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1876

MARINE 1876 ENGINES.

Geo. W. Main.

1876

A Thesis
on
The Efficiency of Marine Engines.
by
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Class '76. Mass. Inst. Tech.

Boston, May. 1876.

Preface.

The steam engine is a machine in which the motive power of heat is utilized with a certain amount of efficiency, and the theory of its action forms a part of the general theory of heat, and the convertability of heat, and mechanical power.

Passing over in this thesis the General Theory of Heat, I propose to pass directly to the different modes of using steam, and to the different styles of engines, and to show with the aid of theory and various experiments, which is the most economical mode of using steam, and which is the most efficient combination of mechanism.

It may be desirable to mention those authors whose works have been most frequently referred to, in gathering much of the information that may herein be written.

Isherwood's "Experimental Researches on Steam Engineering."

Rankine's "Memoir of John Elder".

Bourne. "On the Steam Engine".

Emery. "Compound an Non-compound

Engines"

Burgh, "Marine Engineering"

Paris, "L'art Naval l'Exposition Universelle de Londres de 1862."

Where other authorities are referred to they will be mentioned.

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Part I.

On the different modes of using steam.

Efficiency. For every machine a certain amount of power is required, and the whole work done is equal to the energy expended. A part of this energy is used in accomplishing the object aimed at; another part is lost or wasted. That part which is lost in overcoming the friction of the machine is useless as far as any outside work is concerned. The proportion which the useful work bears to the energy expended is called the efficiency. This is alway a fraction.

Memoir of John Elder. Rankine's Steam Engine §259, p 332.

In the steam engine there are successive causes for the loss of energy.

First. The whole heat produced by the combustion of the fuel is not utilized, for a part (from 1/5 to 2/5) is lost by radiation and the escape of hot gases. The fraction of the heat which is utilized (from 6/10 to 8/10) is called the efficiency of the boiler.

Second. The whole energy of the heat in

the form of steam is not used in driving the piston. The work done in driving the piston corresponds to the difference between the heat brought from the boiler by the steam, and that carried out by the same on leaving the cylinder. It is a very small fraction of the whole heat in the boiler, and this fraction is called the efficiency of the steam.

Third. A certain part of the energy exerted by the steam on the piston is used in overcoming the friction of the engine (1/8 to 1/4). The difference between this fraction and unity is the efficiency of the mechanism.

Fourth. When the ~~steam~~ engine drives a propeller, a part of the energy is wasted in agitating the water, the other part is used in driving the ship ahead. The ratio of the latter to the energy expended on the propeller is the efficiency of the propeller.

The efficiency of the combination is represented by the product of the several factors of efficiency, and is smaller than either of the factors.

The study of the second, and third factors is that which directly belongs to this subject. For the development of the first factor, I refer the reader to Mr. Bennett's thesis on Steam Boilers, and for the fourth factor to Mr. Prichard's thesis on Screw Propellers.

Second factor. That of the steam on the piston.

I. Effect of using steam expansively. Memoir on John Elder.

In the expansive engine the forward stroke is accompanied by two stages of action, namely, admission and expansion. During admission the steam is coming from the boiler into the cylinder, and the difference of pressure in the two is only that required to overcome the friction of the pipes and valves. Admission is terminated by cut-off, and then follows expansion in the cylinder, when steam goes on increasing in volume and diminishing in pressure. The exact law of expansion is complicated, and varries under different circumstances as to heat. In practice however it can be assumed that the pressure varies inversely as the volume.

It is obvious that work is performed just so long as the pressure in the forward stroke is greater than the back pressure and friction. Hence to realize the full effect of the steam, the expansion must be carried on until the forward pressure is just sufficient to overcome the back pressure and friction, and to end the expansive working before this period would be a waste of power. In other words, the cut-off should occur in such a place that the expansion shall continue to the end of the stroke, and that just at the end of the stroke, the expansion shall have been so far completed, that the forward pressure is just equal to the back pressure plus the pressure equivalent to friction.

There is however an exception to this in the case where the reciprocating parts are so heavy as to store up energy in the early part of the stroke, and pay it out in the last part, as in the case of the Allen engine. But in ordinary engines this need not be taken into account.

To find the increase of work gained by expansion. Take for granted the principle stated above, that the pressure varies inversely as the volume. Let v = the volume before expansion, and x after a certain amount of expansion. p = pressure before, and p_1 after. Then $p_1 : p :: v : x$, or $p_1 = \frac{pv}{x}$. Now for a very small amount of expansion $p_1 = \frac{pv\,dx}{x}$, and the sum of these from $x = v$ to $x = v_1$ would give the mechanical effect gained by expansion. Hence $\int_v^{v_1} \frac{pv\,dx}{x} = pv \log x_1 - pv \log v = pv \log_e \frac{v_1}{v} = pv \log n$, where $\underset{\sim}{n}$ is the ratio of expansion. Then the whole work done equals $pv + pv \log n$, and in order to find how much the effect of the steam has been multiplied by expansion, it is only necessary to divide the result by that obtained without expansion, and we have $1 + \log_e n$.

For example suppose cut-off is at $\frac{1}{2}$

stroke, then $n = 2$ and $\log 2 = .3$, hence the effect is multiplied 1.3 times.

The following may be studied at greater length in Isherwood's Experimental Researches on Steam Engineering.

But there are practical obstructions against the use of steam expansively which are not included in the preceding discussion, and which it is necessary to consider. As the dynamic power of a given weight of steam increases in a higher ratio than the heat required to generate it, owing to the increase in the temperature of the same, it is obviously desirable to use it at the maximum pressure throughout the entire stroke. This is a practical point of gain of smaller measures of expansion over large ones.

If there were no friction in the engine, and if the condensation were instantaneous the above calculation might answer, but here we have to take into account back pressure, and the equivalent pressure of the friction. When steam is used at a low pressure, the effective pressure is a much smaller fraction of the entire pressure than when high pressure is used. Therefore a greater proportion of power is utilized with high pressure than with low; or what is the same thing a less proportion of power is utilized when steam is used expansively than without expansion. This will tend to reduce the theoretical results as regarding the gain by expansion.

But there are other reasons far more potent for desiring high pressure and high temperature in the cylinder throughout the entire stroke, whether the steam be used with or without expansion.

The transference of heat from the metal of the cylinder to the condenser, due to the variable pressures and temperatures in the cylinder during the stroke, takes place in two seperate ways, entirely independent of each other, and differently influenced by different rates of expansion.

First. The loss of heat due to the difference of temperature between the metal of the cylinder, and the back pressure vapor. Heat is abstracted from the vapor in the same manner as a gas would absorb it, and this tends to superheat it, and as the cylinder full is pushed back into the condenser at each stroke, it carries with it the amount of heat which is measured by the superheating, the whole of which tends to reduce the economic effect produced by the coal. This law is independent of pressure, entirely separate from the loss due to evaporation of water of condensation, and is attended with less loss the higher the rate of expansion.

Second. The loss due to the reevaporation of the water formed by condensation of steam, which absorbs and renders latent a certain amount of heat. The temperature of the cylinder at the begining of the stroke is less than the entering steam, and a certain amount of heat is taken from the steam to equalize the temperatures; this causes the condensation of a portion of the steam. This state continues up to cut-off, when the pressure diminishes, and reevaporation continues so long as the pressure diminishes. Beside this continual evaporation, there is a continual condensation during the expansive part of the stroke, for as the piston recedes it continually exposes parts of the cylinder having a less temperature than the steam expanding on them. The heat producing the evaporation is derived from the metal of the cylinder, and from the water itself, and whatever quantity is thus abstracted must be resupplied during the next stroke. The economic result is greatly affected by this cause, and this phenomenon of cylinder condensation is the "bugbear" of using steam expansively. All the heat absorbed from the metal while the exhaust is open is an entire loss to the fuel required to generate it. As regards the heat taken from the entering steam by the cylinder, only a part is loss to the fuel, for the reevaporated steam produces a useful dynamic effect on the piston; but the whole dynamic effect of the steam, due to the time it remains water, is lost.

The loss of heat due to the cause just

mentioned increases with the rate of expansion, because the more expansively the steam is used, the greater will be the reduction of pressure, which reduction is not only the efficient cause of evaporation, but it graduates the quantity by determining the minimum boiling point of water. Further, the greater the measure of expansion, the greater will be the surface in equal time from which evaporation takes place.

