



18667<sup>s</sup>

# Napier Sabre II

By F. C. SHEFFIELD

**Twenty-four Cylinder, Sleeve-valve, Liquid-cooled Twin-crankshaft Engine Now in Full Production**

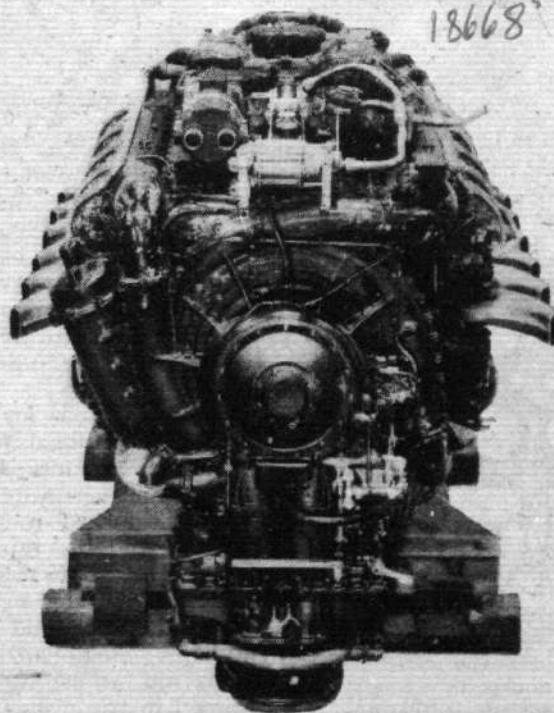
EARLIER in the war the German propagandists were very fond of explaining that the Allied nations, softened by long years of living under a democratic régime, were decadent or effete and would be no match for the virile young Nazi state. For a variety of reasons, of which the strength and prowess of the Allied air fleets are not the least important, this specious philosophy does not now enjoy the same measure of popularity. Any dupe, at home or abroad, who may still be suffering from the effects of such propaganda can be recommended to examine the new Napier Sabre aircraft engine. No signs of decadence, either in conception or execution, will be found in this latest technical achievement. Perhaps no better praise can be given than to state that the Sabre II has already proved its merit operationally in the Hawker Typhoon and has taken its place alongside other famous British engines.

It was towards the end of the year 1935 when the Napier company decided to proceed with the development of a twin crankshaft engine of about 2,000 b.h.p. Experience had already been gained with the 24-cylinder Dagger engine, but this was of the poppet-valve,

air-cooled type and had a much lower power output. The new engine was projected as a 24-cylinder, liquid-cooled unit with single sleeve valves, and the layout was completely changed by the decision to position the cylinders horizontally instead of vertically as hitherto. This arrangement enables all auxiliary components to be grouped accessibly above and below the cylinders instead of at the front and rear. The two-speed supercharging blower was still located at the rear.

As at that period the most powerful engines available had an output of only 1,000-1,200 b.h.p., some doubts were expressed concerning the wisdom of embarking on an entirely novel design for a unit of 2,000 b.h.p. However, the confidence of the company was not shaken, and due to the admirable foresight of the management, the Sabre is now in full production to meet a genuine need for an engine of this class. Actually it passed the Air Ministry's 100-hr. type test with a maximum output of 2,200 b.h.p. in June, 1940.

It will perhaps be remembered that a brief description and external views of the engine in its developed form, known as Sabre II, were published in *Flight*, January 13th,



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2,200 h.p. in compact form.

