INFLATABLE INNOVATION –DEVELOPING AN INFLATABLE SEA KAYAK

A thesis presented in fulfilment of the requirements for the degree of Masters In Manufacturing and Industrial Technology at Massey University, Turitea, Palmerston North, New Zealand.

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2003

ABSTRACT

There are many kayaks available and many of these are sea kayaks or inflatable kayaks. During an investigation by this researcher (referred to throughout this document in the first person), of the current sea kayaking market, a gap was identified for a sea kayak that was lightweight, portable and capable of touring and expeditions. An inflatable kayak often offers the initial two features of being lightweight and portable. The additional features of being capable of touring and expeditions, however, were the area of concentration.

The problem was approached through a combination of expertise, facilities and finance provided by an inflatable boat manufacturer, Incept Marine Ltd (Incept), an experienced sea kayaker (Audrey Sutherland), and a fellow (this researcher), supported by a Graduate in Industry Foundation (GRIF) scholarship, payable over 12 months.

The objectives of the project were to produce an inflatable sea kayak capable of carrying the equipment required for expeditions, be reliable, and have features that were found in most hardshell sea kayaks. Features for development included room for storage, a deck and a rudder to ease steering. In addition the inflatable sea kayak needed to perform better than most inflatables that were on the market, as they were often slow due to a lack in strength and rigidity. Stability was important and just as a whitewater kayak should be able to negotiate its way through rapids on a river, a sea kayak should be able to guide itself over waves and cover the distances it was expected to travel, while keeping the paddler safe.

The detail required in the pattern and processes could only be known by those with experience in the industry who had learnt to foresee potential problems. There was little room for error, right from the pattern design to the small but often essential processes that made Incept boats recognised around the world for their quality. It was the small and sometimes obvious areas that caused problems; for example, having to trust other manufacturers' specifications, which could lead to glues becoming

susceptible to humidity and heat after a prolonged time, or the need for pressure release valves in order to fix I-beams.

The final prototype was a synergy of ideas and experience brought together to form an inflatable kayak that had characteristics to fit a consumer market wanting a kayak for paddling in exposed and open water environments . The direction and input from an experienced sea kayaker moved the project to an area that could not have been reached without considerably more market research.

Working in a small innovative business created its own set of difficulties to be overcome in such a project. However, it also allowed involvement from everyone in the company to input into the outcome of the project.

The project ended successfully with two working prototypes known as the Incept inflatable sea kayak K40 (K40).

To attain serious speeds with limited power, it is more efficient to travel completely underwater, or in the air above it. As land creatures, we are unable to successfully do either in a self propelled and sustainable manner, so we are stuck on the surface.

(Dickson, 1996, p.42).

ACKNOWLEDGEMENTS

With ongoing flitting backward and forward between Taihape and Palmerston North for almost 11 months during 2000, the project was finally drawn to a close. Some would say; better late than never... it certainly took a long time, and I am sure some people thought I would never make it.

With thanks to Foundation for Research Science and Technology, a GRIF scholarship set the project in motion, we set out to develop an inflatable sea kayak in conjunction with the team at Incept Marine Ltd in Taihape. At the end of 12 months we definitely had made progress in looking at the market and coming up with a working prototype. By the end of the project we sent one of the final prototypes over to our "target market," Audrey Sutherland, who provided information and feedback throughout the project as well as her own evaluation of the project. All of who made the project possible.

It wasn't too hard to keep on track until a full time job came along, and progress slowed remarkably. That has to be where I begin; not only would I like to thank Harvey Barraclough and Ralph Ball for their help but also their seemingly gracious patience with the time that it has taken to submit this thesis. Harvey and Ralph have had the onerous task of being my project supervisors. During the time I spent in Taihape through till now they have been on call to hear about my difficulties, successes, provide advice and slowly encourage progress on the imminent thesis. Thank you for your patience.

I would like to acknowledge Rodney Adank, my Product Development lecturer and tutor through my undergraduate degree in Product Development who initially convinced me of the opportunity to do a Masterate. Even though he moved on to Wellington during the project, he definitely encouraged me in the early stages of the project while he was at the Turitea Campus.

Many things have changed in my life since the beginning of this project, including changing my name along with gaining a husband. His own temptation overcame him as initially he promised not to propose until I had finished... we got married in January 2002. His pleasure in hearing that I no longer "have to work on my thesis this weekend" will be immense.

And my parents; thanks Mum for always encouraging me no matter what, and Dad for making sure that I follow through with the things that I start. You have been very supportive of me, given me great advice (although I am sure you thought it sometimes went in one ear and out the other) and never given up on me.

"Perseverance must finish its work so that you may be mature and complete, not lacking anything." **James 1:4 NIV**

Whaia e koe ki te iti kahurangi; ki te tuohu koe, me maunga teitei

Seek the treasure you value most dearly: if you bow your head, let it be to a lofty mountain. (www.maori.org.nz/quote.htm, 2003)

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1 INTRODUCTION

The fundamental objective of this project was to help Incept Marine Ltd (Incept) to develop a new product, an inflatable sea kayak. Incept is an established manufacturer of inflatable boats but not of kayaks. Inflatable sea kayaks are a rare item, so there were lots of novel aspects of the project. Although the inflatable sea kayak would be competing with well-established rigid craft, as well as other inflatable kayaks, the inflatable sea kayak would need some very distinct advantages of its own.

The project team who worked on the project consisted primarily of:

- This researcher (referred to throughout this document in the first person) – Elizabeth Watkins (nee Ussher)
- Managing director of Incept – John Booth
- Marketing Manager of Incept – Cliff Kingston
- Production Manager of Incept – Alistair Booth

In addition, valuable advice and design input was given by an expert sea kayaker Audrey Sutherland. Other employees at Incept participated in this research in a number of ways.

The project was broken into five well-defined stages, according to the Project Plan (Refer to section , in order to facilitate the progress of the project in a logical fashion. This document will be broken up into the following chapters:

1. Introduction

The introduction to the project was required familiarising with the project background, the history and involvement of Incept and the basic understanding of a sea kayak.

2. Initial Investigation

This familiarisation included looking at existing manufacturing techniques, materials available that were in use, and the factory layout at Incept. In conjunction with this initial investigation was the literature review to collate information on small boat design, inflatable craft design and the techniques of 3D modelling.

3. Market Review

Before specifications can be confirmed they need to be created. To ensure that the design and product met consumer requirements it was essential to investigate the market arena and identify competitive products. Throughout this stage, areas in need of particular attention for development were identified by consultation with users of sea kayaks and those particularly looking for an inflatable or compact sea kayak.

4. Technical Development

This was the stage where areas previously identified for development were investigated independently, prior to prototyping. The areas for development were those characteristics that directly affected the performance of the kayaks, and although most were interdependent variables they will be discussed independently.

5. Initial Design

Information was put together into the design stage for the critical elements of the inflatable sea kayak to form some initial design concepts.

6. Prototyping and Detailed Design

Alpha and beta prototypes, integrating the aspects investigated in the technical development, were constructed in order to evaluate the progress of the project and evaluate the development occurring. Four prototypes were used in the detailed design process. Each prototype is looked at as a step in the detailed design.

7. Future Work

This examined where the project required further resources and what would need to be done for the inflatable sea kayak to get to market.

8. Conclusions

A personal summary of my project experience.

1.1 INCEPT MARINE LTD

1.1.1 History

Incept is a small family company based in the farming community of Taihape, New Zealand, traditionally manufacturing inflatable rafts for the commercial whitewater market. With an engineering background and filled with enthusiasm for whitewater rafting, John Booth, the director at Incept and a qualified engineer, has given particular attention to hydrodynamics and hand-crafted quality in all the products made.

The company employs over a dozen staff and manufactures on premises situated in Taihape. Incept is in a strong position and is likely to see continued growth as it expands to supply a growing international market.

1.1.2 Why they were interested in the GRIF scheme?

The development in 1993 of a closed deck inflatable whitewater sport kayak, the K30, with the guidance of a top New Zealand paddler, Richard Sage, demonstrated that Incept was capable of innovative design in small inflatable craft. Given the advance in innovation of the whitewater kayak the potential for the development of a sea-going kayak was identified a number of years ago. The concept of a sea kayak was not pursued at the time as John Booth felt that Incept did not have the methods or development time to do it justice (J. Booth, 9 June, 1999, personal communication).

Although there were still design issues to overcome, there were constructional possibilities highlighted in the development of the K30, which would help with development of a sea version. With the GRIF scheme, Incept benefited from a full-time person dedicated to resolving the design issues identified, as well as the provision of a product development structure to work through. Incept also required an analysis of the market to confirm the need for an inflatable sea kayak, which was available for me to investigate.

1.1.3 Product Range

The Incept *Whitewater* range of rafts and kayaks was introduced in NZ in 1989 and by 1991 had captured about 90% of the local riverboat market. The original product range of whitewater rafts had grown to include other whitewater craft including kayaks and canoes. Incept also produced rescue craft for use on ice as well as one-person fishing tubes, tubes for inflatable rigid boats (commonly known as RIB's), and numerous products custom made for other manufacturers that utilised inflatable manufactured parts.

1.2 THE PROJECT

1.2.1 GRIF Funding

I was funded through the Graduate in Industry Foundation (GRIF) scheme over a 12-month period as a scholarship payment. This allowed me to work with an industry partner, namely Incept, who could supply resources for the project and who ultimately benefited from the research.

1.2.2 Massey Involvement

Massey University provided the academic structure to enable me to complete a Masterate degree in Manufacturing and Industrial Technology, by the content of the GRIF project being compiled as a master's thesis. Massey also provided the academic support throughout the practical stages of the project. The time that was not spent at Incept was allocated to the university. It was expected that over 50% of the time on the project would be spent with the company.

1.3 SEA KAYAKS

A sea kayak differs from many other kayaks in that it is designed for a different environment, namely the sea. A sea kayak can be specific for the type of water (whether sheltered or exposed) but, undoubtedly, must be able to cope with a wide variety of conditions and levels of paddler experience. Kayaks can be designed for a specific purpose but usually they are not, unless aimed at the specialist market. The following diagram shows the key features of a sea kayak and will be used as a reference for terminology.

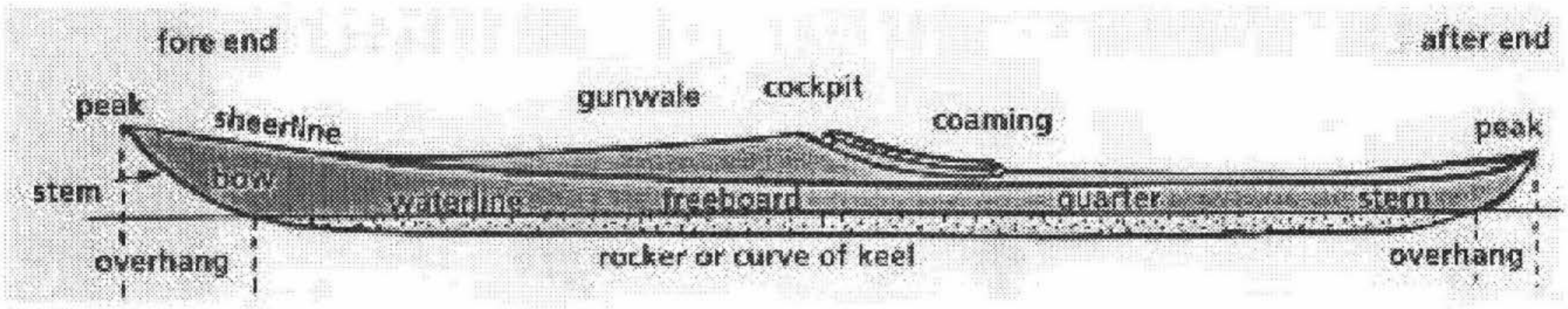


Figure 1 - Key features of a sea kayak

(Hutchinson, 1994, p.1)

2 INITIAL INVESTIGATION

2.1 MANUFACTURING TECHNIQUES

Three main manufacturing techniques were examined for the joining of airtight materials to maintain airtight seals.

1. Thermo bonding (commonly called hot air welding)
2. High Frequency (HF) welding
3. Glueing

Most of the investigation was undertaken at Incept Marine Ltd (Incept).

2.1.1 Thermo bonding or hot air welding

Thermo bonding and hot air welding are two names for the same thing: the use of external heat to join thermoplastic materials together. Only thermoplastic materials can be hot air welded. The principle of welding with hot air is to apply heat to adjacent faces of the joining material and melt the plastic. A small amount of pressure can then be applied so the material will fuse together to give a homogenous bond. The materials must be of the same type of plastic so that the melting points are the same and each piece can fuse with the other. The temperature applied depends on the plastic being joined and should be sufficient to make the plastic flow, but not so great as to cause a chemical change or decomposition in the material (Berman, 1988).

At Incept thermo bonding was principally used for long narrow continuous bonds, such as the joining of tube tape, panel joining or butt welding (with the addition of a mediator material). A hand held electric hot air gun was used for smaller jobs and for making temporary small tacks to hold material in position for later, joining processes. A small rubber roller was used to apply pressure to the welded surface in order for the plastic to mix. The main hot air welder at Incept was a modified rotational welder.

Material was fed through a set of two rollers; at the entry point a hot air nozzle was positioned to apply hot air to adjacent surfaces of the pieces of material. As it went through the rollers, pressure was applied and the bond was formed. The bond formed was controlled by the temperature of the hot air, the speed at which the rollers rotate and pressure of the rollers. All these were adjustable on the machine through manual controls. These could be varied in order to control the time the material was exposed to the heat, and the time it took for the plastic to flow. The rotational welder allowed long lengths of material to be welded continuously with less probability of leaks occurring due to areas of overlap in welds.

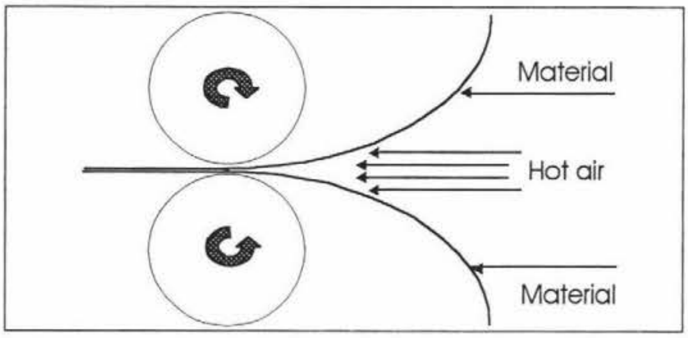


Figure 2 - Thermo welding rollers feeding material

The large rotational welder had the disadvantage of requiring up to three people to operate the machine. A person was required to tension each edge of the material as it was guided through the rollers. A third person was often required to tension the material from the other side of the rollers after the weld had been formed. The third person also helped guide the fabric so that it maintained a straight course on the rollers. Although the process itself did not require a high level of skill, an understanding of the process, temperatures and speed of the rollers was essential to the success of the weld. Therefore, skill and experience were required to use the equipment effectively. Incept required a log be kept of the work completed so time and temperature settings could be referenced for future work.

2.1.2 High Frequency (HF) Welding

According to Cox (1988) the industrial use of high frequency (HF) (sometimes referred to as radio frequency (RF) welding) started before the 1950s. HF welding is primarily used for welding flexible poly vinyl chloride (PVC). It is also good for welding other materials with a sufficiently high dielectric loss factor. The dielectric loss factor relates to the ability of the molecules of the plastics to oscillate. The higher the loss factor the greater the temperature rise. This allows the materials to bond together, and the plastic to flow at the conjunction point of the weld. When a material such as polythene has a very low loss factor (about 0.001), regardless of the applied frequency or voltage, sufficient heat cannot be generated for welding.

Incept had three HF welders of varying size and power output, with another one being prepared for installation during the period of this research.

When welding, the plastic sheet or components to be bonded are normally laid on a press base plate. The die (or electrode) is mounted on the press head and, when under pressure, is directly connected to an RF generator, creating a strong electric field between the die and the base plate. The molecules of the plastic material tend to oscillate in sympathy with the frequency of the applied field, causing molecular friction, and the temperature of the material under the electrode rises to its melting point. The electrodes used at Incept were made from solid aluminium, and were produced to the shape of the weld required.

Cox (1988) maintains that the main cost of an RF welder is the electrical power consumption. Most machines have a power efficiency of around 60%, and thus a generator with an output of 6kW will be taking out 10kW of power from the mains supply. The actual power required for the weld is dependent on:

1. Area of weld
2. Type and thickness of materials to be welded
3. Edge factor, (the total edge length of the welding electrode, compared with its area)
4. Type and thickness of barrier material, if any
5. Whether fast weld time is required.

PVC has a conversion factor typically of around $25cm^2$ to the kilowatt. The power required for welding PVC can therefore be calculated by dividing the number of square centimetres of the weld area by the conversion factor, in the case of PVC, $25cm^2/kW$.

For example: to weld two layers of PVC, with an electrode 30cm x 2cm the following power consumption would be used:

Area of weld: 30cm x 2cm = $60cm^2$

For 2 x 0.5mm PVC use $25cm^2$ / kW

Power required: 60 / 25 = 2.4kW

Some of the employees using the machine expressed concern about the safety of exposure to radio frequencies emitted by the RF plastic welding machines. However, on the machines of higher output, a shield can be used to form a ground for the emitted frequencies protecting the operator from being slowly cooked, causing cell damage if over exposure occurs. Most applications of the RF welders rarely reach the recommended limits of exposure levels when allowance is made for the normal duty cycle of RF welding. The normal duty cycle takes into account the time taken for the weld to be made (often very short), the time required for curing of the bond and then the time for setting up the next weld.

$$\text{Duty cycle} = \frac{\text{Actual weld time}}{\text{Total time between welds}}$$

Care must be taken when operating an RF welder as high electrical currents are produced and arcs may occur if the frequency or length of a weld is too high. If the operator touches the platen during the weld time then severe shocks will occur. Other safety issues include the time of exposure to radiation, as discussed earlier. Due to the design of the electrode plates some areas of the weld are more vulnerable to the frequencies and some sides of the weld may produce more bleed.

Bleed is the excess plastic that gets squeezed from the weld area. Getting the right amount of bleed on a weld is one method of determining whether the weld is sufficient and has formed a good bond.

Generally the fabrics being welded have to be of similar material, as some will heat faster than others. This is especially true when using heat to weld, as some fabrics will not react as quickly to heat as others.

2.1.3 Glueing

It must be realised that before HF and thermo-bonding methods were introduced at Incept rafts were constructed by glueing and this was the primary method for bonding flexible materials. In some particularly extreme environments the glues used did not cure properly and leaks occurred due to high humidity resulting in air bubbles on the glued surfaces. Therefore, it was important that glues were chosen according to the environment in which they were to be used, particularly if high heat or humidity was involved, as any bubbles formed during preparation may have caused bond failure at a later period. Therefore, thermo-bonding and HF welding were Incept's preferred methods of bonding in appropriate cases.

General adhesive technology has advanced with the use of chemical catalysts and advancement of other techniques such as the preparation and methods of joining materials. New compounds are being produced to decrease curing time and enhance the strength of the bond. Incept primarily used Bostik 777, for the bonding of PVC and polyurethane (PU). All surfaces had to be cleaned with solvents usually Methyl Ethyl Ketone (MEK) for the PVC. This had to evaporate before applying the glue to either side of the bond. The Bostik 777 had to be left to cure for up to 30 minutes depending on the external environment, such as heat and humidity. The glue became dry to the touch once it had cured and at this time the bonding materials could be joined.

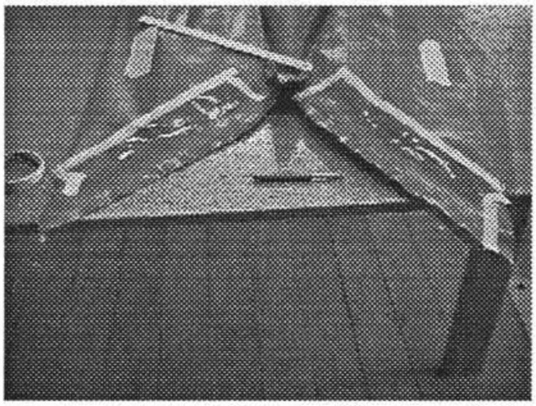


Figure 3 - Glueing up the bow of a kayak.

Because of these two extra steps (preparation and application) this makes the process more expensive than welding because there is more labour involved. Once the material layers have been positioned together then the material is rolled using a small rubber or wooden hand roller so that the glue interfaces can bond together. The resulting quality of any glued joint will be determined by the ease that the surface can be prepared, how well the surface is prepared and the environmental factors that may affect the adhesive such as humidity or cool temperatures.

The table below summarises the merits of the joining methods discussed above.

Process	Advantages	Disadvantages
Thermo-welding	• Long continuous seams can be formed • Quicker than glueing • Can be inflated immediately after seams cooled • Bond strength almost equal to that of parent material • Tolerant of external conditions	• Smoke emitted as surface heats up – ventilation required • Labour intensive to run machines • Loud and intrusive to environment
HF welding	• Quick for small areas • Can weld many shapes when electrodes fit • Can weld 3D fittings as well as flat material • Selectivity – power goes more strongly to wetted surfaces • Thorough-heating technique - the inner sections are heated as much as the outer sections • No start up time necessary	• Machines expensive to run • Large power requirements – large overheads • High levels of radiation emitted • High electric currents – danger of shock • Arcing can degrade material • Electrodes may be expensive to manufacture
Glueing	• Can bond different materials • Bonds can be semi-permanent • Not dependent on area required to be joined	• Toxic fumes • Effected by external conditions such as heat and humidity • Long curing times

Table 1 - Advantages and disadvantages of processing methods.

2.1.4 The need for practical understanding.

When gaining knowledge there are two obvious types of information required. The first is theoretical knowledge, gained through gathering written or verbal information. This type of knowledge was important for my understanding of the processes but of equal importance I needed practical knowledge, gained through hands on experimentation and experience. The main objective of this section was to understand the processes in manufacturing inflatable boats. During the first trimester of working with the company, I spent some time experimenting and helping with various processes. The HF welding machines were rather specialised and although I used them on occasion, I always made sure that there was someone with more experience available to help if required.

It is possible to design and construct prototypes without understanding the manufacturing process on a theoretical level. Problems can occur if the prototypes are designed in a manner that is not consistent with standard manufacturing processes. With this in mind, I tried to involve the staff who would normally construct the sea kayak parts. This meant that I could concentrate on the development rather than machine operation. I did have an opportunity to experiment with some equipment including the smaller HF welders. I learnt most from experimenting with frequencies and time to see the outcome of overexposure (when the power was too high, or the time was too long, for the size of the weld). I found that it was essential that the material was clear of foreign objects and marks. As the current took the easiest path to travel, when there were lines drawn on the material, this could cause arcs to occur if the medium conducted electricity, such as in the case of a lead pencil.

In terms of objectives for the project the most frustrating part was progressing from paper to plastic. It became evident that the best and often only way to progress in inflatable design was to build a prototype in physical form, evaluate the results, make changes and try again, aiming for positive improvement. Many times I could say what I wanted and had the image in my head but it was only through experience that someone could produce a two-dimensional pattern and create what I expected in three dimensions. I viewed the process like dressmaking (in that when a garment is designed it is patterned and then sewn together and, before the final stitching is put in place, a fitting is required). It was at this stage that adjustments could be made to the shape. This was only possible with a prototype as the repositioning often meant leaving traces of past glue patches or registration marks. But just as a garment should be seen on before it can truly be appreciated, an inflatable needed to be blown up before it became apparent whether the pattern was a success.

It was not until I had to actually start making the kayak prototypes that I realised the limitations on design imposed by inflatable manufacturing. In order to join material, the same length and surface area in each seam was required and the material generally had to lie flat. When trying to create three-dimensional shapes, when the edges were curved the material did not lie flat, making joining seams more difficult. It was also difficult to get corners on the boat, as each layer of fabric had to sit flat in order to hold air and seal properly. The fabric was easily delaminated, so to try and pull it apart after glueing or welding would most often result in leaks. If too much heat was applied the material expanded and became thin and would not hold air. HF welding, if set to the wrong frequency, could create holes into the fabric because of arcs, and if welded insufficiently, would not form a permanent bond. Sometimes forming such a temporary bond was useful when trying to ensure correct placement, particularly during prototyping.

2.2 MATERIALS

There are particular requirements for the materials that can be used for inflatable manufacture and even more that are particular to inflatable boat manufacture. The following was constructed from observing the methods used by Incept. It is a list of the basic requirements for materials used for inflatable boat manufacture. The material must be:

- Air tight
- Flexible to allow for inflation
- Limited in elasticity to maintain rigidity
- Abrasion resistant, i.e., material must not leak due to small scratches.

Types of material:

The materials used for inflatable boats must have the requirements above if used for the body of a kayak. However, some material may be used for deck fabric, that is not necessarily airtight but only water resistant. This section will concentrate on those materials used for the manufacture of the inflatable sections of the sea kayak. Different materials with varying properties were used on different parts of the kayak to strengthen it; for example, on areas of the kayak expected to be more vulnerable to abrasion, a material with high abrasion resistance was used. The following diagram shows various types of materials that can be used for manufacturing an inflatable section.

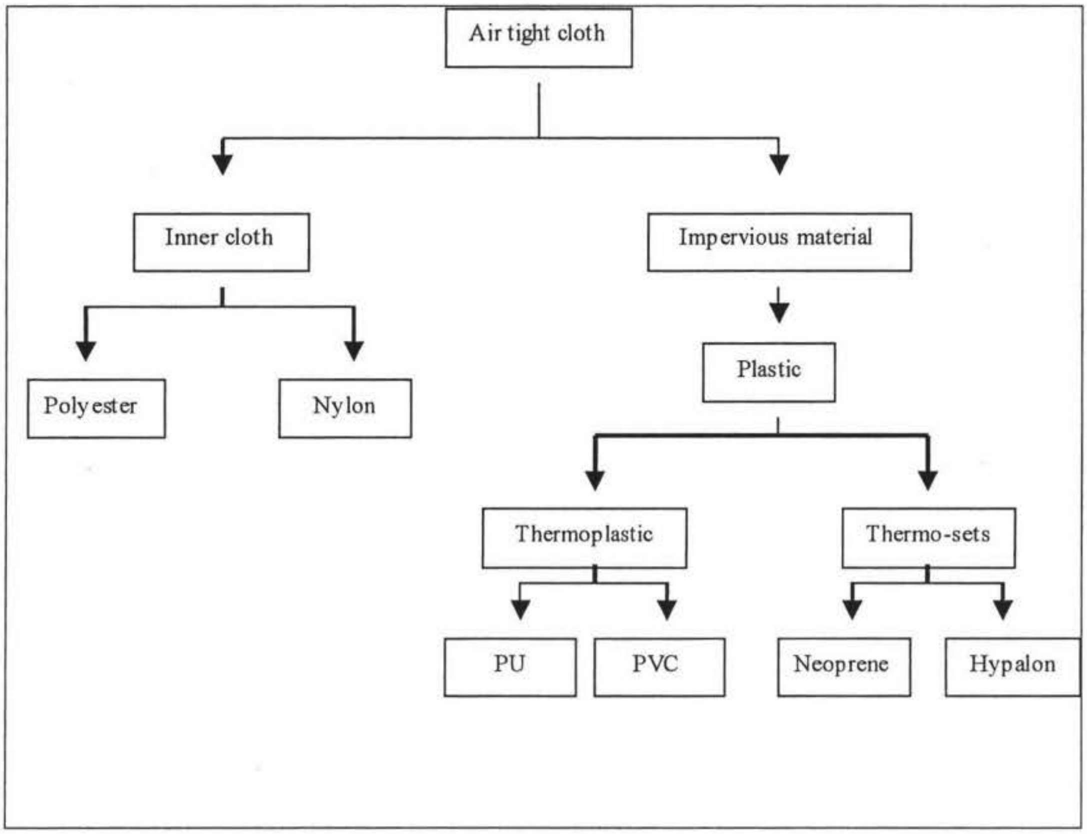


Figure 4 - Air tight cloths

There are two types of plastics used for coating air retentive fabric: thermoplastic and thermo-set plastics. The word plastic refers to a property of the materials that has permanent deformation under stress. Thermoplastics deform more than thermo-set plastics under stress. There are a number of types of materials that can and are used in the manufacture of inflatable boats, but they are principally made from PVC. PVC is a thermoplastic material, which can be welded. In a thermoplastic material the long chain-like polymer molecules are held together by relatively weak forces that are weakened even further when heated. The PVC becomes soft and flexible and at high temperatures becomes a viscous melt. In this condition the material can be moulded or extruded into the required shape and when the material is allowed to cool it solidifies. In principle, thermoplastics can be repeatedly softened by heating and hardened on cooling, and hence can be welded by the application of heat (McGregor, 1988). PVC and PU (another plastic used for air retentive materials), both tend to have a better adhesion to the base fabric than the thermo-set plastic coatings and this enhances the air retention. Employees at Incept indicated that due to the implementation of new processes, that saturate the base cloth before the plastic is melted into place, pathways for the air to travel through the material are reduced. Having the plastic melted into the base cloth also helps to reduce delamination between the coating and base cloth.

Water is a lubricant for thermoplastic coated fabrics; hence they wear better in the water. Thermo-set plastics have a high dry abrasion quality that makes them wear better when they are dry. Hypalon® and Neoprene would normally be considered thermo-set plastic fabrics. Both these materials, when used at Incept, were glued. As the use of the fabric is for a sea kayak and it will be used in water, thermoplastics are better for wear resistance in this environment.

It was the fabric inside that added the strength to the coated fabric and limited the elasticity of the material as it was inflated. Plastics such as polyester or nylon can be used as the inner fabric, usually referred to as the "base cloth". According to staff at Incept Polyester is a stiffer material and has less strength for the same size of thread in the overall weave with only a small elasticity before becoming tight, requiring less air pressure to keep a kayak rigid. Nylon on the other hand has a higher tensile strength and about a 25% elasticity and will, therefore, stretch a lot more. Nylon is more flexible and is a stronger material, but depending on the number of strands in the base cloth, polyester fabric is able to have a stronger tensile strength than a nylon based fabric. The major disadvantage of Nylon is that it absorbs water causing the threads to expand, and the material can become loose.

The base cloth is classified by the detx (industry classification for the weight of the thread) and by the thread count in each direction. The material used for the Incept inflatable sea kayak (K40) was EREZ TPU 2300. It had a polyester base cloth, detx of 1100, weighing 270gm/m^2. The total weight of the base cloth and the PVC was 1050gm/m^2 (Refer to section 9.2 for EREZ TPU 2300 Product Data Sheet). There are a number of fabrics similar to TPU 2300, but which have a heavier PVC layer or a higher weight thread or thread count. The TPU 2300 was used for the K40, mainly due to its availability as it was also used for the K30 (the Incept inflatable whitewater sport kayak) and also Incept fishing tubes and had known properties. It had a higher puncture resistance than the standard PVC. A concern with inflatable kayaks was their likelihood of puncture, but as the material was able to flex, the energy from the impact could be absorbed, thus avoiding damage. Also, due to the bonding and layering of the material, it was more likely to develop slow leaks at high wear places than to explode.

PVC also has the advantage, due to it being a thermoplastic, that it can be easily welded using thermo bonding and HF welding. It also glues well. Cox (1988) notes that it has a dielectric loss factor of around 0.3, which is high enough to permit industrial heating at available frequencies.

I found that Incept had usually sourced their materials from Italy, as they believed they were of higher quality, and the materials were made specifically for use in inflatable boats. In one past case the material used was degraded and discoloured as it reacted to the sun-screen lotion used by tourists on the boats. Problems like this are often unforeseen. Awareness of such reactions of the material arise only after products are used in the real environment.

I noted that Incept used PVC for the K40, as well as combinations of PVC, PU, Hypalon® and Neoprene. Neoprene was used on many Incept rafts as an armouring material where areas were vulnerable to wear. All the rubber based composites and thermo-set plastics were glued to the material used on the body (usually a PVC/PU composite).

The fittings were usually made from the same PVC as the shell of the boat so that fittings could be welded. This was less time consuming than glueing and reduced production time.

Inner cloth		**Major Properties**
	Nylon	Absorbs water. Flexible, 25% elasticity, strong.
	Polyester	Stiffer, 5% elasticity. Less strength for same size thread.
Impervious Layer	**Thermoplastics**	Better wear in water. Weldable.
	PVC	Dielectric loss factor ~ 0.3. Good adhesion to base material.
	PU	Good adhesion to base material.
	Thermo-set plastics	Better dry abrasion resistance.
	Hypalon®	High dry abrasion. Stiff.
	Neoprene	High abrasion resistance. Flexible.

Table 2 - Properties of materials used in airtight cloth

All Incept craft had the air chambers as the outer cloth, where the craft was directly inflated. I located another kind of construction that manufacturers Aire Inflatables (AIRE) used. They made a separate bladder that zipped inside a protective shell that was then in contact with the water.

2.3 FACTORY LAYOUT

I regarded the Incept factory layout as critical to its production processes in order to maximise time efficiency and product flow throughout the factory. The following is a simple process flow chart showing the movement of the production stages of manufacture from the basic materials through to the end product.

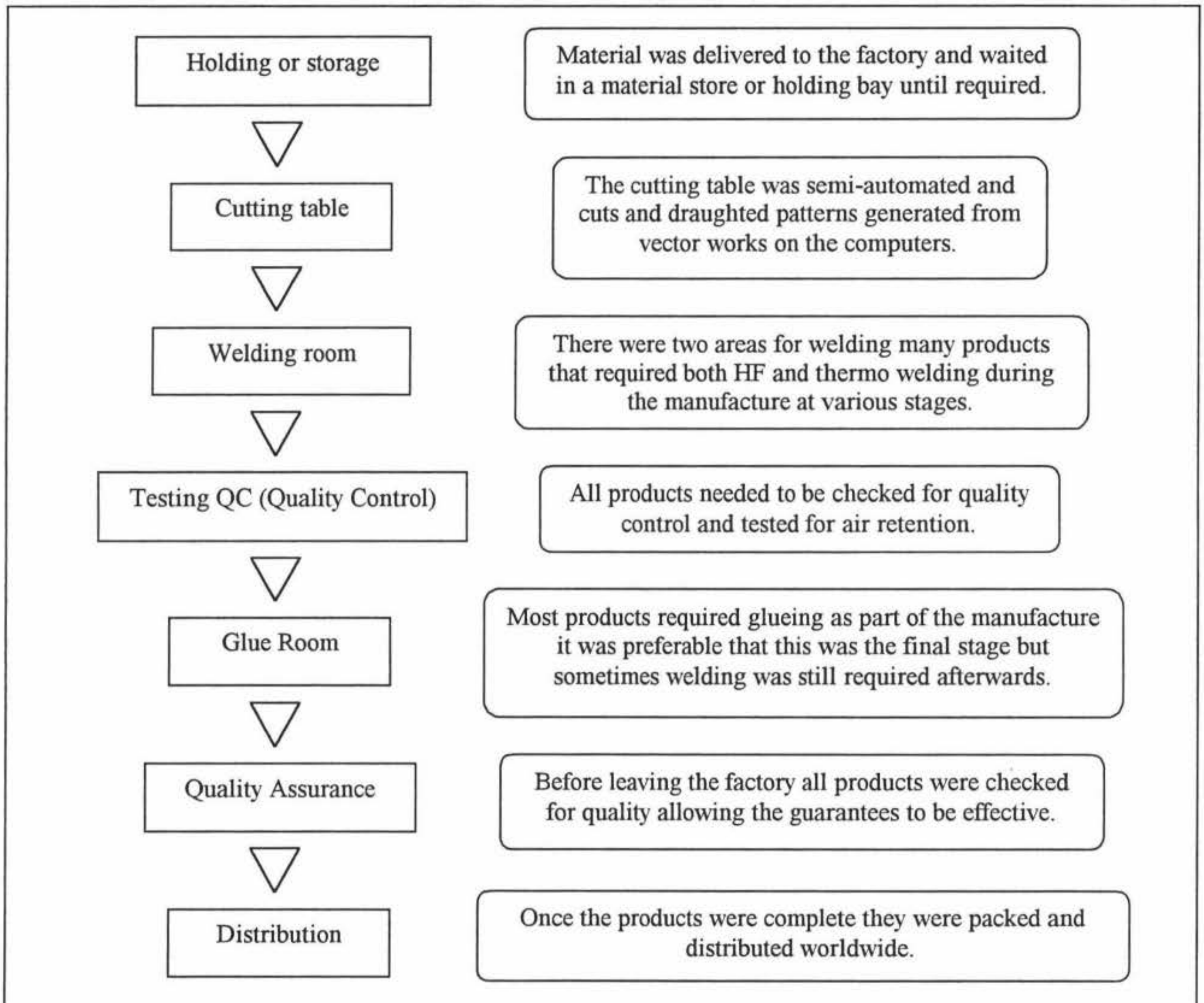


Figure 5 - Incept factory process flow chart.

Many of the processes required repetition and relied on other parts of the boat being completed first. For example, some boats required armour materials to be glued on before any welding could take place. Often one panel was rotationally welded and then passed back to be HF welded in order for the tube to be closed and become air tight.

Quality control and quality assurance occurred in different places, depending on the product and processes required to complete the product. Most boats had quality control checks at least once during production, particularly on any independent air retaining cells. All boats received a workmanship quarantee in the outward goods area before being released.

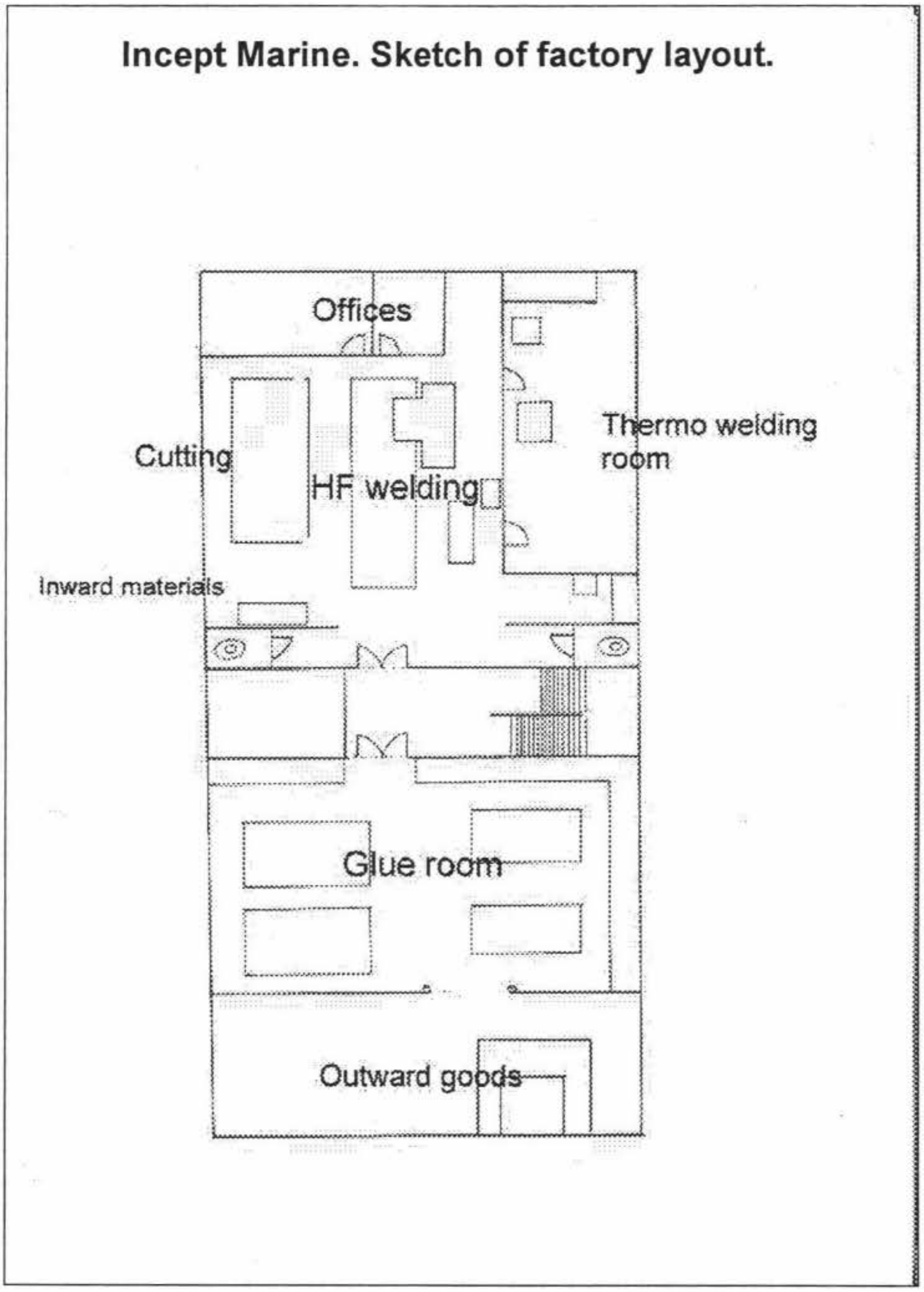


Figure 6 - Sketch of factory layout

Also refer to section 9.3.

2.4 LITERATURE REVIEW

The literature review located as much relevant information as possible so that it could be collated and be evaluated to increase my understanding of the world of sea kayaks and their design. Several information gathering methods were used.

- Written publications including books, magazines and articles relating to sea kayaking and paddle sports, and also to eco-tourism and outdoor recreation. The publications were found mainly by doing subject searches on electronic search engines including OVID and other library references, and also from retailers of outdoor equipment and magazine specialists.
- Internet information on particular products or manufacturers together with publication references and general information. This was a great way to extend the search to an international level. Many manufacturers are now online, and provide product information on their websites.

I felt it important to understand the history of sea kayaking and inflatable kayaks. The second area was small boat design and the principles behind the design of inflatables. The third major section was information to aid in understanding the market of sea kayaks and inflatable sea kayaks. This included looking at current products and for what markets they were already catering. Identifying trends in sea kayaking and kayaking markets enabled a forward outlook for the project, as well as identifying niche markets, as yet unsaturated, where a new product could make an impact. As this is a large section it will be covered in the chapter on the market review.

2.4.1 History of sea kayaks and inflatable kayaks

Many authors including Hutchinson (1994) allude to sea kayaks originating with Eskimos for hunting and carrying passengers. Most modern kayaks are designed to the same basic shapes as traditional kayaks and the basic design is so distinctive that a modern sea kayak would be immediately recognised by the stone-age hunters. Although there were two ancestral strains of kayak design (the West Greenland Inuit kayak and the Aleut Baidarka Kayak), it would be difficult to trace today's designs back to either ancestor, as modern naval architecture has interbred the two of them. One of the beauties of the kayak is that as long as the basic principles are adhered to, many changes can be made but the final product is an excellent boat. Most changes made will merely enhance certain desired characteristics and detract from others.

According to information from *www.allinflatables.com* [Retrieved 27 November 2000] the history of the inflatable boat dates back almost three thousand years. The history of the inflatable boat began when, in 880 B.C., the Assyrian king Ashurnasirpal II ordered troops to cross a river using greased animal skins, which they inflated continuously to keep the vessels afloat. In ancient China, during the Sung and Ming dynasties, inflated, airtight skins were also used for crossing rivers. They are still in use in northern Pakistan and Afghanistan.

It was in 1839, however, that the Duke of Wellington tested the first recorded inflatable pontoons. In 1840, the Englishman Thomas Hancock designed inflatable craft and described this work in *The Origin and Progress of India Rubber Manufacture in England* published a few years later. In 1844, a Lieutenant Halkett designed a round-shaped inflatable boat that was used in several Arctic expeditions. The Frenchman Clement Ader devised a floating vessel too. Indeed, many other pioneers invented craft that foreshadowed "inflatables". In 1913, the German Albert Meyer came up with a fairly novel design. By 1920, his company, A. Meyer Bau Pneum. Boote, was marketing his "pneumatic" boats, of which nine were already in use by the German Army. In France and Great Britain, Zodiac and RFD claim paternity of the first modern inflatable kayak (IK) and since then there have been many other competitors into the market (*History of Inflatable Boats*, www.allinflatables.com, Retrieved 27 November 2000).

> In the beginning, inflatable kayaks (IK's) were built primarily for commercial outfitters to give their clients a more exciting ride in their own one-man raft. This was the age of duckies; the craft and paddler looked like a flock of ducklings chasing the guide downriver (Mowrey, 1994, p.84).

A market place review comparing IK's in 1994 from publication *Paddler* stated that "IK's are one of the fastest growing products in paddlesports." (Mowrey, 1994, p.84) This comment still seems applicable looking at continuing trends while companies continue to produce high quantities of IK's and new products and innovations are still entering the market.

The IK's required less skill than the equivalent hardshells as they were open deck craft so the anxiety or risk of being trapped was reduced and they tended to be more forgiving on rapids with less opportunity to capsize. IK's have moved on to provide a more recreational craft on flat and sheltered water for use by a greater number of people, as well as benefits on whitewater.

During the early 1990's Incept started development of an IK for use on whitewater. Richard Sage, one of New Zealand's top Rodeo paddlers at the time, helped with the design of the Incept K30. The K30 changed many previous perceptions of inflatable kayaks when Richard Sage managed top placings in the 1993 New Zealand Rodeo competition in the inflatable K30. It is a kayak with very different requirements and characteristics from those required for sea touring (Refer to section 9.4 for Sage Product sheet).

2.4.2 Small boat design

The literature on small boat design indicates that the basic factors in boat design are the stability principles of a boat, the importance of speed and the ease of paddling including manoeuvring and tracking. Because we are looking at an inflatable kayak the strength and rigidity are also important design factors, but these are dependent on a few extra parameters specific to inflatable design, and these will be discussed as we look later at inflatable design.

The four main parameters that affect the performance characteristics of a small boat are hull shape, length, beam (width) and depth. These will be defined briefly before looking at their effect on the characteristics. It should be noted that this discussion will only sweep the surface of these characteristics and parameters as the topic of small boat design in itself is too extensive to be discussed in depth within this thesis. The discussion that follows is to aid those with little or no current understanding of small boat design.

Hull design

The shape of the hull is critical to performance. It will be the main contributor to the performance of the kayak, including drag, stability and manoeuvrability. There are many different variations of hull shapes and most kayaks incorporate different identifiable shapes at different intervals along the hull for varying effects. Figure 7 shows the three basic hull shapes through a cross-section that most variations will be derived from:

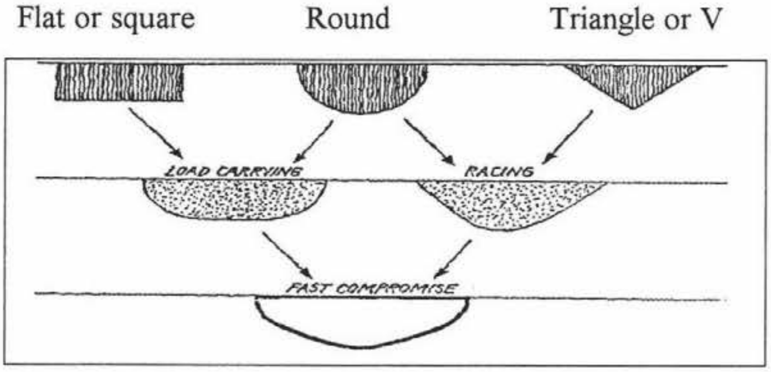


Figure 7 - Basic hull shapes (Byde, 1975, p.147).

The shape of the hull determines the wetted surface area of the kayak as the same amount of water is displaced for any given weight, according to the Archimedes principal.

The cross-section of the hull shape varies along the length of the kayak, but the position most commonly considered when categorising the hull shape is the master section. Byde (1975, p.146) simplifies the three main hull shapes at the master section as " a rectangle, a triangle, and a semi-circle. A square is stable, but has the greatest wetted area for a given buoyancy. The triangle is next, with a lesser wetted area and hence less skin drag. The semi-circle is best of all with a minimum wetted area and hence lowest skin drag. It is also the most difficult to balance." Most kayaks will be a combination of hull shapes with a more obvious V towards the ends of the kayak, and flatter in the centre, thus gaining stability through the centre but minimising the skin friction over the kayak as a whole.

The other dimension of the hull shape is the shape along the longitude of the kayak most often referred to as the rocker of the kayak. Further discussion of the rocker is included in the section on manoeuvring and tracking.

Length

The length seems a fairly obvious measure when initially confronted with the parameter. However, there are two measures that are important in relation to the length of the kayak. The first, and most common in relation to performance characteristics, is the waterline length. The waterline length is the length of the kayak that is in contact with the water, measured in flat water when the kayak is normally loaded. The actual waterline length will vary for most kayaks depending on the amount of mass carried and, therefore, the displacement of the kayak at any given time. The reason for defining the waterline length is that this will determine the wetted surface area as well as the distance between the bow and stern waves (Dickson, 2000 p.51).

The actual length of the kayak is an obvious measure and is exactly that, the measurement from one extremity of the kayak to the other. This is also a consideration for design as it affects characteristics such as windage. Most manufacturers will state the actual length of the kayak for dimensions.

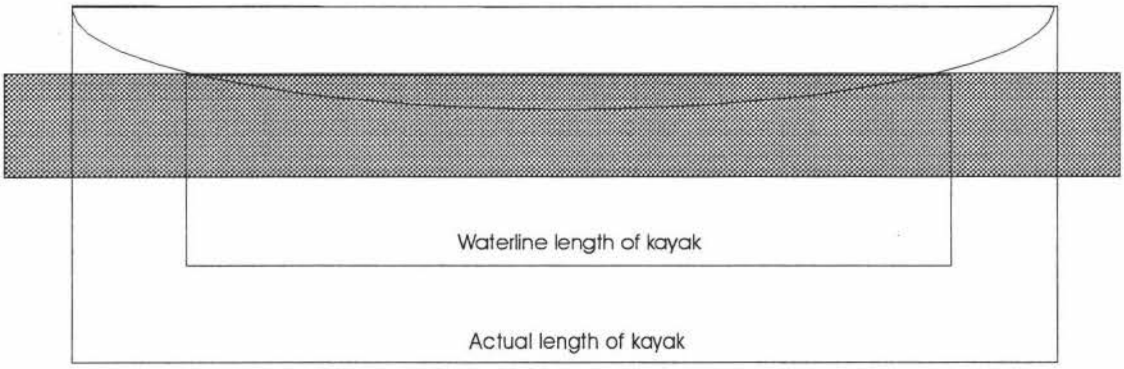


Figure 8 - Difference in actual and waterline length.

Beam

The beam is the width of the kayak usually measured through the master section. On a hardshell kayak the beam is measured directly from the outside of the boat. On an inflatable, however, with the side tubes being a significant diameter we may refer to the inner beam, or outer beam.

The inner beam is measured between the inflated tubes of the sides. This measurement (specified by population statistics of anthropometrics data) when taken at the cockpit is determined by the maximum size of the paddler expected to use the kayak (Refer to section 9.5).

The outer beam is measured at the widest part of the kayak, on the outside of the side tubes. It determines the distance that the paddler has to reach in order to put a proper stroke into the water and affects the stability of the kayak, and its load-carrying ability.

The difference between the inner and outer beams determines the diameter of the side tubes, which is an important measurement in determining the rigidity of an inflatable kayak.

Depth & Draught

Again the depth has two measurements mainly due to the inflation aspect of the kayak. The depth of the kayak is measured from the upper most point on the kayak through the centre position to the bottom. This would be measured at the master section. In effect, the depth of the kayak is the sum of measurements of the freeboard and the draught. The part of the depth that remains above the water is called the freeboard. The freeboard is also a factor in design as it will also determine windage especially at the extremities of the kayak.

Draught is "the depth of the lowest part of the hull, excluding keel or rudder, below the waterline" (Byde, 1975, p.143). The draught affects the ability of the kayak to track, and also the speed, as the greater the draught, generally, the greater drag on the kayak under the water. The draught and the freeboard need to balance between windage and drag, as the more draught the kayak has the more counteraction it has against windage, but the increased draught will affect the overall drag.

The above boat characteristics are discussed in relation to performance ideals in the following section.

Stability

Stability was considered in a number of different environments. There are primary, secondary and longitudinal stabilities that were usually associated with the general stability of a sea kayak. (Stability was associated with the amount of hull that is in contact with the water and the ability of the kayak to return to an upright position). Dudley Dawson (1998) explained stability in relation to small craft. Although not specific to sea kayaks he gave an idea of the necessity behind stability and the complications surrounding designing a stable boat.

Stability was of critical consideration when designing the inflatable sea kayak "since smaller boats are inherently more vulnerable to wind and sea" (Dawson, 1998, p.98). Or in other words they were lighter and were more likely to get pushed around by the elements; therefore, maintaining stability (especially in the undesirable conditions) was important. In looking at stability in relation to sea kayaks, we used a definition close to that of positive stability, which was the ability of the boat to return to its original position after being disturbed by waves and the disturbance has stopped.

There are three situations or environments in which stability was considered:

1. Primary Stability

Primary stability was the ability to maintain an upright position in flat water. As Derek Hutchinson (1994) pointed out, a wide flat-bottom boat (refer to Figure 7 - Basic hull shapes (Byde, 1975, p.147).) was good for primary stability. On flat water there was little or no tendency for a flat-bottomed boat to favour a particular side. However, in general, flat-bottomed boats are unseaworthy. Because the hull shape also followed the slope of the wave, it was unsuitable for anything but a flat, calm sea, and the boat was likely to capsize as in Figure 10. A round or V-shaped hull could have compensated for the wave slope and the shaped hull allowed the occupant to lean into the wave for the necessary bracing stroke and maintain a positive position in relation to the wave.

2. Secondary Stability

When a boat was exposed to rougher weather and waves, the stability of the kayak or boat suddenly took on a different meaning. In dangerous circumstances, dependence on the kayak having stability in the waves was important. For example, capsizing in some places, such as Alaska, may result in hypothermia, due to the very cold temperatures. What was required for secondary stability is for the kayak to remain upright and not be compromised in the wave zone. This specification was identified in the project proposal and it must be emphasised that secondary stability was more important than primary stability for even an experienced paddler especially when paddling in open or rough water.

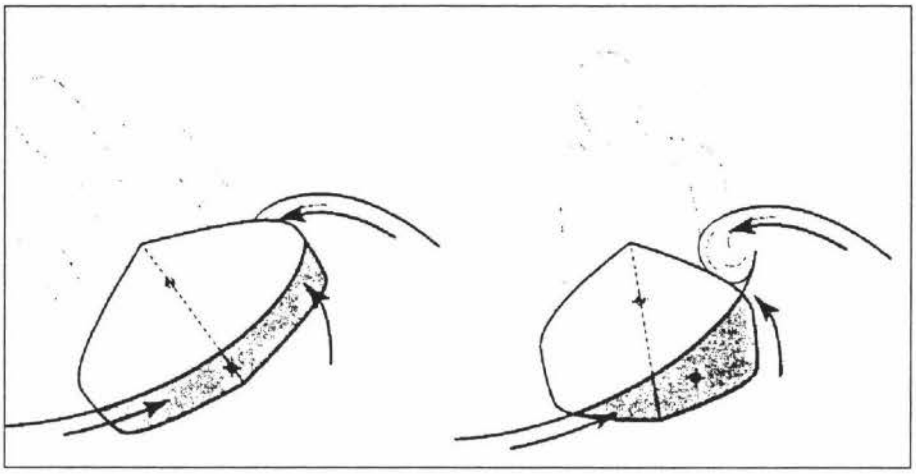


Figure 9 - Secondary Stability.

Because there were so many compromising factors for stability, it was not usually a measured characteristic. However, it was often easier to understand in a practical sense after an experience of paddling in a stable verses an unstable kayak. Each form of stability related to different circumstances and often having a kayak that was really stable on flat water (primary stability) may reduce its stability when it was in the wave zone (secondary stability). Refer to section 9.6 for a simple illustration of how each of the three basic hull shapes can determine primary and secondary stability.

3. Longitudinal Stability

There was also a third type of stability often referred to as longitudinal stability, which related to the ability of the kayak to track effectively. This is discussed under tracking and manoeuvring later in this chapter.

Speed

Speed was important to most paddlers as a slow boat is going to require more work and effort by the paddler to get to any location:

> To attain serious speeds with limited power, it is more efficient to travel completely underwater, or in the air above it. As land creatures, we are unable to successfully do either in a self propelled and sustainable manner, so we are stuck on the surface (Dickson, 1996, p.42).

There were two speed definitions that could be compared. There was the average speed, that was the set level of work or effort required by the paddler, that the paddler had to exert in order to maintain a satisfactory paddling speed in a touring kayak. The faster a kayak moved for a set amount of input the better. Speed testing in hardshell boats showed that a strong paddler in calm conditions might reasonably expect to travel at 4 to 4.5 knots while working steadily (Dickson, 1996, p.42). In an inflatable an average speed of between 3 and 4 knots would have been a reasonable expectation.

There was also a maximum or potential speed, that was the fastest speed that the kayak could be expected to go when the paddler was putting in 100% effort. Potential boat speed was limited due to wave making resistance.

> As speeds increase the proportion of losses attributable to wave making resistance becomes higher while the total drag increases exponentially. At around 5 knots in a sea kayak, the losses are about equal, and ultimate sprinting speed is mostly determined by wave making resistance. A waves speed is measured by the length between the two crests being a distance the same as the waterline length, of the kayak. Therefore as a general rule, waterline length is one of the major factors limiting maximum speed (p.42).

As the speed of the craft increased it tended to make waves that would not occur if it were completely submerged. The waves grew higher as the kayak speed increased, so the kayak became trapped trying to climb over its own bow wave. If sufficient power was applied, such as a motor on a powerboat, a vessel could climb over the bow wave and "plane". However, it was impossible even for the strongest paddlers to achieve this without the help of wind and waves where surfing may occur on the naturally occurring waves in the sea (Dickson, 1996).

Dickson (2000) discussed the issue of speed in relation to the differences between the effort required to reach the same speed in a double and single kayak. He pointed out that "potential boat speed is related to the distance between bow and stern waves, the greater the distance the greater the [potential] speed" (p.51) This statement referred to the potential for a double sea kayak to have greater average speed due to an extended length, and having two paddlers' to contribute to the propulsion.

In a touring kayak the ability to maintain a reasonable speed over a long period of time was more important than the maximum potential speed in a touring kayak.

There were a number of different factors that effected speed and speed was one of the most preferred characteristics for measuring performance of the kayak. Unfortunately, speed will always be a variable factor in a kayak, as it depends on the ability, strength and technique of the paddler as well as the dynamics of the kayak in different water conditions.