There is one other cause which must be mentioned, which tends to reduce the economic effect of the fuel, and unequally for different grades of expansion. It is due to clearance and steam ports. When working without expansion, the steam which fills this space passes into the condenser without having performed any dynamic effect on the piston, except to transmit the initial pressure across the space. But when steam is used expansively, the quantity which fills this space produces a dynamic effect which becomes absolutely greater and greater as the measure of expansion is increased: but as the proportion which this quantity bears to the quantity used, increases with the expansion in a higher rate than its dynamic effect, the cause in question acts to lessen the economic result from the fuel, as the measure of expansion is increased.

From Chief Engineer Isherwood's experiments on the engine of the steamer Michigan, to find the effects of different cut offs, it was found as regards the number of pounds of coal, and the number of pounds of feed water per gross effective horse power, that the most economic results are obtained when cutting off at 4/9 of the stroke. But he says, if the proper corrections be made for the difference of cylinder temperatures due to the different measures of expansion, it would doubtless be found that when cutting off at 7/10 of the stroke, which causes scarcely any expansion, more economic results are obtained than when cutting off at any less fraction. In these experiments the cylinder was not steam jacketted, and this is the case of a great many of the older marine engines.

The result of these experiments is a very curious one, and does not seem to agree with the opinion of most engineers on the expansive action of steam. It may be correct for the engines on which Mr. Isherwood experimented, but it does not hold good in all cases by any means. The effect varies with the conditions of various engines, and with the steam pressure and the piston speed. In his experiments, the boiler pressure was about 35 lbs. and the piston speed varied from 330 to 220 ft. per minute.

In the experiments made at the U.S. Navy Yard in Charlestown, it was found that when the engine of the Bache operated non-compound with an approximate steam pressure of 80 pounds, that the efficiency was greatest at a cutoff of about 1/5 stroke, and with the single engine of the Dexter, using an approximate steam pressure of 40 pounds, and with the engine of the Dallas with pressure approximately 35

Note. The experiments on the "Bache" were made at Baltimore. Md. Those on the "Rush", "Dexter" + "Dallas" at the Charlestown N.Y.

pounds, it was concluded that an expansion of 3½ to 4 times is the most economical degree for steam pressures of 35 to 40 pounds. The cylinder on the Bache was steam jacketted; those on the Dexter and Dallas were not, but were covered with a non-conducting covering.

Emery's experiments.

As a general rule in designing an expansive engine, too much expansion is attempted and the cylinder is made too large for the work to be done. Nearly all the marine engines constructed have cylinders of such a capacity, that they might develop the power intended with a mean pressure of 25 and **20** pounds per square inch, and even lower. The experiments at the N.Y. show that the best results are obtained at a mean pressure of 34 to 37 pounds, when the boiler pressures are from 70 to 80 pounds, and therefore the cylinders of non-compound engines should not be made more than two-thirds the size they usually are. Engines so proportioned would not only work with greater economy, but also with less expansion than those of larger cylinders, so that there would be more equable pressure throughout the stroke when high pressure steam is used, and less trouble to the engineer.

There is a question which arises here, and this is, whether, in an engine which is worked at different rates of power, it is more economical to employ increased rates of expansion, or to reduce the initial pressure and keep the expansion the same. The first employs the use of an expensive and changable cut-off, and the second requires the use of a simple throttle valve.

When the expansion is increased greatly the condensation in the cylinder is great; and when using steam throttled an amount of power is lost by wire drawing the steam. Mr. Isherwood says, that where the reduction is exceedingly great there is a positive gain in favor of the throttle, and in every respect the choice is immeasurably in favor of the throttle valve.

I find in Engineering, Oct. 1874, page 305, a report of some experiments by B. Donkin & Co. to find the effect of the steam jacket. During these experiments a reduction of half the power was made, both by the throttle and by increasing the expansion, and there was a gain of twelve pounds of feed water with a shorter cut-off than with the throttle. These experiments were on a small engine.

My idea of the subject is this:- The most efficient cut-off varies for different steam pressures. For a high pressure is required a greater expansion than for a a low pressure. Now if the pressure is reduced, the expansion must be diminished to agree with the pressure, and in this manner, by changing the cut-off, and throttling at the same time, we should have a more economical result. I have not verified this statement by experiment, but I see no reason why it is not true. An experiment to answer this question was started in the labratory, but the calorimeter, which was being used as a condenser, gave out, and the experiment could not be conducted. It is a very interesting question, and might well be tried when the apperatus is in working order.

Steam Jacket. The condensation and reevaporation, before mentioned, when using steam expansively can be in part prevented by the use of the steam jacket, which tends to keep the steam at constant temperature, thus keeping the temperature above that of condensation. Thus is saved the amount of heat transferred from the metal of the cylinder to the condenser by the reevaporation.

If the steam jacket works efficiently, that is to say, supplies heat fast enough to counteract the refrigerating effects, then on the steam side, the entire dynamic force of the steam is realized at the expense of an amount of heat equivalent to the refrigerating influences; and on the exhaust side, it would save all the heat that is transferred from the cylinder to the condenser by vaporization of the water of condensation.

When steam is used without expansion, there will be no reevaporation during the stroke on the steam side, consequently there will be no heat absorbed from the metal or jacket to supply it. On the exhaust side the jacket will save, as in the case of using steam expansively, the amount of heat that would pass into the condenser from the metal of the cylinder by the vaporization of condensed water, while the exhaust port remains open. The gain, therefore, by the jacket will be less the less expansively the steam is used, and a minimum when the steam is used without expansion.

There are some modifications to be made to the results obtained by the steam jacket. In the first place, the loss of heat by radiation is greater with the steam jacket than without it. Second, more heat is lost with the jacket than without it, by superheating the back pressure vapor. Third, when the engine is used, only a part of the time, it requires more heat to raise the increased amount of metal to the temperature of the steam. Fourth, there is the increase of cost, and, in a vessel, the additional weight and space.

On the other hand, with the condensing engine, it saves the power required to pump out the condensed water from the cylinder, formed when the jacket is not used. Also there is less power expended on the feed pump.

The jacket cannot act with anything approaching the theoretical efficiency because the transfer of heat through the metal is so slow. The jacket then can only be a partial prevention of deposition of water of condensation, and of course is a saving only to the extent of the prevention.

In Isherwood's experiments on the Brooklyn pumping engine, of 90 inches diameter, of cylinder, 10ft. stroke, covered at the ends with nonconducting material, and the steam jacketting forming 3/4 the entire surface, the engine run 42 hours with the jacket, and 43 without, making a saving of 5.5% purchased at a cost of 2%, thus making the saving 3.5%.

On the Bache, during the experiments mentioned before, when operating with one cylinder without steam jacket 26.247 pounds of feed water was required per horse power per hour, and *with* the steam jacket only 23.154 pounds was required, thus showing that the saving on that engine when acting as a single engine, and cutting off at the most economical point ~~of~~ was 11.78%.

The Bache was also operated as a compound engine not jacketted at a cost of 23.036 pounds of feed water per horse power per hour, and with the jacket on the large cylinder at a cost of 20.322 pounds. The saving by the use of the steam jacket on large cylinder is shown to be 11.73%.

These experiments also show that the jacket on the small cylinder was not of much advantage.

Superheated Steam. Superheated steam may be used as a substitute for the steam jacket. For the purpose of preventing condensation, the steam must have such an excess of superheating on entering the cylinder, that the temperature of saturation shall not be reached before leaving the cylinder.

As the refrigerating effects increase with the increase of expansion, it is obvious that the amount of superheating must increase with the increase of expansion, and when steam is used without expansion, the superheating temperature, and economic effect become zero.

The term "superheated steam" is applied to steam whose temperature, after its formation, is raised without increasing its weight, by direct application of heat. This superheating expands the steam, and evaporates any moisture which may be held in suspension; consequently, under constant volume the pressure is greater than the same amount of saturated steam, or under constant pressure the volume is greater.

The potential energy of the steam is increased by superheating, but a certain amount of heat is required to do this superheating, and hence, the question is, whether it will be more economical to use the amount required for superheating for that purpose, or to use the same heat for producing saturated steam of a greater quantity. This question can be answered for the conditions of ordinary marine practice in the following manner, based on the supposition that saturated steam expands as a perfect gas when heat is applied.

