat and electrical conductor: Aluminium is an excellent heat and electricity conductor and in relation to its weight is almost twice as good a conductor as copper.
- Reflectivity: Aluminium is a good reflector of visible light as well as heat, and that together with its low weight, makes it an ideal material for reflectors.
- Strength at Low Temperatures: In contrast to steel, which rapidly becomes brittle at low temperatures, aluminium shows increased tensile strength as temperatures drop.

"T" indicates that the aluminium alloy has undergone thermal treatment. Aluminium heat treatment is a process by which the strength and hardness of a specific subset of aluminium alloys, namely the wrought and cast alloys that are precipitation harden-able, are increased.

The only real downside with aluminium for this project would be the high cost of aluminum. In raw materials costs, aluminium is about three times more expensive than steel, while in terms of conversion costs it is about twice as expensive. And in assembly costs, aluminium is 20-30% more expensive than steel.

Figure 3-5 below shows the various shapes and sizes of aluminium available to the consumer.

Figure 3-5: Raw aluminium material

Material choice:

A multi criteria analysis was performed to choose between the above suggested materials for the final design. These criteria were also weighted based on importance. The importance was determined based on discussion with the mechanical engineering workshop and supervisor Dr Keith MacHutchon.

Criteria (weight)	**Acetal**	**Vesconite**	**Aluminium**	**PVC**
Cost (0.3)	0.7	0.6	0.3	1
Machinability (0.15)	0.7	1	0.85	0.7
Durability (0.2)	0.5	0.6	1	0.5
Low temperature workability (0.35)	0.6	0.7	1	0.4
Total	**0.625**	**0.695**	**0.768**	**0.645**

Table 3-2: Multi criteria analysis of possible material choices

Aluminum is therefore chosen for the device construction. This information is relayed to the mechanical engineering workshop with the design drawings for the construction process to begin.

3.2.4. Lighting:

As stated previously in the literature review, the device uses light to determine the crystal orientation of the sample.

Lighting considerations:

- Light can create heat:

  Energy can't be created or destroyed, but it can be converted between the different types of energy. Light energy is a type of energy. When light hits an object, it either bounces off, and stays as light energy, or it is absorbed by the object. When it is absorbed, it is converted into heat energy, and the object heats up. Some materials and colours absorb more light energy than others and thus create more heat. Given the cold room working condition needed to maintain the low temperature for the ice sample to remain in its solid state it would be counterintuitive to create the device out of a material that will absorb large amounts of light and then heat up and melt the sample.

  The material choice of aluminium is therefore perfect as it is both an extremely good reflector and a good conductor of heat and will thus attune to the cold surroundings without deforming.

- Light can be reflected:

  The problem of heat and reflection go hand in hand within this project and thus a tailored solution needs to be implemented. Although high reflection will keep the aluminium stage and the sample cool it also means that light will possibly strike the sample from different reflected angles. This could jeopardize the readings, as the measurements are solely focused on coordinating the c-axis in relation to a uniform light source. Figure 3-6 below shows the different reflection possibilities and redirection from a uniform light source.

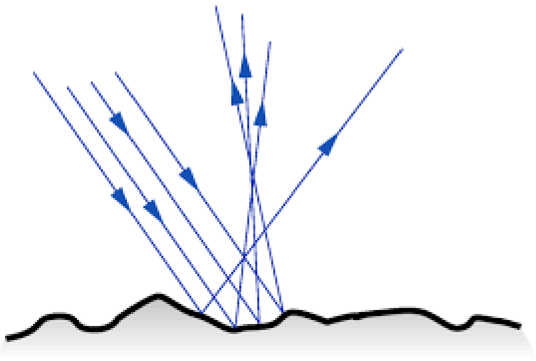


Figure 3-6: Reflection of light to different locations from a uniform source

The method of creating a uniform light source will require a set of 2 polarized film sheets. How this film works is that light is a wave, and it usually vibrates in all directions. A polarizing filter is a device that allows light only with a certain vibration to pass through in a certain direction. These filters are like bars that only let through the light that travels in the same direction as the slots. This method creates light that vibrates just up and down or just side to side by making it go through the polarising filter (Science world, 2021). Figure 3-7 below demonstrates this polarising effect.

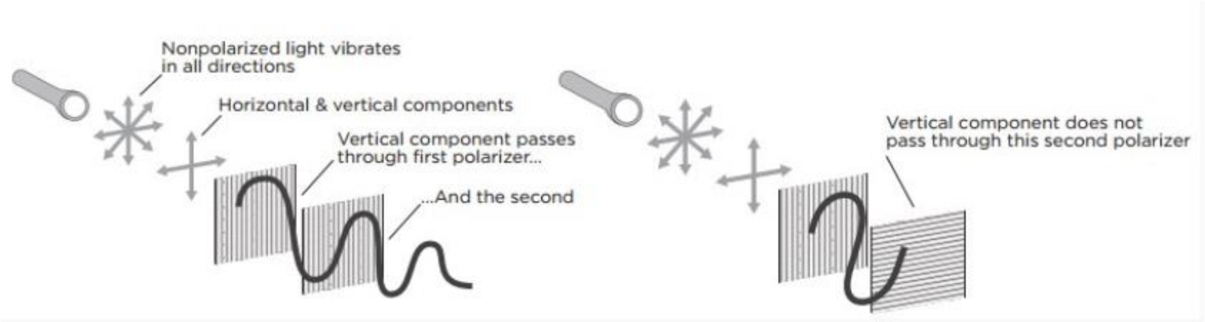


Figure 3-7: Polarizing film mechanics

To prevent the light from still being reflected by the aluminium casing after it has gone through the polarising process, the polarising film will be placed close to the sample. This means the film will be placed between the sample holding rings and the lightbox as close to the rings as possible. The next film will be placed above the sample, on a stand-like structure.

3.3. Prototype

An initial sketch was made on Autocad and expanded upon with a homemade model of a Rigsby Stage. This model was an important tool to portray the desired idea to the various professionals who would aid the design and construction of the final device. The device was not the correct dimensions, material, or complexity; however, it did importantly represent all the axis movements, the sample size and position. Figure 3-8 below shows the Autocad drawing used as a basis for the prototype construction.

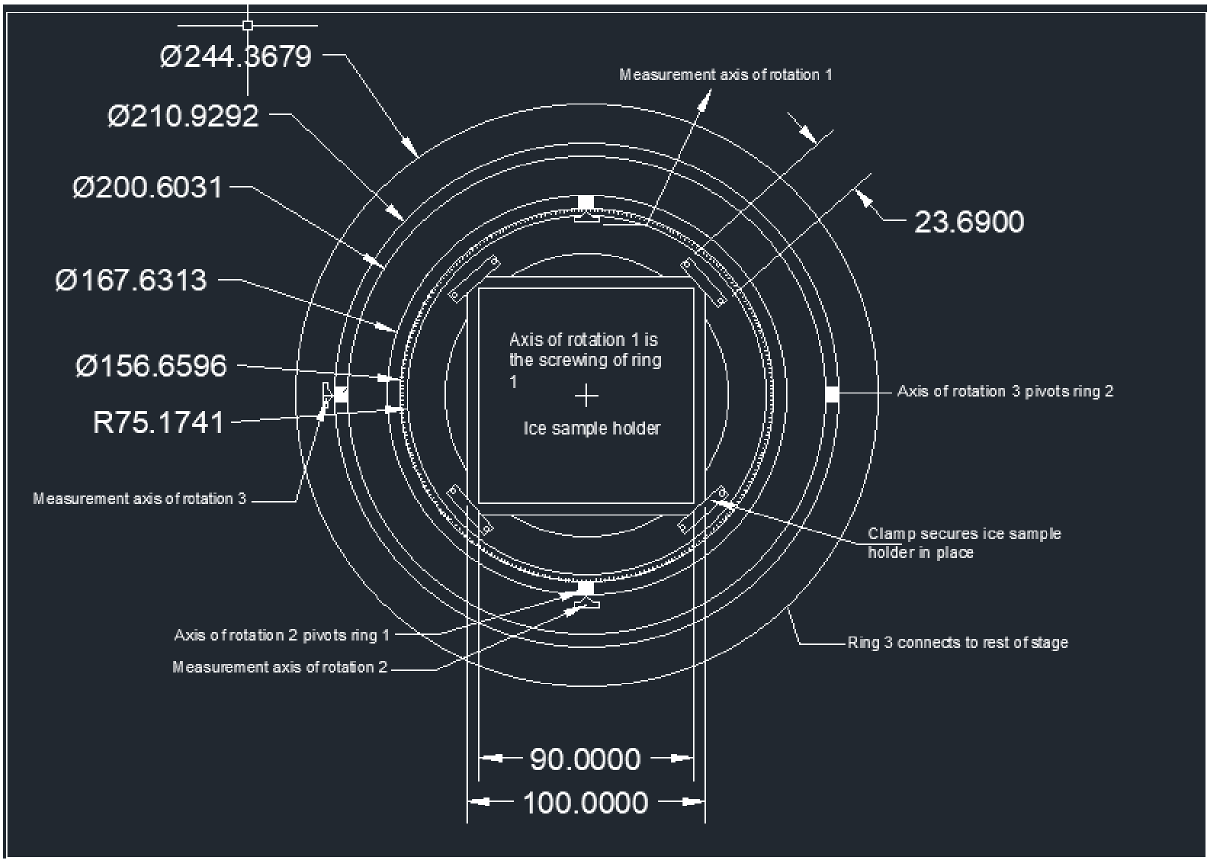


Figure 3-8: Preliminary Autocad drawing for model

Figure 3-9 below is a picture of the homemade prototype that was used as a demonstration tool to all the professionals involved. It was found to improve their understanding of the project vision in all interactions.

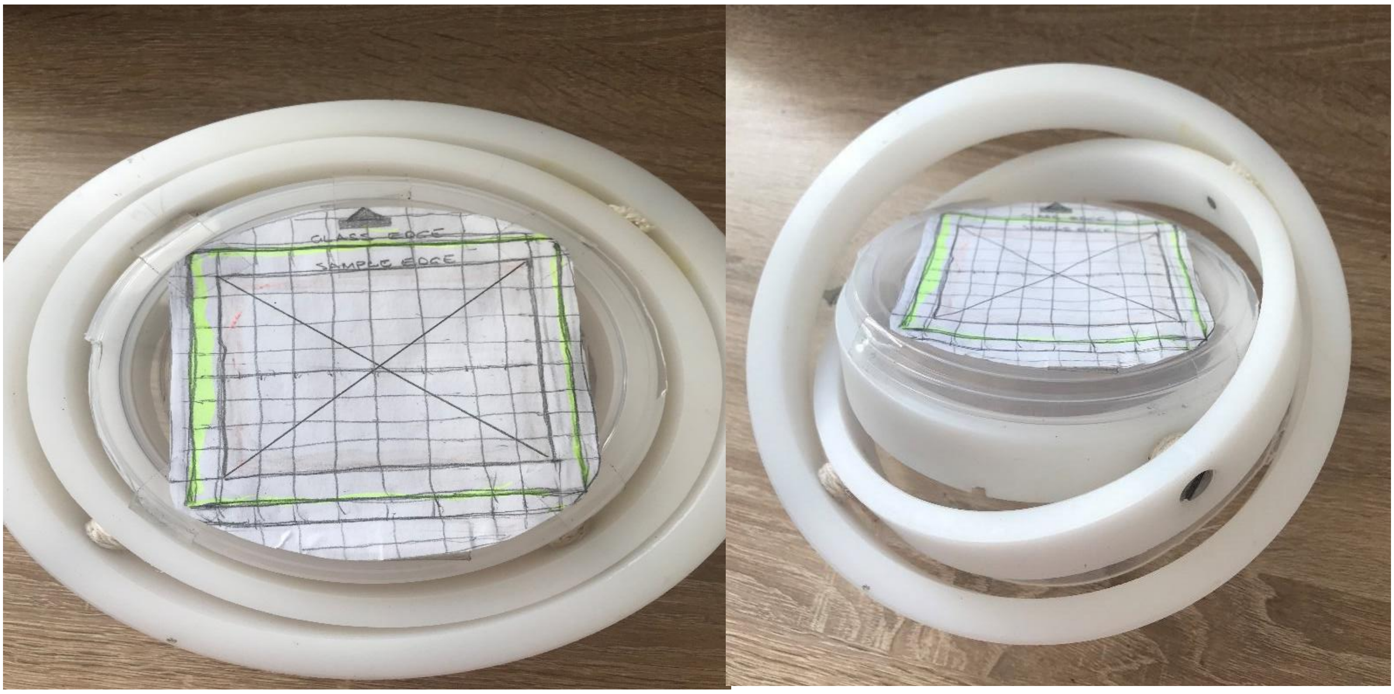


Figure 3-9: homemade prototype of Rigsby Stage rings and sample holder

The prototype also highlighted unforeseen problems such as rigidity, ring dimension and axis measurement that would only have been discovered after the final construction was produced by the workshop. Thus, wasting costs, materials, and the time of the workshop.

