TWSBA
TEACHING WITH SMALL BOATS ALLIANCE

Teaching with Small Boats Alliance Conference 2017

April 26-29, 2017

Chesapeake Bay Maritme Museum

St. Michaels, Md.

Lofting and Measurements

The Boatbuilding Process from Line Drawing over Table of Offsets to Full Size Lofting, and the Learning Opportunities We Encounter in many Steps

Inka Petersen

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Measurements and Lofting

After the consideration of all important measurements of the vessel, and the initial measuring while setting up the lofting, there is not much measuring left in the lofting process…

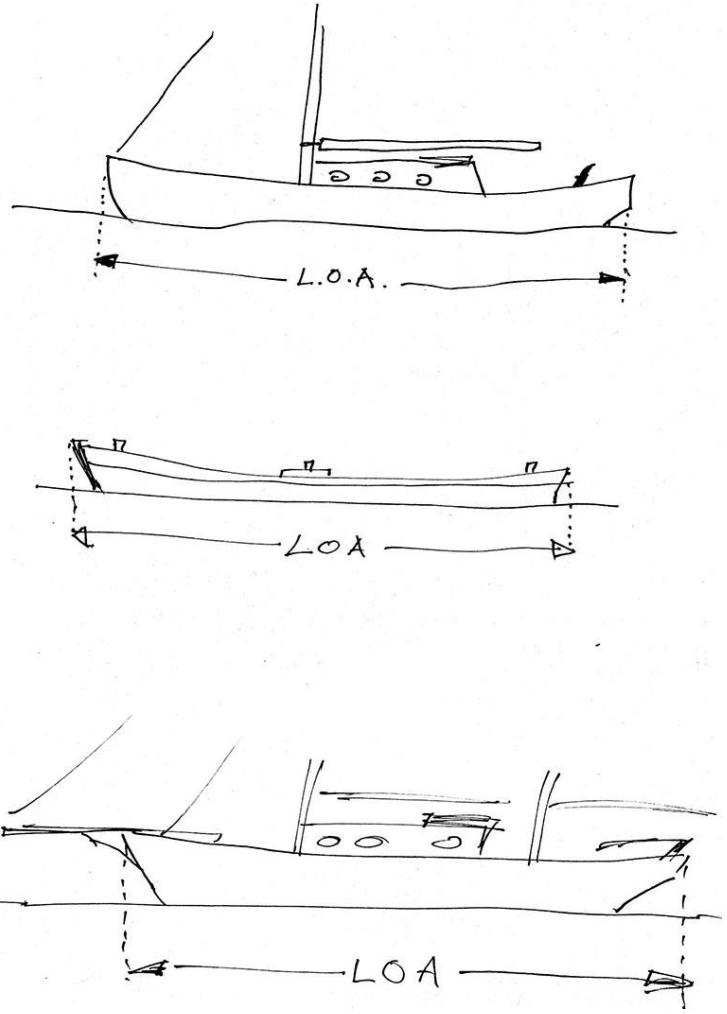
What Measurements Define a Boat?

Measurements that define a boat

LOA - length over all

Measurements that define a boat

LOA - length over all



Measurements that define a boat

Beam – width of the vessel at its widest part

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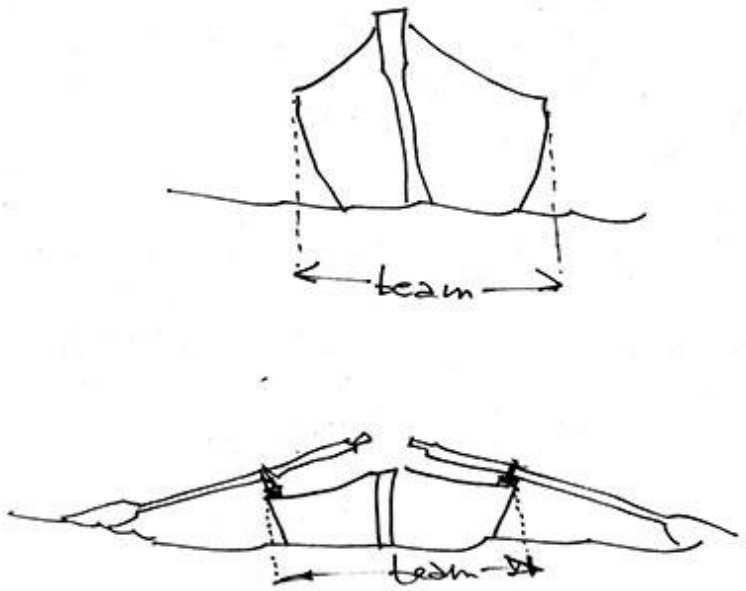

Measurements that define a boat

Draft (or Draught) – depth of the underwater part of the boat from the waterline down to the deepest point

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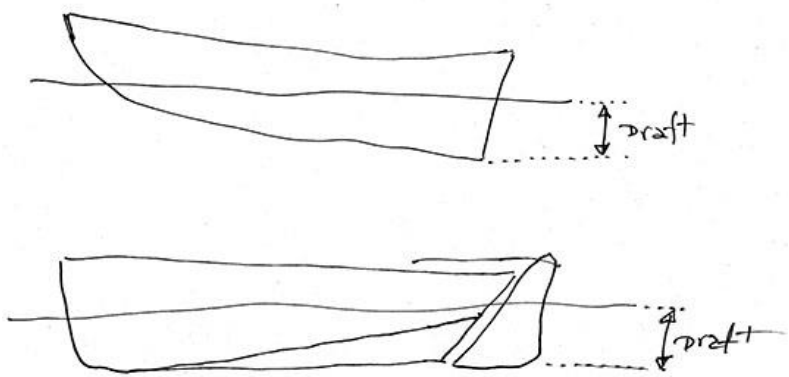


Measurements that define a boat

Displacement /Tonnage

The weight of the vessel as measured in the weight of the water it displaces.

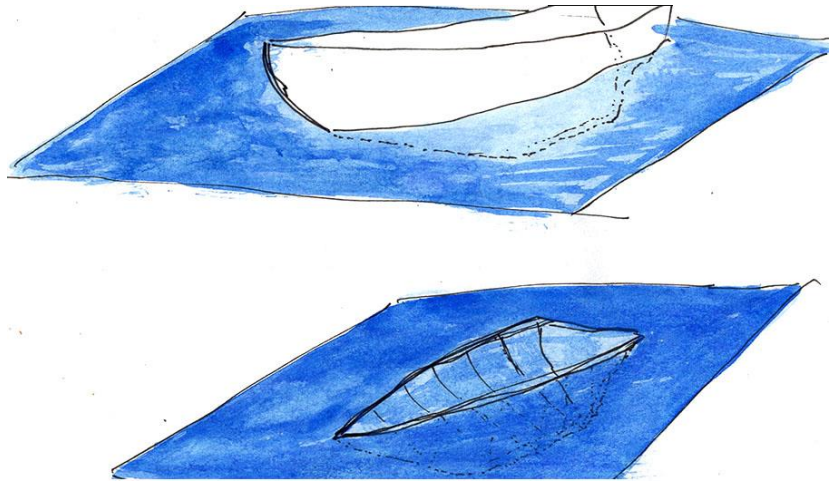
This usually goes for bigger boats with “displacement hulls” or ships.

Figure out the cubic feet of water displaced by the vessel (the volume of the hole in the water made by the boat)
multiply these by the weight of water

64lbs/ft^3 for salt water
62.43 lbs/ft^3 for fresh water

in metric this would be

1027kg/m^3 salty
1000kg or 1metric ton/m^3 fresh



Teaching Opportunity

Volume Calculation

Calculating the volume of the odd underwater shape of a boat can be a fun exercise.
(think Prism)

More about this once we know how to read a line drawing…

Teaching Opportunity

Metric Conversion

We know:
1l freshwater =1000cm^3 =1kg
1ft = 30.48 cm

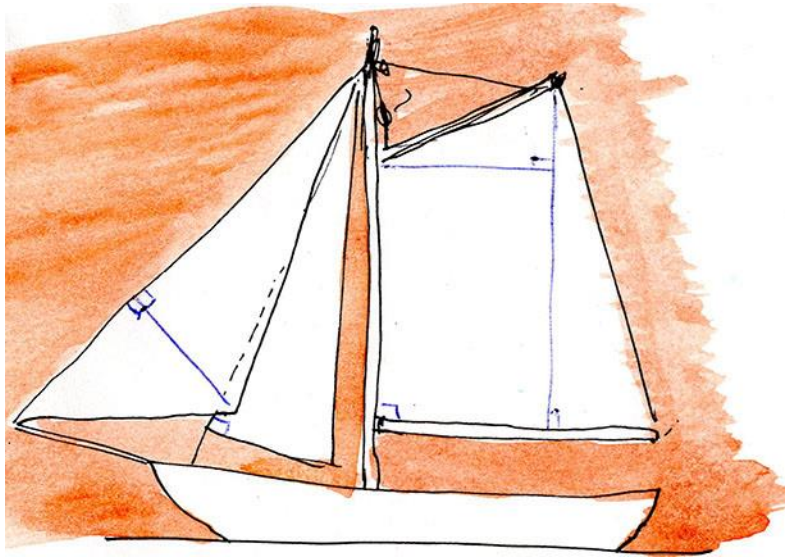
$1ft^3$=1ft x 1ft x 1ft =
30.48cm x 30.48cm x 30.48cm =
28,316.8466 cm^3

divided by 1000 to convert to liters
(knowing that 1l = 1kg, and 1000cm^3=
10cm x 10cm x 10cm = 1l)
we get 28.317kg

