National College of Art and Design

Faculty of Design

Department of Industrial Design

Canoe Design

by

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INTRODUCTION

This thesis analyses the factors that influence canoe design, such as, historical evolution, operating environment, users, materials, methods of production and aesthetics. It will show that the many shapes and dimensions of canoes are the result of a multitude of design decisions and compromises. In essence to explain how these products have enabled us to achieve skilful interaction with all water types on a personal basis.

Canoe design may not have been written on as extensively as chair design or have such names as Dreyfuss or Behrens in its design history. From the industrial design point of view canoes have only been industrially produced for the past 40 years. However canoe design has a history of design nearly as old as the invention of the wheel itself. It could be argued that canoeing started with the first land dwelling homo sapiens attempts to float on top of water. Indeed on every continent and in nearly every ancient culture canoes have been used as a means of transport and fishing for food. Canoes were an object of survival and fulfilled an important role in these cultures. They have obviously evolved over the years to fulfil different functions and are made from different materials and by processes. The history of canoe design illustrates humans ingenuity in solving our physical and biological problems inherent with us interacting with the still relevantly alien element of water.

Canoeing has a history of invention and innovation and in more recent times it was a sport where many people designed and made their own craft for recreation or to tried to produce a craft to beat all its rivals in competition. People designing and making their own boats in their backyards may sound unprofessional from an industrial design point

of view. But from the beginning of this century there has been a tradition of many canoeist making their own boats especially with the introduction of fibreglass and resin manufacture.

It is an interesting proposition for the industrial design world for the user (canoeist) to both design and manufacture their own product. A product that they have considerable knowledge of the user requirements, the product's environment, its materials (i.e. fibreglass which is affordable and easily available) and even the manufacturing process as fibreglass use can be relatively easy to master.

In fact most of the main canoe designers and manufactures of both fibreglass (GRP), composite and thermoplastic products were firstly canoeists and it is big business. For instance, Graham Mackereth, Managing Director and a designer for Pyranha Mouldings who produce polyethylene canoes, used to be an Olympic canoeist. Frank Goodman, a teacher and lecturer in art, was a division 1 slalom canoeist before he founded Valley Canoe Products in 1970 to design and manufacture kayaks. Ernest Lawrence was an avid canoeist before starting designing and manufacturing in Ireland.

The following sources proved essential in the research of this thesis. The British Canoe Union, Canoeing Handbook (Rowe, 1989.) contained valuable information on the history and manufacturing processes of canoe design, especially as it was co-written by eminent figures in canoe design such as the aforementioned Frank Goodman whose chapter on hydrodynamics was particularly informative. The Complete Book of Canoeing and Kayaking (Richards, 1981.) was useful for the history of canoe design it contained. There was a great deal of information on the technical side of canoe building, especially with GRP in Canoe Design and Construction (Byde, 1975.) which gave an insight in to the widespread enthusiasm there was, and still is to some extent, for building canoes by canoeists themselves. Among quite a lot of irrelevant information, on the internet, Dick Wold's website, while being up to date, had some invaluable specialist design information relating to surf kayak design. Other current information on new designs and materials was gathered from the canoeing magazines Canoe Focus and Canoeist.

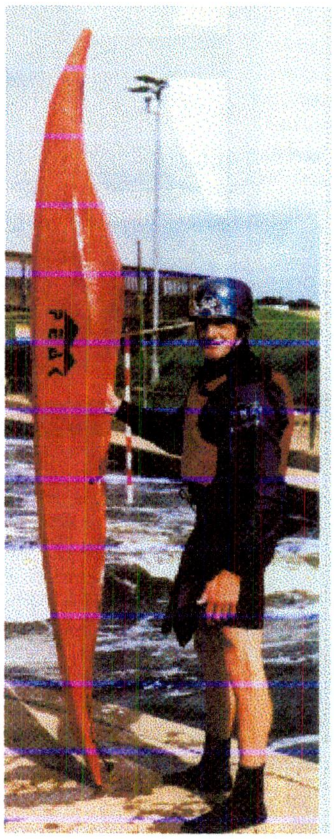

Figure 1: One such up to date design from the November '97 edition of the Canoeist that is claimed to be the world's most advanced playboat (i.e. designed for technical tricks on rapidly moving water).

CHAPTER 1 :

Natural Design Solutions

'Canoeing' is a general term that encompasses several different activities and designs of craft. The basic sub-division is between kayaks and open canoes. A kayak is defined as a craft that is propelled with a double bladed paddle. An open canoe, often referred to as a Canadian canoe, is defined as a craft that is paddled with a single blade paddle. For the purpose of this thesis the generic term 'canoeing' is used throughout unless specific reference to either of the two aforementioned sub-categories is warranted.

The origins of canoeing go back to the first man or woman who straddled a log and drove it through the water using the five finger paddles on the ends of his or her arms. The natural progression of this, of course, had the logs insides hollowed out, its leading end shaped to cut through the water and a sturdy pole for a paddle. This open top form is the origin of what we term an 'open canoe' to be today. In South America the indigenous people still hollow out a tree trunk as their ancestors did, by burning it away.

The North American Indians took this concept into new dimensions. The massive lakes and extensive river systems which riddles their continent were highways through difficult terrain and the canoe naturally evolved into a portable, lightweight travelling machine. Made from a pinewood frame covered with stitched together sections of bark cut from the abundant birch trees, the canoe could be built and repaired using instantly available materials. Designed for use on the lakes and rivers of their environment, it was usually about 20 feet long with a high bow and stern to negotiate rough water encountered when going over rapids. Wide in the beam for stability, these canoes had no deck and were usually propelled by two men, one at the fore (front) and one at the aft (back) using single-bladed paddles. Both roomy and stable these 'Canadian canoes', as they have come to be called were able to carry heavy loads. Sensibly, when the French conquered parts of North America they used this native craft. French voyagers and fur trappers used the rivers as we use roads today, as lines of communication between one settlement and the next and their equivalent of the modern truck was a 35 foot canoe.

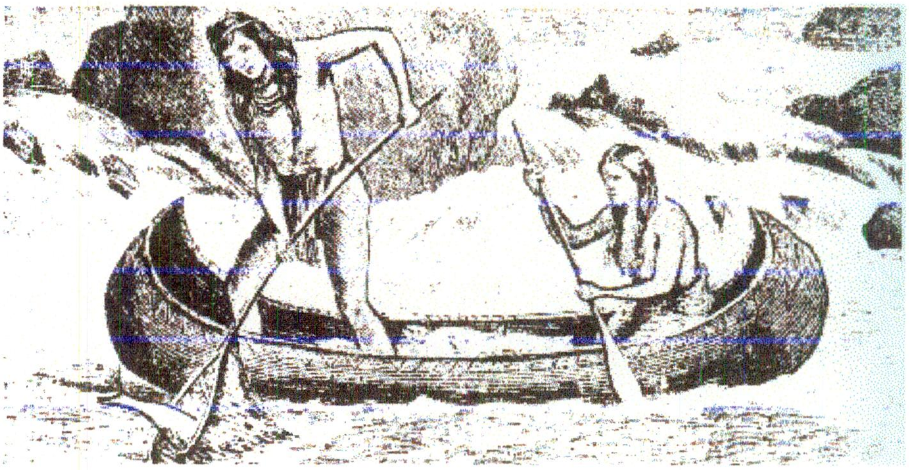

Figure 2: North American Indian canoe.

In Africa and Asia canoes were also an important part of early cultures. They made canoes using similar techniques to the South Americans 'dug-out' canoes, made by hollowing out a tree trunk. While in the Pacific, heavy canoes using an outrigger and several paddles were the main means of transport between the islands. Local water conditions as well as local materials governed the design of the boats, which is why several paddlers were needed in the Pacific in order to burst through the huge waves that pounded the coral reefs.

In the frozen wastes of the Arctic, the Inuit and Aleut Eskimos developed a fast, manoeuvrable and virtually silent boat for hunting on the sea. The word ‘kayak’ comes from the pronunciation of *quajaq*, which means hunters boat and describes the boat used for hunting by the Inuit people of Greenland. The *quajaq* and its bigger and slower counterpart the *umiak* were both made from sealskin or walrus skin. The skin was chewed to make it supple before being stretched and tightened over a frame of bone and driftwood. The frame was held together with thong lacing and ties, which were sometimes made out of the rear flipper of a ring seal. The skin was stitched in place using the leg sinews of caribou. The *quajaq* being used on the sea needed to keep the waves out so it was covered with a deck, with only a small hole, called a cockpit today, where the kayaker sat. Covering the gap that was left was a sealskin spray cover, to act as a waterproof barrier. Because he and his craft were so watertight, the Eskimo hunter could be overturned by a wave or a seal and still right himself without having to get out of the boat which could have meant the difference between life and death in the icy water. This manoeuvre, discovered much later by Europeans, was dubbed the ‘Eskimo roll’. The *quajaq* was long and narrow, and due to its effective design bears a great deal of similarity to the sea kayaks of today. It was paddled using a two bladed paddle by hunters who were traditionally men. The large, spacious *umiak*, meaning woman’s boat in Inuit, was capable of carrying several people or goods for trading and was paddled by the women. An early illustration of the design and function of an object reflecting the gender roles of a society. Canoes are still in use for hunting, fishing, trading, and warring in some parts of the world today.

Figure 3: An Eskimo kayak.

From essential forms of transport, hunting and communication, the canoe and kayak have developed into one of the cheapest and most popular forms of recreation available on water. Hundreds of thousands of individuals all over the world enjoy Canadian canoes and kayaks, because these crafts are not only able to navigate nearly any stretch of water but can themselves be easily transported.

