Individual Design Portfolio

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Introduction

Rowing is a sport that is available to all levels of commitment, intensity and competition. It involves early mornings, cold mornings, wet mornings and a fair amount of dedication. At the higher level of competition, the boat used to compete in can make a reasonable difference over the course of a 2,000 metre race. This portfolio aims to find a rowing boat for customer that will help them achieve success at a high level. This client wants a high quality racing scull that isn't overly expensive. By investigating their requirements and using these to follow the systems engineering design process, several different racing scull suppliers will be researched and compared in order to find the best boat to suit this clients desires. There is a basic diagram below in Figure 1 of a racing scull along with the names of the different parts for reference (Rowing Australia 2008).

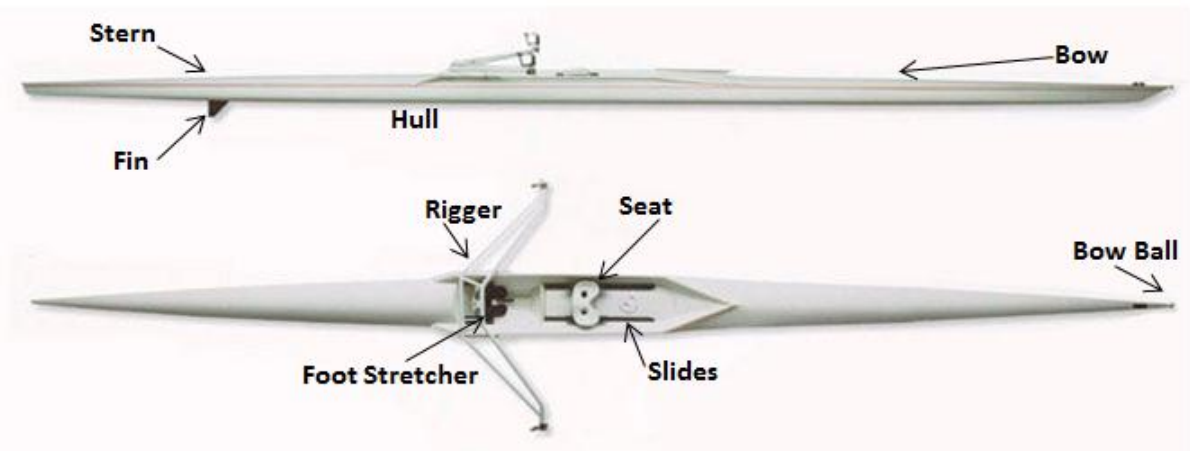


Figure 1. The side and top view of a single scull (1)

Rowing Australia is the governing body for rowing clubs and the competitions. They define rowing as, '*the propulsion of a displacement boat, with or without coxswain, by the muscular force of one or more rowers, using oars as simple levers of the second order and sitting with their backs to the direction of movement of the boat'* (Rowing Australia 2008). They have a long list of rules, regulations, codes and ethics that competitors, clubs and boat builders must adhere to. Those referring to the manufacturing and safety standards of boats will be accessed for this portfolio.

The 'Client'

The client for this portfolio is a rower looking to buy a new high performance boat. They would like it to be of race quality whilst still being affordable. Stability is an issue so a boat that assists in balance is preferred. These are the main concerns of the client. There are still many more 'wants' which can be seen below in the customer requirements section. Along with these customer requirements, there are rules and guidelines set by Rowing Australia. These include regulations about race weight, safety standards and boat specifications. These can also be seen in the requirements engineering section.

Systems Scoping

Systems scoping is useful for determining what will fall within the concern of the design process and what will not. It can be seen below in Table 1 that the only aspect that will not be designed for is the type of water that the boat will be used upon. This was deemed irrelevant to be designed for as it is the duty of the carer to maintain their boat, regardless of the water. The endogenous column contains only elements that are directly related to the physical boat. Exogenous elements are those that have an effect on the system but are not directly a part of it. This is used later when determining the subsystem integration and the relationships each subsystem has upon one another.

Table 1. System Boundary Chart

Endogenous	Exogenous	Excluded
Weight of boat	User weight	Salt or fresh water
Materials used	Cost	-
Rigger	Rowing Australia Rule Book	-
Shoes	Oars	-
Seat	-	-
Paint and Sealant	-	-

Requirements Engineering

Customer Requirements

The customer requirements are what the client wants. They are obtained from the customer in an initial meeting and the design process should aim to satisfy as many if not all of these requirements (Eisner 2011). A system is successful if it can satisfy all of these requirements while still being functional.

