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By
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Summary.—Reasons for Enquiry.—The variation of full throttle engine power with height was required on a Spitfire Vc (Merlin 46) for comparison with that obtained previously by the same method on a Hurricane II (Merlin XX).

Range of Investigation.—This, the locked propeller method, gives the ratio of full throttle powers at any two altitudes and in the present tests the ratio was obtained at the following altitudes :—

37,000 ft. and 16,000 ft.
35,000 ft. and 16,000 ft.
33,000 ft. and 16,000 ft.

37,000 ft. represents the maximum height at which accurate performance measurements can be made with this aircraft.

Conclusions.—(i) The variation of full throttle power with height of the Merlin 46 engine under still air conditions, expressed as a function of density is

$$P \propto (1\cdot 10\,\sigma - 0\cdot 10).$$

This result is virtually the same as obtained from previous flight tests on Merlin engines.

(ii) The observed supercharger compression ratio temperature coefficient is $0\cdot 00248$ which compares with the accepted value of $0\cdot 002$ for Merlin engines.

(iii) In the absence of a torquemeter the electric constant-speed propeller which can be locked in pitch provides a very useful apparatus for determining the power law of an engine.

Further Developments.—None contemplated.

1. *Introduction.*—1.1. The establishment of the law governing the variation of full throttle engine power with height is of considerable importance and in the absence of torquemeters various methods of measurement have been proposed. Previous flight tests carried out at this Establishment on the subject are described in Refs. 1, 2 and 3.

1.2. In the report on the locked propeller method[1] the hope was expressed that the test would be repeated on a Spitfire having a Merlin 47 engine. Such an aircraft was provided, equipped with a Rotol electric variable pitch propeller of No. 5 hub size and metal blades, capable of being locked in pitch during flight. It was expected that this aircraft would be able to reach 38,000 or 39,000 ft. when flown light and that the fitment of the electric propeller and an additional fuel tank would permit of the high altitude full throttle level and the medium altitude throttled partials being done on the same flight. Such a procedure would have obviated the necessity for refuelling between the two stages in question and thus having to take off with the propeller in fixed pitch. However, even without the extra fuel tank which could not be installed easily, the climb performance of the aircraft was rather disappointing, possibly due to the small diameter of propeller, and considerable difficulty was encountered in reaching even 37,000 ft. with the result that there was insufficient fuel remaining to carry out the throttled partials, and a separate flight was required for the latter.

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1.3. Thus the general technique remained much as described in R. & M. 2212[1], the principal change with, and advantage of, the electric propeller being that it dispensed with the necessity of doing a number of preliminary high altitude levels in order to obtain the correct fixed-pitch setting for maximum power at those conditions.

2. *Theory.*—This is given fully in R. & M. 2212[1] and need not be recapitulated here.

2.2. The ratio of full throttle power at two widely different altitudes is obtained by determining the J and n for full throttle level flight at high altitude, and then by throttling the engine, realising the same J and n at a suitable low altitude. This throttled power is adjusted to full throttle at the same boost and r.p.m. by a suitable correction.

That is,

$$\frac{F.T.P.H.A.}{F.T.P.M.A._1} = \frac{F.T.P.H.A.}{T.P.M.A._2} \times \frac{T.P.M.A._2}{F.T.P.M.A._1},$$

or

$$\frac{F.T.P.H.A.}{F.T.P.M.A._1} = \frac{\sigma_a\,(H.A.)}{\sigma_a\,(M.A.)} \times a_1 \times a_2 \times a_3 = P_r, \text{ say,}$$

where the symbols have the same meaning as in R. & M. 2212[1].

Corrections a_1 and a_3 are related to b.h.p. in accordance with the formula

$$\text{b.h.p.} \propto (P_B - \tfrac{1}{6}P_E) \times \frac{1}{T + 127},$$

where P_B = boost pressure absolute,

P_E = back pressure abs.,

T = intake temp. deg. C. abs.

It should be noted that the power ratio, P_r, is referred to the air intake densities, σ_e, corresponding to the appropriate full throttle high altitude level and full throttle at medium altitude$_1$.

3. *Condition of Aircraft during Tests.* (*See* photographs).—3.1. The aircraft, a Spitfire Vc, was lightened by removal of all guns and ammunition and certain armour but the radio equipment was retained; the take-off weight was 6,160 lb. with the C.G. at 6·9 in. aft of datum, undercarriage down. Apart from the stub exhausts, which were fitted to eliminate the thrust power obtained from the ejector type of exhaust, and the electric propeller the aircraft was a normal Spitfire Vc.

3.2. The instruments fitted were similar to those employed on the earlier tests except that a Cambridge type of electrical resistance thermometer was used in the air intake instead of the capillary type. No automatic observer was employed. The total head of the air entering the intake was read on an altimeter connected to the intake pitot-static tube, whilst the local speed was also obtained from this source.

3.3. *Engine.*—Merlin 46 No. A.314195/78141. The boost control was inoperative throughout to ensure that full throttle conditions were obtained as necessary. Magnetos—Rotax NSE 12/4. Rich mixture was used at all times.

3.4. *Propeller.*—Rotol Electric V.P. Type E5RW–RM–FB. Serial No. EE.171. No. of blades, 3 (Magnesium) to Drg. No. RA.630. Diameter 10 ft. 3·8 in. Direction of rotation, R.H. Serial Nos. of blades A.4154–5–6. Fine pitch angle 28 deg. 10 min. Feathering angle 87 deg. 15 min. Spinner No. RA.7355 No. 49. Reduction gear R.125.

4. *Flight Tests.*—The technique which was employed is given below :—

4.1. *High Altitude Level.*—The aircraft was flown level at maximum power for 3,000 r.p.m. at 37,000 ft. with the propeller constant speeding ; towards the end of the run the pitch was locked and the necessary observations made on completion of the level. The aircraft was landed and the propeller pitch measured.

4.2. *Medium Altitude Throttled Partials.*—At the same pitch as above the aircraft was flown through the height range of 15,000 to 17,000 ft. at a number of airspeed and throttle openings to include the same V and n as at high altitude. The principal observations were made at 16,000 ft. though secondary sets were taken on either side of this height to provide a check on the consistency.