Dickson (1996) also suggested that skin friction on the outside of the kayak played a major part in the cruising speed of the kayak. If the kayak had a smooth finish it would have had a lot less friction on the water over the amount of wetted surface area: "At low speeds, friction losses account for virtually all of the kayak's total drag. In tests conducted by *Sea Kayaker* magazine, they concluded that at 3.5 knots (multiply by 1.85 to give km/h = 6.48), 85% of the total drag was skin friction" (p.42).

Laminar flows only occurred in the bow region and Frank Goodman (the designer of the Nordkapp sea kayak) suggested that "any scratch over 0.1mm will cause frictional loss." (Dickson, 1996, p.42) This was difficult to assess in an inflatable as the manufacturing methods created join lines, which if aligned in the wrong direction, would immediately cause frictional loss over the whole kayak.

Dickson (1996) maintained that at low speeds laminar flow occurred all over the kayak but as the speed increased it would quickly break down to turbulent flow, except at the bow. Turbulent flow needed to be minimised at all speeds.

As mentioned low speeds were influenced by the amount of drag on the kayak, and most were attributed directly to the skin drag. As speed increased the drag could be determined by different characteristics. Two of these were the form of the hull and how it interacted with the water. The key to reducing the drag at higher speeds was associated with the way in which the water parted around the kayak and also the resistance at the stern as the kayak passed the water. A bow that gently parted the water would create less drag than a full bodied bluff entry. "Swedish form" kayaks (Refer to Figure 13 to see the Shakespeare craft) that had their widest point to the rear of the centre were generally faster than "fish form" kayaks that had their widest point in front of centre. Another factor influencing drag was the width of the boat. This was also related to speed and the way that the water was displaced around the kayak. A long slim boat needed less effort to part the water than a wider boat and therefore, was likely to create less drag due to reduced turbulent flow at the stern (Dickson, 1996, p.42).

The rocker (Refer to Figure 1) also affected residual drag. Excessive rocker increased wave making, although it could have helped reduce skin friction through lower wetted surface area. Obviously a lighter kayak and paddler would have less drag than a heavier kayak and paddler with greater overall weight due to the amount of water displacement.

This was where graphical analysis could have been important as speeds could be associated with the effort required and the drag created at different speeds. Some boats would perform well at slower speeds having low frictional losses, and other kayaks would have much higher potential speeds due to length and shape but have more drag at lower speeds. This was due to the combination of frictional losses and wave making resistance as speed increased. The surface finish of the material used will determine the skin friction.

Therefore, the consideration of how fast the kayak was, related directly to the expected use and conditions and, more often than not, the kayak that was better at slower speeds would be a more suitable kayak for rougher conditions and the use of sea touring.

Tracking and Manoeuvring

To try and maintain a direct course without a rudder would result in a lot of effort. The ability of a kayak to maintain a straight course without veering or favouring one side was often referred to as tracking or longitudinal stability. In a sea kayak most of the effort of paddling should go into the maintenance of speed, rather than losing speed as the kayak veers from one side to the other.

In some kayaks, such as whitewater kayaks, this manoeuvrability was very important. In whitewater it was essential that the paddler could make precise moves in and around rocks and currents in fast moving water. This performance characteristic was brought about by the amount of rocker shaped into the kayak. The rocker is "the degree of curvature, in the vertical plane, of the keel line. With the centre of the canoe [kayak] on the ground, the ends rise up towards the bow or stern" (Byde, 1975, p.155).

Generally a sea kayak had very little rocker compared with a whitewater boat as the sea kayak paddler was seeking a boat that tracked well and the paddling effort directly benefited the forward propulsion of the kayak. In a sea kayak the preciseness of turning was not so important, but when a new direction was required the rudder was used to direct the kayak while maintaining speed. Due to this, it was important that the kayak had internal tracking through longitudinal lines on the kayak and also a rudder as a standard fitting.

The project team found that because the K40 was an inflatable and therefore had tube shapes that were rounded rather than distinctive chines, it was essential for the K40 to have a rudder.

Comfort

Ergonomics were an important consideration when designing any product that would be interacting with the human body, especially one that interacted as directly as a kayak. Spending considerable time in the cockpit of a kayak emphasised the need for comfort while paddling. The seat and backrest needed to be comfortable and allow for movement of the paddler so that blood flow was maintained, especially through the legs. Body movement needed to be within normal positions of the paddler without straining the body with irregular muscle use. This was important so that the paddling motion could be maintained over long periods of time. It also allowed the paddler to have an efficient paddle stroke without stretching too far over the edge of the kayak in order to reach the water.

It was important that ergonomics were considered for the population expected to use the kayak and that the kayak was suited to these people.

At this point, one of the major tasks for the project team was trying to assess anthropometric data for different populations that might use the Incept sea kayak. This information helped to set the width at points along the kayak as well as room for legs and height of the deck for room for the arms. There were lots of different places and ways in which anthropometric data was given. Thanks to a discussion with Stephen Legg, a Massey University Lecturer in human ergonomics, it was realised such a versatile boat really would not have optimum parameters unless designed for an individual; yet the aim was to be as versatile and flexible in the design as possible in order to accommodate the widest general population expected to use the kayak. Refer to section 9.5 for a summary of anthropometric data used.

Portability

The most obvious advantage of an inflatable was easy portage. A hardshell kayak required roof racks and ties or a special trailer to transport, and at over 4.5 meters in length they were difficult to manage by one person trying to lift or carry them. Therefore, the inflatable kayak needed to be compact and easy to carry. There were marketing advantages in supplying a carry system such as a bag or backpack as part of the portable kayak package. The lighter the overall package the easier and cheaper it would be to transport. From the packed position it also needed to be simple and quick to inflate and for rudder and decks to be assembled into position. All parts should go together in such a way that they could not be misplaced or lost.

Safety

Any craft used in water should be seaworthy according to the purposes for which it is to be used. Seaworthiness included minimising risks or dangers and foreseeing potential dangers. One feature of design to enhance the safety of an inflatable craft was to ensure it maintained buoyancy even if one of the air chambers deflated and the paddler could not be trapped inside the kayak if capsized. No specifications could be sourced regarding inflatables and the New Zealand Marine Safety Authorities.

Durability

All products needed to have a degree of durability. The material had to be suitable to the environments and withstand standard use. Some of the considerations in the durability of an inflatable kayak included wear on sand, rocks and coral. Consideration was also given to whether the materials and adhesives would be adversely affected by salt water or excessive UV. In an inflatable a small degree of flexibility was an advantage for puncture resistance. Obviously sharp objects that could pierce the inflatable were undesirable, but a general knock would not cause deflation. Small scratches may have caused a slow leak to occur, which could easily be repaired.

Air pressure

Air pressure was a variable that only affected inflatable kayaks and those with inflatable sections. However, it was an important consideration for an inflatable kayak as it determined the general rigidity of the kayak, as well as its strength and vulnerability to puncture. The air pressure of the tubes will be discussed in the chapter on structural strength in relation to the diameter of the tubes and the force required to resist bending.

Volume

There were two areas to consider when thinking about the volume of the kayak, the first was the volume required to carry gear or luggage. For an expedition kayak it would require a minimum equivalent to an expedition tramping pack of around 100 litres. This was not difficult to obtain in any standard hardshell sea kayak. However, the space was found to be difficult to utilise efficiently due to small access hatches.

The second was that volume also effected how the kayak reacted to oncoming waves. Volume in the bow allowed the bow to rise over the oncoming waves as opposed to ploughing into them and sending excess water over the paddler. Therefore, higher volumes in the bow of the kayak would give the paddler a drier ride.

Windage

We found that inflatables were especially susceptible to the effects of the wind. The more of the kayak that was above the water, the more the wind could catch and move it. It would, therefore, be expected that the freeboard should be kept as low as possible to minimise the windage.

2.4.3 Inflatable craft design

The design process

It was important to consider the design process used within the project, especially considering that the project was dealing with something unfamiliar to the project team. Every design and development project would be different according to the project specifications. However, there would be a similar process in reaching the final product.

The five generic steps of the product development process used were:

1. Idea generation
2. Screening these ideas with product and consumer specifications
3. Development of ideas to concept design
4. Testing of concept
5. Evaluation of the outcome.

At any stage the process was iterative allowing for the ongoing and continuous development of one or more initial ideas.

It was important that during the design process the project team continually referred back to the specifications in the project to ensure that the end product met the specifications. The evaluation of the outcome was the step ensuring that the specifications were being met. There were many iterations of the concept design as it was tested against the specifications and the design went through concept development in order to ensure that it fulfilled the specifications.

Requirements

An inflatable craft of any sort had some criteria that must be fulfilled in order for it to be considered an inflatable:

- It must be able to retain air and therefore have closed seams
- In order to inflate and deflate it required a valve
- The materials used must be airtight
- It must maintain an inflation pressure appropriate for use.

Any craft would be made from a two-dimensional pattern and panels, and then bonded together using one of the methods mentioned earlier, and then be inflated into something of three-dimensional character.

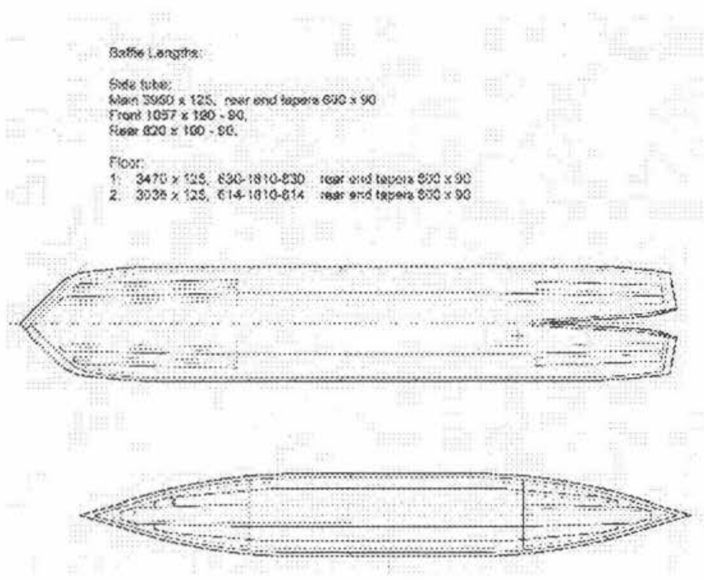


Figure 10 - Example of a pattern for a kayak.

The material was then cut (at Incept this was done on a semi-automated cutting table) according to the pattern and then assembled into a kayak (refer to Figure 52).

Typical Products

Originally inflatable craft were developed for the navy and military, for transporting torpedoes and other cargo. And according to website www.allinflatables.com as the inflatable boat properties of stability, floatation and seaworthiness became known inflatables were used for lifesaving and rescue tenders on larger vessels. Over time recreational applications evolved for smaller boats due to their ease of use and storage. In New Zealand the main use of inflatable craft is seen on rivers, with the large whitewater tourism network, as well as tubes on Inflatable Rigid Boats (IRB's), used as rescue and recreational boats seen on many waterways of New Zealand.

As most large inflatable craft are for some sort of cartage for passengers, it was important that they were safe for the environment in which they were being used. Along with the inflatable boats and rafts, there were a number of other products that were inflatable. Other products included: beach balls and water toys, flotation aids, inflatable castles and obstacle courses. There were many different products that required special materials in order to hold air.

2.4.4 Solidworks and 3D modelling

> The CAD [computer aided design] process when used by a person skilled in naval architecture allows us to take this [designing kayaks] process from the subjective to the objective (Gorter, 2000, p.7).

CAD/CAM

Computer aided design and computer aided manufacturing are increasing in popularity as their simplicity and versatility is realised. At the commencement of the project it was expected to use Solidworks or other three-dimensional (3D) solid modelling computer software to design and develop the sea kayak. Due to the complexity of the Solidworks programme and methods of product development at Incept, 3D CAD was not implemented during the project. Although there were some interesting ideas for discussion surrounding the use of CAD in the development of small craft, none were sufficiently well developed for use in this project.

Naval architecture is the science of boat design and was started late in the 19^{th} century (Dickson, 1999). Through the progressive development and understanding of naval architecture most aspects of boat performance can be predicted. Although all the calculations can be done by hand they are very time consuming. With the aid of computers these calculations can be completed very quickly and the computer acts as a draughting and analysis tool at every change of the hull design.

With the speed of the computer, fine-tuning can be completed prior to construction while comparing analysis results with those from existing designs. There are a few drawbacks to CAD in trying to relate the real world to the computer and actually simulate real world environments. There will always be a gap between computer simulation and actually paddling a kayak.

Solidworks

Solidworks was a programme utilised at Massey University for industrial design. It had properties that enabled solid objects to be drawn and then the programme to work and unfold the object to a series of flat sections, just like a pattern. Initially it was thought that this feature of Solidworks would be useful in the design of inflatable boats. It was found that the unfolding property is restricted to rigid materials. Without extensive experience and knowledge of the programme it was very difficult to use in order to produce complex shapes. It was felt that because of the time it would take to get up to speed on the programme it was easier to utilise programmes already used at Incept. The programme used at Incept was Vector works.

Vector works

Vector works was another 3D modelling programme. Incept already used Vector works for 2D modelling of patterns in order to semi-automate the patterning process. Patterns for the boats were draughted in Vector works and then converted to a DX plot, to be cut on the cutting table. Vector works had the capability to work in 3D objects, but Incept did not use Vector works to this level, rather using only two dimensions and patterning the flat surface of the material.

No CAD software was available that allowed 2D patterns of stretchable material to be generated from a 3D model.

3 MARKET REVIEW

At the commencement of the project the objective was to develop an inflatable sea kayak for Incept Marine Ltd (Incept) in Taihape. Some critical factors in design including paddle reach, windage, and comfort had been identified within the project proposal (Refer to section 9.1 for project plan) but there was little guidance as to the specifications of the kayak in regards to satisfying customer expectations. Through personal contact with people who are enthusiastic about sea kayaking, who have experience in sea kayaking, and retailers selling products related to sea kayaking, an idea of the market became clearer. Also I was able to experience sea kayaking personally to understand the involvement levels and environment, in which it was enjoyed, and talked to people involved in the kayaking industry and eco-tourism.

Once we knew what the customer expected then we were able to use product development techniques and research of current sea kayak designs to determine ways in which to best deliver the requirements specified by the customer.

Firstly we needed to find out what the requirements were:

3.1 EXISTING BOATS AND TRENDS IN THE MARKET PLACE

The objective of this section was to find the designs and trends currently available in the sea kayaking market and hence where inflatable craft currently fitted into this market. The outcome of this task was to enable the team to classify the area of the market that would most benefit from an inflatable sea kayak produced by Incept. In order to achieve this I looked at kayaks available on the market by identifying manufacturers from publications and retailers. I compared designs and particularly new products that were entering the market.

I initially looked for sea kayaks that were available in New Zealand. This was done by visiting and talking to manufacturers and retailers. It was found that there were not many inflatable sea kayaks available in New Zealand; therefore, initial comparisons were made among hardshell kayaks (plastic, fibreglass and composite materials). It was noticed, as a second summer season approached since the commencement of the project, that a greater number of inflatable kayaks were available from retail shops as well as being advertised in magazines. This confirmed trends, later mentioned, of the increasing popularity of inflatable kayaks.

A great preliminary resource for sea kayak information in New Zealand was from the Kiwi Association of Sea Kayakers (KASK), *Kayak, Paddle & Equipment Handbook.* This publication listed the boats that were available in New Zealand, either locally constructed or imported. The list was compiled in 1998, but was a good starting point for a database which was developed from all the information collected. The database allowed comparisons between hardshell kayaks to be made as well as comparisons between hardshell and inflatable kayaks (Refer to section 9.7). Comparisons were made in order to construct a picture of the market place and which areas were already saturated with products.

Some of the information gathered for the database on existing products included the following:

- Materials and Construction methods
- Price
- Internal volume
- Intended environment and use
- Intended paddler ability
- Weight.

3.1.1 Sea kayaks available

There were many kayaks available on the market. They ranged from short, flat-bottomed boats for extreme play boating on whitewater rivers to the long sleek racing kayak with a rounded hull, very little stability, and designed to go as fast as possible over long distances. Although it was important to look at a range of different types of kayaks to understand the compromises made in the design, it was more important to focus on kayaks that were used especially for sea kayaking - that is, designed to maximise the paddler's safety, comfort, efficiency, and enjoyment in the environment. It was noticed that none of the inflatable kayaks found were designed particularly for sea touring. The specific use, skill level, and ability of the paddler had still to be determined for the Incept design.

The most recognisable single plastic sea kayaks seen when paddling the Abel Tasman National Park were the *Puffin* and *Penguin*. These two kayaks were made by Quality Kayaks in Ashhurst. They were robust and sturdy and suited a range of paddlers. They were relatively stable, yet could maintain a good speed. These were popular because they were versatile and reasonably priced. They also seemed common among recreational paddlers. Even more evident than the single Quality kayaks were the larger double sea kayaks. Most commercial operators encouraged the use of double kayaks for tours, mainly for safety reasons. The *Sea Bear* and *Packhorse* double kayaks were both a common sight around the Abel Tasman National Park. The more popular boats were identified from those available, from observations, talking to commercial operators and retailers, and from written product reviews in magazines such as *New Zealand Wilderness* publications. This information led to a valuable understanding of the benefits of an inflatable verses a hardshell kayak and identified possible niche markets that were not currently catered for. The largest area of interest was the boat characteristics and their use in relation to the skill level of the paddler. These were plotted in the following graph.

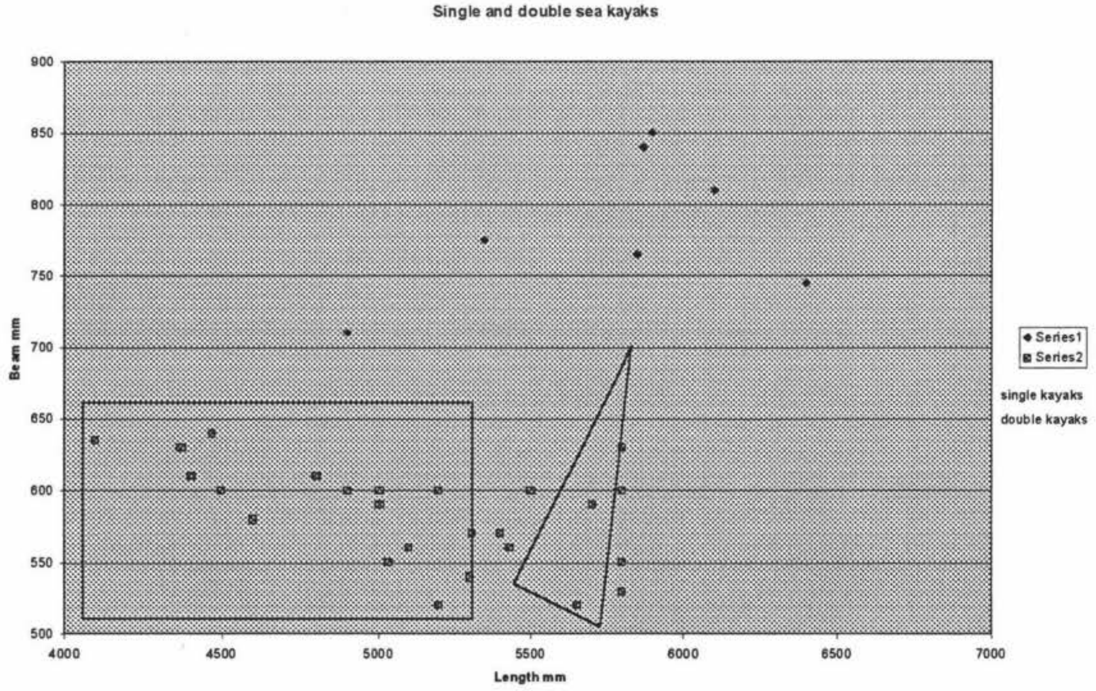


Figure 11 - Comparison of length and beam of single and double sea kayaks.

In the graph both the single and double kayaks were plotted, all the points above the beam of 700mm were double kayaks shown by series 1. All the square data points below were single kayaks shown by series 2.

When comparing the single kayaks with each other it appeared that generally the beginner boats had a wider beam than other boats. Those contained in the rectangle on the left of the chart were specified for novice, beginner or some intermediate paddlers. A wide beam appeared more stable to beginners, when in fact, its stability is limited to calm conditions.

The parameters compared included the width and length of the kayaks, to see whether there was any correlation between them. Although little correlation was found against these two characteristics there were clusters shown in the graph of intended paddler ability and intended use. Those boats contained within the triangle to the right of the chart were single kayaks all specified for experienced paddlers and expedition type craft. It was noted here that the length was considerably greater than the boats specified for recreational purposes by people with lower paddler abilities.

3.1.2 Inflatable kayaks

From Audrey Sutherland's book *Paddling Hawai'i* (1998), a market place review from *Paddler* (1994, p.92) and internet searches, the project team were able to identify manufacturers and inflatable kayaks that were being used. From there inflatable sea kayak characteristics and differences were looked at. Very few inflatable kayaks were specified primarily as sea kayaks.

The following table illustrates inflatable kayaks available on the world market.

Maker	Model	Material	Deck	Length (m)	Width (m)	Weight (kg)	Rudder
Achilles	KSB-94	Hypalon/nylon	No	2.84	0.945	15.4	No
Aire	Sea Tiger I	Urethane/nylon	No	5.10	0.889	20.8	Yes
	Sea Tiger II	Urethane/nylon	No	6.02	0.889	23.1	Yes
Custom Inflatables	Thrillseeker	PVC		3.65	0.813	12.7	
Duckworks	SuperDuck	PVC		3.50	0.953	13.6	
	UltraDuck	PVC		3.65	0.838	14.5	
Grabner	Explorer I	Hypalon/nylon	No*	3.86	0.711	16.8	Yes
	Explorer II	Hypalon/nylon	No*	4.88	0.787	23.1	Yes
	Holiday Economy	Hypalon/nylon	No	3.61	0.787	9.5	Yes
	Holiday	Hypalon/nylon	No	3.91	0.79	14.9	Yes
	Dolphin 1	Hypalon/nylon	Yes*	3.91	0.74	17.7	Yes
	Dolphin 2	Hypalon/nylon	Yes*	4.22	0.77	19.0	Yes
	Dolphin 2SL	Hypalon/nylon	Yes	4.60	0.74	19.9	Yes
Hyside	Padillac 1	Hypalon		2.90	0.79	19.1	
Incept	K30	PVC	Yes	3.0	0.7	12.0	No
Innova	Helios 340	Rubber/nylon	No	3.36	0.74	11.0	No
	Helios 380	Rubber/nylon	No	3.79	0.74	13.0	No
	Junior	Rubber/nylon	Partial	2.44	0.64	5.2	No
Jumbo	Tramper	PVC/nylon	No	3.86	0.79	12.0	Fixed skeg
Northwest River Supplies	Rascal	Metzler		2.44	0.98	10.0	
	Scamp	Metzler		2.74	0.91	18.1	
Momentum	SB-1	Hypalon		3.23	0.91	17.7	
Riken	Cherokee S.E	Hypalon		2.90	0.89	18.6	
	Seminole	Hypalon		2.90	0.89	20.0	
Shakespeare	500	PVC/nylon	Yes	2.95	0.94	14	No
Shakespeare	501	PVC/nylon	Yes	3.56	1.1	16	No
Sevylor	K79	PVC	No	3.23	0.86	11.3	No
SOAR	Lucky 12	Metzler		3.65	1.02	23.6	
Vista	Python	PVC		3.50	0.74	12.7	

Table 3 - Available inflatable kayaks on the world market.

* Decked means a full length, built in top cover to keep out water. The Grabner boats marked have a separate cover that can be fastened on.

(Sutherland, 1998, p.10, *Paddler*, 1994, p.92, *Wilderness*, 2000, p.65)

A comparison of inflatable sea kayaks with the hardshell sea kayaks showed there were some differences that were quite distinctive. Inflatables generally:

- Were shorter
- Were wider
- Had a greater freeboard above the water
- Were not as fast
- Had less internal storage capacity.

Advantages	Disadvantages
Lightweight	Lacks rigidity
Compact	Speed compromised
Portable	More likely to develop leaks
Good inherent stability	

Table 4 - Advantages and disadvantages of inflatable sea kayaks.

It was thought by the project team that most of these characteristics showed why inflatable kayaks were not used as touring sea kayaks. Most of these characteristics could be attributed to the design associated with inflatables requiring large air chambers to increase rigidity. This project tried to deal with some of these issues in enhancing the performance of the Incept sea kayak above other inflatable kayaks. Being able to compare competitive products and see gaps in the market, we could set target values for the different metrics that were listed and find out more about how we could realistically achieve these different metrics.

3.1.3 Trends

There were noticeable trends in the kayak market and also more specifically in sea kayaks. We felt that looking at current market trends could help with design and the prediction of what the market may be looking for in a design. Our findings are discussed below.

1. Sit-on-tops

With the increasing popularity of sit-on-top kayaks more manufacturers were responding with an increase in the number of sit-on-top varieties available. Dickson noted that a major trend for 1999 was "the huge increase in 'sit-on' kayak models, and while there are more new models this year, the growth of that market sector appears to be in line with the 'sit-in' kayaks" (Dickson, 2000, p.61).

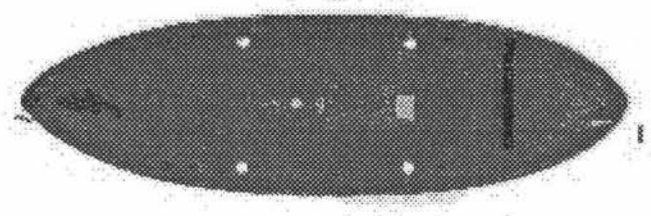


Figure 12 - Rotationally moulded plastic sit-on-top sea kayak (Yak Board, Pacific Kayak, product brochure, 2002).

Dickson (1999) noted a trend towards general-purpose recreational kayaks. The sit-on-top kayaks were more exposed to the environment, so were better suited to paddlers in a tropical climate where the weather and water were warmer. These kayaks were still popular in the north of New Zealand and were often seen over the short summer vacation period in use by holidaymakers.

Sit-on-tops were generally made from rotationally moulded plastic, making them more robust and hardwearing than fibreglass. They could be used in many situations and were similar in design to the traditional surf ski, which had fins protruding from the bottom and was used for playing in the surf. These craft were particularly suited to novice paddlers and children as there was no danger of being trapped inside in the event of capsize. They were easy to right and climb back on board, as they were generally very stable in flat water due to a flat-bottomed hull. But they had a high centre of gravity due to the position of the paddler, so capsizing was more common among novice paddlers.

The recreational kayaks were usually relatively short and lacked speed compared to traditionally shaped sea kayaks. Some sit-on-tops however, were being designed to cater for touring. They had internal storage compartments for luggage and the hull shape was redesigned to give more secondary stability in the wave zone. This brought them into competition with other sea kayaks, particularly in tropical regions where it was desirable to be close to the elements.

2. Radical shapes

Some companies like Shakespeare K2 Outdoor Products (N.Z.) Limited were found to be moving away from traditional shapes. The unusual shape of the Shakespeare craft would cause most traditionalist kayakers concern, due to its obvious differences from a traditional long slim shape, but reviews were promising. These kayaks were advertised as suitable for use on river, lake or sheltered waters, and they were available either as a single or double. Although not intended for extended touring, they appeared popular with day trip users where the need for gear storage was minimal. The general shape is radical compared with other traditional kayak designs.

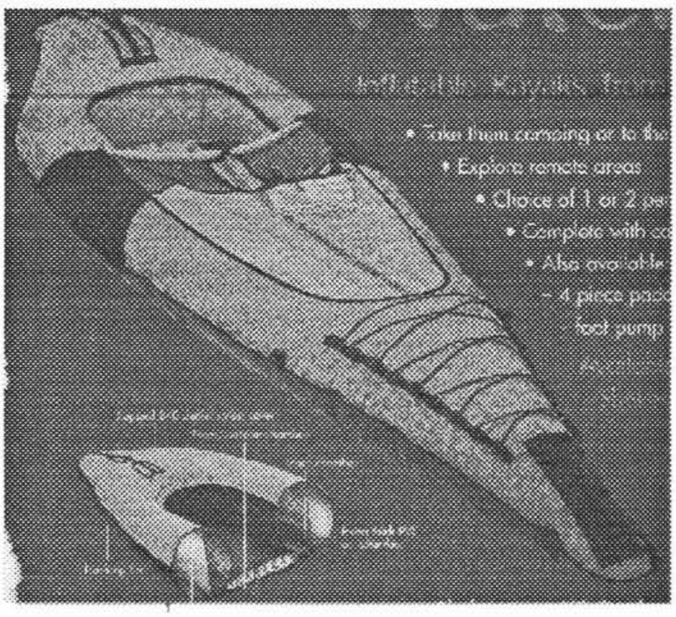


Figure 13 - Radical Shakespeare craft (*Boating New Zealand*, December, 2000, p.91**)**

3. Plastic

Trends were also seen in the use of construction materials. With the advances of plastics technology, particularly in rotational moulding techniques, there appeared a greater number of plastic kayak designs than were seen half a decade earlier. The time that it took for design was decreasing and, therefore, the frequency of new designs entering the market was increasing. Because of this we were seeing many more plastic and rotationally moulded kayaks on the market. Part of the increasing frequency of design changes was due to the materials that were being used as well as the greater variety in colours and materials that were available. This added a fashion element to the designs, possibly to increase flagging sales, and filled the continuing desire to upgrade to the latest styles. Plastic manufacturing techniques were more cost efficient and the cost of the plastic kayaks was coming down, so they were becoming a more dominant product in the recreational kayak market.

4. Do-it-yourself

As the global culture expanded, the use of the World Wide Web allowed people to seek their own plans to make wooden or fibreglass sea kayaks. The plans were available along with instructions and discussion pages to guide enthusiasts through the process. An advantage of building a personal kayak was being able to fit it to suit personal needs.

5. Computer aided Design (CAD)

As a recent development, boat building has seen an increase of the use of computer aided design and computer aided manufacture (CAD/CAM) packages especially for the design and development of boats. Some manufacturers and designers have designed new boats solely from CAD packages. There were advantages in the use of these programmes, as they were able to analyse many of the performance factors that often affect a design, before money and capital was committed to tooling and production (Refer to section 2.4.4 for initial investigation on computer aided design).

6. Promotion of Eco-Tourism

As environmental awareness increased more people were looking towards ecological forms of tourism. Sea kayaking fitted perfectly into environmentally friendly eco-tourism. With the growth of public awareness of sea kayaking, it grew as a form of holiday recreation as well as personal transportation on extended vacations and sea kayak expeditions. It had limited impact on the environment and allowed the paddler to enjoy remote locations not already spoilt by civilisation.

7. Increase in general use

Due to the trends discussed above, kayaking, in its many forms, appeared to be increasing in popularity. This included higher numbers of plastic kayaks, a general increase in the use of kayaks, as well as inflatables. I believe the popularity of inflatables was in part, due to the improvement in the quality of materials and bonding methods.

3.2 CONSUMER MARKETS AND MARKET NICHES

By looking at all the different sea kayaks available and identifying some of the market trends, we distinguished five different consumer groups. By looking at how each consumer group was currently catered for by existing sea kayaks, we identified where a new inflatable sea kayak could most benefit the market. Often consumers could be categorised by their expectations or requirements of a product. The classification led to profiling each consumer group for their needs and preferences of what they might expect for a sea kayak.

The following question was asked when classifying groups of people according to their product needs: Why would anyone want a sea kayak?

And to determine what kind of sea kayak to buy, there were other questions that were considered: What was the purpose of buying a sea kayak? Was the kayak required for fitness, pleasure, transport or other needs? Where was the kayak expected to go? Was it mainly to sheltered estuaries, lakes and harbours, or out in the surf and along exposed coastlines? Dickson (1999) states that extended tours on exposed coastlines require the performance, storage and handling of expedition kayaks. This question determined the environment in which the kayak would be used and the conditions that it must cope with.

Who was expected to use the kayak? In groups, solo, or two people? For instance if there was someone always to go with, then a double was fine, two people might want to use it together. This raised the question of whether there was a guarantee of someone else to paddle with. For what time spans was the kayak expected to be used and how far was it expected to go? Whether the kayak would be paddled for short bursts or for days at a time would make a difference to the kayak that should be bought, as well the distance intended to be travelled in that time.

How important was speed and ease of paddling? If the kayak was only required for a leisure activity for an hour or so at a time and for paddling around a sheltered inlet, did it matter whether it was fast or not? How much experience did the paddler have? Was stability or speed of primary importance? Was performance or safety (i.e. parent buying for children) the main characteristic? The consideration of the skill level of the paddler was important, although as more experience was gained their skill level was expected to increase. It was important that the kayak was not initially beyond their capabilities. Which characteristics of the kayak would they find most important?

How much gear was required to be taken on board the kayak? Was there a base camp that would be ventured from daily, or was it an expedition and all the equipment needed to be carried on the kayak? For example the amount of gear required would usually depend on the length of the trip. Sea kayaks appeared to always cater for some gear storage, but of varying capacity.

These questions helped specify some of the more general requirements of the sea kayak that people might buy. By the different answers that were given in response a picture of different types of consumers could be built. Obviously a sea kayak was not intended for narrow rivers or whitewater and although boats designed for these conditions could be used, they would not highlight the benefits really desired of a sea kayak. Five groups of users were identified from researching the market, and from combinations of answers to the previous questions. These were the following:

1. Commercial operators in New Zealand
2. Commercial operators in Asia and Pacific
3. Private recreational paddlers
4. Club paddlers
5. Private enthusiast paddlers

Table 5 breaks up and defines different uses of sea kayaks. This was done by considering many of the sea kayaks, both hardshell and inflatable, available and who they catered for and in what environment. Obviously people fitted into more than one user type, but the kayaks required for the different uses listed below varied. Many boats were compatible for different uses. For example the same boat might be used by a commercial operator as well as owned privately.

Recreational		Adventure		Expedition	
Private	*Tourism*	*Exploring*	*Travelling*	*Exploring*	*Travelling*
User groups: 3	User groups: 1 & 2	User groups: 1, 2, 3 & 5	User groups: 4 & 5	User groups: 5	User groups: 5
Privately owned for purely fun on a holiday at the beach. Generic use as a toy, used periodically. For moderate to high-income family. Generally low skill levels.	Rented by operators to tourists. Short trips, safe, minimal gear, high usage seasonal, income range, non-committal guided or freedom. A range of paddler abilities.	For paddling sheltered areas, exploring coastlines, lakes, flat rivers. Minimal gear up to a week. Typically hired by operators who also provide gear and basic instruction. All paddler abilities.	Used for a short time to get from one place to another. Requires transport of gear. Expect need for high volume. Primarily enthusiast and experienced paddlers.	Long trips relying on a safe and durable kayak. High volume required for gear cartage, but supplies may be picked up along the route. Primarily enthusiast and experienced paddlers.	Long trips relying on a safe and durable kayak. High volume required for gear cartage. Expect all gear to be carried. Primarily enthusiast and experienced paddlers.

Table 5 - Consumer markets for inflatable kayaks.

When combining this information with details of kayaks available, areas could be identified where an inflatable kayak could benefit the market. The project team saw opportunities in a number of different markets but the market that was least supplied by products was the expedition market. There were hardshell sea kayaks that were designed for touring and expeditions but none of the inflatable kayaks that were investigated were designed specifically for this purpose. The inflatable had a unique advantage that the other sea kayaks could not compete with and that was portability, especially to remote locations. A need was identified for an inflatable in this area as the only other compact sea kayaks available were folding kayaks that were still more bulky and often heavier than inflatables.

After markets had been identified and the characteristics that were desired defined, the objective from the project plan was re-written to be more specific to include the target market. From this point the objective was from the development of an inflatable sea kayak to the following:

To design and develop an inflatable sea kayak that is suitable for touring expeditions with the characteristics required by an experienced paddler.

This market was chosen, as there was nothing currently available to fully satisfy its needs. It was found that people who wanted the convenience an inflatable offered were generally willing to pay for a top quality inflatable kayak. Enthusiasts and experienced paddlers wanted to explore and travel with their own kayak. Many enthusiasts already tolerated the designs available but were looking for a higher performance, higher quality inflatable that also had the benefit of portability. There were several known cases where paddlers had modified existing kayaks to suit their individual needs, especially suiting them to expedition and touring use.

The characteristics that this market was looking for were primarily a portable boat. Our aim therefore, was to make a kayak that was light and compact, and that was comparable in performance to a rigid kayak. For a touring and expedition market it was necessary to increase the load carrying ability of the inflatable, which meant increasing the internal volume that was often low in inflatable kayaks. We had found that an experienced paddler would normally prioritise secondary stability over primary stability.

We now had a target market that we believed was not catered for and which the industry partner could realistically fulfil.

3.3 CONSUMER NEEDS AND SPECIFICATIONS

Now that we had a market to focus on we could look at the consumer specifications for that market.

3.3.1 Determining customer needs and specifications.

Ulrich and Eppinger (1995) discuss a collection of methods to help design teams develop products. Their methodology was used as a guide to specifying the customer needs and then to set the product specifications. In order to identify customer needs Ulrich and Eppinger recommended the following five steps:

1. Gather raw data

2. Interpret raw data in terms of customer needs
3. Organise needs into hierarchy
4. Establish importance of needs
5. Reflect on results and process

The project team endeavoured to meet one of the first requirements of product development by the identification of customer needs through gathering raw material on consumer wants and needs. The project team also tried to cater for latent needs (those needs that were not initially recognised or assumed in the design process). Understanding what the customer wanted would result in specifications that would be more likely produce a popular product.

Initially the project team's data was gathered from existing published material. This allowed brainstorming for ideas on the basic requirements for the product. Once customer needs were identified these were then confirmed through more practical means including the project team's personal experience and by asking people with experience in the industry for their comments and ideas.

From literature:

Most of the literature on kayaking focused on the benefits of their portability, ease of transport and how, in the off season, inflatables do not take up as much storage space as other rigid kayaks. There was not much published material available on the expectations of an inflatable sea kayak.

For example Audrey Sutherland has captured many of her experiences in her book, *Paddling Hawai'i* (1998). She has experienced a lot of criticism about her inflatables but she travels the world with her inflatable by slipping her arms through the straps on the duffel bag. She is completely aware of the logistical problems and cost of shipping a hardshell boat to the many locations where she travels. Sutherland considers inflatables also to be safer than hardshells and feels their benefits in the light weight, enabling her to paddle solo and still manage the boat during mooring. After corresponding with her and reading some of her book I was fortunate also to meet her in person.

From Sutherland's book and other small amounts of literature a basic list of consumer needs was developed for the expedition inflatable sea kayak:
Portable, easy to carry, easy to transport, lightweight, stable in the waves, safe and durable, easy to paddle, fast and able to carry gear.
Confirmation of these needs was collated from the project team's personal experience, manufacturers and sea kayak paddlers. Opinions were assessed to ensure that the interpretation of the needs from the literature correctly associated the needs of paddlers with actual kayak characteristics.

From personal experience:

I spent time sea kayaking in the Abel Tasman national park during April 2000 for five days on a tour with Abel Tasman Kayaks in Marahau. The time allowed interaction and participation with other paddlers to gain feedback from their experiences. While sea kayaking, it was not necessary to be particularly fast, but to have a kayak that moved easily through the water was beneficial as after 8 hours paddling, paddlers' muscles do get tired. It was a time spent enjoying the scenery rather than trying to get from one location to the next as quickly as possible. One of the inconveniences I experienced was trying to pack and unpack luggage through small deck hatches on the kayaks. Small hatches meant that the storage space was difficult to access and the space could not be used very efficiently.

Extensive time in the kayak also meant that comfort from the seat and in particular from the backrest was paramount. We were fortunate that we had calm weather for most of the journey, but the kayaks always appeared stable no matter what the external conditions. Every person in our group had previous paddling experience so stability on flat water was not a high requirement. Feedback from others in the group was mainly the need to have rudders and fittings that worked effectively, were reliable, and that could be easily worked from the cockpit by the paddler. When one of the rudders was not working, the effort needed to keep the kayak on course increased dramatically.

From manufacturers:

John Booth, the managing Director at Incept, considered that lightweight and portability were the most important features required of an inflatable. He noted that without being lightweight and portable an inflatable kayak would lose most of its advantages over a hardshell kayak. Another type of boat that had similar benefits in terms of the portability aspect of an inflatable kayak was the folding kayak. Folding kayaks could also be folded down to create a more portable boat. The main brand of folding boats identified was Klepper from Germany. The folding kayaks tended to be slightly heavier than inflatables, and did not fold down to be as small as an inflatable kayak.

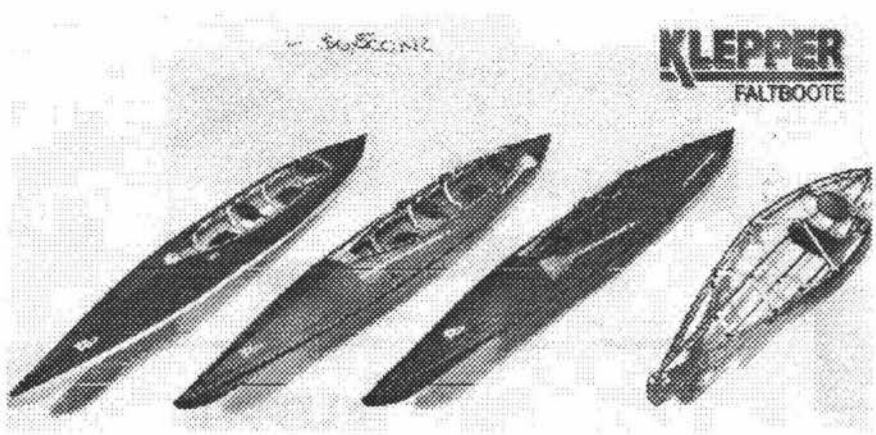


Figure 14 - Klepper folding Kayaks (Klepper Faltboote product brochure from Auckland Canoe centre, Auckland)

From the different sources of raw data, the data could be interpreted in terms of customer needs and this was done in a needs tree analysis (Refer to section 9.7). From the needs tree each customer requirement could be organised into a hierarchy and listed in terms of the importance of each need, based on the frequency that it was mentioned and the interpreted emphasis placed on it. This list could then be evaluated and analysed and would form the basis of the metric list in reaching the specifications for the sea kayak.

From experienced paddlers:

Incept had pre-established contact with a very experienced inflatable sea kayaker, already mentioned in this research, Audrey Sutherland from Hawai'i. When Incept initially had the concept for a sea kayak, contact was made with Sutherland. Sutherland has paddled over 10,000 miles in sea kayaks since 1967 and has written several books including *Paddling Hawai'i*. She had vast experience in over 12 different models of inflatable kayak, including the Incept prototype and was always on the look out for a faster boat. It was understood that Sutherland was considered by the kayaking fraternity to be one of the most experienced inflatable kayak paddlers in the world, especially in the area of sea kayak expeditions. Sutherland had also spoken at a number of sea kayaking symposiums in the United States.

The encounter with Sutherland was invaluable. After consultation, it was decided that the kayak project team would try and resolve some of the problems that Sutherland experienced with her current boats. She wanted a kayak that was lighter and more compact then her existing boat and designed as a touring and expedition sea kayak to be used by a highly experienced paddler, rather than as a recreation or sport boat. Sutherland wanted a fast boat that was designed to carry a large amount of bulky gear. She also wanted a rudder and a proper deck included in the design of the kayak. Many companies do not currently offer these features.

During her visit, the project team was able to see Sutherland's favourite boat, the Semperit. The Semperit is no longer manufactured, but is best suited to the expeditioning that she undertakes. It is a stable kayak that has an open deck, which can be packed with gear. Sutherland has made a deck for it as well as assembling a basic rudder system on the stern. We were able to get a fairly clear idea of this craft and its limitations and were able to use this as a benchmark for improvements in design.

An inflatable kayak is light enough to be carried around as hand luggage if necessary and can be loaded into the boot of a car or tucked away as cabin luggage on an aeroplane. In *Paddling Hawai'i* (1998) Sutherland states, "A boat that weighs less than 30 pounds opens up the world of kayaking to women going solo" (p.9). [Although it is not recommended people paddle on their own], she goes on to say that this is important as the light weight of the inflatable allows women to carry the kayak on their own whereas many kayaks are difficult to carry even with two people. Sutherland appreciates the convenience of a kayak that she can put in a duffel bag, and take on a plane. Small aircraft are the only transport to some of the remote islands that she enjoys exploring around Hawai'i. Sutherland considers that people inclined to kayak would relish the chance to be able to take their own kayak with them as they explore the world with a kayak as small and portable as this (Sutherland, 1998).

The team found that due to Sutherland's knowledge and experience she also had many associates in the arena of inflatable kayaks. This was good as many of her personal opinions reflected and included thoughts from other people of similar interest levels as enthusiasts of inflatable sea kayaking.

Another group of people considered for their expertise in the area although not experienced with inflatable sea kayaks, were retailers and commercial operators for sea kayaks. Greg Boyd of Rotorua has had experience with inflatable craft, mainly on rivers but now catered for sea kayak expeditions.

Peter Sommerhalder of Auckland Canoe Centre, retailed sea kayaks and also enjoyed paddling sea kayaks. Some of Sommerhalder's experiences included the use of folding kayaks. This was useful in identifying the benefits of folding kayaks and seeing where they sat in a competition sense as they had similar benefits to those of an inflatable kayak.

I was also able to talk to a few manufacturers of sea kayaks, and it was interesting to note that most of those communicated with had very limited perceptions of inflatable kayaks. One reaction recorded by Sutherland when she was showing her boat to someone who was an advocate of hardshell boats was "He looked at my boat, snarled something about a sluggish rubber boat, took it out to sea, put it through all of his technical manoeuvres, and came back muttering, 'Surprisingly responsive'" (Sutherland, 1998, p.11).

With the customer needs assessed we thought we had a fair understanding of what the paddler wanted. We now sought products that were already on the market, which we could use for competitive comparison and as benchmark products. With the list of metrics, competitive kayaks could be identified with similar characteristics and these could be used as competitive comparisons. These kayaks were identified from the investigation of existing boats. Many of the other kayaks also aided in concept generation for different qualities that were required for sea kayaks.

The continuing concepts for such an inflatable kayak included a small compact boat that could be used for expedition type trips, portable to an international level and, therefore, being of minimum cost to take when travelling by air. A kayak was required that was durable, would withstand ocean conditions, and that was stable in open waters, relating to a high secondary stability. Greater speed than that offered by current kayaks was considered a great benefit. Overall, there was a need to produce an inflatable kayak that was designed for the above conditions, thus avoiding the inconvenience of adapting existing boats for the purpose.

The three kayaks that closest resembled the qualities that we were looking to develop were the following:

- The Semperit (Sutherland's current boat)
- The Sage (Incept inflatable whitewater sport kayak, K30), for its advancements in inflatable design
- A basic hardshell, such as the Penguin by Quality Kayaks.

The Incept K40 was identified to be in direct market competition to large mass produced inflatable kayaks such as Aire, who produce a range of inflatable kayaks of a high quality. Incept would have the product advantage of an inflatable kayak that was designed especially for a specific market and used as a touring and expeditions sea kayak with a high handmade component.

3.3.2 Confirm Specification

Sutherland typifies the niche market and with her many expeditions has identified areas where she personally would like to see a product to fulfil her needs. Most of the inflatable kayaks available aim towards recreational paddling for families. But the enthusiast, such as Sutherland, wants to see a product that can withstand the pressures of expeditions. A comfortable sea kayak with reasonable performance characteristics, which is safe in rough weather and can carry the gear required for trips' lasting beyond a week was required.

4 TECHNICAL DEVELOPMENT

The technical development covered the practical information needed to design a technical product such as an inflatable sea kayak that could not be covered in the literature review alone. It was moving from paper to practical, using the results and information found in the initial investigation and market research to develop the technical aspects of a physical product before making a prototype.

The following section focuses on the design and development considerations for individual characteristics or components including the following:

1. Pressure requirements to maintain rigidity and structural strength
2. Bow shape
3. Air chambers
4. Floor construction
5. Rudder and fittings.

4.1 STRUCTURAL STRENGTH

It was important that the kayak did not collapse in the middle when loaded, especially when bridging between two waves. Using basic strength and bending equations it was found that an inflatable would need a certain air pressure to resist collapse when only simply supported with point loads, such support would be expected to be relatively common during sea kayaking for brief moments at a time.

With the help of the project supervisors at Massey University, I worked out the loading on a singular circular tube, representing one of the sections that would form the sides of the kayak, with a diameter 150mm.

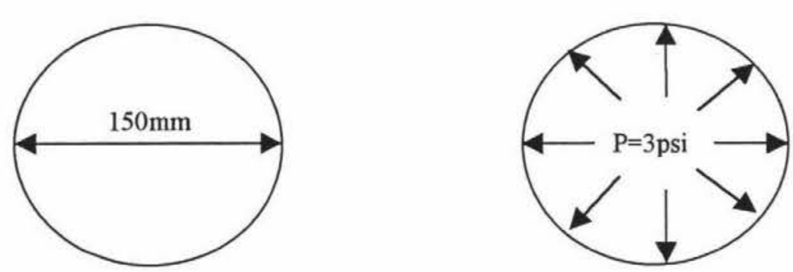


Figure 15 - Pressure inside circular tube

It was found that over a length of 4 meters the air pressure required to maintain rigidity was 3PSI with a central load of 100kgs (Refer to section 9.9 for equations and explanations).

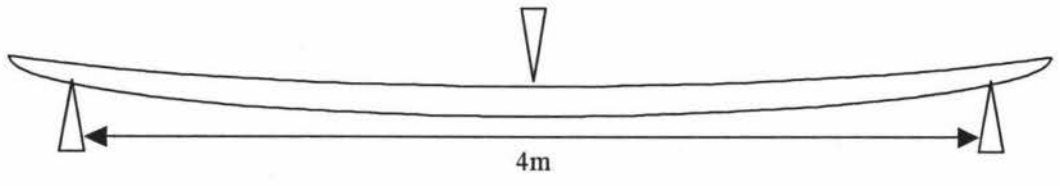


Figure 16 - Loading over a 4 meter length

4.2 BOW SHAPE

The bow shape was important. It was the first thing met in the approach of a wave and the bow shape would effect how the kayak reacted to the wave. The hull approach should be an acute V to slice through oncoming waves. Some fullness in width should be retained near the bow if possible as a high volume bow would tend to rise over the wave to give the paddler a drier ride and would plunge less. An excessively high bow would cause problems with windage, as it would be the first thing to catch the wind. An extremely fine and narrow bow would cause the kayak to plunge into the waves and thus submerge the fore end and throw spray over the paddler.

Sharp angles cannot be created in an inflatable because "compressed air always forces circular surfaces" (J. Booth, 6 April, 1993, personal communication). So in coming up to the bow the circular sections used, had to be reduced and narrowed. I-Beams (Refer to section 5.1 for full explanation of I-Beams) were used at the bow and stern to reduce the beam of the kayak. The angle of the floor became more acute as it rose into the side tubes and allowed the floor and sides to come together. As the tubes came together they started to compete for space as they were inflated and pushed against each other to make the bow section relatively rigid.

4.3 AIR CHAMBERS

There were three main air chambers in the body of the inflatable sea kayak. These were the two individual sides and the floor. Each air chamber of the kayak was constructed separately. Each air chamber needed to have a valve where it could be pumped up and deflated. The valves were imported and worked with a spring and seal for closure and a turn, lock, open mechanism. The valves were screwed on to the fabric as a male/female pair, with a seal around the edge of the fabric.

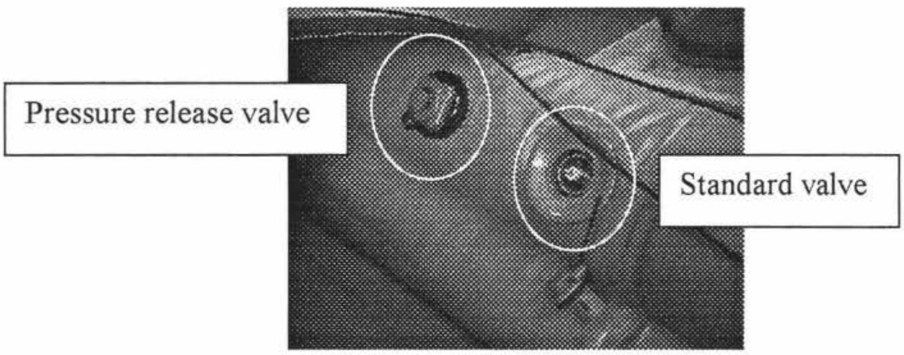


Figure 17 - Valves used on inflatable sea kayak.

As the materials and construction methods would only contain a certain air pressure, relief valves were inserted that operated if the inner tube pressure exceeded a predetermined pressure. The pressure release valves reduced the likelihood of I-Beams popping as they were almost always going to release before the outside seams. For the sea kayak the pressure was 3PSI. It was not uncommon for I-Beams to rupture under increased pressure, particularly if left in the sun, because, the air pressure rose inside the tube as the air temperature increased. All the air chambers were lined around the seal edge with "V tape" maintaining the air tightness of the sections. The V tape reinforced the outer seam and also released tension on the edge of the weld by increasing the surface area that was pulling away.

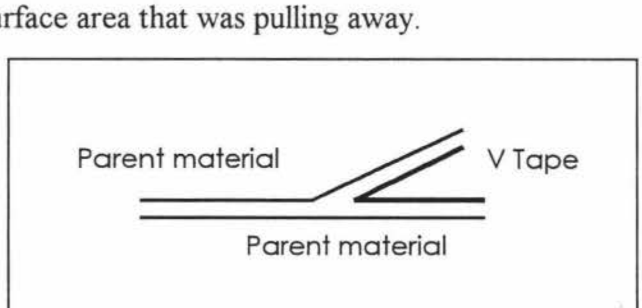


Figure 18 - Seal edge lined with V tape.

4.4 FLOOR CONSTRUCTION

The floor construction dictated the shape to which the sides bent once they were joined. There were two main types of inflatable floors constructed at Incept (refer to section 5.3). Both floors were constructed using a series of I-Beams, to form an air mattress type shape. The two forms were "self-bailing" and "closed". A self-bailing floor is commonly used in whitewater rafts where a lot of water is expected to enter the raft and allows it to exit typically via holes around the perimeter of the floor, which is raised above the holes. This will be referred to as a "self-bailing cap and base" configuration. The other type of self-bailing floor is that used in some K30 editions. A "duck bill" is used on a closed floor that allows water to drain during forward motion. The "duck bill" folds up on the underside of the floor not allowing more water to enter, but when water is inside the kayak the pressure allows the "duck bill" to open and release water. A self-bailing floor is particularly useful in a boat without a deck and could be considered for an open deck sea kayak.

The closed floor did not allow water to drain, but a covered kayak would not be expected to acquire excessive amounts of water unless after a capsize, where a hand bailer could be used. The floor was typically made with the base and cap made from the same pattern making it symmetrical. This type of floor normally sat lower than the sides of the kayak.

With I-Beams being the main component of the floor shape, I-Beam construction was important.

4.5 RUDDER AND FITTINGS

Because the advantage of the inflatable was its ability to be deflated and compacted for transportation and storage, it was important that fittings and accessories such as the rudder could also be detached from the body of the kayak. Most of the smaller fittings made from PVC, once positioned, could be welded on to the body of the air chamber before being closed up. These kinds of fittings included brackets and beckets for ropes.

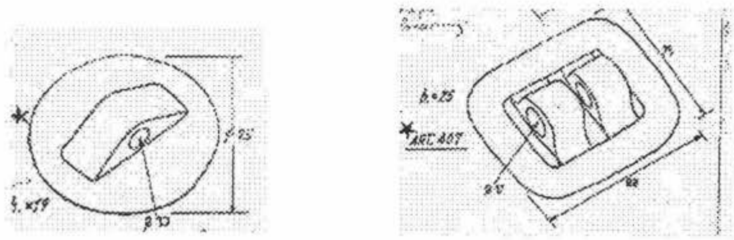


Figure 19 - Rope Beckets (From Scoprega product sheet, Italy)

Other fittings for the inflatable sea kayak such as D-rings and beckets were chosen from those currently in use on other boats manufactured by Incept. These fittings were usually imported, with long lead times. The project team tried to utilise fittings already available at Incept so there was no pressure to confirm these decisions early in the project. Beckets were also used to attach the rudder, to the stern of the kayak. The stern closure (where the two sides meet at the stern to close the kayak) needed to form a platform for the beckets to be secured.

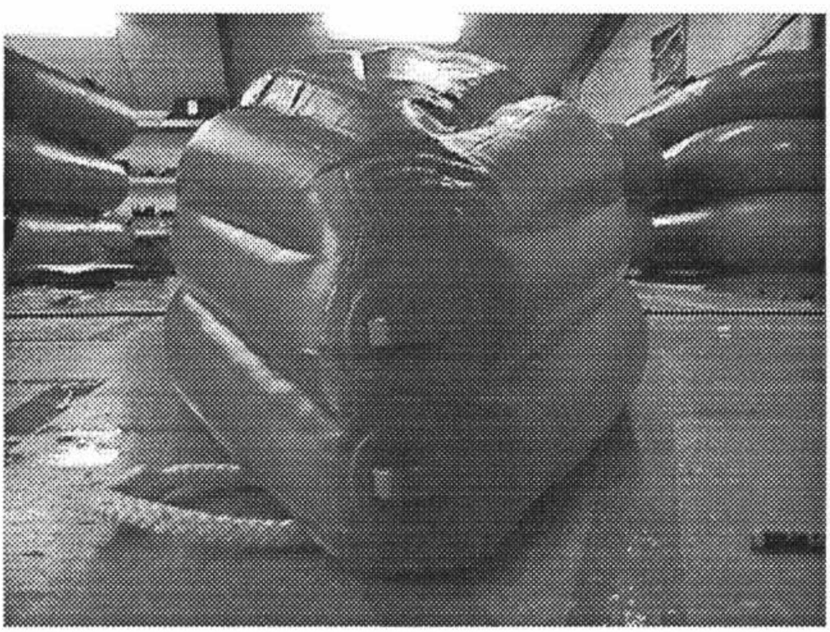


Figure 20 - Stern closure with beckets for rudder to be attached

John Dobbe from Nelson, New Zealand is an experienced kayak paddler as well as a designer of kayaks and rudders. Trying to design a rudder would have been a separate project in itself, so we used Dobbe's expertise and used a prefabricated rudder. Dobbe visited Incept during the project to look over our concept and discuss options for using the rudders that he had already designed. The rudder is used primarily on hardshell kayaks and has varying sizes for single and double kayaks. He liked the concept of an inflatable sea kayak and also commented on areas for attention. He advised that to be most effective the rudder should sit on an angle between 7 and 15° to the vertical as it entered the water. This angle was meant to enhance the efficiency of the rudder in steering and minimise the drag. Therefore, an angle could be incorporated into the stern closure by the pattern where the sides came together for closure, having an angle cut away.

