the breast to the back, which was before perpendicular, is now inclined to the right, part of the upward reaction will be diverted to the right, and will therefore turn the bird in that direction. Of course the force thus diverted will be taken from that necessary to counteract gravity, so that the bird would fall if it did not compensate for this loss by increasing the angle to the horizon at which it was flying. So that if a bird wishes to turn to the right all it has to do is to elevate the left and lower the right side of the body, and at the same time elevate the fore and lower the hinder parts of the body; if it wishes to turn to the left, it will elevate the right and fore parts, and lower the left and hind parts, and the sharpness of the turn will depend entirely upon the angle that the wings, or rather the line drawn from tip to tip of the wings, makes with the horizon. This movement may be easily seen in the pigeon, gull, pheasant, or indeed in almost any bird.

Art. XVII.—*On Compound Engines.* By William Lodder.

[*Read before the Auckland Institute, 19th August, 1872.*]

The engines of the "Star of the South," as originally fitted, were inverted, low pressure condensers of the ordinary type, with cylinders of 22 inches diameter and 18 inch stroke; nominal horse-power about 27; they were manufactured by Hawthorne, of Newcastle-on-Tyne, in 1863.

In June of last year the boiler was found unfit for much further use. It then became a matter for consideration what kind of boiler should be adopted, and it was finally determined to put in a small multitubular circular boiler, capable of sustaining a working pressure of 80 lbs. per square inch at sea; also to compound the engines and introduce a surface condenser.

It was calculated that by adopting this plan a saving in fuel of one half would be effected, the speed of the vessel remaining the same as before.

Plans and specifications were prepared by Mr. James Stewart, C.E., at whose suggestion the compound principle was adopted, and the contract for the new machinery and alterations was carried out by Messrs. Fraser and Tinne, of Auckland, in a highly creditable manner.

For the benefit of owners of steamers and others unacquainted with the method of conversion of single into compound engines, it may not, perhaps, be out of place to explain more fully the plan adopted, because nearly every screw steamer running on the coast of New Zealand could be similarly converted, and with equally good results.

The engines were compounded simply by the addition of high pressure cylinders, of 9 inches diameter, fixed above the existing cylinders, the piston rods being lengthened to enable both pistons of high and low pressure cylinders to be fixed on one rod, while the same pair of eccentrics were arranged to work the valves of the upper and lower cylinders of each combined engine. The steam from the upper cylinders exhausts into the valve chest of the lower cylinders, exerting its remaining pressure in them. It then escapes into the surface condenser, whence it is conveyed back again to the boiler in the shape of fresh water at a temperature of about 135° Fahr.

Both of the old air-pumps are brought into use, one as a circulating pump to force the water through the tubes of the condenser, the other to operate in the usual way. By this system two separate compound engines are made, using the same condenser.

The high-pressure cylinders are steam-jacketed, as also are the covers of the lower cylinders and the exhaust pipes leading from the upper cylinders to the lower ones. There is also an interheater placed in the lower steam chest between the slide valves to assist in keeping up the tension of the steam. The supply of steam for the jackets is taken from the superheater at a temperature probably of 350° Fahr.

The surface condenser is cylindrical, and contains 735 brass tubes, four feet long and five-eighths of an inch outside diameter, giving a cooling surface of 465·5 square feet, the tubes being fixed into brass tube plates with screwed glands and indiarubber washers.

The boiler is 7 ft. 3 in. in diameter by 9 ft. long, having two furnaces 2 ft. 2 in. by 6 ft. There is a superheater with the uptake passing through it, and the total heating surface, including the superheater, is 502·56 square feet.

These combined engines are of 38·8 horse-power, by Watt's rule, and 45 nominal horse-power by the Admiralty rule; the ratio of cylinder areas is as 6 to 1 nearly, all four cylinders cutting off at three-quarter stroke, so that the steam is expanded about eight times.

On the trial trip the boiler pressure was 80 lbs. per square inch, and the diagrams taken by Mr. Stewart, Government Inspector of steamers, showed an initial pressure of 72 lbs. per inch; mean pressure 61·75 lbs., and the terminal pressure, 37·5 lbs.; average number of revolutions per minute 80, indicating 58 horse-power for the upper cylinders.

The effective pressure in the lower cylinders was only 7·6 lbs., indicating 42 horse-power, making a total of 100 indicated horse-power for the combined engines, with a consumption of 376 lbs. per hour, or 3·76 lbs. per indicated horse-power per hour.

