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E.2872

ROYAL AIRCRAFT ESTABLISHMENT

Interim Report No.E.2872

Tests on the Application of Dimensional Relationships to a Centrifugal Air Compressor.

- By -

W.L.Taylor, G.V.Brooke, and J.F.Bargman.

A.M.Ref: Nil.

R.A.E.Ref: T.C.1301.

January 1930

Item No 26.

Summary

R. In R.A.E.Report No.U.3.* (I.C.E.No.650) relationships based on dimensional theory were derived by which the performance of a compressor at one set of intake conditions may be deduced from tests at other conditions. It was shewn that inclusion of the Kinematic viscosity of the air among the variables affecting the performance of the compressor introduced a scale effect variable, the influence of which, however, was assumed to be negligible.

Tests on a centrifugal supercharger have been carried out to check the validity of this assumption and to ascertain whether distortion of the compressor casing or any other factor requires to be taken into account. These tests have been performed under conditions of reduced intake pressure but at approximately constant intake temperature.

The results obtained show that, within the limitations of the test plant, no important error is introduced by the omission of the scale effect variable, and there is no evidence of any definite influence from any other factor whose effect has been neglected.

The /

* Note on Dimensional Relationships for Air Compressors. By: R.S.Capon.

The dimensional relationships derived in Report U.3 appear, therefore, to be sufficient to define the performance of a centrifugal compressor under all conditions of inlet pressure.

No reliable information has been obtained regarding the effects of low inlet temperatures, owing to choking of the supercharger air intake with snow. This work will be continued.

In R.A.E.Report No.U.3. the following non-dimensional variables associated with the performance of an air compressor are derived :-

$$\frac{p_1}{p_0},\quad \frac{\rho_1}{\rho_0},\quad \frac{T_1}{T_0},\quad \frac{P}{W.n^2 D^2},\quad \frac{W}{D^2\sqrt{p_0\,\rho_0}},\quad nD\sqrt{\frac{\rho_0}{p_0}}\quad \text{and}\quad \frac{nD^2}{\nu}$$

where p_0, T_0 and ρ_0 are the absolute pressure temperature and density of air at inlet to compressor,

p_1, T_1 and ρ_1 are the absolute pressure temperature and density of air at delivery from compressor,

W = rate of (mass) flow through the compressor

n = rotational rate of the rotor

D = a linear dimension of the compressor

P = the power absorbed by the compressor, exclusive of friction in driving gears and bearings.

ν = the Kinematic viscosity of the air.

It is shewn that, if the effect of the variable $\frac{nD^2}{\nu}$ is negligible, curves of $\frac{p_1}{p_0}$, $\frac{\rho_1}{\rho_0}$, $\frac{T_1}{T_0}$, adiabatic temperature efficiency, and $\frac{P}{W.n^2 D^2}$, plotted against $\frac{W}{D^2\sqrt{p_0\,\rho_0}}$ for constant values of $nD\sqrt{\frac{\rho_0}{p_0}}$

should /

should be applicable to all inlet conditions.

To verify this, tests were carried out on a Lion supercharger at normal intake temperatures and at intake gauge pressures of 0, -5, -10, and -15 inches of mercury, the rates of rotation being adjusted to provide data at four different values of the variable $nD \sqrt{\frac{\rho_0}{p_0}}$ at each of the four conditions of inlet pressure.

The supercharger was mounted within a closed metal box, from the interior of which its air supply was drawn. The air inlet to the box was fitted with a valve for control of the internal pressure, and the supercharger delivery system was connected to an exhauster pump, enabling the delivery pressure at constant intake conditions to be varied over a wide range. The pressures and temperatures of the air at the supercharger inlet and delivery were observed, and the rate of air discharge was determined by means of a calibrated parabolic nozzle fitted in the delivery pipe-line.

From these quantities the values of the several non-dimensional variables have been calculated, and are plotted on Figs. 1 and 2. As all the tests were carried out on one compressor, the value of the linear dimension D has been considered as unity. Also, as $\frac{\rho_1}{\rho_0} = \frac{p_1}{p_0} \div \frac{T_1}{T_0}$, the density ratio has not been plotted separately, and the variable $nD \sqrt{\frac{\rho_0}{p_0}}$ has been replaced by $\frac{n}{\sqrt{T_0}}$.

On /

On Fig.1, the ratios $\frac{p_1}{p_0}$ and $\frac{T_1}{T_0}$ at each of the conditions of intake pressure are plotted for constant values of $\frac{n}{\sqrt{T_0}}$, the units adopted being as follow :-

n : revolutions of the impeller per minute
T_0 : degrees C. absolute
W : lb. of air delivered per minute
p_0 : lb. per sq.inch absolute
ρ_0 : lb.per cubic foot.

