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Evaluating the Effect of Surfboard Stringers on Performance

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サーフボードストリンガーによるパフォーマンスへの影響の評価

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Abstract:
A stringer in a competitive surfboard provides strength while still allowing the surfboard to flex. The flex of a surfboard affects the speed, maneuverability, and feel of the surfboard, ultimately influencing the board's performance. With various stringer materials and configurations being used in the surfboards of pro-surfers, research on surfboard stringers may provide valuable insight into understanding and improving surfboard performance. This research attempts to evaluate the role that stringer materials and stringer configurations play in the performance of surfboards. Three high-performance shortboards of approximately the same size were manufactured with different stringer materials and/or configurations. These boards were tested and evaluated by a pro-surfer. The results show that stringer materials and configurations do influence the performance of surfboards. In addition, valuable insights were gained about the challenging process of manufacturing surfboards of the same size for research purposes.

Keywords: Surfboard Stringers, Stringer Materials, Flex, Surfboard Performance, Surfboard Manufacturing.

1. Introduction

Manufacturing a competitive surfboard and then evaluating that surfboard for performance is a challenging endeavor. There are many elements of a surfboard that affect a board's performance. Board size, weight, design (e.g., convex vs. concave), and the materials (i.e., foam and FRP types) used all play a significant role in how that board will perform.

One aspect that seems easiest to evaluate in a surfboard is the stringer material. The stringer is the material that usually runs down the middle of the surfboard from the nose to the tail and divides the board into two halves. Traditionally, the stringer material of a performance board has been a light-weight strip of wood, usually of balsa or pine. These wood stringers are approximately an eighth- to a half-inch wide, maintaining the same thickness as the board from top to bottom. The stringer gives the board stiffness and added strength while still allowing the board to flex. The flex of the board is critical to the performance of the board as it aids in generating speed, maneuverability, and feel. From experience with student surfers of various levels, a surfboard that is too rigid and has no flex will not perform well. Thus, the stringer of a board seems like an ideal area to research, since the stringer plays such an essential role in the strength and performance of a surfboard. Also, there are many different types of stringer materials and configurations being used by pro-surfers today. It seems apparent that research on stringers may open doors to understanding and improving surfboard performance.

The goal of this research is to manufacture three surfboards of the same size, apply different stringers to each board, and then do a comparative study of their performance. In addition, we will address the problems associated with manufacturing surfboards of the same size, as we feel it will be useful in conducting future research in this area. The section about the manufacturing process is aimed at surfboard manufacturers, shapers, and researchers who are evaluating

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marine sports equipment and the materials that go into this equipment.

2. Selected Surfboard Design and Stringer Configurations

To the untrained eye, surfboards look rather simple and uncomplicated. However, the design of a surfboard is, in fact, very complex. The rocker height for the tail and the nose; the shape of the tail, nose, and the rails; the number of fins, their placement and the fin angle or cant; the length, width, weight, and overall volume of the board; and the bottom design of the board, among many other things, all affect the performance of a surfboard.

The bottom design of a surfboard dramatically affects the performance of a board and is primarily concerned with water dynamics and how the water flows under the board. A competitive shortboard needs to be maneuverable like a jet fighter, and, thus, the bottom of the board is designed to reduce drag and channel water for increased speed, thrust, and maneuverability. On the other hand, a competitive longboard needs to be somewhat stable like a passenger airliner to allow the surfer to walk the board and do nose maneuvers without the tail moving out of control. In the case of a longboard, stability is traded for drag and speed. In a big wave board or *gun*, the bottom side of the board, along with a huge nose rocker, is designed with built-in brakes to slow the board as it falls down the face of, for example, a 20-foot-plus wave. Flex and generating speed are not a concern with a gun, but preventing damage from huge waves is, and so these boards are made much stronger with many layers of FRP. Overall, the bottom design of a surfboard can have both concave and convex (Vee) features depending on the desired performance of the board and can vary tremendously between boards. Some of the more common surfboard bottom designs are represented in Figure 1 below:

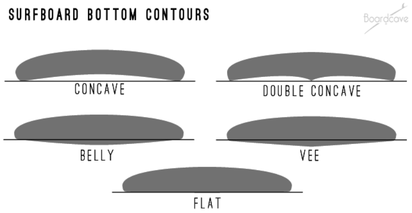

Figure 1: Surfboard Bottom Designs

Advancement in surfboard design usually comes through surfboard manufacturers. Renowned surfboard companies develop different surfboard designs by hiring professional surfers to help design and then test these designs under various wave conditions. Through trial and error, these pro-surfers tweak various designs over months and years until they come up with a design that produces wins on the pro-circuit, which, in turn, puts that design in surf shops for sale to the public, usually at premium prices. Of course, these designs incorporate various stringer materials and configurations, which play a significant role in the flex and performance of the board.

As mentioned earlier, stringer materials vary tremendously from wood to advanced composites. However, the most popular material used for stringers other than wood is carbon fiber. Carbon fiber is approximately twice as strong in tensile strength as glass fiber, the most common fiber used in surfboards, and it has excellent bending strength. Its only drawback, besides its high price, is that it has weak impact strength, which can be a problem in big-wave conditions. However, carbon fiber is an ideal material to use in surfboards because it is light-weight, flexible, and strong. The most popular form of a carbon-fiber stringer is a tape material that can be purchased in different widths. This material can be applied to the bottom and the deck of a surfboard in various configurations. Carbon-fiber tape can be used in combination with wood or other stringer materials as hybrids and is quite easy to apply in most cases.