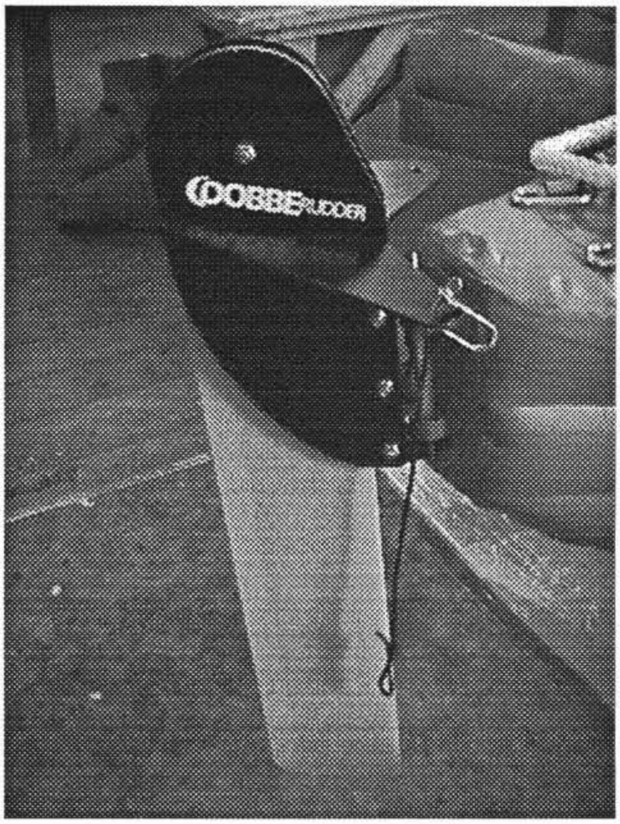


Figure 21 - Dobbe rudder mounted on kayak

For the initial prototypes we used the rudder Dobbe normally used on double kayaks. The rudder was to be fitted on to two permanent beckets that would be glued on to the stern closure (refer to Figure 20). Our main concern with the Dobbe rudders was their 1.32kg of weight and their size as they were not made to be disassembled. However, Dobbe was willing to work with us in this area for development so we agreed to use the basic design on these prototypes. The two obvious ways to make the rudder lighter were to use lighter materials and also to decrease the amount of materials used. The way an inflatable sea kayak was constructed it was unlikely that the blade needed to be as long as his standard rudder and instead of the fully formed wings a rotating rod could be used to change direction.

Once we had a rudder to work with, we had to develop the system for pulling the rudder up and down to get it into position and also for pulling the left/right action controlled by the paddler. Also the platform and attachment system needed to be developed.

The rudder was not intended to be disassembled and was already fitted with a 6mm diameter screw pin that attached through a moulding on a hardshell kayak. We located two large rubber beckets that could be glued on to the stern platform, in order to locate the pin in the right place. The rudder needed to be removable to minimise the size of the kayak when folded. The only problem was that the pin was secured by way of screwing and was difficult to assemble without entangling the operating cords. It was concluded that the pin would, therefore, need to be a slotted pin (rather than "screwed") in order to ease the assembling and disassembling of the rudder.

When setting it up and trying to pull the rudder up and down, the stern section (where the side tubes join) flexed considerably, as pressure was applied to the rudder. It was suggested that a solid insert be used to strengthen the stern. This suggestion was not used in making the original prototypes. The rudder was also very difficult to operate due to the force required to take it from the extreme resting positions (either in the water or resting on the deck) through the complete arc. Although, with lubrication from the water this was expected to get easier, it was not acceptable for current use. We felt it was important that while the rudder locked into place, which was a current feature in many hardshell kayaks, it must be easy to use and reliable.

5 INITIAL DESIGN

With a basic understanding of sea kayaks and the market requirements now achieved it was time to put all the information together and look at designing a finished product (Refer to section 10 for sketches and concept designs).

The design brief specified that the design should be an inflatable sea kayak that was used for touring and expeditions by experienced paddlers. The following table shows the minimum and maximum recommendations for the width, length and depth of the kayak:

Parameter	Minimum dimension	Maximum dimension
Beam inner	320mm	508mm
Beam outer	380mm	780mm
Length	4000mm	4800mm
Depth	250mm	400mm

Table 6 - Recommendations for inflatable kayak design.

The task was to incorporate the design specifications with the manufacturing methods and technical development that would produce the kayak that was identified earlier. The large task of designing a sea kayak can be broken up into smaller more manageable sub-tasks, for development and understanding. The design implications of each part will become evident as part of the process.

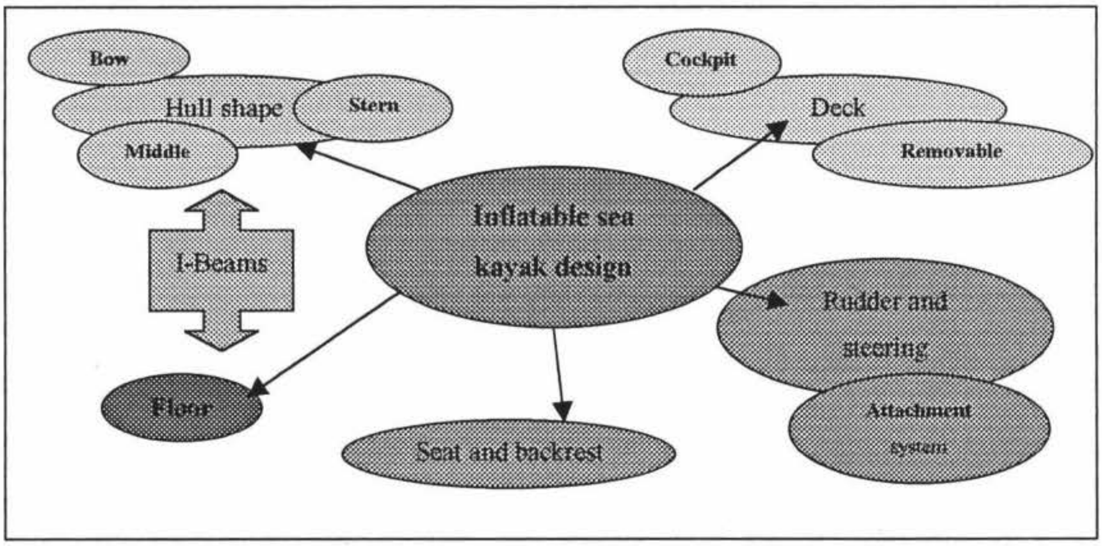


Figure 22 - Sub tasks for development.

One of the areas that I felt required particular attention in the initial design was the tube layout in the kayak. There were three sections where the tube layout was important and should be considered:

1. The side tubes
2. The floor plan
3. The bow join.

The following section will look at the influence and interaction of tubes. Tubes were the vital component of the kayak shape. It was important to look at how they affected the performance of the kayak. Before considering the hull and side tubes as separate units, it is necessary to discuss I-Beams because of their influence on design, as they form the shape of the tube sections.

5.1 I-BEAMS

My personal observation at Incept Marine Ltd (Incept) highlighted that I-Beams were used in the construction of many small inflatable craft and were an essential element to inflatable kayaks. I-beams could help where the tube sections needed to be narrow in places in order for the kayak to function in the desired manner. The I-Beams helped to create shape in the kayak. They were primarily used on floors in rafts but could be used in side tubes. An advantage of I-Beams was that they did not have to run the full length of the parent tube. An I-Beam was a material partition in the main tube that reduced the diameter of a section while maintaining the height, appearing to make it essentially into two smaller interlocking tubes. For example, if the required height on the side of a kayak was 150mm, but the maximum width of the side was only 75mm, then the I-Beam could be constructed in the middle of the tube, forming two smaller tubes on top of each other.

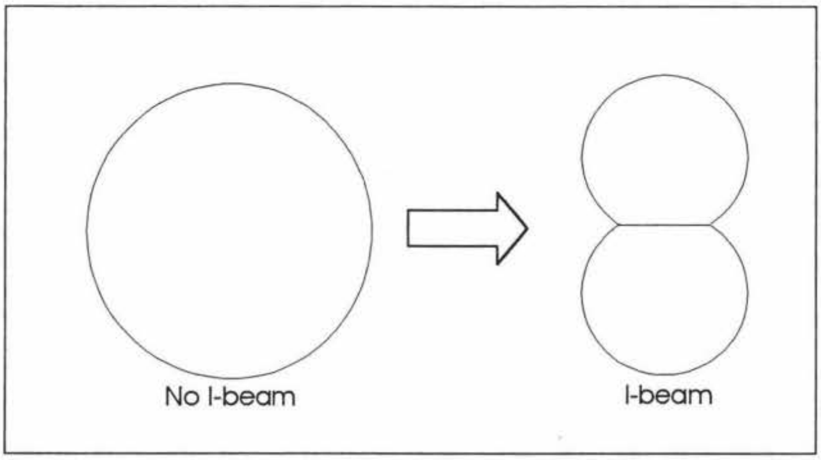


Figure 23 - The use of an I-beam

I-Beams are so named because when inside the tube they form an "I" shape once adhered to the outside material. In Figure 24 below, A and B show the different pieces of material that form the I-Beam. As can be seen the material causes the body of the tube to be restricted in movement forming a second tubular section and, by the way the piece is welded, an "I" is formed.

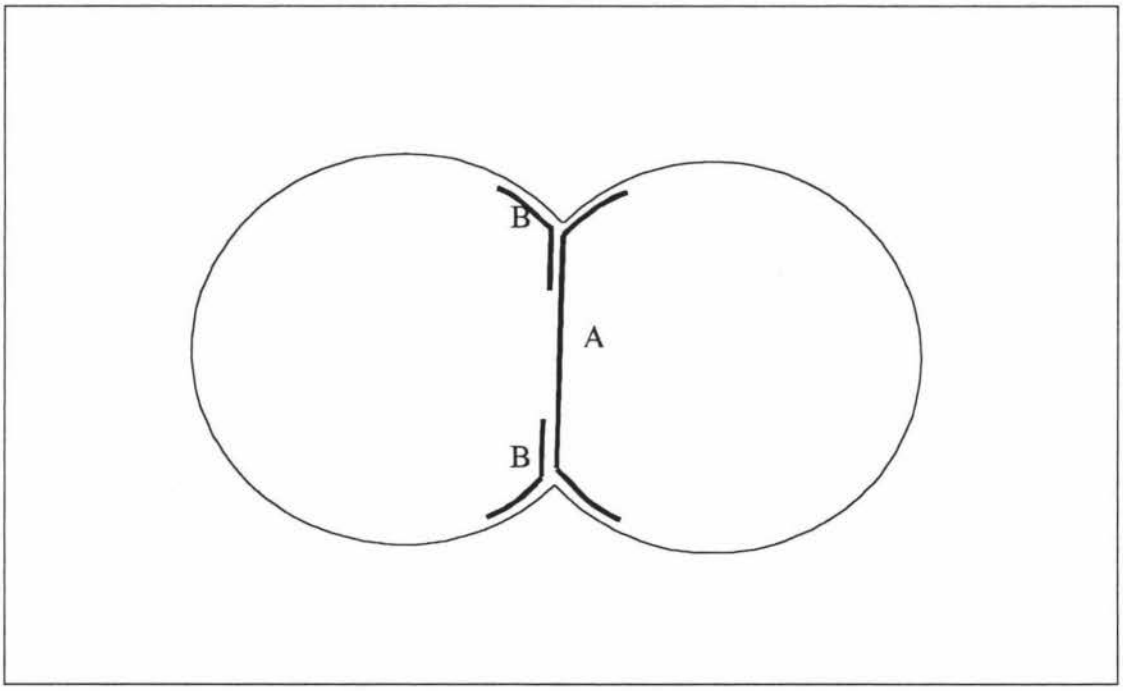


Figure 24 - I-Beam illustration inside the tube.

At Incept I-Beams were made from green PVC/polyester cloth that could be welded on to the body material. The green cloth had white tape sewn on to it that had one side with PVC on it. The white tape was folded in half and then sewn down each side 25mm from the edge of the green cloth. This tape formed the I-Beam with the body material once it was all welded together. The inside of the white tape did not bond together as it was just a polyester weave. The I-Beams had to be strong in order to withstand the pressures inside the tubes themselves and, therefore, construction was important. In other boats where I-Beams were used, it was observed that the I-Beams in the floor were often the first places to fail, rather than the outer material. Initially this may have been seen negatively but it was better for an internal I-beam to fail because the boat would remain buoyant as it maintained its air tightness even though a large inflated section would appear.

As the I-beams were not purposed to have an air tight seal, industrial sewing machines were able to join the pieces of fabric together. The sewing was meant as a temporary measure to fix the V tape in the correct place so that it could be welded to form a permanent bond to the outer fabric. The problem with sewing was that it put small holes in the material. These holes weakened the overall strength of the I-beams. It could be seen when repairs came in, particularly where I-beams had burst in floors, that the material weakening caused by needle holes on the I-beams resulted in weakening bonds in the end weld.

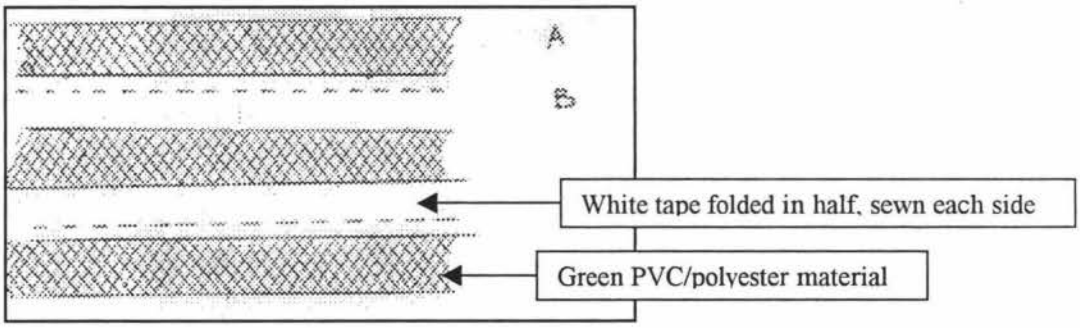


Figure 25 - Sketch of I-Beam during construction

This sketch shows a basic I-beam as it is sewn together and still lies flat before being welded into the tube. The I-beams were formed from a width of material cut on the bias to allow longitudinal stretch (note the weave is indicated on the diagonal). White webbing coated on one side with PVC was folded in half and sewn on to the bias cut material to form the V tape. The V tape was sewn on to the main piece of material before welding in order to hold it in place. When the I-beam was welded on to the tube the V tape was also welded on to the bias material simultaneously. The reason the I-beam needed to stretch was that the I-beam had to be held tight when it was welded to the body of the kayak to reduce the distortion of the tube. The welding tools available at Incept allowed for the width of the V tape being 25mm wide as well as a 25mm weld on the I-beam material when being fixed on to the body of the kayak. The weld was this width to reach the right strength of the parent material to the welded material. If the width of the weld were less, then the ability of the tube to withstand pressure was compromised. To allow for the welds with a 50mm tool for either side, the I-beam had to be a minimum of 100mm. Although tools could have been made to reduce this width, the weld made would lose strength and the I-beam may not have withstood the pressures to which the tube was inflated.

More than one I-beam could be placed in a section and a flatter unit would have been produced, suitable for the floor of a boat. Below is a sketch of a cross-section of a panel that has four I-beams inside. This would be similar in shape to a standard floor. The floor in the K40 was expected to have at least four I-beams in it, allowing for the centre tube to act as a keel line to maintain tracking for the kayak. Using I-beams of different lengths and positions in the tubes allowed for the boat to take different shapes. It was often the I-beams and their placement that decided the form of the boat.

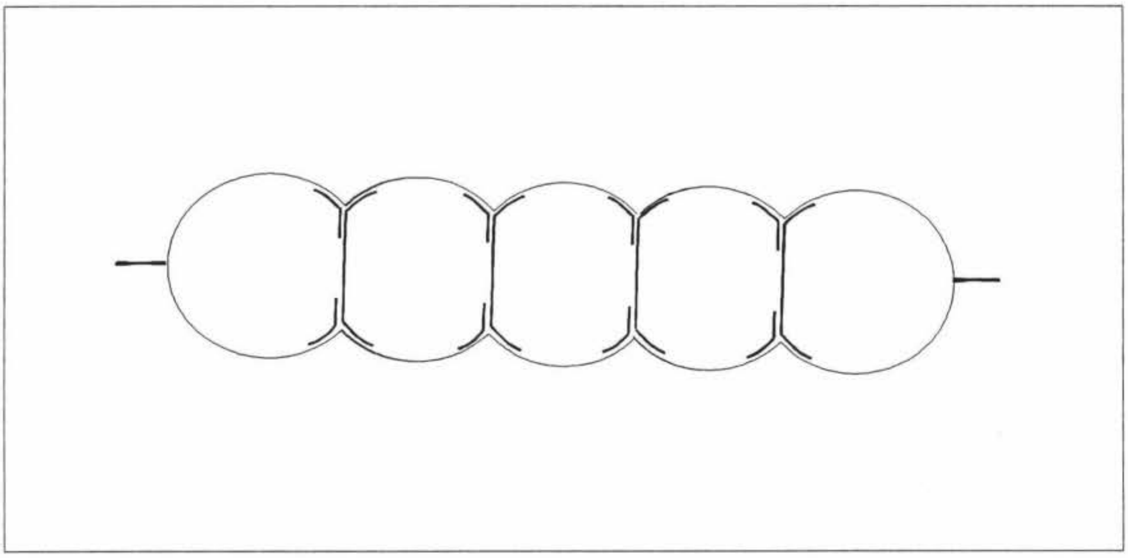


Figure 26 - I-beams in series creating a mattress effect.

On one particular occasion during the project, while using one of the K30 boats on a trip, we experienced the effect of a burst I-beam due to an increase in pressure inside the tube and the I-beam not being able to hold to this pressure.

In the K30 whitewater kayak, the side tube had a pod that ran part way down the tube in the region of the cockpit. A short I-Beam that ran past the area of the cockpit formed the pod.

With any inflatable boat that is made from material with a base cloth that restricts inflation, the pressure must not rise above certain levels that the material and joined materials can not hold together. The first obvious way to increase pressure is to add more air, the second is to increase the temperature. Usually an inflatable boat is surrounded by cool water to maintain a constant temperature, with the ambient temperature of the water counteracting the temperature from a hot sun for example.

During this particular trip we stopped for lunch, something not uncommon on long trips. As we were sitting on the bank of the river enjoying the heat of the sun, we heard a loud noise similar to that of a shotgun being fired. We thought little of it being out in the middle of the farming Rangitikei district. As we finished lunch and headed back to the boats we realised that we had not released the air pressure in our boats. The K30 no longer had a cockpit but an over-enlarged tube taking over half the seat. Luckily, there was room in one of the rafts so we could continue the trip without worry but the K30 needed some work before it could be back on the water.

Everyone on that trip was aware of the problems associated with pressure in the tubes and the effect that the heat from the sun would have in increasing pressure inside the tubes, even over a relatively short period of time. In this case it did not take very long for the sun to raise the temperature and, therefore, the pressure inside the tubes of the kayak without water temperature to balance it out. In this case, the pressure was greater than the strength and bond of the material used in the kayak. This trip illustrated that even when people are fully aware of the effects of increasing pressure this is still a likely scenario. This had to be considered no matter how experienced the user of inflatable boats was expected to be. Already identified with other boats, it was agreed that in the final sea kayak this situation was also a likely scenario. To combat such problems pressure relief valves could be used as discussed earlier.

5.2 SIDE TUBES

The side tubes were important in determining the shape of the kayak. The side beams were directly related to the beam inside and outside the kayak. They also determined the cockpit area and volume of the kayak. Having close fitting side tubes would help the paddler control the kayak for stability, as the paddler would have more contact points with the kayak. Externally the side tubes determined the boat width and therefore the paddle reach. As determined from the market research it was established that the inner beam should be at least 380mm and the outer beam suggested was 660mm. These measurements were not technically possible because the minimum tube diameter was 150mm, immediately adding 300mm on to the internal beam. So with the inner beam at 380mm, the outer beam would be at least 680mm, unless the tube widths could be lessened or the inner beam reduced. However, the inner beam was initially determined by the width of the floor section as side tubes were created as individual straight units that conformed to the shape of the floor.

The diameter and number of tubes also determined the height of the freeboard. For example, one large tube with a diameter of 250mm could have been used. If the inner beam was 380mm then the outer beam would be 880mm and the free board would be 250mm assuming the tube was completely out of the water. If two smaller tubes of 150mm were used and the inner beam was still 380mm, then the outer beam would be 680mm and the freeboard would be 300mm.

Sutherland suggested a minimum freeboard of nine inches (228mm), this was to keep the paddler away from the water, but 300mm was also considered as a maximum to keep the windage low. The height of the tubes would also affect a number of performance features for the paddler. For instance, the volume inside the kayak, the comfort of paddlers, whether they could rest their arms on the sides or whether it was too cramped, and the distance the paddler had to reach in order to make a paddle stroke would all depend on the height of the tubes, combined with the height of the seat.

It was important to determine the placement of the side tubes and how they fitted together with the floor. They could sit at various angles on the main body tube. Figure

27 shows arrangements of the main side tube with a pod (a smaller tube created using an I-Beam as in Figure 23 but only running part way down the length of the main tube) and the first section of a possible floor. A pod was used for the K30 to increase the height around the cockpit where the spray skirt attached. It was thought that volume would be created on the K40 with a pod section rather than two conjoint tubes. Although not vastly different in construction methods, the pod could be a smaller diameter over a shorter distance because it was possible to weld the section inside-out and then turn it back the right way after welding. This exercise assumed that one of the tube sections would be significantly smaller than the other and the other small section would represent the joining of the floor.

The exercise was to develop creative ideas on the placement of I-Beams in creating the side tubes. Some of the placements such as numbers 1, 2 & 9 in Figure 27, clearly looked impractical in trying to create the desired kayak, but allowed for further idea generation. For creative alternatives, numbers 1, 2 & 3 also in Figure 27 suggested that the main side tubes could be in contact with the water creating a catamaran style kayak with a floor raised up within the sides.

After this exercise it was noted that it was not necessary to have a pod as such, but a section could be created from two tubes of the same size. If one tube could be smaller why not even make the lower tube smaller than the top? This would increase the inner beam at the lowest part, where the paddler's hips and buttocks would be expected to sit. The beam would narrow slightly towards the deck with the larger tube on top. The upper tube would then be slightly closer to the paddler and increase the surface area of the kayak with which the paddler is in contact. This also would enhance stability. This concept was not accepted by the whole project team and was not considered further in prototyping.

With the use of I-Beams, tubes could be manipulated to have diminishing diameters. This was particularly useful when creating a narrow or narrowing section. The bow or stern were areas where a wedge shape and narrowing would be beneficial as the kayak entered the water. The sides (although not having a great effect on the drag of the kayak) were involved with the hull as it first came into contact with the water at the bow.

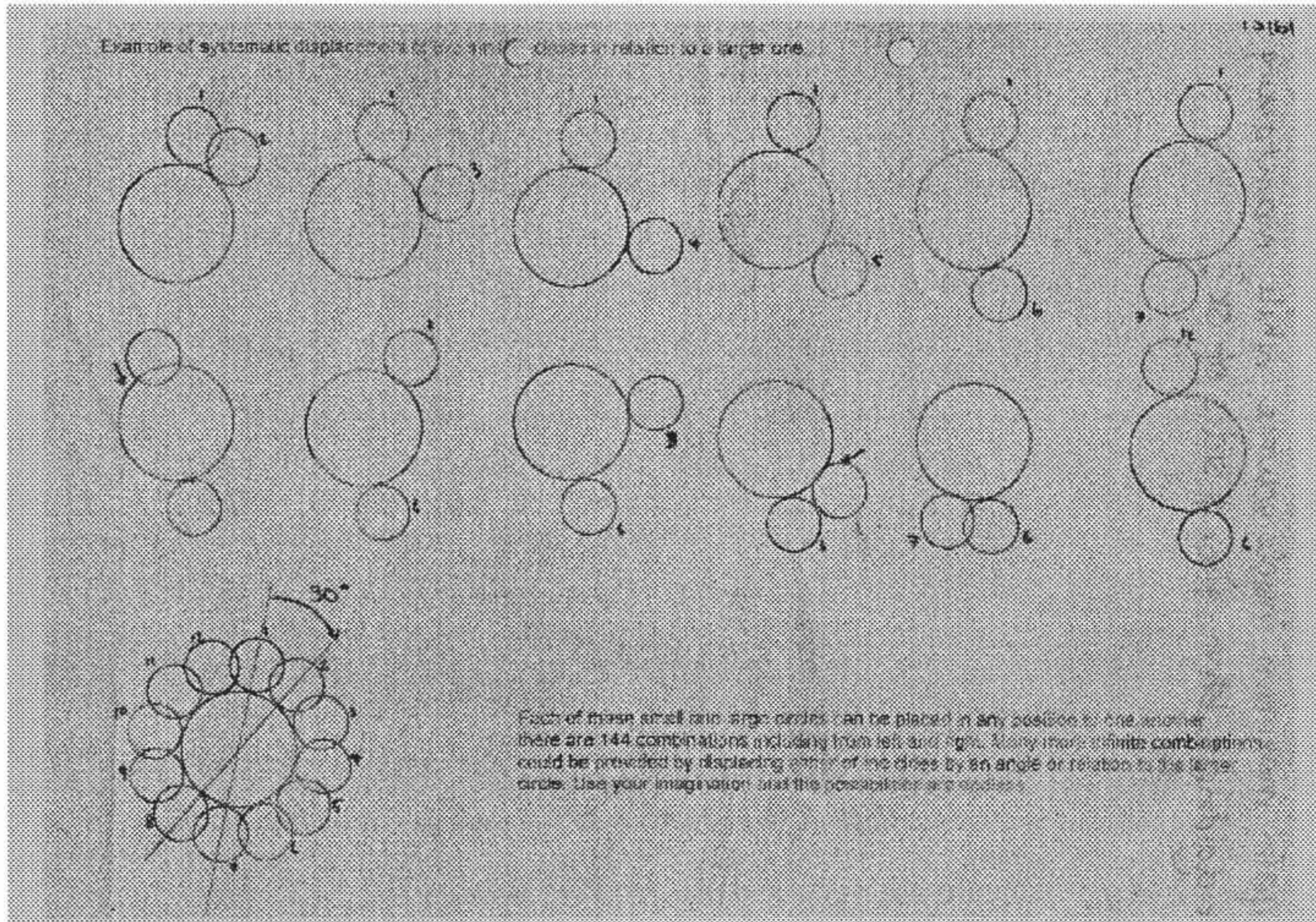


Figure 27 - Side tube with pod attachments (also refer to section 10.1)

It was identified that the pod effect had little significance on the performance of the kayak, but this meant that the project team could not stay within the parameters set. In order to keep the beam to a minimum and maintain the longitudinal strength the side tubes needed to have a diameter of no less than 150mm. This was not only for the strength factor but also for ease of manufacture. If the tubes were smaller than 150mm in diameter then the tools would not fit in the tube and could not be made by efficient methods such as HF welding. A single tube of this diameter would not be appropriate. There would not be enough internal volume and the paddler would not have enough protection from the elements. The internal volume if low, especially in the bow, would create difficulty for the kayak to rise over waves.

The pod concept used on the K30 could be utilised and used along the whole length of the kayak. In order to create shape, the size of the pod could be increased or decreased and placed above or below the main tube for different affects. By determining the main tube diameter, calculations could be completed to determine the required internal pressure of the tubes to resist bending under the influence of a 100kg load (Refer to section 9.9 for strength calculations). This was also one of the specifications identified at the commencement of the project requiring that the kayak would resist bending under a 100kg load. A tube with a diameter of 150mm could resist bending under the influence of a 100kg load if the pressure inside the tubes was at least 3PSI.

In order to get the tube shapes there were two ways to pattern the tubes. For a symmetrical tube the pattern could be made out of a single piece of material, but in order to give the tubes three dimensional curves the tube had to be dissected into two pieces enabling the pattern to be unfolded flat. This was very difficult to pattern. For ease of manufacturing the tubes could be made symmetrical and made from one piece of material. The sideways curvature to bring the tubes together could then be created from the floor shape as it pulls the tubes inward. The project team decided to use a symmetrical pattern and use the shape of the floor to dictate the bend in the side tubes for the K40.

5.3 HULL SHAPE AND FLOOR LAYOUT

The hull shape was important to the overall performance. Not only was the outer shape of the floor important but also the individual tube layout within the hull. The hull could be made in several ways but as one of the specifications was the minimal size of the kayak when deflated there was little advantage in investigating solid hull materials as they would increase the size of the transportable package beyond what was beneficial for this type of product. The inflatable hull had, therefore, to be created from inflated sections and the shape determined by the placement of I-beams.

There were two types of inflatable floor used at Incept for various boats. There was the standard floor which was formed by a series of I-beams and inflated with one valve. The floor sat below or partly inside the sides. The cap and base pattern were usually the same.

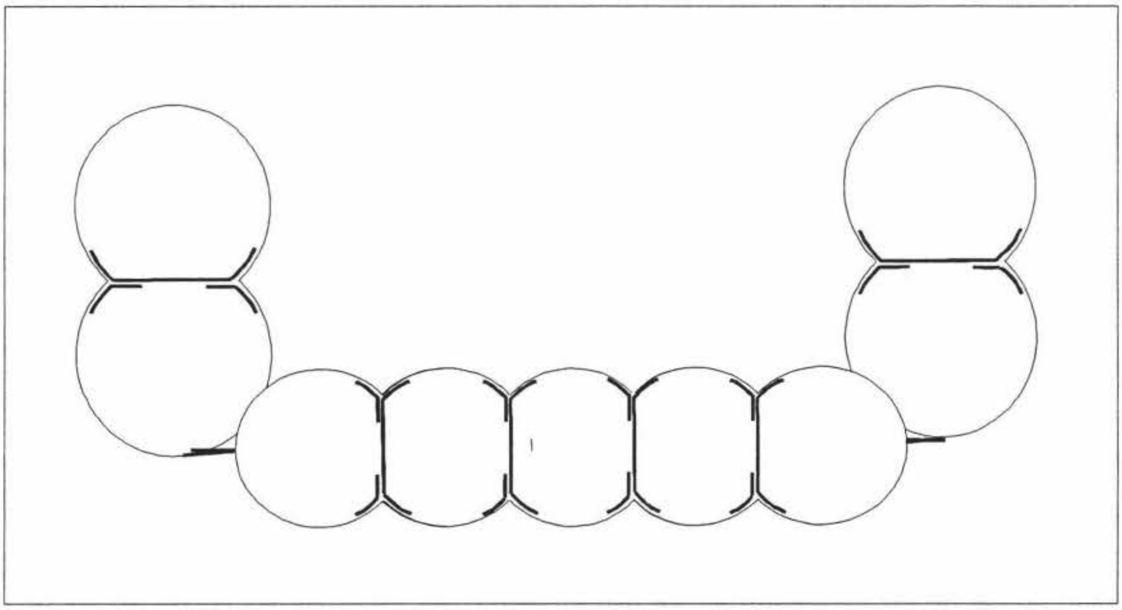


Figure 28 - Sketch of standard floor with side tubes.

The other type of floor was a self-bailing floor. The self-bailing floor allowed water to flow out from the boat. This was important if the boat took a lot of water on board, such as could occur when a whitewater raft was swamped. The cap and base patterns were different with the cap allowing it to sit over the base and be inflated upwards. The base then had holes punched around the perimeter, beyond where the cap had been joined and from where the water could drain. This type of floor tended to sit inside the side tubes, as they were formed to curve as independent pieces and, therefore, kept the floor rigid. The sides dictated the shape of the boat in this case.

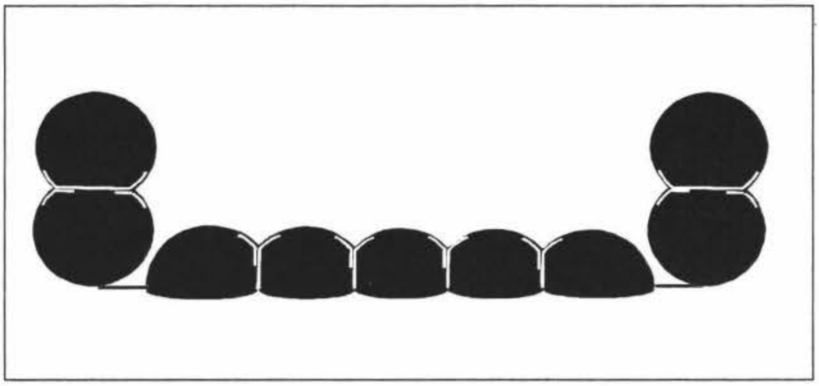


Figure 29 - Sketch of self-bailing floor.

The hull shape affects the stability of the kayak due to the cross-sections along the kayak. As discussed in earlier chapters a flat floor will be stable on flat water but not in waves, just as although a round hull is faster, it is more difficult to keep upright. We needed a compromise. The floor could have different cross-sectional shapes at different places along the hull. With the construction of an inflatable floor we needed to determine ways to produce a floor that varied along the length and, preferably, was slightly curved. It will be noted that both sketches illustrating general floor types typically produce flat hull shapes.

How the I-Beams were then positioned inside the floor cap and base could determine the shape of the hull and stability factors. One of the concepts I examined included placing the I-Beams on various angles inside the cap and base pressuring the floor to bend.

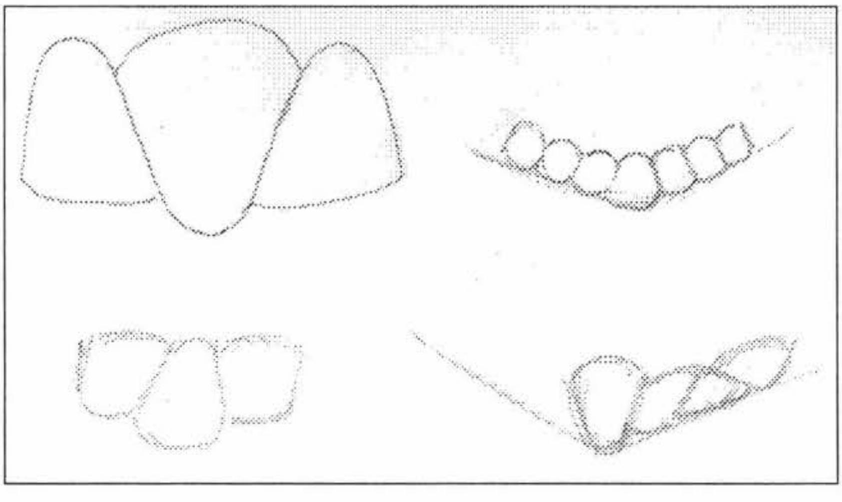


Figure 30 - I-beam sketches for floor shape.

This placement did not work as initially anticipated. Inflated objects always form circular shapes and, with unequal pressure due to different shapes, the floor created odd shapes.

Another concept we examined was to use I-Beams of different widths and placed at different widths apart according to the tube required at that position.

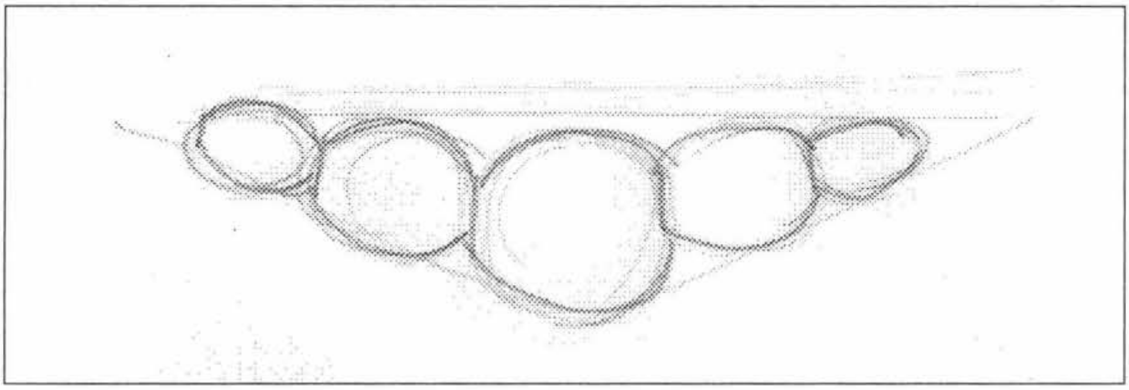


Figure 31 - Sketch of floor with different length I-beams.

In order to create a flat cap where the paddler would sit, the pattern needed to be adjusted, meaning that the cap and base would not be symmetrical. In this case the floor could be made similar to the pattern of the self-bailing floor but without holes for water drainage. Without the holes in the floor, inflated tubes could still sit directly alongside the side tubes. The floor would be inflated downwards in the opposite direction to the self-bailing floor, allowing the sides to still sit above the floor.

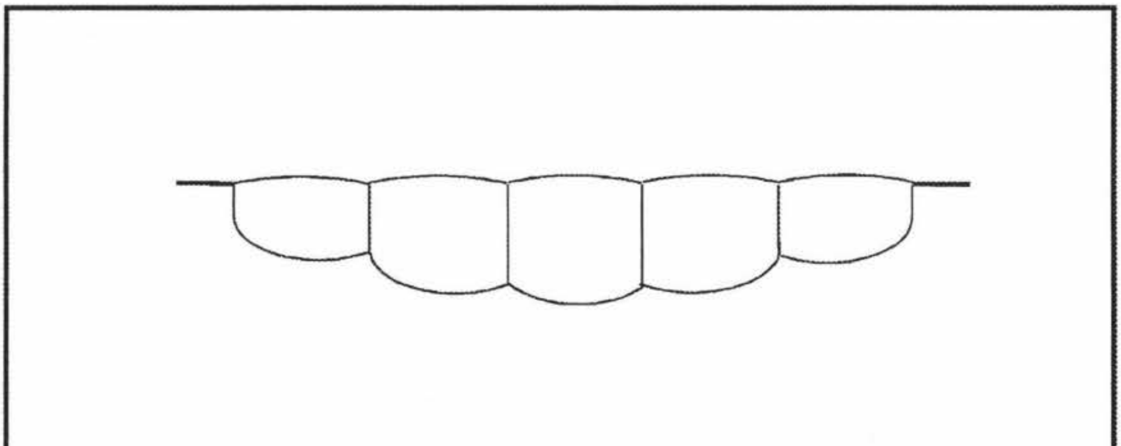


Figure 32 - Floor with distinctive cap and base inflated downwards.

The hull shape also affected the ability of the kayak to track efficiently with more of a V shape. The largest factor in the natural tracking tendencies of a boat is the keel line. This is the centre of the hull running longitudinally along the boat. To create the keel line an inflatable or solid keel could be inserted. The formation of a V shaped hull means that the centre baffle acts similarly to an inserted keel. The direction of the floor cells also resists the water currents running across the direction the kayak is going. The possibility of adding a solid keel to the hull was, therefore, considered. For example, when the kayak was inflated a fibreglass keel could have been inserted via a pocket on the centre baffle. However, the advantages of this were quickly outweighed by the cost and additional weight added to the kayak.

Not only was the hull shape important for performance but also the floor shape would determine the overall shape and appearance of the kayak. With the side tubes being straight the floor dictated the bend in the sides as it pulled the sides to join according to the plan of the floor. So the angles of the floor and the graduation of the floor were very important to the outcome of the overall shape.

The side tubes had a lot of effect on the width of the kayak and, therefore, the reach of the paddler. The following diagram (Figure 33) shows the different widths and sections possible for the side tubes and their affect on the beam of the kayak (Refer to section 10.4 for a clearer diagram). It was clear from observation that the greater number of tubes that the side consisted of, the smaller the beam of the kayak. Although the smaller beam was beneficial it had its downfalls. The tube not only had less longitudinal strength or rigidity to resist bending (which was one of the initial requirements of the sea kayak) but it had less resistance to twisting.

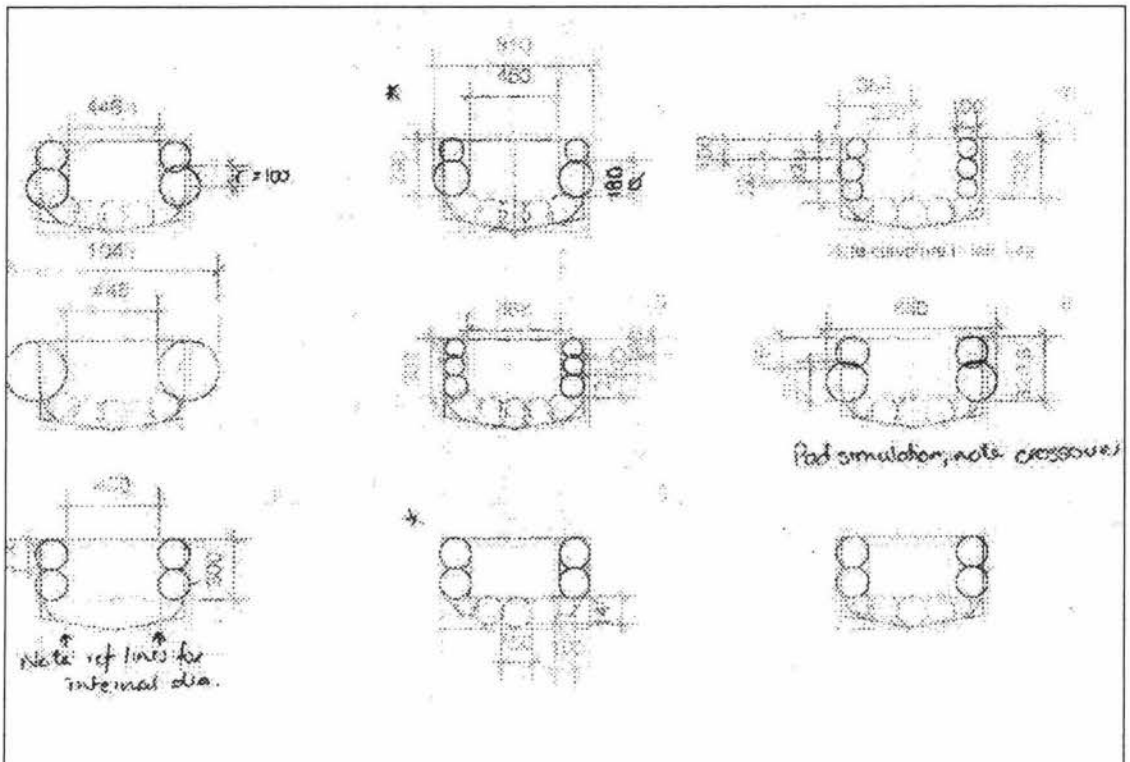


Figure 33 - Various master sections

5.4 BOW SHAPE AND CLOSURE

Construction of the bow was also very important. The bow is the first part of the kayak that contacts oncoming water. How the bow responds to the water and waves impacts on the overall performance of a kayak. A high volume in the bow helps to lift the bow over waves rather than ploughing through them, which can hinder speed. The bow brings the sides together and determines how the rest of the kayak reacts to oncoming waves, whether it rises over top of them or ploughs through them.

Another area of attention was the bow-closure, due to its obvious position and influence over the aesthetic appeal of the kayak. The Semperit used a wooden prow over the two side panels that pulled either side together. The shape of the Semperit prow was considered blunt but it was thought that the wood could be shaped more smoothly over the diminishing tubes.

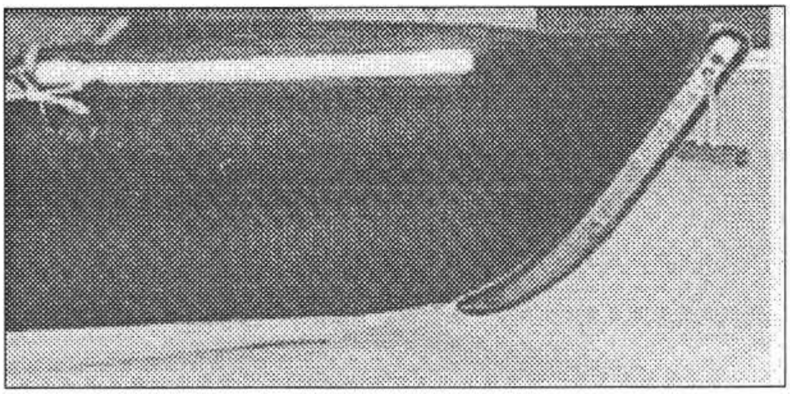


Figure 34 - Side view of Semperit wooden prow.

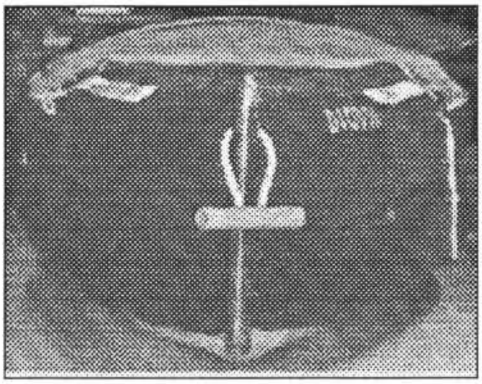


Figure 35 - Front view of Semperit wooden prow.

Another idea was to form a prow section to graduate the finish as the sides came together; it would be solid and would enhance the aesthetics as it flowed into the body of the kayak. A disadvantage of having a large solid prow section was that the volume when deflated would increase and make it difficult to fold up.

Ideally we would be able to form the prow without using any extra materials or pieces, other than flaps existing on the side tubes. However, as Incept already used a nose cone as a standard part for other products including the K30, John Booth also wanted to use this on the K40. The two side tubes came together to form the basis of the prow with the cone used purely at the top to tidy up and solidify the front. The solid cone at the front was ideal for protection when exploring around rocks. It was also meant to reduce lateral twist between the side tubes.

To best fit over the side tubes as they came together, the nose cone, that was initially circular, was heated and squashed so that it would fit over the shape of the side tubes as they came together. The nose cone used was most similar in shape to 'D' in Figure 36.

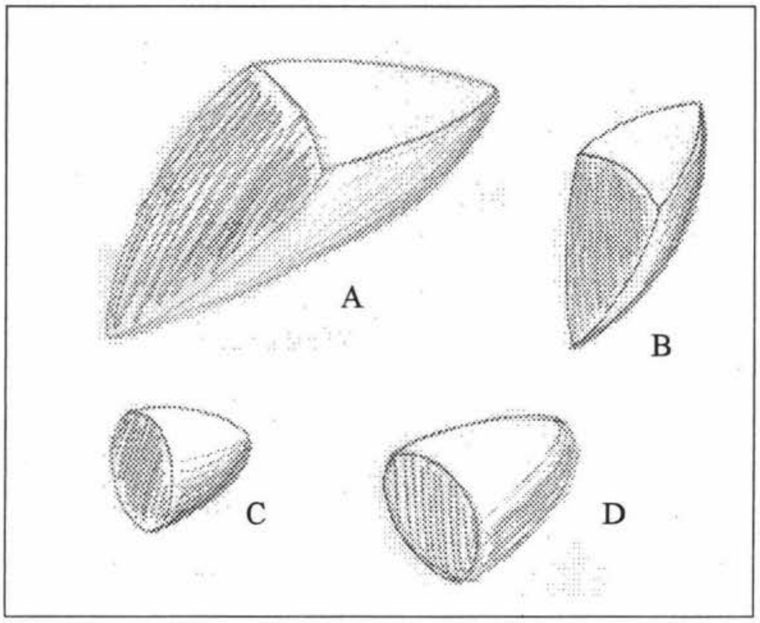


Figure 36 - Sketches of moulded prow forms.

The nose cones were used in the final prototypes and due to the expertise of people at Incept having used them before we were able to squash them and get a really clean finish on the nose of the prototype kayaks.

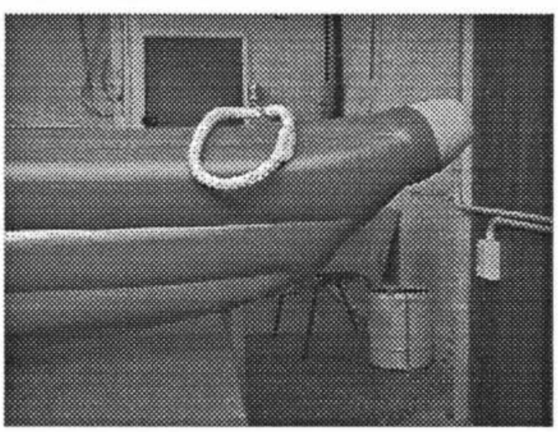


Figure 37 - Fitted nose cone on final prototype.

6 PROTOTYPING AND DETAILED DESIGN

This area of the project was mainly practical; the information had been gathered and now was the time to try and turn it into something tangible. As with most development projects there were iterations of prototyping. The purpose was to identify the improvements and needed developments during this time. Prototyping puts all the elements of the product together and the manufacturing and cost issues can be evaluated if necessary, while ensuring that the product is what the consumer wants.

The subject of this chapter is prototype iteration from the first attempt at a sea kayak to the final working prototype that was used for consumer testing.

6.1 PROTOTYPE 1 (P1)

6.1.1 Objectives

- To look at the actual shape of the design of the inflatable sea kayak and to ensure that the interdependence between tube sections resulted in the desired outcome.
- To help understand the manufacturing processes, patterning and assembly issues for the inflatable sea kayak.
- To identify areas for development.

6.1.2 Development

Using the basis of the Semperit kayak that Audrey Sutherland had brought to New Zealand, the project team developed the initial prototype (P1). P1 was basically a duplicate of this boat using the dimensions and measurements taken when it was available. Sutherland's ideal specifications for a sea kayak are as follows. The team felt that most of these features could be improved upon.

Parameter	Imperial measure	Converted to metric
Length	14'	4.27m
Beam ext/int	26"/20"	660/508
Freeboard	9"	228mm
Weight	25lbs	11.3kg

Table 7 - Sutherland's specifications for an inflatable sea kayak.

The two beams stated above could not be produced as the minimum tube diameter had already been stated at 150mm; therefore, the difference between the internal and external beam had to be at least 300mm.

Sutherland also wanted the kayak to be able to carry bulky gear. She claimed that the Semperit was already satisfactory in this area because she was able to load up above the actual freeboard with the removable deck she had fabricated herself to fit her Semperit. Therefore, it was adjustable according to the amount of gear that she took on a trip. Sutherland and Booth (20 April, 2000, personal communication) commented that because the kayak was an inflatable the weight of the gear was not as important as the volume of gear that the kayak needed to cope with. Most hardshell kayaks have a large capacity for storage but the space is difficult to utilise due to small hatches. Packing of large bulky gear in a kayak needs to be carefully balanced out to avoid raising the centre of gravity of the kayak and making the kayak easy to capsize.

Along with these ideas, there were other areas that were identified for development:

- The floor had to flow upwards toward the bow in a more progressive manner in order to reduce drag. This initially led to a faster kayak by reducing drag; however, it also reduced the waterline length and therefore limited the maximum speed.
- The prow needed to be finer at the entry point. The prow is the furthermost portion of the bow that cuts through the water and first comes in contact with the waves. The more gradual the angle that the bow has in reaching the prow the less resistance there is in parting the oncoming water.

The whole design needed to be simple and cheap to manufacture. At this stage the expected market quantities did not justify new tools being made. Therefore, it was most desirable that all prototypes and preferably final products be made using existing tools. This limited the curves and arcs used in manufacture on the HF welders particularly in the bow and shape of the floor, where numerous smaller welds had to be used to create a curve effect.

For the floor a basic symmetrical shape was used with the cap and base being cut from the same shape. This was easier for patterning and it was not until the detail was added, such as valve placement, that the distinction was made between the cap and the base. Having them symmetrical meant that the floor had no natural rocker, so was completely flat before being attached to the sides. The end hull shape when inflated, however, did have some rocker from the side tubes that pulled the floor upwards to its seams.

The sides were straight, when seen as an independent unit, but the shape of the floor dictated the bend in the tubes when they were inflated. Using the interdependence of the sections to dictate the shape made the overall manufacture much easier than trying to make curved tubes, and avoided twisting. It was not until the sides and floor were put together that the final shape could really be seen as they did interact together.

The sections of P1 were constructed and assembled according to the general manufacturing techniques used with other boats at Incept and the manufacturing methods outlined in section 2.1 Manufacturing Techniques.

6.1.3 Evaluation

P1 was never fully completed. It was easy to make, quick and, therefore, cheap. The basic structure was good but there were many areas of detail that needed a lot of work. But as soon as the sections were constructed, areas for improvement were identified:

General Parameters:

Figure 38 - Inside P1

• The length was 3900mm when inflated; this was less than the specification of 4.27m.

• The inner beam was 320mm at the widest point. According to anthropometric data this was too narrow to cater for any of the populations considered to be using the kayak and was below Sutherland's specification of 508mm.

Bow and stern design:

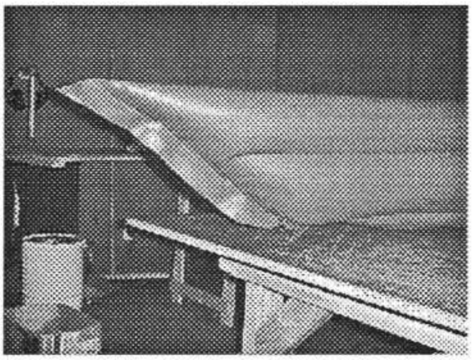


Figure 39 - Bow P1

• The angle of the bow looked correct but it was difficult to get the floor up into the bow, sealing the three sections neatly.

• Large flaps were created where the side tubes joined at the bow. These would need to be incorporated into the closure.

• The bow needed a greater taper. This could be achieved by graduating the side beams. As the side tubes were not in the water this would not effect the drag, only the windage.

• The stern needed to have better flow lines where the floor joined with the flaps from the side tubes.

Side tubes:

• The top and bottom of the side tubes needed tapering so that where they joined was the same height as the general diameter of the tubes, rather than creating a duckbill effect.

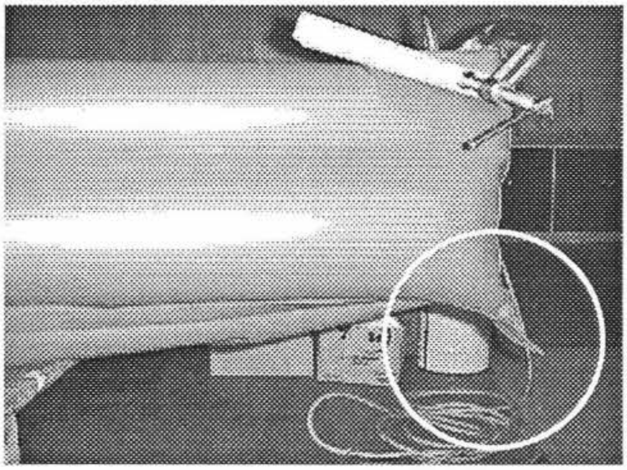


Figure 40 - Protruding duck bill at stern of P1

- The side tubes tended to crease at different places when inflated due to the pressure created where the floor pulled them inwards. This led to an unsymmetrical shape of the kayak and this would probably favour one side in the water.
- There was little point in having a smaller tube on the top unless it was to increase the height. The present body-contact was only with the lower tube, causing the top tube to be pushed out on a diagonal, increasing the outer beam and therefore paddle reach. The possible benefits of having a smaller tube under the top tube include the following:
    - Increased width at position of hips
    - Increased gear storage
    - Reduced overall beam
    - Tightened body position and greater contact with the kayak for greater stability and control.

Floor and hull section:

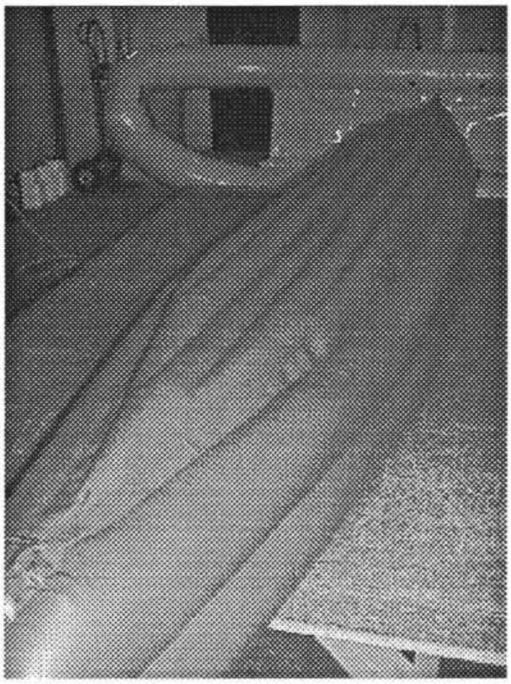


Figure 41 - Floor P1

- The floor in P1 was flat. We needed to create a curve or V shape in the hull to enhance the kayaks secondary stability. The centre baffle section could be made larger and this would allow it to sit lower in the water.

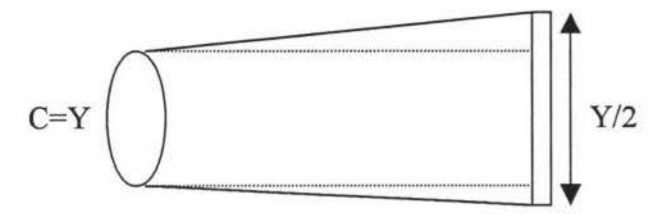
Detail:

- It was difficult when closing the sections, and welding the tubes, to line up the sides or pieces of material. Registration marks had been put on by hand but were on the wrong side of the materail. Registration marks were needed on both sides of the material, on the inside when rotationally thermo welding, on the outside when HF welding, and for joining the floor and the sides together for symmetry of sides. Consideration needed to be given also whether stretching would occur during thermo welding through the rotational welder, as high tensions would be placed on pieces.
- Initial placement of the valves made the kayak difficult to inflate, particularly with the compressed air. In order to get up to pressure, initially the kayak was inflated to 4PSI to test seals (this is common practise after welding).

From P1 there were a number of small changes that could be simulated using only a section of the entire kayak. Producing a full prototype was very costly in both materials and labour. To prototype a smaller section of the kayak was definitely a better way to develop different ideas.

6.1.4 Modification 1 – smoothing out top area of stern:

The objective of the first modification was to eliminate the protruding edge created when the end of the section was closed, as the length of the close related to the surface area and needed to be closer in length to the diameter of the tube.



