AERONAUTICAL ENGINES.

By A. GRAHAM CLARK (Member).

The problems involved in the design and construction of engines used for aeronautical purposes are such as should make a direct appeal to the automobile engineer for solution, not alone on account of the commercial possibilities of the situation, but because the practical and scientific difficulties experienced are somewhat akin to those which have been overcome in the evolution of modern car engines, and because the production of a satisfactory engine would go far to eliminate one of the chief sources of danger. This is especially so as regards the members of this Institution in view of the comments of the judges in the Military Aeroplane Competition of this year, to the effect that the British engines entered in the competition had "not yet proved themselves capable of equalling the performances of the best foreign high-powered engines." Unfortunately, with comparatively few exceptions, motor car manufacturers have not given the subject the serious attention it deserves, but have, in some cases, endeavoured to obtain a high power/weight ratio by reducing the dimensions of the engine parts of their standard productions, especially those of the cylinder and the crankcase. It cannot be too strongly emphasised that the conditions of service are not less arduous than those under which the ordinary car engine is employed, and therefore, any sacrifice of strength or rigidity should not be countenanced for one moment. Going even further, it might be asserted that it is not at all improbable that the aeronautical engine of the future will be adapted for use on automobiles, although, it must be confessed, the trend of aero engine design in many quarters at the present day, would appear to be opposed to any such prospect.

Before considering the requirements which, from one cause or another, it is either essential or desirable that aeronautical engines should conform to, a few of the outstanding features embodied in current designs will be examined. To facilitate this as well as to render much descriptive work unnecessary, Table I., page 96, has been prepared, giving the construction of and materials employed for the principal parts of a number of engines; where the engines produced by any particular manufacturer vary, the data given relate to the type of engine constituting his principal production. The table is instructive as showing the extensive use which is now made of high tensile strength steels for crank and cam shafts and for connecting rods, and of aluminium for the crankcase. With but one exception (a 35 h.p. rotary valve engine by the Frontier Iron Works of U.S.A.) the engines are of the poppet valve type, and these, in the majority of designs, are placed in the head, and are operated by means of rocking levers and push rods.

Table II., page 96, gives the principal dimensions, etc. of various engines, and in compiling this, wherever it has been possible to ascertain the b.h.p. actually developed at any speed of revolution, the data have been employed in calculating the brake mean effective pressure in preference to taking the maker's horse-power at normal revolutions. For comparative purposes, the brake horse-powers at 1,200 revs. per minute have been tabulated and the weights given are those per b.h.p. at that speed, as it will be admitted that before any comparison as to relative lightness can be effective this important factor must receive some attention. For the same reason, the weight of the radiator, with water and piping, has been added to that of the water-cooled engines in order to obtain the weight of the complete power unit excluding fuel and oil; so far as has been possible, the additional weight has been ascertained from the makers, otherwise it has been estimated from probable average values.

In Table III., page 96, are the results of tests which have been made by a number of manufacturers on their engines and supplied to the author by them, but those shown in heavy type have been carried out by independent authorities. The high brake thermal efficiency attained by the 6-cylinder 70 h.p. Chenu engine should be noted, as this test was made in the laboratory of the Automobile Club of France.

Table I.

Construction and Materials of Principal Parts.

Name.	Country of Origin.	Form of Cooling.	Cylinders.		Valves.		Pistons.		Connecting Rods.	Crank Shaft.	Main Bearings.	Crank Case.
			Body.	Jacket.	Position.	How actuated.	Body.	Rings.				
A.B.C.	G.B.	Water	Forged steel	Steel-plated with copper on inside, secured by oxy-acetylene welding.	Overhead vertical.	Rocking lever and push rods	Steel	Cast iron and phosphor bronze.	H. section, steel	3 per cent nickel chrome, 2 connecting rods per crank.	White metal between each crank.	Steel casting, no horizontal joint.
Alvaston	G.B.	Water	Cast iron	Sheet metal, riveted	In head	Single push rods for both valves	......	......	Chrome vanadium steel.	Chrome vanadium steel, two throw.	Phosphor bronze, two bearings.	Aluminium alloy.
Albatross	U.S.A.	Water	Semi-steel..	....	In head	Rocking lever and push rods	Semi-steel..	Cast iron	H. section, vanadium steel.	Solid nickel chrome, two throw.	White metal, two bearings.	Aluminium alloy.
Anzani	F.	Water	......	....	In head	Auto. inlet. Exhaust by rocking lever and push rod.	Cast iron	Cast iron	H. section	Nickel chrome, two throw (6 cylinder).	White metal, two bearings.	Aluminium alloy.
Argus	G.	Water	Cast iron	Integral with body	Overhead vertical.	Rocking levers and push rods	Pressed steel	Cast iron	H. section	Nickel chrome	White metal between each crank.	Aluminium alloy.
Austro-Daimler	A.	Water	Cast iron	Copper electrolytically deposited	Overhead V	Rocking levers and push rods	Pressed steel	Cast iron	H. section, 4 bolts	Nickel chrome	White metal between each crank.	Aluminium alloy.
Bariquand and Marre	F.	Water, air-cooled head	Cast iron	Aluminium. Steel rings shrunk on.	Overhead vertical.	Auto. inlet. Rocking levers to exhaust.	......	....	....	....	....	Aluminium alloy.
Chenu	F.	Water	Cast iron	Integral with body	On one side	Camshaft in crank case	Pressed steel	Cast iron	H. section, chrome steel.	Nickel chrome steel	Die cast. White metal between each pair of cranks.	Aluminium alloy.
Curtiss	U.S.A.	Water	Cast iron	Monel metal brazed	Overhead V	Rocking lever and single push rod.	Cast iron	Cast iron	Tubular nickel chrome	Nickel chrome steel	White metal bearing between each crank.	Aluminium alloy.
Dorman	G.B.	Water	Cast iron	Spun copper. Steel rings shrunk on.	Overhead V	Rocking lever and single push rod.	Cast iron	Cast iron	H. section. (See description.)	Nickel chrome steel. Two connecting rods per crank.	White metal bearing between each crank.	Aluminium alloy.
Daimler-Mercédès	G.	Water	Cast iron	Integral with body	Overhead vertical.	Rocking levers and push rods. 100 H.P. overhead camshaft.	Pressed steel	Cast iron	H. section, nickel chrome.	Nickel chrome steel	White metal	Aluminium alloy.
Frontier	U.S.A.	Water	Cast iron	Copper electrolytically deposited	At side	Camshaft in crank case.	Cast iron	Cast iron	Tubular, nickel chrome	Nickel chrome steel	Ball bearings between each crank.	Aluminium alloy in one piece.
Fox	U.S.A.	Water	Cast iron	Cast aluminium	At side	Piston	Cast iron	Cast iron	H. section, nickel chrome.	Nickel chrome steel	White metal bearing between each crank.	Aluminium in one piece.
Gnome	F.	Air	Nickel steel.	....	In piston for inlet; in head for exhaust.	Auto. inlet. Rocking levers to exhaust.	Steel	Bronze	H. section, nickel chrome.	Nickel chrome steel	Ball bearings	Steel.
Green	G.B.	Water	Steel	Pressed copper with rubber ring.	Overhead vertical.	Overhead camshaft	Cast iron	Cast iron	H. section	Chrome vanadium steel	White metal bearing between each crank.	Aluminium alloy.
Gyro	U.S.A.	Air	3 per cent nickel steel	....	Inlet in piston. Exhaust overhead.	By connecting rod. By rocking lever and push rod.	Steel	......	H. section, nickel steel.	Chrome nickel steel	Ball bearings	Vanadium steel in halves.
Hall-Scott	U.S.A.	Water	Cast iron. Separate head.	Steel shrunk on and nickel plated	In head	By rocking lever and push rod.	Cast iron	Cast iron	Tubular, nickel steel	Chrome nickel steel	White metal	Aluminium alloy.
Kirkham	U.S.A.	Water	Cast iron	Integral with body	In head	By rocking levers and push rods	Cast iron	Cast iron	H. section, 3 per cent nickel steel.	Nickel chrome steel	White brass bearing between each crank.	Magnalium alloy.
Maximotor	U.S.A.	Water	Semi-steel	Integral with body	At side	Camshaft in crank case	Semi-steel	Cast iron	Manganese bronze	Nickel chrome steel	Ball bearings between each pair of cranks.	Aluminium in one piece, with head holes.
N.E.C.	G.B.	Water	Cast iron	Copper electrolytically deposited	At side	Special	Cast iron	Cast iron	H. section, vanadium steel.	...	White metal	Aluminium.
Panhard	F.	Water	Cast iron	Integral with body	At side	Camshaft in crank case	Pressed steel	Cast iron	H. section, nickel chrome.	Nickel chrome steel	White metal	Aluminium alloy.
R. E. P.	F.	Air	Cast iron	....	In head V	Both valves by single rocking lever and push rod.	......	......	H. section	......	Ball bearings	Aluminium alloy.
Renault	F.	Air	Cast iron	....	At side	Camshaft in crank case	Cast steel	Cast iron	Special steel	Special steel	White metal end ball bearings. Others in phosphor bronze housings.	Aluminium alloy.
Salmson	F.	Water	Steel	Copper brazed at head and silver soldered at bottom.	In head, vertical	Rocking levers and push rods	Cast iron	Cast iron	Special steel, H. section.	Special steel. One crank	Ball bearings	Aluminium alloy or steel.
Sturtevant	U.S.A.	Water	Semi-steel	Integral with body	On one side	Camshaft in crank case	Semi-steel	Cast iron	H. section, nickel chrome.	Nickel steel	Die-cast white brass between each crank.	Aluminium alloy.
Wolseley	G.B.	Water	Walls of steel, heads of cast iron	Aluminium. Bottom joint, Dermatine ring.	In head V	Camshaft in crank case. Rocking levers and push rods.	Drawn steel	Cast iron and phosphor bronze.	Nickel chrome	Nickel chrome steel	White metal between each pair of cranks.	Aluminium alloy.

Countries of origin: A. = Austria, F. = France, G. = Germany, G.B. = Great Britain, U.S.A. = United States of America.

GRAHAM CLARKE.

TABLE II.

Principal Dimensions, &c. of Aeronautical Engines.