It should also be mentioned that there are surfboards that have no stringers at all. These *no-stringer* boards rely on the FRP material that is used to coat and waterproof the foam core, or *blank*, of the board. The advantage of a no-stringer board is that the board will have more flex than a stringer board, which may produce an advantage in small-wave conditions depending on the quality of the flex and how quickly the board can return to its original shape. It should be noted that not all flexes are created equal; that is, the flex in a no-stringer board will be very different from that of a wood or carbon-fiber stringer. Another advantage of a no-stringer board is that it will have less material and should be lighter. However, a no-stringer board is weaker and in big-wave conditions is susceptible to damage. Furthermore, the flex of a no-stringer board may lose its spring faster than a board with a stringer. From this brief explanation, the complexities of stringer materials become more apparent. A surfboard needs to be strong enough to endure the forces put on it from the weight of the surfer and the wave conditions but still needs to be flexible enough to generate speed, maneuverability, and provide the feel necessary to maintain the proper timing for turns and other maneuvers. As mentioned before, there are many stringer materials and configurations. The basic stringer types are illustrated in Figure 2 below:

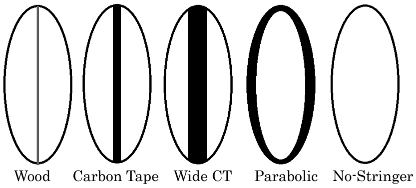

Figure 2: Basic Stringer Types

For this research, we consulted a surfboard manufacturer about a suitable surfboard design for this project. The design recommended was a 5’7” high-performance, single-concave machine-shaped blank – a design that is manufactured specifically for pro-surfers in Japan. This design was appealing because of its simplicity. A more complex double-concave bottom design, for example, was more likely to be subjected to human error during manufacturing than a single concave. A machine-shaped blank was also used to reduce the potential for human error during the shaping process. In the past, we had attempted to completely hand-shape our surfboards with the cooperation of senior seminar students, but the end products differed so significantly that the boards could not be used for research purposes. The machine-shaped blanks are 80% completed, which significantly reduces the potential for human error in addition to speeding up the shaping process.

The stringer configurations selected for this research were 1) a wide (6.5 cm) carbon-fiber tape (CFT) stringer applied down the center of the bottom side of the board three-quarters the way down the board from the nose to just before the tail section, 2) a parabolic stringer of CFT (same as in 1) applied to the outside rails of the entire board, and 3) no stringer. We should add that we also wanted to manufacture a traditional wood-stringer board for this project. However, the wood-stringer blank that we ordered was considerably different in size from the other boards, which made it unsuitable for this research. The cause of this problem with the wood-stringer board is addressed in Section 4.

3. Isolating the Stringer Materials

To research stringer materials, isolating the materials used for the stringers from those materials used to manufacture the boards becomes crucial. In this way, the stringer material can be evaluated for its effect on the performance of the board. A no-stringer board has no stringer, and, thus, the materials used to make a no-stringer board would be the essential materials used to manufacture any board, i.e., a foam blank, glass-fiber cloth, resin, three fin plugs, and a leash plug.

A CFT stringer that is applied to the center of the bottom side of a board would naturally increase the weight of the basic board as a result of adding the CFT and the resin needed to apply it. This board would also be a little thicker (1 mm) in the middle than the other two boards because of the added stringer material and resin. In the case of a parabolic stringer in which CFT is attached to the rails encircling the entire board, the weight of the stringer material including the resin would be more than double that of the center-stringer board's CFT since the distance around the entire board is more than twice as long as that going down the CFT center stringer board. Logically, the parabolic board should weigh the most of the three boards. In addition, the thickness of the rails on a parabolic board would also be more than the other two boards since the CFT is added to both the upper and lower sides of the rails. Therefore, when manufacturing the three boards, it is essential that the blanks be the same size and that the basic materials used be the same amount for all three boards. The only difference between all three boards should be the weight of the added stringer materials, including the difference in thickness that these materials add. If the stringer materials can be isolated in this way, we can then evaluate the influence that the different stringers have on the boards' performance. Making surfboards of the same size while isolating the stringer materials is not an easy task and is the main reason why this type of research is so challenging.

4. Surfboard Blanks, Foam Materials, and Resins

The manufacturing process for a surfboard starts with a foam blank. There are two main types of foam blanks: Polyurethane (PU) and Expanded Polystyrene or EPS. PU foam blanks are much more flexible than EPS blanks, and this flexibility can lead to some problems when machine- or hand-shaping a no-stringer PU blank because these no-stringer PU blanks bend too much when any pressure is applied to them as takes place during the machine- or hand-shaping process. This excessive flex makes it challenging to machine-shape a no-stringer PU blank the same size as a stiffer wood-stringer PU blank. That being said, a shortboard no-stringer PU blank still has much more stiffness than a longboard PU blank and can be both machine- and hand-shaped in most cases.

Longboard no-stringer PU blanks are so flexible that they bend too much to machine-shape them reliably. Even shaping such a board by hand is problematic because of the extreme flex of the blanks. However, some techniques can be used to minimize the problems, such as shaping these boards on top of a finished board or on a blank with a wood stringer. Again, the extreme flex in these blanks makes it challenging to shape surfboards of the same size accurately. Also, the foam in PU blanks gets gradually softer toward the center of the foam blank. The softness of the material makes these blanks more susceptible to dings and other damage while awaiting the laminating (glassing) process.

No-stringer EPS blanks, on the other hand, are much more rigid even without a wood stringer and can be both machine- and hand-shaped without a problem. Even longboard no-stringer EPS blanks are stiff enough to machine- and hand-shape. This more rigid material will naturally affect the flex of the board in the final product – a flex that experienced surfers can easily feel. Also, EPS foam is stronger than PU foam and does not get damaged as easily, though these foam blanks also need to be treated with extreme care until the laminating process has been completed.