Ideally the tube diameter and the flat would be the same height indicated by the dotted line.

Figure 42 - Trying to remove the duckbill effect at the stern.

When joining side tubes together at the stern we found there was a need to eliminate the sharp edge that protruded (duckbill – refer to Figure 40). To help reduce this, a pinch or tuck could be made to reduce the material height in the welded edge. Although the area might not have affected the performance of the kayak in the water, the height that it created could effect the amount of windage that the kayak experienced. It would also enhance the aesthetics of the kayak by creating smoother lines. It was decided that the best option was to cut a section out of the pattern and then re-weld it back together using flat tape (Refer to section 11.2 for the modification of the pattern).

For economical reasons, in order to simulate the modification in physical form rather than re-producing an entire side, a one-meter section of the tube was simulated. A section was cut 75mm deep and 900mm long from the top of the side tube. Flat tape was then used to weld the two edges back together. The extra material added in the joining of the edges had created additional issues in closing the section because of the many layers of material. The weld of the flat tape, therefore, had to stop before the edge. The wedge cut went part way to solving the initial problem of the height of the closure of the weld.

6.1.5 Modification 2 – Addition of an I-Beam

The objective of the second modification was to reduce the diameter of the side tubes as they approached the extremities of the kayak, particularly at the bow. This meant that instead of two cylinder sections there were three.

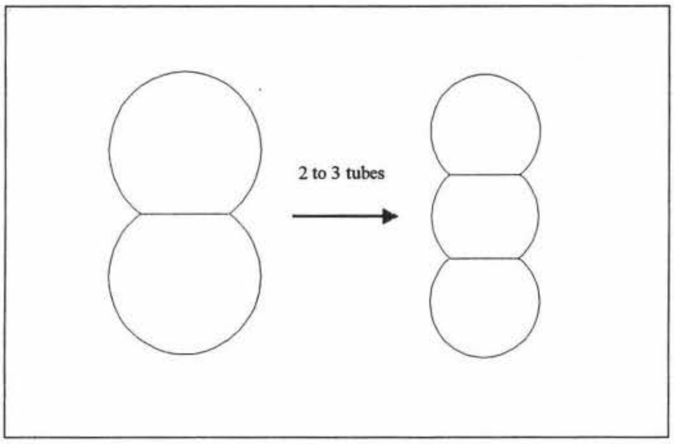


Figure 43 - Two tubes to three in the side tube.

As can be seen from the very simple diagram above, the overall width of the side tube was reduced and the height was increased, due to the overall perimeter being the same. To maintain the same height, a wedge as in modification 1 would be used. The other requirement was to taper the I-Beams to reduce the width as they reached the ends of the tube sections.

This modification was also simulated on a one-meter section of the side tube similar to that of modification 1.

The other change made to this section was to create an angle at the bottom edge of the side tube where it was closed by the HF welder. Trying to eliminate the crease that occurred in the side tube meant that the side tubes would have greater force on pulling up the floor into the side tubes, giving the hull greater rocker at the stern.

Both these modifications would be carried through to the next iteration of prototype.

6.2 PROTOTYPE 2 (P2)

With all the development areas identified in the first prototype there were many small changes to the pattern as well as the process in prototyping P2. The project team disagreed with regard to the need to increase the internal beam of the kayak and this was not continued through in this iteration. It was agreed to increase the length toward the specification of 4.2m.

6.2.1 Objectives

To get a complete shell prototype to start initial testing.

6.2.2 Development

The following is a list of areas that were modified from P1 to P2.

General Parameters

- We increased the overall length by 300mm. To do this we added to the mid section of the cockpit in the floor and side tube sections to increase the room in the cockpit and increase the overall length of the kayak.

Bow and stern design

- We cut down the side section at the stern as done in modification 1 to smooth out the closure of the stern.
- A second I-Beam was added at both bow and stern to reduce the diameter of tube sections as simulated in modification 2 of P1.
- One of the areas that leaked was the closure at the bow, particularly after the extra cut had been made to smooth the section out. In order to try and remedy this we used seal tape that allowed for extra material to be squeezed out of the closure while retaining a seal.
- The stern closure needed to close properly. It was in an untidy state and this made it difficult to form a seal.

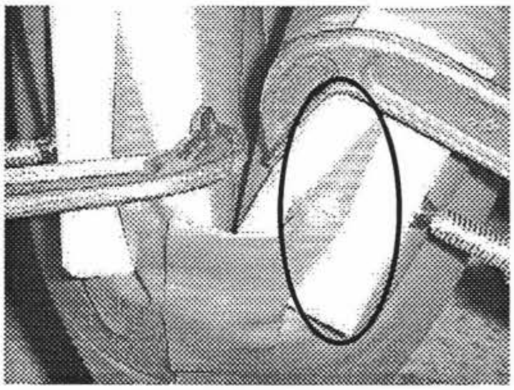


Figure 44 - Stern closure P2

The circle indicates extra seal tape that was used to compensate for the plastic lost in the seam during welding. The clamps were being used to hold the seam together after extra glue had been applied to try and keep the whole seam airtight. It was not successful.

Side tubes

- The side tube sections were made equal in size rather than one being larger than the other. Although this was still not what was intended from the initial design, it was an improvement on having the top section smaller because it slightly increased the internal beam.
- All the I-Beams were tapered at the end to deduce the diameter of the tube sections. In many cases the tapers had to be increased to enhance the effect that the I-Beams had on the width of the tube sections.

Floor and hull section

- We extended the stern floor section 50mm, to help the transition of the floor into the closure with the sides. The extra length was added from the middle of the floor where the shape of the floor was essentially parallel-sided.
- We extended the bow floor section 120mm, to help transition into the closure with the sides. Again, the extra length was added from the middle of the floor where the plan of the floor was essentially parallel-sided.
- The two inner I-beams in the floor were moved wider apart to try and create more keel on the hull.
- The floor shape was modified. The angle from the mid section to the ends was made more gradual and flowing, and made to suit tools available. We needed to make

the angle more gradual as it approached extremities, to reduce drag on the hull. A series of small electrodes were used to weld around the bend.

Detail

- The V tape that was used to form a seal and allow the inside of the tubes to open up properly on the inside, while increasing the strength of the sections also created problems. In order to get a proper opening, the position and cut of the V tape was important. Although a minor detail, the team found it was difficult to communicate the importance of this and, with several different people being involved with the sections, everyone did things differently.

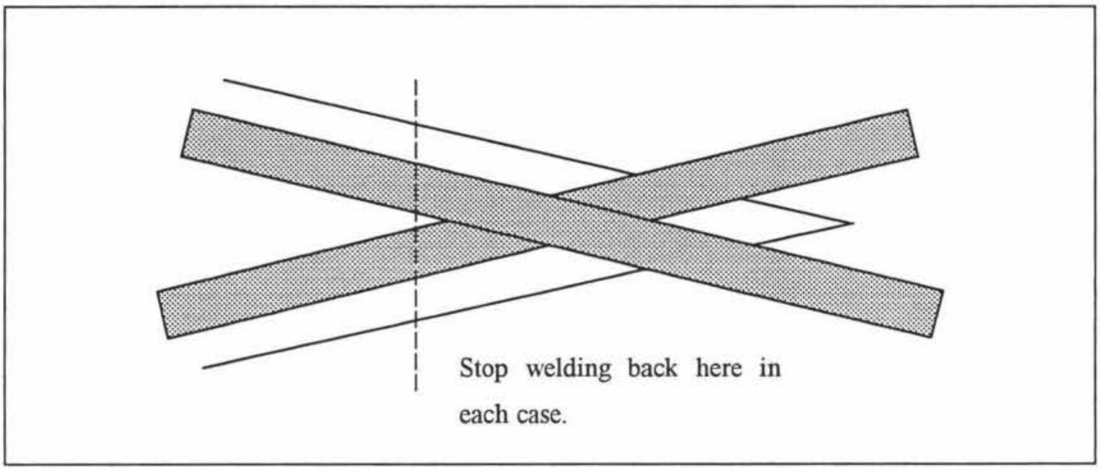


Figure 45 - Welding V tape to floor.

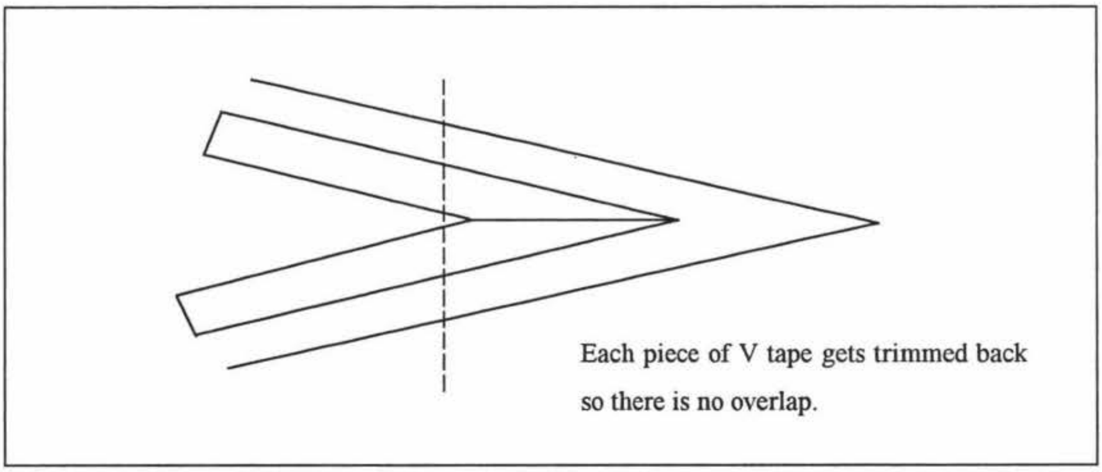


Figure 46 - Trimming the V tape on the floor.

Each side of the V tape was cut so that there was no overlap when it was welded. Once welded, the V tape allowed the cap and base to open up and form an inflated point in the floor.

- We added a deck. Although we were sure by this stage that the main deck would be removable, a good concept was to have a small permanent deck on either end of the kayak. Although small, the deck would help to maintain rigidity and reduce twisting around the longitudinal axis by forming a closed section. Refer to Figure 47 to see the types of permanent decks envisaged.

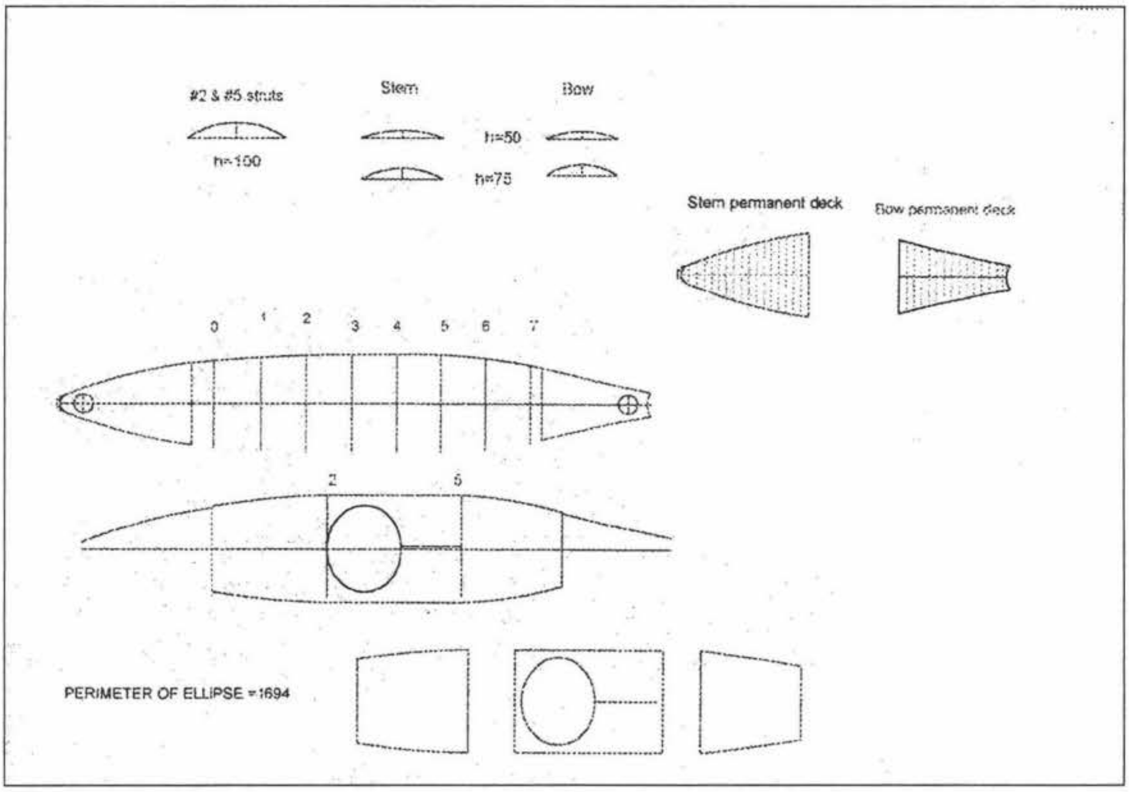


Figure 47 - Decks for prototypes generated using Vector works

Permanent decks could be put on in production and would help to protect and seal the paddler away from the waves. The removable main deck could be more easily attached to the permanent decks. Having the small decks would allow the paddler the option of using the main deck, as kayak rigidity would be primarily from the permanence of the bow and stern decks.

• Each tube required a valve to be used so that there was a point from which the tube could be inflated and deflated. Where the valves were attached, "donuts" had to be used:

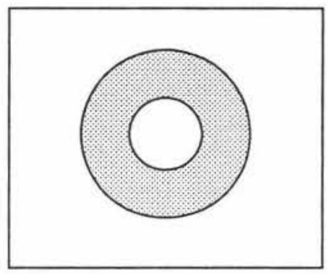


Figure 48 - Donut for valves.

Donuts are made from clear PVC and are welded onto parent material to maximise the seal around the valve and minimise leaks. They are a standard feature used under all valves on boats made by Incept. Problems arose when the sections where the I-Beams were placed were very narrow and the donuts then interfered with the I-Beams. It meant the donuts needed to be trimmed to fit in the small section available. This limited again the positions where the valves could be located because the I-Beams could not be welded effectively if the donuts were in the way, but the valves required the donuts in order to form a seal.

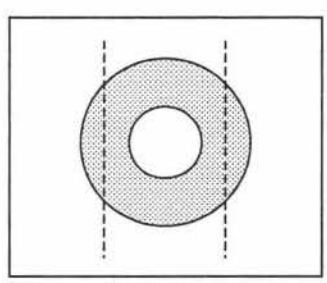


Figure 49 - Donut requiring trimming.

• We moved the valve positions forward towards the bow by one meter to ease the access to the valves. It was important that the valves did not get in the way but at the same time were accessible and easy to use. It would be counter productive to have the valves at the end where they could not be reached from the paddling position when the tubes were inflated.

• We generated registration marks from the computer patterns, eliminating human error and the inconvenience of drawing them on by hand. Using the computer ensured uniformity and precision of pattern pieces that were assembled.

6.2.3 Initial Evaluation

General Parameters

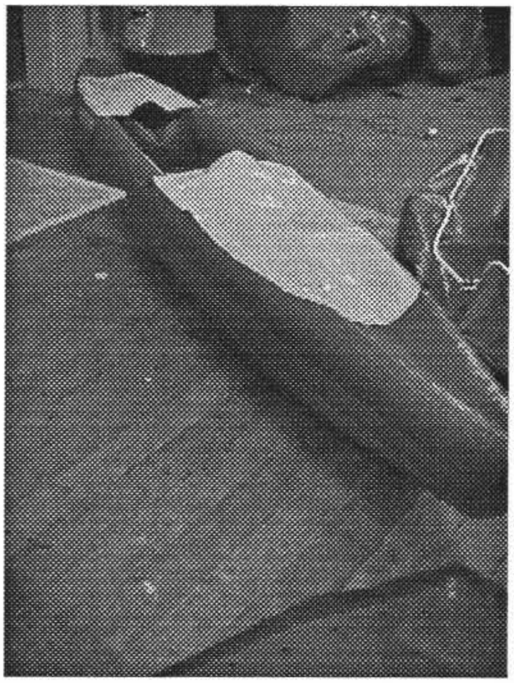


Figure 50 - A rough looking P2

Key dimensions of P2:

Overall length	4170mm
Width ext/int	630/330
Depth ext/int	370/240

• The extension of the length of the kayak was good. Aesthetically it looked more like a sea kayak. It allowed more room for a second paddler if necessary. Although further extension would continue to be preferable for a double sea kayak, the effect of the length on the performance and ability to maintain rigidity would be compromised too much. With increased length the kayak was expected to track better and have a higher potential speed, but at slower speeds the greater surface area meant an expected increase in drag over the kayak.

Bow and stern design

• The additional I-Beams at the bow and stern gave the sides a better shape.

- Cutting the lower corner of the side section at the stern put more shape in the end and helped eliminate the excess material hindering the closure. There was still more material than required which hindered our ability to make an easy closure with the floor.
- The seal tape helped the closure but it still leaked in the same place. The weave that was visible earlier was no longer seen. This particular problem would most likely be solved through trial and experience (refer to Figure 44).
- One of the continuing problems with this prototype was trying to get a satisfactory finish on the stern and bow closures where the three sections of the floor and sides met together. These details were essential, as rough lines would create extra drag.

Side tubes

- The tube sections of equal size gave more width in the cockpit, and showed an improvement over the top tube being smaller.
- Although the side tubes seemed to be bending inward more uniformly it would be preferable in the long run to have curved side tubes rather than straight. This would allow them to dictate the plan view of the kayak more than the floor, which was currently dictating the shape. Curved side tubes were more difficult to pattern and created more room for error, but creased less when inflated to a curve.
- The top side tubes tended to lean outwards especially when the paddler was larger than the beam and, therefore, put stress on the inside of the kayak. With the deck under tension it was expected that the top of the side tubes would pull in more.

Floor and hull section

- The small alteration of the floor baffles being made wider, appeared not to have made any difference. The plan was to make the middle baffle wider and create a keel from the enlarged section. It would still be good to get a greater keel action from the hull to assist with tracking.
- In trying to create a keel on the floor, we tried to modify the arrangement of the I-Beams on the floor section. The inside I-Beams were made shorter and the outside I-Beams were made longer and turned inward. (Refer to section 11.4 for the pattern of P2).

• The general extension of the floor towards the ends meant an easier closure but a further increase of the floor to 50mm towards the bow would continue the improvement here.

Detail

• The valves were now easily accessible but it must be ensured that they did not interfere with the paddlers especially if there were two people paddling the kayak. In addition there was another consideration not identified earlier and that was the position of the valves when the kayak was folded up. With three valves (one on the floor and one on either side) it could create extra bulk in the final package; therefore, the valves needed to be offset in such a way that when the kayak was folded the valves sat next to each other, rather than on top of each other.

Figure 51 - Folding P2, what about the valves?

The valves would also have to be away from the bend in the floor where the side tubes were likely to crease and bend. The valves on the side tubes also hindered seating positions. Currently the furtherest back position for the paddler was 1030mm from the stern.

• When the kayak was sitting on a flat surface it was noticed that the kayak already tended to one direction and showed a twist. This may have been due to the method in which the tubes were joined to the floor, favouring one side more than the other. The rotational welding staff at Incept noted it and they suggested welding each side on to the floor in the same direction i.e. stern to bow. Although this would be time consuming - having to change nozzles over from left to right, - when doing a bigger run of kayaks rather than one the difference it could make would be worthwhile.

- From the bottom of the boat the different sides also sat at different angles to the floor. The join in some places was vertical and in others horizontal, and the side tubes should have mirrored each other as they were joined on the floor. Joining the floor on the inside of the side tubes may have reduced these different angles as the side tubes should have pushed out on to the floor. The other idea was to use a floor with an asymmetrical cap and base as in
- Figure 32 - Floor with distinctive cap and base inflated downwards.
- , similar to self-bailing floors where the floor sat inside the tubes, but in this case the cap would be the flat piece pushing the floor to sit below the tubes. This method would require the side tubes to be curved.
- A small area that needed attention was the need for wear patches on certain parts of the kayak where the material was likely to experience more wear. Such places included under valves (particularly on the floor) and at the bow and stern where the kayak was more likely to come into contact with obstacles. Normally neoprene was used as a protective layer. It is a rubber and can be scratched without damaging or losing air retention. The main problem associated with the neoprene was that it was very labour intensive to apply as well as expensive.

6.2.4 Testing

Once P2 was put together, the seams closed up and the small decks put on, it was ready for initial testing.

The objectives of this testing were:

- To determine the water tightness of the kayak particularly at the bow and stern closures.
- To observe how the kayak sat and reacted in the water.
- To identify areas for performance improvement.

Method:

We took P2 down to the Turitea lagoon. The kayak was blown up and put on the water and then paddled around. The method of evaluation was purely qualitative, by those paddling and from the observers.

Figure 52 - Looking at P2 in the water.

When the kayak was first in the water we had a look at how it floated in the water. It floated well, but there was a noticeable twist in the stern end, with the port side of the stern protruding higher than starboard. I was the first person to sit and paddle in the kayak.

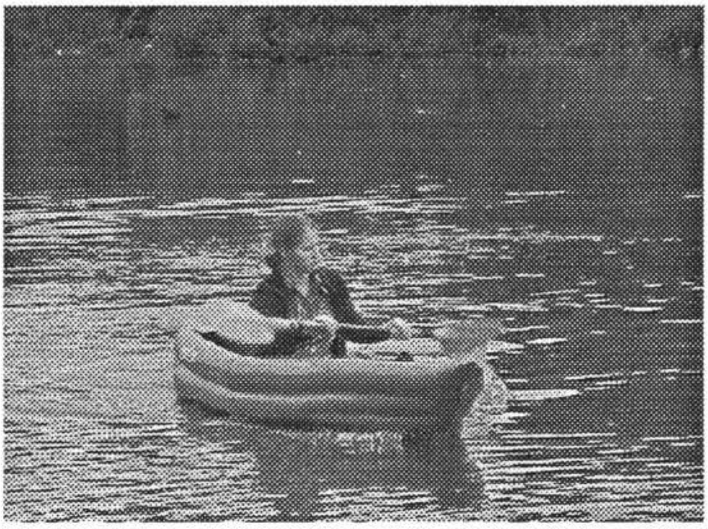


Figure 53 - Liz trusting her workmanship...

I found that it continued to float well, was easy to paddle and there were no problems with forward propulsion. As can be seen from Figure 53 the bow sat quite high out of the water. The twist that seemed obvious when looking at the kayak on dry land was not noticeable when the kayak was on the water except that there was a tendency for it to pull towards the port side. Two things may have contributed to this pulling. The first, as already stated, could have been the manufacture of the kayak and it not being symmetrical. The second factor and one that is very common to kayaks especially in exposed cases, was from the wind and this could become a push as opposed to a pull. However, both these problems could be compensated for by using a rudder.

Figure 54 - It was not scary for Harvey either...

Generally we were pleased with the progress that had been made with the kayak and to have actually had something physical to evaluate was a great milestone. It can be seen in Figure 54, as the kayak moves away, that it appears quite wide, and the paddler appears to be sitting very low. The paddler is actually sitting directly on the floor of the kayak and would normally have an inflated seat. Although a seat raises the centre of gravity and decreases stability, the kayak appeared very stable and the seat would provide a better paddle position.

Results:

1. The kayak floated and there did not appear to be any major leaks of either water in, or air out.
2. The draught (amount of kayak under the water) was very small. With the kayak unloaded less than 35mm was in the water, which did not reach the side tubes. This meant that most of the kayak was above the water (freeboard). This would be adversely affected by the wind and there was little of the kayak under the water to compensate the action occurring above the water while it was not loaded. While carrying a load, as expected for an expedition sea kayak, the draught would be expected to increase considerably.
3. The kayak tended towards one side, possibly due to the kayak not being perfectly symmetrical or the slight breeze. It was confirmed from this effect that a rudder was essential to the needs of a sea kayaker.
4. It was a very easy boat to paddle in terms of propulsion through the water. There seemed to be very little drag.
5. The way that the kayak was inflated was important, i.e. the order in which the sections were inflated. Both sides needed to be ¾ inflated, followed by the floor and then the completion of the sides. A proper fitting on the pump was essential for ease and efficiency.
6. There was a noticeable crease in the sides of the kayak while it was being paddled, probably because it was bending from the load and it was not inflated to the correct pressure. The lack of rigidity could hinder potential speed.

6.2.5 Evaluation of testing and P2

1. There was a need to apply a load to simulate the use of a sea kayak. This loading should make the kayak sit lower in the water as the weight would lead to higher displacement. This means a greater wetted surface area and, therefore, an increase in drag, but less windage.
2. When testing, the kayak must be inflated to the specified pressures. The floor needs to sit further inside the side tubes, to minimise the drag on the hull and reduce the overall depth of the kayak. The greater the freeboard the more likely it is to be affected by wind. Uniform, symmetrical floor joins are essential.
3. The position of all fittings is essential to the comfort of the paddler. A few small fittings had been attached on the outside of the kayak. It was found that they

interfered with the paddler particularly when close to the position of the knuckles as they past through a paddling stroke.

6.3 PROTOTYPE 3 (P3)

6.3.1 Objectives

To get a boat that we could test at a quantitative level. We were happy with the structure and concept but we needed to know that it was better than its counterparts and competitors.

6.3.2 Development

General Parameters

We were reasonably content with the general parameters. The inner beam could still benefit from an increase, but the flexibility of an inflatable that allowed it to be tight and a firm fit on the paddler was beneficial for stability and control. The length as a single sea kayak was good although extra length would be required for a double sea kayak used for expedition purposes.

Bow and stern design

- We removed the lower I-Beam at the bow, reduced the height by cutting an angle off the bottom to create more flowing lines and pulled the floor upwards.
- We put an extra 25mm of material at bow and stern for the closure. The extra material at the stern allowed for a flat closure for the rudder attachment. The bow needed to have the flaps drawn in together with a nose cone to tidy up the end.
- Ideally the bow needed to be more slender but (due to the way that the I-Beams were welded on) this could not be reduced any further or there would be insufficient material on which to weld the I-Beams. The I-Beam that was left in the section was angled upward to make that section less bulky. (Refer to section 11.6 for the pattern of P3).

Side tubes

- We increased tapers on the side I-Beams by a further 10mm to make 100mm total.
- I would have liked to have seen the lower side tube reduced as discussed in the earlier concepts. There would be further benefits in the smaller lower tube as it would

decrease the freeboard, resulting in less windage and an easier paddle reach. However, this did not happen and the two side tubes continued at the same diameter.

- It was suggested that we extended the third I-Beam down the rest of the side of the kayak, in order to try and increase the inner beam by having a smaller tube width next to the floor. This could increase the volume of the kayak as well as the inner beam by the paddler' s hips. However, the additional I-Beam would create additional work and from a manufacturing perspective it was desirable to get rid of it. It was felt that similar results could be gained by shaping the bow of the side tube to taper, and angle the existing I-Beam upward which also reduced the diameter of the tube sections.

Floor and hull section

Having the outside I-Beams longer and coming inward was more difficult to manufacture and did not enhance the keel line. Bulges were created in the hull and these may have created drag for the hull. The hull design went back to the standard placement of I-Beams, with the inside I-Beams being longer than the outside I-Beams.

Detail

We moved valves towards the cockpit area but were still not happy with the position. There was a need to make sure that they were cut to fit in with the I-Beams before they were welded on.

Removable and attached decks

Intending this iteration of prototype to go through to completion and full testing, it was necessary to fabricate the decks required. It was thought that the permanent stern deck was not required to remain fixed and got in the way during manufacture, so the area was incorporated into the removable deck (Refer to Figure 47). Not only was the shape and strength of the deck important but also the ease and method of attachment. The purpose of the convex shape in the deck was to encourage any water to run off and to avoid unnecessary loading.

There were many ideas for attaching the deck, ranging from interlocking tooth zips and slide mechanisms to hook and loop systems, including Velcro®. The easiest and most logical was the hook and loop. Incept already had both a standard and a self-adhesive hook and loop available. There were concerns about the quality of the self-adhesive but it was potentially much more labour intensive to sew the hook on to PVC and then glue the PVC on to the boat so we agreed to try and use the self-adhesive Velcro®. We did a few tests using different solvents for preparing the PVC. The solvents used were:

- MEK (Methyl Ethyl Ketone),
- IPA (Iso Propyl Alcohol),
- Toluene.

A small sample patch 50 x 40mm of loop was prepared; the adhesive on the Velcro® required 24 hours to reach full bond strength. After 24 hours each patch was tested using a hook sample to do 50 rips. The IPA and Toluene appeared to show more weakness than the MEK. There was little confidence in any of the samples and it was expected that some other type of hook and look with self-adhesive would have to be used for the final product. We used the Velcro® that was available for the prototype.

The Velcro® (that was meant to be water and heat resistant) was found to be deficient. After the first outside use, the hook and loop had a stronger bond to itself than the self-adhesive had to the kayak. Other brands have since been tried and have proven more successful, including the sample that Audrey Sutherland sent from her local hardware store in Hawai'i.

In order to give the deck a convex shape, struts were needed, unless the deck itself was solid. The requirements included something lightweight and compact. When in place a deck should provide stiffness to the general structure of the kayak. Two main concepts were tried:

1. Flexible material under tension.

The materials considered were light plastics and also fibreglass such as that used in windsurfer sails. The concept was that the flat; plastic, fibreglass or a high tensile steel struts would, when under compression, bend into the right shape and then return to their original state when not under compression. The first idea of achieving this was using cord under tension, pulling a piece of plastic into an arc. The concept was successful but the cord potentially got in the way of luggage under the deck, which meant there was less storage space.

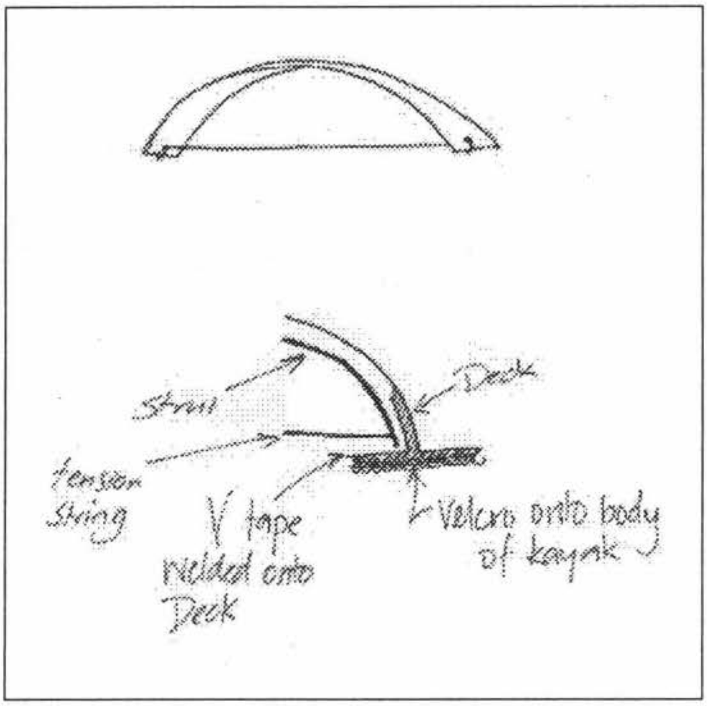


Figure 55 - How to tension the deck with a cord.

The other way was by making the length of the strut longer than the width of the kayak and forcing the kayak sides inward causing the plastic or fibreglass to bow upward to support the deck. The ends of the strut were placed in small pockets at either side of the deck. It was found that the kayak was not rigid enough nor was the joining of the deck to the boat sufficient to maintain the bow in the strut. The final modification tried here was attaching the strut to the boat by small pockets and again relying on the kayak sides to be pushing inwards. However, the inward pressure of the sides was less than the flexibility of the materials.

A problem with fibreglass was that fibres were noticeably left in a person's skin after handling the material. It was thought that the fibres would, therefore, probably work their way into the material used on the kayak and form leaks in the material, proving unsuitable for use around an inflatable boat.

2. Preformed/moulded strut to a desired shape.

The most obvious materials to use were moulded plastic or aluminium. It was difficult to form the specific shape without a mould. A disadvantage of moulded plastic is the cost of manufacture. Aluminium also had disadvantages in that, over time, it would leave black grime as well as potentially have sharp edges to puncture or rip the kayak if not properly finished. Aluminium, however, was cheap and available in lengths from most aluminium joiners or engineers. It was easily attainable to use for prototyping and although the shape might not be reproducible by hand, the method of bending could be modified at a later stage if the concept worked. The aluminium was cut according to the beam and amount of curve required in the deck at any given position. Four struts seemed an appropriate starting place with two struts at either end of the cockpit. This concept was the most successful and was used for the final prototype.

6.3.3 Initial Evaluation

Overall length	4025mm
Width ext/int	670/330
Depth ext/int	340/240

Table 8 - Key dimensions of P3.

There were some results (compared to P2) that might be considered undesirable, particularly the reduction in length and the outer beam becoming greater, especially without any increase of the inner beam.

The development changes, although minor, seemed to have brought the team to a position in the project where we were satisfied with the basic design. We moved on to the detail of decks, rudder, seat and fittings that now required attention. As the detail components were developed we started doing some testing.

Figure 56 - Even the life jacket matches!

Part of the evaluation of P3 was taking it out on the water. There were three people who were able to try out the kayak. Two people had previous experience and one person was a complete novice. Unfortunately, there were many small details requiring work. All three participants were satisfied with the kayak's stability, although it rolled easily to one side. However, it did not roll further than the upper side tube. During the concept generation, consideration was given to a kayak that could be used as a single or double. Through the current development, it was found that there was not enough room in the cockpit area for the kayak to be considered as a double.

All three people commented that the beam was too narrow and that there was no body contact with the upper tube as it was just pushed outward due to the pressure on the lower tube. Because the upper tube was being pushed out, the Velcro® did not retain its hold and pulled off. The largest area of feedback on the kayak was that the lower tubes needed to be further apart as that was where the pressure was when a person was sitting in the kayak.

The speed and ease of paddling seemed satisfactory but the need was immediately recognised for a rudder, especially in trying to compensate for the wind. Because there was no rudder, no one paddled for more than half an hour, so we did not know the effort required for extended trips.

6.3.4 Testing

There is always a need to test products during development. Testing is an essential part in ensuring the product fulfils its requirements. John Booth made a comment as we prepared for testing that qualitative testing was more valuable than quantitative testing as this could be undertaken at any time. However, from a design perspective we needed to ensure that we had improved upon past prototypes and the development was achieving the objectives initially specified.

The objectives of this testing were:

- To evaluate the improvements made in the different iterations of design
- To determine whether the modifications enhanced the design above the benchmark (the Semperit)
- To identify further areas for development.

Method:

There were two sets of testing done to P3. One was comparative testing with other kayaks that resulted in quantitative results. The other was qualitative testing that was used as part of the general evaluation of P3. The kayaks used for the comparative testing were:

- P2 and P3, to determine development improvements on performance
- The Semperit, using previously recorded data
- The Helios, as an alternative sea kayak
- A canoe from Incept was used in the belief that it portrayed the hydrodynamic properties we hoped to achieve in the sea kayak.

There was discussion as to the relevance of also testing against a hardshell sea kayak. It was concluded that the hardshell was not the competition but rather other inflatable kayaks, which (although not specified in most cases as sea kayaks) were still being used by the same target market. Initially we expected to use a hardshell as the benchmark product. However, there were areas of performance where an inflatable would not be expected to equal a hardshell, such as strength and potential speed. So as the target market expressed concerns over what was available, the benchmark became the Semperit, although it is no longer manufactured, as it was the closest equivalent to the Incept concept. A number of product features were also specified in the design brief that the Semperit also illustrated.

A testing process was designed to test the drag on the kayak at various flow rates. This enabled a basic comparison of drag on different boats. This measurement was taken under a number of different loading situations as well as different flow rates.

A small flow meter was made to measure the flow of the water, using a small propeller that had to be calibrated for certain speeds. The flow meter used a sensor from a computer mouse to transform the propeller speed into hertz to a multimeter. We used a flow tank where the volume of water in the tank was known and the flow rate could be calculated and then calibrated to a hertz reading from the flow meter.

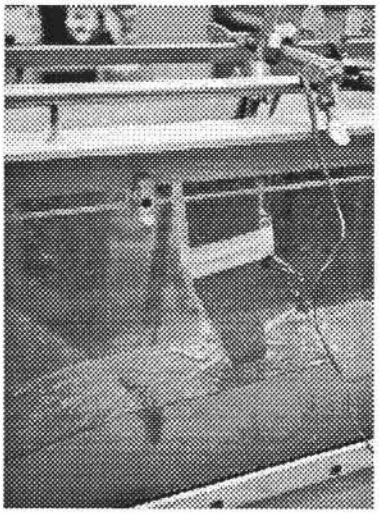


Figure 57 - Measuring flow in a flow tank.

Once the flow meter was working well we were able to use it to test the flow where we were recording the drag on boats in a river. Obviously with varying river levels and flow rates it was important that the flow was recorded at the same time as the drag was recorded. The different boats were then stationed in the river, attached with a spring balance and tow line to a fixed position. The spring balance displayed the drag on the kayak.

In order to utilise this experiment a suitable location was needed for testing. The criteria being:

- Laminar water flow
- Constant and measurable flow rate
- Location and method for anchoring the spring balance and kayak tow line.

The location also had to be accessible from the road due to the need to carry boats and equipment to the water, and safe from snags and obstacles that might limit the safety of the experimenters.

Two locations were used for testing:

- The Turitea Stream about 2km up Turitea Valley Road, Palmerston North.
- The Pohangina Valley stream by Pohangina reserve, Manawatu.

Figure 58 - Initial testing of flow meter.

Each location first had to be tested for a constant flow rate. It was discovered that in a river it was very difficult to get a laminar flow that had a flow rate high enough to be recorded on the flow meter and for the propeller to commence rotation. It was found that after initial testing the flow meter needed modification to ease the propeller rotation and that the propeller needed to sit lower in the water. Figure 58 shows a small object (circled in the photo) sitting in the water. This was the initial flow meter body. It was found that this was easily swamped and so we created a larger more stable body (to house the meter) out of polystyrene, with the propeller shaft and blade directly in the water and with less interference from the housing itself.

With the river being tested independently for the flow without interference from any boats, the laminar flow could be established. At each location each boat was placed sequentially in the flow area with the flow meter. The flow reading and the balance reading were recorded at the same time. The flow reading could be converted into the actual flow using the flow testing data gathered during use of the flow tank.

The kayaks were also tested with various loads on them. It was soon apparent that the greater the load the kayak carried the greater the drag on the kayak.

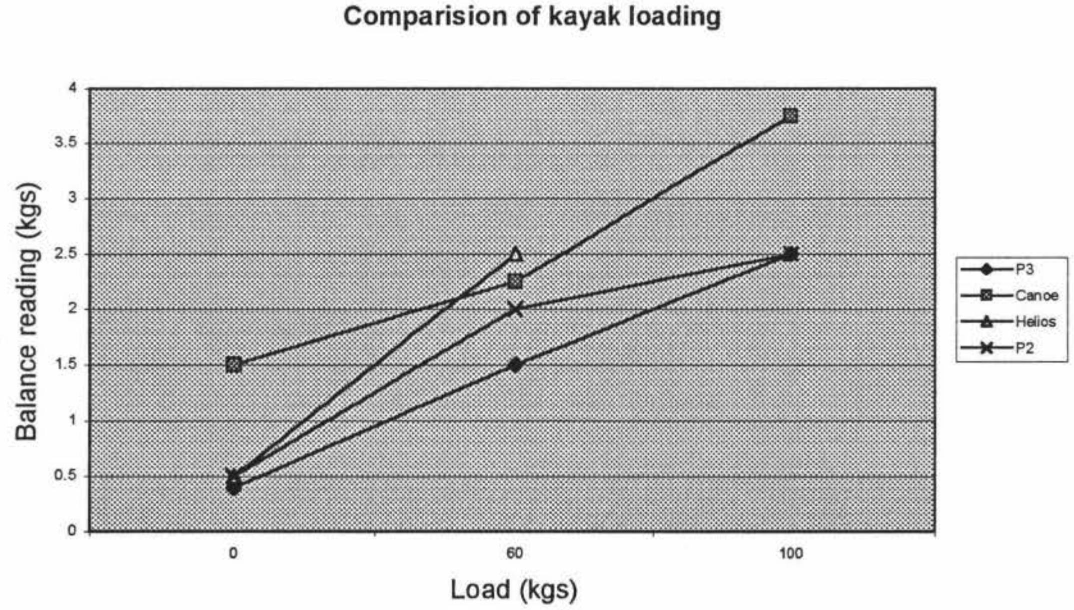


Figure 59 - Graphical analysis of loading comparisons

It can be seen from the graph above that the drag while there was no loading was similar in all cases, with the exception of the canoe. With only a small load of 60kgs, the equivalent of a small paddler with no gear, the P3 performed better than all the others. However, when reaching a more likely load of 100kgs both of the sea kayak prototypes performed at a similar level.

Due to weather and conditions varying beyond our control, further testing to confirm the results any further was cancelled. The results, however, indicated that P3 showed improvements over all the other kayaks and canoes tested, and when comparing the results with the Semperit, we found improvements had been made with regard to the drag experienced.

There were minor adjustments still to be made before production, but the next iteration of prototyping would be for consumer testing to ensure that the kayak that we had developed did actually fit with customer expectations and the specifications gained from my initial market research.

6.4 THE FINAL PROJECT PROTOTYPE – P4

6.4.1 Objectives

We were satisfied with the development so far and it was time to make sure that the development fitted with customer expectations. Two prototypes were to be made, one grey model, to be sent to Audrey Sutherland (our key consumer evaluator), the other, a red model, for local evaluation. With Sutherland's input from the beginning of the project and her vast experience in inflatable sea kayaks, it was a good opportunity to get her expert opinion on the Incept kayak. For manufacturing purposes the sea kayak was named the K40, K(kayak) 40(4.0 meters long), as boats manufactured at Incept are identified according to their use and their length. The actual branding for the name of the product would come later and we would again ask Sutherland's input for this.

With the time period of the project quickly reaching a close, finishing these prototypes would mark the end of the project with the fulfilment of the project brief stating the project aim, "the development of a prototype marine kayak that meets the identified needs". The needs had been identified and through the testing we felt that they had been fulfilled according to the information that we had.

It was not expected that this would be the end of the development of the kayak as a marketable product. The consumer evaluation was expected to identify further changes particularly in the detail design where the kayak could not be truly tested until used in the environment.

6.4.2 Development

The developments made on this kayak were no longer structural; the team was content with the general shape and the initial testing had indicated its potential. Any kayak is best evaluated qualitatively by human judgement, when comparing it to other boats.

The only major modification to the body itself was in the joining of the floor to the side tubes. We pulled the floor further inside the kayak sides by the location of the joins. These were adjusted according to the pattern with reference marks to indicate the position. This modification was to allow the shape from the floor to influence the shape of the sides more. We also had to tidy up some of the aesthetic areas such as the joining of the nose cone, the stern platform, and the location of D-rings and beckets on the kayak.

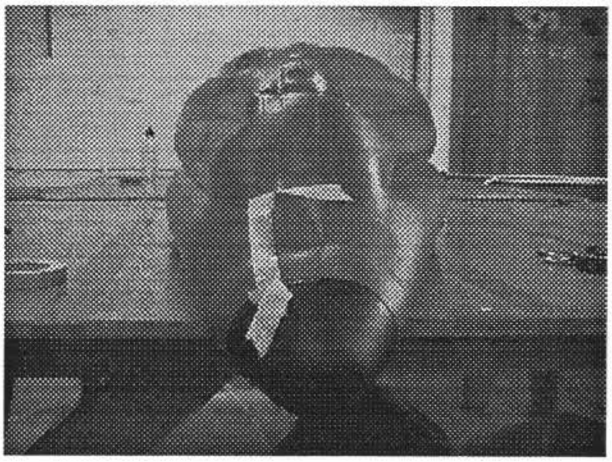


Figure 60 - Finishing of the nose cone at the bow.

Foot pedal

Further development of the foot pedal or foot brace was required. Sutherland used individual stirrups that she had fabricated herself from left over canvas from the deck. These were identified as a risk if the kayak capsized, appearing to hinder the exit from the kayak if the paddler's feet were still in the stirrups.

Development in this area led to making a cross bar that went across the beam of the kayak and was adjustable according to the size of the paddler. From here we ran independent lines down either side of the kayak with bungee anchors at the bow so that the cross bar would return to a standard position and also return the rudder to the straight position.

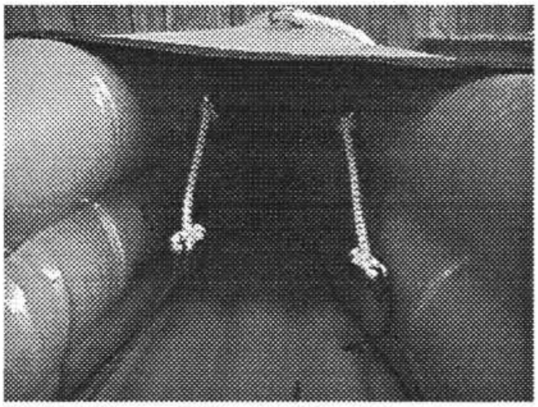


Figure 61 - The bungees...

The system, although good in concept and theory, was difficult to prototype. Trying to find a simple mechanism that fixed the cross bar in place but that could also be shifted in position from the cockpit if necessary was difficult. A number of ideas were tried including toggle clips and different knot combinations but no one of these was easy to adjust and many allowed the cross bar to slip further along the lines so it was then out of reach. The most simple of ideas that still held potential was where the cord was secured to the cross bar. It was thought that if threaded in an appropriate way that (as long as the cord and crossbar were under tension) it would not slip, but when released it would then move up and down the length of the kayak on the cord that was secured by the rudder and anchors at the bow. It was also felt that the cords also needed to be out of the way of the paddler and should run down the trench in the side tubes where the I-Beam pulled the sides together. These could be permanently attached on the kayak by small beckets or tubing and then the rudder cords attached above the deck. This meant extra attachments on the boat, more weight and more cost, although in the larger picture this was minimal.

The rudder system for pulling the blade up and down was still very stiff. When in the water it became a little easier (being lubricated by the water) but the stern of the kayak was still lacking rigidity and, therefore, flexed under the pressure when pulling the rudder up. It was suggested the rudder be attached lower on the stern where there was greater stiffness due to the added layers of material. Also considered was whether having the attachment brackets set on the inside or outside of the rudder mounts would effect the movement of the rudder and the stern. The original pin used on the Dobbe rudder needed to be extended to protrude above the deck so that it would not interfere with the stern and get caught up in the pulleys.

Seat and backrest

Very little thought at this stage had gone into the seat and backrest. Because of the time expected to be spent in the boat, it was important that the seat and backrest were comfortable. Although Sutherland used only a semi-inflated wine bag as a seat and extra luggage as the backrest this was not seen as a suitable option. We wanted to provide comfort as part of the package. If people were going to pay for a good kayak, they would also require a good seat and backrest.

Options for the seat and backrest included the following:

1. **A modified combined seat and backrest.** This concept came from the Incept fishing tubes. It allowed for the seat to be made at Incept and moulded similarly to those used in the fishing tubes. The unit was HF welded and sealed using small sections to provide a soft cushion. The unit could be inflated according to the desired comfort and hardness of the paddler. Being inflatable it still packed down tightly for transportation and fitted in with the overall concept. This was the concept used for the prototypes and that was expected to receive further attention for development after evaluation and further ergonomic considerations had been identified.
2. **A simple backrest and seat on the floor** as in the K30, the Incept whitewater kayak. This was simple, without baffles or separate sections, so it was quick, easy and cost effective. However, it limited the comfort level and support a paddler required over longer periods of use.
3. **A formed seat moulded from foam** This concept came from padded sporting safety equipment. There were pre-manufactured seats available in the market that could be detachable as well as fixed into the kayak. The largest setback with this form was the size it would add to the transportable package, and that

it would be costly for Incept to either import the seats or get them manufactured locally.

4. **A plastic preformed seat and backrest** as provided in hardshell sea kayaks. Again there was extra financial cost and without the benefit of being compact for transportation. This type of seat could be used as a gauge for the beam ensuring the space required in the cockpit was suitable for the paddler.

Out of all the concepts considered above, the combined inflatable seat and backrest offered the greatest potential in fitting with the brief and specifications of comfort yet compact when packaged. In developing this concept further it was important that the seat and backrest did provide comfort and support to the essential areas of the buttocks and lumbar regions. In order to maximise comfort, the inflated chambers varied in size depending on the support required for various regions. The lumber area was considered important and had a larger inflated section, while maintaining airflow around the entire seat and backrest with only one valve.

The seat was initially attached using hook and loop tabs that sat directly on top of the side tube and under the hook and loop on the deck. This meant that the deck created tension across the beam of the kayak, counteracting the sides pushing outwards at the position of the paddler. The seat could also be attached to the body of the kayak by clips, in the same way that the backrest was attached on to the K30.

A further concept was that of adding a small pocket for high use items such as snacks, a first aid kit, maps and other safety equipment, which could be constructed on the back of the seat for easy access by the paddler but still not be in the way of the legs or arms while paddling. This concept was not brought through for further development but could be considered at a later stage.

Deck

The decks had gone through a number of iterations and a full deck had been made for P3. The material used had a number of disadvantages including the colour. Black was too dark and would have made the temperature in the cockpit unbearable. The weight and thickness of the material were also too high. John Booth found some material made from Nylon with PVC coating that was lighter and less bulky. A turquoise colour was chosen by John that could be used for both decks on the grey and red prototypes.

The join between the front deck and the spray deck needed to be straightened for ease of manufacture and use. This allowed further concealment of the hook and loop and increased the strength of the join. It also helped with patterning, and variability when the kayak was inflated to different pressures.

We went back to the use of a front and rear permanent spray deck for rigidity and also for ease of attachment of the removable deck. It was difficult to join a detachable deck directly to the stern. The permanent decks were made from the same material as the body of the kayaks and had large metal D rings attached on which to put toggles for carrying. The D rings were good for a solid mooring point, were more durable in the environment, and although heavier than plastic alternatives would not become brittle and break with extensive and intense UV light.

The removable deck needed further modifications particularly where it attached to the body. The hook and loop needed to be placed further out on the side tubes, making the deck wider. The deck could then reach further over the sides, allowing the water to run off and maintaining water tightness. The hook and loop placement would also increase the strength of the deck pulling the sides inwards. The actual shape of the deck also needed adjustment according to the shape of the kayak to make the lines on the kayak flow aesthetically. The rigid aluminium struts were placed inside webbing pockets sewn on the inside of the deck. The struts were still removable by the small gap left in the side of the pocket. Eyelets were added on the corners of the removable deck, so it could be tied down, and to ensure that the deck did not separate from the body of the kayak.

The decks were sized according to the position of the cockpit and the position of the struts in the deck. Each deck had to be a manageable size in order to be easily attached and removed. It was important to decide whether to make three separate decks (back, skirt and front) or to combine the back and the skirt to make less work. It was decided to make a combined skirt and back deck for ease of manufacture and less parts in the entire package. In the event of capsize the deck would stay on the kayak, and the paddler could exit by undoing the full zip down the front of the deck and tie cord around the waist.

With the struts being curved the deck was strengthened and this allowed the water to run off the edges so that the kayak was not weighed down with additional weight.

Grab lines

There was thought of adding grab lines, as were commonly used on traditional hardshell boats. Grab lines were used for securing the boats on dry land, providing something to hold on to in the event of capsize and (those on deck) for securing drinks, maps and other essentials to the deck while paddling. Simple lines were used on P4, but their necessity was later questioned during the consumer evaluations, as hand toggles for carrying the kayak were on the front and rear spray decks and could be used sufficiently for mooring. On the issue of securing things on deck, it was thought that an internal pocket could be used for the same purpose.

6.4.3 Testing

There was no formal testing at a quantitative level as the structure and body of the boat was thought to be a direct derivative of P3 aside from the pulling in of the floor intended for enhancing the performance. The purpose of P4 was, as mentioned, to get feedback from consumers and paddlers that are part of the market for the Incept sea kayak. The grey P4 was sent to Sutherland and was made in colours more suited to her expectations although it is expected that the final product would be made in red for it was safer (when needing to be seen) and available.

John Booth was going to do "in-house" testing of the red P4, after the project component was completed. Results of this testing have not been included.

6.4.4 Evaluation of P4

This was the end of the Massey graduate project in that the fully working prototype was ready to be sent out for testing. The evaluation came mainly from feedback from the grey boat that was sent to Sutherland. The following comments are based on Sutherland's letters (A. Sutherland, 21 March & 14 April, 2001, personal communication).

- The Velcro® that was used did not maintain adhesion as expected. A different securing system was needed, whether another form of hook and loop or something different entirely.
- Sutherland found the kayak "more tippy" (less stable) than her previous boat but did not find that a concern and thought that with time she would become used to it in any case.
- The seat needed separate valves for the actual seat and the backrest. This would be useful in rough weather when, by deflating the seat, the paddler's centre of gravity could be lowered and more stability gained.
- The sides were also thought to be too high and Sutherland wanted them lowered two or three centimetres. The reason for this was to cut down the freeboard, reducing windage and reducing the effort needed to push through head winds.

7 FUTURE WORK

Even though my involvement with the project came to an end, there was still work to be done. P4 still required testing and development as well as marketing and distribution strategies. While I had been writing, Incept Marine Ltd (Incept) had sent the P4 prototype kayaks out for testing and continued with its development (with feedback and evaluation from Audrey Sutherland), and with getting it ready for a marketable state. With intensive testing by Sutherland it was expected that modifications would be made before the sea kayak was launched.

Even after a prototype is ready there is considerable effort required in getting it into a stable position in the market and maintaining its position. A product always needs evaluation and assessment when looking for areas for improvement and development to keep up with an ever-competitive market.

7.1 CONSUMER TESTING AND CONTINUED DEVELOPMENT

Consumer testing is vital for any prototype before an official market launch in order to ensure any products 'bugs' in either manufacture or design are found and corrected before sending out a product run. Using people uninvolved with the actual design process should ensure they would give an unbiased opinion and a critical evaluation of the product through a set of fresh eyes.

Incept was expected to continue with product testing until they were satisfied that the product met the expectations of those using the product. It was not clear how long this process would take and it would depend greatly on other commitments to other products by Incept.

As stated earlier, the testing was undertaken in two environments. Sutherland was the key consumer agent willing to evaluate the product and had many of her own expectations for the product. She was a valuable part of the development process and will be a factor in the success of the marketing of the product for endorsement and distributing information to experienced paddlers. Sutherland used her network of paddlers in Hawai'i to get feedback for Incept on the K40 prototype. There appeared to be an interest in having a two person kayak. The current prototype did not cater for this because it was not long enough to comfortably fit two people.

Sutherland found the K40 less stable than her other boat, as did my personal evaluation in calm water. Kayaks suited to rough water will often feel less stable in flat water. Due to the uncertainty of where Sutherland tested the boat, I consider stability in waves to be more important than a sense of stability on calm water.

There was a requirement for further development in the system used for attaching the deck. The Velcro® used was unsuitable, and continued to detach itself from the body of the kayak. Alternative systems needed to be investigated more thoroughly in order to find an appropriate solution.

7.2 MARKETING PLAN

Direct competition would be with large mass producers of sea kayaks such as Aire, who have a range of good quality inflatable boats. The product advantage that Incept can gain is with the design specified for the more specific market area of touring and expedition inflatable kayaking.

Part of the marketing needs to be giving the product an identity. Incept called it the K40 to fit in with the manufacturing codes of other products manufactured at Incept. This was not going to make a strong identity for the K40 in the market. The kayak needed to be branded with a name that appealed to the target market and represented the kayak so that it would be distinguished from other boats. Especially during initial stages of marketing, the brand name needed to be recognisable and able to be recalled. Incept may need to use someone else to do the branding of the sea kayak on their behalf as it is a vertical development from existing products. It had very little relation to other products currently produced by Incept. This is a sea kayak and most of the other products produced and marketed at Incept are products for use on rivers.

Once a name had been established for the kayak, it would be necessary to get the product and the name into the market in order for it to be recognised and then endorsed by people in the field.

How the product will get this recognition has yet to be determined. Some ideas for this area include:

1. Having someone to endorse the product either by referring back to Incept or
2. Endorsing the product and working as an agent for Incept and receiving commission on sales
3. Using a sister company already in the field of sea kayaks to buy the product and sell it using existing networks
4. Incept marketing and distributing the kayak through exposure in national and international magazines
5. Selling to existing Incept agents to sell on Incept's behalf
6. Establishing entirely new distribution networks for the K40.

All of the above are only suggestions. This area was discussed only on a casual and inconclusive level. The marketing of the K40 would not be part of this project.

My suggestion was to do an initial production run of a dozen kayaks and distribute them to key customers who would be able to constructively evaluate the product before it reaches a full market launch. After Incept placed an early production run with key customers and the market reaction had been gauged, it may be a better time to pursue some of the options for marketing stated above.

Incept had an active web page that allowed orders to be placed for products and could be used for initial marketing of the K40. As the acceptance of e-commerce increased, the opportunities available through the World Wide Web continued to appear more appealing to smaller manufacturers to distribute products to a greater market. Using the internet means that selling sea kayaks was not restricted by having distributors selling only in some locations around the world.

The idea to use a major paddling magazine to raise the general profile of Incept and launch the K40 at a similar time would obviously seek to also benefit other products in the product range produced by Incept.

7.3 DISTRIBUTION NETWORK

The distribution network is the structure through which Incept will decide to distribute its products to their target market. At this stage Incept has made the task quite difficult unless they are happy with a very small distribution area. The target market is quite small as Incept looks to sell the product to experienced paddlers that use the kayak for expeditions; therefore the portability of an inflatable is important. Incept are trying to directly cater to a market that does not seem to have been addressed specifically before by a manufacturer, but which seems to currently adapt existing products to the purposes required.

Incept currently exports to countries including Australia, Japan and USA. Products to these areas are mainly in the area of river craft, specifically whitewater rafts. Although the sea kayak has greater market potential beyond these countries, Incept already has confidence in and an existing business relationship with these countries. In the project proposal Incept forecast that they had a market for 1500 sea kayaks in the first five years of production. It is unlikely that existing distributors would fulfil this number so it would be expected that they find other methods of promoting the K40.

There was considerable interest during the project from one of the Australian distributors who was very enthusiastic to see the sea kayak come to fruition, often ringing to see how progress was coming along and keen to see a prototype even at early stages of development. Already distributing whitewater craft for Incept, the distributors were enthusiastic and confident of their ability to also cater to a sea worthy market.