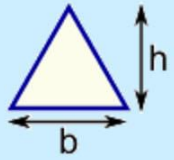
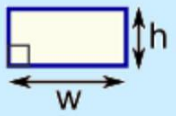
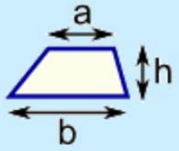
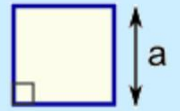
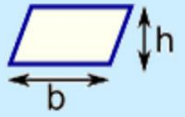
1kg=2.205lbs
ergo: our cubic ft of fresh water weighs 62.43lbs

Measurements that define a boat

Sail Area
The sail area is measured in square ft (ft^2)



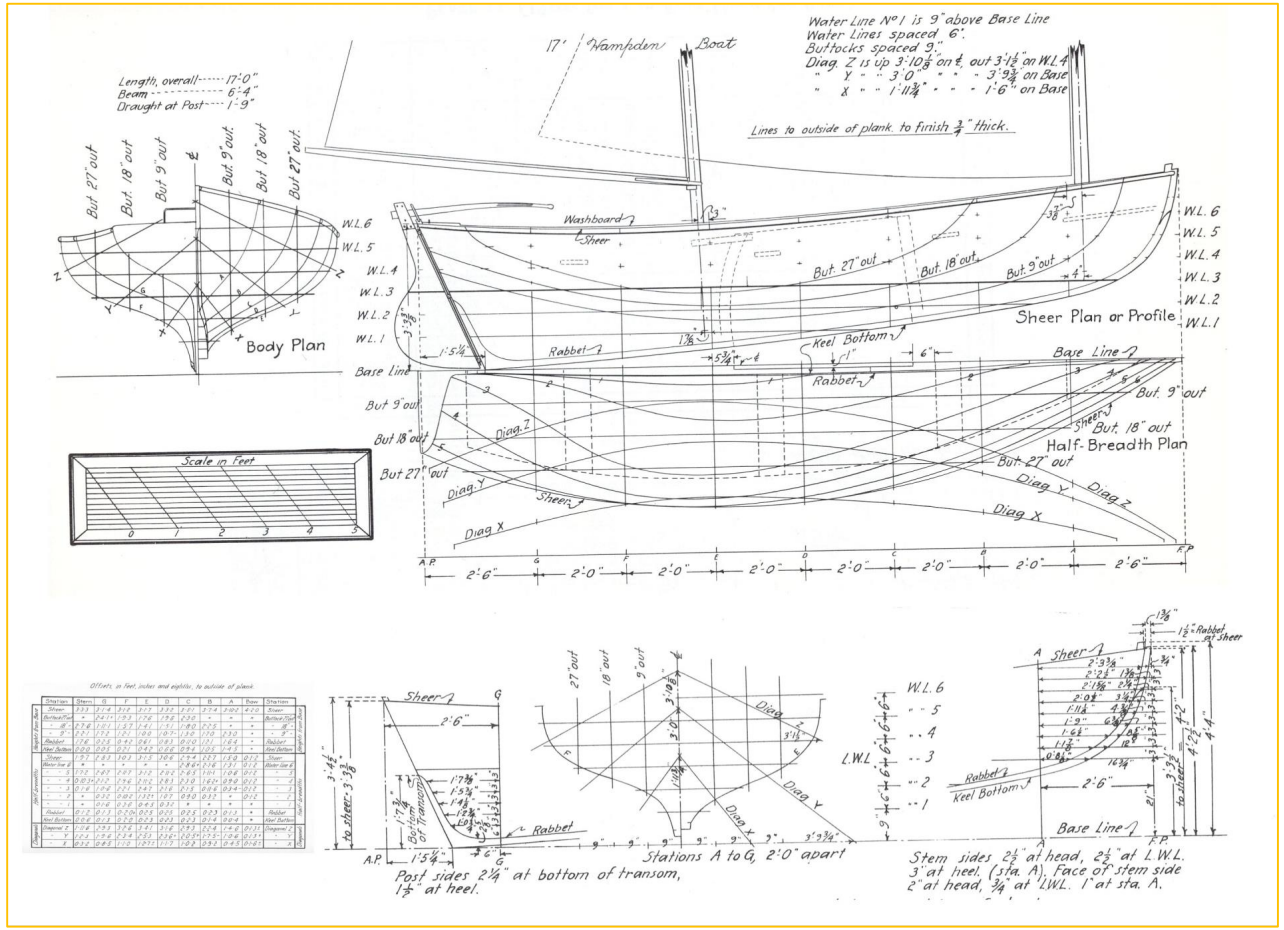
Teaching Opportunity
Area Calculations

	Triangle Area = ½ × b × h b = base h = vertical height
	Rectangle Area = w × h w = width h = height
	Trapezoid (US) Trapezium (UK) Area = ½(a+b) × h h = vertical height
	Square Area = a^2 a = length of side
	Parallelogram Area = b × h b = base h = vertical height

A Set of Plans

After picking a design to build, the designer will provide (or you will purchase/receive) a set of plans, also called lines. This includes the following:

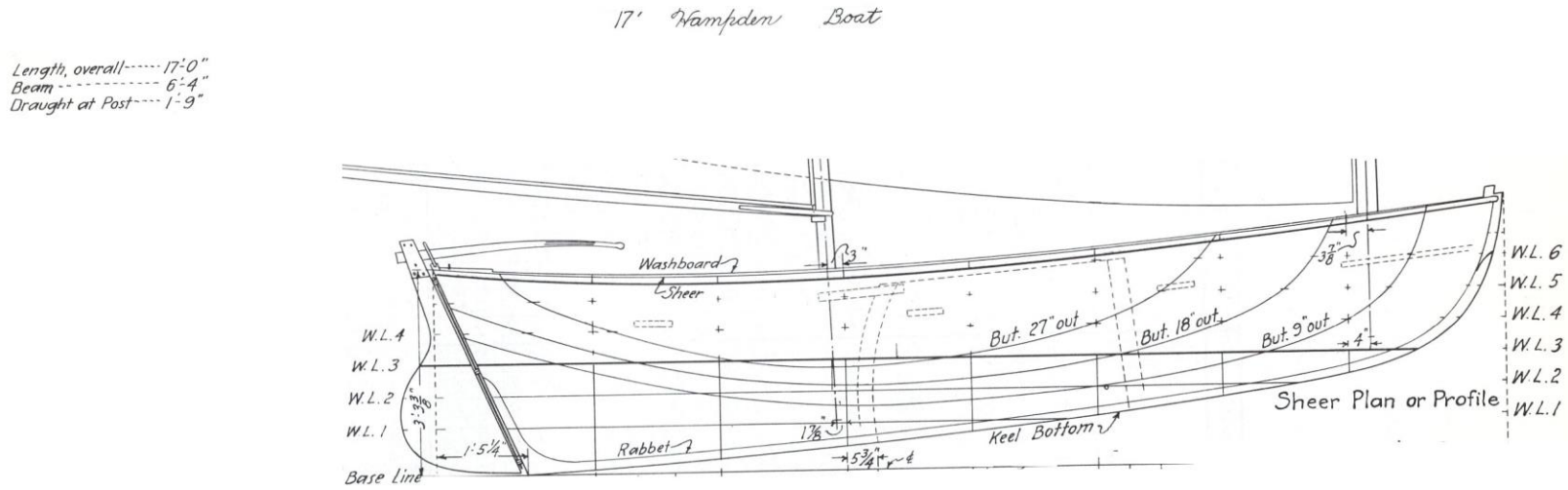
- the sheer plan or profile
- the body plan
- the half-breadth plan with diagonals
- bow and stern/transom detail measurements
- a measuring schedule for distances and positions of lines
- a statement of scale
- a table of offsets



Howard I. Chapelle's plan of a 17' Hampden Boat which he used to teach lofting

What are we building?

What are the defining measurements?



Sheer Plan or Profile

Line drawing of the boat as seen from the side.

Horizontal lines: *Base line, water lines, LWL (load water line)*
Vertical lines: *Perpendiculars* or *Stations*
Shaped lines: *Sheer* (as part of the *Profile*), *Buttocks*

Note: some designers use the LWL as base line and count waterlines above and below

Teaching Opportunity

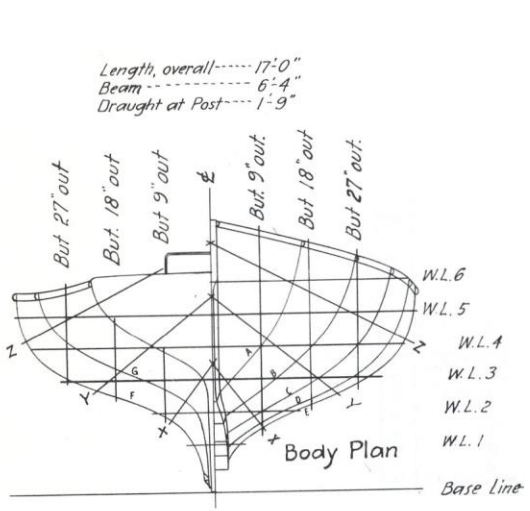
Understanding parallel, perpendicular

Lines are **parallel** if they are always the same distance apart (called "**equidistant**"), and will never meet. (They also point in the same direction). Just remember:

Always the same distance apart and never touching.