4.3. *Full Throttle Height Determination.*—With the propeller constant speeding at 3,000 r.p.m. the aircraft was climbed at full throttle from 16,000 to 24,000 ft. over a wide range of speeds, the observations being made each 1,000 ft.

4.4. *Repeat Tests.*—The high altitude level and medium altitude throttled partials were repeated at pitch settings appropriate to all out level at 35,000 and 33,000 ft. whilst a check was made of the 37,000 ft. results.

In addition the full throttle height determination was checked towards the end of the programme.

4.5. *Position Error Measurement.*—Though well-known on Spitfire aircraft the position error of the normal Mk. VIII electrically heated pitot-static head was checked on this particular aircraft.

5. *Results.*—5.1. Most of the observed results have not been given in tabular form but are presented in the form of curves on Figs. 3–7.

The high altitude level results and the principal medium altitude results are given in Table 1; Table 2 is the position error correction.

The change in propeller power coefficient C_p with $V_{t/a}$ at constant J was calculated for certain specific conditions for the Aero Dept. of the Royal Aircraft Establishment and their results are given in Table 3. Table 4 gives the pitch settings of the propeller as measured after each flight.

5.2. A sample calculation of the methods employed in calculating the power ratio for each test has not been given here as the theory shows quite clearly how it is done and Table 1 gives the numerical values at each stage. If reference to an actual calculation is required recourse can be had to that given in R. & M. 2212[1].

5.3. From the experimental results the power law of the engine has been plotted in Fig. 1 assuming a linear variation with density. This result can be compared with those from other engines as quoted below :—

Present tests,	b.h.p. $\propto (1 \cdot 10\ \sigma - 0 \cdot 10)$,	Merlin 46, Locked propeller
Ref. 1	b.h.p. $\propto (1 \cdot 08\ \sigma - 0 \cdot 08)$,	Merlin XX, Locked propeller
Ref. 2	b.h.p. $\propto (1 \cdot 094\ \sigma - 0 \cdot 094)$,	Merlin XX, Fage method[2]
Ref. 4	b.h.p. $\propto (1 \cdot 074\ \sigma - 0 \cdot 074)$,	Merlin 46, RAE Bench tests

As will be seen the present results give virtually the same expression as with the other flight tests and are in fair agreement with the R.A.E. bench tests, and thus little further comment is necessary. It might be pointed out though, that the large discrepancy in the 33,000 ft. results in Fig. 1 can be attributed to the excessive change in propeller pitch ($1\frac{1}{2}$ deg.) which occurred during this part of the tests. Further reference to this is made in Section 6 of the report.

5.4. In R. & M. 2212[1] an analysis of the likely errors was made and though the air intake temperature measurement has been considerably improved in the present tests the increase in accuracy has probably been offset by the small propeller pitch changes which occurred.

Thus the probable accuracy which might be expected for the quoted power law is as before, *i.e.* it lies within the range

$$P \propto 1 \cdot 115 \ \sigma - 0 \cdot 115$$

and

$$P \propto 1 \cdot 085 \ \sigma - 0 \cdot 085 \text{ approximately.}$$

This is equivalent to an error of about $\pm$ 10 b.h.p. at 37,000 ft.

5.5. The full throttle height determination was checked at the end of the tests, and as will be seen from Fig. 7A and B, a small change has apparently taken place. In view of the fact that a cylinder block change was made during the test schedule, it seemed advisable to use the first determination for those tests made prior to the block change and the second determination for the later ones.

Under still air I.C.A.N. conditions the mean full throttle height for 9 lb./sq. in. boost at 3,000 r.p.m. is 17,500 ft., which compares with the value of 18,000 ft. quoted by the R.A.E. from bench tests[4].

5.6. Sufficient full throttle data being available the supercharger compressions ration correction C in the formula $R_c = R_0 [1 + C (t_0 - t_c)]$ has been obtained by plotting observed compression ratio, boost/intake total head *versus* intake temperature for a number of different conditions as shown in Fig. 2.

The value of C so derived is $0 \cdot 00248$ which compares with the figure of $0 \cdot 002$ commonly used on Merlin engines. The results from Ref. 5 on a Merlin 45 engine gave a C of $0 \cdot 0027$, a figure with which the present results agree quite closely.

5.7. The measured total head of the slipstream has been compared with that expected from the theoretical slipstream speed

$$V_s = V\sqrt{\left(1 + \frac{8}{\pi} \times \frac{T}{\rho V^2 D^2}\right)} \cdot$$

Several cases were taken including the high altitude levels and one or two points from the full throttle height determination and in each case the ratio of the measured total head to the calculated was within $\pm$ one or two per cent. of unity.

6. *Notes on Propeller Operation.*—6.1. It has been found to be much quicker and easier to carry out the foregoing test schedule with this type of propeller than was the case with the ordinary propeller used earlier. The Spitfire, however, does not carry sufficient fuel to do the fairly lengthy schedule of climb and high altitude level, followed by throttled partials, all in one flight, and thus the undoubted advantage of the propeller could not be fully exploited. In the absence of satisfactory torquemeters, however, there seems to be no reason why the power variation of new types of engine should not be measured by this method using this type of propeller.

6.2. The propeller was fitted with an electrical pitch indicator but in the first few flights this did not seem to be giving the pitch to the required accuracy, and thus no use was made of the indicator. When it eventually failed to work no attempt was made to put it right owing to the delay which would have been caused. There seems to be no fundamental reason, however, why this design could not be modified to give pitch indications to the required order of accuracy.

6.3. In general throughout the tests there was a tendency for the propeller to " creep " about $\frac{1}{4}$ deg. from its locked position though the direction of movement was not always consistent. This change in pitch was thus liable to introduce a fair error into the results. Later tests on this propeller have shown a more satisfactory technique which is advocated for this or any tests of a similar nature, viz. :

Instead of locking the propeller on the high altitude levels and keeping it locked for the subsequent throttled partial climbs, the pitch should be measured on descent from the high altitude levels and one or other of the pitch range stops adjusted to this value The ensuing take-off and climb can then be made with the propeller constant speeding. Prior to commencement of the actual partials the engine controls can be adjusted to make the propeller go to the appropriate stop, where it can be locked and the test carried out. Such a procedure obviates the necessity of taking off and climbing in an unsuitable fixed pitch.