Let the conditions be at the average steam pressure, 39.264 pounds, the average temperature of feed water, 100°, the temperature of the saturated steam 266°, and the temperature of the superheated steam 401°. Take the number of units required to evaporate the water under the stated conditions. This is 1094.5. Find the volume of a cubic foot of water in the form of saturated steam, and the work developed during the expansion. If this saturated steam be now superheated it will expand, and produce by this expansion a certain amount of work which is calculated. Now the specific heat of water and steam under constant pressure are 1 to .475, and it requires a certain amount of heat for superheating (135 × .475) = 64.125 thermal units. Now find the relation between the energy exerted, and the thermal units required to produce that energy in both cases, and compare the results, and we find that under the stated conditions, it is 3½ times more economical to obtain work by superheating steam than by generating it. By dividing the quantity required ~~by~~ for superheating by the entire quantity expended, we find the percentage expended in superheating.

The relative economy will of course vary with the different degrees of superheating, and with the different steam pressures, but admits of calculation by applying the above rule. In the present case the economic result would be 18,564 per centum. But the gain produced by the expansion of the steam alone as a gas is not the only gain, for superheating the steam is a part prevention of cylinder condensation. The gain of course cannot be accurately determined, but varies under different circumstances, but "Practically the gain by superheating, when effected by the waste heat of the boiler, and for average boiler pressure, and average temperature of feed water, will average 33 per centum for medium sized cylinders."

Isherwood.

The greater the degree of superheating, the greater the economic gain, but not proportionally; for the process is limited to the temprature at which the metal will work satisfactorily, and the joints remain tight. Beside this it requires only a slight degree of superheating to prevent condensation to any great amount, and there is less loss by radiation, friction, and leakage on account of the packing drying.

In experiments on the "Georgianna" the gain by superheating was three-eights of the effect of saturated steam from her boiler, and it was more economical to expend heat in superheating than in generating steam of its equivalent, by 21%.

In the experiments on the Adelaide, it was found, using steam which came directly from the steam chimney, very moderately superheated, that cutting off at .35 of the stroke of the piston from the beginning, was 11.53% more economical than by cutting off at .60 of the stroke. When using steam highly superheated the gain of a cut-off of .36 over one of .63 was 16.05%. Hence we see that with highly superheated steam the gain over moderately superheated was 4.5%. It was also found that cutting off at .35 and .36 of the stroke of the piston, the additional gain in superheating was 17.37%, and when cutting off at .60 and .63 the gain was 12.93%, thus showing a gain of 4.44% in favor of the higher expansion.

In experiments of the Eutaw it was found that by increasing the superheating from 87°.1 to 124.°7 or 37°.6, that the increase of economy was 6.76%; and from 65°.2 to 107°.2 or 32° the gain was 5.23%. This determination gives for a mean, an increased economy of about 6% for an increased amount of superheating of 40° Fahr.

Compounding. So far as the theoretical action of the steam on the piston is concerned, it is immaterial whether it takes place in one cylinder or a succession of cylinders. The force of the steam on the piston is transmitted through ~~all~~ the piston rod, to the crank and shaft, and from the moving pieces through the bearings to the frame. All these parts must be made strong enough to resist, not the mean, but the greatest strain produced. Now the greater the rate of expansion, the less is the *mean* pressure: for example, if the expansion is ten times the original volume, the mean pressure is one third the maximum pressure, or the maximum pressure is three times the mean. If this were in a single cylinder engine, we see that, all the pieces must be made three times as strong as an engine producing the same power, but working without expansion. The additional strength not only increases the expense of construction, but also the friction, thus neutralizing the economy of expansion. It was to obviate these objections that the compound engine was invented. The diminution of friction by causing the forces which drive the shaft to be balanced, and neutralize as far as possible each others action of the bearings is an important subject, and this is one of the advantages belonging to the combined engine. Thus the two cranks may be arranged diametrically opposite, and thus the forces tend to balance each other With this arrangement there can be direct communication between the high and low pressure cylinders, which also is a gain.

In the experiments on the Bache it was found that a saving of 12.19% was made with the compound engine over the single acting engine under similar circumstances.

When the compound engine of the Rush was working, the relative power in this engine with both cylinders jacketted, and in the single engine of the Dexter with unjacketted cylinder, the compound engine showed a gain of 22.94% in economy, as compared with the single engine, or an equivalent of 12.65% by the use of the compound engine with jacketted cylinders, compared with the single engine with jacketted cylinder.

High Steam Pressure, and High Piston Speed. Investigations which have been made show invariably that, other things being equal, the higher the steam pressure the greater the economy. The saving however, decreases rapidly, using the ordinary engine, after a pressure of 80 pounds has been reached, so much in fact that is doubtful if pressures above 100 pounds would give sufficient gain to counterbalance the increased expense in construction and maintenance of boilers. Little information can be obtained about engines particularly designed for pressures above 100 pounds, but it is probable that particular cases might warrant it. Within the limits of ordinary practice, the saving by the use of higher pressures is very important, and some valuable information may be obtained from Engineer Emery's experiments before refered to. In the Dexter a gain of 20.73% is shown for an increase from 40 to 70 pounds pressure. On the Bache we find

Journal of the Franklin Institute June 1881.

a gain of 29.6% for an increase of 31 to 78 or 47 pounds. On the Rush a gain of 20.18% from 37 to 69 pounds.

The loss in the steam engine, which the expansive working cannot diminish, but, on the contrary, tends to increase it, is that which is due to cylinder condensation. Steam is only a medium of the conversion of heat into mechanical work; but before this conversion can be effected, a large part of its heat is lost. This part is for the most part by internal radiation.

Journal of the Franklin Institute, Jan. 1871.

Time is the necessary condition without which this wasteful action cannot take place, and the extent to which it proceeds, other things being equal, is directly as the time allowed. Hence we see from this that the higher speeds are the most economical. This explains how Mr. Isherwood, in his experiments on the Michigan, realized a loss rather than a gain by expansion, by running at such a slow speed.

From the report of the trial of the Corliss Pumping Engine at Providence, it appears that the duty of the engine when running at .866 revolutions a minute was 8,487,370 ft. lbs, with the consumption of 100 pounds of coal, and when making 10.167 revolutions per minute, the duty was 25,865,740 ft. lbs. In the first case the duty was only one twelfth of the duty of the best engines, and in the latter case only one fourth the duty. We see the great gain of this increase, but if the engines were smaller, and ran at 80 revolutions we should see a duty much greater than either stated above.

Part II

Third Factor - That of the efficiency of the different combinations of mechanism.

Marine engines are now divisible into two great classes, Paddle Engines and Screw Engines. These may again be divided into Direct-acting and Indirect-acting: The direct acting being, in the case of paddle engines, those which have no sway beams, such as oscillating engines, trunk engines, &c. In of screw engines all are direct acting except those connected to the shaft by gearing.

With either the screw or side wheel engine, the vessel is driven ahead by the reaction of the propelling instrument on the water, and in both cases there must be bearings to resist the thrust and transmit it through the ship. The amount of thrust can be measured by the dynamometer, and by multiplying the thrust by the space passed through in a given time, we have the useful power exerted in propelling the ship, and by comparing this with the indicated power, the loss by the slip and friction of the screw can be ascertained. The losses incident with the use of the paddle wheel can be determined by a similar process.

The following is an abstract from Bourne on the comparative advantages of the Paddle and Screw vessels.

With light head and beam winds it is found that paddle wheel vessels with the ordinary radial wheel, and screw vessels fitted with the common screw are about equally efficient. If however the vessels are loaded deeply the screw vessel has the advantage. But when a screw and paddle wheel vessel of the same model and power are set to encounter head winds, the paddle wheel has the advantage, not in speed, but in economy of fuel; the speed will be the same unless the wind is so strong as to bring the vessels almost to a standstill, and on that supposition the screw will have the advantage.

If a screw and a paddle vessel of the same model and power are tied stern to stern, the screw will predominate and tow the paddle vessel against the entire force of her engines. If however, they are tied bow to bow and the engines reversed, the screw will not predominate. He says, from this we must not judge that the screw is more efficient, but that the preponderance of the screw must be imputable to some other cause than the superior thrust of the screw. But I think this is sufficient proof of the superiority of the screw; and the reason why the paddle wheels were not overcome in the case was that the column of water from the screw struck the stem of the vessel, and thus produced sufficient resistance to counterbalance the higher power. In the first case this same force of the column sent out from the screw was in favor of the paddle wheel, and against the screw, only differing in degree from the second case.