Name.	Country of Origin.	Number of Cylinders.	Bore and Stroke.	Type.	Form of Cooling.	B.H.P.	Revs. per Min.	ηp lb. per sq. inch.	B.H.P. at 1,200 revs.	Engine Weight complete.	Radiator Water and Piping.	Total Weight.	Weight per B.H.P. at 1,200 revs.
										lb.	lb.	lb.	lb.
A. B. C.	G. B.	16	5 by 4½ in.	90° V	Water.	225	1,400	95·4	193	490	*150*	640	3·32
		12	,,			170	1,400	96·0	145·7	390	*130*	520	3·57
		8	,,	,,	,,	115 / 140	1,400 / 1,700	97·4 / 97·6	98·6	290	*90*	380	3·85
		6	,,	,,	,,	85 / 105	1,400 / 1,700	96·1 / 97·7	72·9	220	*70*	290	3·98
		8	3¾ by 3½ in.	,,	,,	60 / 85	1,450 / 2,375	118·8 / 102·6	49·7	175	*56*	231	4·66
		6	,,	,,	,,	45 / 65	1,450 / 2,375	118·6 / 104·6	37·2	175	*50*	225	6·05
		4	,,	,,	,,	30 / 44	1,450 / 2,375	118·6 / 106·1	24·8	110	*45*	155	6·25
Alvaston	G. B.	2	114 by 114 mm.	Horzl. opposed.	,,	20	1,200	92·9	20	95*	*40*	135	6·75
		2	132 by 127 mm.		,,	30	1,200	93·3	30	120*	*45*	165	5·50
		4	114 by 128 mm.	,,	,,	50	1,200	103·5	50	160*	*56*	216	4·32
Adams Farwell.	U.S.A.	5	6 by 6 in.	Rotary.	Air.	72	950	70·7	90·9	285*	...	285	3·14
Albatross	U.S.A.	6	4½ by 5 in.	Radial.	,,	50	1,230	67·5	48·8	250*	...	250	5·13
		6	5½ by 5 in.	,,	Water.	100	...	...	...	275*	*90*	365	...
Anzani	F.	3	105 by 130 mm.	72° semi-radial.	Air.	44	1,575	105·8	33·0	154*	...	154	4·67
		3	105 by 120 mm.	Radial.	,,	30+	1,300	94·7	27·3	121*	...	121	4·43
		6	90 by 120 mm.	,,	,,	45+	1,300	99·1	41·0	154*	...	154	3·76
		6	105 by 120 mm.	,,	,,	60+	1,300	94·7	54·6	200*	...	200	3·67
		10	90 by 130 mm.	,,	,,	80+	1,250	98·9	75·6	238*	...	238	3·15
		10	105 by 140 mm.	,,	,,	100+	1,100	96·0	107·5	308*	...	308	2·96
Argus	G.	4	124 by 130 mm.	Vertical.	Water.	50+	1,250	81·6	47·3	264*	33	297	6·28
		4	,,	,,	,,	70+	1,250	114·3	66·3	287*	40	327	4·94
		4	140 by 140 mm.	,,	,,	100+	1,250	118·8	94·7	309*	46	355	3·75
		4	155 by 165 mm.	,,	,,	150+	1,250	123·4	142	420*	53	473*	3·34*
Austro-Daimler	A.	4	100 by 120 mm.	,,	,,	40+	1,450	93·7	32·7	165	Rad. 27 Wa. *22*	214*	6·55*
		4	120 by 140 mm.	,,	,,	65+	1,350	97·3	57·0	232	Rad. 38 Wa. *28*	298*	5·23*
		6	,,	,,	,,	90+	1,300	93·3	82·0	316	Rad. 44 Wa. *35*	395*	4·72*
		6	130 by 175 mm.	,,	,,	120+	1,200	91·9	118·4	420	Rad. 50 Wa. *45*	515*	4·35*
Bariquand and Marre	F.	4	112 by 100 mm.	,,	Water, Air-cooled head.	30+	1,400	69·6	25·4	266	28	294	11·5
Burlat	F.	8	95 by 120 mm.	X Rotary.	Air.	35+	956	68·8	43·3	187*	...	187	4·32
		8	,,	Rotary.	,,	35+	956	68·8	43·3	187*	...	187	4·32
		8	120 by 120 mm.	X Rotary.	,,	60+	940	75·2	75·5	264*	...	264	3·5
		8	,,	Rotary.	,,	60+	940	75·2	75·5	264*	...	264	3·5
		8	120 by 170 mm.	X Rotary.	,,	75+	940	66·3	94·3	308*	...	308	3·27
		16	120 by 120 mm.	Rotary.	,,	120+	900	78·5	157·6	495*	...	495	3·14
Chenu	F.	4	110 by 130 mm.	Vertical.	Water.	52·4+	1,309	103·6	47·4	257*	*56*	313	6·61
		6	,,	,,	,,	83·7+	1,356	106·6	73·1	394*	*72*	466	6·38
		6	150 by 200 mm.	,,	,,	210+	1,200	105·6	207·1	860*	*150*	1,010	4·88
Clement	F.	4	100 by 120 mm.	,,	,,	41+	1,500	90·7	31·6	242*	*45*	287	9·09
		4	190 by 230 mm.	,,	,,	220+	1,200	90	217	1,100*	*150*	1,250	5·77
Clerget	F.	7	120 by 120 mm.	Rotary.	Air.	50—60+	1,200	56·9	50	198*	...	198	3·96
		4	110 by 120 mm.	Vertical.	Water.	50+	1,500	93·7	39·5	165*	*50*	215	5·45
		4	140 by 160 mm.	,,	,,	100+	1,250	103·9	94·6	341*	*90*	431	4·56
		8	,,	V	,,	200+	1,250	103·9	189·2	495*	*150*	645	3·41
Curtiss	U.S.A.	4	4 by 5 in.	Vertical.	,,	40	1,200	105·0	40	162	48	210	5·25
		6	,,	,,	,,	60	1,200	104·8	60	256	61	317	5·28
		8	,,	90° V	,,	75	1,200	98·5	75	286	69	355	4·74
Dorman	G.B.	8	4 by 4¾ in.	90° V	Water.	80	1,300	102·0	73·8	360*	*72*	432	5·86
De Dion	F.	8	100 by 120 mm.	,,	Air.	80+	1,700‡	79·9	55·7‡	484*	...	484	8·69
		8	125 by 150 mm.	,,	Water.	150+	1,600	81·5	110·9‡	968*	*130*	1,098	9·91
Daimler-Mercédès.	G.	4	120 by 140 mm.	Vertical.	,,	70+	1,400	101·1	59·2	278*	*70*	348	5·88
		6	,,	,,	,,	100+	1,350	99·8	87·7	420*	*90*	510	5·81
		8	175 by 165 mm.	,,	,,	240+ / 270+	1,100 / 1,200	90·7	266·3	1,830*	*160*	1,990	7·48
Frontier	U.S.A.	8	4⅛ by 4⅜ in.	90° V	,,	60	1,200	84·7	60	290*	70	360	6·0
		4	,,	Vertical.	,,	35	1,400	98·5	30	...	*45*	...	...
Fox (Two stroke.)	U.S.A.	3	4 by 4 in.	,,	,,	45	1,000	70·6	54	150*	*56*	206	3·82
		4	,,	,,	,,	60	1,000	70·6	72	190*	*63*	253	3·52
		6	,,	,,	,,	90	1,000	70·6	108	280*	*90*	370	3·42
		4	,,	Opposed.	,,	60	1,000	70·6	72	175*	*63*	238	3·31
		6	,,	,,	,,	90	1,000	70·6	108	250*	*90*	340	3·15
Gnome	F.	7	110 by 120 mm.	Rotary.	Air.	50	1,200	68·8	49·3	167*	...	167	3·39
		7	130 by 120 mm.	,,	,,	70	1,200	69·0	69·0	182*	...	182	2·64
		7	124 by 140 mm.	,,	,,	80	1,200	74·1	78·9	191*	...	191	2·42
		14	110 by 120 mm.	,,	,,	100	1,200	68·8	98·6	220*	...	220	2·23
		14	130 by 120 mm.	,,	,,	140	1,200	69·0	138·0	286*	...	286	2·07
		14	124 by 140 mm.	,,	,,	160	1,200	74·1	157·9	308*	...	308	1·95
Green	G. B.	4	105 by 120 mm.	Vertical.	Water.	30	1,100	85·1	32·7	182	*45*	227	6·95
		4	140 by 146 mm.	,,	,,	62	1,155	77·5	64·4	302	73	375	5·82
		6	,,	,,	,,	100	1,150	83·7	104·3	420*	90	510	4·88
Gyro	U.S.A.	7	4·3 by 4·75 in.	Rotary.	Air.	50	1,150	71·4	52·2	160*	...	160	3·06
Grey Eagle	U.S.A.	6	4 by 4½ in.	Vertical.	Air.	50	1,100	106·0	54·5	260*	...	260	4·77
Hall-Scott	U.S.A.	4	4 by 5 in.	,,	Water.	44	1,500	92·4	35·2	160*	Rad. 12 Wa. *20*	192	5·45
		8	4 by 4 in.	90° V	,,	65·5	1,500	86·0	52·4	265*	Rad. 21 Wa. *28*	314	6·0
		8	4 by 5 in.	,,	,,	83	1,500	87·2	66·4	290*	Rad. 36 Wa. *32*	358	5·4
Kirkham	U.S.A.	4	4⅛ by 4¾ in.	Vertical.	,,	40·4	1,400	89·9	34·6	180*	46	226	6·53
		6	,,	,,	,,	54·5	1,300	87·2	50·3	235*	58	293	5·82
Laviator	F.	6	130 by 160 mm.	,,	,,	110+	1,100‡	100·5	118·4‡	616*	*100*	716	6·05
		4	145 by 175 mm.	,,	,,	120+	1,200‡	110·8	118·4‡	484*	*110*	594	5·03
		6	180 by 200 mm.	,,	,,	250+	1,050‡	99·8	281·8‡	1,210*	*180*	1,390	4·94
		8	100 by 130 mm.	V	,,	80+	1,200‡	104·5	78·9‡	275*	*75*	350	4·45
		8	114 by 160 mm.	,,	,,	120+	1,200‡	98·0	118·4‡	418*	*110*	528	4·46
		8	147 by 175 mm.	,,	,,	200+	1,100‡	98·0	215·2‡	715*	*150*	865	4·02
Maximotor	U.S.A.	4	4½ by 5 in.	Vertical.	,,	50	1,200	103·5	50	210*	53	263	5·26
		6	,,	,,	,,	75	1,200	103·5	75	300*	72	372	4·96
N. E. C. (Two stroke.)	G.B.	4	3 11/16 by 4½ in.	90° V	,,	50	1,250	82·4	48	155*	*50*	205	4·28
		6	...	Vertical.	,,	90	1,250	...	86·4	320*	*85*	405	4·69
N. A. G.	G.	6	150 by 130 mm.	,,	,,	120+	1,300	85·7	109·2	770*	*100*	870	7·96
Nieuport	F.	2	135 by 150 mm.	Horizl. opposed.	Air.	32+	1,120	85·2	33·8	173	*45*	218	6·45
Panhard	F.	8	110 by 140 mm.	V	Water.	100+	1,500	80·2	78·9	440*	*90*	530	6·72
R. E. P.	F.	5	100 by 140 mm.	Semi-radial.	Air.	50+	1,100	105·9	53·8	242*	...	242	4·5
		5	110 by 160 mm.	,,	,,	60+	1,100	91·9	64·6	330*	...	330	5·11
		7	,,	Radial.	,,	95+	1,100	90·6	102·2	462*	...	462	4·52
Renault (Propeller on camshaft.)	F.	4 with fan.	90 by 120 mm.	90° V	,,	25	1,800	59·2	33·4	242·5*	...	242·5	7·25
		8 with't fan.	75 by 120 mm.	,,	,,	40	1,800	68·1	53·4	242·5*	...	242·5	4·84
		8 with fan.	90 by 120 mm.	,,	,,	55	1,800	65·0	73·4	375*	...	375	5·1
		8 with fan.	96 by 120 mm.	,,	,,	78	1,800	79·8	102·6	397*	...	397	3·865
		12 with fan.	,,	60° V	,,	100	1,800	79·8	133·4	639*	...	639	4·79
La Rhône	F.	7	105 by 140 mm.	Rotary.	,,	50	1,200	62·8	49·3	176*	...	176	3·67
		9	,,	,,	,,	80	1,200	78·2	78·9	242*	...	242	3·07
		14	,,	,,	,,	100	1,200	62·8	98·6	308*	...	308	3·12
		18	,,	,,	,,	160	1,200	78·2	157·8	374*	...	374	2·37
Rossel-Peugeot	F.	7	109 by 110 mm.	,,	,,	30—40	1,100	...	...	165*	...	165	...
		7	110 by 110 mm.	,,	,,	40—50	1,100	...	...	172*	...	172	...
		7	,,	,,	,,	50—55	1,150	...	...	165*	...	165	...
		4	140 by 140 mm.	Vertical.	Water.	100	1,300	114·1	91·0	352*	*90*	442	4·86
Salmson	F.	7	120 by 140 mm.	Radial Vertical.	,,	80	1,250	75·0	76·8	286*	*75*	361	4.7
		9	,,	,,	,,	110	1,280	78·2	103·1	352*	60	412	4·0
		9	150 by 210 mm.	Radial Horizl.	,,	300	1,200	78·0	300	990*	*200*	1,190	3·97
Sturtevant	U.S.A.	4	4½ by 4½ in.	Vertical.	,,	46	1,200	106	46	200*	*54*	254	5·52
		6	,,	,,	,,	69	1,200	106	69	285*	*70*	355	5·15
Wright	U.S.A.	4	4⅜ by 4 in.	,,	Water, Air-cooled head.	39	1,600	80·2	29·25	190	43·1	233·1	7·98
		6	,,	,,	Water.	50	1,150	95·5	52·2	230*	*56*	286	5·5
Wolseley	G.B.	8	5 by 7 in.	90° V	,,	126	1,150	78·9	131·5	695	*110*	805	6·12
Verdet	F.	7	112 by 140 mm.	Rotary.	Air.	55	1,100	72·7	59·2	176	...	176	2·98

* No flywheel. + Metric. ‡ Crankshaft speed. Propeller on camshaft. Data in italics have been assumed.

GRAHAM CLARKE.

Table III.

Performances of various Aeronautical Engines.

Name.	Country of Origin.	Number of Cylinders.	Bore and Stroke.	Type.	Form of Cooling.	B.H.P.	Revs.	mp lb. per sq. in.	Fuel Consumption per B.H.P. hour.	Brake Thermal Efficiency.	Oil Consumption per B.H.P. hour.	Engine Weight. Complete.	Engine Weight. Fly-wheel.	Engine Weight. Total.	Radiator and Piping.	Water.	Total Weight Power Unit.	At 1,200 Revs. per Min. B.H.P.	At 1,200 Revs. per Min. Weight per B.H.P.	At 1,200 Revs. per Min. Fuel Consumption per B.H.P. *for 5 hrs.*	At 1,200 Revs. per Min. Oil Consumption per B.H.P. *for 5 hrs.*	At 1,200 Revs. per Min. Weight *per B.H.P.* for 5 hrs. run.
									lb.	per cent.	lb.	lb.	lb.	lb.	lb.	lb.	lb.		lb.	lb.	lb.	lb.
Albatross	U.S.A.	6	in. 4½×5	Radial.	Air.	50	1230	67·5	0·86	15·91	·26	250	None.	250	—	—	250	48·8	5·13	4·3	1·3	10·73
Anzani	F.	3	mm. 105×120	,,	,,	30	1300	94·7	0·632	21·65	0·25	121	None.	121	—	—	121	27·3	4·43	3·16	1·25	8·84
	F.	6	105×120	,,	,,	60	1300	94·7	0·526	26·01	0·18	200	None.	200	—	—	200	54·6	3·67	2·63	0·9	7·20
Austro-Daimler	A.	6	130×175	Vertical.	Water.	120	1200	91·9	0·61	22·43	0·044	420	None.	420	50	*45*	515	118·4	4·35	3·05	0·22	7·62
Bariquand & Marre	F.	4	112×100	,,	,,	30	1400	69·6	0·77	17·76	—	243	23	266	10	18	294	25·4	11·5	3·85	—	15·35
Chenu	**F.**	**4**	**110×130**	,,	Air cooled head. Water.	**52·4**	**1309**	**103·6**	**0·617**	**22·17**	**0·006**	**257**	**None.**	**257**	*32*	*24*	**313**	**47·4**	**6·61**	**3·085**	**0·03**	**9·725**
Chenu	**F.**	**6**	**110×130**	,,	,,	**99·7**	**1617**	**106·5**	**0·542**	**25·3**	**0·005**	**394**	**None.**	**394**	*40*	*32*	**466**	**73·1**	**6·38**	**2·71**	**0·025**	**9·115**
Curtiss	**U.S.A.**	**4**	in. **4×5**	,,	,,	**40**	**1200**	**105·0**	**0·684**	**20·00**	**0·05**	**162**	**None.**	**162**	**28**	**20**	**210**	**40**	**5·25**	**3·42**	**0.25**	**8·92**
Daimler Mercédès	G.	6	mm. 120×140	,,	,,	100	1350	99·8	0·53	25·81	0·033	420	None.	420	50	40	510	87·7	5·81	2·65	0·165	8·625
Green	**G.B.**	**4**	**140×146**	,,	,,	**62**	**1155**	**77·5**	**0·59**	**23·18**	**0·11**	**265**	**37**	**302**	**41**	**32**	**375**	**64·4**	**5·82**	**2·95**	**0·55**	**9·32**
Gyro	U.S.A.	7	in. 4·3×4·75	Rotary.	Air.	50	1150	71·4	0·72	19·0	0·17	160	None.	160	—	—	160	52·2	3·06	3·6	0·85	7·51
Hall Scott	U.S.A.	8	4×5	90° V	Water.	83	1500	87·2	0·61	22·43	0·106	290	None.	290	36	32	358	66·4	5·4	3·05	0·53	8·98
Kirkham	U.S.A.	6	4⅛×4¾	Vertical.	,,	54·5	1300	87·2	0·58	23·59	0·06	235	None.	235	32	26	293	50·3	5·83	2·9	0·3	9·03
Maximotor	U.S.A.	4	4½×5	,,	,,	50	1200	103·5	0·54	25·33	0·08	210	None.	210	28	25	263	50·0	5·26	2·7	0·4	8·36
R.E.P.	F.	5	mm. 110×160	Semi-Radial.	Air.	60	1100	91·9	0·595	22·99	0·1	330	None.	330	—	—	330	64·6	5·11	2·975	0·5	8·585
Renault*	F.	8	96×120	90° V	,,	78	1800	72·6	0·64	21·37	0·045	397	None.	397	—	—	397	102·6	3·865	3·2	0·225	7·29
Salmson	**F.**	**9**	**120×140**	**Radial.**	**Water.**	**110**	**1280**	**78·2**	**0·61**	**22·43**	**0·059**	**352**	**None.**	**352**	**25**	**35**	**412**	**103·1**	**4·0**	**3·05**	**0·295**	**7·345**
Wright	**U.S.A.**	**4**	in. **4⅜×4**	**Vertical.**	,,	**39**	**1600**	**80·2**	**0·75**	**18·24**	**0·041**	**167**	**23**	**190**	**24·8**	**18·3**	**233·1**	**29·25**	**7·98**	**3·75**	**0·205**	**11·935**
Wolseley	G.B.	8	5×7	90° V	Air cooled head. Water.	126	1150	78·9	0·54	25·33	0·044	635	66	695	60	50	80·5	131·5	6·12	2·7	0·22	9·04

* Propeller driven off camshaft.

Note :—Data in italics have been assumed from average values. Data in heavy type obtained from official tests.

GRAHAM CLARKE.

Turning now to the consideration of the details of engine construction:—

The A. B. C. Engines.—The makers of these engines employ a form of construction which is not at all uncommon in the United States, in that a range of powers is obtained by varying the number of cylinders and by making the crankcase in sections, which are spigoted and bolted together. This enables the engines to be produced at a lower cost without the sacrifice of good workmanship and manufacture. At the same time, however, it would appear to involve some sacrifice in accessibility, although in other directions provision in this respect is ample in the A. B. C. engine. The crankcase, of cast steel, is well ribbed on the interior to prevent transverse distortion. The wisdom of mounting the valve levers on the water outlet from the cylinders, which is at a high temperature, notwithstanding the large bearing area of phosphor bronze obtained, is questionable on account of the difficulty of ensuring the efficient lubrication of the part. The flywheel is mounted on a key at the end of the crankshaft remote from the propeller. A single cam operates the inlet valves to the two cylinders opposite each crank, and lubricant is carried to the gudgeon pin through a hole passing up the web of the connecting rod. If desired, a reduction gear may be fitted and the engines run at a higher speed of revolution; the ratio employed for the larger engines is 2 to 1, and the reduction gear weighs 28 lb., while that for the smaller sizes is $2\frac{1}{2}$ to 1, and the weight 19 lb.

The Alvaston Motor is one of the few engines extant in which horizontal opposed cylinders are employed, although the advantages of such an arrangement in respect of balance are well known. This engine has an auxiliary exhaust. The cylinders are held together by four long vanadium steel rods which pass through the crankcase and through bridge pieces placed over the ends of the cylinders, so that the crankcase is relieved of stress. It will be clear that this ensures a strong, rigid construction, albeit it is open to objection on the score of accessibility, especially in view of the fact that these four rods also support the engine upon the fuselage, and hence the engine has to be removed in the event of examination or repair becoming necessary.

In the *Adams Farwell Engine* there is but one valve placed in the head of each cylinder for both inlet and exhaust; it is mechanically operated and opens direct into the atmosphere. Thus the valve is opened at the end of the power stroke and remains open during exhaust and inlet periods. During the suction stroke, the fuel is injected into the cylinder in the path of the incoming air. The system is apparently very simple, but there would probably be some difficulty in controlling the supply of petrol, so that the engine would be extravagant in fuel. The induction of a sufficient charge of air through a valve in the head of the cylinder of a revolving motor is also extremely doubtful.

The Albatross Engine employs two cranks at 180 degrees with each other, while one inlet and one exhaust cam operate the inlet and exhaust valves of all the cylinders, so that the order of firing is 6, 5, 4, 3, 2, 1. Auxiliary exhaust ports are used, and there is a chamber formed on the front of the crankcase into which the explosive mixture is drawn by the engine and from which the inlet pipes are led, for the distribution of the gas to the cylinders, somewhat similar to the arrangement used on the Anzani engines. The makers of this motor do not machine the outside of the cylinder, and claim that by this practice greater strength is obtained, but since the walls cannot be made of excessive thickness in this class of work this claim would appear to be more than counterbalanced by the risk of an unduly thin casting on one side and the distortion produced by the unequal cooling resulting therefrom. Adequate lubrication is a special feature of this engine, no fewer than four pumps being utilised for this purpose, and in order to prevent over-lubricating the inverted cylinders, the casting is extended so as to project into the crankcase itself to the extent of about $1\frac{1}{2}$ in.