7. *Conclusions.*—7.1. The variation of full throttle power with height of the Merlin 46 engine under still air conditions follows the law :—$P \propto (1 \cdot 10\sigma - 0 \cdot 10)$. This result is approximately the same as obtained from other tests on Merlin engines.

7.2. The supercharger compression ratio correction has been evaluated as $0 \cdot 00248$ which compares with the accepted value of $0 \cdot 002$ for Merlin engines.

7.3. In the absence of a torquemeter the electric variable pitch propeller provides a very useful method of determining the power law of an engine.

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No.	*Author*	*Title, etc.*
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TABLE 1

Test No.	Engine conditions	r.p.m.	Boost lb./sq. in.	Press ht. ft.	Press ht. in. of Hg.	Temp. deg. C. abs.	Rel. Dens. σ_a	Tip Speed V_t ft./sec.	a ft./sec.	$\frac{V_t}{a}$	V_1 m.p.h.	True Speed m.p.h.	J	Prop. Pitch Blade No. 1	Total head ft.	Total head in. of merc.	Speed m.p.h.	Temp. deg. C. abs.	Rel. Dens. σ_e	I.C.A.N. Press σ_e in. of merc.	Corrections a_1	a_2	a_3	Power ratio $\sigma_a \times a_1 \times a_2 \times a_3$	Density ratio σ_e
← AIRCRAFT →															← INTAKE →										
1. 12/3	F.T.P.H.A.	3,000	−2·6	37,000	6·40	211	0·292	862	956	0·901	134	249	1·49	37° 48′	34,250	7·29	133	220	0·319	7·27	0·995			0·489	0·319
37,000 ft. 17/3	T.P.M.A_2	3,000	7·94	16,000	16·20	251	0·618	862	1,042	0·828	197	250	1·49	37° 30′				259	0·664			1·092	0·953	—	—
28/3	F.T.P.M.A_1	3,000	7·94	21,400	12·95						197							244	0·561					1	0·561
2. 28/3	F.T.P.H.A.	3,000	−1·3	34,875	7·08	217	0·315	894	968	0·923	166	296	1·77	41° 46′	31,500	8·29	137	229	0·349	8·07	0·993			0·509	0·349
35,000 ft. 3/4	T.P.M.A_2	3,000	9·17	15,980	16·23	261	0·599	894	1,062	0·843	229	296	1·77	42° 03′				267	0·659			1·038	0·938	—	—
28/3	F.T.P.M.A_1	3,000	9·17	20,750	13·3						229							247	0·595					1	0·595
3. 5/4	F.T.P.H.A.	3,000	+0·3	32,860	7·78	218	0·344	903	974	0·928	181	309	1·84	42° 55′	29,320	9·16	147	228	0·388	9·29	0·992			0·691	0·388
33,000 ft. 15/4	T.P.M.A_2	3,000	9·85	16,000	16·20	260	0·601	903	1,061	0·851	239	309	1·84	41° 28′				266	0·665			1·26	0·965	—	—
20/4	F.T.P.M.A_1	3,000	9·85	20,600	13·4						239							256	0·596					1	0·596
4. 16/4	F.T.P.H.A.	3,000	−3·0	37,000	6·4	216	0·286	861	968	0·890	134	249	1·49	39° 36′	34,450	7·23	125	223	0·312	7·13	0·996			0·486	0·312
37,000 ft. 18/4	T.P.M.A_2	3,000	7·17	16,000	16·20	263	0·591	861	1,068	0·807	192	249	1·49	39° 28′				268	0·637			1·073	0·94	—	—
20/4 Check	F.T.P.M.A_1	3,000	7·17	22,250	12·5						192							249	0·536					1	0·536

Year of tests: 1943.

TABLE 2

Position Error Correction for 6,160 lb.

ASI m.p.h.	100	120	140	160	180	200	220	240	260	280	300
PEC m.p.h.	+10	+5½	+2½	+½	−1	−2½	−3½	−4½	−6	−7	−8

TABLE 3

Rotol No. 5 Electric Propeller. Blades to Drg. No. RA.630
Calculation of Power Coefficients by R.A.E.

Test No.	Blade Pitch (No. 1)	J	V_t/a	C_p
1. 37,000 ft.	37° 48′	1·49	0·901	0·1835
	37° 48′	1·36	0·804	0·205
	37° 48′	1·44	0·823	0·188
	37° 48′	1·49	0·828	0·175
	37° 30′	1·49	0·823	0·168
	37° 30′	1·56	0·830	0·1475
2. 35,000 ft.	41° 46′	1·77	0·923	0·224
	42° 03′	1·65	0·830	0·263
	42° 03′	1·72	0·837	0·233
	42° 03′	1·80	0·845	0·209
	42° 03′	1·58	0·830	0·270
3. 33,000 ft.	42° 53′	1·84	0·928	0·227
	41° 28′	1·80	0·843	0·191
	41° 28′	1·87	0·853	0·168
4. 37,000 ft. check ..	39° 36′	1·49	0·890	0·234
	39° 28′	1·39	0·796	0·241
	39° 28′	1·47	0·805	0·223
	39° 28′	1·53	0·809	0·207

TABLE 4

Measured Pitch Settings of Propeller after Flight Tests

Test No.	Date in 1943	Condition	Pitch at 0·7 radius		
			Blade 1	Blade 2	Blade 3
1	12/3	37,000 ft. Level ..	37° 48′	37° 42′	37° 38′
	17/3	16,000 ft. Partial ..	37° 30′	37° 30′	37° 30′
2	28/3	35,000 ft. Level ..	41° 46′	41° 39′	41° 48′
	3/4	16,000 ft. Partial ..	42° 03′	42° 00′	42° 07′
3	5/4	33,000 ft. Level ..	42° 55′	42° 57′	43° 01′
	15/4	16,000 ft. Partial ..	41° 28′	41° 28′	41° 31′
4	16/4	37,000 ft. Level ..	39° 36′	39° 32′	39° 28′
	18/4	16,000 ft. Partial ..	39° 28′	39° 23′	39° 28′