1. Boat should be as light weight as possible
2. Boat must be stable in rough water
3. Must be quick and simple to adjust the settings
4. Must have a drink bottle holder

5. Must have suitable mounting block for a speed coach
6. Must have a fast design
7. Needs a nice paint job
8. Modern design, materials and parts
9. Reasonably priced, between $9 000 and $11 000 AUD.

Rowing Australia Requirements

Whilst satisfying the customer, there may be other rules, standards and regulations that need to be adhered to. In this case these rules are of Rowing Australia, the authoritative body for rowing. These rules have been taken from the *Rowing Australia Rules of Racing and Related By-Laws Rule Book – 2008 Edition* and can be viewed at the Rowing Australia website. Part 4 of the rule book the section that is of concern for boat manufacture (Rowing Australia 2008). These rules are listed below.

By-Law to Rule 31 – Boats and Equipment

1. Requirement for racing boats:

1.1 The bows of all boats shall be fitted with a white ball, minimum diameter 4 cm, in rubber or similar material fitted in a safe manner unless the bow of the boat is so constructed as to afford equivalent protection and visibility

1.4 No substances or structures like riblets capable of modifying the natural properties of water or of the surface layer of the water shall be applied to the hull

1.5 To avoid accidents arising from capsizing, all boats shall be equipped with stretchers or shoes that allow the competitors to get clear of the boat without using their hands and with the least possible delay.

1.12 Length of Boats – Minimum length of racing boats — The minimum overall length of a racing boat shall be 7.20 metres. This will be measured from the front of the bow ball to the furthest aft extent of the boat, which may include an extension beyond the hull.

By-Law to Rule 32 – Boat weights

1. The minimum weight for a single scull is 14kg
2. The minimum weight of the boat shall include only the fittings essential to their use (riggers, stretchers, shoes, slides and seats). The minimum weight shall not include the oars, bow number or any electronic equipment.

Design Requirements

A customer will often not be descriptive with what they want. They might say I want it fast, or it has to be pretty. These are quite broad and open to interpretation. The customer requirements must be translated into design requirements. These are characteristics which are measureable, as well as neutral (Eisner 2011). This means that the system can be determined as successful or not if it meets these requirements. These can be seen below in Table 2.

Table 2. The design requirements

Light weight Boat	DR01-01	Light materials
	DR01-02	Minimal materials
	DR01-03	Limited additions
Fast design	DR02-01	Minimal drag
	DR02-02	Stiff materials
	DR02-03	Hull shape
	DR02-04	Minimal contact with water
	DR02-05	Fluid dynamics
	DR02-06	Aerodynamics
Paint job	DR03-01	High quality paint
	DR03-02	Waterproof sealant
	DR03-03	Colour
	DR03-04	Weather proof
	DR03-04	Resilient
Reasonably priced	DR04-01	Capital cost not too high
	DR04-02	Replacement parts aren't too expensive
	DR04-03	Resilient system
	DR04-04	Minimal moving parts
	DR04-05	Cheap parts used where possible
Stable Boat	DR05-01	Wide hull
	DR05-02	Deep fin
	DR05-03	Low centre of gravity
Quick and Simple Adjust-ments	DR06-01	Simple adjustment mechanisms
	DR06-02	Fast adjustment time
	DR06-03	Minimal adjustment steps
	DR06-04	Adjustable foot stretcher
	DR06-05	Adjustable slides
	DR06-06	Gates with snap on/off spacers
Accessories	DR07-01	Drink bottle holder
	DR07-02	Speech coach mount and wiring
	DR07-03	Water tight storage compartment
	DR07-04	Bow Number Holder
Meet Rowing Australia safety standards	DR08-01	Bow ball
	DR08-06	Minimum weight is 14kg
	DR08-02	Smooth hull
	DR08-03	Heel ties
	DR08-04	Single pull shoe release
	DR08-05	Length requirements

Requirements Engineering

Pairwise Analysis

A pairwise analysis is a comparison of the customer requirements. It allows the trade-off of the requirements against one another in order to determine the most important design aspect, according to the customer (Elahi and Yu 2012). An analysis can be seen below in Table 3. From this the major concerns of the design process should be developing a reasonably priced racing scull that is light and able to perform at a high level. The top ranked requirement was not in fact a customer one. Meeting the requirements of Rowing Australia was ranked first, as without complying the boat would be unable to race. All of the requirements of the customer should be met but with these standards in mind. These ranking were determined based upon the fact that the customer wanted to be able to afford a high performance boat. Because of this the lowest ranked requirements are the paint job and the accessories. However, they still must be considered as the quality of the paint finish may have an effect on the boat speed due to the friction with the water.

