A Family of Weldless Water-tube Boiler Designs

1 Background

This Article is a summary of a section of a much larger paper on boiler design. This article concentrates on my own range of water-tube boiler designs. For those interested in a more in-depth paper, which also covers other designs, materials and the design calculations, the unabridged version is also available.

Boiler types are a 3-drum of the generic Yarrow type, a 2-drum design comparable to the later Simpson Strickland boilers, and a straight tube plate header design to Babcock principles. These boiler types were current at the very end of steam launch construction and hence have the benefits of design evolution over the time that small steam launches were in volume production. They are therefore inherently efficient concepts.

2 Consideration of the "Complete System"

The boiler is the first stage in the design of the total system. When you are designing the machinery installation for a steam launch you will probably first decide the size and style of boat that you want. The next stage is to decide what performance you are looking for.

Once you have settled on the engine you like, you will need to consider the speed and pressure drop at which you intend to run it. This will then give you a figure for the ihp produced. This will drive the propeller design, and you will then need to ensure that there is enough clearance to swing a screw of something near the optimum diameter.

The next stage is to finalise the design of the boiler. There are a number of rules of thumb that are often quoted, but many are overly simplistic and tend to ignore some of the variables that are affecting the answer. The first consideration is to determine the capacity of the boiler, and for a given type this will be a function of its heating surface and grate area. Suffice it to say that if the boiler cannot supply steam continuously at the pressure you have assumed in your calculations, the engine will be developing less power, at a reduced pressure drop. This is associated with reduced speed, and the propeller design will no longer be correct, a classic case of "garbage in garbage out". The majority of our present day boats have performance limited by an inadequate boiler, and this is to be regretted.

3 Economisers and Superheaters

The inclusion of an economiser in a boiler has profound effects, and is well worthwhile. The gains made by fitting an economiser may be considered to be "free of charge" as the temperature in the smoke-box of an efficient boiler is too low to be of much use if one is merely increasing the heating surface of the generating section. Heat transfer is directly proportional to the temperature gradient, so an economiser is around twice as effective in using this low grade heat as would be normal boiler tubes.

When designing the economiser we must consider what can happen if there is no flow for a significant period of time. The boiler will blow off, and the temperature of the economiser contents may also rise to a point where the boiling point is reached, at which time steam will be generated in the economiser and pass to the boiler drum. As a general rule a heating surface for the economiser of 10% of the heating surface of the generating section has been adopted. This is of course a bit of a simplification, as a boiler working at a higher pressure and hence temperature can accept a higher temperature in the economiser, and hence a larger economiser, without risk of steaming.

As a general rule superheat was not used in small marine engines, and in many cases we are only looking to ensure that even if we get some water carry-over, the engine will still receive dry steam. A small radiant superheater will have the same effect as a very much larger non radiant superheater in the smoke-box. Once again the concern is for no or low flow conditions. We will very rapidly achieve at slug of very hot steam in the radiant superheater under no flow conditions, and even at reduced power output the steam temperature may rise to an unacceptable level. I was a passenger on a boat where we were struggling to maintain 100 psi, yet the temperature of the steam was 280˚C. We ended up cooking the PTFE in the regulating valve!

I think we have to come to the conclusion that the radiant superheater is often the most practical option, but we must remain well aware of the pitfalls.

4 Theoretical steam generation

The SBA Boiler Design Library quotes steam generation capacity for the boilers listed. This is given in pounds of water evaporated per hour at 215 ˚F (100˚C) per square foot of heating surface. This is stated to be 5lbs/hr for natural draught operation, and 10lbs/hr for forced draught. As all the boiler designs are credited with the same performance, the figures are clearly nonsense and of no practical use whatsoever. Forced draught will normally give an increase in steam generation of around 50% for a doubling of fuel consumption, not the 100% suggested.
Lune Valley were the only manufacturer to give evaporation rates for their boilers, and these range from 10lbs/hr for the smallest size to 12.5lbs/hr for the largest.

5 Sizing the boiler, Proportions and “rules of thumb”

It will be seen that in spite of initially setting out to design a boiler by rigorous calculation, the cumulative acceptance of approximations and assumptions soon invalidates the whole thing.