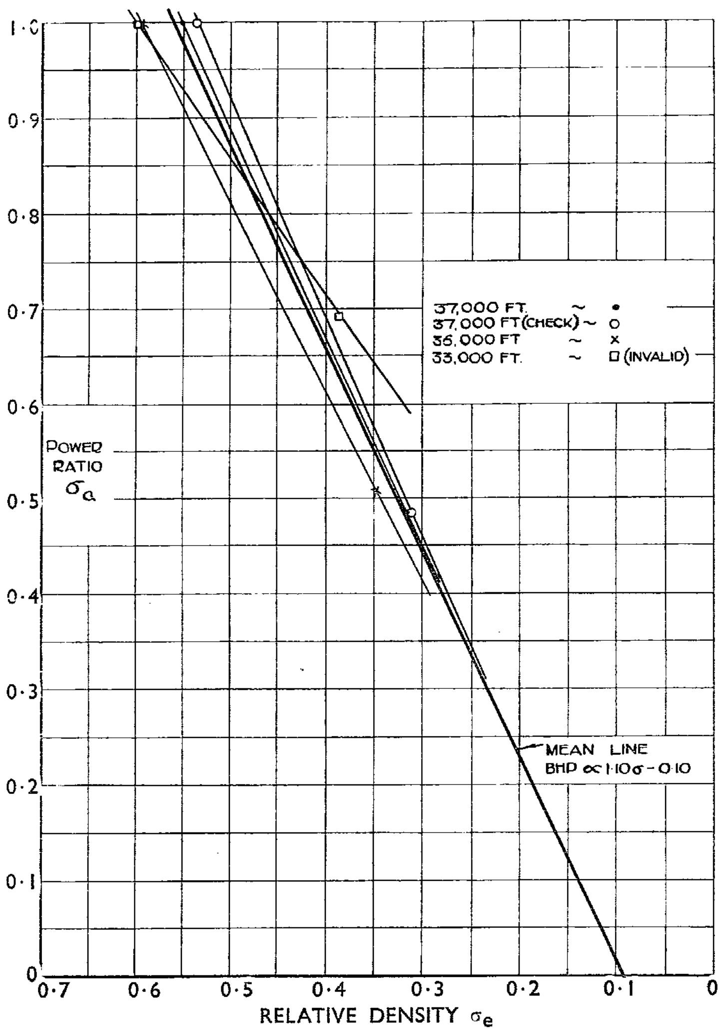

FIG. 1.—Variation of Static Full Throttle Power with Height at 3,000 r.p.m.

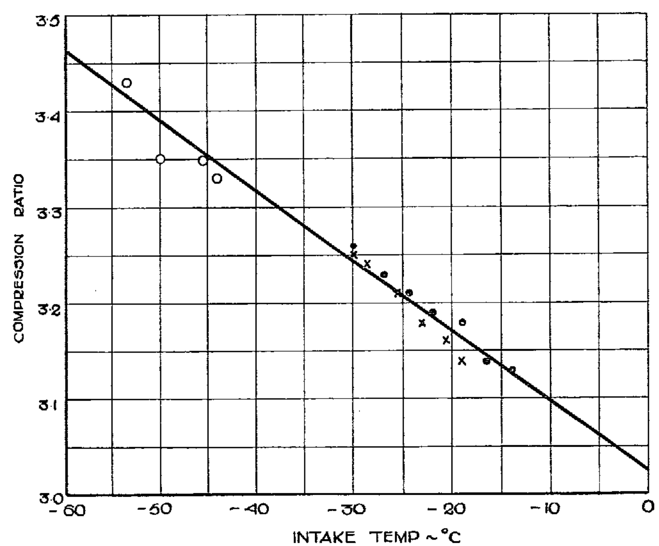

FIG. 2.—Supercharger Compression Ratio *vs* Intake Temp.

$R_c = R_o\,(1 + C\Delta T)$, $C = 0{\cdot}00248$

F.Th. height determination 20/4/43 .. •
F.Th. height determination 28/3/43 .. X
High altitude levels .. .. .. O

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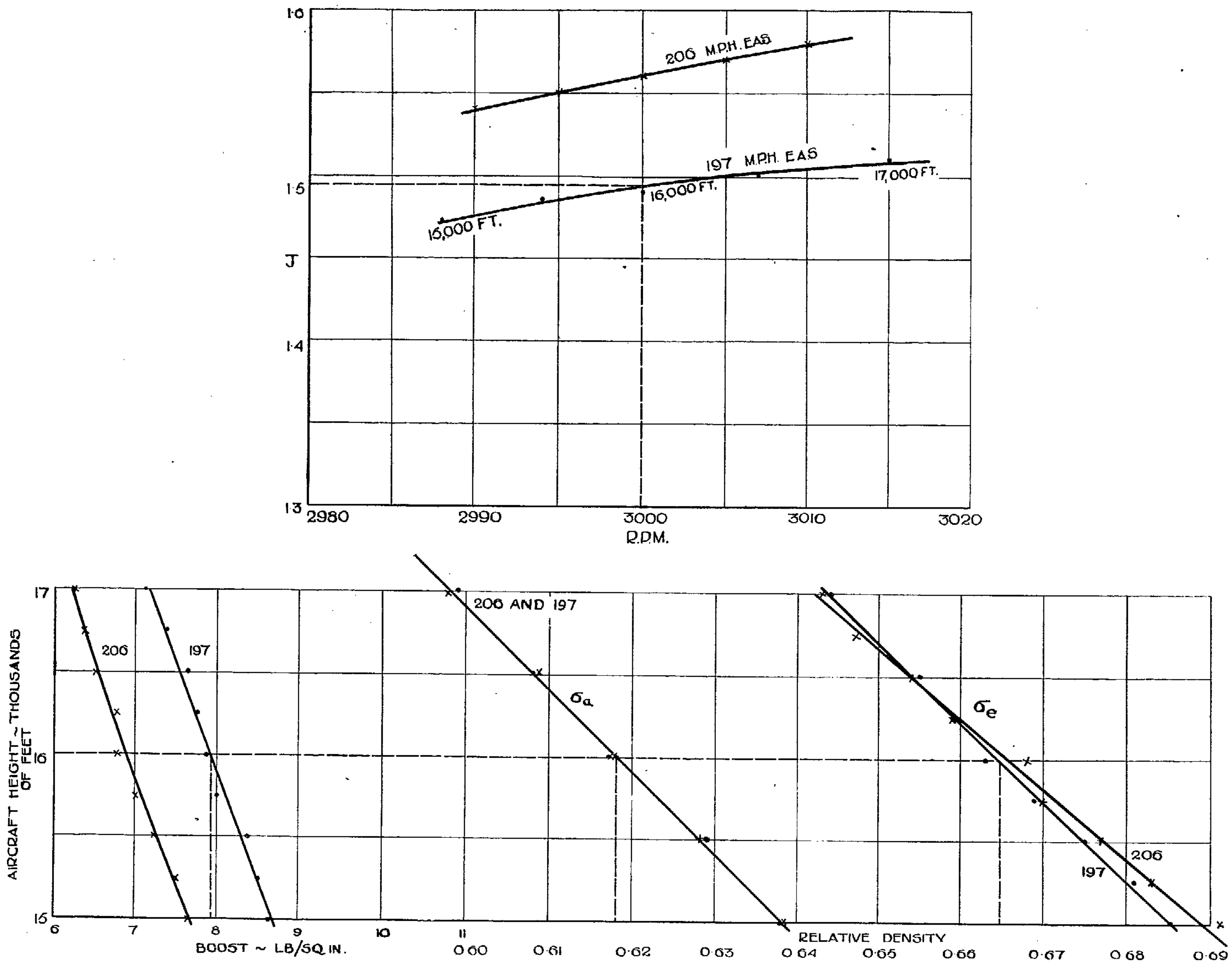