Perpendicular:

At **right angle** (90°)



Teaching Opportunity

Point, Line, Plane and Solid

*A **Point** has no dimensions, only position*
*A **Line** is one-dimensional*
*A **Plane** is two dimensional (2D)*
*A **Solid** is three-dimensional (3D)*

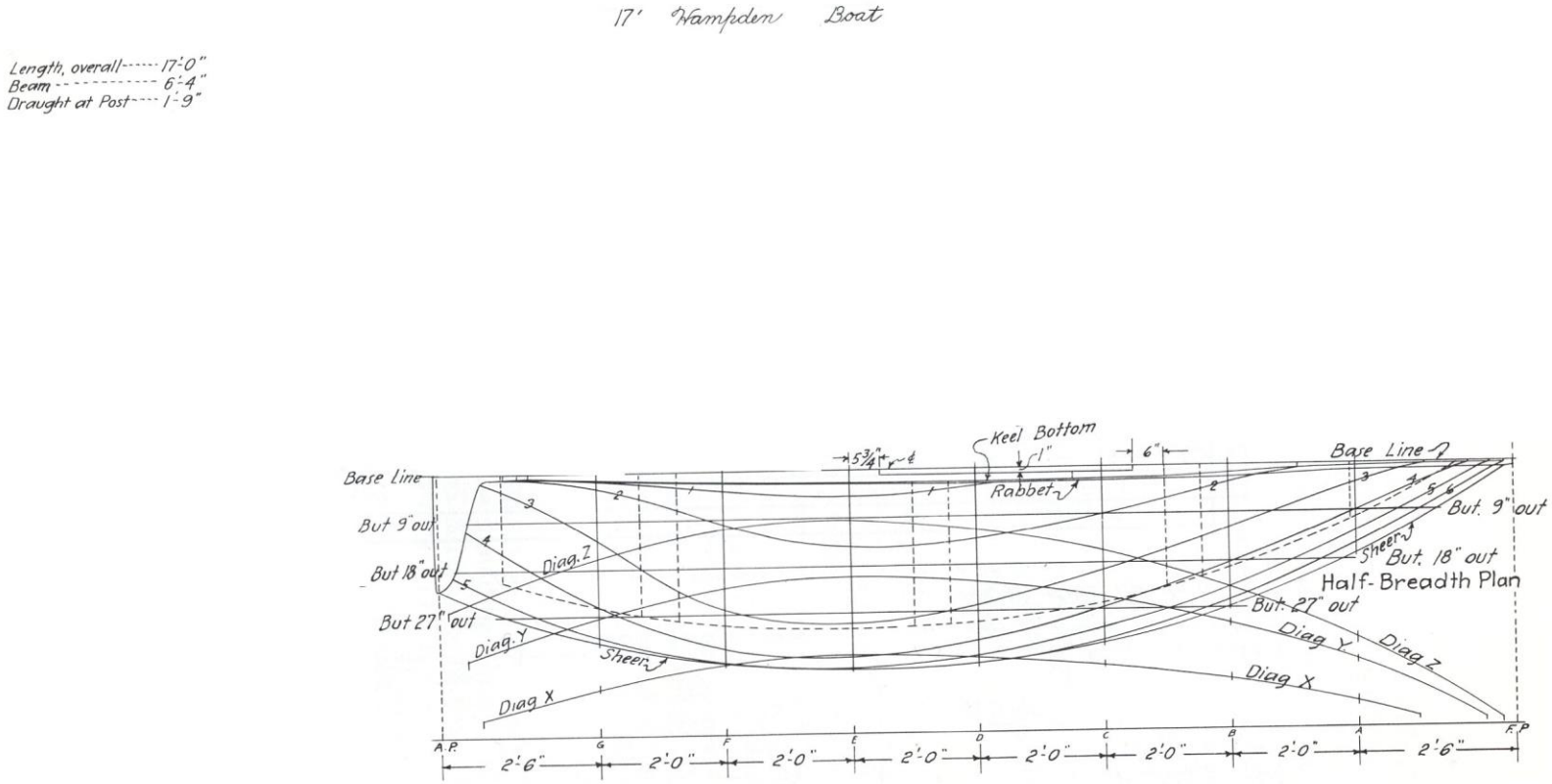
Teaching Opportunity

Symmetry

***Line Symmetry** or **Mirror** or **Reflection Symmetry** is the simplest kind, because one half is the reflection of the other half.*

Body Plan

Line drawing of the boat as seen from the front to the widest beam (on the right side), and from the back to the widest beam (on the left side.)
Horizontal lines: *Base line, water lines, LWL* (load water line)
Vertical lines: *Center Line, Buttocks*
Shaped lines: *Sheer, Transom, Perpendiculars*
Diagonal lines: *Diagonals*



Half-Breadth Plan or Plan, and Diagonals

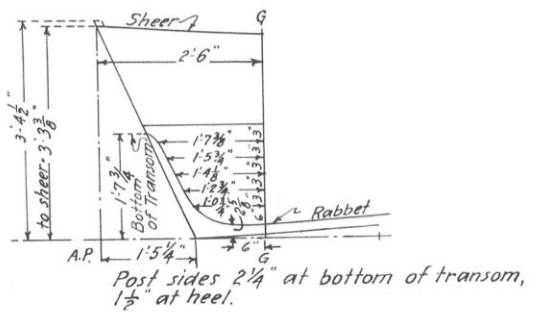
Line drawing of half the boat as seen from the bottom(or top),
Horizontal lines: *Base line=Center Line, Buttocks*
Vertical lines: *Perpendiculars*
Shaped lines: *Sheer, Transom, Water Lines*
And on a separate baseline: Diagonals

17' Hampden Boat

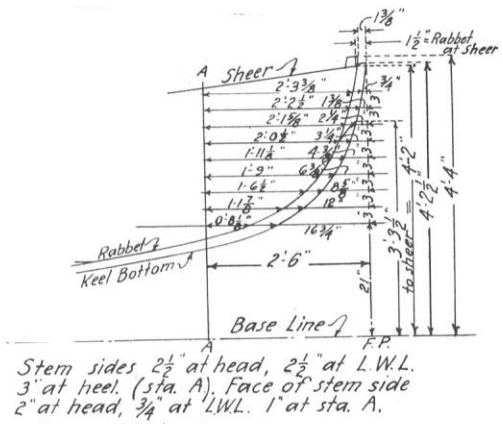
Length, overall------ 17'-0"
Beam ---------- 6'-4"
Draught at Post---- 1'-9"

Bow and Stern details

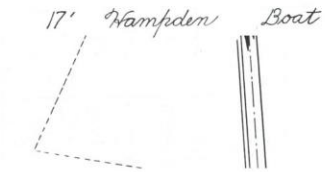
Here we find exact measurements from one of our horizontal or perpendicular lines to certain points, thus determining exactly the curvature of the bow, the placement of the rabbet, timber sizes, and the shape of the transom post.

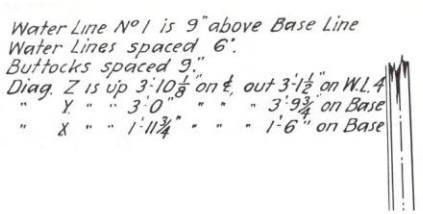


Post sides 2¼" at bottom of transom, 1½" at heel.



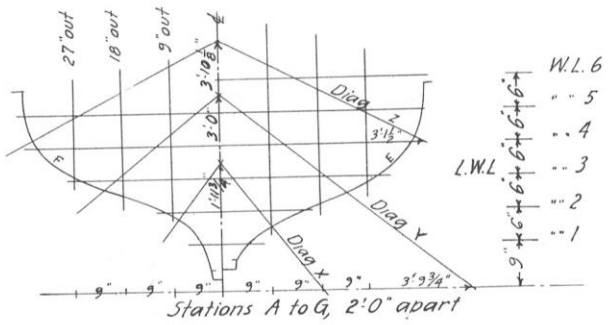
Stem sides 2½" at head, 2½" at L.W.L. 3" at heel. (sta. A). Face of stem side 2" at head, ¾" at L.W.L. 1" at sta. A.





Measuring Schedule

Here we find out exact distances between our lines and Base Line or Center Line, their spacing, and the starting and ending points of the diagonals



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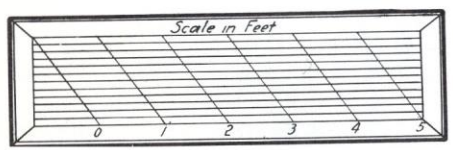
Teaching Opportunity

Scale, Ratio

A ratio is used in scale drawings of maps, charts, buildings, or boats: The scale of a drawing = Drawing Length : Actual Length



Statement of Scale

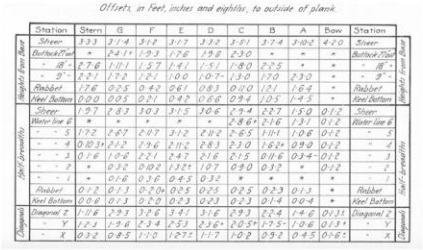
Sometimes it will just state a scale as a ratio, i.e.: 1:10
On most traditional plans it is written out, i.e.: "*One inch = 1 foot*"
But most often it will be drawn out, either on a line, in a bar, or in a box, like here, where we can easily see/measure up to 6 ft, but also have a reference for one inch. One can use dividers to take a measurement on the plan, then check on the scale box what that distance is. The Diagonal lines go from 0 to 12". The advantage of this kind of scale statement is obvious: even in an enlargement or smaller copy, the dimensions of the boat stay clear.

17' Hampden Boat

Length, overall------17'-0"
Beam ----------6'-4"
Draught at Post----1'-9"

Table of Offsets

-Way to small to see anything-



Offsets, in feet, inches and eighths, to outside of plank.

