strain upon the metal per square inch from an interior pressure of 2,000 pounds, then it will be found that the weight per cubic foot of interior capacity will be 115 pounds. The weight of the last importation of the German reservoirs was 106 pounds per cubic foot of interior capacity.

As the 115 pounds per cubic foot under 2,000 pounds pressure contain 136 cubic feet of free air compressed into 1 foot, the required weight of reservoir will be 0.856 pound for each cubic foot of free air that may be enclosed.

If, in addition, it should be assumed that 400 cubic feet of free air should be provided to run an 8-ton motor 1 mile, with sufficient allowance for contingencies, the weight of reservoir per mile run would be 338 pounds. This weight, it must be understood, applies to the motor only, and is the equivalent of 42 pounds per ton of motor weight. Trail cars will require only about one-third as much per ton.

[To be concluded.]

RESULTS OF THE WORKING OF TWO-CYLINDER COMPOUND LOCOMOTIVES ON AMERICAN RAILWAYS.

BY JOHN H. COOPER.

I have the pleasure of presenting in detail the following results obtained during the year 1896, in regard to the working of compound locomotives.

These data relate exclusively to comparisons of performance between two-cylinder compounds and simple engines, when alike in every respect except the compounding devices, and working under similar conditions.

Two-cylinder compound locomotives may be treated under three heads or types, which may be defined in general terms as follows:

(1) Those in which the intercepting valve is automatic and which cannot be run as a simple engine. This type is without a reducing valve.

(2) Those in which the intercepting valve is operated by steam, but is under the control of the engine-driver, and is provided with a reducing valve, which is automatic.

(3) Those in which the intercepting valve is operated by a rod connection from the cab, under control of the engine-driver, either by hand or by steam or by air; this type also has a reducing valve, which is automatic, allowing the engine to be run either simple or compound, at will.

These types will be found fully illustrated and described in the technical journals.

Should it be desirable to obtain the results of the working of other types of compounds, in order that the comparison shall be of value to railway men, the data must come from persons running them with simple engines of like size and type, under exactly the same conditions as has been done in the case of the two-cylinder compounds.

The simple engine constitutes the standard of cost and running expenses, and is, therefore, the measure for ascertaining the commercial value of the several systems.

Were this comparison obtained, there would be little difficulty in determining the relative value of every type of compound, providing the performances of the simple engines exhibit such a similarity of result as will admit of easy and correct equating.

The writer and his colleagues, who have aided him in obtaining the facts here presented, have been particularly requested to withhold names of persons, roads and locomotives for reasons best known to the parties furnishing the data. Whether authorities are given or not, they offer truth for authority, upon which they rest our case.

They have been careful in getting these results of performance that they should be derived solely from the official records, which are made by persons whose duty it is to furnish the facts of experience.

With these preliminary explanations we present extracts of performance sheets of twelve compound engines, having cylinders 21 and 31 x 24; also of a simple engine, which is an exact duplicate of the compounds, except that the cylinders are single expansion. This engine carried the

same steam-pressure as the compound, and worked under precisely the same conditions. It will be noticed that these reports are for May and June, 1894, being the last ones received, and were furnished after the engines had been in use more than a year.

EXTRACTS FROM PERFORMANCE SHEETS FOR THE MONTH OF MAY, 1894.

	<i>Consolidation Compound.</i>	<i>Consolidation Simple.</i>
Number of miles run in freight service	16,520	2,425
Cost per mile for oil and waste (cents)	0'34	0'33
Cost per mile for fuel (cents)	13'52	16'66
Number of miles run to one pint of valve oil .	53'02	86'61
Number of miles run to one pint of engine oil .	21'34	14'97
Pounds of coal per loaded freight car, mile . .	3'41	4'46
Number of miles run to one ton of coal	21'49	17'43

VOUGHIOGHENY AND HOCKING COAL USED.

Cost of fuel-wood per cord	\$1 86
Cost of fuel-coal per ton	2 87

MONTH OF JUNE, 1894.

	<i>Consolidation Compound.</i>	<i>Consolidation Simple.</i>
Number of miles run in freight service	13,478	1,827
Cost per mile for oil and waste (cents)	0'34	0'42
Cost per mile for fuel (cents)	11'68	18'09
Number of miles run to one pint of valve oil .	63'07	39'72
Number of miles run to one pint of engine oil .	17'81	14'50
Number of miles run to one ton of coal	25'08	16'13
Pounds of coal per loaded freight car, mile . .	3'43	4'30

VOUGHIOGHENY AND HOCKING COAL USED.