Slight discrepancies exist in the families of pressure ratio curves, and, as in general the observations obtained during each separate test are consistent, it appears improbable that the discrepancies are entirely accounted for by experimental errors. The maximum difference in the value of the pressure ratios in any of the groups of curves, however, does not exceed 3%. The temperature ratio curves at the various intake pressures are in almost exact agreement, and have been combined in a single curve for each value of $\frac{n}{\sqrt{T_0}}$

As the temperature ratio curves coincide almost exactly, it necessarily follows that there is no important disagreement in the values of the variable $\frac{P}{W.n^2}$ at the different intake pressures. For, if K_p is the specific heat of air at constant pressure,

$$\frac{P}{W.n^2} = \frac{W.K_p\,(T_1 - T_0)}{W.n^2}$$

$$= K_p \frac{T_0}{n^2} \left\{ \frac{T_1}{T_0} - 1 \right\}$$

And /

And $\frac{T_1}{T_0}$ is a constant for constant values of $\frac{n}{\sqrt{T_0}}$ and $\frac{W}{\sqrt{p_0 \rho_0}}$

Therefore $\frac{P}{W.n^2}$ is also constant for constant values of $\frac{n}{\sqrt{T_0}}$ and $\frac{W}{\sqrt{p_0 \rho_0}}$, and values of this variable have not been included in the diagrams.

On Fig.2, curves of adiabatic temperature efficiency are plotted for each of the four constant values of $\frac{n}{\sqrt{T_0}}$. The efficiencies have been calculated directly from the pressure ratio and temperature ratio curves of Fig.1, and the discrepancies in the pressure ratio curves produce corresponding divergencies in the efficiency curves.

The intake temperatures during the several tests varied from 6 to 18°C. Attempts to determine the performance at low inlet temperatures provided no useful results, as, owing to the humidity of the atmosphere at the time of the tests, the supercharger air intake became choked with snow. Methods have been adopted to avoid this trouble as far as possible, and the tests at low temperatures will be completed when suitable atmospheric conditions prevail.

It is proposed subsequently to carry out similar tests on a Roots type of displacement supercharger.

Investigation /

Investigation of the effect on the dimensional relationships of heating the compressor casing, as proposed in R.A.E. Report U.3, will be undertaken when means for supplying the necessary external heat are available.

Attached:- Prints C.3943 Fig.1.
C.3967 Fig.2.

Tests at values of $\frac{n}{\sqrt{T_0}}$ equal to 828, 944, 1066, and 1188 at various intake pressures. Intake temperature approximately constant.

Intake gauge pressure of zero: ——×——×——×——

" " " −5 ins. of mercury: –⊗– –⊗– –⊗–

" " " −10 " " : - -⊙- - -⊙- - -⊙- -

" " " −15 " " : —⊡·—⊡·—⊡

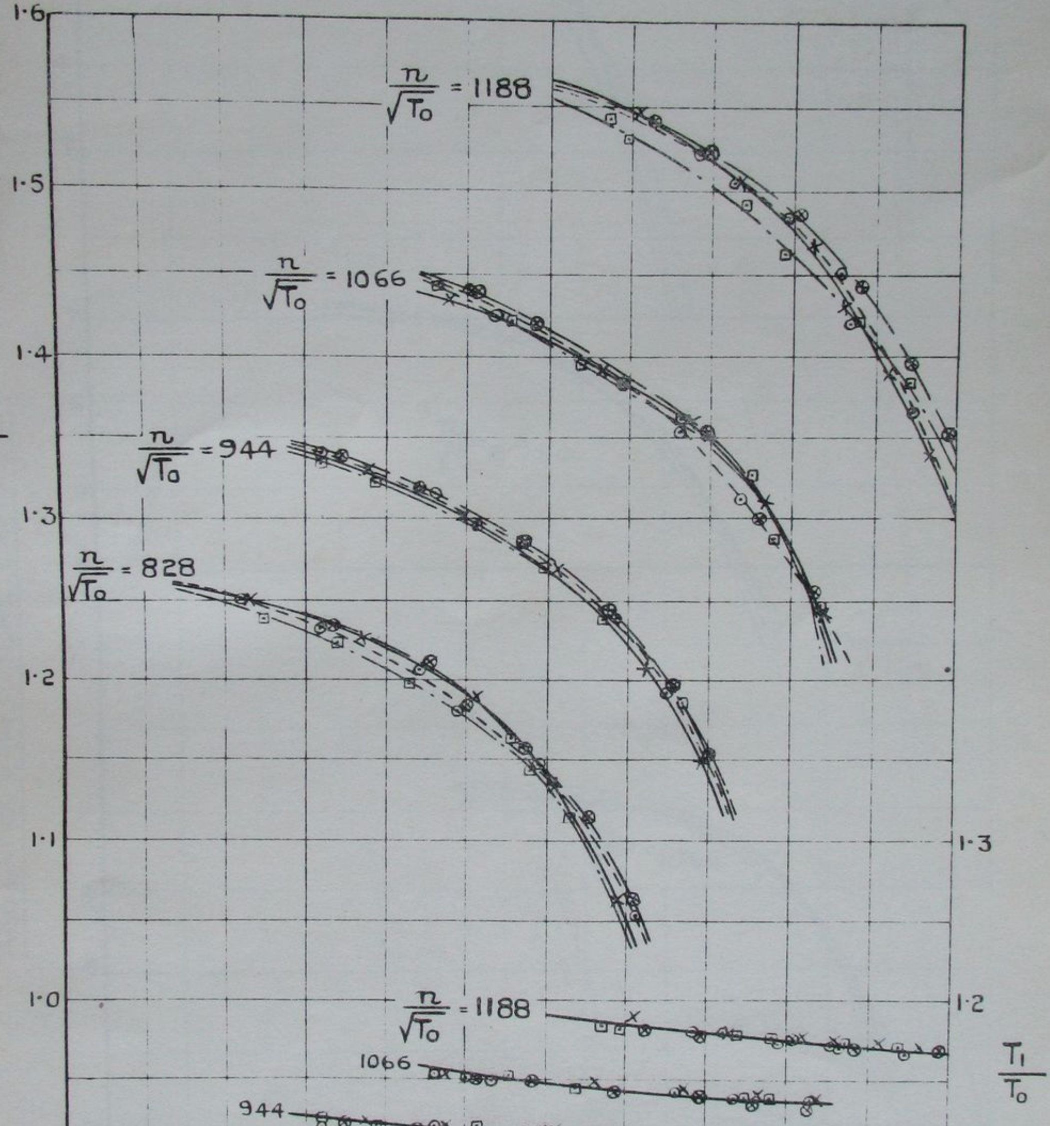

FIG. 1.