The popularisation of canoeing as a sport began in the Victorian era. Victorians explored every corner of the globe, playing and refining all forms of games and developing into recreational sports and pastimes, ancient survival skills such as mountaineering and skiing. In 1865, John (Rob Roy) MacGregor, a Scot, and a barrister by profession, who after seeing canoes and kayaks in North America and the Kamschatta (in northern Russia) persuaded Searle's of Lambeth to make him a craft based on his observations. Clinker built (a form of construction where by timber planks are overlapped resulting in stepped appearance) the very first 'Rob Roy' weighed 90lbs (41kg) including a double-ended paddle, mast and sail with oak hull and cedar decks fore and aft. The occupant sat on the floor and propelled the vessel with the double-bladed paddle, although the small lug sail could be set to take advantage of a following wind or a beam wind.

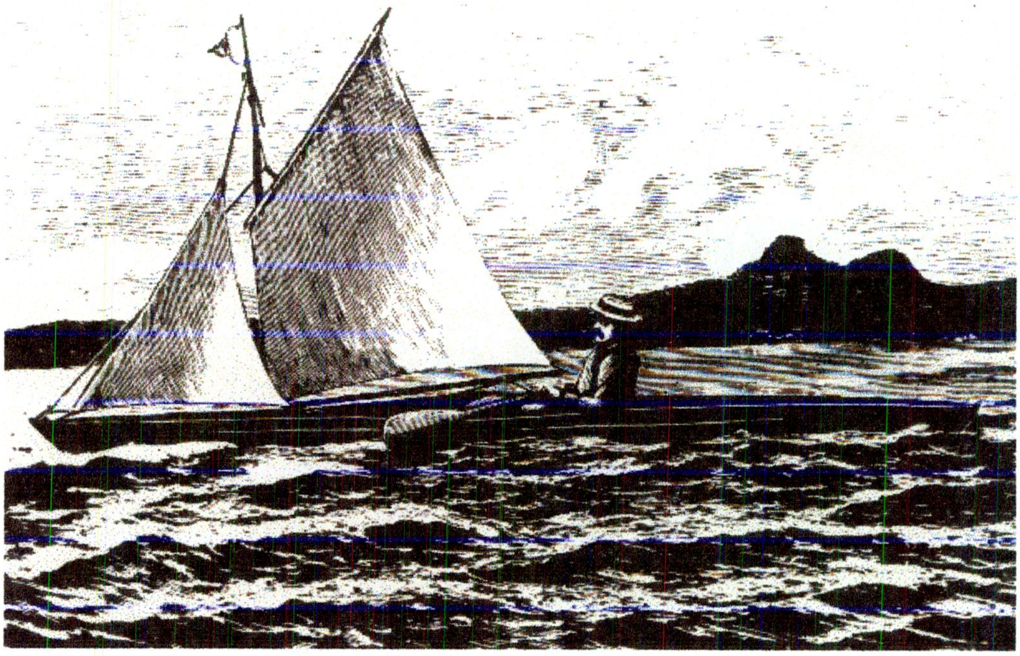

Figure 4: The Rob Roy canoe.

It was the amazing journeys which John MacGregor undertook covering over 1000 miles of continental waterways as well as canoeing in the Jordan, Nile, and Baltic and his subsequent lecture tours and books that popularised the sport in Britain. This was also aided by the emergence of a nation-wide canoe club in 1866 on the river Thames, the first of its kind in the world.

> The first period between 1865 and 1930 evolved from the founder of British canoeing, John MacGregor. His book, A Thousand Miles in the Rob Roy Canoe, fired the imagination of the Victorians. The 'Rob Roy' was a stable kayak, went in a straight line and had a large cockpit. Made of wood it was easy to handle and a boat in which any beginner would have felt safe. In this period, wooden canoes were imported and were used for family outings and touring. The limitation to the growth was the cost of wooden craft. (Rowe (Ed.), 1989, p. 122).

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After the 1930s there was an advance in the materials and production methods used. Wooden frame and canvas kayaks were developed. Their low cost and do-it-yourself designs were stable and further increased the accessibility of canoeing. The competitive side of the sport was also growing and in 1936, nineteen nations took part in the first canoe races to be included in the Olympics. It was again a change in materials and manufacturing processes in the early 1950s that advanced canoes design, performance and popularity. Once canoeing had caught the imagination of those in Western Europe many new applications evolved. New forms, materials and manufacturing processes have revolutionised canoe design since the first 'Rob Roy' canoe.

The relatively rapid evolution of open canoe and kayak design in recent years would not have been possible without similar advances in new materials and manufacturing processes. As more and more people took up the sport from the beginning of this century and higher levels of technical proficiency were being achieved on the water, so higher demands were being required from the performance of the equipment they were using. This has only been possible with improved designs and new lighter, stronger materials. Therefore the following chapter will trace these advancements in materials and how they directly related to advancements in open canoe and kayak design.

CHAPTER 2 :

Materials: The Design Catalyst

Canoeing has been revolutionised in the last 50 years by new materials and the subsequent design advantages and improvements that they allow. The boats that followed the clinker-built 'Rob-Roy' used a lath and canvas construction. This was possible by the development of plywood and waterproof glues after the First World War. Their construction consisted of several plywood cross-sections connected by longitudinal laths and covered by water-proofed canvas used to sheathe the frame. Although this method was very close to the traditional skin boats of the Eskimos, the boats retained the shape of their clinker-built predecessors. This type of construction was very easy to build at home and in Britain, the PBK (Percy Blandford Kayak) designs were built in large numbers until the early 1960s.

Beyond the capabilities of the home-builder was the folding kayak, which used essentially the same construction materials but the frame could be partially assembled and then unfolded inside the skin. This stretched the skin and the whole kayak became virtually as rigid as its un-collapsible lath and canvas counterpart. Originating in Germany, these boats became very popular and could be packed into bags for road and rail.

Although the basic material of the canvas and its waterproofing improved dramatically over the years abrasion was always a problem, especially the unseen attack made by sand within the craft. It was virtually impossible to keep this unwelcome abrasive out of the boat, where it collected between the frames and the inside surface of the canvas, wearing away the covering with every movement of the boat. Sharp rocks could tear the covering of a boat from end to end, and needle and thread were an essential part of a repair kit. A heavy blow could break the frame even if it did not puncture the covering. This meant that if the boat was wrapped around a rock by the force of oncoming water, so much feared by white water paddlers, there was the particularly dangerous possibility of splintered bottom ends being crushed into the legs of the paddler. In spite of this lath and canvas kayaks were pretty tough and light. The main problem was the maintenance of the wooden frame which could only be achieved by the hazardous and time consuming removal of the canvas.

Many improved methods of construction became possible when chemists synthesised glues capable of bonding at room temperature. Stripwood kayaks and canoes were made using longitudinal strips of wood the thickness of the boats skin, usually around 6mm thick. They were glued side by side over a temporary framework and fixed with staples until the glue had set. The finished product was a boat without any internal frames. Only a coat of varnish needed to be applied, although later a thin coat of GRP (glass reinforced plastic) was added to increase the strength.

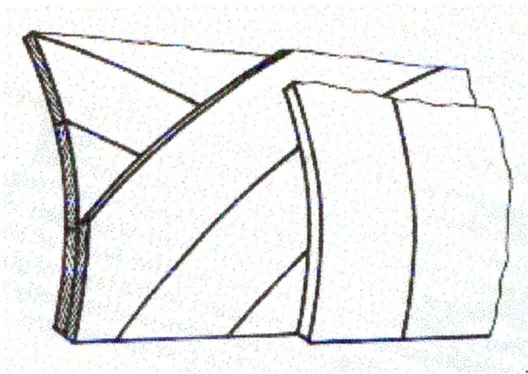

Figure 5: The cold-moulded ply canoes had at least 3 layers of veneer.

A lighter, stronger solution was to laminate thin veneers of wood in different directions. This construction method is currently being used today in the manufacture of sprint racing canoes. The smooth outer surface of these wooden boats keeps friction down to a minimum, and this means faster boats. Wood is also a very stiff material - far stiffer the either GRP or polyethylene and this too meant that very stiff, fast boats could be produced out of timber. Indeed in the sprint racing world, wooden canoes and kayaks still reign supreme. It is also quite remarkable that sprint design has been totally dominated for decades by one person, the Dane, Jorgan Samson, designer for the only two manufactures of wooden sprint boats in the world.

To date he is the only designer who has seriously undertaken scientific tank-testing of canoe designs. Although having said this it is very difficult to successfully apply scientific test results to actual full scale craft as there are so many variables in canoe design that precise simulation is impossible. In fact sprint racing canoe design has the least number of variables as the water type is calm and the overriding design goal is speed. The following chapter will cover the problems that relate to the form and hydrodynamics of canoe design.

The main problem with wood as a material for canoe manufacture is that it needs a high level of maintenance relative to GRP and polyethylene. Wood also has a higher water absorption ratio which is especially prevalent after an extended period of immersion. This being the main reason there are some canoes made from GRP for sprint racing. Finally, wood construction methods do not lend themselves well to mass production which in turn adds to their price.

