



University of Wales Trinity Saint David

School of Engineering

The influence of core materials on the structural
behaviour of skis.

Major Project (M6X00417)

Joshua Grant Brimecombe

1701440

BEng Extreme Sports Engineering

Third year

1/10/2019

This thesis is the result of the authors original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed:

A handwritten signature in black ink, consisting of several overlapping horizontal strokes with some vertical and diagonal lines, appearing to be a stylized name.

Date: 04/05/2020

1 Abstract

The modern Alpine ski is packed with technology and design features, but at the heart of most of these high-performance skis, a wooden core can be found. Which we are told gives the ski 'pop' and increase stiffness, so the aim of this report is to discover the purpose of the core material, correlate its effect to specific properties.

In this report you will find extensive secondary research that looks at alpine skis, their performance and the mechanical characteristics that influence it. Whilst, also investigating what components of the ski effect the skis mechanical characteristics. This led to primary research in the form of FEA testing to link core materials and their material properties to individual characteristics. The FEA tests a carbon fibre sandwich composite with a series of different core materials; Ash, Beech, Fir, Titanium and Titanal (Aluminium 7075). These panels were tested for the flexural stiffness, torsional stiffness and their normal vibrational modes.

There was a significant relationship between material properties and a relating characteristic, such as torsional stiffness and the shear modulus of a material the greater the difference in shear modulus between two cores the greater the difference in the torsional rigidity. Young's modulus effects flexural stiffness and the first mode of vibration. The results are negatively correlated to the material properties, as the modulus increase the panel become stiffer and therefore, the panels deflected less. This report concludes with a result of negative correlation between material properties and mechanical characteristics that effect a skis performance.

2 Acknowledgements

I would like to say thank you to all those who have helped me with my Major project and throughout my journey at university; there have been many people who have supported me from beginning to end. I would like to thank my parents and grandparents who have emotionally and financially supported me through this endeavour. They have always had my best interest at heart and encouraged me to achieve my best. Kelvin Lake, my supervisor, has been the most invaluable support; from my initial ideas of this dissertation, the given direction and guidance from Kelvin has enabled me to finish this project to a high quality. Andy Tibbot's supervision and guidance in the early stages of being in the workshop was instrumental to the finishing of this project. Thank you to the University and all its staff as they all had time to discuss and assist me with any questions or queries, as well as allowing me access to materials and workshop space and time. I would like to thank Claire Evans for the additional academic support she has given me, she has kept me focussed and on track with my workload along with proof reading assignments. Lastly, I would like to thank Kiara Sullivan for being there to support me when I could not go home, for making my life a little easier and for the endless proof reading of my work. As well as a huge thank you to everyone else who have proof-read my report and given up their time to support me.

Table of Content

1	Abstract	2
2	Acknowledgements	3
3	Introduction	6
3.1	Aims	6
3.2	Objectives	6
4	Literature Review	7
4.1	Secondary Research	7
4.1.1	Ski History	7
4.1.2	Ski Construction	7
4.1.2.1	Materials	7
4.1.2.2	Layup	9
4.1.3	Characteristics of a Ski	10
4.1.3.1	Design Characteristics	10
4.1.3.2	Physical Characteristics	11
5	Methodology	14
5.1	Survey	14
5.2	Market Research	14
5.3	Research Based Conclusions	16
5.4	FEA	17
5.4.1	Carbon FEA Material Validation	17
5.4.2	Core Sample Material Tests	18
5.4.2.1	Core Materials FEA Data	18
5.4.2.2	FEA Tests	19
6	Results and Analysis	20
6.1	FEA LDV Carbon-fibre Validation	20

6.2	FEA Core Samples Tests	22
7	Pandemic Impact (Recommended Further Work)	24
7.1	Physical Testing.....	24
7.1.1	Methodology	24
7.1.2	Methodology for Flexural Testing	25
7.1.3	Methodology for Torsional Testing	25
7.1.4	Methodology for Vibrational + Damping Testing	25
7.2	Computational Access.....	26
8	Conclusions	27
9	References.....	28
9.1	Table of Figures.....	30
9.2	Table of Tables	30
10	Appendices.....	31
10.1	Primary research.....	31
10.1.1	Independent Market Research.....	31
10.1.1.1	Table	31
10.1.1.2	Graph	32
10.1.2	Market Research Survey Responses Breakdown	33
10.1.3	Construction and Physical Testing Plan.....	36
10.2	Supervisor Meeting (Minutes and Notes).....	37

3 Introduction

This report is an investigation into the core materials used within Alpine skis. A combination of primary and secondary research will be used to analyse the use of core materials in a composite panel for a skiing application. This engineering report will express and discuss the importance of the mechanical characteristics and their manipulation. There is a connection between the performance of a ski and the mechanical properties of its construction given by combination of the material properties (Glenne, et al., 1997).

The ski industry has seen many changes over the span of the last 2500 years (Glenne, et al., 1997); there has been some major changes in the types of materials and construction used, from complete wood construction to metal and fibre glass composite constructions. Different constructions are laid up in different ways, these major changes have affected the design of the ski including construction, shape and size. Additionally, the changes in ski construction have resulted in skiers having to adapt their skiing techniques, thus making the sport easier to learn and more popular.

The core materials will be evaluated and analysed through the use of FEA and physical testing.

3.1 Aims

The aim of this report is to develop a key understanding of how core materials affect the overall characteristics of a ski, and their effect on the ski's performance and behaviour. To be able to inform the design and construction of a ski, from the analysis of results of physical testing and FEA, to inform key design decisions.

3.2 Objectives

In order to meet the aims, the following objectives were set out:

To evaluate desirable ski characteristics, to determine the importance of the core materials and their mechanical properties to enable the design and planning of physical testing.

To link performance characteristics to specific mechanical properties and the contributing material properties allowing for performance outputs of the ski to be selected.

To carry out physical testing on a selection of different core materials within composite carbon panels.

To use FEA simulation to validate and correlate with physical testing, allowing to evaluate past the manufacturing restrictions.

4 Literature Review

4.1 Secondary Research

4.1.1 Ski History

Skiing has existed for thousands of years, according to Mastroguseppe (2007) 4000 years, which was reinforced by Lund and Masia whom state that skiing dates back to “at least 5000 years ago” (Lund & Masia, n.d.). This has been established by rock paintings and “skis preserved in peat bogs” (Olympic Games, n.d.). Cross country style skis were originally used by hunters and farmers (Brimecombe, 2019) (Lund & Masia, n.d.), as an age-old form of transport (Glennie, et al., 1997).

Advancements in materials and technology have transformed the equipment used in the manufacture and design of skis. The skis of today use composite construction, with steel edges, composite plies and polyethylene sintered bases. Throughout these advancements the use of wood has remained. The use of wooden cores in high performance skis can strike as a bit of an oddity, as it is a natural material with impurities. Although, wood has been used as a construction and engineering material for centuries which means that the characteristics and material properties are well known. The ski industry uses this knowledge and manipulates and manufactures the wood; by laminating (normally vertically) the work material properties can be made more consistent.

4.1.2 Ski Construction

4.1.2.1 Materials

The materials of skis have evolved over the last 2500 years (Glennie, et al., 1997). A modern ski is constructed from many different components of different material composition each providing a particular purpose or characteristic, the sum of which is a composite structure that behaves and performs in a desirable way for skiing. The major components of a ski are the base, edges, composite reinforcement layer (skin), core material, sidewalls and top sheet.

The base of a ski is made from polyethylene and is either manufactured using an extrusion or a sintering process. A sintered base allows the ski to glide over the surface of the snow better due to its ability to hold wax well as the porosity of its composition absorbs and holds the wax. The increased durability of the material prevents damage, keeping the base smooth and flat allowing it to glide efficiently.

A skis edges often are either a high-carbon steel or a stainless steel to prevent oxidation. They allow the ski to grip the surface as they dig into the snow creating a groove for the ski to glide through or

put force though, allowing the ski to turn by ‘carving’ or ‘skidding’ turns. Metal edges are integrated into today’s modern skis, the ‘T’ shaped hooks are bedded into the composite of the ski.

Sidewalls enclose the core material and allows the transfer of power from the ski through the ski and to the snow. The plastic sidewalls found in sandwich construction skis allow for a greater edge grip and transfer of power as they transmit and distribute the pressure onto the edges. The plastic sidewalls also absorb and dampen vibrations, increased by a thin strip of rubber tape that is laid between the edges and sidewalls.

The composite layer sits above and below the core material and acts as structural support and reinforcement. This layer is commonly constructed from fibre glass construction but the weave pattern, number of plies and ply orientation are optimised to suit the design and create the desired response and performance. These composite layers add strength and stiffness to the overall construction. It has been questioned in the past whether ski stiffness is given to the ski via the core material or the composite reinforcement layers. As the core separates the two layers “increasing the second moment of area so the stiffer outer composite layers are further away from the centroid and therefore, increasing h and $\therefore I = \frac{bh^3}{12}$ second moment of area also increases” (Brimecombe, 2019).

The composite layer in high-end skis will often contain more exotic material such as carbon or possibly graphene. They may provide some performance benefits but most likely that it is a marketing technique, this enables them to sell the product at a higher price or make customers believe that it will perform better than the alternative.

The core material is the heart of a ski. The “core’s contribution to flex is moot” (Mastrogiuseppe, 2007) Philippe later concludes “up to 85% of the final ski’s flexural stiffness may depend on the core material” (Mastrogiuseppe, 2007). The materials used in ski cores have varied over time between brands and across streams and skiing disciplines to include many different woods, different density foams, honeycombs, air and metals. Today, it is common to see a combination of these in a single ski, which can be seen in the market research (5.2).

The top sheet protects the ski and normally contains or covers the graphics for the ski. This layer also protects the ski from damage caused by the tips of ski poles or the parallel ski whilst skiing. A large amount of damage occurs for recreational skiers in the tussle that is a ski lift queue.

4.1.2.2 Layup

Skis are constructed by bonding all the desired materials together in an order that creates a structure that will behave in a certain way. The construction can be laid up in different ways; these have different advantages and disadvantages both performances based, and process based.

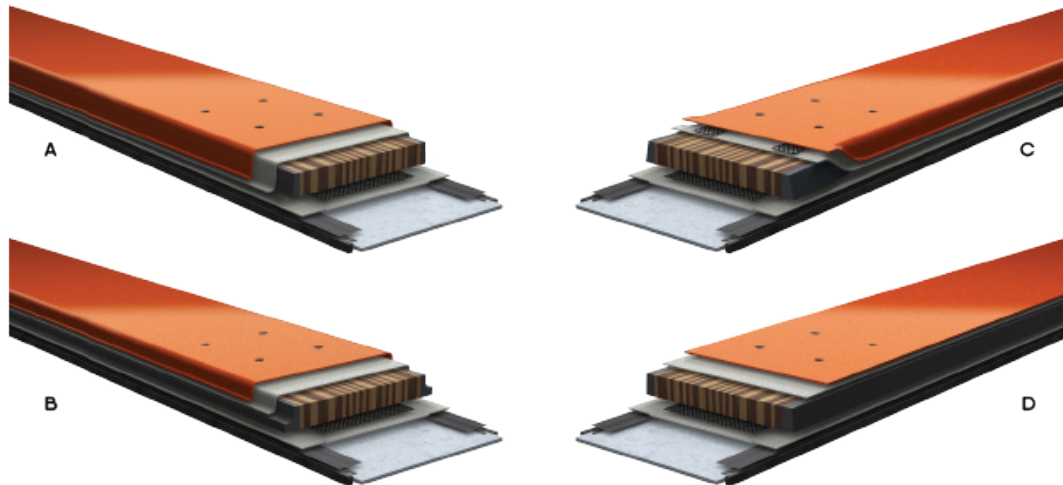


Figure 1 Ski Construction (Freeskier, 2016) (A) Capped, (B) Hybrid, (C) Half-Capped, (D) Sandwich

Sandwich construction (Figure 1, D) is the most common in today's elite racing skis and it has many performance benefits which offsets the expense. The sandwich construction layers all the materials and bonds them together using a wet layup process. The core material is laminated between the structural 'skin' layers (Howe, 2001) and flanked by plastic side walls which allows transmission of power from the skier to the snow (Freeskier, 2016) (Michaelsen, 2010). The full-length sidewall construction also gives better torsional rigidity and impact resistance (Mechanics of Sport, n.d.). Hugh Casey's (2003) report on 'materials in skiing' looks at the impact of materials and technology on the ski industry with regards to the development of skiing technique. It describes the overview of the difference between internal stresses in a monolithic and a composite material or structure. This is further investigated by John Howe (2001) which is expanded on below in 4.1.3.2 Physical Characteristics.

Capped construction shown above (Figure 1, A), provides more protection to the core, as the top skin layers wrap around the side of the skis. The lack of sidewalls in the construction reduces costs and mass. It is ideal as a recreational ski as it is both cheaper and durable but does lack some performance attributes that the side walls provide. Half capped construction (Figure 1, B) gives the power transfer and performance benefits of sandwich construction on the bottom due to the small sidewalls with the protection of capped construction over the top of the ski, as the top sheet and skin wraps halfway down the sidewalls (Freeskier, 2016) (Mechanics of Sport, n.d.).

Hybrid construction (Figure 1, C) again takes attributes of both sandwich and capped construction but rather than combining them along the length of the whole ski, much like half capped. Hybrid construction uses sandwich construction under foot where the power transfer is of the greatest benefit and utilises capped construction at the tip and tail where weight reduction effects the swing weight the most (Freeskier, 2016) and where torsional rigidity is less important (Howe, 2001).

Torsion box is an older technique that “involves wrapping the core material in fiberglass or carbon fibre.” (Mastrogiuseppe, 2007). This technique is now obsolete due to more efficient and effective manufacturing methods.

