Stability and Trim Characteristics of Native Watercraft: A Computerized Simulation Study

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Paper presented at the 1982 CESCE Annual Meetings, 7-11 May, Vancouver, B.C. *My grateful thanks to Ronald Horn who conceived the initial mathematical development of this program. Bruce Winterbon was very helpful in refining parts off the program. Any remaining errors or omissions, however, are my own responsibility. My thanks also to Eugene Arima who provided measurements for a number of National Museum of Man kayak specimens.

Introduction

People of the western world have been fascinated with the Eskimo kayak ever since these unique craft were first seen in Greenland, Canada, Alaska and Siberia. Aesthetically and functionally the kayak has few peers in the world of watercraft. It was a highly complex and efficient hunting tool used by the Eskimo, Aleut, Koryak and Chukchi people of the Arctic.

My long term research on kayaks has been aimed at discovering the place of the kayak in these cultures. How was it made, used and sung about? That was its importance within the culture? Where did it come from and how was the technology spread? How did it influence European exploration and settlement?

The more I discovered in both field research and searches of the literature, the more I came to appreciate the diversity of kayak types based on materials, use, environment and culture. This led me to try and reconstruct different kayak types in order to do comparative testing of handling characteristics. Eventually, however, I decided that while this gave excellent qualitative data, I needed more quantitative measures that would enable me to do some testing in a reasonable amount of time. I wanted answers to such questions as how fast were the different kayaks; how did this compare with explorers accounts; what were the load carrying capabilities; how stable were the kayaks under varying conditions?

By this time in my research I had traveled to museums from California to Leningrad studying and making detailed drawings and measurements of kayak specimens. In many of these, the design changes over time were rather subtle, but quite radical in others. I had no way of knowing what they meant functionally. Then I discovered the field of Naval Architecture and learned that my neighbor was a top notch mathematician.

Combining my neighbor, textbooks on naval architecture and my former career in computers, the answers to my comparative questions seemed obvious. Write a computer program that would take as input the kayak measurements and then perform the calculations under varying load conditions that would provide data for comparative analysis of a number of functions.

The rest of this paper details the computer program, how it was written, the basic assumptions behind it, the mathematics used, and the results along with some initial comparative analysis.

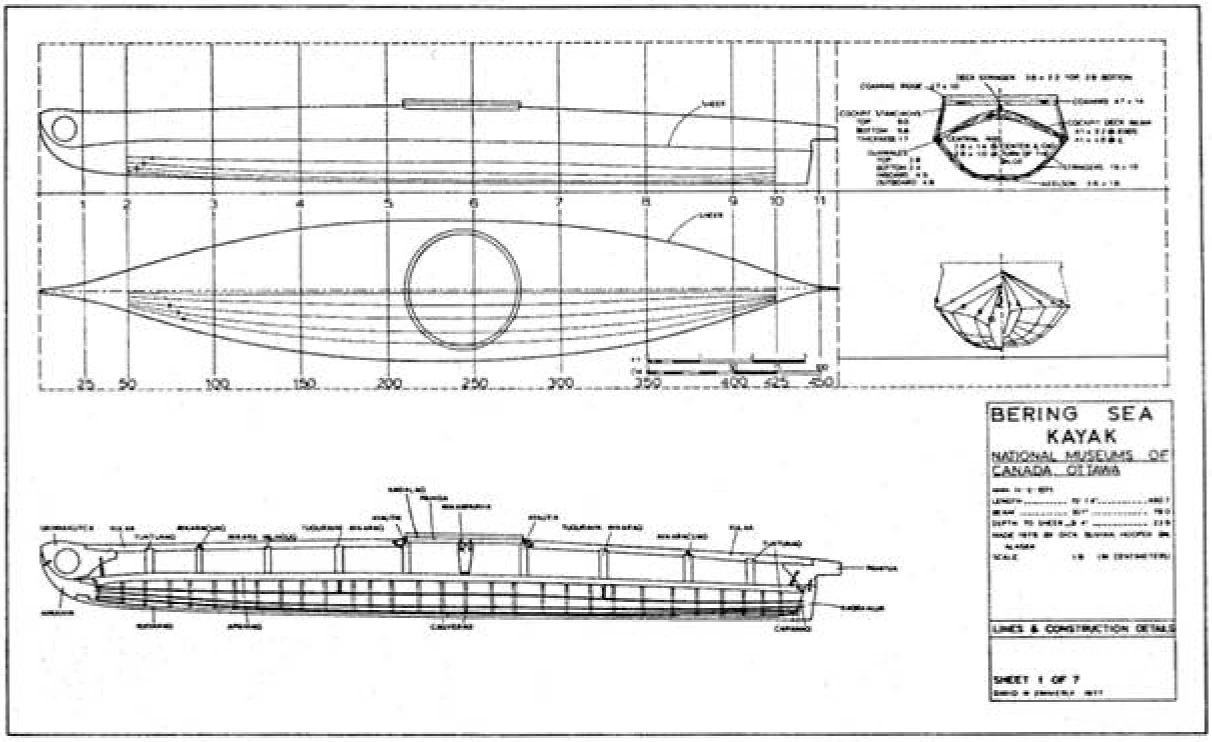

Figure 1 Lines and construction details of Bering Sea Kayak II

The Computer Program

The first version of this program was written in Fortran IV to run on the National Museums of Canada Univac 90/30 computer. Time on this computer was provided through the courtesy of Peter Homulus, director of the National Museums of Canada's National Inventory Program.