Wood seemed to be a natural choice of material for canoe manufacture in every sense of the word. But during the 1950s and 1960s aluminium was the most popular material for open canoes in America. The reason for this was more economic than anything else as it was cheaper to press the open canoe form into a sheet of aluminium than building it up with veneers of wood. However there were several disadvantages with aluminium that has rendered it quite impractical for mass produced canoes or kayaks. Firstly, it is a good conductor of heat which means that cold water cools the knees of canoeists or a hot sun could also unpleasantly overheat the boats surface. Secondly, aluminium is a soft, malleable metal which is liable to 'stick' to the rough rocks in white water rivers. An aluminium white water kayak could also become very dangerous if it bent around a rock and trapped the occupant. A further problem is metal fatigue, this is where an impact load, not high enough to cause a fracture initially, is repeated. For example when the boat bumps into rocks, the accumulated effect over time leads to fracture. Finally metal canoes and kayaks are considered the ugliest boats on the water.

Today aluminium is only used to manufacture a small percent of general purpose open canoes. This is because the lower costs of manufacture are not enough to make up for the losses in performance.

It was only when designers adopted glass reinforced plastic (GRP) as a material for a manufacture, that high performance craft became available at low costs. Costs of manufacture were reduced as the skill levels and the length of time required dropped. Performance levels were increased as regular maintenance, previously essential, was practically abolished while at the same time the canoes life span was greatly increased. Glass reinforced plastic canoes are a combination of a matt fabric of thin glass strands set in polyester resin which results in a water resistant material.

It is this resistance to water absorption that explains the reduced maintenance. Glass in thin strands is extremely strong in tension while being flexible. The resin, which cures at room temperature with the aid of a catalyst, adheres very well to glass threads and the combination results in a very strong matrix. The simplicity of this procedure, in contrast to laminating veneers of wood with steel clamps or in ovens, was the reason for cheaper and less skilled workers. The moulds for the canoes can also be made relatively cheaply further reducing the manufacturing costs.

The result was that hundreds of amateur builders sprung up in countries all over Europe which in turn led to several manufactures being established who produced GRP canoes. In Great Britain alone the handful of manufactures of GRP canoes who were established by the late seventies were collectively producing a range of well over five hundred designs. This was a direct result of the change in materials. Not only was there a greatly improved product range but the ease and cheapness of changing the moulds meant that full scale test models could be produced which in turn improved canoe designs and ultimately their performance.

With the introduction of GRP it raised a fundamental design question for canoe designers which is still open for interpretation today. GRP or "fibre glass" as it is commonly referred to has almost no constraints in the shapes possible to be produced even undercuts can be accommodated at an extra cost. This gave a knew freedom to the designer. Previously the decoration or aesthetics of a boat were dictated by the materials used. The designer can fall back on decorative elements that have evolved in other materials but this often produces quite an unpleasant aesthetic and an impractical design.

Today, you can still see some fibreglass dinghies whose hulls are replicas of clinker-built planked boats. The steps in the surface are poor in design hydrodynamically speaking but can be justified in wooden boats as the out come of the construction method, which is a good design solution for the material and results in a beautiful appearance. Replicated in GRP, when in fact the repeated steps are very hard to mould satisfactorily, is quite ridiculous. Some GRP kayak manufactures have designed sea kayaks to Greenland 'specifications' but because the Eskimos craft was so suited to the sea environment these are still practical boats, just with more pronounced bow and stern sections. There is obviously no attempt to recreate the seals skin effect with the fibre glass.

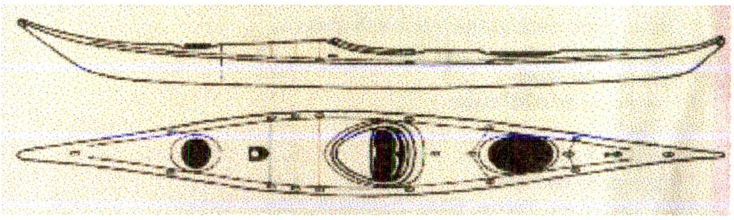

Figure 6: An example of a modern interpretation of the traditional Greenland style.

With the huge advances in material science, materials are being designed with properties to suit the product rather than the products design being compromised to suit the materials properties. This means that materials like GRP, compound materials or polyethylene, all used in canoe manufacture, are designed to deliver improved mechanical properties and seldom produce their own aesthetic in the construction process of a product as wood does. In canoe design materials are primarily chosen for their performance and secondarily for their price and ease of manufacture, aesthetic considerations are at the bottom of the list.

As there are many problems associated with movement in a half submerged vessel, combined with the volume and load it must carry relative to its own volume and the possibility of rapidly moving water, canoe forms are always dictated by hydrodynamics and not aesthetics. Having said this hydrodynamic solutions produce there own aesthetic just as Raymond Loewy recognised that aerodynamics had its own aesthetic. As a result it is the hydrodynamic forms of canoes and kayaks combined with the different surface finishes and colours that the materials can take, that produce the distinctive canoe aesthetic.

Perversely, while GRP exceeded wood in a strength to weight ratio instead of boats of equal strength being produced at a common weight and cost, lighter and lighter canoes were produced reducing their strength. The reason for this was the competition and racing communities demands for lighter, faster craft and what was good for them was good for the recreational user.

However, the growth in popularity of the sport mushroomed during the period after GRP was introduced into the sport. This was partly due to the aforementioned advantages of this material resulting in a wealth of new designs on the market and a combination of other factors. These being the increase in discretionary spending, the time available for leisure activities, the interest in the sport generally and finally, the increase in the number of car owners as light-weight GRP kayaks could easily be transported on their roofs.

Subsequently demands for stronger materials than GRP were met by materials with higher tensile strengths than the strands of glass. Diolen, a cloth woven from specially treated polyester - Terylene in the UK, Dacron in the US - possessed a higher tensile strength and increased the impact resistance, but the search for lighter materials continued. Originally developed in the early seventies, for a replacement for steel in radial tyres, Kevlar has twice the tensile strength of glass while being significantly lighter, around 30%. It is a petroleum product closely related to nylon and was prone to delaminate when used with polyester resins. Later polyvinyl resins were introduced being more compatible, while epoxies were found to be even better though quite expensive. However, recently in the search for stronger, lighter materials by canoe designers, Spectra has been applied to canoe manufacture. Now used by the military for bullet proof vests and helmets, Spectra has far superior impact resistance properties than Kevlar with the added advantage of being lighter.

Canoe designers realised that no one material held all the answers. The result was a combination of the right materials in the right places. A popular combination is a sandwich of layers of carbon, Kelvar, a foam core, followed by another layer of Kelvar, then carbon and finished with a gel coat of resin. The reasoning behind this was that carbon, although not as strong in tension as Kevlar, is very stiff therefore adding to a canoe's speed. Carbon is virtually unstretchable and for a material to bend, its inner surface must be compressed. As a canoe can be prone to bending on several planes it is necessary for a layer of carbon to be present on both sides of its skin. The reason for a foam core is that increased thickness equals increased stiffness so the greater the distance between the two layers of carbon the stiffer the canoe. Canoe design is often about compromises to get the best solution and an increase in thickness means an increase in weight, therefore a light weight material is used. But down the centre of the laminate there is neither tension or compression, this is called the neutral plane and is where sheer forces are greatest. So the light weight material must be strong enough to resist these forces. Another advantage of GRP and composite constructed boats is that they are the only type of boat on the market that can be relatively easily customised for the individual or that the individual can customise themselves. They are also easier to repair than wooden, aluminium or polyethylene canoes.

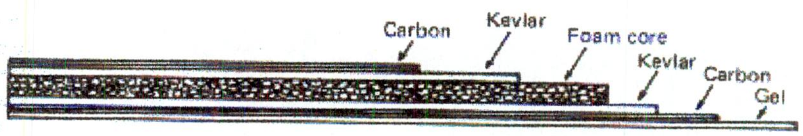

Figure 7: A cross-section of the layers of a sandwich construction of kevlar, carbon and a foam core.

Probably the most important aspect of GRP's introduction to canoe design was that it encouraged many canoeists themselves to turn their hand to designing and making their own boats. And out of the large number of these amateur builders there were a few individuals who have managed to establish themselves as designers and manufacturers of canoes on a national and international scale.

> …virtually all kayak manufacturers are paddlers who started their businesses when enthusiasm and commitment to developing their own ideas was more important than a large loan from the bank. (Rowe (Ed.), 1989, p.77).

The most recent leap forward in canoe design and performance began in the eighties with the first polyethylene canoes. Polyethylene, known by the trade name polythene, and the subsequent thermoplastic composites are the only materials that are truly able to be mass produced. Strangely enough, the first plastic canoe was produced by a Californian bin manufacturer, but a huge commission to produce bins for Phoenix, Arizona halted the first run of plastic canoes to go into mass production. Polyethylene had many applications before canoeing, most of these products being considerably smaller. Therefore it was the manufacturers who manufactured much larger products comparable in scale with canoes that made the first attempts to produce them. The resulting crafts were usually crude and badly designed as no one in these companies had sufficient knowledge of canoe design. The advantage of polyethylene was that it was a cheap material, which could be mass produced easily. Although the capital costs, for instance the moulds and heating systems, could run into hundreds of thousands of pounds. The other two advantages of polyethylene canoes were their freedom from regular maintenance and resistance to impact.

Most polyethylene canoes are produced by roto-moulding. Briefly, roto-moulding involves filling a metal mould with a plastic powder, heating it until it melts and by carefully tilting and rotating the mould, achieving an even covering of plastic on the inside of the mould. Polyethylene canoes can also be made by blow-moulding which allows for a higher molecular weight of material to be used. This results in tougher, stiffer canoes but is far more costly to produce, this is why there are only two manufacturers producing blow-moulded canoes today. Essentially the blow-moulding process involves a metal mould closed over a molten lump of polyethylene that is expanded with an injection of air to take the form of the mould's inner surface.