Issued by Drawing Office Directorate of Technical Development AIR MINISTRY	TITLE:- Lion Supercharger. Tests at various intake pressures.	Drawn: [illegible] Traced: N A H 31.1.30	SKETCH Nº C.3943
	Issue Nº 1 Altn Nº	Checked: [illegible] Approved: [illegible]	

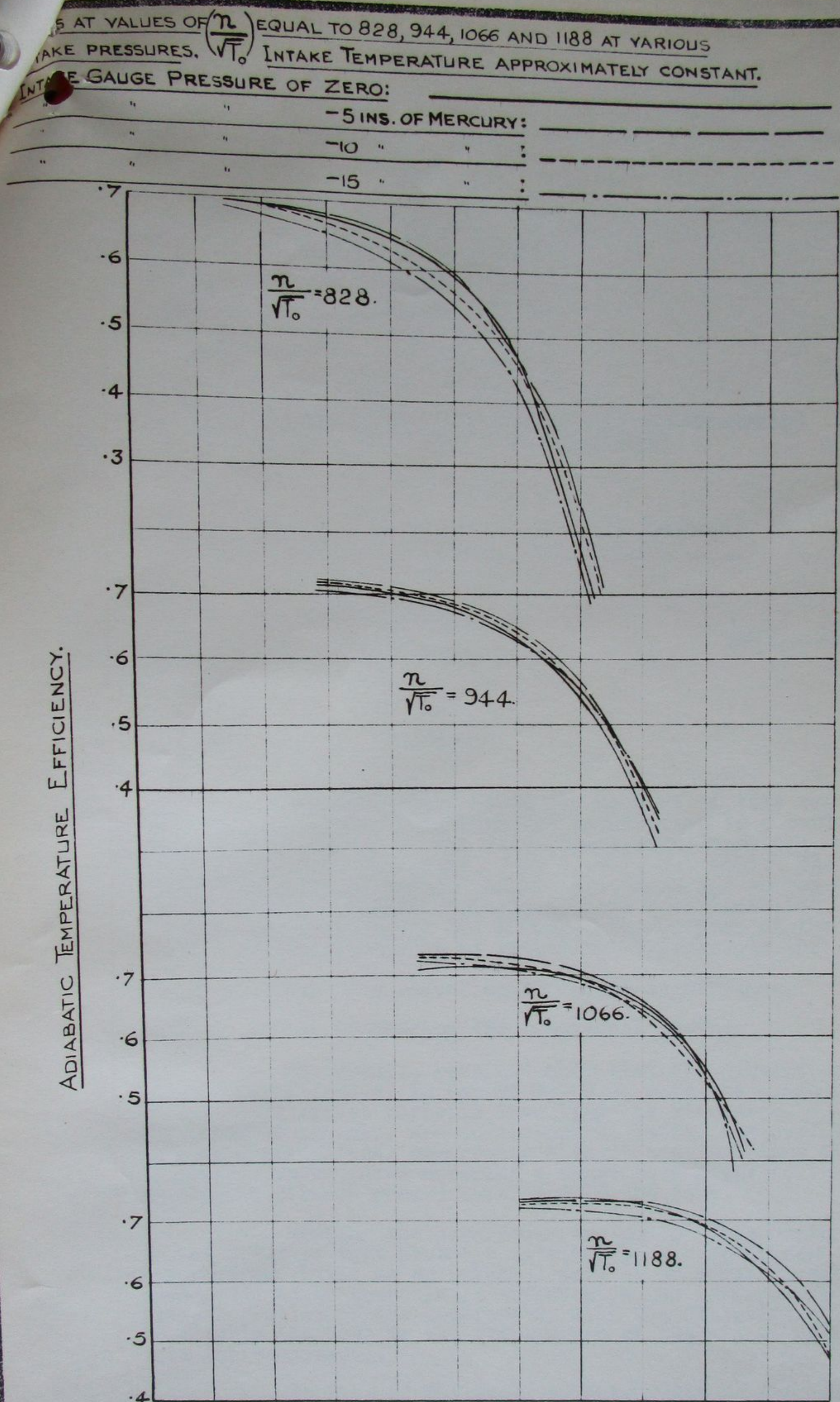

FIG. 2.

Issued by Drawing Office DIRECTORATE OF TECHNICAL DEVELOPMENT AIR MINISTRY	TITLE:- LION SUPERCHARGER. TESTS AT VARIOUS INTAKE PRESSURES.					Drawn G.V.B.	Traced EB 1-3-30	SKETCH No
	Issue No	1				Checked G.V.B.	Approved [illegible]	C.3967.
	Altn No							

ROYAL AIRCRAFT ESTABLISHMENT.