Cost of fuel-wood per cord	\$1 86
Cost of fuel-coal per ton	2 87

From another source we make the following extracts :

"All conditions should be alike, save the compounding, and then the engines should be manned alike and have the same character of fuel, substantially the same loads, weather, etc. Further than this, the trial should be of sufficient length to carry it down to every-day work, and should cover the changing of engineers and firemen, as well as all the vicissitudes of weather and work. In no other way can we answer the criticisms or overcome the scepticism of many regarding the value of the compounding principle. We

must be able to show that we not only do save fuel, but that we do not have excessive repairs arising from the changes in machinery.

"It is of a trial of this character that I write, the compound engines being of the two-cylinder type. This paper is intended simply to show what these particular engines did, and not to demonstrate that other engines, or types, would or would not do just as well. The writer was able to cause this test from the fact that, in ordering a lot of engines, he had one ten-wheel passenger out of three, built on the same specifications, compounded, and two 'Consolidation' freight engines out of eighteen, on the same specifications, compounded. The weight of all these engines was the same, 126,000 pounds, without the tender, and they were delivered and put into service about the same time. The simple 'Consolidation' engines were 20 x 24-inch cylinders, while the compounds were 20½- and 29 x 24-inch. The cylinders of the ten-wheeled simple engines were 19 x 24 inches, while those of the compound were 19 and 27 x 24 inches. The 'Consolidations' were substantially duplicates of a large number of other engines of the same character, which, after some years' use, had been worked up to a very economical point. During the previous years, we had procured a ten-wheeled passenger engine, which had been changed, experimentally, until it had become unusually economical in fuel. This was the basis of the three new ten-wheeled engines, and they were found most excellent in their workings.

"The comparisons of the ten months' work of the passenger engines are shown in the following tables:

COMPARISON OF PASSENGER ENGINES.

	Miles Run.	Car-Miles.	Average Cars Per Train.	Pounds Coal Consumed.	Pounds Coal Per Car-Mile.
Two simple engines	107,885	564,995	5'23	6,263,654	11'086
One compound engine	48,100	254,204	5'17	2,097,911	8'252

"Saving, 2'834 pounds of coal per car-mile, or 25'56 per cent.

"The work of four simple and two compound freight engines for eleven months is shown, as follows :

SIMPLE ENGINES.

	Miles Run.	Car-Miles.	Average Cars Per Train.	Pounds Coal Consumed.	Pounds Coal Per Car-Mile.
Four engines, East End, 6 mos. .	81,226	1,335,045	16'43	8,252,533	6'132
Four engines, West End, 5 mos. .	61,318	1,190,786	19'41	5,977,917	5'029
Total, 11 mos.	142,544	2,525,831	17'23	14,230,450	5'634

COMPOUND ENGINES

	Miles Run.	Car-Miles.	Average Cars Per Train.	Pounds Coal Consumed.	Pounds Coal Per Car-Mile.
Two engines, East End, 6 mos. .	27,682	495,050	17'88	2,454,142	4'957
Two engines, West End, 5 mos. .	31,550	712,291	22'57	2,667,505	3'746
Total, 11 mos.	59,232	1,207,341	20'38	5,121,647	4'242

"Saving, 1'392 pounds of coal per car-mile, or 24'70 per cent.

"Here we have a marked saving in a year's work. We believe the conditions were such that the test is of more value than were the first ones made, as it shows the everyday work of the compound engines compared with exactly the same simple engine under the usual working conditions. No tests can be fairer, and I have seen none of more value.

"I regret to state it, yet it is true, that there was at the start a universal prejudice against the compounds among the engineers and firemen. They were pronounced failures before they were set up, and long after they had shown their good qualities the unfavorable criticism continued. They 'would not start the train,' but they did it. They 'could not run up the long hills,' but somehow they did it quite as easily as the other engines. They 'could not pull within two or three cars of the other engines,' but a year's work shows they averaged larger trains, and in repeated cases, they have pulled as heavy trains as any engines on the road.

"But when they saw the compound passenger engine run the round trip with a tender of coal, and run easily 100 miles with one tank of water, they had to admit that there was some good in the new departure.

"It is our belief that this test of nearly a year in everyday work, with changing engineers and firemen, against exactly similar simple engines, doing the same work at the same time, is more valuable than any tests yet reported in this country, and demonstrated beyond a question the value of the compound principle in locomotive engines, in the matter of coal consumption.