3.4. Design

3.4.1. Design components:

precise rotational measurements and axis

The device records the exact direction of an ice sample by rotating about 4 different axes.

A1 = Inner vertical axis

A2 = North – south axis

A4 = East – west axis

A5 = Outer vertical axis (axis of the stage)

Initially, in what is referred to as the rest position, A1, and A5 are parallel to the line of sight (normal to the thin section) and A2 and A4 are mutually perpendicular and lie in a horizontal plane. This rest position is shown in the aerial conceptual view (top left) of the concept image shown below in figure 3-10.

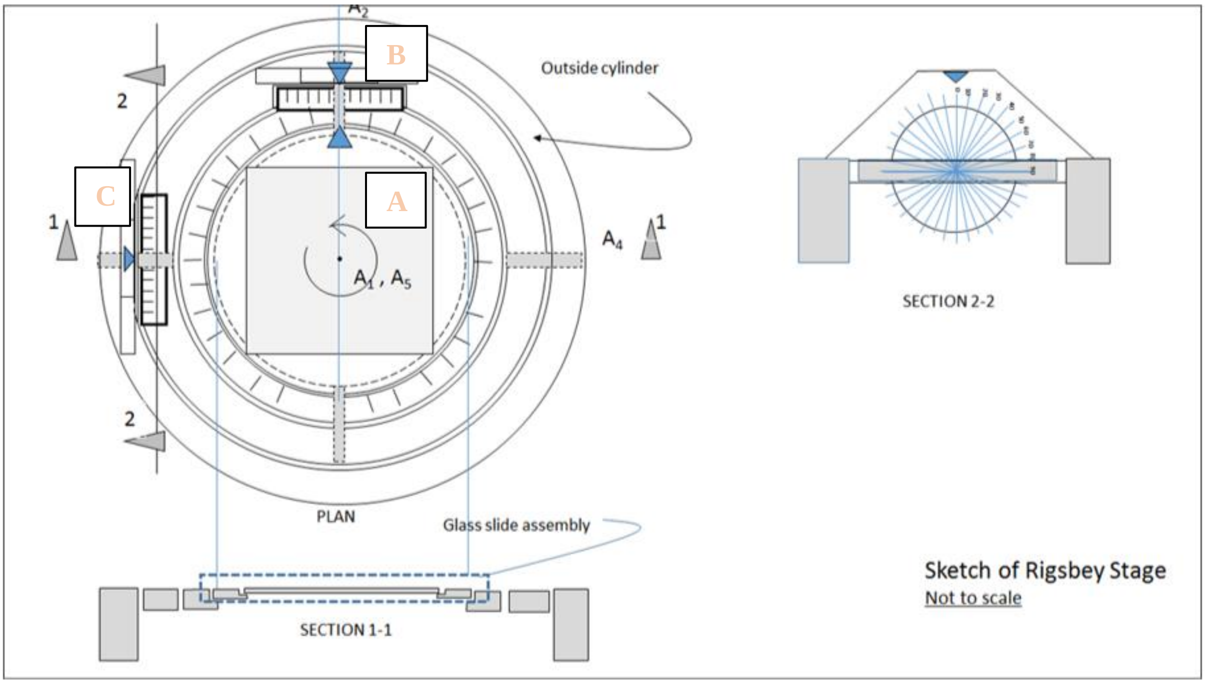


Figure 3-10: Concept image of Rigsby Stage rings with axis measurement considerations

To accurately record all these positions a measurement device is needed for each axis.

These measurement devices are labeled above as A,B and C and are described below.

A- Scale A is a flat 360-degree circle that can record the full range of movement performed in axis 1. For this movement to be possible a screw-in device holder was designed. This also allowed for the sample to be transported without moving the entire device. The sample holder required 4/5 full 360-degree rotations before it could be removed from its tightest position. This ensured that the sample holder would not detach from the full stage when rotational measurements were being carried out. Figure 3-11 below shows the 3D representation of the removal of the sample holder from the stage.

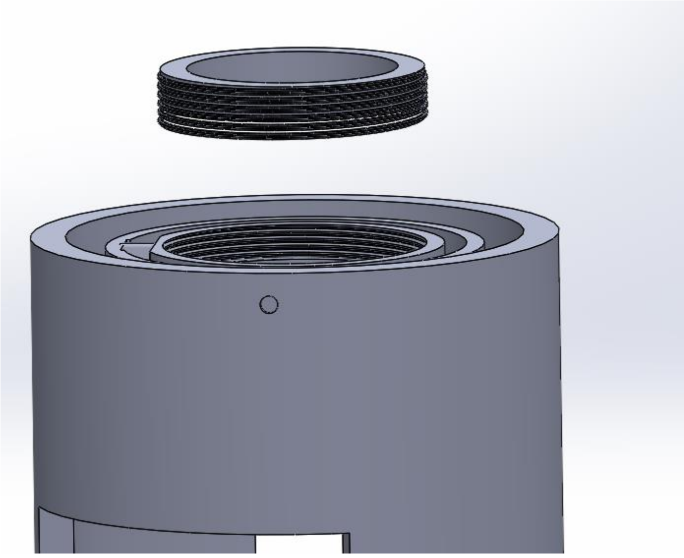


Figure 3-11: Sample holder removal from Rigsby Stage

B- Scale B will record the rotations for the inner ring, which is Axis 2. The ring will be flattened at a point and allow a compass like extrusion with markings to represent and record the rotations about A2. A static pointer will indicate the exact position of movement about A2 for recording. To fit this compass into the device, a 20mm extrusion will be placed on the inner ring exterior and will fit into the second ring's interior. This is depicted in figure 3-12 below. Also refer to the blue highlight of figure 3-13 below to see where the second ring will allow the first ring to fit.

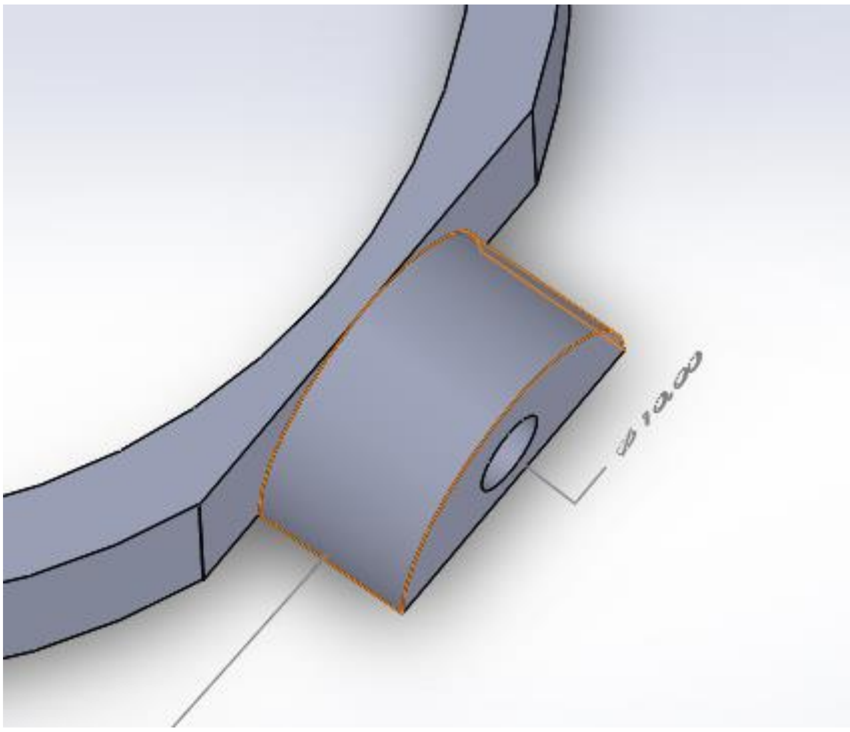


Figure 3-12: inner ring axis 2 measurement attachment

C- Scale C follows the same concept as Scale B; however, it is performed on the second ring to measure the rotations of movement about Axis 4. Figure 3-13 below shows the position of this on the 3D model.

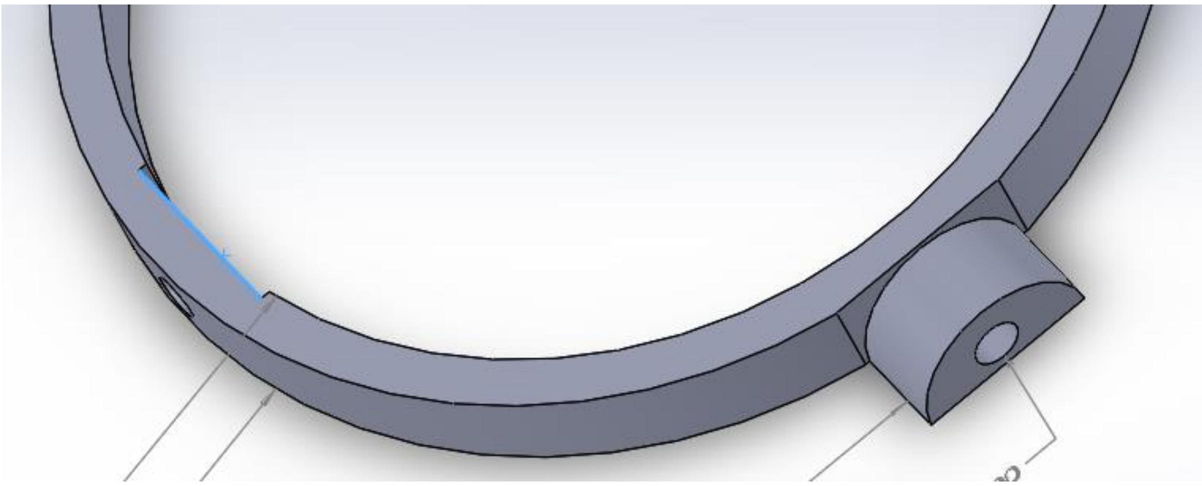


Figure 3-13: Outer ring axis 4 measurement attachment

With these values, contours can be drawn on a Fabric diagram to show orientation density. At least 200 axes should be plotted if a reliable statistical analysis is to be made.

Another problem becomes apparent when measurements are required, and that is the problem of rigidity. The rings need to be able to rotate about their respective axis for multiple measurements to take place on the stage. However, once the rings require measurement they will need to be fixed into place. This fix in place will allow for the crystal observation to be carried out and for the recording of results. The rings therefore need to be both rigid enough to stay in place and moveable enough to be rotated at the same time.

material

As stated in the research section, the material that was selected for use was aluminium. The material considered best for the device overall. The material benefitted the device in the following ways:

- Didn't absorb the light's heat – Given the reliance on keeping the samples at a low temperature it was important that the aluminium wouldn't get hot after being exposed to extended periods of direct lighting. The surface of aluminum can reflect 95% of the infrared rays which strike it, thus reducing the level of conduction that takes place.
- Malleability – Aluminium is non-ferrous and is thus easier to work with than iron alloys; it was easy to form into the desired Rigsby Stage.
- Durability – Aluminium is naturally corrosion resistant and will be able to last for many generations of future research in the relatively hostile sub-zero conditions.
- Unaffected by the cold environment – Tests revealed that the strength of aluminum and its alloys increase at extremely low temperatures, including tensile, yield and impact strength measurements. Unlike other metals, which can become brittle in extremely cold temperatures, aluminum, and its alloys rise to the occasion, and become even stronger.

Light box

The light box holds the LED strips that will provide a light source for the observations. LED strips were chosen for the following reasons:

A) Low energy requirement

LED lights use 75% less energy than incandescent bulbs. This means power plants aren't working as hard or producing as much pollution. Since LED light strips last a long time and don't use much energy, they won't cost UCT as much money.

B) Direction

LEDs emit light in a specific direction, reducing the likelihood of reflection on the aluminium casing. This problem was highlighted as a lighting concern in the previous section. With other types of lighting, the light must be reflected to the desired direction, and more than half of the light may never leave the lightbox (LED Lighting, 2021).

C) Low heat

LEDs emit very little heat. By comparison, incandescent bulbs release 90% of their energy as heat and CFLs release about 80% of their energy as heat (LED Lighting, 2021). The stage will need to reduce heat generation anywhere that is possible.This will lower the risk of overheating the sample. The lights and lightbox will also importantly be placed as far away from the sample as possible, thus the device's 380mm height.