Report No. E.2872.A.

Tests on the Application of Dimensional Relationships to a Centrifugal Air Compressor.

- By -

W. L. Taylor, G. V. Brooke, and J. F. Bargman.

A.M. Reference: Nil.
R.A.E. Reference: T.C.1301.
Item No: 2b.

April, 1930.

Summary.

'R' The work which forms the subject of this report completes the tests to confirm the application to a centrifugal air compressor of the dimensional relationships derived in R.A.E. Report No. U.3. (I.C.E. No. 650). The results of tests at reduced intake pressures and approximately constant intake temperature have been described in R.A.E. Interim Report No. E.2872. The purpose of the further investigations is to extend the experiments to:

(1) The effect of a reduction in intake temperature.

(2) The effect of heating the compressor casing.

The results obtained show that the dimensional relationships derived in Report No. U.3, with the omission of the scale effect variable involving the kinematic viscosity of the air, are sufficient to define the performance of a centrifugal compressor without any important error at intake temperatures covering a range equivalent to the conditions between ground level and 15,000 feet.

Heating the compressor casing to a temperature of the order of that probably attained by a gear-driven supercharger built as an integral part of an engine crankcase produced no appreciable effect upon the performance characteristics of the compressor, with the exception of the inevitable increase in the temperature of the air at deliver from the compressor.

In view of the small effect, tests of the validity of the dimensional reduction under conditions where the casing is heated were abandoned. It was considered that it would be sufficient in practice to derive the compression

ratio/

ratio, etc. from the non-dimensional diagram prepared from the results of experiments under normal test bench conditions, correcting the delivery temperature subsequently to allow for the effect of the heating of the casing which might occur under working conditions in an engine.

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(1) Tests on the effect of reduced intake temperature.

The test plant was similar to that used during the tests at reduced intake pressures, a Lion supercharger being mounted within a closed metal chamber, through which cold air from a refrigerating plant was circulated. Both the chamber and the supercharger delivery system were connected to separate exhaustor pumps, as the production of a low temperature within the test chamber necessitated a simultaneous reduction of the internal pressure.

Tests were carried out at intake temperatures of -15°C. and -25°C., (corresponding to the standard atmospheric temperature at altitudes of 15,000 and 20,000 feet respectively) the intake pressures being regulated as required to obtain the desired temperatures. The speed of the impeller was adjusted to provide results at each of the four values of the variable $\frac{n}{\sqrt{T_0}}$ at which the tests at low intake pressures were performed and the same quantities were measured as during those tests.

During all the experiments at low temperatures, but more particularly at an intake temperature of -25°C., sudden fluctuations of the pressure-measuring gauges were noticed, and, in view of the possibility of deposition of snow or ice at the supercharger air inlet, arrangements were made in some of the tests to measure the pressure before and after the guide vanes at the air intake. The ratio of

these /

these pressures has been plotted on Fig. 3 and the contrast between the uniformity of the results at normal temperature and the irregularities at the reduced temperatures is significant. It was decided to discard the results obtained at -25°C. inlet temperature, as the majority of these were inconsistent, due either to restriction of the passage through the inlet guide vanes by the deposition of ice or to the difficulty of maintaining steady operation of the cold air plant when working at its full capacity.

The non-dimensional variables, calculated from the tests at normal temperature (Interim Report E.2872) and at -15°C., are plotted on Figs. 1 and 2, the units adopted being the same as utilised for Figs. 1 and 2 of Interim Report E.2872. The pressure ratio curves show slight discrepancies, similar to those resulting from the tests at reduced intake pressures. There appears to be a small disagreement in the temperature ratio curves at the two higher values of the variable $\frac{n}{\sqrt{T_0}}$, the maximum difference in the values of the temperature ratios being equivalent to an error of 4°C. in the delivery temperature in the tests at -15°C. intake temperature. The efficiency curves reflect the discrepancies in the pressure ratio and temperature ratio curves, from which they are deduced.

(2). Tests on the effect of heating the compressor casing.

Arrangements were made during these tests for the supercharger to take its air supply directly from the atmosphere, a pipe leading through a pressure-tight gland in one end of the closed test chamber being connected to the supercharger inlet. The chamber was disconnected from the cold air plant, and was fitted with a pipe through which steam could be admitted, an exhauster pump serving to extract the

condensate /

condensate and maintain a continuous flow of steam through the interior of the chamber.

Two series of tests were carried out at each of the four original values of the variable $\frac{n}{\sqrt{T_0}}$, steam being passed through the chamber during the first series only. In the second, the exhauster pump was allowed to draw a small quantity of air through the chamber from the surrounding atmosphere, in order to prevent any appreciable rise in the temperature of the air within the chamber.

During the tests with steam-heating, the internal temperature of the test chamber, measured at a point near the top, was maintained at 100°C., and the temperature of the external surface of the supercharger casing in the region of the delivery volute, measured by means of a washer-type thermo-couple, was found to be practically the same as that of the chamber. The increase in the temperature rise of the air during its passage through the supercharger, due to heating of the casing, varied from 13°C. at the high rates of rotation to 28°C. at the low rates.