Anzani Engines.—Figs. 1 and 2, Plate II., and Figs. 3 and 4, Plate III. The principal improvements that have been made in these engines since 1909 have been in regard to the method of valve operation, the use of long bolts for securing the cylinders, the formation of a mixing chamber upon the crankcase, and the employment of helicoidal feet to the connecting rod. Air-cooling is still employed, as is also the automatic inlet valve, but the exhaust valves are now operated by overhead levers as seen in Fig. 3, Plate III.

The construction employed in these engines for the attachment to the crank is somewhat similar to that on the old Brotherhood engines, in that a central bronze bush is fitted to the crankpin upon which the ends of the rods rest. To secure the parts in position, two clips in halves are bolted together (one on each side of the rod) over longitudinal extensions from the connecting rods. The two forms differ as regards the shape of the connecting rod ends, for whereas in Brotherhood's engine they were made parallel to the axis of the crank, in the Anzani engine they have a helical shape, the object of the latter being to obtain a greater angular contact between the rod and the bush.

The inlet pipes are now placed at the back of the cylinders on account of the strong cooling effect produced at high speeds in their former position.

In addition to the types of engines illustrated in Figs. 1 to 4, there is one other—the military type or Y engine—in which three cylinders are arranged at an angle of 120 degrees, though in all other respects it is similar to Fig. 1. The cylinders of these engines are offset with relation to the crankshaft. The large wind resistance area offered by the class of engines in which the cylinders are arranged about the crankshaft is obvious by an inspection of Fig. 4, Plate III. Attention may also be drawn to the high speed at which it is necessary to drive the armature of the magneto (should a single magneto be employed) with a large number of cylinders. In the 10-cylinder Anzani, the armature must be run at two and one-half times the speed of the engine.

The Austro-Daimler Engine of 120 h.p. is shown in Figs. 5 and 6, Plate IV., from which it will be seen that it somewhat resembles the conventional car engine, as do also the 45, 65, and 90 h.p. engines. A single rod operates a rocking lever placed over each cylinder for actuating the valves, and is therefore subjected alternately to tension and compression. To the engine illustrated, two magnetos and two carburettors are fitted, so that in the event of the failure of one of the former, the other will keep the engine in action; while when two carburettors are employed, the probability of both becoming defective is not so great, and hence a safe descent can be made under power. From the shape of the combustion chamber, the author would not anticipate that any increase of power is likely to be obtained from having two sparks in the one cylinder. The fitting of helical springs to the valves would probably be preferable to the laminated springs which are now employed, on account of the lag due to the friction between the leaves, especially since the force required to operate the valve gear of this type must be great.

Chenu Engines.—The 70 h.p. engine is illustrated in Fig. 7, Plate V., and is supplied with or without the reducing gear shown in the figure. It will be observed that the suspension is from the bottom half of the crankcase.

The compression pressure used in these engines is not known but it is presumably high, having regard to the brake mean effective pressure and the thermal efficiency obtained during tests carried out in the laboratories of the Automobile Club of France and the Conservatoire des Arts et Métiers, while the oil consumption is very low.

In the *Curtiss Engines,* a peculiar construction is adopted for the exhaust valve. This has a cast iron head which is reinforced by a perforated steel disk embedded therein, the whole being electrically welded to the carbon steel stem. In the two smaller models, the connecting rod ends dip into a sheet metal trough, but this form of splash is supplemented by oil which is ejected from radial holes in the hollow camshaft on to the rods. Bosch dual ignition is fitted to the two larger engines.

The Dorman 80 *h.p. Engine* is shown in Fig. 8, Plate V., and the feature which calls for special mention is the method of cooling the crankcase and bearings, and the exhaust from the engine. For the former, a bell-mouthed orifice covered with gauze is formed upon the bottom half of the crankcase, which opens above into the interior. To the upper half a connection is made with the carburettor inlet, so that the air taken by the engine must first pass through the crankcase. It will be clear that such an arrangement will conduce greatly to the cooling of the oil and the bearings and result in the more efficient lubrication of these parts, while it will be attended with practically no harmful effects, having regard to the conditions under which the engine is intended to be employed. Judging from the satisfactory operation of similar systems in other classes of work, no trouble is to be anticipated from the carrying over of oil in suspension into the cylinders.

Respecting the method of expelling the exhaust from the cylinder, the greater volume will naturally be ejected through the auxiliary exhaust formed by a number of small holes opening into an extension of the water jacket, at the bottom of the cylinder, while the exhaust valve fitted in the head, opening later, will release the remainder. But it would seem to be preferable for the gases emitted through the latter to pass through an aperture in the side of the valve cage rather than over the valve spring as at present, since they may be at a sufficiently high temperature to affect the spring detrimentally.

The engine has flat seated valves and a non-float carburettor.

The cylinders are mounted exactly opposite each other so that in order to avoid the use of offset or forked connecting rods, one piston of each pair has two rods attaching it to the crankshaft.

Mercédès Daimler Engines.—There are three different sizes of these engines manufactured, namely, 70, 100 and 240 h.p., the last-mentioned being employed for dirigible work. The 70 h.p. engine is similar in general arrangement to the 240 h.p. excepting that the water pump and magneto are placed at the end of the engine and driven off the crankshaft, the former direct and the latter through gearing, and that the inlet manifold from the carburettor is taken over the top of the engine, while the suspension is from the top half of the crankcase.

It will be seen from Figs. 9 and 10, Plate VI., that an overhead camshaft driven by bevel gear is employed on the 100 h.p. engine, thereby avoiding the use of long push rods which become necessary with the arrangements for the 70 and 240 h.p. engine. The method of circulating the water in the 70 h.p. (Fig. 10) and the 100 h.p. would appear to be capable of improvement, since the discharge from the pump is taken through the cylinders in succession, and hence the last cylinder to receive the water will be at a higher temperature than the first. In the 240 h.p., Figs. 11 and 12, Plate VII., the water is delivered to branch pipes attached to the tops of the cylinders.

Fox Motors.—These are operated on the two-stroke cycle, and the particular class of engines manufactured for aeronautical purposes embody what is termed a "fourth port." The three port type of engine resembles the ordinary two-stroke engine used in this country, excepting that the connection between the cylinder and the crankcase during cylinder induction is by way of a port cut in the wall of the piston beneath the rings and a chamber in the wall of the cylinder, while the main inlet port is formed in the cylinder wall and is covered by the piston when at the bottom of its stroke. The merit of the "fourth port" lies in the fact that it is so constructed that the direction of the air which alone passes through it (and which is, in addition to the air, passing through the main inlet port), is upwards towards the interior of the piston, so that when the cylinder induction com-

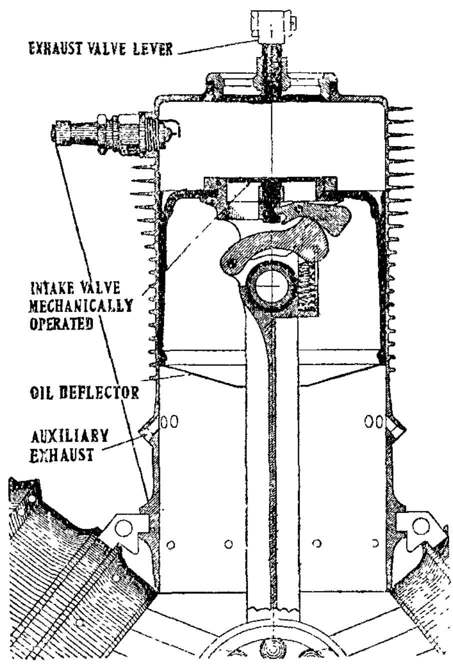

FIG. 13.—Mechanically operated Inlet Valve on Gyro Motor.

mences, the mixture from the crankcase is preceded by the pure air thus admitted. The claims made are that greater economy in fuel consumption and greater power are obtained, but it is difficult to see how the latter is effected unless the engine is working inefficiently when on the three port system.

The Gyro Motor.—This rotary engine employs an interesting form of inlet valve construction which is shown in Fig. 13. The valve is placed in the head of the piston and is operated by a lever. Upon an extension from the top end of the connecting rod a second lever is pivoted, the free end of which makes contact with the first lever near to its fulcrum. The method of operation is extremely simple. By centrifugal force the mass of the lever supported on the rod is thrown outwards and presses against the valve operating lever, so that, according as the contact is made on the side of the lever nearest to or farthest from the valve by the oscillation of the connecting rod, so will the valve be opened or closed—the period of opening being approximately 180°. It will be clear that this effect will be produced on the power stroke of the piston, but on account of the higher pressure within the cylinder, it will be insufficient to open the valve.

Auxiliary exhaust ports and guard plates to prevent oil reaching the valve and so entering the cylinder, are provided, but it would appear that the oil consumption is likely to be higher than is indicated by the figure given in Table III., since it would tend to collect, under the action of centrifugal force, around the circumference of the guard plate, and therefore, when the lower edge of the piston reaches the level of the auxiliary ports the oil would be ejected into the atmosphere.

The 60 *h.p. Hall Scott Motor* is seen in Figs. 14 and 15, Plate VIII., but there are two other engines rated at 40 and 80 h.p. respectively. In all of them detachable heads are fitted to the cylinders, and these are held in position by five long bolts passed through from the interior of the crankcase, as shown, the joint being made by a copper asbestos gasket. A separate pipe is fitted to connect up the jacket round the cylinder barrel with the water-cooled heads. It would seem that a more satisfactory construction could have been devised than one which entails draining the jackets, the dismantling of the whole of the valve gear and the breaking of the joint in the head in order to gain access to the valves. Cooling of the oil is effected by passing it round the carburettor, as in the Maximotor engines. All parts not made of aluminium are nickel plated for the purpose of obtaining a clean finished appearance and for protection against atmospheric influences. It is claimed that these engines are very flexible, and that aviators in the United States use more of this make than of any other.

This firm also produces special lightweight radiators, weighing only 12, 21 and 36 lb. for engines of 40, 60 and 80 h.p. respectively.

Kirkham Engines.—One of the features of these engines is the concentric inlet and exhaust valves shown in Fig. 16, from which the method of operation will be apparent. Such a construction allows of some small reduction in weight and enables a rather higher volumetric efficiency to be attained, while the

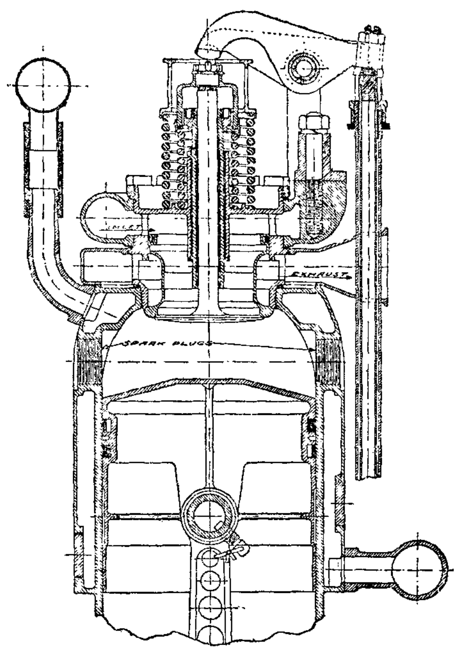

Fig. 16.—Concentric Valves on Kirkham Motors.

passage of the fresh mixture into the cylinder tends to cool the exhaust valve. The system has been tried on various Continental motors, but has generally been abandoned on account of overheating. In these engines, however, it has been employed for over three years, and its continued use is evidence that no serious trouble is experienced.

Oil-cooling is provided for by the fitting of two finned copper tubes through the oil reservoir in the bottom of the crankcase.

There is another model manufactured by this company in addition to those enumerated in the table, namely, a 6-cylinder water-cooled vertical engine $4\frac{5}{16}$ in. by $5\frac{1}{8}$ in. giving 76·3 b.h.p. at 1,680 revs. per minute, and weighing 285 lb. This is fitted with a 4 to 7 ball-bearing reducing gear, so that the propeller speed is 960 revs. per minute.

The 100 *h.p. Panhard Engine* is illustrated in Fig. 17, Plate IX. This engine has eight cylinders arranged in Vee fashion in sets of four, each set being cast *en bloc*, a rather unusual construction for engines of this class. On the sides is a large ribbed aluminium coverplate to the jackets, while to assist in supporting the overhanging weight of the cylinders two light tie rods are employed.

The propeller is geared down by attachment to an extension from the camshaft, a method employed in a large number of Vee engines, including the Renault, De Dion, etc. The extremely long inlet pipes from the carburettor are very noticeable.

The R. E. P. Motors.—The special form of cam gear referred to in a paper read by Mr. J. S. Critchley before this Institution in 1909 is still employed. It is formed by a groove on the side of a disk within which rollers attached to the side of the valve plungers engage and which is rotated in a direction opposite to that of the engine. The groove is plus and minus a circle in order to alternately pull and push the rods actuating the valves. It would appear, however, that although the arrangement is simple, it would be subject to great wear owing to the high linear velocity at which the cam is operated. Two cranks are used on all models.

The 90—95 h.p. engine is shown in Fig. 18, Plate IX.

The Renault Engines.—The two special features in these engines are that they are cooled by air drawn through a casing fitted over the cylinders by a fan driven by the crankshaft, and that the drive for the propeller is taken off the camshaft, thereby enabling a low propeller speed to be attained without sacrificing the power/weight ratio. The former is advantageous when an air-cooled system is intended to be used, as more efficient and uniform cooling can be relied upon; at the same time it must not be forgotten that the weight of the casing and fan, together with the fins on the cylinders, may (except in very special cases) raise the weight per b.h.p. considerably, while the lower mean effective pressure normally obtained with air-cooled engines may entirely eliminate any advantage it might otherwise possess.

The Salmson Engines with water-cooled radial cylinders belong to a class of which there are few representatives. The difficulty in engines with cylinders so disposed lies in devising an efficient system of water circulation, but it has been met in the engines under consideration by the arrangement seen in Fig. 19, Plate X. A centrifugal pump discharges water to the heads of the two lowest cylinders, from whence it emerges at the top end, passes to the inner ends of the jackets of the two cylinders next to them, out at the same ends of the jackets but on the opposite side, and so on. It would appear that there is some possibility of the overheating of the cylinders next to the two lowest ones, especially as the water spaces at the ends of the cylinders are rather narrow, while the division of the stream of water by branch pipes does not ensure the circulation of water on both sides in the event of the formation of steam on one side; at the same time from the more or less vertical direction of flow a steam lock is hardly to be expected.

The peculiar springs employed for closing the valves are clearly shown in Fig. 19. The timing gear is driven by a pinion on the crankshaft, through two wheels on a layshaft carried by the crankcase and back to the cams which are carried on a sleeve surrounding the crankshaft.

The 60 *h.p. Sturtevant Engine* shown in Fig. 20, Plate X., and Fig. 21, Plate XI., is in all respects, excepting that of the means by which the water circulating pump is driven, an engine of the standard car type, in which weight has been reduced by the employment of high grade materials. The ultimate tensile strength of the steels used is 56 tons per sq. in., while the cylinders and pistons are cast from semi-steel having an ultimate tensile strength of 18 tons per sq. in. It may, however, be remarked that the high brake mean effective pressure indicates that an extremely high compression is used. With regard to the wearing qualities of the engine, it would seem to be desirable for the side thrust on the piston to be taken on bearing rings, rather than on the body of the piston itself. All parts subject to atmospheric influences are nickel plated as in the Hall Scott motors.

The 120 *h.p. Wolseley Engine* is illustrated in Fig. 22, Plate XI., from which the general construction is apparent. It should be observed that provision is made to prevent the diversion of the water into one set of cylinders in the event of a steam lock being formed in the other set, by taking off the leads to the cylinders from two different points on the periphery of the pump case. Steel pistons and cylinder walls are employed, but they are kept from coming into contact with one another by the use of two phosphor bronze bearing rings. It would, however, seem to be preferable to bolt or otherwise secure the head to the barrel, rather than to rely upon a thread in cast iron for a part subjected to the full explosion pressure.

Bosch dual ignition is fitted; air is taken by the engine from the crankcase, and the remarks made anent a similar arrangement in the Dorman engine will also apply here.

Having dealt with the principal features of representative types of engines, the qualities it is either desirable or essential that an aeronautical engine should possess will be considered. They are:—

(1) Reliability.
(2) High power/weight ratio.
(3) Economy in fuel and oil.
(4) Low air resistance.
(5) "Controllability."
(6) Freedom from vibration.
(7) Accessibility.
(8) Silence.
(9) Cleanliness.

The need for the first requirement will at once be obvious, as the failure of the engine necessitates the immediate descent of the machine, if of the heavier than air type, which, should it occur at an inopportune moment may be attended with disastrous consequences. Hence, reliability must be placed above all other considerations.