FIG. 3.—Throttled Partial Climbs at 37,000 ft. Setting Blade No. 1 = 37 deg. 30 min.

Smoothed results at 3,000 r.p.m. and J = 1·49
Height = 16,000 ft.
Speed = 197 m.p.h. E.A.S.
= 250 m.p.h. T.A.S.

Boost = 7·94 lb./sq. in.
Air Temp. = − 22 deg. C.
Intake Temp. = −14 deg. C.
Density σ_a 0·618
σ_e 0·664

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B

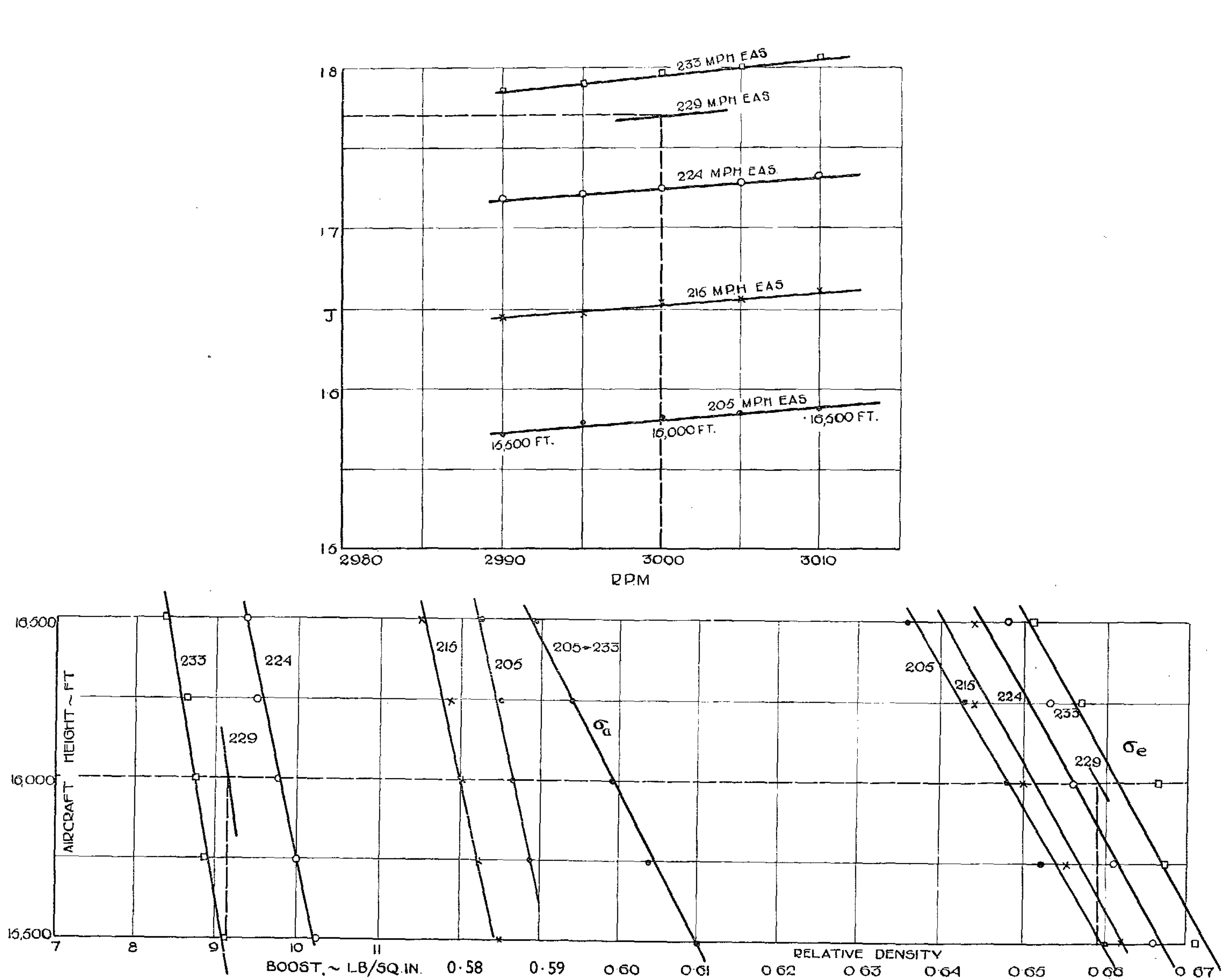

FIG. 4.—Throttled Partial Climbs at 35,000 ft. Setting Blade No. 1 = 42 deg. 03 min.