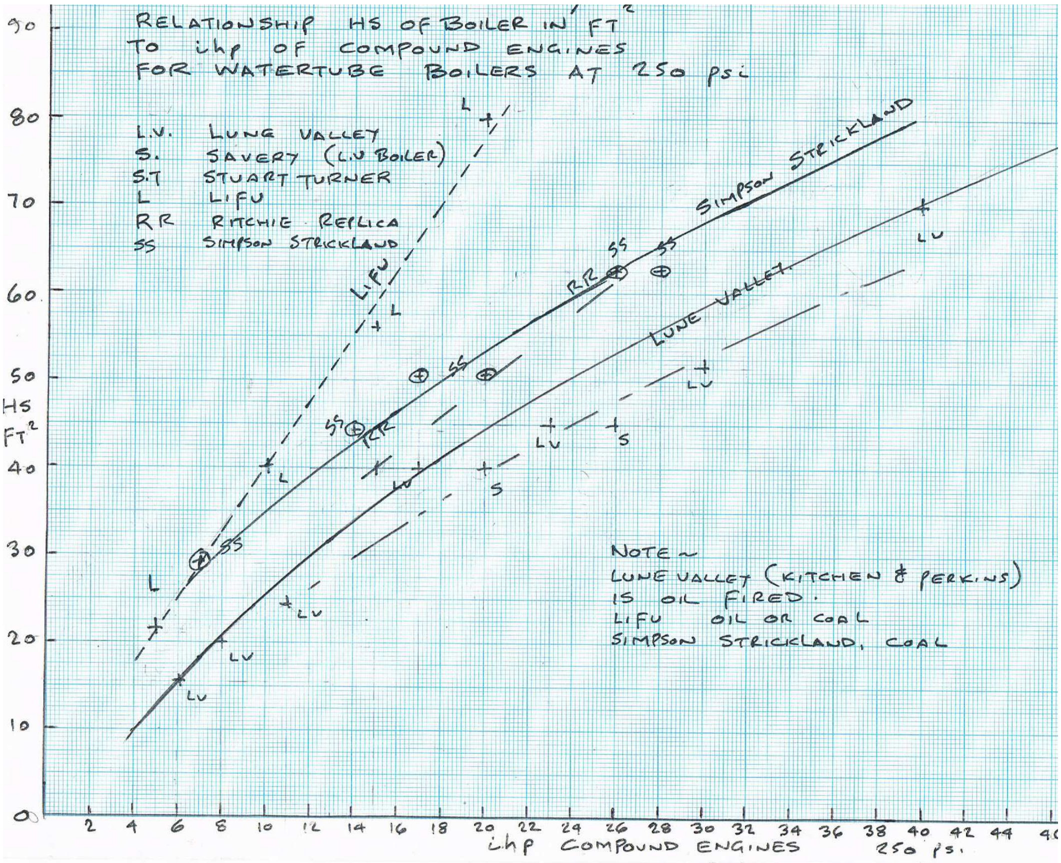
Our forebears designed and built numbers of boilers that exceed many times the total built by us latter-day hobbyists. They also matched their boilers to their engines. Using data from this source, the curves below seek to present the ratio between boiler heating surface and the power of a compound engine that can be driven by an efficient design of watertube boiler working at 250 psi design pressure
The curves below are fitted to boiler data that is available. They relate heating surface of the boiler with production of steam at 250 psi in sufficient quantity for use in compound expansion engines. Simple expansion engines are much less efficient and will use more steam, hence a larger boiler is required. For these engines the boiler heating surface should be around 140% of the figure derived from the curves.
The curves only apply to efficient watertube designs What we have done in the curves below is to directly relate power with heating surface. However there is no point in having an adequate heating surface if the grate area is not capable of supporting a fire capable of producing the required heat input.

The Simpson Strickland boiler data gives grate area as a percentage of the heating surface and this is normally around 20 to:1 to 30 to 1, though it must be mentioned that these boilers were normally arranged for forced draught.

My boiler designs achieve a more generous provision of grate area, which will facilitate operation under natural draught, a typical ratio being 16 to 1. for larger boilers and 13 to 1 for smaller boilers.

It will be seen that Lifu were the most generous in the provision of heating surface, and Lune Valley the least. I would suggest that the Simpson Strickland curve be adopted. What we see is a heating surface of around 42ft^2 for a 12bhp, (15ihp) engine. If an economiser is fitted this area should be added to the tube heating surface.

Name	HS ft^2 (gen section)	Grate area ft^2	Surface ratio	Type
Asphodel VFT	38	2.32	16.0	VFT
King Babcock 6” steam drum	23	1.72	13.4	WT
King Babcock 8” steam drum	38	2.44	15.6	WT
King 2-drum 6”steam drum	28	2.17	12.9	WT
King 2-drum 8” steam drum	45	2.77	16.0	WT
King 3-drum 6” steam drum (short)	28	1.92	14.6	WT
King 3-drum 6” steam drum (long)	31	2.13	14.6	WT



6 Working Pressure

If you look at the catalogues of the major manufacturers you will see that without exception they offered their smaller watertube designs at a design pressure of 250 psi. For boilers as small as ours the material thicknesses produced by this pressure are the minimum thicknesses one would consider suitable on considerations of minimum practical thickness, manufacturing considerations and general robustness.

Certainly for watertube boilers, even if you intend running at a low operating pressure a set pressure of 250 psi will contribute greatly to a docile boiler. The only advantage of the tank boiler is its greater thermal mass and ability to store energy. A watertube boiler that can store energy by increasing the pressure above normal working pressure is achieving the same thing.

