convenient usage which is now pretty general the name “ Woolf engine" is restricted to those compound engines which discharge steam dicectly from the high to the low pressure cylinders without the use of an intermediate receiver.

55. *Receiver Engine.—*An intermediate receiver becomes necessary when the phases of the pistons in a compound engine do not agree With two cranks at right angles, for example, a portion of the discharge from the high-pressure cylinder occurs at a time when the low-pressure cylinder cannot properly receive steam. The receiver is in some cases an entirely independent vessel connected to the cylinders by pipes; very often, however, a sufficient amount of receiver volume is afforded by the valve casings and the steam pipe which connects the cylinders. The receiver, when it is a distinct vessel, is frequently jacketed.

A receiver is frequently applied with advantage to beam and tandem compound engines Communication need not then be maintained between the high and low pressure cylinders during the whole of the stroke, admission to the low-pressure cylinder is stopped before the stroke is completed ; the steam already admitted is allowed to expand independently; and the remainder of the discharge from the high-pressure cylinder is compressed into the intermediate receiver. Each cylinder has then a definite point of cut-off, and by varying these points the distribution of work between the two cylinders may be adjusted at will. . In general it is desirable to make both cylinders of a compound engine contribute equal quantities of work. If they act on separate cranks this has the effect of giving the same value to the mean twisting moment of both cranks.

56. *Compound Diagrams.—*Wherever a receiver is used, care should be taken that there should not be a wasteful amount of unresisted expansion into it; in other words, the pressure in the receiver should be not greatly less than that in the high-pressure cylinder at the moment of release. If the receiver pressure is less there will be what is termed “ drop" in the steam pressure between the high-pressure cylinder and the receiver, which will show itself in an indicator diagram by a sudden fall at the end of the high- pressure expansion. This “ drop ” is, from the thermodynamic point of view, irreversible, and therefore wasteful. It can be avoided by selecting a proper point of cut-off in the low-pressure cylinder. When there is no “ drop ” the expansion that occurs in a compound engine has precisely the same effect in doing work as the same amount of expansion in a simple engine would have, provided the law of expansion be the same in both and the waste of energy which occurs by the friction of ports and passages in the transfer of steam from one to the other cylinder be negligible. The work done in either case depends merely on the relation of pressure to volume throughout the process; and so long as that relation is unchanged it is a matter of indifference whether the expansion be performed in one vessel or in more than one. In general a compound engine has a thermo­dynamic advantage over a simple engine using the same pressure and the same expansion, inasmuch as it reduces the exchange of heat between the working substance and the cylinder walls and so makes the process of expansion more nearly adiabatic. The com­pound engine has also a mechanical advantage which will be pre­sently described. The ultimate ratio of expansion in any compound engine is the ratio of the volume of the low-pressure cylinder to the

volume of steam admitted to the high-pressure cylinder. Fig. 16 illustrates the com­bined action of the two cylin­ders in a hypothetical com­pound engine of the Woolf type, in which for simplicity the effect of clearance is ne­glected and also the loss of pressure which the steam undergoes in transfer from one to the other cylinder. ABCD is the indicator diagram of the high-pressure cylinder. The exhaust line CD shows a falling pressure in consequence of the increase of volume which the steam is then undergoing through the advance of the low-pressure piston. EFGH is the diagram of the low-pressure cylinder drawn alongside of the other for convenience in the construc­tion which follows. It has no point of cut-off; its admission line is the continuous curve of expansion EF, which is the same as the high-pressure exhaust line CD, but drawn to a different scale of volumes. At any point K, the actual volume of the steam is KL 4- MN. By drawing OP equal to KL + MN, so that OP represents the whole volume, and repeating the same construction at other points of the diagram, we may set out the curve QPR, the upper part of which is identical with BC, and so complete a single diagram which exhibits the equivalent expan­sion in a single cylinder.