Table 3. Pairwise Analysis

	Light Weight	Stable	Fast	Quick Adjstments	Nice Paint	Accessories	Reasonable price	Meets RA Rules	Total	Rank
Light Weight		1	1	1	1	1	0	0	5	3
Stable	0		0	1	1	1	0	0	3	5
Fast	0	1		1	1	1	0	0	4	4
Quick Adjustments	0	0	0		1	1	0	0	2	6
Nice paint	0	0	0	0		1	0	0	1	7
Accessories	0	0	0	0	0		0	0	0	8
Reasonably Priced	1	1	1	1	1	1		0	6	2
Meets RA rules	1	1	1	1	1	1	1		7	1

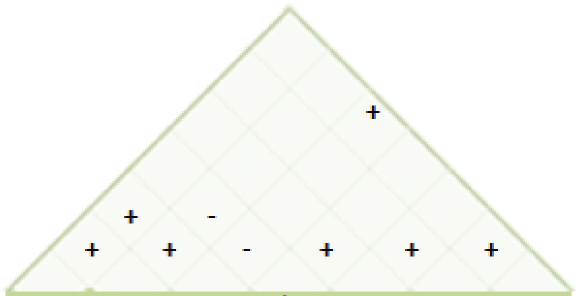
House of Quality

A house of quality is a tool which allows the relationship between the functional requirements and design requirements to be recognised in a tabular format. The relationships between each are graded as strong, medium or weak (Hauser and Clausing 1988). This can be seen in Table 4 to act vaguely along the leading diagonal of the table due to the functional requirements being determined from the design requirements. The way the functional requirements then correlate to one another can then be seen in the 'roof' of the house.

Of note from this table are the strong relationships between the requirement for light materials and the functional requirements that address weight, stiffness and the contact area with the water. The design and the weight will affect the amount of boat that is in contact with the water. There are technical performance measures (TPM's) which can be seen under the house. These are the units that the functional requirements are measured in. Those that are not widely understood can be seen in the reference key in the top left corner of the table below.

Table 4. House of Quality

9 = Strong Relationship
3 = Medium Relationship
1 = Weak Relationship
+ = positive correlation
- = negative correlation
*TKE = Turbulence Kinetic Energy
#k = Elastic Modulus



ID	Deisgn Requirements	RANK	no water can pass	smooth surface	aerodynamic design	reduce conatact w water	Minimum weight	Honeycomb structre	Stiff materials
DR03-01	Waterproof paint	1	9	9	9	1	3		1
DR02-01	Minimal drag	2		9	9	9	3		1
DR01-01	Light Materials	3			1	9	9	9	3
DR02-02	Stiff design	4			3		3	9	9
		TPM	mL	TKE*	TKE*	m^2	kg	N	k#

System Functions Analysis

This is an analysis of the functions a system is expected to perform. It describes how a system is used and what it does. This can be performed in a structured way using a Functional Flow Block Diagram (FFBD) as seen below in Figure 2. This provides the basic steps that a system would undertake while operating, arranged in a traceable and logical sequence. The main steps that the system undertakes are in the top level of the functional flow. Some of these are expanded upon in the second level flow (Blanchard 2011). This allows for a single step to be explored in greater detail, while still falling under the same parent step. There are two parent steps in this FFBD. They are 'check boat' and 'prepare boat'. The children steps are the steps within the parent step that must be completed before the parent step is completed (Dept. of Defence 2001). There is also a maintenance flow which consists only of a single top layer. These steps stem from the children steps of the 'check boat' function. They address any issues that may arise while checking over a boat before running by providing the next step in order to fix it. In order to reach this maintenance level, the 'no-go' option from the children steps above must be taken. This is represented by a red arrow and shows the course of action when a step cannot be completed due to various reasons.