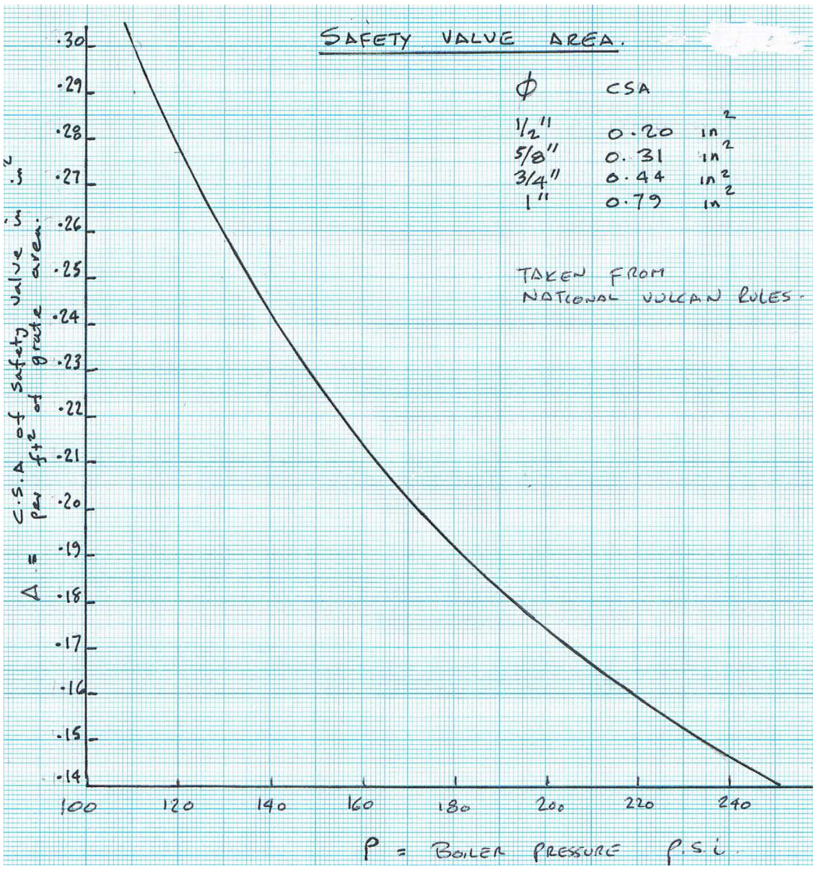
All my watertube boiler designs have a design pressure of 250psi, which is the set pressure for the relief valve. This would correspond to a working pressure of say 225 psi, and this value should be that used for calculation of the ihp of the engine and the propeller design.

7 Safety Valves Sizing

Full size rules do not properly address the size requirement for safety valves in boilers as small as ours. Their blanket stipulations tend to be over conservative. At the end of the day the whole matter is resolved when the accumulation test is carried out. If equilibrium is reached within a pressure increment of 10% of the design pressure the result is a pass. If not it is a fail.

Lloyds give a tolerance on the lift pressure for the safety valves of 3%. In other words, for a boiler of 250 psi design pressure the valve must lift before 257 psi, and the pressure at the accumulation test must not exceed 275 psi.

What must be appreciated is that the required clear area through the valve is effected by both the generative capacity of the boiler and it's working pressure. Imagine a boiler of 150 psi WP under the accumulation test. The safety valve could lift and the pressure accumulate until equilibrium was reached at say 200psi. This size of safety valve would be a resounding fail for this boiler, but would be perfectly adequate for the same boiler if it was pressed to say 250 psi.



The curve above is derived from pre War National Vulcan Rules. Tony Dunn used a ½" safety valve on my smaller 3-drum boiler and it passed the accumulation test OK for a 250 psi design pressure. This is actually slightly smaller than the size indicated by the curve. It is obvious that if the safety valve does its job there is no point in having an over-size fitting. We are also trying to make our boiler designs elegant and avoid clumsy appendages.

8 Considerations relating to Expanded Tubes

My "weldless" boiler designs use Cu-Ni-Fe tubes secured into the drums by expanding. The size of the 4" NB mud drums in the 3-drum and 2-drum designs is driven by the minimum diameter that will permit the use of the Wicksteed "E" series tube expander. A number of these boilers have been built and no one has had a problem with access for expanding the tubes.