D) High lifespan

LED lighting products typically last much longer than other lighting types. A good quality LED bulb can last three to five times longer than a CFL and 30 times longer than an incandescent bulb (LED Lighting, 2021). This will reduce the frequency of mid test light source removal in the future.

E) <u>Flexible and lightweight</u>

The light box will be made in a cylindrical shape with a defined directional sample to shine at. The higher the level of controllability of the light source the lower the source of error. The device will also be relatively heavy, being made entirely of metal. The reduction in weight of LED stripping will aid in the transportation

An opening for the wiring will be constructed into the lightbox. Although there will likely be limited wiring requirements, this hole will be large enough for multiple wires, should a future technology that requires more wiring allow for a decreased margin of error.

Dimensions

The total height of the Rigsby Stage will be 380mm, with the largest diameter being 300mm. All specific dimensions for each individual part of the Rigsby Stage are indicated in the next section.

To facilitate the construction of a stage with these specific dimensions the order of aluminium will have to be 330mm x 400mm long.

An important dimensional consideration is that the spacing between the rings needs to be significant enough so that the 20mm deep rings don't collide whilst rotating.

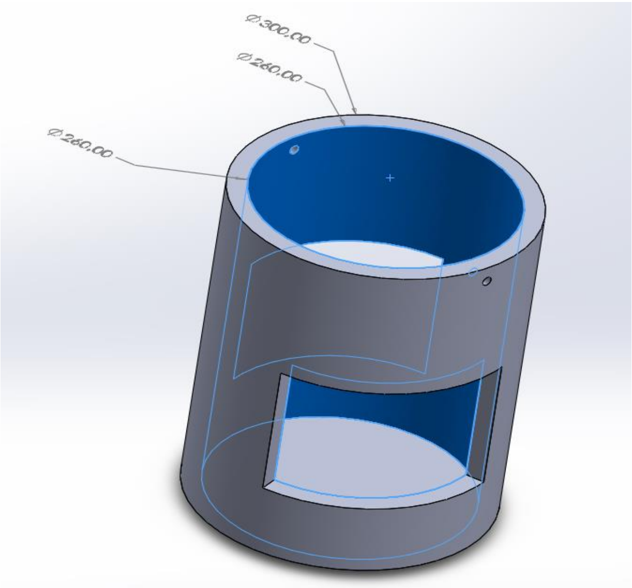
The casing will have gaps on either side, this will allow the stage to be easily lifted and transported, it will also give space for any adjustment within the lightbox.

3.4.2. Rigsby Stage parts

To give a proper understanding of the device, a screenshot of each of the 3D concept parts are shown in the figures below, along with a brief description of the piece.

<u>Stage:</u>

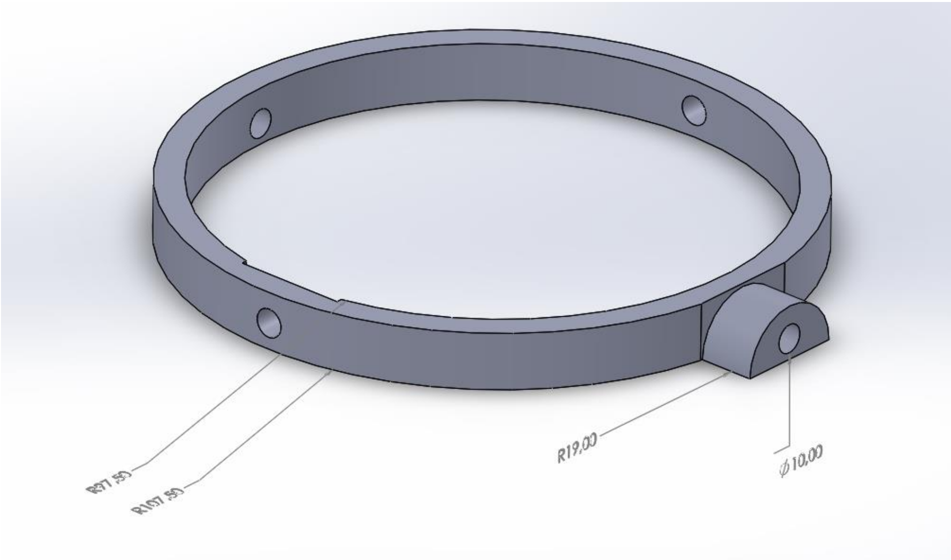
The outer stage is the casing of the device. The stage connects directly to the outer ring by way of two connecting pieces and its associated 10mm diameter holes. The stage is cast from aluminium. The lighting sits at the bottom of the stage with wiring being thread through a small opening in the bottom.



<u>Figure 3-14: Stage Part</u>

<u>Outer ring:</u>

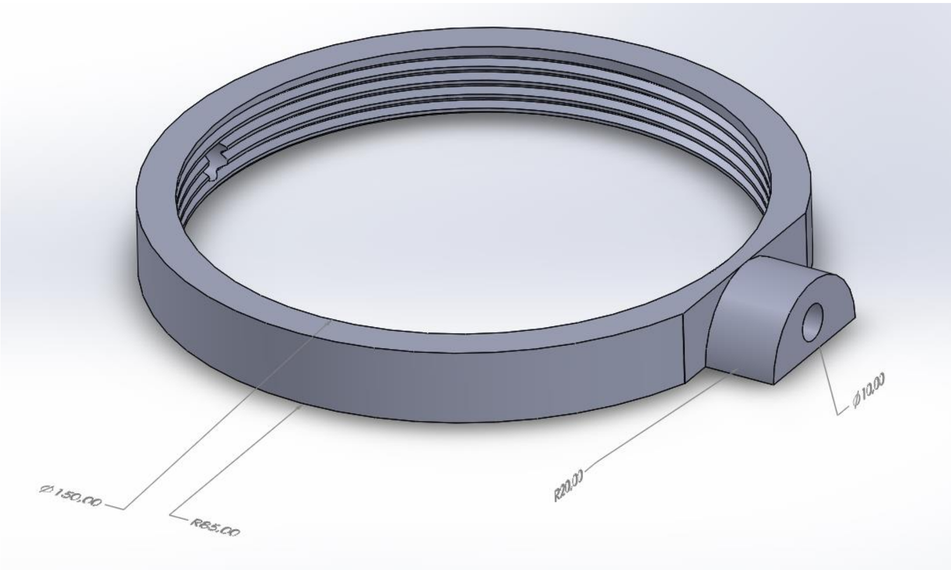
The outer ring serves as the rotational disc for Axis 3 rotations. The rotations are measured via a connected measurement device. There are two sets of 10mm diameter holes on this ring to connect it to both the stage and to the inner ring.



<u>Figure 3-15: Outer ring part</u>

<u>Inner ring:</u>

The inner ring serves the rotational disc for Axis 2 rotations. The rotations are measured via a connected measurement device, much like the outer ring. There is only one set of 10mm diameter holes on this ring to connect it to the outer ring. This ring allows the sample holder to rotate into it via the rotational indentations.



<u>Figure 3-16: Inner ring part</u>

Sample holder:

The sample holder will be used to secure and easily transport the 10mmx10mm glass plate which will have the ice sample attached to it. This holder will rotate into the inner ring, allowing a secure fit and the Axis 1 measurement to take place. Although not displayed on figure 3-17 below, the sample holder will have grooves whereby the glass plate will be secured in the sample holder.

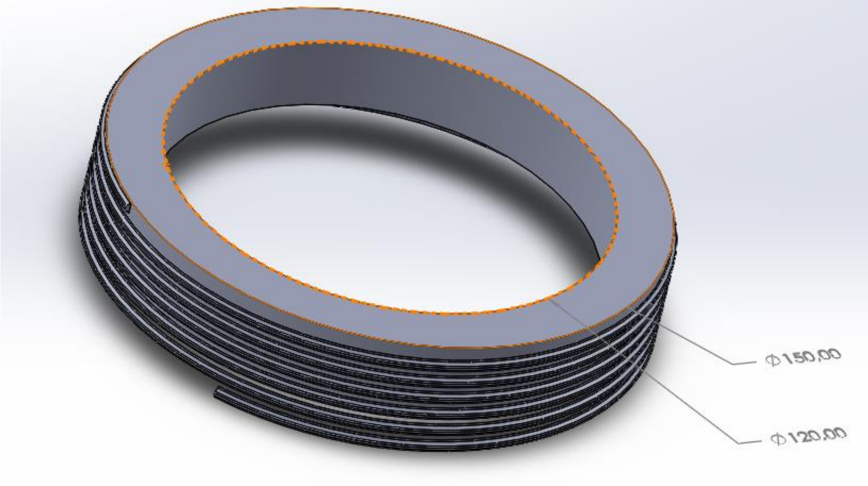


Figure 3-17: Sample holder part

Connecting pieces:

Two sets of connecting pieces will be used to connect the inner ring to the outer ring, and then the outer ring to the stage (on a different axis). The connecting pieces are 10mm in diameter and 30mm and 40mm long for the inner and outer connectors respectively. These connecting pieces will importantly be able to allow the rings to rotate into place, however be rigid enough to maintain the rings' positions during the observation process.

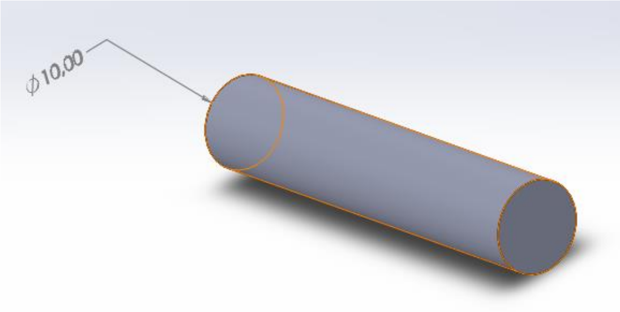


Figure 3-18: Connecting piece part

Assembled Rigsby Stage:

Figure 3-19 below shows the construction of each of the previously explained parts that will be created by the mechanical engineering workshop. This assembly will still require some extra construction of basic pieces before it is a fully operating Rigsby Stage.

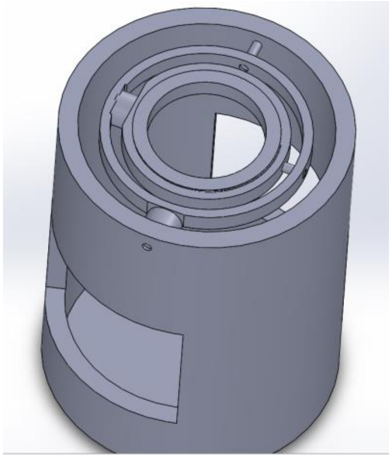


Figure 3-19: Assembled Rigsby Stage

3.4.3. Design Drawings:

The design drawings were done using SolidWorks, to give the mechanical engineering workshop personnel a proper understanding of the dimensions and assembly associated with each of the individual pieces used to make the Rigsby Stage. The drawings are attached in appendix 1.

3.5. Costing

Once the design drawings and materials were sent through to the mechanical workshop, an initial quotation was received. This quotation came in two stages. The initial stage focused on the material costs. The material quotations were given as follows:

- Material for rings:

Aluminium: 275x275x25 @R1,320 per ring.

- Material for the casing:

Aluminium: 330 diameter x 400 length @ R14,450

Nylon: 300mm diameter x 400 length @ R7,000

The material costs for the rings were approved. These costs were steep, yet justifiable, given the material requirements for the sample holder rigidity, low thermal expansion, and good dimensional stability.

The material costs for the casing, however, could not be justified. Therefore, to cut the costs, it was decided that the casing would be made from PVC plates and constructed into a square box. The material characteristics of the aluminum box were not as necessary, and PVC would be less expensive. The construction and provision of materials for the lightbox were kindly provided for free by Pierre Smith of the engineering workshop, once again significantly cutting the project costs.

