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MINISTRY OF SUPPLY

AEROPLANE AND ARMAMENT EXPERIMENTAL ESTABLISHMENT

BOSCOMBE DOWN

CANBERRA PR 3 VX 181.
(2 x AVON 1)

LATERAL AND DIRECTIONAL BEHAVIOUR AND THE EFFECT ON SURVEY PHOTOGRAPHY

by

H.J. KEYES, B.A.

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AEROPLANE AND ARMAMENT EXPERIMENTAL ESTABLISHMENT
BOSCOMBE DOWN

Canberra PR 3 VX 181.
(2 x Avon 1)

Lateral and directional behaviour and the effect on survey photography

by

H.J. Keyes, B.A.

A. & A.E.E. Ref: 5704,a/A/H.J.K.
M.O.S. Ref: 7/Acft/2711/01.
Period of Test : May, 1952.

R. & D.

Progress of issue of Report

Report No.	Title
2nd Part of AAEE/861/2	VX.181 Cockpit Appraisal.
3rd - do -	VX.181 Handling at the Design Aft C.G.Position
4th - do -	VX.181 Handling Trials at the Aft C.G. with Wing Tip Tanks.
5th - do -	VX.181 Stalling Speeds on Canberra Aircraft.
6th - do -	VX.181 Further Comments on Cockpit Comfort and Handling arising from Castel Benito Trials.

Summary

Previous trials on the Canberra PR 3 VX 181 had indicated that its lateral and directional behaviour might preclude the flying of an accurate compass course and might well adversely affect its usefulness for photography in the survey role. Further measurements have now been made to find the effects of height, airspeed, and configuration on the lateral and directional behaviour when either the pilot or the autopilot was controlling the aircraft.

The present trials showed that even under calm air conditions there were both short period oscillations and also general wanders in heading and angle of bank. The average magnitude of each of these disturbances at Mach numbers near 0.8 whilst the pilot was attempting to maintain the aircraft on a constant heading with wings level by normal use of the three flying controls was of the order of 1 degree, though maximum values of 2 degrees and above were measured. The effects of freeing the rudder and also of using the standard autopilot Mk 9 are described in the report.

The effects of the oscillations and wanders on the aircraft's usefulness in the survey role have been discussed in the report. It would seem from the evidence provided that most of the photographs obtained under calm air conditions with the pilot controlling the aircraft could be used by a survey mapping section willing to make allowances for up to 2 degrees of camera tilt. In these same air conditions it is probable that the use of the standard autopilot Mk 9 would enable the angle of tilt to be kept within the 1 degree considered by the American Engineer Laboratories as the limit for general mapping coverage. Any further reduction in the angle of tilt, either to meet the present War Office

/policy.........

policy requirement of 15 minutes tilt limit or the ultimate War Office target of 1 minute limit or to allow a margin for flight in rougher air conditions, would require further improvements in control. Such improvement may be given by a modified autopilot Mk.9 or by the autopilot Mk.10 now being developed, with or without the use of some such device as the auto-stabiliser that has been evolved at RAE for the elimination of snaking, but it seems probable that gyroscopic stabilisation of the camera may be required.

This Report is issued with the authority of

Air Commodore
Commanding, A. & A.E.E.

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1. Introduction

In the 4th part of A&AEE/Report No. 861/2, it was stated that the lateral and directional behaviour of the Canberra PR 3 VX 181 without wing-tip tanks was worse than on Canberra B2 aircraft previously tested and precluded the flying of an accurate compass course. It was suggested that the wallowing or 'dutch-rolling' found at indicated Mach numbers above 0.7 might well adversely affect the photography in the survey role.

The more recent photographic trials made on this aircraft at Castel Benito appeared on preliminary analysis to confirm this view. The pilot reported that at high altitude there was a continuous dutch-roll which could be only partially stopped by continuous heavy pressure on the rudder pedals. The degree of concentration demanded from the pilot was such as to make him very tired, particularly by the end of a 12 to 15 minute continuous photographic run on a constant heading.

After the return of the aircraft from Castel Benito, continuous trace recordings of aircraft heading and angle of bank were made at various heights, airspeeds, and Mach numbers in an attempt to determine the characteristics and magnitude of the lateral and directional oscillations. These trials form the subject matter of this part of the report.

2. Problems involved in survey photography

The usual aerial photograph measures 9 inches by 9 inches. The centre of it, corresponding to the optical centre of the camera lens, is marked by a cross which is called the 'Principal Point'. (see figure 1(a)) Four other lines, at the mid-point of each side, are called 'Collimating Marks'. The five marks on each photograph serve as axes of reference in correcting the image distances on the photograph to true distances.*

The photographs are obtained in series along parallel tracks, the aircraft courses and positions and the camera operating intervals being so chosen that the photographs overlap each other on all sides, as shown diagrammatically in figure 1(b).

Ideally each photograph should be taken vertically downwards, whilst the aircraft flies straight and level on a constant heading. To this end, the camera is pre-set on the ground so that it is vertical when the aircraft has its wings level and is at an attitude equal to that expected to obtain during the photographic run. However the aircraft deviates from these ideal conditions for several reasons and the effects are discussed below:-

(a) Incorrect setting of the camera from the fore-and-aft vertical means that the area photographed is in front of or behind the optimum area, as illustrated in figure 2(a) where the area B_1 B_2 B_3 B_4 or C_1 C_2 C_3 C_4 is photographed instead of A_1 A_2 A_3 A_4. The point vertically beneath the aircraft is no longer at the optical centre of the lens and this complicates the calculation of true ground distances and angles from the photographic images and angles.