As regards the transportation of merchandise in paddle, screw, and sailing vessels. The comparative cost depends on the locality where the comparison is made; but an auxiliary screw vessel will convey merchandise at one-third the cost required for the full power paddle wheel steamer, and for coasting purposes it appears that the screw steamer is about one third less expensive than a sailing vessel, the greater expidition of the screw steamer much more than compensating for the expense which the maintenace of the machinery involves. We see therefore that the screw engine is the one which is most economical to use, and now the great majority of marine engines are screw engines.

The following are the results of experiments made on the U.S. Steamers "Spencer" and "Mc Lane," as calculated by Mr. Isherwood.

Engineering Precedents, pp. 117-121.

The Spencer was propelled by a Loper screw, and the McLane by the common paddle wheel. When influenced by no wind or current, the economical efficiency of the screw was 31½ % greater than that of the paddle wheel. There is a decided gain in favor of the screw, but it must be borne in mind that neither the screw nor paddle wheel were by any means perfect. In case of strong winds on the bow, and turbulent sea, the efficiency was 62 % more for the screw than for the paddle when measured by the net power applied, and 57 4/5 % when measured by the gross power. With a strong gale on the quarter, and turbulent sea, the efficiency of the screw was 37% more than the paddle wheel when measured by the net power, and 31.6 % more if the gross power be taken as a measure.

The general result of these experiments measuring the cost by the net power applied shows a very decisive gain for the screw, and if the comparison be made with regard to the fuel consumed, the efficiency was the same in calm weather; with heavy seas and wind on the quarter 6% in favor of the screw; with head winds and heavy sea 29% in favor of the screw.

There are other things of convenience which advocate the employment of the screw even more perhaps than those stated above. When using the auxiliary power of sails, the screw can be easily lifted from the water, thus preventing any drag, beside this there are no paddle boxes which are in the way when using sail. With the screw the machinery is always below, leaving a clear deck room, which is a great advantage, especially in heavy weather.

J. Scott Russell on Naval Architecture.

The Size of Engines. The size of the engine is governed by the work which it has to accomplish, and by the size of the tool by which it does it. The paddle engine is governed by the wheel in so much as a long stroke, and consequently a long crank is leverage for the engine, while a long arm in the wheel gives power to the waves, and is leverage against the engine. A long stroke against a small radius of wheel is power, speed, and durability to the engine. The maxim for successful steam navigation is "A wheel no larger than is necessary to the ship, and a stroke as long as you can conveniently get it." To reduce the size of the wheels feathering is a great auxiliary. To use a long stroke efficiently, high steam pressure, superheating and expansive working are our powerful allies.

According to Russell, in good practice, the range of proportion of length of stroke to diameter of wheel is from 1/3 to 1/4. If the wheel is large and narrow with light work to perform, the ratio should be about 1/4; if short and broad with heavy work, such as towing, it should be about 1/3.

With the screw engine there is no similar proportion between the diameter of the screw and the stroke, but there must be a fixed relation between the pitch of the screw and the stroke. With paddle wheels the ship is driven through the length of the circumference of the wheel, and with the screw through the length of the pitch of the screw, for each double stroke, due allowance being made for slip in both cases.

The usual proportion of stroke to pitch is from 1/6 to 1/7. From this we see that the piston speed for screw engines is much higher than for paddle engines.

The reason why slow piston speed is not suitable for screw engines is, because the pitch cannot be made as great as the circumference of of the paddle wheels. The paddle wheel is a direct acting propeller, while the screw is oblique acting, and if the thread is too large, too much power is wasted in driving the water across the wake of the vessel instead of along it. The pitch is not generally made more than one half the diameter, now we cannot have a screw as great as the draft by three or four feet, whereas the paddle wheel can be as large as we please to make it, and we can obtain from this three times the speed of the propeller. High speed therefore is necessary for screw propulsion.

Paddle Wheel Engines. The old walking beam engine so much used in our own country, especially for river and coasting purposes, is doubtless as true and good a method as any for transfering the power from the piston to the crank; and it has stood the test since the first days of steam engineering. A sketch of the engine of the riverboat Reindeer may be seen in plate I. This is a good illustration of American river and coasting engines. The style is varied by having instead of one beam above the cylinder one on either side, that is two for each engine. The last form has been very successful as an ocean engine. It has the advantages among which are:- The necessary parts can be stowed away very conveniently between the cylinder and the engine shaft. Its parts are easy of access for inspection and repairs.

But that thing which tends to diminish its merits is the roominess. It is too bulky and heavy for modern ships, especially for war purposes, which require that the engine shall be light, compact and powerful. On this account the side lever engine has not been used more generally, especially for screw propulsion. The large tracing shows a section of the engines of the Mail Steamer Humboldt. It shows the general form of side lever engines, and is so plain as to need no explanation. It resembles in it's general appearance the engines constructed by Messrs Caird & Co. Greenock, for the vessels of the original Royal Mail Steam Packet Company; also those of the "City of London" built by Messrs. Napier of Glascow. All of these engines have given entire satisfaction for many years.

A great many direct acting engines were invented, but the great trouble with them all was, that, on account of the length of the connecting-rod and piston-rod, the shaft was elevated about three times the length of the stroke from the top of the cylinder. To obviate the undue elevation of the shaft, Mr. Penn invented his trunk engines.

which allowed the shaft to be lowered to the length of the crank above the cylinder. There is great prejudice against the trunk engine by some engineers, and for my own part I would rather use the oscillating engine.

The double cylinder engine of Messrs Maudslay was constructed with the idea of getting rid of the trunk without raising the shaft extremely high, and for saving room by the dismissal of the side levers. They imperfectly fulfilled this latter indication for they save very little room. The two piston rods rise and fall at the time, and by a division between the cylinders it becomes practicable to introduce a cross-head between them, whereby the necessary length of connecting rod becomes attainable without giving an undue elevation to the paddle shaft. This is done by connecting the rod to the end of a T cross head, the perpendicular part of which descends between the cylinders and is guided thereon. This engine has never be come very popular or general, but the oscillating engine which is a very much better species of direct-acting engine has obtained a very wide introduction.

Messrs Penn's oscillating engines, as shown in Plate II. are the engines of the Admiralty Steam Yacht Black Eagle. These engines have attracted great attention as being the first oscillating engines applied to large vessels. In beauty, workmanship and efficiency they are fine engines, and during the trial they were found so satisfactory as to induce the Admiralty to order more engines of the same kind.

The oscillating engine has now come into universal favor for marine purposes, when the vessels are propelled by paddle wheels. Some objection is made to this sort of engine on account of the moving of the cylinder, which it is claimed would be a formidable evil in case of a ship in heavy sea. The objectors do not seem to have remarked that the movement of the cylinders is independent of the movement of the vessel.

Beside, is this any worse than the movement of a similar quantity of matter in the form of side levers? The oscillating engine occupies small space, consists of few parts, and is easily accessible in case of repairs. It is strong and light at the same time, and seems to be one of the best single engines for paddle wheels for marine purposes.

Among the most efficient of the compound engines are the three cylinder engines of John Elder. In this engine the low pressure cylinders are so constructed, that the power generated in them is equal to that obtained from the high pressure cylinder. The cranks ~~are~~ of the low pressure are parellel, and on the same side of the shaft; that of the high pressure is parellel with them but is diametrically opposite. The cylinders of two engines are inclined to each other, and when one engine has reached the dead point the other is past it.

There are many other forms not very much used.

Screw Engines. The modern screw engine is the great puzzle which has set engineers to thinking, and as a result of their labors we have a multiplicity of forms. A higher piston speed, shorter stroke, and consequently a higher number of revolutions are the three difficulties with which they had to battle. Another great difficulty which appeared was the driving of the shaft so near the bottom of the vessel. This seemed to be an insurmountable obstacle, and it was evaded rather than overcome, by driving a gear by the engine and the shaft by the gear. This is a clumsey method, although it has been greatly used, and even in some modern ships. This is not the true method to adopt for screw propulsion. When the screw was first used for propulsion it was thought to be a less evil to use gearing than to run at such high speed as was required; but now we know that high piston speed is conducive to economic results, and beside this, the engines have been greatly improved. When using the geared engine the whole machinery must be a great deal larger than the direct acting engine. This increase of bulk and weight is an increase of expence, and a loss of room in the vessel. Even if there were no gain in high piston speed, yet these latter considerations would be sufficient to give the direct-acting the preference. For these reasons the direct-acting engine is to be considered as the *screw engine proper*.