9 Configurations

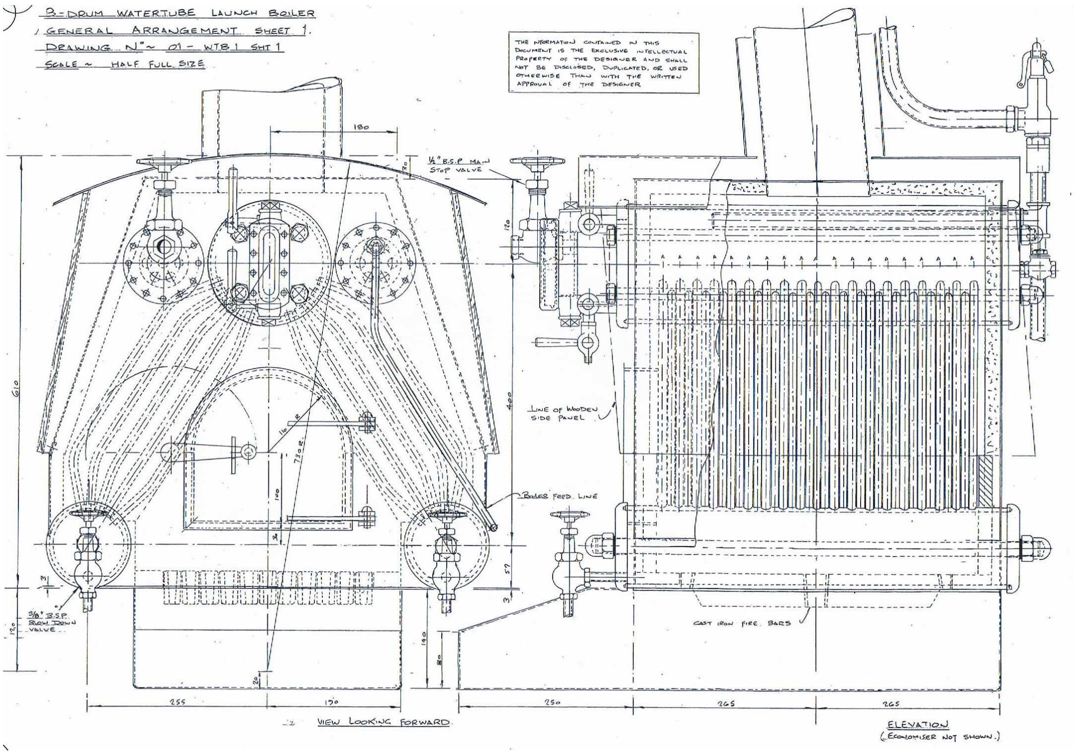
3-Drum

The original version of the smaller boiler was of 30 ft^2 heating surface in the generating section. Tony Dunn built the first one with the length reduced. Others have been built at the original length. The width was found to be on the large side for some applications. This is a fundamental feature of the 3-drum geometry. For a given grate area you have an additional 8" of width represented by the two 4" mud drums.

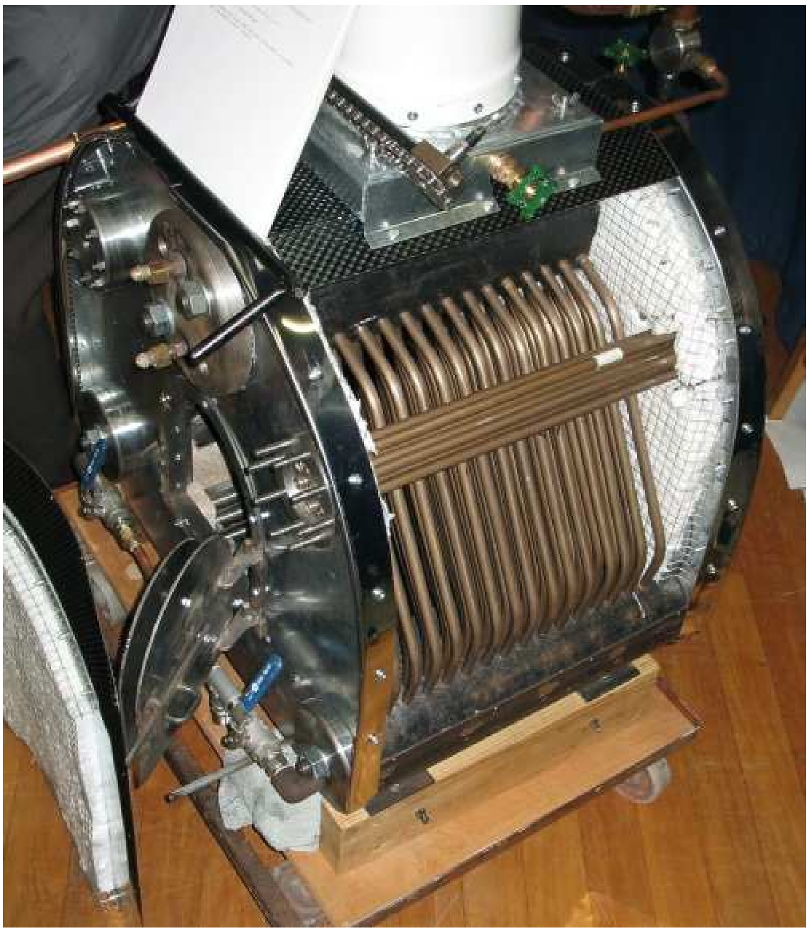
The design has now been redrawn with the angle between the tube banks reduced. The drawings are now fully detailed and some worthwhile refinements added.

The drawings depicting the MK II boiler are for a nominal heating surface in the generating section of 25 sq ft for the standard, shorter, version. This makes the boiler directly comparable with the smaller Babcock design.