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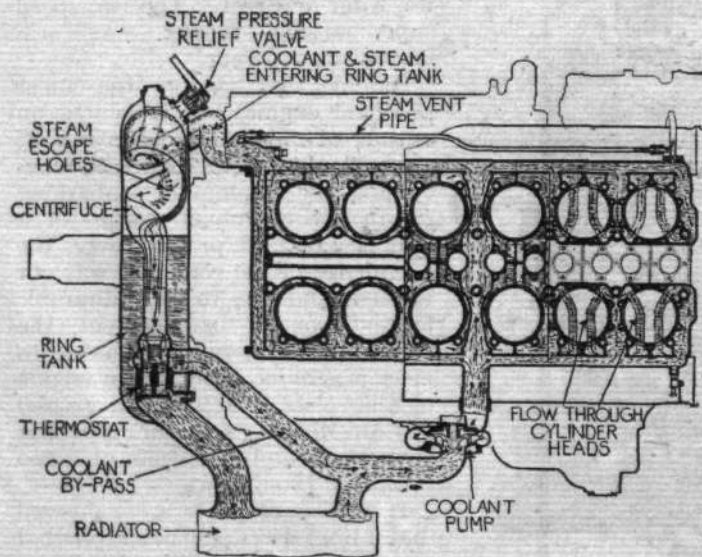
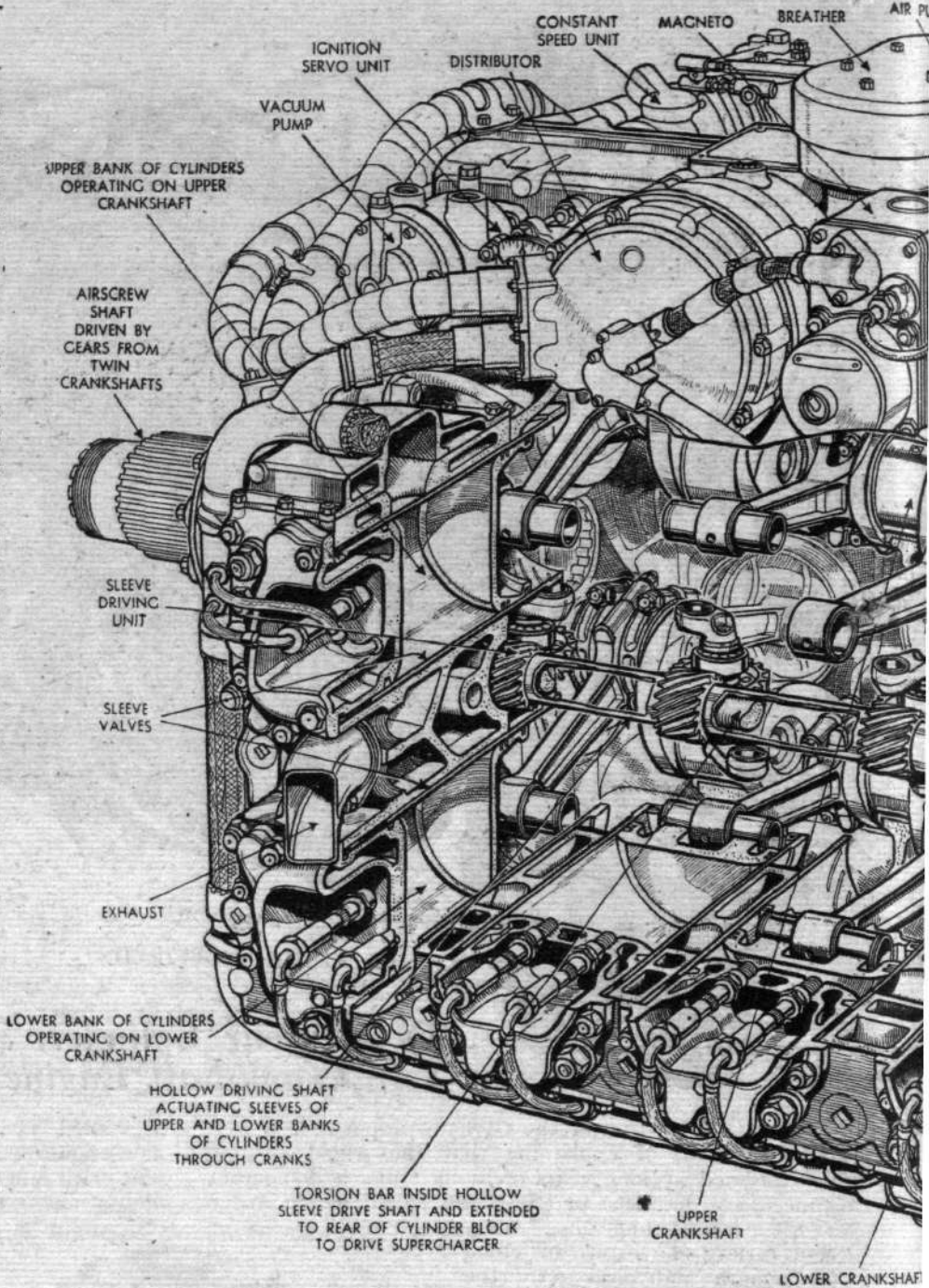
1944, but it is now permissible to give further particulars and to disclose internal details of the design. As installed in the Typhoon the engine delivers a maximum of 2,200 b.h.p. at 3,700 r.p.m. Dry-weight is 2,360 lb., equivalent to a specific weight of 1.07 lb. per brake horse-power.

Merely to recount the bare specification: two crankshafts, 24 cylinders, sleeve valves, liquid cooling, geared-down airscrew shaft, two-speed supercharger with torsion shaft drive and hydraulic clutches, suggests a high degree of complication. The first sight of this compact mass of mechanism tends to confirm the impression. Only when it is carefully examined is the logical and convenient layout fully appreciated. Accessibility and ease of maintenance have been well provided for, and components can be inspected or serviced with a minimum of dismantling. There is no doubt that Major Frank Halford and his team of designers have done a brilliant job.

### Twin Crankshafts

At the outset it is perhaps best to think of the unit as two complete 12-cylinder horizontally opposed engines arranged one above the other. The two six-throw crankshafts run in seven lead bronze, steel shell bearings in a common light-alloy crankcase divided vertically across the main bearings on the longitudinal centre line. On each side of this crankcase are bolted light-alloy cylinder blocks, each embodying upper and lower rows of six cylinders. These three units constitute the main engine structure. Each crankshaft at its forward end is meshed with a pair of compound reduction gears, and from the forward helical pinions of these four gears is driven the large-diameter helical gear of the airscrew shaft on the centre line of the engine, midway between the two crankshafts. Both crankshafts rotate in the same direction—that is, anti-clockwise when viewed from the rear, and the double reduction gear gives a ratio of 0.274:1 to the left-hand airscrew.

Cylinder dimensions are 5in. diameter bore and 4.75in. stroke, giving a total swept