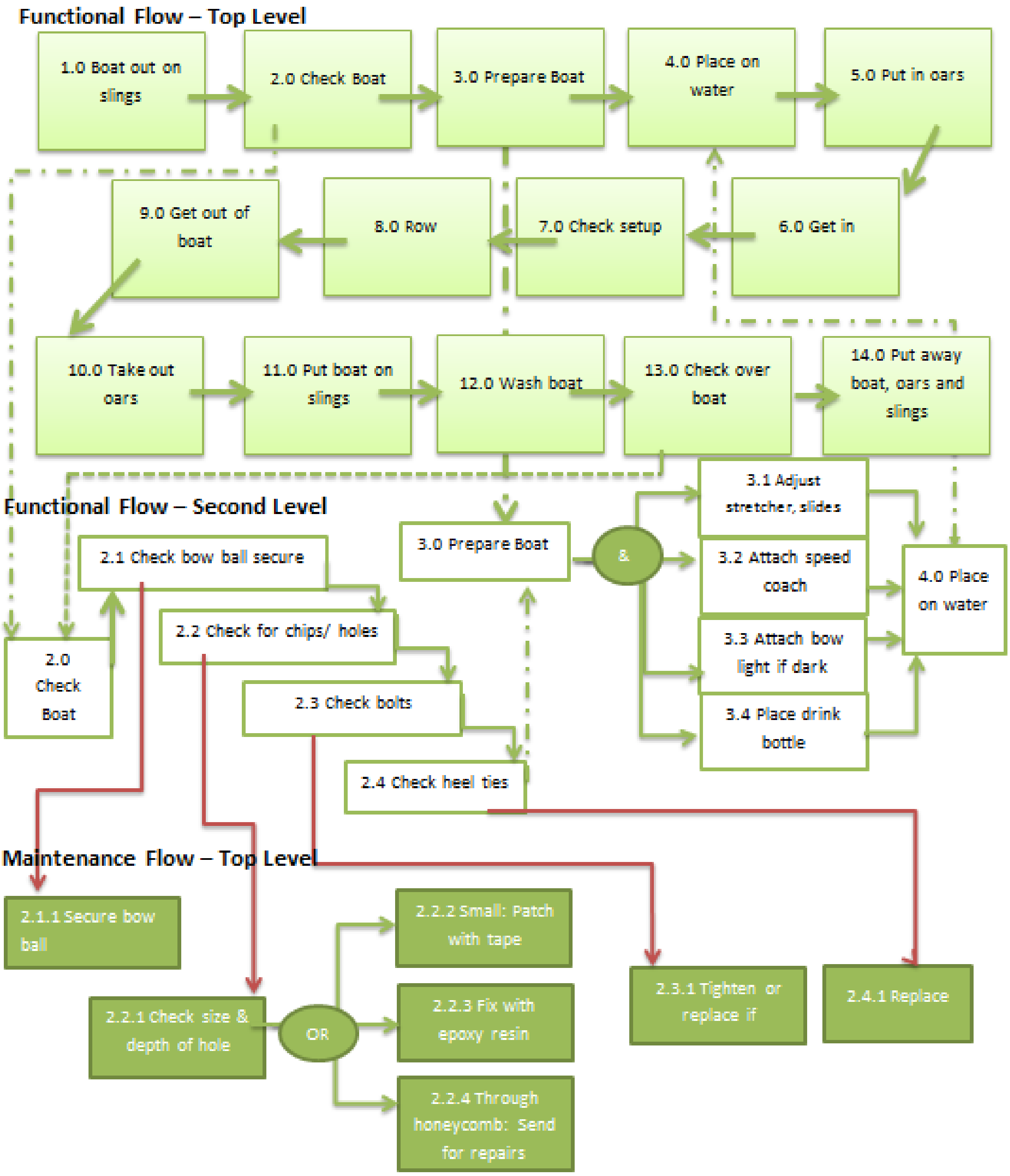


Figure 2. A Functional Flow Block Diagram

Concept Generation

In order to develop ideas and concepts for the final design, all options should be considered. From this point they can be eliminated if they do not satisfy customer and design requirements. This means only viable options remain that should be considered for the final design. A concept generation for all of the materials that are available for a boat design can be seen below in figure 3. All of the options below are viable to some extent as they satisfy some requirements but not others. For example a HDPE boat would be light cheap, very tough and also balanced. It would not be, however, fast or of race quality. Carbon honeycomb would make a suitable boat as it would be very light and of race quality but not cheap. The best option is later determined in an evaluation matrix using the customer requirements and compliance scores.