A drawing of the MkII design with a new casing design and LIFU style "dog kennel" is reproduced below.



The photo of the boiler below is of the first prototype of the shorter version of the smaller boiler to the original design built by Tony Dunn a few years ago.
This also shows the alternative casing design.

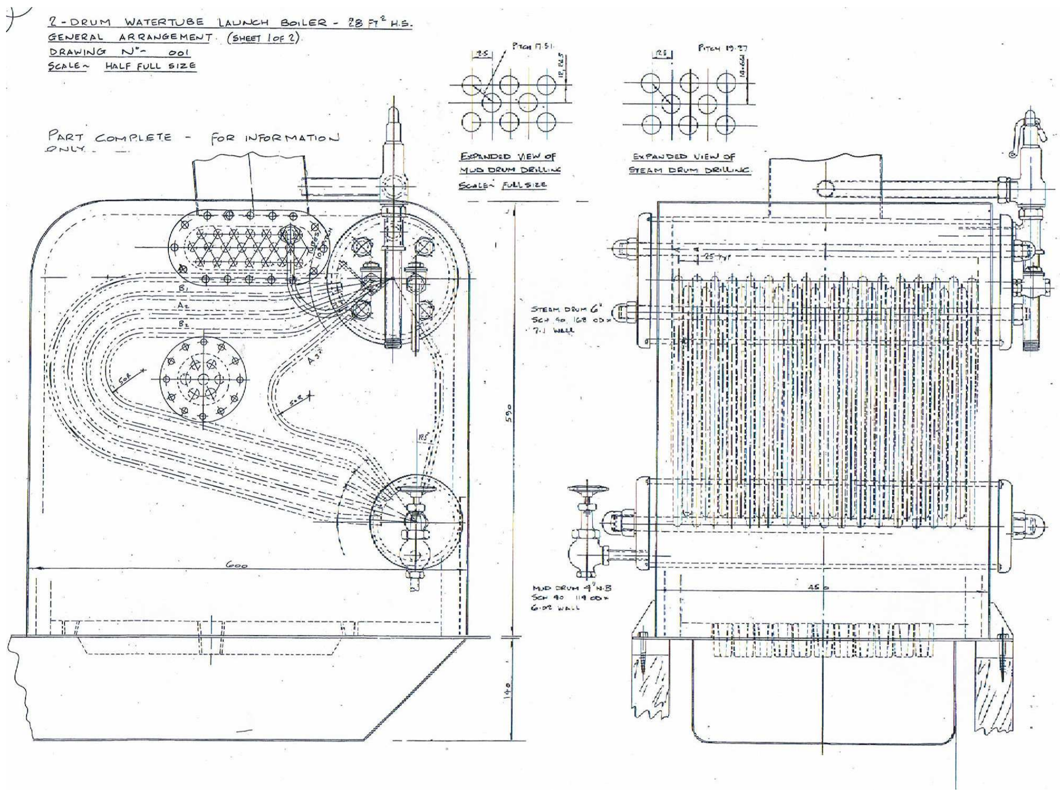


The photo below is of the pressure parts of a pair of the long version 6” drum MkII boilers under construction in New Zealand.

2- Drum designs

This configuration is quite common. The later Simpson Strickland boilers were either of this type or the 3-dum, the smaller size boilers being predominantly 2-drum.

I have drawn out the pressure parts for boilers with 6” and 8” steam drums. This is as far as the project progressed so far, and the layout of the smaller boiler is shown below. These may well be the most practical design that I have come up with to date, as the elimination of one of the mud drums is a worthwhile simplification and results in increased grate area.