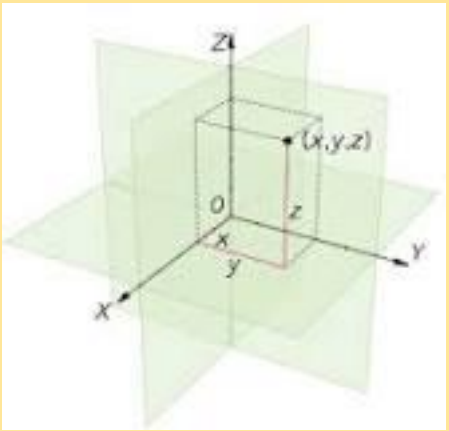
	Station	Stern	G	F	E	D	C	B	A	Bow	Station
Height from Base	Sheer	3-3 3	3-1 4	3-1 2	3-1 7	3-3 2	3-5 1	3-7 4	3-10 2	4-2 0	Sheer
	Buttock/Keel	*	2-4 1+	1-9 3	1-7 6	1-9 6	2-3 0	*	*	*	Buttock/Keel
	" 18"	2-7 6	1-11 1	1-5 7	1-4 1	1-5 1	1-8 0	2-2 5	*	*	" 18"
	" 9"	2-2 1	1-7 2	1-2 1	1-0 0	1-0 7+	1-3 0	1-7 0	2-3 0	*	" 9"
	Rabbet	1-7 6	0-2 5	0-4 2	0-6 1	0-8 3	0-11 0	1-2 1	1-6 4	*	Rabbet
	Keel Bottom	0-0 0	0-0 5	0-2 1	0-4 2	0-6 6	0-9 4	1-0 5	1-4 5	*	Keel Bottom
Half-breadths	Sheer	1-9 7	2-8 3	3-0 3	3-1 5	3-0 6	2-9 4	2-2 7	1-5 0	0-1 2	Sheer
	Water line 6	*	*	*	*	*	2-8 6+	2-1 6	1-3 1	0-1 2	Water line 6
	" 5	1-7 2	2-6 7	2-10 7	3-1 2	2-11 2	2-6 5	1-11 1	1-0 6	0-1 2	" 5
	" 4	0-10 3+	2-1 2	2-7 6	2-11 2	2-8 3	2-3 0	1-6 2+	0-9 0	0-1 2	" 4
	" 3	0-1 6	1-0 6	2-2 1	2-4 7	2-1 6	2-1 5	0-11 6	0-3 4	0-1 2	" 3
	" 2	*	0-3 2	0-10 2	1-3 2+	1-0 7	0-9 0	0-3 2	*	0-1 2	" 2
	" 1	*	0-1 6	0-3 6	0-6 5	0-3 2	*	*	*	*	" 1
	Rabbet	0-1 2	0-1 3	0-2 0+	0-2 5	0-2 5	0-2 5	0-2 3	0-1 3	*	Rabbet
	Keel Bottom	0-0 8	0-1 3	0-2 2	0-2 3	0-2 3	0-2 3	0-1 4	0-0 4	*	Keel Bottom
Diagonal	Diagonal Z	1-11 6	2-9 3	3-2 6	3-4 1	3-1 6	2-9 3	2-2 4	1-4 6	0-13 1	Diagonal Z
	" Y	1-2 3	1-9 6	2-3 4	2-5 3	2-3 6+	2-0 5+	1-7 5-	1-0 6	0-13+	" Y
	" X	0-3 2	0-8 5	1-1 0	1-2 7 ±	1-1 7	1-0 2	0-9 2	0-4 5	0-1 6 ±	" X

Diagonal — Half-breadths from Keel — Half-breadths from Base

Teaching Opportunity

Cartesian coordinate system/
Cartesian Plane

*A three dimensional Cartesian coordinate system, with origin O and **axis** lines X, Y and Z, oriented as shown by the arrows. The tick marks on the **axes** are one length unit apart. The black dot shows the point with coordinates x = 2, y = 3, and z = 4, or (2, 3, 4).*



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Draught at Post----1'-9"

Offsets, in Feet, inches and eighths, to outside of plank.

	Station	Stern	G	F	E	D	C	B	A	Bow	Station	
Heights from Base	Sheer	3-3-3	3-1-4	3-1-2	3-1-7	3-3-2	3-5-1	3-7-4	3-10-2	4-2-0	Sheer	Heights from Base
	Buttock 27" out	*	2-4-1+	1-9-3	1-7-6	1-9-6	2-3-0	*	*	*	Buttock 27" out	
	" 18" "	2-7-6	1-11-1	1-5-7	1-4-1	1-5-1	1-8-0	2-2-5	*	*	" 18" "	
	" 9" "	2-2-1	1-7-2	1-2-1	1-0-0	1-0-7-	1-3-0	1-7-0	2-3-0	*	" 9" "	
	Rabbet	1-7-6	0-2-5	0-4-2	0-6-1	0-8-3	0-11-0	1-2-1	1-6-4	*	Rabbet	
	Keel Bottom	0-0-0	0-0-5	0-2-1	0-4-2	0-6-6	0-9-4	1-0-5	1-4-5	*	Keel Bottom	
Half-breadths	Sheer	1-9-7	2-8-3	3-0-3	3-1-5	3-0-6	2-9-4	2-2-7	1-5-0	0-1-2	Sheer	Half-breadths
	Water line 6	*	*	*	*	*	2-8-6+	2-1-6	1-3-1	0-1-2	Water line 6	
	" " 5	1-7-2	2-6-7	2-11-7	3-1-2	2-11-2	2-6-5	1-11-1	1-0-6	0-1-2	" 5	
	" " 4	0-10-3+	2-1-2	2-9-6	2-11-2	2-8-3	2-3-0	1-6-2+	0-9-0	0-1-2	" 4	
	" " 3	0-1-6	1-0-6	2-2-1	2-4-7	2-1-6	2-1-5	0-11-6	0-3-4-	0-1-2	" 3	
	" " 2	*	0-3-2	0-10-2	1-3-2±	1-0-7	0-9-0	0-3-2	*	0-1-2	" 2	
	" " 1	*	0-1-6	0-3-6	0-4-5	0-3-2	*	*	*	*	" 1	
	Rabbet	0-1-2	0-1-3	0-2-0+	0-2-5	0-2-5	0-2-5	0-2-3	0-1-3	*	Rabbet	
	Keel Bottom	0-0-6	0-1-3	0-2-0	0-2-3	0-2-3	0-2-3	0-1-4	0-0-4	*	Keel Bottom	
Diagonals	Diagonal Z	1-11-6	2-9-3	3-2-6	3-4-1	3-1-6	2-9-3	2-2-4	1-4-6	0-1-3±	Diagonal Z	Diagonals
	" Y	1-2-3	1-9-6	2-3-4	2-5-3	2-3-6+	2-0-5+	1-7-5-	1-0-6	0-1-3+	" Y	
	" X	0-3-2	0-8-5	1-1-0	1-2-7±	1-1-7	1-0-2	0-9-2	0-4-5	0-1-6±	" X	

Table of Offsets

All points of intersection of lines from our 3 views are noted in the table of offsets. Once as Height (distance up from the base line), and once as Half-breadth (distance out from the center line.)

Measurements of Offsets are either in mm or look like this:

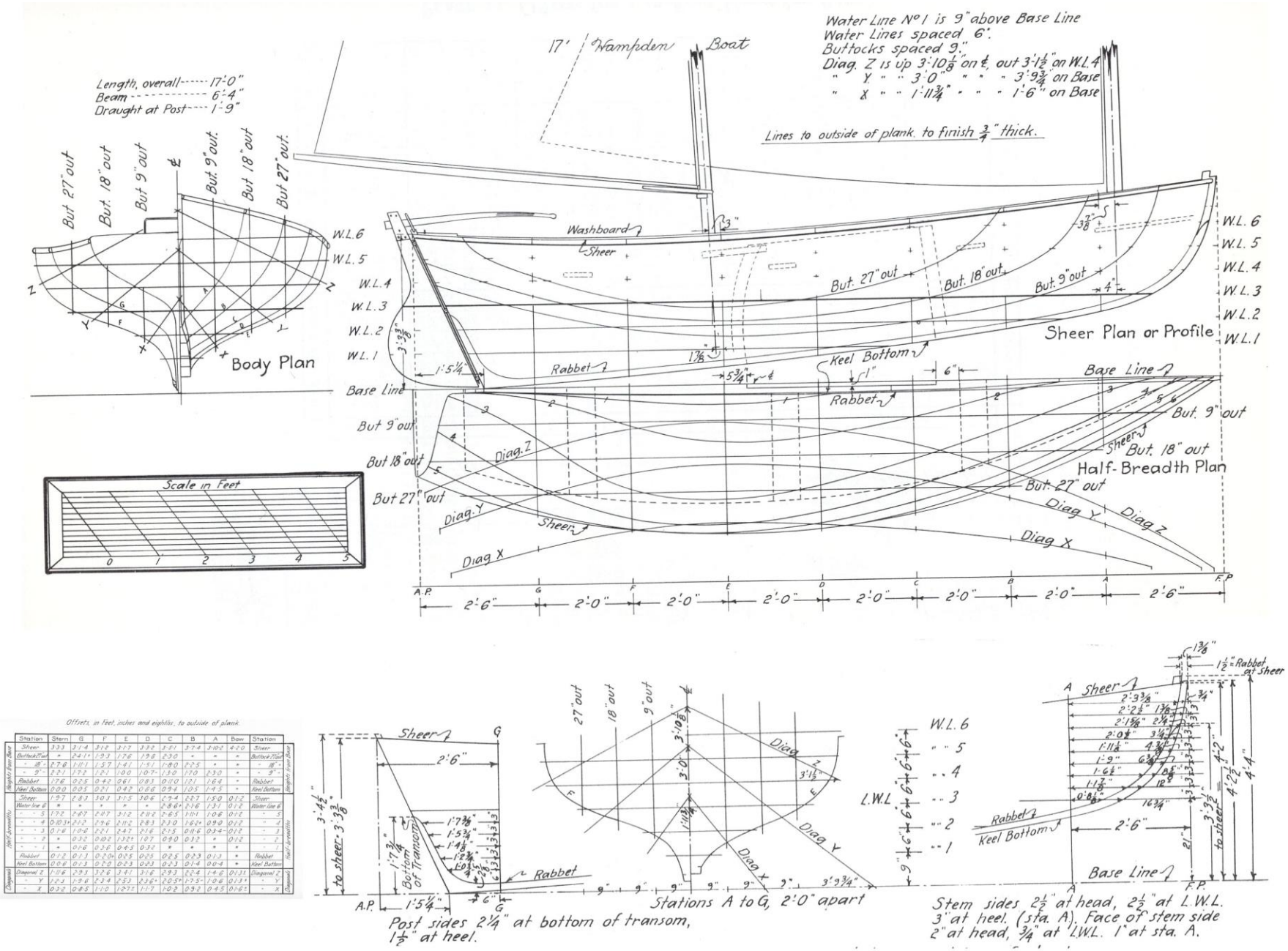
3 – 1 – 4 or 2 – 1 1 – 7 + or 1 – 2 – 6 ±

the first number represents ft, the second inches, and the last eights of inches
+, - or ± assumes 1/16" more/less/more or less

Teaching Opportunity

fraction conversion
i.e.: 4/8"= 1/2"
or
0–6–2+ = 6-5/16"

The Set of Plans
that now should
make sense to us



Offsets, in Feet, inches and eighths, to outside of plank.