The list of all the engines built would be a long one, especially if it comprehends all the geared engines, and all those forced conceptions which are gradually disappearing, in order to adopt the most simple, such as the oscillating, trunk, horizontal with direct and return action, the inverted type, and the inclined engines. And one might say, indeed, that omitting those mentioned, the vast number of inventions have only injured the marine engine, by a complication entirely useless and even hurtful to navigation.

Let us first consider, as in the case of the paddle engine, the oscillating engine. This is the only vertical engine which is placed directly under the shaft, and when great power is required this is difficult, and the method adopted is that of inclining the engine; a great many of these engines are used in foreign countries, but not much in our own country. We have already spoken of the simplicity and accessibility of its parts and the saving of space and weight.

The inverted engine is a good form, especially for merchantile purposes, but for war purposes it is too exposed. There is room enough to lengthen out the connecting-rod by raising the cylinder, and thus obtaining direct connection. There is only one disadvantage in this form, and that is the top weight of the cylinders must be ballasted, for this weight is quite sensible when the coal bunkers are nearly empty; but this objection is slight, and for merchantile purposes where the cargo is ballast, it can be entirely removed. The arrangement is good and has been used by Thomson, Elder, and other builders in Europe, and by many of our own makers. A short time ago a new steamer, the "City of Santiago" was in this port, and some of class '76 visited her. The engines are of the inverted type, compound, with an intermediate reservoir between the cylinders; the cranks are at right angles with direct connection; the cylinders were covered with a nonconducting material, and were not steam jacketted; a surface condenser with an independent pump for a circulating pump; feed pump connected with the engine, and an independent feed pump; variable cut off, worked in heavy weather by a water pressure governor, double eccentrics and link for each cylrider; reversing gear &c. &c. I liked very much the general arrangement. Tracing No. 2. is a very good example of these engines. It shows the general arrangement of parts so well, that there is no need of any description. I said it was a very good example, I am afraid that it is <u>too good</u> for ordinary engines.

But by far the greatest number of engines, especially for war and ocean purposes are those belonging to the horizontal type. When these were first attempted, the engine was so made, that the entire weight came on one side of the vessel; but this was overcome by Mr. Penn, who placed the condenser and air pump on one side and the cylinder on the other side of the shaft. It was considered an evil to remove the condenser from the cylinder, but this is a comparatively small evil and is willingly and graciously accepted. Plate III. shows a sketch of Mr. Penn's trunk engine. This symmetrical arrangement of parts forms the standard of some of the best American, English and French builders. At the Atlantic works in East Boston, the standard for ocean and war purposes is the compound, back or return action engine with the cylinders on one side and the condenser and air pump on the other side of the shaft. Another way of arranging the parts, is to have two engines split, so to speak, there being the cylinder of one engine directly opposite the other's air pump. In this way the condenser is not seperated from the cylinder. Among the horizontal class come also the twin engines which are either separate engine on both sides of the shaft, or are driving two shafts.

There are the inclined engines, a great many of which are used. We have spoken of the inclined oscillating engine. John Elder's three cylinder engine which has been explained as used for paddle wheels, requires only a few changes of detail to apply it to screw propulsion, I take this as an example of all the inclined engines.

From what I have said about Mr. Elder's three cylinder engines, the reader may suspect that I am partial to his engines; and so I am, for I think that the arrangement described is the most perfect arrangement yet devised, and the duties of these engines have been very high.

Details.

The various conditions of space and purpose to which different engines are applied have produced this variety of forms, and if it has contributed to producing some perfection of detail, it has also been injurious in creating a confusion, and even in making too-much give way to the desire of manufacturing newer inventions.

But this multitude of arrangements has gradually reduced to those engines already mentioned, with very a few exceptions.

Every engine has its indespensible parts: the cylinder with its piston,

piston-rod, and crank: the motion is always transmitted by a connecting-rod; the necessary parts as the valves, the condenser, the air pump and feed pumps, are destined to the same functions in all engines. Nevertheless they are worked by numerous combinations of known movements. But what are the best forms of the details? This is a very unsatisfactory and almost unanswerable question, but it may be answered in a general manner as follows, "Simplicity of construction and access for repairs." To answer this in a fuller manner, we must consider each detail seperately, and try to ascertain which form is best.

Condenser. The jet condenser is very simple, while the surface condenser is complicated and expensive. It requires for surface condensation three or four times the amount of condensing water as with the jet condenser, and to supply this water work must be done by the engine, and although it requires a smaller air pump, yet the work of the circulating pump will more than counterbalance this. But the great saving in the boilers by using for feed water fresh water, and the water of condensation is more than sufficient to warrant the increase of expense. The saving is great by preventing such frequent blowing off as is required with salt feed water, and in boilers themselves by preventing such incrustations as is injurious to the boiler, and detrimental to the production of steam.

The following is an abstract from an abstract from the log of one of the Pacific Mail Steamers.

Under similar circumstances there is a gain of 18% realized by the use of the surface condenser, over the jet condenser as shown during five trips lasting 163 days with the surface condenser, and five trips lasting 164 days without the surface condenser. With the jet condenser, the water entering contains 5% of air which expands and impairs the vacuum; all the injection water together with this air must be discharged by the air pump. In warm climates so large an amount of injection water is required, that sometimes to relieve the engine of the enormous load caused by the increase of work by the air pump, a less quantity is used and consequently a less vacuum is produced; the loss of power from this cause being less than that from overloading the air pump. With surface condensers the air and water does not enter into the vacuum space; only the water contained in the steam (being only 1/15 to 1/45 that part required above) is discharged by the air pump, consequently a smaller pump is required, and a better vacuum obtained. There is also a large cooling surface exposed to the steam, and the condensation is more nearly instantaneous.

In the middle latitudes 10% of the power is required, or allowed rather, to work the air pump, with the jet condenser. The power required to work the pump, independent of the friction, varies as the amount of water discharged. Hence there is a great saving in favor of the surface condenser.

The following is an estimate of the value of the gain referred to.

First.	Less power required to work the air pump ----------	.05
Second.	Less heat blowout to keep the boiler at least partially clean ----------------	.12
Third.	Heat lost by incrustation, sometimes more than 20%	.05
		.22
Fourth.	A high pressure can be more easily and economically produced.	

In this estimate there is no account of the extra work of the circulating pumps for surface condensation.

The forms of surface condensers, although very different, amount essentially to the same thing. The placing of tubes, whether vertical, horizontal or inclined is a matter of convenience as much as any thing else. It has been found better to pass the steam through the tubes, and the water around them. In tracing No. 1 can be seen the jet condenser, with air pump, injection pipe, hot well, &c. In tracing No. 2. can be seen the surface condenser in section, with the air pump.

There are some differences in the air pump, and circulating pumps which deserve notice. In some cases the air pump is single acting, with single acting circulating pump. Mr. Penn has used pumps where one end is the air pump, and the other end the circulating pump. Each one is single acting for the seperate duties, but double acting in arrangement. In some cases the circulating pump is independent of the engine, this is very common and very successful. The double action air pump has become universally used, for by this arrangement there is a saving of space.

There are two general positions, the vertical and horizontal, used according to convenience of design. In the section on Plate II is depicted the double acting horizontal air pump. And on both tracings single acting vertical pumps.

Cylinders. We have already spoken of cylinders by saying that steam jacketting was advantageous. We have also spoken of the gain of compounding. A direct passage of steam is desirable from the high to the low pressure cylinder, but where this cannot be done, as when the cranks are at right angles, there must be an intermediate reservoir between. For the direct acting engine, the single piston rod arrangement is the most efficient, the trunk arrangement causing too much friction, and too much cooling surface, while the packing is more troublesome to keep tight. With the return action engine the double piston-rod cylinders are sometimes used.

The pistons now in use are generally made with spring or steam packing; with the latter there is no difficulty about keeping the piston steam tight, which was once a difficult thing to do with high pressures and superheated steam.

Relief valves should be fitted to all cylinders to prevent accident, by allowing the escape of water caused by priming of the boiler, or by any other cause. These are shown in tracing No. 2.