The two main problems of manufacture is getting a consistent supply of good quality raw material and getting the minute chemical processes correct so that the resulting boats have the correct material properties. Polyethylene can be produced with many different types of properties depending on the chemical arrangements of its molecules. Essentially, plastic canoes are made from either linear or the superior cross-linked polyethylene. Polyethylene's resistance to impact depends on its stiffness which mean thicker, heavier canoes. This has meant that larger canoes and kayaks are too heavy to be manageable in or out of the water. Some designers have attempted to resolve this weight problem by reducing the size of canoes but it is not good practice to let the material dictate the design. It is also possible to form polyethylene so it foams in the middle, producing a foam-like composite material therefore increasing buoyancy to counteract the increased weight. But the ability for polyethylene kayaks and canoes to literally 'bounce' off rocks means that it is the most popular material for general purposes and white water boats.

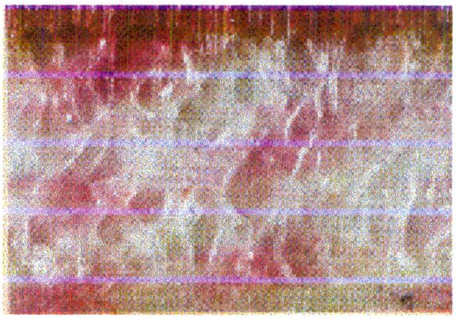

Figure 8: A cross-section of the foam core it is possible to produce in the manufacture of polyethylene canoes.

The disadvantage for white water boats is due to polyethylene's softness. There is the serious risk of a paddler getting caught by a rock and the force of the water bending the kayak around them and possibly drowning. Another disadvantage relating to its softness is its lack of resistance to abrasion. Even though canoe manufacturers advice against dragging boats many paddlers still do, especially if the canoe is made from the heavier polyethylene. Rough hard surfaces cut the underneath of the canoe like a cheese grater. This leads to another disadvantage of polyethylene, compared with GRP and compound materials it is extremely difficult to repair.

Due to polyethylene's superior impact resistance it doesn't need to be repaired as frequently as GRP canoes. However, repairing damage to a polyethylene canoe is incredibly difficult whereas repair to GRP canoes are relatively simple. This is mainly due to the difficulty of bonding polyethylene, this also means that most parts are riveted to the canoe. Polyethylene also has a useful property for canoe design, it has a 'memory', all be it not very accurate. A material that has memory can return to its original shape when dented. So large dents can be removed by relieving the pressure and applying gentle heat - even sunlight.

The only notable advance in materials since the introduction of polyethylene is a material called Royalex. It has a similar sandwich construction to other composites consisting of ABS, vinyl and a core laminated together. The ingenious thing about Royalex is that the heat from the vacuum-forming process used to form the sheets of Royalex into canoes also expands the central core layer so it cools into a strong foam layer. This means that while Royalex is tough, easy to maintain and repair, light with integral buoyancy, it also has a far superior 'memory' to that of polyethylene. So much so that it can bend around rocks and return to its original shape.

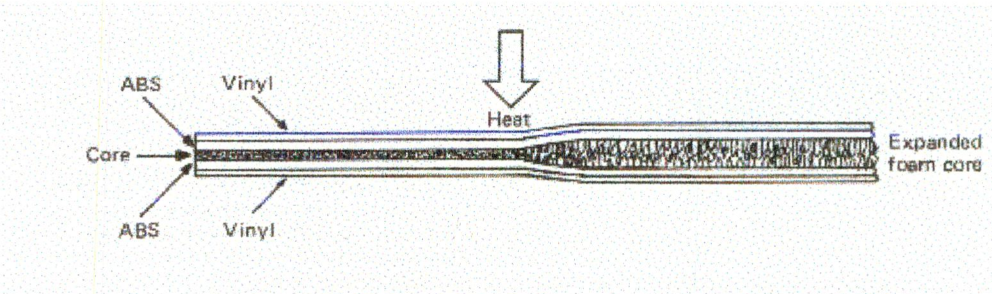

Figure 9: A cross-section of Royalex.

CHAPTER 3

Water: The Design Problem

The way a canoe interacts with the water is of great interest to the canoe designer, as is the level of proficiency of the paddler. The reason there are so many designs of canoe is mainly in response to these two variable factors, the paddler's proficiency and the water conditions.

The scientific analysis of motion in water is referred to as hydrodynamics and for a full understanding of its complexities would warrant an entirely separate thesis. However, to understand the current shapes of canoe designs it is necessary to explain some of the basic principles of hydrodynamics.

It is no coincidence that in nature practically all marine animals do not swim on the surface, with the exception of a few species of bird, this is to avoid the unpleasant consequences of travelling half submerged. The basic problem is that an object in motion on water creates waves which leads to resistance slowing the object. Other problems are created when designing a feature to overcome one problem an other is usually created, for instance, speed and manoeuvrability are mutually incompatible so canoe design is always a combination of compromises to achieve the best possible performance. Due to the wide and variable range of conditions canoes are expected to perform under, the application of scientific data has its limitations. The following are the basic fundamentals that shape a canoe's design.

Extending a canoe's length will increase speed, directional stability and potential carrying capacity. Short canoes will be more manoeuvrable and lighter in weight. Widths, or beams as they are called, are given in two measurements; the beam at the gunwale - the top edge of the hull where it meets the deck - and the beam at the waterline. The waterline beam has the greatest influence on performance. Wide beamed canoes offer great stability but as a result are usually slower. Narrow canoes may be less stable but afford better efficiency and hull speed. Greater depth allows for increased carrying capacity and better water shedding ability. However deep canoes are harder to handle in windy conditions and will be heavier. The shape of the bottom of the canoe and how it blends with the sides will influence its performance. Stability of a canoe is affected greatly by it's cross section. The shape of a canoe's cross section from side to side gives a good indication of its lateral stability or 'tipsiness'.

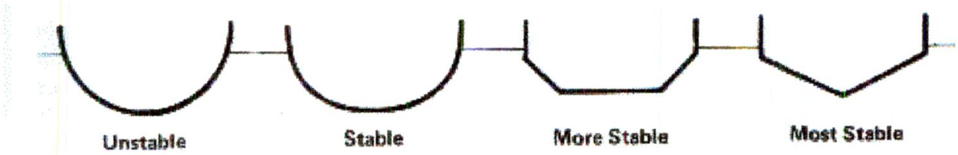

Figure 10: The different cross sections and how they effect stability, note the chines on the two most stable. The first cross-section while being unstable in calm water can be quite stable in white water.

Lateral stability can be split into two categories, initial stability and secondary stability. Initial stability is a measure of how stable the canoe feels when it is rocked from side to side. Canoes that have a lot of initial stability generally have a very hard chine, or sharp corner on the hull, when viewed in cross section. Canoes with hard chines have a lot of initial stability and generally very little secondary stability. In other words, when the canoe begins to tip it is stable up to a point, but then it will suddenly pass the point of stability and capsize. Canoes that have solid secondary stability tend to have a rounder hull in the cross section. These canoes are not quite as stable when first entered but are less prone to tipping over even when rolled far up on their sides. A semi-circular cross-section displaces the least amount of water which reduces drag but are very unstable, whereas a "V" shaped hull is very stable. But in the case of a wave broadside to the hull the semi-circular hull will feel more stable as it is easier to keep upright. In the case of a flat bottomed hull, which is stable, a broadside wave would lift the hull at an angle, following the surface contour of the wave.

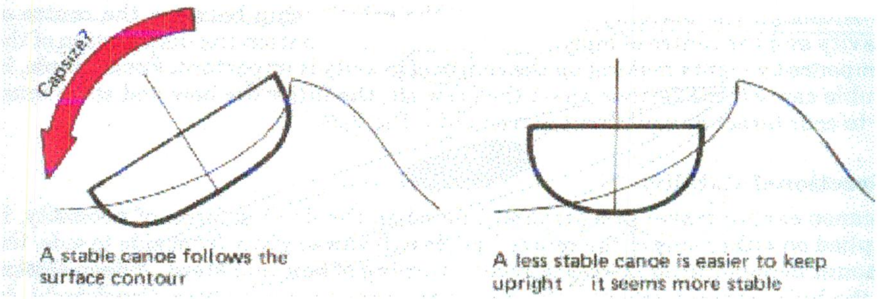

Figure 11: The effects of a broadside wave on different hull cross-sections.

Another design feature which effects a canoe's performance is the curve of the keel line from bow to stern which is called the rocker. A straight keel line has no rocker, which allows for exceptional directional stability or tracking but lacks manoeuvrability. An extremely rockered keel line (i.e. banana-shaped) offers exceptional manoeuvrability but poor directional stability. Moderately rockered canoes usually have straight keel line with a rise towards the bow and stern and are a common feature for general purpose craft.

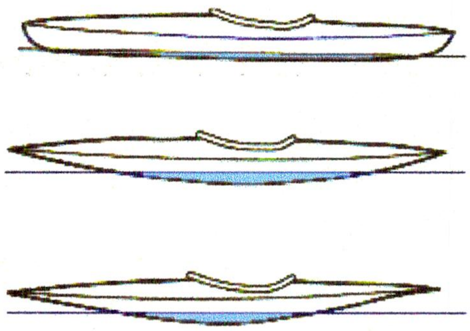

Figure 12: The top canoe is typical of the sea kayak, designed with little rocker, whereas the bottom canoe has a more extreme rocker, typical in slalom design.