One excellent advantage of an EPS blank is that it is approximately 30% lighter than a PU blank. This weight difference is a huge factor between the two materials. Lighter is almost always better when it comes to competitive surfboards, though a board that is too light has its problems, too. Here are some rough examples of the weight differences between EPS and PU boards of the same design glassed with epoxy. A completed 5'7" EPS board with a wood stringer, tri-fin system, wax, and deck pad weighs 2.18 kg, and the same PU board weighs 2.58 kg. This is a difference of 400 grams, which is significant for a shortboard. For the same comparison in a 9'2" competitive longboard design, the EPS board weighs 5.25 kg, and the PU board weighs 6.52 kg, for a difference of 1.27 kg. These examples clearly show the weight advantage that EPS boards have.

Another important factor about the two foams is buoyancy. The buoyancy of the two foams is considerably different, with the EPS foam being more buoyant and bouncier in the water. This buoyancy definitely affects the feel of the board. Surfers naturally have preferences, and some surfers prefer one foam over the other for various reasons, including both the buoyancy and flex factors. In addition, the EPS/Epoxy combination can result in much lighter boards, which some surfers say makes the boards harder to control in more extreme weather conditions, e.g., strong winds.

Despite the advantages and disadvantages of the two foams, the main dilemma with EPS blanks for our particular research is that they require the use of epoxy resin, which is four to five times more expensive than polyester resin, the industry staple, based on the prices of our supplier in Japan. Also, the cheaper polyester resin will melt EPS foam, and so it can never be used with EPS blanks. Thus, for this research, we are only left with one choice in foam, and that choice is PU-foam blanks, the industry standard.

Beyond just costs, the advantages and disadvantages of the two main types of surfboard resins, i.e., polyester and epoxy resins, need to be discussed. First of all, the hardening time of polyester resin can be controlled better through manipulating temperature and by regulating the amount of catalyst added to the resin. This faster curing time can result in less resin movement in the hot-coat stage, which means fewer resin waves and less sanding. However, from experience, polyester resin reacts with the glass fiber cloth, possibly caused by the coupling agent in the glass fiber or the PU foam, and becomes thick and less viscous during the laminating process, making it difficult to remove all the excess resin after the glass-fiber cloth has been wetted out. Any excess resin remaining on the board results in a board that is heavier and less desirable. The difference in the viscosity can easily be observed by comparing the leftover polyester resin in the container with the resin on the board during the laminating process. Comparably, epoxy resin remains very viscous even after applied to the board. It wets out the glass-fiber cloth quite easily and is also easy to remove, resulting in a lighter board. Also, epoxy is approximately 30% stronger than polyester resin. The only problem that we have experienced with epoxy is the influence of high levels of humidity during Japan's summer months. The humidity appears to prevent the epoxy from curing completely, though this analysis is only based on observations and not scientific data. In addition, epoxy generally takes longer to harden than polyester resin; and during the hot coat stage, the resin will flow toward low areas on the board and cause waves in the coating, which will require additional sanding to remove. The main consideration about resin is to use the same amount of resin during each of the four glassing processes for each board and reduce the need to sand one board more than another. This will significantly aid in creating boards of the same size.

Despite the many advantages of using EPS foam and epoxy resin, we chose the PU foam/polyester resin combination because this combination of materials represented the industry standard and was within our budget restraints, as we stated earlier. If budget considerations were not a concern, we would choose EPS foam and epoxy resin because these materials are more accurate to use. The final product would also be lighter, though the flex performance would undoubtedly be different from a PU foam/polyester-resin board.

One more aspect about resin, especially polyester resin, is that it has a shelf-life, usually around six months, depending on how the resin is stored. Polyester resin is susceptible to warmer temperatures and may start to cure in the container, forming little clots. There is nothing more upsetting than shaping a near-perfect board and then finding out while glassing that the resin has clots in it. It is incredibly disappointing when such situations occur. Our recommendation is to purchase new resin just before glassing and laminate all the boards used in the project within a week or two of one another using the same resin. Laminating your boards all at the same time under the same atmospheric conditions will help guarantee that the quality and strength of the resin will be the same for each board.

The same advice can be applied to the

glass-fiber cloth. We have experienced bad cloth on one occasion. The glass cloth was almost impossible to attach to the rails without causing any air bubbles to form. It was our first experience with bad cloth. Of course, the board that we painstakingly shaped was unusable as a result. In addition to costing ¥40,000 for the machine-shaped blank, all that time put into the project was lost. Psychologically, whenever a board is lost, it causes a heavy toll on the research project.

The main lesson here is that when manufacturing boards for research, make sure that there are enough essential materials to complete all the boards. Being prepared in this way will guarantee that the boards will all be made of the same materials and, as a result, should have approximately the same strength. It will also reduce the effects of Murphy's Law .

5. Manufacturing Boards for Research

In this section, we will discuss the manufacturing process as it relates to making surfboards for research purposes on a tight budget. The main point when manufacturing surfboards for research purposes is that every step of the manufacturing process has to be standardized and each step needs to be painstakingly followed with weights and dimensions religiously recorded. To those readers who are not involved with the manufacturing process, this section of the paper will have little meaning. Although there are many steps to the manufacturing process, we have only included those points that we thought were especially important. Our research was done on a very tight budget and required that we do a lot of the manufacturing process by hand with very elementary equipment. We understand that there are more advanced techniques to manufacture boards with much more precision. This section explains our approach to manufacturing surfboards with the limited resources available to us.

The manufacturing process has many steps, from applying four layers of FRP to installing fins and leash plugs. The primary stages are 1) measuring and weighing, 2) shaping, 3) stringer application, laminating, and hot coating (applying FRP), 4) installing fin and leash plugs, and 5) sanding. This section will only discuss those critical points in each stage that will aid in making surfboards of the same size. Also, this section will not just draw on the lessons learned from this particular research project but will draw on all the lessons learned from attempts to manufacture surfboards of the same size, including the manufacturing of longboards. As noted above, there are many stages in manufacturing surfboards; and because of these many stages, there are also many opportunities for Murphy's Law to influence the final product.