To warm the cylinders and cause a vacuum in the condenser before starting the engines, supplementary valves are necessary These are called blow-through valves.

Slide valve. The steam engine is indeed a poor affair when the slide valve is out of order. it is from this cause that many productions are introduced to accomplish the best effect. The valve mostly used in the present day is that type known as the double ported equilibrium. The valves now made are very large, and a great amount of surface is exposed to the steam pressure, which would produce such a pressure on the valveseat as to make it almost impossible to move it. The power requisite to move the slide valve can be easily estimated. It is only required to know the surface, the steam pressure and the weight, together with the coefficient of friction. As the pressure times the surface forms the largest part, the reduction of the latter exposed to the direct action of the former is the only means of lessening the power required. And to accomplish this, we have the valves referred to above, in which there is packing at the back to prevent the action of the steam thereon.

Different firms used different sorts of packing, which probably are equally efficient in accomplishing the designed purpose.

Slide valve link motion, and starting gear.

The arrangement of the detail requisite to impart motion to the slide valve forms an important consideration in the marine engine. The combination is to produce three effects at will—Starting, stopping, and reversing. It would be a simple matter if only starting and stopping were required; but when reversing must be accomplished by the same gear, the simplicity and effectiveness of arrangements demand closer attention. Each maker escapes the other in design, yet all accomplish similar results. The most common form, and probably as good as any other, is the slotted kind with the eccentrics connected within the extremeties, and the suspending point at the centre of the link.

The requisition of this gear to raise and lower the slide valves, without motion of the crank or steam piston, has brought forth many combinations. In some cases the shifting rod is connected to a lever, the latter being keyed on a weigh shaft, and motion imparted by a worm and toothed quadrant, In other instances a pinion and wheel have been preferred; while a third example dispenses with the wheel, and the rod is connected with the shifting rack, the latter being worked by a pinion. But the simplest form is the direct action or sliding motion, where the motion is communicated by a screwed rod, this being worked by a wheel or by gearing. Hand power for raising the link is, after all, a slow process, and scarcely suitable for large engines. It is for this cause that supplementary engines are often introduced, termed "steam starting gear".

Expansion valves and gear. We have already spoken of the gain by using steam expansively, and we should say a word about expansion gear by which the cut-off can be changed at will. The cam expansion gear is much used. It consists of a series of cams, placed side by side, any one of which may be thrown into gear, every one produces a different motion. Then there is the eccentric expansion gear, in which the motion of the eccentric is so transmitted to a rotary valve through a system of levers, that the position of the levers being changed, the cut-off is changed. But the best form is the expansion link, which is placed between the eccentric and the valves. This link is formed with a screw passing through a sliding block, which moves in a slot in the link. To the block is connected the eccentric and valve rods. The block is shifted by turning a screw rod passing through it, and the position in the slot detemines the grade of expansion. Independent of this there is the throttle valve by which the supply of steam is regulated. This needs no explanation. In tracing No. 2. can be seen the expansion valve, on the slide valve, but the mode of working is not shown.

Main frame. The frame supports the crank shaft, and resists the steam imposed by the piston rod; the aim of the designer should be to produce the most simple but correct form to perform the requisitions. It is generally made of cast iron, and an example can be seen in Plate III. which has the requirements requisite for this style of engine, but even with this aquisition some makers demur at adopting it. For beam engines the frame is generally made of wood, and in Plate I. it is shown in the usual form. For oscillating engines Plate II is a good illustration, and for "side lever" engines, tracing No. 1 is about the only style used.

Crank. The crank is an important part of the engine, and its manufacture is a tedious process, and somewhat scientific. Nearly all the makers follow the same design, that is, with counterbalance to compensate for the weight of the crank and connecting-rod affecting the motion of the piston.

Turning gear. When steam is not available on board, and when the engine requires repairs, it is obvious that the pistons must be shifted for inspection; or should the slide valve require adjustment, the position at each end of the stroke, and at other positions must be noted. When the screw propeller requires to be lifted from it's coupling a certain position is required. All these duties must be done independent of the engine. The most common way to turn the engine is by the worm and wheel motion. The wheel is a toothed arc on the end of the shaft, as shown in tracing No. 2. The worm is vertical or horizontal. In some cases this work is done by a donkey engine.

Feed and bilge pumps are about the same in all engines. With the direct acting engine they are most always cast with the condenser, and motion derived from the steam piston. With the return action they are generally beyond or at the sides of the guide channels. There should be some connection so that in case of a dangerous leak, the feed pump can use from the bilge. This ought not to be allowed however except in cases of necessity: this is for jet condenser. With the surface condenser it would be a good plan to use the bilge water as circulating water in case of a bad leak. In most cases now there are donkey feed pumps, which can be worked by an independent boiler, while the main boilers are lying still.

We must not slight the Kingston valve, which is fitted into the ships side, to admit sea water for injection, feed water, cleaning, &c.

As to the piston-rods, connecting-rods, cross-heads, bearings, stuffing-boxes &c. These are for the most part the same for all builders, and are about equally efficient in their duty, and there will be no need of expatiating on them.

The matter of thrust blocks, and screw alley fittings belongs to the subject of screw propeller, more than to that of engines.

Judgement as well as skill must be used in increasing the efficiency of marine engines- in practice; for their improvements, adds more or less to the expense, and thus the question arises- Whether the economy to be attained by the increase of efficiency will counterbalance the additional expenditure? In deciding this question, regard must be had to the length of the voyage, the speed, price of fuel, and nature of the traffic. If these are not taken into account, needless expenditures may be made, where, under the circumstances the great degree of mechanical efficiency was not needed. The engineer should also use some judgement as to the adaptation of engines of a given kind to a given vessel, intended for a certain trade.

And as Rankine says "Judgement and skill are the requisites of the engineer", so therefore ought judgement to be used in closing a thesis on a subject which is almost inexhaustible.

No. 1.

