Sheffield
Hallam
University

Alpine Ski Vibration Analysis

Tom Wills
BSc. Sports Technology
4/11/14

i. PREFACE

This report describes work carried out within Engineering, Design & Technology at Sheffield Hallam University between October 2013 and May 2014.

ii. ACKNOWLEDGEMENTS

First and foremost, I have to thank my supervisor, Sean Clarkson. Without his assistance and dedicated involvement throughout the process, this paper would have been far more difficult to accomplish. I would like to thank you very much for your support and understanding.

I would also like to thank Jess Walrond of Pitney Fabrication. Without his help I would have not have been able to produce the test rig to such a high standard in such a short time span.

I would also like to thank Dr Tom Allen for his constant support and willingness to answer any questions I had. His welcome advice throughout the year has also been a huge help, as he was always happy to offer his expert opinion as to how I should go about completing the study. He also recommended that I apply for a place on the 2013 ISEA Winter School, which was the inspiration for this project.

The project would also not have been possible without the help from Dr George Dixon. His expert knowledge in laser vibrometery and its set up, was invaluable. I apologise for the constant questions but your help is greatly appreciated.

iii. ABSTRACT

The aims of this project are to design and manufacture a test rig to test the vibration damping of downhill Alpine skis. A literature review was conducted in order to highlight existing testing methodologies and the physics behind skiing. A series of skis were then tested to determine the development of skis through to the modern day.

The literature review highlighted an international standard ISO 6267 (International Organization for Standardization (ISO) 1980) that conducted a vibration analysis of the front part of the ski. Work done by (Gary C. Foss 2007) concluded that the frequencies of these vibrations were in the region of 10 – 200 Hz with the first mode of vibration having the largest effect on the performance, as this mode has the largest amplitude.

A test rig was then designed to test to ISO 6267 standards (International Organization for Standardization (ISO)). This rig allowed for skis to be clamped to a test bed with a release mechanism developed to depress the ski and freely release it as stated in the standard.

A set of 9 skis were then tested ranging from 1980s long skis to modern day skis.

The results showed that there was a significant improvement from early skis to modern day skis. There was a small increase in half-life of vibration from 2000 onwards.

TABLE OF CONTENTS

1 TABLE OF FIGURES

2 LIST OF TABLES

3 NOMENCLATURE

Modern day = Skis from the 1980s to the present day.

Length = Total length of the ski.

Toe bindings = The front binding on the ski where the toe of the boot is placed.

Waist Width = Width of the base of the ski at the toe binding.

Tip length = The distance from the toe binding to the tip of the ski.

Tip Width = Widest point of the ski at the tip.

“= Inches

LDV = Laser Doppler Vibrometer

4 INTRODUCTION

4.1 BACKGROUND

This project builds on work I took part in at the ISEA 2013 Winter School in San Vito di Cadore, Italy. This research looked at the work of G. Fanti, R. Basso and V. Montauti on Dampening Measurements of Bending Vibration In Alpine Skis (G. Fanti 2006). We used the procedure to test a set of Völkl Skis with the UVO system; a damping system designed to increase the damping coefficient of the ski.

The ski industry is constantly growing with changes in skis every year. These developments are needed to improve performance and safety of skiing. Vibrations are one factor that can be considered when trying to improve the performance of a ski. The damping of these vibrations also effects performance (Gary C. Foss 2007).

Therefore, this project is to design a procedure to test the Damping coefficient of Alpine Skis and test a range of skis to determine the accuracy of the procedure.

4.2 AIMS

The aims of this project are to design and manufacture a test rig to test the vibration damping of downhill alpine skis. The test rig should be suitable for the lab. The testing should be simple to set up and be able to be completed with minimal training.

4.3 OBJECTIVES

The main objectives of this project are to:

1. Conduct a review and critique of any existing literature that covers vibration analysis in downhill alpine skis. This is shown as D1 in the Gantt chart as Appendix 13.3.1.
2. To Design and construct a test rig to test vibration damping in alpine skis. This is shown as D2 and D3 in the Gantt chart as Appendix 13.3.1.
3. To test a range of skis from the late 1980s to the modern day. This is shown as D8 in the Gantt chart as Appendix 13.3.1.

My personal outcomes for this project are to improve my knowledge in alpine skiing and sports instrumentation, as well as improve skills in communication through presentations and one to one meetings.

4.4 LITERATURE REVIEW

4.4.1 Background of skiing

Alpine skiing has developed over the last 100 years. Current figures suggest that there are approximately 40 million alpine skiers, skiing in over 300 alpine resorts worldwide (A Ackery 2007).

It is said that modern skiing developed in 1850. Sondre Norheim, a Norwegian, invented the first stiff bindings. These were made by soaking birch tree roots in water and tying them to his boots. When the roots dried they became stiff. This allowed for greater control of the ski (www.abcofskiing.com 2012).

Skiing really became popular as a recreation in the early 1900 with the origins of competitive skiing. The first slalom race was held in 1921 in Switzerland. Soon after, alpine skiing became part of the Winter Olympic Games in 1936 (A Ackery 2007).

4.4.2 Modern ski design

Modern ski design is complex and is always developing to create a lighter, faster, more responsive and durable ski. Different manufacturers use varying techniques resulting in a wide range of skis of different shapes, sizes and material make up. Yet designing the perfect all mountain skis is impossible due to the varying nature of snow and the terrain being skied (Nash 2002).

Different characteristics can be used to develop skis for a range of conditions such as longer skis are better at high speeds as they tend to be more stable and have greater control yet they tend to be less manoeuvrable due to the shallower side cut radius. Whereas, the hour glass design for piste skis allows the rider’s weight to be concentrated around the bindings allowing for a greater contact area with the snow, with the majority of force put through the blade edge. This is to cause a flex in the ski, forcing the tip and tail of the ski into the snow forming two pivot points. The centre of the ski then flexes under the weight of the skier forcing the blade edge into the snow thus creating a greater contact area. This allows the edge to dig deeper into the snow creating a sharper turn (Nash 2002). Flexibility in skis is therefore essential to allow the ski to flex into the turn to create a larger contact area with the snow to make for a more responsive ski.

4.4.3 Vibrations in skiing

As a skier rides down the slope the ski is put under irregular forces due to snow conditions, surface irregularities and turning of the skies. These force functions and snow irregularities impact upon the base of the ski. These forces excite several modes of vibration in all axes of motion especially in hard pack snow or during high speed turning when the ski is placed upon the edge. During these turns frequencies appear to be around 10 -200 Hz (Gary C. Foss 2007).

Falls by skiers commonly occur from the result of a loss of control of the skis. When the skis vibrate at a high frequency, edge contact with the snow is reduced. Therefore, the ski will not remain on the anticipated arc making control a large problem. (Gary C. Foss 2007).

As vibration amplitudes are small at low speeds this problem tends not to effect casual or low level skiers. Yet for more advanced and professional skiers skiing at high speeds in events such as Downhill or Super G, on hard packed, icy race tracks, high amplitude vibrations regularly occur creating a large need for damping in their skis. By having a high damping coefficient in a ski, this creates a better edge control due to a longer edge snow contact time. The half time of vibration can be used to characterise this damping. This is where the maximal amplitude is calculated and the time taken for this amplitude to decay by half is recorded (Gary C. Foss 2007).

On snow, testing shows that the majority of these vibrations centre around the toe binding, yet distribute disproportionately across the whole length of the ski. Lab and on snow testing has shown that the tip of the ski vibrates with the largest amplitude with the tail vibrating with an amplitude of around 20%. (Nash 2002)

4.4.4 Standards

ISO 6267 is the international standard for measuring the bending vibration in alpine skis. (International Organization for Standardization (ISO) 1980; International Organization for Standardization (ISO)) This standard was developed to define a testing method to test the half time of vibration in alpine skis. This is achieved by clamping a ski to a stationary object (a bench is commonly used). It measures the first mode of vibration only by lab testing and only allows for optimization of damping in the first mode. The standard states that the clamping object must be clamped in 3 locations along the binding plate, a release mechanism must freely release the ski after an initial displacement of 25mm from the tip of the ski has been made as shown in figure 1.

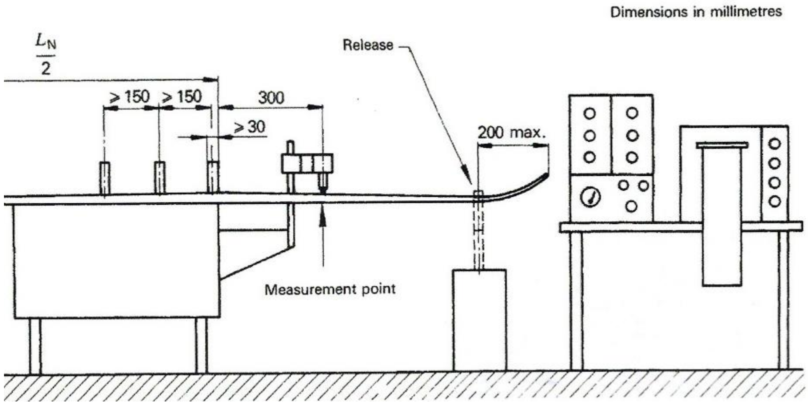


Figure 1 The layout of the clamping procedure and release mechanisms as stated in ISO 6267 (International Organization for Standardization (ISO))

The data collected must then be used to calculate the halftime of vibration, frequency and time period as stated in ISO 6267. All of this data then must be reported with the brand of ski, the designation of model, manufacture’s registration number, nominal length of the ski, time period of vibration, frequency of vibration and half-life of vibration.

By completing this procedure allows for an easy comparison of halftime of vibration for each ski.

4.4.5 Instrumentation systems

A single point laser Doppler vibrometer could be used to determine the vibration of the ski. An LDV works on the Doppler Effect. An optical transducer is used to determine change in wavelength of laser pulses. This change is then used to calculate displacement and velocity (Polytec 2013).

Advantages of a single point laser vibrometer is the fact that there is no mechanical change to the ski as there is no adding to mass of the ski as this may affect the skis performance. Also they can be set up and calibrated easily to a neutral point so many skis could be tested quickly without the need to change the instrumentation system. This also reduces the chance of error in the results as there is no need to set up the system again for each ski (Polytec 2013).

The disadvantages to the laser vibrometer are that they are relatively expensive compared to accelerometers so may not be feasible for mass production in a competitive market. Another disadvantage to this technique is it cannot be used in the field due to it being a large piece of equipment and the laser head cannot move.

Advantages to accelerometers are that they are cheap and easy to set up and can detect acceleration in all 3 axes of movement. This can be useful when analysing multi axial vibrations as all vibrations can be determined from one console on the ski, reducing weight on the ski that would affect performance (Engineering 2012). They can also be used in the field as they are small and can be attached to the ski. A data acquisition system can then be carried by the user.

The disadvantages of piezoelectric accelerometers are that they need wiring to a data acquisition system so movement in the wires may affect the signal from the accelerometer producing greater levels of noise that could interfere with results. Also, this is a contact system so there will be the addition of a mass to the ski. This will slightly affect the performance of the ski as the moment of inertia around the binding will be affected. (Engineering 2012)

A high speed camera could also be used to determine the frequency and amplitude of the ski. A calibrated checker board could be used to calculate the exact position of a set point on the ski. A computer tracking algorithm could then be used to connect the locations and create a graph of displacement against time (David Mas etal 2011).

Advantages to using high speed cameras are that compared to LDVs they are relatively cheap (David Mas etal 2011).

The disadvantages to using a high speed camera are the increased time in data analysis as each frame has to be manually assessed to mark the position of the ski. This will introduce random error into the readings as a human discretion is required for every location. There are also issues with parallax error in the reading as the camera will not be constantly perpendicular to the vibration of the ski.

A light gate system could be used to determine the frequency of vibration by setting up a light source on one side of the ski with a light detector on the other side producing a pulse of voltage when the light form the source is broken. This would be a relatively cheap solution to work out the frequency of vibration although there are several difficulties with this system. Firstly, the amplitude of vibration could not be determined. Also, the resolution of the system may not be able to detect high frequency vibration.

4.4.6 Final summary

In summary, it is clear to see the relationship between vibration and ski performance, yet flexibility needs to be maintained to ensure for a tight turn radius. Therefore, making the ski more rigid would increase the damping of vibration yet would have an adverse effect on the performance of the ski. There is a need for clever design of the ski through methods such as damping ridges along the ski or external free body damping systems.

The vibrations that naturally occur during a downhill run have a significant impact on performance of the athlete and the performer due to low edge snow contact adhesion, with a worst case scenario of a loss of control of the skis, resulting in a high speed crash.

To maximise damping, the tip of the ski needs to be focussed on as the majority of the vibrations occur in this section of the ski. Therefore, to test the damping properties of the ski this area should be looked at due to the largest amplitudes of vibration occurring in this region.

ISO 6267 has the basis for a usable testing system with the procedure suggested by (G. Fanti 2006) potentially being a more realistic and life like test. I will use this procedure to design my test rig.

The best instrumentation system to use is the laser Doppler vibrometer as it is a non-contact system that will need no setting up after initial assembly apart from calibration of the system before testing. The only set up of this system is getting the laser to contact the correct area of the ski. This can easily be achieved with an instrumentation system being mounted on a slider with a tape measure to measure the distance from the edge of the test rig to the laser. I intend on collecting and analysing the data in a Lab View program that will collect, filter and analyse the data showing a graph of the amplitude v time of the signal. This program will allow the operator to easily analyse different skis by comparing the half time of vibration and seeing the decay of the amplitude on the waveform graph. They will be able to set time frame they wish to analyse. A systematic trigger system shall be used to only collect the data of the vibration once the test has started. This program should be user friendly so that minimal training is needed to operate the whole system. Thus, enabling the rig to be widely used in testing facilities.