Smoothed results at 3,000 r.p.m. and $J = 1\cdot 77$
Height = 16,000 ft.
Speed = 229 m.p.h. E.A.S.
= 296 m.p.h. T.A.S.

Boost = $9\cdot 17$ lb./sq. in.
Air temp. = $-$ 12 deg. C.
Intake temp. = $-$ 6 deg. C.
Density σ_o $0\cdot 599$
σ_e $0\cdot 659$

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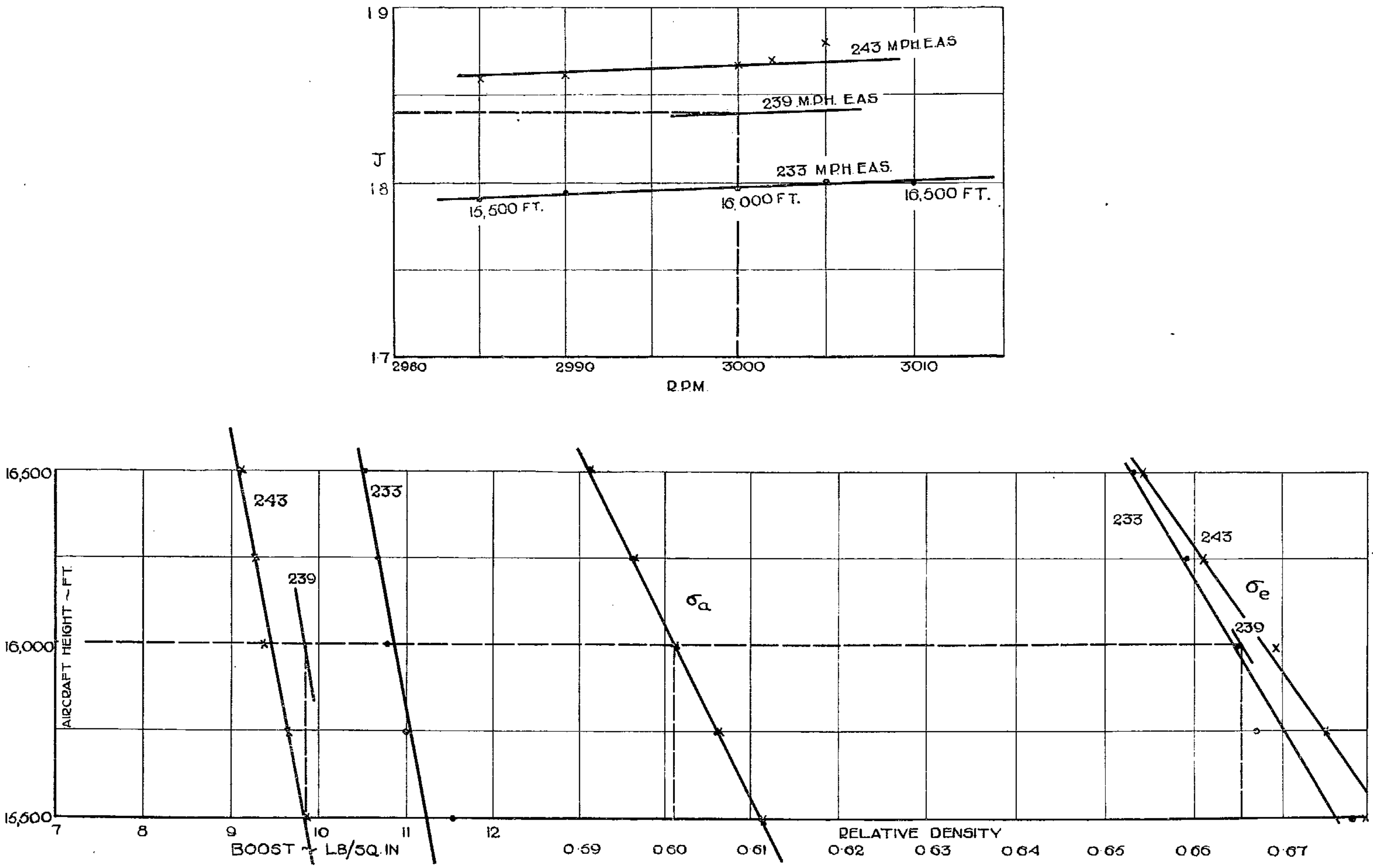

FIG. 5.—Throttled Partial Climbs at 33,000 ft. Setting Blade No. 1 = 41 deg. 28 min.

Smoothed results at 3,000 r.p.m. and $J = 1 \cdot 84$	Boost $= 9 \cdot 85$ lb./sq. in.
Height = 16,000 ft.	Air temp. $= -13$ deg. C.
Speed = 239 m.p.h. E.A.S.	Intake temp. $= -7$ deg. C.
= 309 m.p.h. T.A.S.	Density σ_a $0 \cdot 601$
	σ_e $0 \cdot 665$