NOVELTY IRON WORKS

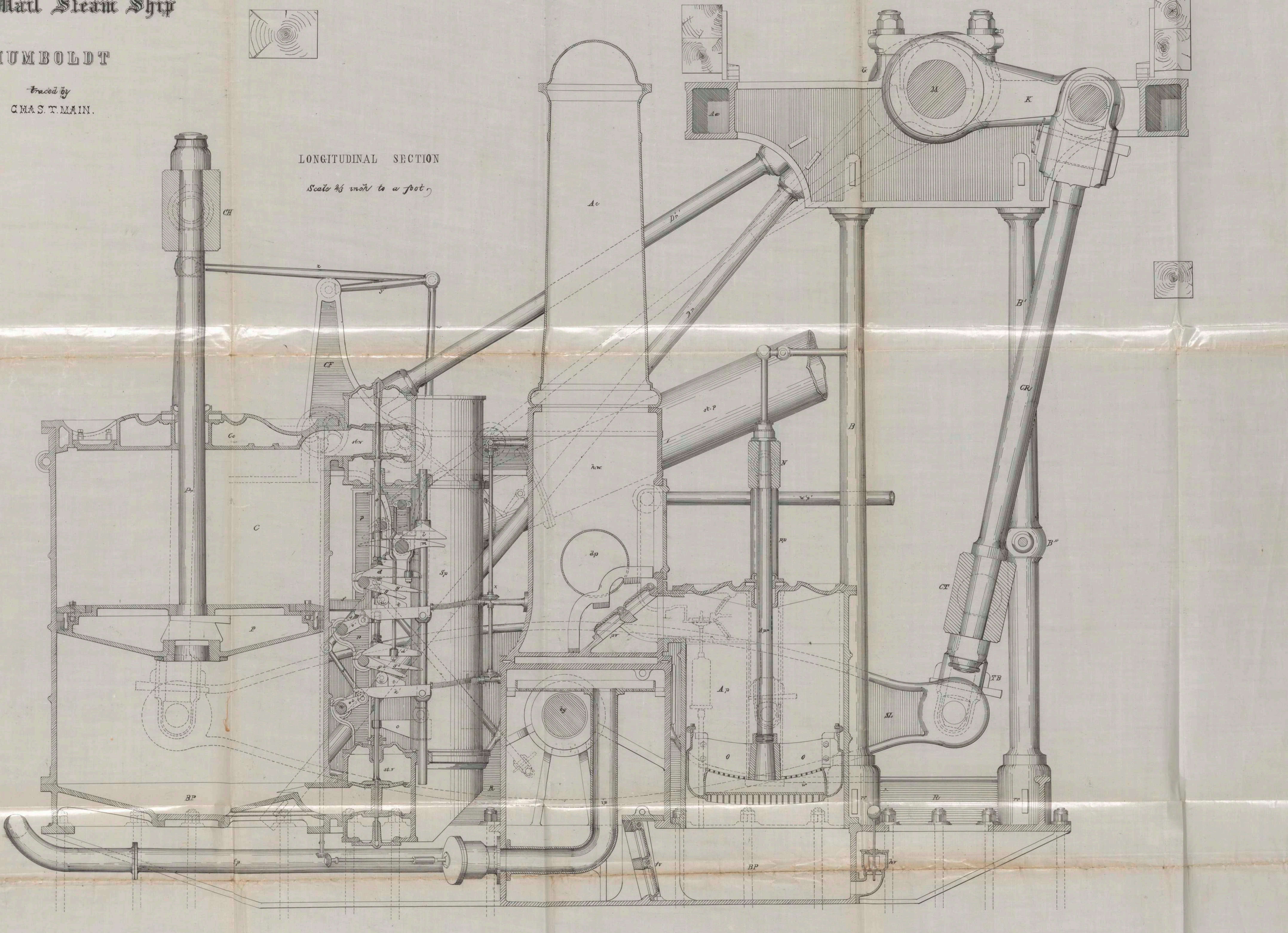
NEW YORK

Pair of Marine Engines
of the
U. S. Mail Steam Ship
HUMBOLDT

traced by
CHAS. T. MAIN.

LONGITUDINAL SECTION

Scale 2/3 inch to a foot



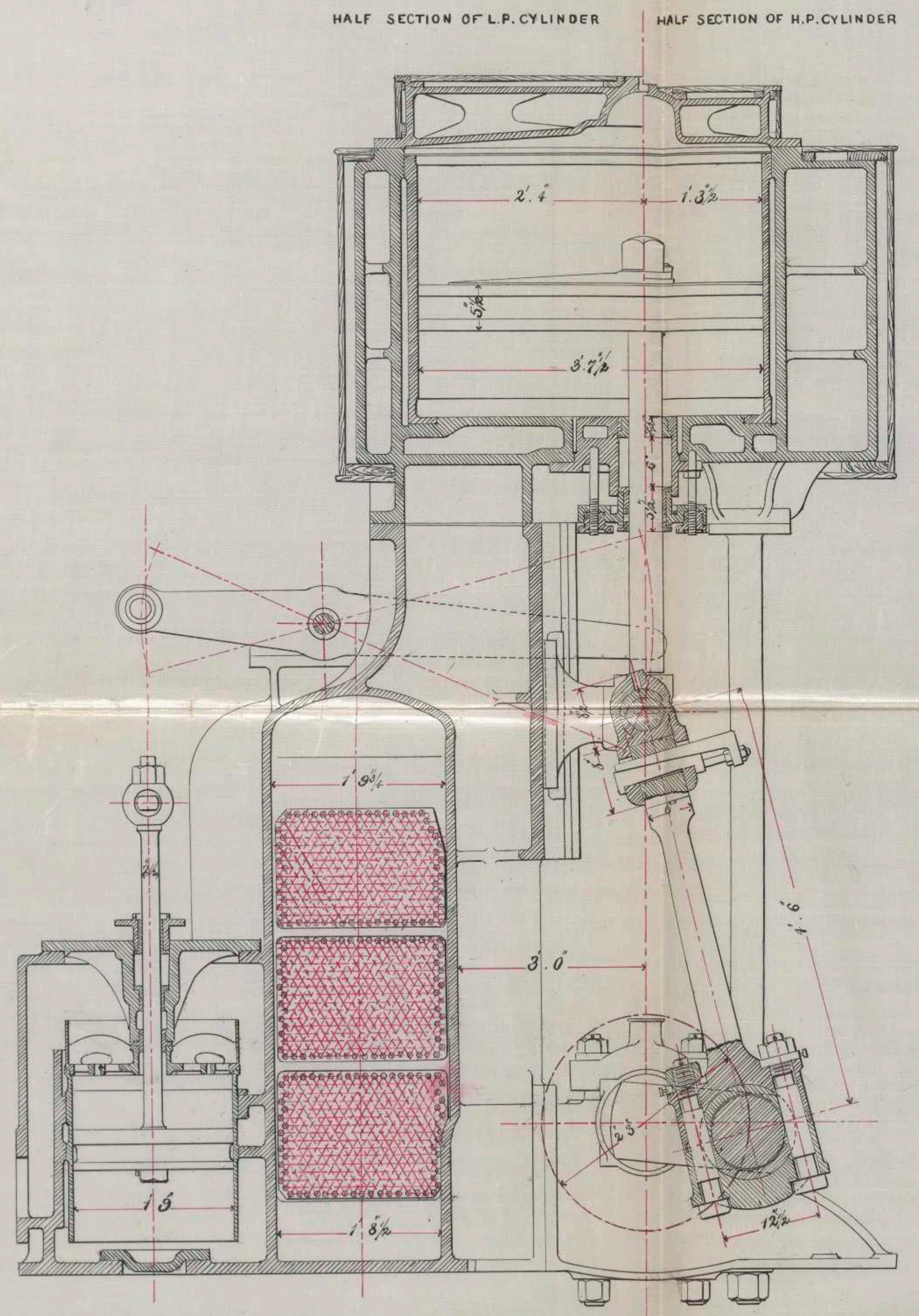
C. T. Main.

No. 2.

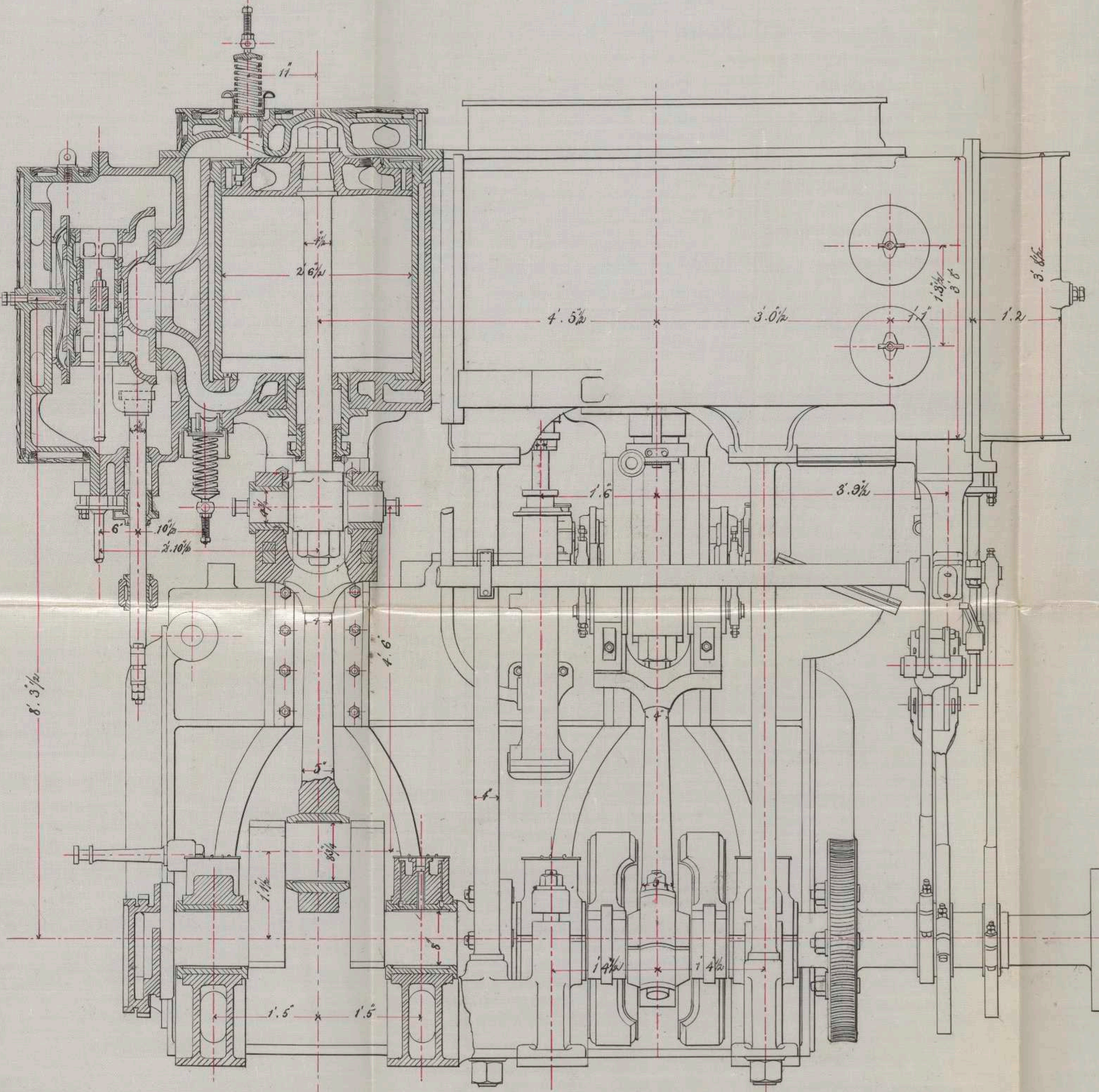
COMPOUND ENGINES 100 HP. NOML. COLLY. AS FITTED IN H.M.S. "HYDRA" & "CYCLOPS"