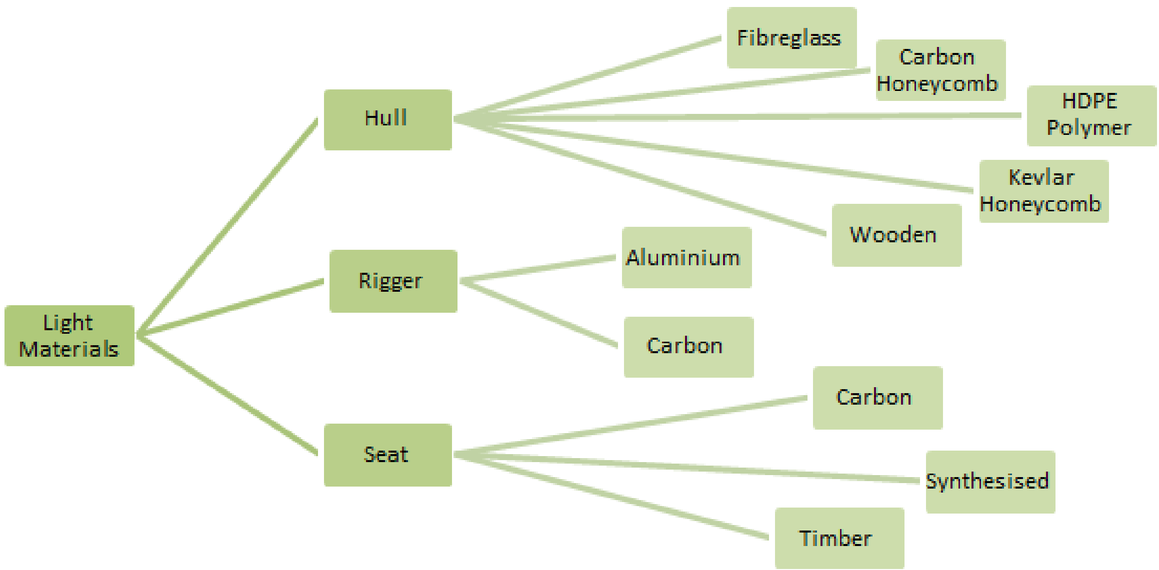


Figure 3. Boat materials concept generation

Subsystem Integration

By looking at how the subsystems affect one another through their inputs and outputs, the interactions can be mapped and any effects from changes can be traced and efficiency improved (Beale 2013). A Functional Block Diagram has been created for this system and can be seen below in Figure 4. The elements within the subsystems have come from the system boundary chart developed at the start of this portfolio. There are only four subsystems within the system boundary line; safety, the hull, appearance and the drive system. The ‘drive system’ is defined as the parts of the boat that connect to the user and allow them to apply force to the system, propelling themselves forward or driving the boat through the water.