	Station	Stern	G	F	E	D	C	B	A	Bow	Station
Height above Base Line	Sheer	3-3 3	3-1 4	3-1 2	3-1 7	3-3 2	3-5 1	3-7 4	3-10 2	4-2 0	Sheer
	Buttock Flat	*	2-4 1+	1-9 3	1-7 6	1-9 6	2-3 0	*	*	*	Buttock Flat
	" 18"	2-7 6	1-11 1	1-5 7	1-4 1	1-5 1	1-8 0	2-2 5	*	*	" 18"
	" 9"	2-2 1	1-7 2	1-2 1	1-0 0	1-0 7+	1-3 0	1-7 0	2-3 0	*	" 9"
	Rabbet	1-7 6	0-2 5	0-4 2	0-6 1	0-8 3	0-11 0	1-2 1	1-6 4	*	Rabbet
	Keel Bottom	0-0 0	0-0 5	0-2 1	0-4 2	0-6 6	0-9 4	1-0 5	1-4 5	*	Keel Bottom
Half-breadths	Sheer	1-9 7	2-8 3	3-0 3	3-1 5	3-0 6	2-9 4	2-2 7	1-5 0	0-1 2	Sheer
	Water line ℄	*	*	*	*	*	2-8 6+	2-1 6	1-3 1	0-1 2	Water line ℄
	" 5	1-7 2	2-6 7	2-10 7	3-1 2	2-11 2	2-6 5	1-11 1	1-0 6	0-1 2	" 5
	" 4	0-10 3+	2-1 2	2-7 6	2-11 2	2-8 3	2-3 0	1-6 2+	0-9 0	0-1 2	" 4
	" 3	0-1 6	1-0 6	1-7 1	2-2 1	2-4 7	2-1 6	1-1 5	0-11 6	0-3 4	" 3
	" 2	*	0-3 2	0-10 2	1-3 2+	1-10 7	0-9 0	0-3 2	*	0-1 2	" 2
	" 1	*	0-1 6	0-3 6	0-4 5	0-3 2	*	*	*	*	" 1
	Rabbet	0-1 2	0-1 3	0-2 0+	0-2 5	0-2 5	0-2 5	0-2 3	0-1 3	*	Rabbet
	Keel Bottom	0-0 6	0-1 3	0-2 2	0-2 3	0-2 3	0-2 3	0-1 4	0-0 4	*	Keel Bottom
Diagonals	Diagonal Z	1-11 6	2-9 3	3-2 6	3-4 1	3-1 6	2-9 3	2-2 4	1-4 6	0-1 3+	Diagonal Z
	" Y	1-2 3	1-9 6	2-3 4	2-5 3	2-3 6+	2-0 5+	1-7 5-	1-0 6	0-1 3+	" Y
	" X	0-3 2	0-8 5	1-1 0	1-2 7 ±	1-1 7	1-0 2	0-9 2	0-4 5	0-1 6 ±	" X

What is lofting?

Lofting is the transfer of a lines plan to a full size plan.

What is the Purpose of Lofting?

"Lofting the plans, that is, drawing them full size, is the foundation of good workmanship in building a boat[…]

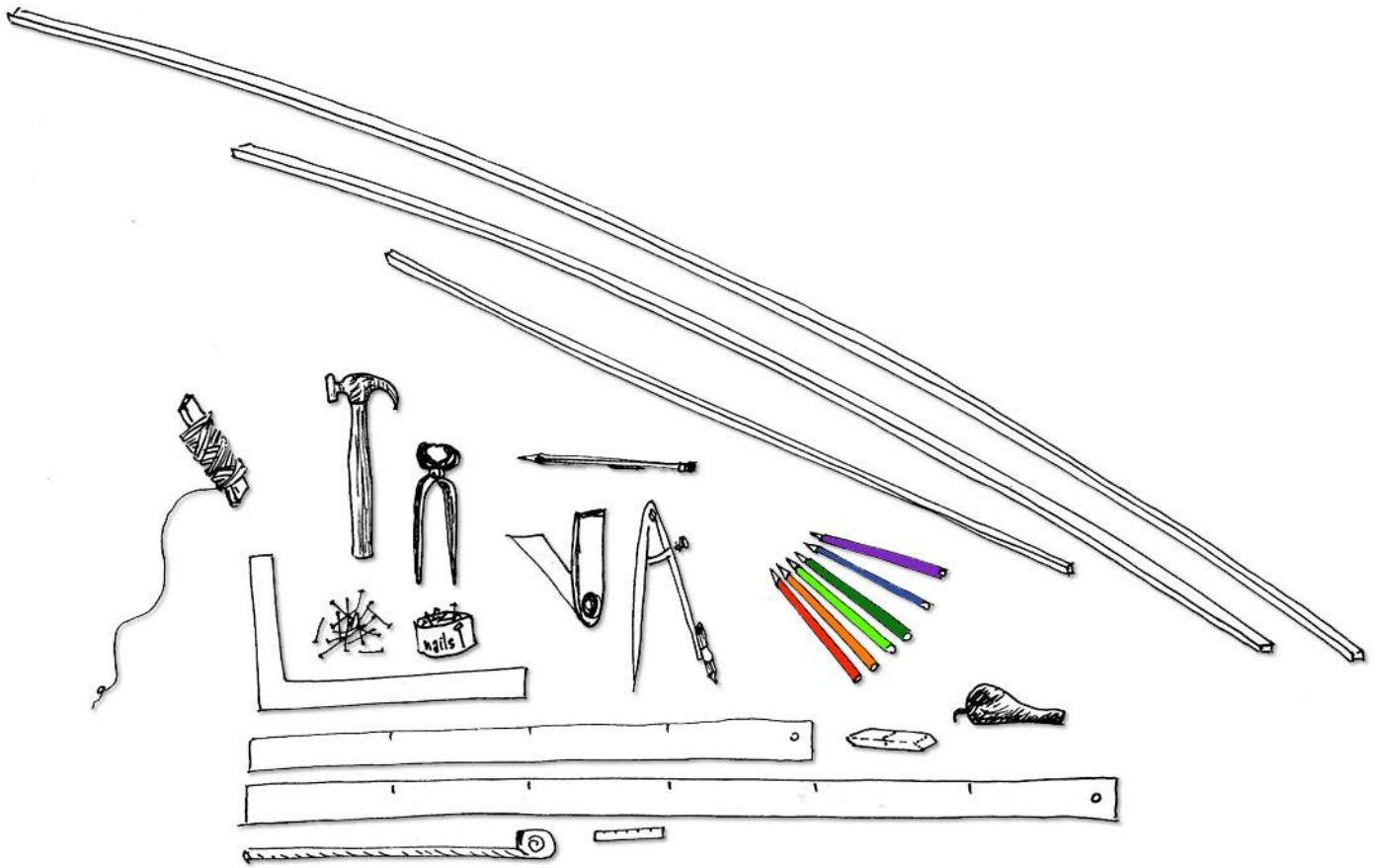
Making the full size drawings avoids much 'trying and filling', which represents a great saving in time and labor.

