C.P. No. 126
(A.R.C. 14,758)
A R C Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL
CURRENT PAPERS

Pressure Error Measurement using the Formation Method

By

K. C. LEVON

LONDON HER MAJESTY'S STATIONERY OFFICE
1953
THREE SHILLINGS NET

Report No. A.A.E.E./Res/262.

AEROPLANE AND ARMAMENT EXPERIMENTAL ESTABLISHMENT
BOSCOMBE DOWN

Pressure error measurement using the formation method

by

K.C.Levon

A. & A.E.E. Ref: 5782/R8/KCL

M. O. S. Ref: PDSR/Bi - Monthly/2.5.

Summary

Measurements of pressure error at altitude have been made by flying several aircraft in formation with a reference aircraft whose airspeed system had previously been calibrated by radar.

Tests made show that analysis by comparison of indicated airspeeds (comparison of differences between static and total head pressures) gives more consistent and reliable results than pressure altitude comparison (comparison of direct measurement of static pressure). An accuracy of $\pm 1\frac{1}{2}$ knots in measurement of pressure error is obtained using the 'speed comparison method', whereas the inadequacy of present altimeters can lead to errors of up to ± 3 knots in pressure error.

Consideration is being given to the use of a better instrument than the usual altimeter, for direct measurement of pressure to improve the accuracy of the altitude comparison method; and to the use of a fly past technique, to enable routine pressure error measurements to be made at speeds above the speed range of the calibrated aircraft.

/1......

List of Contents

List of Appendices

List of Illustrations

/1. Introduction.......

1. Introduction

Tests were required to measure pressure error at altitude by flying an aircraft in formation with a reference aircraft whose airspeed system had previously been calibrated. The purpose of these tests was to assess the suitability of the test method, and to estimate the accuracies of two methods of measurement, pressure altitude comparison (comparison of direct measurement of static pressure) and indicated air speed comparison (comparison of differences between static and total head pressures). A check was also made at low altitude, for comparison with results of the aneroid method.

The reference aircraft used on these trials was a Meteor 4 whose pressure error had been established at low altitude by the aneroid method and at high altitude by the radar tracking method. Brief trials were conducted with three aircraft:- Vampire Mk.3, Sea Hornet 21 and a Hastings 1 (the latter at low altitude only).

The calibration of a test aircraft by formation flying must be limited to the maximum speed of the reference aircraft unless a "fly past" technique is used in conjunction with altitude comparisons. It is proposed to investigate this as an extension to the formation flying method reported here, and this emphasises the importance of the accuracy of pressure error. measurements by the altitude comparison method.

2. Aircraft airspeed systems

2.1 Meteor F. Mk.4 RA.438. The reference aircraft was a standard Meteor 4, but having as extra another independent pitot-static system connected to a Mk.8B leading edge pitot-static head mounted near the starboard wing tip. For the period of the tests with the Vampire, the starboard pitot-static head was mounted on a non-standard strut fitted for another investigation and this system was not used. Two A.S.I.'s, two altimeters, and a clock were contained in an auto-observer situated in the ammunition bay; one A.S.I. and altimeter was fitted to each pitot-static system.

2.2 Vampire Mk.3 VV.190. This was a standard Vampire 3 except that it was fitted with a Goblin 4 engine. The airspeed system was connected to a Mk. 8B pitot-static head mounted on the leading edge of the port fin. An auto-observer containing an A.S.I., two altimeters and a clock was fitted in the ammunition bay. A full description of a Vampire 3 is included in Ref.1.

2.3 Sea Hornet Mk.21 VV.430. This aircraft was a standard Sea Hornet 21, the airspeed system being connected to a Mk. 8B pitot-static head mounted on the leading edge of the port wing near the tip. Relevant instruments in the auto-observer were A.S.I., altimeter and clock. A full description of this aircraft is included in Ref. 2.

2.4 Hastings Mk.1 TG.503. The A.S.I. and altimeter system was connected to a Mk.8 pitot head mounted beneath the port wing and to interconnected R.A.E. type static vents situated on either side of the nose of the fuselage. Relevant instruments fitted in the auto-observer were A.S.I., altimeter and clock. A full description of this aircraft is included in Ref. 3.

3. Scope of tests

The ground level pressure error correction of each aircraft was measured before the calibration trials by the formation method commenced. The static pressure error correction was obtained by the standard A. & A.E.E. aneroid method and the pitot pressure error correction by comparing the pitot pressure with that of a venturi pitot head.

Pressure error measurements by the formation method were carried out at two altitudes. At a moderately high altitude to measure p.c.c. at altitude, and at 5,000 ft. to check the accuracy and reliability of the method, as the results from the flights at 5,000 ft. would be expected to agree with the results obtained by the aneroid method. The tests at altitude served also to check whether the change in p.e.c. with altitude agreed with that estimated from the ground level results using the method of Ref.4 and assuming the Glauert law. Brief checks were made for interference effects in the tests with the Sea Hornet and the Hastings.

4. Test procedure

Both aircraft climbed to the test altitude together, being in V.H.F. contact from take-off. The auto-observer clocks were synchronised on the climb by taking simultaneous single records.

