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Class No. 533.6.015.001.4(42)-Vampire I

Report No. Aero 2280

August, 1948.

ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

Flight tests on the level speed performance of Vampire I T.G.299 with an investigation into the accuracy of the thrust measurements

by

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SUMMARY

Flight tests have been made on Vampire I T.G.299 to measure its level speed performance. Engine thrust was measured by means of two jet pipe pitots and from this the aircraft drag coefficient has been obtained up to a Mach Number of 0.77.

An investigation into the method of thrust measurement has shown agreement between measurements from two jet pipe pitot positions to within 2%. However, it is shown that large inaccuracies can arise due to the choking of the final nozzle, if the jet pipe pitot tubes are located very close to the final nozzle.

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1 Introduction

The rapid development of jet propulsion engines has enabled compressibility effects to be encountered in level flight on some aircraft. In the case of the Vampire for instance, a Mach Number of 0.77 can be obtained in level flight and, since the thrust developed by the engine can be measured by pressure instruments and thermocouples only, measurements of drag can therefore be made up to these Mach Numbers without the complications involved in measurements in dives.

The usual method of thrust measurement is to use one pressure point and one thermocouple in the jet pipe. Recently there has been some doubt as to the reliability of such measurements as the method assumes that the flow pattern in the jet pipe at all heights is equivalent to that obtained on the test bed. As performance tests on a Vampire I were to be carried out, it was decided to obtain some idea of the accuracy of the method by installing a second pressure point and comparing the thrust values so obtained. Only one thermocouple was used as the gross thrust, the major contribution to the final answer, is independent of the temperature measurement and also as the intake momentum loss, depending only on the square root of the absolute jet temperature, is fairly insensitive to small temperature differences.

2 Description of the aircraft

The Vampire I is a high speed jet-propelled aircraft with twin booms supporting twin fins and a raised tailplane. It is powered by a de Havilland Goblin II jet-propulsion unit, with a maximum R.P.M. of 10,200 giving about 3,000 lb. static thrust at sea-level. A General arrangement drawing of the aircraft is given in Fig.1 and relevant data in Table I.

The wing section is EC.XX40/0940, the thickness ratio at the boom section being 14%, tapering to 10.6% at the tips. Inboard of the booms, the wing roots have been thickened to 16.2% to accommodate the entry ducts, which are in the wing leading edge close to the fuselage. All control surfaces are metal-covered; the ailerons are fitted with geared tabs, the elevator with a geared trimming tab and the rudders with fixed trimming tabs.

The aircraft allotted for this work was Vampire T.G.299, an operational aircraft in most respects. The surface finish was good although no special care was taken for its maintenance. The guns were removed to make room for the auto-observer, and the blast tubes faired over. A leading edge pitot-static head was fitted to the port wing tip (Fig.2) in preference to the normal position on the port fin, as it was not known what effect high Mach Numbers would have on the position error there. An auto-observer containing the following instruments was fitted in the gun-bay:- aircraft AS1, altimeter, clock, engine R.P.M. indicator, two jet-pipe pressure gauges, jet-pipe temperature gauge and an air temperature gauge. Two total head tubes were fitted in the jet pipe (Fig.3) in order to obtain some indication of the reliability of the method of thrust measurement.

3 Description of the tests

The static position error at the pitot-static head was measured by the aneroid method and the compressibility correction to the position error for the chosen range of speed and altitude calculated by the method of Ref.1. The position error curves for airspeed and altitude, together with the experimental points obtained from the ground level run, are given in Fig.4. A special flight was made to determine the constant for adiabatic heating of the air thermometer, which was of the impact bulb type and was fitted to the bottom of the fuselage just behind the cockpit.

All the tests were made in level flight at a range of altitudes from 5,000 ft. to 35,000 ft. During each flight, a number of levels were made at constant altitude, flying through the same mass of air each time. This was done in order to get an accurate measurement of the ambient air temperature. Thus each level had to be made at a different value of $(W/_p)$ [W = weight of aircraft, P = ambient air pressure ÷ 14.7]. The results should therefore have been corrected to a constant W (or $W/_p$) but the corrections were examined in a few cases, found to be very small and so were neglected.

4 Results

All the instrument readings were corrected for instrument error. Position error corrections were applied to the airspeed indicator and altimeter readings and the ambient air temperature was obtained from the reading of the impact bulb thermometer, allowance being made for the adiabatic heating effect. Mach Numbers were obtained from the corrected altimeter and airspeed indicator readings.

From the measurements of altitude, airspeed, engine R.P.M. and ambient temperature, the non-dimensional level flight performance values are shown plotted in Fig.5.

The engine gross thrust and mass flow were obtained from measurements of the total head pressure and temperature in the jet pipe in conjunction with a test-bed calibration of the engine supplied by the de Havilland Engine Co., using the method described in Ref.2. Subtracting the intake momentum loss from the gross thrust, the nett thrusts were obtained and the non-dimensional values are shown in Fig.6. Several points have been omitted from the figure and they, together with the reasons for their omission, will be discussed in detail in para.6.

The total aircraft drag was obtained by equating it to the engine nett thrust. In Fig.7, the values for the aircraft overall drag coefficient obtained below a Mach Number of 0.72 are shown plotted against (lift coefficient)^2. From this curve, it was found that the induced drag factor up to the drag rise is 1.10. Insufficient points at higher Mach Numbers were obtained during these tests to determine the induced drag factor above the drag rise. The low Mach Number value was therefore used for all the results and the profile drag coefficients so obtained are shown plotted against Reynolds Number in Fig.8. The estimated variation of profile drag coefficient with Reynolds Number, as well as a curve obtained from performance tests on the prototype aircraft when in its fully operational condition (Ref.4), are included. No curve has been put through the points as it is considered that the method of thrust measurement is not sufficiently accurate to determine a variation with Reynolds Number. The agreement with the de Havilland flight tests however is quite good.

Important to determine this.

The profile drag coefficients are shown plotted against Mach Number in Fig.9. Using the faired curves for profile drag coefficient against Mach Number, non-dimensional nett thrust and the value found for the induced drag factor, the non-dimensional performance curves were calculated and these are the curves that are drawn through the experimental points of Fig.5. From these curves, the level speed performance on a standard day has been obtained for a range of engine R.P.M. and is given in Fig.11.

5 Aircraft Drag

From Fig.9, it will be seen that the profile drag coefficient starts increasing at a Mach Number of 0.72 and has increased by 21% by a Mach Number of 0.77, the highest Mach Number reached in the tests. The results agree well with performance tests on the prototype aircraft by the firm (Ref.5) except that the value for the low Mach Number drag coefficient is 0.014 compared with 0.0135. It has been shown from more recent tests on this aircraft that a shock wave is first formed on the upper surface of the wing at a Mach Number of 0.73, which agrees very well with the drag rise obtained here.

In Fig.10, the drag curve is shown compared with that for Meteor IV E.E.454 (Ref.2). It will be seen that the drag rise for the Meteor IV starts at a Mach Number of 0.70; this is 0.02 lower than for Vampire I and is probably due to the breakaway from the wing-nacelle junction. It might be expected that the drag rise for the Vampire would start at about M = 0.68, the Mach Number at which the drag rise normally starts for the E.C.1640 section, that it does not, indicates that the entry ducts are probably having a relieving effect over the inboard part of the wings and so increasing the critical Mach Number over that region. The rapid drag rise, however, starts at about M = 0.76 for the Vampire as compared with 0.80 for the Meteor and this is probably due to the thicker wing of the Vampire (The Meteor IV wing is 12% thick at the root and 10% thick at the tip).

6 Accuracy of method of thrust measurement

Two total head tubes were fitted in the jet pipe of the engine about one inch forward of the final nozzle (Fig.3). One was the normal position used by the de Havilland Engine Co., projecting $\frac{3}{4}$" into the jet; the other was fitted in the same plane and diametrically opposite, projecting $2\frac{7}{8}$" into the jet.

A test-bed calibration of the engine was carried out by the de Havilland Engine Co., in a condition closely resembling that of the engine when installed. Both jet pipe pitot positions were calibrated.

The engine gross thrust and mass flow were calculated from the readings of each jet-pipe pitot by the method described in Ref.2. The means of the two gross thrust values so obtained are shown plotted non-dimensionally in Fig.12. As no measurements were made in the duct entry, the free stream stagnation pressure, as determined from the airspeed and altitude readings, was used to reduce the gross thrust to non-dimensional form. The discrepancy from the true value so introduced should however be small as the duct losses for a short duct of this form are small.