Once the material quote was approved, a final work quote from the mechanical engineering workshop was provided:

Quotation					
	TIME	RATE			
CNC Machinig time	5hrs	R400 per hour	R2 000	CNC machine two rings	
Convensional machine time	2hrs	R300 per hour	R 600	Machining of threaded ring	
Consumables					
Labour time		R300 per hour			
Material	R3 836		R 3 836,00	three aluminium pieces	
Welding		R250 per hour			
Welding consumables					
Inter departmental CNC mach time		R300 per hour			
Transport		R 200			
				TOTAL	
PAINT					
Sub Total					
Total			**R 6 436**		

Figure 3-20: Quotation for construction of Rigsby Stage

Lighting costs:

Order summary

LED Power Supply - IP67 Meanwell 12VDC 60W / 100W / 150W × 1 — R 546.00
60 Watt

LED Striplight 12V - 3528 Waterproof (5M Roll) - Cool White & Warm White × 1 — R 419.00
Cool White (6000K)

LED Strip Light Connectors (3528 & 5050) × 3 — R 60.00
3528 (8mm)

Subtotal	R 1,025.00
Shipping	R 0.00
Taxes	R 133.70
Total	**R 1,025.00 ZAR**

Figure 3-21: Receipt for lighting materials

All these quotations were sent to Co-supervisor Dr Keith MacHutchon, who gave the preliminary go ahead. The final approval was then granted by Professor Sebastian Skatulla. The R6,436 would be covered by an interdepartmental invoice sent from one department (mechanical engineering) to the other (civil engineering). The remaining R1,025 was personally financed and claimed back as expenses connected with the Honors thesis from the department. To do this, a vendor request was submitted. This is a tedious process but is necessary as UCT has become more vigilant due to the rise in incidents of fraud. Bank documents and a detailed receipt of the transaction was provided to Ms Verster who assisted with this process.

3.6. Construction

As stated previously, the construction process for the majority of the device was solely undertaken by the mechanical engineering workshop. This construction was done under the supervision of Pierre Smith, who provided constant and important feedback and knew the vision of the device. This allowed for a seamless construction period which lasted 7 days. The figures below show the construction process within the workshop.

Figure 3-22: Aluminium rings were machined in the workshop

Figure 3-23: Outer Ring machining

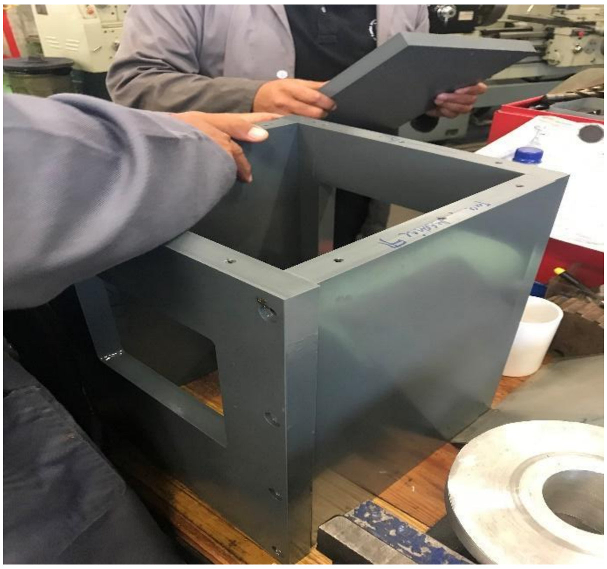


Figure 3-24: Stage was constructed with PVC pieces in the workshop

Once the mechanical engineering workshop finished the major construction, smaller additions were personally integrated into the device to complete it.

These additions included:

Sample holder clamps:

Two precautions were implemented in the device construction to ensure that the sample will remain fully secured throughout the entire testing process. The first precaution was a 10cm x 10cm ridge that was machined into the aluminium. This ridge provides a secure "hole" for the sample to settle into. The second precaution is four clamps that are placed on each corner of the ridge. These clamps can be loosened and tightened with an allen key. Once the sample is sitting within the ridge, all four of the clamps are tightened into place, safely securing the sample during all possible ranges of movement. Figure 3-25 below shows the ridge and clamps implemented into the sample holder.

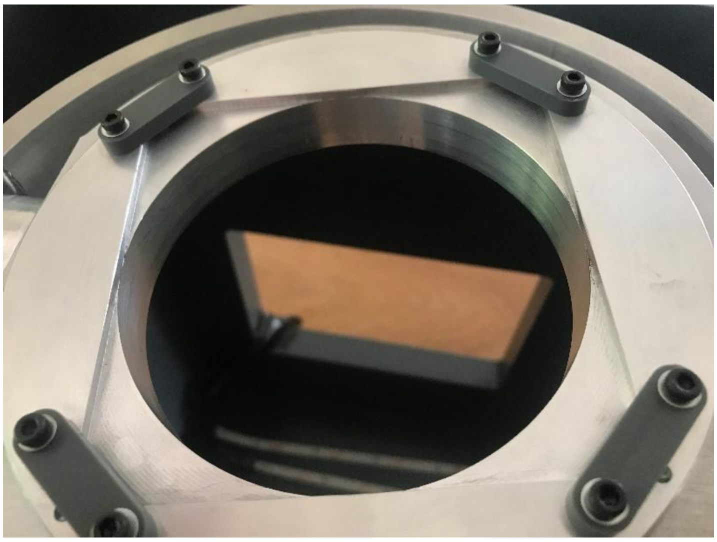


Figure 3-25: Sample holder

Light source

It was decided that the light source would be LED strip lighting. The reason for this choice of light source is explained in section 3.1.4. The 5m long light source was placed into the light box. A high quality 12V- 3528 Cool White LED strip light was used. High quality strips are manufactured with top-tier authentic electronics and premium grade LED diodes. By using premium LEDs, you get higher luminous flux, longer life, and better color temperature consistency. Manufacturers of this strip lighting used a lead-free Hot Air Solder Leveling (HASL) technique (soldering) to protect the environment and stabilize the welding pots. These strips are also waterproof.Considering the cold room and ice related testing samples, this is an important characteristic.

This LED Strip Lighting operates at a low temperature which allows it to be used for this application without any malfunction. Low-grade LED and low-grade electronic components will result in light decay acceleration, which could potentially jeopardize the results of experiments.

The supplier of the lighting has backed the quality by providing a product warranty. This warranty lasts for 2 years. The power source is an IP67 Meanwell 12VDC 60W. This power supply will be contained in the light box. An important characteristic for the power supply is that it is waterproof, thus there is no risk of damage from water falling from the top of the Rigsby stage onto the power supply.

Figure 3-26: Lighting power supply

Meanwell is a global leader in LED Power Supply products and their quality is well known.

Specifications:

- Wattage: 60 Watt
- Input Voltage: 90 to 264Vac
- Output Voltage: 12Vdc
- IP Rating: IP67 Waterproof
- Operating Temperature: -30°C to 70°C
- Dimensions: 163 x 43 x 32mm

Figure 3-27: LED lighting used for Rigsby Stage

Voltage	12Vdc
Length	5 Meters
Power	4.8 Watts per Meter
LED Type	SMD 2835, 60 pieces per meter
Cutting Unit	5 cm
Dimensions	10mm x 3mm
Colour Options	Cool White (6000K), Warm White (3000K)
Operating Temperature	-25° to +40°C
Waterproof	Yes, IP65 Click for the non-waterproof option
Max allowable single length	10m

Table 3-3: LED lighting specifications

The light strips were cut in the designated areas and connected using the purchased light strip connectors. This allowed the lights to bend and thus fit more lighting into the light box. Figure 3-28 below shows the positioning of the lights within the light box.

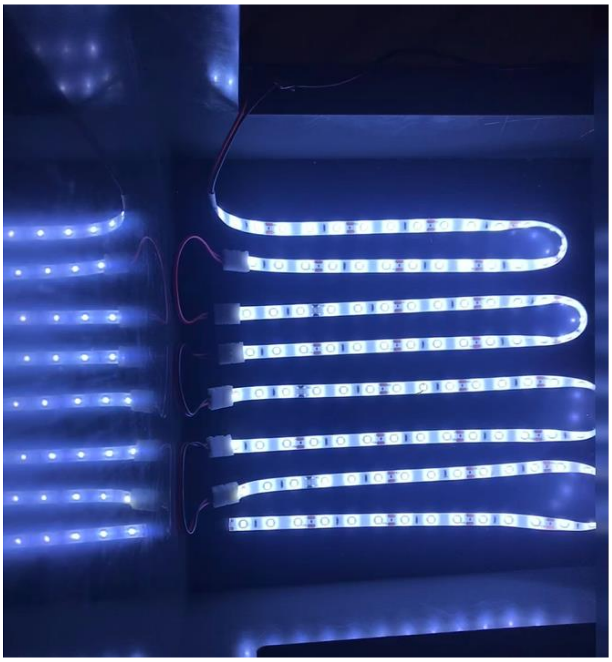


Figure 3-28: Lights positioned in rows within the light box

Further construction required:

Due to time limitations, the following construction was unable to take place, however the requirement of the construction piece will be described.

Pointer and a degree scale for the measuring devices

The device was designed and constructed to have aluminium cuttings that can allow a scale to be inserted and used as a measurement device. One of these parts is shown in figure 3-29 below.

Figure 3-29: constructed axis of measurement for A1

An unforeseen issue was presented, whereby due to the location of the center of rotation of the axis within the semi-circle, the readings were not constant and the axis itself was being displaced upon rotation. To fix this problem, a protractor plate concept was proposed to tackle the two problems at hand:

(i) Attach a measurable scale to the device

(ii) Create a new center of rotation

This solution is shown in figure 3-30 below

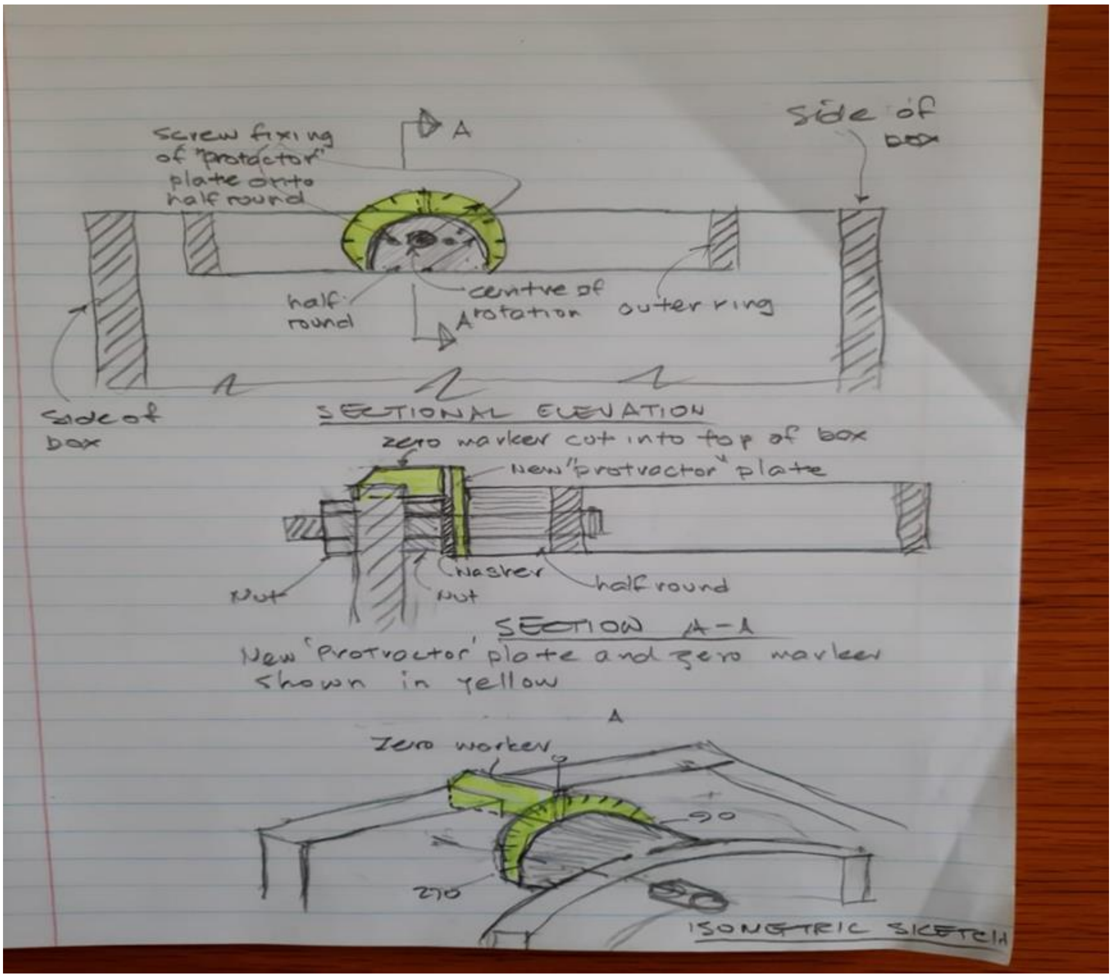


Figure 3-30: Sketch of solution to axis measurement issue.