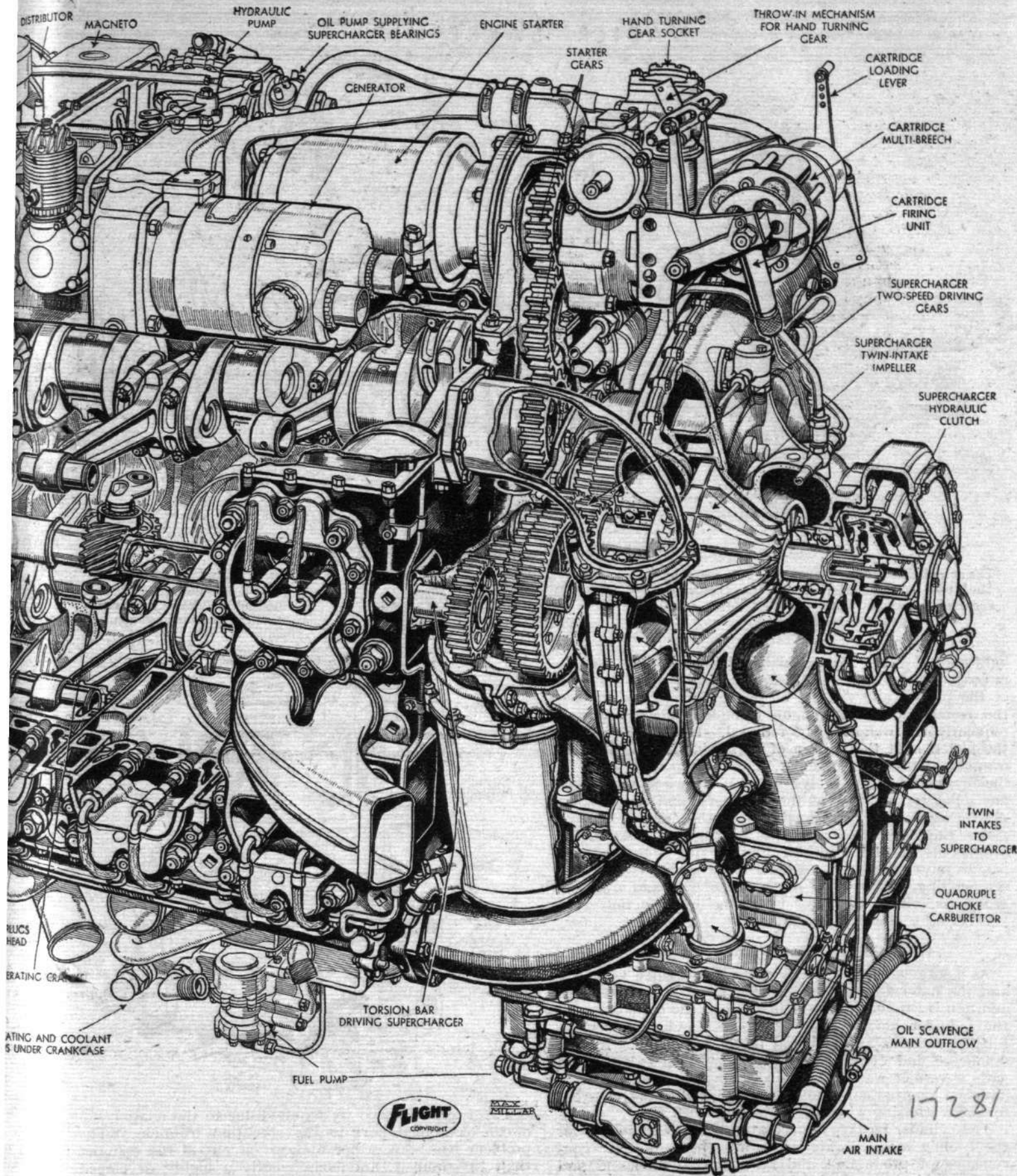
The ethylene-glycol pressure cooling system is thermostatically controlled.

volume of 2,240 cu. in., or 36.65 litres. The compression ratio is 7:1.

The crankshafts are of straightforward design with hollow journals and pins sealed by discs and bolts. In its earlier form the shaft was balanced by counter weights integral with the webs, but these were found to be unnecessary and the shaft has been simplified and lightened by their elimination. At present the webs are of elliptical shape. In addition to rotating in the same direction, the two shafts operate in the same phase. This, of course, affects the firing order of the cylinders, which will be referred to later.

Connecting rods for the opposed pairs of cylinders are of the conventional fork and blade type, and the disposition of the forked rods is by groups of three, horizontally and vertically. In other words, the upper crankshaft has forked rods for the three forward left-hand cylinders and the three rear right-hand cylinders, whilst on the lower shaft this arrangement is reversed. Big-end bearings are formed by steel shells, lined inside and outside with lead bronze, and are located by two pins in the fork-end caps. Small-end bushes are of phosphor bronze fixed in the rod, whilst the gudgeon pin is fully floating and retained in the piston by circlips.