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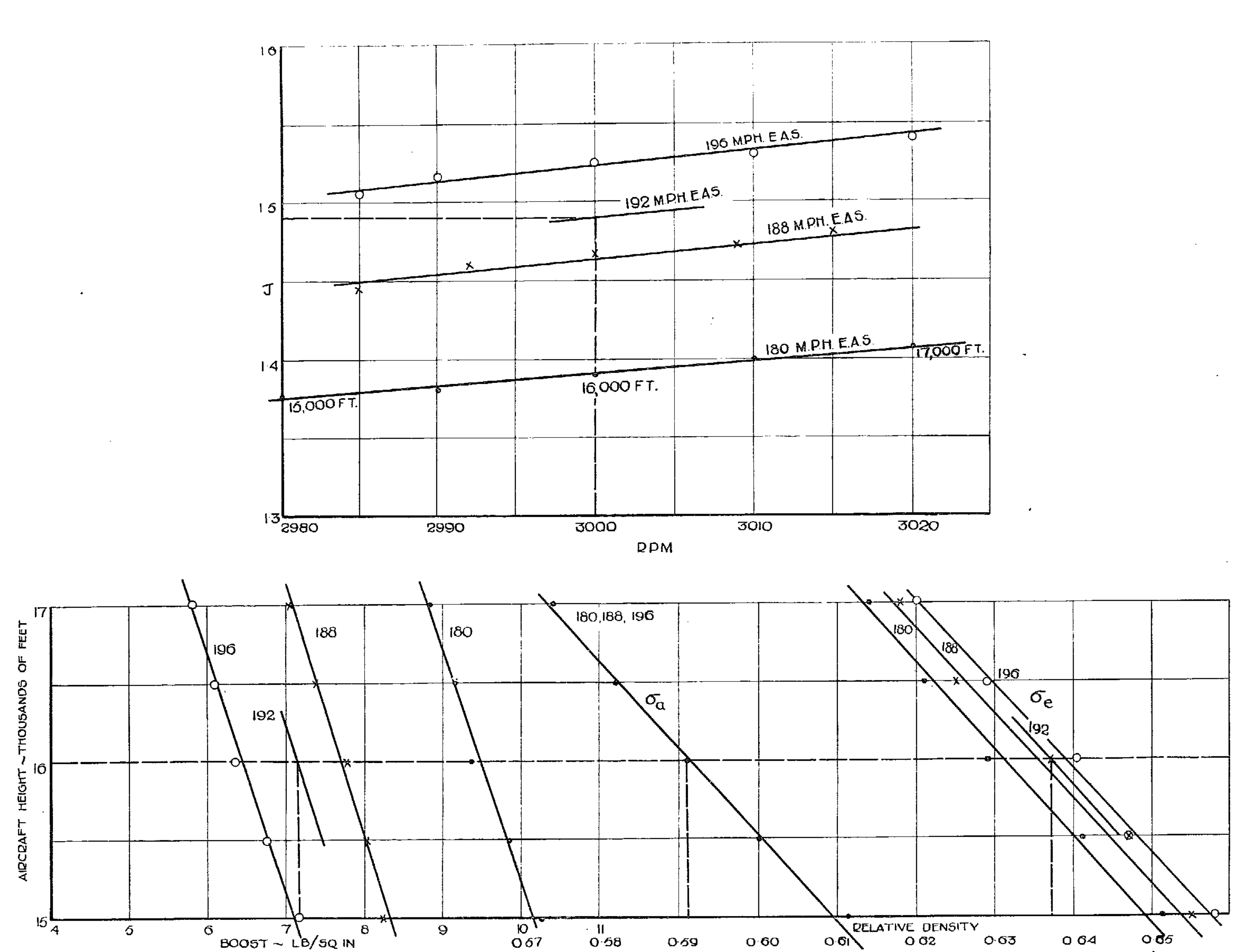

FIG. 6.—Throttled Partial Climbs at Check 37,000 ft. Setting Blade No. 1 = 39 deg. 28 min.

Smoothed results at 3,000 r.p.m. and $J = 1 \cdot 49$
Height = 16,000 ft.
Speed = 192 m.p.h. E.A.S.
= 249 m.p.h. T.A.S.

Boost = $7 \cdot 17$ lb./sq. in.
Air Temp. = − 10 deg. C.
Intake temp. = − 5 deg. C.
Density σ_a $0 \cdot 591$
σ_e $0 \cdot 637$

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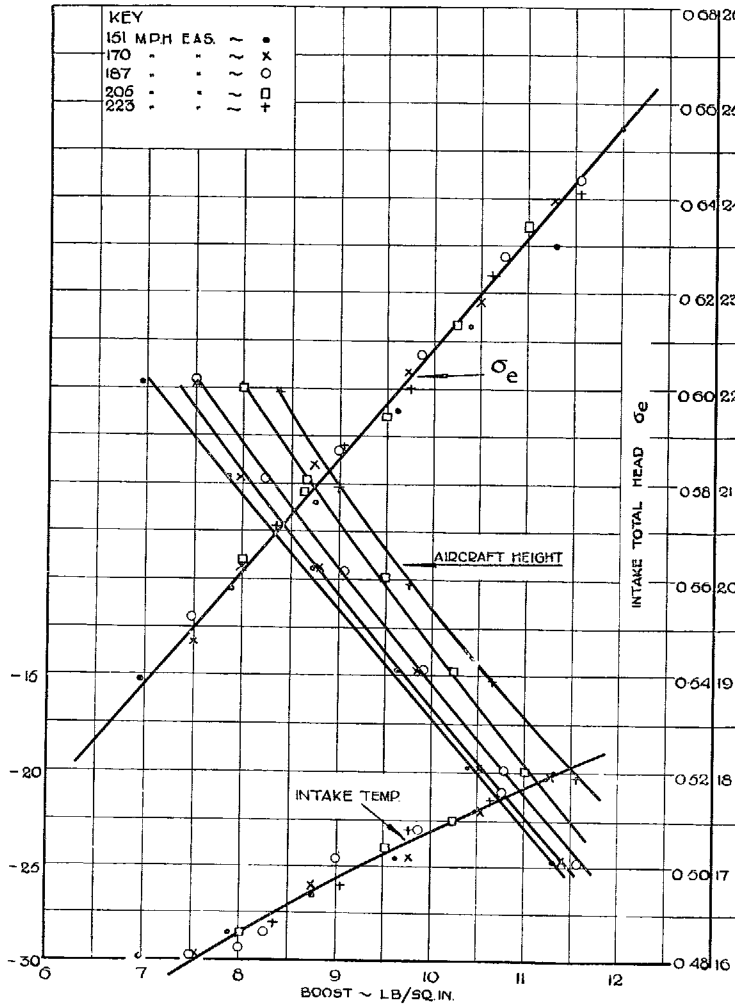