Currently Incept boats are generally made to order directly for a customer. There are some distributors that buy-in the boats and then on-sell them to the public and other clients. Most of the boats are made to order and it would be expected that Incept would initially use a similar method for the sea kayaks to determine initial market reaction to the new product.

In countries like New Zealand, people are rarely more than 50km from a coastline and, therefore, distributors of existing Incept products could also distribute a range of products suitable for open water use. In fact, many key distribution centres in New Zealand, such as Tauranga, have both river and sea focuses already. New Zealand may be the exception for this and I was concerned that the sea kayak was catering to a very different market to the products that Incept currently produced and that the sea kayak may not get a market launch in the area that would be most beneficial.

If the Incept sea kayak met the expectations and specifications of consumers, it was hoped that Audrey Sutherland might endorse the product internationally. She has access to a wide share of the market through her own acclaim and expedition experiences and knows many of the active international expedition paddlers. This means distribution would be as wide as Sutherland's contact and experience has taken her, as well as her reputation. If, indeed, her reputation continues to other levels of contact with other international paddlers this would be a low capital way to initiate distribution from anywhere other than existing centres, especially beyond New Zealand.

8 CONCLUSION

8.1 THE KAYAK

Due to a press release on the project, there was a positive response regarding the inflatable kayak, especially from an academic perspective and the media (Refer to sections 12.2 and 12.3 for newspaper articles). It was certain that Incept has the potential to meet market needs in the commercial arena, once they had gone through further consumer evaluation and development.

There were definitely areas of the kayak that I would have developed differently. There was a problem in that I did not have the knowledge or experience in inflatable design to know the limitations or possibilities involved with inflatable manufacture. I was limited in the development of the kayak once we reached a prototyping stage. There were constraints due to time in experimentation and the cost of that experimentation not being willingly undertaken by Incept. I felt that some of the essential elements of a traditional sea kayak were missed in the design of the inflatable for one of two reasons:

1. They could not be reached (or so the project team believed) because it was an inflatable.
2. We did not understand the true elements of a sea kayak and how to combine them into the development of an inflatable.

I would hope that it was the first rather than the second reason. It will not be until after thorough consumer testing and evaluation that it will be known how well the project team reached customer expectations.

The fact that at the end of a 12 month period we had made a working prototype, made us feel we achieved what we had set out to do. It was known that work was still required but we reached a point that had filled the requirements of the initial brief. I was happy that it looked like a kayak and had some of the elements that we identified at the beginning of the project.

8.2 THE SCHEME

The GRIF scheme has excellent potential under the right company and the right support from an academic institution. It worked particularly well for me with the scholarship enabling my time to be focused on the project. I do feel that either the proposal stage needs to receive more input from the student or, have more specific expectations. I felt there was limited support from the project manager due to other priorities. This may have been helped if expectations for each party were more defined in the proposal and the limitations on the student more evident from the beginning.

It is important to have desired outcomes set out at the outset of the project and milestones to be reached during the project. I felt at times that my time was not used as effectively as it could have been had we developed a more thorough outline of the project in conjunction with the company at the beginning. From my personal perspective I believe such projects are undervalued by industry. Although the initial process can be time, labour and effort intensive, with the right support many students would thrive on the opportunities available in a company, especially in research and development areas. Companies would gain a valuable human resource to add to the value of their company and gain greater relationships with educational institutions for research. With an attitude of giving from all parties involved I feel that everyone would come out of the project with a greater knowledge base in many different areas.

8.3 THE PROJECT

Over an eleven-month period a full prototype was constructed as well as much of the necessary background information concerning the design and expectations of a sea kayak. Even though these were not taken into much consideration during the course of the project, it is anticipated that there will be further use for much of the information gathered for further development or future products.

It was quite an achievement to complete a prototype of this nature in such a short period of time. In this sense the project was a success. The brief and specifications of the proposal were fulfilled. Unfortunately, as the fellow who completed the project, I felt that there was still plenty of work to be done on the sea kayak and as the project finished I would no longer be involved with seeing the project through to marketing. The project manager would continue with the project at a less intense level until he was satisfied with the outcomes.

I have found the writing of the thesis the most time-intensive part of the project. Since the end of the physical project, and through my being in Taihape and prototyping, I have had very little contact with Incept and with what the actual outcomes of the project have been.

Finally I felt that it was a valuable time for me in learning and experiencing the culture of a small manufacturing business. Incept had huge innovative potential and I was encouraged to see the progress when there was someone backing a project as in the case of this GRIF project.

Due to my initial expectations, not being able to enhance my skills in the area of CAD was disappointing.

I would like to thank the Foundation for Research Science and Technology for giving me this opportunity to develop my knowledge in the area of manufacturing and industrial technology in inflatable boats and to put into practise many of the elements of a product development process that had been a focus during my undergraduate degree.

9 APPENDIX A

9.1 PROJECT PLAN

The fellow will develop a new inflatable sea-going kayak. We know that there is 'no' right way to design an inflatable craft as there are a number of compromises to be made. We have identified the following critical factors:

- Paddle reach – distance the paddler must stretch over the side of the craft
- Windage – wind drag on craft - especially sideways
- Rudder systems
- Comfort – suitable for 'all day' use, ability to carry luggage
- Stability – stable in rough seas, crew can clamber on board at sea
- Structural strength – can ride across wave peaks without collapsing
- Lightweight – less than 18kg so suitable for in-home storage and as airline luggage

Although our primary focus is on inflatable construction we will consider the use of other materials e.g. composites, aluminium sections etc where there are design benefits.

1. Introduction

Incept marine

- Range of product and manufacturing techniques

Literature review

- Small boat design – stability, centre of buoyancy, etc
- Inflatable craft design
- Inflatable structures
- Solidworks 3D modelling including 'unfold' option to produce 2D patterns from 3D shapes

Duration 1 month
Location 30% Incept 70% Massey
Milestone Fellow up-to-speed with Incept and inflatable boat design, by 20 December 1999.

2. Confirm specification

The fellow will meet with lead users and kayaking specialists to confirm the technical specification for the sea-going kayak and to identify current best-performing products to allow comparative testing (e.g. hydrodynamic drag). We will arrange visits with

- Ian Ferguson – Fergs sports centre, Auckland
- Audrey Sutherland – 'the' marine kayaking authority based in Hawaii
- Glyn Dickson – columnist in NZ Wilderness Magazine and influential in NZ Sea Kayaking Association
- Local sea kayaking enthusiasts

From the specification, the fellow will identify aspects requiring development and will modify the next section where necessary.

Duration 2 months
Location 70% Incept 30% Massey
Milestone Initial technical specification confirmed, by 28 February 2000.

3. Technical development

The specification will identify a number of key factors that are best investigated independently, prior to bringing this knowledge into the prototype design section.

- **Structural strength**: The Kayak must not collapse when bridging two waves. Our criterion is for a simply supported kayak to withstand a central 100kg load without buckling. Using structural analysis techniques and loading of simple prototypes a design solution will be determined. We may have to introduce composite materials or other lightweight materials to arrive at an acceptable solution.
- **Hydrodynamic Drag**: We know that the design of the kayak below the water-line will influence hydrodynamic drag. A 'low drag' kayak will be easier to paddle over long distances. The fellow will develop a simple comparative test, measuring drag on a tethered kayak in a flowing river. We do not have a definitive measure and so will have to measure actual drag on a competitor's product and then set a goal of having our kayak to at least meet this level.
- **Windage**: Crosswinds can drive the kayak off course and make paddling more difficult. We will determine an appropriate 'balance' of submerged versus above-water area to limit the influence. This factor will be investigated using simple model tests, and practical river tests.
- **Buoyancy**: The kayak must be stable and self-righting. Boat design rules will help here and we will confirm performance using simple models. The occupant must be able to get back in the kayak from the sea. We will use our existing fresh-water kayak to determine the critical factors.

Following these independent investigations Liz will bring these threads together to design the basis of the marine kayak. A first prototype will be constructed to confirm that the basic design meets the technical goals, listed above.

Duration 5 month
Location 70% Incept 30% Massey
Milestone Prototype tests confirm that basic kayak shape meets goals for strength, drag, windage and bouyancy by 30 September 2000

4. Prototyping

An integrated design bringing together aspects of the kayak invested in previous section, and other requirements from the specification (e.g. a rudder system) will be developed. Liz will use the Solid Works 3D solid modelling software to design the kayak. This software will 'unfold' 2D shapes that will speed up prototyping.

The fellow will work with the manufacturing team to produce the prototype and will then put it through a test programme to test out:

- Strength – does not collapse when simply supported and a central 100kg load applied,
- Hydrodynamic drag – less than best competitors kayak,
- Windage- effect of side winds minimised
- Bouyancy- self righting
- Ergonomics – ease of paddling, day long comfort confirmed
- Entry and exit on land and in water is easily accomplished
- Loading – people plus packs
- Weight – less that 18kg,

Following the test programme the kayak will be redesigned and re-tested where necessary to meet the technical specification.

Duration 2 month
Location 50% Incept 50% Massey
Milestone Full-size prototype meets strength, drag, windage and bouyancy goals as well as specification shown to meet developed, and shown to meet design criteria by 30 September 2000.

5. Report

Prepare design report for Incept, covering

- Product development process
- Key factors and trade-offs
- Test procedures
- Final design
- Potential refinements
- Potential parallel products, e.g. two person kayak

Prepare thesis

Duration 2 months
Location 30% Incept 70% Massey
Milestone Design report completed, by 30 November 2000

Note: Time split Incept/Massey is 57%/43% with 6.8 Months of the 12 month masters spent at Incept

PRODUCT DATA SHEET
TPU 2300

TEST & METHOD	TYPICAL CHARACTERISTICS			
	STANDARD		METRIC	
Fabric, Type	Polyester 1000 Den 8.0 Oz/yd²		Polyester 1100 dtx 270 gm/m²	
Total Weight ASTM D 751	31.0 Oz/yd²		1050 gm/m²	
Coating Type	Top Side: Pu Back Side: PVC			
Breaking Strength (Strip) ASTM D 751 procedure. B	385 / 360 lbs / inch		350 / 330 Kg / 5 cm	
Tear Strength ASTM D 751 Procedure B	33 / 28 lbs		15 / 13 Kg	
Tear Strength BS 3424 Part 5 Method 7B	77 / 66 lbs		35 / 30 Kg	
Adhesion (HF Welding) ASTM D 751	Top	Back	Top	Back
Dry	27.5 lbs / inch	22.0 lbs / inch	25 Kg / 5 cm	20 Kg / 5 cm
Wet (24 hours in 3% Saline Solution)	27.5 lbs / inch	22.0 lbs / inch	25 Kg / 5 cm	20 Kg / 5 cm
After Hydrolysis (42 days @ 70°C)	24.2 lbs / inch	20.0 lbs / inch	22 Kg / 5 cm	18 Kg / 5 cm
Blocking Resistance ASTM D 751-70°C(160°F) 6 hrs.	# 1			
Air Porosity BS. 4F 100 Clause 32.1	Pass (10 minutes at 7 psi)			
Weft Distortion	1.6 inch max.		40 mm max.	
Puncture Resistance Fed. Std. 101 - 2031	220 lbs		100 Kg	

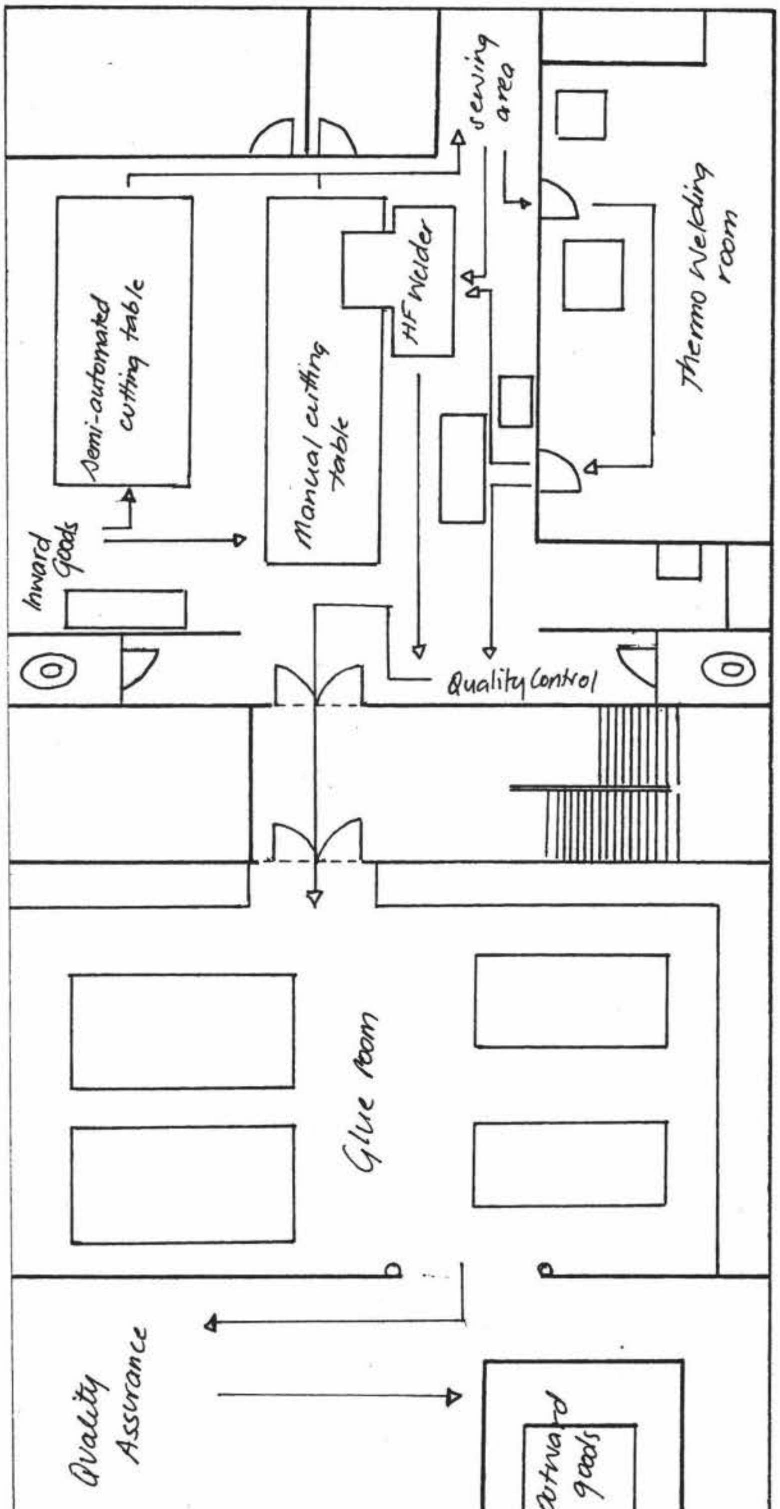
Update: August, 1999

Comments: Preliminary specification based upon initial production run.

Recommended end use: Boats

We believe this information is the best currently available.
It is subject to revision once additional know-how is gained. We make no guarantee of results and assume no obligation liability whatsoever in connection with this information.

9.3 FLOW OF MANUFACTURING PROCESSES



9.4 SAGE PRODUCT SHEET

EXPLORE

The Worlds' Finest Inflatable Kayaks
Made In New Zealand

Welcome to the exciting new dimension of inflatable kayaking. This is no ordinary inflatable. It is the world's first lightweight backpackable high performance inflatable kayak. The SAGE boldly enters a new realm of adventure kayaking never before explored. There has been no compromise in design, workmanship nor materials to offer you the very best available. Whether it's leaping off waterfalls, performing rodeo tricks, exploring remote rivers or simply surfing your favorite wave, the SAGE does it all with style. Its friendliness and stability appeals to the beginner; so too its performance and portability to the expert. Its unique design achieves exceptional rigidity and takes just minutes to inflate. Innovative outfitting allows easy (eskimo) rolling, makes the boat supremely comfortable to paddle, and provides a large accessible compartment for stowage. These are just some of the features which make the SAGE simply awesome. Go ahead, try it. Be warned - you'll love it.

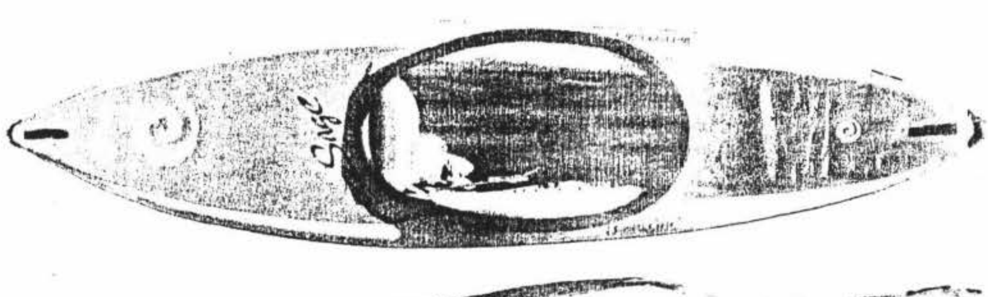
fety:
signed with major consideration to safety, the GE kayak has EasySlip thigh braces and a super ge cockpit to make exiting easy and certain in / situation. It is perfect for self rescue, easy to over, can be remounted in midstream.

atures:
ḥ performance capabilities, unsinkable, (eskimo) able, exceptional rigidity. Fully collapsible, itweight and back-packable. Large stowage com- ment, grab handles, heavyduty materials, pro- ive end cones.

iipment:
ded quick-release thigh straps. Adjustable foot back rests. Pump and repair kit. Neoprene spray ; included.

terials and Construction:
eptionally strong. Manufactured with care by pt New Zealand using finest quality 32oz .YMAR (TM) fabrics containing 1100 denier en polyester basecloth. All air compartments are ed using state-of-the-art High Frequency and mo-bonding processes.

ranty:
ırs against faulty materials and workmanship.



Specifications:
Length 10' 0" (3.0 m) Width 2' 4" (0.7 m) Weight 26 lb (12 kg)
Folded 14"x 14"x 12" (.35 x.35 x.30)

[redacted]

[redacted]

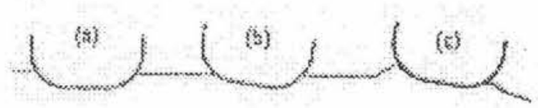
Hip Height		Men 5th %ile	50th %ile	95th %ile	SD	Women 5th %ile	50th %ile	95th %ile	SD
British Adults	19-65	840	920	1000		740	810	885	
	19-25	850	935	1020	52	745	815	885	43
	19-45	845	925	1005	49	745	815	885	43
	45-65								
	65-85								
	elderly people	785	875	965	55	700	780	860	49
US Adults	19-65	835	915	995	50	760	835	910	45
Japaese adults		765	830	895	41	700	755	810	33
hong Kong Chinese Adults		790	855	920	41	715	785	855	42

Hip Breadth		Men 5th %ile	50th %ile	95th %ile	SD	Women 5th %ile	50th %ile	95th %ile	SD
British Adults	19-65	310	360	405		310	370	435	
	19-25	300	350	400	31	300	350	400	29
	19-45	310	355	405	29	300	365	425	37
	45-65								
	65-85								
	elderly people	290	340	395	32	285	355	425	43
US Adults	19-65	310	360	410	30	310	375	440	39
Japaese adults		280	305	330	14	270	305	340	20
hong Kong Chinese Adults		300	335	370	22	295	330	365	21

Pheasant (1986, 1987)
Tilley (1993)
http://home.earthlink.net/~stevejp/amthro.html. Fundamental Anthropometric Data sourced 15 February 2000

9.6 HULL SHAPES AND SECONDARY STABILITY

Round-bilged or shallow-arched hull



a). Primary stability. These hulls appear less stable on flat water than flat-bottomed hulls because there is less of the hull in the water. However they offer the best all-round performance

b). Secondary Stability. When the canoe is leaned on flat or moving water the widest part of the hull is in the water, so its stability is greater.

c). On waves the canoe rocks less that the flat-bottomed hull and is therefore easier to keep upright. They perform well in waves and white water.

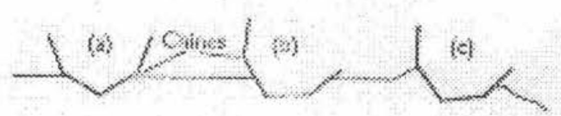
Flat-bottomed hull

a). Primary stability. This hull appears very stable on flat water. They are good for general recreation where initial stability is needed.

b). Secondary Stability. When the boat is leaned, less hull is in the water making it les stable than when kept level.

c). On waves it rocks from side to side a lot and demands an effort from the paddler to keep it upright in rough water.

Shallow V-shaped hull



a). Primary stability. This hull appears less steady on flat water. Only a small surface area is in contact with the water so initially is will rock from side to side onto its chines and feel less stable.

b). Secondary Stability. When leaned its stability is much greater as more hull is placed in the water as its widest part. This design is the most stable overall although it is not as fast in the water as the round-bilged hull.

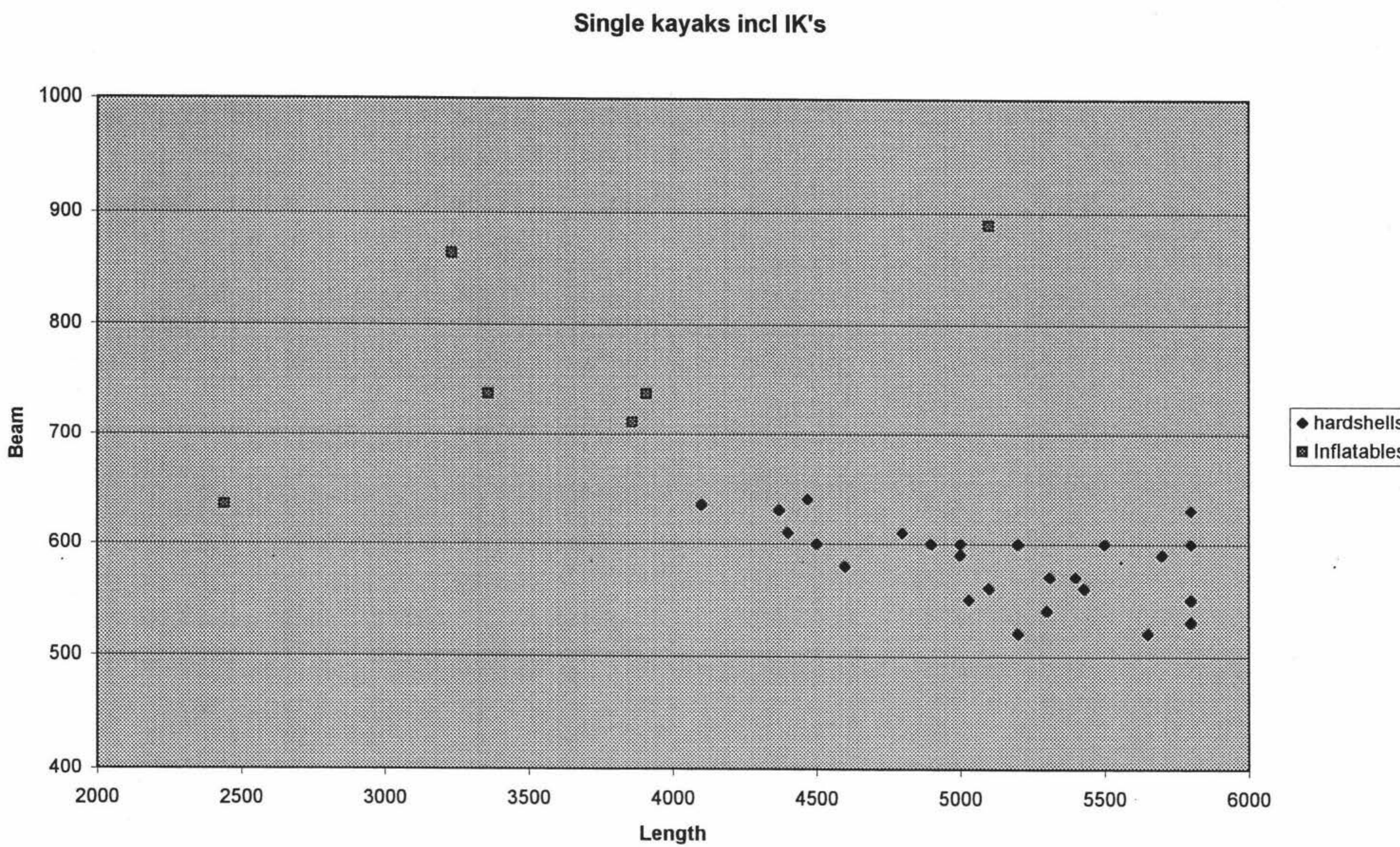
Annat (1995).

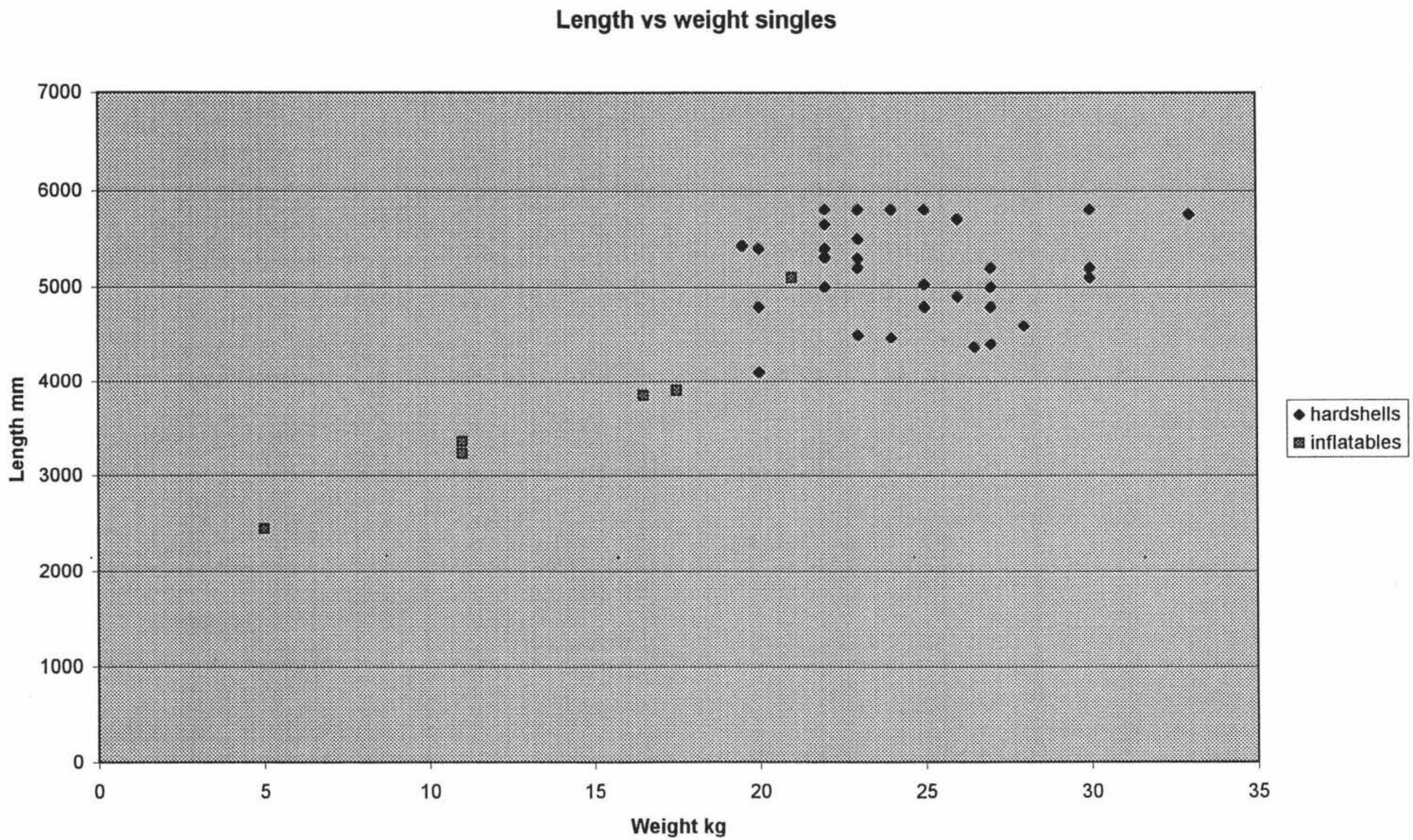
Single sea kayaks

Boat	Length	Beam	Material	kg's	Cost	Pad	Volume	Stability	Use
Pacifica	4100	635	rotomoulded	20	995	b/i			Small touring
Spectrum	4370	630	rotomoulded	27	1220	b/i			touring
Yukon Experience	4400	610	HTP Blow Moulded	27	1500	b/a	high		long distance open water and river
Carolina	4470	640	rotomoulded	24	1550	b/a	high		performance touring
Breeze	4500	600	roto in polyethylene resins	23	1450	b/a	low	good	
Scimitar	4600	580	rotomoulded	28	1800	l/e			performance/ cruising
Penguin 2000 - lightweight	4800	610	rotomoulded	20	1910	b/a			
Penguin 2000 - standard	4800	610	rotomoulded	25	1775			good	
Penguin 2000 - with pod	4800	610	rotomoulded	27	1810				
Seayak	4900	600	HTP Blow Moulded	26	2299	b/a	high	good	sporty open water touring
Challenge 5	5000	590	fibreglass	22	2700	b/a	medium	good	touring
Narpa	5000	600	rotomoulded	27	1990	ab/l			big water
Squall	5030	550	rotomoulded	25	1856	b/i	medium	good	
Sea Lion	5100	560	rotomoulded	30	2100	l/e	good		performance/cruising
Looksha	5200	520	rotomoulded	23	2200	l/a	medium	good	
Sea Quest	5200	600	roto in polyethylene resins	30	1600	b/i	high	v good	
Storm	5200	600	plastic	27	1856	b/i	medium	good	
JDS Breaksea	5300	540	kevlar		4050				
JDS Breaksea	5300	540	fibreglass	23	3650	b/e			
X Factor	5310	570	kevlar	22	3558	l/e	low/med		
Albatross	5400	570	kevlar		3175				
Albatross	5400	570	fibreglass	22	2815	b/e		good	high performance
Cutlass	5400		kevlar	20	3400	b/a	350 litre		touring
Khatosalano	5430	560	Hypalon	20	5800	e			high performamce
Sea Bear 1	5500	600	kevlar	23	3450	b/a	high	yep	rough
Slingshot	5650	520	kevlar	22	3975	e	med/high		high performacne touring
JDS Expedition	5700	590	kevlar		4150				expedition
JDS Expedition	5700	590	fibreglass	26	3750		large	good	
Sabre	5750		kevlar	33	3900	a	450 litre		sport touring
Discovery	5800	530	fibreglass	30	2950				open water fast
Discovery	5800	530	kevlar	25	3450				
Arluk 1.8	5800	550	fibreglass	23	2850	l/a			Rough water
Pacific 19	5800	600	kevlar						

Pacific 19	5800	600	fibreglass	24	3039 l/a	med/high	good	
Barracuda Expedition	5800	630	kevlar	25	3200			
Barracuda Expedition	5800	630	fibreglass	30	2800	high		open water
Explorer 580	5800	630	fibreglass		2800			
Explorer 580	5800	630	kevlar	22	3200	high		
Junior	2440	635	Rubber/nylon	5				
K 79	3230	864	PVC	11				
Helios 340	3360	737	Rubber/nylon	11				
Explorer 1	3860	711	Hypalon/nylon	17				
Dolphin 1	3910	737	Hypalon/nylon	18				
Sea Tiger 1	5100	889	Urethane/nylon	21				

Ranges excluding IK's
Beam range 520mm - 640mm
Length 4100 - 5800mm
weight 19.5kg - 33kg
cost $995 - $5800

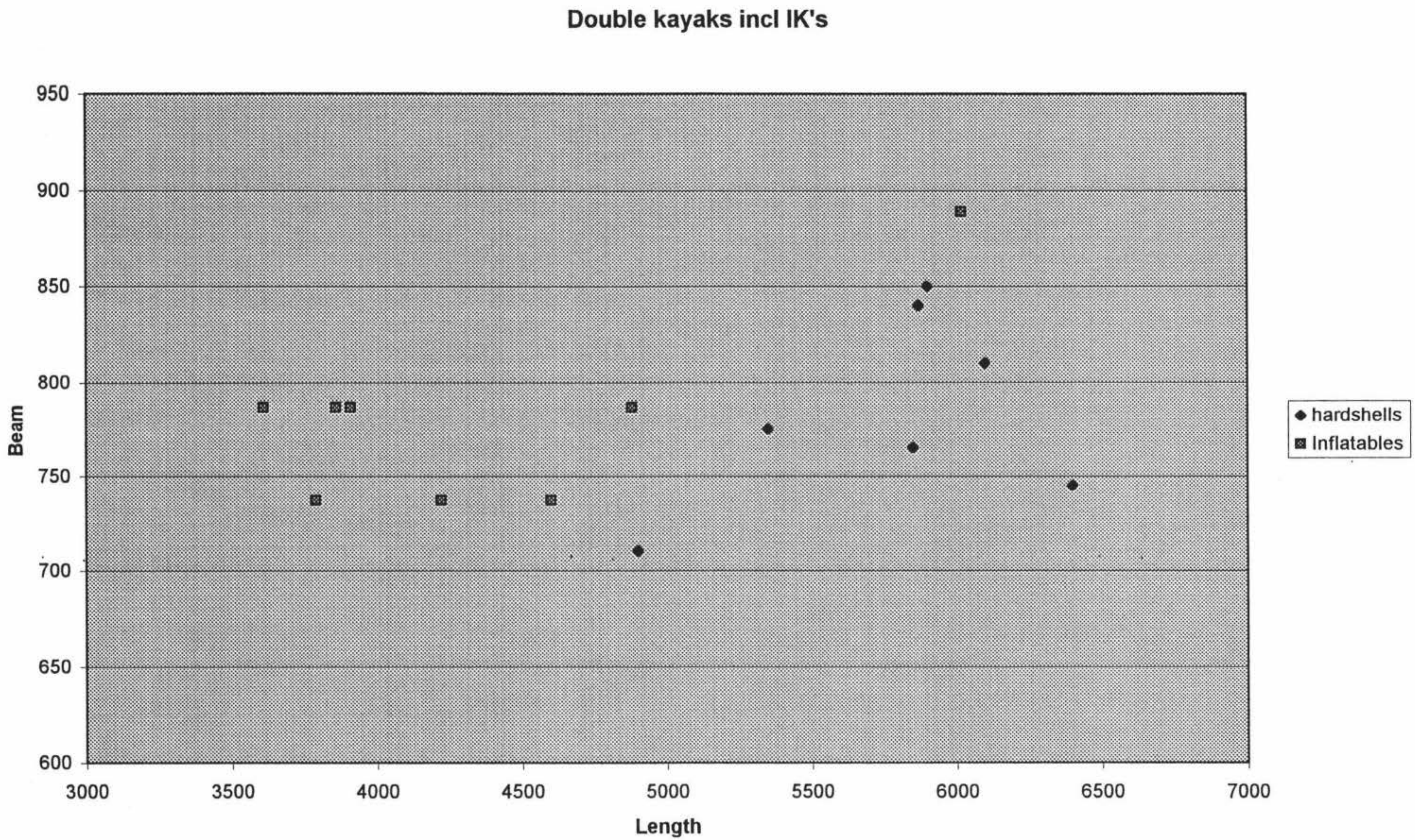

Single kayaks incl IK's
1000
900
800
700
600
500
400
Beam
2000
2500
3000
3500
4000
4500
5000
5500
6000
Length
hardshells
Inflatables


Length vs weight singles
Length mm
7000
6000
5000
4000
3000
2000
1000
0
0
5
10
15
20
25
30
35
Weight kg
hardshells
inflatables

Double Sea kayaks

Boat	Length	Beam	Material	kg's	Cost	Paddler	Volume	Stability	Use
Odysee	4900	710	HTP blow moulded	33	2690	b/a			tourin,
									high speed cruising
Klondike	5350	775	Hypalon	34.5	6500	b/e	med	excellent	Folding kayak
						Comes standard as a double			
Dobbe Tuart	5850	765		46	4850	b/e	med		
K2 Expedition	5870	840	Hypalon	39	7200			good	
Sea Bear II Packhorse and Packhorse Express	5900	850	kevlar	40	5295	All	high	outstandin	Tourers with superb
									rough water handling
Dobbe Double	6100	810		54	4750	b/e	high		all-round
						low bow entry and longer exit stern gives the ...			
Outbacka Double	6400	745	fibreglass	45	4000				High performance
Outbacka Double	6400	745	kevlar	38	4600				
Tramper	3860	787	PVC/nylon	12					
Helios 380	3790	737	Rubber/nylon	13					
Dolphin 2SL	4600	737	Hypalon/nylon	20					
Dolhpin 2	4220	737	Hypalon/nylon	19					
Holiday	3910	787	Hypalon/nylon	15					
Holiday Economy	3610	787	Hypalon/nylon	9.5					
Explorer 2	4880	787	Hypalon/nylon	23					
Sea Tiger 2	6020	889	Urethane/nylon	23					

References:
Sutherland, 1998
Dickson, 1999
Ferguson, 1998


Double kayaks incl IK's
Beam
950
900
850
800
750
700
650
600
3000
3500
4000
4500
5000
5500
6000
6500
7000
Length
hardshells
Inflatables

9.8 CUSTOMER NEEDS

A needs tree was made in gathering consumer feedback of needs. Each comment was collected and then similar comments relating to the same or similar needs were collated together. The following list is the outcome of the needs tree with the comments evaluated according to the topic that each related to. Each need identified by customers has been sorted under general headings as many are similar. The layers imply a need within a need in that a need may be directly related to achieving another need.

Durability
- Material is resistant to the marine environment
- Material is resistant to UV

Windage
- Not blown around by wind
- Low windage
- Low profile in the water
- Can get through surf

Portability
- Carried easily
- Lightweight
- Comfortable to carry
- Dimensions when stowed enable it to be considered cabin luggage

Stability
- Can be re-entered at sea
- Easy to get in and out of
- Primary and secondary stability
    - Stable on flat water
    - Stable in rough water
        - The Kayak has a wide beam

Comfort
- Is comfortable over long periods of time

Easy to paddle
- Fast
- Tracks well
    - Will go straight without correction strokes
    - Rudder
    - Good keel line
    - Easy to turn
    - Manoeuvrable
- The paddler is not required to reach excessively over beam to paddle

Safety
- Does not fill with water
- Buoyant even if one cell deflates
- Safe in rough weather
    - Seaworthy
    - Stiff/rigid

Use
- Use as transport
- Capable of expeditions
- Able to store large amounts of gear
- Hold bulky gear
- Easy to pack with gear
- The Kayak is able to carry equipment

Decks
- The Kayak has a spray deck
- The Kayak has a stiff cockpit
- The Kayak has hard hatch for cutting things on

9.9 EVALUATING NEEDS

Need	Comments
1.	Durability Durability is of utmost importance in a sea kayak for performance and so that the paddler feels safe, and that he feels he has got value for money. In practical terms the kayak must be manufactured from materials that have proven performance in marine environments and the harshest of conditions. Environmental ailments include U.V radiation from the sun, heat, salt, water, wind, seaweed, fish, rocks, chemicals, etc.... Therefore it is important to set a minimum expected product life cycle for the materials and methods used during manufacture. This product life cycle should be comparable with hardshell kayaks and be perceived as more that existing inflatables'. The material chosen must meet these specifications. The manufactures of the material would be expected to have this information and equivalent testing for the materials. As a preliminary guideline the kayak materials are expected to last around 5 years before degradation is apparent. Degradation will be more apparent in boats that have been misused, so the design should consider abuse such as over inflation, being left in the sun, and provide instructions on use and storage to gain the best durability of the kayak. Punctures are likely in an inflatable boat and therefore the ability to fix a hole is included in the aspect of the kayak's durability. As well as the need for the kayak to be able to be paddled if one cell deflates until safety is reached and it can be fixed. The manufacturer may wish to use a product warranty. The user must also feel confidence in the boat, in that it is safe, stable and rigid.
2.	Windage " In strong beam winds nearly all kayaks have a tendency to 'weathercock', i.e. their bows tend to swing round into the wind, causing the paddler to make tiring corrective strokes on the upwind side." (Hutchinson, 1994). The problems that the wind can create are potentially disastrous. To ease the problem the kayak should have minimal amount of free board above the water line as practical so there is less for the wind to catch. The use of a skeg or rudder can help to stop the bow or stern being blown in the wrong direction of the wind. Metrics that may be useful to

	minimise windage would be to measure the surface area exposed to the beam wind especially at the bow and stern, also to measure the angle the boat 'weathercocks' to measure the positive effects of the rudder. Something to consider is that a larger volume bow helps the kayak over waves and give the paddler a drier ride, so these two characteristics may need o be compromised.
3.	Portability The main benefit of an inflatable kayak is its potential to be lighter and smaller than hardshell's for portability reasons. This includes the transportation from storage to location including as baggage on aeroplanes, trains, boats and in cars. As well as being carried by an individual with relative ease and comfort. Three components as can currently be perceived are: the weight of the kayak, the dimensions of the kayak when it is rolled up, the method of portage ie trolley, straps, carry bag etc.... The weight and dimensions will have upper limits one suggestion from Sutherland is 18kg. Airlines and such have various restrictions on baggage weights and size.
4.	Stability The kayak must be able to be re-entered at sea in case of a capsize, as well as be easy to get in and out of at mooring, these can only be evaluated by experience. The kayak is expected to have both primary and secondary stability as the kayak will be expected to go on expeditions and exposed water, having looked at hull shapes something with some sort of chines would be beneficial for overall stability. Metrics to help evaluate the stability will be the surface area of the kayak in the water, and the angle of heel to continue a positive upright state.
5.	Comfort The paddler will consider comfort essential. The paddler is unable to get out, and when extended journey's are taken the comfort of the kayak will determine the pleasure of ones journey. Comfort includes the position of the lower body in a seated position as well as warmth and comfort of the upper body as it paddles for hours on end. This is particularly if the kayak is used in colder climates as the paddler would wish to stay as dry as possible, therefore the amount of spray that comes over the deck and reaches the paddler is also of interest. A spray deck would come in handy here.

	In terms of lower body position back support and leg position and movement are important to stop stiffness becoming prevalent. The bracing of the paddler to the boat is important especially in rough conditions where secondary stability is important. How is this going to be achieved? A formed seat and backrest could be developed for the kayak with ergonomic considerations for support areas.
6.	Ease of paddling Speed, maintaining speed or pace with less effort than acceleration, not requiring over extension during paddle stokes, keeping straight without correction strokes, going where you want to go (including turning and manoeuvrability). A range of metrics may give a general evaluation of ease of paddling but there will be areas that require considerable compromise so no areas will be optimised individually in the overall design. Drag and effort would be two useful metrics that may help to give an overall evaluation.
6.a	Manoeuvrability This is developed through the rocker on the hull of the boat. A WWK will have a considerable rocker but the potential to go straight is more important that fast manoeuvring in a se kayak. A rudder can be added to the design to ease the turning ability of the kayak. Manoeuvrability is directly compromised with tracking. A list of methods to help manoeuvring could be considered.
6.b	Paddle reach and beam The beam of the kayak must try to optimise the reach of the paddle stroke to gain maximum effectiveness from a stroke, as well as comfort. The beam width must be correlated with the arm reach of populations expected to use the kayak.
7.	Safety Includes durability, buoyancy, stability and the paddlers perception of risk and their confidence levels. Can the design of the kayak alter the users perceptions of the safety of the boat? Safety also includes the strength of the boat along the length. The kayak must not flex or bend if suspended between two waves. The flex could easily be evaluated by setting up a bending moment experiment with supports and loading, measured by the amount the kayak hogs in any position. Basic physics equations should help to determine the pressure required minimise bending in the tubes.
7.a	Surf The ability to get the kayak through surf is primarily important only when leaving or

	entering a beach area when the kayak is likely to get lifted by the wave and carried uncontrollably back to shore. The paddler would wish to maintain control and direction through surf, and this would be maintained by a secondary stability, with a strong keel line under the water to minimise the kayak turning in the surf.
8.	Ease of use The kayak must be easy to use including getting in and out of the kayak both on land and at sea in case of a rescue. This must be possible in the worst conditions as this is when capsizes are most likely to happen. Factors that may help or hinder the entrance include: stability, cockpit size dimensions, weather, tiredness, skill and co-ordination of the paddler. The most risk occurs with an unskilled paddler with little or no experience, in rough conditions. Having fallen out they may have lost confidence, be tired and cold so the re-entry must be made as easy and trouble free as possible, so the risks are not increased by the extended time in the water. Two metrics to be assessed include the cockpit dimensions and a pass/fail system for ease of getting back in.
8.a	Carrying of Equipment To hold or carry equipment there are three areas that must be considered: How the equipment gets into the holding space? How much space is needed to carry all the gear, and where are these located within the kayak? What are the upper and lower weight limits for the kayak? How much gear is required to be carried over week long trips, what is the expected load carrying capacity, what is normal volumes in a kayak? How is the gear to be packed into the boat, are there going to be hatches? This was one of the most frustrating things of using hardshell boats with small hatches, that there is room for gear but it is difficult to utilise. What are other ways of getting gear into the kayak? Removable deck, stuff back from cockpit, etc... Will additional deck riggings be required to carry gear on the outside of the kayak?
8.b	Bailing The paddler generally wants to keep dry especially in cold climates therefore they will not want water to build up in the bottom of the boat. The kayak being inflatable will be difficult to sink, but could cause discomfort from water build up in the cockpit. What happens to water if it enters in an inflatable?

9.	Decks Not all inflatable kayaks have decks, but they are seen as an advantage and necessity often in cooler waters. A spray deck helps keep the paddler dry and warm. The spray deck may or may not come up into a spray skirt around the paddler and may or may not be detachable. A suggestion included a hard deck for use in storing things and being able to be used for cutting on i.e. if fishing etc.

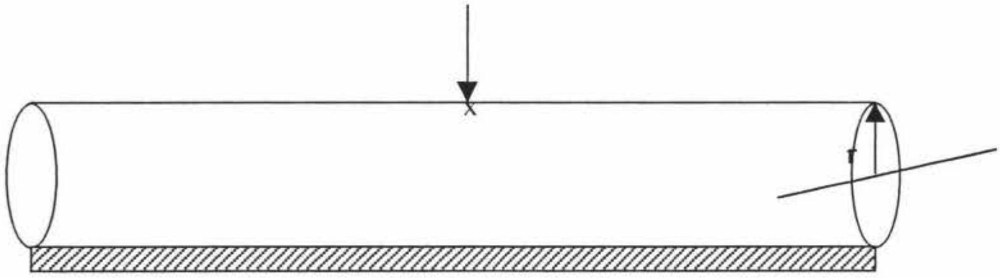
9.10 BENDING EQUATIONS FOR AN INFLATABLE TUBE.

One of the specifications required for the inflatable sea kayak was that the kayak would not bend under a 100kg load.

We needed to work out what P should be for certain tube diameters and lengths of the tubes. It was considered using a single tube.

The tube can be regarded as a simply supported circular beam with a uniformly distributed load (UDL) on the top (reflecting the actual scenario of the kayak uniformly distributed below from the water).

Upward thrust central point load 100 kg



UDL – 100kgs over length L

Part 1

One stress on the beam is when the beam starts to bend and there is compressive and tensile stress at either edge of the tube. Now it is known that just as string has no tension under compression neither does flexible material therefore we need to eliminate compressive stress due to the load by a pressure P, creating an equal and opposite tensile stress.

The bending equation is:

$E/R = f/y = M/I$ Where E is Young's Modulus (stress/strain)

R is the radius of the bend

f is the stress at any distance from the neutral axis

y is the distance from the neutral axis

M is the bending moment

I is the fourth moment of area

Therefore:

$f = y \, . \, M/I$ and we know that at point x that y is equal to the radius of the tube (r)

Therefore:

$f = r \, . \, M/I$

In order to work out the bending moment the easiest way is to invert the scenario vertically so the UDL is at the top and you can work out the bending moment for the UDL. As the load is uniform and the support load is singular and central the beam can be treated as a cantilever.

The BM for a cantilever UDL is –WL/2 (Norman, Cubit, Urry, Whittaker,. 1995)

Putting in that we are only working with L/2 then our equation is WL/4

So the stress at point x is:

$f = r \, . \, WL/4I$

I for a circle with the axis through the diameter is:

$I = \pi D^4/63$ (Norman et al, 1995)

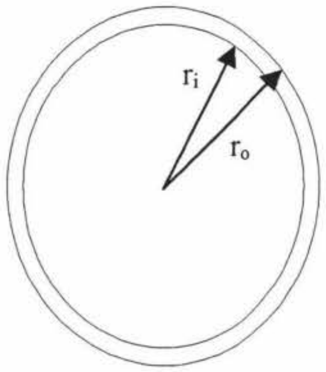
$D = 2 \, . \, r$

So $D^4 = 2^4 \, . \, r^4$

$I = (\pi \, . \, 2^4 \, . \, r^4)/64$

$I = \pi \, r^4/ 4$

We need to find I for the tube that we have so I will be (I for the outer radius r_o) – (I for the inner radius r_i)



$I = (\pi r_o{}^4/ 4) - (\pi r_i{}^4/ 4)$

$f = r \, . \, WL/4((\pi r_o{}^4/ 4) - (\pi r_i{}^4/ 4))$

Part 2:

The other force on the tube is that due to the pressure inside the tube. The pressure is uniform throughout the area of the tube.

Stress f = Force/ cross-sectional area of the tube($2\pi r.t$) where t is the thickness of the material

Force = Pressure (P) . Area (πr^2)

$f = p . \pi r^2 / 2\pi r.t$

Part 3:

Now Part 2 = Part 1 in order to get a value for P.

$P . \pi r^2 / 2\pi r.t = r . WL/4((\pi r_o{}^4/ 4) - (\pi r_i{}^4/ 4))$

So all the measurements for general radius are cancelled out, as is π on the LHS so:

$P/2t = WL/4I$

Therefore $P = 2t . WL/4I$

Where p is the pressure inside the tube

T is the thickness of the material

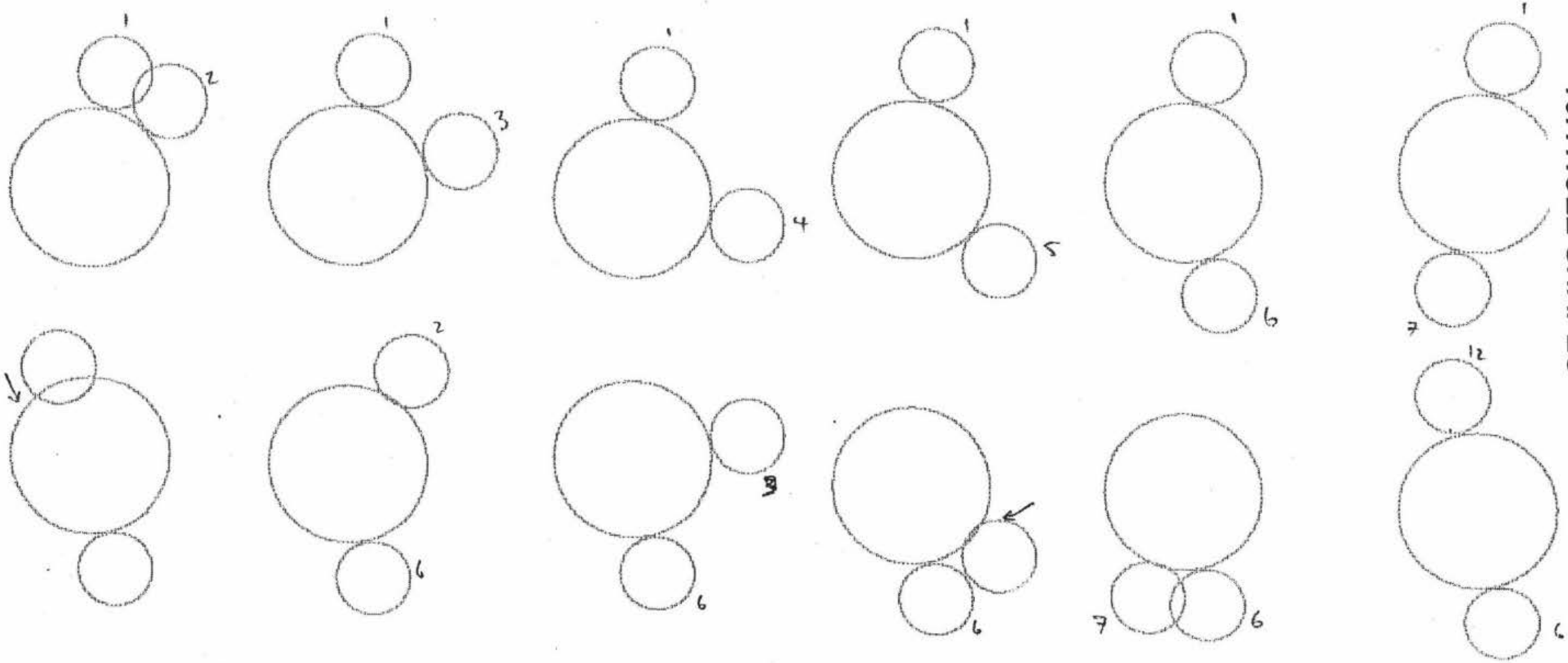
W is the load specified at 100kgs

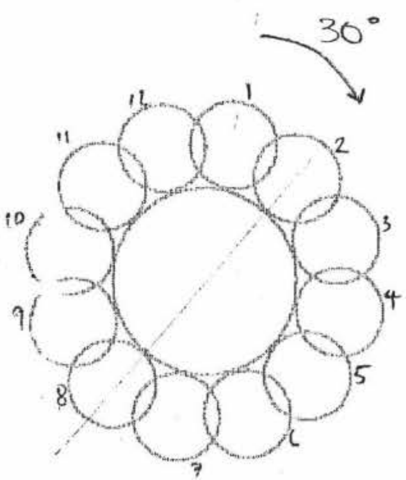
L is the length of the tube

$I = (\pi r_o{}^4/ 4) - (\pi r_i{}^4/ 4)$ which is the fourth moment of area for the tube.