It was found that the nett thrust values deduced from the two jet pipe pitot readings did not differ by more than 50 lb., in readings up to 2,500 lb. (an error of 2%). There are, however, indications that, over a range of values of $N/\sqrt{t}$ from about 10,300 to 11,200, the thrust readings were too high. This was suggested in the first place by Fig.13, in which the results for both pitot positions are plotted, and confirmed by the fact that the drags deduced from the thrusts in this doubtful range were all about 10 - 20% higher than the average value indicated at other values of $N/\sqrt{t}$, although there was no evidence of a drag increase which would be indicated by an increase in slope of the $N/\sqrt{t}$ - $V/\sqrt{t}$ curves (Fig.5). In all these curves the final nozzle was just past the choking point and, on plotting non-dimensionally the total head pressures for both pitot positions (Figs. 14 and 15), it appears that the thrust errors are arising from errors in the pressure measurements. We must conclude therefore, that the pressure distribution across the section near the final nozzle had changed due to the choking of the final nozzle, thus invalidating the assumption on which the method is based.

In similar tests on a Meteor (Refs. 2 and 3) when the thrust was measured by the same method using total head tubes located about four feet forward of the final nozzle, no trouble of this sort was encountered and therefore it is recommended that the total head tube should be placed at a moderate distance (at least a foot) from the final nozzle.

7 Conclusions

The emphasis in these flight tests has been mainly on the level speed performance of the aircraft and they show that the performance is considerably reduced at high engine R.P.M. due to the large drag increase with Mach Number. The maximum speed obtainable with a Goblin II engine giving 3,000 lb. sea-level static thrust is 528 m.p.h. at 20,000 ft.

The low Mach Number profile drag coefficient is 0.014 (43.4 lb. at 100 ft./sec.) and the drag has increased by 21% at a Mach Number of 0.77, the highest reached in the tests.

It was found that the thrust measurements obtained from the two pitot tubes in the jet pipe agreed to within 2%; large inaccuracies can arise, however, due to the change in the pressure distribution across the final nozzle when the final nozzle choked.

References

Ref.No.	Author	Title, etc.
1	Charnley and Fleming	The determination of speed and height corrections due to Position Error and compressibility effects. (Unpublished)
2	Higton and Plascott	Measurement of overall drag of an aircraft at high Mach Numbers R.A.E. Report No. Aero.2241 Jan.1948.
3	Smith, Higton and Plascott	Flight tests on the performance of Meteor IV E.E.454. R.A.E. Report No. Aero.2148 Aug,1946.
4	De Havilland Aircraft Co., Ltd.	Results of preliminary performance tests and estimate of performance in a fully operational condition Part VIII. D.H. Aero.Dept./5056/RMO/SC Jan.1944.
5	De Havilland Aircraft Co., Ltd.	Brief Performance Trials at 2500 lb. static thrust. D.H. Aero.Dept./121/GWT/SC. May, 1944.

Attached:

Table I
Figures 1 to 15 - Drg.Nos. 21750S - 21760

Advance Distribution:

C.S.(A)	
P.D.S.R.(A)	
A.D.A.R.D.(Res)	
A.D.S.R.(Records)	
P.D.T.D.(A)	
D.A.R.D.	
D.M.A.R.D.	
D.D.M.A.R.D.	
A.D.R.D.L.1	2
A.D.R.D.L.2	2
T.P.A.3 (T.I.B.)	170
D.C.A.R.D.	
D.D.R.D.(Perf.)	
A.D.R.D.N.	
A.&.A.E.E.	
M.A.E.E.	
A.F.E.E.	
A.R.C.(Ref.)	45
N.P.L.	
N.G.T.E.	

TABLE I

Aircraft Data

Wing Area, sq. ft.		260
Span ft.		40
Aspect Ratio		6.15
Wing Section		E.C.XX40/0940
Wing thickness/chord ratio	Root section	0.162
	Boom section	0.14
	Tip section	0.106
Tail setting to wing chord		0°
All up weight, lb.		7950
C.G. position at full weight, ins. aft of datum		10.6
" " " " " % S.M.C.		32.8
Full capacity, gallons		202