Mathematically, the watercraft simulation program is not too difficult to understand. It uses only basic high school math and physics. First, Archimedes' principle, paraphrased, says that a boat will float in a tank filled to the top with water, when the weight of the water that spills over the top is equal to the weight of the boat. Secondly, we need to understand the concept of moments which are simply a weight times its distance from a fulcrum. It is the old familiar see/saw problem: for perfect balance, how far from the middle should a 75 lb. girl sit if her 150 lb. father is on the other side 5 feet from the middle (answer: 10 feet)? The mathematics involve a bit of trigonometry no more complicated than finding unknown sides or angles in a right triangle using sine, cosine and tangent functions.

The actual detailed mathematics used are given in the appendix along with a program flow chart and other supplemental data. For purposes of explanation, I will give a somewhat stripped down version of the program's operation, but first a bit of background to the problem.

I started my research on a particular boat type by making a detailed set of measurements of cross sections of the boat every 50 cm along with the profile and plan views. These measurements were then translated into a set of two dimensional lines drawings as shown in figure 1 which is a kayak in the collections of the National Museum of Man. Many of the interesting calculations that are useful for comparative purposes depend on knowing the length of the waterline and its exact location. This will vary depending on where people and cargo are placed in the boat. If I had a usable kayak I could obviously put it in a tank of water and see where the waterline fell under different loading conditions such as when I was in it or when I added a seal inside or one on the after deck, etc. With museum specimens this is not a desirable thing to do. It is simpler and more practical to do a computer simulation of the tank of water and kayak.

Imagine if you will an empty boat in a barn suspended over a large horse trough full of water as in figure 2.

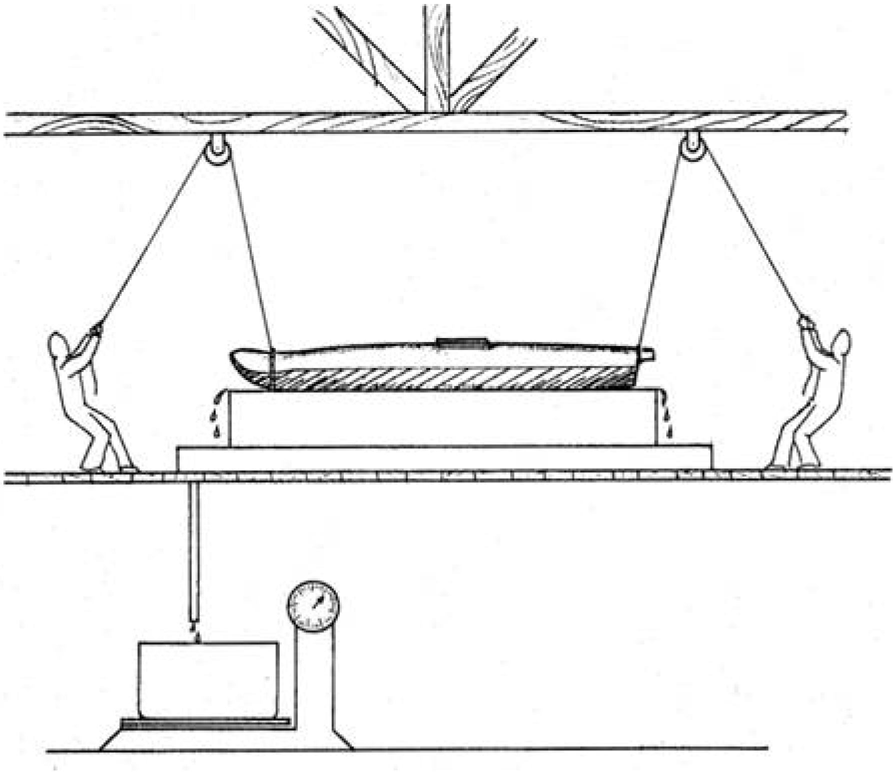

Figure 2 Archimedes principle, the simulation program accomplishes mathematically what the above does mechanically

The boat is held by vertical ropes attached to the bow and stern. The ropes, run through pulleys, can be slacked off to lower the boat. Equate this to figure 1 where the baseline or datum line is equivalent to the water surface in the horse trough. We slowly lower the boat to the surface of the water measuring its vertical travel from the starting position. After it is lowered a little into the water we stop and collect any water that spilled over the side of the tank. We weigh the water and compare it to the weight of the boat which we found previously by putting it on a scale. We find that the boat weighs more than the water so we lower the boat just a little more and add the new water spilled to the amount we had before. Again we compare it to the boat’s weight and again find that the water weighs less than the boat. We lower the boat a little more and go through the whole procedure as many times as necessary until the weight of the water, spilled over the top equals the weight of the boat. It would seem, from Archimedes, principle, that we are now in equilibrium and the boat will stay where it is without the ropes attached to the bow and stern. As you suspected, however, there is more to it than that, but let’s first see what we have found out.