High power/weight ratio and economy in fuel and oil consumption are desirable because of the increased radius of action possible with an engine possessing these qualities, while, in addition, the presence of excessive quantities of oil in the cylinder is a fruitful cause of irregular firing, and consequently falling off of power.

The importance of air resistance becomes more marked with increase in the speed, as the power absorbed in overcoming this varies as the cube of the velocity, and since many designers are raising the speed of their machines for the purpose of obtaining greater stability, the higher powered engines which result from so doing will render it necessary that a greater amount of attention shall be paid to the question in the future. It may be remarked in this connection that the horse power required to propel a flat plate 3 feet in diameter through the air is increased from about 6 to over 16 by increasing the relative velocity of the plate to the air from 50 to 70 miles per hour.

With regard to "controllability" or flexibility, although there is not the same need for this as with engines employed on automobiles, it is none the less a desirable quality since at low speeds of rotation the propulsive or tractive effort of the propeller is insufficient to move the machine along the ground, and hence the pilot will be able to start up without assistance should circumstances necessitate his so doing. Further, as the engine is not required to develop its full power during horizontal flight and when alighting, the ability to vary the speed during descent is certainly preferable to the crude method of switching the ignition off and on. These remarks will apply principally to aeroplane requirements, but in dirigible work such a quality will be an advantage because of the easy acceleration that can be given to the vessel without undue stressing of any part, as well as on account of the desirability of varying the speed while observations are being made.

The necessity for the elimination of vibration as far as possible will be obvious when the slender nature of the supports upon which the engine is carried is realised, especially as vibrations of an objectionable character may be set up in the various parts of the machine.

The question of convenience of access is frequently overlooked or, at any rate, disregarded on account of the care and attention which is now given to this class of engine before any extended flight is made. But it must be realised that from commercial considerations alone, apart from the addition to the time during which the machine can be used, and which may, under some circumstances, be of value, it will be an advantage to be able to readily examine or dismantle any part, especially when the applications of the aeroplane are more widely extended.

Silence is desirable in any mechanism used for pleasure or sporting purposes, but when it is intended for employment on military reconnaissance duties it becomes of increasing importance to be able to manœuvre without giving audible warning of approach, especially at night.

Cleanliness is in the nature of a refinement, but it is none the less necessary, since a dirty appearance is generally caused either by the oil splashed about during hand oiling or by the exhaust, both of which are objectionable—the former because the part requiring such attention is apt at times to run dry owing to the irregularity of the supply of lubricant, and the latter because it indicates an open exhaust.

Reliability and Weight.—Reliability may be regarded from two aspects—firstly, the absence of structural weakness of any kind, and, secondly, an immunity from defects in lubrication, cooling, carburation and ignition.

The first entails a consideration of the question of weight, and in this connection it should be remembered that in any engine lightness must be achieved by construction, not by increasing the stress or by reducing bearing areas. Now there are many ways in which reduction in weight per horse power may be made without the sacrifice of either strength or rigidity, the principal of which are as follows:—

(a) By the employment of materials of low specific gravity or great strength.
(b) By limiting the volume of the material.
(c) By reducing the number of parts subject to stress.
(d) By the more economical use of the material.
(e) By so disposing the material that it is better able to resist the loads which it is called upon to withstand.
(f) By the use of the simplest construction possible.
(g) By the adoption of air-cooling for the cylinders.
(h) By running the engine at higher speeds and gearing the propeller down.

As regards (a), much has already been done in this direction, not only in aeronautical engines but in other classes of work; aluminium alloys are used for the crank case, alloy steels for crank and camshafts and connecting rods, and pressed steel for pistons, etc., until the further reduction of the dimensions of these parts would render them liable to excessive distortion. It has been suggested that pressed steel might, with advantage, be used for the construction of the crankcase, but since many portions would require to be made extremely thin, and owing to the limited extent to which webbing or ribbing can be utilised, the "whip" in such a design, with the consequent distortion of bearings, must always prohibit its employment in this class of engines. The author does not, therefore, anticipate that much further progress will be made by these means unless some other metal is produced possessing similar physical properties to those of steel, but having a lower specific gravity. Some substitute will. however, have to be found for aluminium in the crankcase and other parts of engines for hydroplanes on account of the deleterious action of seawater on this material.

When proceeding as indicated in (b), the pistons may be reduced in weight by shortening the length of skirt; valves, by limiting the length of the stem; water jackets, by the use of sheet metal; the water carried, by having narrow water spaces; the bottom halves of crankcases, by employing sheet metal; entire crankcases, by allowing the minimum amount of clearance for the working parts; couplings, by removing metal where unnecessary; and flywheels, by the use of larger diameters, always provided that no detrimental effects are introduced thereby.

If, however, the pistons are made very short, they have a tendency to tilt, and limitations are thereby imposed. Valve stems must be long enough to allow of sufficient lift to give enough area for the ingress or exit of the gases and to afford an adequate length for the spring and guide. Water jackets of copper or other metal are permissible, providing that the methods of jointing to the cylinder at the ends, at the sparking plugs, and at the gas apertures are satisfactory, and that the jacket is free to expand independently of the cylinder. This is not always the case; for example, where steel rings are shrunk on, or the ends of the jackets are spun into a recess in the cylinder, or the ends are held by screws or rivets, there is a great possibility of leakage taking place after a time due to the deformation of the metal, and this is not entirely eliminated by the insertion of bellows in the jacket. Water spaces must not be made unduly narrow or overheating will occur, while, if the disk of the flywheel is very thin, possibly drilled out to assist in giving lightness, its lateral stability will be impaired. The other methods mentioned will depend for their efficacy upon the details of the particular constructions adopted.

(c) One method in which this is effected is by the use of a single cam to operate two inlet valves, as in some Vee engines, or an inlet and an exhaust valve as in other engines, principally of the Vee and radial type, but yet in many designs long push or pull rods actuate the valves through rocking levers. This, in the author's opinion, is altogether inferior to an arrangement in which the valve is directly operated, as is found in the Chenu, Green or Panhard motors, for, apart from the greater weight entailed, the force required to actuate the gear is very great and necessitates the use of larger camshafts and stronger springs owing to the larger mass to be moved. The adoption of such an arrangement is largely attributable to the difficulty of devising a satisfactory overhead valve gear, on the one hand, and because the employment of the more conventional design used on automobile engines adds somewhat to the weight of the cylinders.

The direction in which many engineers are working is referred to in (d), since it affords an easy way of acquiring a light construction, but it has caused the evolution of some freak designs, the principal claim of which to notice seems to rest upon their ingenuity rather than upon any useful quality. By far the greater number of engines that are now manufactured are of the Vee, the radial, the semi-radial, and the rotary type, as the length and weight of the crankcase and shafts may thus be reduced considerably, but unfortunately other factors are thereby introduced which cause them to be less satisfactory than the vertical engine. Mention has already been made of one disadvantage under which they labour, namely, the types of valve gear which then become necessary and which are especially inferior in rotary engines, while other detrimental features will be referred to later.

The two-stroke engine may also be regarded under this heading, since by virtue of doubling the number of impulses per revolution, a great reduction in the actual weight per horse power should be possible. The fact remains, however, that few engines of this type are in actual use, and that in these there is little advantage in respect of weight, largely owing to the construction necessary to ensure the attainment of as low a fuel consumption as with engines operated on the four-stroke cycle.

The use of hollow shafts and rods, H-section connecting rods, etc., and the care taken to subject parts to tensile rather than compressive stress, are illustrative of the methods referred to under (e), and these may be widely adopted with advantage wherever practicable. Great care must, however, be exercised in determining the proportions of the parts so constructed, in order to ensure that there shall be no risk of collapse. For example, cases might be cited in which the thickness of the metal at the journals of the crankshaft is such as to render it extremely probable that the sides will diverge laterally under load, causing excessive pressures on the bearings, and ultimately, the fracture of the part. All abnormal construction is to be deprecated, and the proportions used should not differ greatly from those accepted in standard automobile practice.

The benefits to be derived from making the design as simple as possible need little comment, as the elimination of all superfluous fittings and the avoidance of an intricate construction must effect a saving of weight, and, in addition, contribute to a lower cost of production. It is necessary, however, to remember that all devices or parts necessary for the efficient working of the engine must not be sacrificed, for "the art of successful design lies in knowing exactly what parts can be left out, and how simply and cheaply we can make and fit those parts which are essential, without impairing their value as regards the functions which they perform."*

Heading (g) raises the oft-discussed question of the relative merits and demerits of air-cooling. Undoubtedly, the weight can be much reduced by this method, and the absence of water joints and connections tends towards simplicity, but it is well known that, in general, a lower brake mean effective pressure is obtained with this type of engine than with that using water-cooling, largely because of the greater frictional losses between the piston and the cylinder and the reduced charge of gas taken. The former is due to the distortion of the cylinder owing to the unequal expansion which results from lack of uniformity of cooling, as well as the higher temperatures at which these engines are run, while the reduction in the charge taken is attributable to the high temperatures within the cylinder. Further, the additional details which become necessary to ensure sufficient air passing over the cylinders should receive attention. If a separate fan is employed, and the cylinders are closed in by a sheet metal casing, the design requires very careful development to ensure that the ultimate results achieved are even equal to those ob-

* See Proc. I.A.E., Vol. IV., p. 269, T. B. Browne on "Design of Petrol Motor Vans."

tainable with water-cooled engines—in fact, in most cases the weight per horse power is greater for the same speed of revolution of the crankshaft. With engines of the radial or semi-radial type, and especially with rotary engines, the air resistance is enormous and increases with the power developed, since the bore of the largest cylinder to which air-cooling can be effectively applied is limited, and, therefore, increase in power can only be obtained by increasing the number of cylinders. This is, however, undesirable on account of the greater number of parts from which trouble may arise; at the same time, the greater the number of cylinders, the less will be the proportionate loss of power in the event of one cylinder becoming disabled.

The whole matter is obscured by reason of the fact that many of the most successful flights have been made with air-cooled engines of the rotary type; indeed, it cannot be denied that but for the advent of such engines aviation would never have progressed as far as it has, because water-cooled engines at that time derived much of their lightness from a reduction of the factor of safety employed and an increase in bearing pressures, with the result that the reliability was impaired. Any engine, therefore, that could give equal results with a reduction in weight was welcomed with avidity. The author is of opinion, however, that the large amount of power absorbed in rotating the cylinders, the increased air resistance offered, the non-uniform distribution of heat in the cylinder walls, and the variation in cooling effects at varying speeds renders the adoption of this method of reducing weight a very doubtful expedient for obtaining a high effective horse power per unit of weight now that reliability has come to assume such an important aspect.

With regard to the method indicated in (h), it must not be forgotten that the increase of power obtained by raising the speed of revolution is not an entire gain, for the weight of the gearing and its supports, possibly some reduction in the mean effective pressure, and certainly the loss of power through transmission by gearing will cause the ratio of weight to power to be somewhat greater than is indicated by the increase in the speed. Also, higher speeds of revolution naturally tend to increase the wear of the moving parts and render the possibility of engine failure greater, since few engines are able to run for prolonged periods under such conditions. Hence such a system is not recommended for general adoption.

Turning to the second aspect of reliability, namely, the absence of trouble from defects in lubrication, cooling, carburation and ignition, it will be found that the problem of cylinder lubrication is closely connected with that of cylinder cooling, and the water-cooled engine is superior in this respect for heavy and sustained loads to the air-cooled engine on account of the lower and more uniform temperatures employed. Furthermore, the vertical engine is superior to any other form of engine so far as cylinder lubrication is concerned, because the supply of lubricant is under better control and is more uniformly distributed, as the conditions are practically the same in all cylinders. With cylinders placed beneath the crankshaft, provision must always be made to prevent oil draining into them, and this may or may not be entirely effective, according to the quantity of oil in the crankcase. In any event the lower cylinders will receive a larger amount of oil than the upper cylinders, which may be sufficient to cause flooding. In a modified degree these remarks will apply to Vee and semi-radial engines. To overcome the difficulty of insuring the uniform distribution of oil, the rotary engine may be adopted, but in addition to its defects in respect of cooling (it is hardly possible to use water-cooling for this type of motor) and of air resistance, there arises another in that the oil consumption of such engines is excessive. This is only to be expected, since with ordinary engines there is quite enough difficulty in keeping the oil down from the cylinders, while in this case the oil is fed by centrifugal force and carried by the fresh incoming mixture through the inlet valve into the cylinders. To reduce these troubles, which must always exist to a greater or less extent, forced lubrication to the gudgeon pin and the cylinder seems to be the only remedy, as by this means the quantity of oil may be regulated by experiment to a nicety.

With regard to the bearings, it is essential that there always should be a film of oil between the surfaces. The maintenance of this oil film depends upon the use of suitable bearing pressures, the elimination of distortion at the bearings, and the continuance of sufficient viscosity in the oil. Granted that the bearing pressures are not excessive, it will be clear that the shorter the distance between the bearings the more rigid will be the shaft, and therefore the less the liability to distortion. Hence, a bearing should be provided between adjacent cranks, and it is preferable not to attach two connecting rods to one crankpin, as is necessary with Vee engines, on account of the increase in the distance between the bearings which this leads to. The viscosity of any oil depends upon its temperature, and since the oil will reach very high temperatures when engines are run for prolonged periods at heavy loads, it is desirable to fit some cooling arrangement. This may take the form already mentioned as provided in the Dorman and the Wolseley engines, but preferably a separate cooler should be included in the design. It is noteworthy in this connection that the Napier, the Sunbeam and the Green engines, which have successfully undergone severe trials of long duration, have fully forced lubrication systems and bearings between adjacent cranks. To ensure that the oil delivered to the bearings shall be free from any foreign substance, it is necessary that a filter should be inserted in the system. By the adoption of these means it is possible to obtain some immunity from trouble from over lubrication, as a supply of pure cool oil in sufficient quantities can be fed to every part continuously. It may be added that practically all these engines have forced lubrication to the main bearings, but it would appear that the advantage to be gained by the extension of the system throughout the engine more than compensates for the increased cost of manufacture entailed.

Carburation difficulties may arise in any petrol motor, since the mode of carburetting the air depends for its efficiency upon the particular design of carburettor employed, but on account of the comparatively small variations in power output required during flight, there should be little difficulty in satisfactory working.

There is, however, one aspect of the question which should receive attention, namely, that of the effect of altitude.

Assuming that the barometric pressure at the sea level is 30 in. of mercury and the temperature 15° C., at a height of about 5,000 feet the barometric pressure will have fallen to 25 in. of mercury and the temperature to 8° C., assuming average atmospheric conditions. Since the weight of one cubic foot of air is 0·0807 lb. at 0° C. at the sea level, the weight of one cubic foot will be $0·0807 \times 273/288 = 0·0765$ lb. at 15° C. at the sea level and $0·0807 \times 273 \times 25/(281 \times 30) = 0·0653$ lb. at 8° C. at a height of 5,000 feet, that is, the weight of air will be in the ratio of 1 to 0·854. Further, the difference of pressure causing petrol to issue at the jet so far as velocity and static head are concerned will remain practically the same at any elevation, while the engine is running at a constant speed except for an increased viscosity of the fuel. Sorel gives a chart on p. 166 of his book on "Carburetting and Combustion in Alcohol Engines" from which it will be seen that the quantity of petrol discharged through a capillary tube under constant pressure at 8° C. is 0·965 of that at 15° C. Hence the mixture will tend to become richer in the proportion of 0·854 to 0·965 or 1 to 1·13.

Since most engine builders employ high tension magnetos for igniting the charge, and these have reached a high standard of perfection, it is not anticipated that trouble is likely to arise from this cause provided that extraordinary conditions do not prevail, that is, as long as the speeds at which they are driven are kept within reasonable limits. In general, these are satisfactory, but with the tendency to increase the number of cylinders or to run at high revolutions and gear down the propeller, it is preferable to fit two magnetos (as is sometimes done) rather than to risk failure in such an important part. The two magnetos will obviously require careful synchronising and adjustment, and will increase the weight slightly, but the advantage derived will more than compensate for this addition.

Economy in Fuel and Oil.—These will be the greater with engines having high mechanical and thermal efficiencies and embodying very careful design, but although the air-cooled engine works at a higher temperature, the compression pressure that can be employed is limited, and hence the thermal efficiency is not greater than that obtainable with water-cooled engines, and on account of the greater frictional losses in the pistons, the mechanical efficiency is lower. Therefore the fuel consumptions per b.h.p. are, in practice, slightly less with the water-cooled than with the air-cooled engine. This is indicated in Table III., for, with the exception of the result recorded for the 60 h.p. Anzani, and which, it may be added, is open to considerable doubt, the average results for air-cooled motors are worse than for those using water-cooling. It should be noted, however, that practically all the results, excepting that for the Albatross, are excellent and hardly likely to be improved upon.