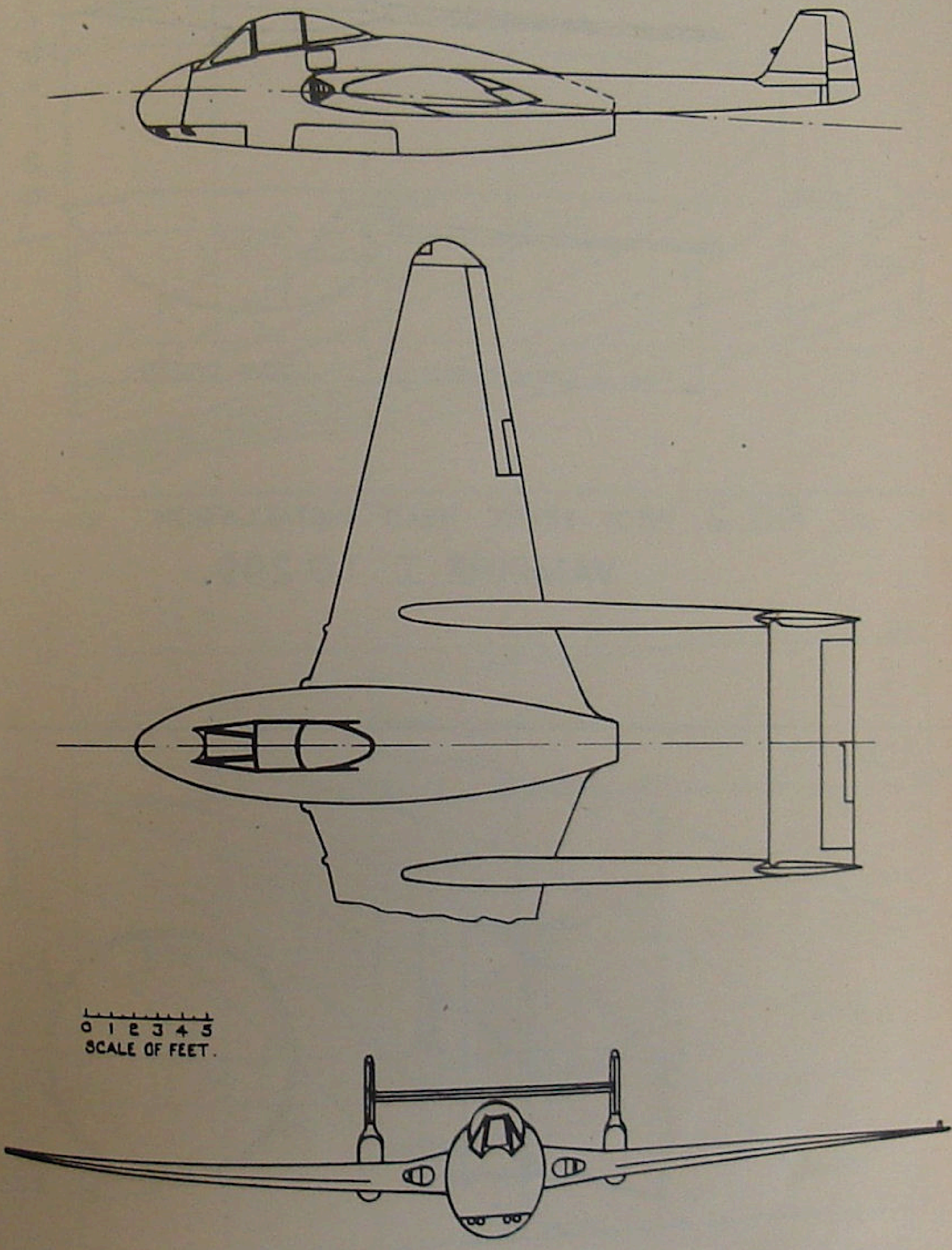

FIG. 1. G.A. OF VAMPIRE I TG299

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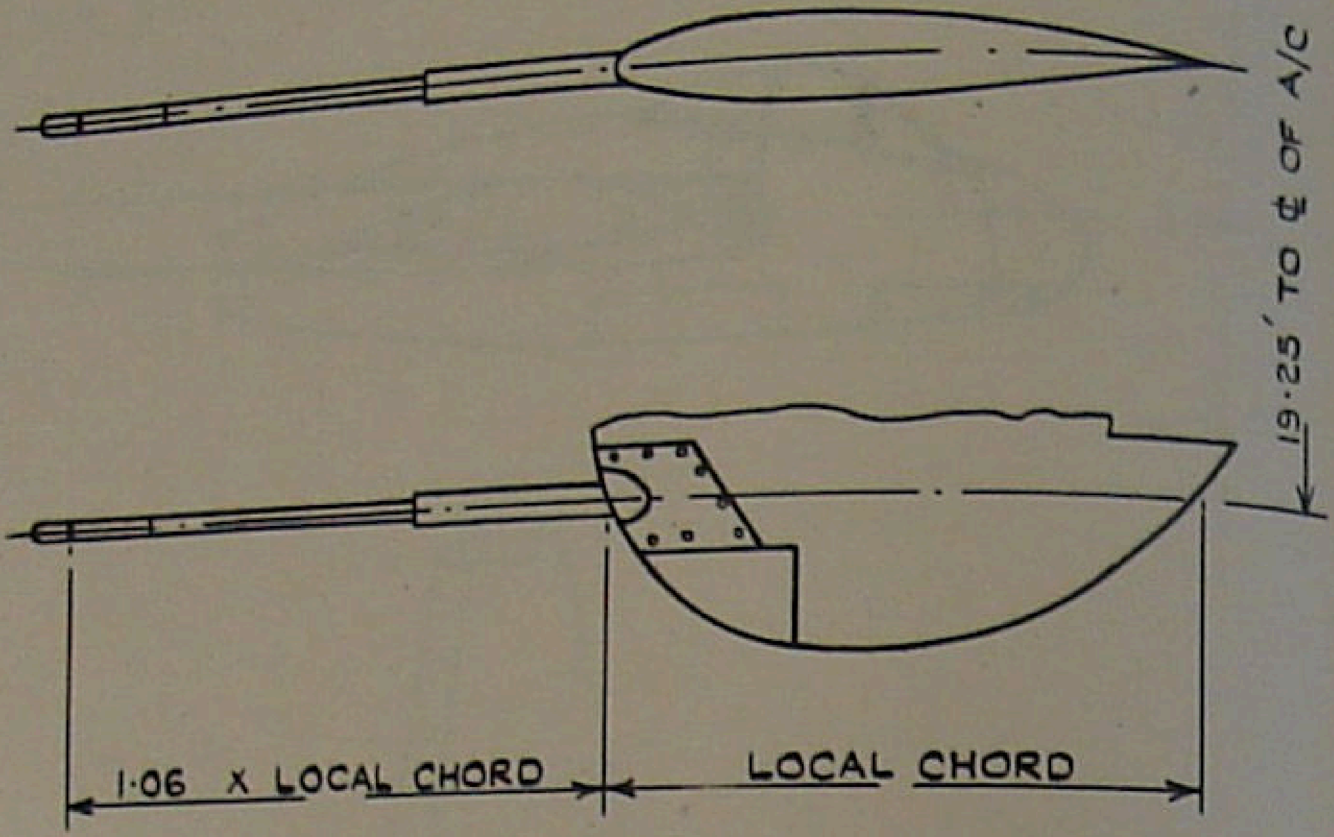

FIG. 2. PITOT STATIC HEAD INSTALLATION
VAMPIRE I TG 299.

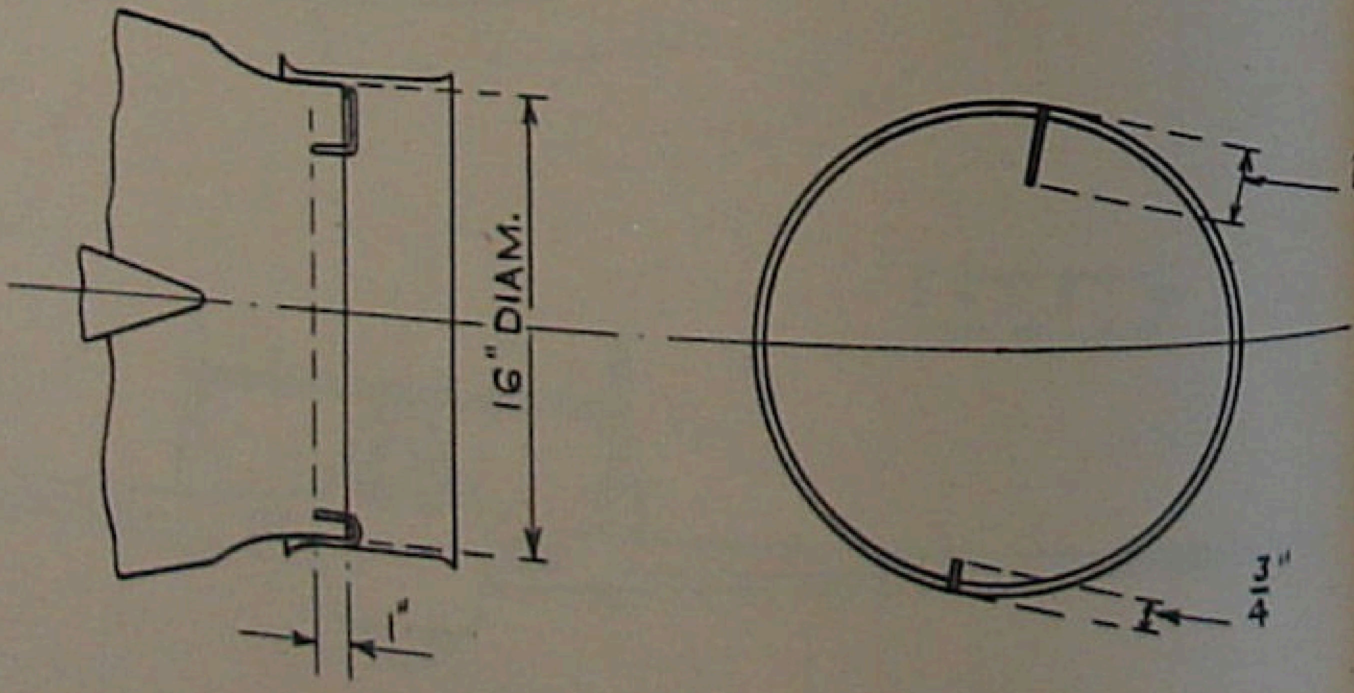

FIG. 3. INSTALLATION OF TOTAL HEAD TUBES IN JETPIPE.
VAMPIRE I TG 299.

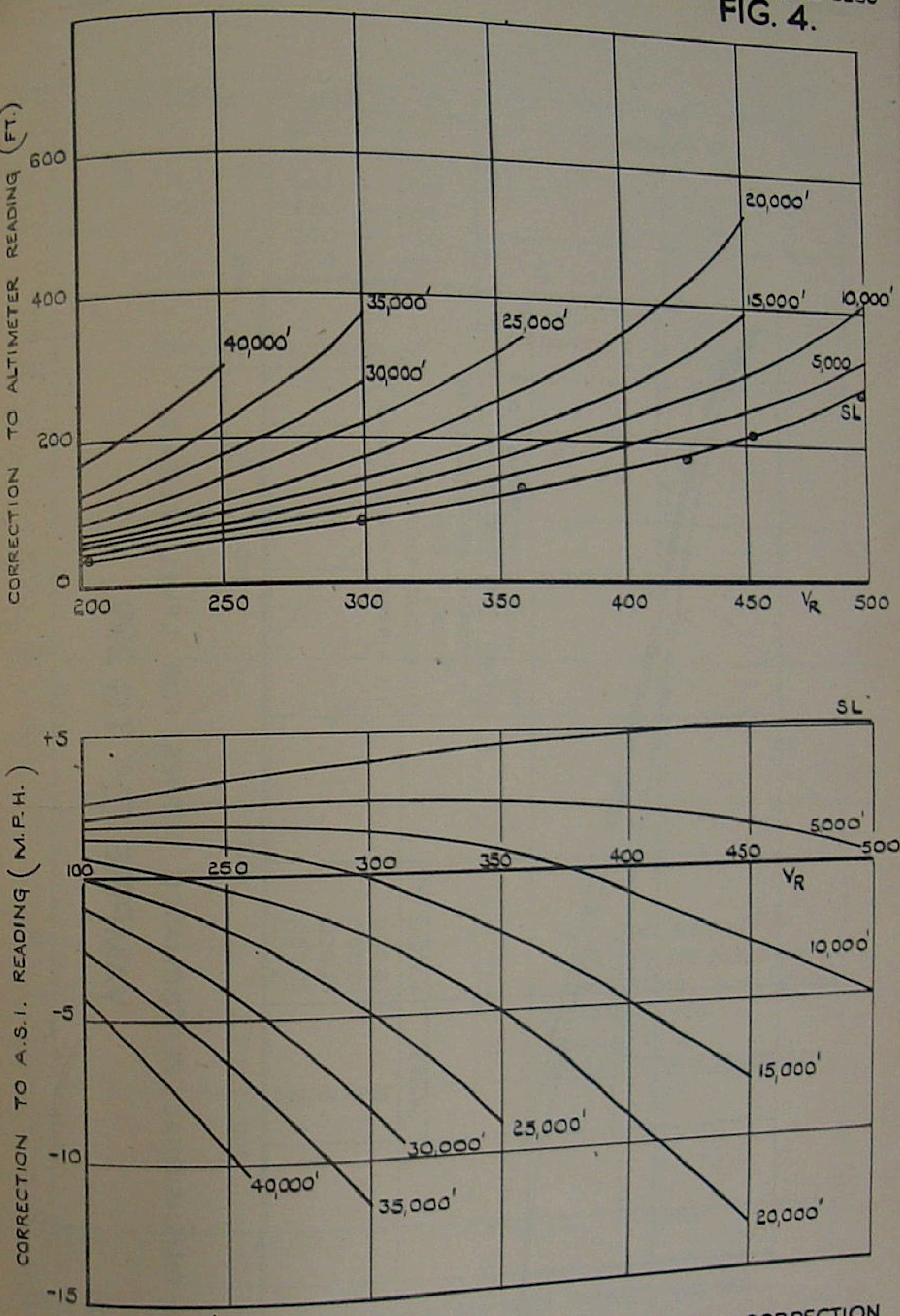

FIG. 4. POSITION ERROR AND COMPRESSIBILITY CORRECTION TO INDICATED AIRSPEED AND ALTITUDE.