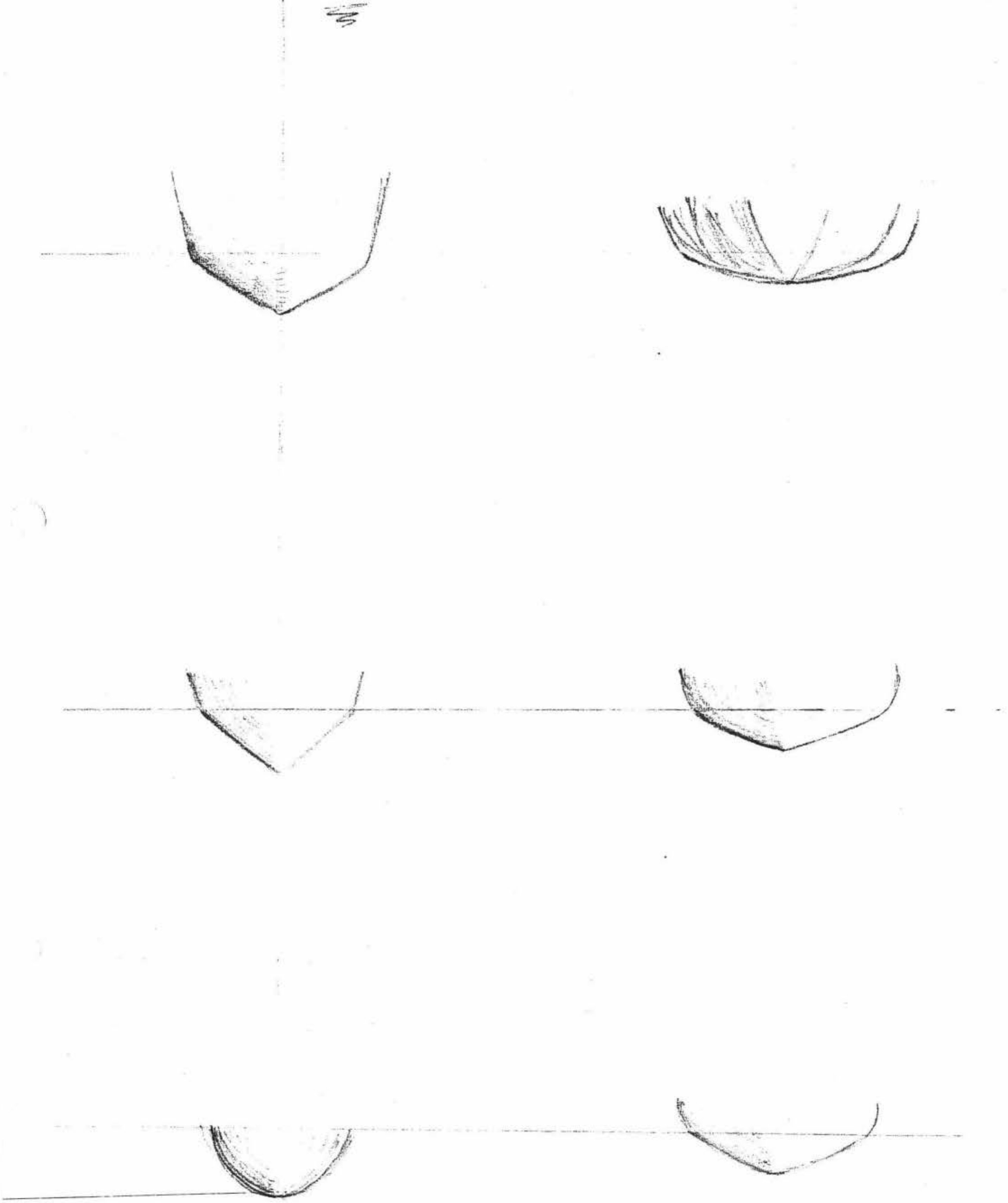
10 APPENDIX B

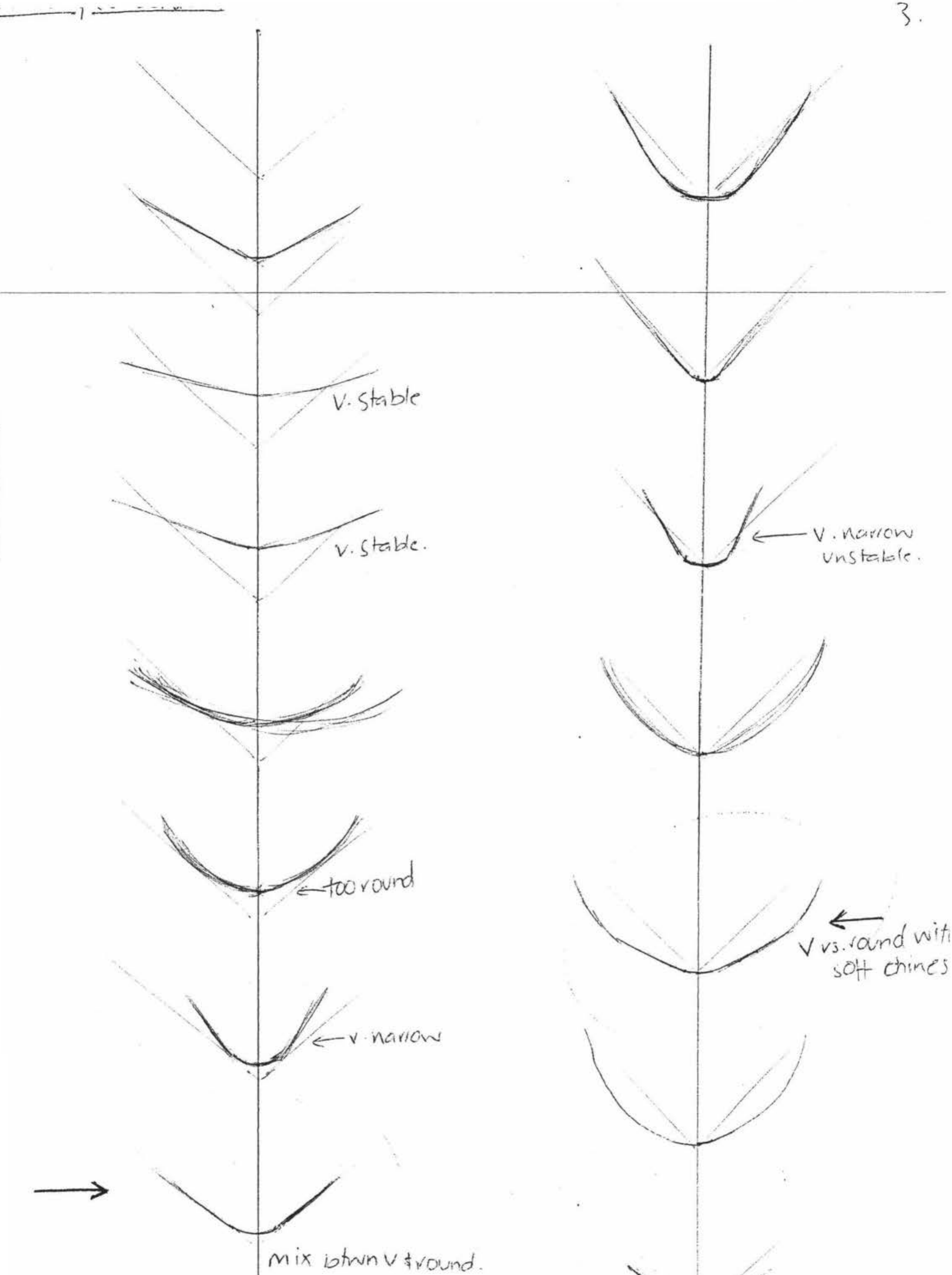
10.1 HULL SHAPES



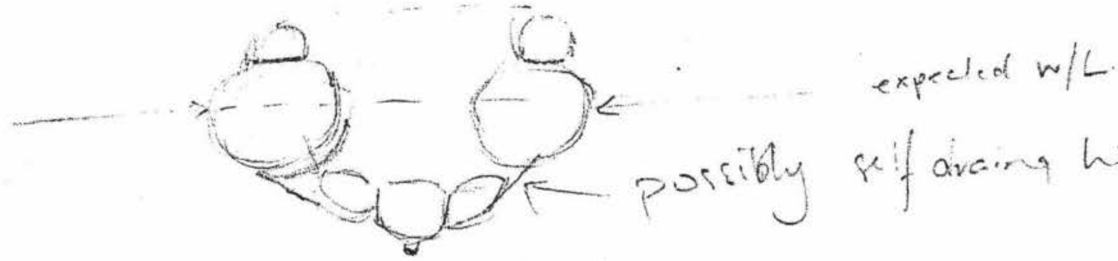


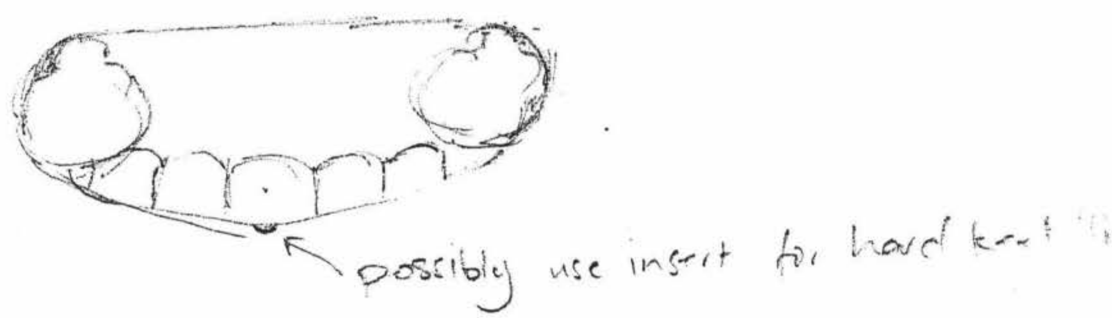
Each of these small and large circles can be placed in any position to one another there are 144 combinations including from left and right. Many more infinite combinations could be provided by displacing either of the cirles by an angle or relation to the larger circle. Use your imagination and the possibilities are endless.

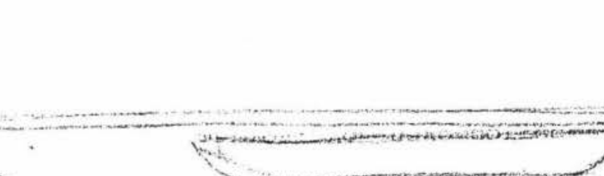



3.
V. Stable
v. stable.
too round
v. narrow
mix btwn v & round.
v. narrow
unstable.
V vs. round with
soft chines

8/3/12

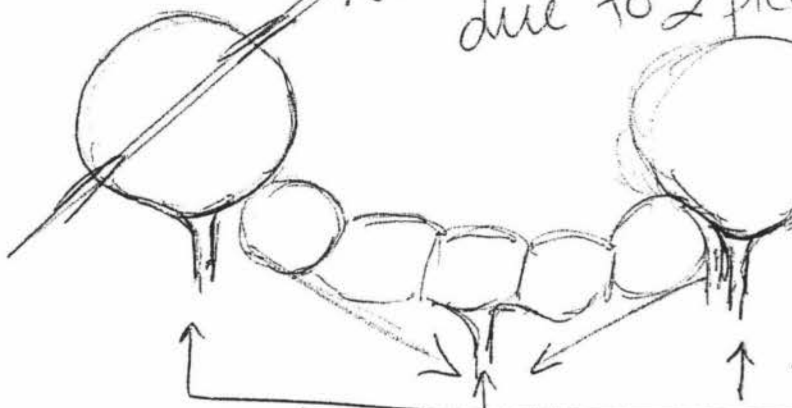

expected w/L
possibly self draing hole

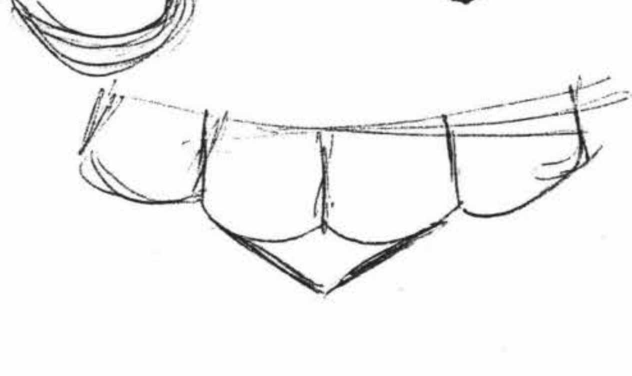

possibly use insert for hard keel



21/5/1

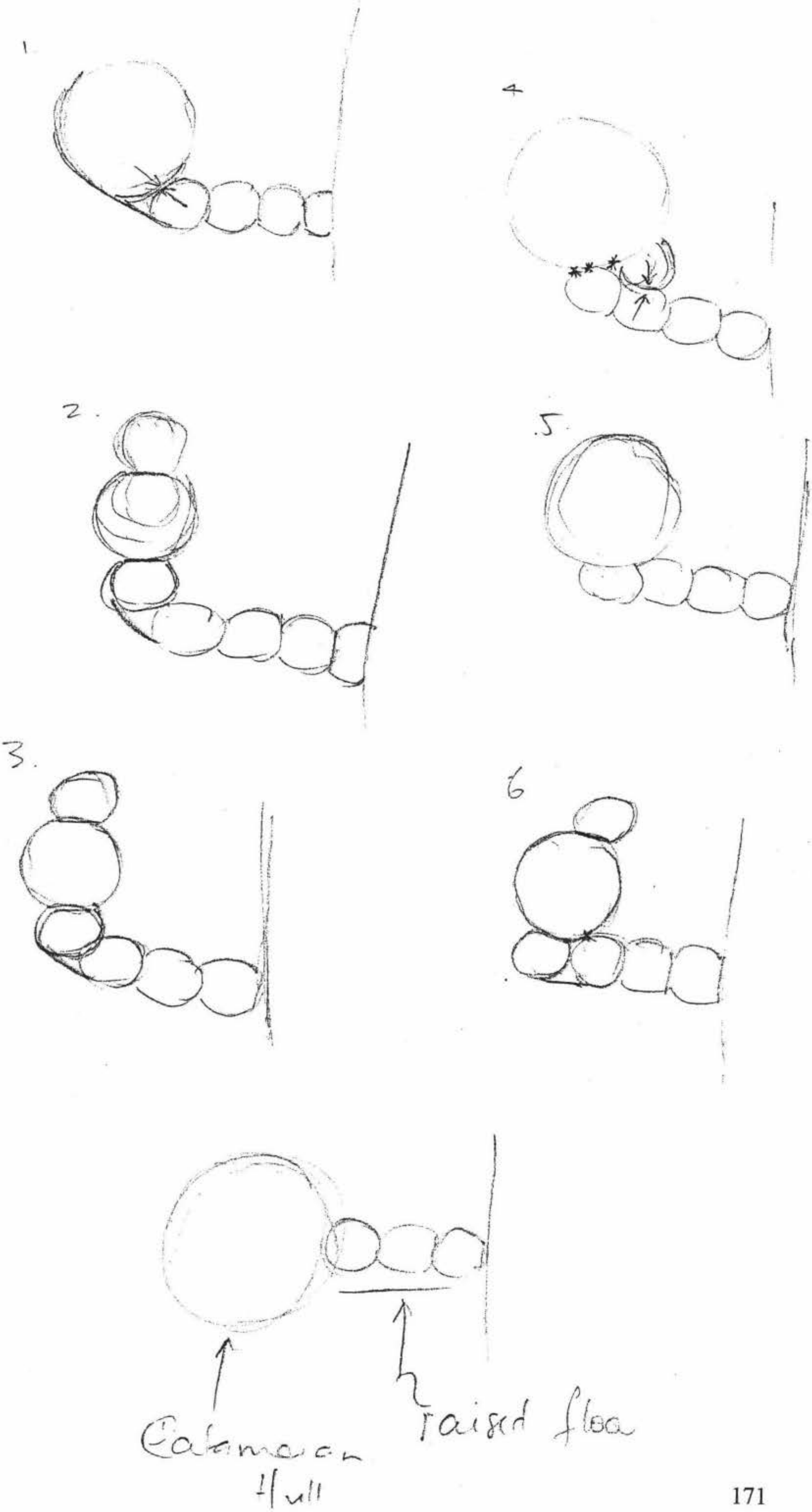
John suggested use of flanges on side tubes, to act as artifical chine or keel.

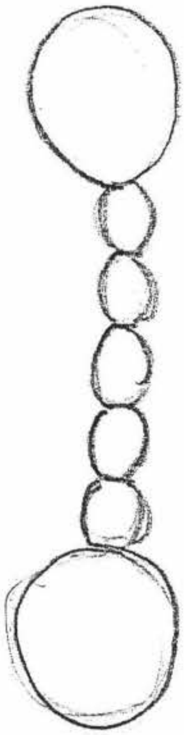


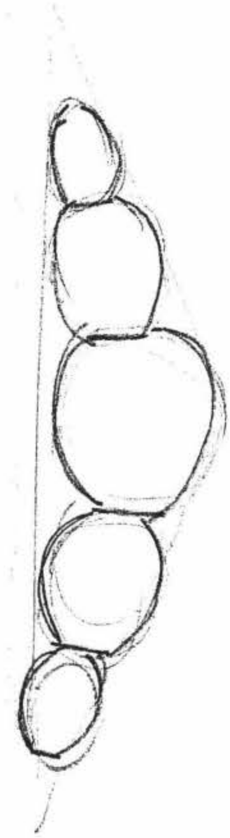


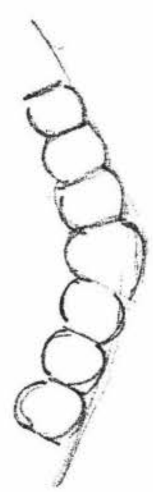
Hull Shape :

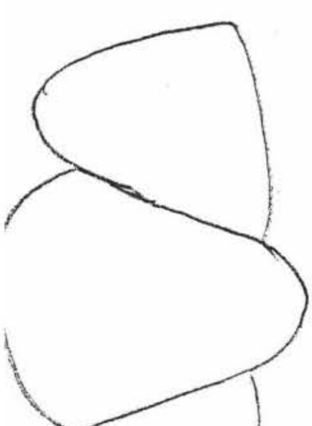
14/7/

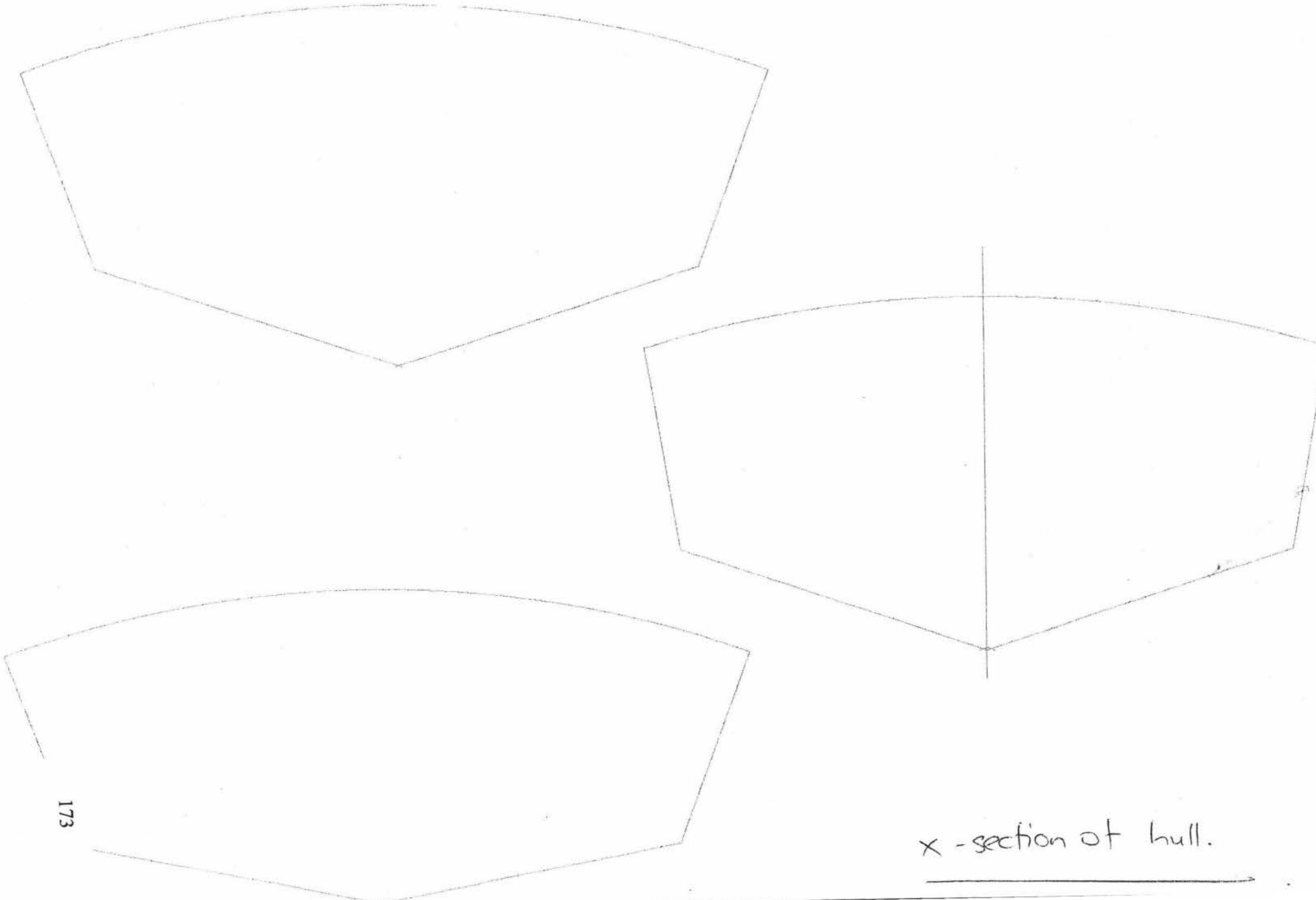






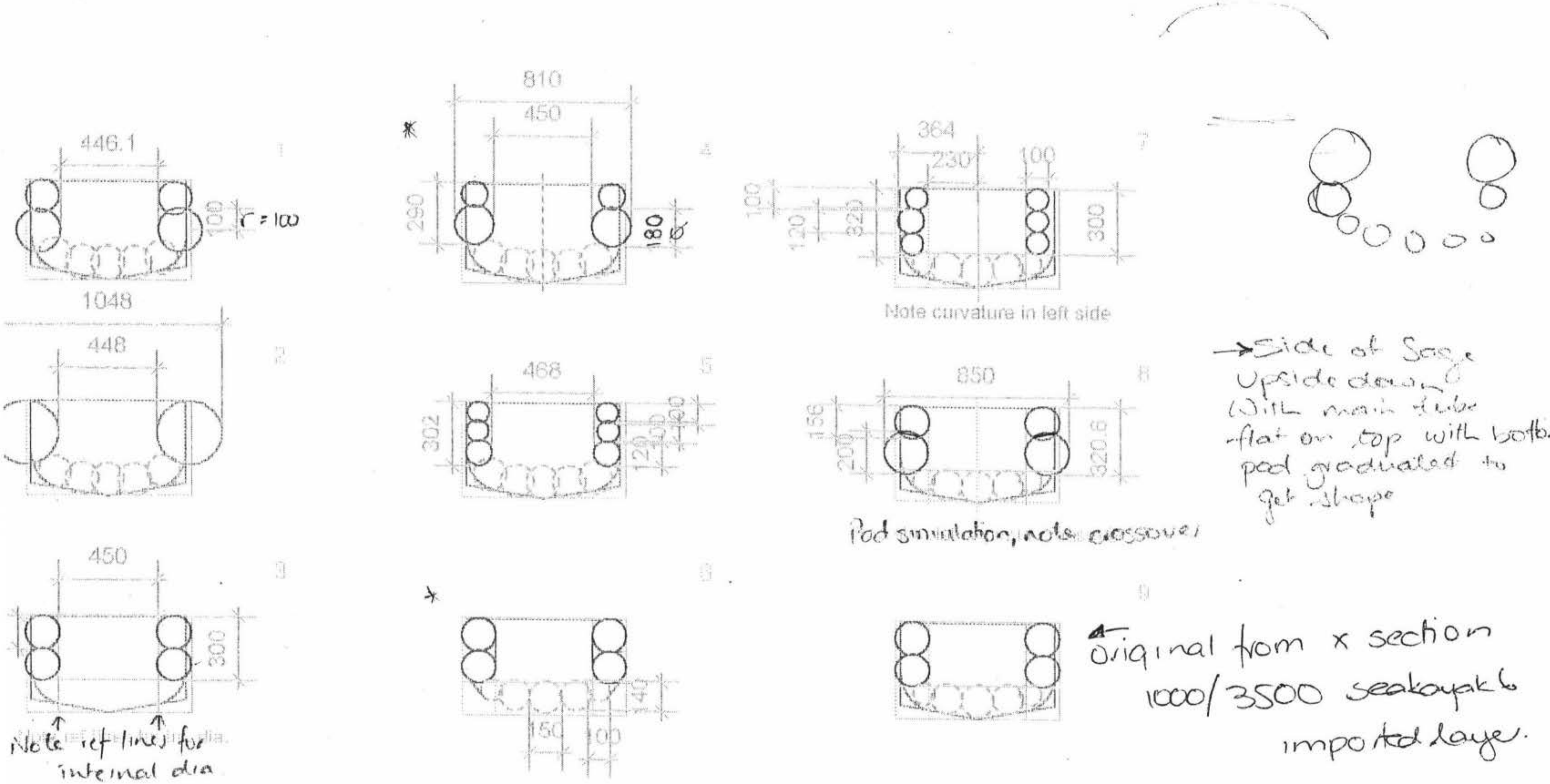




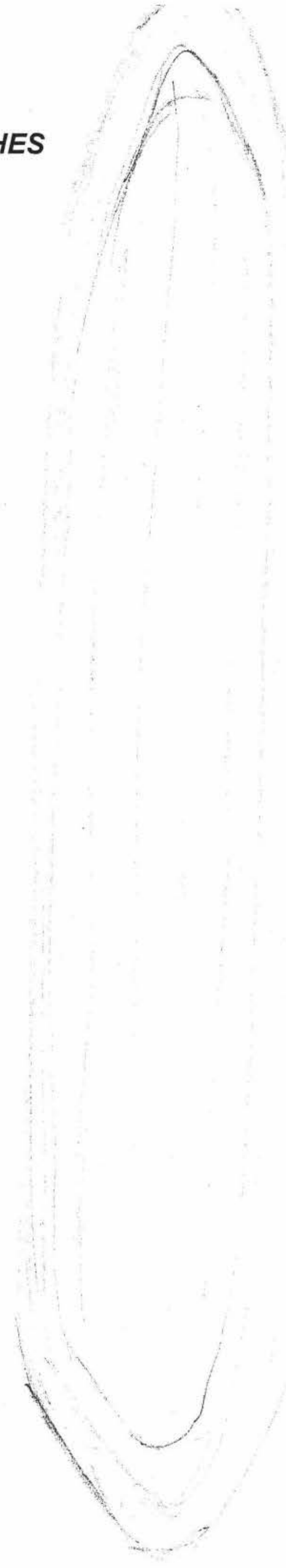


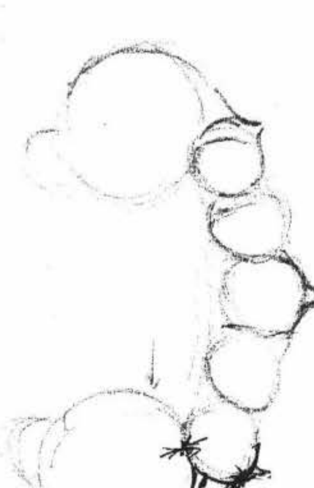
x - section of hull.

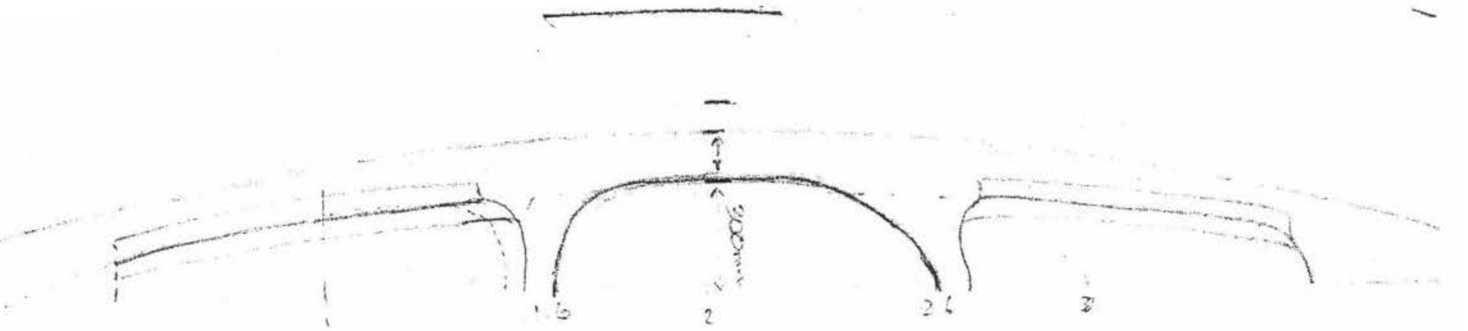
and external beam of the kayak. 15/6/00



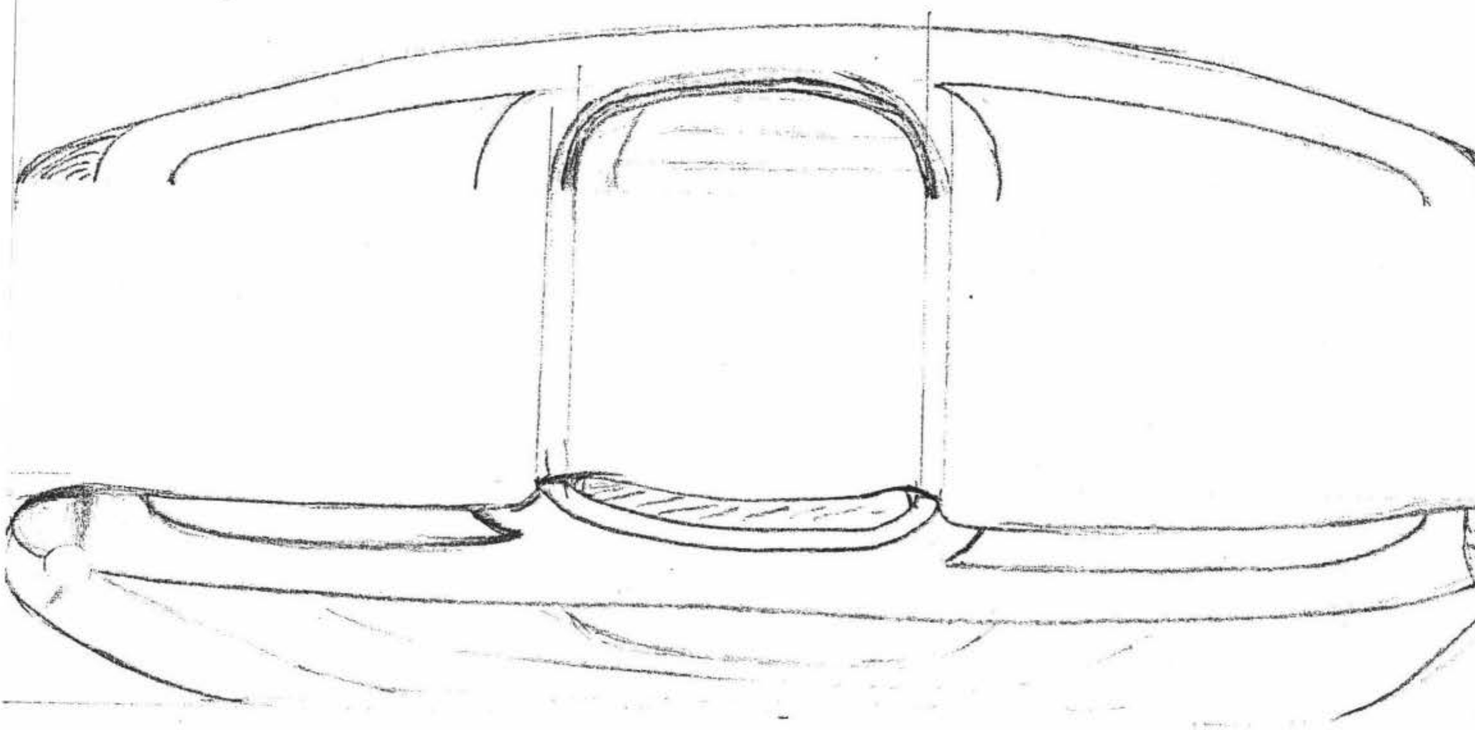
10.2 CONCEPT SKETCHES

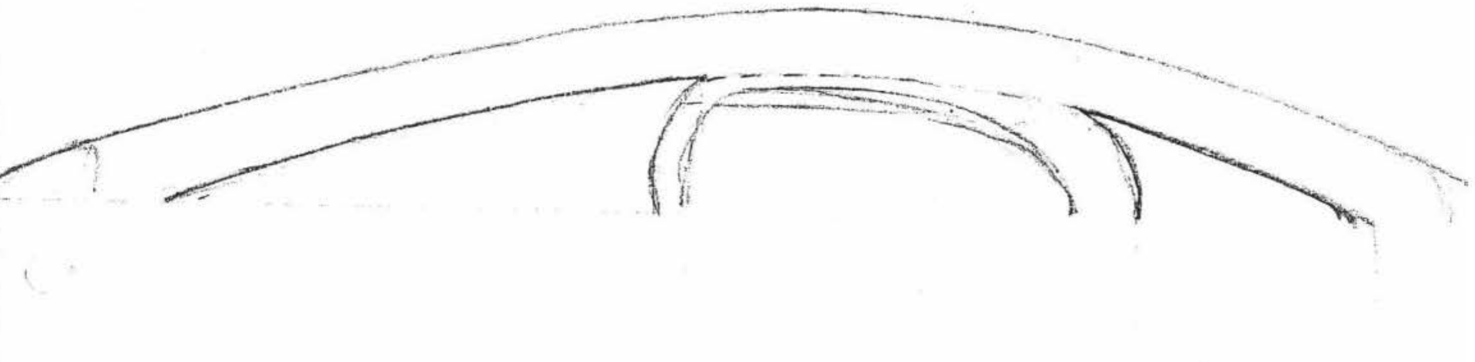




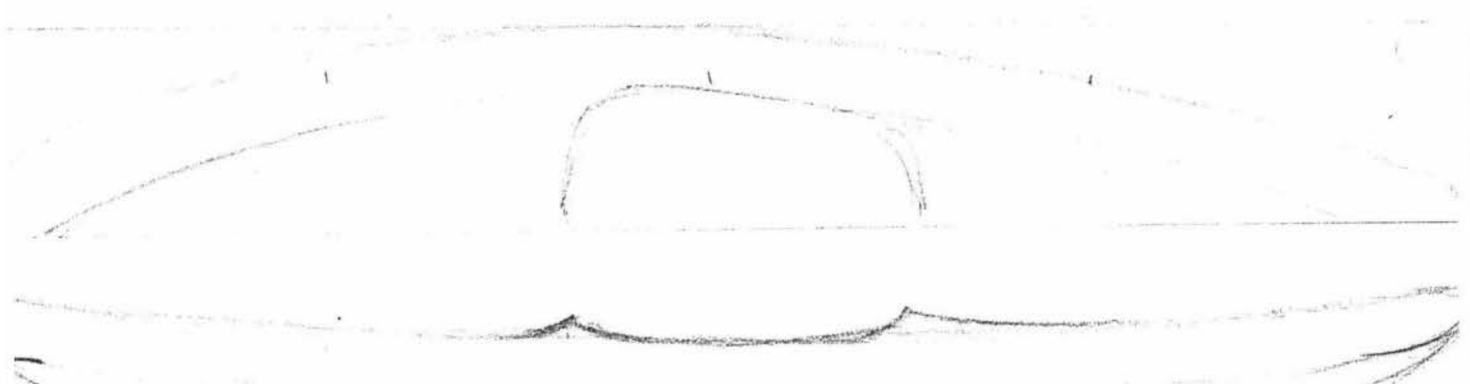


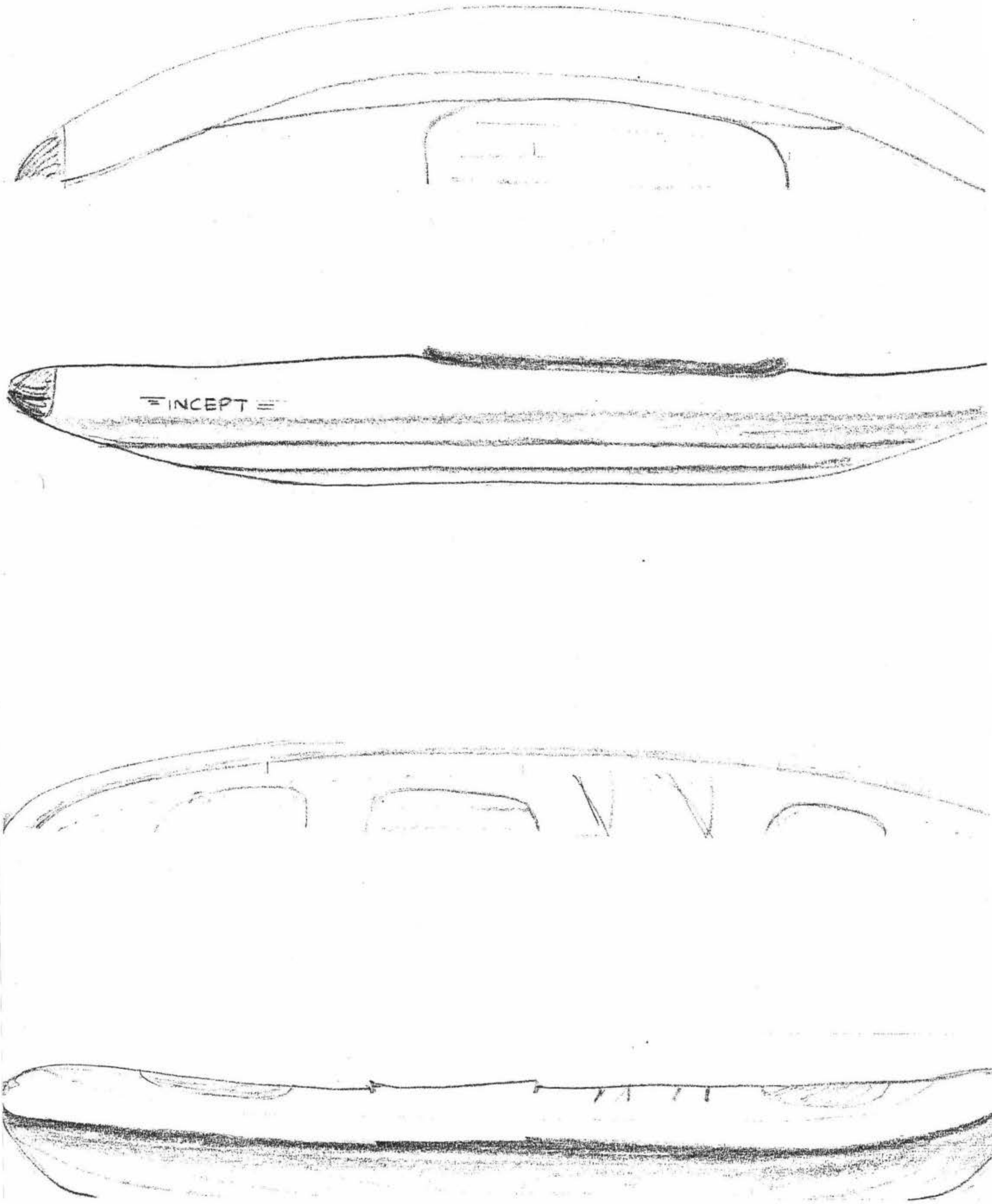

INCEPT

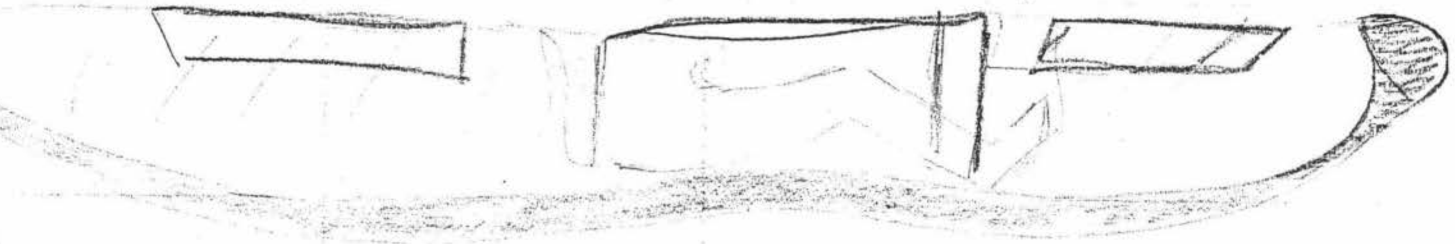


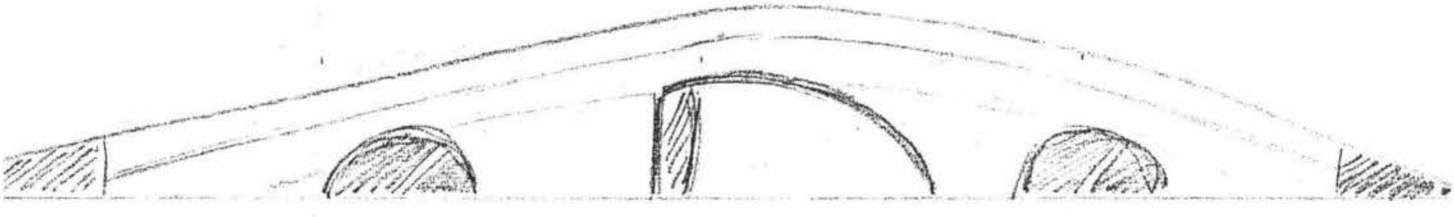


8




INCEPT





10.3 SHAPE AND SEATING CONCEPT GENERATION

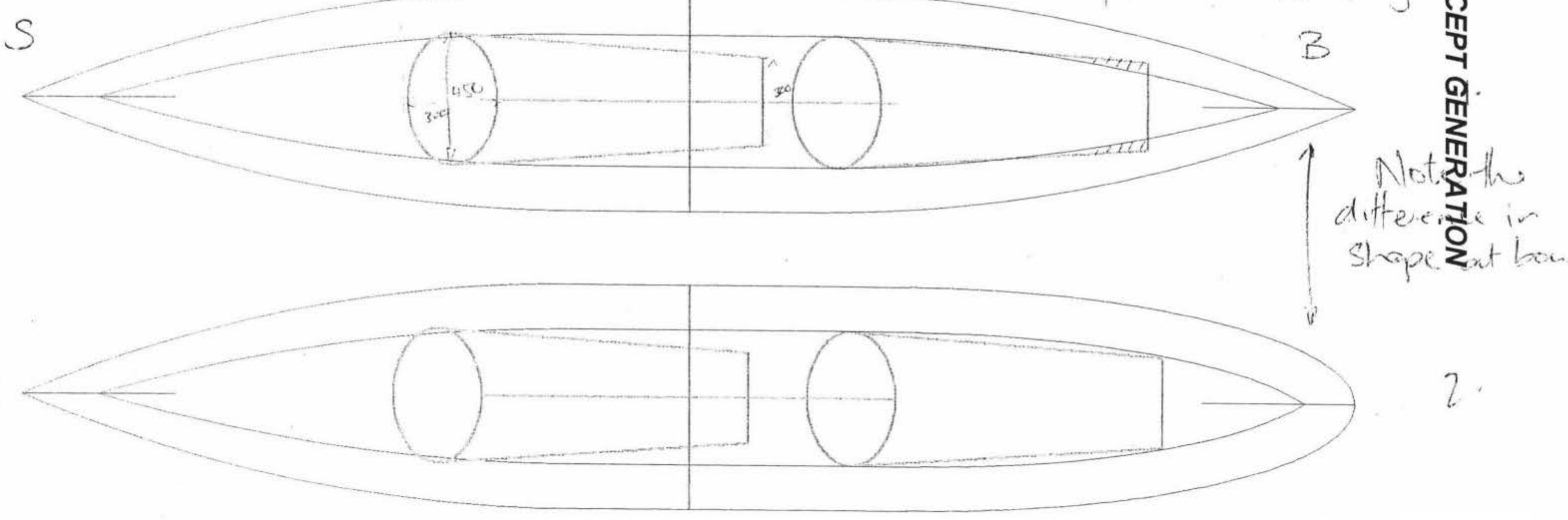
Seakayak kayak - registration marks 7/6/00

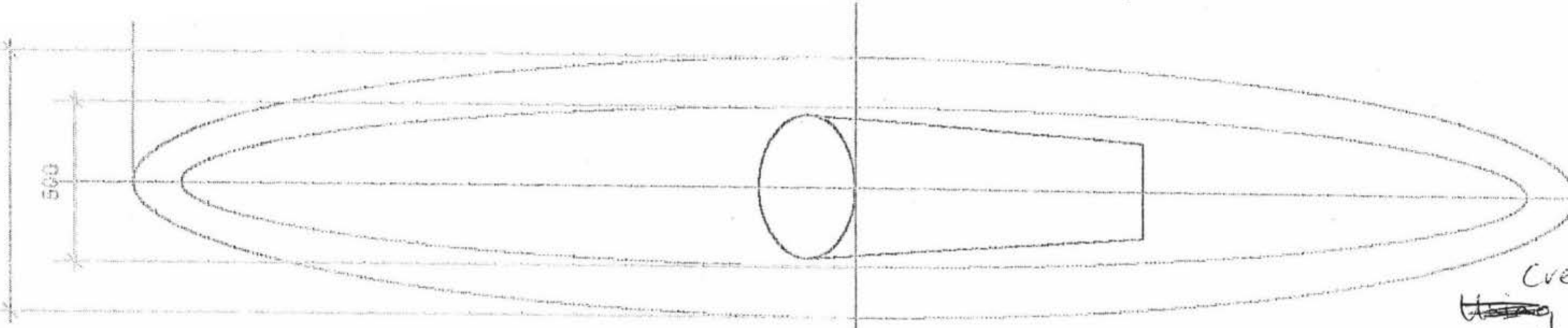
Dimensions of the person allows only 450mm in the cockpit at the hip area. This would allow 95% of british adults, to fit in comfortably with 95%ile of women only at 435

Looking at a range of populations 450 would allow for 95%ile to fit this dimension. The qurshon is wether this is a reasonable assumption.

There has been 1.2m allowed for leg length. This includes a seat of ~~and~~ btwn 50-100 mm and expecting most people to sit in a kayak with legs slightly bent. This assumptions leads to the design of foot rests into the boat.

Also allowed for about 300mm for foot room across. It was discussed and thought it was undesirable to have feet squashed together. → Flexibility.

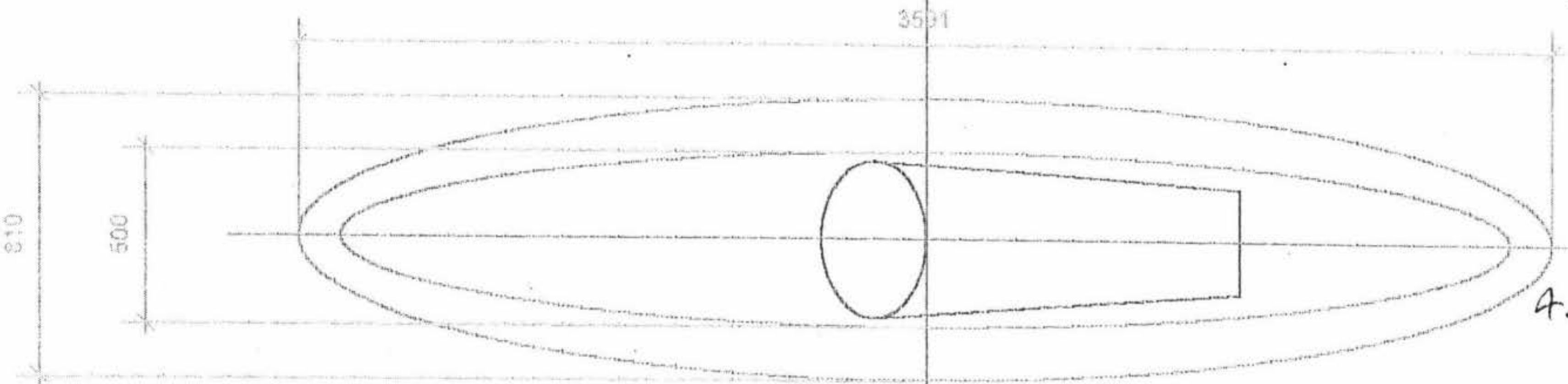




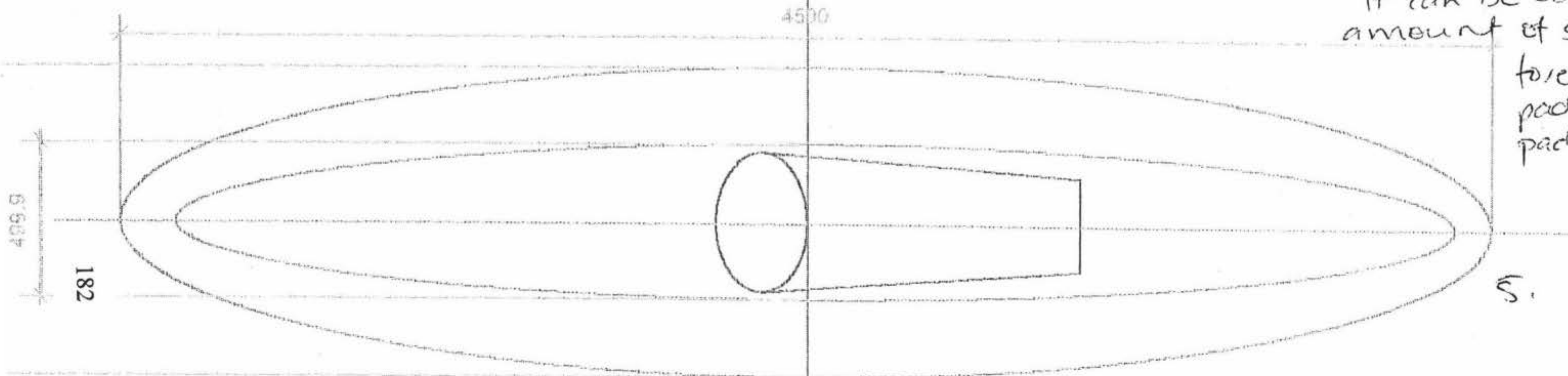
3.

Created using ellipses with 150mm offset.

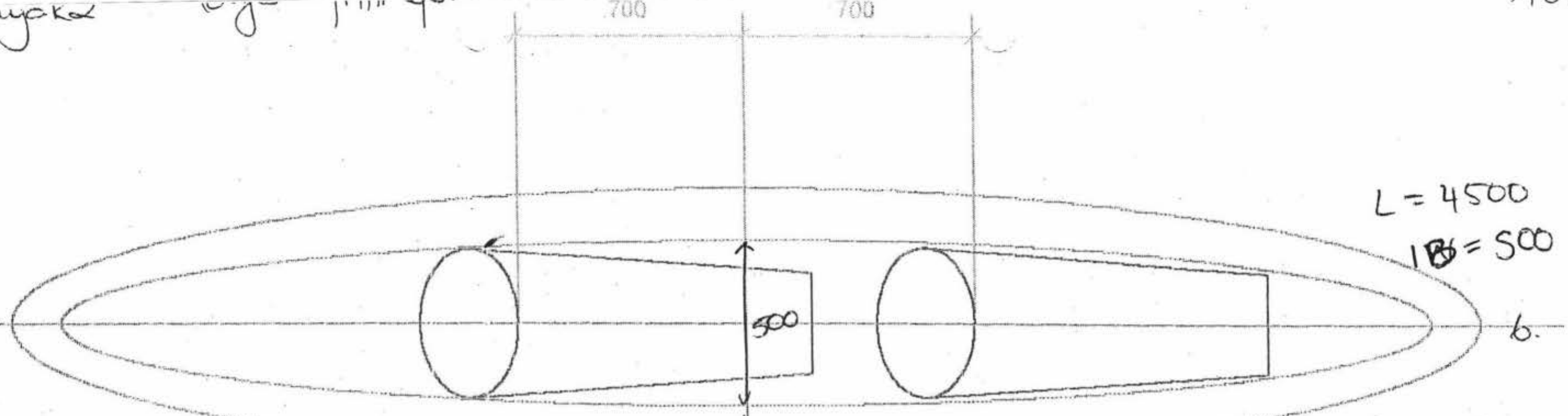
Boat length has been set at 4500 mm to go much shorter would mean not being able to have 2 people in the boat.



4. The beam has been extended in the cockpit to 500mm. It can be observed the amount of storage space fore and aft the paddler if paddled solo.



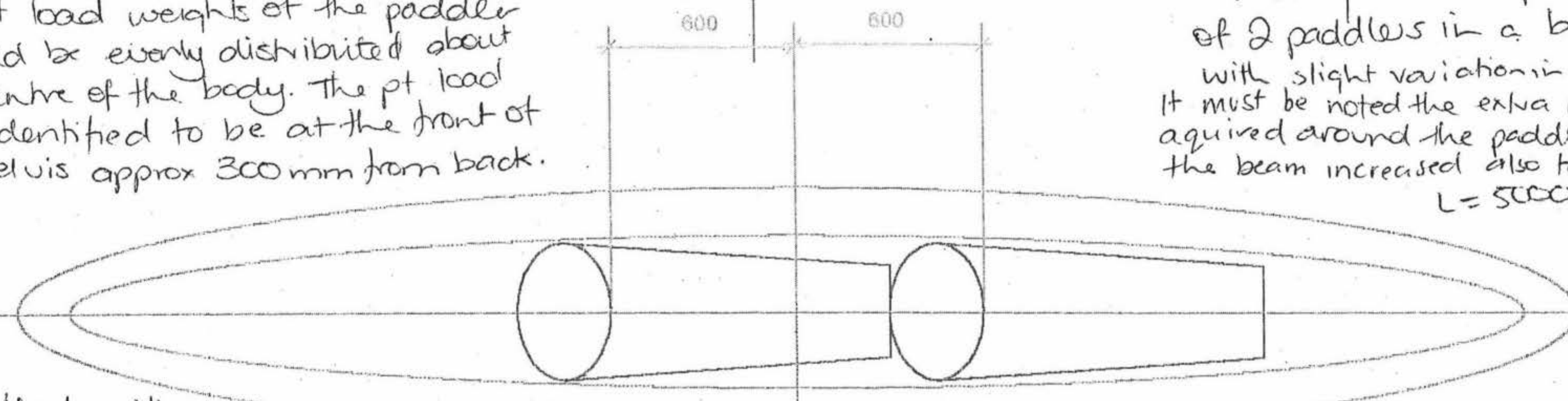
5.



L = 4500
B = 500

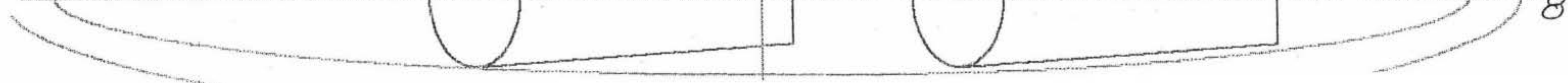
Alistair decided that the pt load weights of the paddler should be evenly distributed about the centre of the body. The pt load was identified to be at the front of he pelvis approx 300 mm from back.

Looking at the positions of 2 paddlers in a boat with slight variation in length. It must be noted the extra room aquired around the paddle with the beam increased also to 500mm from 450mm
L = 5000



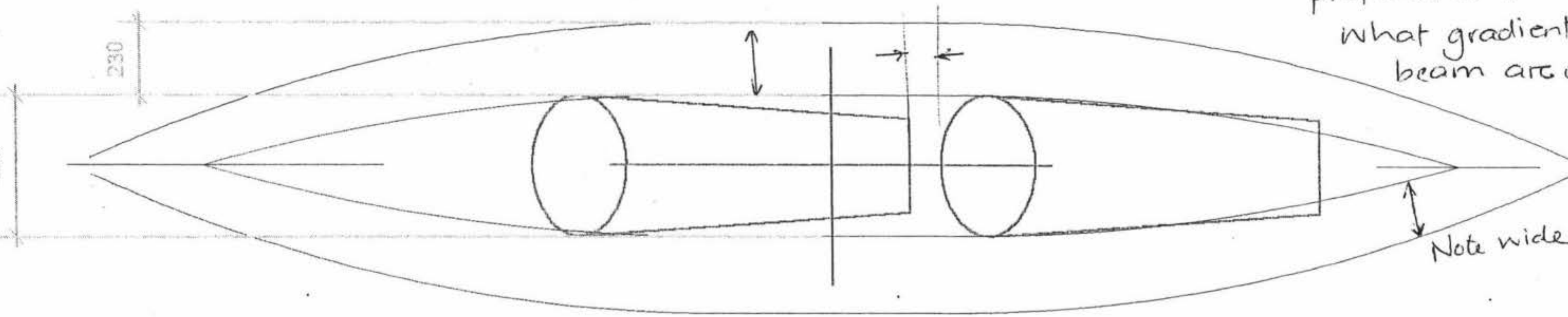
hat effects will addle position & weight istribution have on the performance f the boat?

L = 5000

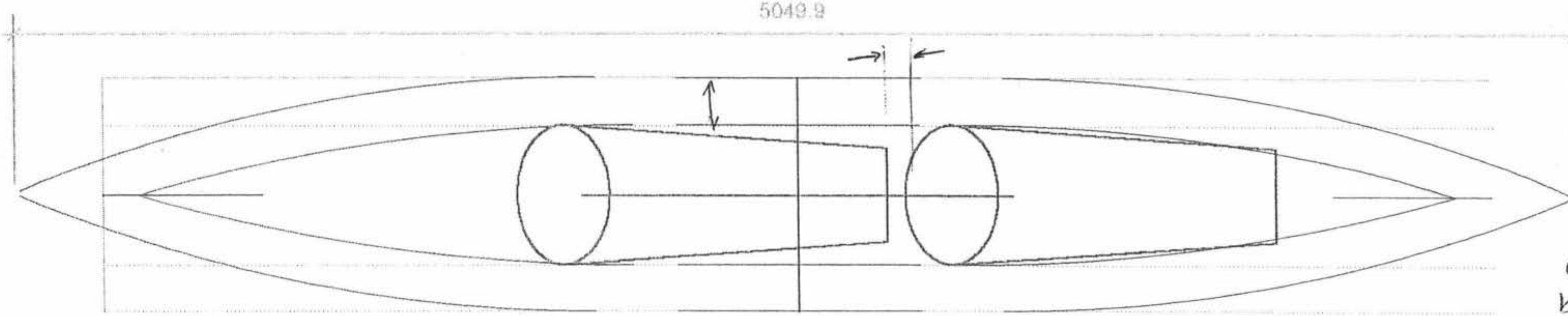


Boat form.

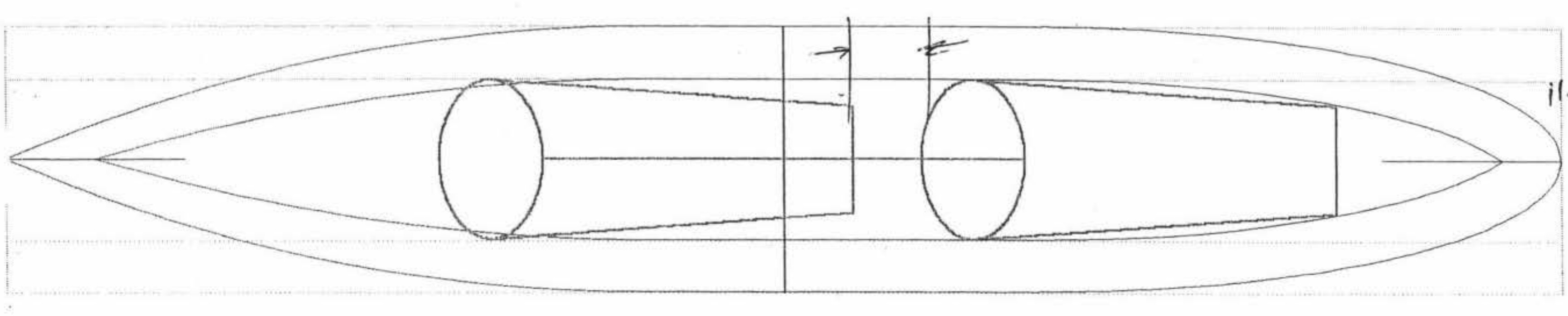
What entry and exit shapes are preferred at the bow and stern?
What gradients into the beam are desirable?