In the simulation program we mathematically collected and weighed the spilled water by looking at given waterlines on the boat as we lowered it. In other words, we assumed or assigned a waterline and then checked to see if it was correct by computing the volume of that part of the hull that was below the water. Calculating this volume in liters and knowing that one liter equals one kilogram made it simple to compute the weight of water that would fill this volume.

But back to our boat which is part in and part out of the tank. If we let loose the bow and stern ropes we would be in trouble. The boat's bow would rise and the stern fall because the boat was originally suspended from the ceiling with the bow too low. Perfect trim of the boat is achieved when we can let go of the ropes and the boat will not move in any direction. On our boat under test, we have to raise the bow and lower the stern. How much of each is determined by moments.

Mathematically we get the boat into proper trim by finding the center of balance of the whole boat out of the water. This is called the longitudinal center of gravity (LCG). It is the point somewhere between the bow and stern around which all the boat's weight is acting. We take this position, measured in cm from the bow, and multiply it by the weight of the boat. This is the boat's moment. Similarly we take the total underwater volume of the boat as it now sits in the water and compute its longitudinal center of gravity. The distance of this point, measured from the bow, is multiplied by the weight of the amount of water what would fill the underwater part of the hull. This is the moment of the water displaced by the underwater hull. If this moment is equal to the boat moment, then trim is achieved, the ropes can be loosed and the boat will remain stationary in the water. If the moments are unequal, as in our example where the bow is too low, the water moment is less than the boat moment and we must raise the bow, pivoting the boat about its longitudinal center of gravity. This causes the underwater hull volume to be shifted towards the stern. Again we compute the water moment. Because the distance of the underwater hull volumes center (called the, longitudinal center of buoyancy) is increased, the moment will be greater and after repeated increments, eventually the moments will be equal. At this point the whole system is in static equilibrium. The see/saw is balanced. This assumes, of course, that all parts of the deck or tops of the hull sides are still above water and the boat is floating.

Now we know where the waterline is and can draw it in on a profile drawing of a museum specimen as in figure 1. All this without the boat ever having been out of the storeroom or off the drawing board.

The next question we want to ask is what happens to the waterline when a ton of fish is placed in the cockpit or two dead seals are tied on the after deck? Going back to our example boat, we take it out of the water, place the weights where we want them and again lower it into the tank computing new centers of gravity and buoyancy and moments until the boat is again in perfect trim. The computer program assumes that if excess weight is added such that the bow or stern are under water, the craft, is sunk and the trial is aborted. Up to ten different weights per trial and up to twenty trials are accepted by the program for any one boat. The last major question to be solved by the computer concerns the stability characteristics of the boat. Imagine yourself standing on the gunwale of a canoe. The force of your weight trying to capsize the boat is far greater than the buoyancy force trying to keep the canoe upright and you know the result. Quantitatively, we want to know the buoyancy force, called the righting moment (expressed in meter kilograms), when the boat is heeled over a given number of degrees. The greater the righting moment, the greater the stability of the craft. When the righting moment becomes negative, the boat is in a capsize condition.

In the simulation program, the boat is tilted or heeled around a transverse section through the longitudinal center of gravity and it is assumed that the trim previously calculated does not change for different degrees of heel.

Figure 3 shows the stability data for a typical Bering Sea kayak. Column 2 contains the data for the kayak and kayaker heeled over at 1°, 10° and every 10° up to 90°. Looking at the row under each angle of heel labeled “righting moment (m kg)” we see that this, figure is greatest at 20° of heel and that at 50° of heel the righting moment is negative and the kayak is capsizing. Column 4 data is for two people in the cockpit back to back. Since their vertical center of gravity is higher than for one kayaker, they are less stable and reach capsize condition at about 40° of heel. Column 5 data is for one kayaker, one seal inside and forward of the cockpit, and one seal inside and aft of the cockpit. All this low weight tends to put the center of gravity lower than for the kayaker alone and the craft, while also unstable at 50°, has greater righting moments at 10° and 40°.