The pressure ratios and temperature ratios obtained from the two series of tests are shown on Fig. 4. The temperature ratio at definite values of the variables $\frac{W}{\sqrt{p_0 \rho_0}}$ and $\frac{n}{\sqrt{T_0}}$ is necessarily increased considerably by the external heating of the compressor, and there appears to be a tendency for the pressure ratio to be decreased, but the latter effect is evidently negligibly small.

The temperature rise of the air when external heat is supplied through the compressor casing has no

significance /

significance as a measure of the work done on the air by the impeller, and values of adiabatic efficiency based upon the temperature rise under these conditions are meaningless. During all the tests, the supercharger was driven by a swinging-field electric motor, the power output of which was determined by measurement of torque reaction. The losses in the impeller speed-increasing gear and bearings are included in this power, and it is not permissible to treat the adiabatic efficiency based upon it as one of the dependent variables in the system of dimensional relationships unless the mechanical efficiency of the driving gear is constant, the adiabatic efficiencies based respectively upon the total power input to the compressor and upon the work done on the air by the impeller being then directly proportional to each other. The power transmitted through the gearing at any definite values of the variables $\frac{W}{\sqrt{P_0 \rho_0}}$ and $\frac{n}{\sqrt{T_0}}$ was observed to be approximately the same in each series of tests, and the oil level in the gearbox was kept constant by means of an extraction pump. The change in viscosity of the oil at the higher temperatures existing during the experiments with steam-heating remains the only factor liable to cause any appreciable difference in the power loss in the driving gears in each of the two series of tests. The possible slight alteration in the mechanical efficiency at given values of the variables $\frac{W}{\sqrt{P_0 \rho_0}}$ and $\frac{n}{\sqrt{T_0}}$, due to heating of the oil by the steam-jacket, has been neglected, and on Fig. 5 the adiabatic efficiency, based upon the total power input to the supercharger, has been plotted for both series of tests. The curves at

each /

TO ACCOMPANY REPORT Nº E.2872. A.

TESTS AT VALUES OF $\frac{n}{\sqrt{T_0}}$ EQUAL TO 828, 944, 1066 AND 1188

AT DIFFERENT INTAKE TEMPERATURES AND PRESSURES.