Polarizing film

The purpose of this film was explained previously in section 3.1.4. It is recommended that a thin polymer sheet will cross the middle of the stage and be secured in the opening provided during construction.This is highlighted in figure 3-31 below. The orange arrows in the figure show the location that the sheet will lie across the device

Figure 3-31: Opening and location for polarized film

A hole will be created within the center of this polymer covering. This hole will allow light to shine from the lights in the light box towards the sample without being restricted by the non-transparent polymer covering. This hole will then have the polarising film placed and secured above the polymer sheet. Therefore, all the light that reaches the sample will have undergone the polarising process. The polarising sheet that will be used has already been acquired and is depicted in figure 3-32 below.

Figure 3-32: Polarized film sheet

A second polarising sheet will then have to be placed above the sample for the full optical process to be undertaken. This polarising sheet can be placed on a stand.

Clear plastic covering with a grid like distribution

This covering shall be placed above the sample and secured into position with the same clamps used to secure the glass sample holder. The plastic must be etched with a centimeter grid for direct grain-size measurements. This grid will be helpful to systematically work through the high quantity of readings for all the grains in an efficient manner(i.e., square A1 first then A2 etc.). Langway used an identical concept as shown in figure 3-33 below.

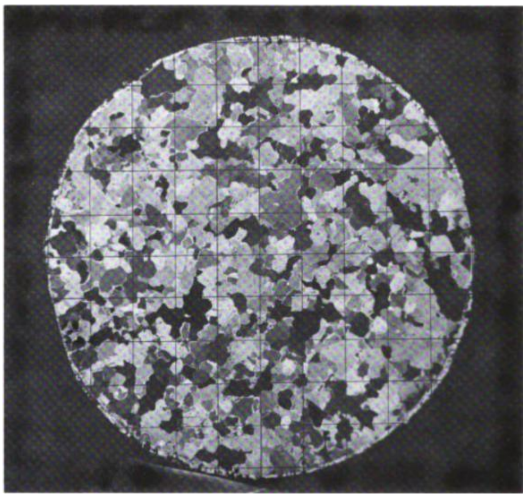


Figure 3-33: Transparent covering with centimeter grid (Langway, 1958).

3.7. Device reliability testing

Before the Rigsby Stage can be used in a research study it is important to determine whether the device has effectively provided a solution to the problems that required its initial construction. Furthermore, it requires reliability in its ability to perform analysis. This reliability means that its margins of error are considered and accounted for. As stated previously, it is believed that the total error shouldn't be greater than 5°.

The test is as follows:

The device will be categorized based on its ability to first meet the general functional requirements needed for a fully operational device. Once these general requirements are shown to be of the required standard, the device's ability to solve the problem statements described in section 3.1 will be assessed. The third and final stage of testing will use the four margins of error that Langway proposed and assess whether this device shows any outstanding issues within the following error source. These sources of error are listed below.

(1) The error in measuring the exact extinction position at high angles, and

(2) the possible parallax effect when the eye is not quite normal to the plane of the thin section and in line with the grain being measured.

(3) the measuring error in reading the values from the A1 and A2 axes of the stage, and

(4) the inherent mechanical error of the universal stage itself (reproducibility of readings from the same grain is usually between 1 ° and 2°).

When all the above sources of error are considered, it is believed that the total error shouldn’t be greater than 5° (Langway, 1958).

Given the non-existence of any preexisting Rigsby Stage reliability testing conventions, the test will be self-created based on the source of error principles highlighted by Langway above. Please note there isn’t any way to test the reliability fully without the use of a second Rigsby Stage to cross check the same samples.

Testing stage 1: General requirements

Requirement	**(pass/fail)**	**Description**
No external light that can be mistaken for light source	pass	Only available light source perpendicular to sample is from polarised light source. Remaining is blocked by plastic sheet.
Double polarisation of light source	pass	Double polarised sheets placed between light source and sample.
Can clearly see sample subjects	undetermined	Ice crystals must be visible upon test, however didn’t have access to polar lab to perform the test.
Sample remains in place through all movement possibility	pass	Sample is firmly secured by clamps
Sample won’t overheat and deform during experiments	pass	Heat from light source doesn’t reach sample. Aluminium absorbs cold temperature from environment.
Appropriate axis rigidity	fail	Axes A1,4 and 5 remain rigid when in position. A2 requires further stabilising
Full range of axis movement	pass	Full range of A1,2,4 and 5 movement
Appropriate waterproofing of light source and wiring	pass	Wiring insulated; lighting has silicone protection. All waterproofing of IP67 rating.

Table 3-4: Testing stage 1: General requirements table

Testing stage 2: Problem statements

Problem Statement	**(pass/fail)**	**Description**
High performance in a sub-zero environment	Undetermined	No deformation of material, lighting and battery operate at -25 and -30 degrees respectively. However, unable to test in polar lab.
Relatively high level of durability	pass	Casing is high durability PVC.Aluminium rings very durable.
Cost effective	pass	Costs reduced where possible. PVC casing was free (provided by workshop).
Accurate axis movement and measurements	fail	Axis movement is sufficient; however, the measurement is insufficient due to the location of the connectors in relation to the axis. They were not placed within the center of the semicircle axis of movement.
Efficient and coherent	pass	.The device operates at maximum possible efficiency, without any blockages.

Table 3-5: Testing stage 2: Problem statements table

Testing stage 3: Source of error

Source of error	Within parameters ?	Description
Error in measuring the exact extinction position at high angles,	pass	All angles measurable and accurate from 0 to 180 degrees (180 to 360 not required)
Possible parallax effect	Pass	No excessive parallax effect observed
Measuring error in reading the values (A1 and A2 axes)	fail	For same reason that failure occurred in the “Accurate axis movement and measurements” section.
Inherent mechanical error of the universal stage	pass	Stage constructed with high grade machinery, by professionals.

Table 3-6: Testing stage 3: Source of error table

Due to the time restrictions from the completion of the stage by the mechanical engineering department certain problems were unable to be fixed. Thus, the provided device can be considered a prototype device. The device doesn’t pass all the requirements and is thus not fully reliable for university experimentation. Once the final device is constructed, the provided test above can be used to legitimise the reliability of the device.

3.8. Improvements

As stated in the previous section the device was unable to be fully completed in the given timeframe. The device testing stage also highlighted some problem areas. For that reason, the following improvements are recommended to be made on the device.

Improvements necessary for device use:

1. Rigidity of A2 axis

A solution was found within the connectors of the rings to address the axis rigidity problem. Due to the nature of the build, two different solutions are needed to be found for the inner and outer rings respectively.

The outer rings utilised a bolt that had an adjustable nut. This created a tensile like force between the outer ring and the stand. This tensile force was strong enough to hold the outer ring in place once in position, however not too strong that the ring could not be rotated further. The bolt can be tightened further if it were to lose this tensile strength over time. This setup is shown in figure 3-34 below.

Figure 3-34: Outer ring setup to create rigidity

The inner rings unfortunately lacked the ability to utilize this same design due to the limited space between the inner and outer ring. Although construction was unable to take place it is recommended that the same concept of tensile force creation should be utilised for the inner rings. A recommendation would be to use rubber stoppers and compress them to create tension. These stoppers could then be placed in the points indicated below in figure 3-35. This tensile force would also be heightened by roughing the aluminium connectors that the rubber rings would be placed on. The tension once again would be strong enough to hold the inner ring stationary, however not strong enough to be unable to rotate the ring.

Figure 3-35: Location for rubber stoppers on inner ring connector

2. <u>Need a portable light source:</u>

   The device requires a light source to shine through the polarised filters towards the sample in order for experiments to be performed. However, this is impossible if there is no power point for the light source to be plugged into. This power point certainly won't be available if the device is being used on a field work session in the poles. To address this problem, I would suggest a polished stainless-steel sheet is attached to the bottom hinged door of the base, similar to the one depicted in figure 3-36 below. This sheet would be used to reflect light and transmit it through the instrument during field use. This idea is inspired by Langway's design, detailed in section 3.1 of this report.

Figure 3-36: Reflective stainless-steel sheet recommended for reflection

3. <u>Wiring needs improvement:</u>

   The wiring for the light source is currently vulnerable to damage and then potentially water damage. The wires are currently insulated by a wrap of insulation tape. This is, however, not particularly durable, and damage could result in a water leak. If this device is to be used on the field, I would recommend proper insulation and soldering of the wires where the power source connects to the LED strips. Figure 3-37 below shows the current insulation being used (left) and the insulation that would be recommended for a device in these conditions (right).

Figure 3-37: Current insulation (left) vs recommended insulation (right)

4. Dimmer for lighting:

To perform tests the operator needs to look directly into the light source, this could cause some discomfort to the eye over a long period. To balance this problem a dimmer could be implemented in the lighting system. This dimmer could adjust the lighting to a point where the crystal orientations are visible with the light reducing its harshness.

5. Camera:

In conjunction with the fabric diagrams, a camera and camera holder could be placed above the sample holder to record the c-axis orientations. This camera will give a graphical data bank of the different crystal orientations that can be referred to and collated for an improvement in the experimental process. The stand recommended is shown in figure 3-38 below. This is the stand used in Lange's Rigsby Stage setup

Figure 3-38: Recommended camera stand layout (Lange, 1988)

4. Device implementation

4.1. Final device

The device presented differs in many ways to the original design. This was due to change in circumstances and advice by the professionals during the construction process. This device can be considered an initial device as it is not entirely complete. The further required improvements are listed in the improvement section 3.8 above.

The device to be presented upon submission of the research project is pictured below.

Figure 4-1: Rigsby stage submitted upon completion of project

The device completes the following purpose to an effective standard:

The provided Rigsby Stage allows for high quality observation of c-axis orientations within thin ice samples. The Rigsby stage can operate at an optimal performance up to a temperature of -25 degrees Celsius. This high tolerance for the cold environment allows it to observe the ice samples at a temperature that is optimal for the sample to maintain its solid state.

4.2. Thin ice analysis procedure using the Rigsby Stage

This section highlights the various procedures that are to be undertaken to acquire accurate results from a Rigsby Stage experiment.

Preparation of thin ice samples:

The method used to prepare the thin ice samples is outlaid in the literature review of this report, however a brief description will be repeated. The preparation of thin sections requires a cold area of about minus 10 degrees Celsius. For that reason, the UCT mobile polar lab will be used for both the process of sample preparation and research.

UCT purchased a microtome that arrived on the 17th of October 2021 in preparation for the construction of the Rigsby Stage. This microtome will use a slab of ice cut from an ice core and slice it down to a thin section, only 0.5 mm thick. The upper part of the machine with the microtome knife moves back and forth, each time removing a thin layer of ice. This glass slide with the thin ice sheet is then removed from the cutting machine and placed into the Rigsby Stage sample holder and appropriately secured. The sample holder is then rotated into the first ring and is ready for analysis.

Procedure for orienting a crystal with the universal stage.

There is no standard or proper way to orient a crystal when using the universal stage. This is because each investigation involves different considerations. The following procedure is an attempt to establish the simplest and most efficient technique to orient an ice crystal in our sample (Langway, 1958).

Optical measurement of ice crystals

With ice crystals, either the optic axis is oriented parallel to the line of sight and referred to as the polar position, or the plane normal to the optic axis is oriented in a vertical position parallel to the A2 axis, referred to as the equatorial position. The A1,2,4, and 5 axis orientations are the same as previously listed.

Step 1 – Set the horizontal axes (A2, A4) at zero readings. Thus, the rings will all be flat in resting position.

Step 2 – Select a particular ice grain for measurement and rotate on the A1 axis until it disappears.

Step 3 – Test that it remains extinct by rotation on A2. If the grain departs from extinction, return A2 to zero; rotate 90° on A1 to the alternate extinction position and test again to see if the grain remains dark upon rotation of A2. In this position, it will remain dark, indicating that the east-west plane contains the optic axis.

Step 4 – Rotate A4 15° to 20° (or as much as necessary to illuminate the grain) and then rotate A2 to an extinction position.

Step 5 – Return A4 to the zero position, then rotate approximately 45° on A5. If the grain remains dark, the optic axis coincides with the line of sight (polar position). If the grain becomes illuminated, the optic axis is normal to the line of sight and A2 (equatorial position).

There are, however, two special orientation cases that commonly occur, these are:

6. When in its initial position, the crystal remains dark for all positions of A1.

This indicates that the optic axis is parallel, or nearly so, to the line of sight. However, because of the difficulty of estimating the entirety of the grain's extinction, it should not be assumed that the axis is exactly parallel to the line of sight.

The following additional steps are recommended:

a. Rotate on A2 until grain is visible.

b. Rotate on A1 until it disappears again.

c. Return A2 to zero, retaining the A1 position.

d. Continue with steps 4 and 5.