This research provides an in depth analysis of the background information to begin the design phase of this project.

4.5 PROPOSED METHODOLOGY

The testing procedure set out in ISO 6267 (International Organization for Standardization (ISO) 1980) isolates the front section of the ski. This is the region of the ski with the greatest amplitude of vibration. The first mode of vibration has the largest amplitude so therefore will have the largest effect on performance. As a result, this mode of vibration will be analysed. As set out in ISO 6267 (International Organization for Standardization (ISO) 1980) the ski shall be clamped on a table with a weight greater than 100kg. The ski shall be clamped as close as possible to the front of the toe binding with a further two clamps at 80mm intervals. The ski will then be deflected 25mm at the measurement point. The ski is then released with a non-contact measurement system measuring the displacement of the ski from initial displacement through to complete damping of the initial vibration.

In this project I will be completing many tasks to achieve the deliverables set out. These fall into 3 main phases. Phase 1- research and design. Phase 2- manufacturing and assembly. Phase 3- testing. Firstly, in phase 1 I will be researching a broad spectrum of resources around the areas of alpine skiing and vibrations to achieve an in depth over view of the effects of vibration on alpine skiing (Task 2). I will then start researching competitive products to analyse how other people have designed and produced test rigs to meet the specification set out in ISO 6267 (Task 6). From this research I will then start producing initial designs (Task 7). I will also start to research suitable instrumentation kits to use (Task 10). Once I have completed my initial ideas I will then begin to compile a final design that will be created on CAD to work out parts and components that I will need to begin manufacture (Task 8). Once the design has been finalised I will then move into Phase 2 where I will begin manufacturing the test rig as well as sourcing all the parts for the instrumentation system (Task 9, 11). At this stage I will be able to begin the design of the lab view program to collect and analyse the data collected from the instrumentation systems (Task 12). Once I have collected all of the necessary equipment from Task 11 I will be able to begin assembly (Task 13). Once assembly has been completed, I begin testing the instrumentation system to smooth out any floors in the program or data acquisition (Task 14). Once tested and attached to the test rig (Task 15) I can begin stage 3 of the project. This has been shown in the project Gantt charts shown in 13.3.1.

4.6 BENEFICIARIES

The Beneficiaries of this project fall into two main categories. Firstly, the designers will be able to us it as a simple lab test. This will allow a precise and accurate analysis of the first mode of vibration of a ski. It will also allow for quick testing of many skis, with easy repeatability.

The second beneficiary is myself, by producing this work I have developed skills in communication with multiple audiences and used their feedback to ensure that the project has been kept on track. This has also developed project management skills, CAD Skills to produce CAD models to aid in the manufacture, presentation skills and also increased my knowledge in the alpine winter sports industry.

5 DESIGN AND MANUFACTURE

5.1 INITIAL TEST RIG DESIGNS AND DEVELOPMENT

Figure 2 Initial test rig design

Initial designs used an I beam structure with 10 mm holes punched through the top plate to provide a surface on which to mount the ski. The use of circular tube welded onto the I beam provides extra mass to the design. This part is to be made from plain carbon steel. This is due to the cost of material and ease of access. Plain carbon steel is also heavy and hard wearing which allows for an increase mass with a reduction in wear over time. Once these material properties had been added to the part the design weight was 39Kg. This is far short of the minimum weight stated in the ISO standard that specifies a minimum weight of 100kg.

Figure 3 Rig design with additional table structure.

To achieve this minimum weight a table structure has been included to allow for the addition of extra masses and to hold the instrumentation systems. This brings the total mass of the bed to 62kg. As shown in figure 3.

The release mechanism works by a set of release pins clipping onto the top face of the ski. These are held in place by adjustable brackets that are held in place using standard M10 bolts with nuts. This system can slide in a Y axis to allow for the displacement of the ski in this axis. The ski is pulled down by a ratchet system operated from the back of the main bed. Once the correct displacement has been achieved a cable system releases the pins that allow the ski to freely vibrate.

Figure 4 Rig design with screw legs

Figure 4 Rig design with screw legs shows a slight development in the main bed where by the legs of the bed are bolted onto the bottom of the-I beam structure. This is due to transportation issues as welded legs would mean that the transportation of the bed would be impractical and storage of the devices in a commercial setting could be difficult. Due to this enhancement the table structure has been removed as this is no longer feasible. This brings the weight of final bed to 57.42kg. To allow for the addition of more mass, standard Olympic weight bars have been added to the legs. This allows for standard off the shelf weights to be used to increase the mass of the bed.

Figure 5 Release clip

The release pins have also be developed by the introduction of a fillet on the edge of the pin to allow for a cleaner release of the ski. This is to prevent a rotational displacement in the ski if one pin releases before the other. This part is to be made from ply wood as little damage will be caused to the top surface of the ski, therefore preventing the need for any cover for the release clip. This is shown in Figure 5 Release clip.

5.2 FINAL TEST RIG DESIGNS

Figure 6 Final test rig design.

Figure 6 Final test rig design.shows the final assembly of the test rig. The tubular bar structure of the legs has been changed to a standard box section, this is due to ease of manufacturing after consulting Pitney Fabrications. The use of a tubular bar would increase the manufacturing time and complexity of the assembly and welding. Also the addition of a 100mm box section onto the bottom of the I-beam structure allows for the legs to slot into it and locate them, which are then secured by a grub screw that stops them from moving. Also the addition of plates on the end of the I-beam allows for a smaller weld along the length of the structure. This will reduce bowing in the I-beam as a result of the weld. This will also increase the mass of the bed.

5.3 MANUFACTURE OF THE TABLE

Figure 7 Final assembly of test rig main bed.

The manufacturing of the main body of the test rig was done by Pitney Fabrications LTD. The main body of the design was made from a set of 10mm thick sheet steel pieces. This was cut to size using a mechanical press with the holes for the top plate punched though using a hole punch. Once all of the pieces for the main body were cut to length the I beam structure was stitch welded in place. A 4mm end cap was then welded to each end. 50mm x 50mm Box section was cut into 100mm lengths as stated in the working drawings (see Appendix 13.1.1.2). An angle of 25° from the top surface was then cut. A 10mm hole was then cut into these sections with an M10 bolt welded over the hole. This was to allow for grub screws to be added to ensure a tight fit of the legs. These sections were then welded to each corner of the top beam.

To create the legs 40mm x 40mm box section was cut to length and welded together as shown in appendix 13.1.1.3. The top of each leg then had an angle of 25° cut off. This was to allow the top of the leg sit flat against the bottom of the main beam. The same was then done to ensure that the table sat flat on the floor.

5.4 MANUFACTURE OF CLAMP

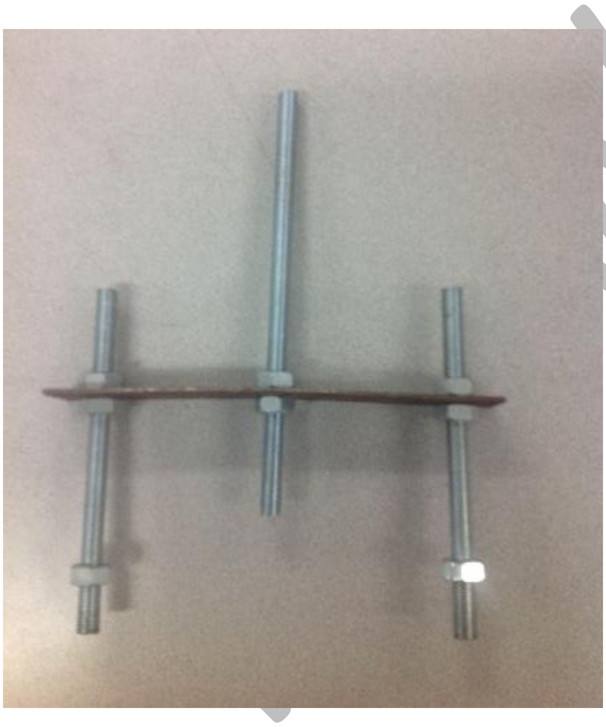


Figure 8 The clamp plate.

The clamping plates were made from 3mm thick mild steel. This was to avoid bending in the plate when excessive forces being applied to the central hole from the clamp screw. The plates were cut from plate using the guillotine to ensure that a clean edge was achieved. This prevented the need for any post processing of the part. Each hole was then measured and centre punched before drilling an 11mm hole. As shown in **Error! Reference source not found.** Once the holes had been drilled burs were removed with a flat file.

Each section of bar was measured and cut to length then filed down to ensure that no sharp edges occurred.

5.5 RELEASE MECHANISM

Figure 9 The whole release mechanism in its assembled state.

Figure 9 shows the final assembled release mechanism. The slide rails that the mechanism is sat in is made of aluminium C channel. This allows the mechanism to slide vertically yet restricts movement laterally and forwards and backwards. This allows for the mechanism to fall away from the ski upon release allowing free vibration.

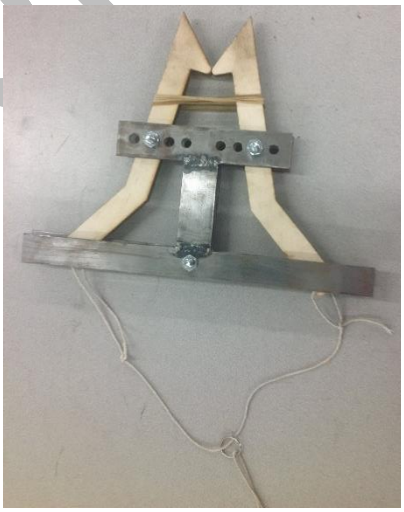


Figure 10 Release mechanism.

The final release mechanism relies on a pivot system whereby a force is applied by the elastic bands below where the ski is clamped in place. This forces the tip of the release clip in to lock onto the ski. This mechanism is then released by pulling a cord tied to the end of each clip. These are then secured to the release cord by a key ring. This allows for the clips the release at exactly the same time. Once the release cord is pulled the string connecting the two clips are pulled down. This pulls the bottom of both clips down and towards the centre therefore releasing the ski at the other end of the clip.

5.5.1 Release Clips

Figure 11 Release clip.

The release clip as shown in figure 11 is made from a laminate of 4 layers of 4mm Ply wood cut on a laser cutter. The precision of a laser cutter allowed for exact replication of the clip as designed allowing for identical clips to be produced.

5.5.2 Release clamp plate

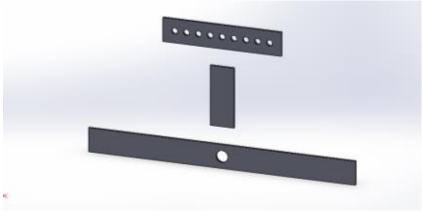


Figure 12 Exploded view of each component in the release clamp plate.

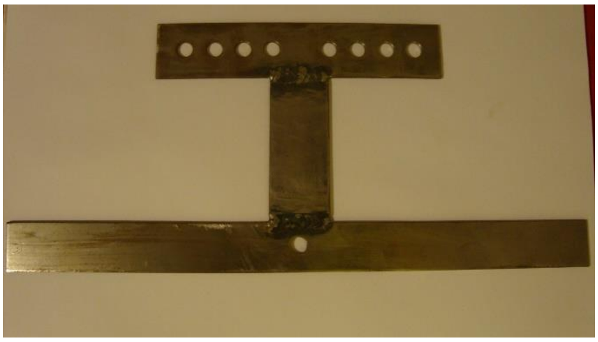


Figure 13 The release clamp plate from the release mechanism.

The Release clamp plate was made from 3 individual plates cut to size. The holes were then marked out centre punched and drilled. As shown in figure 12. These individual plates were then welded together as shown in figure 13.

6 DEVELOPMENT OF DATA CAPTURE AND ANALYSIS SOFTWARE

6.1 DATA CAPTURE

The LDV has a built in data capture system that can export data as ASCII .txt files that can be used for analysis.

The collected data was imported into Excel. A five point moving average was then taken of the data to smooth the data. This was to further reduce anomalous points. This data was then exported as an ASCII.txt file to a Lab-View program to analyse the captured data.

6.2 DATA ANALYSIS SOFTWARE

6.2.1 Data Import

The data collected then needed to be imported into the Labview analysis as .txt file.

6.2.2 Frequency Analysis

The created Labview program imports the .txt file created in the data manipulation phase. As shown in Figure 14 import .txt files into Labview program..

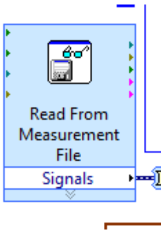


Figure 14 import .txt files into Labview program.

This data is then displayed on a graph to ensure the user is happy with the imported data. The Frequency is then calculated using an FFT frequency analysis. The largest frequency is the displayed on the user interface as shown in Figure 15 frequency measurement block.

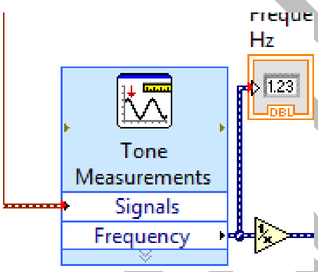


Figure 15 frequency measurement block.

The time period is then calculated by taking the reciprocal of the frequency. This is also displayed on the user interface.

6.2.3 Half Life Analysis

To automatically calculate the half-life of vibration a peak detection system was used. This was used to detect the local maximum point of each oscillation. The location of this point was then exported and multiplied by the time differential to obtain its relative time location. Each of these values and there amplitudes where then put through an exponential fit block. This was used to calculate the damping ratio.