In these series of trials the role of 'leader' aircraft in the formation was given to the less manoeuvrable aircraft of the two. At test altitude the leader aircraft started his run, and when stabilised on speed and height gave the signal for the second aircraft to formate. The two aircraft formated at the same level, with the wings of the following aircraft abreast of the tailplane of the leader aircraft. The lateral distance between tail tip and wing tip of the two aircraft was approximately 4 Meteor semi-spans. All runs, with the exception of two runs with the Sea Hornet, were carried out with the following aircraft formating on the starboard side of the leader aircraft. The run commenced when the following aircraft was in steady formation and was held for about three minutes, at the end of which period cameras were switched off and a new run at the next speed commenced. The clocks were synchronised again at the end of the flight.

5. Methods of analysis

Two methods of measurement were used; comparison of airspeed indicator readings and comparison of altimeter readings. All results were corrected to a standard weight for each particular aircraft, this correction was very small, of the order of $\pm \frac{1}{2}$ knot.

5.1 Speed comparison method. The mean A.S.I. readings, V_R, corrected for instrument error, for each run, were obtained from the auto-observer film records of both aircraft.

The A.S.I. total pressure error correction of the test aircraft was deduced by comparing the mean A.S.I. reading of the test aircraft with the "Rectified air speed*", V_r, of the reference aircraft.

5.2 Altitude comparison method. The mean altimeter readings, h_P, corrected for instrument error, for each run, were obtained from the auto-observer film records of both aircraft.

The altimeter pressure error correction of the test aircraft was obtained by comparing the mean altimeter reading of the test aircraft with the true pressure altitude h_p as indicated by the reference aircraft. From this data the A.S.I. static pressure error correction was obtained by the method of Ref. 4.

The A.S.I. total pressure error correction could then be obtained by adding the pitot pressure error correction obtained from other trials.

6. Results

6.1 Pitot Error Measurements. Pitot error measurements were made on all three aircraft up to the Max. Mach No. reached on these trials. In all cases the pitot error was negligible.

6.2 Pressure error measurements of Vampire 3. Tests were made at two heights, four flights being carried out at 35,000 ft. and five flights at 5,000 ft., the speed range at both heights was covered fully. The Meteor led the formation on all flights made.

/In......

* i.e. the reading which a correctly scaled A.S.I. would have given if connected between true total head and static pressures.

In calculating the results both methods of analysis were used; replicate results by the altitude comparison method were obtained by fitting two altimeters in the auto-observer of the Vampire. Pressure error correction measurements obtained from tests are shown plotted in Figs. 1,2 and 3.

6.3 <u>Pressure error measurements of Sea Hornet</u>. This aircraft was available for two flights only, one of which was made at 5,000 ft., the other at 25,000 ft. The Sea Hornet led the formation on both flights made.

On both flights carried out, a constriction in the pitot line caused misreadings of the A.S.I.'s. This error was not discovered until after both flights had been made, so that no speed comparison results were obtained on this aircraft. Results have been deduced using the altitude comparison method.

The two independent pitot-static systems of the Meteor provide two separate pressure error corrections using the altitude comparison method, these corrections are plotted in Fig. 4.

During the flight at 25,000 ft., the reference aircraft was flown on either side of the leader aircraft to determine whether the proximity of the leader aircraft had any effect on the readings of the two A.S.I.'s of the reference aircraft. As can be seen from the following table no significant differences between A.S.I. readings was obtained. The small change in V_r from the port and starboard heads noted in para. 6.4 is not apparent here, but different pitot-static heads had been fitted for these tests.

Meteor I.A.S. Readings.

Run	Position of following aircraft	A.S.I. Reading, Knots		V_r. knots	
		Port system	Starboard system	Port system	Starboard system
1	Starboard	198	$198\frac{1}{2}$	199	199
2	Starboard	$233\frac{1}{2}$	236	237	238
3	Port	$198\frac{1}{2}$	$198\frac{1}{2}$	$199\frac{1}{2}$	199
4	Port	$233\frac{1}{2}$	235	237	237

6.4 <u>Pressure error measurements of Hastings</u>. Due to other commitments on this aircraft only one formation flight was possible. This flight was carried out at 5,000 ft. with the Hastings leading the formation. Formation positions were as those mentioned in para. 4.

Measurements of the total pressure error correction were obtained from both pitot-static systems of the Meteor. Both methods of analysis were used in calculating the pressure error correction; the results are found plotted in Fig.5.

On this flight it was found that the A.S.I. and altimeter connected to the port pitot-static system of the Meteor were giving higher readings than the A.S.I. and altimeter connected to the starboard pitot-static system. The difference in the A.S.I.'s was of the order of 2 knots after correction to rectified airspeed. To provide a check on these discrepancies between the pitot-static systems the Meteor was flown alone over the same speed range, readings of A.S.I's and altimeters being taken. The results of the two flights were collected together and analysed statistically using the 'Analysis of Variance". From this analysis* the following results have been obtained:-

(a) There was a significant difference between port and starboard A.S.I. readings of the Meteor whether the aircraft was flown alone or in formation with the Hastings.

(b) The difference in A.S.I. readings was significantly reduced when the Meteor was flown alone, thus showing a significant interference effect due to the proximity of the Hastings.

/(c)...

* Analysis due to A.K. Weaver.

(c) The differences in A.S.I. readings varied with speed when the Meteor was flown in formation, but did not vary when the Meteor was flown alone.

These differences are, in pressures (with 95% probability limits):-

Meteor flown alone	1.1 ± 0.45 lb/sq.ft.	(1.0 ± 0.4 kts. at 155 kts.) (0.7 ± 0.3 kts. at 235 kts.)
Meteor flown in formation	1.3 ± 1.0 lb/sq.ft. at 155 knots increasing to 3.3 ± 1.0 lb/sq.ft. at 235 knots.	