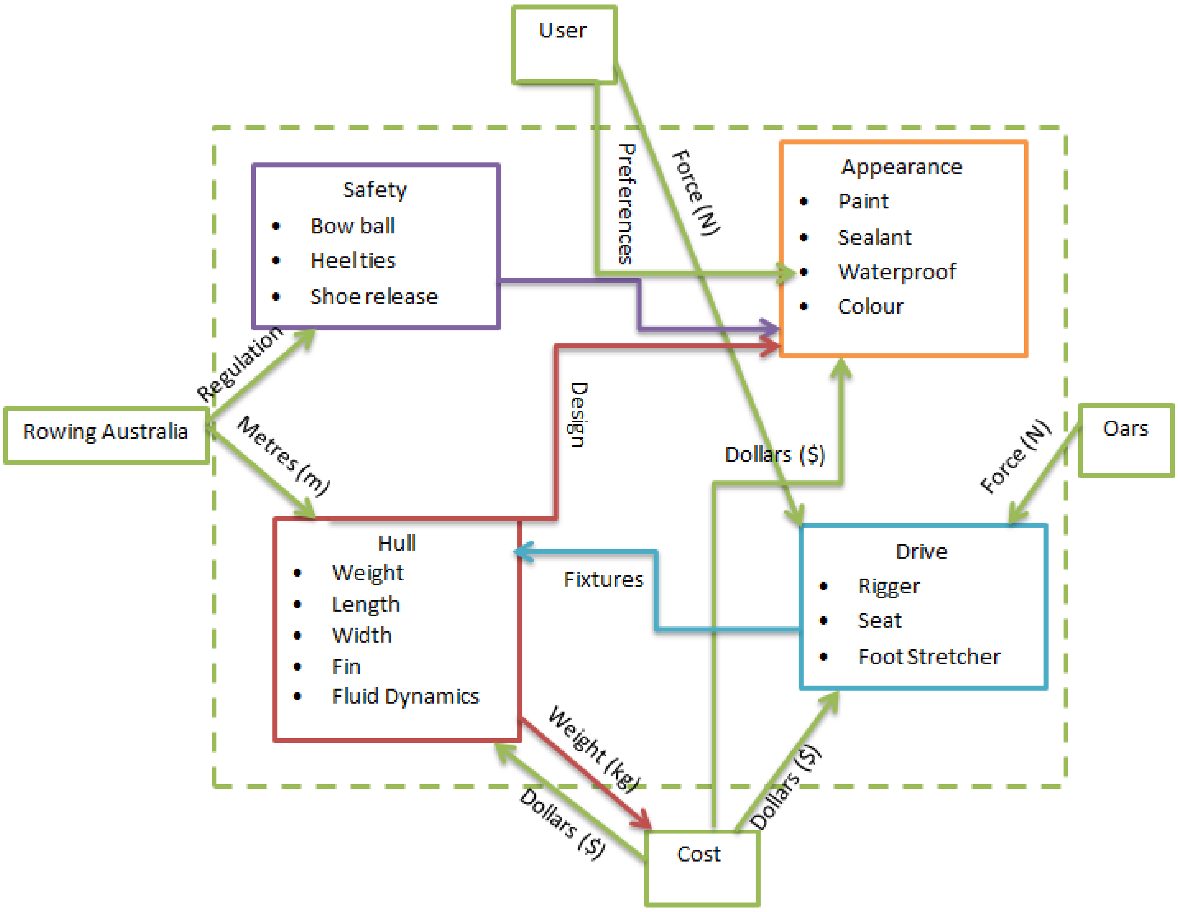


Figure 4. Functional Block Diagram

The output of the external cost subsystem on the other subsystems can be seen to be dollars. This must be taken into account during the design process of the boat, as cost is to be minimised but it has an effect on so many aspects. In order to reduce the final cost of the boat, it is these sections that must be changed. The appearance of the boat doesn't have any outputs onto other sections, but many inputs, meaning it will be affected by many subsystems. The main inputs are from the user as they ultimately decide what they would like the boat to look like when finished, the cost available as this will determine the final paint job and finish as finally the actual hull design itself. The hull is affected by the drive system as it attaches to it, and also Rowing Australia as they specify minimum lengths for the boat.

System Attributes

The system attributes cascade maps out the qualities of the system, linked back to their original requirements which are the primary attributes. The primary attributes are taken from the design requirements developed in the requirements engineering stage. In the final column the subsystems which they relate to is also listed. Any changes made to the system during the design process can then be traced back using this cascade the functional block diagram above to see which subsystems they will affect. In order to obtain each level of the attributes cascade, the parent attribute must be 'unpacked'. A good method is to ask *how* that attribute would be achieved and the methods that are developed that answer that question become the next level down of the cascade. This process can be seen below in table 5 for the boat system. The tertiary attributes are a combination of functional (buoyancy, yield strength, friction) and non-functional requirements (tough, strong, hull design). The related subsystems are fairly spread out among the entire table which shows how dependant and easily affected all of the subsystems are upon one another.