As will be noted from the sectional drawings, the forged

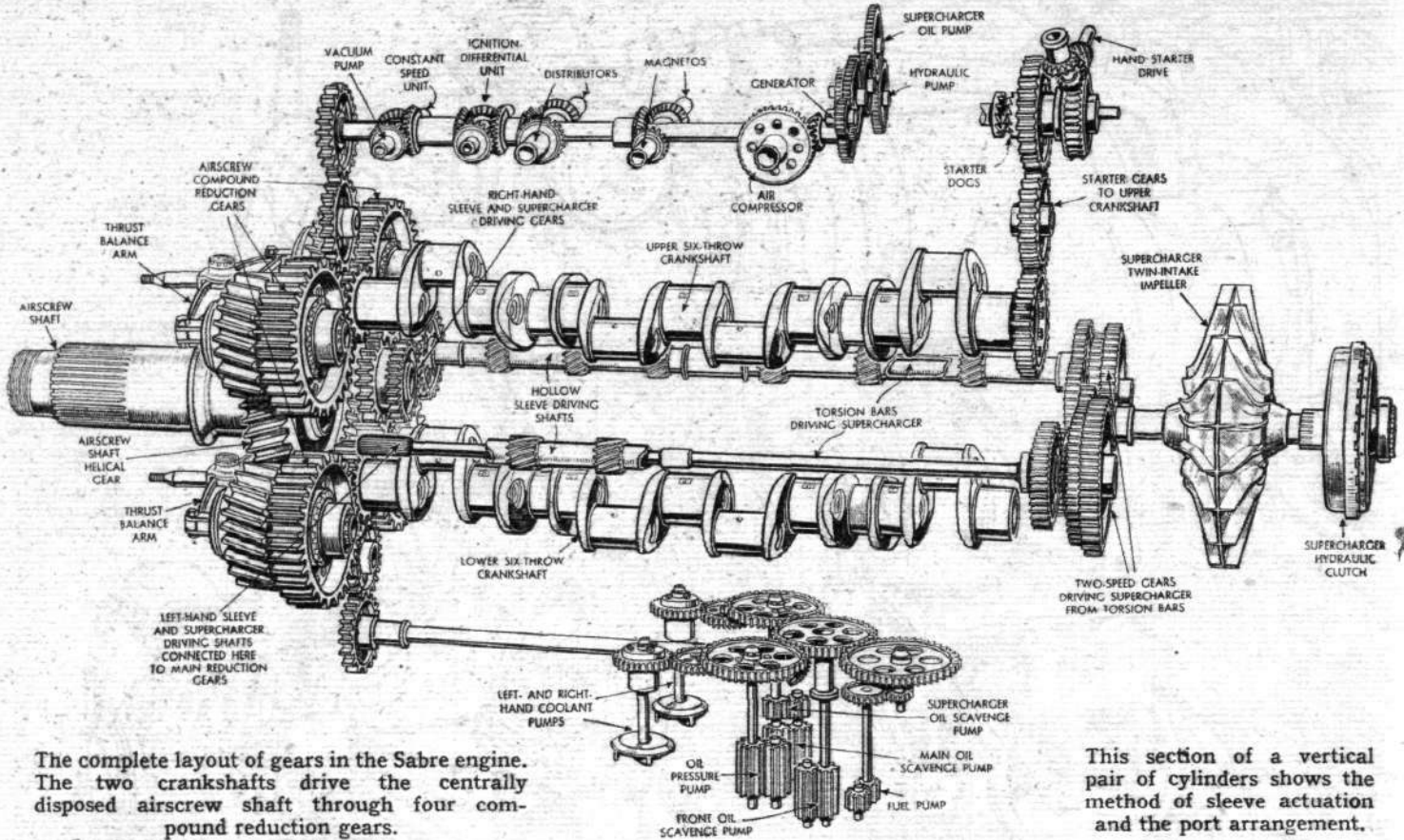


### 2,200 h.p. NAPIER SABRE

The Sabre engine partly sectioned to reveal important features of its design. There is a separate six-throw crankshaft for upper and lower groups of twelve horizontally opposed cylinders. Valve sleeves of vertical pairs of cylinders are actuated by 180 deg. cranks geared from hollow shafts driven from the airscrew reduction gears at the forward end. Within each hollow shaft is

a torsionally resilient rod which furnishes the drive for the double-entry 2-speed supercharging blower. Medium- or high-gear is selectively engaged by a fluid-actuated double-conical clutch unit. A special four-choke S.U. carburettor supplies the mixture to the supercharger. The Coffman combustion starter and its five-cartridge breech will be seen above the rear end of the crankcase.

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The complete layout of gears in the Sabre engine. The two crankshafts drive the centrally disposed aircrew shaft through four compound reduction gears.

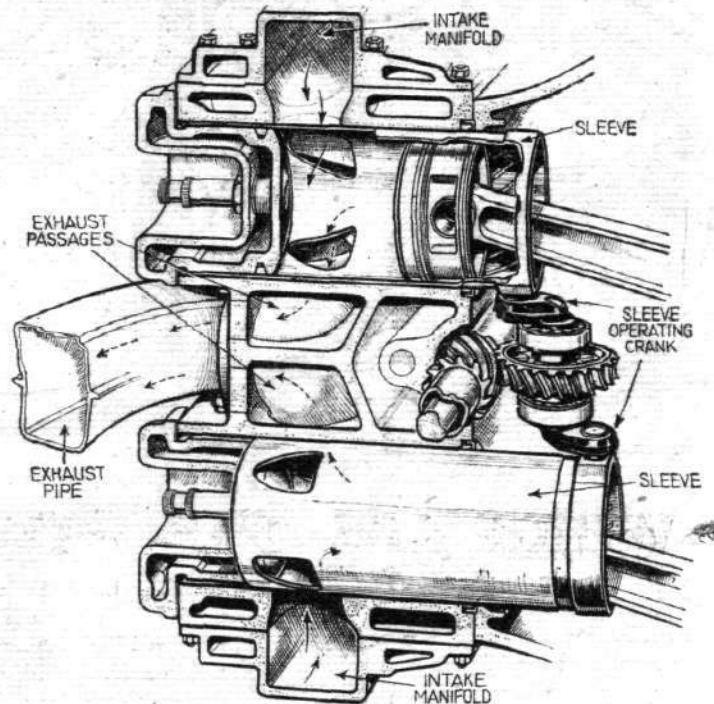
This section of a vertical pair of cylinders shows the method of sleeve actuation and the port arrangement.

light-alloy pistons are unusually shallow. This feature, in conjunction with the short stroke (less than the diameter of the piston) and the use of sleeve valves, has enabled the overall width of the engine to be kept down, and consequently the weight to be reduced. Incidentally, when the piston is at the bottom of its stroke, it is withdrawn completely from the cylinder, and is supported solely in the lower end of the valve sleeve. In shape the piston has a flat top radiused at the periphery, and the gudgeon pin bosses are webbed directly from the crown. All the piston rings are of special types; the upper pressure ring is tapered, whilst the second pressure ring is tapered and has an oil-scraper groove on the lower side. The bottom scraper ring, with a bevel on the upper face and a scraper groove on the lower face, is of the wedge-action type backed by a plain spring ring.

**Interchangeable Cylinder Blocks**

As mentioned earlier, the crankcase is divided vertically and the halves are drawn together by 20 long bolts. In addition, 12 tie bolts pass right through the crankcase and the cylinder blocks. To secure each cylinder block a further 26 studs are anchored in the crankcase. All the crankcase and cylinder block bolts and studs are fitted with a vernier washer engaging two pegs in the casting and two longitudinal grooves in the bolt or stud to avoid torsional stressing when the nuts are drawn up.