Directional stability or tracking is a measure of a canoe's ability to hold a straight line. Directional stability is also improved by increasing the depth, decreasing the width or beam, a "V" shaped hull and sharpening the bow and stern sections. The shape of the bow where it cuts the water is referred to as the entry line. A very sharp, knife-like entry will cut through the water easily and while improving the directional stability, also increases speed. A blunt bow will add fullness and give buoyancy in waves, thus a drier ride. Directional stability is also influenced by the centre of gravity. Canoe designers can use the shape of the canoe to alter the centre of gravity. If the widest section is behind the centre of the canoe this will also allow the centre of gravity to be moved aft. In this case once a turn commences, it will continue to grow in magnitude. Canoes of this shape are known as 'Swedish form' canoes. The reverse is true if the centre of gravity is front of the centre of the canoe, then any change in direction will lessen, until the canoe continues to travel in a straight line again.

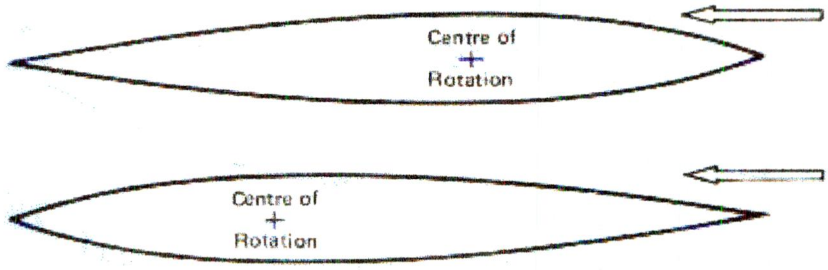

Figure 13: The 'Swedish form'(top) and what is referred to as the fish form of canoe.

There is also frictional resistance acting on a canoe moving through the water. Put simply frictional resistance can be split into two levels of drag. Firstly there are the small frictional losses created from the water molecules passing parallel to the canoe, called the laminar flow. As speed is increased the laminar flow rapidly changes into what is referred to as turbulent flow. This is basically when the molecules cease to flow parallel and a wake is being formed from the canoe. It is difficult to significantly reduce these frictional losses although a fine entry line and a smooth surface finish with no imperfections bigger than 0.1mm will help. Such a smooth finish is possible with GRP and compound materials and not with polyethylene, another reason why they are used in the construction of racing canoes, where speed is of the essence.

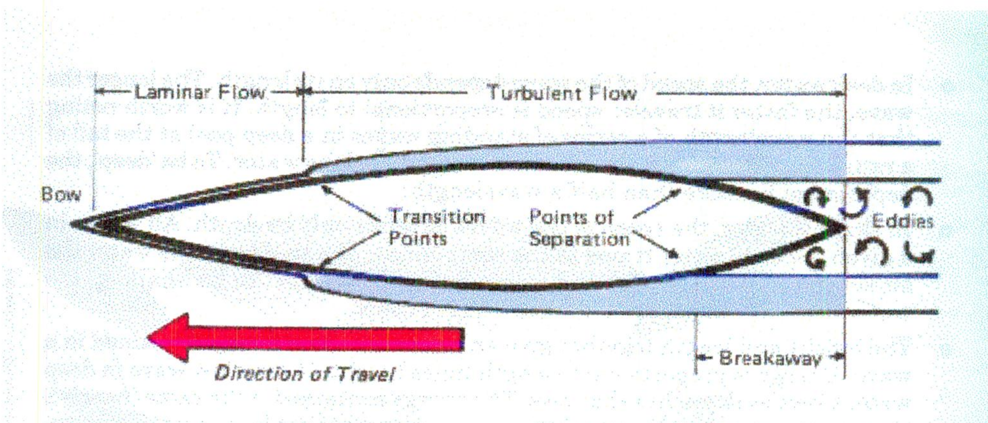

Figure 14: The frictional forces that result in drag.

As it would be futile for the canoe designer to focus in great depth on the theoretical hydrodynamic specifics, it is no accident that many of the best canoe designers are experienced canoeists themselves, as most good designs are the result of experience and intuition.

CHAPTER 4 :

Form follows Function

As previously mentioned in Chapter One the design evolution of a particular canoe has everything to do with the type of water it was used on and the materials local to that environment.

In the case of sea kayaking the first Eskimo kayaks, evolved over many years and were very sophisticated in their design and construction. So effective was the design that even though the materials used have changed the overall shape has not. It could also be said that there is a lack of sophistication with today's methods of production, with the result that ancient craft had some advantages over modern ones. For instance, the Inuit Eskimos of Greenland had to rely on driftwood for timber which they split down for the kayaks framework. Splitting actually produces stronger timbers than sawing, as the grain direction is followed perfectly and tapered cross-sections that are not prone to warping are easily produced. Modern machinery will turn out 'squared' timber very quickly, but it will be inferior to that produced by the more 'primitive' method. Although for the last 45 years most kayaks have been made from GRP, compound materials or polyethylene plastic. Another more remarkable design feature of the early sea kayaks which today's manufactures would have serious problems trying to equal was used by the Aleut people of the Alention Islands, Alaska. Their kayaks called *baidarka's* were generally wider and more buoyant than the Greenland style of kayak. They were extremely sea-worthy and among other interesting design features had bone ball and socket joints built into the kayak's framework. The flexible joints were said to increase speed by letting the craft 'sit' onto the moving sea surface. Although one current manufacturer of folding canoes, made from a reinforced PVC skin and an interlocking aluminium framework, claims their canoes hulls have enough flexibility to ride over the waves rather than crashing into them. This keeps the paddler drier and could simulate the flexibility of the *baidarka* that enables a faster ride on the sea. Although today it is generally accepted that when canoeing on flat water stiffness rather than flexibility equals speed. Whether a degree of flexibility would be more favourable in producing a faster ride for sea kayaks is still up for debate by canoe designers.

Today the best sea kayaks are made from GRP or composite materials, as they are lighter and can be customised. The reason for the differing forms of canoe design is directly related to their function. In the case of sea kayaks they are designed for cutting through waves, stability in windy conditions and being able to hold a straight line. For these reasons they are designed with elongated sharp bows and sterns for speed and directional stability and shallow arched decks giving stability even in a broadside wind. Sea kayaks also have straight keel lines and therefore no rocker which helps them hold a straight line. As sea kayaks have no rocker and are the longest type of kayak, ranging from 4.5 to 5.5 metres, they are very difficult to turn. To aid this nearly all sea kayaks have a foot operated rudder at the stern end, which is designed to flip up and out of the water when going onshore or over logs or weeds.

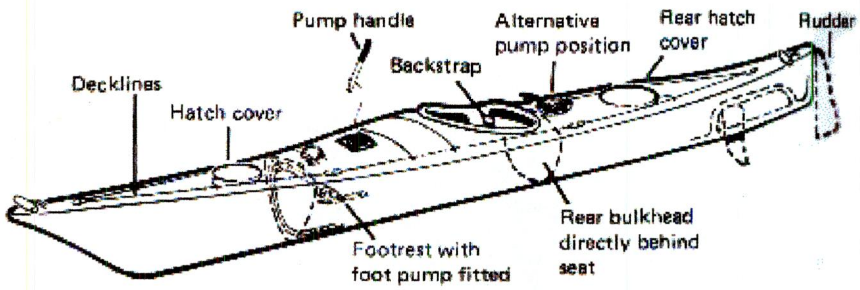

Figure 15: The anatomy of the modern sea kayak design.

Most sea kayaks are designed with a compartment in the bow and/or stern that is both air-tight and water-tight. These compartments are created by cross-sections of the canoe being sealed off and entry holes on the deck of the kayak with air- and water-tight lids. The wall of material that seals the bow and stern off into compartments is called a bulkhead and is usually made from GRP or polyethylene foam, relative to the material of the rest of the kayak. The advantage of the foam wall for polyethylene kayaks is that damage to the hull often occurs at the inflexible point of a rigid bulkhead, therefore the polyethylene foam being more compressible, provides a less vulnerable form of construction.

As previously mentioned in the last chapter, polyethylene is very difficult to bond together and as a result polyethylene foam bulkheads which have to be bonded after the moulding process, are prone to leaks. This is another reason why GRP and the composite materials are the best for sea kayak designs. The water-tight compartments are designed to fulfil two functions, to store equipment for journeys (e.g. food, clothes or camping equipment) and to act as added buoyancy. Especially for the latter reason bulkheads are designed as close to the paddler's body in the kayak as possible. This also makes good safety sense as there is the minimum available space to fill with water in the event of capsize. Another interesting design feature that is exclusive to sea kayaks are internal pumps. All kayaks have a cockpit which the paddler sits in, to form a seal between the paddler and the canoe a spray deck is worn. A spray deck is like a waterproof skirt which is elasticated at both ends, one end surrounds the paddler's torso, the other end fits over the cockpit all of which have a lip to facilitate this.

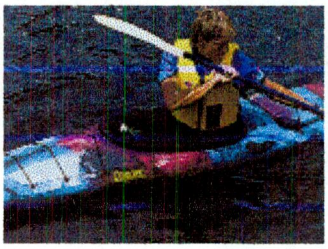

Figure 16: A sea kayaker wearing a spray deck.

Water can leak through the clothing of the paddler which is worn underneath the spray deck or even through the spray deck as the material used is seldom totally waterproof. This means that the unsealed area of a sea kayak can fill with water and out on the open sea where there is nowhere to get out and empty the boat, internal pumps are designed to empty the kayak instead. Of course, on the other hand, if a paddler capsizes and they are unable to right the kayak again with an eskimo roll, then the boat will also need to be emptied. Today sea kayaks are designed with either a forward and backward action hand pump on the front deck, with a removable handle, or a high volume foot pump. There are also electric pumps designed for the same purpose.