5.1 Measuring and Weighing

Before starting the shaping process, all the machine-shaped PU blanks used in the project must be of approximately the same size. "Approximately" means that the blanks (boards) should be within 0-2 mm in thickness at every measured point on the board. In total, there were 13 points (See Figure 3) that were measured and compared among the three boards (Note: In subsequent research, we increased the measuring points to 29 locations to improve the accuracy of the shaping process). These measuring points were scribed on a 5'7" cardboard template, and holes were punched in the template at each of the 13 points. The template was then placed over the board, and the holes were marked on the board with a felt-tipped pen. This template made it quicker and more accurate to mark the boards each time measurements were needed during the shaping process. While measuring the thicknesses, we quickly discovered that the wood-stringer PU blank was excessively thin and could not be used for this project. The other three no-stringer PU blanks were very close in thickness, that is, within 2 mm at each of the 13 locations. The blank that has the overall thinnest measurements should be the board that is shaped first. The other two boards should then be shaped to match the thinnest board.

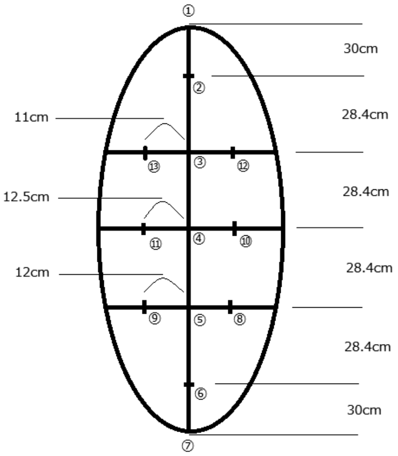

Figure 3: Thirteen Measuring Points

The weight of the three boards must also be taken and should be of approximately the same weight before starting. Fortunately, the three boards used in the project weighed 1020 grams each, giving clear evidence of the accuracy of machine-shaped boards over hand-shaped boards.

Measuring the thicknesses of the boards is one of the more essential tasks in this research. It must be done in an accurate, reliable way. For this research project, we made a long, circular device out of wood that opened and closed in the middle. This device is called *calipers* and is often used by surfboard manufactures to measure the thicknesses of boards. However, this device is not the most accurate way of measuring the thicknesses of boards, especially when measuring millimeters. The distance between the two tips of the device must be measured with a ruler. While measuring the distance, there is a possibility that the two tips will move slightly. Also, there can be a slight difference in the measurements depending on the person taking and reading the measurements. Again, we noticed that there was a range of approximately 2 mm among the members taking measurements. For this reason, we chose to have the person who took the most accurate measurements do all the measuring. Again, the potential for human error in this stage of the research is quite high. There are electronic devices that can improve the accuracy of these measurements, including 3D scanning machines, but unfortunately, these devices were beyond our budget for this project. A 3D scan can provide accurate width measurements as well as the board's volume. However, each scan of a board costs more than ¥20,000, and to shape a board properly would require three or four scans, making this approach too expensive. In retrospect, it might be easier to use a narrow metal rod to measure the thicknesses of the boards. A small hole at each point in which the metal rod could be inserted would more than likely increase the accuracy of the measurements during the shaping phase and would not add any extra costs. These small holes would be filled in during the laminating process and would not affect the performance of the board. However, once the surfboards were laminated, this technique would no longer be an option. The final thickness measurements would have to be taken with calipers, once again subjecting this research to human error.

5.2 Shaping

The shaping process has both easy and challenging stages. The boards have already been machine-shaped to 80% of the desired size. These machine-shaped PU blanks have all the design features and look almost like a finished board. The only shaping that remains to be done is to remove the machined grooves on the board, finish the rails, and trim off any excess foam on the nose and tail, which can be quickly done at the beginning before the real shaping process begins. (Note: We understand that there are shaping machines that can deliver a final product that is more complete than the one we utilized.)

Removing the grooves from the board is somewhat easy and can be done with 80-grit dragon skin and a block of wood and soft spongy foam that is commonly used in bedding. The main point is to maintain the current shape of the board throughout the shaping process and avoid rubbing too much in one area and creating a depression in the surface. The best approach is to use light strokes from the nose to the tail and vice versa. The goal is to have a smooth, balanced transition from the nose to the tail while maintaining the concave shape of the bottom. Once the grooves are almost entirely gone, 240-grit dragon skin can be used to smooth out any remaining small nicks or scratches on the surface of the board. The dragon skin prevents the shaper from taking too much off at one time. Please keep in mind that once the foam is removed, it cannot be replaced, and thus it is best to take a slow, methodical approach to the shaping process and not make any errors. The same person using the same strength must shape all the decks and bottoms in order to help ensure that all the boards are done uniformly. Allowing different people to do the shaping will produce very different results.

Like the bottom and the deck, the rails also must be done by the same person to maintain uniformity. The rails are challenging because there is a transition from a flat rail (aka., hard rail – 100/0) at the back third of the board to a 60/40 rail in the upper two-thirds of the board. Generally, only an experience shaper can do the rails accurately and make the transition in approximately the same place on each of the three boards. Shaping the rails is usually done with 240-grit dragon skin for machine-shaped PU boards since the foam is softer at this stage. It is essential to count the number of strokes for each session and maintain the same angle on the rail with the dragon skin. We usually do five strokes on each rail for all three boards before going back to the first board and moving on to the next step in the process. The rails usually take four steps to complete. Again, the rails must be shaped in such a way that they all come out the same. This step in the shaping process is probably one of the most challenging aspects of trying to manufacture surfboards of the same size.

Once the boards are shaped, the boards are again weighed and measured at the 13 locations according to the template. If there are any differences of over 1 mm, the areas are marked and then carefully shaped with dragon skin on both the deck and the bottom. Again, it is essential to shape the board in a smooth, balanced way without creating any sudden dips in the board's surface. Once the shaping is completed, the board's weight and thicknesses are recorded. Since the boards can be easily damaged, it is vital to store the boards in a safe place away from any people until it is time to laminate the boards. From our experience, boards get easily damaged and become unusable for research, showing that Murphy's Law always needs to be anticipated, especially when tired and rushed. With the exception of the laminating process, none of the manufacturing processes should ever be rushed because this is how mistakes occur.