The waterlines for this kayak are all given in figure 4 along with the specific load conditions. The loads are added by specifying their weight and location in the boat measured from the bow. The program assumes that the center of gravity of a paddler is 26 cm above the bottom of the hull and 7 cm forward of where the kayaker is sitting. This latter measurement accounts for the kayakers legs being straight out in front of him. Any inside cargo is assumed to have its center of gravity 10 cm above the hull bottom. Deck cargo, human or otherwise, is assumed to have a center of gravity 10 cm above the deck.

Figure 5 shows the computer output for the boat documentation and some details of the test runs. Hull displacement is the weight of the amount of water that would completely fill the inside of the hull up to the deck or sheer line. Although data may be input in either English or metric units, the program converts most of it to metric for purposes of internal calculations and output.

The actual hull measurements, often called a table of offsets, are illustrated in figure 6 for the sample Bering Sea kayak. They consist of *x* and *y* coordinates for cross sections of the kayak at specified distances from the bow. The *x* corresponds to half breadths and the *y* to heights above baseline in a typical boat plan table of offsets. The, computed area of these cross sections is given in square centimeters.

The last page of program output is shown in figure 7. Each numbered column refers t the loading conditions given in figure 4. Column 1 is the kayak by itself, 2 is the kayak and kayaker, 3 is a kayaker weighing 120 lbs. and so forth. Two interesting and related rows in this figure are the speed in knots and the wetted surface area. The theoretical or hull speed of a self propelled displacement boat varies directly with the waterline length of the hull A long waterline boat should go faster than a shorter boat As a boat approaches this hull speed it is trying to climb its own bow wave and for the kayaker, it is an, uphill battle. For small boats there must be a major increase in waterline length before the hull speed increases appreciably. The real limiting factor for small boats is the amount of wetted surface area which directly influences the frictional resistance. Hull designs that keep the wetted surface area low will be easier to paddle for long periods than one with a higher area, everything else, being equal.

The row titled pounds per inch immersion indicates how much weight may be put in the boat that will depress a given waterline one inch. In our example Bering Sea kayak in figure 7, we note that for column 2, the kayak and kayaker, it will take 87 pounds (if it were located at the center of gravity) to settle the boat another inch into the water.

Figure 8 is a sample coding form as made up for the Bering Sea kayak. While the Fortran program itself is stored on disk, the input is on punched cards. An explanation of how to code the various fields on the coding form may be, found in the appendix.

The Kayak Research

In the table of comparative data from the simulation program, figure 9, it is important to keep in, mind that there are many questions we could ask that only make sense in a contextual way. If we wanted to know which kayak was the most stable, we should also specify the environmental conditions under which it was used, the skill of the kayaker in that area, and what sort of hunting and fishing was taking place. For example, most of the eastern arctic kayak types, i.e., E. Hudson Bay, H/D Straits, Cumberland Peninsula, and N. Baffin Island, are stable to between 50° and 60° while the South and East Greenland types are initially unstable, that is, they have a negative righting moment at 1° of heel. The contextual difference is that the Canadian Inuit relied on broad stable flat bottomed kayaks that could carry killed game on the after deck. They also constructed the cockpit coaming to be higher in the front than in back to keep waves out of the kayak. The Greenlanders, however, sealed themselves into their, kayaks so they became a single unit, often towed their game, and developed over two dozen roll techniques in case of capsize. These capsizes could be the result of an accident or they might be done on purpose when they wanted to escape the force of a breaking wave. These were two different solutions to the basic problem of hunting and retrieving marine mammals in a seaworthy craft.

Both the Koryak and Aleut hunted sea mammals from very crank craft and neither developed capsize recovery techniques. They both achieved acceptable stability, however, by carrying rock ballast in the boat to lower the center of gravity. In addition, the Aleut carried water in inflated bladders or skin containers. These could be emptied of water and filled with air and then tucked into the bow and stern to act as a buoyancy bag in case the kayak cover was torn or otherwise holed.

Hunters pursuing sea mammal relied on stealth rather than speed to capture their quarry, unlike the people who hunted caribou crossing inland lakes and rivers. The latter’s kayaks had to be long, narrow and almost round bottomed to achieve maximum speed for successful pursuit of the fast swimming caribou. This was accomplished at the expense of poor stability. The Caribou Eskimo kayaks are fine examples of this type. The Copper, Netsilik, Pt. Barrow and Nunamiut Eskimo kayaks were also used mainly for this activity.

The Mackenzie Eskimo kayaks are also initially unstable, but they were used more extensively, to pursue white whales in a community hunt on the Mackenzie River than to hunt caribou. There are other interesting design features of the Mackenzie kayak that raise questions about the origin of these people and some other uses of their kayaks. Unfortunately, the Mackenzie Eskimo became culturally extinct shortly after 1903 when they were hard hit by European diseases and it is no longer possible to conduct field research on these questions.