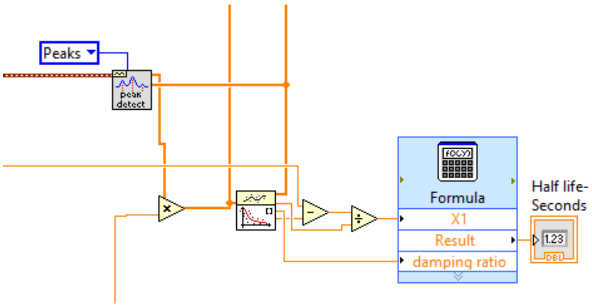


Figure 16 Half-life calculator

A cursor backup system is also put in place to check the half-life. As shown in figure 17.

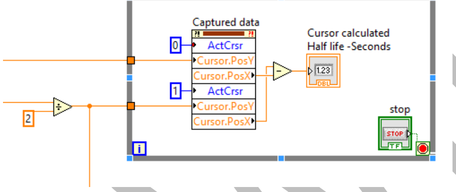


Figure 17 Half-life cursor back up system.

This is due to some unexpected peaks in the data set can interfere with the calculation of the half-life. This data is then displayed on the front panel for the user to see clearly. This all happens almost instantaneously to give quick reliable feedback to the user.

7 TESTING

7.1 TESTING PROCEDURE

Firstly the laser is positioned 300mm away from the ski is clamped onto the test bed in a relaxed state. The ski is then clamped to the test bed. This is done by adjusting the clamps by screwing the clamp plate as low to the ski as possible, then locking the nuts on either side of the plate to secure its position. The central screw is then clamped onto the top of the ski using the same procedure which secures the ski in position.

Once the ski was in position the laser is projected onto the bottom of the ski. A piece of retro reflective tape was then placed onto the bottom of the ski where the laser is shining. The laser was then focused on to the bottom of the ski to ensure that the highest possible power could be achieved. The power is shown by the LED scale on the laser head.

Once the laser is set up the release mechanism is placed 200mm away from the tip of the ski. The base of which is then weighed down to stop the guide rails from moving. The clamp is then raised to secure the ski. The release mechanism is then pulled 25mm to depress the ski as stated in ISO 6267 and secured. (International Organization for Standardization (ISO) 1980).

The data capture system then needed to be configured. The system was set to capture 32678 data points over a 6.4 second capture window. This allowed for enough points to be collected to ensure that no oscillations were missed. This gave a sampling rate of 5.12 KHz. A trigger was set at 2% to allow for the system to trigger only when the ski was released. 4% of the pre trigger samples were captured to ensure that any pre trigger data was captured.

The system was then armed ready to trigger. Once ready a sharp pull on the release cable released the ski.

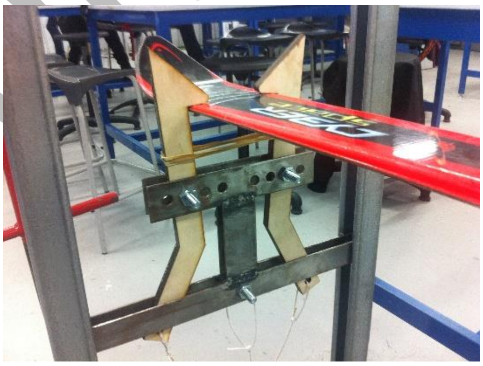


Figure 18 Armed ski in clamping devise.

The captured data was then exported to excel. The ski was pushed back down into the clamp to ensure that the same initial displacement and the system was rearmed ensuring the laser pointing at the retro reflective tape.

This procedure was repeated 5 times per ski for all 9 skis.

7.2 SKIS SELECTION

In order for testing to occur a wide range of skis were selected from a range of release dates with varying geometry's and constructions

Manufacture	Model	Nominal length (mm)	Year released	Core material	Waist width (mm)	Tip length (mm)	Tip width (mm)
Atomic	C9	1690	2002	Texalium 100	67	720	105
	Drive 7	1450	2009	Fibreglass	75	635	114
	MID	1640	1980	Birch Wood	70	807	83
Fischer	AMC 70	1630	2001	Fiberglass	72	680	117
Head	Cyber Space	1790	1999	Fiberglass	65	790	110
Rossignol	A100	1620	2008	Fiberglass	73	635	110
Salomon	Enduro RS800 Ti	1700	2014	Titanium	84	700	125
	Crossmax	1620	2002	Fiberglass	64	634	107
Völkl	Skinetik Perfection 33	1790	1985	Birch Wood	70	813	80

Table 1 The selection of skis selected to test along with key dimensions and core materials.

7.3 PRELIMINARY TESTING

Preliminary testing was undertaken to smooth any issues with the testing procedure. Several issues occurred during this phase of the project. The first of which was weighed plates did not fit onto the sections as intended. This was due to an error in the fabrication where 2” box section was welded on instead of 2” diameter tube section. This meant that the diagonal distance between the two corners opposite each other had a length of greater than 2”. Therefore an aluminium plate was made to fit across the cross struts. This allowed for the addition of extra masses to the top of the main body to ensure that the frame met ISO 6267 Standards.

There was also issues with the release mechanisms. As the skis was clamped in and ratcheted down the whole slider tilted away from the table. This was due to the release clips moving down the ski from the Initial start point at 200mm as set out in ISO 6267. To overcome this problem a rope system was devised to hold the guide rails in a vertical plane. This was done by tying the clamping table to the top of each guide rail stopping movement away from the table. This reduced the problem but sliding along the ski still occurred but at a reduced rate.

There was also issues with the LDV. The displacement channel of the LDV was not working due to technical issues, therefore the velocity channel was used.

During the preliminary testing data capture parameters were adjusted to ensure that a suitable sample rate was achieved. This was to ensure that enough data points were collected through 1 oscillation of the ski without excessive data points. The capture window was also adjusted to ensure that enough oscillation were captured. The final data capture parameters were set at a capture rate of 5.12 KHz with a capture window of 6.4s. This allowed a resolution of 195.3µs. A trigger value of 2% was set to ensure that the system would not trigger until the ski was released. With a 4% pre trigger samples collected to ensure that the beginning of the oscillation was captured.

8 RESULTS

8.1 ATOMIC C9

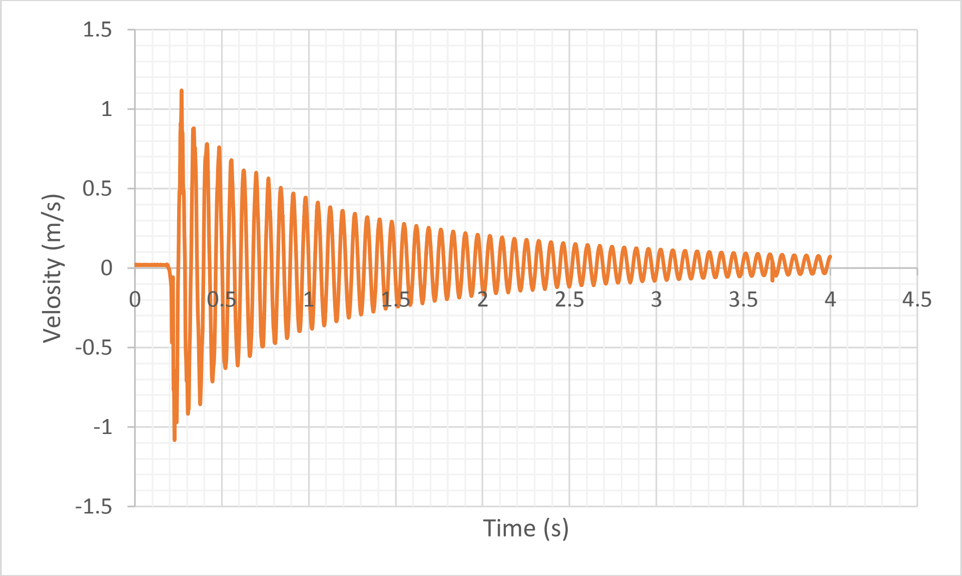


Figure 19 Test data from test 1 for the Atomic C9.

Figure 19 shows the data collected from test 1 of the Atomic C9 ski. This data has been cropped at 4 seconds to remove excess data collected after 4 seconds.

Test Mean			Standard deviation
Time period	0.070	Seconds	0.0002
Frequency	14.197	Hz	0.0313
Half-life	0.410	Seconds	0.2108

Table 2 Average Time period, Frequency and half-life of vibration for the Atomic C9 ski.

Table 2 shows the average data calculated from all 5 tests of the Atomic C9 ski. The time period and frequency of the oscillation of the ski as well as the halftime of vibration was calculated for each test with the average of all the tests shown above with the standard deviation of each set of data also shown.

8.2 ATOMIC DRIVE 7

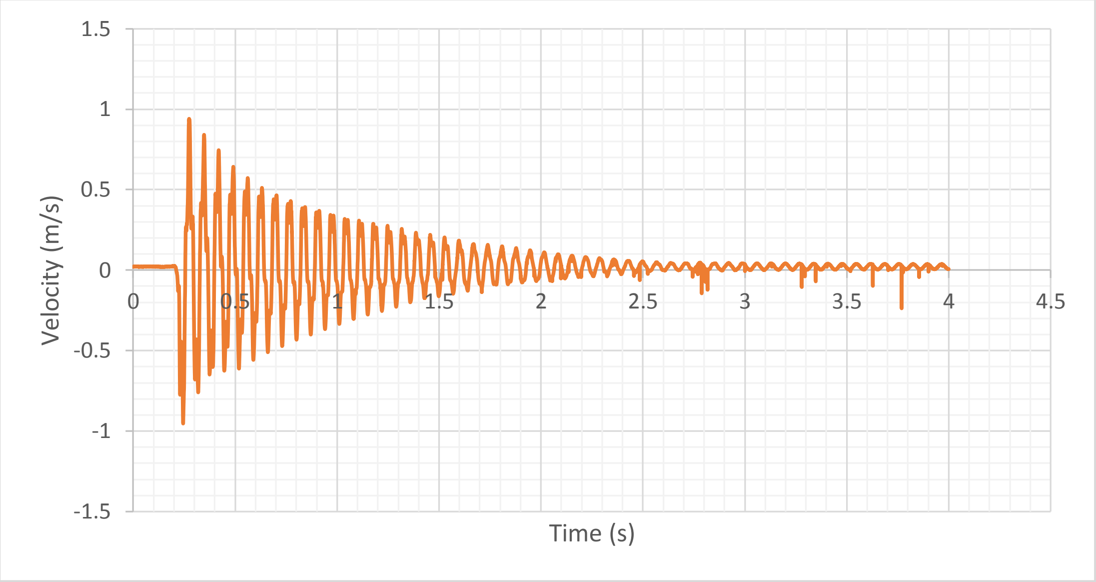


Figure 20 Test data from test 1 for the Atomic Drive 7.

Figure 20 shows the data collected from test 1 of the Atomic Drive 7 ski. This data has been cropped at 4 seconds to remove excess data collected after 4 seconds.

Test Mean			Standard deviation
Time period	0.0787	Seconds	0.000
Frequency	12.7036	Hz	0.009
Half-life	0.7987	Seconds	0.200

Table 3 Average Time period, Frequency and half-life of vibration for the Atomic drive 7 ski.

Table 3 shows the average data calculated from all 5 tests of the Atomic Drive 7 ski. The time period and frequency of the oscillation of the ski as well as the halftime of vibration was calculated for each test with the average of all the tests shown above with the standard deviation of each set of data also shown.

8.3 ATOMIC MID

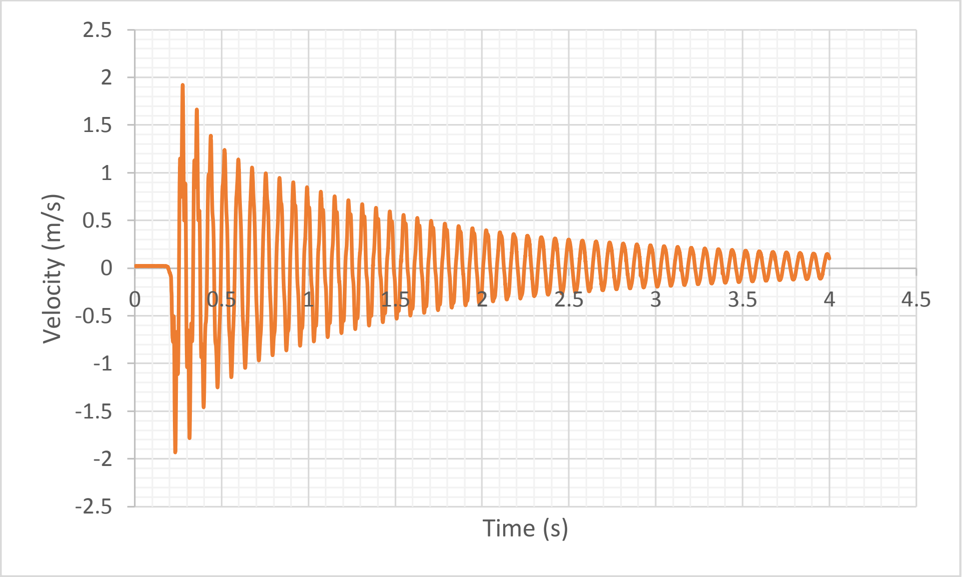


Figure 21 Test data from test 1 for the Atomic MID ski.

Figure 21 shows the data collected from test 1 of the Atomic MID ski. This data has been cropped at 4 seconds to remove excess data collected after 4 seconds.

Test Mean			Standard deviation
Time period	0.0694	Seconds	0.000
Frequency	14.4147	Hz	0.007
Half-life	0.4086	Seconds	0.032

Table 4 Average Time period, Frequency and half-life of vibration for the Atomic MID ski.

Table 4 shows the average data calculated from all 5 tests of the Atomic MID ski. The time period and frequency of the oscillation of the ski as well as the halftime of vibration was calculated for each test with the average of all the tests shown above with the standard deviation of each set of data also shown.