"The importance of this is seen when it is known that the cost of fuel is about 10 per cent. of the whole cost of operating, and when we consider that the 32,000 locomotives in this country probably consume 30,000,000 tons of coal per annum.

"There is, however, another matter to be considered, and it is one that has rendered American engineers sceptical as to the real value of the compound engine; that is, one of repairs, as well as first cost. It stands to reason that the cost of maintaining three cylinders or four cylinders will be larger than the cost of maintaining two.

"I have a report of the repairs upon the engines under consideration from January 1 to June 30, 1891, a period of six months, while they were running together, and for six months of the time in which the consumption of coal is considered.

"Considering first the freight service, we find that the

Four simple engines in six months ran	76,827 miles.
Total cost of running repairs done	\$1,312.66
Cost per mile run (cents)	1'70

"In the same time and over the same ground, the

Two compound engines ran	39,268 miles.
And the running repairs cost	\$612.72
Or per mile (cents)	1'55

"Showing that for six months the compound ran more economically than the simple, as far as repairs are concerned. It is quite probable, however, that in another six

months this would be evened up, and the cost per mile would have likely been equal to that of the simple engines.

"When we consider that with cheap coal (say \$1.50 per ton) the cost per engine mile for fuel is, for freight trains, about 7 cents per mile, and for passenger $4\frac{1}{2}$ cents, we can see that a saving of even 20 per cent. in fuel means over 1 cent a mile, and that it cannot be outweighed by any reasonable, or I may say possible, increase of repairs, as but a small part of such repairs pertain to, or are affected by, the parts compounded.

"We believe this to have been a good practical test of the two-cylinder type of compound engines, and while no claim is made to perfection, it seems to have covered a sufficient length of time, amount of work and variety of climatic and other conditions, to have overcome the influence of any prejudices, or efforts for or against any particular engine or of any special skill on the part of any one man, that in a short run or experiment might have a marked effect."

From another source we quote :

"Where coal costs from \$3.50 to \$4 per ton, of course economy in the quantity consumed is a matter that is looked after.

"One of these two-cylinder locomotives has been running for about three years past, and the reports we have received from the officials of the railway company go to show that the saving in fuel, due to the compound system, has averaged about 17 per cent. comparing it with simple engines of the same type and capacity, doing practically the same work, and run on the same division.

"The saving of fuel in the case of the other four compounds on the same line which have been in service for about one year past, is said to be about the same—17 per cent.—as compared with the simple engines. No special tests or efforts have been made, so far as we know, in the matter of saving fuel; but the results are obtained from the monthly reports of fuel consumed by the locomotives on the line.

"The reports as to the cost of repairs of these compounds

indicate that they are little, if any, more than the simple engines, doing the same work on the same line.

"In the case of the other four compound locomotives, sent to another road, we have as yet received but little data as to their consumption of fuel. Some tests that were made, but continued for about ten days only, showed results that indicate a saving of about 20 per cent.

"We think that on an average, 'taking things as they come,' the saving will result about the same as in the other case, namely, 17 per cent."

From another source :

"Four compounds are reported, one of them running two years, one ten months; in all running 117,945 miles in freight service, and 2,946 miles in passenger service. Also, five simple engines, making 1,063,975 engine-miles in freight service, and 3,324 miles in passenger service.

"The chief results are in favor of the compounds, and are as follows :

	<i>Per Cent.</i>
Engine-miles per ton of coal	25'36
Pounds of coal per 100 ton-mile	23'59
" " " " engine-mile	19'00
" " " " car-mile	24'17
" " water per 100 ton-mile	28'85
" " " " engine-mile	16'84
" " " " car-mile	18'91

"We have reports as follows :

	<i>Simple.</i>	<i>Compound.</i>
On one road, repairs per train-mile (cents)	2'1	1'5
On another road, repairs per train-mile (cents)	4'11	3'90
" " " " " " (cents)	3'13	2'88

"These are all the data we have on repairs; and it will be noticed that the compound beats the simple by about 13 per cent.

"The data on lubrication shows that on one road the compound used 12 per cent. more oil than the simple, and on another road 17 per cent. less."

From another source :

"Without giving you the results of any experiments or tests, I should say, in a general way, that a compound loco-

motive, when new, will save about 25 per cent. in fuel over a simple engine.

"I am convinced from our experience here that the compound engine in passenger service is of great value for fast trains, because a run of a hundred miles can be made with one tank of water, thus avoiding any stops, except at division terminals. The use of such engines avoids the necessity for building track tanks, and of course is a great saving. In addition to this, the engines run very much cleaner and make but little smoke when properly handled."