A detailed analysis of the data for each different kayak type is beyond the scope of this paper but is being incorporated into a future book on the subject. It would be instructive to tank test a reproduction of each kayak type to determine the residual resistance, a factor that cannot be mathematically computed. It is the resistance of an object moving through the water other than that due to the wetted surface area. It is determined by towing the boat at a given speed and measuring the amount of force necessary to maintain that speed. The frictional resistance is subtracted from the test figure and the remainder is the residual resistance. I have been able to test a reproduction of an east coast Hudson Bay kayak and found that it took 8 pounds (3.6 kg) of force to tow it at 5 knots with a load of 150 pounds (68 kg) in the cockpit. This compares to 75 pounds (34 kg) of force necessary to move a scuba diver at 5 knots. The kayak, almost 22 feet long (670.6 cm), is obviously a very efficient means of water transport. How this resistance figure compares with other kayaks is again beyond the scope of this paper.

Conclusions

One of the results of this computer study is that it makes many formerly obscure ethnographic statements quite reasonable and understandable. For example, an Aleut, proscription against dumping ballast overboard in stormy conditions even though loaded down with game now makes sense. Rock ballast kept the center of gravity lower in the kayak than did dead, sea otters and the craft was more safely operated.

Another example displacement with the waterline up at the deck level (hull displacement in figure 5) provides a maximum figure for loading the kayak. That is, the weight of the kayak, plus the kayaker, plus a cargo of dead seals, for instance, must be less than this hull displacement figure. The displacement to sheer (Disp. to Sheer) amount for the third kayak down in figure 9 is 114.3 kg, an average man of 68 kg (150 lbs.) and a dead seal of 68 kg together weigh more than this figure. The conclusion is that the Koryak user of this kayak had to tow back any game killed as the weight of it in or on the boat would have caused a capsize or sinking.

These are just two examples of the use of the computer data in verifying, both positively and negatively, the ethnographic accounts, of people and lifestyles long disappeared. Statistical analysis of the comparative data could shed some light on similarities and differences of design related to movements of people and ideas.

While I have used the computer program specifically for the study of kayaks, it could be used with little or no modification on canoes, dugouts and almost any small displacement vessel. The lines and weight of a craft are basically all that are necessary for a computer analysis. The program needs a computer with a Fortran compiler and 140 KB of memory.

Anyone interested in using this program may contact me at the National Museum of Man, Ottawa K1A OM8 for further information.

Table Set 1A

Collection				Disp.to		
Type Number	Length	Beam	Weight	Sheer	LWL	VCG
Koryak MEP 11413	322.50	71.00	19.20	235.50	284.60	29.70
Koryak AMNH 70-3358	270.30	64.30	30.00	128.00	245.00	21.50
Koryak MAE 956-49	258.50	72.00	15.00	114.30	242.20	27.70
Chukchi EMS 1880.4.1255	462.70	62.90	20.00	316.70	420.90	28.60
Chukchi MEP 2083-61A	489.50	49.40	12.20	254.90	452.80	27.20
Aleut-l BM PE.10	528.30	49.50	20.00	292.20	482.90	24.20
Aleut-1 USNM 76282	539.70	50.80	15.40	300.80	468.20	23.70
Aleut-1 MAE 593-76	581.40	43.40	27.00	251.50	527.10	27.00
Aleut-1 IN 2-14886	509.50	51.70	12.00	275.20	460.40	27.20
Aleut-2 USNM 160336	629.00	55.90	15.80	444.50	581.10	28.70
Kodiak-1 DNM 160	434.00	65.50	20.00	279.40	411.20	24.10
Kodiak-2 WSHS N/N	596.40	74.90	36.30	477.50	544.30	23.70
Bristol Bay USNM 76285	459.70	73.70	30.00	315.60	440.00	21.60
Nunivak USNM 160341	455.90	76.20	30.00	346.90	389.00	22.00
Hooper Bay NMM IV-E-1071	460.70	78.00	25.00	370.10	410.10	28.20
Norton Sound BM PE.9	511.80	64.80	18.10	353.70	436.80	27.50
Norton Sound USNM 160175	517.70	59.70	30.00	306.40	472.80	22.00
Norton Sound LM 2-1674	522.70	71.80	40.40	342.90	457.10	22.10