VAMPIRE I TG 299.

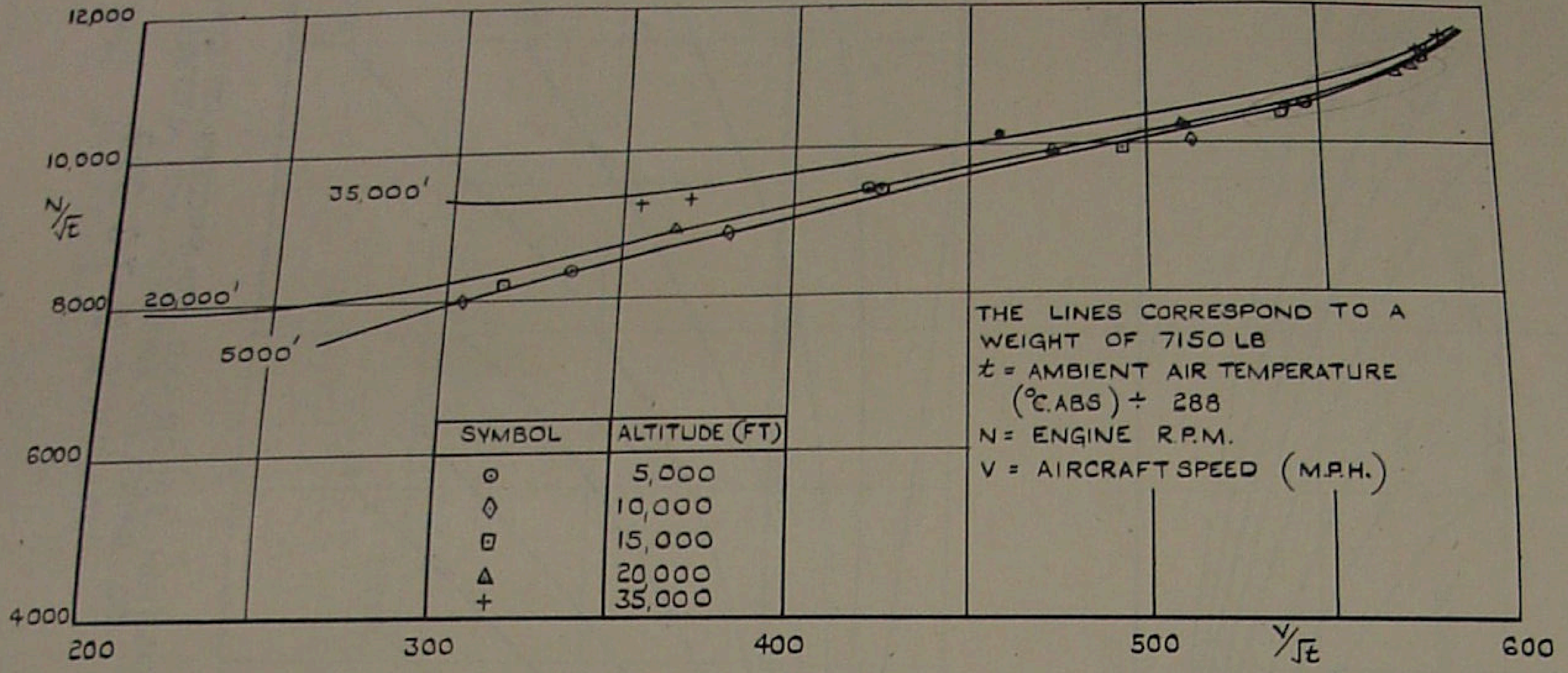

FIG. 5. NON-DIMENSIONAL PERFORMANCE CURVES FOR LEVEL FLIGHT.

VAMPIRE I TG 299

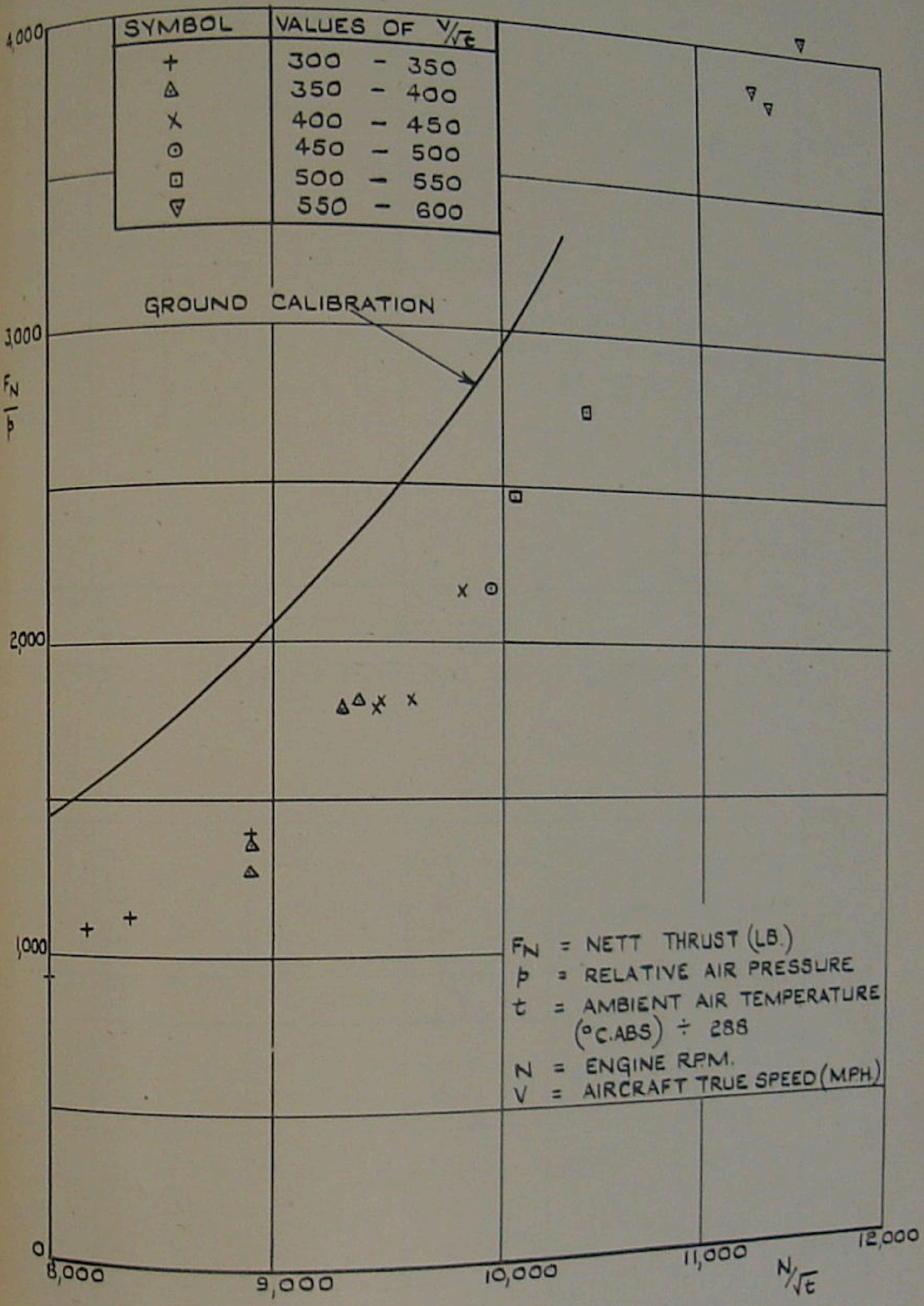

FIG.6. GOBLIN II – EXPERIMENTAL NETT THRUST VALUES.
VAMPIRE TG 299.