(d) The interference effect on the Meteor, varied with speed from 0.4 ± 1.1 lb/sq.ft. (0.4 ± 1.0 knots), at 155 knots increasing to 2.8 ± 1.1 lb/sq.ft. (1.6 ± 0.6 knots), at 235 knots.

7. Discussion of results

7.1 Suitability of technique. The technique as used on these trials was satisfactory, but it is recommended that, if the following aircraft is equipped with a leading edge pitot-static head, it formates such that it's pitot head is on the opposite side and at least two semi-spans (of the larger aircraft) clear of the leader aircraft. This precaution should avoid any appreciable interference effects. With this technique, it is not possible to measure the pressure error correction of aircraft faster than the reference aircraft using the speed comparison method, but the altitude comparison may be used in conjunction with a "fly past" technique. The technique also has the disadvantage of requiring the service of two aircraft and two pilots. The present series gave no reliable guide as to the extent of the latter drawback as it had to be fitted in with more important tests on both aircraft. If the method were used as a routine the calibrated aircraft would have to be kept available for this work.

7.2 Pressure error measurements. The only conclusive results obtained from these trials were those obtained from the tests made with the Vampire. Several flights were carried out at each of two altitudes and the speed range was covered fully. From these flights a comparison of the accuracy and reliability of the two methods of measurement and analysis have been made. Results obtained from the other aircraft have been used to substantiate these comparisons.

From results obtained, the speed comparison method was found to give the more reliable and consistent results.

The Vampire speed comparison points plotted in Fig. 1 show very good agreement between flights at both 5,000 ft. and 35,000 ft. Overall scatter at both heights is about ± 1½ knots, the accuracy of the low level points comparing favourably with the points obtained by the aneroid method. The accuracy of the Vampire tests is borne out by the speed comparison results of the Hastings test, good agreement being shown between the results obtained by the aneroid method and results from the formation flight (using results obtained from the starboard pitot-static system of the Meteor).

Results obtained, from the Vampire, using the altitude comparison method are plotted in Figs. 2 and 3. These results show that this method gives rise to a larger scatter than the speed comparison method. This scatter was a variation between flights, scatter between runs on a flight being small. It will also be seen that though one of the altimeters gave a pressure error curve agreeing with that obtained by the aneroid method, the other altimeter produced a curve lying about 1 knot below the aneroid points. The flight to flight variation is much worse on altimeter A than altimeter B. The large discrepancies obtained on two of the flights at 5,000 ft. on altimeter A must be due to errors in the altimeter, and not to a change in pressure error as all the flying at 5,000 ft. was carried out on the same day.

A brief statement on errors in altimeters and their likely effect on pressure error correction is given in Appendix 1.

This shows that the inadequacy of altimeters can lead to errors up to $\pm$ 3 knots in p.e.c. depending upon the altimeter used, and shows that improvement in pressure measurement are very desirable.

Results obtained from tests with the Hastings and Sea Hornet, using the altitude comparison method, though inconclusive, do to some extent bear out the results obtained from the Vampire.

7.3 Variation with height. Examination of the pressure error curve of the Vampire, Fig. 1, shows good agreement over the range M = 0.58 - 0.75, between the pressure error correction measured at 35,000 ft. by the formation method, and the pressure error correction estimated from the ground level pressure error correction by the method of Ref. 4, assuming the Glauert Law.

7.4 Interference effects. It would be expected that the interference effects on either aircraft would depend on the value of C_L/Aspect Ratio $\frac{\text{span loading}}{\frac{1}{2}\rho_0 V_i^2}$ for the other and the distance between the two, measured in, say, semi-spans of the second aircraft. These were as follow during the tests to check interference.

A/C formating with Meteor	C_L/Aspect Ratio	Distance in semi spans
Hastings	0.076 - 0.175	$1\frac{1}{2}$
Sea Hornet	0.125 and 0.176 (two values only)	

Interference on the Meteor was perceptible with the Hastings but not with the Sea Hornet.

Thus it would seem that for values of C_L/A in this range (up to 0.2) interference may become significant at distances less than, say 2 semi spans of the interfering aircraft.

8. Conclusions

The tests made show that the formation method is a convenient method of measuring pressure error at high altitude, the one drawback being that it is not possible to measure pressure errors, using the speed comparison method, at speeds higher than the maximum speed of the calibrated reference aircraft. This drawback may be overcome by using the pressure altitude comparison method in conjunction with a 'fly-past' technique.

Results obtained from this series of tests shows that the speed comparison method gives more consistent and reliable results than the altitude comparison method. This is due to the inadequacy of present altimeters and shows the difficulties likely to be encountered in the 'fly-past' method, as this method relies on altitude comparison. Comparison of results obtained by the altitude and speed comparison methods show that whereas the speed comparison method gives rise to a scatter of $\pm$ $1\frac{1}{2}$ knots, lag and drift errors of available altimeters can lead to errors of up to $\pm$ 3 knots in pressure error correction, but these may be reduced by selection of altimeters with small lag errors.

The pressure error correction of the Vampire measured at high altitude by the speed comparison method shows good agreement with the value estimated from the ground level aneroid results by the method of Ref. 4, assuming the Glauert Law to apply.