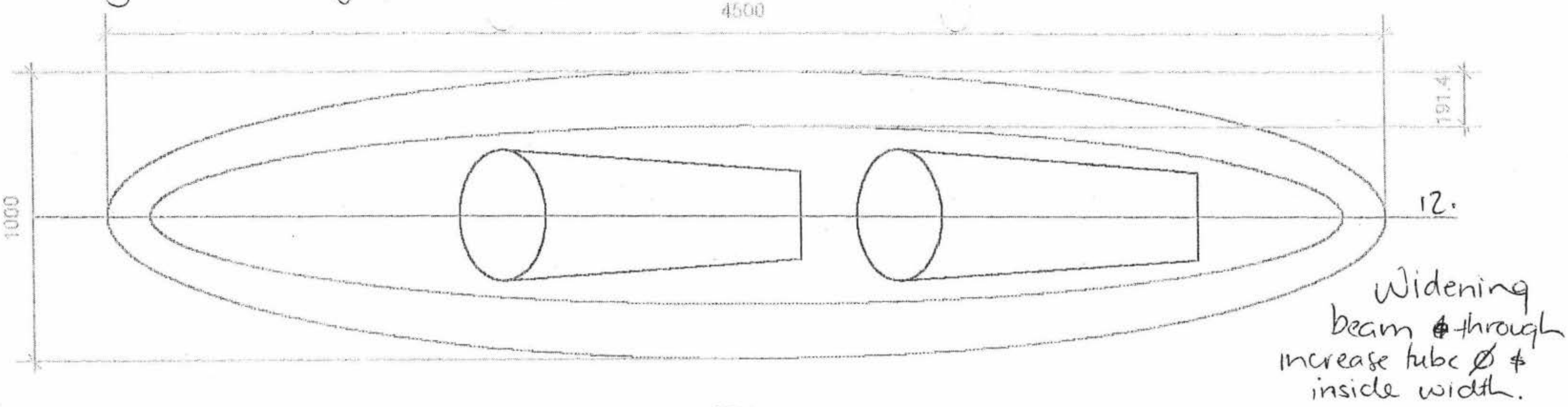
9.
Note wider tube diameter.
230 mm

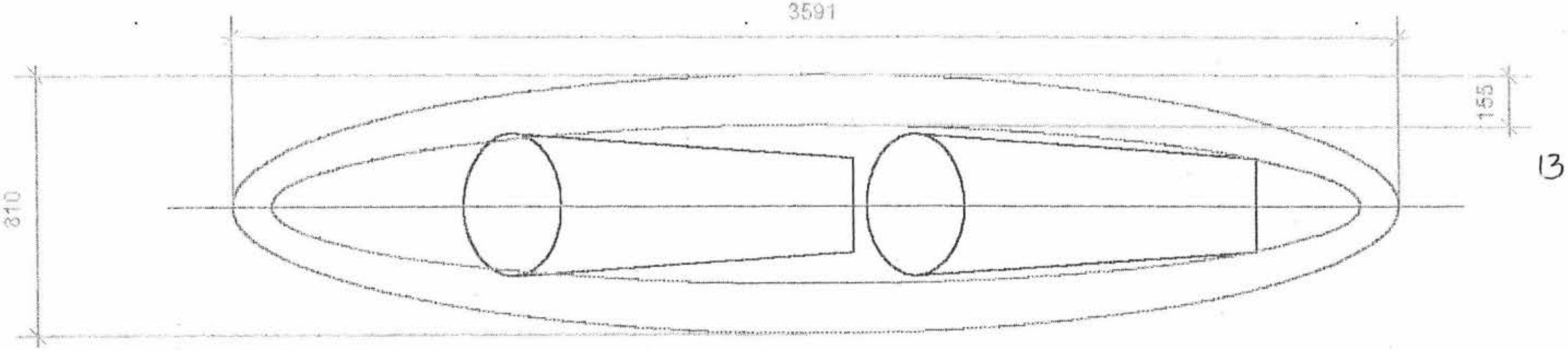


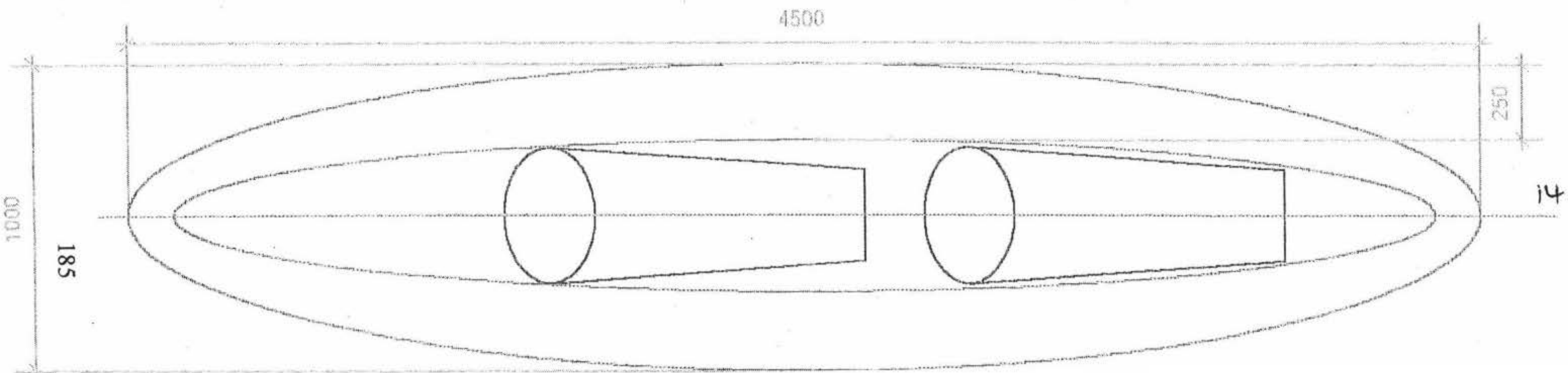
10.
Increase in length
from where
Can the boat be extended?

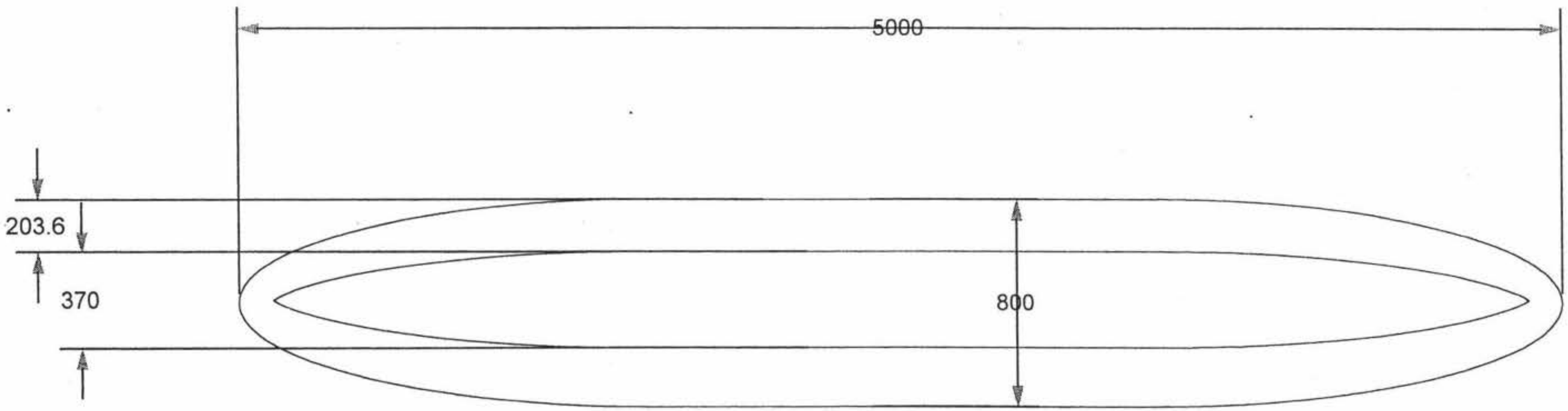


11. Rounded bow
How would each be manufacteol?
Desired form vs manufacturability
cost etc..
performance

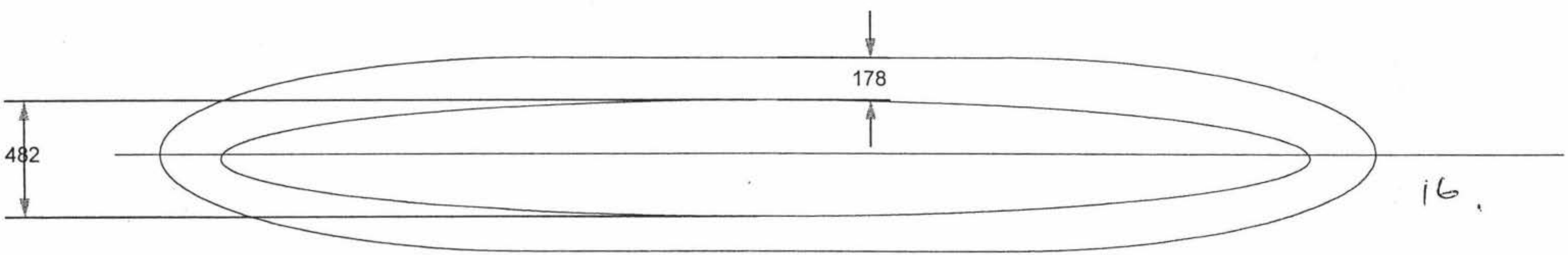

4500
1000
191.4
12.
Widening
beam through
increase tube Ø
inside width.


3591
810
155
13.


4500
1000
250
14.



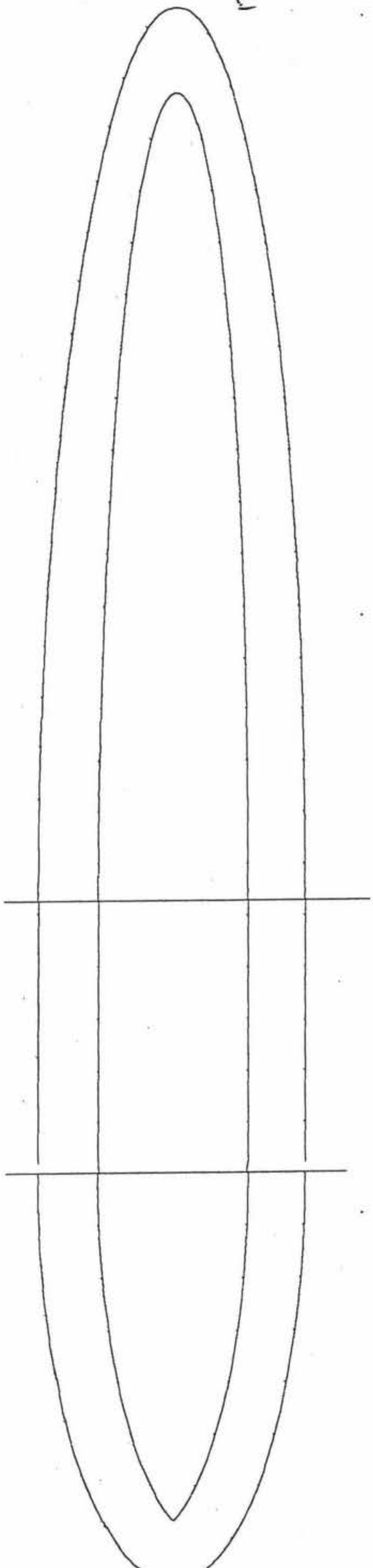
15.



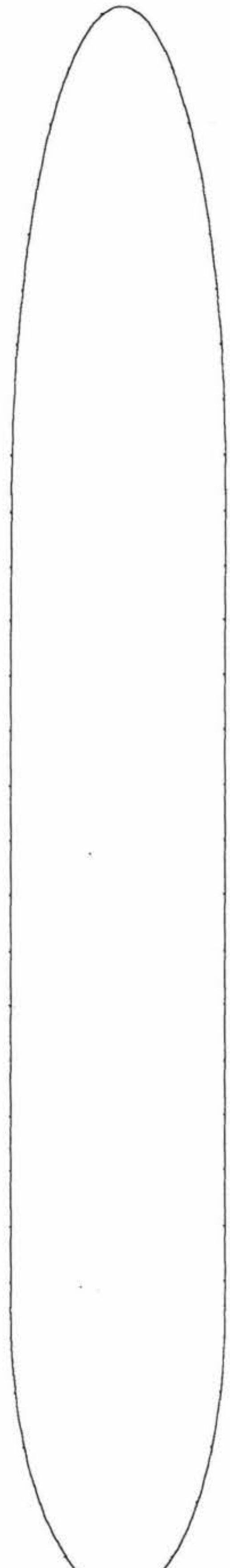
16.

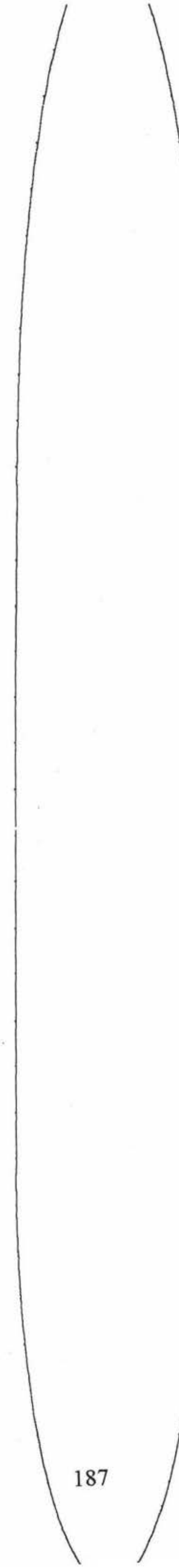
General boat shapes.

17.

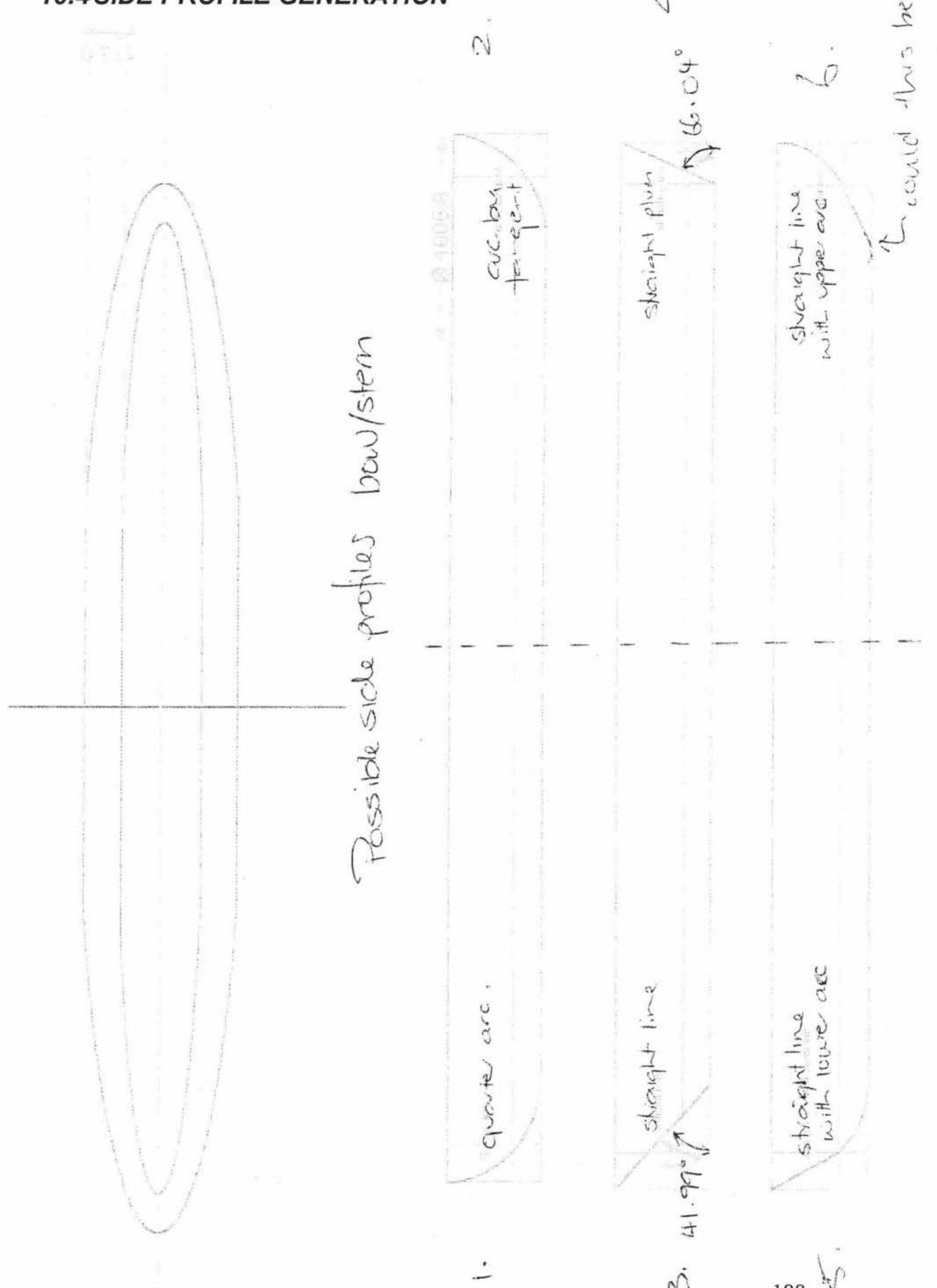


18.

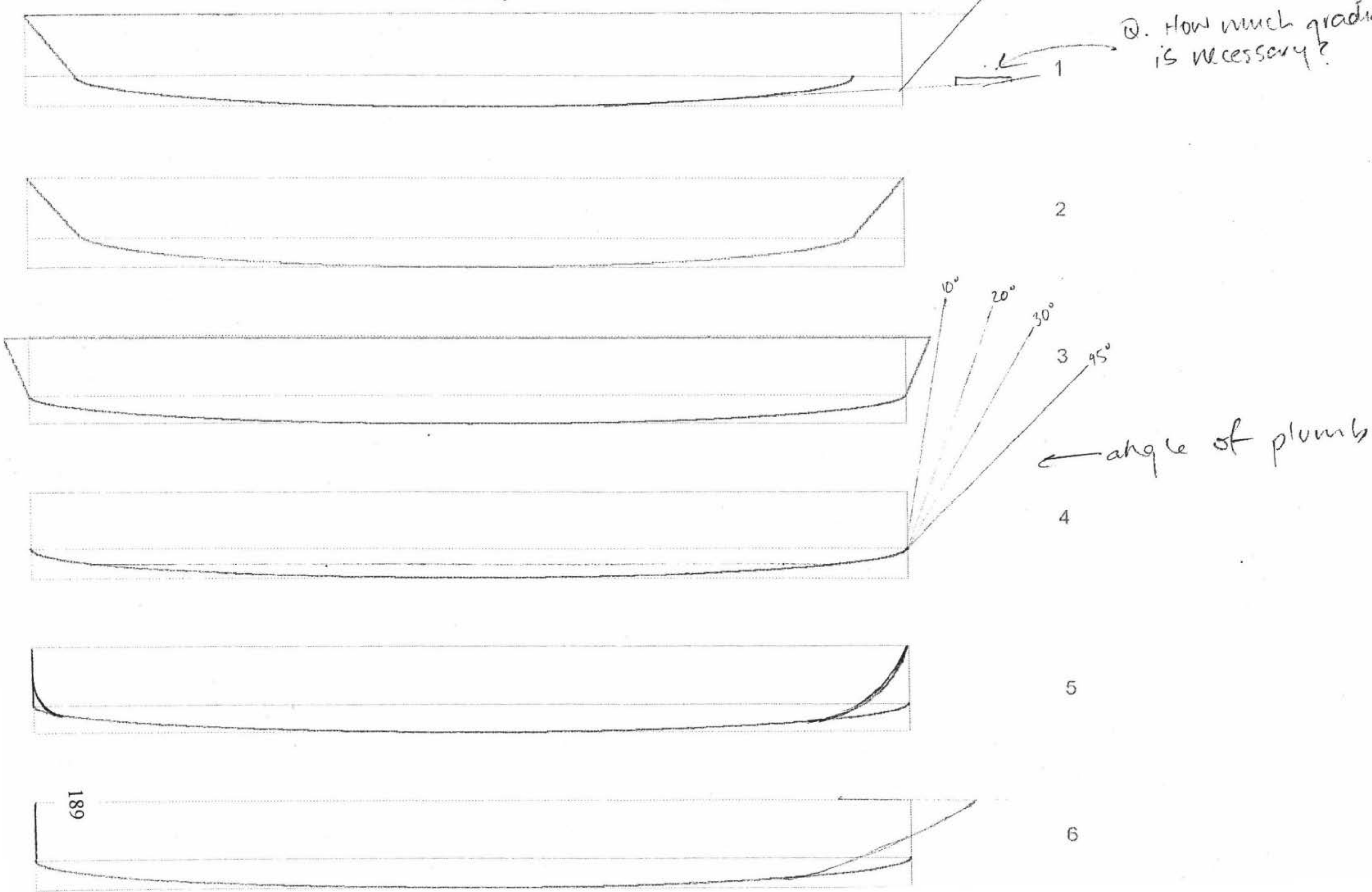




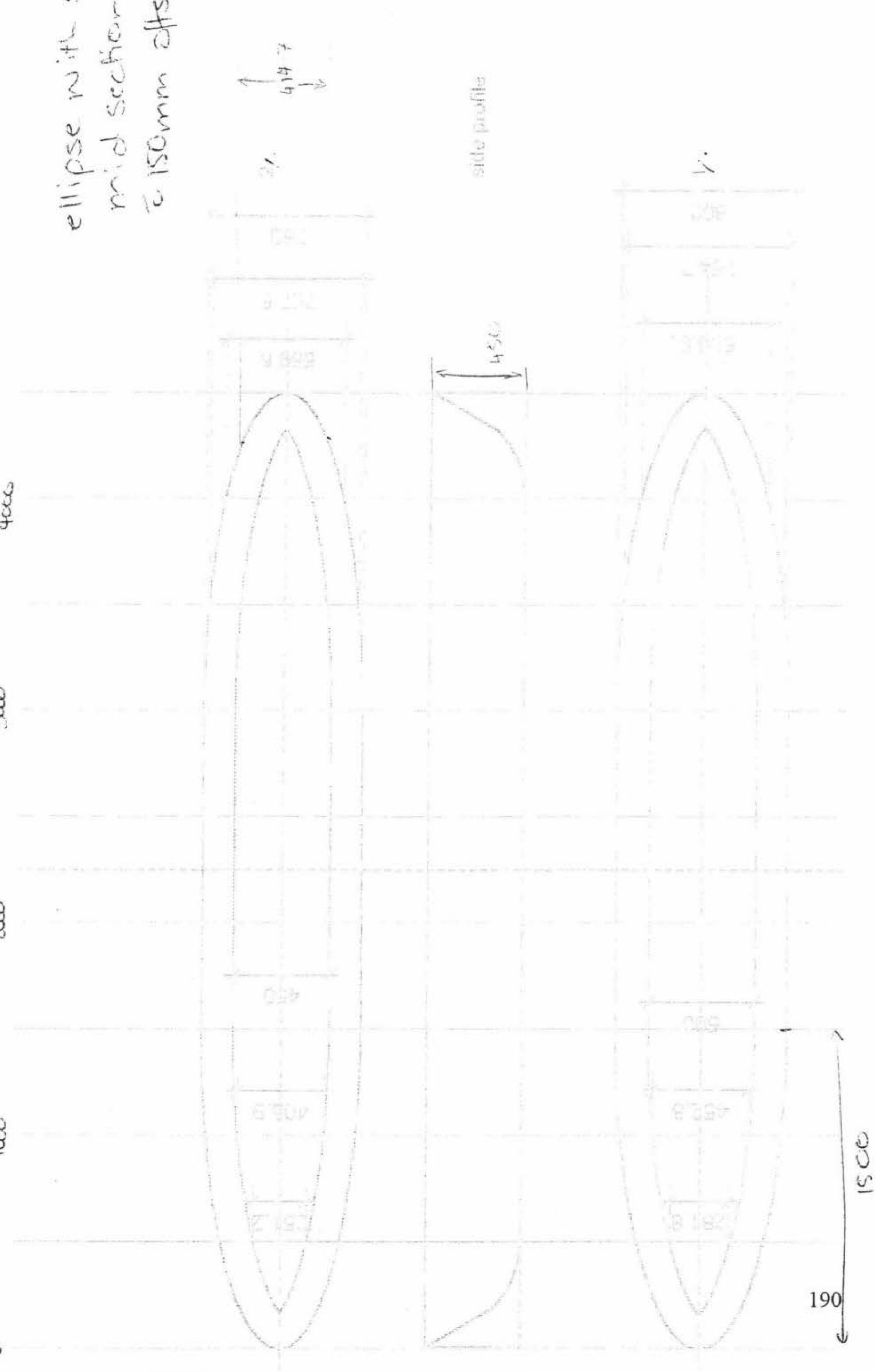
10.4 SIDE PROFILE GENERATION



~~Rounder~~ Slight longitudinal rocker.



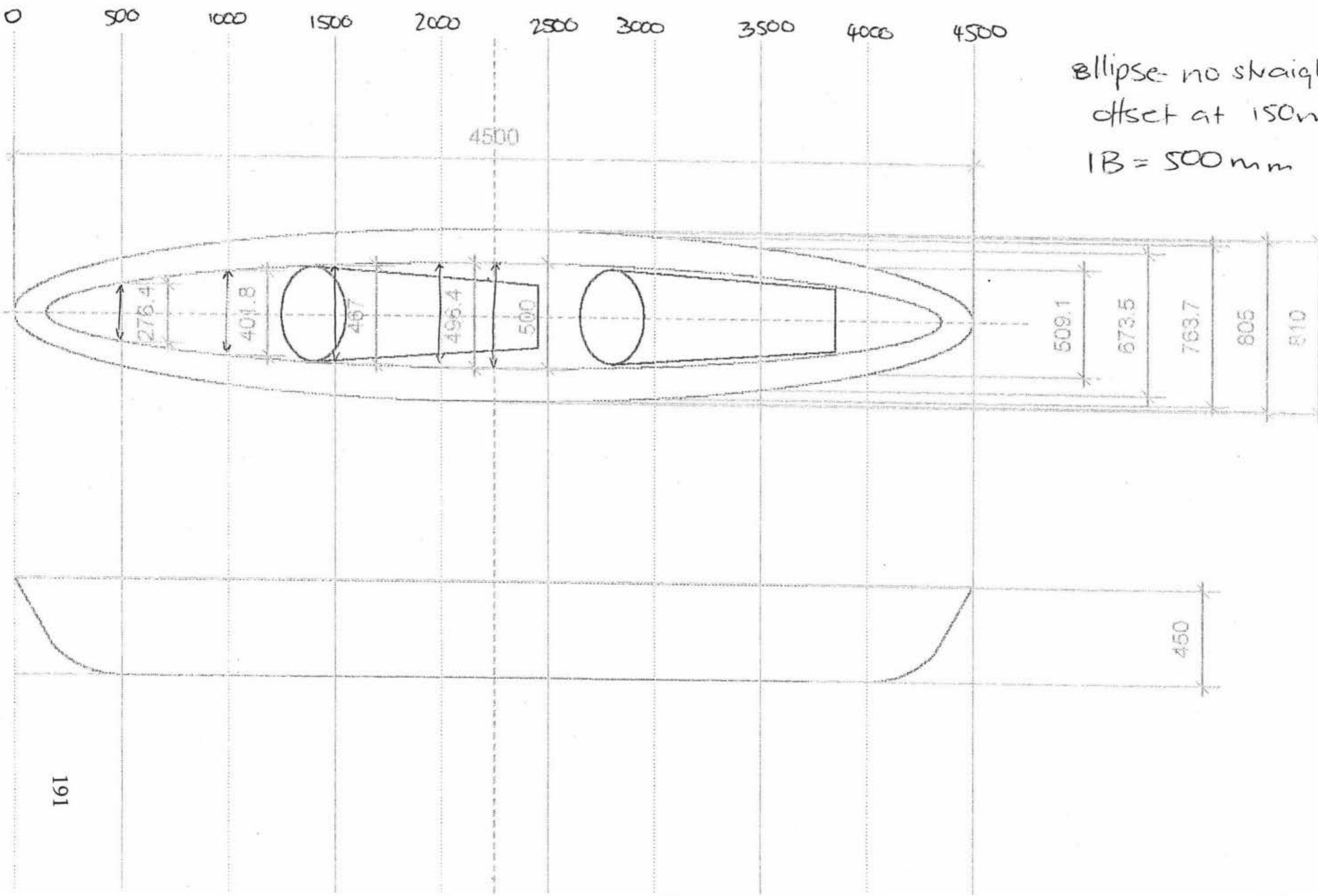
10.5 CONCEPTS GENERATED ON COMPUTER

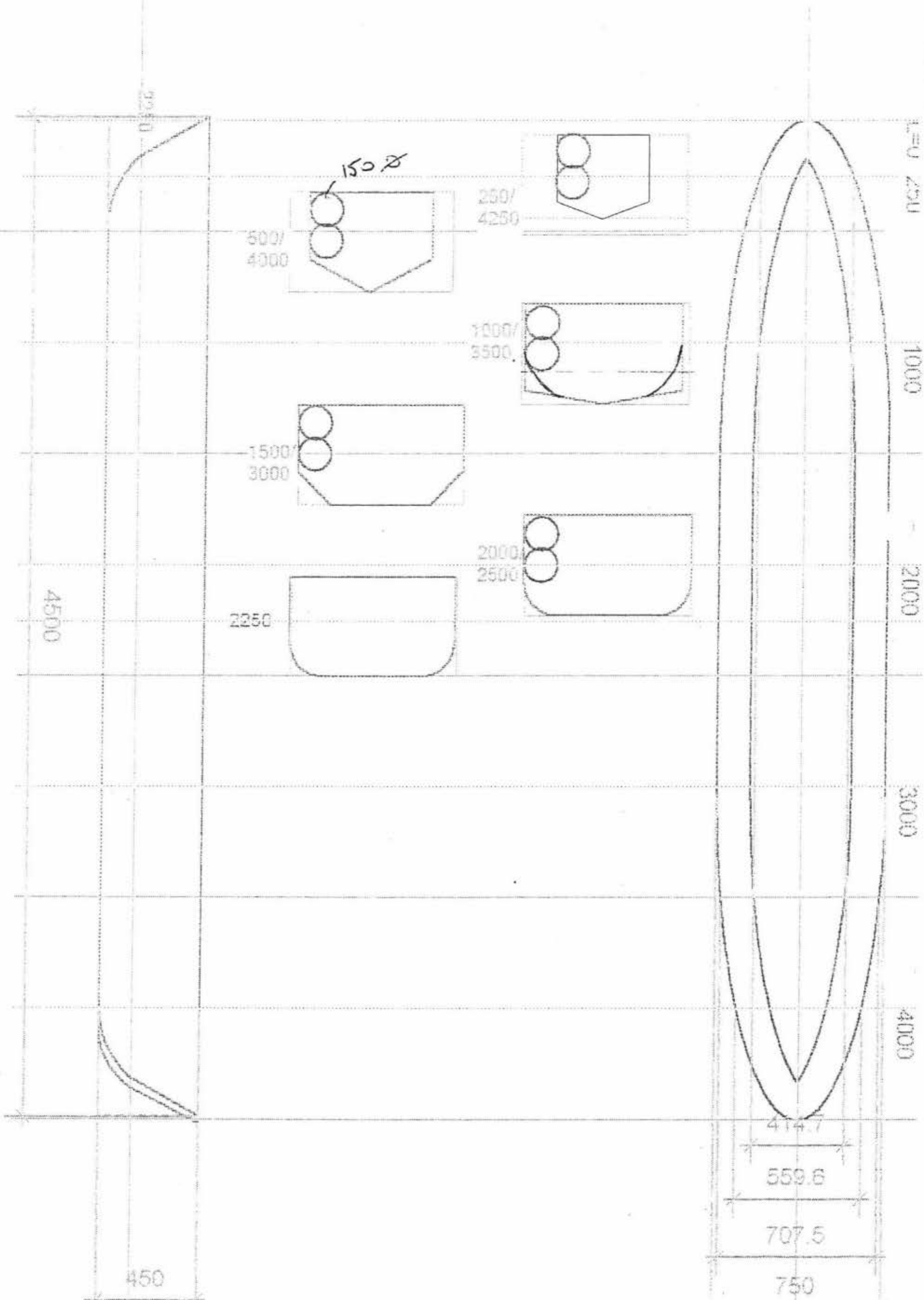


Seakayak 5 - bottom panel.

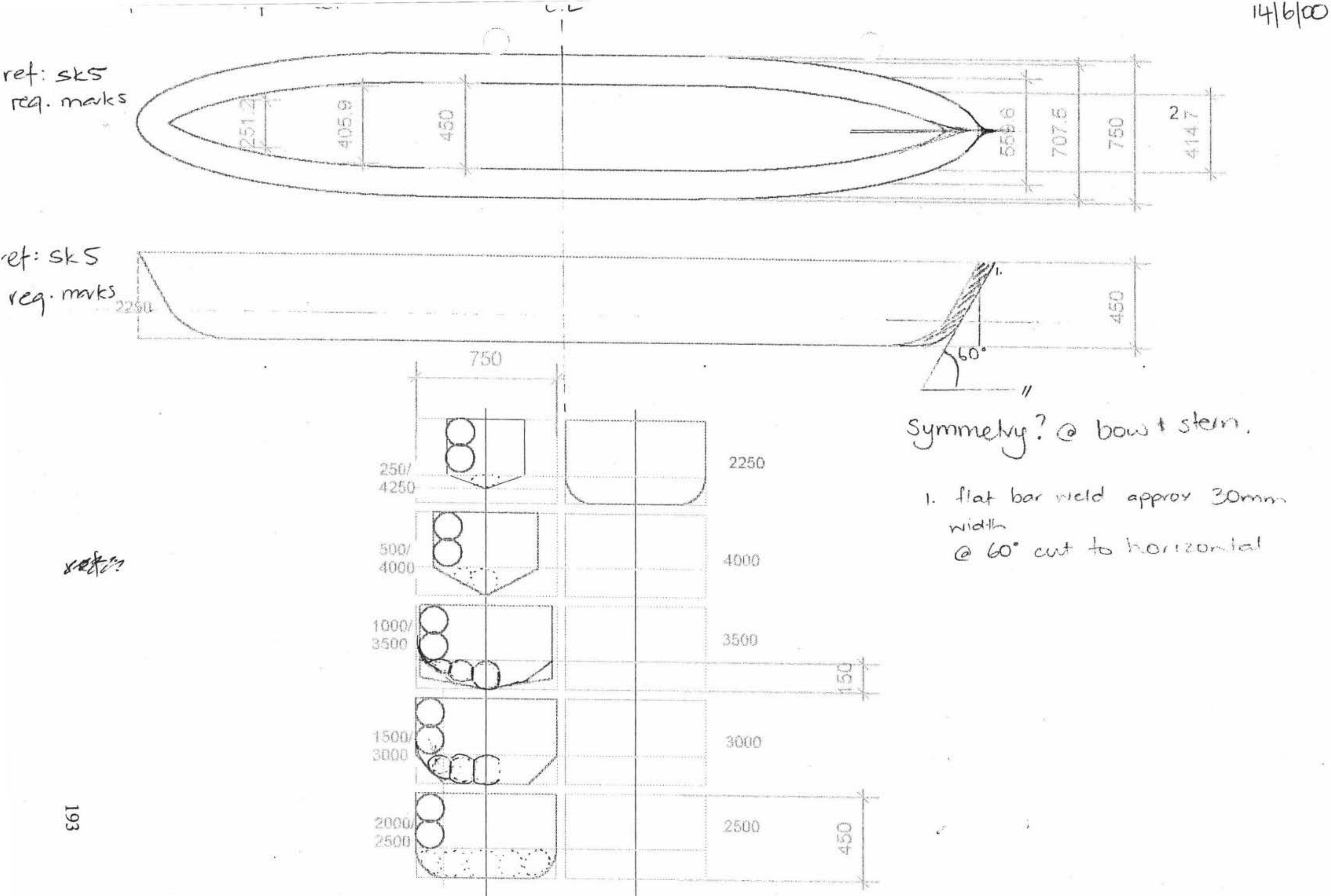
14/6/00

Ellipse- no straight edges
offset at 150mm
IB = 500mm



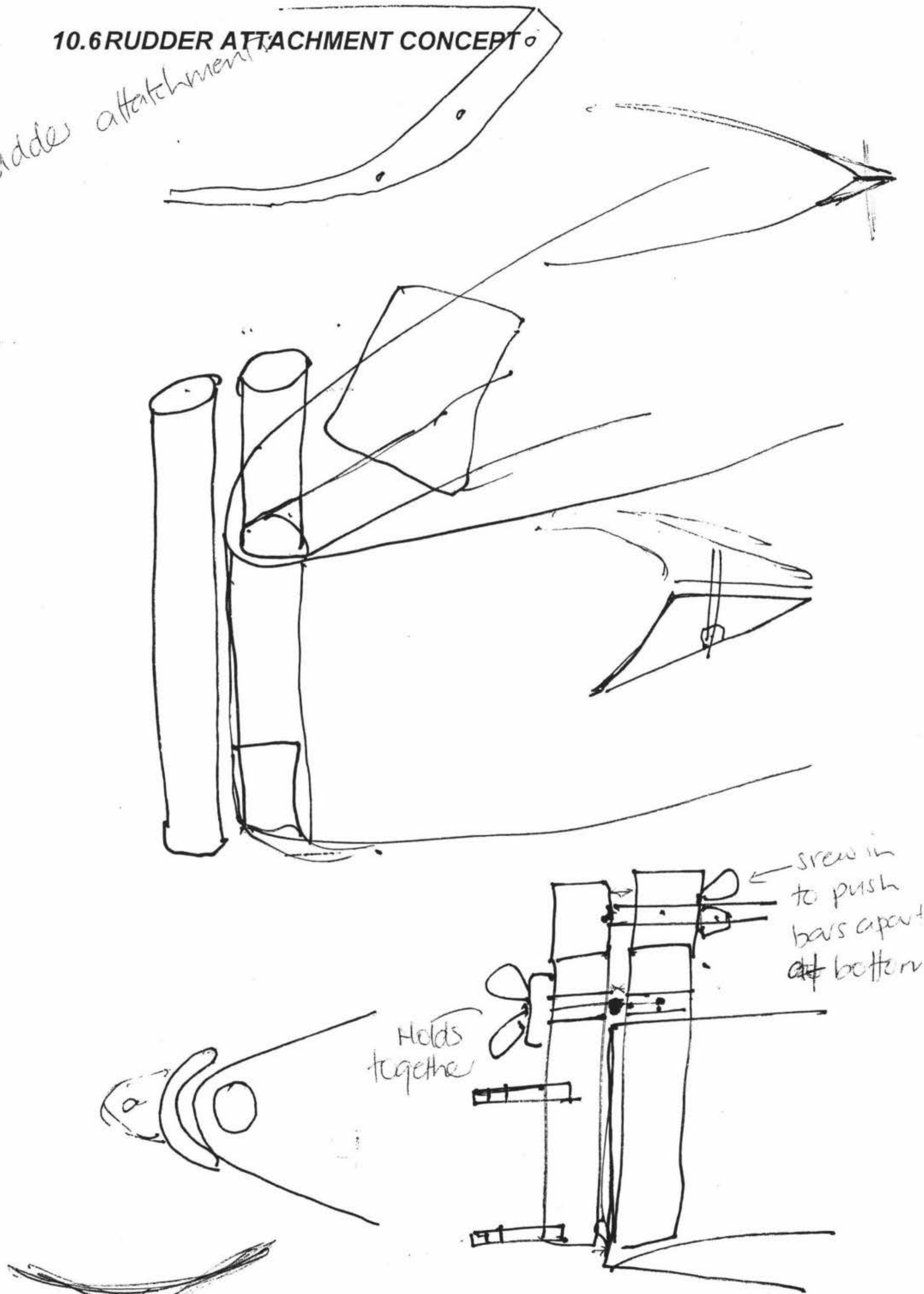

150 ⌀
600/
4000
250/
4250
1000/
3500
1500/
3000
2000/
2500
2250
4500
450
1000
2000
3000
4000
414.7
559.6
707.5
750

14/6/00


14/6/00
ref: sk5
req. marks
251.2
405.9
450
559.6
707.6
750
414.7
ref: sk5
req. marks
2250
450
60°
750
Symmetry? @ bow + stern.
1. flat bar weld approx 30mm width @ 60° cut to horizontal
250/
4250
2250
500/
4000
4000
1000/
3500
3500
150
1500/
3000
3000
2000/
2500
2500
450

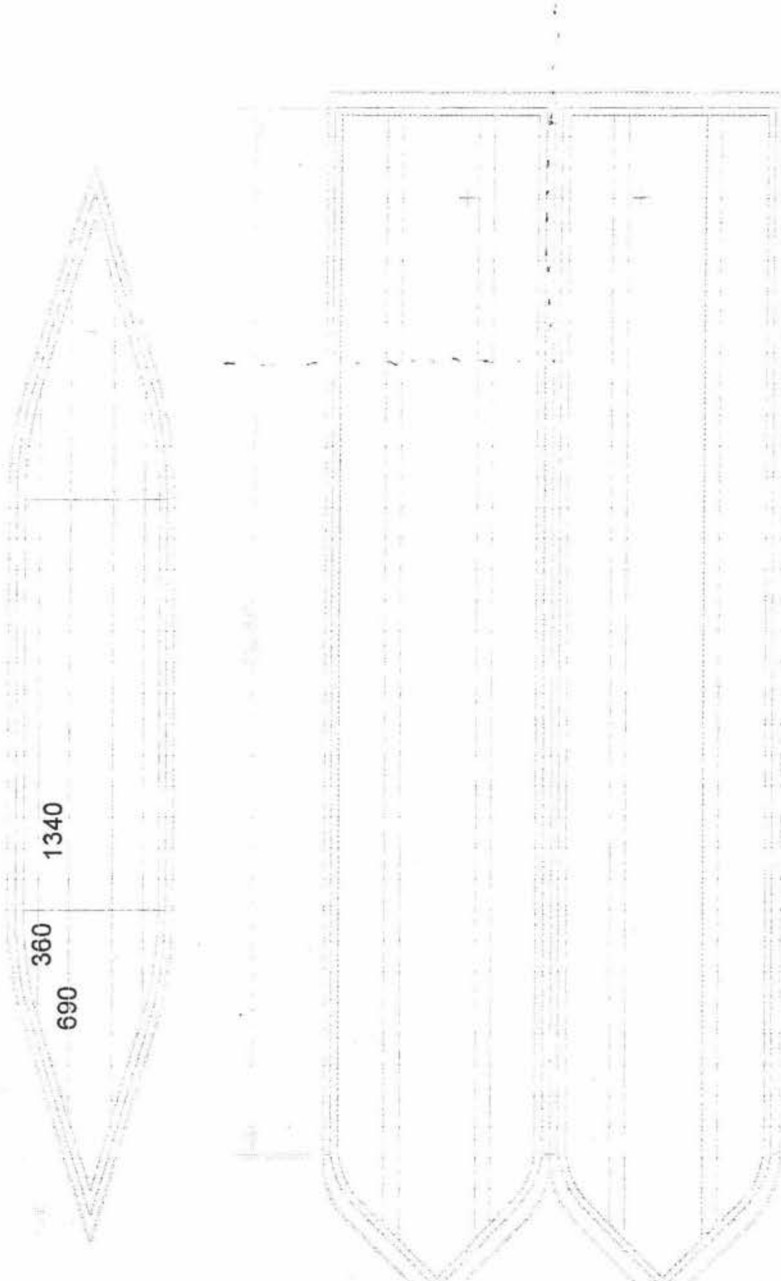
Harvey 21/7/00

10.6 RUDDER ATTACHMENT CONCEPT

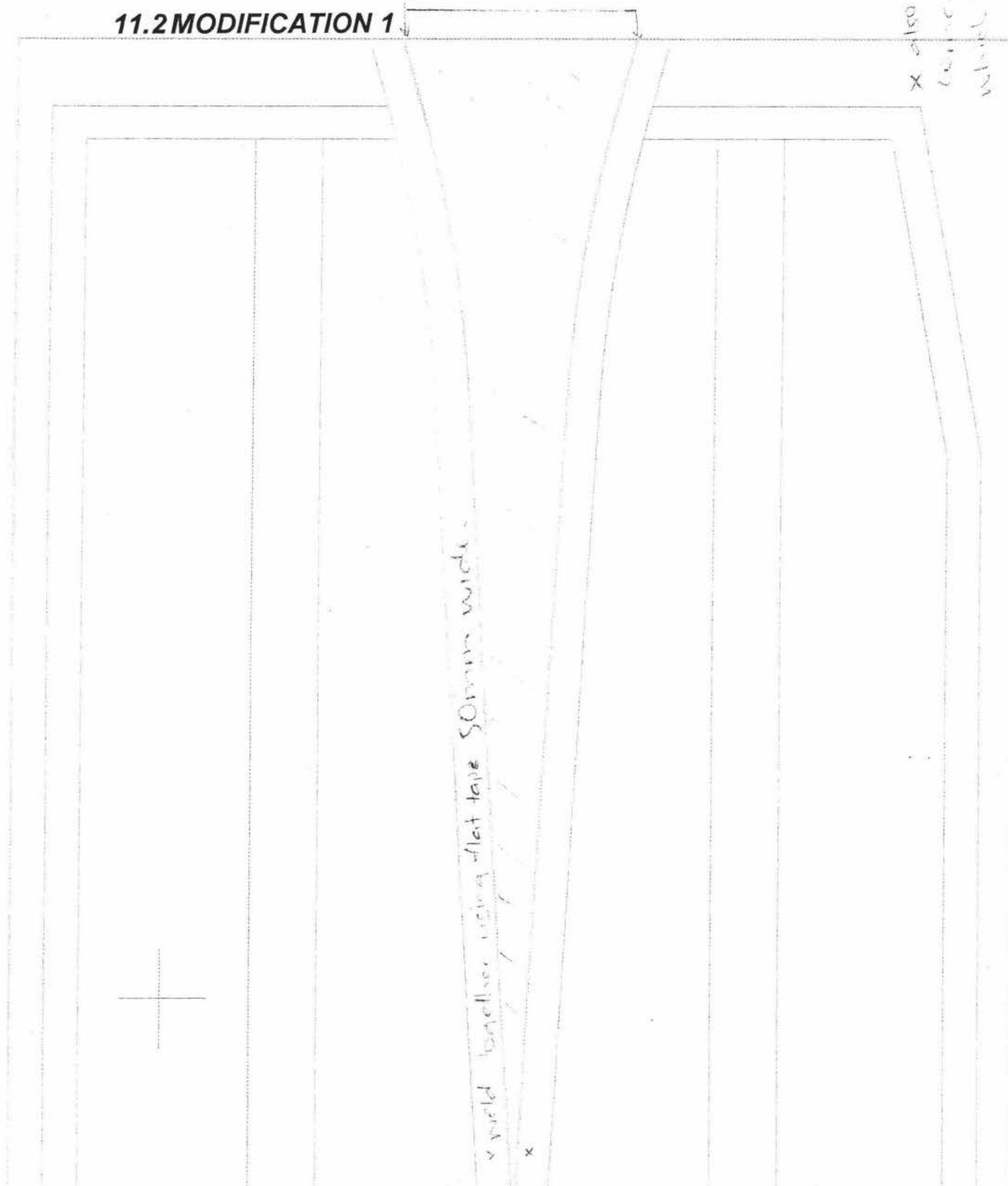


11 APPENDIX C

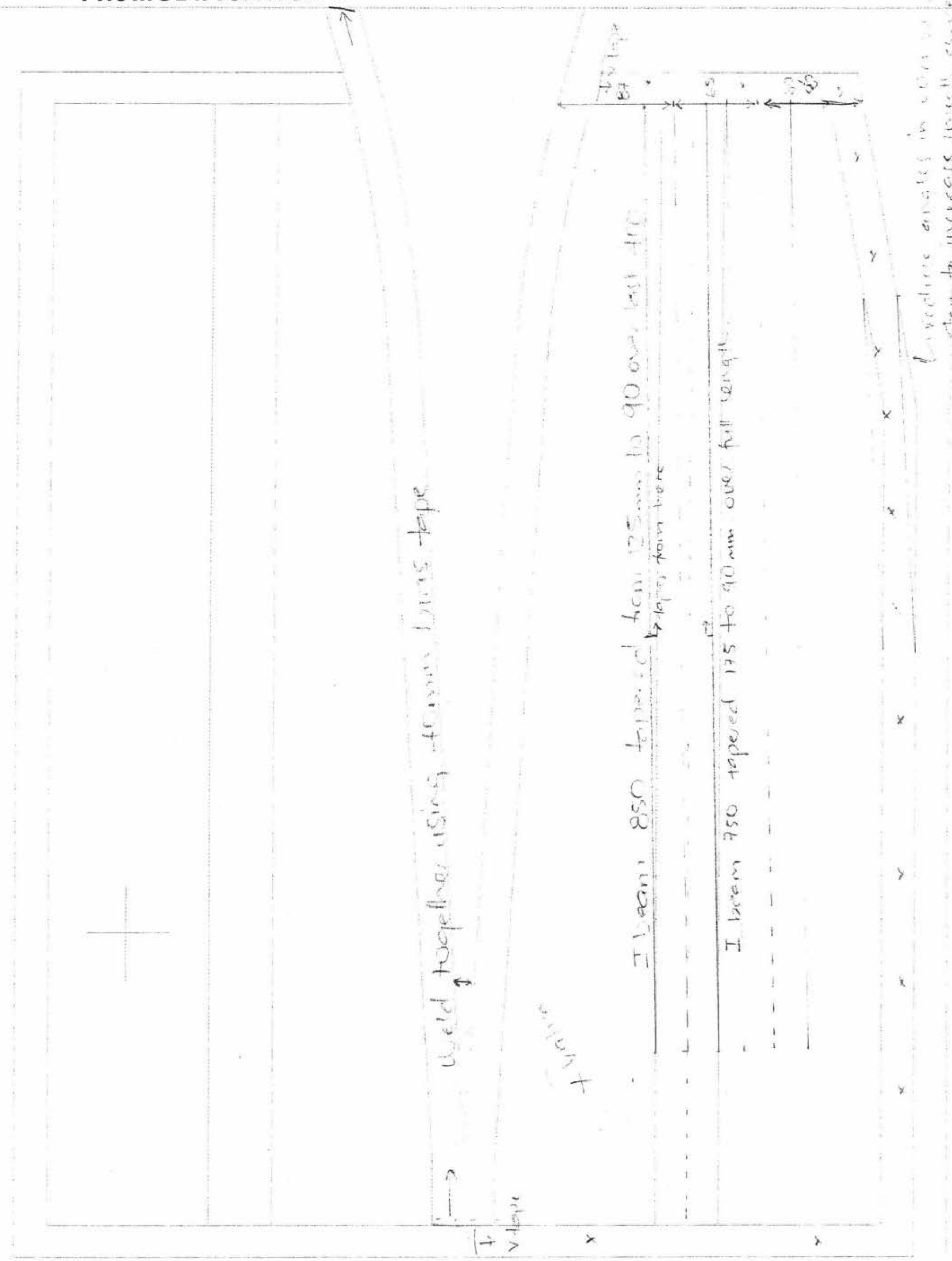
11.1 PATTERN P1



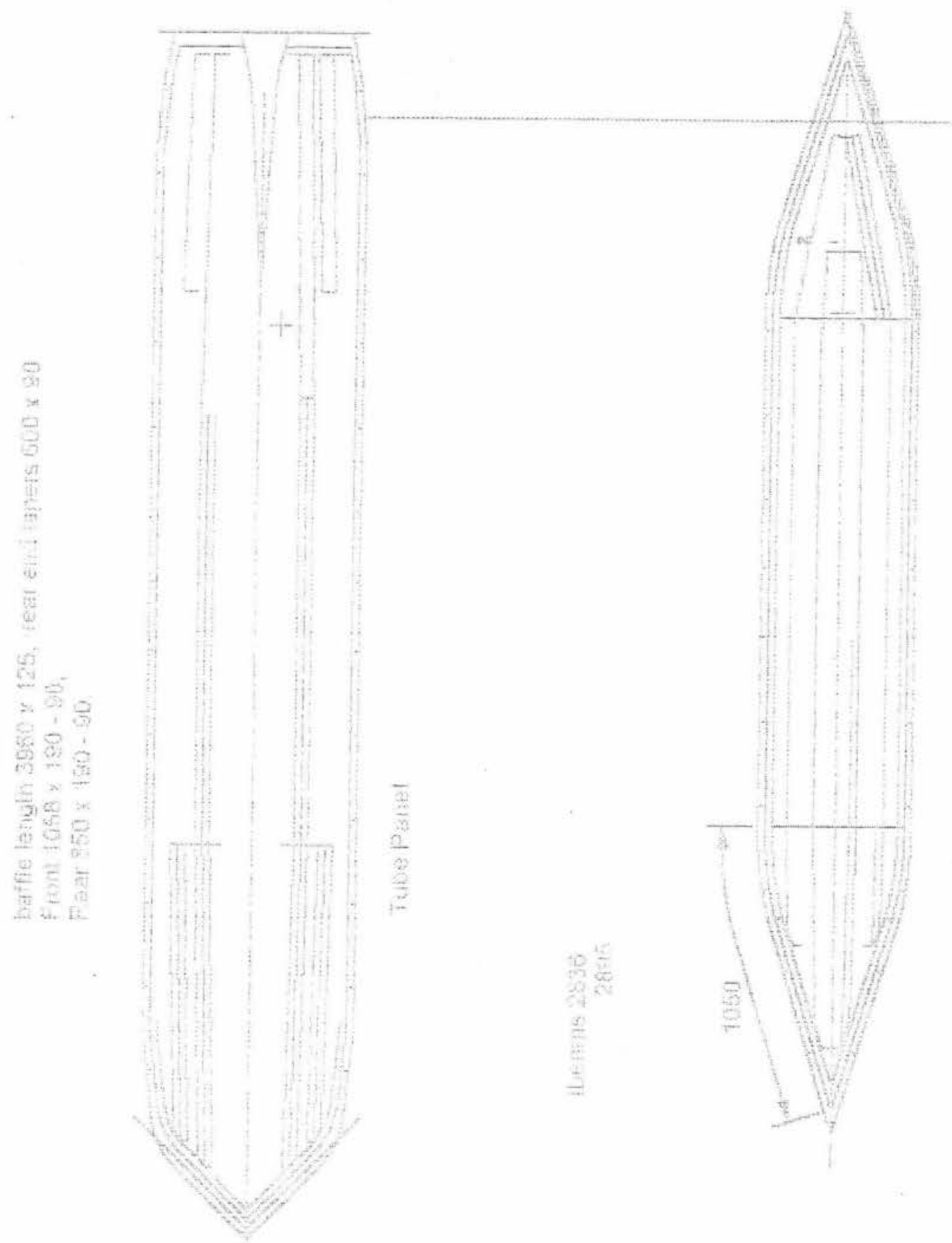
11.2 MODIFICATION 1



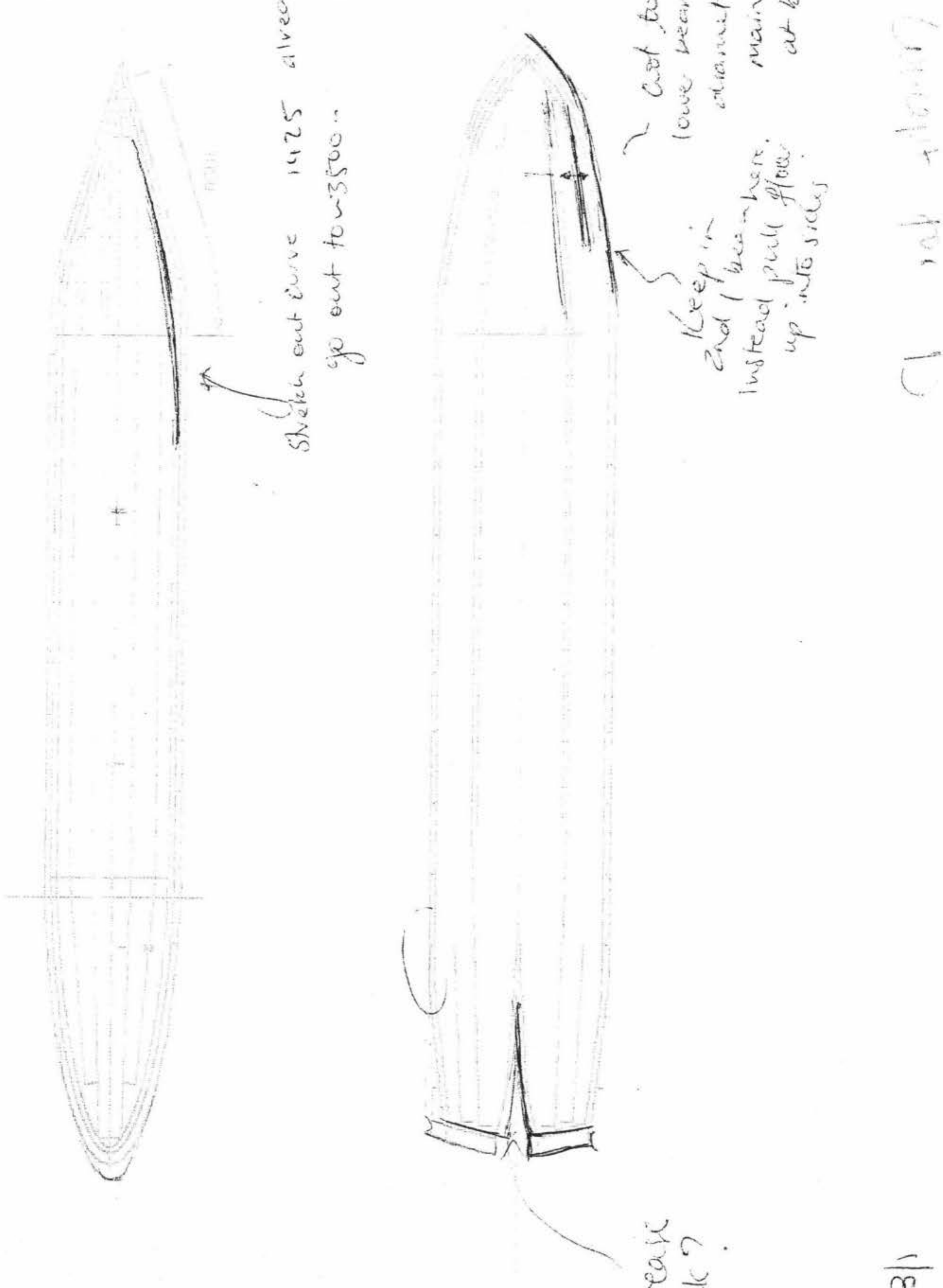
11.3 MODIFICATION 2

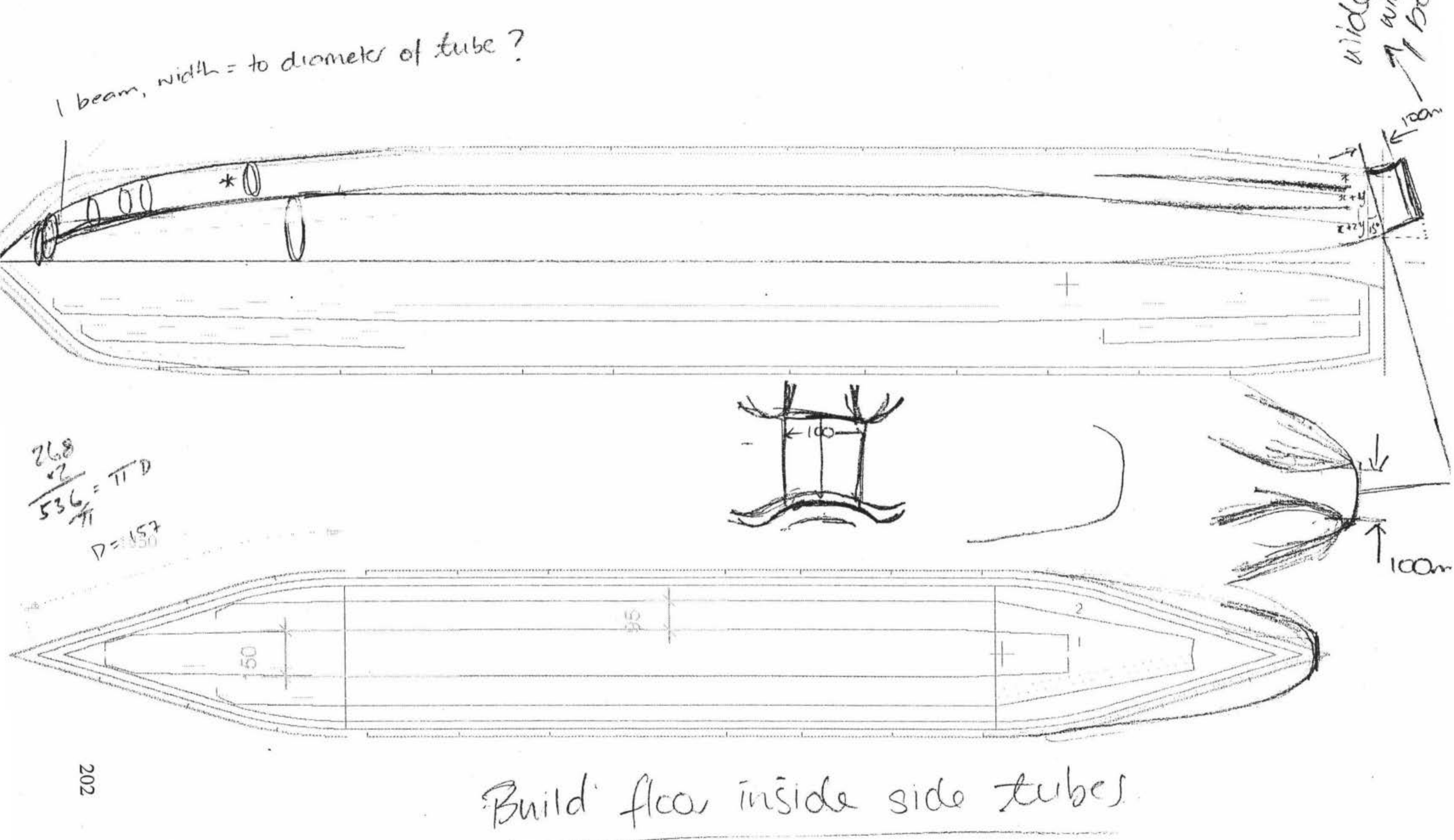


11.4 PATTERN P2



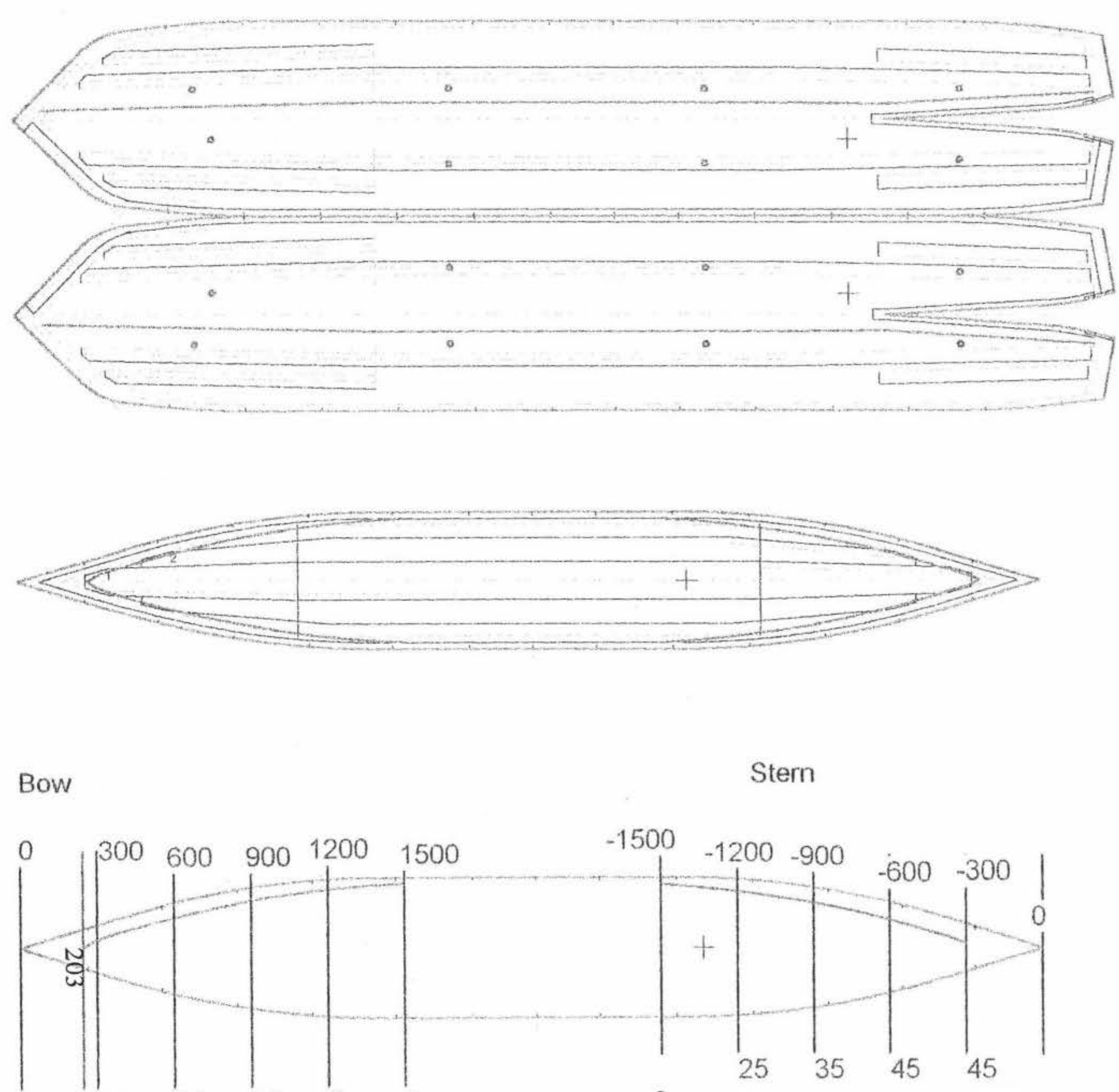
11.5 MODIFICATIONS TO P2




I beam, width = to diameter of tube ?
wider the width / beam
100mm
x + y
x + 2y
15°
100
268
×2
536/π = π D
D = 157
150
95
2
1
100mm
Build floor inside side tubes