4.1.3 Characteristics of a Ski

4.1.3.1 Design Characteristics

Design characteristics can influence the performance of a ski and its use. This makes it easier for a manufacturer to alter and to make different models without increasing research and development cost. This also allows for a simpler manufacturing process. The drawback is that the product line is all the same apart from shape and size, which works but some models benefit from further physical changes of construction and materials; beginner skis, or all mountain skis benefit from different core materials than downhill race skis.

Design characteristics include the geometry and other geometric features; such as camber, side cut, core profile and polar moment of inertia.

Polar moment of inertia is the torque applied on a body during rotation in the application of a ski; it is affected by weight distribution and effects how the ski spins in the air during rotational tricks. Polar moment of inertia was reported to have a 20% overall impact on the ‘forgiveness’ and ‘quickness’ of a ski in a QFD (Quality Function Deployment) (Darques, et al., 2004). The report investigates the technical characteristics of skis which after laboratory testing and field testing were analysed and plotted in a QFD (Darques, et al., 2004).

The drive to make skiing more popular, meant that skis were designed to make skiing easier. This was achieved through both design and material changes. Side cuts and cambers were initially to distribute load to the tips and tails for cross country use (Howe, 2001). The benefits from these design features were utilized by reducing the skis length, deepening the side cuts, and exaggerating their effect on turning, make carving easier. This saw changes in geometry to alter performance characteristics. The sport of snowboarding was an influencer in these changes; this is where some research and development of the technology comes from. Twin tip skis, were started when Jason Levinthal started Line, having made a ski by halving all the dimensions of a snowboard.

4.1.3.2 *Physical Characteristics*

The characteristics of a ski can be described as either performance or physical characteristics. These are both influenced by the properties of the materials used in the ski's construction. As Glenne et al. expressed (1997), in modern day the connection between the performance of a ski and the mechanical properties of its construction is given by the combination of the material properties. This report continues to describe skis as "beams which transmit riders loads to the snow" and goes on to specify the most important properties of skis. Ignoring design characteristics leaves you with "stiffness (bending + torsion)". Although this report on 'The Modern Alpine Ski' (Glenne, et al., 1997) is peer reviewed and appeared in the Cold Regions Science and Technology journal, it is relatively old and biased towards the K2 Corporation who were involved in creating the technical report. That being said, the initial statement referenced in this report stands true today and are backed up by (Darques, et al., 2004) and (Nachbauer, et al., 2004). In further sections of Glenne et al. (1997) on the 'skiers load distributions on the snow' and 'Skiers steering forces' the report shows its age as it uses old geometry and ski data.

The effect of the skis stiffness on its performance was examined by Nachbauer W. et al. (2004) from University of Innsbruck departments of Technical Mathematics and Sport Science. It evaluates flexural and torsional stiffness against the ski performance in a controlled field study whilst also investigating the difference in stiffness of unmounted and mounted skis. A short fall of the report is that it does not attribute the different mechanical characteristics to specific material properties. The report states that the manufacturer constructed all skis with the "same geometric features" (Nachbauer, et al., 2004) and using a sandwich construction, but was not specific about materials used in the constructions or how the materials or construction differed to alter the flexural and torsional stiffness. Although, it did underline the importance of both flexural and torsional stiffness, through the practical field testing that they undertook; which saw ski testers evaluate the different flexural and torsional stiff skis. The report then goes on to conclude the relationship between the two types of stiffness using the data and input from the testers to determine the desired amount, albeit a qualitative determination. Nachbauer et al. reference John Howe as a source of evidence in that their results and conclusion on the relationship between a ski stiffness and its performance are correct.

Chapter 2 of John Howe's book 'Skiing Mechanics second addition' (2001) looks at ski properties and construction. The second edition of Howe's book makes several revisions to certain chapters which aligns with some of the older research. Howe revised and changed his work to coincide with the changes in technique due to the advancements in ski design. Longitudinal (flexural) ski stiffness is

investigated initially as the distribution of load, which effects how traditional skis perform. Whilst this is still of importance it is not the driving feature of the characteristic. Flexural stiffness is mentioned again in the revised chapter but this time with a differing result of “softer is better” (Howe, 2001), this now disproves Nachbauer et al. (2004). The revision of torsional stiffness suggests “that softer torsional stiffness at the ski’s extremities is better.” (Howe, 2001) backing up Nachbauer et al. (Nachbauer, et al., 2004), and is the reasoning behind hybrid construction. The original version of torsional stiffness still states that too much torsion is bad, it suggests that stiffer skis are better for experts and softer skis are more forgiving so are suited to beginners, which is another characteristic that is taken into consideration (Howe, 2001).

Although more of a design feature, the profile of a core can affect the flexural stiffness of a ski. The stiffness can be altered by the skis thickness as this changes the skis second moment of area (I). The stiffness also changes with the material as each material has a different material stiffness (E). This is why stiffness is often referred to as EI . A detailed theory of longitudinal bending is discussed in the appendix of ‘Skiing Mechanics’ (Howe, 2001). Howe’s appendix examines the basic equations used in determining structural stiffness, then discusses their use in a composite structure such as a ski with the effects of different materials in different positions and the position of the neutral axis. He then suggests the effect of certain structural components on the mechanical properties of a ski.

The authors of ‘Effect of ski stiffness on ski performance’ (Nachbauer, et al., 2004) appear with two further colleagues from the University of Innsbruck to write ‘Effects of ski and snow properties on the turning of Alpine skis – a computer simulation’ (Nachbauer, et al., 2006). It aimed to show the effects of ski geometry, bending and torsional stiffness on the radius of a turn whilst including the snow conditions. It concluded that to achieve the smallest radii in a turn the ski needs to bend longitudinally which is constrained mechanically by the flexural stiffness. Increased edging angles and large side cuts also “cause high ski bending and thus small ski radii” (Nachbauer, et al., 2004).

The proven importance of flexural and torsional stiffness in a ski’s performance is also evident in the research undertaken by Darques et al. (2004). Their report on QFD of a ski, evaluates five laboratory tests based on five technical characteristics, “dimensions, bending, torsion, damping and polar moment of inertia” (Darques, et al., 2004). The research evaluates three mechanical characteristics of flexural stiffness, torsional stiffness, and vibration dampening. Whilst the laboratory tests gave quantitative data to complete the QFD, a complement of practical field tests were conducted which evaluated the performance of the ski (skidding and carving response, accuracy, liveliness, and forgiveness).

Many of the articles and reports that look at stiffness, in particular torsional stiffness, also discuss vibration and therefore damping. Darques, et al. (2004) describes the cause and negative effects of vibration as “the micro-relief of the track when the product slides” (Darques, et al., 2004) over the surface. The testing method used for vibration damping, as shown below in Figure 2, clamps half of the ski and imposes an initial deflection with the use of an electromagnet. The displacement of the oscillation is then measured by a sensor. The QFD indicated that the dampening ratio influence on the overall impact of the ski by 13% (Darques, et al., 2004).

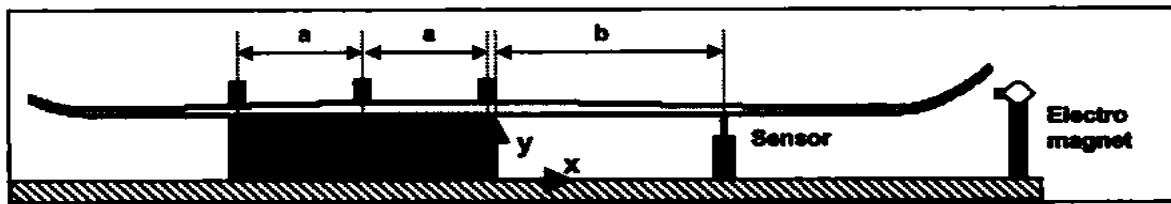


Figure 2 Vibration Test Rig (Darques, et al., 2004)

On a ski which has stiff extremities, the tip and tail will load the edge too much causing it to break away from the surface and bounce around, this whole process causes a lot of vibration. Vibration is also caused by snow conditions such as hard icy conditions, especially if the surface is rough and has chatter marks, as well as the increase of vibration with speed (Howe, 2001).

The report by Philippe Mastrogiuseppe (2007) on ‘The effects of core material and thickness on the performance and behaviour of a ski’, “evaluates the effect of core materials” (Mastrogiuseppe, 2007). Philippe constructed several samples with differing cores, both the core material and their thickness were changed. By changing two variables, it makes it hard to compare data across the samples. The change in thickness effects the distance between the fibre glass layers altering the second moment of area is why it states “A direct correlation between the stiffness of the core and stiffness of a ski cannot be made, due to the composite nature of a ski.” (Mastrogiuseppe, 2007). The method looks at three types of core materials (all wood), Jatoba, Yellow Birch and Spanish Cedar. Although the physical testing that was conducted by Philippe was rudimentary and not extremely scientific, his research and experimentation showed promise and strong fundamentals. The report also lacked extended vocabulary and literacy awareness; however, it discusses and analysis of the results of the physical testing in detail.

5 Methodology

5.1 Survey

The survey was conducted using SurveyMonkey.com; ten comprehensive questions were written up on what type of skiing was being conducted by participants and what equipment they use, including specific equipment specification. The questions and results from the survey can be found in the appendix (10.1.2 Market Research Survey Responses Breakdown).

The survey was shared on a number of social media pages including ski specific community pages. The survey received one hundred and twenty-five complete responses; the responses received were from British participants of mixed ability. This is both beneficial and a limiting factor, as it allows demographic and geological conclusions to be drawn and added to the equation.

The survey first asked questions to build a picture of the participant, including how many days they ski a year, what equipment they own and what type of skiing they take part in. The survey then asks more ski specific questions such as; what make and model skis they own, the skis construction, the core materials in the skis and the skis dimensions.

5.2 Market Research

Research was conducted into the market; this allowed the author to draw conclusions of the current market. The primary research collected data and information from manufacturers websites including product pages, specification, technology pages and reviews. The research was conducted on a sample of the market including a range of ski types and brands.

Table 1 Market Research

Types of Core Materials with skis.										LWTSO Bing Extreme Sports Eng			
Major Project: The influence of core materials on the structural behaviour of skis.													
Preliminary Primary Research in to current ski cores and ski market.													
Ski cores										Side Cut			
Company / Brand Name	Ski Type (2019-2020)	Model Name	Core Material	Construction	Camber / Rocker	Ski Length Range	Tip	Waist	Tail	Widths (Tip/Waist/Tail)	Radius (m)		
Whiteheads	Freeride	Ragnarok 118	Ash and Poplar wood	Sandwich	Rocker / Camber	190	143	118	130	143-118-130	30		
Whiteheads	Freestyle	Ronde 96	Ash and Poplar wood	Sandwich	Rocker / Camber	168, 177, 186	132	96	115	132-96-115	17, 18, 19		
Whiteheads	All mountain	Altium 104	Ash and Poplar wood	Sandwich	Rocker / Camber	174, 179, 187	133	104	123	133-104-123	20, 21, 22		
Salomon	Racing - Giant Slalom	SRACE GS FIS	Ash / Poplar / Osage and Titanium layers x2	Sandwich	Rocker / Camber	183, 186, 193	103	85	81	103-85-81	30		
Salomon	Racing - Downhill	Slalom DH FIS	Ash / Poplar / Osage and Titanium layers x2	Sandwich	Rocker / Camber	213	85	80	80	85-80-80	30		
Salomon	Piste	S/Max Blast	Ash wood and Titanium layers x2	Sandwich	Rocker / Camber	166, 165, 170, 175, 180	121	76	106	121-76-106	13		
Salomon	Racing - Super G	SRACE SG FIS	Ash wood and Titanium layers x2	Sandwich	Rocker / Camber	185, 192, 200, 210, 212	85	80	81	85-80-81	30, 35, 40, 45		
Salomon	Freestyle	WFX	Beech and Poplar wood	Sandwich	Rocker / Camber / Rocker	160, 170, 176, 182	122	82	115	122-82-115	15		
Salomon	Racing - Slalom	SRACE SL FIS	Beech, Poplar and Titanium layers x2	Sandwich	Rocker / Camber	157, 165	115	63	101	115-63-101	12.6		
Salomon	Freeride	DS1 118	Poplar wood and Titanium layer	Sandwich	Rocker / Camber / Rocker	171, 178, 185, 192	128	118	126	128-118-126	22		
Salomon	Piste	S/Force Bold	Poplar wood and Titanium layers x2	Sandwich	Rocker / Camber	170, 177, 184	132	84	116	132-84-116	15		
Salomon	All mountain	KDR	Poplar wood and Titanium layers x2	Sandwich	Rocker / Camber / Rocker	166, 172, 178, 186	129	88	112	129-88-112	15		
Rossignol	Freestyle - Mogul	Hero Athlete Mogul Acceler	Ash wood	Sandwich	Rocker / Camber	166, 177	82	63	81	82-63-81	23, 26		
Rossignol	Racing - Slalom	Hero Athlete FIS SL	Ash wood and Titinal layer	Sandwich	Rocker / Camber	150, 157, 165	116	87	103	116-87-103	11, 12, 13		
Rossignol	Racing - Giant Slalom	Hero Athlete FIS GS	Ash wood and Titinal layer	Sandwich	Rocker / Camber	185, 188, 193	102	85	84	102-85-84	30, 27, 30		
Rossignol	All mountain	Experience 94Ti	Titinal core	Sandwich	Rocker / Camber	173, 180, 187	122	94	122	122-94-122	15.5, 16.5, 18.5		
Rossignol	Freeride	Super 7 HD	Paulownia wood and Carbon Alloy Matrix	Sandwich	Rocker / Camber	172, 180, 188	140	116	130	140-116-130	17, 19, 22		
Rossignol	Piste	On Piste React	Poplar wood and Titinal layer	Sandwich	Rocker / Camber	160, 168, 176, 182	124	78	110	124-78-110	12, 13, 14, 15		
Line	All mountain	Tom Waitech Pro	Maple Macrobloc (maple + aspen)	Capped	Rocker / Camber	157, 164, 171, 178	117	90	112	117-90-112	20		
Line	Freeride	SUPERNATURAL 100	Maple Macrobloc (maple + aspen)	Hybrid	Rocker / Camber	172, 179, 186	132	100	121	132-100-121	21.3		
Line	Powder	Outline	Paulownia & Maple	Hybrid	Rocker / Camber	178, 186	150	117	142	150-117-142	18.5		
K2	Piste	Super Charger	Aspen, Paulownia wood and Titinal layers x2	Sandwich	Rocker / Camber	168, 175, 182	123	72	99	123-72-99	18		
K2	Powder	Catamaran	Fir and Aspen wood	Sandwich	Rocker / Camber	177, 184, 191	136	120	131	136-120-131	21		
K2	Freestyle	PONZOON	Fir and Aspen wood	Capped	Rocker / Camber	156, 169, 179, 189	157	132	122	157-132-122	30		
K2	Freeride	Mindbender 116C	Maple and Paulownia wood	Hybrid	Rocker / Camber	179, 186, 199	143	116	133	143-116-133	23		
K2	All mountain	Mindbender 90Ti	Maple, Aspen wood and Titinal Y layer	Sandwich	Rocker / Camber	163, 170, 177, 184	177	90	114	177-90-114	18		
Head	Freeride	Kore 117	KARUBA wood, Koroyd, Graphene and Carbon	Sandwich Capped	Rocker / Camber / Rocker	171, 180, 189	143	127	115	143-115-127	20, 22, 24		
Head	Racing - Slalom	Worldcup Rebels 1 SL RD	Silver Fir wood, Graphene and Titinal layers x2	Sandwich Capped	Rocker / Camber	165, 168	119	87	103	119-87-103	12		
Head	Racing - Giant Slalom	Worldcup Rebels 1 GS RD	Silver Fir wood, Graphene and Titinal layers x2	Sandwich Capped	Rocker / Camber	183, 188, 193	101	85	80	101-85-80	30		
Head	Racing - Downhill	Worldcup Rebels 1 DH RD	Silver Fir wood, Graphene and Titinal layers x2	Sandwich Capped	Rocker / Camber	210, 215, 217	82	66	79	82-66-81	30		
Head	Piste	Superlight 1 Speed	Silver Fir wood, Graphene and Titinal layers x2	Sandwich Capped	Rocker / Camber	156, 163, 170, 177, 184	124	68	104	124-68-104	12, 13, 14, 15, 16		
Head	All mountain	Monster 88 Ti	Silver Fir wood, Graphene and Titinal layers x2	Sandwich Capped	Rocker / Camber / Rocker	156, 163, 170, 177, 184	130	87	113	130-87-113	14, 15, 16, 17, 19		
Head	Racing - Super G	Worldcup Rebels 1 SG RD	Silver Fir wood, Graphene and Titinal layers x2	Sandwich Capped	Rocker / Camber	202, 207, 213	85	66	81	85-66-82	40, 42, 45		
Head	Freeride	Caddy	wood and Titinal layer	Sandwich	Rocker / Camber / Rocker	161, 171, 176, 181	120	83	109	120-83-109	16, 18, 20		
Blackcrows	Powder	Noctis	Paulownia and Poplar wood	Sandwich	Reverse Rocker	177, 185, 190	140	122	132	140-122-132	26		
Blackcrows	All mountain	Nova	Poplar wood	Sandwich	Rocker / Camber / Rocker	166, 179, 185	131	102	120	131-102-120	19		
Blackcrows	Piste	Nova	Poplar wood and Titinal H layers x2	Sandwich	Rocker / Camber	169, 174, 179, 184	124	88	110	124-88-110	21		
Blackcrows	Piste	Divus	Poplar wood and Titinal H layers x3	Sandwich	Rocker / Camber	172, 177, 182	124	82	110	124-82-110	17		