The cylinder blocks, incorporating jackets and ducts for the cooling medium, are made interchangeable for convenience of production and servicing. Right-hand and left-hand blocks are only differentiated by the fitting of the special coolant and induction manifolds. Individual cylinder heads, also jacketed for coolant, are spigotted in the cylinder bores and secured by two of the main cylinder studs and seven smaller studs directly from the block. Each cylinder bore has two exhaust ports and three inlet ports, while the steel valve sleeves, nitrided internally and machine lapped, each have four ports. One of these, designated the combined port, acts alternatively for exhaust and inlet.



Two types of sleeve are required due to the relationship of the combined port to the actuation trunnion. The problem has been rather to keep oil out of the cylinder than to admit it, and consequently a highly developed scraper device is fitted in the face of the cylinder block and operates on the outer diameter of the sleeve. This is in the nature of a contracting wedge-action scraper ring, resembling that used at the bottom of the piston. A clamping plate is fitted to retain these rings when the cylinder block is withdrawn from the crankcase. Internally the lower end of the sleeve is furnished with a series of helical grooves which facilitate the return of oil to the crankcase and tend to prevent it from being forced past the piston scraper ring. At its upper end the sleeve

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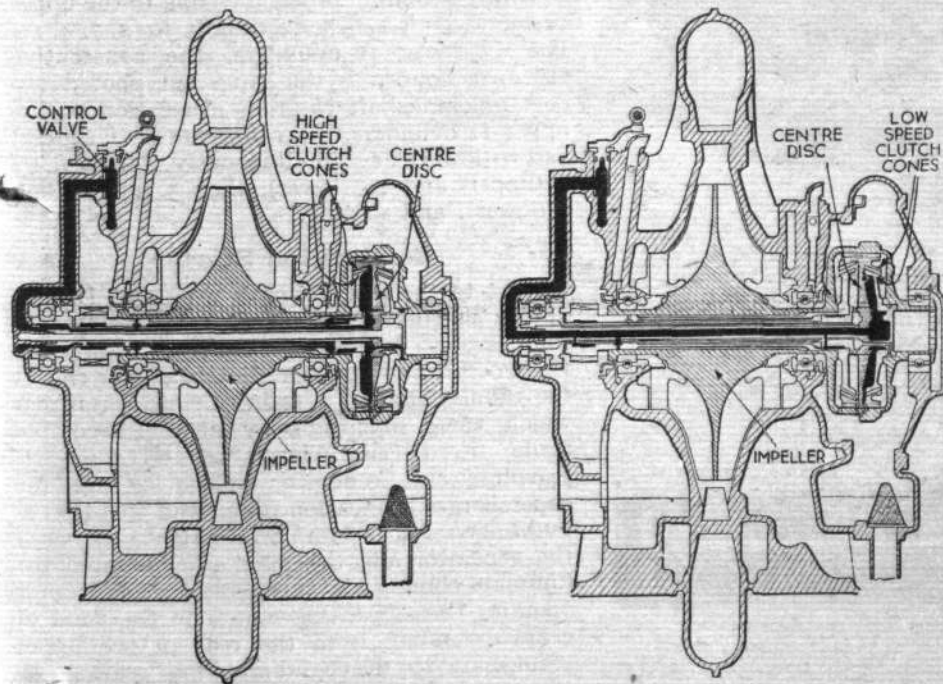
is sealed by a single taper-type pressure ring in the cylinder head.

The drive for the 12 sleeve valves of each cylinder block is by a divided hollow shaft driven at crankshaft speed through an idler gear from the rear pinion of the upper airscrew reduction gears. Each half-shaft runs in bearings bolted to the face of the cylinder block and has three integral worm gears for driving the sleeve cranks. A splined coupling joins the half-shafts at the centre. Sleeve cranks, arranged at 180 deg. and fitted with a bronze worm wheel to mesh with a drive-shaft worm, are mounted in roller bearings in pedestals which also form the caps for the drive-shaft bearings. The worm wheel has 22 teeth and is bolted to a vernier flange on the crank, which, in combination, furnish an adjustment of 1.48 deg. from the assembly datum for the timing of the sleeves. Each of these cranks actuates the sleeves of a vertical pair of cylinders. As will be seen from one of the illustrations, the sleeve-drive gear remains intact when a cylinder block is removed from the crankcase. Actually, sleeve phasing and timing can be made on the bench and final adjustment for the twelve cylinders effected in the meshing of the drive shaft pinion with the idler wheel transmitting the drive from the main reduction gears. Sleeve travel is somewhat longer than in common practice and, in fact, is almost equal to the piston stroke.