The same tendency is also exhibited in the table with regard to oil, and as this has been referred to previously, nothing further need be added.

The *Air Resistance* offered by air-cooled engines has been considered when dealing with the methods by which the weight may be reduced, and it would appear to be one of the necessary accompaniments of this type, since, in order to assure that an adequate quantity of air will pass over the cylinder, they must be arranged in fan or radial fashion. For low machine speeds, stationary cylinders are almost impossible, and render the use of the rotary engine essential, but with higher speeds now employed, a radial or semi-radial motor can be successfully fitted. Air-cooled Vee engines, or any other type of engine in which the cylinders are arranged in line, should not be used unless a system of fan-cooling is adopted (as in the *Renault*), since the leading cylinders obscure those that follow and do not allow of effective cooling.

In regard to the water-cooled engines, that type will offer least resistance which has the least exposed area in the direction of motion, and the smoothest exterior. This is in favour of the vertical engine, since it can be more efficiently enclosed with a casing having a stream line formation.

Vibration.—Little fault can be found with most engines in regard to balance on account of the care taken during manufacture to ensure the uniform distribution of weight, but the absence of flywheels on many stationary motors and hence the reliance which must be placed upon the propeller for uniformity of torque calls for a few remarks. In cars the variation in the torque transmitted from the engine is largely absorbed in the elastic deformation of the transmission gear and the stressing of the tyres, and any excess or deficiency above or below the mean energy required to propel the car are thereby compensated for. But when the conditions are such as those under which the aeronautical engine is most frequently employed, namely, when the propeller is directly coupled to the engine, the variation in torque will extend to accelerate or decelerate the rotating parts, thus conducing to the inefficient working of the propeller by augmenting the "slip."

It is not at all improbable that the flywheel effect of the large rotating mass in rotary engines is one of the reasons why they have been so successful, for it is well known that they do not develop within 10 per cent of their rated horse power, yet stationary engines of equal rated power have, in many instances, failed to produce superior results. Beneficial results will, of course, be obtained from the increase in the number of cylinders on account of the smaller fluctuations in magnitude of torque.

Accessibility.—Opinions differ as to the extent to which provision should be made in this respect, but there would appear to be no reason why adequate access should not be given to valves and to the interior of the crankcase. With many of the engines now used for aeronautical purposes it is necessary practically to dismantle the valve gear in order to examine the valves, and in the case of rotary engines, to remove the cylinders. It is true that a cylinder of, say, a Gnome engine, can be dismounted in twenty minutes, but seven cylinders will absorb two hours and twenty minutes at least, and on account of the excessive oil consumption of this class of engine frequent attention to the cylinders, pistons and valves for cleaning is very necessary. This is, to some extent, recognised in the particular engine referred to, although access to the inlet valve can only be gained after the removal of the exhaust valve and its operating gear and by the use of special tools. As regards other parts of the motor, the principal point to bear in mind is the abolition of a large number of small screws or bolts and nuts for the attachment of parts, while it should be possible to effect the removal of, say, the bottom half of the crankcase without disturbing any portion of the gear other than that which is actually carried on that half, and this should be of limited extent.

Silence and Cleanliness.—All working parts should be totally enclosed and be automatically or mechanically lubricated, otherwise trouble may arise from this cause. Considerable success has attended the efforts of designers of automobile engines to silence the valve actuating mechanism by enclosing these parts and improving the details, but with many aeronautical engines there is ample room for improvement, as the form of gear resembles a type that has been long discarded in road vehicles on account of the chatter and vibration which it is impossible to prevent.

Further, the engine exhaust should enter a common pipe which may then be led to some convenient position, where it will not cause discomfort to the pilot and spread unburnt oil in all directions. This is, of course, quite impossible on rotary engines, and becomes a complicated matter on engines fitted with an auxiliary exhaust. Preferably some form of silencer should be employed.

In conclusion, the author has adopted a somewhat critical attitude with the object of bringing out the views of those who, from experience in the construction and the working of these engines, are well qualified to speak. It is to be hoped that the subsequent discussion will fulfil a useful purpose in forwarding the development of the aeronautical engine in this country, so that it may soon arrive at a position in the world as high as that now held by the British automobile.

The author acknowledges with pleasure the assistance he has received from Mr. MacIvor in calculating the values of ηp and the thermal efficiencies of engines given in the tables; also of the manufacturers who have been good enough to favour him with photographs and particulars of their productions.

THE DISCUSSION.

Mr. L. A. LEGROS, in opening the discussion, said: I have practically no information to give on the subject of these light motors, but there are just a few questions I would like to ask the author. On p. 105 he alludes to vibration; as one who has had little or no practical experience of these motors, I should like to ask him whether there is any form of vibration due to the absence of a flywheel which is called flutter of the propellers, i.e., the propeller has a form of vibration which is due to a change of forward velocity, and whether that fluctuation in velocity causes a big reduction in the efficiency of the propeller on the machine. I do not know whether any research has been done on this subject, but several airmen have told me that those engines which have a big flywheel capacity, or which have a large amount of inertia in the revolving parts, such as those with fixed crankshaft, are much less liable to produce that effect than are engines with fixed cylinders and a small flywheel. If the author has any information on this subject, I am sure it will be most interesting.

Mr. S. F. CODY: The author of the paper said one or two things which rubbed me up the wrong way, especially when he said that all the best performances had been made by air-cooled engines. I do not agree with that. I cannot speak for other countries, but I may say that all the best performances in England have been done with water-cooled engines. Our excellent performance for the Michelin duration prize this year was with a water-cooled engine. It was not an $11\frac{1}{2}$ hours' flight, such as was done in France, but remember, the man who did it was a young aviator, and the constructor who built the machine was a youngster at the game; I think it was about the first or second machine that he had built. Whether he took his design from somewhere else or not is neither here nor there. The weak points showed up under the vibration of the engine, and I think they took three or four tests before they got an eight hours' flight, but by strengthening the different parts, I believe of the motor section, they eventually got it. They did not tell me exactly what they did because I was a rival, but I am pretty sure I have hit the right nail on the head there. With regard to the vibration of the propeller, or propeller flutter, mentioned by the previous speaker, I do not know any engine which produces this more noticeably than the Gnome, which has an enormous mass as a flywheel; I mean the Gnome that is held on one end only, because each throb of the engine is transmitted throughout the propeller, and in the 50 h.p. Gnome engine the propeller has a very fine pitch, and has very little pressure of air against it, and it is allowed to twist in the air. The flutter can be almost entirely eliminated in the case of a high powered engine driving a coarse pitched propeller if the propeller is fitted on a shaft of sufficient length to leave a good space between the propeller and the back end of the machine or front end of the machine, as the case may be. The propeller of the Gnome engined Farman biplane is within two or three inches of the main parts of the machine, which, of course, was one of the biggest mistakes ever made by a man who understood aeronautical efficiency in reference to dynamic flight. I keep the propeller as far away as I can from any other obstacle, and I use as heavy a flywheel as I can get the engine designers to supply me with. In regard to the failure of the joint at the bottom of the water jacket, the author has not mentioned one of the most permanent successes I have ever known, and that is the rubber ring between the copper jacket sleeve and the steel cylinder used in the Green engine, which is certainly a success. I have won a good deal of money mounted in front of a Green engine, and I am speaking from experience, which, I understand, has been asked for. It is the Green engine that has taken all but one of the Michelin prizes in England. One Green engine took three Michelin prizes for me, and a six-cylinder Green engine took the fourth. The reason I did not enter for the duration Michelin was not because of engine failure, but because one machine could not easily be equipped for speed and for duration also. It took time to go from the speed test, which I won, and get the machine ready for the duration test. The weather failed, and I had not a chance to go up, but the engine did not fail, neither did anything else but the weather. Therefore, you can rest assured that we have nearly as good an engine here in England as anywhere, but it has not been given a proper chance by other people than myself. I think the Roe people gave it a very fair chance, but they were under-powered, as I was in the *Daily Mail* circuit. I built a machine for a 120 h.p. engine, and had to put in a

(Mr. S. F. Cody.)

60 h.p. Green and go round the tour. That speaks volumes for that engine to work as it did. I tell you now that if I had to fly from here to France, with my experience of engines, I should have a water-cooled, British made, Green engine to do it with. My work in aviation was not all accomplished this summer at the military trials. The admission of the public was gained this summer for the first time, but that was not when I did my best work at all. I did just as good work two years ago, and I flew just as well three years ago as I can to-day, perhaps better, because I did not then know the risks that I ran. I think I was a better flyer then than I am now. I was, in fact, more anxious to accomplish something good, but now, having done it, I am not keen to run any more chances than I have to. I have had a little experience with foreign engines; the E. N. V., for instance. I had an E. N. V. engine, with which I failed to fly to Manchester. I tried to get the makers to put it right, but they did not. I took it to Doncaster, because the Doncaster people compelled me to go, not because I wanted to; but the makers failed to put it right there. I came back, and we entered into a law suit. I sent the engine on to them and they kept it for four months. They did get it right themselves after breaking a crank shaft and one or two cylinders on separate occasions. I then took up the Green. I will admit there were some little faults to find with this engine at first, but we overcame them, and we started to win money gradually. Then I wanted high power, but I could not induce that company to build me an engine with high enough power, so I took an Austro-Daimler. The author has referred to the valve springs in this engine and the rocking system on the top to actuate the valves. I think it is a most excellent system myself, and the springs are most efficient. They are very quick in action. In all there are eleven leaves to them, and these make a very flexible spring, which is perfectly successful in the Austro-Daimler engine. The two magnetos referred to in the paper are also a most necessary thing to have. With two magnetos it is almost certain that I should have accomplished the Michelin speed cross-country flight at the first attempt, because one magneto failed and let me down at Lewes. If I had had two, it is hardly likely that two would have failed. I have had one magneto fail on an Austro-Daimler, and I went on, so the value of two magnetos is most pronounced, and when both sparks are perfectly synchronised, the power is greater; at least the propeller goes quicker, so there must be more power.

I can run on one magneto or on the other, and with one magneto the engine runs slower than with two, so that there is some proof there that if the two sparks occur instantaneously together there must be more efficiency in the explosion. The author has been very careful not to lay himself open to criticism, because he has hit on almost everything that it is possible to refer to in a petrol engine, and he has backed himself up against the air-cooled engine by the water-cooled; and, then again, he has backed himself up against the water-cooled by the air-cooled. I think that most of you will notice that, and I hope that some of you will agree with me that I am right in my contention, because so many points are brought out in favour of each, but I certainly am in favour of the water-cooled engine.

Mr. MAX. LAWRENCE: On p. 95 the author enumerates and puts in relative order the features he considers most desirable in comparing engines designed for use on flying machines. He puts reliability first, and power/weight ratio second, but I think that the proper order is reliability first, controllability, economy in oil and fuel second, freedom from vibration third, silence and cleanliness fourth, though I find it hard to say which of these last three things should take precedence. We have just heard Mr. Cody say that reliability is the essence of good design, and he even prefers to double the power/weight ratio in one instance, and to carry two magnetos instead of one, to make sure that his engine shall function properly.

Therefore, it is clear that Mr. Cody values reliability at a very high price, even to the extent of carrying a complete duplicate. It is essential to have an engine that goes on functioning and turning the propeller. If this line of thought is carried to its logical conclusion the engine cannot be separated from the rest of the power unit and its attendant cooling organs and consumable stores of fuel, lubricant, ignition organs, etc., and I think that in making comparisons as to the suitability of all engines for flying, only the installation as a whole must be considered, otherwise a very misleading conclusion may be drawn. The author goes on to make a great point of accessibility. I think, of course, that accessibility has its advantages, but what will be appreciated more than accessibility is absence of necessity to get at the parts, and I think that that ought to carry the greatest weight in all designs, and that it is accentuated more than ever in aeroplane work. All parts must be immune from failure. This is absolutely essential,

(Mr. Max. Lawrence.)

for when in the air the machinery cannot be adjusted and must go on running for just as long as the driver wills.

The author gives in the last column of Table II. the power/weight ratios of various engines. The lowest figure quoted refers to a Gnome engine, which actually gets down to 1·95 lb. per brake horse-power, and its cylinder dimensions are 124 mm. by 140 mm., but I also notice that in Table III. the Gnome engine is not quoted, and I think that this power/weight ratio will be considerably modified if the Gnome is compared with other engines and other things, such as lubricant, fuel, and water for a given period of continuous running are added to both. Another matter which must also be taken into account in considering these figures is, that in comparing and rating these engines the author has settled his own speed of revolution, quite irrespective of the speed of revolution which was in the mind of the designer. It is obviously wrong to impose a different revolution speed for the purposes of comparison. The designer has naturally to make compromises and sacrifices, and in considering the merit of any product for a certain purpose the whole of his design must be considered as it stands, and not with a variation in such an important feature as the speed. I know it is very difficult for a man in the author's position to get at any true facts as to how these engines will perform, but the point I wish to make is that if an engine is designed for 900 or 1,800 revolutions and designed satisfactorily for these speeds, it is not fair to have the design judged at a speed of 1,200 revolutions.

Later on in the paper the author goes on to say that he considers that five bearings for the crank-shaft on the four-cylinder engines are better than three, but this does not appeal to my mind. If the bearing surface is sufficient I consider three bearings better than five, because, in my experience, they are cheaper and lighter.

Mr. L. H. Pomeroy: I should be very pleased if we could obtain some information as to the class of failures to which aeronautical engines are subject. Every man I talk to about these engines seems to be agreed that there is no good one; they are all bad; on the other hand, when I ask what happens the only information I can get is of a very vague nature indeed, and I should like to know whether it is the crank-shaft that breaks, or the cylinders that burst, or whether it is trouble with the valves, or what it is that happens. The first thing that strikes me about the paper is the point raised in connection with the construction of the various types of A. B. C. engine, and although this seems as simple as the name would indicate, I do not think it is quite so simple as it sounds, since the criterion for the suitability of crank-shafts for their work should be stiffness for weight and a diameter of crank-shaft sufficient for a four-cylinder engine will not be large enough for a six, even though the stress is the same. Another point raised is that of the auxiliary exhaust. I have had some experience with an engine with an auxiliary exhaust, and the only things I could find out were that it wasted a large amount of oil through the holes in the cylinder walls, and completely ruined the carburation, so that the engine would not run at anything like a reasonably slow speed; the only thing it did not do was to relieve the exhaust pressure, for which purpose it was put in, and I think it is quite reasonable when the nature of the problem is considered. The length of time which it takes for the crank to pass through a distance sufficient to uncover the auxiliary ports and close them up again is not very great, and can only assist exhausting if the normal exhaust valves are too small. Dealing with the points on p. 97, which I think are really the gist of this paper, there is the item number 2, the power/weight ratio. I quite agree with the other speakers that this should not be looked upon as the be-all and the end-all of an engine. If it should be looked upon in that light in an aviation engine, then it should also be looked upon in that light in a motor-car engine, but it has been found that it is not necessarily the lightest engine that does the best work, and many engines are to be seen now which, although they have hardly varied in design during the past two or three years, yet they have got heavier during that period, showing that practical points, possibly wear of bearings, springiness of crank case, etc., have come under the observation of the designer and have had to be improved upon, and made heavier. It seems to me that there is another point bearing on this question of weight, and that is, not only the weight per b.h.p., but the absolute weight. I am told by airmen that it is desirable to be able to plane at a comparatively low angle, and also to have a large angle of glide in rising, and it follows that any engine which is heavy in itself, no matter whether its h.p. per unit weight is high, necessitates a correspondingly steep gliding angle. It is necessary, then, not only to have high h.p. per unit of weight, but also to keep the total weight of the whole engine as low as possible. With reference to silence, it seems to

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me, from what I have heard of aeroplanes and their engines, that the propeller makes as much noise as the engine, and that propeller-silence is required rather than exhaust-silence. With reference to the question of aluminium in the crank cases of hydroplane engines, I have had a limited experience in this direction, and I have found that a good coat of paint once a fortnight effectively prevents deterioration of aluminium, and it seems a pity that we should be debarred from using such a useful metal for crank cases for hydroplane engines for the sake of giving it a coat of paint now and again. The author also refers to a point in the design of engines, namely, the operating of the valves through rocking levers. In certain cases it is desirable to put large valves in engines, and I think it is for that reason that the combustion chamber of the form in which there is a valve on the top and a valve on the bottom has been used. It is then easy to attain the compression desired, and also to obtain good large valves. The point that is raised here is that a lot of force is required to actuate the gear while using rocking levers, but I do not think that need be so if a little care is taken in the design. The additional facilities for long valve springs make it possible for the maximum valve spring tension for the overhead valve to be equal to the maximum tension in the direct operated valve where the valve spring is usually heavily loaded, so that the push-rod gear can be the same in each case. One thing which has astonished me in looking at aviation engines is the number of studs used in aluminium. I cannot conceive a more wanton thing than the use of a stud, taking anything like a load, in aluminium. I have always found it necessary in all my engines to use ordinary bolts, which I specify for all parts which are attached to aluminium.