5.3 Stringer Application, Laminating, and Hot Coating

Applying the CFT stringer, laminating the surfboard with 4 oz. glass-fiber cloth, and applying the final coating, or hot coat, are all critical steps in creating a surfboard of the same size. The main point to remember is that resin is heavy and can make a significant difference in the weight of the board if it is not applied and removed correctly. At the same time, the different fiber materials used in the board play a significant role in the strength of the board. It is crucial that the glass-fiber cloth is handled as little as possible to prevent any damage and that the amount of this material used for each board is the same. We want to ensure that all the boards are of approximately the same strength. Naturally, this is a very challenging stage and requires someone with proper know-how and attention to detail.

Applying the CFT stringer down the middle of the bottom side of the board is not very difficult. The biggest challenge is applying the material in a balanced way, straight down the middle of the board without any curves or waves in the CFT material. The best way to do that is to put a line down the middle of the board and then add some guidelines on both sides of the centerline that are approximately 5 mm wider than the carbon tape. These outside lines will help lineup the CFT down the middle of the board.

Laminating the CFT to the bottom of the

board can be done in different ways. The easiest way is to first apply resin directly to the board on the middle section of the board with a squeegee where the CFT will be applied. After the resin is applied, apply the CFT on top of the resin so that the tape is attached straight down the middle of the board in a balanced way between the lines. Next, add more resin to the top of the CFT and carefully work the resin into the material with a small squeegee until it has been wetted out thoroughly. For the best results, start from the middle and work toward the nose and tail, being careful not to create any folds or waves in the CFT. Do not move the squeegee from side-to-side on the tape, as it will create bends/waves in the material. Once the CFT is wetted out, carefully remove any excess resin and let dry overnight. It is a good idea to have a little CFT extending out beyond the ends of the board. This extending CFT makes it easier to trim off the tape neatly once the resin hardens. (Note: This procedure was not done for this project but was done in subsequent projects.) The next step is to weigh the board.

Applying a parabolic stringer to the rails is a much more complicated process, though it is done in a similar way as the center stringer. The only difference is that CFT is wetted out before applying the tape to the board. Guidelines must also be carefully drawn on the board to help apply the tape to the middle of the rails in a balanced manner. It is easiest to do one side at a time. Also, do not apply any CFT to the back edge of the tail, as the material obstructs the flow of water out the back of the board and will affect performance. (Note: This procedure was not done to the parabolic-stringer board in this project.) Once one side has dried, trim off the excess tape, and then apply the tape to the other side, repeating the process. After the tape has dried and been trimmed, the board must be weighed to understand the added weight of the CFT and resin.

Laminating the board with 4 oz. glass-fiber cloth requires a minimum of two people to do quickly and accurately. When the cloth is put on the board, it must lie flat on the board, with none of the fibers being stretched. The cloth is then trimmed with scissors so that the cloth will attach smoothly to the board without any folds in any of the problematic locations, such as the tail, nose, and rails. To keep the weight and strength of the boards the same, the cloth must be cut the same length for each board. Once the cloth is cut and ready for the resin, weigh the board to determine the weight of the cloth. The goal is to apply the same amount of cloth to each board based on weight. Since this is a competitive board for a Japanese pro-surfer, who are generally lighter than most Westerners and thus require less compression strength to the deck, only apply one layer of glass cloth to both the bottom and deck. Applying only one layer to the deck will reduce the possibility of human error. Typically, there are two layers added to the deck to give the board more compression strength on the deck, the side of the board that the surfer stands on. We generally do not apply two layers to the decks of our competitive boards to help keep them as light as possible. Up to now, I have not had a single competitive shortboard or longboard break with only one layer of 4 oz. glass-fiber cloth applied to the deck, provided that the board has a stringer of some sort for added strength.

For the laminating process to go well, it is vital that the resin is applied at the same room temperature using the same amount of catalyst for each board. Try to use the minimum amount of catalyst required for the resin to harden properly for this stage. In addition, keep the room cool. Doing these two things will lengthen the initial curing time to approximately ten minutes, which is plenty of time to remove the excess resin once the cloth has been wetted out. Air bubbles can occur, which can be easily removed with a squeegee. However, when removing these air bubbles, try not to overstretch the cloth with the squeegee. Stretching the cloth may weaken the material.

When the laminating process is done, examine the board and sand any rough edges, making sure the board is suitable to continue. If the fiber has been applied properly without any major problems, the board can be weighed. Then, the deck is laminated in the same way as the bottom side, keeping in mind that the other two boards will have to be done in precisely the same way as the first board. Again, it is quite challenging to achieve the same weight each time a board is laminated. However, if the procedures are standardized and each step is carried out under strict scrutiny, the odds improve tremendously.

After the bottom and top have been laminated, it is time to apply a thin coat of resin with a styrene wax additive so that the resin dries hard enough for sanding. This thin coat of resin is called the *hot coat*. As a general rule, the hot coat uses half the amount of resin used in the laminating process. In addition, the amount of catalyst is double that of the laminating resin, and the room should be warmer so that the resin hardens quickly. Again, the conditions for the hot coat should be the same for each board manufactured. The hot coat is applied with a brush as thin as possible and as quickly as possible. The same type of brush should be used each time. The hot coat resin should start to harden within five to ten minutes once the catalyst is added. If it is done correctly, it will cure with fewer waves or brush-lines forming in the resin, keeping the board as light as possible. After this step, the board is weighed again. Then the other side is completed and weighed.