Table Set 1B

Collection				Disp.to		
Type Number	Length	Beam	Weight	Sheer	LWL	VCG
King Island USNM 160326	467.40	64.80	15.50	236.40	387.60	25.20
Bering Strait DNM Hb.221	442.00	58.60	15.90	246.40	358.10	24.00
N Alaska R UPM Xl	291.50	59.00	11.30	178.20	255.50	25.70
Pt. Barrow IM 2-6349	525.60	47.80	12.20	283.40	463.90	25.50
Nunamiut UAM UA72-78-1	585.50	59.60	13.50	408.70	514.60	26.40
Mackenzie MAI N/N	487.70	48.50	30.00	286.20	435.80	22.40
Mackenzie DNM P31:64a	443.40	49.40	15.00	253.90	391.90	26.60
Mackenzie NMM IV-D-2039	501.00	48.20	20.00	282.90	438.20	23.10
Mackenzie NMM IV-D-1058	388.50	48.00	15.00	225.00	344.40	24.20
Copper 14V IV-D-1057	711.20	40.10	20.00	305.80	643.20	22.60
Netsilik NMM IV-C-708	615.90	45.70	16.30	306.40	562.90	23.20
Caribou BM 4:1900/2:11	588.00	53.10	18.10	379.20	415.70	25.70
Caribou BM 4:1900/1:11	735.30	46.00	30.00	422.70	556.00	28.40
Caribou NMM Acc.76/13/87	596.90	45.70	13.20	331.60	485.50	24.20
E Hudson B. NMM 77/22/1	487.70	74.90	27.20	350.00	338.60	22.70
E Hudson B. NMM IV-B-743	548.60	70.60	29.50	455.00	438.60	22.00
E Hudson B. NMM IV-B-744	709.90	71.10	54.00	684.50	584.30	20.90
E Hudson B. NMM IV-X-705	563.90	72.40	40.80	600.00	395.10	22.10
H/D Straits MAI N/N	685.80	63.50	34.00	534.90	573.40	21.80
H/D Straits USNM 160346	665.50	59.20	27.20	432.30	471.00	23.00

Table Set 1C

Collection				Disp.to		
Type Number	Length	Beam	Weight	Sheer	LWL	VCG
H/D Strait NMM IV-B-1620	777.20	67.30	64.90	650.00	615.30	20.20
H/D Straits (f) MAI N/N	732.30	59.20	34.00	452.90	569.50	18.20
H/D Strait NMM IV-B-1445	449.60	64.30	20.40	253.30	364.00	22.60
Cumb. Pen. NMM IV-X-96	401.30	63.50	25.40	340.90	312.00	22.80
Davis St. NMM IV-C-4550	614.70	67.30	33.10	422.50	446.60	22.10
N Baffin RSM UC 765.1	542.30	59.20	34.00	315.90	408.50	23.70
Iglulik NMM IV-C-4094	657.90	70.60	31.80	463.40	507.50	23.20
Polar USNM 160388	518.20	56.10	22.70	330.60	461.50	22.60
Polar (f) MAI 18/6541	490.20	55.90	30.00	304.80	404.70	22.70
Upernavik Ken Taylor	504.80	53.20	30.00	214.60	411.70	22.10
Disko Bay BM PE.3	535.30	47.30	30.00	178.40	452.50	22.00
Disko Bay CUM Z.15360	499.10	51.10	18.10	198.00	401.50	25.70
S Greenland BM AM.10	585.50	43.40	18.10	165.80	461.20	30.90
E Greenland RGS N/N	566.40	48.30	18.10	175 6	438.20	24.60
Gantock Single (modern)	487.70	58.40	14.50	234.40	394.50	24.00
Umiak, N. Alaska	895.10	179.00	136.00	4900.00	619.70	33.70
Umiak, W. Coast Alaska	631.20	146.00	136.00	2009.00	525.80	27.60
Sharpie	1013.50	244.00	1772.00	9413.00	803.40	46.70
Sharpie, N. Carolina	610.90	173.00	771.00	2622.00	495.80	29.80

Table Set 2A

Collection Type Number	LCG	CP	Speed	Speed / Length	Wet Surface Area	Frictional Res.
Koryak MEP 11413	169.40	0.52	3.80	1.60	1.30	1.90
Koryak AMNH 70-3358	128.90	0.62	3.50	1.80	1.30	1.70
Koryak MAE 956-49	142.20	0.53	3.50	1.80	1.20	1.50
Chukchi EMS 1880.4.1255	229.10	0.53	4.60	1.40	1.70	3.30
Chukchi MEP 2083-61A	244.70	0.81	4.80	1.30	1.60	3.40
Aleut-l BM PE.10	301.30	0.65	5.00	1.30	1.80	3.90
Aleut-1 USNM 76282	300.00	0.59	4.90	1.30	1.60	3.50
Aleut-1 MAE 593-76	330.40	0.55	5.20	1.20	1.80	4.30
Aleut-1 IN 2-14886	283.70	0.50	4.90	1.30	1.60	3.50
Aleut-2 USNM 160336	334.60	0.57	5.50	1.20	2.50	6.50
Kodiak-1 DNM 160	235.60	0.62	4.60	1.40	1.70	3.30
Kodiak-2 WSHS N/N	329.10	0.54	5.30	1.20	2.70	6.70
Bristol Bay USNM 76285	234.10	0.59	4.70	1.30	1.80	3.60
Nunivak USNM 160341	225.80	0.63	4.50	1.40	1.70	3.20
Hooper Bay NMM IV-E-1071	238.10	0.69	4.60	1.40	1.60	3.10
Norton Sound BM PE.9	269.00	0.56	4.70	1.30	1.60	3.30
Norton Sound USNM 160175	277.20	0.60	4.90	1.30	1.70	3.70
Norton Sound LM 2-1674	281.70	0.57	4.80	1.30	1.80	3.80