The data was collected (Make, Model, Type, Core Material, Construction, Camber/Rocker, Length, Width, Radius) and recorded into a Table 1 (above) in excel which allows the data to be sorted by category and analysed. Design trends can be seen from this with regards to the relationship between

types of ski and the geometric features, such as the side-cut radius of racing skis; downhill skis 50m, giant slalom around 30m, slalom around 12m and Super-G varying with length between 30m to 45m. The other noticeable trend was all racing ski waists are under 70mm (this is due to FIS [Fédération Internationale de Ski] regulation as 65mm is standard waist width of a racing ski along with other regulations on base plate height). The skis looked at in the research are production world cup replicas and do not have to conform to regulation unless used in competition. For competition, manufacturers will produce slightly different skis for their professional athletes. These may be designed for specific slopes, conditions or for the athletes themselves and may possibly contain prototype technology which they are hoping to improve before taking into production.

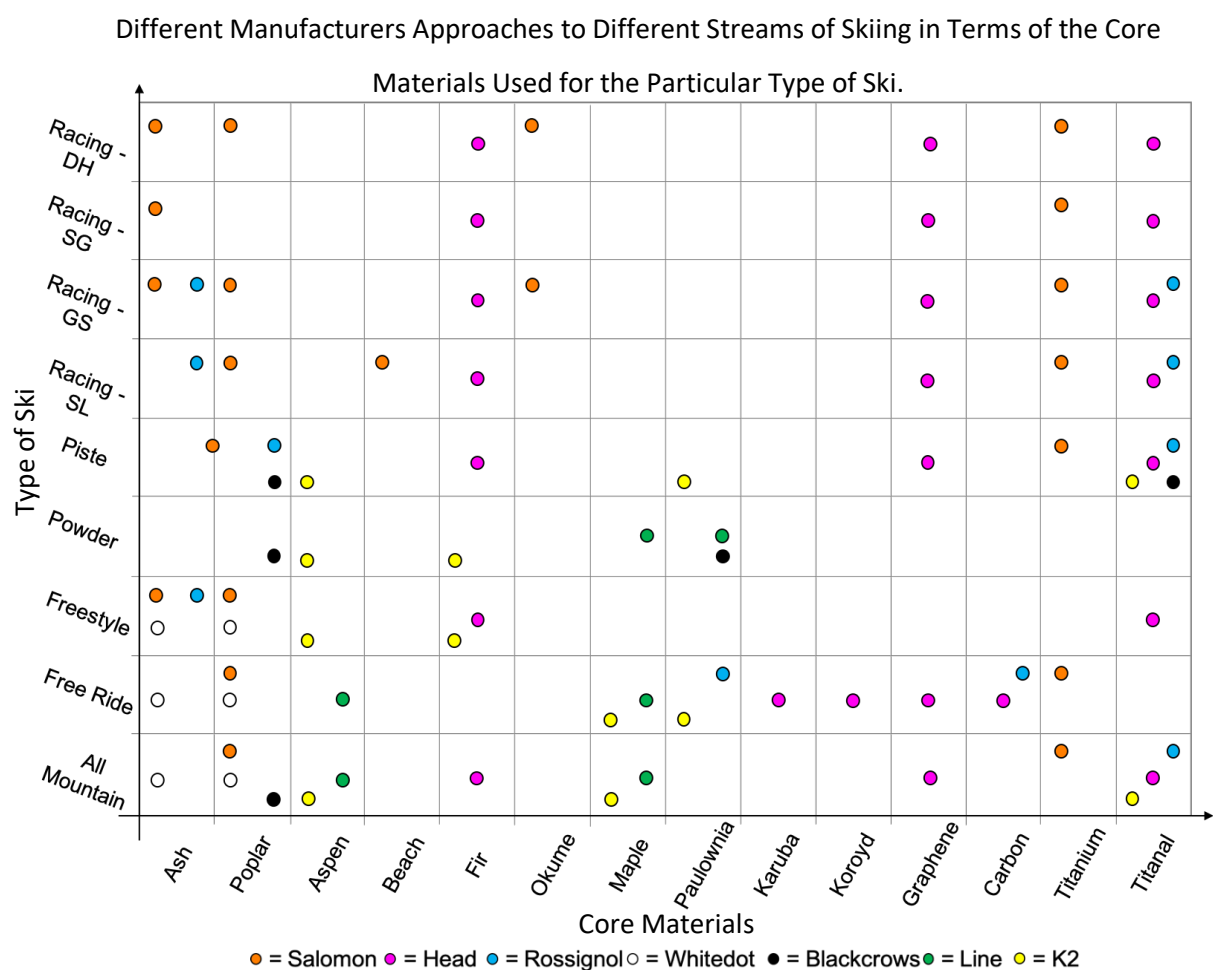


Figure 3 Core Material Market Research (Graph)

Trends in the usage of core materials was more difficult to analyse, so a graph (Figure 3) was produced to visualise the data. There are several trends that can be seen in the figure above. It can be seen that whilst the core material does alter between the different ski types, a larger factor is manufacturing trends. Using the same material across different models and streams of skiing reduces costs and simplifies manufacture, which are beneficial to the company. The only benefit to

the end user is the reduction in cost. The end performance of a ski will be hindered if the materials and construction of the ski has not been optimised for its purpose. To combat this, the characteristics of the ski are altered by design changes alone. This is ideal for building similar types of ski, for example a brand will use the same materials and construction for all their racing skis but will use design to adapt for specific use.

5.3 Research Based Conclusions

Primary and secondary research was used to inform further research such as Finite Element Analysis (FEA) and physical testing. The following conclusions and decisions are based on the forementioned research.

In all further analyses, sandwich construction was used as it is the most common construction in today's market based on the market research, survey, and the secondary research that analyses the core materials (Mastrogriuseppe, 2007) (Casey, 2001). Sandwich construction also allows for easy construction and simplification to isolate the effect of the core material. Simplification of the construction was done to simplify FEA processing and reduces the computational solving time. The steel edges, sidewalls, base material and top sheet were all removed. Therefore, materials do not have to be sourced for physical testing.

The size of the sample for both FEA and physical testing were kept the same and were informed by the market research and the survey responses. The result of the primary research was an average underfoot waist width of 88mm. The sample length was at a ratio of 2:1 of the width (length equals 176mm) (Lake, 2019).

The FEA model required validation. A coreless sample was constructed and tested to validate the material model and PCOMP. The sample was tested using the LDV to measure the normal modes of vibration which could then be used to scale the material property data (engineering constants). This is done by altering specific engineering constants to manipulate individual results until they meet the experimental data counterparts gathered from the physical tests.

The use of FEA to compare data is invaluable, allowing for hypotheticals such as changing material thickness to comparing different materials thus enabling the comparison between dissimilar materials, making the material thickness a control variable.

5.4 FEA

Finite Element Analysis (FEA) was conducted to analyse the mechanical characteristics given to that sample by the materials used in its construction. This would have been used to verify the physical mechanical testing. Computational methods allow for theoretical tests such as comparative tests between materials that are manufactured to different thicknesses which would affect results. The thickness can be altered so that the thickness of the core material becomes a controllable variable.

The test sample of 88mm x 176mm x 2mm was modelled and a 2D planar created which was meshed as a static model in Solidworks which was then exported as a Nastran file and imported into Genesis Design Studios which was used as a computational FE solver. In Design Studio, a PCOMP was set-up with the number of plies and their individual thickness, orientation and the material of the layer.

5.4.1 Carbon FEA Material Validation

As the manufacturer refused to release a datasheet and technical specification for 200g 2x2 Twill T800 Prepreg Carbon that was used, a coreless test sample was produced to validate the material properties. Material properties were set by type as a composite panel MAT8 (PSHELL/PCOMP Orthotropic), and specific engineering constants, which make up the material properties, were populated. These include Youngs moduli, Passions ratio, and shear moduli (Lake, 2020). The FE models material properties were populated with general 2x2 twill carbon provided by Kelvin Lake (2020) as shown below.

Property	Supplier Values	Comments
Youngs Modulus in the longitudinal direction (E ₁)	58.0 GPa	1
Youngs Modulus in the lateral direction (E ₂)	58.0 GPa	2
Poissons Ratio (Nu ₁₂)	0.04	1
Inplane shear modulus (G ₁₂)	27.9 GPa	3
Transverse shear modulus (1-Z plane)(G _{1z})	27.9 GPa	2
Transverse shear modulus (2-Z plane)(G _{2z})	27.9 GPa	2
Mass density (Rho)	1.51 g/cm ³	4
Allowable longitudinal stress in tension (Xt)	641.2 MPa	1
Allowable longitudinal stress in compression (Xc)	605.8 MPa	5
Allowable transverse stress in tension (Yt)	641.2 MPa	2
Allowable transverse stress in compression (Yc)	605.8 MPa	5
Allowable inplane shear stress (S)	59 MPa	1
THICKNESS /laminate	0.26mm	6

Figure 4 General 2x2 Twill Carbon Data (Lake, 2020)

To validate the material properties of the carbon fibre, a matching FEA model and test sample were constructed. The physical test sample was tested using the LDV (Laser Doppler Vibrometer) test rig and the modes of vibration (1st, 2nd and 3rd modes) were found. The sample was impacted with a controlled tap from a speaker and the LDV measured and recorded the vibration on a specific point on the panel. It then cycles through a series of points and then maps out the data recorded. The LDV uses a laser and a digital camera (optical lens) to measure the frequency of vibrational modes.

5.4.2 Core Sample Material Tests

The FEA testing was conducted with several different core materials. Core materials were chosen based on the market research and the survey. The materials were also picked on their ability to be modelled in the FEA software. For this reason, honeycomb core was taken out of the equation. The main issue with the modelling of materials in FEA is finding the relative material properties to input into the software; specific material property data can be found on material data sheets and specification sheets from manufacturers or suppliers. In this case, book values were used as the materials were not sourced and the natural nature of wood means that its material information can differ from source to source.

5.4.2.1 Core Materials FEA Data

Ash, Fir, Beech, Titanium, and Titanal were the materials chosen for this project. The material data for the three wooden cores were sourced from the 'Wood Handbook: Wood as an Engineering Material', this book provided values for Young's modulus ("Modulus of elasticity" (Kretschmann, et al., 2010)), Poisson's ratio and shear modulus ("Modulus of Rigidity" (Kretschmann, et al., 2010)). The data for the metal cores were sourced from online, the Young's modulus, Poisson's ratio and shear modulus for Titanium were all sourced from AZO-Materials (2001).

