original design soon ran into a number of difficulties, however, and Rolls Royce shortly decided to take a license for the Farman drive which had been developed in France.[22] The two-speed supercharger with Farman drive for the Merlin was first flown in September 1937, and production of the Merlin X bomber engine with this feature began in December 1938. Except for a few details, such as a different reduction gear ratio, the Merlin X was otherwise the same, including the design of the compressor itself, as the Merlin II.

It was with these two basic models, the Merlin II and the Merlin X, differing only in their supercharger drives, that Rolls Royce entered the war.[23] The combat ratings, on 87-octane fuel, were 1,030 hp at 16,250 feet for 1,375 lb weight in the II (same rating but 40 lb heavier than in 1936) and 1,010 hp at 17,750 feet or 1,130 hp at 5,250 feet for the X with a weight of 1,430 lb.[24]

Beginning just at the outbreak of the war one important change was introduced as standard on all new models of the Merlin. This was a new cooling system. Development done since 1936 (cf. pp. 238-239) had shown that a pressurized cooling system containing 70% water with 30% glycol added simply as an anti-freeze was distinctly superior to pure glycol at atmospheric pressure; cylinder temperatures were at least 70°F lower for any given coolant temperature when the new system was used, and in addition the mixture had much less tendency to creep through joints than pure glycol and was not inflammable. The reduction in cylinder temperature meant considerably prolonged engine life. There was no increase in drag or weight with the new system, since by maintaining the pressure at 18 lb (i.e., at a temperature of 255°F) the same size radiator sufficed as with pure glycol. The new cooling system was used on all production models after the single-speed II (and the almost identical III) and the two-speed X. It was introduced to production on the Merlin IV (basically the same in other respects as the II), deliveries of which began in August 1938, but very few engines of this model were produced, and the first important production was on the Merlin XII, production of which began in September 1939.

[22]Rolls Royce's original drive was designed to fit in the same space as the old single-speed drive, so that the engines would be interchangeable, whereas the Farman drive was several inches longer.

[23]Before the beginning of the war Rolls Royce also put in production the Merlin III, which was identical to the II except for the propeller shaft and the accessory drive, and the Merlin IV, identical to the III except for the cooling system, on which see below.

[24]The international ratings were 990 hp at 12,250 feet for the II and 1,035 hp at 2,250 feet or 960 hp at 13,000 feet for the X.

100-Octane Fuel

At the beginning of the war the first-line British fighters, the Hurricane I and Spitfire I, both with Merlin engines, seem to have been superior to the German first-line fighter, the Me 109, in top speed and in the altitude at which the top speed was attained. They were inferior, however, in speed above this critical altitude, and in climb at all altitudes. The reason was simply that the Daimler-Benz 601A engine of the Messerschmitt Me 109E fighter developed about the same power for about the same weight to about the same critical altitude as the Merlin, and was installed in a considerably lighter airplane.[25] Since despite the fact that the DB weighed very little more than the Merlin (1,460 against 1,375 lb) it had a 25% greater displacement (2,069 cu in. against 1,649), Rolls Royce was obliged both to develop the Merlin to tolerate much higher manifold pressure, in order to obtain equal performance at the lower altitudes, and to develop superior supercharging, in order to compete at the higher altitudes.

The development to tolerate higher manifold pressure was the simpler of the two problems, since the Merlin was inherently a stronger engine than the DB (as can be seen from its weight of 0.83 lb/cu in. of displacement against the 0.71 lb/cu in. of the DB). Rolls Royce had already in 1937-1938 done a good deal of development on a special, very highly boosted Merlin with which it had for a time hoped to recover the world's speed record; in May 1938 this special engine had been approved for flight at 84.9 in. manifold pressure, at which it de-

[25]The normal loaded weight of the Hurricane I fighter in April 1940 was 6,730 lb; the figure for the Hurricane II in November 1940 was 6,970 lb. The Spitfire II A of 1940 weighed 6,300 lb all-up. The all-up weight of the Me 109E in service in 1939-1940 was 5,520 lb.

veloped 2,160 hp at 3,200 rpm.[26] The fuel used in this racing engine, however, was of a character unsuitable for service use.[27] Beginning about 1938 Rolls Royce experimented with the use of water injection to prevent detonation, but by 1940 had decided that the necessary apparatus was too complex and gave it up.[28] In 1940 Rolls Royce experimented with an air-cooled intercooler for engines with single-stage superchargers, and flew such a device with a single-stage blower running at 1,400 fps impeller tip speed on a Merlin engine in a Fairey Battle, but this too was given up as being too heavy for the gain to be made.