Interference effects may become noticeable if either aircraft is less than 2 sem-spans from the other.

/9.........

9. Further developments

Consideration is being given to:-

(a) The development of a fly past technique for routine performance tests at A. & A.E.E. for speeds above the speed range of the calibrated aircraft. It can only be used in conjunction with comparison of altimeter readings.

(b) Using a better instrument than the usual altimeter for direct measurement of pressure.

10. References

1.	2nd Part AAEE/819,d	Vampire 3 TG.275 Handling trials.
2.	5th Part AAEE/828,c	Sea Hornet NF. Mk.21 VV.430 A.S.I. and altimeter pressure error correction, climb and level speed performance, speed power analysis, and specific air range (without external stores).
3.	15th Part AAEE/843	Hastings TG.503. Climb and level speed performance at maximum take-off weight.
4.	A.A.E.E./Res/244	The Calibration of airspeed and altimeter systems by A.K. Weaver.
5.	R.A.E. T.N. Inst.769	Altimeters Mk. XIV, Errors by A. Dobson.

/Appendix.....

Appendix 1

Altimeter Errors

The main errors in altimeters may be defined as follows:-

(a) Lag Error. The difference between altimeter readings at a given pressure, with a vibrated instrument, the calibration being made firstly with descending pressure and then with ascending pressure. (Note. The lag appears to be a function of the mechanical design of the altimeter and is not appreciably affected by the speed of calibration).

(b) Hysteresis. The instrument error, after elimination of lag, due to its immediate past history.

This is a change in altimeter reading at a fixed applied pressure, following a change in pressure. It appears that the rate of change of altimeter reading approaches zero after about 40 minutes on current British test altimeters.

(c) Long Term Drift. The change in instrument error which occurs during the life of the instrument; after lag and hysteresis errors have been taken into account.

Information obtained from the calibration of a sample of 50 altimeters shows that lag is approximately a constant pressure error over the height range of the altimeter. Calibration of the altimeters fitted in the Vampire for these tests, show that the lag in Altimeter B is much less than that in Altimeter A, the approximate mean lag errors being:-

Altimeter A 6 lb/sq.ft. (90 ft. at 5,000 ft. - 250 ft. at 35,000 ft.)
Altimeter B 2 lb/sq.ft. (30 ft. at 5,000 ft. - 80 ft. at 35,000 ft.)

Drift errors shown up by the calibrations vary from ± 20 ft. at 5,000 ft. to ± 50 ft. at 35,000 ft. on both altimeters. From comparison with other altimeters it appears that, from lag characteristics, Altimeter B is a particularly good altimeter whereas Altimeter A is a bad altimeter, the average altimeter having a mean lag of approximately 4 lb/sq.ft.

The altimeter fitted in the reference Meteor (port system) was an average instrument having a mean lag of 4 lb/sq.ft. (160 ft. at 35,000 ft.).

Using the mean calibration to correct the altimeters, the following maximum total errors could be obtained: Altimeter A - ± 65 ft. at 5,000 ft. and ± 175 ft. at 35,000 ft., Altimeter B - ± 30 ft. at 5,000 ft. and ± 90 ft. at 35,000 ft. These errors converted to a final pressure error correction in knots at different speeds and heights are shown in the following tables:-

5,000 ft.

Altimeter	Error in P.E.C. kts. 200 kts.	400 kts.
A	± 3.0	± 1.3
B	± 1.4	± 0.6

35,000 ft.

Altimeter	Error in P.E.C. kts. 200 kts.	270 kts.
A	± 3.1	± 2.3
B	± 1.4	± 1.0

It should be noted that the altimeter error results in an error in A.S.I. independent of altitude at a given A.S.I. The percentage error in A.S.I. increases as A.S.I. decreases and is therefore likely to be more important at high altitude.