Table Set 2B

Collection Type Number	LCG	CP	Speed	Speed / Length	Wet Surface Area	Frictional Res.
King Island USNM 160326	251.50	0.60	4.50	1.40	1.40	2.50
Bering Strait DNM Hb.221	246.60	0.61	4.30	1.50	1.40	2.50
N Alaska R UPM Xl	153.60	0.66	3.60	1.70	1.20	1.60
Pt. Barrow IM 2-6349	264.90	0.67	4.90	1.30	1.60	3.50
Nunamiut UAM UA72-78-1	294.00	0.71	5.10	1.20	1.90	4.40
Mackenzie MAI N/N	253.90	0.62	4.70	1.30	1.60	3.30
Mackenzie DNM P31:64a	241.20	0.61	4.50	1.40	1.40	2.60
Mackenzie NMM IV-D-2039	259.00	0.62	4.70	1.30	1.50	3.10
Mackenzie NMM IV-D-1058	214.70	0.61	4.20	1.50	1.30	2.30
Copper 14V IV-D-1057	413.50	0.85	5.70	1.10	2.00	5.80
Netsilik NMM IV-C-708	367.40	0.63	5.40	1.20	1.90	4.90
Caribou BM 4:1900/2:11	276.90	0.58	4.60	1.40	1.60	3.10
Caribou BM 4:1900/1:11	375.70	0.69	5.30	1.20	1.90	4.80
Caribou NMM Acc.76/13/87	328.70	0.67	5.00	1.30	1.60	3.60
E Hudson B. NMM 77/22/1	280.90	0.64	4.20	1.50	1.60	2.80
E Hudson B. NMM IV-B-743	298.90	0.69	4.70	1.30	2.00	4.20
E Hudson B. NMM IV-B-744	403.20	0.68	5.50	1.10	2.60	6.90
E Hudson B. NMM IV-X-705	325.10	0.72	4.50	1.40	2.20	4.10
H/D Straits MAI N/N	374.80	0.71	5.40	1.20	0.80	2.00
H/D Straits USNM 160346	372.10	0.55	4.90	1.30	1.90	4.20

Table Set 2C

				Speed	Wet	
Collection				/	Surface	Frictional
Type Number	LCG	CP	Speed	Length	Area	Res.
H/D Strait NMM IV-B-1620	430.90	0.63	5.60	1.10	2.80	7.90
H/D Straits (f) MAI N/N	419.20	0.57	5.40	1.20	2.20	5.60
H/D Strait NMM IV-B-1445	255.10	0.64	4.30	1.50	1.70	3.20
Cumb. Pen. NMM IV-X-96	225.60	0.69	4.00	1.60	1.70	2.80
Davis St. NMM IV-C-4550	351.70	0.61	4.80	1.30	2.10	4.30
N Baffin RSM UC 765.1	304.40	0.59	4.60	1.40	1.60	3.10
Iglulik NMM IV-C-4094	335.90	0.58	5.10	1.20	2.20	5.10
Polar USNM 160388	272.70	0.58	4.90	1.30	1.90	4.00
Polar (f) MAI 18/6541	268.80	0.59	4.60	1.40	1.80	3.40
Upernavik Ken Taylor	265.00	0.54	4.60	1.40	1.60	3.20
Disko Bay BM PE.3	277.70	0.54	4.80	1.30	1.60	3.40
Disko Bay CUM Z.15360	262.80	0.49	4.50	1.40	1.50	2.80
S Greenland BM AM.10	296.90	0.39	4.90	1.30	1.60	3.40
E Greenland RGS N/N	289.60	0.53	4.70	1.30	1.60	3.20
Gantock Single (modern)	227.90	0.52	4.50	1.40	1.60	2.90
Umiak, N. Alaska	460.60	0.55	5.60	1.10	4.10	11.50
Umiak, W. Coast Alaska	340.70	0.62	5.20	1.20	4.50	10.80
Sharpie	472.50	0.55	6.40	1.00	13.?	41.?
Sharpie, N. Carolina	291.50	0.54	5.00	1.20	7.10	16.10