21755S

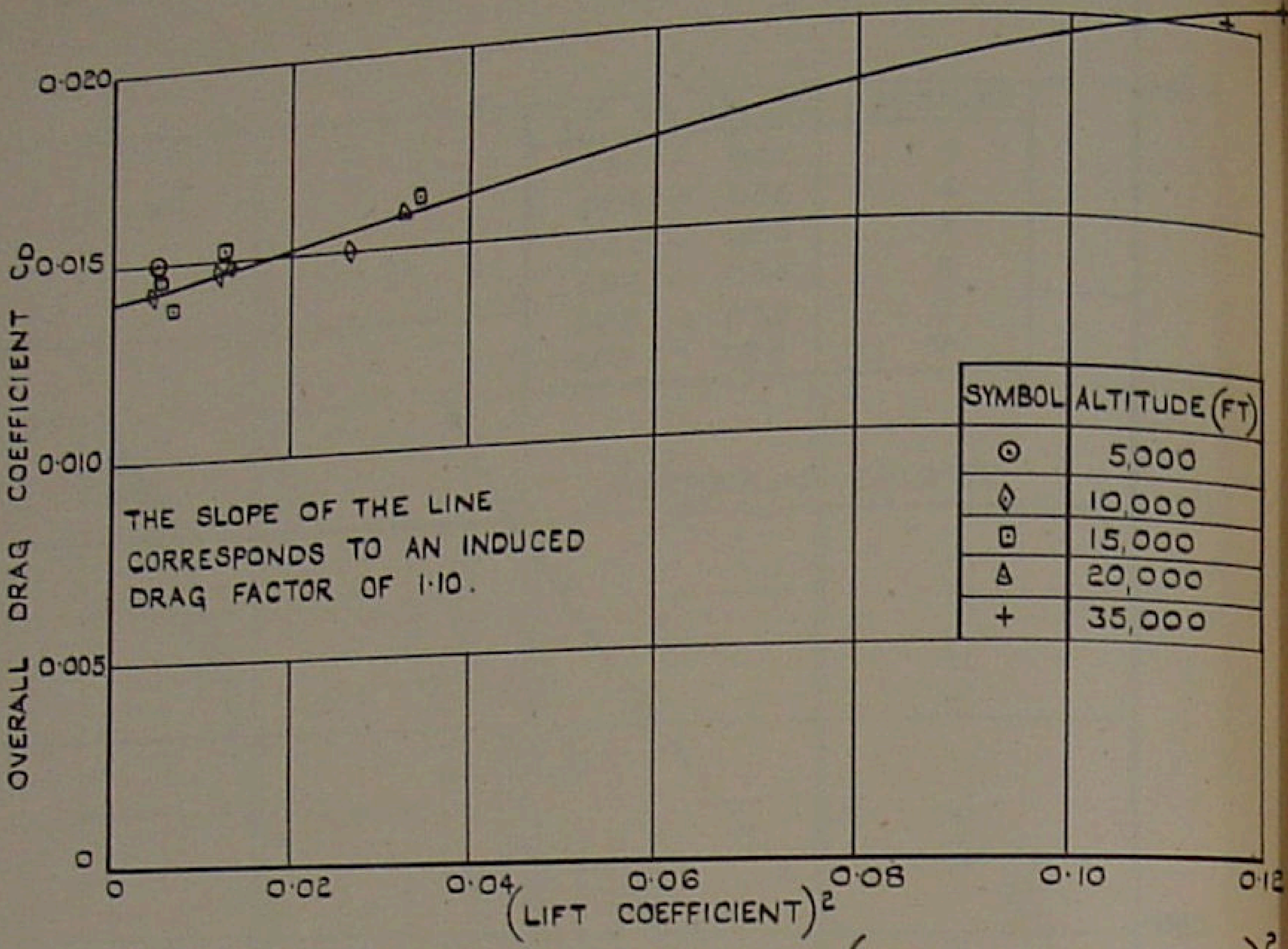

FIG. 7. OVERALL DRAG COEFFICIENT – $(\text{LIFT COEFFICIENTS})^2$

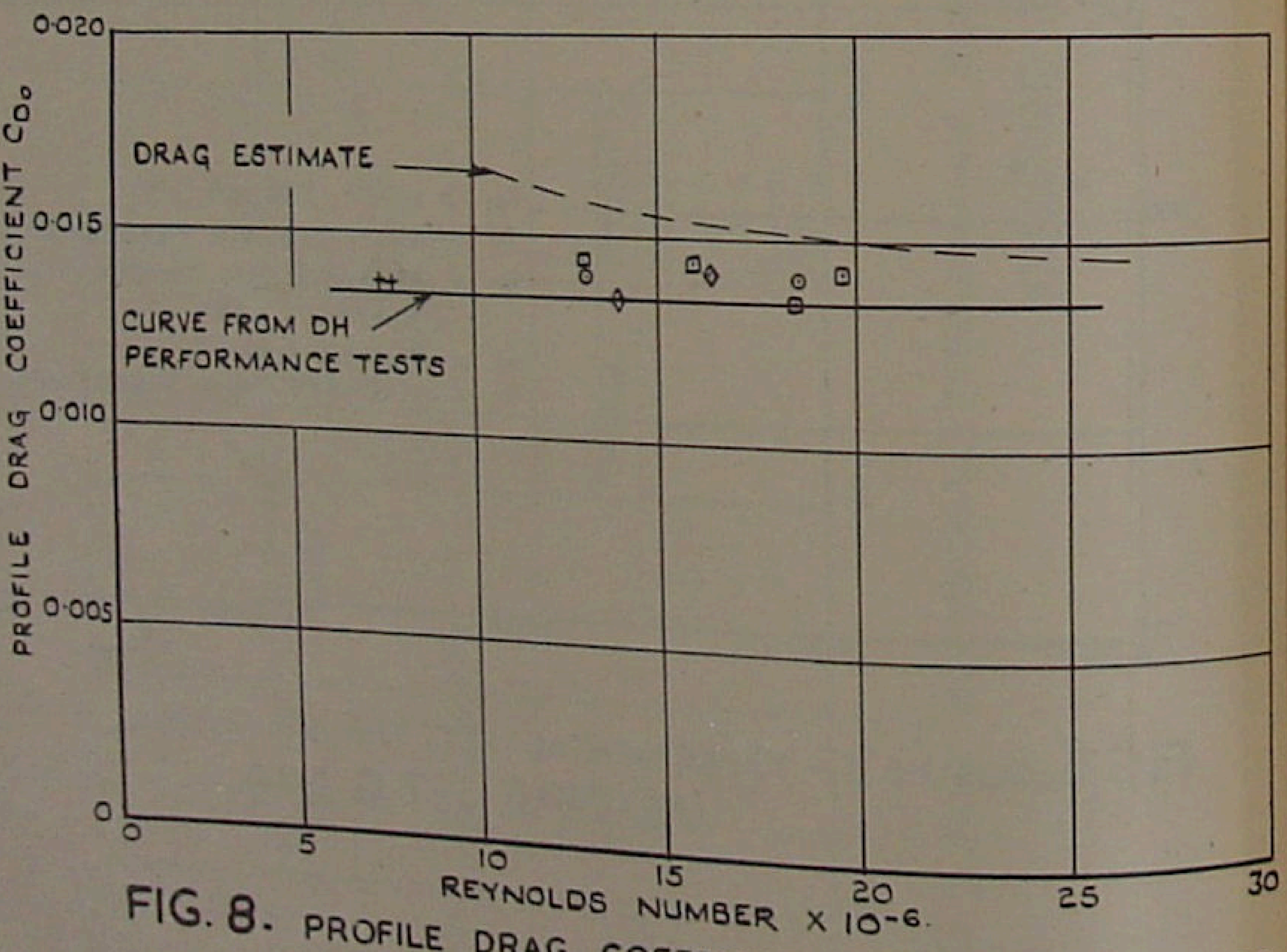

FIG. 8. PROFILE DRAG COEFFICIENT – REYNOLDS NUMBER.

VAMPIRE I TG 299.