It is important to remember that the bottom side of a board is concave and that resin flows toward the lower concave areas. When applying the hot coat, a conscious effort must be made to keep these areas as thin as possible and to keep the board's weight down. The two sides (i.e., the top and bottom sides) of one board may have different increases in weight, but each side of the other boards should have approximately the same increase in weight, that is, the increased weight of the deck after being hot-coated should have the corresponding increase in weight as the decks of the other boards. This should also be true for the bottom sides as well. Sanding can help a little in rectifying any weight differences between the boards. If the weights of the boards are considerably different, then the boards must be abandoned and redone from scratch. However, it is important to understand where mistakes were made and to change your procedures so that the same mistakes are not made again. It should be pointed out that many products manufactured with machines, such as injection molding, are not all the same. From experience with surfboard products, such as fins and deck pads, the weight of the same products may fluctuate as much as 10%. However, for this project, it is important to try to make the boards as close to the same as possible in every respect. This can only be achieved if you standardize the procedures and are strict about every step in the glassing process.

5.4 Installing Fin and Leash Plugs

The fins of a shortboard are attached to the surfboard using plugs. There are many kinds of fin plug systems. The older FCS fin plugs were used for this research, and a tri-fin system, or thruster, was used for the fin configuration. The leash plugs and the fin plugs are installed similarly. The critical point is not to make the holes for these plugs too big, as they will cause the board to weigh more than is necessary when the resin is added.

Make a point of removing the foam material very slowly and meticulously, only removing just enough foam for the plugs to fit in the holes. Whenever possible, try to push down the foam material and compact it to make room for the plugs. It is important to remember that the resin is much heavier than foam. Also, add Q-cell powder or a similar product as a reinforcing agent to the resin to add strength and lighten the resin a little. Q-cell is much lighter than fiberglass powder. Again, the main thing is to install all the plugs the same way in a slow, methodical manner. After the plugs have been installed, the tops are sanded down flush with the surface of the board being careful not to over-sand the areas around the plugs. Next, weigh the boards once more and look for any differences in weight between the boards. There may be a few grams difference between the boards, which is not a big problem. These differences can be made up, if necessary, by using the lighter fins on the heavier boards and vice versa. Manufactured fins differ by up to 5 grams each, which is plenty of room to make up any weight difference in the fin plugs.

The deck pads and leashes can also be used to tweak any weight differences as they also differ in weight.

5.5 Sanding

Sanding is vital as it allows the surface of the boards to be smoothed out and blended. Sanding also allows for any differences in the thicknesses and weights to be rectified. Do a light sanding of the entire board with 80-grit sandpaper first. After the three boards have been lightly sanded, it is time to weigh the boards for differences and check the thicknesses of the boards in the 13 locations discussed in Section 5.1. Since it is easy to make mistakes in measuring the thicknesses, these measurements must be done several times to ensure accuracy. Based on the weight and widths of the boards, there will probably be areas that will need more sanding to achieve the desired thickness and weight. Usually, resin pools in the concave areas of the bottom side of the board, and these are areas that may have excess resin and can be sanded more aggressively. It is important to use your hand and feel the surface of the board for any subtle rises or bumps that may cause turbulent water flow. These deformities will need to be smoothed out and can be sanded down with 80-grit sandpaper, but it is also important to not over-sand and expose the fiber. Any damage to the board will add weight to the board during the repair process. After the boards are balanced out, a final light sanding with 240-grit and 400-grit sandpaper can be continued. Once the boards are completely sanded, the final weight and measurements can be taken. More than likely, there will be some differences in the weight and thickness that can only be explained as a result of human error. Based on the materials used, the no-stringer board should be the lightest, followed by the CFT stringer board. The parabolic board should be the heaviest since it uses more than twice as much CFT as the center-stringer board. If all is well, the three boards will have their proper weight based on the stringer materials used for that board and will then be ready to test. If there are some differences, the fins, deck pads, and leashes can help resolve these differences within reason.

5.6 Final Sizes and Weights

Figures 4-6 below show the images of the three boards with fins and leashes.

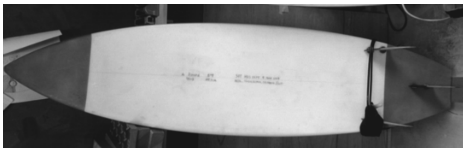

Figure 4: No-Stringer Board

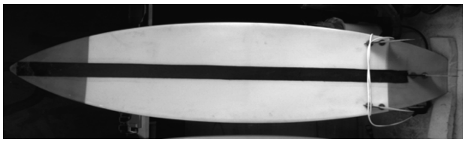

Figure 5: CFT Stringer Board

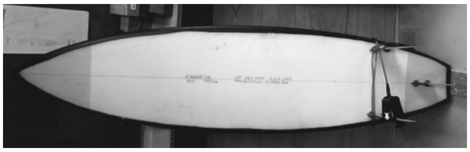

Figure 6: Parabolic-Stringer Board

The weights of the board are listed below in Table 1 and include the deck pads only with no fins or leashes.

No-Stringer	CFT Stringer	Parabolic Stringer
2250 g	2280 g	2380 g

Table 1: Board Weights

If we look at the weights of the three boards, we can see that the weights gradual increase as more material is added, which is what we would normally expect. However, the CFT stringer board is only 30 grams heavier than the no-stringer board. Thirty grams seems a little light considering that the 148 cm long section of CFT applied to the center-stringer board weighs only 30 grams, which would be about .2 grams per centimeter of tape. The parabolic board has roughly a total of 380 cm of tape, which is approximately 232 cm more CFT than the center-stringer board. This would mean that this section of tape plus resin weighs .34 grams per centimeter. This weight per centimeter seems somewhat high compared to the CFT stringer board. It should be noted that it is very challenging to squeegee the rails and remove any extra resin during the CFT application process because the rails are curved. Also, when adding the glass-fiber cloth over the CFT on the rails, a small amount of resin collects along the edges of the CFT on both the bottom and the deck sides. This occurs because the CFT sticks out from the surface of the board 1 mm on both sides. Resin collects in any low spots along the edges and may explain the increase in weight.