Table 5. Attributes cascade table

Primary Attriubte		Secondary Attribute		Tertiary Attribute		Related Subsystems
A1	Light Materials	A1.1	Minimal Mass	A1.1.1	Bouyany	Hull/Safety
				A1.1.2	Honeycomb	Hull
				A1.1.3	kevlar/carbon/aluminium	Hull/Drive
				A1.1.4	Low specific weight	Hull
		A1.2	High strength	A1.2.1	Stiff	Hull
				A1.2.2	Shear Strength	Drive/Hull
				A1.2.3	Yield Strength	Hull
				A1.2.4	Compressive Strength	Hull/Drive
A2	Adjustable Settings	A2.1	Moving Parts	A2.1.1	Bolts with wingknuts	Drive/Hull
				A2.1.2	Different levels for options	Drive/Hull
		A2.2	Tracks	A2.2.1	Teeth to lock in place	Drive
				A2.2.2	Sufficient length	Drive
A3	High Quality Paint	A3.1	Weather-proof	A3.1.1	Waterproof	Appearance/Hull
				A3.1.2	Colour Fast	Appearance/Hull
		A3.2	Resillient	A3.2.1	Scratch proof	Appearance/Hull
				A3.2.2	Tough	Appearance/Hull
				A3.2.3	Easy to patch	Appearance/Hull
A4	Minimal Drag	A4.1	Minimum Contact with water	A4.1.1	Hull design	Hull
				A4.1.2	Smooth hull	Hull/Appearance
				A4.1.3	Minimum area	Hull
				A4.1.4	Coefficient of Friction	Hull/Apperarance

Verification and Evaluation

Verification

The verification process for a rowing boat is extensive and any shell is put under a range of thorough tests before being put on the market. The tests performed by the producers of racing shells are quite different to those that a prospective buyer would perform. The producers must test their design is watertight, buoyant, can support an applied load and move through the water in the most efficient manner with the weight of the rower.

Stiffness of a shell is an important quality to be tested and is of high priority to boat manufacturers. If the boat were to flex, any load applied by the rower would have some of its energy absorbed. The most efficient transfer of energy from the rower to the water is desired (Pocock 2014). The following two tests are modified versions of the flex testing on boats performed by an American boat producing company called Pocock.

Attribute ID: 1.2.1 Stiff Materials – Longitudinal Bending Test of the Shell
Test Person: Boat Building Technician
Pass/fail criteria: Deflection exceeds acceptable range
Testing Procedure

1. Place boat on hard supports, one in the centre and one at the stern, 3 metres from the centre hard and fixed in place with ties
2. A single 20 kilogram weight is attached to the bow at a distance of 4 metres from the centre hard
3. The amount of deflection that occurs at the bow ball is measured and recorded

The placement of the boats on hard supports must be kept the same distance throughout testing, as well as the placement of the weight. This means that the bending moment remains constant throughout the testing process of different boats, allowing for meaningful comparison of different sculls.

Attribute ID: 1.2.1 Stiff Materials – Rigger System Flex Test
Test Person: Boat building technician
Pass/fail criteria: deflection exceeds acceptable range
Testing Procedure

1. Place the boat upright in slings, 4 metres apart with the rigger in the centre
2. Apply a 100kg force upon the rigger using pulleys
3. The direction of this force is the same as the force that would be applied by the rower taking a stroke
4. Measure the deflection from this force

Attribute 4.1.2 Hull Design and Fluid dynamics – Tank Testing
Test person: Boat building technician and tank operator
Pass/fail criteria: suitable movement through water with weight applied

Testing Procedure

1. Place boat in water tank
2. Rig up to testing system
3. Apply weight to boat
4. Move through water at set speed
5. Analyse drag, water movement and wake and record data

This test can be seen to be performed by Canadian boat manufacturers Fluidesign as seen in this video, https://www.youtube.com/watch?v=-XaPrwUgoJs.

This testing is all performed by the manufacturers to ensure they are offering a quality product that meets the required standards. Before choosing a boat to buy, the customer must also test the boat to ensure they are happy with the final product. They can only be assured after trialling the boat. This process differs dependent upon the person; generally a test row with race work performed is sufficient.

Evaluation

The evaluation process allows the comparison of the different options available. Each option is given a compliance score for each customer requirement, from 5 which is high compliance, 3 compliant and 1, not compliant. This is then multiplied by the weighted score, taken from the pairwise analysis. These are added giving the final score.

The first evaluation matrix seen below compares the boat materials. Carbon fibre is the highest ranked material, outscoring the others in weight, speed and compliance with Rowing Australia. Kevlar is closely behind but slightly as it is lighter, also stiffer though this isn't a customer requirement. Wood and HDPE were both quite low scoring due to the higher weight of the wood and the slow speed of both of them.