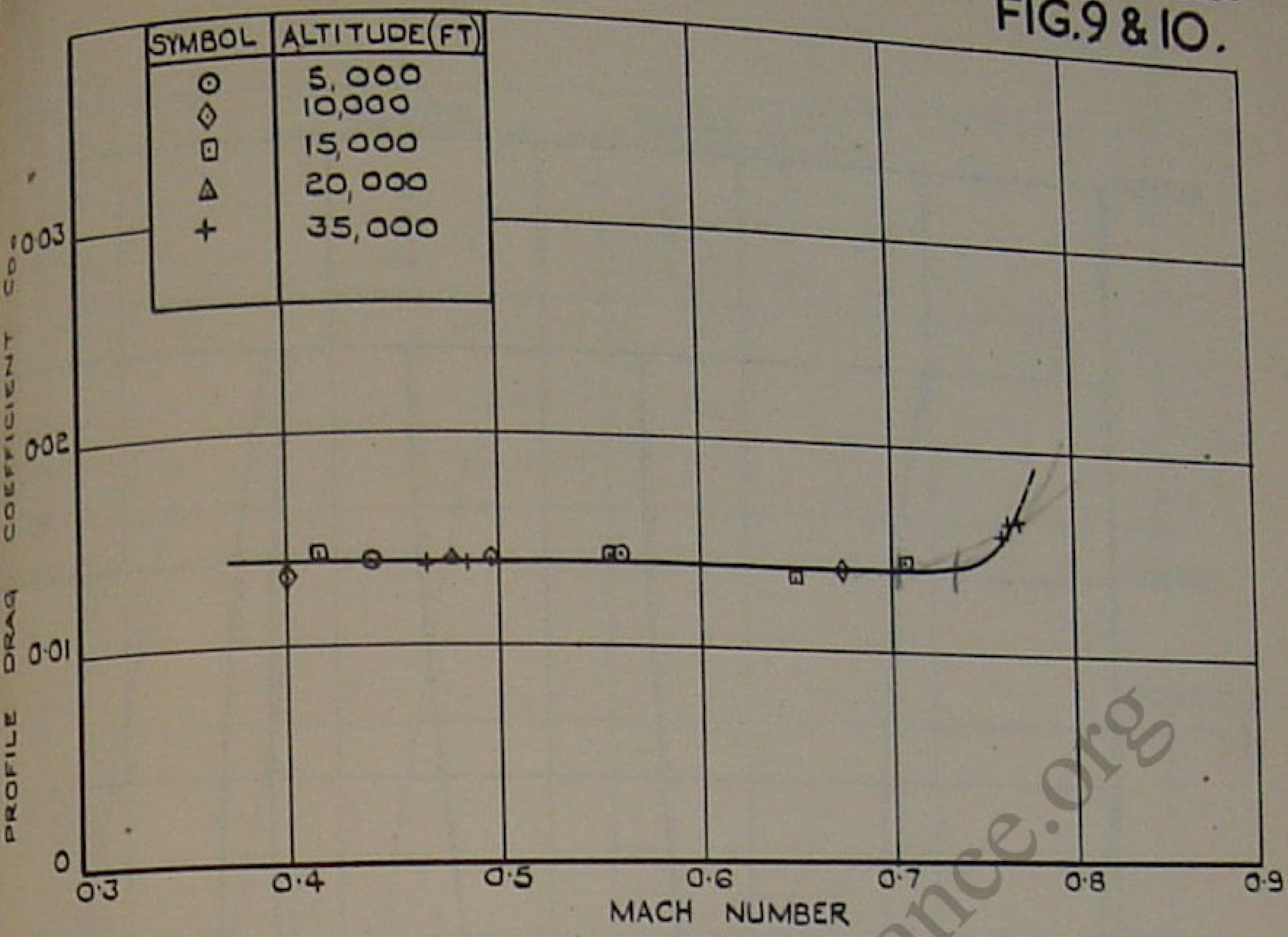

FIG. 9. PROFILE DRAG COEFFICIENT – MACH NUMBER

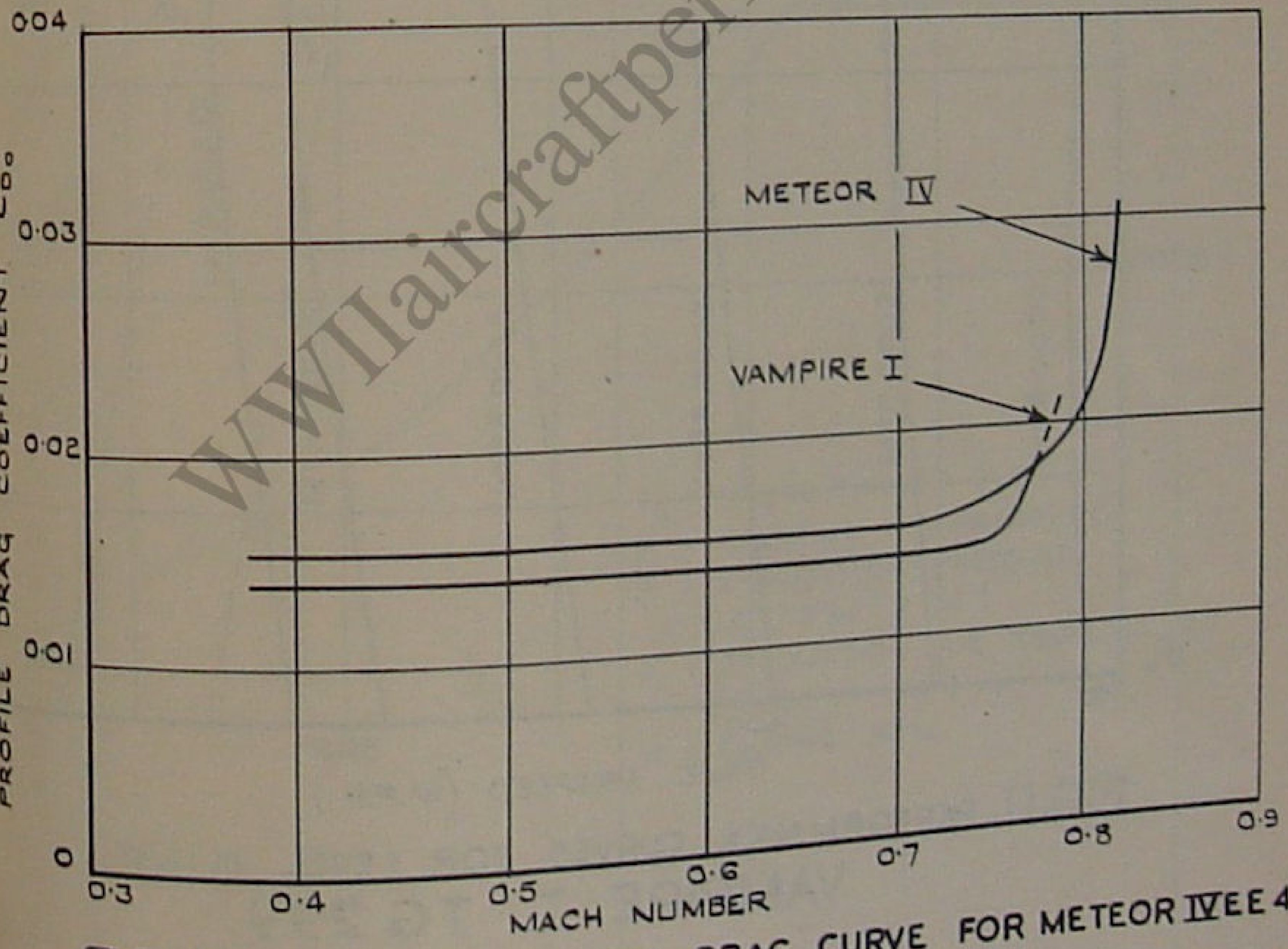

FIG. 10. COMPARISON WITH DRAG CURVE FOR METEOR IV E E 454.
VAMPIRE I TG 299.