Titanal is a material that is used predominately in the ski industry, it is only manufactured by AMAG who had retained exclusive rights to the product for the winter sports market. There is a limited source of data for this material, AMAG state in a product description from a brochure that it is a 7000 series aluminium "Titanal belongs to the 7xxx (AlZn) alloy group" (AMAG - AL4U, n.d.) (AMAG - AL4U, 2019). Even though there is limited data published on this material a patent was filed at the European Patent Office in 1987 and was granted in 1991. This patent covered the "design and application" and "properties and physical metallurgy and phase diagrams" (Austria Metall Aktirngesellschaft (AMAG) & Kutner, 1991). This patent contains a breakdown of the composition of the metal, it contains varying amounts of the following: Aluminium, Silicon, Iron, Copper, Manganese, Magnesium, Chromium, Zinc, Titanium and Zircon. The patent covers six variants of differing mixtures of the above alloy for the use in "ski constructed as a laminate" (Austria Metall Aktirngesellschaft (AMAG) & Kutner, 1991). Based on all the above research, Titanal was linked closely with the Aluminium alloy 7075, as they contain the same elements. Material data for 7075 AlZn was found easily online (ASM Aerospace Specification Metals Inc., n.d.).

The material data for these core materials was entered into the FEA solver, allowing the core material to be added to the PCOMP.

5.4.2.2 FEA Tests

The FEA tests are tests for flexural stiffness, torsional stiffness and the vibrational modes.

Normal vibrational mode tests measure the frequency of the normal vibrational modes; these would affect how the ski would vibrate and at what frequency the oscillation occurs. The test investigated the first, second and third modes of normal vibration. This consisted of clamping the sample at the base and setting up of an eigenvalue method, to analyse the first three modes of vibration. Each core material should then be tested in the PCOMP under these conditions.

Boundary conditions were set up in the 'Analysis -> Grid-Component Sets' tabs of Design Studio. A single condition was set-up for both flexural and torsional tests, a single-point constraint (SPC) was used with 20mm of one end of the material and all the nodes in that area are constrained in all 6 axis (components) of freedom.

An individual static load was set-up for both flexural and torsional loads. Both loads were applied to the 10mm on the other end of the panel from the SPC. The difference between the two loads were that the force for the flexural load was applied on the -Z axis and for torsional testing it was added as a moment around the X axis, both the force and the moment were applied as a UDL (Uniformly Distributed Load), so the load was divided by the number of nodes (elements).

The boundary conditions and static loads were applied to the model in the 'Analysis -> Loadcases' tab in Design Studio.

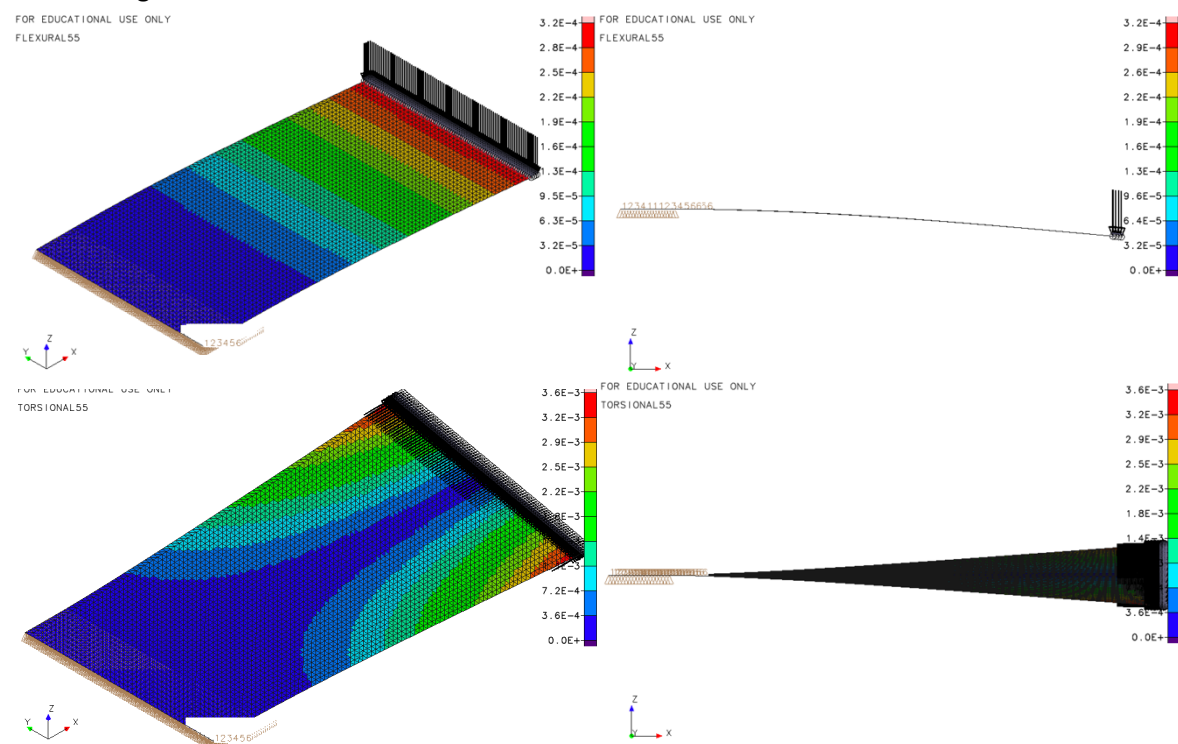


Figure 5 FEA Constraints for Flexural and Torsional Test

6 Results and Analysis

6.1 FEA LDV Carbon-fibre Validation

To validate both the Finite Element model and the material properties of the carbon fibre, an 8-ply symmetrical 0/90 2 x 2 twill carbon fibre panel was constructed without a core and was tested in the LDV to find the normal vibration modes of the material.

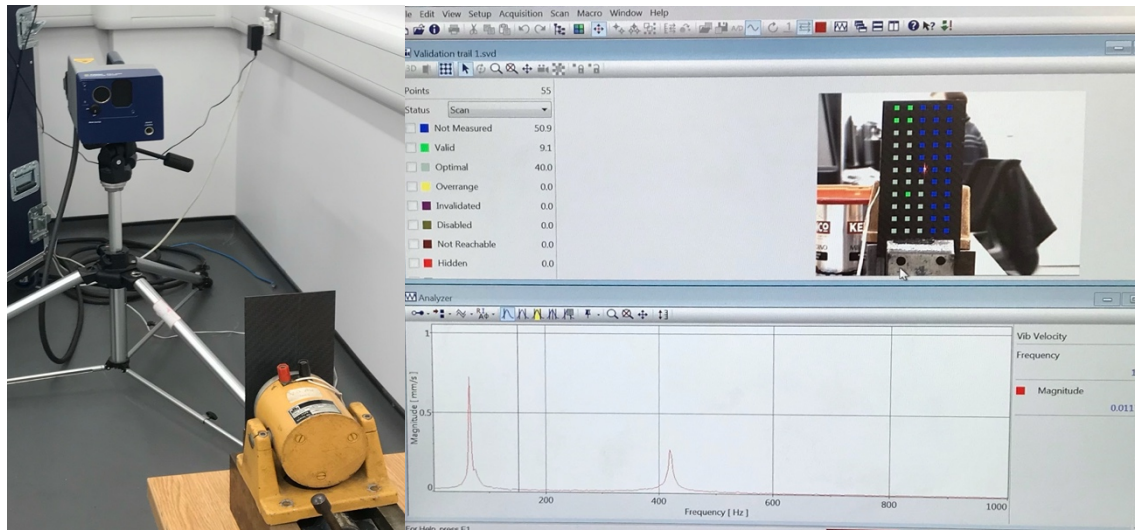


Figure 6 LDV Normal Mode Frequency Testing

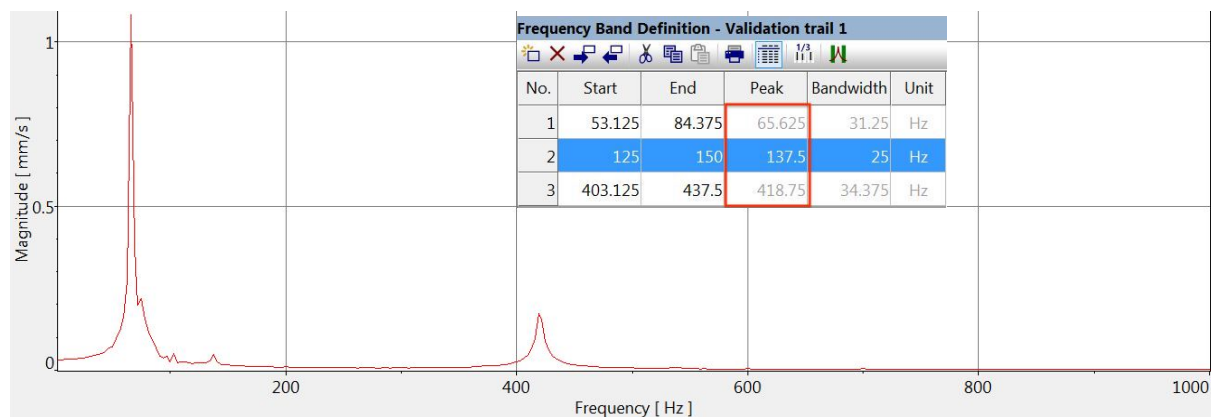


Figure 7 LDV Normal Mode Frequency Results Carbon Fibre Validation

The results from the LDV normal mode frequency tests showed in Figure 7, show peaks at different frequencies, these frequencies are highlighted in the frequency band definer. Each peak represents a normal mode of vibration. The three normal vibrational modes shown in Figure 7 portray the vibration of the material at those frequencies. The frequency of the three modes are first mode peaks at 65.625 Hz, second mode at 137.5 Hz and the third mode at 418.75 Hz.

To simulate the material properties of the test panel, the vibration frequencies of the FEA model must match those of the test panel. This was completed by scaling the generic material properties of the model iteratively by using my knowledge of the engineering constants to determine which value to alter to get a desired response, i.e. E1 was altered to affect the longitudinal stiffness effecting the results of the first mode.

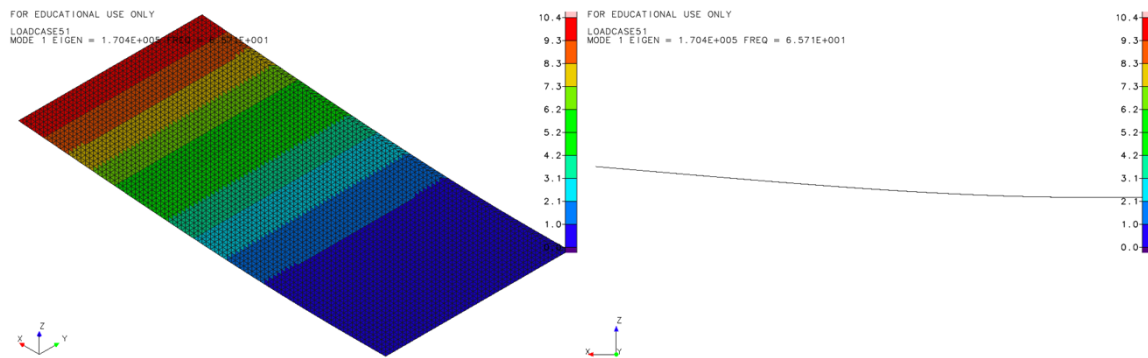


Figure 10 FEA Carbon Fibre Validation Mode 1 (65.8Hz)

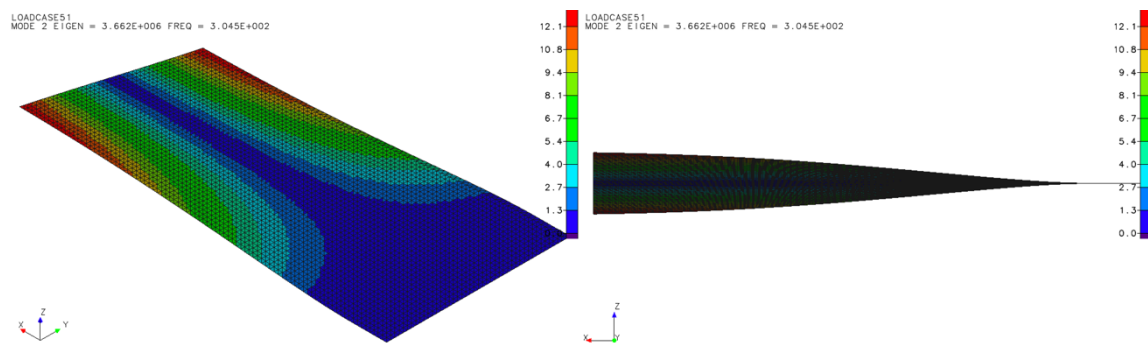


Figure 9 FEA Carbon Fibre Validation Mode 2 (137.2Hz)

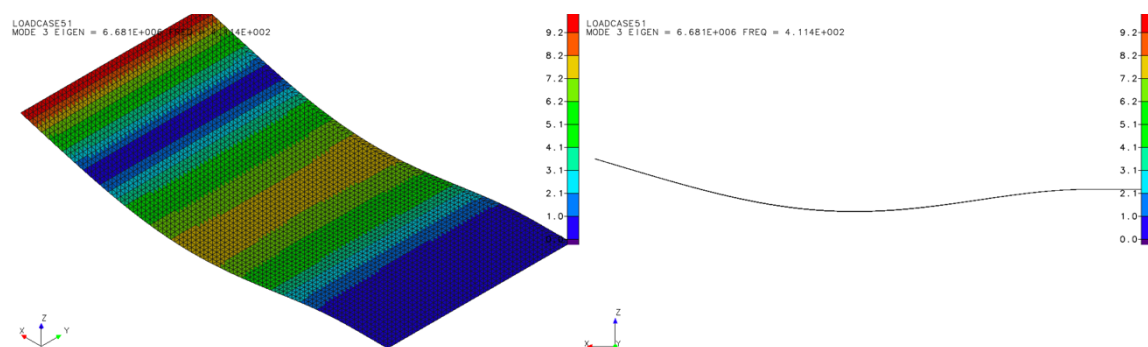


Figure 8 FEA Carbon Fibre Validation Mode 3 (411.2Hz)

The above figures (Figure 8, Figure 9 and Figure 10) show the FEA simulations and the normal vibrational mode results for the coreless 8-ply symmetrical 0/90 2 x 2 twill carbon fibre panel. The frequency of the first mode shown in Figure 10 is 65.8Hz, the second mode in Figure 9 is 137.2Hz and the third mode in Figure 8 is 411.2Hz.