Table Set 3A

	Righting Moment at						
Collection	Degrees of Heel						
Type Number	1.00	10.00	20.00	30.00	40.00	50.00	60.00
Koryak MEP 11413	0.40	2.10	3.30	3.20	1.20	-1.90	
Koryak AMNH 70-3358	0.40	1.40	-2.00				
Koryak MAE 956-49	0.40	2.00	1.30	-0.40			
Chukchi EMS 1880.4.1255	0.04	0.40	0.80	0.70	0.90	-0.50	
Chukchi MEP 2083-61A	0.10	0.10	0.20	0.10	-0.90		
Aleut-l BM PE.10	0.02	0.20	-1.10				
Aleut-1 USNM 76282	0.04	0.40	0.90	0.80	-0.50		
Aleut-1 MAE 593-76	-0.04						
Aleut-1 IN 2-14886	0.03	0.30	0.40	-0.60			
Aleut-2 USNM 160336	0.10	0.70	1.10	-1.40			
Kodiak-1 DNM 160	0.30	2.50	4.70	6.00	5.10	3.00	-1.10
Kodiak-2 WSHS N/N	0.80	8.00	13.20	12.10	7.20	0.50	-7.00
Bristol Bay USNM 76285	0.30	2.50	5.20	4.90	2.60	-1.70	
Nunivak USNM 160341	0.30	3.10	6.40	5.30	2.20	-0.90	
Hooper Bay NMM IV-E-1071	0.20	1.60	3.50	3.10	1.40	-21.3	
Norton Sound BM PE.9	0.10	0.60	1.30	1.30	0.01	-2.30	
Norton Sound USNM 160175	0.03	0.40	1.20	2.90	-0.60		
Norton Sound LM 2-1674	0.20	2.20	5.30	4.40	1.90	-****	

Table Set 3B

	Righting Moment at						
Collection	Degrees of Heel						
Type Number	1.00	10.00	20.00	30.00	40.00	50.00	60.00
King Island USNM 160326	0.03	0.40	1.40	0.70	-1.00		
Bering Strait DNM Hb.221	0.00	0.03	0.40	1.30	-0.90		
N Alaska R UPM Xl	0.10	1.20	2.00	1.30	-0.90		
Pt. Barrow IM 2-6349	0.00	0.10	-0.10				
Nunamiut UAM UA72-78-1	0.10	1.30	1.30	2.50	2.00	0.02	-3.80
Mackenzie MAI N/N	-0.02	-0.10	0.20	-0.70			
Mackenzie DNM P31:64a	-0.10						
Mackenzie NMM IV-D-2039	-0.03						
Mackenzie NMM IV-D-1058	-0.03						
Copper 14V IV-D-1057	-0.10						
Netsilik NMM IV-C-708	0.02	0.30	0.50	-0.20			
Caribou BM 4:1900/2:11	0.02	0.10	0.10	0.10	-1.00		
Caribou BM 4:1900/1:11	-0.10						
Caribou NMM Acc.76/13/87	-0.03						
E Hudson B. NMM 77/22/1	0.30	2.90	4.40	5.30	2.50	-1.70	
E Hudson B. NMM IV-B-743	0.40	4.00	6.30	8.00	4.70	1.10	-2.10
E Hudson B. NMM IV-B-744	0.40	4.30	7.80	10.30	8.10	4.60	1.60
E Hudson B. NMM IV-X-705	0.40	3.90	6.70	9.30	0.40	-5.10	
H/D Straits MAI N/N	0.90	5.50	11.10	9.20	4.50	0.10	-0.90
H/D Straits USNM 160346	0.20	2.10	2.60	4.40	2.40	-0.90	

Table Set 3C

	Righting Moment at						
Collection	Degrees of Heel						
Type Number	1.00	10.00	20.00	30.00	40.00	50.00	60.00
H/D Strait NMM IV-B-1620	0.50	5.40	8.30	10.50	5.90	1.20	-4.00
H/D Straits (f) MAI N/N	0.40	2.90	6.20	6.40	6.20	7.40	2.60
H/D Strait NMM IV-B-1445	0.20	2.20	2.80	1.70	-1.90		
Cumb. Pen. NMM IV-X-96	0.30	2.80	4.10	5.30	3.60	0.60	-3.00
Davis St. NMM IV-C-4550	0.50	4.30	6.40	7.00	4.80	0.70	-4.00
N Baffin RSM UC 765.1	0.20	1.60	3.00	2.90	1.20	-1.50	-4.20
Iglulik NMM IV-C-4094	0.40	4.20	5.80	7.00	5.00	0.90	
Polar USNM 160388							
Polar (f) MAI 18/6541							
Upernavik Ken Taylor	0.8	1.6	0.5	-1.6			
Disko Bay BM PE.3							
Disko Bay CUM Z.15360							
S Greenland BM AM.10							
E Greenland RGS N/N							
Gantock Single (modern)	0.10	1.10	0.50	0.20	-2.00		
Umiak, N. Alaska	2.00	20.90	44.20	66.40	30.30	-****	
Umiak, W. Coast Alaska	4.00	42.50	101.20	78.70	54.30	-314.7	
Sharpie	17.00	33.50	23.70	12.90	0.30	-11.40	
Sharpie, N. Carolina	8.80	91.20	149.60	171.00	125.00	56.20	-36.80