8.4 FISCHER AMC 70

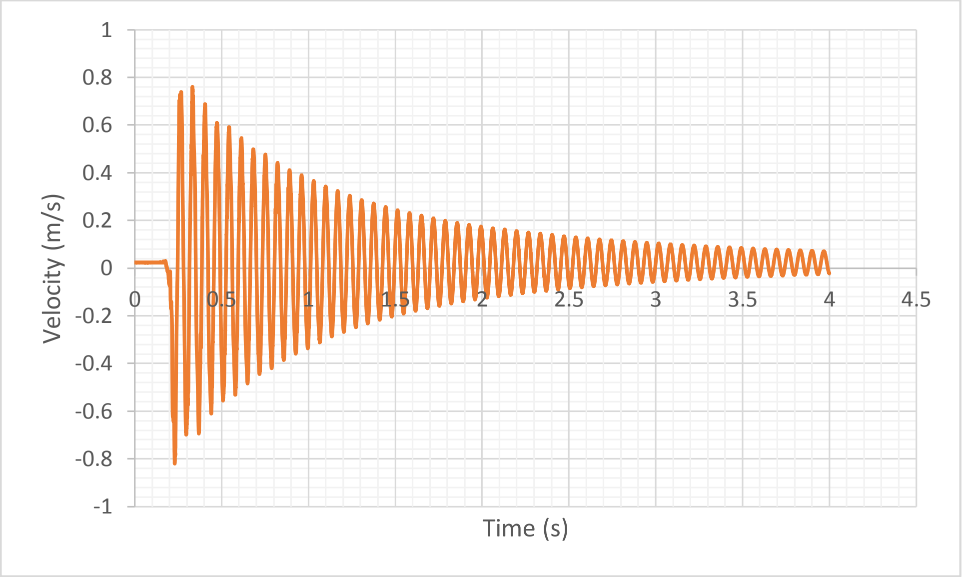


Figure 22 Test data from test 1 for the Fischer AMC 70 ski.

Figure 22 shows the data collected from test 1 of the Fischer AMC 70 ski. This data has been cropped at 4 seconds to remove excess data collected after 4 seconds.

Test Mean			Standard deviation
Time period	0.0684	Seconds	0.0001
Frequency	14.6220	Hz	0.0205
Half-life	0.6792	Seconds	0.2426

Table 5 Average Time period, Frequency and half-life of vibration for the Fischer AMC 70 ski.

Table 5 shows the average data calculated from all 5 tests of the Fischer AMC 70 ski. The time period and frequency of the oscillation of the ski as well as the halftime of vibration was calculated for each test with the average of all the tests shown above with the standard deviation of each set of data also shown.

8.5 HEAD CYBER SPACE

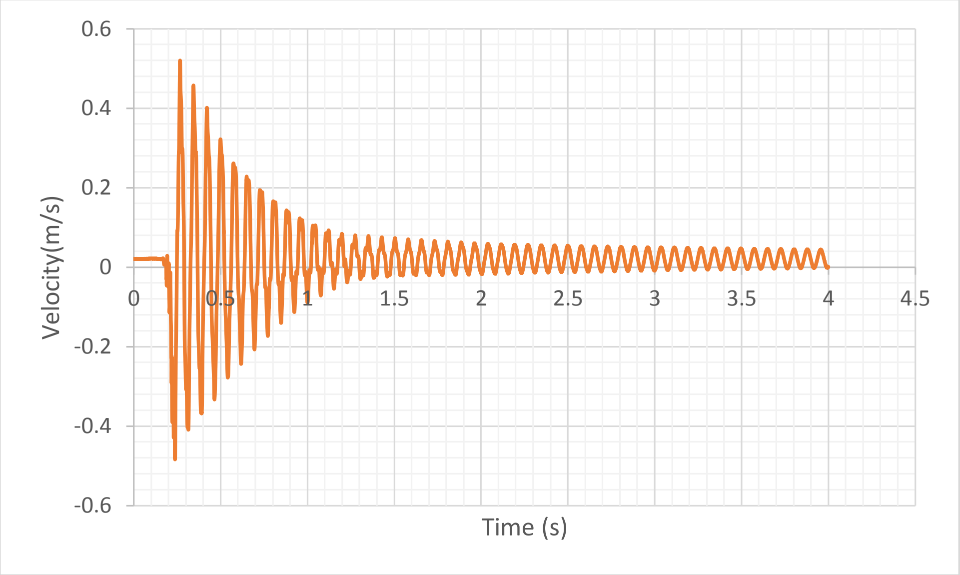


Figure 23 Test data from test 1 for the Head Cyber space ski.

Figure 23 shows the data collected from test 1 of the Head Cyberspace ski. This data has been cropped at 4 seconds to remove excess data collected after 4 seconds.

Test Mean			Standard deviation
Time period	0.0766	Seconds	0.000
Frequency	13.0525	Hz	0.012
Half-life	0.4264	Seconds	0.044

Table 6 Average Time period, Frequency and half-life of vibration for Head Cyberspace ski.

Table 6 shows the average data calculated from all 5 tests of the Head Cyberspace ski. The time period and frequency of the oscillation of the ski as well as the halftime of vibration was calculated for each test with the average of all the tests shown above with the standard deviation of each set of data also shown.

8.6 ROSSIGNOL A100

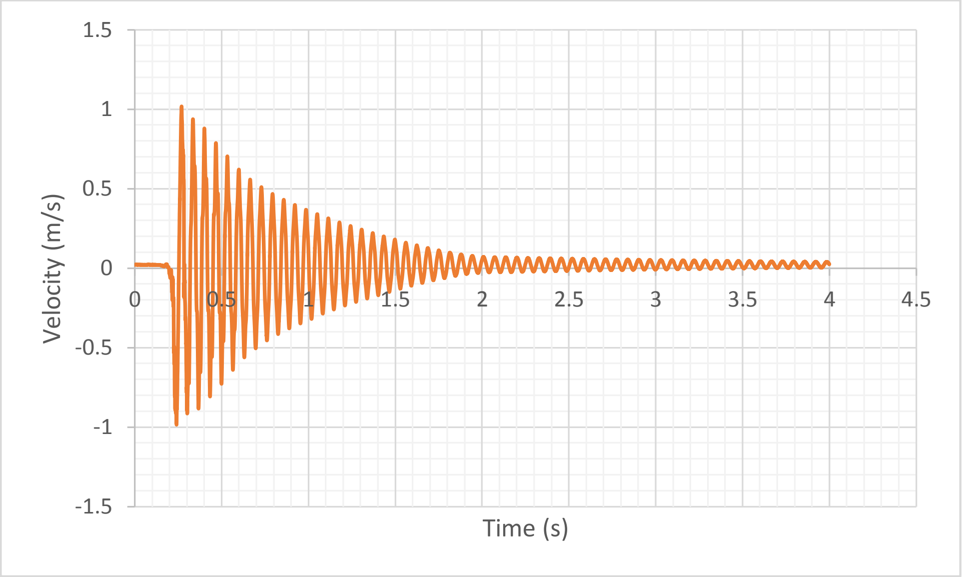


Figure 24 Test data from test 1 for the Rossignol A100 ski.

Figure 24 show the data collected from test 1 of the Rossignol A100 ski. This data has been cropped at 4 seconds to remove excess data collected after 4 seconds.

Test Mean			Standard deviation
Time period	0.0640	Seconds	0.001
Frequency	15.6347	Hz	0.323
Half-life	0.4396	Seconds	0.033

Table 7 Average time period, Frequency and half-life of vibration for Rossignol A100 ski.

Table 7 shows the average data calculated from all 5 tests of the Rossignol A100 ski. The time period and frequency of the oscillation of the ski as well as the halftime of vibration was calculated for each test with the average of all the tests shown above with the standard deviation of each set of data also shown.

8.7 SALOMON CROSSMAX

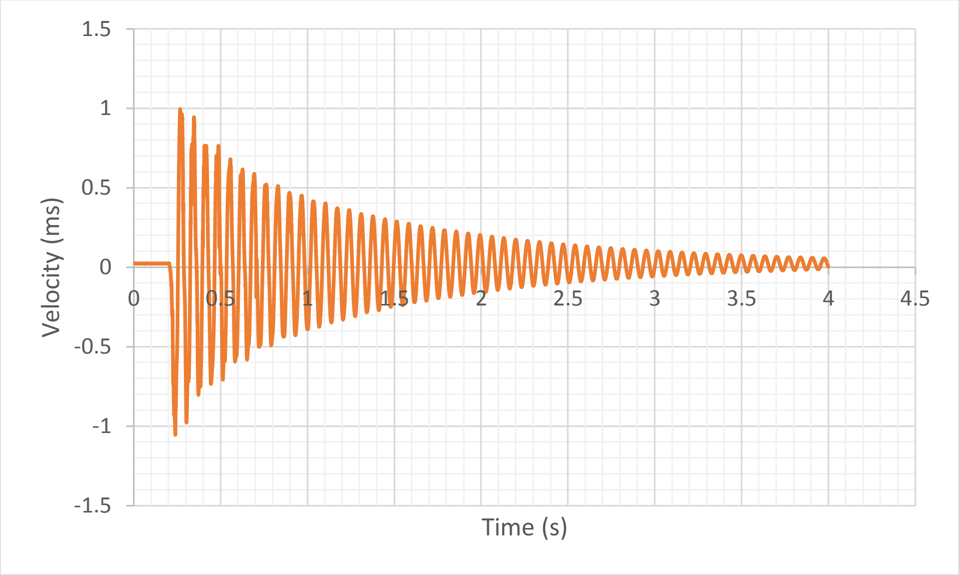


Figure 25 Test data from test 1 for the Salomon Crossmax ski.

Figure 25 show the data collected from test 1 of the Salomon Crossmax ski. This data has been cropped at 4 seconds to remove excess data collected after 4 seconds.

Test Mean			Standard deviation
Time period	0.06843	Seconds	0.0001
Frequency	14.61343	Hz	0.0124
half-life	0.43854	Seconds	0.1131

Table 8 Average Time period, Frequency and half-life of vibration Salomon Crossmax ski.

Table 8 shows the average data calculated from all 5 tests of the Salomon Crossmax ski. The time period and frequency of the oscillation of the ski as well as the halftime of vibration was calculated for each test with the average of all the tests shown above with the standard deviation of each set of data also shown.

8.8 SALOMON ENDURO RS80 TI

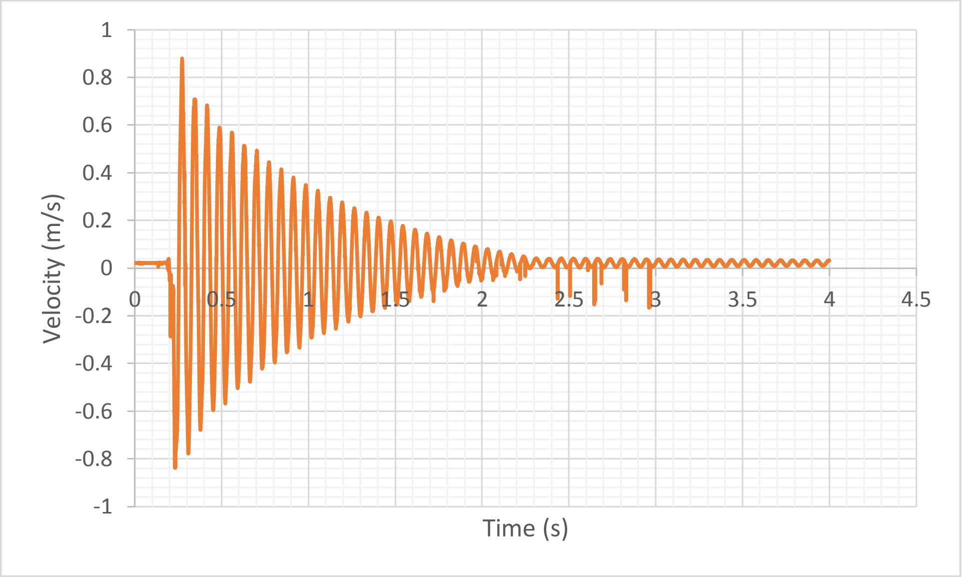


Figure 26 Test data from test 1 for the Salomon Enduro RS80 Ti.

Figure 26 shows the data collected from test 1 of the Salomon Enduro RS80 TI ski. This data has been cropped at 4 seconds to remove excess data collected after 4 seconds.

Test Mean			Standard deviation
Time period	0.0529	Seconds	0.0310
Frequency	14.2449	Hz	0.0417
half-life	0.5361	Seconds	0.0408

Table 9 Average time period, Frequency and half-life of vibration Salomon Enduro RS80 Ti ski.

Table 9 shows the average data calculated from all 5 tests of the Salomon Enduro RS80 Ti ski. The time period and frequency of the oscillation of the ski as well as the halftime of vibration was calculated for each test with the average of all the tests shown above with the standard deviation of each set of data also shown.