BY MESSRS JOHN ELDER & CO

1872.



END SECTIONAL ELEVATION



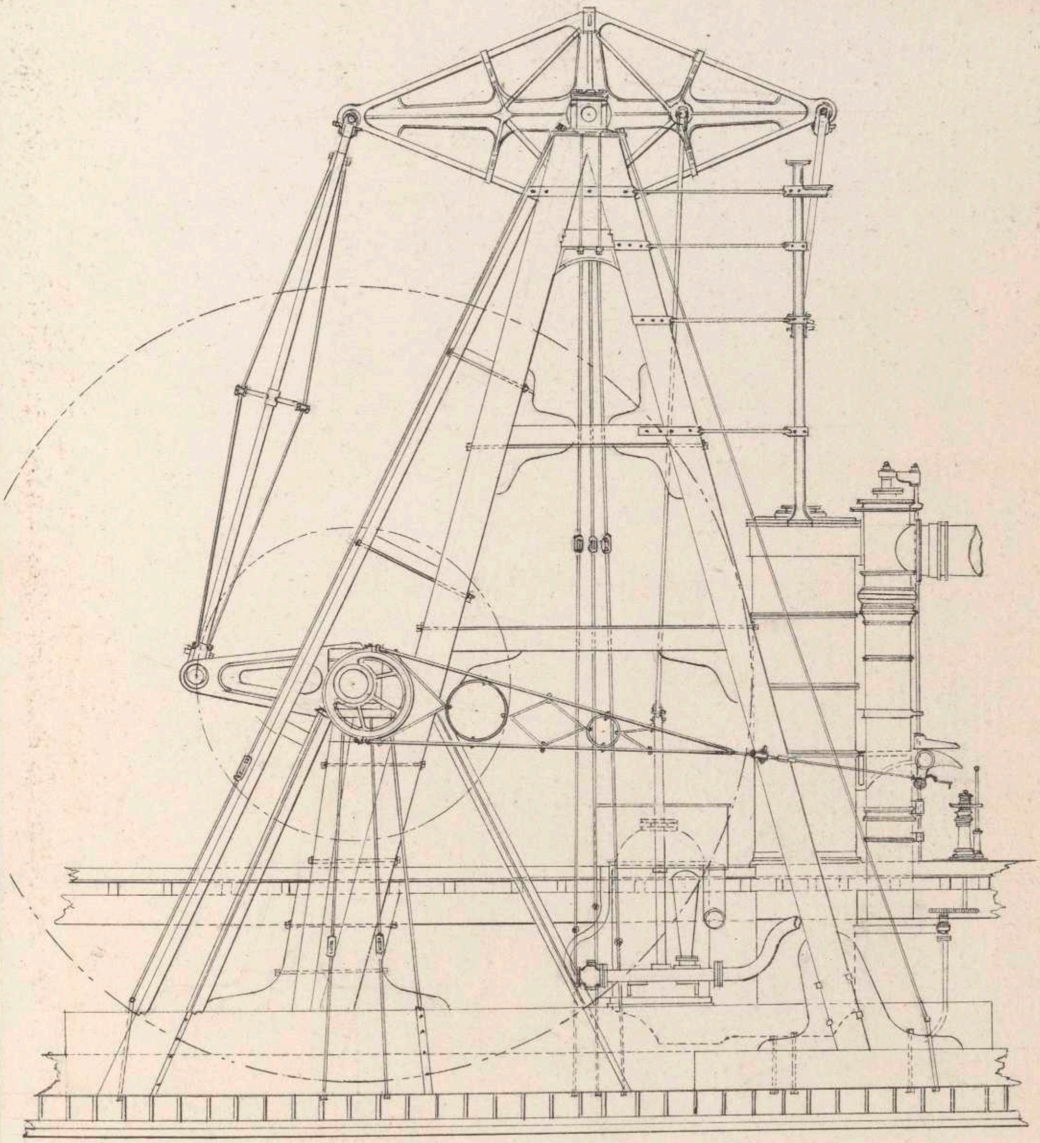
Scale ¾ Inch = 1 Foot.

Ins 12 9 6 3 0 1 2 3 4 5 6 Feet

Chas T. Main.

Plate I.

BEAM ENGINE.

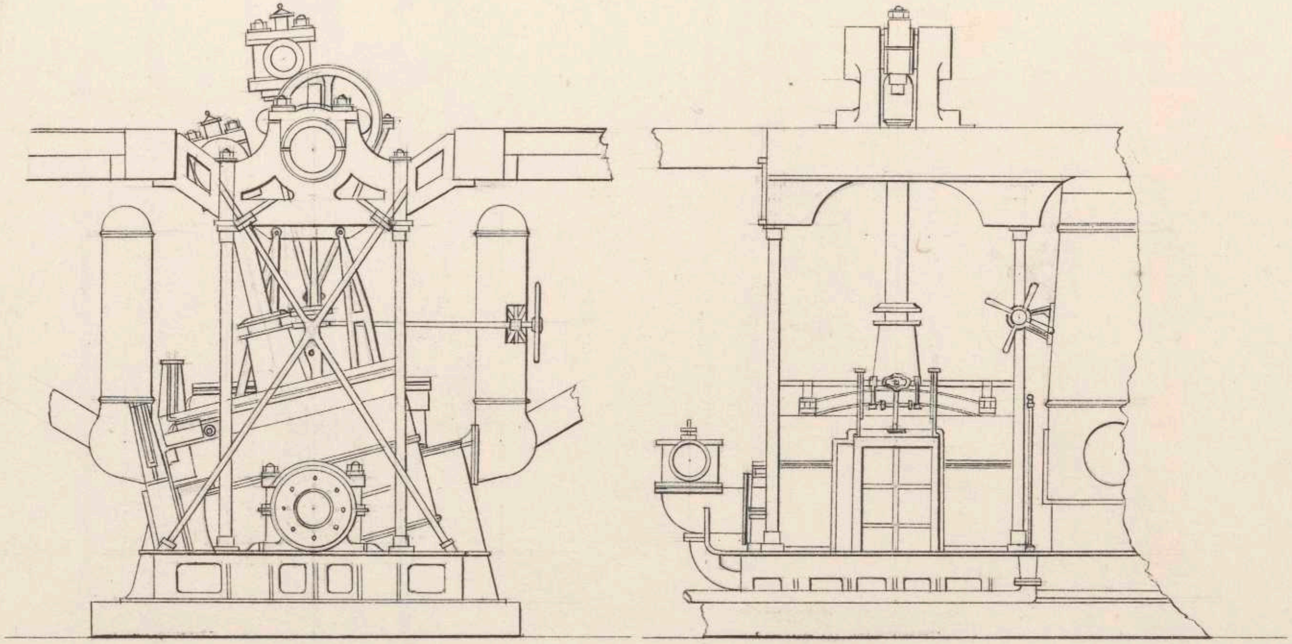


STEAMBOAT REINDEER.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 feet

Chas. T. Main

OSCILLATING ENGINE.



BLACK EAGLE D. 62¼ ins. S. 4ft. 6in.

Plate II.

Chas. T. Main.