An essential design feature of the sea kayaks are deck lines. Deck lines are lines of rope which run over the deck attached to anchor points which should be strong enough to lift a loaded kayak. Deck lines are primarily used as grasp points for launching and landing the kayak as well as for holding on to for rescue or towing. Elastic deck lines are also

used for storing maps and essential rescue equipment like flares. Compasses can also be fitted to the deck of sea kayaks for experienced paddlers on a long trip.

As with all categories of canoeing there are different designs of boats for different levels of experience. One of the big attractions of canoeing is that it is a performance sport between the paddler and nature. There is even a classification system of different types of white water, relating to the level of experience required by the paddler, to reduce the risks. Therefore canoe designs also differ to cater for different levels of experience. So at the high performance end of the scale, there are sea kayaks designed for speed and directional stability. This means they have a rounded or "V" shaped bottom which increases speed and directional stability even in high wind but are much less stable and require a far higher level of handling skill. On the other end of the scale, there are 'day boats' designed for those who are interested in short day trips. These boats are fairly flat-bottomed in design which gives great initial stability, suitable for beginners.

As a sport canoe equipment is relatively expensive, a kayak can cost from £200-£2000, sea kayaks being the most expensive, £600 upwards, and the paddles and protective clothing can add a further £400 or more. Therefore many paddlers purchase a general purpose kayak that is not too expensive but can be used in most types of water with reasonable performance. These kayaks usually have a pointed bow and stern and have a shallow arched bottom for reasonable initial stability and good secondary stability. General purpose kayaks usually have a moderately rockered keel line which offers good manoeuvrability and therefore not much directional stability that is favourable for sea kayaking. As the general purpose kayak has a moderate rocker it also sits out of the water more which means it gets caught by the wind more, making it even harder to control. To improve the directional stability there is a detachable fin, or skeg, designed to attach to the hull at the stern of a general purpose kayak.

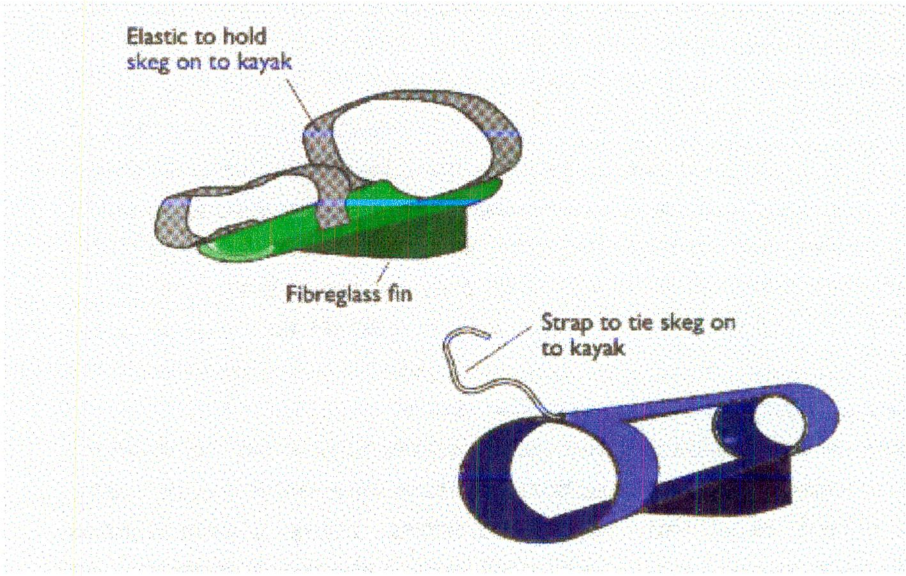

Figure 17: Two of the most common designs for attachable skegs.

While sea kayaks are the longest kayaks, white water kayaks are one of the shortest. As always in canoe design the reason for the difference is down to the different water conditions and user requirements. White water is the description of fast moving water over a very rough river bed, usually found at a river's source. There are four general groups of design used on white water.

Firstly there is the general purpose white water kayak, which is basically the same design followed by the popular general purpose kayak for use on most water types. The general purpose white water kayak has a pointed bow and stern with a moderate rocker as manoeuvrability is the preference over speed or directional stability. It also has a moderately rounded gunwale to give good secondary stability as the waves generated from the rocks on the river bed often immerse the sides of the boat and can easily tip the inexperienced canoeist.

Figure 18: The general purpose white water kayak.

On the other end of the proficiency scale there is the white water kayak for use up to 'extreme difficulty' rated rapids. These boats are sometimes called creek boats, from the American description of the environment, because they have to endure very rough rapids, collisions with boulders and shooting steep waterfalls or creeks. For this reason they are designed with a moderate to extreme rocker for extra manoeuvrability. They are shorter again and have blunt bows and sterns for added buoyancy and to better absorb impact. Often the bow has an extra cap to further absorb impact. Creek boats also have very rounded gunwales, so they have great secondary stability so the experienced paddler can prevent the kayak from capsizing even when it's on its side.

Figure 19: The creek kayak designed for extreme white water paddling.

Both the creek and general purpose types of kayak are usually made from polyethylene for its superior impact resistance. They are also designed with a thick foam pillar running down the centre of kayak from bow to stern with the exception of the cockpit. This adds extra stiffness and much needed buoyancy. As previously mentioned, polyethylene is a soft material and a paddler can get trapped under the water if the polyethylene kayak bends round a boulder. The foam pillar aims to reduce this risk but there needs to be a better solution designed as accidents still happen. Although paddlers have accepted this as a risk they are prepared to take and consequently, many carry large camping knives to cut themselves out of a polyethylene boat when trapped. Extreme environments create extreme problems and often extreme solutions.

Curiously, these creek kayaks are very good beginner boats as they have flat bottoms and rounded sides, therefore good initial and secondary stability and as a result are quite forgiving for the inexperienced. Kayak polo boats share the same blunt appearance as the creek boats but there are more made from GRP and compound materials. This is because they don't have to endure the same extreme conditions, like collisions with rocks, and the lighter the boat the better the speed, as there is no rapid moving water in a swimming pool. Also their shortness is more a reflection of the space restrictions of the swimming pool where the polo matches are played and the rounded sides greatly help the kayak to be rolled upright again even when the paddles have been dropped. This design of kayak can be easily rolled upright by the experienced paddler, by using their arms and twisting their hips.

Another design for recreational use on white water is the inflatable kayak. It is a combination of a river raft and kayak, which is stable and buoyant. For this reason they are often used by rafting companies for the inexperienced clients in low water or if they want a little extra challenge, the other advantage being that they can be deflated and stored in a small space.

For competition and racing purposes the design of white water kayaks are quite different. This is a good example of where the water type is the same but it is the user requirement and function of the kayak which differs, resulting in a different design. Slalom kayaking was developed on the white water rivers that flowed down the same mountains that in the winter were used for slalom skiing. Slalom kayaks need to have a high level of manoeuvrability while having a good degree of handling on turbulent water and if possible good forward speed. The slalom kayak is longer than the creek kayak in an attempt to increase speed. For maximum manoeuvrability the hull has a large amount of rocker to decrease the wetted area so it is concentrated around the kayak's centre of gravity therefore increasing the kayak's turning ability. This is further increased by a concave profile in the end of the rocker contour at the bow and stern. This acts to reduce the wetted area further. The flat bottom of the slalom kayak adds to its manoeuvrability but the lack of depth and flat deck means that the radius of the sides is not that large and the kayak's secondary stability is quite poor. This however is acceptable as slalom paddlers are experienced enough to keep the boat upright most of the time. The slalom kayak is designed as a shallow boat with very thin bow and stern sections and therefore has nominal buoyancy fore and aft. This lack of buoyancy means that the slalom paddler can shift their weight forward or backward to dip the bow or stern under the slalom poles. As the kayak is designed to return to the horizontal, dipping the stern can act to accelerate the kayak forward when it rocks up again.

Figure 20: The slalom kayak.

The other type competition held on white water is straight forward racing, the aim being to find the fastest line down the river from start to finish. Again as white water racing kayaks have a different function their design is different to other white water boats. Speed as opposed to manoeuvrability is paramount to the racer as they do not have to negotiate slalom gates. To achieve maximum speed the bows must be kept fine, but then they will plough deep into the approaching wave. To counteract this the canoe designer can extend the bow section both vertically and horizontally this increases buoyancy when submerged, so that there is little loss to forward speed. The hull is also "V" shaped so it is not thrown off course so easily.

Since the important design specifications for white water racing is ultimately speed, the stability and manoeuvrability are poor. This is where the experience of the paddler comes into the design equation so when kayak and paddler are combined the result is, hopefully, a winning performance of speed, stability and manoeuvrability.

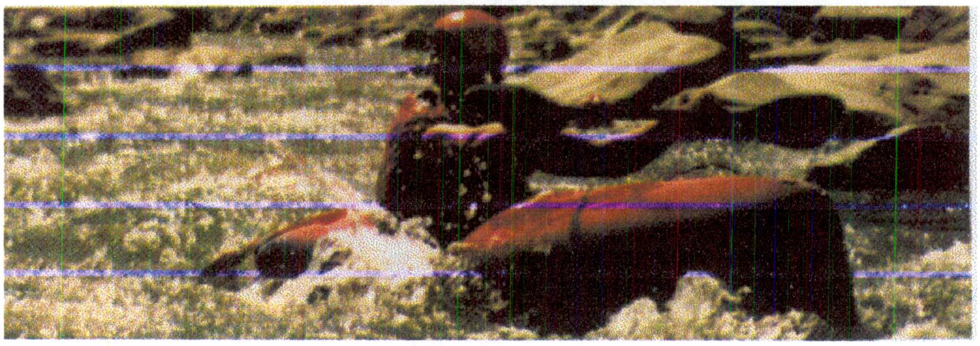

Figure 21: A white water racing kayak in action, note the fine entry line of the bow for speed and the depth of the bow for buoyancy.