Mr. W. E. Dommett: With regard to the question of air-cooling as against water-cooling, the case against the former has been that an irregular cooling effect is obtained, owing to the fact that the advanced portions of the fins are more cooled than those in the rear. I should like to ask whether the proposal to drill the fins so that air passes from one side to the other, and whereby more air actually passes to the rear part, has been put into practice. I know the proposal has been made, but I do not know whether an engine has actually been made with this form of air-cooling. I should also like to ask whether the fluttering of the propeller, which was mentioned by our past President, has been overcome to any extent by the use of an automatic feathering propeller, i.e., a propeller in which the pitch of the blades actually changes in accordance with the work put upon them. I should also like to have some information as to the actual construction of the Frontier engine, which has a rotary valve, as against other engines with poppet valves, and more particularly whether the valve action of such an engine is claimed to be more reliable for aeronautical work. On p. 103 the author refers to the question of carburation, and again in connection with the Adams engine he referred to the fact that fuel was injected. I do not know what the particular constitution of the Adams apparatus is, but I know that in an engine with which I have been connected, injected fuel has been highly successful, and particularly with regard to the ease with which the quantity of fuel can be regulated. The experiments are still going on, and the results seem to show that in the future it would pay designers to consider the question of forcing, rather than inducing, fuel into cylinders.

Mr. R. W. A. Brewer: I should like to ask the author if there is any particular reason why in Table III. there are no figures with regard to the Gnome engine.

Mr. L. A. Bollack: On p. 97, the author deals with desirable qualities of aeroplane engines, but forgets to mention "space requirements." This question is very important, as some engines take so much space, and are therefore difficult to mount into the fuselage.

On the next page the author refers to means of obtaining "lightness." A very important method to obtain it is "combining several parts into one."

Another important method is to make the ratio of average stress to maximum stress a maximum, using the material for as long a time as possible. I can mention an engine (Dufaux) with ten double-acting cylinders, which has a very even torque and a very light crankshaft. This engine even does away with the crank case. I do not know whether the author meant his list of engines to be complete, but I hardly think so, because I have compiled a list of 194 aero engine makers against his 40; 86 of these engines are of the ordinary motor car engine type, and 56 are radial, semi-radial and rotary engines. I do not see why the rotary engine should be regarded as more popular, as there are twice as many engines of the motor car type in use for aviation purposes.

In the Gyro motor it might be expected that, if slow firing

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were to occur, the valve would open against the internal pressure, and that firing would take place in the crankcase owing to the mechanically-operated valve. On p. 85, the author mentions the Alvaston motor as one of the few engines of the horizontal opposed type, but I know of twenty different makers of opposed engines. With regard to Mr. Pomeroy's remarks as to the failure of engines, I can only mention that an aviator friend of mine blew a cylinder off when 3,000 ft. up above Paris on one occasion. As regards accessibility, the de Pishoff monoplane has a water-cooled four-cylinder engine, 70 h.p., with a clutch and starting handle. It is started just like a car, and is given just the same attention as a motor car engine. This is not to be compared with the attention required to be given to a Gnome engine.

Mr. A. C. Hutt: I was rather surprised that so little mention has been made of high speed for these engines. It seems to me that in an aeroplane engine the main thing to get, after reliability, is a light weight for a big power. The author mentions 1,200 revs. per minute as a speed which is most efficient for the propeller of an engine. I have had a good deal to do with the testing of large engines, and I have seen a six-cylinder engine kept running for eighteen months; this engine was $7\frac{1}{2}$ in. bore, 7 in. stroke, with 14 lb. pistons, and it ran at 1,200 revs. per minute, and I can say that it was a sound practical engineering job. From that I see no reason why an aeroplane engine should not run at about 3,000 revs. per minute. At this speed the power would probably be twice that produced at 1,200 revs., if the valves and reciprocating parts were designed correctly. The additional weight of the reduction gear for the propeller would be very small in proportion to the extra power produced. I have tested all sorts of machinery, turbines, boilers, Diesel engines and petrol engines, and the only way of testing an engine that I know of which would make me feel quite confident in it is to run that engine at 30 or 40 per cent overload at least. If an aeroplane engine is tested for a week running at the full power which it is going to produce in ordinary work, it is not a severe test, and I put it down as essential in testing an engine that it should be tested at an overload. It could be run with the spark too far advanced, and if it was supplied with a small amount of oxygen it could be run at the required overload. Double the power could be obtained with oxygen, but there would be no need to test it as severely as that. With regard to testing, I think it would be a very good thing if a Committee somewhat similar to Lloyds were appointed to deal with aeroplane engines, so that they could undergo a test by an official inspector and be classed. It would be like the tests of boilers, which are carried out at 50 per cent over the working pressure. These tests could be made in the form of an oxygen test such as I have suggested. Such a Committee should be, like Lloyds, composed of users and makers of aeroplanes, who would appoint suitable inspectors. If this were done I think it would help the movement tremendously, in that people would have absolute confidence in an engine which had been tested in this way by some satisfactory committee.

The PRESIDENT: Before calling on the author to reply to the discussion, I should like to say that I have constructed some engines with overhead valves, with an arrangement of springs somewhat similar to that indicated by Mr. Pomeroy, though it varied in that I did not have a spring at the centre of the fulcrum of the lever. I fitted one spring over the valve, and also one on the vertical tappet rod, and it greatly improved the quietness of running. It is not clear whether the author has added the weight of the reduction gear between the engine and the propeller in the figures given in the tables. I think that ought always to be included, because with reduction gear it is, of course, necessary to have a flywheel, on account of the very great increase of stress there would otherwise be between the engine and the flywheel. The plan of fitting the propeller on the half-time shaft seems a good one, but unless a flywheel is fitted it must produce very great increase in the stress on the timing wheels. I now have much pleasure in calling upon the author to reply to the discussion.

Mr. CLARK, in replying on the discussion, said: In reply to our President, the weights of the reducing gears which may be added to the A. B. C. engines are given on p. 85, and I will supply particulars of those used on the Chenu engines, but in neither instance have they been included when calculating the weight per b.h.p., because the gear is a separate part, and is an optional fitting. In the other engines which employ a reducing gear, the drive is taken from the camshaft, and it is therefore embodied in the engine itself.

With regard to Mr. Legros' observations respecting propeller flutter, I think that the explanation given by Mr. Cody will have made the matter quite clear.

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As regards the further remarks of Mr. Cody, it was not because I was not conversant with the Green engines that they were not criticised. I know these engines very well indeed, and Table I. gives the construction employed in practically every motor that has been considered in the paper, including the Green engine. I have given the name, the country of origin, form of cooling, the material used for the cylinders, the kind of jacket in the case of separate jackets, and the method of attachment to the cylinders, etc., and it is there stated that the Green engine has a pressed copper jacket with a rubber ring, an overhead camshaft, and so forth.

With regard to my opinion as to the relative advantages and disadvantages of the various forms of engine, I should have thought that it would have been perfectly clear to anybody who had read the paper that I am thoroughly in favour of the water-cooled vertical engine—just the type that Mr. Cody is using. I do not think there can be any doubt about that, if the paper is read through carefully, but I have examined the points for and against the various types of engine, and I cannot, in making such an examination, disregard the points in favour of the rotary engine, which has done such excellent service, in order to bolster up another class of engine that I may consider on the whole to be superior. The vertical water-cooled engine has reached a high state of development for car work, and for reasons which are stated in the paper the water-cooled engine is superior to any air-cooled engine, while any kind of vertical engine is, in my opinion, to be preferred to any radial, semi-radial, Vee or rotary engine for aeronautical purposes. Unfortunately for water-cooled engines in this country, if I may quote records, we find that nearly all these have been made by air-cooled engines. We cannot shut our eyes to that fact, which is largely attributable to the early importance given to lightness and the facility with which it may be attained in air-cooled engines, and this resulted in their more extensive use, but I agree that the water-cooled engine is now doing well. With regard to the laminated valve springs employed on the Austro-Daimler engines, it is practically impossible to eliminate lag with this form of spring, and it is on account of the fact that they damp out the forces that would otherwise produce violent oscillations of the supported mass that they are always used for the suspension of the frame, etc. in the motor vehicle. By increasing the strength, it may be minimised to a certain extent, but the mere fact that the strength is increased throws heavier loads on the valve gear.

As regards the use of rocking levers for actuating the valves, their suitability or otherwise for such employment in high speed engines may be a matter of opinion, but personally I do not consider it good practice to do so, because they are always noisy and require considerable force for their operation.

Mr. Pomeroy has suggested the distribution of a large number of valve springs at various points in the valve mechanism for the purpose of reducing the load on the operating gear. I do not know what such an engine as he describes would look like, but I should say it would be anything but a satisfactory engineering job, while, in addition, it would only diminish the load on the push rods, and would not in any way affect the load on the cams.

Mr. Lawrence suggested that accessibility should be superseded by immunity from failure. Of course, accessibility is not required to such an extent if there are no failures, but that merely emphasises the necessity for reliability, since engines are not immune from failure. Much more consideration should be given to reliability than to any other aspect of the question, as an engine is of little service unless it will perform satisfactorily for a sufficiently long period, but when access is required it is obviously desirable to be able to get at the parts as quickly as possible.

Mr. Brewer and Mr. Lawrence referred to the omission of the Gnome engine from Table III. The reason for this is that I could not obtain authentic and up-to-date particulars of the fuel and oil consumptions of engines from the makers, only those of the catalogue variety being available, and this remark applies generally. Many makers stated that the fuel consumption of their engines was 0·6 pint per b.h.p. per hour, and whereas the representative in this country of one firm of aeronautical engine manufacturers gave me a fuel consumption of 0·6 pint per b.h.p. per hour, the figure I obtained from the manufacturers themselves was 280 grammes per b.h.p. per hour, which effects a reduction of about 25 per cent in the brake thermal efficiency. I have obtained information respecting the consumption of fuel and oil in the Gnome engine from various sources, but the particulars received were so much below any known results that I deemed it inadvisable to include them.

Mr. Lawrence also referred to my remarks as to the necessity

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for a bearing between each crank. It will be generally admitted that a bearing between each crank is desirable, and if any engine that has successfully undergone a prolonged public test is examined, it will be found in practically every case that it has a bearing between each crank. I cannot call to mind a single engine which has made such a test that was not so constructed.

Mr. LAWRENCE: There are some, but I do not know that they have been published.

Mr. CLARK: I am, of course, referring to published performances.

Mr. Dommett mentioned a suggestion that had been made to drill the fins of air-cooled engines in order to pass the air round to the back of the cylinders. I do not think that this is practicable, for the reason that the thickness of the fins in some engines is only about one-sixteenth of an inch, and the possibility of drilling through them would be extremely remote. In any event, sufficient air friction in the holes would result as to eliminate all possibility of air getting through.

Mr. Bollack referred to space requirements. This is dealt with under the heading of wind resistance; as regards the number of engines, I did not anticipate that anybody would imagine that Table II. was supposed to present a complete list of all the aeronautical engines in existence. As a matter of fact, in *Flight* for November 22nd there are tabulated particulars of at least twenty engines that were shown at the Paris Salon but which are not included in my Table. The Table simply enumerates the particulars of those engines which are, at the present time, used to any appreciable extent, and is not an exhaustive list. With regard to the last point raised by Mr. Bollack, the probability of firing back into the crankcase taking place when the inlet valve is opened through the uncompleted combustion of the charge in the cylinders of the Gyro engine, such a defect is, necessarily, present in any engine that employs an inlet valve in the piston head or that draws its charge of fresh gas from a large common mixing chamber.

Addendum by the Author.

The weights of the reducing gears which may be added to the Chenu engines are as follows:—

4-cylinder engine, 110 mm. bore by 130 mm. stroke, 22 lb.
6-cylinder engine, 110 mm. bore by 130 mm. stroke, 30·8 lb.

The 6-cylinder engine, 150 mm. by 200 mm., is not fitted with a reducing gear either as a standard or as an alternative fitting.

As was pointed out by the President, the provision of a flywheel of ample capacity is of the utmost importance in engines which drive the propeller from the camshaft, and it may be added that it is essential that the flywheel should be placed at the same end of the crankshaft as that from which the drive is taken, especially in those engines using a high compression pressure, otherwise the variation in the crank effort, which causes a varying torsional strain on the shaft, may permit exceedingly heavy loads to come upon the timing gears, thereby conducing to a high rate of wear and a rapid diminution of the efficiency of transmission. It is to be regretted that on account of the comparatively short pitch centres of the gearing employed, together with the arrangement which as a rule becomes necessary, it is not generally possible to arrange for this.

Mr. Legros made reference to a phenomenon known as propeller "flutter," and it may be well to amplify the remarks made respecting this on account of its important bearing on the efficiency of the propeller. There are two sources from which propeller "flutter" may arise, namely, the angular acceleration of the propeller in the direction of rotation caused by the fluctuation in crank effort, and the angular acceleration of the propeller in a plane through the axis of rotation caused by the transverse deflection of the crankshaft produced by the load upon the piston. The former is most in evidence in engines having a small number of cylinders, since in that case the variation in torque is high; this may, however, be reduced in magnitude by the use of a flywheel of large capacity between the engine and the propeller, by the use of a rotary engine, by increasing the number of impulses per revolution, by adding to the number of cylinders or by the employment of a two-cycle engine. An instance may be mentioned where a machine fitted with a four-cylinder, four-stroke cycle engine was unable to do much more than hop along the ground, but when it was fitted with a four-cylinder engine operating on the two-stroke cycle, even though of less horse-power, it performed most successful flights. The second source of trouble is experienced, principally, in designs where the propeller is direct-coupled to the engine shaft, where short engine bearings are fitted and where the crankcase is not sufficiently rigid at the driving end, or where the engine is overhung and supported only

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on the side remote from the propeller. The transverse deflection permitted by such constructions may be prevented from adversely affecting the propeller efficiency by the use of a short length of shafting between the engine and the propeller, or by driving the propellers through chains or some other form of gearing, but large rotating masses will not have any great influence in correcting this tendency on account of their small resistance to motion in this direction. It will be observed that Mr. Cody eliminates trouble from both of these causes by availing himself of two of the remedies mentioned, namely, by keeping the propeller as far removed from the engine as possible, and by employing as large a flywheel as the engine makers will supply him with.

As regards the relative merits of the different types of engine, the principal disadvantages of each type may be summarised from the paper as follows. The air-cooled engine has generally a greater air resistance and higher fuel and oil consumptions. Its reliability is often uncertain, and the limitations imposed upon the cylinder dimensions by the risk of pre-ignition, etc. necessitate the employment of a greater number of cylinders for increased power, while with rotary engines the method of introducing the charge into the cylinders can hardly be deemed to be satisfactory. The water-cooled engine has, however, a more complicated construction and is slightly heavier. With Vee, radial and rotary engines, lubrication troubles are likely to be more frequent than in vertical engines unless a fully forced system is used; the exhaust and valve gear arrangement is seldom as good, the air resistance is greater, and the methods of attachment of the rods to the crankpins are either open to criticism or tend to cause an increase in the pitch of the bearing and the curtailment of the bearing areas. There is, moreover, greater complication and less free access to all parts, and those engines which are of the rotary type require to be in perfect rotary balance. On the other hand, vertical engines must of necessity be of greater weight and take up a larger space, longitudinally, on the machine.

Mr. Max Lawrence commented adversely upon the fact that the author had based his calculations in regard to the weight per horse-power developed upon one definite speed of revolution. It is quite true that the assumption of any purely arbitrary value may cause some engines to appear in a less favourable position than that which they really occupy, but it is considered that for any comparison on this basis to be effective, it is first necessary to have decided upon some common factor such as engine or piston speed, and as, with few exceptions, the engines used in aeronautical work gave their rated horse-power at or near 1,200 revolutions per minute, while the propeller revolutions frequently approximate thereto, that speed of revolution was chosen as being the most satisfactory.