The final sizes of the board are listed below in Table 2, according to the 13 points discussed in Section 5.1:

No Stringer	CF Center Stringer	Parabolic Stringer
① 1.7 cm	1.7 cm	2.3 cm
② 3.85 cm	3.8cm	3.9 cm
③ 5.1 cm	5.0 cm	5.0 cm
④ 5.35 cm	5.5 cm	5.5 cm
⑤ 5.1 cm	5.1 cm	5.15 cm
⑥ 4.2 cm	4.2 cm	4.2 cm
⑦ 1.75 cm	1.8 cm	1.95 cm
⑧ 4.8 cm	4.85 cm	4.7 cm
⑨ 4.6 cm	4.75 cm	4.75 cm
⑩ 5.0 cm	5.0 cm	4.95 cm
⑪ 5.2 cm	5.1 cm	5.05 cm
⑫ 4.8 cm	4.8 cm	4.8 cm
⑬ 4.7 cm	4.8 cm	4.7 cm

Table 2: Final Thickness Measurements

If we exam the thickness numbers, we see that most of the numbers are within 2 mm of one another, except for the parabolic board's nose and tail thicknesses at points ① and ⑦. The CFT on the parabolic stringer overlaps at the nose on both the top and the bottom sides of the board and can explain its increased thickness. This board is also thick in the tail, too, where the CFT was applied but doesn't overlap as the nose does and, thus, the thickness is closer to the other two boards in the tail section. Concerning the CFT stringer board, we were expecting to see slightly larger widths in the center of this board at points ②, ③, ④, and ⑤. However, the results didn't confirm this expectation. On the contrary, we see that the CFT stringer board has lower widths in many of the measured areas where the CFT was applied. The only possible explanation is that when the CFT is applied to the center of the board, the foam may have been compressed downward from the force of the squeegee while the excess resin was being removed from the CFT. PU foam does get softer toward the core of the blank, as mentioned earlier. The center of the board on the bottom side is concave, and thus the foam in the concave areas is thinner and, as a result, can be softer and more easily compressed than other locations on the board. However, further investigation is needed to confirm whether this explanation is correct or not.

Although all three boards are not ideal for research as a set, the no-stringer board and the CFT stringer board are, in our opinion, close enough to conduct research on since their difference in weight is 30 grams, which is close to what the added weight from the CFT should weigh. In addition, their average thicknesses were 4.319 and 4.338, respectively, which are also very close.

The 130 grams difference between the no-stringer board and the parabolic board seems a little high for research purposes. The weight difference alone will undoubtedly affect its performance, especially on small waves. From experience, even 20-30 grams difference can be felt by an intermediate-level surfer and negatively affect performance. Additionally, the large amount of CFT used on the parabolic stringer would also make the board unusually stiff, again affecting its performance. It should be pointed out that the parabolic design is quite popular among the top pro-surfers of the world and is one of the reasons why we selected it. Despite the excessive weight of the parabolic board, we decided to include it in the study as well to see how it fared against the other two boards.

6. Testing and Results

Testing and evaluating sports equipment for performance has a subjective element. Athletes like certain sports equipment, usually because they *feel* and perform better. How one may judge that improvement is the subjective aspect of evaluating sports equipment. Sports equipment has a *feel* about it – some athletes may like the feel, while others may not. This feel cannot always be logically explained or quantified, though it is certainly the goal of researchers to try.

A surfboard is an especially tricky item to evaluate because waves are not consistently the same in most locations. However, there was research conducted on fin designs and materials (Gately, Beirne, Latimer, et al., 2017) in which the fins used for this project were made using a 3D printer. In this research, the subjects tested and compared various commercial fins with the 3D printed fins, with the subjects not knowing which set of fins they were using at the time. The goal of the subjects was to turn as many times as they possibly could within a certain distance. Cut-back turns are a key element of competitive surfing and are appropriate for evaluating a fin's performance since fins help a board turn. Fins can also affect speed – another key element in surfing.

The location chosen for the testing of these fins was a surf break in the Mentawai Islands located in West Sumatra, Indonesia, an area that is famous for having consistently good waves for surfing. The subjects were fitted with electronic devices to track wave-count, distance, speed, and the number of turns. The results showed that the newly designed fins improved performance for each of the six participants and were also popular with the surfers in that these 3D fins had a better *feel* than the commercial ones. In other words, the subjects performed better with the 3D fins. From this example, we can assume that a surfboard that improves performance will most likely be liked more than one that does not.

In the above research, the researcher developed a relatively easy test to quantify their fins and fortunately had access and funds to test their fins in an ideal location with consistent waves. Unfortunately, in Japan, we do not have access to ideal waves on a regular basis. Also, researchers have yet to develop a scientific formula for quantifying a surfboard's performance. We do know that the performance of a surfboard can be broken down into the different elements of surfing, that is 1) paddling, 2) take-off, 3) speed, 4) maneuverability, 5) feel/timing/flex, and 6) weight. Weight is not an actual aspect of surfing per se, but it does affect the timing and, thus, the overall performance of the board. It is also one element that surfers can quickly identify during those first moments when a board is picked up and held. An important consideration for future research would be to understand whether each of the above elements deserves equal weight in the overall evaluation process, such as, is paddling equivalent to maneuverability? In time, researchers may develop a way to quantify and evaluate the performance of a surfboard using the above elements and may add other elements as well. For this particular research, however, we decided to have our surfboards evaluated based on how much the boards were liked by a surfer, assuming that if a board performed well, it would receive a higher score than one that did not.