In the lofting of the plans the builder has an opportunity to preview the details of building before setting up the hull and this aids greatly in planning the required sequence of operations.[…]"

– Howard I. Chapelle*, Boatbuilding,* 1941

Start Lofting

Tools needed:
Battens, (colored) pencils, eraser, brush, straight edge, square, bevel gauge, compass, hammer, nippers, tape measure, string, nails/awls



Preparing the Lofting Floor

Teaching Opportunity

Parallel and Perpendicular

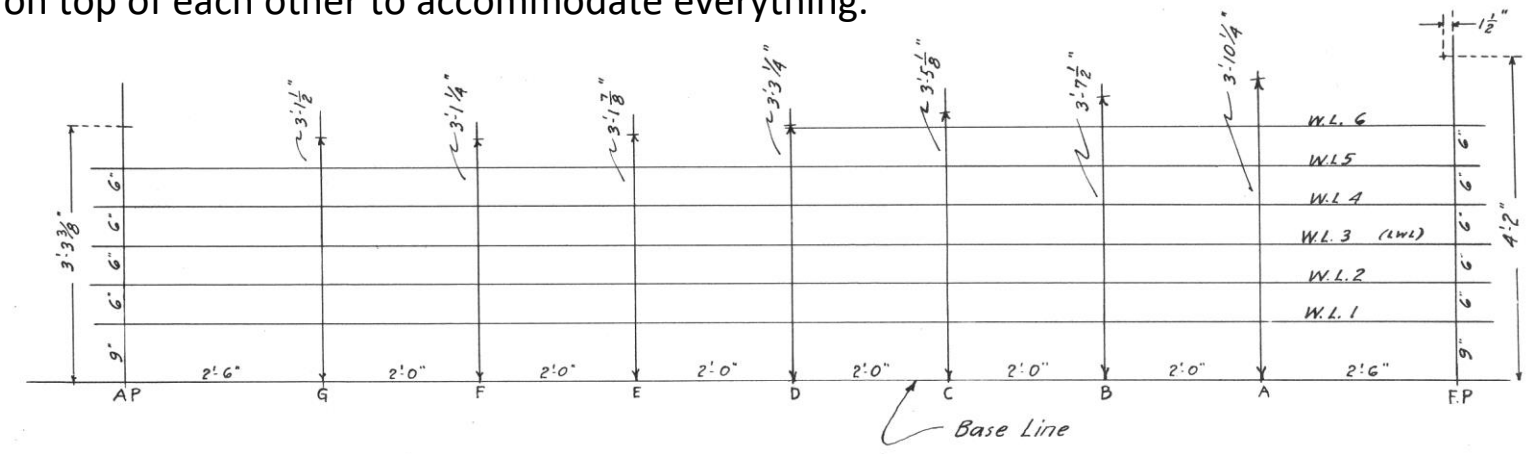
Reiteration of parallel lines by drawing them, making sure they are equidistant.

Introduce various ways of creating a right angle (square, compass, Equilateral or Isosceles Triangle)

The lofting floor needs to be big enough for us to be able to draw the entire boat full size, this means it needs to be at least a bit longer than the vessel, and a bit higher than highest freeboard and deepest draft combined. It is common to use plywood sheets and paint them white with primer. Sometimes they are screwed to a frame of 2x4s that are anchored to the floor. MDO plywood is a good material because it has smooth paper on it. The wood grain on regular plywood sometimes derails a thin pencil line.

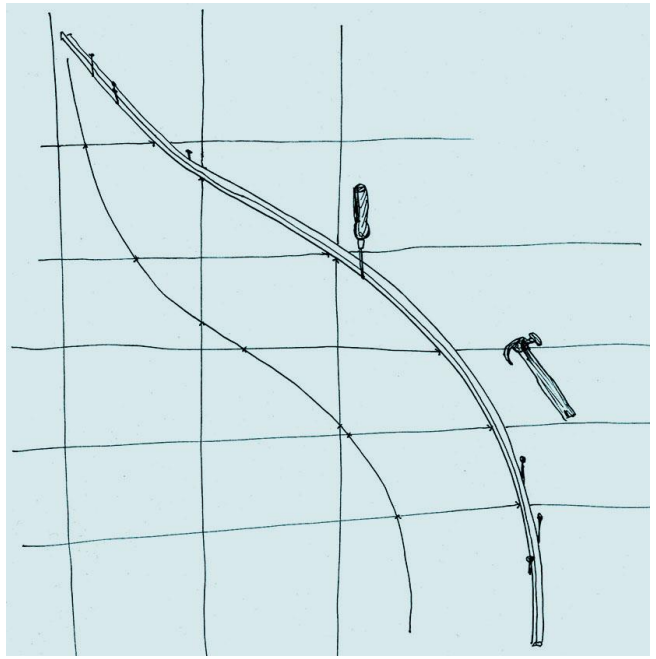
As opposed to the plans, where profile, body plan and half-breadth are often next to each other, on the lofting floor we put them on top of each other to accommodate everything.

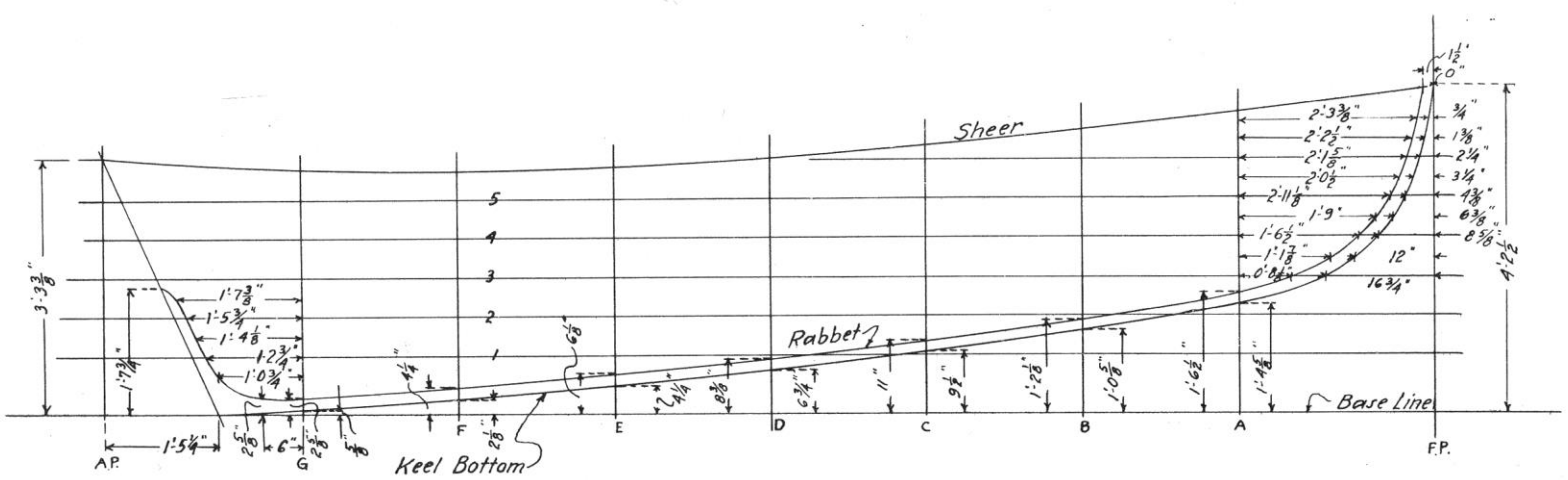
That's one reason I like to work with different colored pencils to be able to tell the lines apart.



Setting of Sheer and Profile

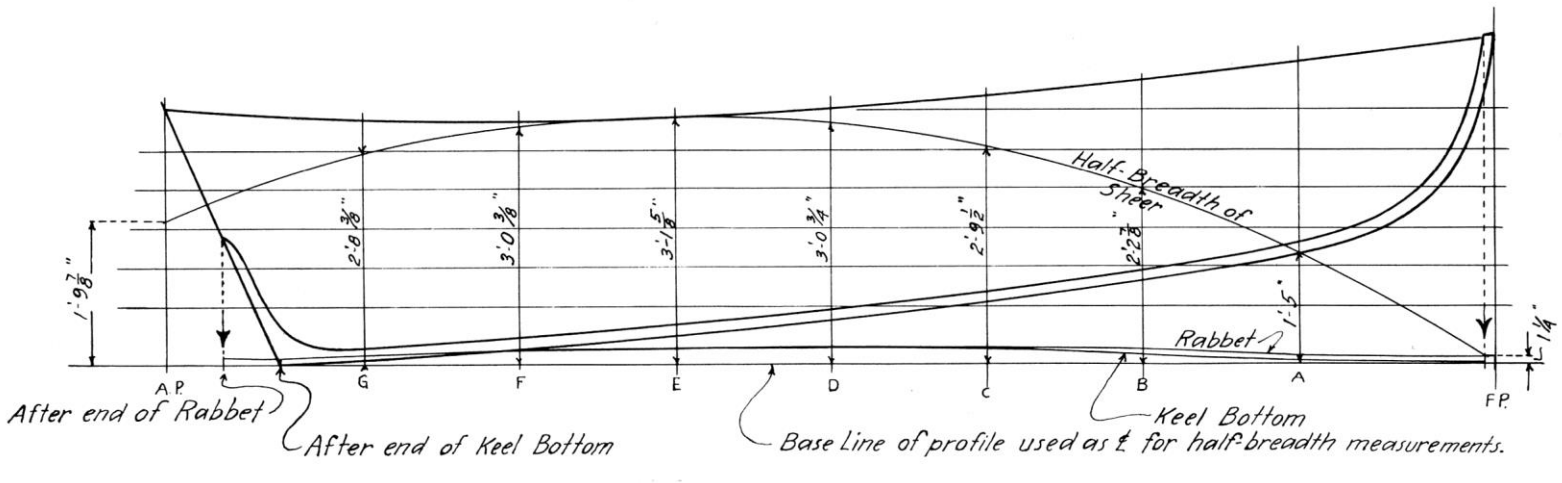
Using the data from the table of offsets we start marking our points for the sheer, and when that has been faired, the rest of the profile.