From another source :

"In compliance with my promise to advise you of the performance of your two-cylinder compound engines, I will state that their work is in every respect superb.

"We have had an engine in our express freight service, in competition with two 'Moguls' (simple engines) with 19 x 24-inch cylinders, carrying 160 pounds working steam pressure. These engines are all rated the same, *i. e.*, they are all given trains of 700 tons each. The consumption of coal is as follows: Compound engine ran in April, 1895, 31.1 miles per ton of coal, while the two 'Moguls' averaged 16.2 miles per ton."

From another source :

"These engines are designed to carry 200 pounds steam pressure. They are as nearly alike as possible, although they vary somewhat in their weight.

"The total weight of the compound is 127,500 pounds, and of the simple engine 117,460 pounds. Average steam pressure on test, 150 pounds. Average amount of coal burnt each trip—the compound, 6,150 pounds; the simple, 6,414 pounds. Average coal per car-mile in pounds—the compound, 6.72; the simple, 7.55. Average pounds of water evaporated per pound of coal—compound, 7.86; simple, 6.67. Relative amounts of coal burned on basis of car-mile—the compound, 100 per cent.; the simple, 112.35 per cent.

"The cost of the maintenance of these locomotives in a test occupying so short a time plays no part. The engines, prior to the test, were put in first-class condition, practically as good as new, and the repairs amounted to nothing."

From another source :

"We have in service three two-cylinder compound engines. They have been in service since November, 1894, and we are very well pleased with the general results given by them. They show from 30 to 33 per cent. saving in fuel; about 25 per cent. in evaporation. While there is no claim made for saving in repairs, we find that the cost of repairs is only a fraction of a cent more than the simple engine. The engines are virtually simple engines, having but two cylinders and no complication of parts over simple engines, with the exception of one intercepting valve and one reducing valve.

"Those comparisons were made with simple engines running in the same service and under the same conditions."

From another source :

"We have in service two ten-wheel compound engines of the two-cylinder type and a large number of ten-wheel simple engines, which, with the exception of the compound feature, are duplicates of the two compound engines. These engines have been used in freight service entirely, with the exception of a very small amount of passenger service, and I take pleasure in submitting below a comparative statement of the performance of the engines mentioned during the past five years:"

	<i>Simple.</i>	<i>Compound.</i>
Cost per mile for oil and waste (cents)	0.18	0.21
" " " " repairs (cents)	2.49	3.69
Miles run per ton of coal	20.51	22.58
Pounds coal consumed per car-mile	3.10	3.00
Total cost per car per mile (cents)	0.56	0.68

From another source :

"I will give you the figures as returned to me by our Comptroller, of the performance of these engines in regard to fuel.

"In the month of May, 1895, a compound engine, in passenger service, made a mileage of 5,558; her average number of miles per ton of coal was 49.5. Simple engine, in the same service, running opposite to the compound, made a mileage of 4,843, and her average mileage per ton of coal

was 41. These two engines were on night runs, consisting of seven-car trains, postal and baggage cars, two coaches and three sleepers, all vestibule.

"We have had the passenger engine for about eighteen months, and she has given entire satisfaction; is very economical on repairs and especially so on fuel.

"In our freight service we have a two-cylinder compound engine, which, in the month of May, on our fast freight schedule, made 3,003 miles—average miles per ton of coal, 33. Our simple engines running in the same service made a mileage of 2,860—average number of miles per ton of coal, 19.2. Same weight of train.

"The distance from terminal to terminal is 143 miles. The simple engines are limited to $7\frac{1}{2}$ tons of coal per trip, and the compound freight engine was limited to 5 tons of coal per trip.

"I have had no complaint from the engineer running the compound engine of being short of fuel, but I had several complaints from the men running the simple engines where they were short of fuel. The compound engines, both passenger and freight, show a remarkable saving of fuel, and we are highly pleased with their performance."

From another source:

"To say the least, we are very highly pleased with the two-cylinder compound engines. The legitimate cost of repairs is no greater than on the simple engines.

"In the use of cylinder oil they are making about double the mileage of the simple engines, and, on fuel, they are saving at least 25 per cent."

From another source:

"I am pleased to record the fact that we have nineteen of your engines in our service from two to three years, and they have given most excellent satisfaction, both in character of workmanship and effective working and maintenance.

"It is a special pleasure to record the advantages afforded by your type of compound engine, evinced by their economy of fuel and moderate repairs."