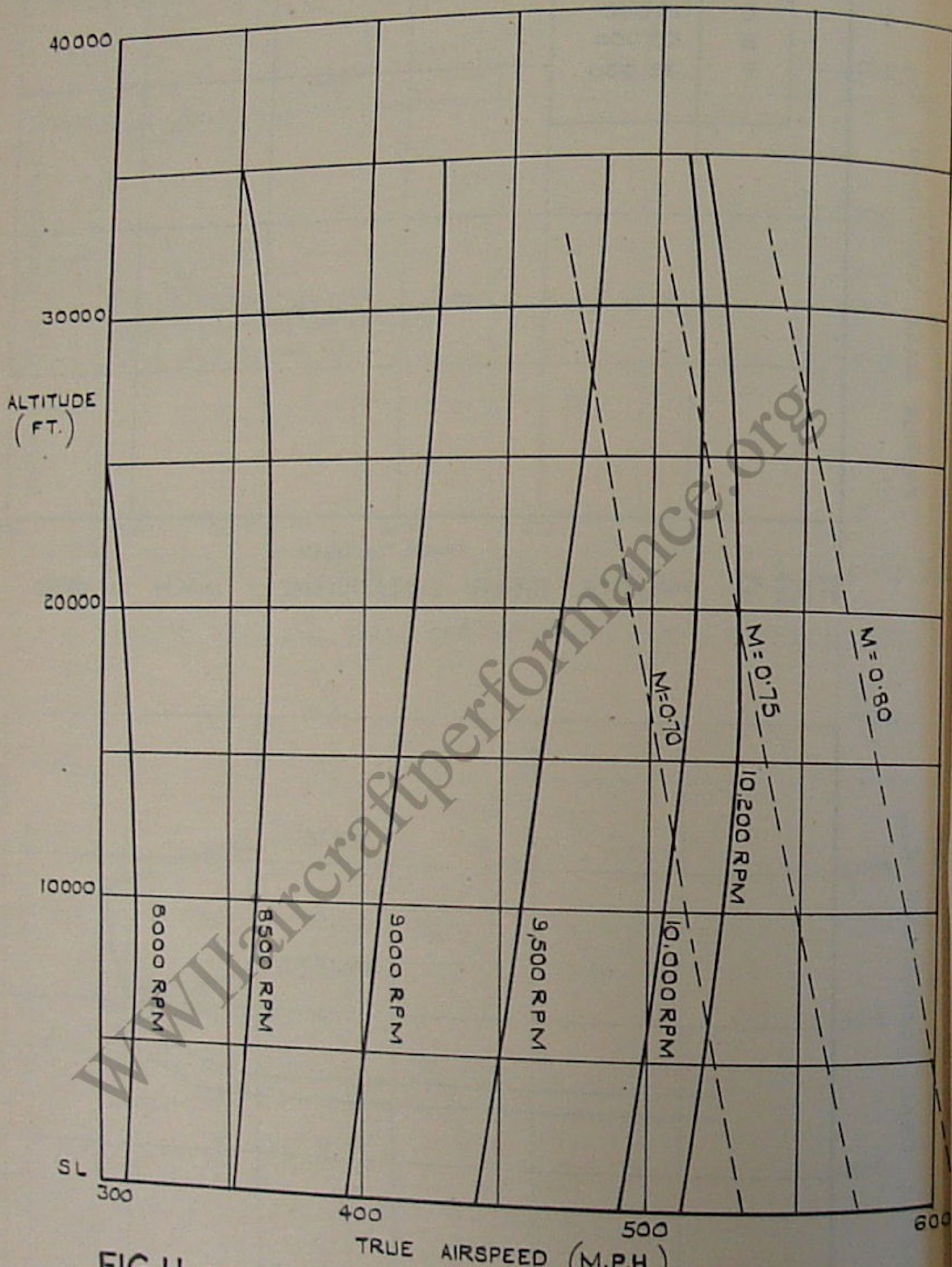

FIG. 11. PERFORMANCE CURVES FOR LEVEL FLIGHT.
VAMPIRE I TG 299.

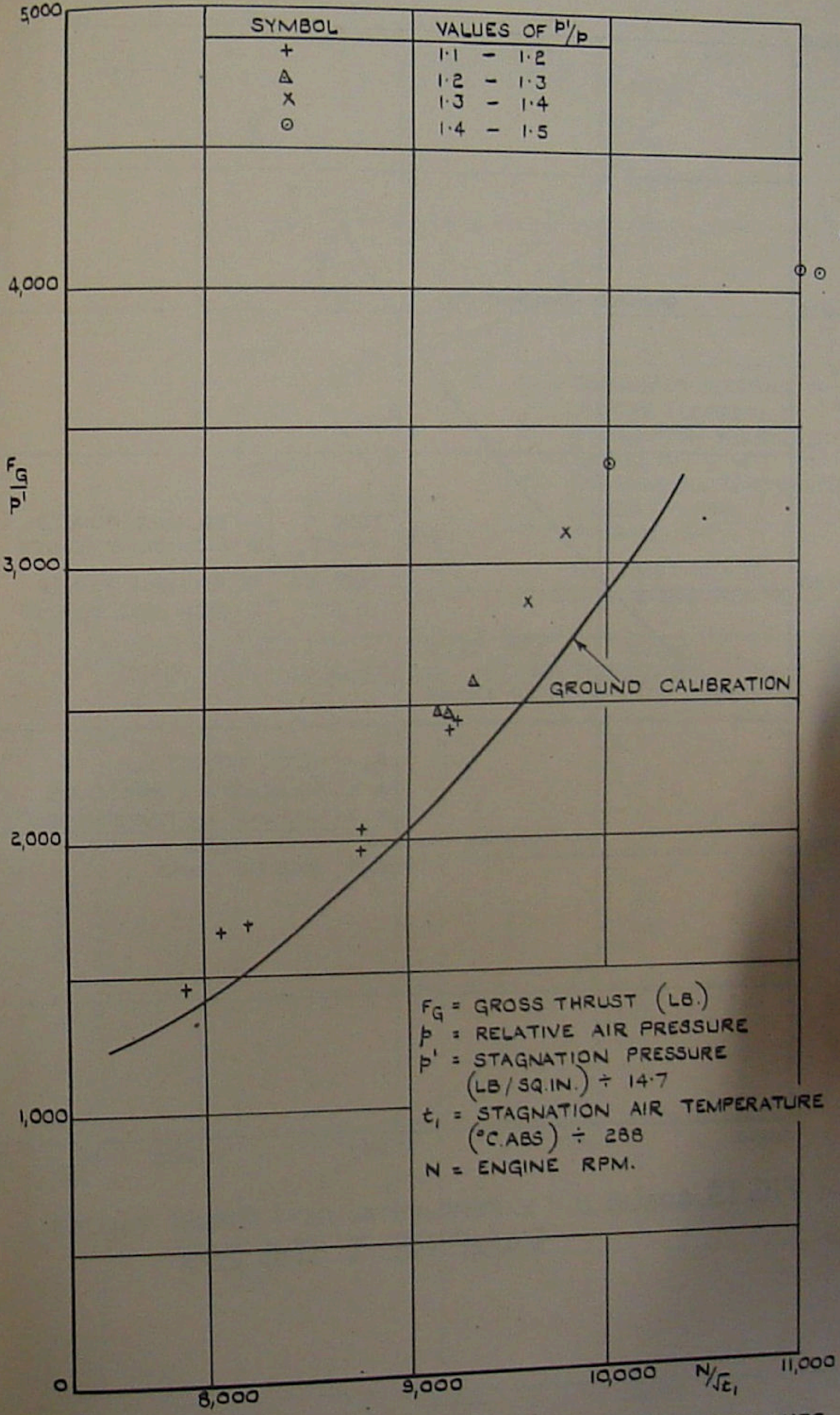

FIG. 12. GOBLIN II – EXPERIMENTAL GROSS THRUST VALUES
VAMPIRE I TG 299.

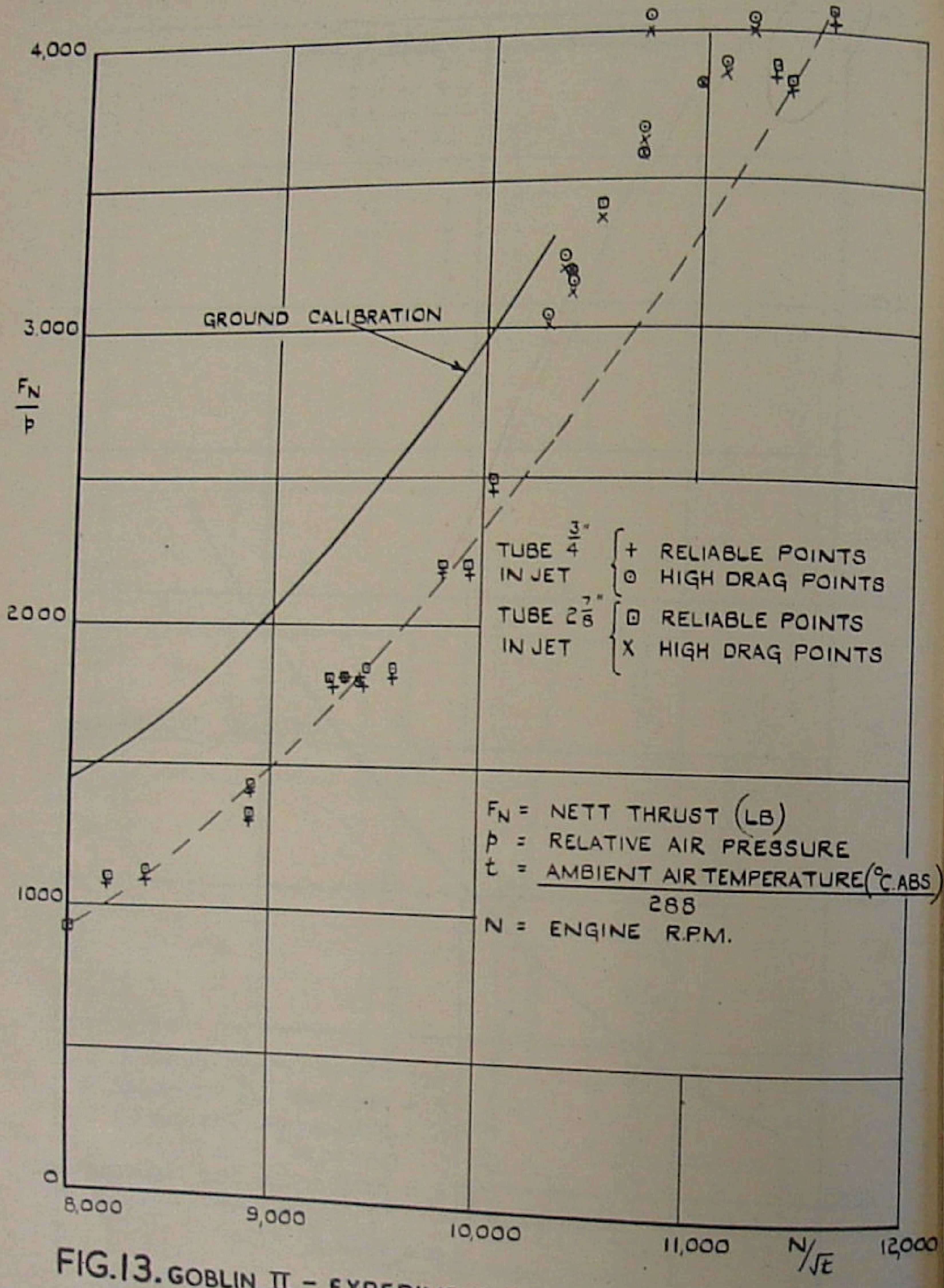

FIG.13. GOBLIN II – EXPERIMENTAL NETT THRUST VALUES.
VAMPIRE I TG 299.