6” NB steam drum boiler

12 The Babcock concept

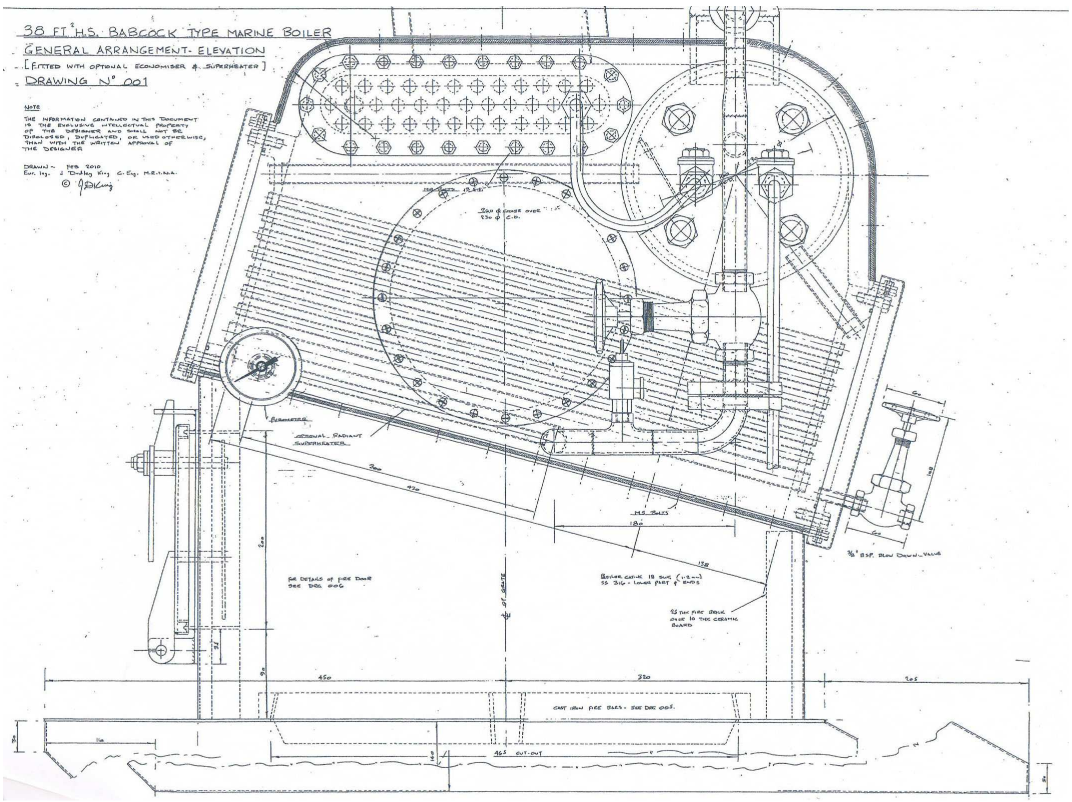
This design of boiler was widely used in “full size” steam ships and derivatives were offered by Savery and Simpson Strickland for use in steam launches.

Before the advent of modern sealing methods and CNC machining this design had serious disadvantages in that the headers consisted of a set of complex steel castings, and the boiler was unavoidably expensive to produce, particularly in small sizes.The logic of this boiler design, as re-worked for 21st Century production techniques, is that all the complexity and most of the man-hours are in the production of the two headers and cover plates. Once the headers have been produced the remainder of the boiler is much simpler than the norm. All generating tubes are straight and of equal length.

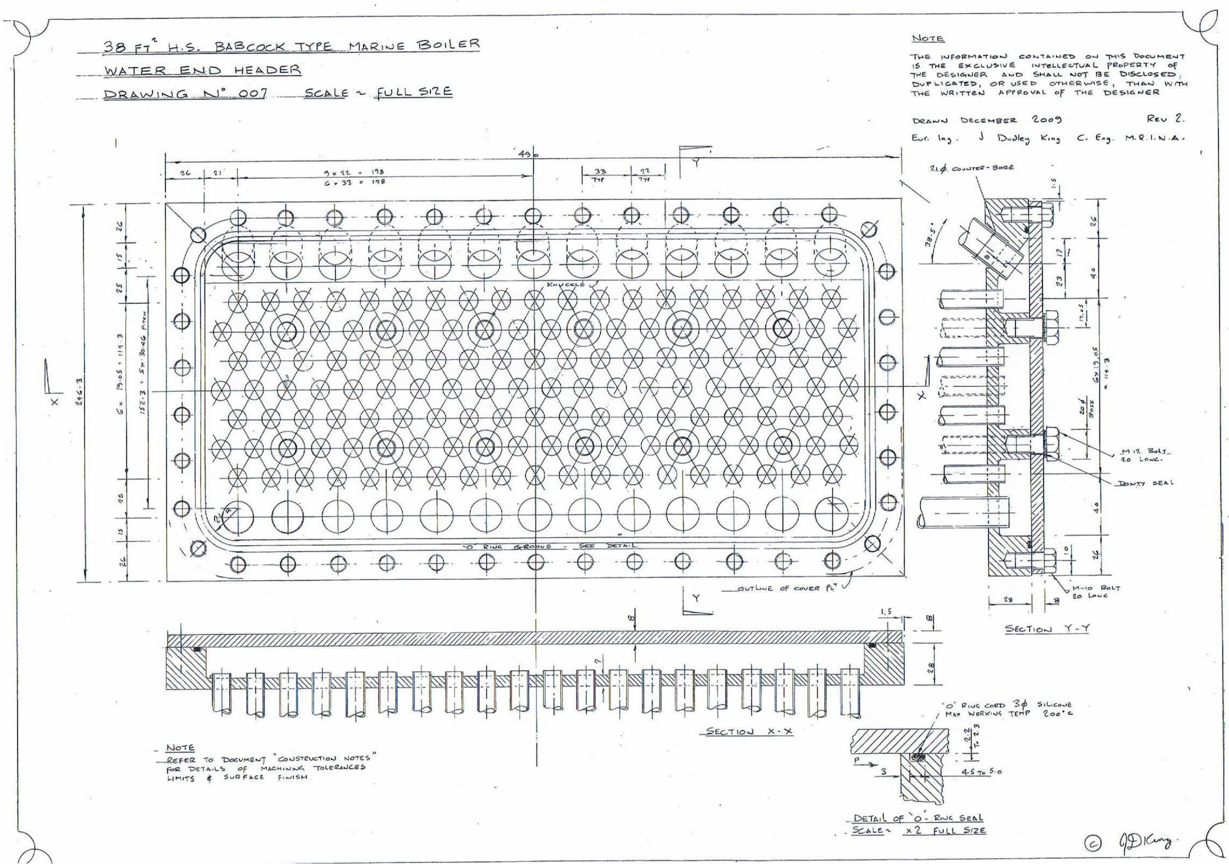
The main feature of the design is the use of flat plate headers to take the ends of the generating tubes. This enables the use of only a steam drum, the mud drum(s) of the other designs being eliminated.