Table 6. Evaluation Matrix for Boat Materials

			Carbon		Kevlar		Wood		HDPE	
	Rank	Weighting	Compliance	Weighted	Compliance	Weighted	Compliance	Weighted	Compliance	Weighted
Lightweight	3	4	5	20	3	12	1	4	5	20
Stable	5	2	3	6	3	6	3	6	5	10
Fast	4	3	5	15	5	15	1	3	1	3
Nice paint	7	1	3	3	3	3	3	3	3	3
Reasonably Priced	2	5	3	15	3	15	5	25	5	25
Meets RA rules	1	6	5	30	5	30	5	30	1	6
				89		81		71		67

The next evaluation matrix was performed on a range of available boats seen in Table 7. These were ones all made from the two top scoring materials from the previous evaluation, carbon and Kevlar. The six that are listed below are some of the more popular choices in Australia, however the available range is much larger then that given below.

Table 7. Evaluation Matrix for Different Boats

			Sykes		Swift		Empache		Race1		Wintech		Fillipi	
	Rank	Weighting	Compliance	Weighted	Compliance	Weighted	Compliance	Weighted	Compliance	Weighted	Compliance	Weighted	Compliance	Weighted
Lightweight	3	6	5	30	3	18	5	30	3	18	3	18	5	30
Stable	5	4	3	12	3	12	3	12	3	12	3	12	3	12
Fast	4	5	5	25	3	15	5	25	1	5	3	15	5	25
Quick Adjustments	6	3	5	15	5	15	1	3	3	9	5	15	3	9
Nice paint	7	2	3	6	3	6	3	6	3	3	3	6	3	6
Accessories	8	1	5	5	5	5	3	3	3	3	3	3	5	5
Reasonably Priced	2	7	3	21	5	35	1	7	5	35	5	35	1	7
Meets RA rules	1	8	3	24	3	24	3	24	3	3	3	24	3	24
				138		130		110		88		128		118

From the matrix it can be seen that the highest scoring race scull was from Sykes, an Australian producer followed closely by Swift and Wintech. These two are definitely the cheaper option but not elite level racing boats. Those at the elite level are Empacher and Fillipi and so some extent a Sykes. Due to the high prices of a Fillipi or an Empacher, this gave them low compliance scores in regards to these customer requirements, therefore eliminating them from contention. The Race1 scored the lowest overall. While being the cheapest boat available out of all of the options, it is heavier, slower and less appealing at an elite level compared to the others. Both Wintech and Swift are made in China then exported into the country. These low costs during production means that these savings are passed along to the buyer. Replacement parts are also cheap with these boats meaning that the cost of repairs is lower. All values for these racing sculls can be seen in Appendix A.

Proposed Designs – The Top Three

Aall three of these boats would be suitable based upon the customer requirements. While the Sykes is more expensive, it performs better at an elite level (Sykes 2014). The Wintech and the Swift are both much more affordable upfront and have lower ongoing costs with maintenance and replacement parts (Swift 2014, Wintech 2014). Stability is relatively the same with all three designs, and all are of race weight. The hull design for each is different however it cannot be gauged how a client would react to this until they have tested the boats. All are made to a high standard and top quality, with similar appearances and paint options. Ultimately the final decision comes down to the cost the customer is willing to pay, the feel of the boat when the client rows it, buying Australian versus importing from overseas and finally the effect of a well-known, high performance brand name such as Sykes or a potentially up and coming brand such as Wintech and Swift. An image of each can be seen below in Figure 5.

Figure 5. A Wintech (left)(2), a Sykes (centre)(3) and a Swift (right)(4)

Design Communication

The design can best be communicated as stated above by the client trialling the boat they are interested in. The specifications of the boat are also very important to be communicated. Boats are designed for weight classes, so for optimal performance a boat designed to support the weight of the client would be best (Rowing Australia 2008). Other important specifications of the boat include the actual weight of the boat and the length. Pedigree plays an important factor as well when choosing a boat. The brands that are used by the elite athletes are those that are in demand also at lower levels of competition. Ultimately it is whatever feels best when being trial rowed by the client.

Conclusions

Through the systems engineering process, different available designs of boats have been contrasted and compared against the customer requirements as well as each other. By applying different analytical techniques and mapping out the processes, a final recommendation can be reached. Three boats were recommended at the end of this process for the client to trial. These were selected as they met the customer requirements, most importantly cost, as well as being up to the standards of Rowing Australia.

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