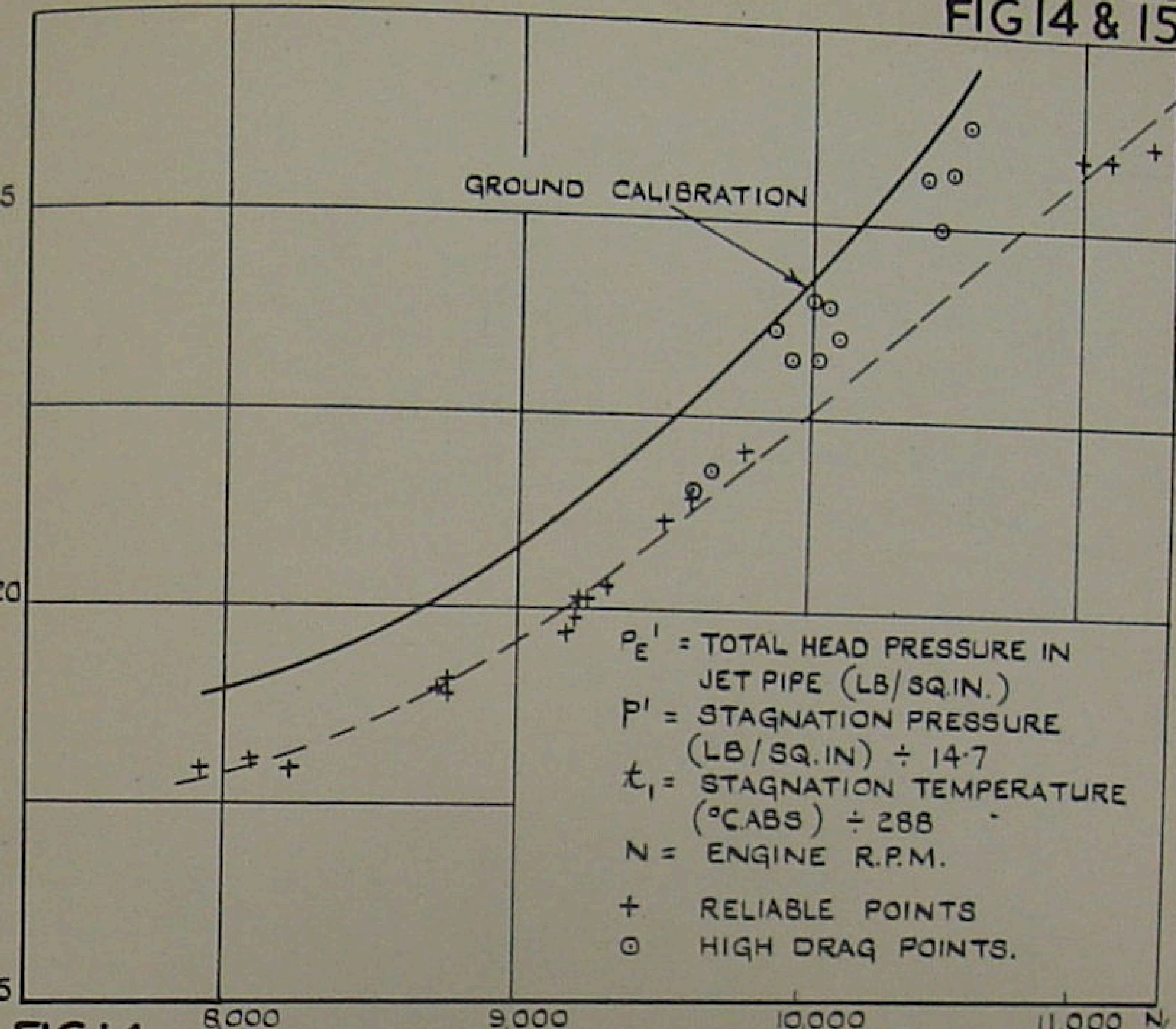

FIG.14. NON-DIMENSIONAL JETPIPE PRESSURES - TUBE 3/4" FROM SIDE OF JET

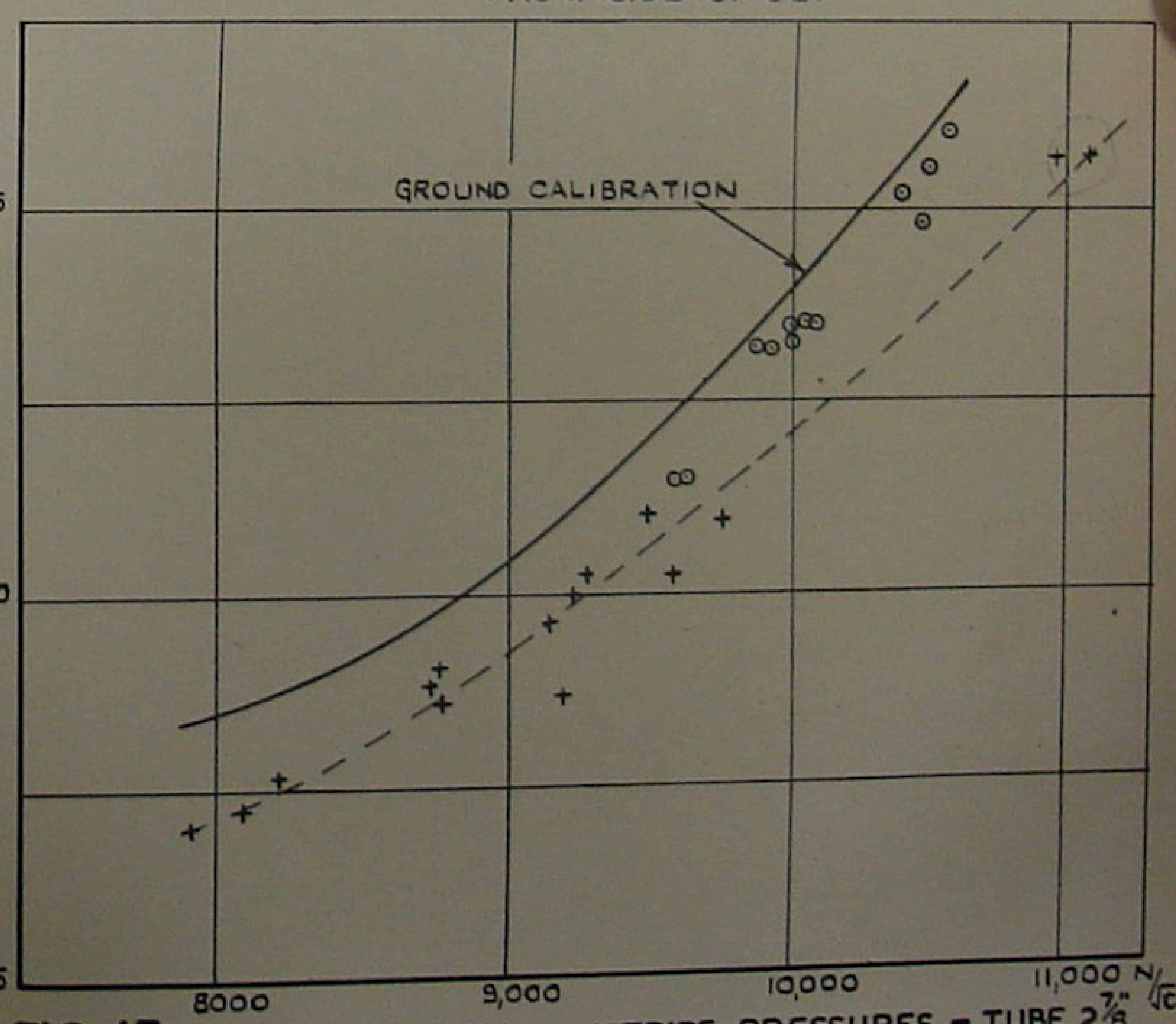

FIG. 15. NON-DIMENSIONAL JETPIPE PRESSURES - TUBE 2 7/8" FROM SIDE OF JET