8.9 VÖLKL SKINETIK PERFECTION

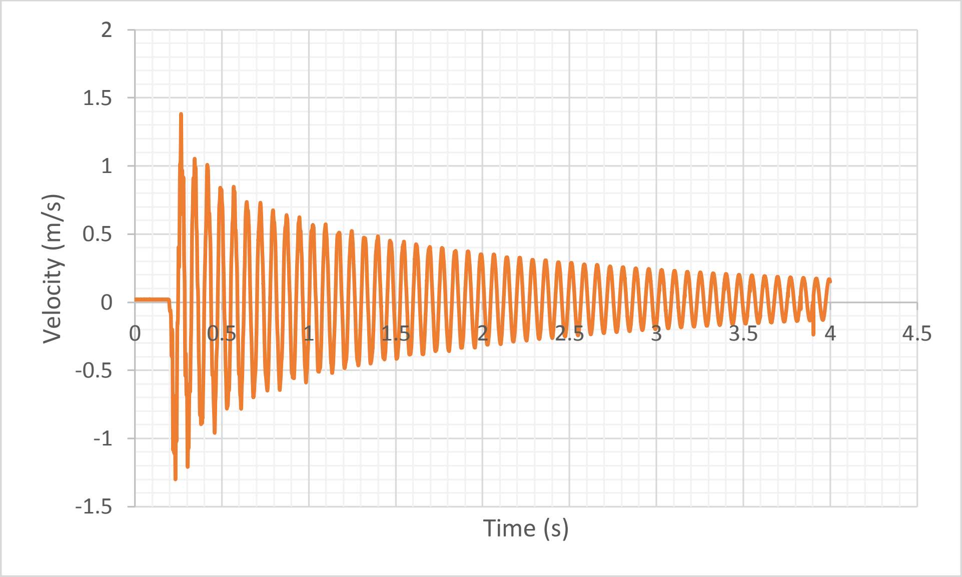


Figure 27 Test data from test 1 for the Völkl Skinetik Perfection ski

Figure 27 shows the data collected from test 1 of the Völkl Skinetik Perfection ski. This data has been cropped at 4 seconds to remove excess data collected after 4 seconds.

Test Mean			Standard deviation
Time period	0.074289	Seconds	0.000
Frequency	13.4605	Hz	0.009
half-life	0.570423	Seconds	0.088

Table 10 Average time period, Frequency and half-life of vibration Völkl Skinetik Perfection ski.

Table 10 shows the average data calculated from all 5 tests of the Völkl Skinetik Perfection ski. The time period and frequency of the oscillation of the ski as well as the halftime of vibration was calculated for each test with the average of all the tests shown above with the standard deviation of each set of data also shown.

8.10 TRACKING VIBRATION OVER TIME

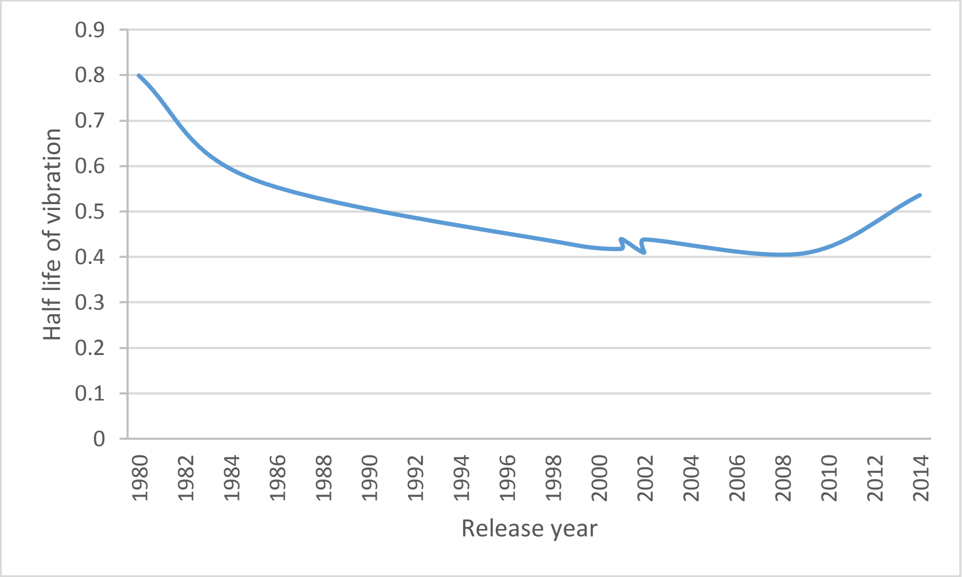


Figure 28 Tracking the development of half time of vibration against year released.

Figure 28 shows the progression of ski halftime of vibration against the year the ski was released.

9 DISCUSSIONS

9.1 FINAL TESTING

Looking at the results collected from table 2 to table 9 there was a wide range of half time of vibration across the skis tested. These ranged from the largest half time of 0.7987 seconds for the Atomic MID ski with the lowest value of 0.4086 seconds for the Atomic Drive 7 ski. This is a range of 0.3901 seconds. However this was expected due to the range in skis tested. When plotting halftime against released year as shown in figure 28 it is clear that when looking at the half time of vibration there has been a significant decrease in damping of skis from the early 80s to the present day. However from 2000 onwards there seems to be an increase in halftime of vibration. This could be due to a change in ski design where flexibility is increased as stated in 4.4.2. However more testing is needed to prove this.

As stated above the data has been cropped at 4 seconds to remove excess data collected after this 4 second period. There was some variation in the amplitude at this time. It was clear to see from the graphs of the older skis the vibration at this point were significantly greater than the current day skis. This can be seen in Figure 27 of the graph of the Völkl ski. At 4 seconds the amplitude is 0.2 ms^{-1} compared to the Salomon Enduro ski in figure 26 where the amplitude is negligible.

There also appears to be a two stage damping in several of the skis. This characteristic is shown in figure 21. There is a significant drop in amplitudes initially until 0.75 seconds where there seems to be a slight change where the decrease in peak values is slightly lower.

9.2 RIG DESIGN

It is clear to see from the standard deviations of all three measurements taken that the rig performed as expected with little deviation within repeat tests. This was due to exactly the same set up parameters for all 5 tests. This was done by initially ensuring that the ski was clamped as securely as possible within the rig. The ski was then forced down by the ratchet system. Once the required displacement was achieved this system was not altered for all 5 tests with the ski manually displaced and clipped back into the release mechanism. This ensured that there was no variation within the initial displacement for all 5 tests therefore reducing random error. This also meant that after initial set up the procedure was quick to execute allowing for multiple tests within a small time frame. This also reduced error within the results as multiple skis were tested under one set up of the rig, reducing differences in measurement distances. Although the laser was positioned as close to 300mm from the edge of the clamp bed as stated in ISO 6267 (International Organization for Standardization (ISO) 1980) under multiple rig set ups a slight error would be introduced.

The use of a gold standard Instrumentation system also ensured that the collected results were accurate and there was a little error within the instrumentation system. The use of this system also ensures that the testing procedure is repeatable by other people.

9.3 CONCLUSIONS

There have been significant improvements in ski vibration damping from the early 1980s to the present day. This is shown by calculating the time it takes to reduce an amplitude of vibration by half (vibration Half-life). Although, as shown above, there is a slight increase in half-life from 2000 onwards. This could be due to a change in ski design as suggested by (Nash 2002). To show these developments and their advantages would require further testing; the rig that I have designed could provide an important part of that test procedure. Overall, the rig performed well abiding closely to (International Organization for Standardization (ISO) 1980). The data collected was accurate and easily repeatable.

In conclusion, this analysis will allow for the improvement of ski design in both performance and safety. This would be achieved by creating a greater damping, therefore a longer ski snow contact. This creates greater control of the ski and reduces the risk of losing control of the ski, so reducing risk of injury.

Whilst modern skis continue to be developed, testing will provide an important source of data. I believe the rig that I have developed and the accompanying tests would complement any series of tests carried out. As standards like ISO 1980 continue to inform ski performance, the compromise between vibration half-life and ski flexibility will form specification points. I have concentrated in this study, on tracking vibration half-life with skis spanning a twenty-five year period. Further study using my rig could be carried out to compare modern skis.

10 FURTHER WORK

Following on from this project several areas have become apparent that more work could be done to further the analysis in ski vibrations.

The first of which is a natural frequency analysis of all of the skis. This would be slightly more realistic in real world test and could add to data collected in this project to further the understanding of vibration damping in Alpine skis.

Also in field testing to further validate the testing procedure set out in this project. This would ensure that the vibration triggered in the testing procedure occurred in the field. This could be done in several ways such as using an accelerometer attached to the front of the ski. The skier could then perform a series of high speed turns such as in a supper G course.

As suggested in the literature review, modern day skis have to be a compromise between vibration damping and ski flexibility. Therefore a flexibility analysis of each ski could be undertaken to see the relationship between damping half-life and flexibility. This could then be used to create a damping flexibility ratio for the comparison of skis.

To further improve the data analysis a streaming technique could be developed to speed up the data analysis phase of testing. This would make for quicker feedback in a commercial environment.

Also the development of a cheaper LDV would make this more suitable to a commercial environment. The development of a cheaper vibrometer would reduce initial investments. A comparison should then be made between the developed system and the system used in the above testing procedure. This would ensure that data collected was accurate.

Finally the testing of a greater range of skis from different areas of skiing such as off piste skis would further understanding of damping half-life throughout the ski industry. This could then be used to ensure that the right ski selection is made for the task being under taken.

11 REFLECTIONS

Completing this project has been extremely satisfying and motivating for me, resulting in a wide range of personal and academic enhancements. It has given me the opportunity to thoroughly research an area that I am passionate about. This took many different routes to improve my knowledge, starting with the ISEA Winter School in Italy. This was the inspiration for the whole of this project where I have learnt a great deal. My skills in communication have developed and knowledge of real world issues such as standard sizes of sheet metal and box section have also improved. Time management has been pushed at stages to ensure that project stayed on track, although the majority of the project was completed on time in terms of my initial time plan. I strayed off this due to a few setbacks. The main setback was learning how to use the LDV and its set up. This took a lot longer than expected and therefore pushed the testing phase of my project back a few weeks. This meant that I did not have as much testing time as initially expected. However this made me spend the little testing time I had efficiently to ensure that I got the data that I required.

As well as personal benefits this project has given me the chance to further my academic knowledge and put skills developed from all areas of study into one final project. I feel that this project shows off skills that I have learnt throughout my time studying the course, from programing in Lab View to CAD design through to manufacture.

If I was to do this project again I feel that I would definitely obtain the training in the relevant instrumentation systems a lot earlier. This would have prevented the hold ups later in the project. I would have also liked to finish the manufacture of the test rig before the Christmas break. This would have allowed me to do some preliminary testing of the rig and allow time to evaluate the system. By going through a thorough design process I alleviated potential problems with the rig that would have taken a long time to correct.

Overall I fell that this project has been a success with a testing procedure that could be used in a wide range of settings with success.

12 BIBLIOGRAPHY

12.1 REFERENCES

A ACKERY, B E Hagel, C Provvidenza, C H Tator (2007). An international review of head and spinal cord injuries in alpine skiing and snowboarding. *Injury prevention*, **13** (6), 368-372.

DAVID MAS ETAL, Belen Ferrer, Ana B Roig, (2011). High speed imaging and algorithms for no-iasive vibrtations measurements. *Optics Applied to Science and Technologies* , 531- 538.

ENGINEERING, Dimension (2012). *www.dimensionengineering.com.* [online]. Last accessed 15th November 2013 at: www.dimensionengineering.com/info/accelerometers

G. FANTI, R.Basso, V. Montauti (2006). Damping of Bending Vibration In Alpine Skis: An Impovement of Standard ISO 6267. *Applied Mechanics and Materials*, **5-6**, 199-206.

GARY C. FOSS, Bard Glenne (2007). Reducing On-snow Vibrations of Skis and Snowboards. *Sound & Vibration*, December, 2007, December,

ISO 6267 Alpine Skis -- Measurement of bending vibration.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO) (1980). ISO 6267 Alpine Skis -- Measurement of bending vibration..

NASH, Brent (2002). enginnering a smooth ride : Creating the perfect ski through shaping and vibration damping. *illumin*, **4** (3),.

POLYTEC (2013). *www.polytec.com.* [online]. Last accessed 15th November 2013 at: http://www.polytec.com/us/solutions/vibration-measurement/basic-principles-of-vibrometry/

www.abcofskiing.com. (2012). [online]. Last accessed 29th October 2013 at: http://www.abc-of-skiing.com/skiinghistory.asp

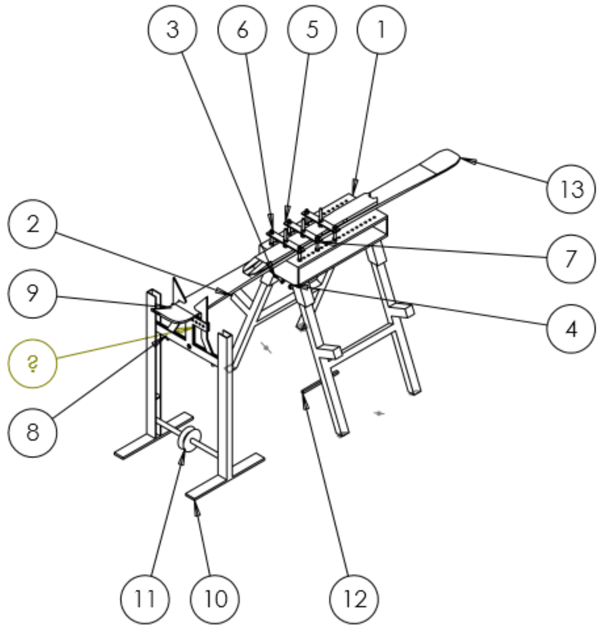
13 APPENDIX

13.1 WORKING DRAWINGS

13.1.1 Main body

13.1.1.1 Final assembly parts list

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Top plate		1
2	Legs		2
3	Hexagon Flange Nut ISO - 4161 - M10 - N		4
4	ISO 4014 - M10 x 45 x 26-N		4
5	Clamp plate		3
6	ISO 4017 - M10 x 80-N		9
7	Hexagon Nut ISO - 4032 - M10 - D - N		24
8	Clip		2
9	Bracket plate		2
10	Slider slot		1
11	Pully wheel		1
12	Pully		1
13	Ski		1



	NAME	SIGNATURE	DATE
DRAWN	T.W		20/12/13
CHK'D	T.W		12/1/14
APPV'D	T.W		14/1/14
MFG			
Q.A			

MATERIAL:

WEIGHT:

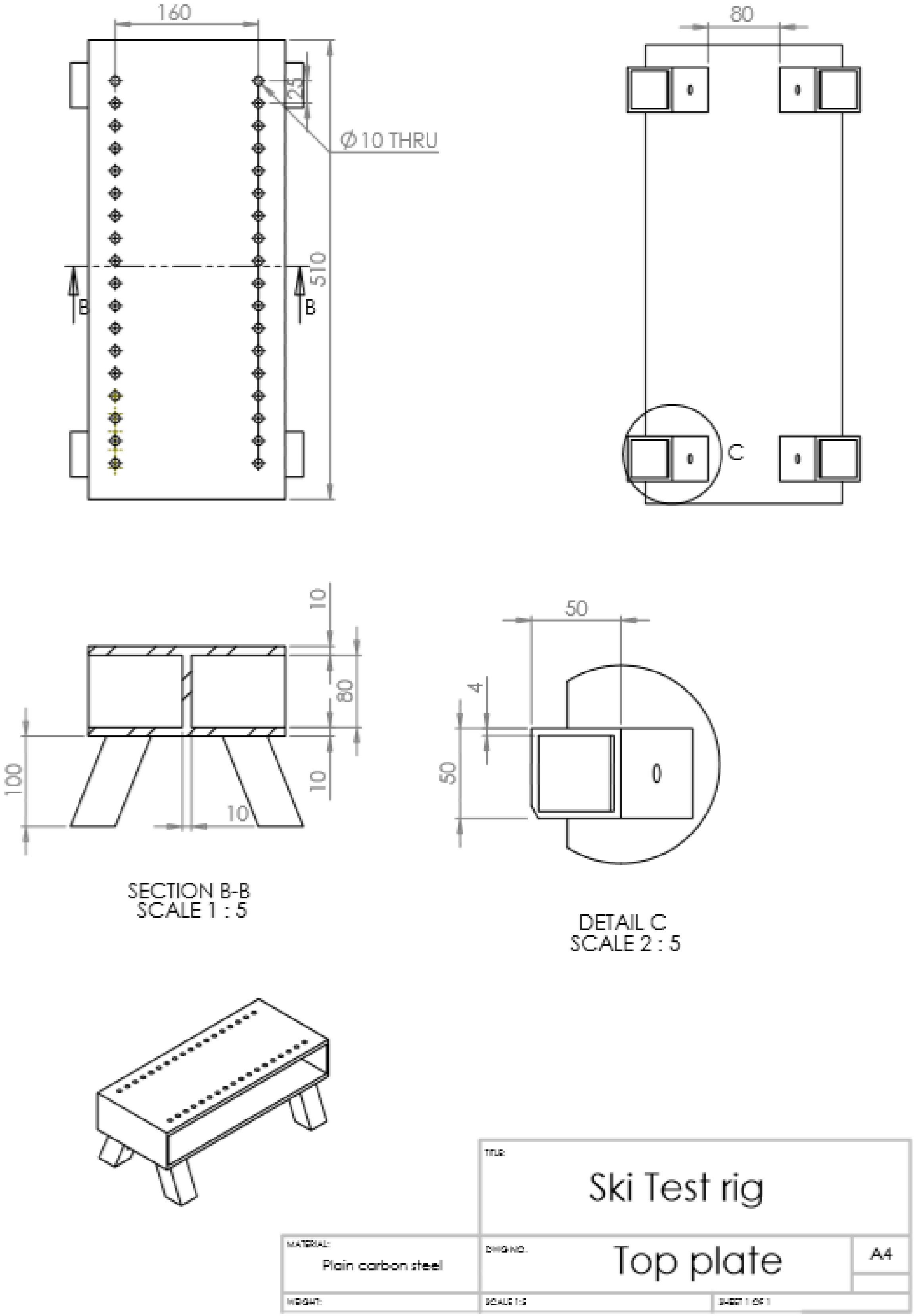
TITLE: Final Assembly

DWG NO. final design parts list

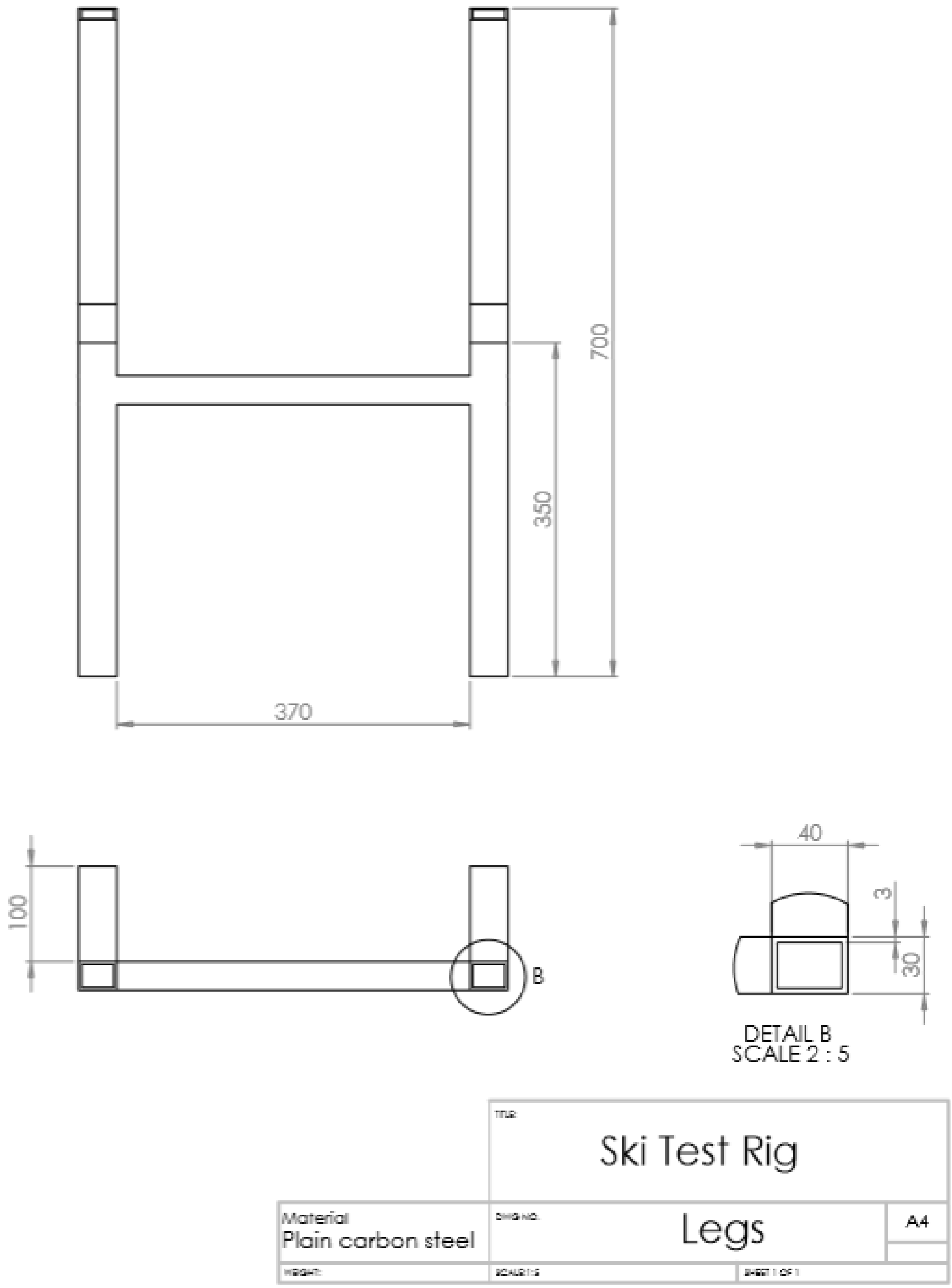
SCALE:1:50

SHEET 1 OF 1

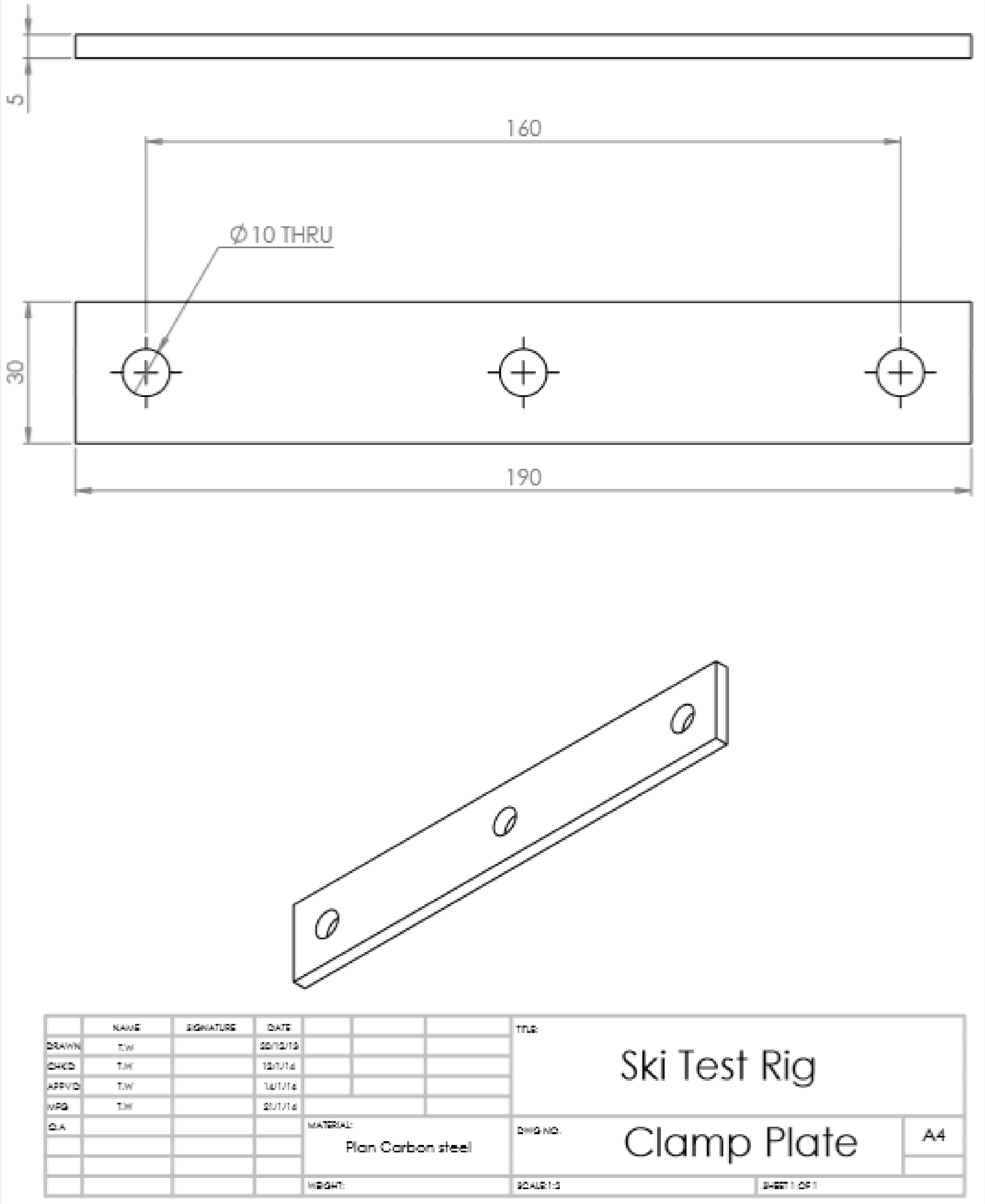
13.1.1.2 Top plate



13.1.1.3 Legs

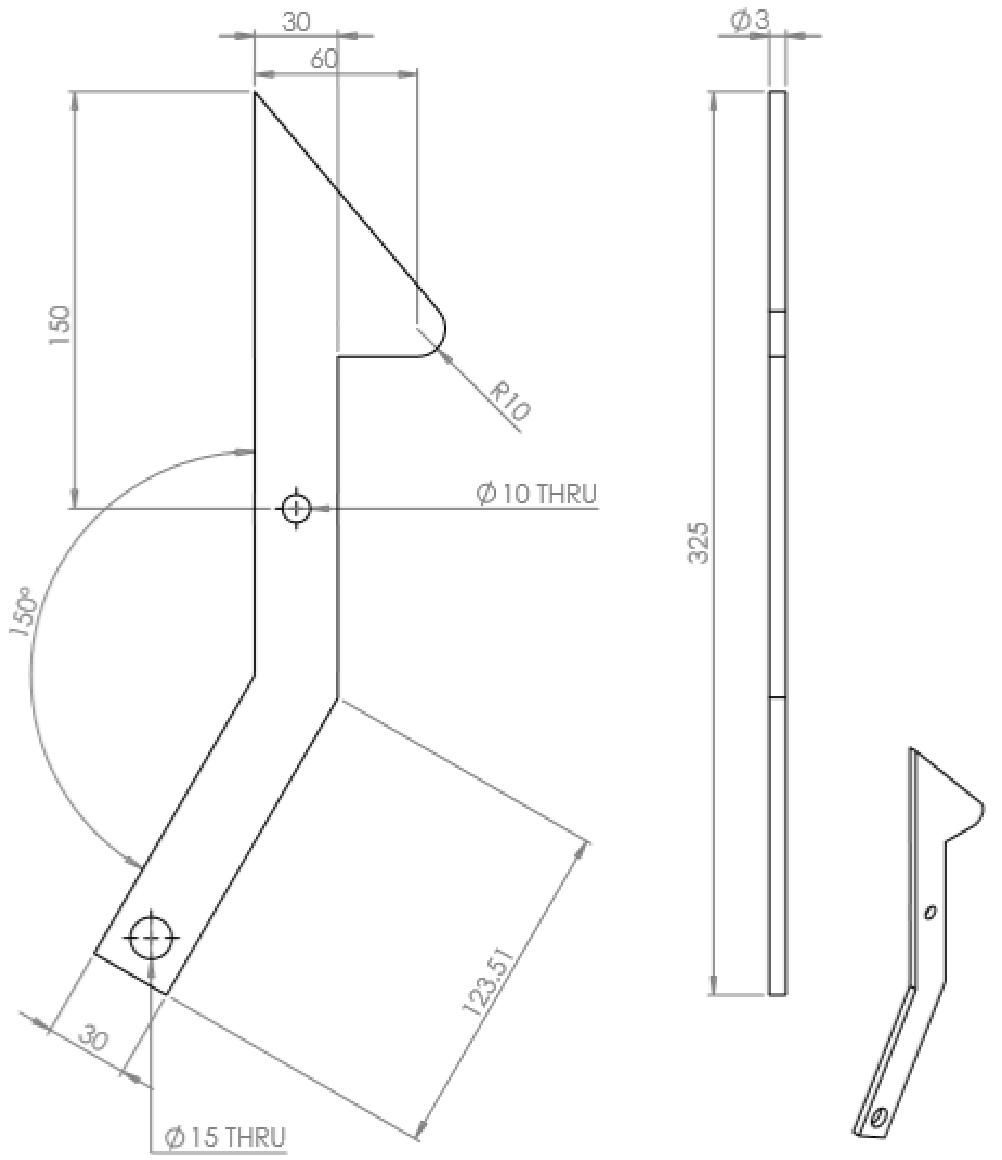

700
350
370
100
B
40
3
30
DETAIL B
SCALE 2 : 5
TITLE:
Ski Test Rig
Material
Plain carbon steel
DWG NO.
Legs
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1