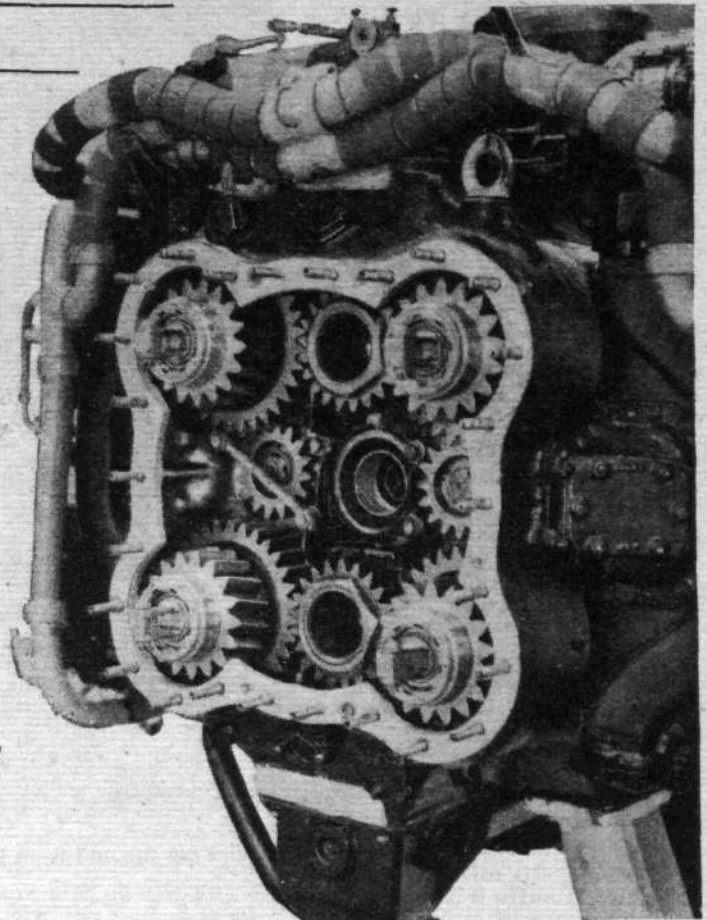
### Torsion Shaft Blower Drive

Arranged within the hollow sleeve-drive shafts are the torsion shafts for the two-speed supercharger drive. At its forward end each torsion shaft is splined to the drive shaft; to the rear end is splined and bolted the first pinion for the supercharger drive. The shaft is freely supported in a bearing at the rear end and also by a steady-bearing in the splined coupling muff joining the sleeve drive half shafts.

From the two torsion-shaft pinions the drive is transmitted to co-axial medium- and high-speed gear shafts of the double-entry centrifugal blower. Each shaft terminates in a cone, the two being spaced to accommodate centrally a floating double-conical member, slidably splined at its periphery to engage the driving drum of the blower impeller. Selective engagement of the two cones is effected hydraulically as shown in the sectional diagrams.



In the supercharger, medium- and high-gear shafts are both continuously driven by the two torsion rods. Selective engagement is effected by a fluid-actuated conical clutch, as indicated.



This view shows the four compound reduction gears driven from the two crankshafts, the central rear bearing of the airscrew shaft, and the two pinions of the sleeve drive shafts.

Mixture is supplied by a special four-choke S.U. carburettor. Two chokes feed the block of 12 cylinders on each side of the engine. The instrument follows usual S.U. practice, embodying oil-warmed throttle valves and automatic altitude and mixture enrichment controls. An automatic boost control unit is a separate component mounted on the supercharger casing.

From the volute collecting chamber of the supercharger the mixture passes through four tangential outlets to cast light-alloy manifolds, each serving a bank of six cylinders. Exhaust ports are arranged between the upper and lower banks of cylinders and each vertical pair is fitted with an individual ejector-type nozzle. These damp the exhaust flames and the efflux has a propulsive effect which improves the performance of the aircraft in which the engine is installed.

Considerable interest attaches to the airscrew-shaft reduction gear at the forward end of the unit. The rear bearing of the airscrew shaft, an undivided steel shell lined with lead bronze, is housed in the crankcase wall. This bearing receives two feeds from the general lubricating system and two separate feeds to the centre and the annulus of the shaft for the supply of pressure fluid for the pitch control of the Hydromatic airscrew. The four compound reduction gears are mounted in roller bearings in steel housings in the front wall of the crankcase and a steel carrier plate.

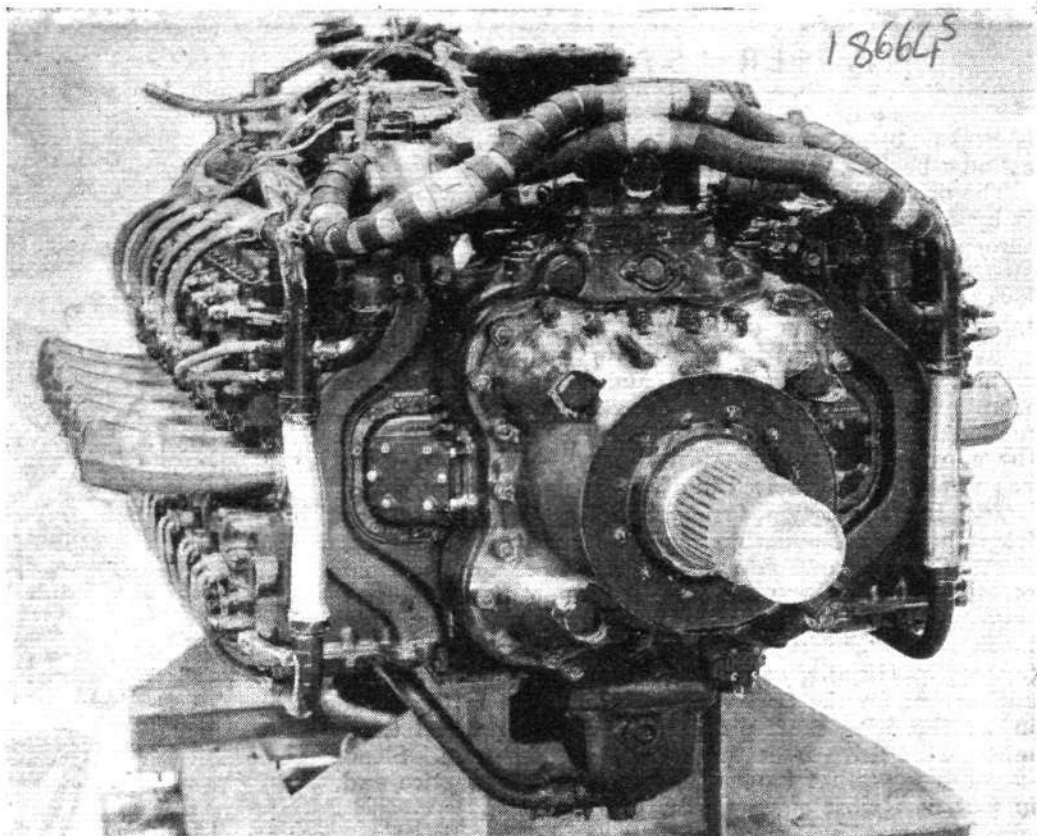
The upper and lower crankshafts

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drive upper and lower pairs of straight-tooth pinions, and the airscrew-shaft gear is meshed with all four helical pinions. To equalise the drive from each crankshaft to its pair of reduction gears, a balancing device is provided. Each reduction gear is permitted a limited axial float and they are held up to their work by a balance beam pivoted centrally on a forked pillar anchored in the nose casing. Movement is damped by spring-loaded plungers on the ends of the beam, yoked to light tubular shafts mounted on two double-duty ball races in the hollow compound reduction gear. The nose casing carries the main ball thrust bearing and the outer roller bearing for the airscrew shaft.