6.2 FEA Core Samples Tests

The material properties data for the core materials selected for FEA analysis (Ash, Fir, Beech, Titanium and Titanal) was sourced and input into the FEA simulation model and the materials added to the PCOMP (Group Properties) with the relative thickness. The material properties are shown in the table below (Young's Modulus, Poisson Ratio and Shear Modulus). The core materials were added, and the normal modes of vibration were tested, this was repeated for each material.

Table 2 Material Property Data and Normal Modes of Vibration

		Materials						
		Wood			Metal			
Material properties		Ash (10mm)	Fir (10mm)	Beech (10mm)	Titanium (10mm)	Titanal (10mm)	Titanium (0.5mm)	Titanal (0.5mm)
Youngs Modulus	E1	1.200E+10	1.180E+10	1.190E+10	1.00E+11	7.17E+10	1.00E+11	7.17E+10
Youngs Modulus	E2	1.500E+09	8.024E+08	9.282E+08				
Poisson Ratio	Nu12	0.371	0.292	0.364	0.35	0.33	0.35	0.33
Shear Modulus	G12	1.308E+09	7.552E+08	8.806E+08	3.60E+10	2.69E+10	3.60E+10	2.69E+10
FEA Test Results								
Normal Modes of Vibration	1st Mode	8.067E+02	7.889E+02	7.954E+02	1.488E+03	1.311E+03	9.646E+01	9.611E+01
	2nd Mode	1.643E+03	1.493E+03	1.532E+03	4.935E+03	4.313E+03	2.065E+02	2.045E+02
	3rd Mode	3.020E+03	2.703E+03	2.787E+03	9.083E+03	7.943E+03	6.023E+02	6.001E+02

The results in the above table (Table 2) showed the first, second and third modes of normal vibration. The normal mode test for each of the core materials reflected the material properties of the core material; for example, the wooden core with the highest Young's modulus (E1) is Ash, which has the highest vibrational frequencies this continues across the board with Fir being the lowest and Beech in the middle. Perhaps the most intriguing note trend is that the results of certain modes correlate to the material properties that influence that vibrational modes. Such as, the Young's modulus value (E1) gives the material its stiffness in the longitudinal direction which affects the frequency of oscillation of the first, therefore the small differences of 0.1e+9 in Young's modulus (E1) between Fir and Beech, and Beech and Ash is represented in the differences between frequency results. The same goes for the second vibrational mode, which is altered by the shear modulus which the difference between is greater. There is a 110Hz difference between Ash and Beech and a 40Hz difference between Beech and Fir, which is linked to the 4.3e+8 and 1.3e+8 differences in the shear modulus.

The metal cores were analysed at both 10mm and at an available 0.5mm. This was done to allow the metal to be analysed against the 10mm wooden cores, as seen in the table both metal cores at 10mm, the vibrational modes appear at much higher frequencies meaning it requires more energy to cause vibration. The 0.5mm metal cores allows for much more realistic representation, of the material. In similar fashion to the wooden cores the metals apply to the same trends as discussed above, Titanium exhibits higher frequencies across all the normal modes, than the Titanal core which exhibits a lower Young's modulus value.

Flexural and torsional test were then run on all the different core material, the results can be seen below in Table 3. All cores were tested individually in the PCOMP with the metal cores being tested at 10mm and 0.5mm, therefore, the same reasons as the vibrational test. Two further groups were tested both combining wood and metal cores in a single construction and PCOMP. One group simply combined the two cores together increasing the core thickness effecting the second moment of area, the other combines the two types of core material whilst keeping the same total thickness not to alter the stiffness given by the carbon fibre reinforcement layers. These combinations cannot be calculated from the sum of the deflections of the other cores as the stiffness of the core material and the reinforcement layers cannot be determined. By keeping the total thickness the same, the stiffness of the carbon fibre reinforcement can be considered a controlled variable therefore, the results can be compared between each other using the differences between the deflections.

Table 3 Flexural and Torsional Stiffness Results

Core Material	Thickness of core	Total Thickness (mm)	Flexural Stiffness	Torsional Stiffness
			10kg (98.1N) mm	10kg (98.1N) mm
Ash	10	11.76	0.4024	5.0581
Beech	10	11.76	0.4094	5.7406
Fir	10	11.76	0.4141	6.0036
Titanal	10	11.76	0.1582	0.6949
Titanium	10	11.76	0.1231	0.5304
Titanal	0.5	1.26	29.3148	360.6813
Titanium	0.5	1.26	29.1074	352.9644
Ash + Titanal	9.5 + 0.5	11.76	0.3442	3.4846
Ash + Titanium	9.5 + 0.5	11.76	0.3261	3.2893
Beech + Titanal	9.5 + 0.5	11.76	0.3507	3.9704
Beech + Titanium	9.5 + 0.5	11.76	0.3327	3.7773
Fir + Titanal	9.5 + 0.5	11.76	0.3548	4.1702
Fir + Titanium	9.5 + 0.5	11.76	0.3368	3.9789
Ash + Titanal	10 + 0.5	12.26	0.3103	3.1394
Ash + Titanium	10 + 0.5	12.26	0.2940	2.9617
Beech + Titanal	10 + 0.5	12.26	0.3166	3.5903
Beech + Titanium	10 + 0.5	12.26	0.3003	3.4155
Fir + Titanal	10 + 0.5	12.26	0.3205	3.7791
Fir + Titanium	10 + 0.5	12.26	0.3042	3.6042

Again, the results in for both flexural and torsional stiffness, follow the order of stiffness of the associated material property. The flexural stiffness of the wooden core is linked to the Young's modulus with the grain with Ash having the highest it also has the least deflection as it is the stiffest, followed by Beech then Fir. Due to the minimal change in Young's modulus of 0.1×10^9 between cores, the change in deflection is also small at only 0.007mm and 0.005mm. The increased Young's modulus of the metal cores significantly reduces deflection of the 10mm by 0.25mm at the closest point. Torsional shows the same trend but with larger differences due to the greater differences in the shear modulus of the materials. A material could have greater differences in torsional and flexural stiffness if the Young's and shear moduli were opposing. This could lead to other issues such as delamination of the composite structure.

7 Pandemic Impact (Recommended Further Work)

7.1 Physical Testing

Due to the outbreak of 'Covid -19' the timeline of the project was hindered, forcing necessary changes to the project. The physical testing that was planned was unable to be completed. The construction of the panels was almost completed with all core materials cut, the metal cores were cut on the waterjet cutter and then cleaned, wooden cores cut to size in the wood shop, and the honeycomb cores had been hand cut along with 80% of carbon fibre prepreg plies were cut.

Once all the materials were cut, they were ready to be laid up, vacuum bagged and cured. One day of cutting prepreg, one day of laying up and a final day for vacuum bagging and curing is what was required to finish the manufacture of all fifty-four of the composite panels. This would have allowed testing to be conducted for flexural stiffness, torsional stiffness and vibration / damping.

7.1.1 Methodology

The three physical tests were to be conducted on six different core materials with three repeats for each material on each test. The materials were chosen based on a combination of the market research, survey and what is available to purchase. The six materials that were chosen were, Ash wood, Poplar wood, Aramid honeycomb, Aluminium honeycomb, Titanium and Titanal (2 x wood, 2 x honeycomb, 2 x metal). The wooden cores were sourced from 'Junksupply' a DIY ski and board material supplier, the Titanal was purchased from 'The Ski Lab' and shipped from the United States and the Titanium was supplied by a private seller. Both of the honeycomb cores and carbon fibre were supplied by the University. Without the ability of practical testing for this project, it led to the majority of the project being changed to FEA investigation. This meant a change in materials which were more suitable as discussed in more detail in section 5.4.2.

Table 4 Test Panel Plan

Core Materials		Tests + No. of tests			Total	no. plys	
Material Type	Category	Flexural Stiffness	Torsional Stiffness	Vibrational Dampaning			
Ash	Wood	3	3	3	9	72	
Poplar	Wood	3	3	3	9	72	
Aramid	Honeycomb	3	3	3	9	72	
Aluminium	Honeycomb	3	3	3	9	72	
Titanium	Metal	3	3	3	9	72	
Titanal	Metal	3	3	3	9	72	
		18	18	18	54	Total # plys	432

As shown in Table 4 Test Panel Plan, there were eighteen tests planned for each test, three repeats for six different core materials. Each panel consisted of eight plies of carbon fibre; the total of number of plies can be seen in the far right-hand column of Table 4.

7.1.2 Methodology for Flexural Testing

The flexural test analyses the longitudinal stiffness of the panel which was outlined in the secondary research as an important characteristic that effects the overall performance of the ski. The tests would show the impact the core material has on the mechanical characteristics of the ski. The flexural tests will be performed on a custom build rig for flexural and torsional test testing.

The panel would have been constrained (horizontally), by clamping 20mm of the base of the panel to a fixed workstation with the remainder of the panel's length protruding out. The panel acts as a rigidly fixed cantilever beam. On the protruding end of the panel the weight was clamped on to the last 10mm of the panel, so the load is distributed uniformly (UDL). A series of DTI (Dial Test Indicators) gauges will be set-up to measure the deflection, this will then be recorded and analysed.

7.1.3 Methodology for Torsional Testing

The torsional test analyses the torsional stiffness of the panel and therefore, the torsional stiffness of the core material used in the panel's construction. The torsional tests will be performed on the flexural and torsional test rig that was produced.

Similarly, to the flexural test, the panel would be constrained (horizontally), with the first 20mm of the panel to a fixed (clamped) to the workstation. The remainder of the panel's length protruding out, acting as a rigidly fixed cantilever beam. On the final 10mm of the panel, a ridged bar will be clamped, with a force acting only on one side and the rigidity of the cross clamped bar converting this force into a movement. A series of DTI gauges will be set-up to measure the deflection, this will then be recorded and analysed.

7.1.4 Methodology for Vibrational + Damping Testing

The vibrational and dampening tests will be conducted on the LDV jig that was used to validate the material properties of the carbon fibre. The process of this is described above in 5.4.1 and 6.1. The damping data is recorded by changing a few settings, the results are then exported into MATLAB where they can be manipulated of the graphs and the damping ratio can be calculated.

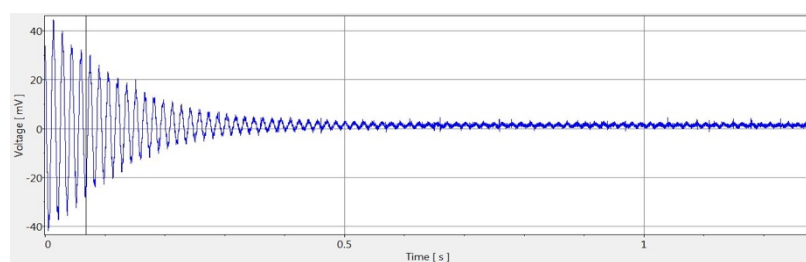


Figure 11 LDV Damping Graph

7.2 Computational Access

The closure of the University building and computer labs meant that access to software such as GRM Genius Design Studio (FEA Software) was inhibited, restricting continuation with the project. A 30-day free trial had to be downloaded on to a virtual windows machine on a laptop. This meant that FEA took longer than anticipated, due to slower processing.

8 Conclusions

To conclude this report, we must look at the question this report asks, 'Do core materials influence the skis mechanical characteristics and therefore, the overall performance of the ski?' The report above investigates this question.

The report conducted both secondary and primary research which allowed conclusions to be drawn and testing to be set up. The market research allowed for a series of published data (accessible to the consumer) to be collected and analysed, drawing conclusions based of both the market and the products in it. The secondary research highlighted three physical characteristic that both effect performance and could be linked to the material properties of the core material.

The effect of the core material on specific mechanical characteristics is evaluated with the use of FEA testing. FEA testing was used to investigate the vibration modes, flexural and torsional stiffnesses. The results stay on a trend of acting like the related material properties shown in the 'Results and Analysis' section of this report. This has determined a link between specific material properties and the resultant characteristics.

A basic computational model has also been produced as a result of the FEA testing, it could be used to optimise for the thickness of core required or number or orientation of composite plies with little adaption. These would allow further FEA and optimisation testing to be conducted with limited time or resources, allowing extensive data to be collected and analysed.

Physical testing would have been ideal to validate these FEA results, especially as generic Book values were used to model the core materials. I plan to finish physical testing as laid out in the pandemic impact section. Physical tests would have allowed for the testing of different materials that were not realistic to model in the time frame; without further investigation into them and the physical test to validate them, such as honeycombs 3D printed infill structures.

9 References

AMAG - AL4U, 2019. [Online]

Available at: <https://www.amag-al4u.com/en/press/publications.html> -
<https://de.calameo.com/read/0034240185f6d8e9e9bce>

[Accessed 22 02 2020].

AMAG - AL4U, n.d. *AluReport*. [Online]

Available at: https://www.amag-al4u.com/fileadmin/user_upload/amag/Downloads/AluReport/EN/AR-2009-3-EN-AR_3_09_EN_Sports.pdf

[Accessed 30 9 2019].