Thus an increase in the permissible boost for service Merlins depended almost entirely on the appearance of a service fuel which would tolerate more boost without detonation, and fortunately 100-octane fuel was made standard for service use by the RAF just in September 1939. A little engine development had been done on 100-octane fuel during the two years previous, but the work had not been intensive since there were no production facilities for tetraethyl lead in Britain and it was considered very doubtful that 100-octane fuel could be available in time of war. The importance of the new fuel can be seen from the fact that the Merlin II, which with a maximum manifold pressure of 42.6 in. on 87-octane fuel had a combat rating of 1,030 hp at 16,250 feet at the outbreak of the war, was authorized before the end of 1939 to use 48.2 in. manifold pressure on 100-octane fuel and received a combat rating of 1,160 hp at about 13,500 feet with no increase in rpm. Before the middle of 1940, a manifold pressure of 54.3 in. was authorized, giving a combat rating of 1,310 hp at 9,000 feet, again with no increase in rpm. Combat ratings based on 62.5 in. manifold pressure became authorized early in 1942, when the Merlin II and III were no longer in front-line service, but at the beginning of 1942 a combat rating of 1,440 hp at this pressure was authorized on

[26] The N 17 Spitfire with this engine made about 410 mph.

[27] It consisted of 20% straight-run gasoline, probably of California type, 60% benzol, 20% methanol, and 3.3 cc lead per U.S. gallon.

[28] During the war Packard experimented with water injection and at the very end of the war went into production with a small number of engines so equipped. Packard's original purpose was to obtain with American 100/130 fuel the results obtainable without water from British 100/150 fuel, but the reason for ultimately going into production was to get a 2,200-hp combat rating on 115/145 fuel from a long-range engine with 7:1 compression ratio.

these engines for catapulted take-off from merchant ships. The engine development for this rating consisted simply in an alteration in the automatic boost control.

An increase in permissible boost contributes nothing at all, however, to the performance of an engine at altitudes equal to and greater than the critical altitude under the old boost rating; improvements in performance at these altitudes can be obtained only from more supercharging, more efficient supercharging, or both. In the earlier part of the 1930's it would seem that relatively little progress had been made in either of these respects: the supercharger used on the Kestrel had very early attained an efficiency of about 65% over all (including elbow and carburetor losses) at a pressure ratio of 2:1, while that of the production Merlins of 1939 had only a slightly higher ratio (2.3:1) and about the same efficiency. Fortunately, however, Rolls Royce was nearly ready to introduce very great improvements in both respects. The subject of the company's supercharger development is important enough to be worth tracing from the beginning in a separate section.

Development of Superchargers

The British, and particularly the Royal Aircraft Establishment at Farnborough, were very early in taking a serious interest in supercharging. Work on this problem went on at Farnborough continuously from 1915 under the direction of James E. Ellor. After trying both reciprocating and Roots blowers in 1915, Ellor suggested the use of a centrifugal blower. The first centrifugal blower tried had an adiabatic efficiency of about 60%, or as good as the Roots blower, and since the centrifugal blower had no need of a tank to equalize a pulsating air delivery, the other types were given up at once. A gear-driven centrifugal supercharger was tried out on the Raf 1A in 1916 and on other engines before the end of the war, and an integral gear-driven supercharger was included in the RAE's original 1916 design of the two-row radial which became the Armstrong Siddeley Jaguar (cf. above, p. 132).

After the war the RAE left the mechanical development of the geared supercharger to the engine companies, but continued