Fig. 7A

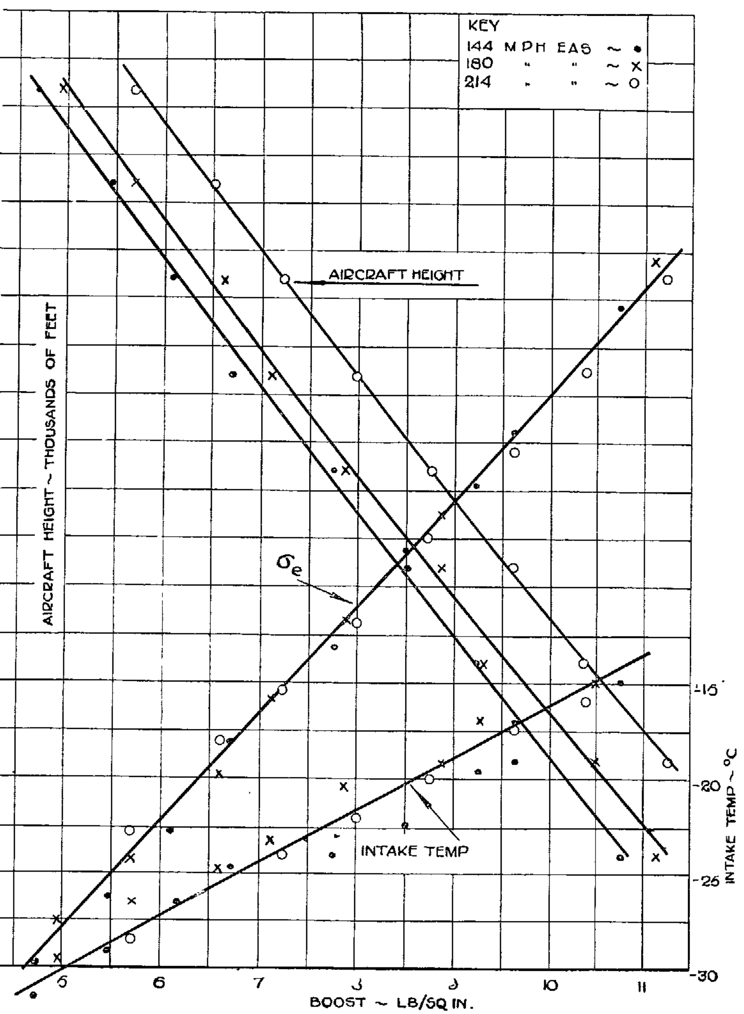

Fig. 7B

FIG. 7.—Full Throttle Height Determination at 3,000 r.p.m.

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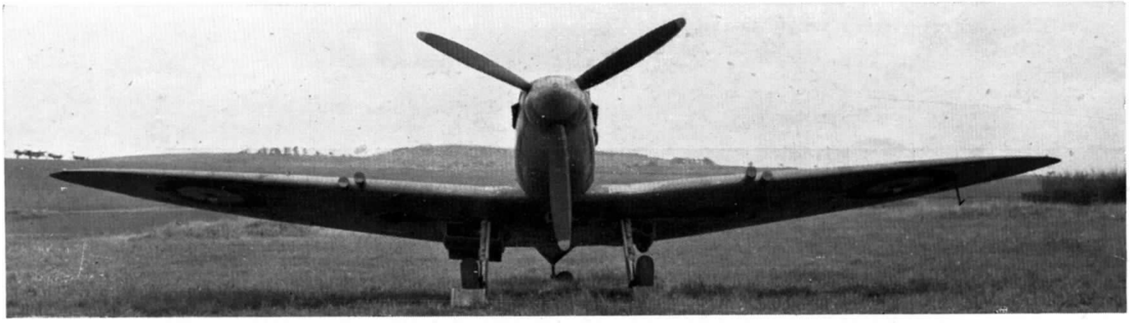

PLATE A

PLATE B

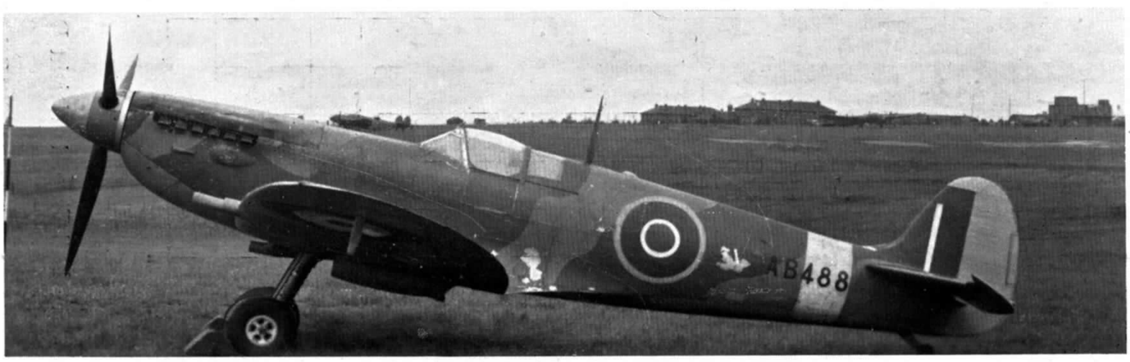

PLATE C

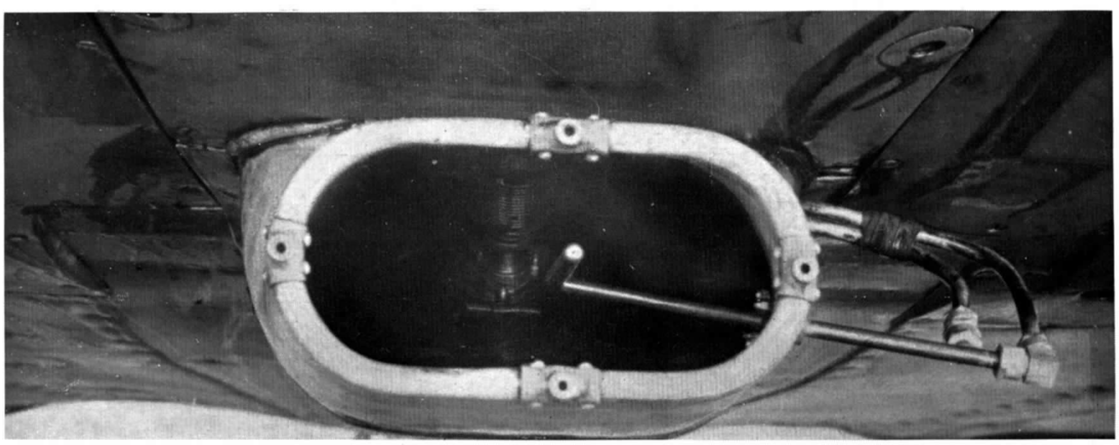

PLATE D

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