Finally, the last in the group of kayak designs are surf kayaks. The fastest growing kayak activity is the relatively new sport of surfing. Not surprisingly due to the infancy and growing interest, kayak surfing has the greatest amount of innovative designs. Surfing in kayaks began to gain impetus in the 1960's which led to organised competitions all over Europe by the end of the decade. Malcolm Percy, designer of the world renowned 'Jester' surf kayak, recalls the early days of surf kayaking in Europe.

> The seventies showed a major boom in the sport with the peak occurring around 1976. The decline of surf kayaking (in Europe) was brought about by the increase of wave skiing. With the two factions going separate directions, most "paddle surfers" chose the less limiting and more radical appeal of wave skiing. Since the late eighties, kayak surfing has been on the rebound, mainly due to the introduction of better designed surf kayaks. (Wold, history.html @ www.humbolt1.com, p.1).

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In the 1960's either general purpose or slalom kayaks were used. Polyethylene kayaks had the advantages of being very durable, making them suitable for the literal, rough and tumble of surfing. Unfortunately few of these existing polyethylene kayak designs had the shape ideal for good surfing. The GRP kayaks had sharper lines due to their material properties and a sharp rear gunwale line means that a surfer can cut into the wave face, side on and the sharp gunwale acts like a fin in the water resulting in increased control. In fact some experienced surfers modified their GRP kayaks to enhance control by curving the nose upwards and adding flanges along the gunwales to act as fins.

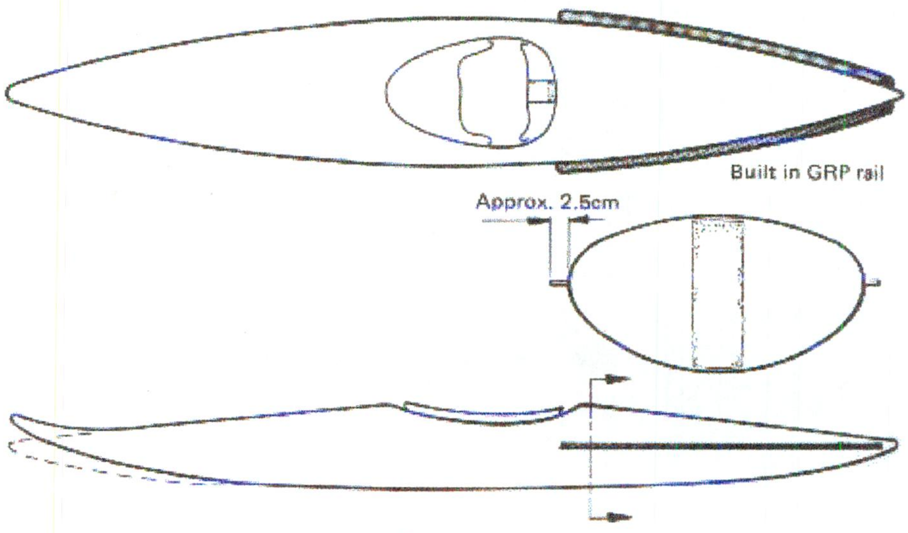

Figure 22: The design alterations possible with GRP to give the kayak surfer more control in a general purpose design.

Surf kayaks are those kayaks specifically designed for surfing and there are many variations of design that are being constantly updated. Out of this group of surf kayak designs, the surf boot now dominates. They are short, between 2.5 to 3 metres. Surf boots are a combination of surf-board and kayak design, their gunwales are rounded in the bow and sharp in the stern, with a low buoyancy especially in the stern. Some surf boots are designed with a channelled hull, or fins, to improve tracking. Due to their design combining surf-board and kayak, surf boots can readily perform a range of tricks like 180's, 360's, forward and backward loops to name a few. It can take a lot of effort by the paddler to paddle out through the surf to catch another wave, but this is greatly reduced by the increased nose rocker and stable hull and buoyancy of surf boots design. Most surf kayaks are made from GRP as they are specialist competition craft and weight is an issue. Although the main reason they are made from GRP is due to the high turnover of new designs every year and it would be very expensive to make a metal mould for polyethylene manufacture for such small scale production. Although one company called Morro Bay Manufacturing introduced the first production plastic surf boot named the Alamax in 1997. Also GRP lends itself well to the cheap and easy production and alteration of test models, which are critical to an innovative and effective canoe design process.

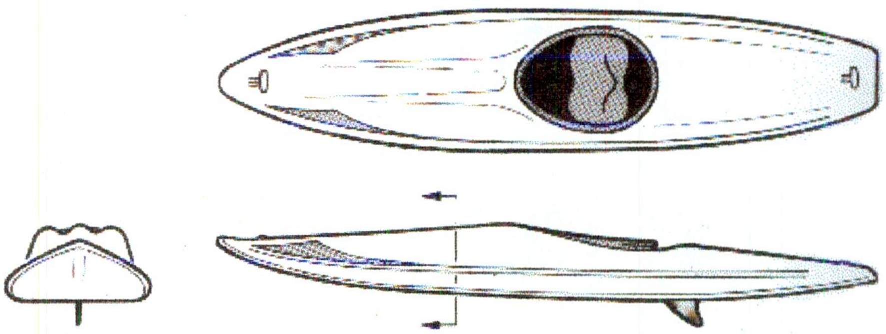

Figure 23: One of the many forms of surf kayak design.

Creek kayaks are also used for surfing, but its more difficult to execute any tricks as they do not get much purchase on a wave as they are designed with very rounded gunwales and a lot of buoyancy.

Sit-on-tops as they are referred to are a new concept in kayaking as they have no deck. Their hulls are as deep as creek boats but instead of a deck they have a moulded recess to sit into with thigh straps and hollows for the paddlers heels, usually with an adjustable foot-bar as optional. These sit-on-top kayaks are longer, wider and more stable than creek kayaks measuring between 3 to 4 metres in length, although they have similar surfing characteristics to the creek kayaks. The sit-on-top kayak is designed for surfing and recreational paddling on the sea and calm inland water but do not offer enough protection to the paddler for use on white water rivers. Their advantage is that the beginner can fall off, turn the kayak over and get on again without having to bring it to shore to empty it. Most sit-on-tops are made from polyethylene as their closed cavity form is easier to produce by blow-moulding or roto-moulding methods and polyethylene's superior impact resistance is more favourable to GRP's lightness in this instance.

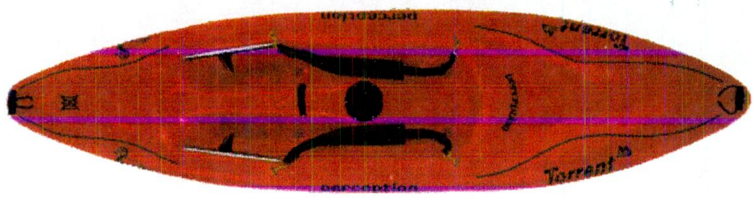

Figure 24: A polyethylene sit-on-top kayak complete with storage hatch (centre), grab loops at both ends, thigh straps and adjustable pedal footrests.

The wave ski is a development of the sit-on-top kayak which is specifically designed for surf as opposed to being a stable, 'self-bailing', recreational kayak. Because it is a sit-on-top kayak, foot straps around the ankles and a waist belt are used to hold the paddler firmly on top. Wave skis are shorter in length than other sit-on-top kayaks, measuring between 2 and 3 metres. All wave skis incorporate a flat hull and surf-board rails in their design. As the wave ski has no deck by definition it cannot have a gunwale, so the outer edge of sides of the ski is referred to as the rails. The sharper the rail the more it will cut into the face of a wave acting as a fin to control the ski. Even though sit-on-tops and wave skis have no deck they are both paddled by two bladed paddles and by definition are kayaks. More importantly they are an evolution of kayak design: a 'self-

bailing' design solution that performs well in short distance, fair weather sea touring and surfing. The design of a 'self-bailing' kayak, in other words one that never needs to be emptied, is very useful for surfing where capsize, or 'wipeout' to use the surfing term, is frequent even for the experienced and swimming after and emptying a kayak in the surf is an inconvenience to say the least.

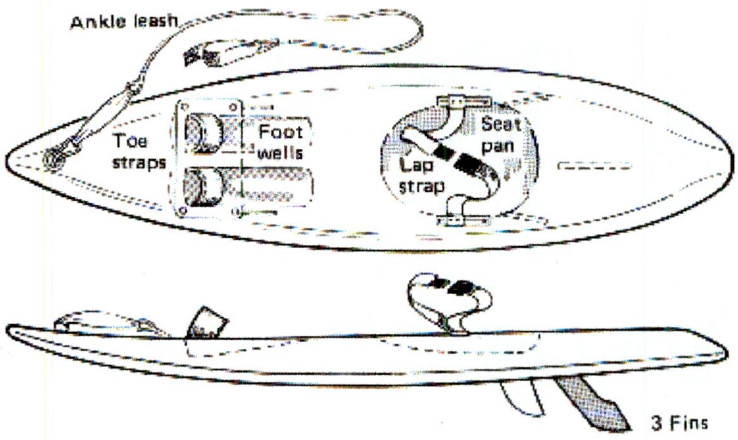

Figure 25: The Wave Ski.