13.1.1.4 Clamp Plate



13.1.2 Release mechanism

13.1.2.1 Release clip



	NAME	SIGNATURE	DATE
DRAWN	T.W		18/11/15
CHK'D	T.W		8/1/16
APPV'D			
MFG			
Q.A			

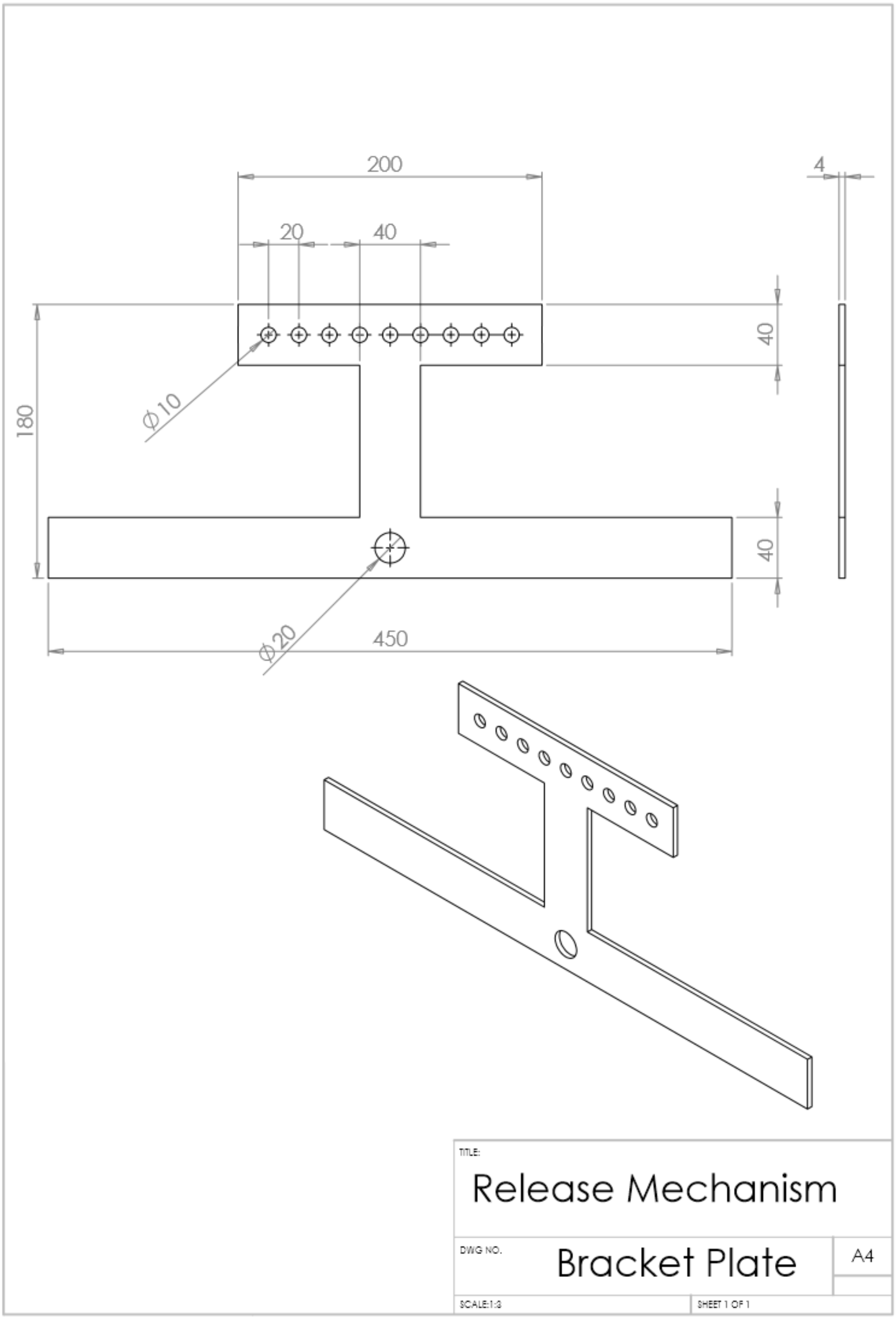
TITLE:
Ski Test Rig

MATERIAL:
Plain carbon steel

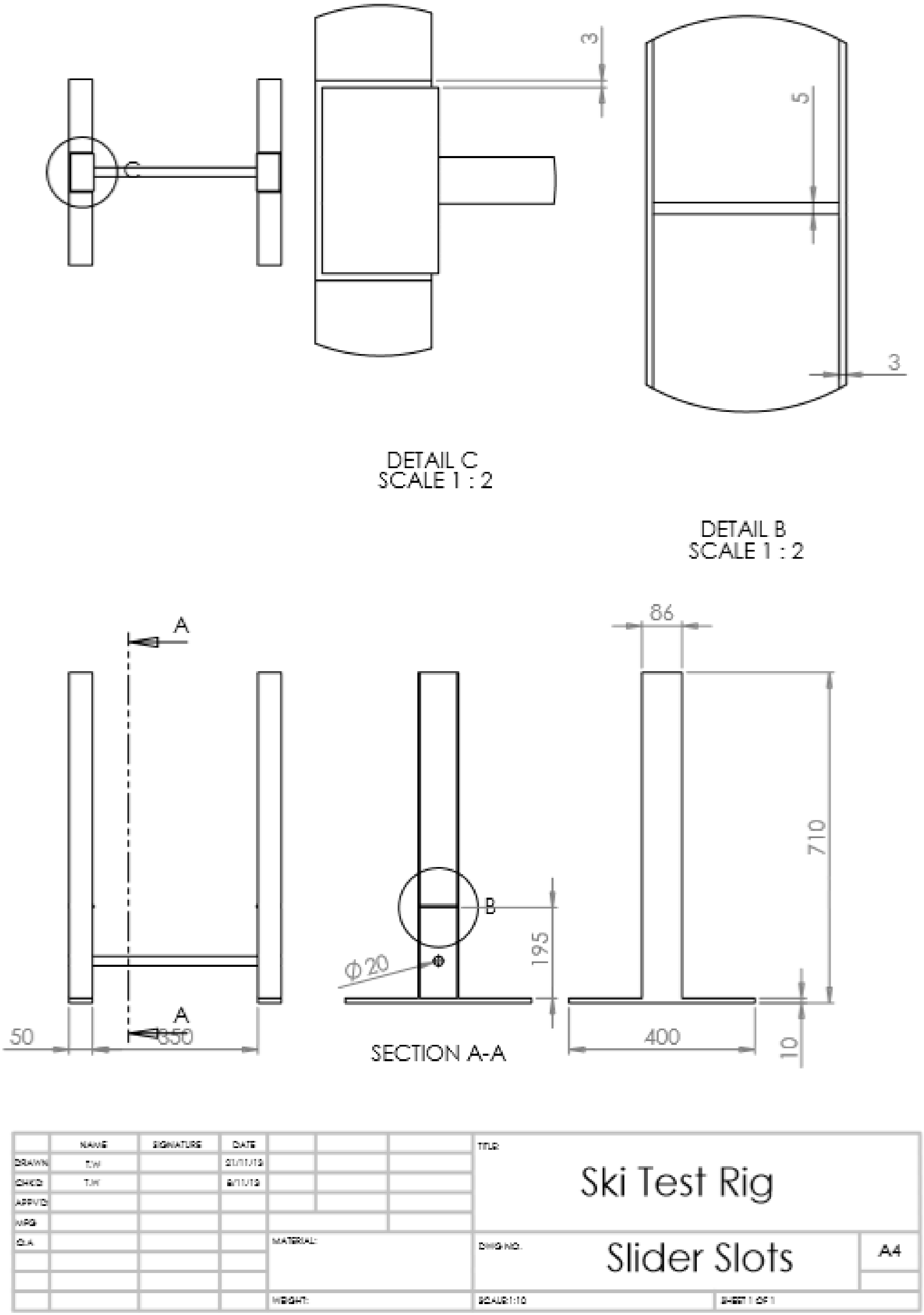
DWG NO.
Clip
A4

WEIGHT:
SCALE:1:5
SHEET 1 OF 1

13.1.2.2 Bracket plate

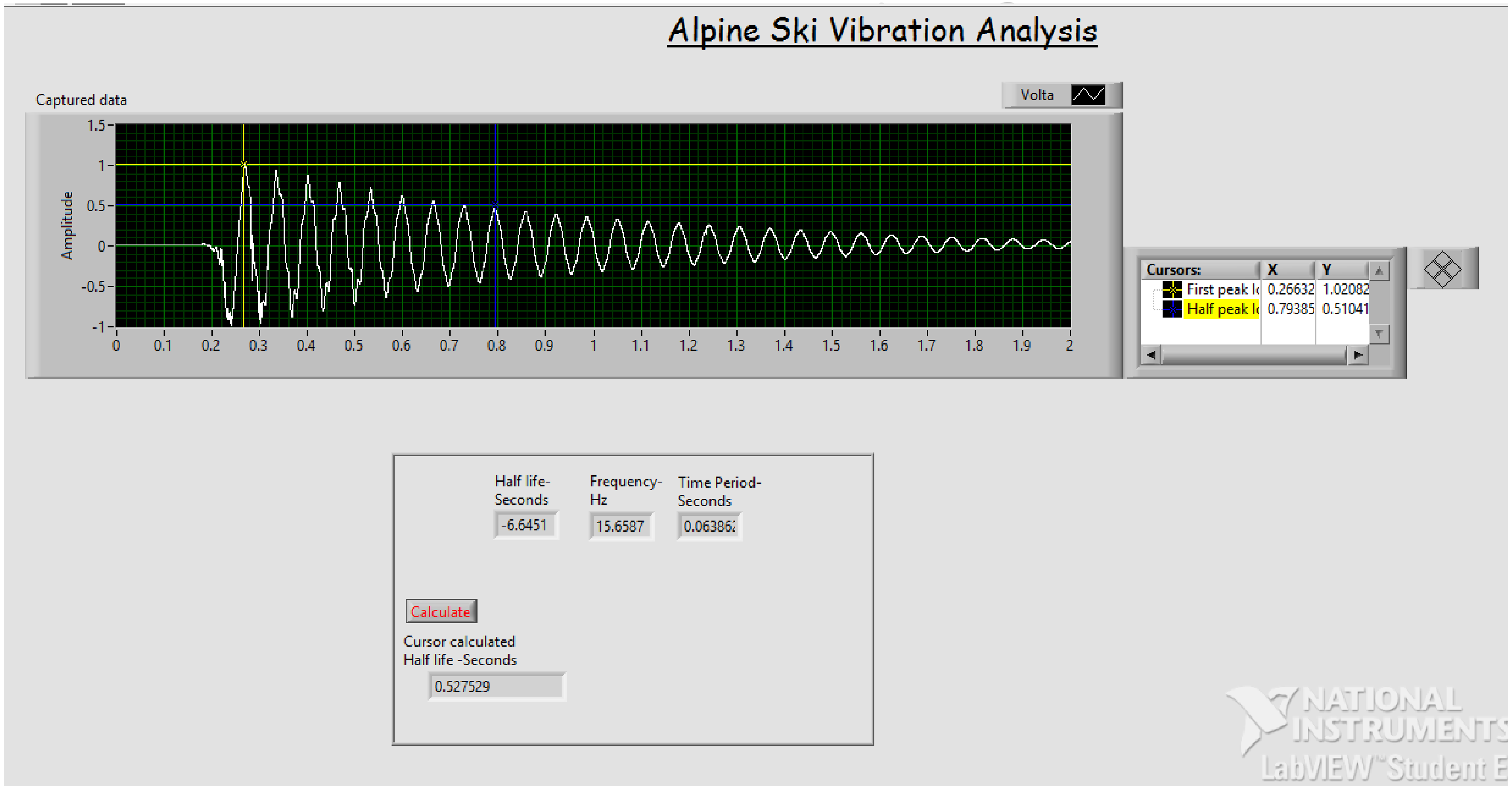


13.1.2.3 *Slider slot*



13.2 LAB VIEW

13.2.1 Front panel



Cursors:	X	Y
First peak l	0.26632	1.02082
Half peak l	0.79385	0.51041

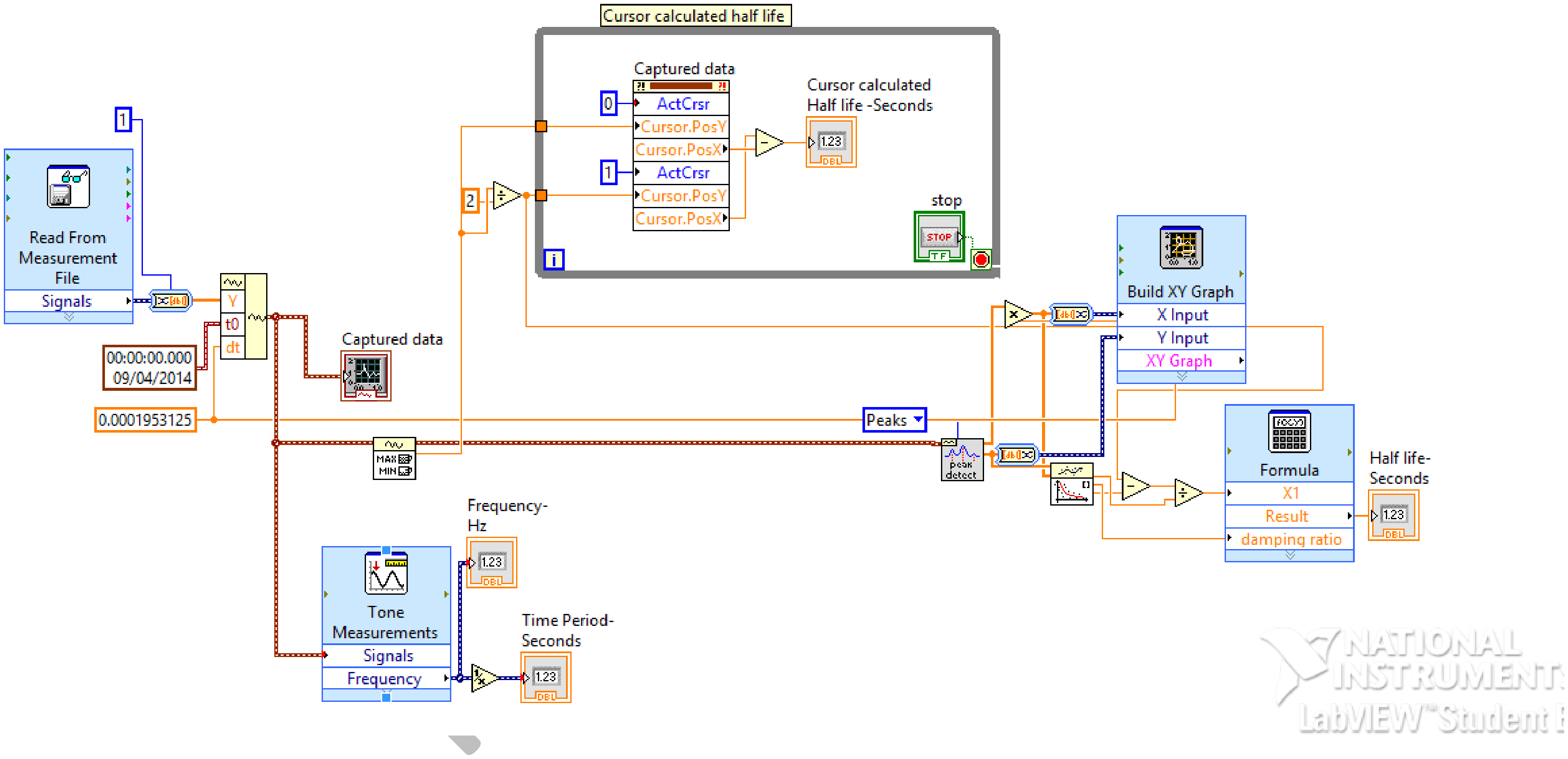
Half life-Seconds: -6.6451

Frequency-Hz: 15.6587

Time Period-Seconds: 0.06386

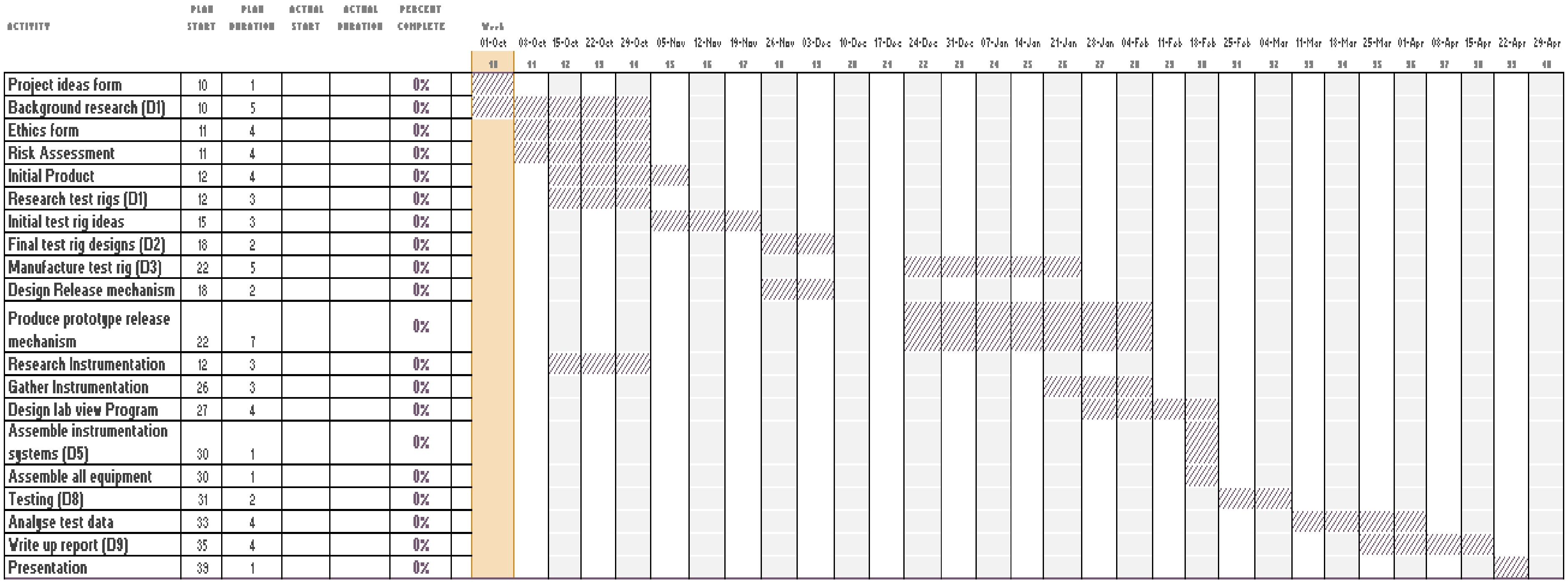
Cursor calculated Half life -Seconds: 0.527529

13.2.2 Block diagram



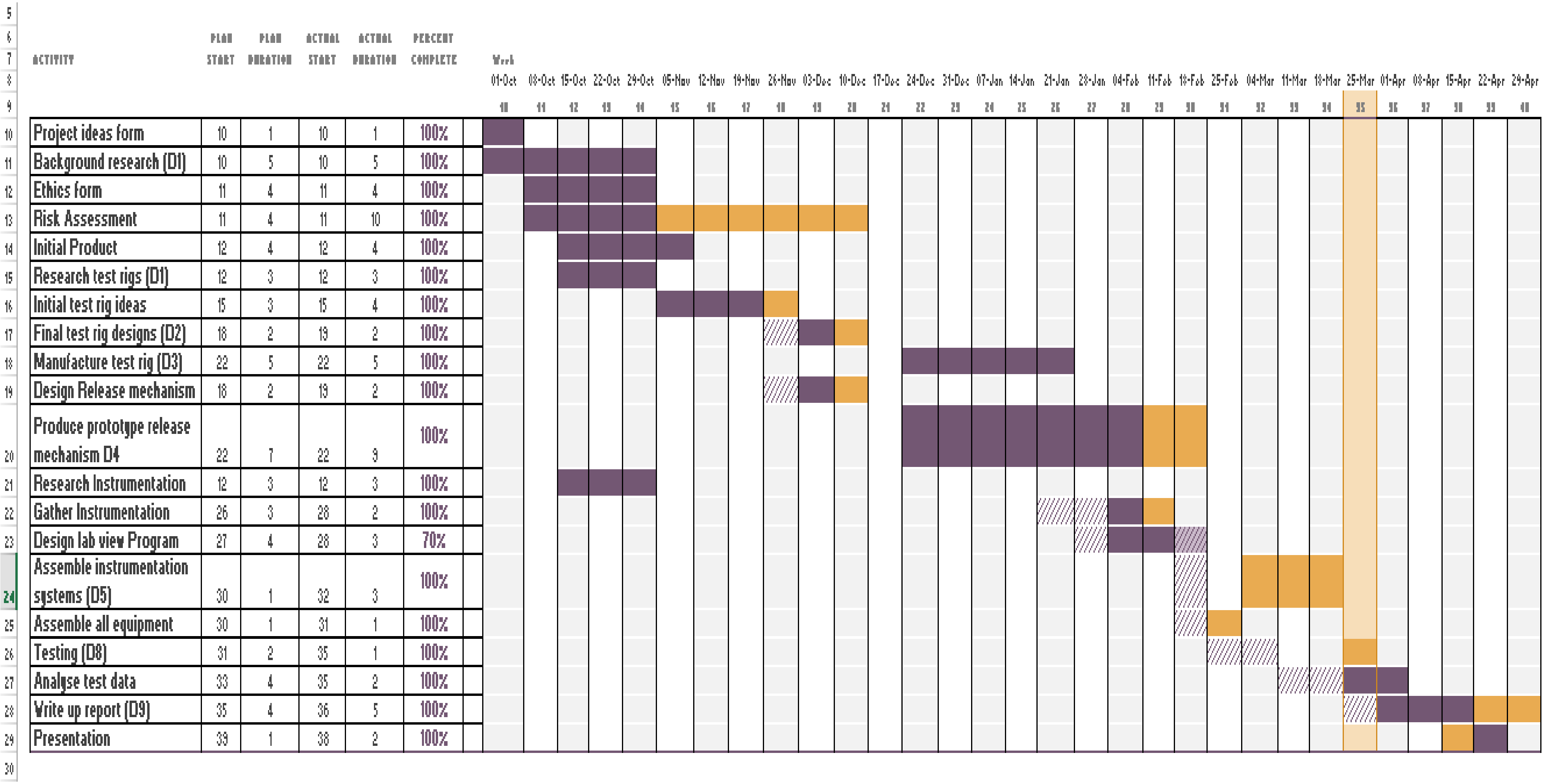
13.3 PROJECT MANAGEMENT

13.3.1 Proposed Project Gant chart



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE	Week 01-Oct	08-Oct	15-Oct	22-Oct	29-Oct	05-Nov	12-Nov	19-Nov	26-Nov	03-Dec	10-Dec	17-Dec	24-Dec	31-Dec	07-Jan	14-Jan	21-Jan	28-Jan	04-Feb	11-Feb	18-Feb	25-Feb	04-Mar	11-Mar	18-Mar	25-Mar	01-Apr	08-Apr	15-Apr	22-Apr	29-Apr
						10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Project ideas form	10	1			0%	▨																														
Background research (D1)	10	5			0%	▨	▨	▨	▨	▨																										
Ethics form	11	4			0%		▨	▨	▨	▨																										
Risk Assessment	11	4			0%		▨	▨	▨	▨																										
Initial Product	12	4			0%			▨	▨	▨	▨																									
Research test rigs (D1)	12	3			0%			▨	▨	▨																										
Initial test rig ideas	15	3			0%						▨	▨	▨																							