11.6 PATTERNS P3

P3 Registration marks 25/10/00



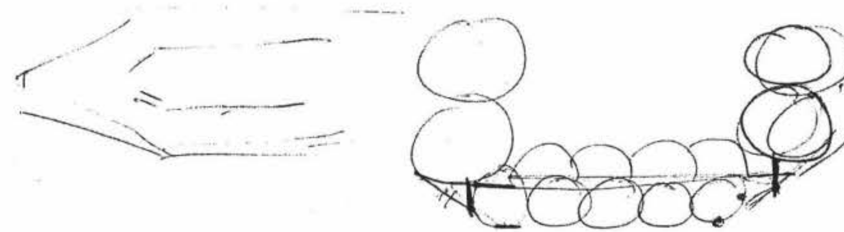
Need to take off
25mm either end

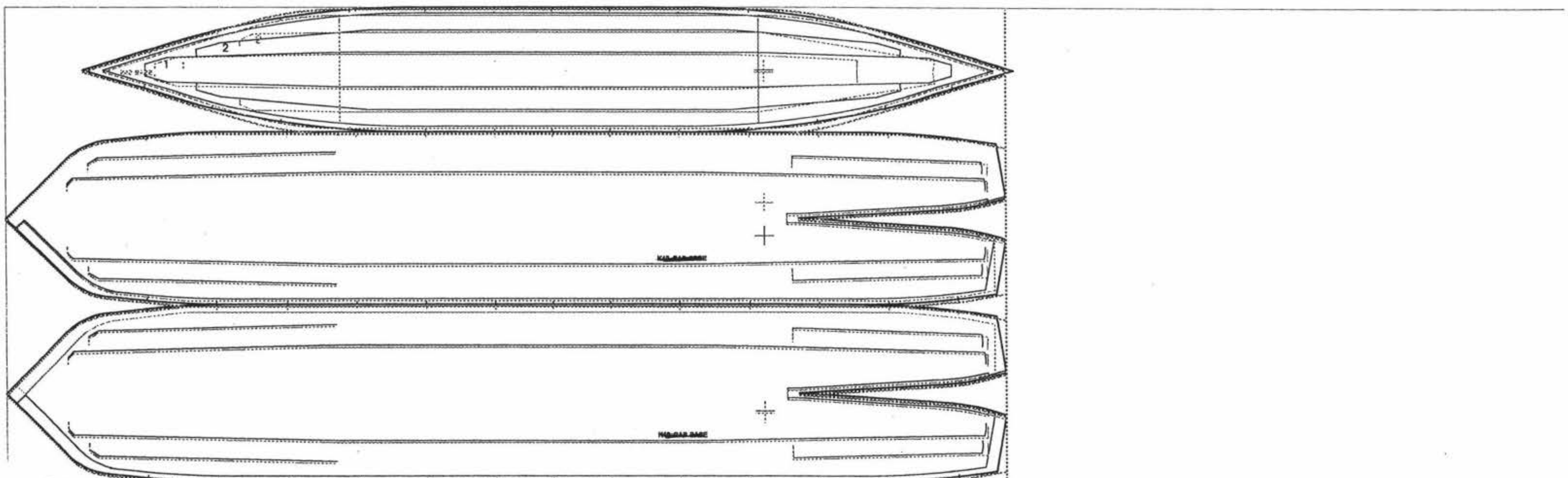
Check velcro line
Is it located by
centre or from I beam?
Should be from I beam.

Baffle Lengths:

Side tube:
Main 3950 x 125, rear end tapers 600 x 90
Front 1057 x 190 - 90,
Rear 820 x 190 - 90.

Floor:
1: 3470 x 125, 830-1810-830 rear end tapers 600 x 90
2: 3038 x 125, 614-1810-614 rear end tapers 600 x 90





Baffle Lengths:

Side tube:
Main 3950 x 125, rear end tapers 600 x 90
Front 1057 x 190 - 90,
Rear 820 x 190 - 90.

Floor:
1: 3470 x 125, 830-1810-830 rear end tapers 600 x 90 * Need registration marks
2: 3038 x 125, 614-1810-614 rear end tapers 600 x 90

Rear 825
607

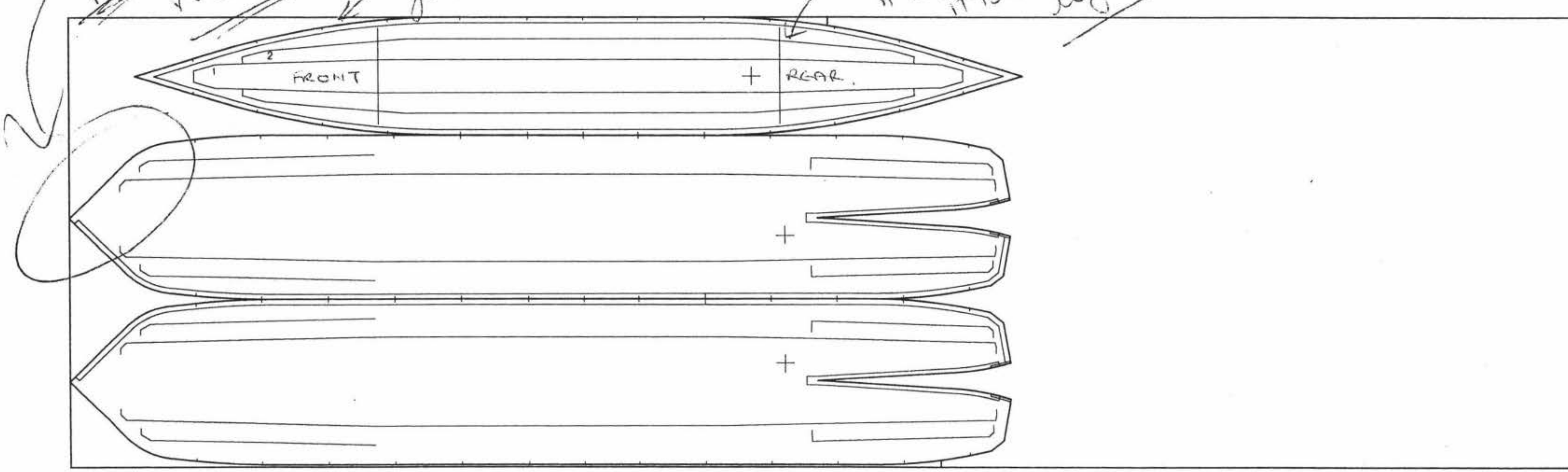
front 826
606

11.7PATTERN.P4

Need registration marks

Ideally want tool to good around this bend.

? What is this line for? If it is registration move it to somewhere more logical!

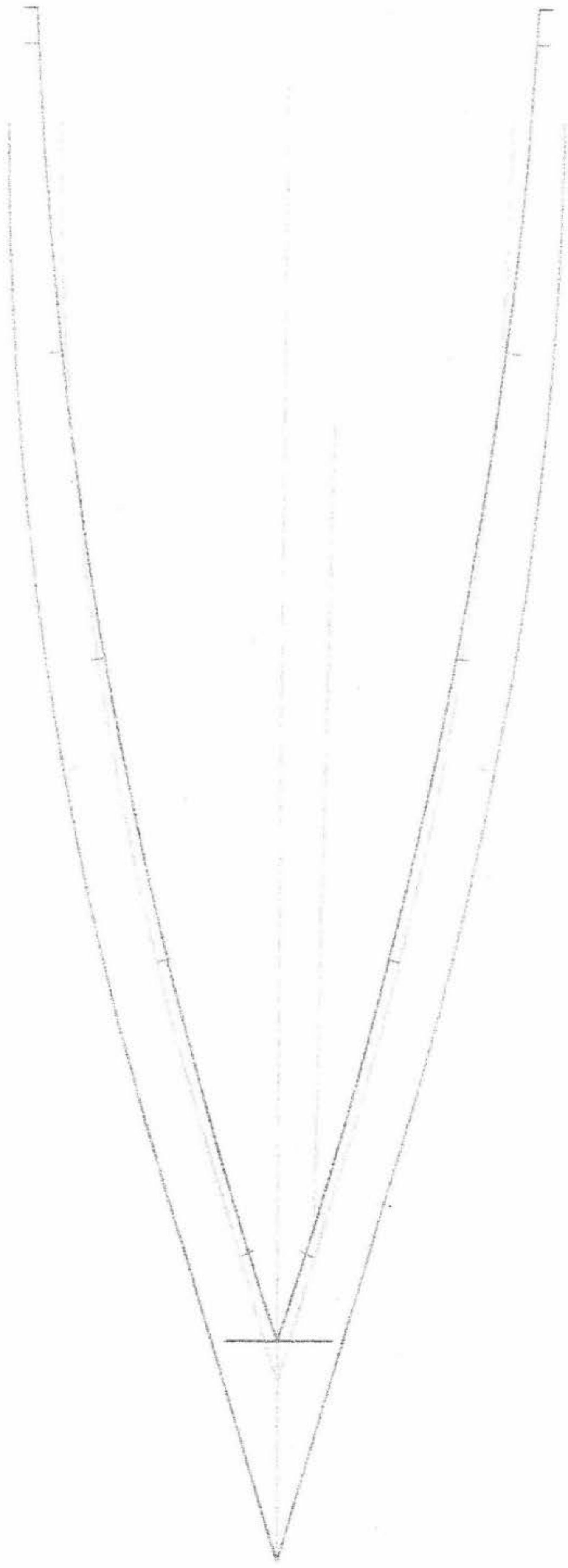


205

INCEPT MARINE LIMITED 118 Hautapu Street, Taihape P.O. Box 26, Taihape. NEW ZEALAND. Ph (64) 6 388 0729, Fax (64) 6 388 0747.	K40 Sea Kayak Proto type IV	Amended:	Mach 4	27/10/00	Drawn	JMB
					Date	27 / 10 / 00
		Scale 1:20			File	K40.mcd

11.8 NEW BOW CLOSING POSITION FOR P4

New bow closing position from red P4, to be used for grey P4. Note small sketch of old positon right hand corner.



Actual close 60mm towards bow, last registration marks 5mm to outer edge, welding line arc by three points from join, 2nd to last registration and finish position on 30mm line.

12 APPENDIX D

12.1 EVALUATING P4

(A. Sutherland 21 March, 2001, personal communication).

21 March, 2001

Dear John

Almost a month since your letter of 27 February, and two weeks since our five person all day evaluation of the K40. Much work that day and since. Last night there were forty people at the local kayak club meeting, nearly all of them experienced paddlers. I took the boat, set it up and explained what I thought were its great features.

One question was could you make it for two paddlers. I said I was sure that people could order two seats and velcro them on in whatever position they wanted, and that there would be space for gear for a week's expedition and certainly for a day paddle.

Here are notes to you in no system of order:

1. Re your two page description of the boat in your letter to me of 27/2/01:

   a. Boat name: My old one that I brought to New Zealand is named Diodon, but that's a personal choice. Diodon hystrix is the scientific name for the balloon fish which seems suitable. Also I had a balloon fish friend who lived in the rocks and who led me out the route from shore to reef in front of the house when I went out snorkeling. How about KSea? Or Intrepid as in Incept/? What names do you have for your rafts and for your canoe that we had out in the river?

   a. Camber: I did find the boat more tippy than mine. I haven't yet had it out with a full load I'm sure I'd get used to it. Is it related to speed?

   a. "Buoyancy: high displacement when swamped" Does this mean "if it's full of water up to the gunwales plus fifty kilos of weight it will still float"?

   d. "Crew 1 person" See above re use by two persons

   e. Pressure Relief Valves. When Mark Rognstad and Neil Frazer and their wives (all experienced boaters) were here two weeks ago we all agreed that the PR valves are a great idea. We've all known of boats that blew seams in the sun. We liked all the valve systems. Could the two side PR valves be placed two cm higher? At present they interfere with the rudder lines. or lower

   (it's shape should be its shape. Apostrophe makes it mean it is shape. Its, possessive, doesn't take an apostrophe, like ours, his, theirs, yours. Secretarial error probably. Sorry – I used to be an editor.)

   f.. Thanks for the repeat of the repair instructions. You didn't mention roughing up the material before the glue, though I remember you emphasizing that when I was there.

   g. For the USA you can't call them canoes. In Britain a kayak is a canoe. In US a canoe is an Indian canoe. In Hawai'i a canoe is a six person outrigger canoe. Argggh!

2. Velcro along the gunwales: Is this the preglued velcro we bought at Kilgo's in Honolulu? It isn't sticking well. It comes off when I pull off the cover. I wonder if the adhesive on the velcro was designed for hypalon material. The Kilgo velcro goop stuck to my hypalon boat better than any tube or canned glue ever did. I'll peel this off, wipe the surface with MEK and see if it sticks better. If that doesn't work, I'll use the glue in the white tube you gave me.

3. Seat: I'd like to see it have separate valves for seat and back. Then in rough seas I could deflate the seat without deflating the back. I believe that raising the seat two cm lowers your stability by 50%. I experienced this in Alaska on a trip in 30 knot beam winds. When I figured it out, I deflated my wine bag seat and did much better.

4. End carrying grips: I changed the rope loop to PVC pipe grips. Easier on hands and can't twist around your wrist if you're coming ashore dumped and rolling in surf.

5. Rudder: This was the biggest complaint by the five of us when we each took the boat out in Hale'iwa harbor two week ago –where you and I paddled. The men could, with some difficulty, pull the rudder in its 270° arc from the deck to the vertical position in the water. We three women could do it with great difficulty, feeling as if we were going to dump the boat in the process. Ken Leghorn, head of "Alaska Discovery" the largest expedition kayak company in the US, says that people with 270 rudders often say, "Please come along side and hit my rudder down". Even Doug Simpson's rudders (Feathercraft) have this problem. What's the experience with them there in New Zealand? I've never felt that any more than a 90° arc was necessary. Yes, the 270° looks neat, lying there on the deck, but if it's too hard to do, people won't, and they'll bash their rudders on rocks or tangle them in kelp rather than try to raise them.

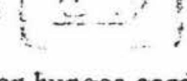
   I find that 50% of the value of a rudder is the stability it gives to a boat. Like a keel it keeps the boat from rolling and from skidding sideways.

   I did adapt my rudder to your boat. I cut a new blade, aluminum, six cm longer than my old blade, to compensate for the rocker. I used a shorter crossbar at the top than mine. I replaced the hook on the outside by my left hip with a jam cleat to hold the line that lifts the rudder blade out of the water. I changed the orange round foot control bar to a flat piece of plywood as my boots and my zori kept rolling off the round one. I may go back to my old stirrup system – awkward to get your feet into them when launching, but sure and simple under way. I use a taut line hitch on the rudder lines to adjust for leg length – works fine.

   I took off the bungee cords from the pedal to the D rings under the bow – didn't seem necessary. I'll glue a 6x9 cm patch on the hull where the heels of my boots rub.

6. Would it be possible to make the whole boat two or three centimeters lower? I realize this would make less space for cargo. I keep remembering head winds as the major problem on expeditions. Maybe I should just erase that bulky body pushing against the wind, or increase the muscles for paddling or....

7. What is the purpose of the small black tubes along the insides and outsides?

8. I prefer D rings that lie flat to these  that stick out.

9. I'll put D rings on the sides to clip on bungee cords and snap hooks for my paddle float system.(see page 70 in Paddling Hawai'i) and toward the bow for snap hooks for the deck bag. The velcro patch I put on for it on may not be enough in a big head sea and a wave that rakes the deck, tho I try not to be out in seas like that.

1 ft longer.

10. Many of these changes are from my own experience in thirteen different models of boats, and in over thirty years of paddling inflatables on the ocean. Mark Rognstad is the only other person I know who has as much inflatable sea time. He also is a very capable engineer. Surely there are other people in the world who would have ideas different from mine.

Now I'm off the reinflate the boat and take photos to show you all of the above ideas.

Please forgive the errors in marginating this letter. I'm only beginning to use this computer.

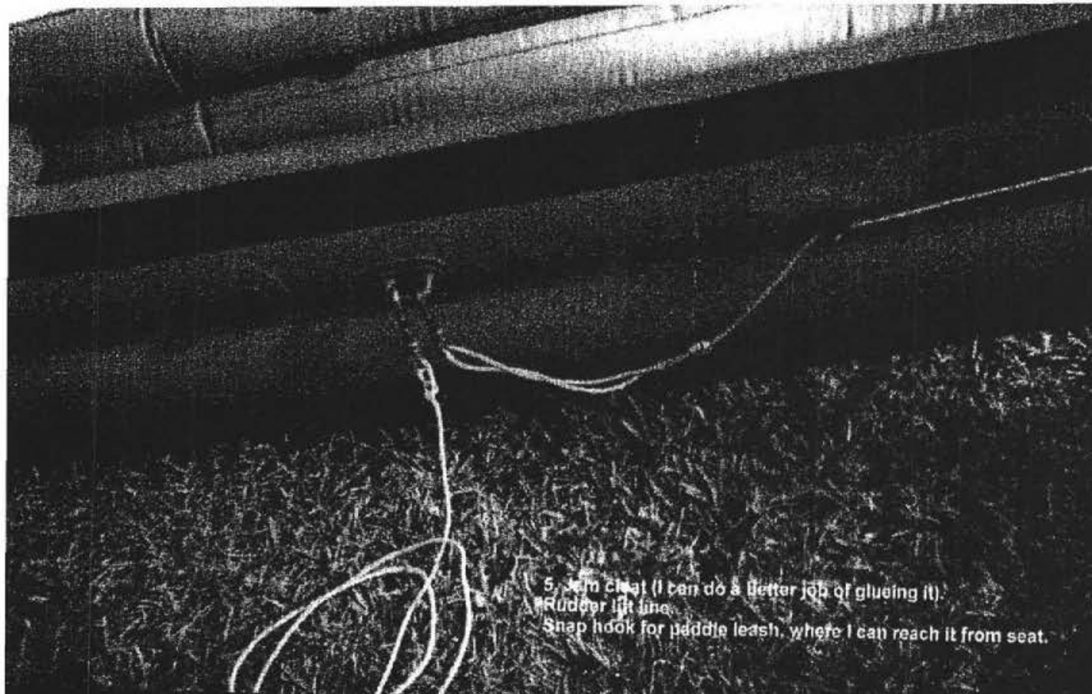
I'll be spending the month of May in France in an Elderhostel program of intensive French language classes for two weels, then paddle down the Dordogne or the Lot river, connecting castles and wineries instead of whales and bears. I'll probably use my little Sevylor Tahiti, three meters long and eleven kilos. It's easier to take with me. Have you some ideas on how best to fold the KSea?. That bullet shaped nose cone and the stiffer material make it difficult to fold as small as my old Semperit. Wanna use my house –your winter? Do you ever take a pure long vacation or is that only for when you're 70 or more?

For USA markets you'd need to translate to non metric language. I'm sure you've had experience with that. You're probably multi lingual/digital.

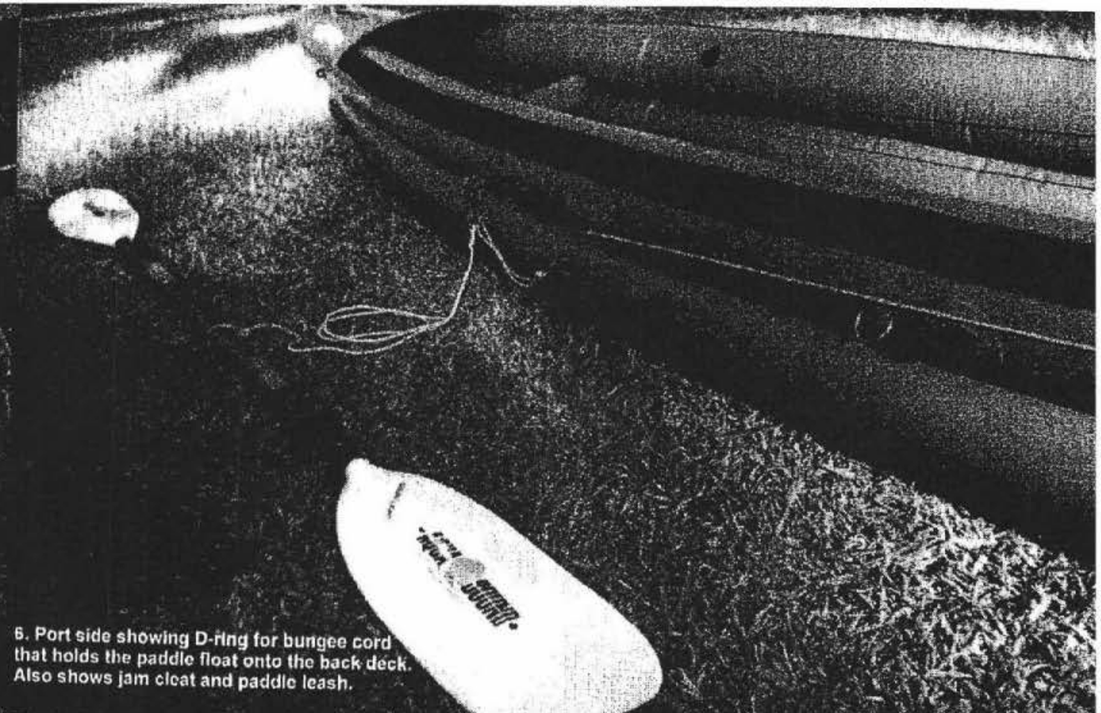
Mar 22 Just had a call from Andy Collins who "talked" with you by E-mail. Told him I'd get this off today. You may get other questions from the Kayak club.
It seems to me I've done a lot of nit-picking. It's based on years of experience in Sevylor and Semperit boats, and certainly there are other solutions. I look forward to yours,

And

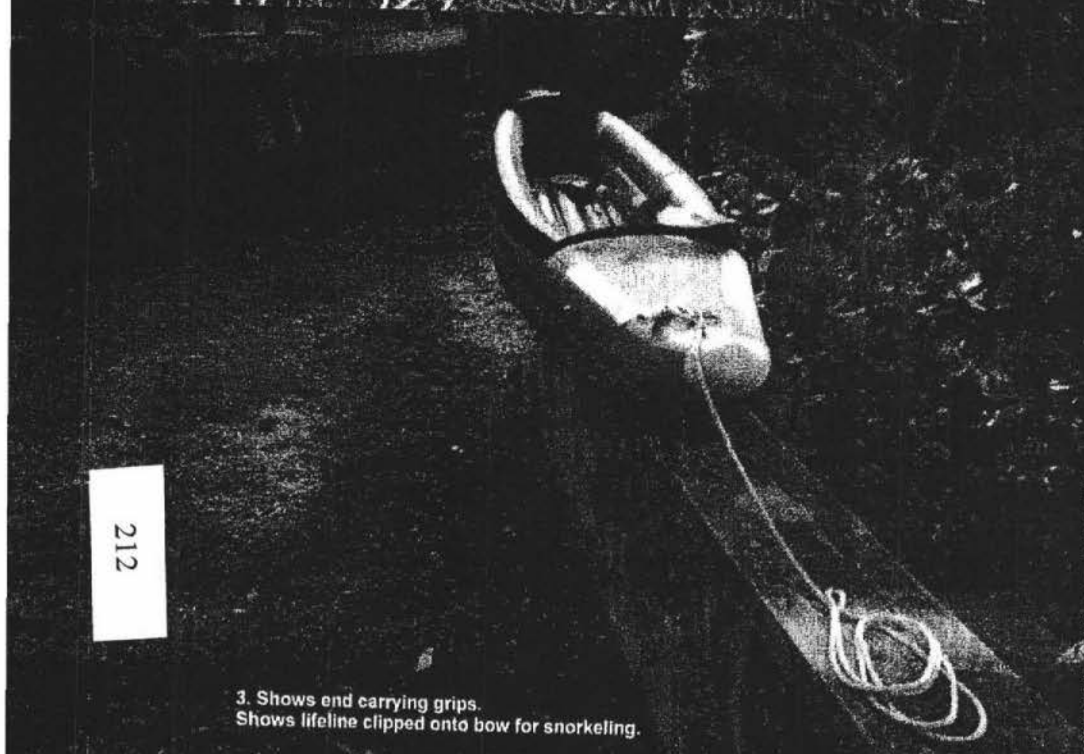

2. Shows camber and length of rudder blade
- I doubt it needs to be that long.
1. Shows rocker.
Increases speed?



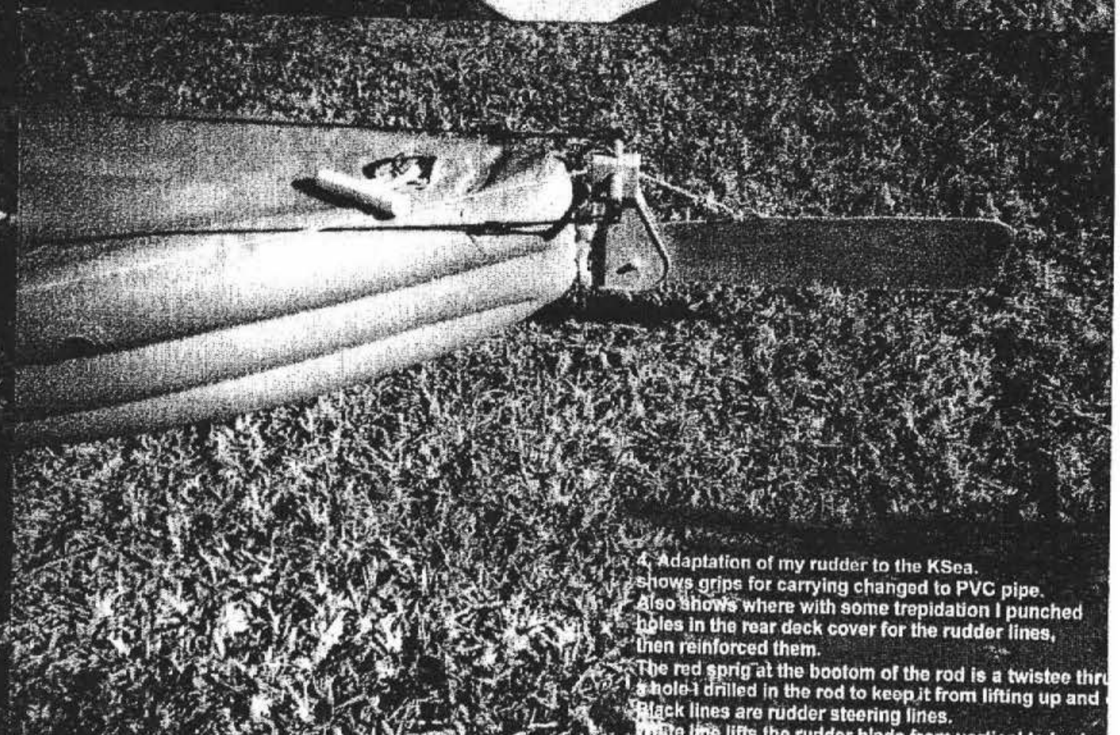
5. Jam cleat (I can do a better job of glueing it).
Rudder lift line.
Snap hook for paddle leash, where I can reach it from seat.



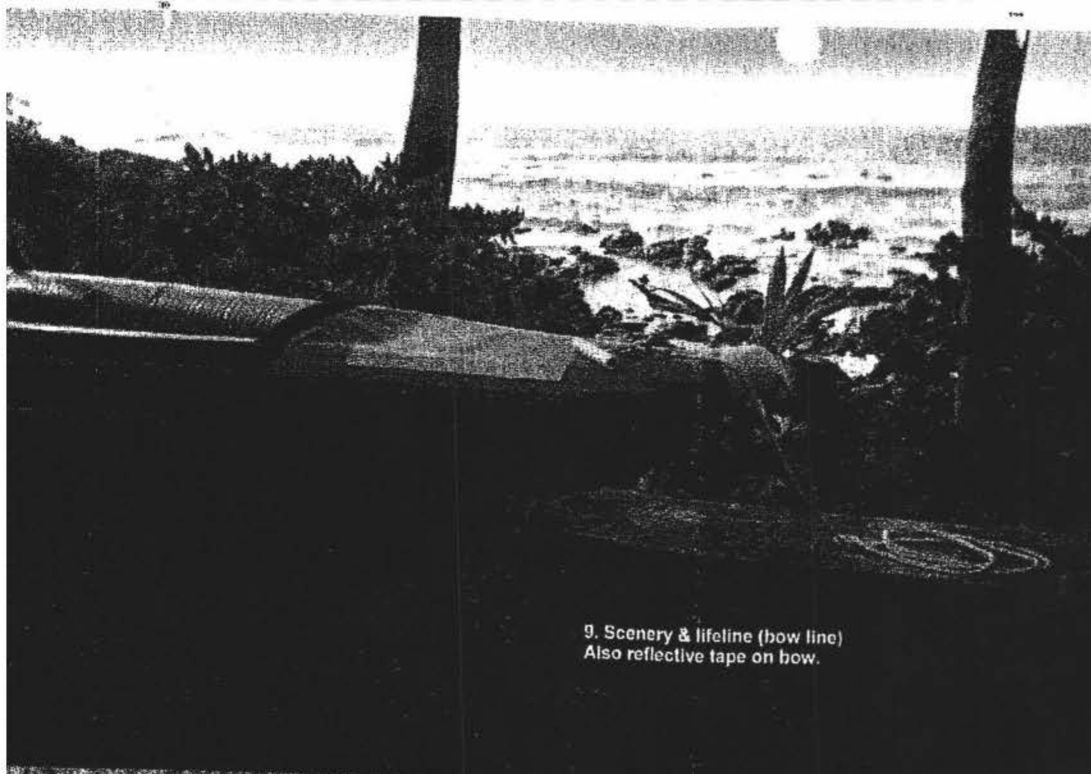
6. Port side showing D-ring for bungee cord
that holds the paddle float onto the back deck.
Also shows jam cleat and paddle leash.



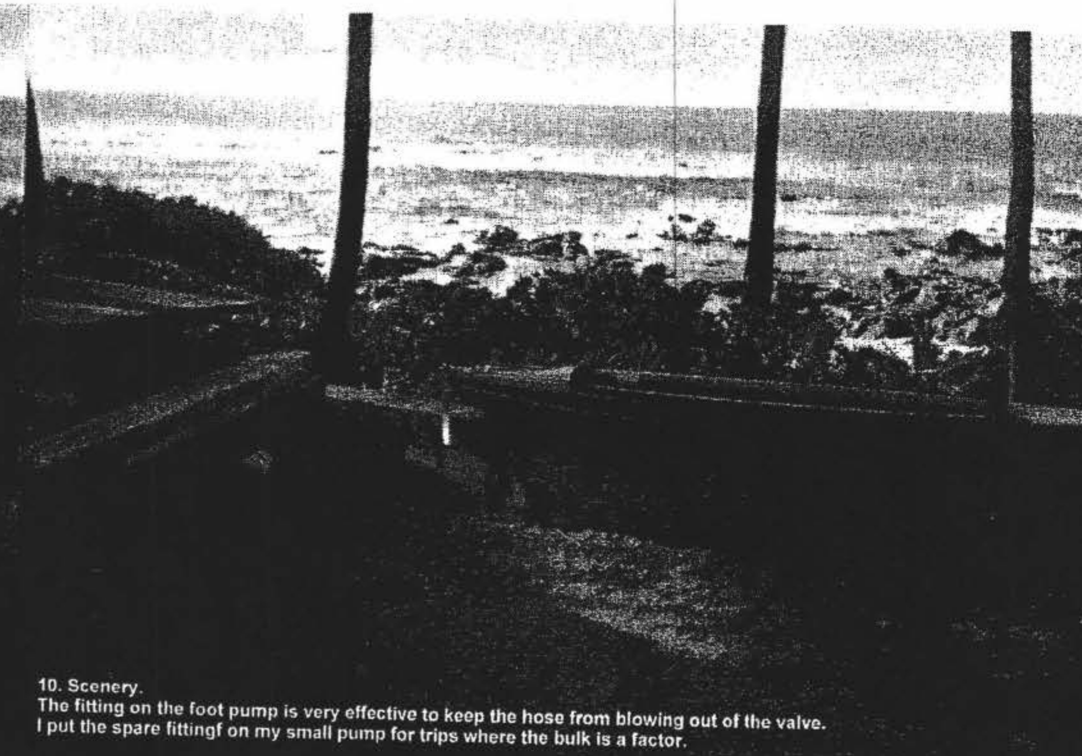
3. Shows end carrying grips.
Shows lifeline clipped onto bow for snorkeling.



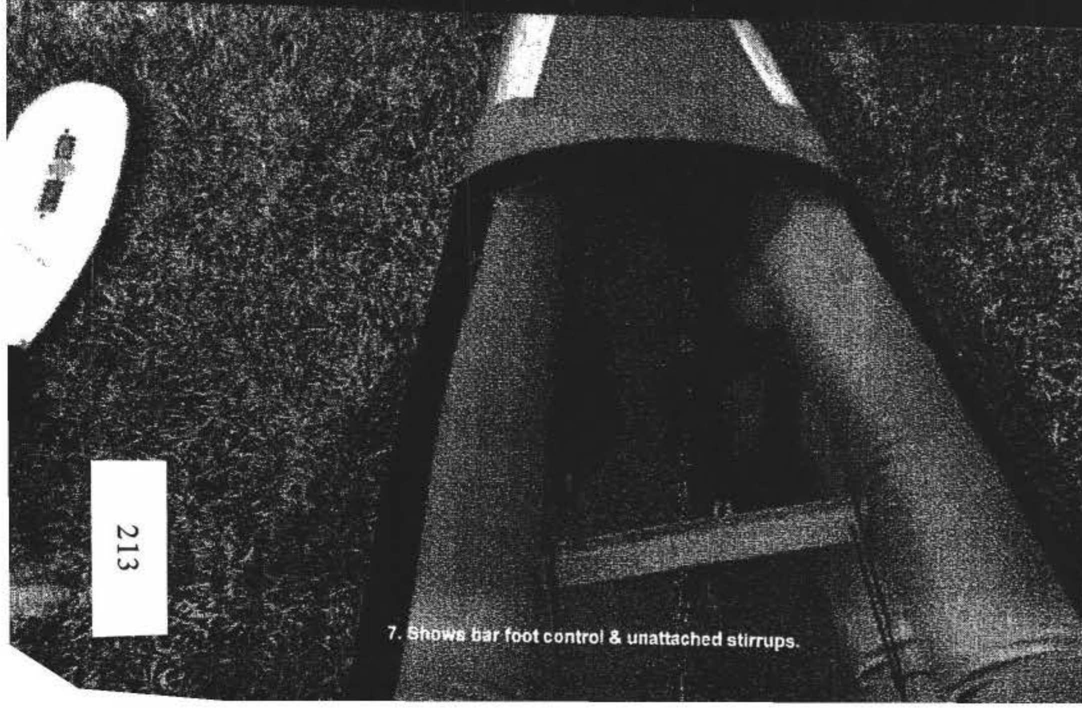
4. Adaptation of my rudder to the KSea.
Shows grips for carrying changed to PVC pipe.
Also shows where with some trepidation I punched
holes in the rear deck cover for the rudder lines,
then reinforced them.
The red sprig at the bootom of the rod is a twistee thru
a hole I drilled in the rod to keep it from lifting up and
Black lines are rudder steering lines.
White line lifts the rudder blade from vertical to horizo



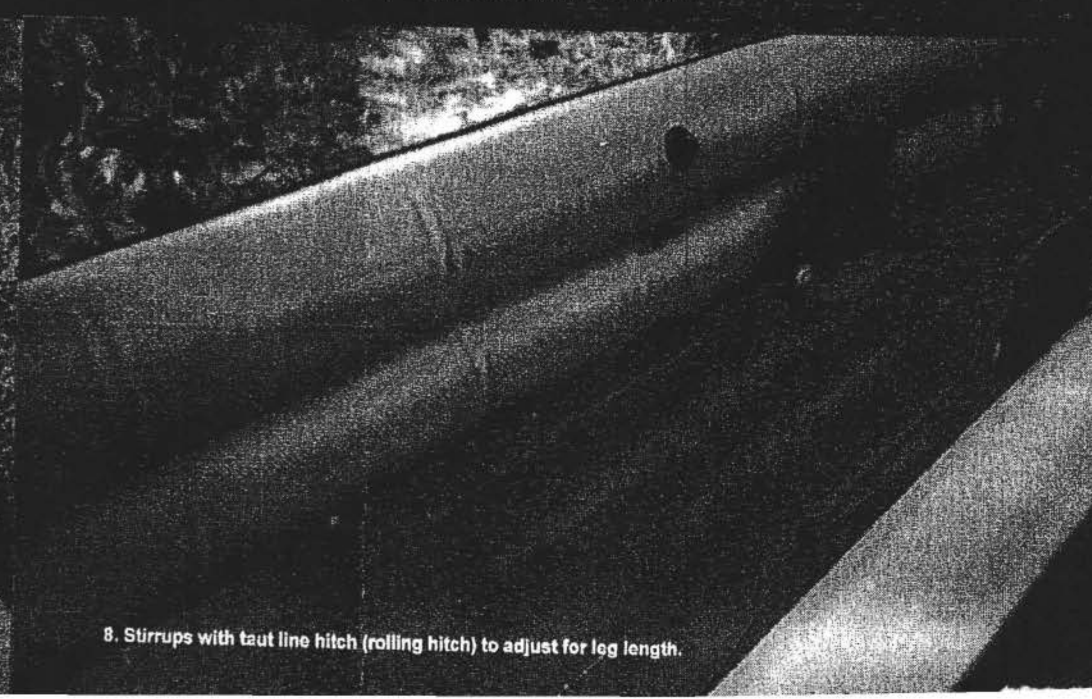
9. Scenery & lifeline (bow line)
Also reflective tape on bow.



10. Scenery.
The fitting on the foot pump is very effective to keep the hose from blowing out of the valve.
I put the spare fittingf on my small pump for trips where the bulk is a factor.



7. Shows bar foot control & unattached stirrups.



8. Stirrups with taut line hitch (rolling hitch) to adjust for leg length.

(J. Booth, 10 April, 2001, personal communication).

10 April 2001.

Ms A. Sutherland,
[redacted]

Dear Audrey,

Thanks for your letter of 21 March, and of course the underlying efforts in evaluating our boat. Thank you. And very glad indeed to know your health is back. Enjoy France. Taking part with a group having a common purpose should be good. I wish you happy times.

Re our little boat!

Stability

This is the most serious issue. Everything else is easily enough fixed. I see the floor is too low. Waterline is at the bottom of the side tubes whereas it should be over an inch higher - the tubes are not in the water without a heavy load. The problem would be worse if the boat were longer.

I spent some time using our little river kayak this past summer and it has the kind of inherent stability I thought was missing in our Diodon descendent. I have spent some time revisiting the boat design and there needs some changes in order to get the floor up inside the tubes. This is not such an easy task as it sounds. The geometry of the boat parts is extremely interactive and in gaining stability we lose in streamlining and native good looks and structural stiffness. There must be a solution and I am living it at this time. (You know the sort of thing - you go about your daily tasks but your mind is never far from the problem.)

Rudder

As I said we have a rudder which hopefully exceeds your expectations. Certainly I am happy with it. It is a prototype also - meaning the only one of its kind in existence - and I want to take it out on a paddle this weekend. I do not anticipate problems with it and will then get some more made. I will courier this one to you immediately after Easter to reach you before you head away to France.

Yes, it will fit your boat. And it takes down flat. It weighs 22 oz. It has the same depth in the water as last.

The blade has the same aerofoil section as the first (the problem) rudder, the section designed by America's Cup designers. It really does make a big reduction in drag when turning or when you need a rudder set to combat wind. I recall you commenting about its turning effectiveness when we were out off Hale'iwa Beach and up the river. I think straight ahead there is little advantage.

Rudder control - I am dreaming up an inflatable foot support with mini pedals hinged off the top. This is a folding version of the popular system widely adopted here in hardshells. It may or may not be practicable, but we look for utility and simplicity. I will keep you posted.

Velcro

Sold to us as the bee's knees (cat's whiskers or whatever) by our NZ supplier, this velcro's adhesive is a disaster. We paid double the usual rate to get this version - outdoor stabilised adhesive, permanent (etc), the top of the range. I am sorry. The usual adhesive is eminently better. Next time...

"Instructions"

Pardon. The manual I sent was rushed, modified from a canoe set, full of errors such as "canoe". Repair instructions are valid. This boat is polyurethane. Do not buff when preparing for glue. (But necessary on your Diodon which is hypalon or equivalent, has oxidised surface barrier and uses different glue).

Buoyancy: yes - if it's full of water, you'll still float. Again, the comments really applied to river boats where swamping of an open boat is common and extra buoyancy helps when you have half the rapid still to negotiate.

Inflatable seat:

Two valves makes good sense. Will do. Do you think the valve tube(s) should be extended for ease of reach?

Fittings

By "black tubes" I think we are talking about the beckets fixed here and there. They were put on by Liz3 - inside for purposes of guiding rudder cords, and outside for grablines, deck tie-downs and whatever. I left more in a plastic bag which could be added to the boat for more tie-downs. If you need more, I can supply.

Are the grey stick-out fittings for attachments of safety lines etc a problem (besides preference?). They are neat and easy. Do you strike them while paddling?

Marketing

Re Tom Holtey & co. Thank you. We are simply not yet ready for marketing apart from raising some interest for later, this boat still needs work. Knocking other manufacturers from their states of complacency is not my aim, and possibly one outcome of early publicity.

Folding

The stiffer material is a fact of life. Polyurethane is wonderful stuff, but certainly stiffer than hypalon. I carefully followed your folding method when at your house and achieved similar package size. But the boat did not naturally fall into that shape. Hopefully with successive foldings, it will get easier. Find the method that works best for you I guess.

(A. Sutherland, 14 April, 2001, personal communication).

14 April 2001

Dear John,

So good to hear your voice on April 9th and to get your letter today.

I'll take the boat out in a quiet lake this week and put a heavy load in it (jugs of water, diving weights, bricks, me) and recheck performance.

I see by your photos (digital camera, eh) that you have another boat there like mine – yours red, mine gray.

Stability: I've paddled so many boats – wooden kayaks by Pygmy of Port Townsend, WA, fiberglass, plastic, the English Nordkapp, racing surf skis – most of then with less stability than this one. I doubt that it will be a problem, though I certainly don't want any kayak that needs a bracing stroke every other minute.

Rudder: The new one looks fine from the photos, and the 22 oz weight (thank you for translating from grams) is lighter than my old one. I note that it will not fold up and over in a 270° arc. Ok by me. In my photos you'll see that I built in a protrusion on the back side for the lift cord, to make sure the cord didn't get jammed between blade and side pieces. Is that not a problem? I assume it will need some kind of jam cleat operable from the seat to hold it in the up 90° position. When I capsized in 1984 in Alaska it was partly from a heavy deck load and surf over a reef, and partly from leaning over from the cockpit to untie the rudder lift line from the D ring I was using, before I installed a jam cleat by my left hip.

Rudder control: I trust you to come up with some ingenious engineering marvel (as creative as the adjustable velcro attachments for positioning the seat) My stirrups work beautifully, but it's awkward getting them on and off my feet.

Velcro: I used your glue in the white tube to glue it down, especially at the corners where I start peeling the cover off. (The glue in the can from when I was there a year ago has gone off. Should I have refrigerated it?) Seems to be holding. I'll keep checking.

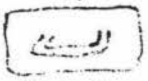
Instructions: Ah. Don't buff this fabric, only hypalon. Okay.

Inflatable seat: Put the valve tube for the bottom of the seat where it can be reached to deflate while sitting on it. Between your legs? Corner?

Fittings "Becket" is a new word for me. I looked it up. I never felt grab lines were useful or necessary, though I know the Brits seem to think so. (I get the newsletter, Ocean Kayaker of the International Sea Kayaking Association, the Nordkapp Trust, and Paddlers International, formerly just Paddlers International. Visited the founder of PI in Scotland in 1992, Peter Salisbury. Lots of stories and a wide knowledge. Editor of Ocean Kayaker is now John

Ramwell) I also get Sea Kayaker magazine - just as regional – from the Pacific Northwest. Then I'm my own region, based on experience in Hawai'i, Alaska, and elsewhere.)

The beckets might be difficult to attach deck tie-downs to – maybe the hooks on the ends of a bungee cord, but not my snaphooks (one enclosed) which I use for many purposes.

Gray fittings:  No, I don't strike them while paddling. I'm just leery of having them amidships where I might need to pull my body over them when reentering after snorkeling or capsize. I'll try doing just that and let you know. They do seem neat and strong.

More to come.

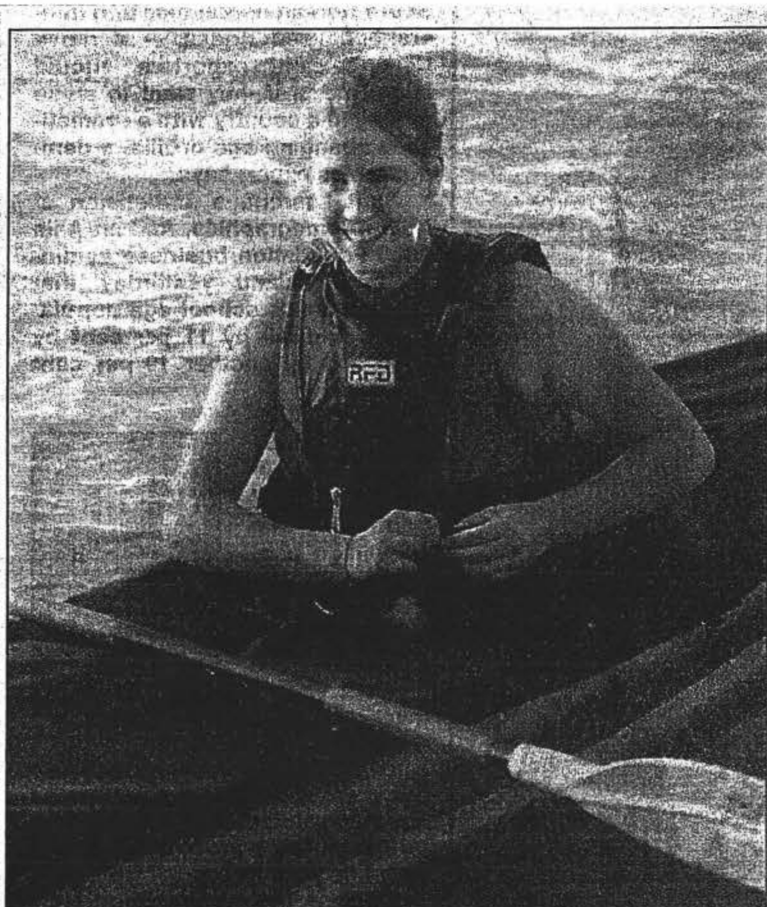
With love,

Audrey

Refer all this to your letter of 10 April

12.2 NEWSPAPER ARTICLES

Talbot, T. (2001). *The Dominion*, 27 March, p.13.



Ms Ussher tries out the new inflatable sea kayak she helped design

Innovation inflates Taihape business

By JILLIAN TALBOT

WHO SAID blowing up a business can't be profitable? Incept Marine thrives on blowing up its products and then making them float.

Even more unusual is that Incept is based in landlocked Taihape.

Despite this, the company has invented an innovative sea kayak that is light enough to be carried in a backpack, tough enough to make long expedition sea voyages and costs under $3000.

The company has produced inflatable rescue boats for the past 12 years and now produces half of its boats for the United States export market.

Incept drew on the expertise of three sources to come up with a design that would be acceptable to the market.

Massey University graduate Liz Ussher, a keen whitewater kayaker and masters student in manufacturing and industrial technology, provided research and development skills. She was able to work with Incept after being awarded a Technology for Industry Fellowship by Technology New Zealand.

An American solo sea kayaker, 80-year-old Audrey Sutherland, helped refine the design for the specific needs of sea kayakers. Manager John Booth said she brought a favourite inflatable kayak and spent a week with the company.

(2001). *Manawatu Evening Standard*. 2 April, p.13

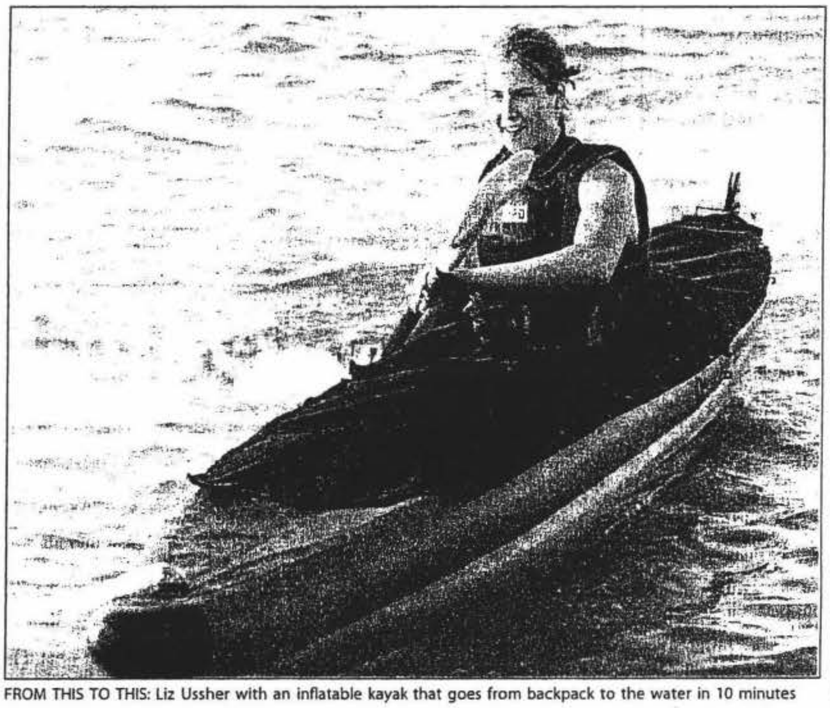
Boat business more than just hot air

TUCKED away in landlocked Taihape, a company that manufactures inflatable boats has produced a New Zealand first — a portable, inflatable sea kayak which costs less than $3000.

Incept Marine, which produces inflatable rafts, river kayaks and rescue craft, is one of the industry's busiest. Half of its factory capacity produces inflatable rescue boats for the US market.

The latest project for the innovative company was the sea kayak, which had to be small enough to fit into an average backpack, but tough enough to withstand long expedition sea voyages. Developing and producing the craft was an interesting team effort, drawing on the company's expertise, the R&D skills of a Massey University graduate student, assistance from Technology New Zealand and the at-sea experiences of an 80-year-old American, long-distance, solo sea kayak expert.

Massey University's Liz Ussher is a keen whitewater kayaker, so the opportunity to work with the company on a Technology for Industry Fellowship, awarded through Technology New Zealand, was a marriage made in heaven. While completing her Masters in Manufacturing and Industrial Technology, Ms Ussher's research skills helped the company take the project from concept to production.



FROM THIS TO THIS: Liz Ussher with an inflatable kayak that goes from backpack to the water in 10 minutes

John Booth, Incept Marine's founder, said: "What we needed was someone who could devote time to the project. Liz's input helped us confirm that we should develop an expedition sea kayak capable of covering long distances over an extended period."

Low drag was also a big factor in the development and various designs were tested in fast-flowing rivers to compare the drag.

Ms Ussher said: "Although I learned plenty about kayak parameters and design, I think the most valuable thing I learned was about teamwork and communication. I also learned how things never go quite your way in history."

Incept Marine was also helped in the design and prototype stage by Audrey Sutherland, an 80-year-old American, solo sea kayaker.

Mr Booth said: "She is always on the lookout for a faster boat, so she brought her favourite European inflatable kayak to New Zealand and spent a week with us. Her input and experience was useful in helping us refine the design for the highly specific needs of sea kayakers."

The 12-year-old company is a quiet success story — running at capacity, plenty of ongoing orders, a strong presence in international markets and looking for more people and space to expand. However, Technology New Zealand's help allowed Incept the luxury of taking time to add new technology into the business and open up a new market — building river kayaks.

"We know the kayak shape would always be a problem, as inflatables tend toward rounded surfaces while streamlined kayaks extend to knife edges," says Incept manager, John Booth.

"We also had to make a product that would be acceptable to the market."

13 REFERENCES

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