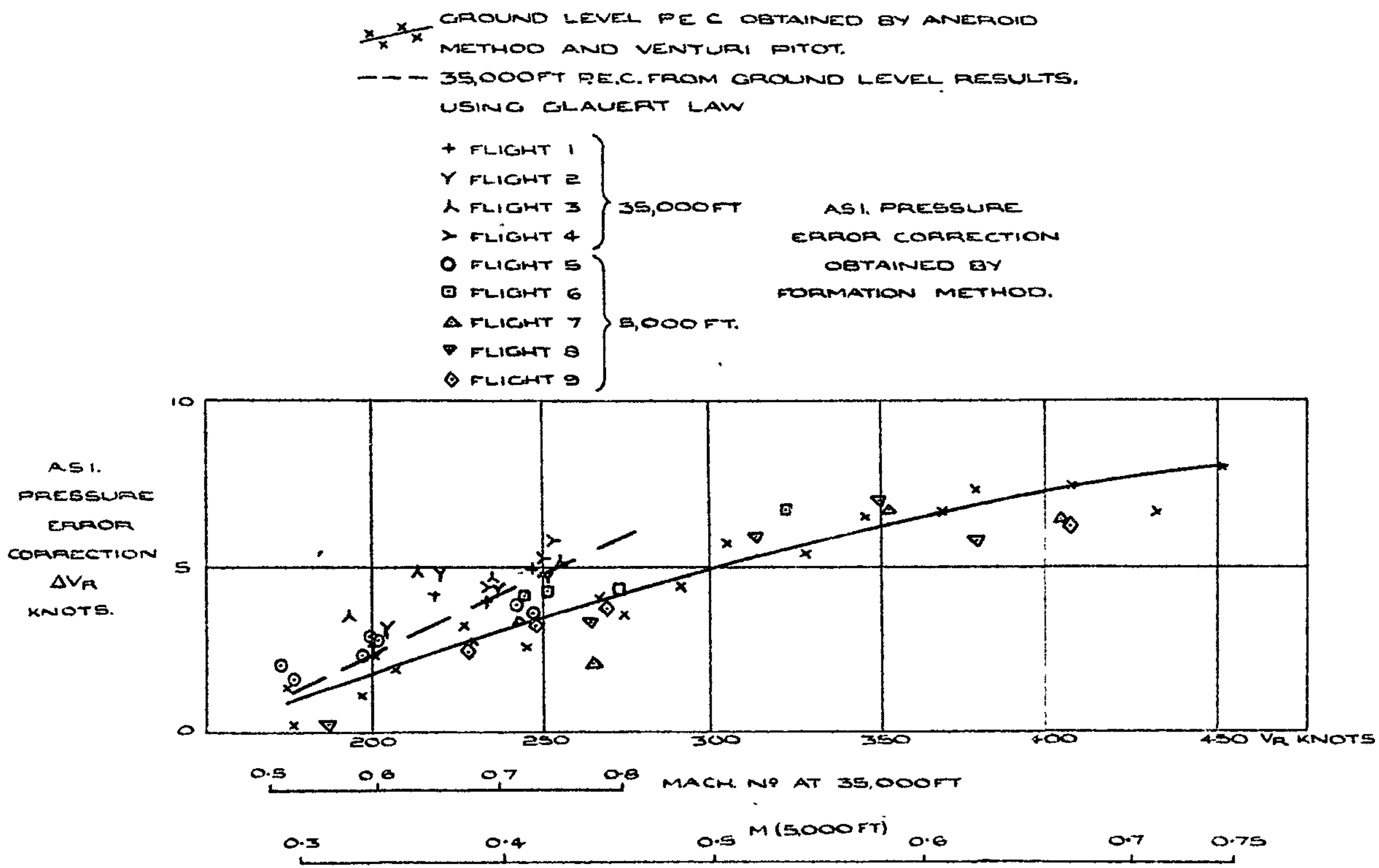
These values are calculated for comparison of an altimeter reading with a correct pressure height, if two altimeters in different aircraft are being compared these errors may be increased.

/If........

If the altimeters in the aircraft under test and the standard aircraft had both had lag errors comparable with Altimeter B the scatter of the results would be expected to have been reduced and this standard should be obtained if possible. In a sample of 50 altimeters only 6 were found to be up to the standard of B so that for routine tests when a number of aircraft have to be dealt with at a time the obtained results are probably realistic.

In comparing two altimeters, with the same immediate past history, the difference in hysteresis errors should be negligible as the errors will be of the same sign and of approximately the same order. However drift and hysteresis errors are masked by the lag error which is the dominating error in altimeters.

The altimeter errors are consistent with the scatter obtained from the formation results using the altitude comparison method, the formation results being in most cases within the limits of the maximum errors quoted. These results are of special interest, as the altitude comparison method must be used if a complete calibration of an aircraft faster than the reference aircraft is required. Improvements in pressure measurements for these and other tests are therefore very desirable and are being investigated.