ASM Aerospace Specification Metals Inc., n.d. *ASM Matweb*. [Online]

Available at: <http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MA7075T6>

[Accessed 15 04 2020].

Austria Metall Aktirngesellschaft (AMAG) & Kutner, D. D. F., 1991. *Use of an alloy made of AlZnMgCuFUr vibrating sports equipment (Verwendung einer Legierung aus AlZnMgCuFUr schwingend beanspruchte Sportgeräte.)*. Deutsche (german), Patent No. 0233858B1.

AZoM, 2001. *Titanium (Ti) - Properties, Applications*. [Online]

Available at: <https://www.azom.com/properties.aspx?ArticleID=712>

[Accessed 30 01 2020].

Brimecombe, J. G., 2019. *Ski Equipment Research*. Swansea: Survey Monkey / Facebook.

Brimecombe, J. G., 2019. *the Impact of Materials on Sports Equipment*, Swansea: s.n.

Casey, H., 2001. Materials in Ski Design and development. In: F. (. Fores & S. Haake, eds. *Materials and Science in Sports*. Warrendale: TMS, pp. 11-17.

Casey, H., 2003. Materials in Skiing. In: *Materials in Sports Equipment, 2003, p.326-342*. Los Alamos National Laboratory: Woodhead Publishing Limited, pp. 326-342.

Darques, J., Carreira, R. P., de la Mettrie, A. & Bruyant, D., 2004. Quality Function Deployment - A means for developing adequate skis and snowboards. In: *Engineering of Sport 5*. Decathlon Technical Center, Villeneuve d'Ascq, France: International Sports Engineering Association (Sheffield, 2004), pp. 428-434.

- Freeskier, 2016. *Guide to Understanding and Buying Skis*. [Online]
Available at: <https://freeskier.com/stories/freeskiers-guide-to-understanding-and-buying-skis>
[Accessed 27 March 2019].
- Glenne, B., DeRocco, A. & Vandergrift, J., 1997. The Modern Alpine Ski. *Cold Regions Science and Technology*, 8 February, Volume 26, pp. 35-38.
- Howe, J., 2001. *The New Skiing Mechanics*. USA: McIntire Publishing.
- Kretschmann, D. E., Green, D. W. & Winandy, J. E., 2010. Mechanical Properties of Wood. In: R. J. Ross, ed. *Wood Handbook: Wood as an Engineering Material*. Centennial Edition ed. s.l.:Forest Products Laboratory, United States Department of Agriculture Forest Service, pp. Chapter 4 (1-45).
- Lake, K., 2019. *Supervisor Meetings*. Swansea: s.n.
- Lake, K., 2020. *2x2 Twill Carbon General Data*. Swansea: UWTSD.
- Lake, K., 2020. *Macromechanical Analysis of a Lamina Extended Notes (Lecture)*. Swansea: UWTSD.
- Lund, M. & Masia, S., n.d. *Short History of Skis*. [Online]
Available at: <https://www.skiinghistory.org/history/short-history-skis-0>
[Accessed 27 March 2019].
- Mastrogioseppe, P., 2007. *The effects of core material and thickness on the performance and behaviour of a ski*, Montréal, Québec: McGill University.
- Mastrogioseppe, P., October 2007 . *The effects of core material and thickness on the performance and behaviour of a ski*, Montréal, Québec: McGill University.
- Mechanics of Sport, n.d. *Ski Construction*. [Online]
Available at: http://www.mechanicsofsport.com/skiing/equipment/skis/ski_construction.html
[Accessed 27 March 2019].
- Michaelsen, G., 2010. *Sidewall vs. Cap Construction*. [Online]
Available at: <https://theskimonster.com/blog/posts/sidewall-vs-cap-construction/>
[Accessed 27 March 2019].
- Nachbauer, W. et al., 2006. Effects of ski and snow properties on the turning of Alpine skis – a computer simulation. *Journal of Biomechanics*, 39(1).
- Nachbauer, W., Rainer, F., Schindelwig, K. & Kaps, P., 2004. Effects of ski stiffness on ski performance. In: *Engineering of sport 5*. University of Innsbruck, Departements of Sport Science and Technical Mathematics(Innsbruck): International Sports Engineering Association (ISEA), pp. 472 - 478.

Olympic Games, n.d. *Alpine Skiing Equipment and History*. [Online]
 Available at: <https://www.olympic.org/alpine-skiing-equipment-and-history>
 [Accessed 10 3 2020].

9.1 Table of Figures

Figure 1 Ski Construction (Freeskier, 2016) (A) Capped, (B) Hybrid, (C) Half-Capped, (D) Sandwich.....	9
Figure 2 Vibration Test Rig (Darques, et al., 2004).....	13
Figure 3 Core Material Market Research (Graph)	15
Figure 4 General 2x2 Twill Carbon Data (Lake, 2020)	17
Figure 5 FEA Constraints for Flexural and Torsional Test.....	19
Figure 6 LDV Normal Mode Frequency Testing.....	20
Figure 7 LDV Normal Mode Frequency Results Carbon Fibre Validation	20
Figure 8 FEA Carbon Fibre Validation Mode 3 (411.2Hz)	21
Figure 9 FEA Carbon Fibre Validation Mode 2 (137.2Hz)	21
Figure 10 FEA Carbon Fibre Validation Mode 1 (65.8Hz)	21
Figure 11 LDV Damping Graph	25

9.2 Table of Tables

Table 1 Market Research	14
Table 2 Material Property Data and Normal Modes of Vibration.....	22
Table 3 Flexural and Torsional Stiffness Results.....	23
Table 4 Test Panel Plan	24

10 Appendices

10.1 Primary research

10.1.1 Independent Market Research

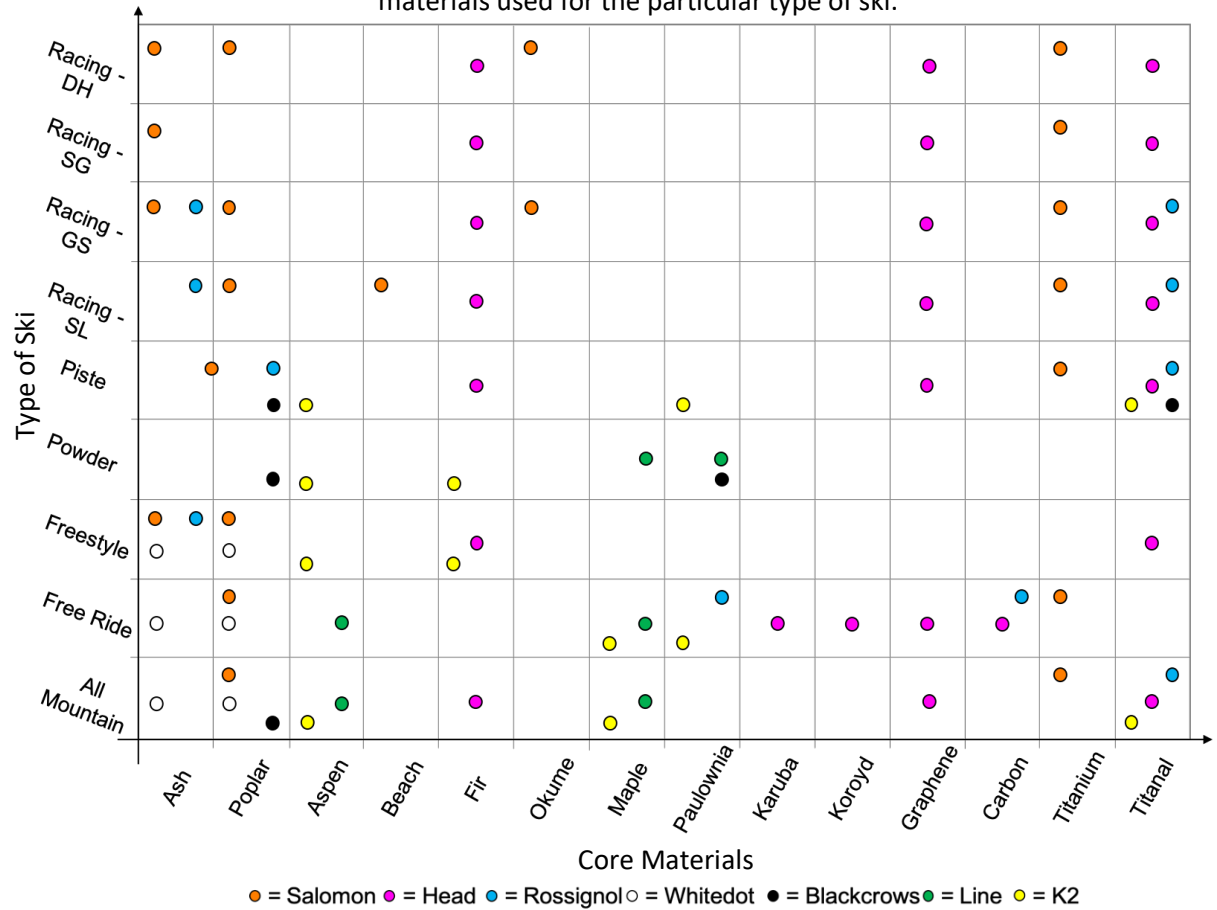
10.1.1.1 Table

Types of Core Materials with in skis.
Preliminary Primary Research in to current ski cores and ski market.

Ski cores	Company / Brand Name	Ski Type (2019-2020)	Model Name	Core Material	Construction	Camber / Rocker	Sk. Length Range	Tip	Waist	Tail	Side Cut Widths (Tip/Waist/Tail)	Radius (m)
Whiteheads	Whiteheads	Freestyle	Ragnarok 118	Ash and Poplar wood	Sandwich	Rocker / Camber	190	143	118	130	143-118-130	30
Whiteheads	Whiteheads	Freestyle	Ronde 96	Ash and Poplar wood	Sandwich	Rocker / Camber	168, 177, 186	132	96	115	132-96-115	17, 18, 19
Whiteheads	Whiteheads	All mountain	Altum 104	Ash and Poplar wood	Sandwich	Rocker / Camber	171, 179, 187	133	104	123	133-104-123	20, 21, 22
Salomon	Salomon	Racing - Giant Slalom	S/RACE GS FIS	Ash / Poplar / Okume and Titanium layers x2	Sandwich	Rocker / Camber	183, 188, 193	103	65	81	103-65-81	30
Salomon	Salomon	Racing - Downhill	S/Race DH FIS	Ash / Poplar / Okume and Titanium layers x2	Sandwich	Rocker / Camber	213, 218	95	80	106	95-65-80	50
Salomon	Salomon	Piste	S/Max Blast	Ash wood and Titanium layers x2	Sandwich	Rocker / Camber	160, 165, 170, 175, 180	121	76	106	121-76-106	13
Salomon	Salomon	Racing - Super G	S/RACE SG FIS	Ash wood and Poplar wood	Sandwich	Rocker / Camber	185, 192, 200, 210, 212	95	65	81	95-65-81	30, 35, 35, 40, 45
Salomon	Salomon	Freestyle	INPX	Beech and Poplar wood	Sandwich	Rocker / Camber	160, 170, 176, 182	122	82	115	122-82-115	15
Salomon	Salomon	Racing - Slalom	S/RACE SL FIS	Beech, Poplar and Titanium layers x2	Sandwich	Rocker / Camber	157, 165	115	63	101	115-63-101	12, 6
Salomon	Salomon	Freestyle	UST 118	Poplar wood and Titanium layer	Sandwich	Rocker / Camber	177, 178, 185, 192	139	118	126	139-118-126	22
Salomon	Salomon	Piste	S/Race Bold	Poplar wood and Titanium layers x2	Sandwich	Rocker / Camber	170, 177, 186	132	84	116	132-84-116	15
Rossignol	Rossignol	Freestyle - Mogul	Hero Mogul	Poplar wood and Titanium layers x2	Sandwich	Rocker / Camber	163, 171, 178, 186	99	84	116	132-84-116	15
Rossignol	Rossignol	Freestyle - Mogul	Hero Mogul	Ash wood and Titanium layers x2	Sandwich	Rocker / Camber	166, 177	92	63	81	92-63-81	23, 26
Rossignol	Rossignol	Racing - Slalom	Hero Athlete FIS SL	Ash wood and Titalal layer	Sandwich	Rocker / Camber	150, 157, 165	116	67	103	116-67-103	11, 12, 13
Rossignol	Rossignol	Racing - Giant Slalom	Hero Athlete FIS GS	Ash wood and Titalal layer	Sandwich	Rocker / Camber	185, 188, 193	102	65	84	102-65-84	30, 27, 30
Rossignol	Rossignol	All mountain	Expreance 94T1	Titalal core	Sandwich	Rocker / Camber	173, 180, 187	132	94	122	132-94-122	15.5, 16.5, 18.5
Rossignol	Rossignol	Freestyle	Super 7 HD	Paulownia wood and Carbon Alloy Matrix	Sandwich	Rocker / Camber	177, 180, 188	140	116	130	140-116-130	17, 19, 22
Rossignol	Rossignol	Piste	On Pistie React	Poplar wood and Titalal layer	Sandwich	Rocker / Camber	160, 168, 176, 182	124	73	110	124-73-110	12, 13, 14, 15
Line	Line	All mountain	Tom Wallisch Pro	Maple Macrobloc (maple + aspen)	Capped	Rocker / Camber	157, 164, 171, 178	117	90	112	117-90-112	20
Line	Line	Freestyle	SUPERNATURAL 100	Maple Macrobloc (maple + aspen)	Hybrid	Rocker / Camber	177, 179, 186	132	100	121	132-100-121	21, 3
Line	Line	Powder	Outline	Paulownia & Maple	Hybrid	Rocker / Camber	178, 186	150	117	142	150-117-142	18.5
K2	K2	Piste	Super Charger	Aspen, Paulownia wood and Titalal layers x2	Sandwich	Rocker / Camber	168, 175, 182	125	72	99	125-72-99	18
K2	K2	Piste	Cammaran	Fir and Aspen wood	Sandwich	Rocker / Camber	177, 184, 191	136	120	131	136-120-131	21
K2	K2	Freestyle	PONZOON	Fir and Aspen wood	Capped	Rocker / Camber	159, 169, 179, 189	157	132	122	157-132-122	30
K2	K2	Freestyle	Windrunner 116C	Maple and Paulownia wood	Capped	Rocker / Camber	143, 156, 193	116	116	133	143-116-133	15
K2	K2	Freestyle	Windrunner 20T1	Maple and Paulownia wood	Capped	Rocker / Camber	143, 156, 193	116	116	133	143-116-133	15
Head	Head	Freestyle	Koro 117	Maple and Paulownia wood	Hybrid	Rocker / Camber	171, 180, 189	143	127	115	143-115-127	20, 22, 24
Head	Head	Racing - Slalom	Worldcup Rebels 1SL RD	Silver Fir wood, Graphene and Titalal layers x2	Sandwich Capped	Rocker / Camber	165, 168	119	67	103	119-67-103	12
Head	Head	Racing - Slalom	Worldcup Rebels 1GS RD	Silver Fir wood, Graphene and Titalal layers x2	Sandwich Capped	Rocker / Camber	183, 188, 193	101	65	80	101-65-80	30
Head	Head	Racing - Downhill	Worldcup Rebels 1DH RD	Silver Fir wood, Graphene and Titalal layers x2	Sandwich Capped	Rocker / Camber	210, 215, 217	92	66	79	95-66-81	50
Head	Head	Piste	Super shape 1Speed	Silver Fir wood, Graphene and Titalal layers x2	Sandwich Capped	Rocker / Camber	156, 163, 170, 177, 184	124	68	104	124-68-104	12, 13, 14, 15, 16
Head	Head	All mountain	Monster 88 T1	Silver Fir wood, Graphene and Titalal layers x2	Sandwich Capped	Rocker / Camber	156, 163, 170, 177, 184	130	87	113	130-87-113	14, 15, 16, 17, 19
Head	Head	Racing - Super G	Worldcup Rebel 1SG RD	Silver Fir wood, Graphene and Titalal layers x2	Sandwich Capped	Rocker / Camber	202, 207, 213	95	66	81	95-66-82	40, 42, 45
Head	Head	Freestyle	Gaddy	wood and Titalal layer	Sandwich	Rocker / Camber	161, 171, 176, 181	120	83	109	120-83-109	16, 18, 19, 20
Blackcrows	Blackcrows	Powder	Nocta	Paulownia and Poplar wood	Sandwich	Reverse Camber	177, 185, 190	140	122	132	140-122-132	26
Blackcrows	Blackcrows	All mountain	Navis	Poplar wood	Sandwich	Rocker / Camber	169, 179, 185	131	102	120	131-102-120	19
Blackcrows	Blackcrows	Piste	O/b	Poplar wood and Titalal H layers x2	Sandwich	Rocker / Camber	169, 174, 179, 184	124	88	110	124-88-110	21
Blackcrows	Blackcrows	Piste	Dwus	Poplar wood and Titalal H layers x3	Sandwich	Rocker / Camber	172, 177, 182	124	82	110	124-82-110	17