Final test rig designs (D2)	18	2			0%									▨	▨																					
Manufacture test rig (D3)	22	5			0%													▨	▨	▨	▨	▨														
Design Release mechanism	18	2			0%									▨	▨																					
Produce prototype release mechanism	22	7			0%													▨	▨	▨	▨	▨	▨	▨												
Research Instrumentation	12	3			0%			▨	▨	▨																										
Gather Instrumentation	26	3			0%																	▨	▨	▨												
Design lab view Program	27	4			0%																		▨	▨	▨	▨										
Assemble instrumentation systems (D5)	30	1			0%																					▨										
Assemble all equipment	30	1			0%																					▨										
Testing (D8)	31	2			0%																						▨	▨								
Analyse test data	33	4			0%																								▨	▨	▨	▨				
Write up report (D9)	35	4			0%																										▨	▨	▨	▨		
Presentation	39	1			0%																														▨	

13.3.2 Actual Project Gantt chart



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Project ideas form	10	1	10	1	100%
Background research (D1)	10	5	10	5	100%
Ethics form	11	4	11	4	100%
Risk Assessment	11	4	11	10	100%
Initial Product	12	4	12	4	100%
Research test rigs (D1)	12	3	12	3	100%
Initial test rig ideas	15	3	15	4	100%
Final test rig designs (D2)	18	2	19	2	100%
Manufacture test rig (D3)	22	5	22	5	100%
Design Release mechanism	18	2	19	2	100%
Produce prototype release mechanism D4	22	7	22	9	100%
Research Instrumentation	12	3	12	3	100%
Gather Instrumentation	26	3	28	2	100%
Design lab view Program	27	4	28	3	70%
Assemble instrumentation systems (D5)	30	1	32	3	100%
Assemble all equipment	30	1	31	1	100%
Testing (D8)	31	2	35	1	100%
Analyse test data	33	4	35	2	100%
Write up report (D9)	35	4	36	5	100%
Presentation	39	1	38	2	100%