This boiler design is based on the designs produced by Mac Scott, and also takes inspiration from the Savery boiler design. Main features are the use of headers machined from heavy plate, use of temperature rated Dowty Seals and ‘O’-rings for sealing, and generating tubes of 12mm OD 90-10 Cunifer material.

Without doubt these are the most compact, light, and efficient of my boiler designs, but the machining of the headers is time consuming and requires considerable skill. I have prepared designs for the “Babcock” type of boiler of 23 ft^2 H.S. with a 6” diameter steam drum, and 38 ft^2 H.S. with an 8” diameter steam drum. Both sizes have been built, the drawings below being for the larger boiler.

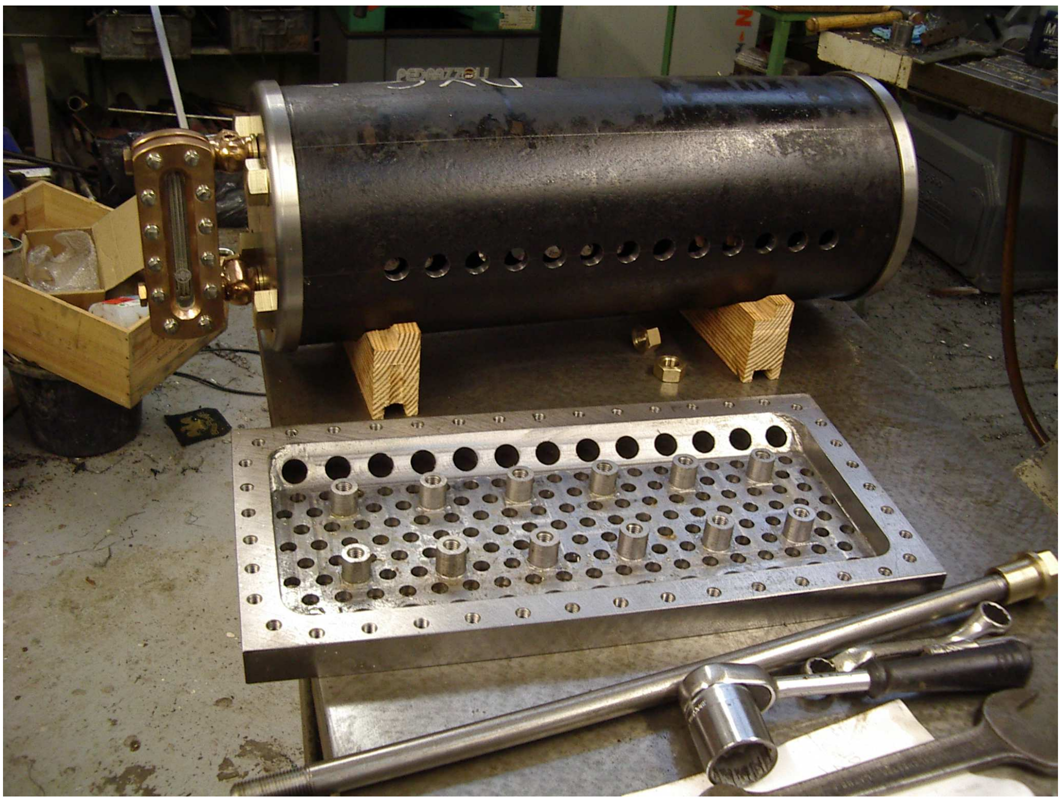


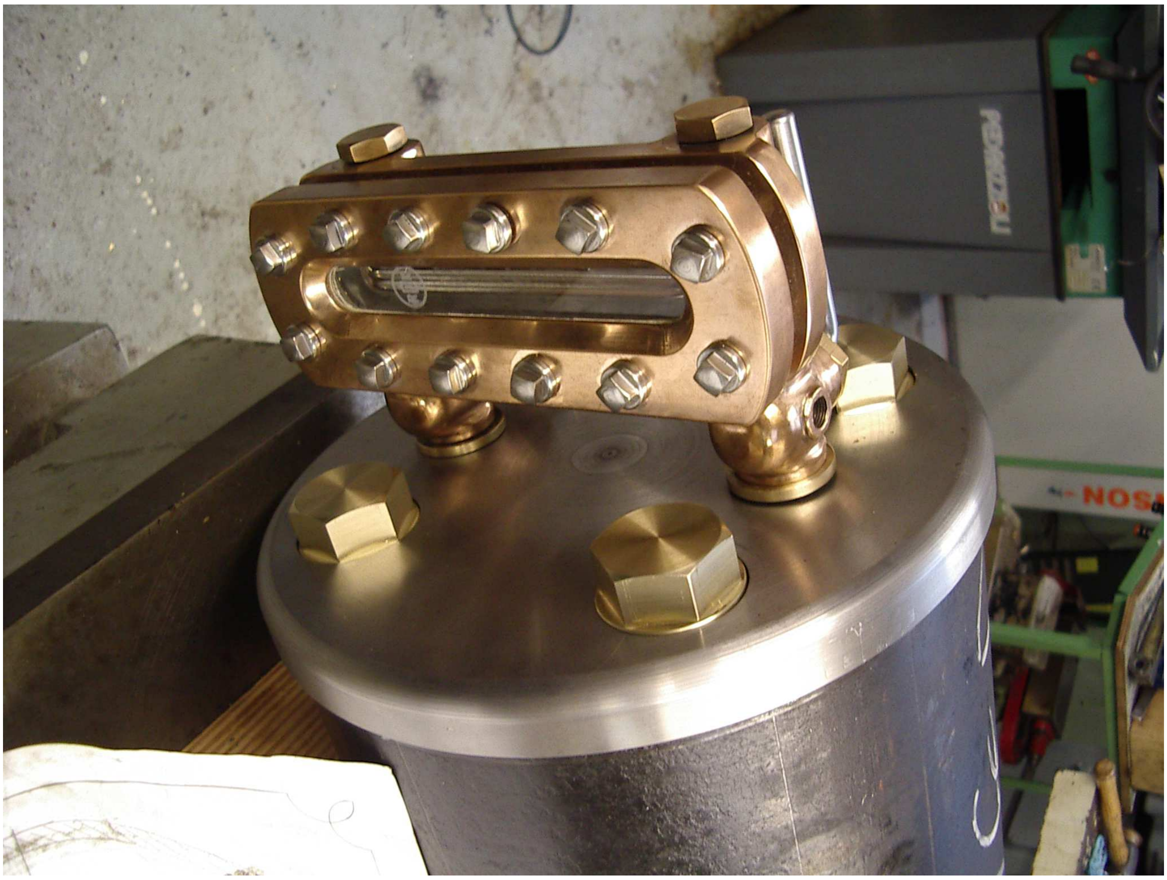
Elevation of the larger size Babcock boiler



Detail of headers machined from plate

The photographs below are also of the larger version of this boiler.





You will note the bronze reflex gauge, which was made to my drawings, also the recessed type nuts for the tie bars, which are considerably neater than the standard dome nuts.

As an option a dome may be fitted to all my boiler designs if desired, but this will mean that the boiler is no longer weldless. The piccolo tube concept is standard marine practice and a dome is probably superfluous, but an owner, particularly if from a locomotive background, may feel more comfortable with it.

13 Use of Cunifer 10 material, 'O'-rings and Dowty seals
Our forebears had rather more limited options for sealing arrangements than we have. Without modern methods the sealing of the large flat cover plates of the Babcock boiler would have been problematical.