INTAKE PRESSURE AND TEMPERATURE 14 LB. PER SQ. IN. ABS. AND +13°C. APPROX. —×—×—×—

INTAKE PRESSURE AND TEMPERATURE 10·5 LB. PER SQ. IN. ABS. AND −15°C. APPROX. --⊙--⊙--⊙--

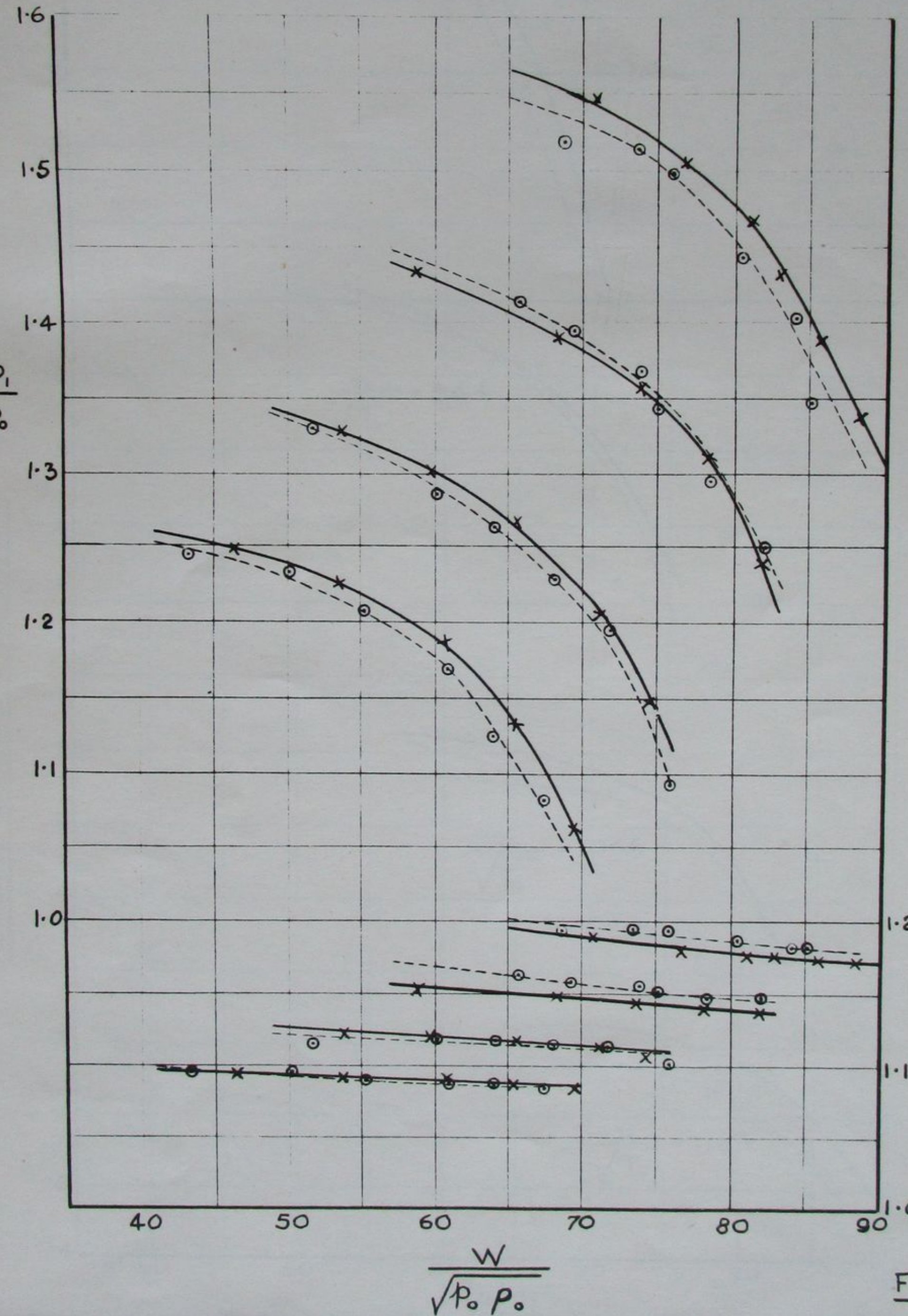

FIG. 1.

ISSUED BY DRAWING OFFICE DIRECTORATE OF TECHNICAL DEVELOPMENT AIR MINISTRY	TITLE:- LION SUPERCHARGER. TESTS AT VARIOUS INTAKE TEMPERATURES	DRAWN G.V.B.	TRACED E. 25-4-30	SKETCH Nº C.3980.
	ISSUE Nº 1	CHECKED G.V.B.	APPROVED WhG	
	ALTN Nº			

TO ACCOMPANY REPORT Nº E.2872 A.

TESTS AT VALUES OF $\frac{n}{\sqrt{T_0}}$ EQUAL TO 828, 944, 1066 AND 1188, AT DIFFERENT INTAKE TEMPERATURES AND PRESSURES.

INTAKE PRESSURE AND TEMPERATURE 14 LB. PER SQ. IN. ABS. AND +13°C. APPROX. } ————

INTAKE PRESSURE AND TEMPERATURE 10·5 LB. PER SQ. IN. ABS. AND −15°C. APPROX. } - - - - -

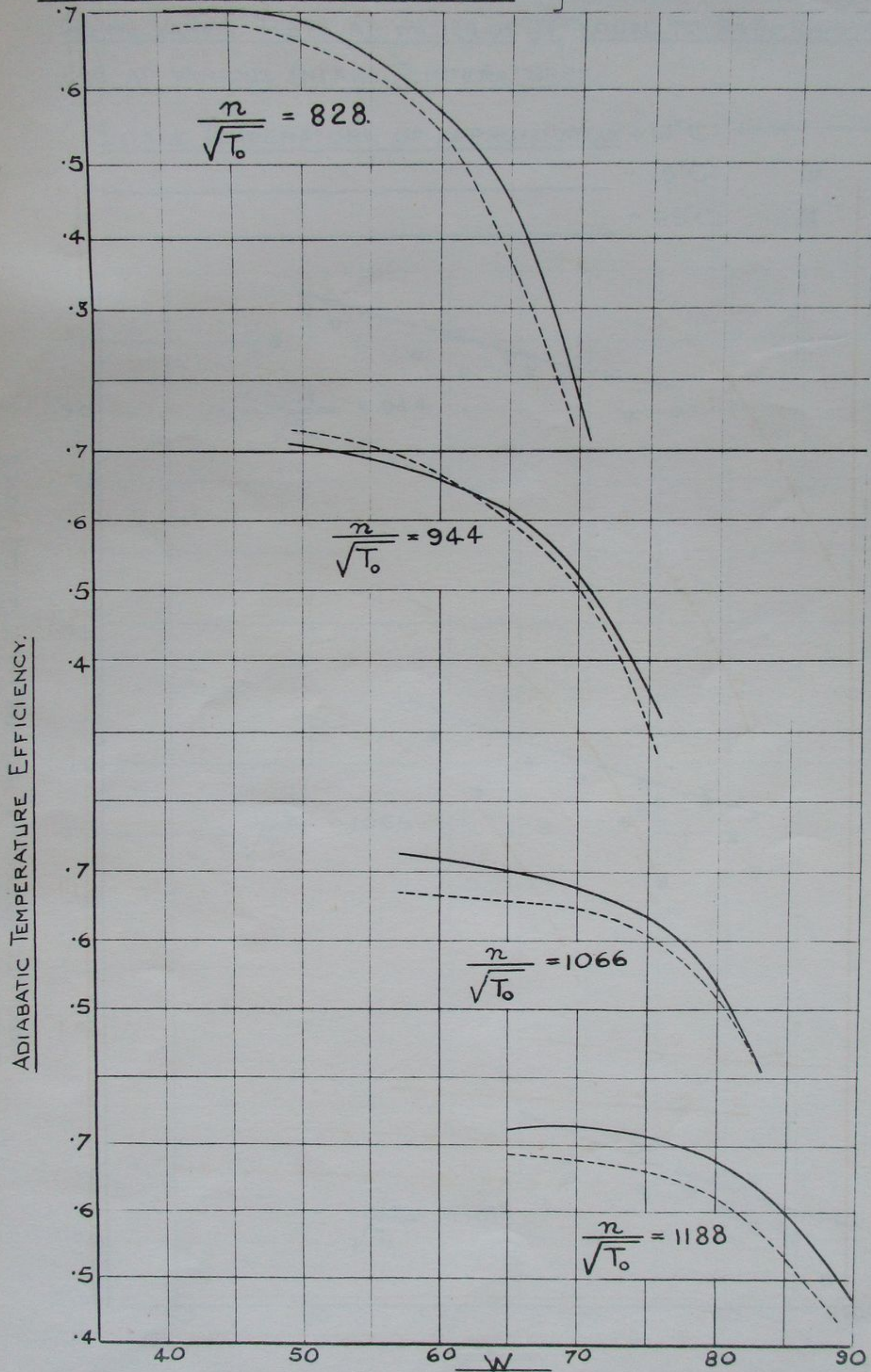

FIG. 2.