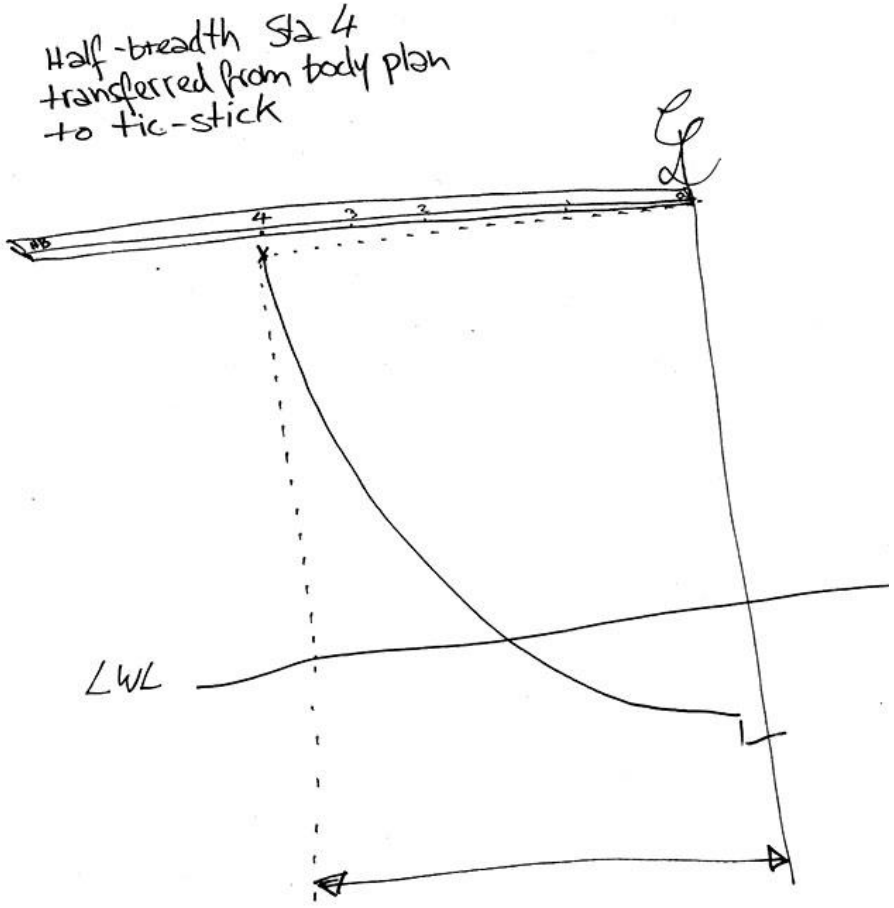
Setting of Half-Breadth

Again using the points from the Offsets, we draw in the points on the corresponding lines, connect, and fair them with a batten to the Half-Breadth of Sheer line.



Tool of the Trade: Tick -Stick

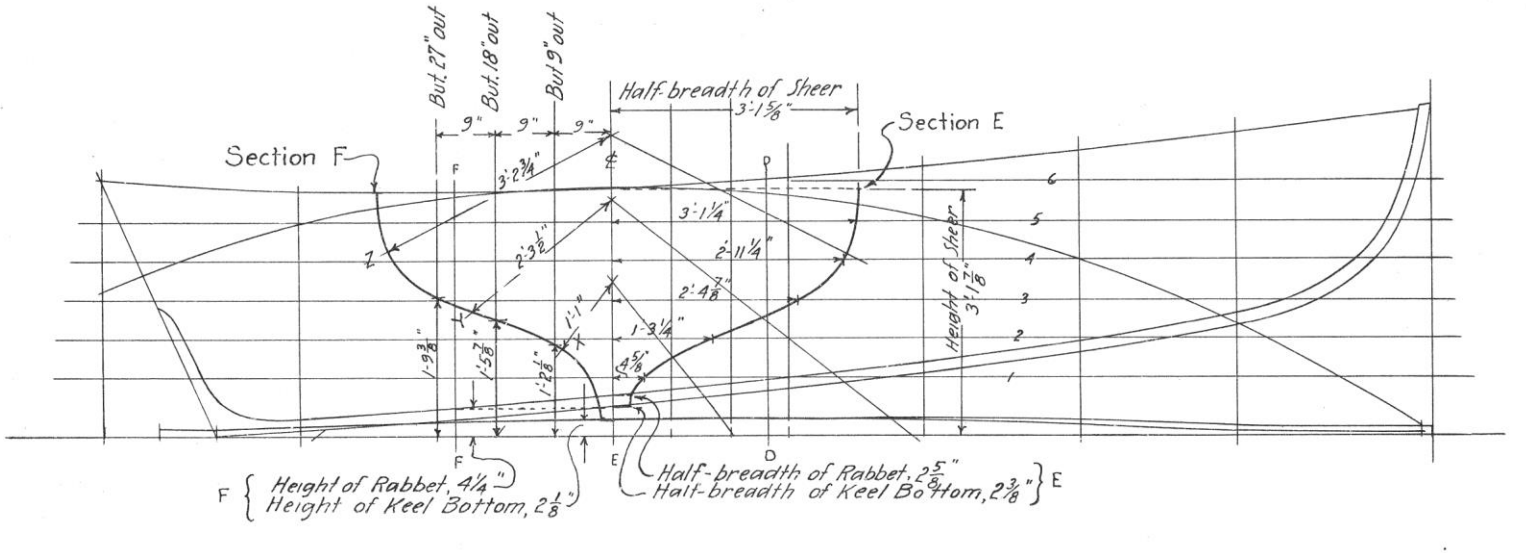
Also called Marking Staff.
Like every practical trades person, the lofting boat builder only measures when s/he must. The moment we have a distance established, we can simply transfer it to a stick and use that to transfer the same distance to the other plan. It is more accurate than a tape measure, and keeps numbers out of the creative head to stay clear for fairing and accuracy.



Body plan

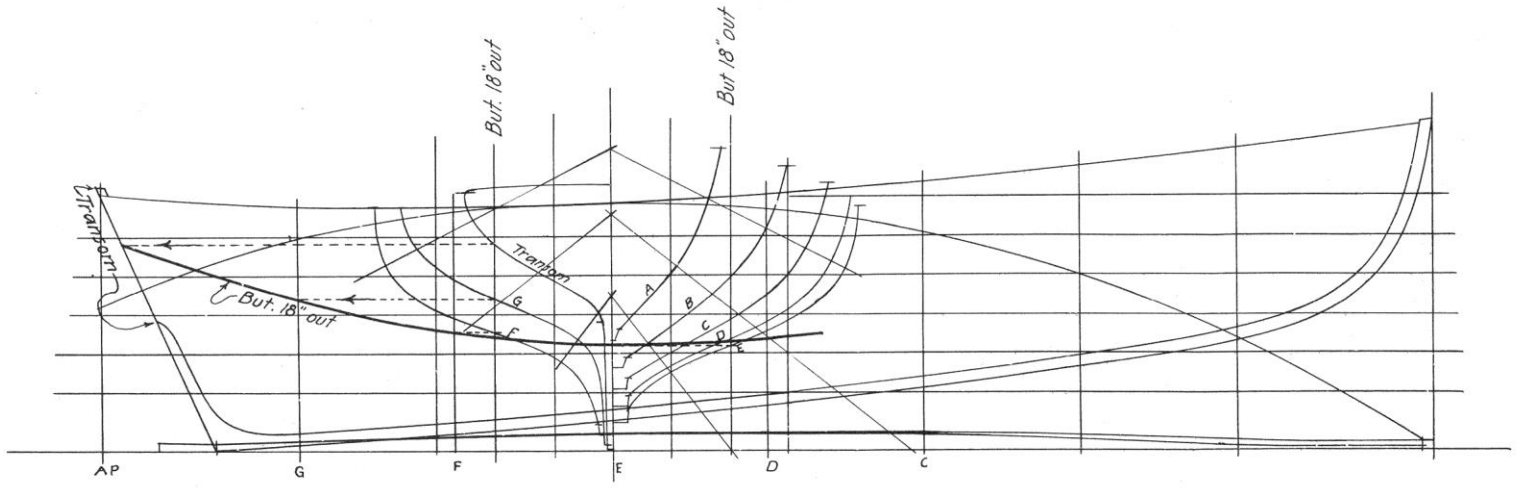
To establish the body plan we choose the widest beam, in this case Section E, and put it right on top using the vertical line of Section E in the Profile and Half-breadth as the Center Line for the Body plan. Most point heights, again, came from the offsets. The Sheer point of the section can already be lifted from the Half-Breadth. So can the Keel bottom and Rabbet.
In addition to the Water lines we now also add the Buttocks and Diagonals.

Now we have the outline of our vessel as seen in three different views.



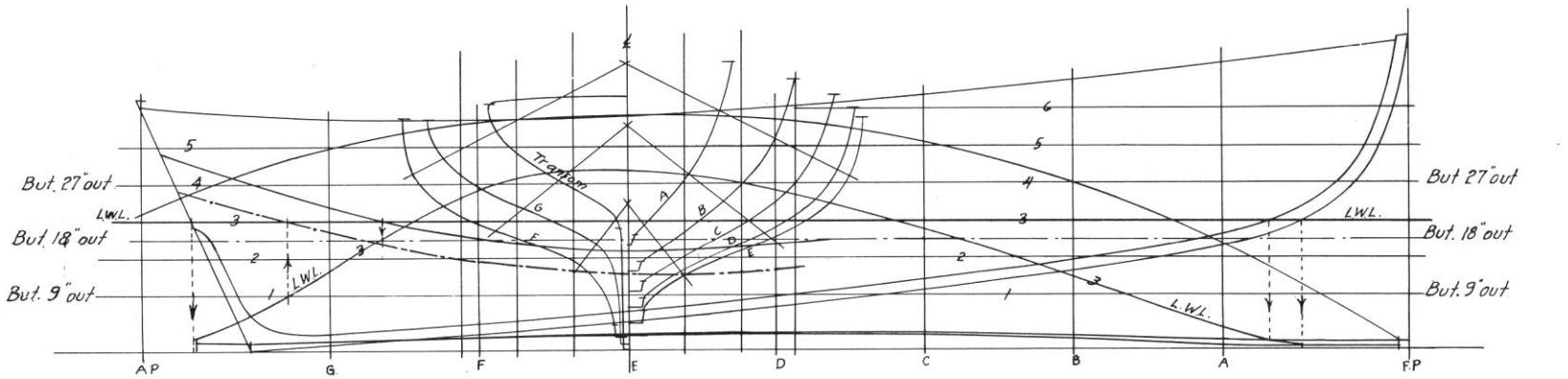
Inserting the buttocks into the profile

Taking the points from the Body plan, we can start filling in the Profile view.