The diagrams also showed that the steam in the lower cylinders is under atmospheric pressure, hence the smallness of the power in them as compared with the power given out in the upper cylinders. There ought to have been at least from 5 to 6 lbs. above the atmosphere in the lower cylinders.

Another important matter in connection with these engines is a loss of from 8 to 40 lbs. of steam between the boiler and the engines. The writer is at present unable to account for so much loss as this, unless the steam pipes be too small.

Since the trial trip a number of indicator diagrams have been taken, and these show, without the supplementary steam jet, a positive pressure on the lower cylinders of from 2 to 3 lbs. per inch; the deficiency is at present about 3 lbs., lost from condensation of the steam passing from one cylinder to the other, and filling up the steam passages in the lower cylinders.

The fact of not having any steam at or above atmospheric pressure in the lower cylinders at first, must be attributable to the steam jackets and interheater not working properly, probably through some of the cones being left in the upper cylinders, or from some other obstruction in the steam-jacket pipes.

COMPOUND ENGINES.

A.						C.								
Departure from Auckland.	No. of Hours on Passage.	Departure from Napier.	No. of Hours on Passage.	Total No. of Hours on Voyage.	Average Boiler Pressure.	Mean Pressure.		Revolutions per Minute.	Vacuum on Gauge.	Indicated Horse-power.		Coals Consumed.		
						Top Cylinder.	Lower Cylinder.			Top Cylinder.	Lower Cylinder.	Per Voyage.	Per Hour.	Per Indicated Horse-power per hour.
					lbs.	lbs.	lbs.		in.			Tons.	cwt.	lbs.
Dec. 30	50·5	Jan. 4	71	131·5	80	...	...	80	24	...	...	27·6	4·2	..
Jan. 11	59	,, 16	75	134	77	62·5	10·65	78	24	56	51·2	27·5	4·2	4·3
,, 22	57	,, 26	60	117	77	...	...	79	24	...	..	24·6	4·2	4·3
,, 30	50·5	Feb. 3	59	109·5	76	...	...	78	24	...	...	23·42	4·28	...
Feb. 9	59·5	,, 13	53	112·5	76	62·8	10·65	78	24	56	51·2	24	4·28	4·3
,, 21	48·5	,, 26	51·5	100	78	...	...	78	24	...	...	21·4	4·28	...
Mar. 1	59	Mar. 6	59	118	78	...	...	78	24	...	...	25·2	4·28	...
,, 12	71·5	,, 20	54·5	126	77	...	...	77	24	...	...	26·9	4·28	...
,, 25	62·5	,, 29	67	129·5	77	...	...	77	24	...	...	27·7	4·28	...
April 3	54·5	April 8	66	120·5	78	...	...	78	24	..	...	25·78	4·28	...
,, 20	48·5	,, 24	94·5	143·5	78	...	...	..	24	...	...	30·7	4·28	...
May 4	61·5	May 8	58	119·5	77	...	...	...	24	...	...	25·5	4·28	...
,, 13	47	,, 17	60	107	78	...	...	...	24	...	...	22·89	4·28	...
,, 21	54·5	,, 25	70	124·5	...	...	..	...	24	...	...	26·2	4·28	...

OLD ENGINES.

B.					D.			
						Tons.	cwt.	lbs.
1871.		1871.						
		Mar. 3	61	61		21·6	7·09	7·94
Mar. 8	58	,, 12	87	145		51·4	7·09	...
,, 26	60		...	60	It is assumed that the old engine worked up to 100 indicated horse-power, as there was no counter fixed or means of taking diagrams.	21·29	7·09	..
Apr. 13	56·5	Apr. 19	54	110·5		39·17	7·09	...
,, 25	57	May 1	56	113		40	7·09	...
May 6	66	,, 11	69	135		47·85	7·09	...
,, 17	52	,, 23	71	123		43·6	7·09	...
,, 31	60	June 6	60	120		42·8	7·09	...
June 13	55	,, 17	68	123		43·6	7·09	...
,, 24	54	,, 29	59	113		40	7·09	...
July 5	47	July 10	62	109		38·6	7·09	...

The Tables on page 146 will show at once the comparative results of the two systems in point of economy and speed. Tables A and B are an extract from the ships' log by the chief officer; they show in the first place the average number of hours on the passage each way.