ISSUED BY DRAWING OFFICE DIRECTORATE OF TECHNICAL DEVELOPMENT AIR MINISTRY	TITLE:- LION SUPERCHARGER. TESTS AT VARIOUS INTAKE TEMPERATURES.	DRAWN G.V.B.	TRACED E.B. 25-4-30	SKETCH Nº C.3981.
	ISSUE Nº 1	CHECKED G.V.B.	APPROVED WHJ	
	ALTN Nº			

To accompany Report E.2872 A.

Indication of Restriction of Passage through Inlet Guide Vanes due to deposition of Snow or Ice during Low Temperature Tests shown by Irregularity in Pressure Difference across Guide Vanes. Tests at values of $\frac{n}{\sqrt{T_0}}$ equal to 944, 1066 and 1188 at various Intake Temperatures.

Intake Temperature of approximately + 13°C: —×—×—
" " " " − 15°C: ⊙
" " " " − 25°C: ⊠

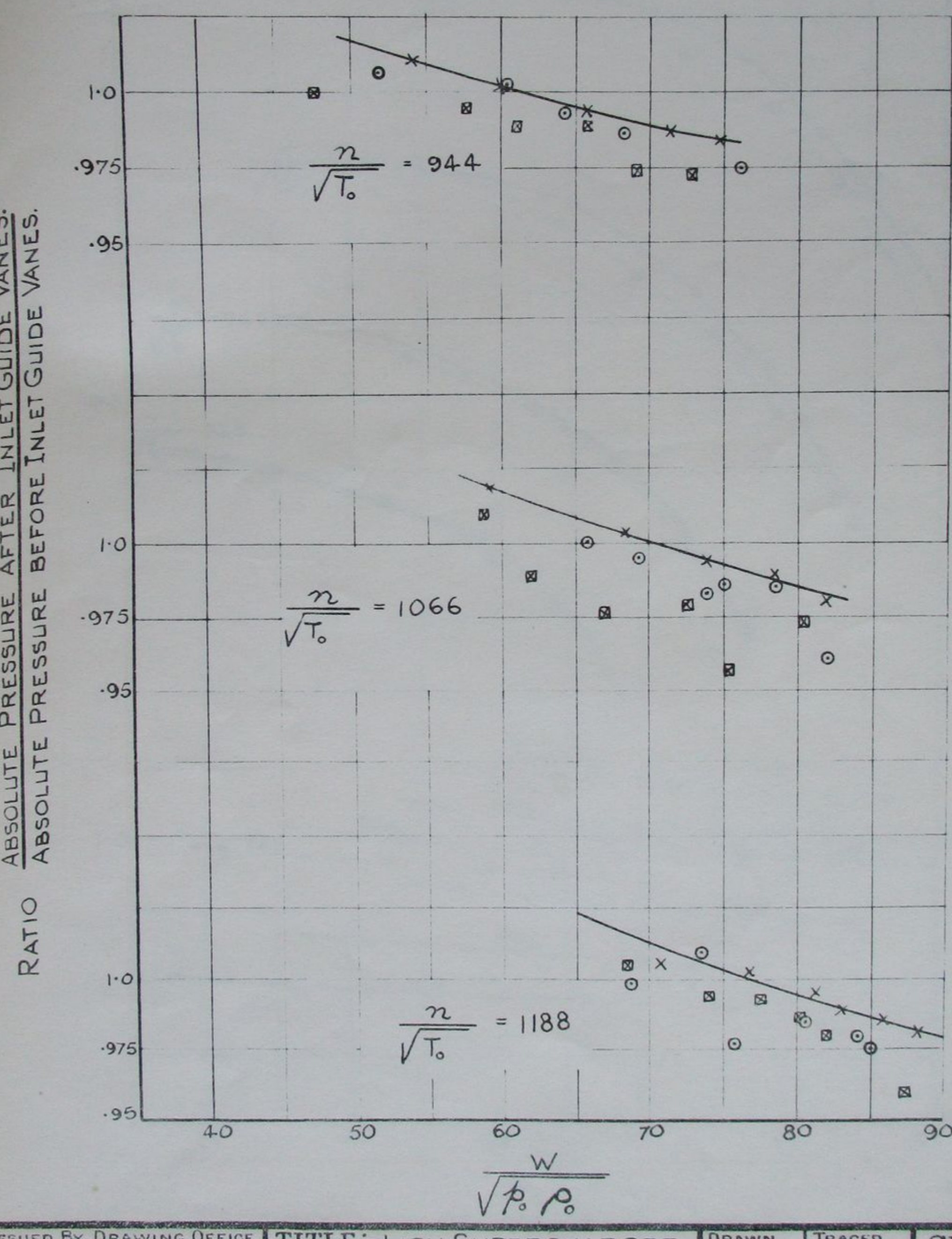

Fig. 3.