Auxiliary components are arranged accessibly in compact groups on the upper and lower face of the crankcase. In each case the drive is by a longitudinally arranged tubular shaft driving through an idler gear from the forward end of the crankshaft.

Above the engine the components are in the main arranged transversely, and thus the drive is taken from the tubular auxiliary shaft by bevel gears. Starting from the forward end is the Pesco vacuum pump on the left and the



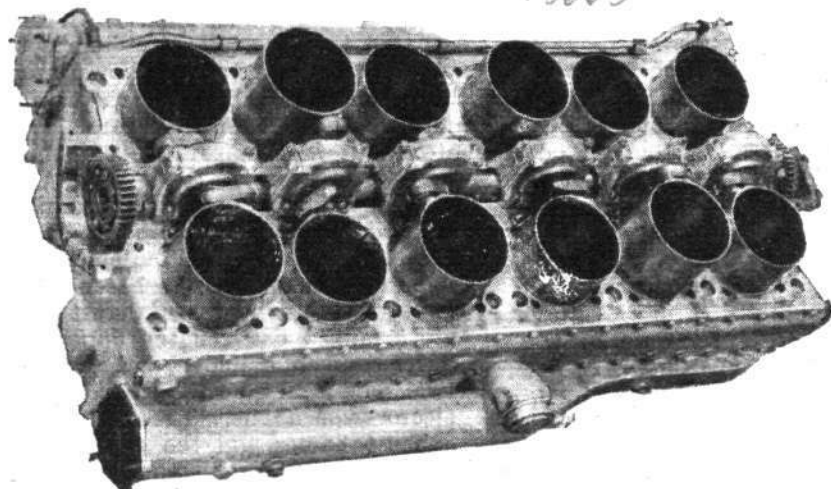
Viewing the unit from the nose, the accessibility of the cylinder heads, sparking plugs and also the auxiliaries is strikingly apparent.

airscrew control unit on the right. Next is the servo control unit which advances and retards the point of ignition in relation to the speed of the airscrew. Then come a pair of B.T.H. distributors running at half crankshaft speed, each of which has two concentric rings of 12 segments. The dual ignition system is divided into four groups controlled by four switches each isolating six cylinders.

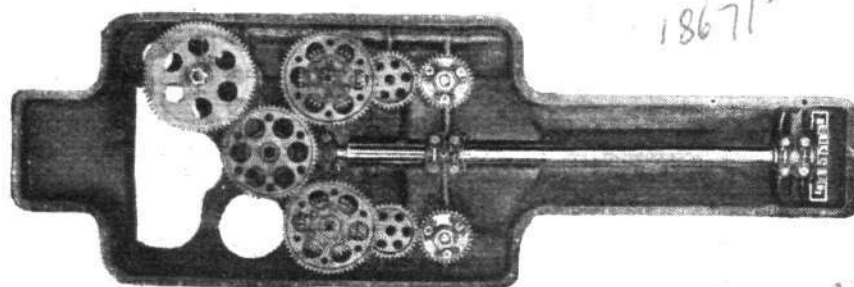
Due to the phasing of the two crankshafts, two cylinders fire simultaneously; thus for the complete unit there are six impulses per revolution. Upper and lower banks of 12 cylinders are numbered on the left 1 to 6 from rear to front and, on the right, 7 to 12 from front to rear. The firing order, referring to the upper 12 cylinders, is 1, 9, 5, 12, 3, 8, 6, 10, 2, 7, 4, 11. For the lower 12 cylinders, the consecutive order, of course, is the same but phased 180 deg. of crankshaft rotation in relation to the upper 12 cylinders. In other words, 1 (upper) and 6 (lower) fire simultaneously, followed by 9 (upper) and 10 (lower), then 5 (upper) and 2 (lower), and so on.

### Combustion Starter

Next to the distributor is a pair of B.T.H. duplex magnetos running at 1.5 times crankshaft speed. The last bevel-driven unit is the Heywood air compressor, but from the end of the tubular shaft is a train of spur gears from which three longitudinally arranged components are driven. These are the 500-watt, 24-volt electric generator on the left and the supercharger lubrication pump and the Dowty hydraulic services pump on the right. Between the generator and the pumps is mounted the Coffman combustion-type starter. This unit operates through a dog clutch to the train of gears extending from the rear of the upper crankshaft to the hand-cranking gear. The starter has a five-cartridge magazine and is started electrically. When the starter is operated, or when the engine fires, an automatic device



The sleeve actuation gear is mounted on the underside of the cylinder block.



The driving gear for fuel, oil and coolant pumps is assembled as a unit in the lower casing cover.

throws out the hand-cranking gear by lifting the hand-crank worm from its complementary wheel.

The tubular auxiliary shaft below the crankcase drives the fuel, oil and coolant pumps. All these units are mounted external to the crankcase with their spindles vertical, and the drive, after initial change of direction by bevel gears, is by trains of spur gears. All the driving elements are mounted in the bottom cover casing and can be detached as a unit; this is shown in one of the detailed illustrations. The lubricating oil pump and filter unit has one main pressure pump, a main scavenge pump (with which is embodied a smaller unit arranged above it serving as a scavenge pump for the supercharger casing), and a scavenge pump for the forward end of the crankcase. With this group are the high-pressure relief valves and two gauze filters. A large pressure filter, of the single felt element type housed in a light alloy cylinder, is mounted on the left of the supercharger casing.