Buttock heights lifted from Body Plan.

Filling in the views



Note :- Water lines #1 and #4 used as buttocks for Half-breadth Plan.

L.W.L. half-breadths lifted from Body Plan, intersections projected from profile. Second Buttock heights (9"out) lifted from Body-Plan, intersections projected.

Order of Things

Usually we go back and forth between the views after the Body Plan is complete to allow for corrections if something doesn't look right (=is not fair).

- Finish Body Plan
- 1st Buttock lifted off body plan
- 1st H_2O and 2nd Buttock
- Rest of H_2O and Buttocks

Then we fair in the Diagonals and find their end points. It is important that they be fair. If a point here or there doesn't land on the line, it must be corrected in all other views. This means that some of the Water Lines or Buttocks will need to be re-faired. This is tedious but crucial.

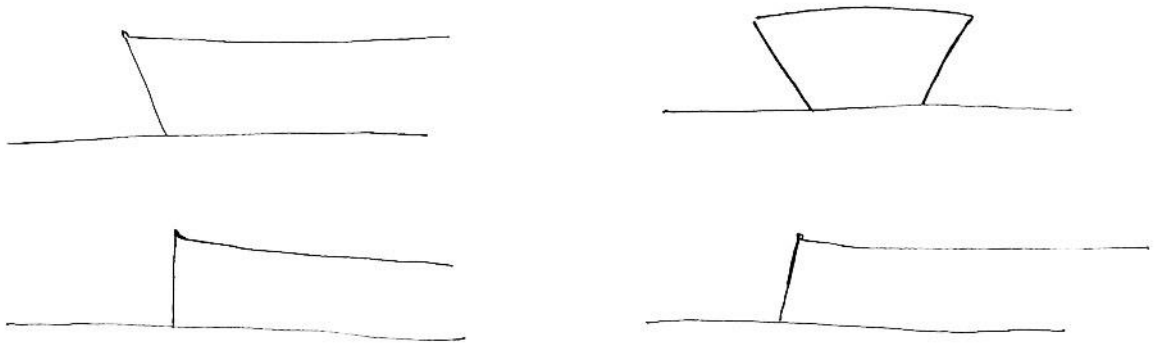
More Lofting

Once the hull is faired in all views and the Diagonals are fair, we can work on more isolated projects, for example the Transom Projection.
Unless the transom is perpendicular to the Water lines, we won't be able to see its exact shape in either of the views.
In the Profile, we only see its length, in the Half-breadth and Body plan it is foreshortened because we can't see the rake.

If the transom is curved, it is even more complicated.

Other items one might want to loft fully before starting construction are the structural timbers for the backbone besides stem, keel, and transom post: knees, horn timber, mast and mast step position, and the rabbet lines.

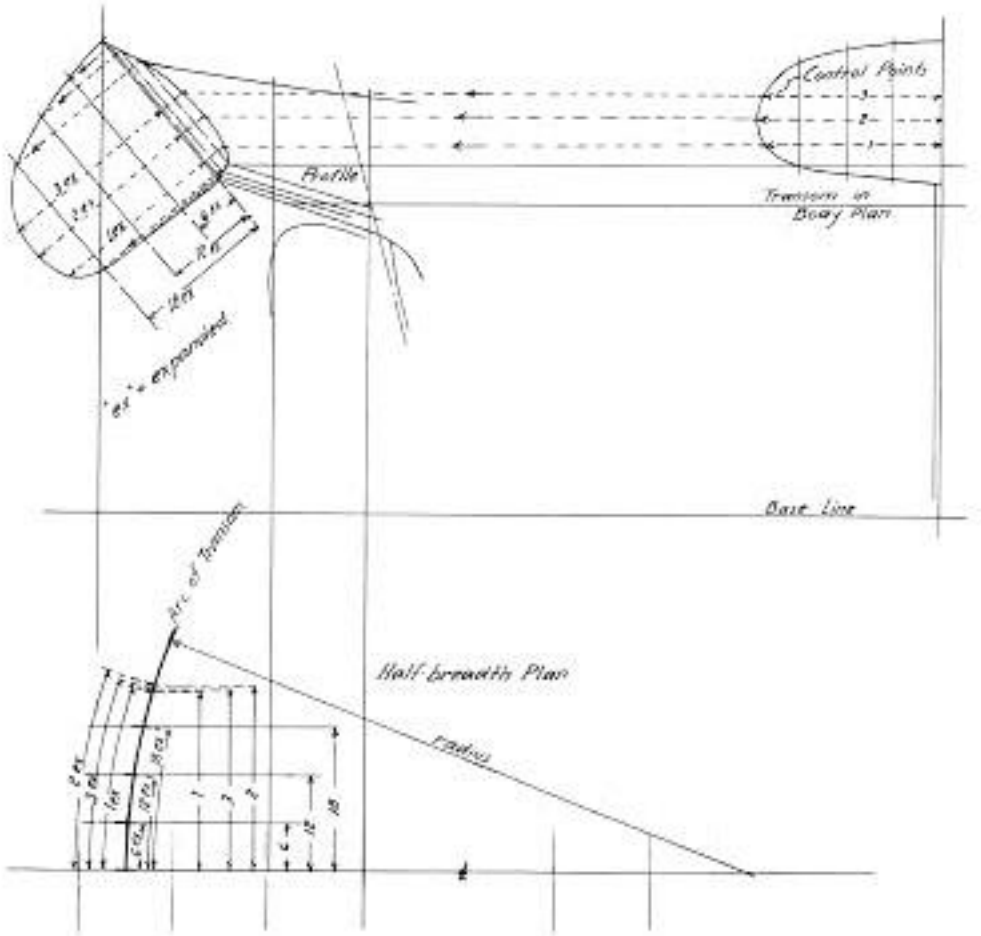
The more we can loft ahead of time, the more time we save with spiling and patternmaking during the building process.



This transom view in the body plan does not tell us if there is a rake or not. Each of the three profiles could be it. Each has different dimensions (and diagonals are longer than the vertical line)

Transom Expansion

Just for kicks, here is an example of a raked, curved transom and how to loft it.



24. Expansion of raking, curved transom.

Tricks to make lofting less messy or confusing

- Use different colors for different lines
- Switch up naming by numerals, roman numerals, and letters of the alphabet
  i.e.: numerals for waterlines: 1, 2, 3, 4, etc
  alphabetical, upper case for stations: A, B, C, D ,etc
  Roman numerals for buttocks: I, II, III, IV
  reverse alphabetical , lower case for diagonals: x, y, z
- Be tidy! Loft floor access only in socks, brush away dust, lint, eraser crumbs right away. If you use knee pads, clean them frequently so they don’t shmear the lines or make streaks.

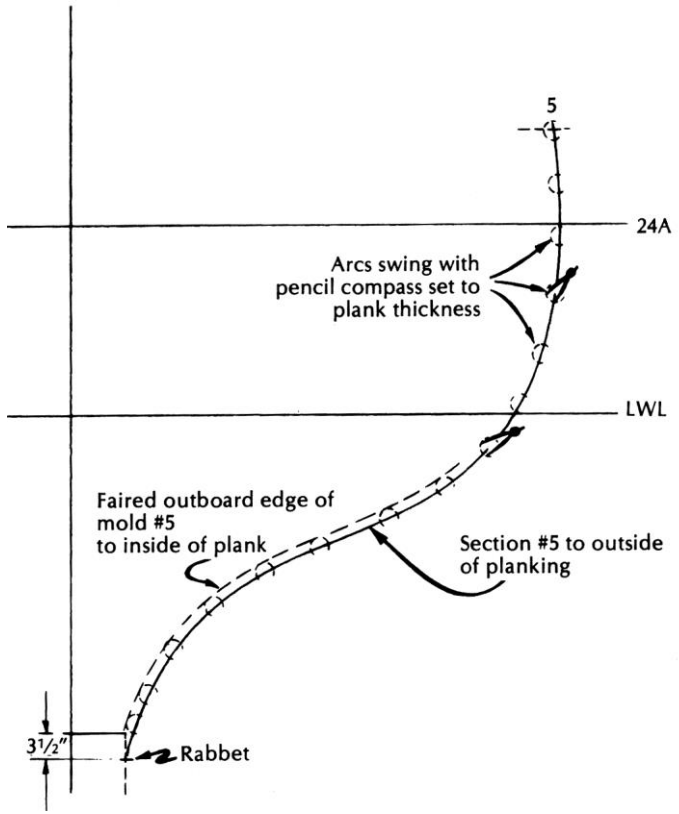
Correcting for Plank Thickness

After finishing the full size drawing of the hull, profile, waterlines and body plan, there is one more thing to do before we can start construction of our boat.

We need to figure out if the plans were to the outside or the inside of the planking. Usually plans are drawn to the outside of the planking, so, for our molds or sawn frames, we need to subtract the planking thickness from our body plan.

Set a compass to the adjusted plank thickness and with the needle end of it on the lofted line, strike a series of arks to get the outline of the mold/sawn frame. Spring a batten, draw the new line.

Rule of Thumb:
If the planking is specified to under ¾”, add 1/16” , if it is between ¾” and 1-1/4”, add 1/8”



Practical Presentation

Practice lofting and the transfer of lofted lines onto our sawn frame, pattern stock, or mold

Thank You

- Howard I. Chapelle: *Boatbuilding,* 1941; *Yacht Designing and Planning*,
- "Bud" McIntosh: *How to Build a Wooden Boat*, 1987

- Robert Darr (Arques School for Traditional Boatbuilding)

- various "Math is Fun" websites

- Erwin Petersen, my dad, who taught me boat design by osmosis and let me play with his ducks, pencils, and ships curves, always having a piece of paper ready for me when I wanted to join in