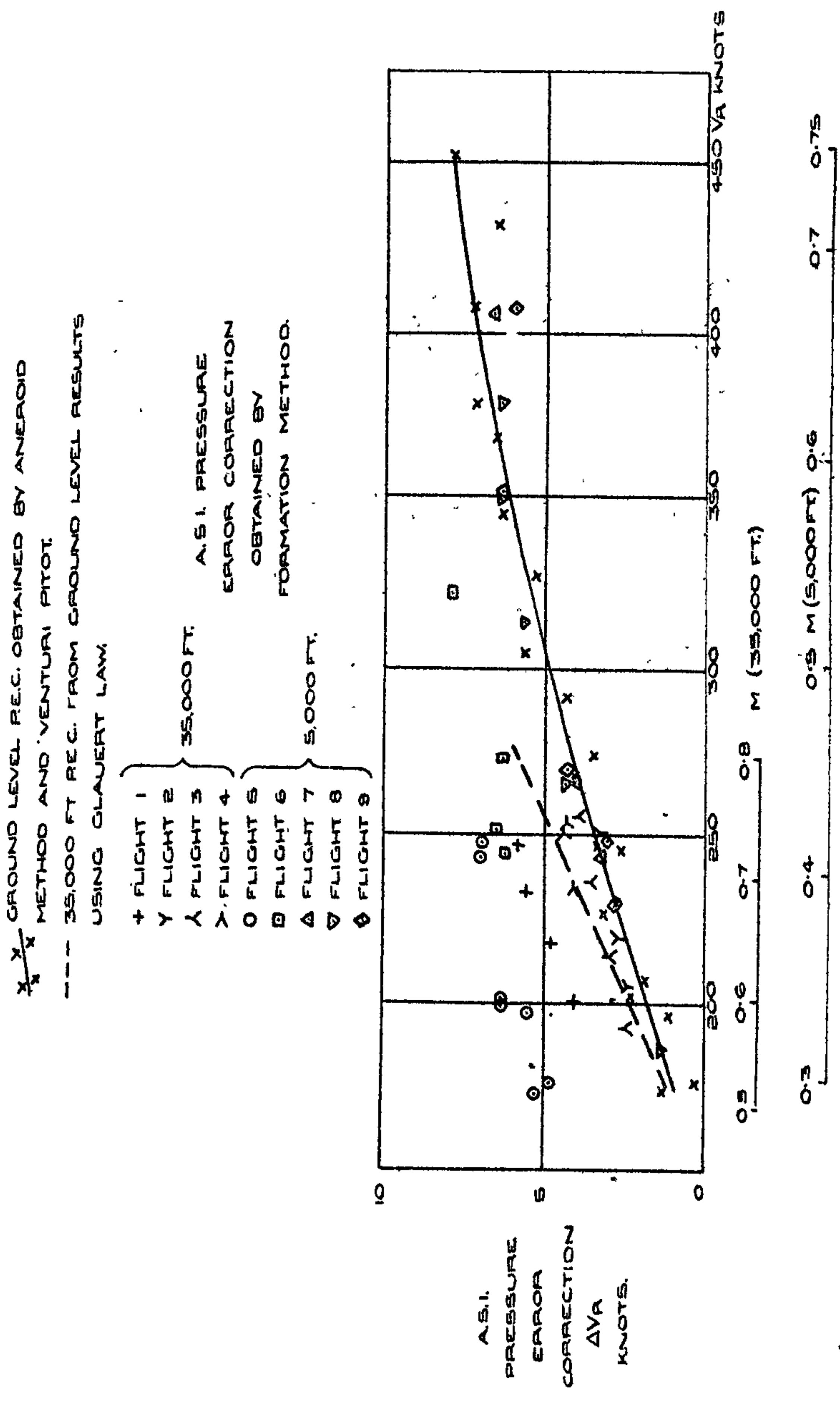


VAMPIRE A.S.I. PRESSURE ERROR CORRECTION. FORMATION RESULTS BY SPEED COMPARISON METHOD.

FIG. 1.

SK No A.3462 | REPORT No A.&A.E.E/ RES/262 | TR. | CH. K. LEVON | APP | for S of P | 6.3.52

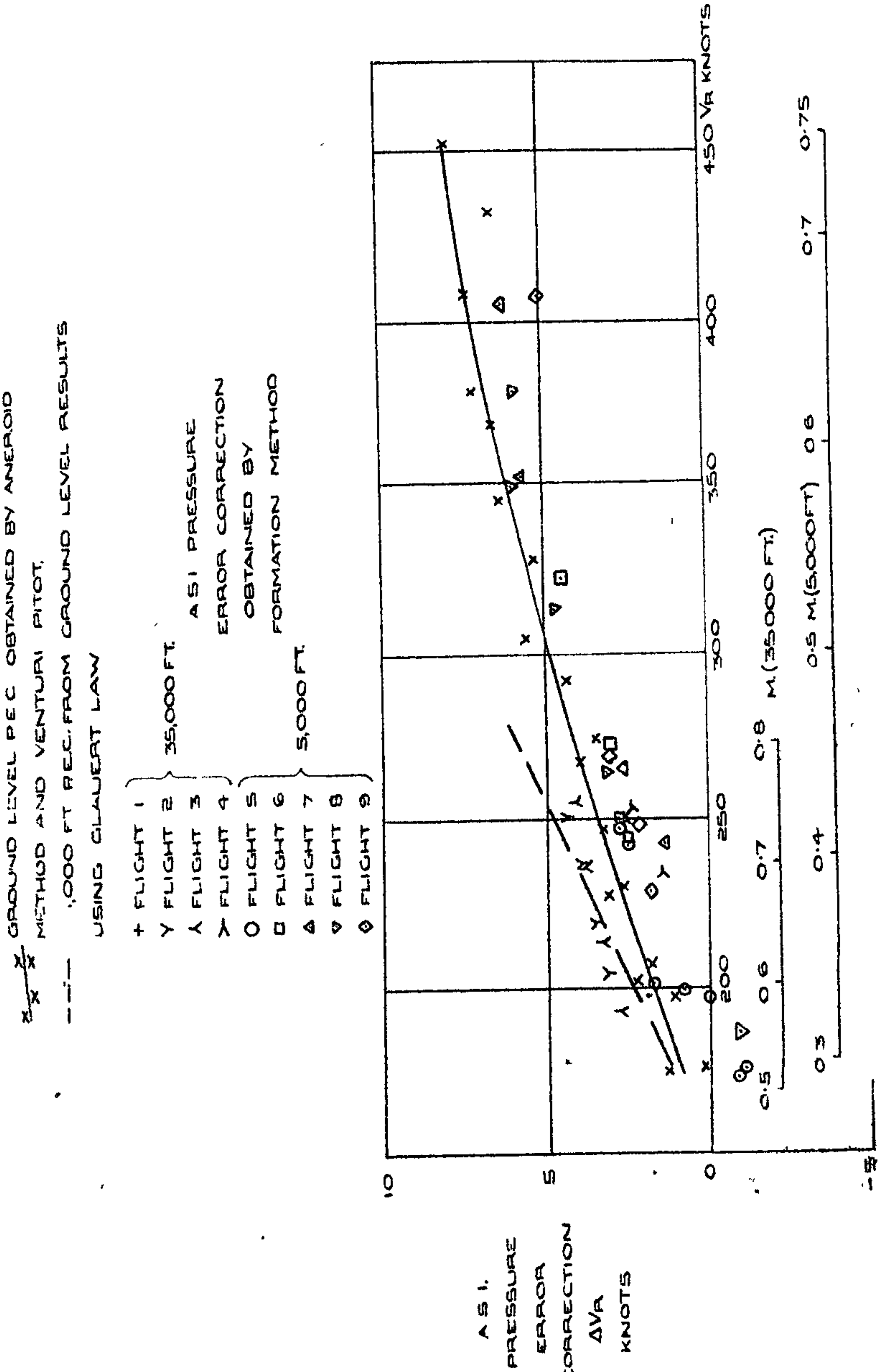
FIG. 2.