The 'O'-ring is 3mm diameter cord in Viton material, which is suitable for working temperatures up to 200˚C continuous and 250˚C intermittent. An alternative material is "Atlas" Tetrofluoroethylene/ propylene copolymers (FEPM), which is suitable for steam duties up to 260˚C, and "Kalrez", which is suitable for steam duties up to 315˚C. Dowty seals are used at the bolts in the plate headers and at the tie bars in the steam and mud drums. These are to be temperature rated to a minimum of 200˚C continuous duty and are readily available.

For 90/10 tube, published data gives a permissible working pressure of 50.9 bar for 20mm OD x 1.0 wall, and 61.3 bar for 12 OD x 0.7 wall, at a temperature of 250˚C. For a superheater application the temperature will exceed this and a permissible pressure of 60.1 Bar applies for a temperature of 300˚C. All these permissible working pressures are greatly in excess of our design pressure of 17.24 bar g.

14 Certificatiion

All of my boiler designs are to Lloyds Rules for the Construction of Ships, Part 5, Ch10 for a design pressure of 250 psi, which corresponds to the set pressure for the relief valve.
As part of the design package a full set of calculations is included. Designer and checker are both Chartered Engineers with the required pressure vessel design experience to satisfy Competent Person requirements.

15 The Design Package

Fully detailed sets of drawings have been prepared for the 3-drum and Babcock configurations, together with supporting information, build notes and drawings of suitable boiler mountings.

The detail of the two drum boilers will be drawn out when the first person decides to build one. As mentioned earlier, I hope this will be soon, as I feel the configuration has many advantages.

Drawing sets are available from the designer.