Both wave skis and surf kayaks, surf boots included, are specifically designed for surfing and their variations are many and growing every year. As this is a relatively new sport as more experience is gained in the surf this can be translated into new designs which combined with higher skill levels hold the key to the progression of the sport. Yet again it is the canoeists themselves that are defining the sport in terms of organising events and pushing the levels of performance through improved skills and designs. These surf kayak designers all surf themselves and they all use surf kayak championships as design forums to launch new designs, analyse how they perform and how their competitors designs perform.

> 1993 saw the introduction of new boot designs by both Merve Larson and myself (Dick Wold). Merve's boot was based on his wave ski designs. This tri hull planing bottom with a balanced deck made it the fastest boot on the market. My design lacked the speed of the Merve boot, but made up for it in turning ability and a more forgiving rail. My design won in the first head to head

> competition. Meanwhile the International class kayak saw a major design improvement with the introduction of the Mega Jester. Malcolm Percy of England showed up at the 1993 World Kayak Surf contest in Santa Cruz with a boat load of Jesters. His entourage was lead by Simone Biscomb, the 1992 World Kayak Surf Champion. He rode the Jester into the final, only to be dethroned by me riding a Sabre. (Wold, Design evolution.html @ www.humboldt1.com, p.1)

Essentially, these designers understand the users and their requirements, the operating environment, the technical aspects from hydrodynamics to their own experience and above all have a passion for what they are designing. This is basically true for all forms of canoe design; past, present and no doubt future.

The open canoe has nearly as many applications on different water types as kayaks with the exception of surfing, exposed sea expeditions and extreme narrow white water. The basic design of open canoes are fundamentally the same as the ancient Indian 'birch bark' canoes of North America. In fact wooden canoes are still popular. This is largely to do with the association open canoeist have with its tradition and history and the 'great outdoors' lifestyle that many open canoeists aspire to. From the point of view of tradition nearly all the techniques used for kayaking have been directly inspired by those used for open canoeing. The open canoe is slower than the kayak by design, by being longer, deeper, wider and heavier. They sit higher out of the water and are easily caught by the wind. The first open canoes were designed by the North Americans for transporting loads down rivers and lakes, and not surprisingly it is this environment, that open canoes perform best in today. It must be said, that there are open canoes used for slalom, white water racing and sprinting. But most of these canoes are designed for speed and even though by definition they are paddled by a one-bladed paddle, to be competitive their design has been altered so much from the traditional Canadian canoe form, that they bear more resemblance to their kayak counterparts.

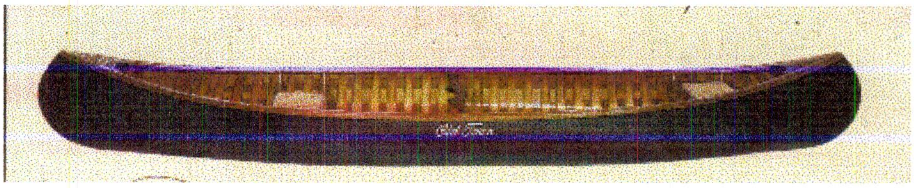

Figure 26: The traditional Canadian canoe design.

The traditional open canoe form is purpose-built for carrying loads, allows greater ease of packing and due to its height out of the water, gives a drier ride for its occupants. Its design makes it ideal for camping and touring. Due to the slower speed, higher viewpoint and the facility to store camping equipment, the design of the open canoe inspires an outdoor, 'in tune with nature' lifestyle. So in this instance of canoe design it is not the higher performance demands that inform the decision on what material to use but rather the lifestyle aspirations and a traditional aesthetic.

Figure 27: The 'great outdoors' lifestyle that the open canoe embodies, its users aspire to and its manufacturers market towards.

Most open canoes are made from materials other than wood though, as they are cheaper. Open canoes can also be propelled by specially designed sails or long poles, or even an outboard motor. Their design also allows for open canoes to be increased in length, and still be stable and manoeuvrable, to carry far more paddlers than is possible with kayaks. Many types of kayaks are also designed for two paddlers and there is even a

Figure 2[illegible]: The traditional Canadian canoe design.

The [illegible] canoe, from its purpose built for carrying loads, allows greater ease of packing and [illegible] its height out of the water acts as a disadvantage for its occupants. Its design [illegible] used for camping and touring. Due to the slower speed, higher [illegible] and the inability to store camping equipment, the design of the open canoe [illegible] with nature [illegible] lifestyle. So in this instance of canoe design it is [illegible] performance demands that inform [illegible] decisions on what material to use but rather the lifestyle implications and a traditional aesthetic.

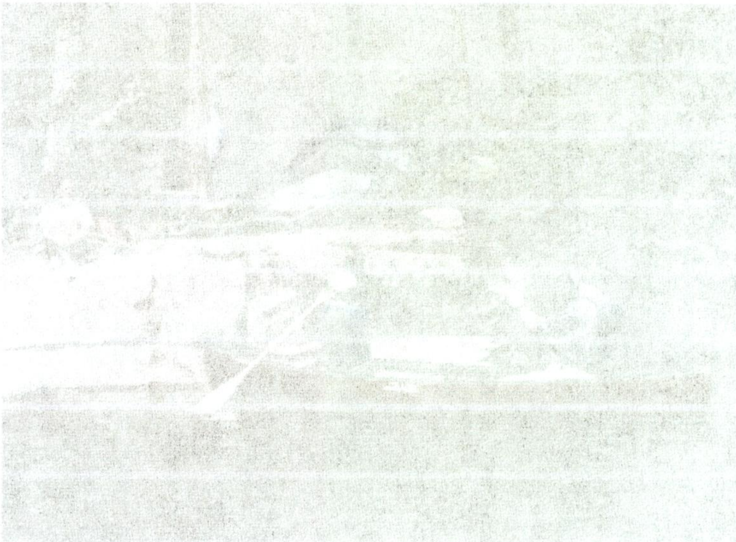

Figure 2[illegible]: The [illegible] lifestyle that the open canoe embodies, its users aspire to and its manufacturers market towards.

Most open canoes are made from materials other than wood [illegible] they are cheaper. Open canoes [illegible] propelled by specially designed sails or long poles, or even an outboard motor. Their design also allows for open canoes to be increased in length, and still be stable and manoeuvrable, to carry far more paddlers than is possible with kayaks. Many types of kayaks are also designed for two paddlers and there is even a four-person kayak (K-4) design for international sprint racing events, whereas there is an open canoe designed to carry nine paddlers called the war canoe. It used to be regarded as a bit of a novelty and is popular in North America for inter-club racing of a light-hearted nature. But the war canoe is finding a new important purpose for the future of canoeing, as it generates a fascination in children, it is being used to encourage them to take up the sport. The open top, stable design of open canoes combined with their capacity to carry more than one paddler, means that they are an invaluable boat for enabling the disabled to enjoy interaction with water on close and personal terms. If required the open canoe can easily accommodate a wheel chair as well.

CONCLUSION

Canoe manufacturers, like the polyethylene bin manufacturers, who attempted to design canoes without an understanding of canoeing and its history generally failed. The key to understanding canoe design is not in the materials and the manufacturing processes. The fundamental basis for successful canoe design is in the experience gathered from using the product itself. This understanding is illustrated by the early canoes and kayaks, which were designed and built by the users themselves. These designs were refined and improved by every generation. So by the time they were discovered in the nineteenth century, the canoes were an accumulation of hundreds of years design development. It is important to remember that all the techniques used for paddling canoes and kayaks today are directly descended from these ancient cultures, who were masters in the skill of canoeing. It was this in-depth knowledge of canoeing and the surrounding water they paddled on, that explains the beauty, simplicity and effectiveness of their design solutions.

While popular, the Rob Roy was not an efficient design solution because he did not possess the generations of knowledge on canoes and their environment. Another failing of the Rob Roy was, that it was made using ship-building technology and not canoe-building technology. While being aesthetically pleasing, it was heavy and slow, compared to the canoes that pre-dated it. Through advances in materials, construction techniques and most importantly designers' understanding of the product and its operating environments, there has been a leap forward in canoe design in the last 50 years.

It is accepted, that at the core of industrial design is the design process. An understanding of the design process from concept, through development to final prototype, combined with an understanding of the history of design and some lateral thinking seem to be the ingredients for successful industrial design. But most canoe designers come from a canoeing background as opposed to a design background. Indeed the design process can be learnt along with materials and manufacturing processes. Instead the key to successful canoe design is in the intimate understanding of the product, its operating environment and its users as opposed to the design process.

It should be noted that these factors are also very important for successful industrial design. While most products do not require first-hand user experience by the designer to be successfully designed, industrial designers, especially in consultancies with ever-changing products to design, should never underestimate the need to have an understanding of the product, its environment and its users. It is also a bonus to be passionate about the object being designed rather than the process it is being designed under.

APPENDIX A : Glossary of Terms

Hull	-	lower part of canoe or kayak that comes in direct contact with water.
Deck	-	top panels of the canoe.
Fore	-	towards the front of the canoe.
Aft	-	towards the back of the canoe.
Lug-sail	-	four cornered sail.
Following wind	-	wind blowing from back to front of the canoe.
Beam wind	-	wind blowing across side of the canoe.
Gunwale/Gunnel	-	the top edge of the hull, where it joins the deck.
Outrigger	-	second hull fixed parallel to hull of canoe, to stabilise it.
Beam	-	width of a canoe at widest part.
Clinker-built	-	a form of boat building whereby timber planks are overlapped resulting in a stepped appearance.
Keel line	-	the centre line of the hull from bow to stern.
Broadside	-	sideways on.
Chine	-	edge created from angular hull.
Skeg	-	a fixed rudder for kayaks to help keep a straight line.

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PERIODICALS

Canoeist and Canoe Focus monthly magazines had some useful current information.