VAMPIRE A.S.I. PRESSURE ERROR CORRECTION. FORMATION RESULTS BY ALTITUDE COMPARISON METHOD~ALTIMETER 'A'

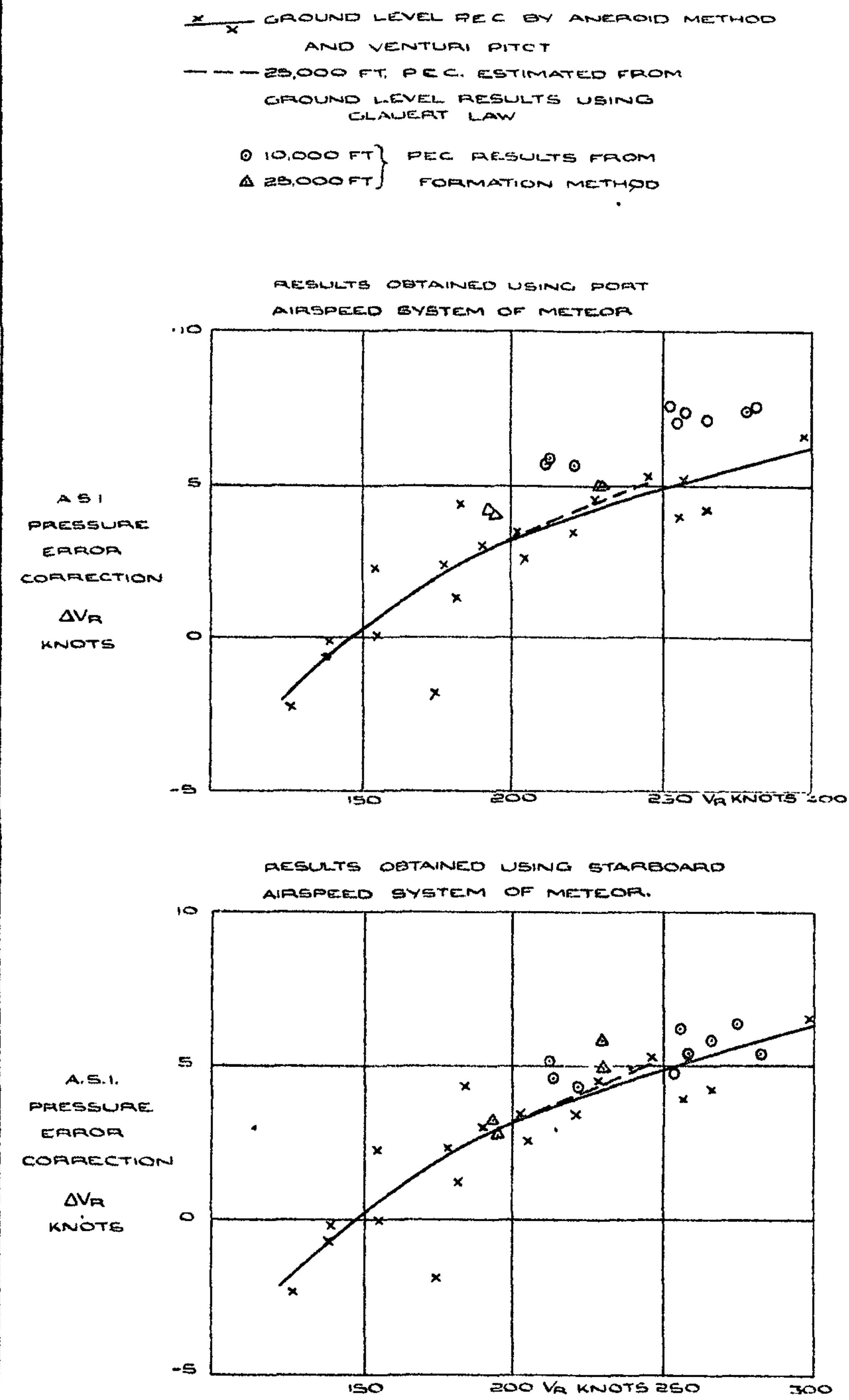
FIG. 3.

SK No. A 34+63 | REPORT No. AERO A.E.E./RES/262 | TR. | CH. K LEVON | APP. | for Sof P | 6.3.52



VAMPIRE A.S.I. PRESSURE ERROR CORRECTION. FORMATION RESULTS BY ALTITUDE COMPARISON METHOD - ALTIMETER 'B'

FIG.4.