10.1.1.2 Graph

Different manufactures approaches to different streams of skiing in terms of the core materials used for the particular type of ski.



10.1.2 Market Research Survey Responses Breakdown

Survey responses (Total 125 responses)

1. On average, how many days do you go skiing per season?

Number of days skied on average: 27

Total number of days skied on average by the responders: 3,375

2. What type of skiing do you take part in?

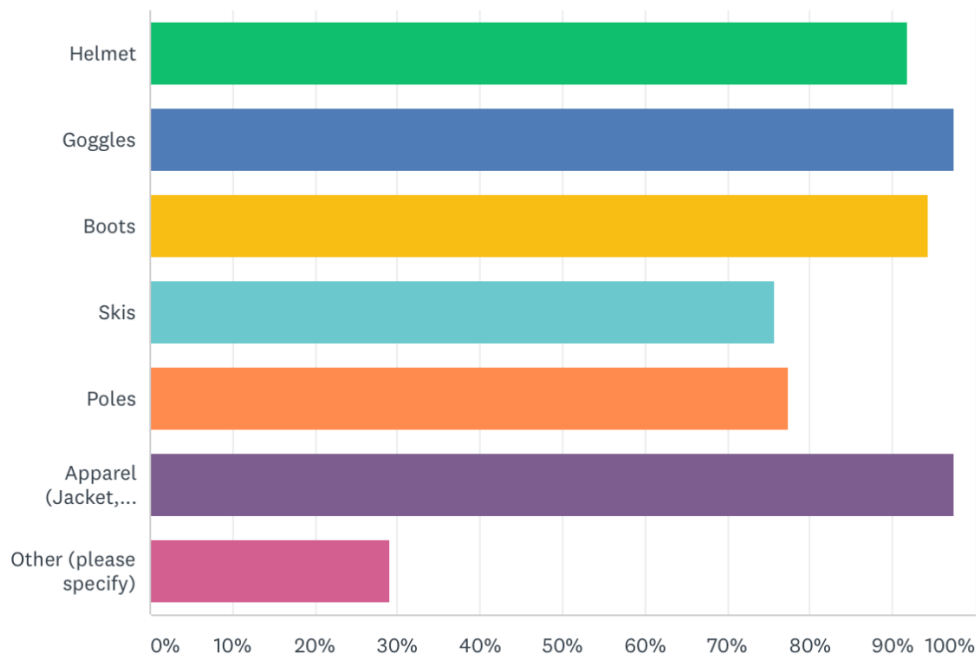
92% of responders ski on piste.

67% of those venture off the piste.

1 or 2 responses take part in racing DH, SG, GS and SL.

35% taking part in freestyle skiing including all mountain.

3. What ski equipment do you own?

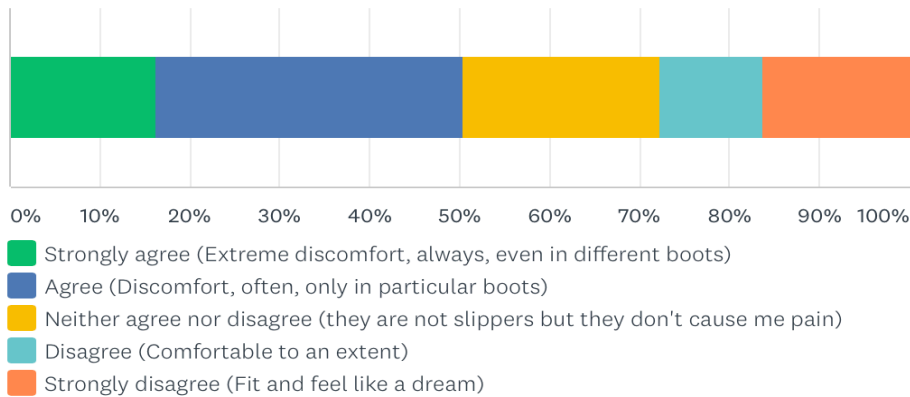


Observations: more people owned goggles and or boots than helmets!?!

65% of the responders owned their own skis.

29% of people selected other and added additional equipment they owned, these predominately included avalanche safety equipment. Which was not included in the survey list due to an oversight.

4. Have you ever had trouble with the fit or comfort of ski boots?



50% agree to some extent that Ski boots are uncomfortable.

17% strongly disagreed with additional 11% disagreeing so 28% find ski boots comfortable.

5. How many pairs of skis do you own?

Number of pairs = percentage (number of responses)

0 = 25% (31)

1 = 25% (31)

2 = 22.5% (28)

3 = 16% (20)

4 = 2.5% (3)

5 = 5% (6)

6 = 0.8% (1)

8 = 1.5% (2)

10 = 0.8% (1)

11 = 0.8% (1)

6. Make and model of your skis?

In order of brand popularity

Salomon

Atomic

Head

Rossignol

K2

Blizzard

Volkl

Scott

Line

Fisher

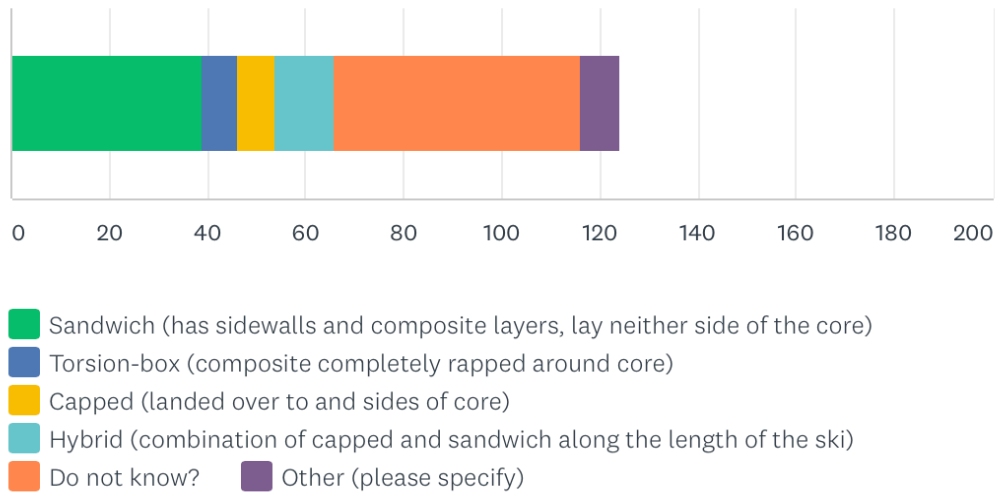
Nordica

Faction

Dynastar

Movement

7. What type of construction are your skis?



45% of responders did not know the construction of their ski.

60% of those who did know said that it was sandwich construction.

Torsion and capped getting 8 responses each and 12 for hybrids of the above.

8. What core material do your skis have?

60% of responders did not know what materials their ski was made up of.

40% of those who did know said that it contained wooden cores.

5% said their skis had honeycomb cores with air and foam cores only having 1 response each.

11% had Titanium and 7% other metals.

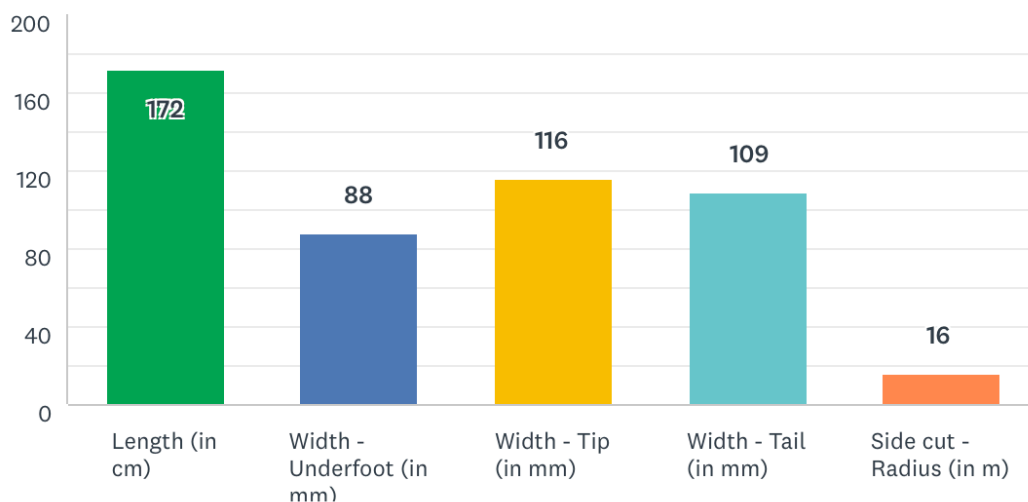
16% Carbon fibre

11% Fibreglass

2% (Kevlar) Aramid

9. Dimensions of your skis?

Averaged dimensions



10. What camber do your skis have?

43% of responses said that they had directional skis with a rocker up front and traditional camber under foot.

35% of responses were for twin tips with rockers front and back and traditional camber under foot.

No responses for reverse camber sides.

And the rest not knowing.

The survey got a great response and has aided my dissertation massively, so thank you for your participation. There are many conclusions that can be drawn from this data. In this case the data is being used to establish the materials and construction methods used and evaluate the big picture in terms of the market and industry.

10.1.3 Construction and Physical Testing Plan

Flexural testing

Fixture / constraint

Fix composite sandwich panel horizontal, with 20mm clamped to ridged surface and the rest of the panel extending out wards. The panel acts as a Rigidly fixed cantilever beam

Load

Weight applied to the end of the panel, clamped on to the end 10mm of the panel

Measurements

A series of DTI (Dial Test Indicators) gauges along the panel

Torsional testing

Fixture / constraint

Fix composite sandwich panel horizontal, with 20mm clamped to ridged surface and the rest of the panel extending out wards. The panel acts as a Rigidly fixed cantilever beam

Load

Weight applied to the end of the panel, clamped on to the end 10mm of the panel

Measurements

A series of DTI (Dial Test Indicators) gauges across the panel

Vibrational + Damping Testing

Fixture / constraint

Fix composite sandwich panel vertically, 20mm in a clamp (centred). The speaker placed behind impacting 10-20 above the clamp.

Load

Impacted force on the panel, from speaker.

Measurements

The use of the LDV (Laser Doppler Vibrometer) will be used to record the modes of vibration and the damping rate of the panel.

10.2 Supervisor Meeting (Minutes and Notes)

Topic: - Core materials in composite within skiing

Title: - The influence of core materials on the structural behaviour of skis.