In a tandem compound engine of the receiver type the diagrams resemblc those shown in fig. 17. During CD (which corresponds to FG) expansion is taking place into the large or low- pressure cylinder. D and G mark the point of cut-off in the large cylinder, after which GH shows the independent expansion of the steam now shut within the large cylinder, and DE shows the compression of steam by continued discharge from the small cylinder into the receiver. At the end of the stroke the receiver pressure is OE, and if there is to be no “ drop ” this must be the same as the pressure at C. Diagrams of a similar kind may be sketched without difficulty for the case of a receiver engine with any assigned phase relation between the pistons.

57. *Adjustment of* *Work* *and “ Drop.”—*By making the cut-off take place earlier in the large cylinder we increase the mean pressure in the receiver; the work done in the small cylinder is consequently diminished. The work done in the large cylinder is correspondingly increased, for the total work (depending as it does on the initial pressure and the total ratio of expansion) is unaffected by the change. The same adjustment serves, in case there is “ drop, to lessen it. By selecting a suitable ratio of cylinder volumes to one another and to the volume of the receiver, and also by choosing a proper point for the low-pressure cut-off, it is possible to divide the work suitably between the cylinders and at the same time prevent the amount of drop from being greater than is practically convenient.

58. *Uniformity of Effort in a Compound Engine.—*An important mechanical advantage belongs to the compound engine in the fact that it avoids the extreme thrust and pull which would have to be borne by the piston-rod of a single-cylinder engine working at the same power with the same initial pressure and the same ratio of expansion. If all the expansion took place in the low-pressure cylinder, the piston at the beginning of the stroke would be exposed to a thrust much greater than the sum of the thrusts on the two pistons of a compound engine in which a fair proportion of the expansion is performed in the small cylinder. The mean thrust throughout the stroke in a tandem engine is of course not affected by compounding; only the range of variation in the thrust is reduced. The effort on the crank-pin is consequently made more uniform, the strength of the parts may be reduced, and the friction at slides and journals is lessened. The advantage in this respect is obviously much greater when the cylinders are placed side by side, instead of tandem, and work on cranks at right angles. As a set-off to its advantage in giving a more uniform effort, the compound engine has the drawback of requiring more working parts than a simple engine with one cylinder. But in many instances—as in marine engines—two or more cranks are almost indispensable, to give a tolerably uniform effort and to get over the dead points; and the comparison should then be made between a pair of simple cylinders and a pair of compounded cylinders. Another point in favour of the compound engine is that, although the whole ratio of expansion is great, there need not be a very early cut-off in either cylinder; hence the common slide-valve, which is unsuited to give an early cut-off, may be used in place of a more complex arrangement. The mechanical advantage of the compound engine has long been recognized, and had much to do with its adoption in the early days of high-pressure steam. Its subsequent development has been due in part to this, and in part to the thermodynamic advantage which has been discussed above.

59. *Ratio of Cylinder Volumes.—*In a two-cylinder compound engine, using steam at 80 to 100 lb pressure, the large cylinder has 3 or 4 times the volume of the small cylinder. In triple engines the pressure is rarely less than 150 lb; the low-pressure cylinder has generally 6 or 7 times, and the intermediate cylinder 21/2 to 23/4 times the volume of the high-pressure cylinder. In naval practice the ratios are about 1 : 2) : 5 for a pressure of 160 lb and 1 : 2∙6 : 7 for a pressure of 250 lb. In the mercantile marine the engines are nor­mally working at full power, whereas in the navy most of the working is at greatly reduced powers, the cruising speed requiring very much less than the full output. Consequently, for the same boiler pressure, the cylinder ratio is made less in war-ships to adapt the engines for economical working under cruising conditions.

60. *The Distribution of Steam.—*In early steam engines the distri­bution of steam was effected by means of conical valves, worked by tappets from a rod which hung from the beam. The slide-valve, the invention of which in the form now known as the long D-slide is credited to Murdock, an assistant of Watt, came into general use with the introduction of locomotives, and is now employed, in one or other of many forms, in the great majority of engines.

The common slide-valve is illustrated in fig. 18, which also shows.