Oil at high pressure lubricates the main crankshaft and big-end bearings, the airscrew shaft rear bearing, the reduction gear balance arms, and, by a series of pressure jets, the airscrew shaft reduction gears. Reducing valves for the low-pressure system are housed in the front and rear of the crankcase. This low-pressure system is employed for the valve-sleeve drives and upper and lower auxiliary drives. The valve sleeves and the small-end bearings of the connecting rods are lubricated solely by oil thrown off by the crank pins. It will be remembered that the supercharger has its separate oil pump driven from the upper auxiliary shaft. This feeds a metered supply to the intermediate and rear bearings of the blower impeller spindle. The outrigger ball bearing of the supercharger, beyond the two-speed clutch unit, depends entirely on oil mist for its lubrication.

Oil drained to the crankcase sump is returned by the main scavenge pump to the supply tank by way of the carburettor throttle valves and the jacket of the supercharger inlet. The front scavenge pump, drawing oil from the bottom cover casing, does not return it to the tank

direct, but instead delivers it to the sump, where it is then dealt with by the main scavenge pump.

Cooling is effected by a 30 per cent. ethylene-glycol mixture circulated under pressure. Special arrangements are made to by-pass the radiator when the temperature of the coolant falls, in order to maintain the engine at a suitable operating temperature at altitude. The coolant is circulated by two centrifugal pumps, each serving one block of 12 cylinders, and the direction of flow can be followed from the circulation diagram. The heated coolant and steam leaving each cylinder block at the upper forward end passes into a centrifuge pipe of electrolytic copper contained in a common annular header tank arranged around the engine nose casing. As the coolant whirls around this tube, the fluid accumulates at the outer wall, whilst any steam escapes through a series of holes in the inner wall into the coolant contained in the header. A spring-loaded valve is provided at the top of the header tank to relieve steam pressure.

At the lower termination of the centrifuge pipe is a thermostatically controlled valve, past which the coolant flows to the divided radiator and thence to the pump, which recirculates it through the cylinder block. Should the temperature of the coolant fall unduly, the thermostat partially or completely closes the valve, thus shutting off the radiator and diverting the flow by way of a by-pass pipe directly from the centrifuge pipe to the pump. Coolant outlet temperatures for various operating conditions range from 110 deg. C. to 125 deg. C.

Owing to the compact rectangular shape of the complete unit, mounting in the aircraft presents only straightforward problems. When installed, all cylinder heads and sparking plugs are accessible from the sides of the engine enclosure and all the auxiliaries from above or below.

The Sabre, despite its novel design, is probably the highest-powered aircraft engine in full production and fully operational. It fills a very real need in our production programme, and has already made its mark in the Hawker Typhoon. More will be heard of it in the future.

## NEW DE HAVILLAND ENGINE COMPANY DIRECTORS

THEIR many friends in the aircraft industry will be glad to learn that at a recent board meeting of the De Havilland Engine Co., Ltd., it was decided to add to the board of directors Mr. J. L. P. Brodie and Mr. Hugh Buckingham. The board previously consisted of Messrs F. T. Hearle, W. E. Nixon, F. E. N. St. Barbe, Major F. B. Halford, and Sir Geoffrey de Havilland.

Mr. Brodie, who becomes director in charge of the engineering division



Hugh Buckingham.

of the company, has been closely connected with de Havilland engine development ever since the first Gipsy was designed and built in 1926. He became first assistant to Major Halford in 1923 and has been his right-hand man ever since.

Mr. Hugh Buckingham, who becomes business director of the company, has been with De Havillands as apprentice, engineer, pilot and executive for 18 years. He has recently returned from New Zealand, where he inaugurated the sixth De Havilland overseas company and built its Wellington factory, at which Tiger Moths have been in production ever since.



J. L. P. Brodie, M.I.A.E.

## X-RAY CRYSTAL ANALYSIS OF METALS

A LECTURE entitled "Modern Views on Alloys and their Possible Application" was given at the 36th annual meeting of the Institute of Metals held in London by Dr. W.

Hume-Rothery, F.R.S. The lecturer dealt with alloys of typical univalent, divalent, trivalent and transition elements, of both scientific and practical interest. He showed that the development of X-ray crystal analysis permitted the determination of the positions of atoms in the different crystal structures, and was the first great step forward towards an understanding of the structures of metals and alloys. The study of the X-ray data and the equilibrium diagrams of alloys enabled a number of factors controlling alloy formation to be discovered empirically.

At the same time the mathematical-physicists were encouraged to examine the behaviour of electrons in the periodic field of the crystal lattices of metals, and the results obtained were found to have an immediate bearing on the properties and structures of metals and alloys. As a result of this work one was enabled to look beyond the mere crystal structure, and could begin to understand some of the factors which determined the structure and properties of alloys. In a limited way, from a knowledge of atomic structures, it was already possible to produce alloys with desired structures and properties.

## WEYBRIDGE BLADES

GRADED strength within a given outline may be said to be the salient feature of modern wooden airscrew blades. Such blades have now been made by the Airscrew Company for many years, and they have come to be taken for granted. It was therefore very welcome for friends of the company to see for themselves the many processes through which the blades go, in a coloured film shown in London the other day.

Mr. Titler, chairman of the Airscrew Company, explained that the film was originally made partly for educational purposes, and partly to enable those workpeople who were tied to one particular job or process to see the many others that go to the making of an airscrew blade.

The film takes one through all the many stages, from the sawing of the spruce planks to the finished product. The manufacture of the compressed wood (Jicwood) used in the root portion was particularly interesting, as was also the scarfing together of this hardwood root to the softwood blade. But most surprising was, perhaps, the comparative ease with which damaged and broken blades can be repaired.