2. When step 3 gives extinction in both A1 positions. This indicates that the optic axis is normal to the line of sight.

The following additional steps are recommended:

a. With the grain at one of the two extinction positions, rotate A4 until it illuminates the grain.

b. Depress A2. If the grain remains dark, the horizontal optic axis lies in the north-south plane; if extinction is lost, the horizontal axis lies in the east-west plane.

c. Either extinction position may be recorded on the fabric diagram. We do however want to be consistent in the readings, thus when the horizontal axis does not lie in the east-west plane (parallel to A4), rotate grain 90° on A1. This procedure simplifies the plotting of each reading on the diagram.

Keeping the line of sight normal to the plane of the stage and vertically over the crystal being measured is difficult without some type of an eye alignment apparatus.

Since the Rigsby Stage doesn't have anything provided to align your eye, it is helpful to place your eye directly over the grain being measured and match your line of sight with your eye image, which is reflected from the top of the analysing polaroid. Care should be taken to pursue this technique because of the possible error in locating the exact extinction position, especially at the higher angles of inclination.

After the individual grain or crystal has been measured on the universal stage, the data should be tabulated so that the angular corrections can be made, and the information can be transferred readily to the Fabric diagram.

Fabric diagrams

Fabric diagrams are the diagrams used to record the readings from the tests that are undertaken with the Rigsby Stage. The diagram ends up being a hand drawn representation of the orientation of the optic axes of the individual ice crystals. When enough optic axes show a certain non-random orientation (a clustering of points on the diagram), it is said to have a preferred orientation. We can assume that this is a statistical preference by counting the number of points that fall within areas corresponding to a given percentage of the whole projection — commonly 1%. From many such values, contours may be drawn to show orientation density.

At least 200 axes should be plotted if a reliable statistical analysis is to be made. If the section shows a very strong pattern, as revealed by inspection, it is possible to use fewer points. However, it is usually advisable to plot at least 200 axes; then, if an axis is not correctly read or plotted, little statistical significance will be attached to this point (Langway, 1958). The fabric diagram is shown in figure 4-2 below.

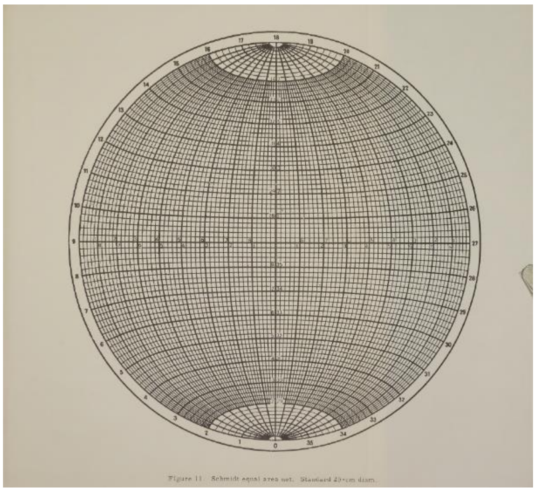


Figure 4-2: Fabric diagram

4.3. Analyzing the Results

Given the time constraints and availability of the mobile polar lab, an experiment with the constructed Rigsby Stage was unable to take place. However, the following section will highlight the data processing procedure and what the different readings could indicate about the samples within a real experiment. This section will hopefully provide any future researcher with a general idea of how to approach and interpret the data of a future study.

As explained above, the c-axis orientations are recorded on a Fabric diagram. Once about 200 axis recordings have been undertaken, we can consider the fabric diagram to be an accurate model of the ice sample. It is then assumed that the researcher has a full understanding of the ice crystals present (Iliescu, Baker and Chang, 2004).

With this knowledge, it is assumed that the orientations of ice crystals in an ice sheet both reflect and affect its flow and are an indication of whether they underwent one of the following three processes:

(1) polygonisation, in which the grains split into two, separated by a sub-boundary of a few degrees of misorientation.

(2) recrystallisation involving nucleation, in which new random orientations appear.

(3) either strain-induced boundary migration or grain growth, in which grains grow, but no new orientations appear.

We can test whether boundary pinning, recrystallisation involving nucleation and growth of strain-free grains, or polygonisation is most important by mapping c-axis fabrics. Boundary pinning should preserve a population of grains, causing nearest-neighbour relations from below 100m to be similar to those above, which are random as shown in the next section. Recrystallisation should cause an increase in large angles between c-axes of neighbouring grains below 100m. Polygonisation should cause an increase in small angles between c-axes of neighbouring grains below 400m (Iliescu, Baker and Chang, 2004).

Future research with this device will establish a better understanding of:

A) How the grains form in specific orientations
B) The effect of grain orientations on the mechanics of ice
C) How to replicate grain orientations with preferable ice mechanics.

This creation of ice with preferable mechanics could shape the way in which we help combat the negative effects of climate change on the Antarctic sea ice.

5. Conclusion and recommendations

5.1) Conclusion

In conclusion, the objectives of this report, which are highlighted in Chapter 1, section 1.3 were all achieved. These included the completion of a detailed design, including drawings of the proposed Rigsby device for construction. The design follows a systematic eight-step process. This allows any future researcher to examine each step of the process that was undertaken to produce the device.

In addition to a report outlining the design, a high grade Rigsby Stage device was constructed and is now available to the University of Cape Town for future research and progression of the understanding of ice samples and their mechanics. Due to the high demand of the mechanical engineering workshop, the major construction of the Rigsby Stage was delayed and therefore there was limited time to complete the smaller personal constructions to complete the device. For that reason, the device requires some additional construction before it is recommended to undertake any proper experimentation. These construction recommendations are laid out, along with a suitable explanation on how the constructions should be carried out. A suitable final product analysis and control test of this Rigsby device is provided. Once the final construction additions are completed this test will be available to determine whether the degree of error falls within the suitable 5-degree range of useability.

Finally, this report includes a procedure on how to conduct a thin ice analysis with the Rigsby Stage. This procedure serves as a guide for any future experimentation.

Although the device was unable to be fully completed due to construction delays, this research project managed to complete the major construction process and serves as a guide on all that is needed to be known about the Rigsby Stage.

5.2) Recommendations

The following recommendations arose while undertaking the study with regards to the operation of the Rigsby Stage and interpretation of the provided design.

- Although the device was unable to be entirely completed, a list of improvement recommendations is laid out in the ‘improve’ section 3.8. These include recommendations such as a dimmer, a portable light source, a camera and more. It is recommended that these improvements are made before the device is used in an experiment.
- Once all additional constructions are finalised, a future researcher should undertake the reliability test on the device. This test is provided in section 3.7 to prove its effectiveness in carrying out experiments.
- The testing with this device is a tedious process. The individual readings take some time and at least 200 readings should be done per specimen study for reliable statistical analysis. For this reason, it is recommended that a future upgrade of this device to the Lange’s automated model should be undertaken. This model is briefly discussed in Section 3.2 of this report.

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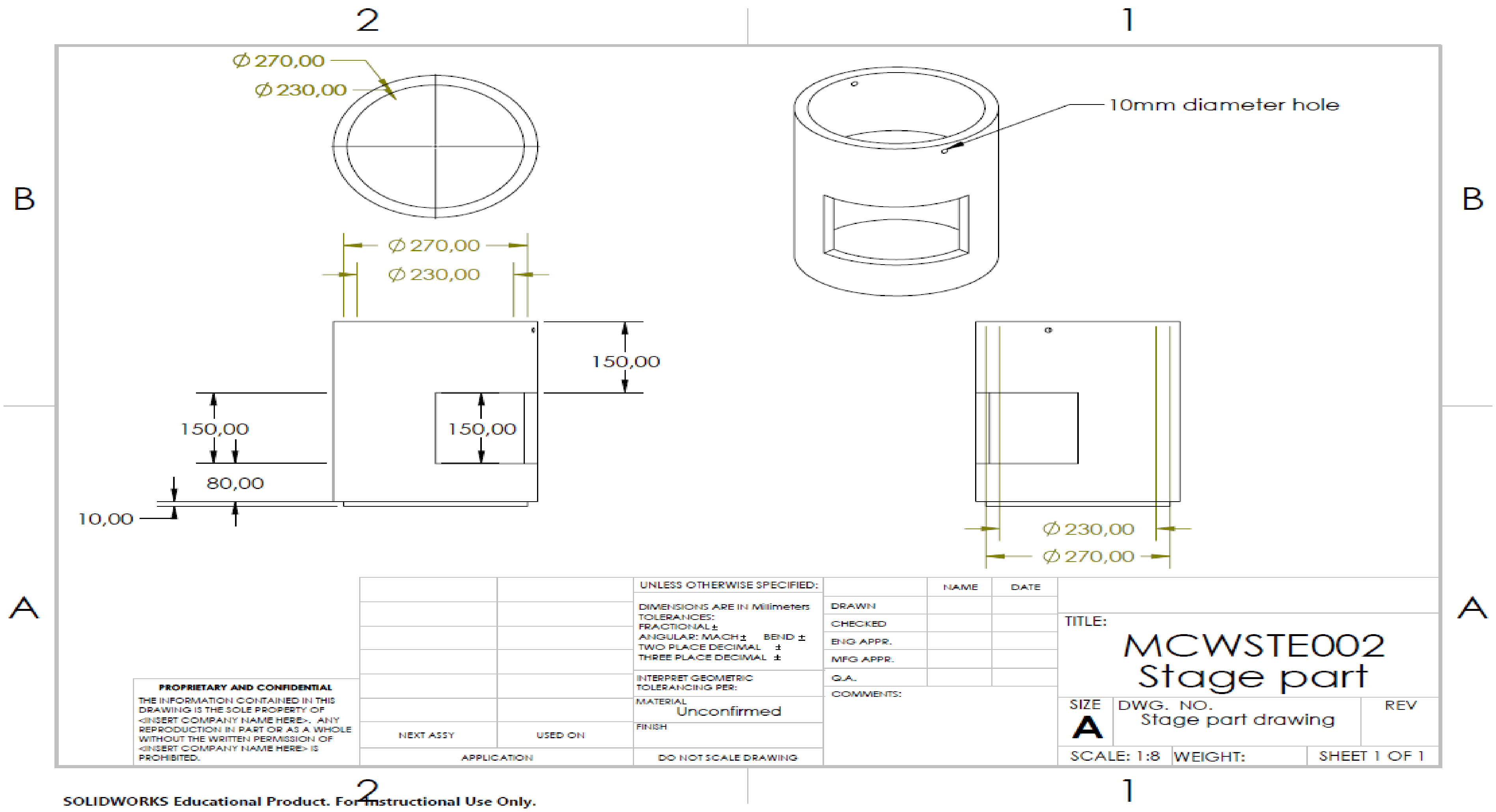
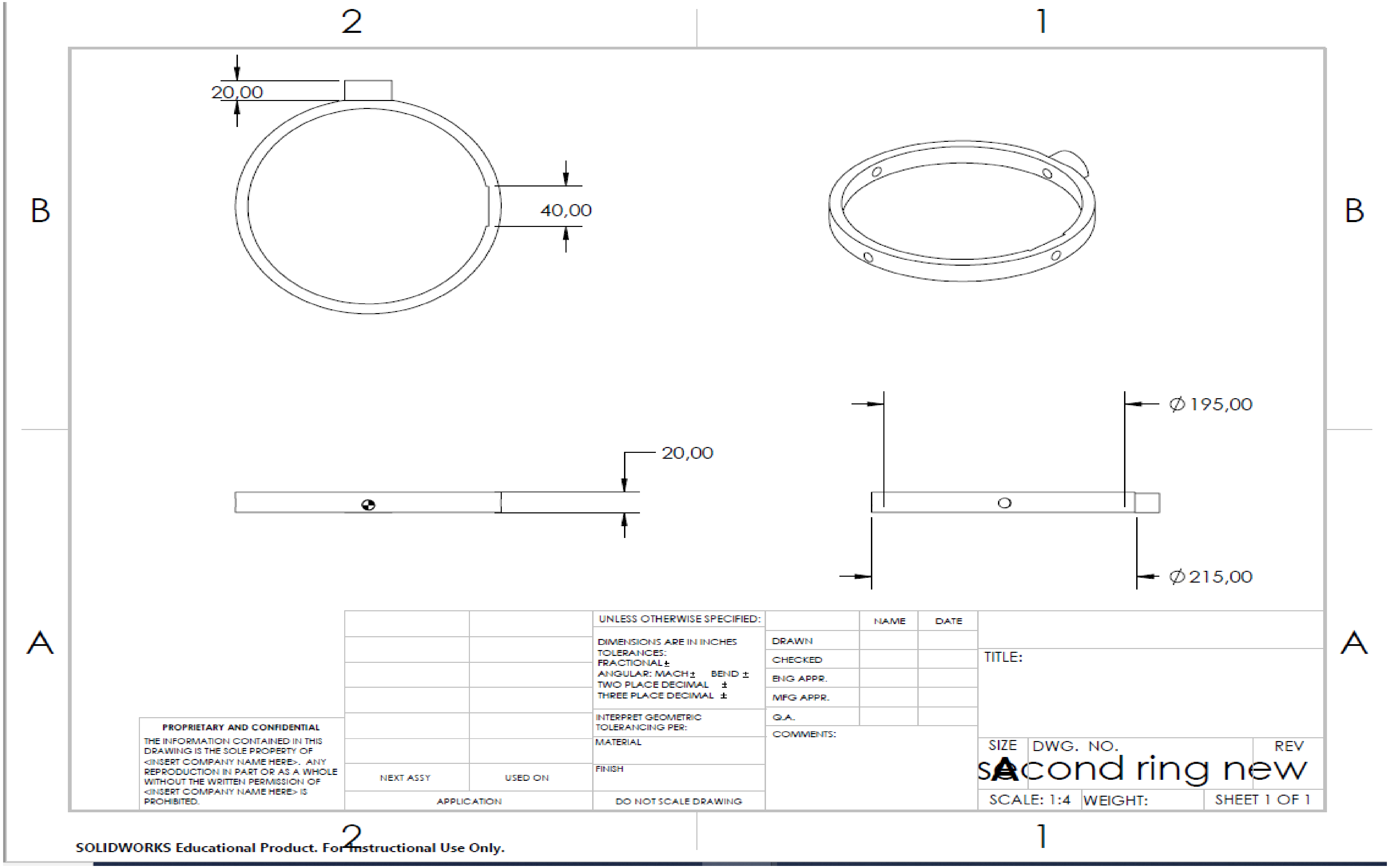
Appendices:

1. Design drawings
2. Ethics approval
3. ESCA Graduate attribute statements

Appendix 1: Design drawings



The design of a Rigsby Stage for the study of thin sea ice sections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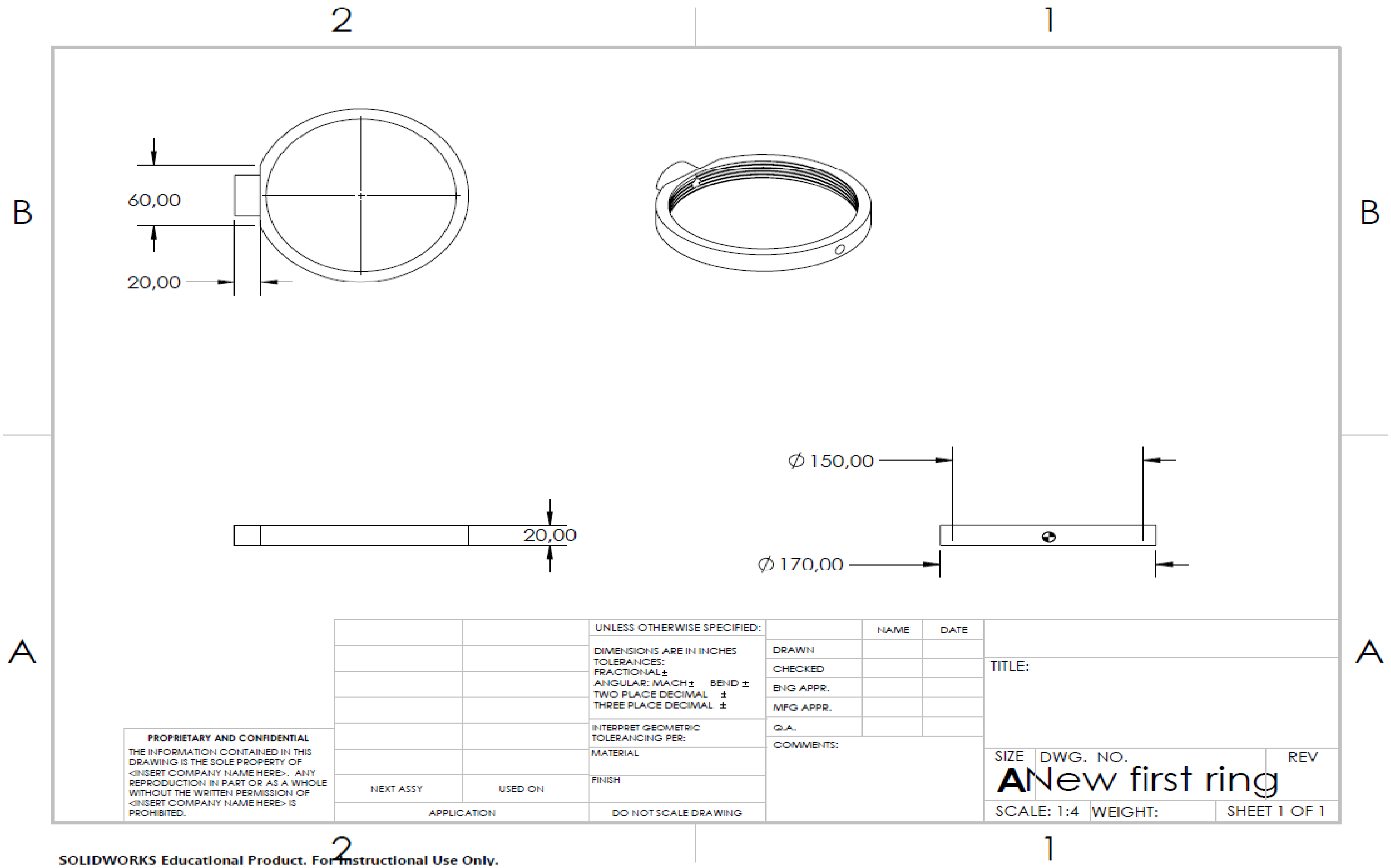
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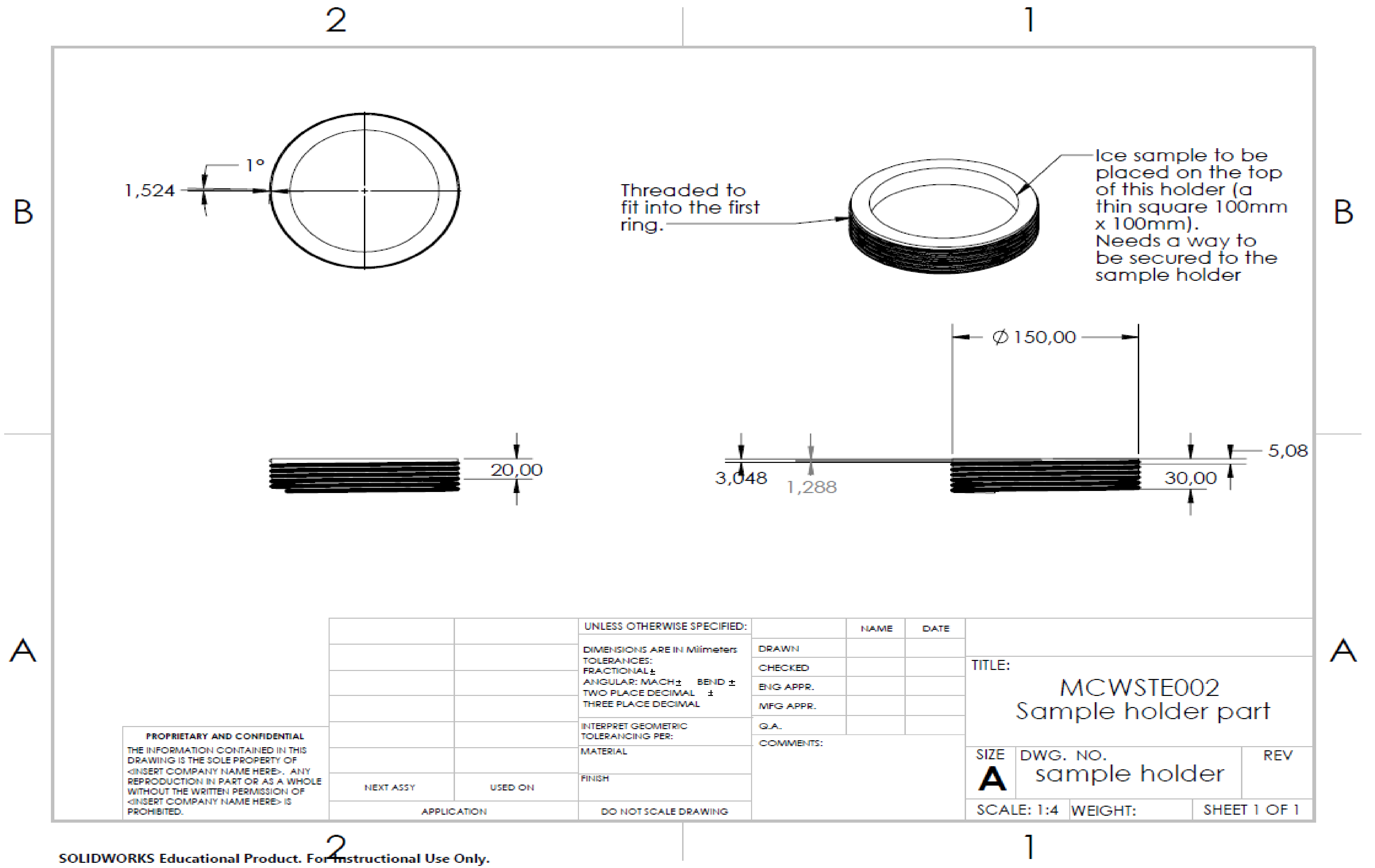
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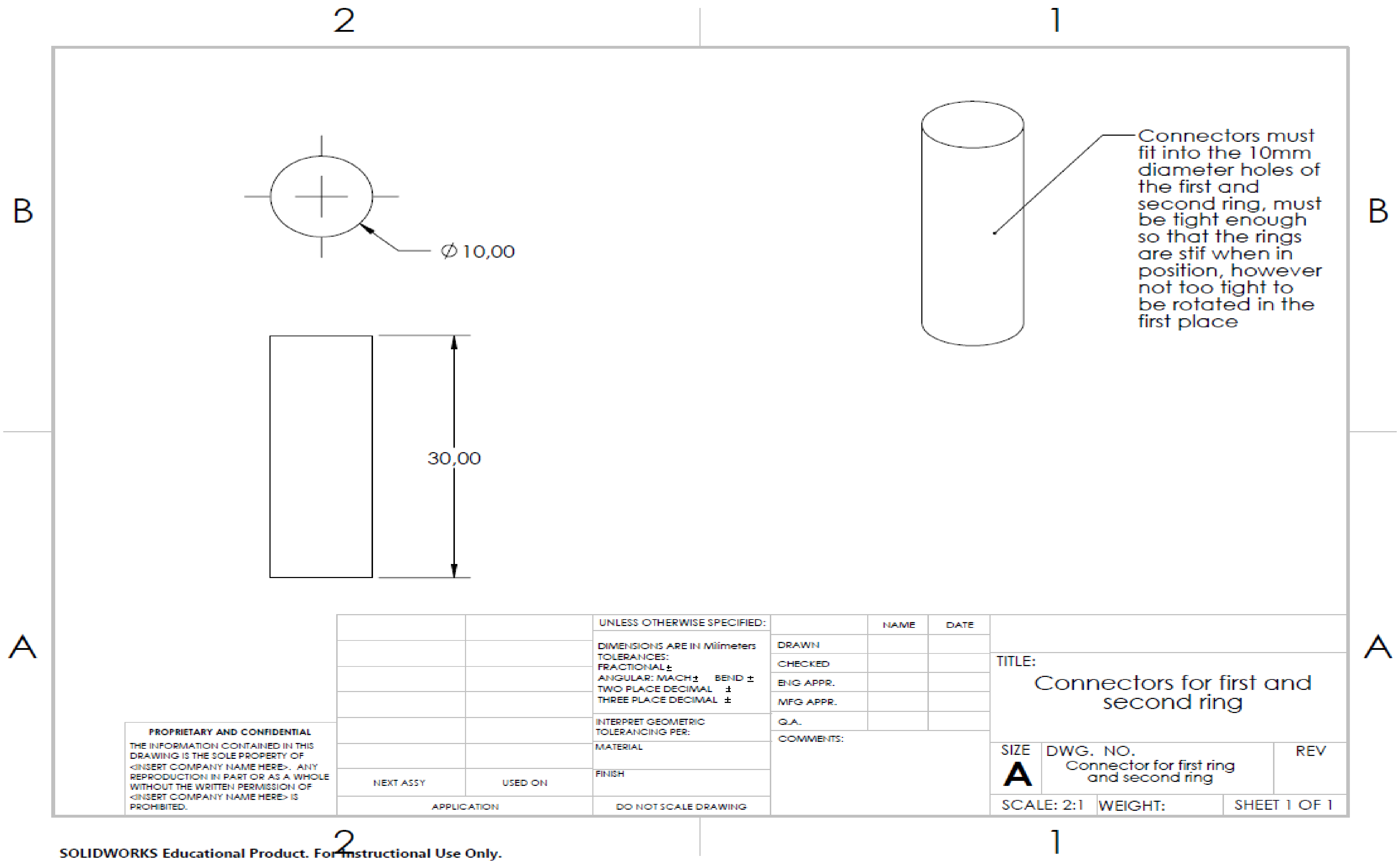