It will be well to notice a coincidence between Tables A and B in point of time on the down trips. Table A gives an average with the compound engines of 56 hours for the down trips from Auckland to Napier, and 64·17 hours for the up trips from Napier to Auckland—thus making the down trips in twelve per cent. less time than the up trips.

In working out the averages in Table B, very nearly the same result occurs. The down trips made with the old engines took 56·5 hours, and the up trips 64·7, being twelve per cent. quicker on the down trips, the same as with the compound engines. The result gives for Table A one per cent. in favour of the compound engines in point of speed, taking the average of five months' running.

Table C shows the consumption of coals with the compound engines for the voyage per hour. Table D shows the same for the old engines.

On comparing C and D we find a saving in fuel of 42·1 per cent. with the compound engines, and this, with the increase of one per cent. in speed, requires for its attainment three per cent. more power.

This consumption does not include the coals used for banked fires, cooking purposes, or steam winch. I have made the same deductions for Table D as for Table C for these purposes.

With regard to the general working of these engines up to the present time there is every reason to be satisfied. Certainly there has been one source of annoyance, and that has been the excessive priming, actually in some instances taking the water right through the engines into the surface condenser; but since the addition of another steam dome on the boiler, connecting it with the superheater, the excessive priming has ceased, but the water still rises in the gauge-glass several inches above its true level. I find from inquiries that this is the case, more or less, in all boats using surface condensers, even with low-pressure steam.

Before going into the various questions that arise with reference to priming, the chemical and electric actions of the steam and water on the boiler, I shall endeavour to show by comparison, theoretically, the superiority of the compound principle. I have stated my belief that nearly every screw-steamer on the coast of New Zealand could be similarly converted, and with equally good results. Supposing we take two examples with a similar class of engines, to those in the "Star of the South," but much larger—say one of the steamers now plying on the coast (s.s. "Phœbe"), of which I have been furnished with dimensions of engines, consumption, etc. We have to find from the data given, first, the approximate indicated horse-power; the quantity of water to be evaporated to supply the engines at a given speed and pressure, with a given known consumption. Secondly—To calculate in the same way the results that would probably be obtained if the same engines were converted into compound engines.

This seems to be a subject of importance to every one concerned or interested in the use or science of steam, but it must not be understood that I pretend to satisfactorily solve the question of the superiority of the compound principle, but to bring it before the notice of this Society for discussion.

At the same time I shall endeavour to show the results of a few simple calculations from the three different examples given.

Commencing then with the before-mentioned examples of engines, whose cylinders are 44 inches diameter, with a piston speed of 297 feet per minute, and an initial pressure of 15 lbs. on the square inch, cutting off at $\frac{5}{8}$ of the stroke, and a mean vacuum of 26 inches, the consumption of coal being 18 tons per 24 hours, or 15 cwt. per hour. Working this out in the usual way, these engines might be expected to indicate 7·11 horse-power, and the quantity of water that would have to be evaporated to supply the engines at the above-named pressure and speed is 241 cubic feet per hour. This is equal to one pound of coal evaporating 10 lbs. of water in the hour, or a consumption of 2·36 lbs. per indicated horse-power per hour.

Secondly.—We will now compare the above results with what would probably be obtained if these engines were compounded with two high-pressure cylinders (similar to those in the "Star of the South") of 22 inches diameter, with a boiler pressure of 80 lbs. per inch, and cutting off at half-stroke in all the cylinders. Still retaining the same piston speed, we shall have for the upper cylinders an initial pressure of 75 lbs. per inch, the mean pressure 63 lbs. The initial pressure in lower cylinders being 9·375 lbs., the back pressure in upper cylinders will be 54 lbs. per square inch, and the ratio of expansion in upper cylinders being 2 to 1, the terminal pressure equalling 37·5 lbs., from which data, using the same formula as in the preceding examples, the two high pressure cylinders would indicate 372·4 horse-power.

The ratio of the areas of the upper and lower cylinders being 4 to 1, the initial pressure in lower cylinders will be say 9·3 lbs., cutting off at half-stroke; mean pressure = 7·6 lbs., but deducting 3 lbs. for loss of steam travelling from one cylinder to the other, and condensation, we shall have a total effective pressure of $4·6 + 13 = 17·6$ lbs. in lower cylinders, which will give 481 horse-power for the lower cylinders, making a total of 854 horse-power for the combined engines, and this with the steam expanding eight times to one.

