20. The adaptation of the steam engine to railways, begun by Trevithick, became a success in the hands of George Stephen­son, whose engine, the "Rocket,” when tried along with others, in 1829, not only distanced its com­petitors but settled once and for all the question

whether horse traction or steam traction was to be used on railways. The principal features of the "Rocket ” were an improved steam-blast for urging the combustion of coal and a boiler (suggested by Booth) in which a large heating surface was given by the use of many small tubes through which the hot gases passed. Further, the cylinders, instead of being vertical as in earlier locomotives, were set in at a slope, which was afterwards altered to a position more nearly horizontal. To these features there was added later the "link motion,” a contrivance which enabled the engine to be easily reversed and the amount of expansion to be readily varied. In the hands of George Stephenson and his son Robert the locomotive took a form which has been in all essentials maintained by the far heavier locomotives of to-day.

21. The first practical steamboat was the tug “ Charlotte Dundas,” built by William Symington, and tried in the Forth

and Clyde Canal in 1802. A Watt double-acting condensing engine, placed horizontally, acted directly by a connecting-rod on the crank of a shaft at the stern, which carried a revolving paddle-wheel. The trial was successful, but steam towing was abandoned for fear of injuring the banks of the canal. Ten years later Henry Bell built the "Comet,” with side paddle-wheels, which ran as a passenger steamer on the Clyde; but an earlier inventor to follow up Symington’s success was the American, Robert Fulton, who, after unsuccessful experiments on the Seine, fitted a steamer on the Hudson in 1807 with engines made to his designs by Boulton and Watt, and brought steam naviga­tion for the first time to commercial success.

22. With improvements in the details of design and construc­tion it gradually became practicable to use higher steam pressures

and higher piston speeds, and consequently to obtain not only greater efficiency, but also a greater amount of power from engines of given bulk. In 1872 Sir F. J. Bramwell, describing the typical marine practice of that time, gave a list of engines, all compound, in which the boiler pressure ranged from 45 to 60 lb, the mean piston speed was 350 ft. per minute, and the consumption of coal 2 to 21/2 lb per hour per indicated horse-power. In 1881 F. C. Marshall gave a similar list, in which the boiler pressure was 77 lb, the speed 460 ft. per minute, and the consumption a trifle under 2 lb. These were compound engines with expansion in two stages. The triple expansion engine, introduced by Dr A. C. Kirk in 1874, did not come into general use until after 1881. It became the normal type of marine engine, with pressures ranging, as a rule, from 150 to 200 lb, piston speeds generally of 500 or 600 ft. per minute, but sometimes as high as 900 or 1000, and coal consumption of about 11/2 lb per hour per indicated horse-power. In some instances quadruple expansion has been preferred, with some­what higher pressures, but it can scarcely be said to be established that the advantage of adding a fourth stage clearly compensates for the extra complication. Some particulars of the dimensions reached in modern practice will be given later. Several of the vessels engaged in the Transatlantic passenger service, and also a few armoured cruisers, have engines in which the twin sets together have an indicated horse-power exceeding 30,000. But even these figures are eclipsed in ships which are driven by turbine engines. The cruisers of the "Invincible ” class have turbine engines of 41,000 horse-power', and the turbines of the great Cunarders "Lusitania” and "Mauretania” (1907) develop about 70,000 h.p. in propelling these ships at a speed of 25 knots. It may be questioned whether such gigantic concentrations of power for the propulsion of a ship would have been practicable had it not been for the new possibilities which the introduction of the steam turbine has opened up.

23. The invention of the steam turbine has in fact revolu­tionized marine engine practice, so far as fast vessels are con­cerned, and has supplied a formidable rival to the reciprocating engine for use on land. The steam turbine has been brought to a degree of efficiency which places it, in respect of economy in steam and coal consumption, on a somewhat higher level than the best engines of the older type in cases where a large amount of power is to be generated. Its greater simplicity, compactness and freedom from vibration are merits which have already gone far to secure for it a preference, notwith­standing the short time that has passed since it became known as a practicable engine. The largest demands for power occur in fast passenger vessels, in war-ships and in stations from which electric energy is distributed for traction or other uses; in all these cases the steam turbine is now taking the leading place. It is to the inventive genius of the Hon. C. A. Parsons that we owe not only the main idea of the modern steam turbine, but also the working out of many novel mechanical details which have been essential to success, as well as the adaptation of the turbine to marine propulsion.

24. In the steam turbine, as in the water turbine (for which see Hydraulics), the force directly operative to do useful work is derived from the kinetic energy of the operative fluid, either by the impulse of a jet or jets sliding over movable blades, or by the reaction of orifices or guides from which the jets issue. The pressure, instead of being exerted on a piston, is employed in the first instance to set the fluid itself in motion. There is a conversion of pressure-energy into velocity-energy as a pre­liminary step towards obtaining the effective work of the machine. But in a steam turbine this implies velocities which are immensely greater than those with which water turbines have to deal, in consequence of the much smaller density of steam as the moving fluid. Attempts to design a steam turbine were made by numerous inventors, but fell short of practical success mainly because of the difficulty of arranging for a sufficiently high velocity in the working parts to utilize a reasonably large fraction of the kinetic energy of the steam, the principle involved being that for good efficiency the velocity of the blades should approximate to half the velocity of the jets which strike them. There is a further difficulty in getting the energy of the steam into a suitable kinetic form, namely, to get the stream of issuing particles to take a single direction, without undue dispersion, when steam is allowed to expand through an orifice from a chamber at high pressure into a space where the pressure is greatly less.

In 1889 Dr Gustaf de Laval introduced a form of steam turbine in which both of these difficulties were to a great extent over­come, partly by the special form of the nozzle used to produce the steam jet and partly by features of design which allowed an exceptionally high speed to be reached in the wheel carrying the vanes against which the steam impinged. This simple type of turbine, which will be described in a later section of this article, has met with considerable success, especially in compara­tively small sizes, as an engine for driving electric generators. Its efficiency is fairly good, but it is not well adapted for work on a large scale, and it has not been applied to the propulsion of ships.

Parsons attacked the problem at an earlier date, in an entirely different way in the invention of his "compound ” turbine. By dividing the whole expansion of the steam into a great number of successive and separate steps he limited the velocity acquired at each step to such an extent as to make it compara­tively easy to extract the greater part of the kinetic energy, as work done upon the moving blades, without making the velocity of these blades inconveniently high. Moreover, in Parsons’s compound turbine the range of pressure through which the steam expands in each separate step is too small to give rise to any difficulty in the formation of the jets. The guide blades, which form the jets, are distributed round the whole