Mr. Pomeroy asked for information as to the causes of engine troubles. These, apart from more or less obscure causes that occasionally arise, may be summarised under four headings:—structural weakness, carburation, lubrication and ignition. The presence of any tendency to structural weakness inevitably results in failure, and therefore no attempt should be made to reduce the dimensions of parts for the purpose of saving weight by lowering the factor of safety employed in the design except under very exceptional circumstances, such, for example, as where special care is taken to ensure that all the materials used are uniformly of the highest quality and free from defects of any kind, or where the oversight of the work as it progresses during manufacture is of a more exacting nature than is ordinarily commercially possible. Carburation troubles may arise from the fact that the engine is not mounted upon a steady platform but is continually changing its angle of inclination to the horizontal, hence the level of petrol in, and the supply to, the jet, will vary, possibly within sufficiently wide limits to cause the gas to fail to ignite, or at least, to result in great variations in the power developed in the cylinders. It was due to trouble from this source that the system of injecting the fuel into the inlet pipe, referred to by Mr. Dommett, was at one time resorted to in the Wright, Antoinette and other engines notwithstanding the fact that the mixture passing to the cylinders was lacking in homogeneïty, and that the control of power and speed was not all that could be desired.

Defective lubrication is probably the most prolific cause of engine failure, which may ensue as the result of either over- or under-lubrication. The manner in which the latter may produce failure is readily obvious, and the former may become operative through flooding the cylinders with oil, thereby causing carbon deposits in the cylinders which may ultimately contaminate the oil in the crankcase, cause leaky and sticking valves and piston rings, etc., and defective ignition through sooted plugs and short circuits. It is largely because of the regularity and control of the supply of clean oil to every part in engines fitted with fully

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forced lubrication, despite frequent and sudden variations in the angle of inclination of the machine, that causes the author to favour this form of lubrication wherever heavy loads are carried for prolonged periods. There is also a secondary effect produced as the result of structural weakness, but which indirectly affects the lubrication, namely, the distortion and flexure of the shafts. Owing to the restrictions in the dimensions of parts imposed by considerations of weight, the ratio of internal to external diameter of hollow shafts, for example, is sometimes made unduly high, or the distances between the centres of the bearings are increased in order to dispense with as many bearings as possible, or to enable two or more connecting rods to be attached to the pin. In both instances the cross section of the shaft may be sufficient from strength considerations, and ample surface may be afforded to conform with the bearing pressure requirements; but the distortion of the section at the journals which must necessarily be present if the thickness of the metal is disproportionately small, and the angle of slope of the shaft near the bearings from the transverse loading will tend to greatly increase the intensity of the pressures at the sides and the edges of the bearings and conduce to the failure of the part, unless special attention is given to this matter in the design.

Mr. Hutt, in the course of his remarks, raised several points that call for some comment. As has been mentioned in the paper, one of the means whereby a reduction in the weight per horsepower can be effected is by raising the speed of revolution of the engine and gearing down the propeller, but it will be observed that, with few exceptions, aeronautical engine manufacturers have not availed themselves of the possibilities in this direction, the majority restricting the engine speed for prolonged periods under heavy loads to between 1,200 and 1,500 revs. per minute. There are several reasons for this. In the first place, these speeds are very high in comparison with those used in other classes of reciprocating engines, and comparatively few petrol engines of this class can be run at much higher speeds under the conditions existing in aeronautical work without some sacrifice in regard to reliability, and no little addition to the weight. Higher engine speed necessitates the adoption of a more rigid construction for the crankcase, stronger connecting rods and valve actuating gear, and the provision of larger diameter shafts so as to withstand the higher loads and eliminate any tendency to whip. Further, bearing and valve areas will require to be increased to afford sufficient surface to carry the loads at the higher speeds and adequate openings for the passage of the gases, while the gearing which then becomes necessary will obviously also add to the weight of the complete power unit.

Respecting the probable gain in power obtainable by raising the engine speed, it should be remembered that in addition to the problems associated with the lubrication and ignition in high speed engine design, there are two others of first importance, namely, that of the provision of sufficient valve area to pass the gases without appreciably increasing the gas velocities, and that of the design of a valve gear capable of operating the valves with sufficient rapidity to afford the necessary openings without excessive hammering and vibration, and these problems must be solved if the engine is to prove successful. Failure to meet either of these problems has the effect of diminishing the volume of fresh charge taken into the cylinder, so causing a hotter engine, and the difficulties become accentuated with increasing engine speed, until, at length, some speed of revolution is reached beyond which it is not profitable to go, both because of mechanical troubles with the valve actuating gear and on account of the fact that the torque curve falls off so rapidly as to actually cause a reduction of power with increasing speed. Further, since the drive is transmitted through gearing, some loss of power must undoubtedly take place. Under favourable circumstances it is conceivable that this loss may not be more than 10 per cent, but in course of time it will probably become far in excess of this figure on account of the severe conditions of working.

Hence it will be seen that the weight of the power unit must be increased to some marked extent to ensure the maintenance of the same high standard of reliability, while the useful power developed by the engine will not, at extremely high speeds, be commensurate with the speed of revolution, so that the question as to whether or not it is advantageous to design for higher engine speeds than those commonly employed, viewed from the combined aspects of reliability, durability, and horse-power/weight ratio, depends largely upon the peculiar circumstances of each particular case, and therefore judgment cannot be passed until all these are known.

There is, however, one influence at work in high speed engines that, within certain limits, acts favourably with an increasing

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speed, namely, the effects of the inertia of the reciprocating parts, since the maximum loads upon the crankshaft bearings are thereby decreased. The inertia pressures in pounds per sq. in. of piston area of a 4 in. by 4 in. engine have been tabulated below for several speeds of revolution, the weight of the parts which may be considered as reciprocating being taken as 4·5 lb., and the ratio of connecting rod to crank being assumed to be 4 to 1.

Revs. per minute.	Inertia pressure in lb. per sq. in.	
	Inner dead centre.	Outer dead centre.
1,000	25	15
2,000	102	61
3,000	228	137
4,000	408	245
5,000	637	382

The table exhibits the marked effects of inertia at high speed, and it is, of course, possible for the speed of revolution to be such that the resultant pressure on the bearings on ignition would be zero. To have this end in view in design is not, however, considered to be desirable, on account of the fact that the effective lubrication of the bearings is so greatly assisted by the variation in bearing pressure, and then the load, with the crank on the inner dead centre at the commencement of induction, would attain to as high a value as that from the full explosion pressure, while when on the outer dead centre it would amount to about 60 per cent of this.

Regarding the suggestion that engines should be subjected to an extended test during which they should be required to carry an overload to the extent of some 30 or 40 per cent obtained by the substitution of oxygen for a portion of the air taken into the cylinder, and that they should be classed by a body constituted similarly to Lloyds, I do not consider that this is in any way practicable at the present day with the high speed petrol engine as now employed, for the following reasons. Firstly, it is doubtful if there are any engines in existence of the class under discussion that could successfully undergo a test of this severity without special preparation involving partial re-design, and it would hardly be feasible to carry the additional weight required to enable them to do so at the present stage of aeronautical development. Secondly, unlike the engines and boilers in the vessels classed by Lloyd's Registry, petrol engines in general and aeronautical engines in particular are too susceptible to derangement from so many causes that may easily arise but which it is extremely difficult, if not impossible, to prevent, that any test of like character to that suggested would afford very little guarantee that the engine would continue to function without mishap on any succeeding day. These difficulties are not, however, altogether insuperable, and it is to be hoped that, sooner or later, by reason of either the material advance made in engine design and construction or the evolution of a practical internal combustion turbine, it will be possible for the surveys and tests carried out by a body of experts to be of advantage principally to constructors and pilots instead of to the engine manufacturers themselves.

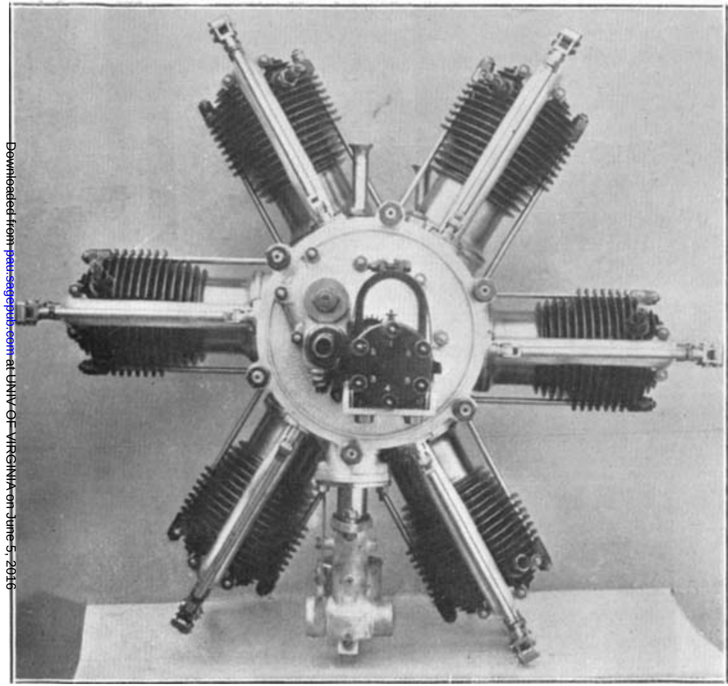

FIG. 2.—45 and 60 h.p. Anzani Engine.

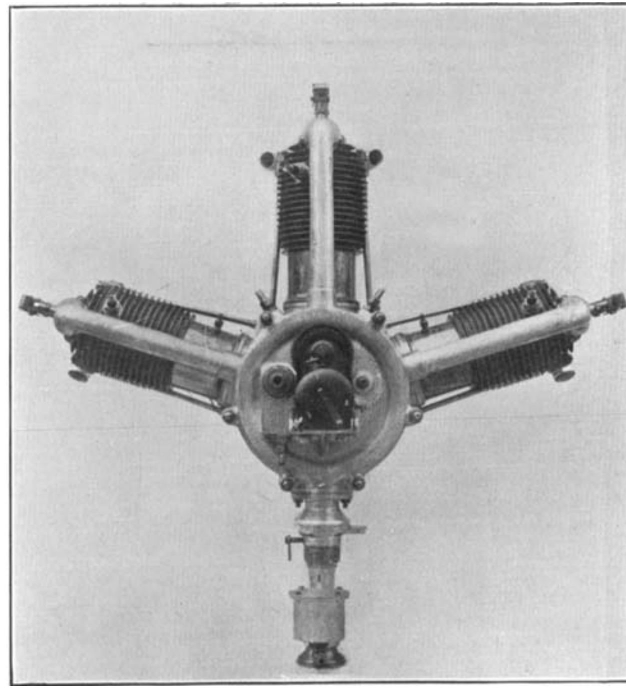

FIG. 1.—30 h.p. Anzani Engine.

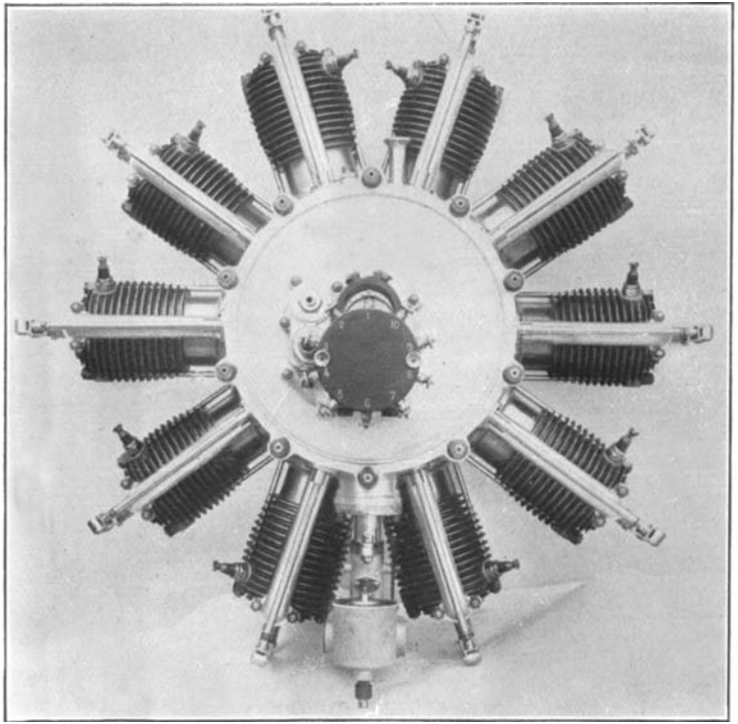

FIG. 4.—80 and 100 h.p. Anzani Engine.

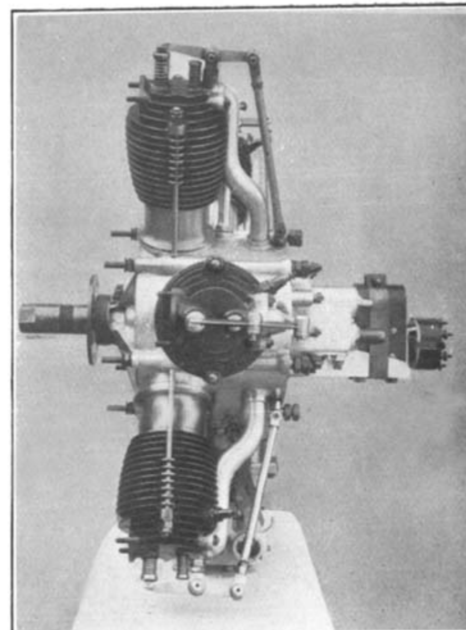

FIG. 3.—45 and 60 h.p. Anzani Engine.

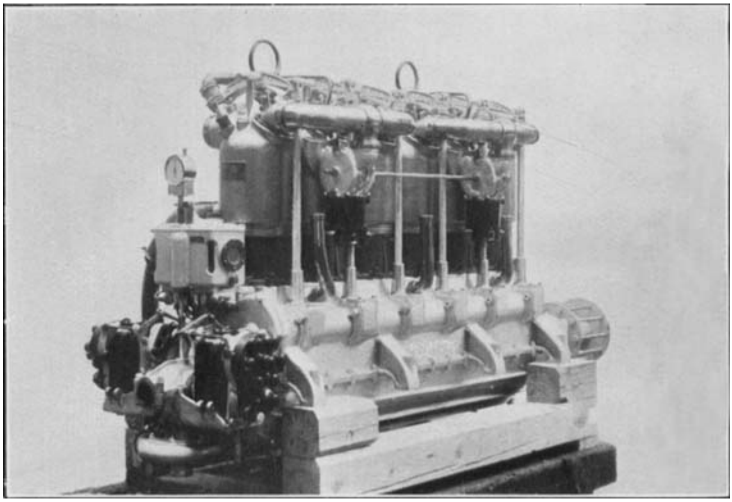

FIG. 5.—120 h.p. Austro-Daimler Engine.

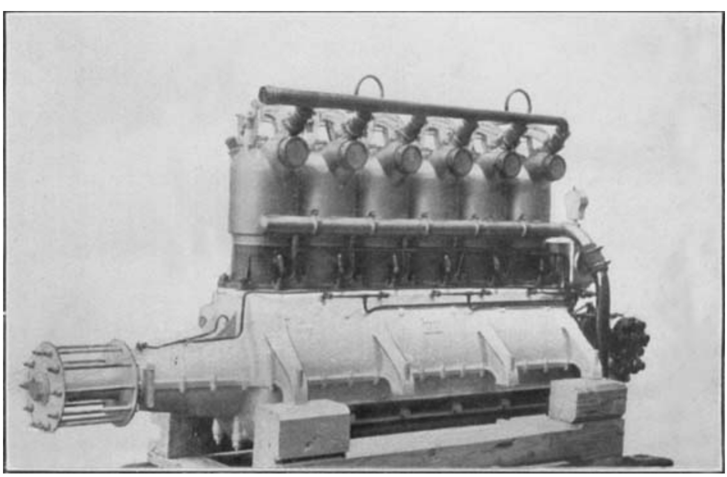

FIG. 6.—120 h.p. Austro-Daimler Engine.

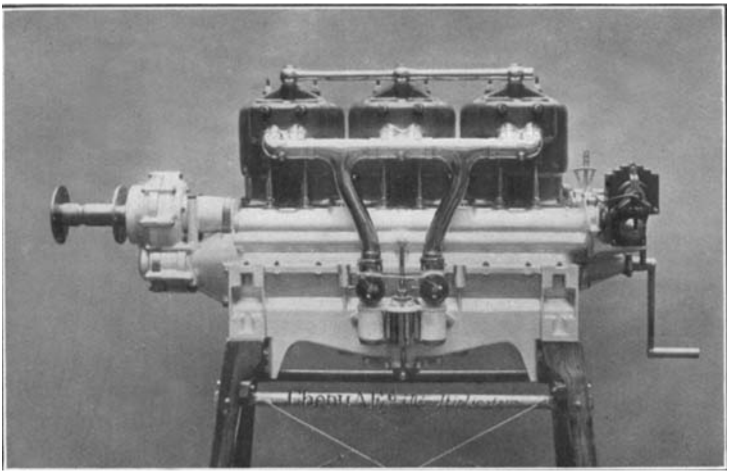

Fig. 7.—70 h.p. Chenu Engine.