The quantity of water required to be evaporated to supply the engines at the speed and pressure above stated will be 165 cubic feet per hour; allowing then the same quantity of coal to evaporate the same number of pounds of water (same as in the first example) this will give a consumption of 8·9, or say 9 cwt. per hour, with an increase of power equal to 143 horse-power more than in the preceding example, and the consumption would be 1·2 lbs. per indicated horse-power per hour.

Taking this then as a purely comparative statement, it shows an increase of power and at the same time nearly 50 per cent. saving of fuel. It must not be taken to mean that these calculations which leave out many sources of loss of heat and force, are likely to be attained in practice in any altered engines, but the least result of 1·2 lbs. per indicated horse-power per hour has been surpassed by compound engines.

It has been stated by some that equally good results could be obtained with using high-pressure steam in single cylinder engines, and cutting of at a fractional portion of the stroke. There are objections to this plan; for instance, in expanding the steam say 6 to 1, as in the other cases, the terminal pressure would be very great, and totally lost as far as exerting any power is concerned, unless it was a very long stroke, and this for screw-engines is impracticable; besides, the vacuum would not be nearly so good, and there would be more loss by condensation than with compound engines.

The compound engine uses the steam down to its very lowest pressure, and none is lost, except a little by condensation, and this can be reduced to about 1·5 lbs.

From what has been advanced it will be seen that there can be little doubt of the superiority of the compound engine in point of economy over the old system with low pressure steam and jet condenser. There is not such a low consumption per indicated horse-power with the "Star of the South's" engines as is stated to be got on the trial trips at home from some of the large boats, but the surest test is, when knowing the consumption and speed of a certain vessel with the old system to compare the obtained results after conversion, as has been done in the "Star of the South's" case, and a saving in fuel proven, of 42·1 per cent., after six months running, with no diminution in speed, but an increase of one per cent., as shown by the above tables; and no doubt even a better result would be obtained with new compound engines than by converting old.

If we consider the two theoretical examples given we find a very small consumption per indicated horse-power. There is no doubt but a very great saving could be effected in a vessel of the class selected.

We now come to some of the disadvantages of using surface condensers and high-pressure steam; and first, with regard to priming, it is one of the phenomena of ebullition, and occurs more or less in all boilers using surface condensers, whether with high or low pressure steam, irrespective of the kind of engine. By mechanical means its action can be greatly retarded and kept within safe limits, but I do not think there is at present any known remedy for its perfect prevention.

In using surface condensers the same water is being continually converted into steam and reconverted into water. Has this anything to do with lifting the water above its true level? Is there a large, or any, portion of the air extracted with this continual distillation?

Secondly.—The effect of using surface condensed water and high-pressure steam in the boiler is to destroy the plates of the boiler, either by galvanic action or from some electrical influence. I am inclined to believe more in the former because we have the brass tubes of the condenser and the copper pipes forming the negative pole, and the boiler and hot well forming the positive pole, the sea water circulating in the condenser and used to supplement the feed, forming a saline solution as a medium. On leaving out the zinc plates for a few trips, streaks of black oxide of iron were discovered about the superheater, and other parts in the boiler, especially where the greatest heat was. The superheater was cleaned and painted, and zinc plates replaced in the water space of the boiler. Since then no injurious effects have taken place.

Another strange phenomenon is the deposition of a calcareous substance thrown against the top of the shell of the boiler as if one were to take a handful of mortar and throw it against the wall, but these deposits only require removing about once in two months. Since leaving off the use of tallow for lubricating the cylinders these deposits on the upper part of the shell are scarcely noticeable.

I must not forget to mention another important matter in reference to the preservation of the boiler, especially where exposed to the action of the steam, viz.,—the application of Portland cement, put on in the same way as white-wash; it is the best preservative that I am acquainted with, and I am indebted to Mr. James Stewart, C.E., for this hint.

In conclusion I may state that some persons imagine that compound engines are complicated. This is not so; neither is there any difficulty in starting or stopping them. When we find boats of 3,000 tons steaming 10 knots on a consumption of 18 tons per 24 hours it speaks well for this class of engine. The "Adriatic," the largest steamer afloat next to the "Great Eastern," has compound engines, and has just made the quickest trip across the Atlantic on record. There is nothing whatever to prevent any of the steamers running on the New Zealand coast from being compounded, with results equal to those here stated, and it is also satisfactory to know that there are special facilities for converting them in Auckland.