Issued by Drawing Office Directorate of Technical Development AIR MINISTRY	Title:- Lion Supercharger. Tests at Various Intake Temperatures	Drawn G.T.B.	Traced E 26-4-30	Sketch No C.3982.
	Issue No 1	Checked G.T.B.	Approved WhG	
	Altn No			

TO ACCOMPANY REPORT E.2872.A.

TESTS AT VALUES OF $\frac{n}{\sqrt{T_0}}$ EQUAL TO 828, 944, 1066 AND 1188;

(A) SUPERCHARGER CASING SURROUNDED BY ATMOSPHERIC AIR AT A TEMPERATURE OF APPROXIMATELY 15°C.

(B) SUPERCHARGER CASING SURROUNDED BY STEAM AT APPROX. 100°C.

TESTS UNDER CONDITIONS "A": —×—×—×—

" " " "B": --⊙--⊙--⊙--

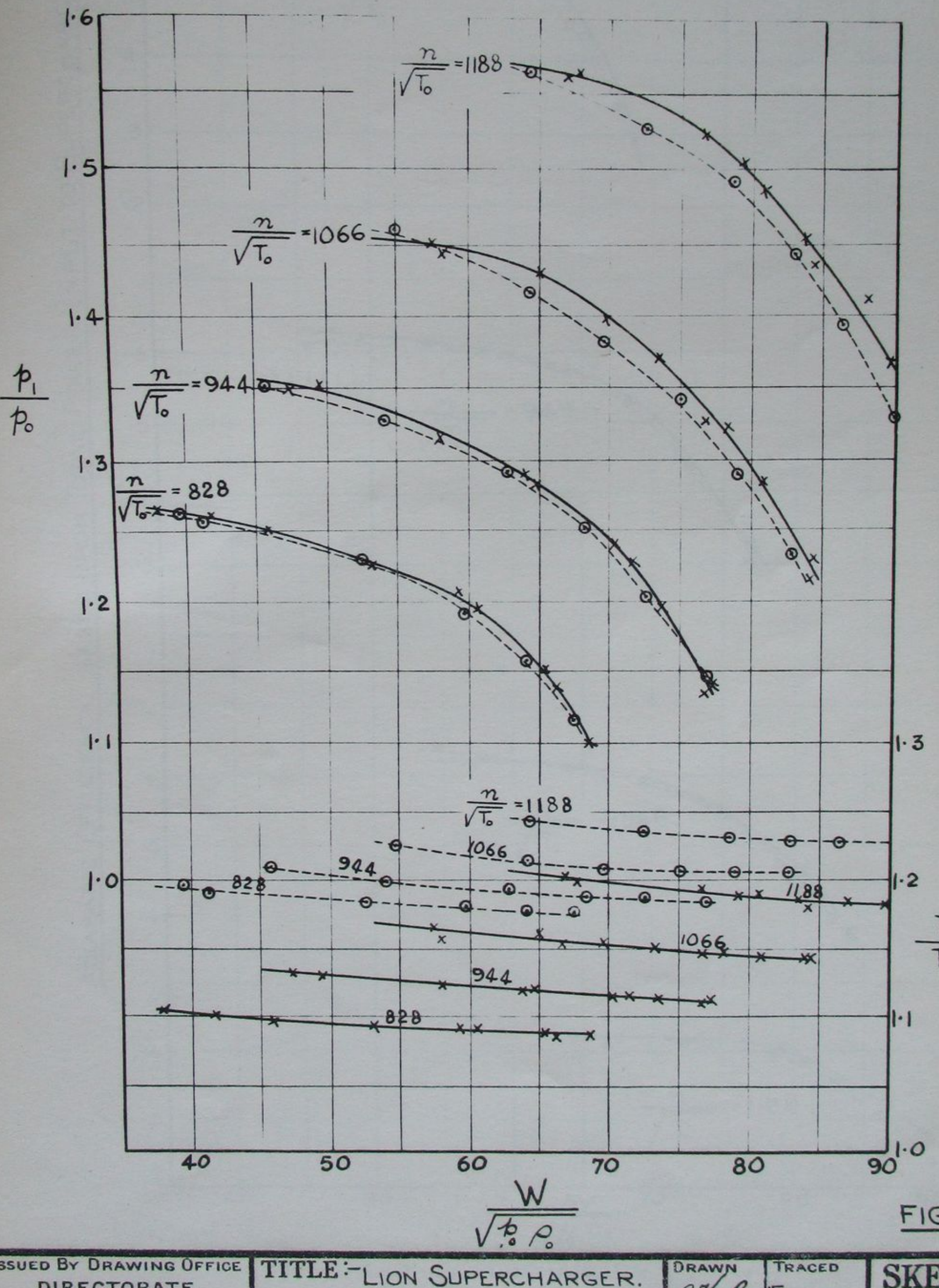

FIG. 4.

ISSUED BY DRAWING OFFICE DIRECTORATE OF TECHNICAL DEVELOPMENT AIR MINISTRY	TITLE:- LION SUPERCHARGER. EFFECT OF HEATING SUPERCHARGER CASING.	DRAWN G.V.B.	TRACED E.B. 28-4-30	SKETCH Nº
	ISSUE Nº 1	CHECKED G.V.B.	APPROVED W.W.M.	C.3983.
	ALTN Nº			