Degree: - BEng Extreme Sports Engineering

Author: - Joshua Brimecombe

Tutor / Supervisor: - Kelvin Lake

Weekly sessions

Day of the Week: Monday

Time of Day: 2pm

Duration: 30 minutes/session

Agender from first session 21/10/20

Talk about weekly sessions (Monday 2:00 - 2:30)

Discuss Project Proposal

- Title
- Brief
- Goals
- Time plan
 - Gantt chart
 - Network diagrams
 - Timelines

Talk about research and referenceable material

Discuss lay out

Minutes from first session 21/10/20

Discussed Project Proposal

- Title (The influence of core materials on the structural behaviour of skis)
- Talked about the goals and the brief that was set out in my proposal. Aim to go away and concisely compile them into a strong brief scope and SMART goals. These goals include specific research points.
 - To research what skis currently use as cores / ski history. Core materials vs applications research, manufacturer marketing shit?
 - To research how skis are constructed.
 - To research cores materials. (Look at other applications and see if lessons learnt can be applied to the ski industry.)
 - To research what characteristics or specific prosperities are desirable in skis or are unwanted. Sky type vs characteristic. (Use other outside research to justify characteristic reasons.)
 - To research what cores could be used in skis and the possible benefits.
 - Should this project contain numerical techniques? JB to research if this has been successfully modelled before. Or, is modelling a natural material such as wood problematic due to the naturally occurring inconsistencies in the material.

Talked about research and referenceable material, wide variety of references is better, look outside of the sports industry from some more academic source.

Talked about the FEA and the inclusion of it in report, decision was that it was too complex to include in the time frame, as requires simulating composite materials and natural composites such as wood.

Discuss lay out (not level 4 or 5) needs to be a body of text.

Did not get on to...

- Time plan
 - Gantt chart
 - Network diagrams
 - Timelines

References Patten's

Supervises notes from first session 21/10/2019

One-off 1-hour session

1. Potentially the core material will influence bending stiffness, torsional stiffness, vibrational behaviour etc.
2. Research is to be undertaken as to what characteristics are desirable. In which type of ski.
3. Samples can then be produced so that they can be tested, and the results related to the application.
4. Bending/torsional stiffness is simply related to stiffness of the materials?
5. Research the construction of skis.
6. Research what core materials are currently being used for which applications and if there is any proof of this, or is it just manufacturer marketing?
7. Is the project looking at vibrations in CFRP bound by an NDA - KL to look into this and to feedback to JB.
8. In your research, do not limit yourself to the ski industry. Look at other applications and see if lessons learnt can be applied to the ski industry.
9. Should this project contain numerical techniques? JB to research if this has been successfully modelled before. Or, is modelling a natural material such as wood problematic due to the naturally occurring inconsistencies in the material.
10. KL to send JB an example of report structure.

Agender for second session 28/10/2019

Assessments

- Interim viva Spec
- Final
- Survey Monkey
- When is the major project week? 4th
- How to reference people at the engineering show? How to record or make notes of what there are saying?

Minutes from second session 28/10/2019

Major Project week is next week beginning the 4th. To meet with Kelvin several times over the week.

Discussed interim viva (viva to included).

- Research so far
- Planning (title, brief, scope, goals, Gantt chart, timeline, network diagram)

Target (Survey Monkey) survey at right audience. Post on relative sites, pages, email lists and forums.

Continue research...

- Ski construction
- Current cores research table and graphs
- Core materials in other applications and industry's

Supervises notes from second session 28/10/2019

1. Initial research into the study of ski mechanical properties has begun - continue this.

2. Next week is CAD week - meet on Monday as usual and other meetings in the week TBC.
 3. Survey monkey survey has been built - this is to be placed on various online forums.
 4. What is expected in the interim viva was discussed. How to integrate your timing plan and your research etc.
 5. Research the construction of skis.
 6. Research what core materials are currently being used for which applications and if there is any proof of this, or is it just manufacturer marketing? - ongoing
 7. Is the project looking at vibrations in CFRP bound by an NDA - KL to look into this and to feedback to JB.
 8. In your research, do not limit yourself to the ski industry. Look at other applications and see if lessons learnt can be applied to the ski industry.
 9. Should this project contain numerical techniques? JB to research if this has been successfully modelled before. Or, is modelling a natural material such as wood problematic due to the naturally occurring inconsistencies in the material.
 10. JB to discuss potential manufacturing schedule with AT.
 11. Testing to be limited to materials only, not geometry also?
- To action before next meeting... on (4/11/2019)
- 1, 3, 5, 6, 8, 9, 10

Agender for third session 4/11/2019 Major Project week Start

Advanced engineering show discus.

Discuss meeting plan for the week: -

Monday	4/11/2019	2pm
Tuesday	5/11/2019	3pm
Monday	11/11/2019	2pm

Minutes from third session 4/11/2019 - Major Project week

Discussed Advanced Engineering show

- Mentioned companies that specialised in different core materials
- Collaboration with company who look at non-destructive testing on composites, JR Technology Limited.

Continue secondary research into mechanical properties of a ski, ski construction,

Write message to Facebook groups to send survey off too.

Write FB post for survey.

Vibrations in CFRP dissertation is covered by an NDA.

Supervises notes from third session 4/11/2019 - Major Project week

1. Initial research into the study of ski mechanical properties is ongoing.
 2. Survey monkey survey has been built - this is to be placed on various online forums.
 3. Research the construction of skis - write this up
 4. Research what core materials are currently being used for which applications and if there is any proof of this, or is it just manufacturer marketing? - ongoing
 5. Alternative industries that you take lessons learnt from is ongoing.
 6. Could simple FE models be set-up in Solid works to correlate your physical tests to?
- To action before next meeting... on (5/11/2019)

2, 4

Agender for fourth session 5/11/2019 - Major Project week

Discuss the survey and message, that was sent out to Facebook pages and groups.
Discuss the spreadsheet, in terms of research and how to graph it and sort it.

Minutes from fourth session 5/11/2019 - Major Project week

Short chat on what had been done in the 25 hours since the last meeting.
Meet next Monday do as much research as humanly possible.
Planning documentation, project management.
Start presentation. Titles of slides. Start formatting.
Research from other industries

Supervises notes from fourth session 5/11/2019 - Major Project week

None...

Agender for fifth session 11/11/2019 - Major Project week

Discuss the spreadsheet, in terms of research and how to graph it and sort it.
Discuss survey
Discuss presentation

- Budgeting
- Referencing

Minutes from fifth session 11/11/2019 - Major Project week

Continue work on presentation
Add assessment key dates to milestones

- Viva
- Dissertation
- Final Viva and Poster

Update Gantt chart
Work out when the panels can be constructed.
Schedule time in composite workshop to construct the panels.
Research standard panel size.
Discussed FEA model plan.

- Watch video sent by Kelvin.
- V Design Studio on uni computers.
- Try design study

To-do this week
Message Jurij Franko

Supervises notes from fifth session 11/11/2019 - Major Project week

1. Ski survey is now live. Message the forum when this is about to finish.
2. Data collected on material usage from various manufacturers has been collected. Create a graphic of this. (x-axis is cores, y-axis is application and then each manufacturer can appear on the chart)
3. Research is ongoing.
4. Is the core to change the stiffness or to dampen the vibrations? Both can be tested and simulated.
5. Set up Design studio of the tests that you plan to carry out. Complete the tutorial that I have sent you. Once you have done this contact me and we will sit down together and set up your vibration tests. DS Research the size of your samples. If nothing can be found, perhaps use a ratio of twice the ski width by the ski width?

6. Complete your Gantt chart. Speak to the technicians when you do this to make sure that you do not schedule manufacturing at inappropriate times.

To action before next meeting... on (19/11/2019)

1, 2, 3, 5, 6

Agender for sixth session 19/11/2019 - Major Project week

Design Studio - struggled to import 2D elements from

Minutes from sixth session 19/11/2019 - Major Project week

Continue

DS composite and natural frequency

Graph Manually digitalises

Supervises notes from sixth session 19/11/2019 - Major Project week

1. Design studio was reviewed. Complete the composite design studio file previously sent to you to set up composites. Try to assess NVH as discussed. We can review this next week.

2. Close your online survey and warn people that it is about to close.

To action before next meeting... on (25/11/2019)

1, 2

Agender for seventh session 25/11/2019 - Major Project week

Terry and Jurij Franko conversations

Minutes from seventh session 25/11/2019 - Major Project week

Ran through the Design studio stuff that I had completed, covered the next steps to complete the FEA and start looking at NVH

Supervises notes from seventh session 25/11/2019 - Major Project week

1. Design studio tutorial was discussed and demonstrated.

2. Graphic summarising the ski industry was reviewed. Could price of skis/size of company be added to this.

3. Create your NVH FE models.

4. Close your online survey.

To action before next meeting... on (02/12/2019)

2, 3

Agender for eighth session 02/12/2019

Presentation

- When?
- Who?
- How to improve it

Discus Survey results

Minutes from eighth session 02/12/2019

Hold off on FEA

Focus on presentation

Presentation is on the 12/12/2019 09:00 am, IQ 110, Kelvin Lake + Andrew Thorn

Presentation slide

Supervises notes from eighth session 02/12/2019

To action before next meeting... on (13/01/2020)

Presentation 12/12/2019

09:00 am, IQ 110, Kelvin Lake + Andrew Thorn

Mark: 66.8%

Grade: 2.1 (Very Good)

Agender from ninth session 13/01/20120

Discuss presentation

Discuss next steps:

- Manufacture Plan
- FEA
- Manufacture
- Test
- Results
- Analysis
- Write-up

Minutes from ninth session 13/01/20120

Discussed presentation review feedback

FEA Next week

Check with Andy:

- Composite availability (prepreg) loads
- Composite Spec (material information)

Plan Manufacture and Testing

Book Manufacture and Testing

Testing for 3 variables 3 repeats

9 panels of each core

Manufactured in plates then cut down to sample size (3 plates of 3 samples)

5 or 6 core materials

45 or 54 tests

Sandwich panels construction

Supervises notes from ninth session 13/01/20120

- 1.
- 2.
- 3.
- 4.

To action before next meeting... on (20/01/2020)

Meet with Andy 14/01/2020

Agender for Andy

Check with Andy:

- Composite availability (prepreg) loads
- Composite Spec (material information)

Plan Manufacture and Testing

Book Manufacture and Testing
 Testing for 3 variables 3 repeats
 9 panels of each core
 Manufactured in plates then cut down to sample size (3 plates of 3 samples)
 5 or 6 core materials
 45 or 54 tests
 Sandwich panels construction
Minutes for Andy

- Loads of prepreg
- 2x2 Twill 200g T800
- From Ferrari so Andy in checking if we can have the spec / data sheet

 Andy agrees with above.
 5 or 6 cores is up to me (FEA 8 - 10)
 Manufacture book in for Monday 27/01/2020
 Testing hopefully the week after

Agender from Tenth session 20/01/20120

Discuss Manufacture and Testing Plan/Schedule
 Discuss FEA

Minutes from Tenth session 20/01/20120

Make full carbon test sample 88 x 176.
 Get materials prosperity's for prepreg supplier.
 Research my 6 core materials.

- Ash
- Popular
- Honeycomb (Kevlar/Aramid)
- Honeycomb Aluminium
- Titanium
- Titanal

Supervises notes from Tenth session 20/01/20120

1. A pre-preg has been identified with AT. Obtain the material properties of this from the supplier so that these can be fed into your FE models. This is a 2x2 CFRP twill.
2. Produce a 'coreless' sample that has the same width/depth as your proposed tests, this can be approximately 2mm thick. You can then carryout some vibration testing on the LDV with this sample.
3. A correlation exercise can then be carried out with the model generated using the supplier values to the test carried out in 2. Alternatively, 'generic' properties can be used and then scaled in order to get good correlation. You will then have confidence in you CFRP properties in your FE models.
4. 6 core materials have been identified (these are a mix of modern and traditional)
5. Establish the micromechanical properties of the core materials that you plan to use through secondary research.

To action before next meeting... on (27/01/2020)
 1, 2, 5

Agender from Tenth session 27/01/20120

Discuss Manufacture
 Discuss Testing Plan/Schedule
 Hot-press Mould 3-piece

Minutes from Tenth session 27/01/20120

Tooling required to hot press sandwich composite panels, is unable to be completed due to lack of machine availability.

Discussed ways around lack of data sheets for the composite material.

Supervises notes from Tenth session 27/01/20120

1. Make the core-less CFRP sample.
2. The core may bleed into the cores could these be put under the microscopes.
3. KL to send JB 'generic material properties so that these can be put into your FE model
4. During the next meeting we will go to the NDT lab to try some LDV testing of your core-less sample.

To action before next meeting... on (03/02/2020)

1,3

Did not meet on the 03/02/2020 due to deadline priority for ACM

Agender from Tenth session 13/02/2020

Conduct LDV Testing on coreless composite

Minutes from Tenth session 13/02/2020

Conducted tutorial on LDV Testing and leant software

Conducted LDV Testing on coreless composite

Ran test

Agender from Tenth session 17/02/2020

Minutes from Tenth session 17/02/2020

Create testing plan

Core materials ordered and awaiting delivery

Honeycomb cell size compromise to manufacturing standards

Supervises notes from Tenth session 17/02/2020

- 1.
- 2.
- 3.
- 4.

To action before next meeting... on (24/02/2020)

Agender from Tenth session 24/02/2020

Discuss materials and there processing

Discuss FEA

- What values to use in FEA

Discussion with Andy on honeycomb (Sourced)

Discuss testing

Minutes from Tenth session 24/02/2020

Get core material cut

- Titanium and Titanal (water jet cut) started 25/02/20 get back 29/02/20
- Ash and Popular on band saw

- Honeycomb hand cut?

Finish Scaling Carbon in FEA and graph data

FEA Core material

- Compile and collect book values for the core materials
- And input data into PCOMP in FEA module on Design studios

Start manufacture

- Process metal cores
- Cut plies / laminae
- Lay-up panels with core materials
- Vacuum bag
- Cure in autoclave

Take Damping results and try to graph results

- For coreless panel as an exercise to use as a technique during comparative testing between panels
- Use text file point data from LDV testing to created graph in excel
- How to look at damping in Design Studios

Supervises notes from Tenth session 24/02/2020

- 1.
- 2.
- 3.
- 4.

To action before next meeting... on (02/03/2020)

MATLAB

- Smooth
- Hold on
- Graph