SEA HORNET A.S.I. PRESSURE ERROR CORRECTION. FORMATION RESULTS BY ALTITUDE COMPARISON METHOD

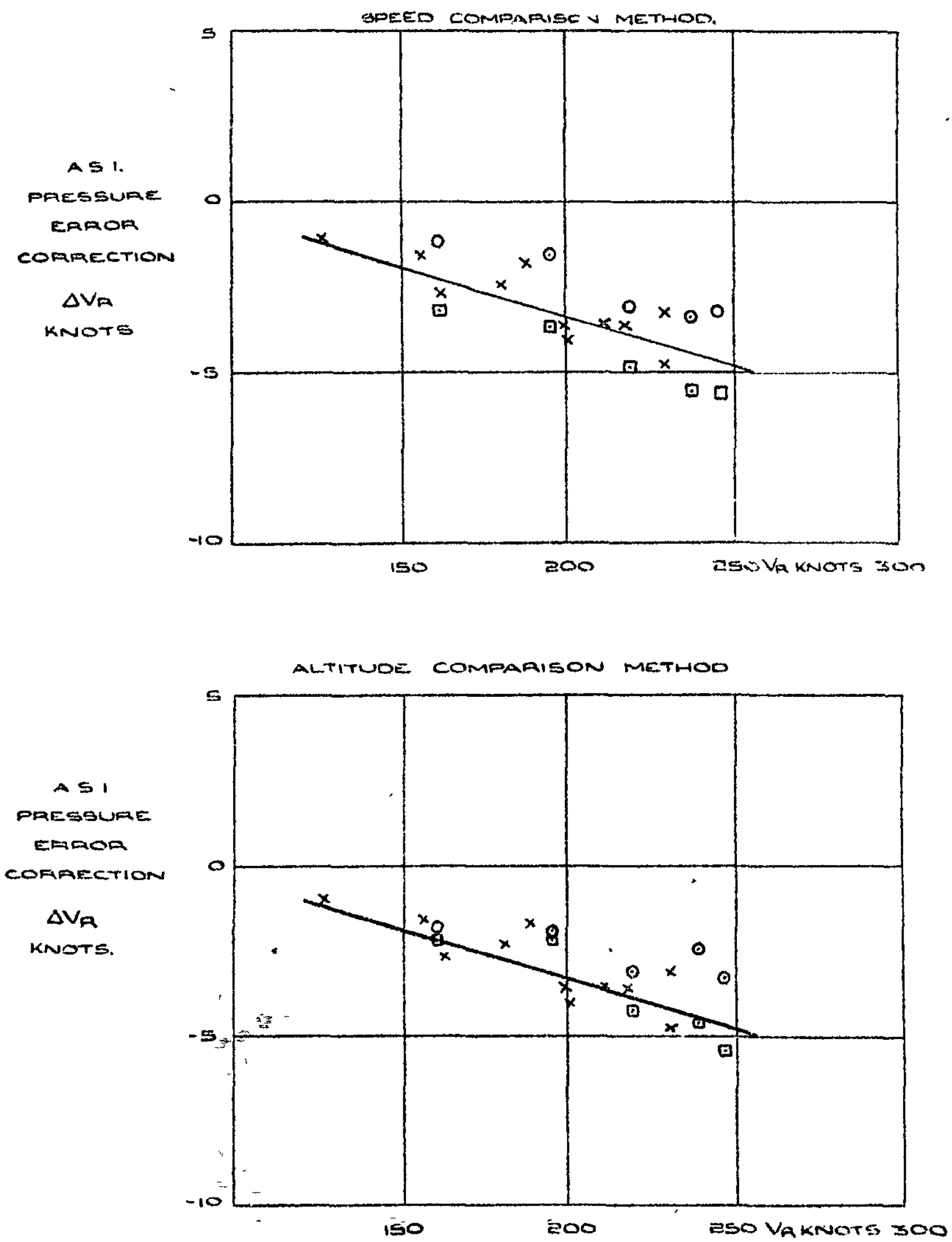
SK No A 3464 | REPORT No A&AEE | RES/262 | TR. M.L. | CH. K. LEVON | APP | for Sof P | 6.3.52

FIG. 5.

× TOTAL GROUND LEVEL P.E.C. BY ANEROID METHOD AND VENTURI PITOT

○ P.E.C. OBTAINED BY FORMATION METHOD AT 5,000FT. FROM PORT AIRSPEED SYSTEM OF METEOR.

⊡ P.E.C. OBTAINED BY FORMATION METHOD AT 5,000 FT. FROM STARBOARD AIRSPEED SYSTEM OF METEOR



HASTINGS A.S.I. PRESSURE ERROR CORRECTION. FORMATION RESULTS USING SPEED AND ALTITUDE COMPARISON METHODS

SK. NºA 34-65 | REPORT NºA&A.E.E/RES/262 | TR. | CH. K. LEVON | APP. | for S of P | 6.3.52

C.P. No. 126
(A.R.C. 14,758)
A.R.C. Technical Report

PRINTED AND PUBLISHED BY HER MAJESTY'S STATIONERY OFFICE
To be purchased from
York House, Kingsway, LONDON, W.C.2 423 Oxford Street, LONDON, W.1
P.O. Box 569, LONDON, S.E.1
13a Castle Street, EDINBURGH, 2 1 St. Andrew's Crescent, CARDIFF
39 King Street, MANCHESTER, 2 Tower Lane, BRISTOL, 1
2 Edmund Street, BIRMINGHAM, 3 80 Chichester Street, BELFAST
or from any Bookseller

1953

Price 3s 0d net

PRINTED IN GREAT BRITAIN

S.O. Code No. 23-9007-26