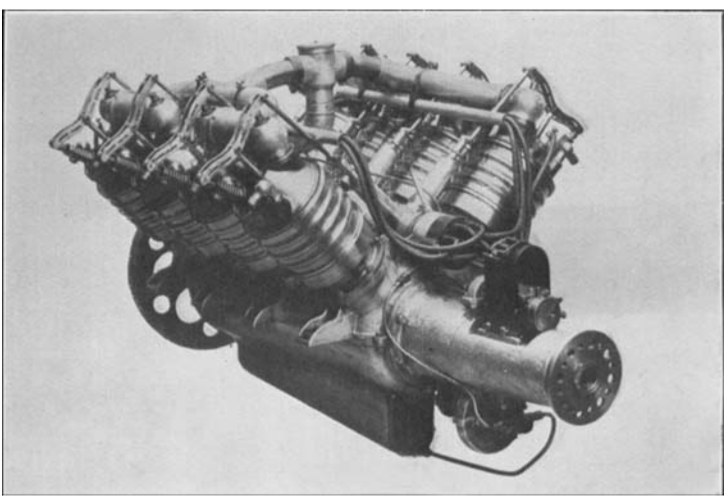

Fig. 8.—80 h.p. Dorman Engine.

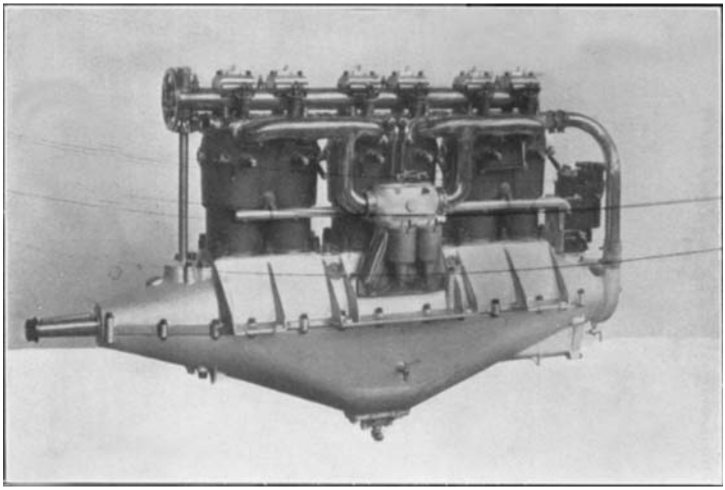

FIG. 9.—100 h.p. Mercédès Daimler Engine.

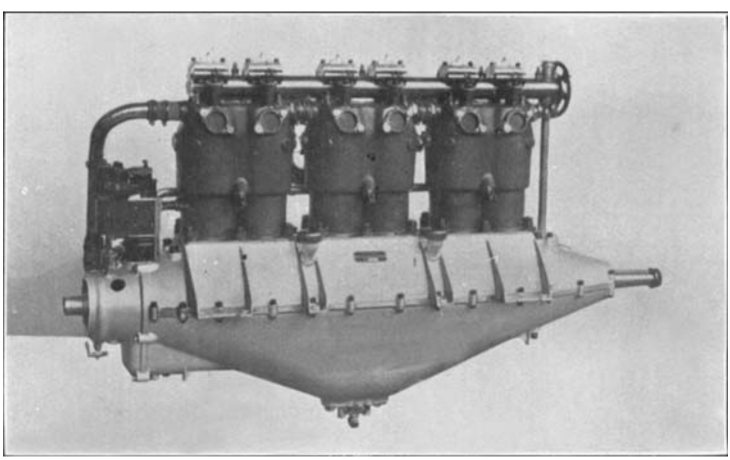

FIG. 10.—100 h.p. Mercédès Daimler Engine.

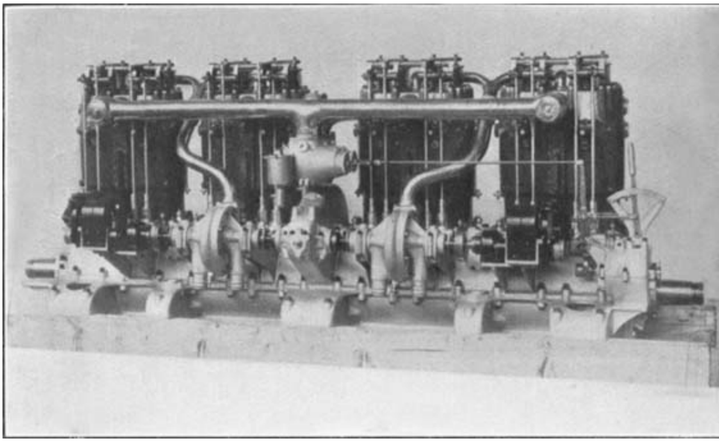

FIG. 11.—240 h.p. Mercédès Daimler Engine.

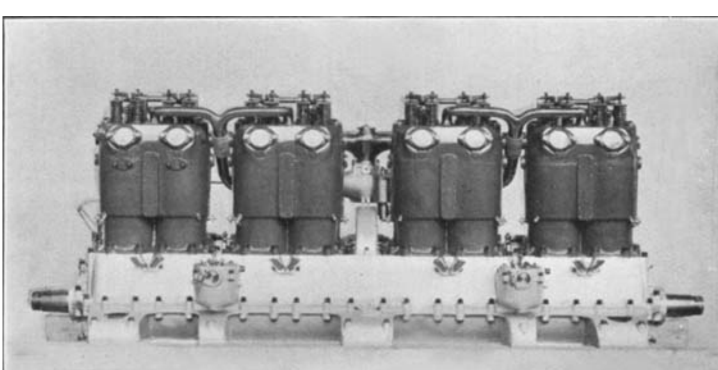

FIG. 12.—240 h.p. Mercédès Daimler Engine.

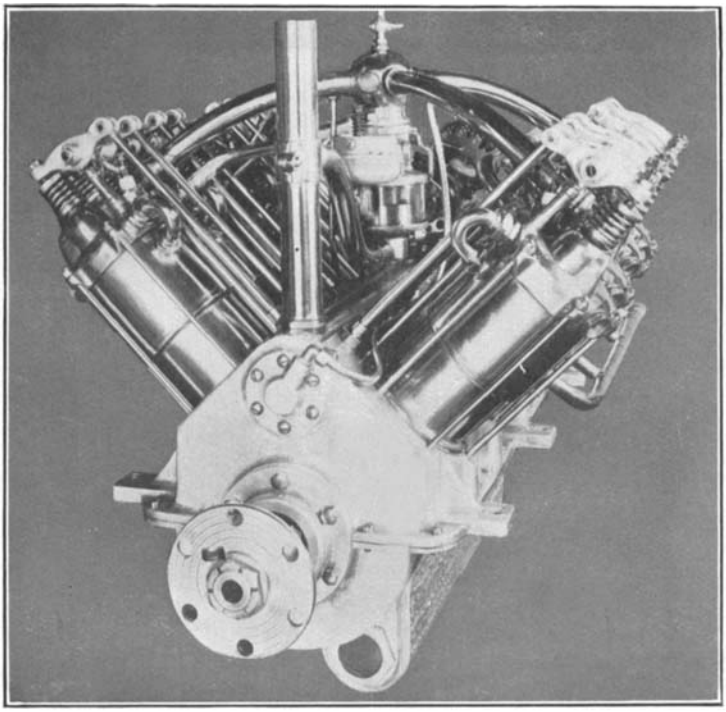

FIG. 14.—60 h.p. Hall Scott Engine.

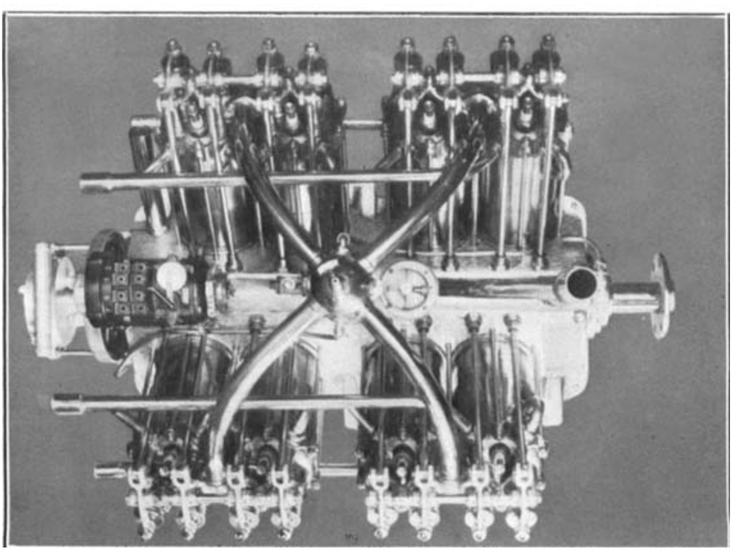

FIG. 15.—60 h.p. Hall Scott Engine.

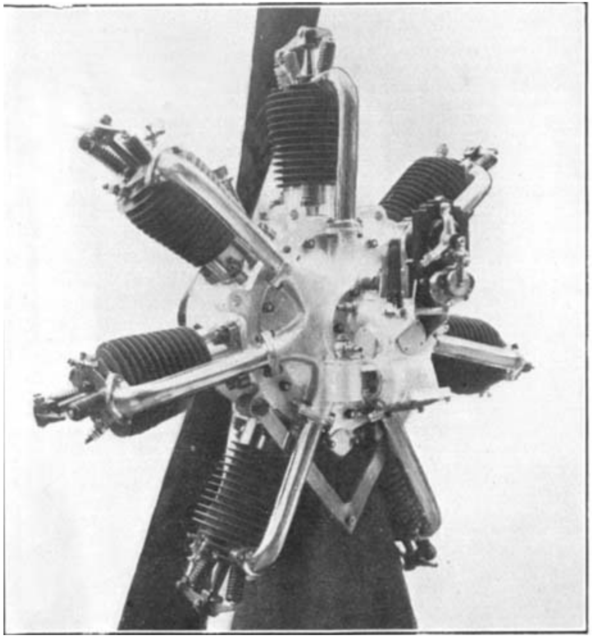

FIG. 18.—95 h.p. R.E.P. Engine.

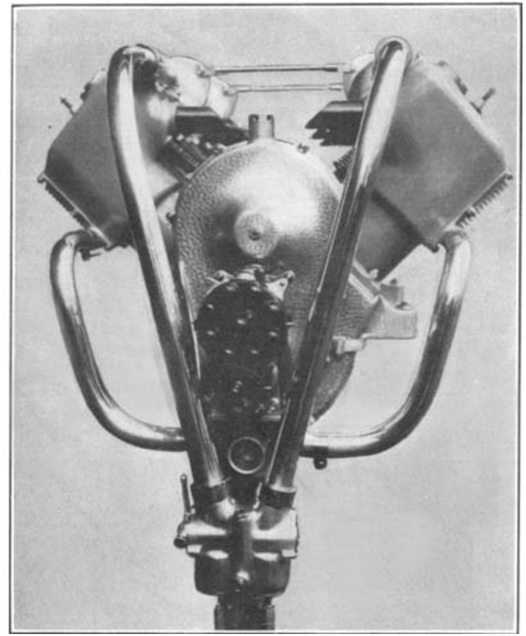

FIG. 17.—100 h.p. Panhard Engine.

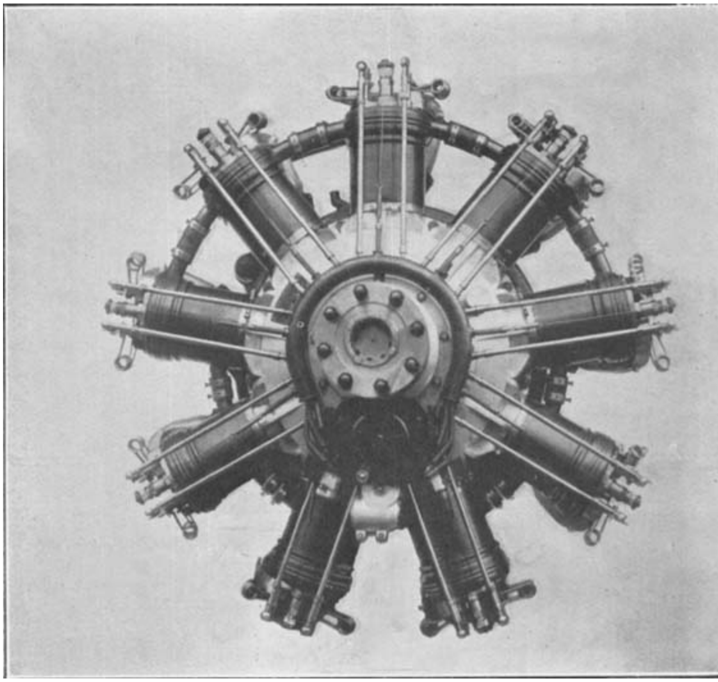

FIG. 19.—110 h.p. Salmson Engine.

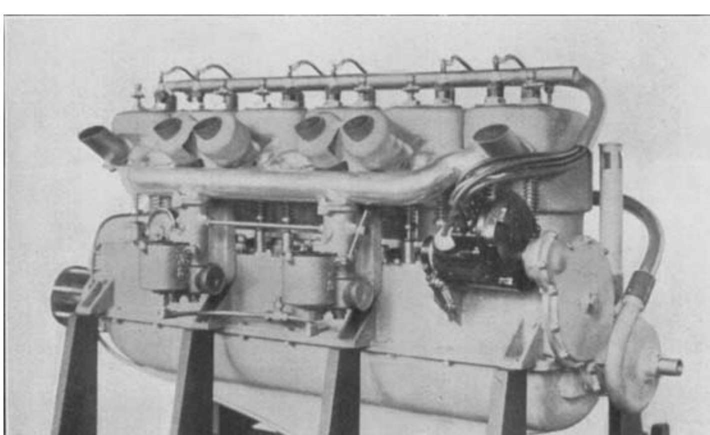

FIG. 20.—60 h.p. Sturtevant Engine.

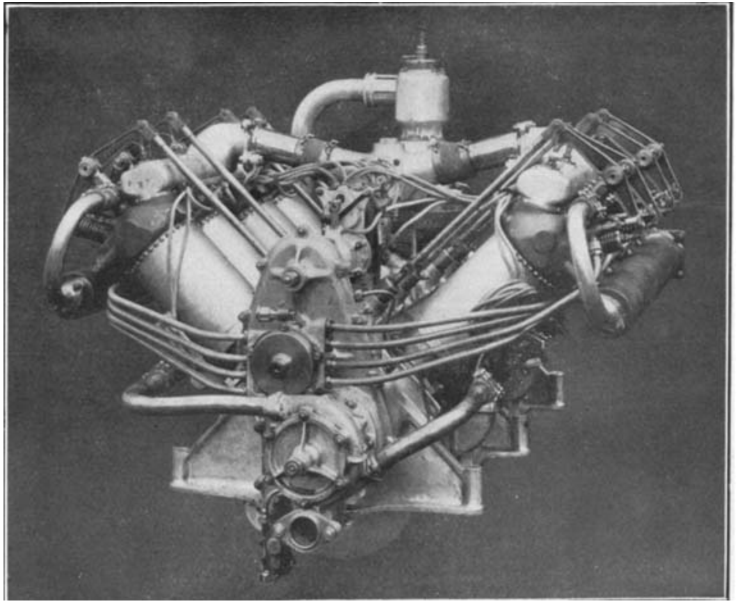

FIG. 22.—120 h.p. Wolseley Engine.

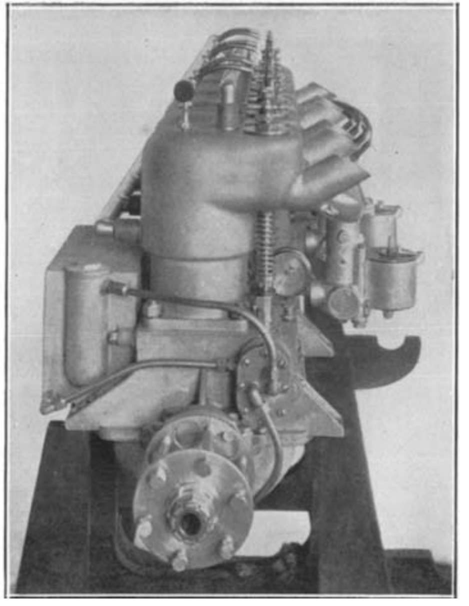

FIG. 21.—60 h.p. Sturtevant Engine.