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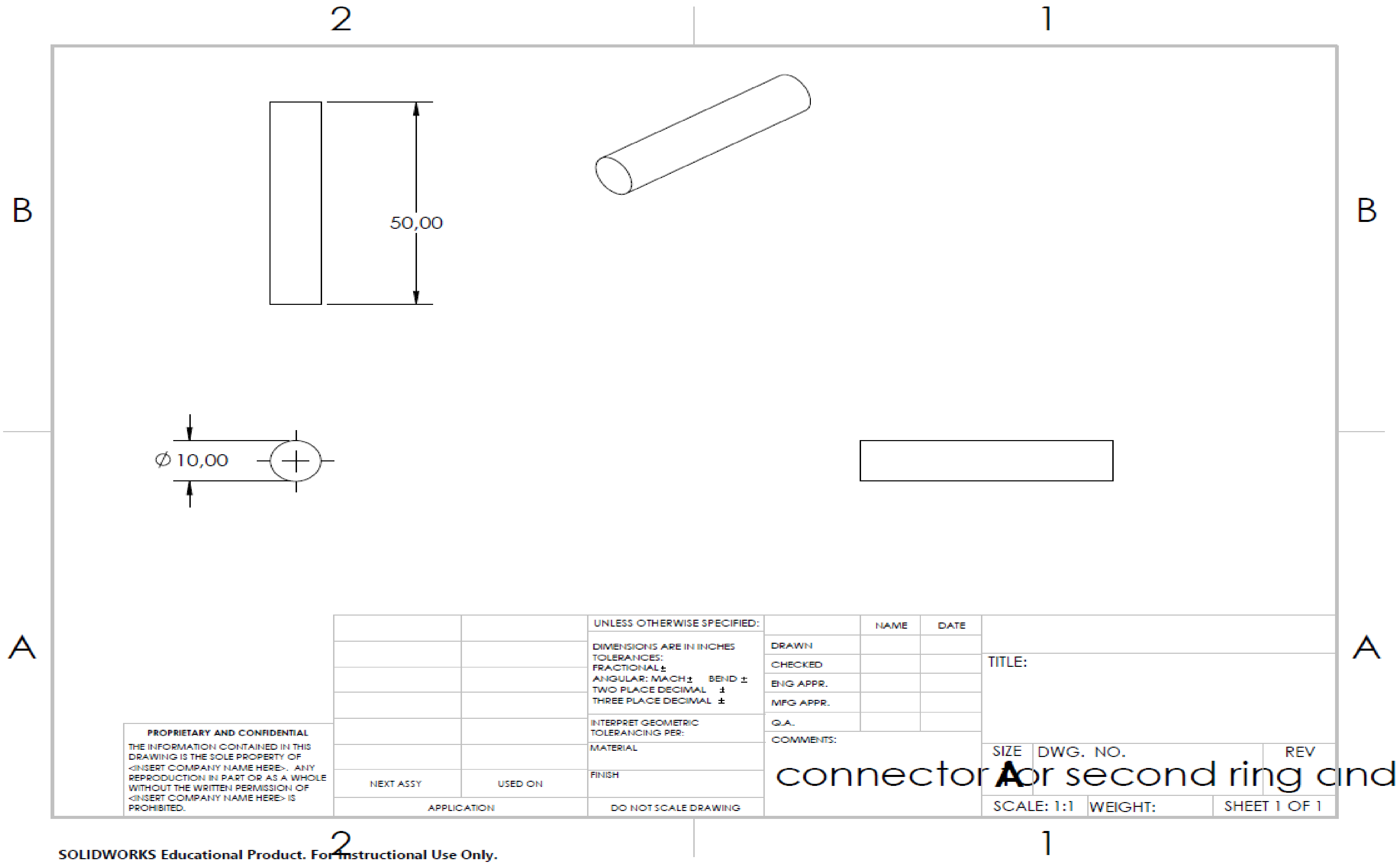
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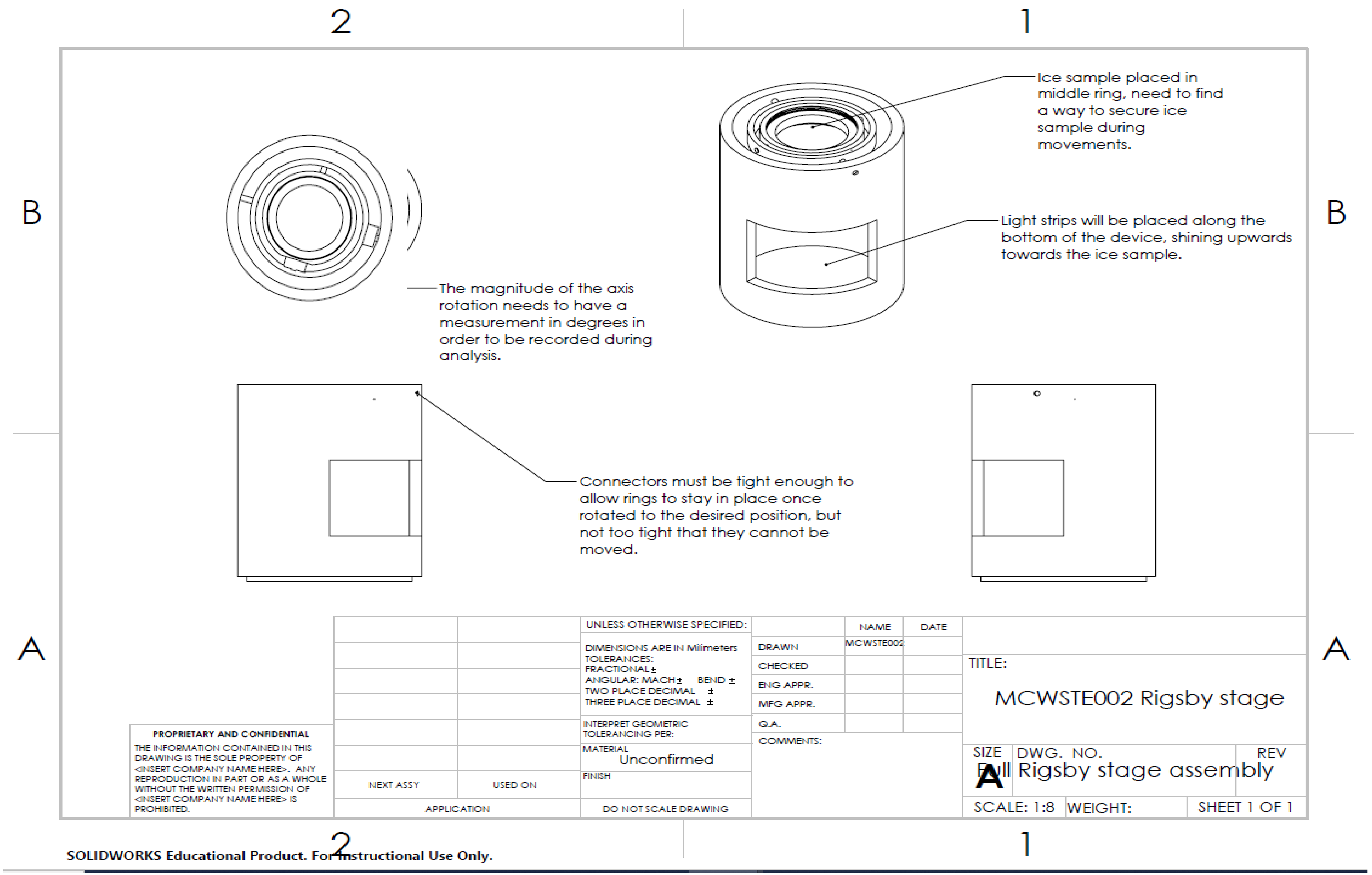

The design of a Rigsby Stage for the study of thin sea ice sections

Appendix 2: Signed Ethics Approval

Application for Approval of Ethics in Research (EiR) Projects
Faculty of Engineering and the Built Environment, University of Cape Town

ETHICS APPLICATION FORM

Please Note:
Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form **before** collecting or analysing data. The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook** (available from the UCT EBE, Research Ethics website) prior to completing this application form: http://www.ebe.uct.ac.za/ebe/research/ethics1

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		Steven McEwen
Department		EBE Civil Engineering
Preferred email address of applicant:		MCWSTE002@myuct.ac.za
If Student	Your Degree: e.g., MSc, PhD, etc.	Bsc Civil Engineering
	Credit Value of Research: e.g., 60/120/180/360 etc.	48
	Name of Supervisor (if supervised):	Dr Sebastian Skatulla
If this is a researchcontract, indicate the source of funding/sponsorship		
Project Title		The design of a Rigsby Stage for the study of thin sea ice sections

I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

APPLICATION BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Steven McEwen		2021/07/20
SUPPORTED BY	Full name	Signature	Date
Supervisor (where applicable)	Sebastian Skatulla		

APPROVED BY	Full name	Signature	Date
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section 1; and for all Undergraduate research (Including Honours).			
Chair: Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the questions in Section 1.			

Appendix 3: ESCA Graduate attribute statements

1. **<u>ECSA Graduate Attribute 1</u>: Problem solving**

Q: Did the candidate demonstrate competence to formulate and solve the CIV4044S problem creatively and innovatively?

A: When the initial problem was presented an eight-step method was laid out to create a device that would solve the problem. This systematic eight-step method included defining the problem and requirements, research and preparation, design and more. Once the device was constructed, a testing procedure was created and followed to ensure the accuracy of the device. This accuracy provided assurance that the device could solve the initial problem effectively. These findings were presented in an appropriate manner and gave a base for further device improvement.

2. **<u>ECSA Graduate Attribute 4</u>: Investigations, experiments, and data analysis**

Q: Did the candidate demonstrate competence to design and conduct an investigation?

A: The eight-step design that was laid out in this report included all essential steps required by another party that was needed to construct a final device. This Device was built by the mechanical engineering department based on the design presented. An investigation was carried out on the completed device to prove the accuracy of the device and thus provide assurance on the reliability for future research with the equipment. The evidence was presented and proved an appropriate source of error. This investigation was used to draw up a conclusion and further recommendations for the final device.

3. **<u>ECSA Graduate Attribute 6</u>: Professional and technical communication**

Q: Did the candidate demonstrate competence to communicate effectively in written form with an engineering audience, and with the community at large?

A: All sections of this project were explained clearly and effectively in a way that is not too basic to be considered an unprofessional document, yet not too complex to be non-understandable to a range of interested individuals. Thoughts and solutions were also graphically depicted to improve the understanding of the reader. None of the concepts used in this project were relayed without the appropriate reference of the ideas' author.

4. **<u>ECSA Graduate Attribute 8</u>: Individual, team and multi-disciplinary working**

Q: Did the candidate demonstrate competence to work effectively as an individual?

A: All individual requirements were completed on time and to the highest standard. The timelines and goals set out in the original research proposal were stuck to without delay. Not only were the individual requirements for this project large, but the nature of the task required involvement of the mechanical engineering workshop. This involvement required a high level of quality communication for both parties to create a device that effectively represented the vision of the designer.

5. **<u>ECSA Graduate Attribute 9</u>: Independent learning ability**

Q: Did the candidate demonstrate competence to engage in independent learning through well-developed learning skills?

A: The content of this research project required far more knowledge and understanding than the previous civil engineering courses provided. This was not a structure or a geotechnical investigation that we had studied in previous coursework. The project required the development of design skills, device construction understanding, fundamental understanding of ice and polar mechanics and much more. These skills were learned through literature searches and communication with colleagues and superiors in other faculties such as the mechanical engineering and the materials department. Once the skills were developed, they were implemented throughout the project's lifespan to provide a functioning device that effectively solved the initial problem.