To test our surfboards, we took a very straightforward approach. We decided to hire a pro-surfer (PS), an expert, to test our boards and evaluate them, especially since the boards we manufactured were designed for a Japanese PS. We asked the PS to ride and test all three boards and give each board a score ranging from 0-100 based on performance. It was assumed that a board that performed well would get a higher score than a board that did not. We also assumed that the PS would have his own system, whether conscious or not, for evaluating the performance of a surfboard. We did not explain to the PS anything about the boards or the type of research we were conducting, though the PS could clearly see the differences in materials and feel the difference in weight. Interestingly enough, the PS thought that the boards were all made of epoxy resin, which we did not correct. Additionally, we also asked the PS for advice on how our boards could be improved for future research projects on high-performance shortboards.

The three boards were turned over to the PS, and he was asked to test the three boards at his leisure. He was also asked to test all the boards on the same day under the same wave conditions. We assumed that once the PS started surfing, it would take no more than 2 hours to test the boards. Also, we asked the PS to video the testing of each board. The pro-surfer was paid ¥45,000 for his services.

The testing of the boards took over two months for various reasons. Understandably, the PS had to wait for just the right conditions to test the boards, considering his work schedule. The wave conditions on test day were waist-high with good breaks to both the right and left. The video showed a very conservative approach to testing the boards with no aggressive maneuvers, which, honestly speaking, was a bit disappointing, as I have seen this PS perform some aggressive maneuvers in the past. He has also posted videos online of him testing U.S.-manufactured surfboards to be sold in his own shop. In these videos, he was quite aggressive in how he tested these boards.

The PS evaluated the boards and gave the following scores: The CFT stringer board was given a relatively high score of 80. The no-stringer board received a score of 70, and the parabolic-stringer board was given a 50. These results show that under the tested wave conditions, there were apparent differences in how the boards performed based on the stringer materials used on these boards. Although the CFT stringer board was 30 grams heavier, it performed better than the lighter no-stringer board. This particular example suggests that a stringer material like CFT does make a noticeable difference in performance for those specific wave conditions. It would have been especially interesting if a wood-stringer board was also included in this study to see if there was any difference between a CFT stringer and a wood stringer.

Concerning the parabolic stringer, we should point out that this board had more than twice as much CFT applied as the CFT stringer board, making this board much stiffer and heavier than the other boards. One hundred to 130 grams difference in weight is a big difference in a shortboard. This board is about 5.5% heavier than the no-stringer board and 4.2% heavier than the CFT stringer board. We can assume that both the extra weight and the added stiffness made the board perform worse than the other two boards, giving some supporting evidence that a board can be too strong and needs to have a certain amount of flex to perform well in certain wave conditions. Also, in the case of the parabolic board, we can say that lighter is indeed better. I do think that the weight of this board can be reduced by 20-30 grams. Whether this is enough to make it comparable to other stringer boards is difficult to say. In big wave conditions, the parabolic board may perform better. Likewise, the no-stringer board could very well break under larger wave conditions. In retrospect, a better approach for making the parabolic stringer board may be to change the amount of material added to the rails so that it equals that of the CFT stringer board. Instead of applying the material on the rails from the nose to the tail, the material could be applied to the middle of the rail section of the board on both the right and left sides. This would also make the manufacturing process easier. Undoubtedly such a board would perform differently from the popular parabolic boards that are completely encircled in CFT. Another choice may be to use a narrower tape, which would reduce the overall weight. A final choice may be to exclude the parabolic stringer board from the study altogether and focus on a wood-stringer board and CFT boards with either a wide or narrow CFT. In this way, we might be able to understand better which type of material, i.e., wide/narrow CFT or wood, provides the right amount of flex to improve performance for a surfer of a particular weight.

One more test that could be added to this study is a final strength test of the boards.

The boards could be bent in the middle until they broke in half or structurally failed. We could then compare the strength data of the no-stringer board with the data from the other stringer boards. In this way, we could actually see how much the different materials add to the overall strength of a board. I think that such data would be of interest to all surfboard manufacturers.

Concerning the testing of the three boards, we also learned that we need to be quite specific in how a PS tests the boards. We prefer a more aggressive, real-life approach to testing the boards, such as takes place during a surfing contest. We can certainly make this point clearer in any future research. Perhaps the PS was worried about what might have happened to our research if any of the boards had broken, which may explain his soft approach to testing the boards.

In the future, with the advancement of wave parks producing perfectly breaking waves every time, we will be better able to test surfboards for performance and conduct comparative studies on different types of boards and materials more accurately. In addition, as newer testing technologies for surfboards are developed, researchers will be better able to test the quality of flex that different materials can add to a board. Already, there is a company called TorFlex in the Basque area of Spain that has developed a machine that can test the flex of a surfboard on several different planes, including the twists and vibrations of a board. This technology, over time, may make it possible to take the best performing boards, test them, and begin to quantify their attributes based on their construction and the types of materials used. This would be revolutionary for the surfboard industry and would make it possible to build technology-driven custom-made surfboards specifically designed for athletes with different body types.

7. Conclusion

This research showed that the stringer material and stringer configuration or lack of a stringer can indeed affect the performance of a surfboard under medium-wave conditions. It is speculated that once more research in this area is completed with numerous pro-surfers, the stringer materials and stringer configurations can be quantified to produce better performing boards for pro-surfers of different weights and wave conditions.

For more research to continue in this area, more reliable surfboard manufacturing techniques need to be developed to make it easier to produce surfboards of the same size and weight. As we have found out through our many failures over the past five years, this is not an easy task.

In this paper, we have also included the more important lessons learned over the past five years in trying to manufacture boards for research purposes. It is hoped that this paper will contribute, if only in a small way, toward improving future surfboard stringer research and producing better performing surfboards.

With surfing growing in popularity and coming to the Olympics in 2020, it is time for academia to support the sport and develop materials and boards specifically designed to help surfers perform at their very best.

References

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