(b) Oscillation of the aircraft in pitch leads to difficulties similar to those described in (a). It is unlikely that it will give the added difficulty of inadequate fore-and-aft overlapping of the photographs.

(c) Yawing of the aircraft without accompanying bank causes rotation of the photograph so that points originally on the fore-and-aft centre line through the optical centre appear to be displaced from the line. Thus the area B_1 B_2 B_3 B_4 of figure 2(b) is photographed instead of A_1 A_2 A_3 A_4 and the object O, originally on the fore-and-aft centre line X_1 Y_1,

/no.....

* It will be appreciated that if the camera is tilted, equal distances on the photograph do not necessarily imply equal true ground distances; this depends on the positions of the particular lines in relation to the principal point.

no longer lies on the centre line X_2 Y_2. This in itself does not introduce any errors but it is difficult on a photograph to distinguish between displacement of a point for this reason and a displacement due to the aircraft banking, when a correction to the calculated distances is required to allow for the slant view. It should be noted that a similar apparent rotation of each photograph may be present whenever the aircraft is flying in a cross-wind relative to the 'track-made-good' as the fore-and-aft line through the aircraft will then be at an angle to the track, though on the Canberra PR.3 aircraft means are provided on two of the three survey camera installations for rotation of the camera into the direction of the track-made-good.

(d) Banking of the aircraft causes a displacement of the area photographed to either side of the intended area. Thus in figure 2(c), the area B_1 B_2 B_3 B_4, for example, is photographed instead of A_1 A_2 A_3 A_4. The difficulties introduced are those already given in paragraph (a), namely the complication of the corrections to distance, but there is also the confusion likely to arise with the yawing case considered in paragraph (c).

Difficulties due to divergences from the ideal set of survey photographs come under two main sections, firstly the changes that can occur between successive photographs and which will make more difficult the marrying together of these photographs and secondly the long term changes that can arise between the beginning and end of, say, a 15 minute survey run, such as for instance two allegedly parallel tracks on opposite headings diverging so that finally there is inadequate overlapping of the photographs in the two tracks.

This part of the report deals with the changes that can occur between successive photographs. Although each of the divergences (a) to (d) above might be expected to occur together, attention has been concentrated on the lateral and directional divergences which had already been the objects of criticism by the pilots. To help in getting the correct perspective of these divergences, it is important to know the time intervals between successive photographs. The following table gives the time intervals in seconds for various heights and ground speeds when the F.49 camera has the 6 inch lens which is likely to be used in much of the survey work and a 60% overlap of successive photographs is required:

Height (feet) \ Ground speed (knots)	200	300	400	500
	Time interval (seconds)			
10,000	18	12	9	8
20,000	36	24	18	16
40,000	72	48	36	32

With a 12 inch lens these intervals are halved and with a 24 inch lens halved again.

3. Condition of aircraft relevant to tests

3.1 General. The aircraft was as described in the 1st part of this Report. The wing-tip tanks used were 65030 (port) and 56006 (starboard).

3.2 Instrumentation. A Hussenot (A 20) recorder was used to give continuous traces of the changes in the aircraft ~~the~~ angle of bank indicated by a German Mk.1 B gyroscope (for further details see 3rd part

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of Report AAEE/866). The recorder was set to give a trace length of approximately 1 millimeter per second,* and transverse scale displacements of 2½ millimetres per degree change of heading or angle of bank.

It should be noted that the gyroscope remained "caged" until the required trimmed conditions had been reached, with the aircraft flying as nearly as possible on a constant heading with zero bank as indicated by the G4B compass and the artificial horizon. The gyroscope was then uncaged for the single test and was then re-caged. The uncaging of the gyroscope occupied some 2 to 3 seconds and it was impossible therefore to assert that the apparent zero datum showing on the Hussenot recordings did in fact correspond to zero angle of bank and zero change of heading, even if there were means of measuring those angles accurately in the initial carefully trimmed conditions.

The precession of the gyroscope was assessed by bench calibration as causing apparent changes of 1 degree per minute to port in heading and 1/5 degree per minute to port in angle of bank.

3.3 Aircraft loadings. The aircraft weight at take-off when tip-tanks were fitted was 38,330 lbs., with the C.G. at 0.247 S.M.C., undercarriage down, (0.245 S.M.C., undercarriage up). The corresponding values without the tanks fitted were 38,090 lbs. and 0.246 S.M.C. (0.244 S.M.C. undercarriage up). The design C.G. range, undercarriage down, was 0.211 to 0.30 S.M.C.

4. Scope of tests

All tests were made in steady trimmed level flight under calm air conditions (with occasional periods of turbulence) at indicated Mach numbers (I.M.N.) of 0.7 to 0.8✓.

Without wing-tip tanks fitted, the tests were made at 10,000, 25,000 and 45,000 feet, with the pilot attempting to maintain the aircraft on a constant heading by the normal use of ailerons and rudder.

With tip tanks fitted, the tests were made at 25,000 and 45,000 feet only, as at 10,000 feet the limiting airspeed for this configuration would be exceeded at the Mach numbers considered. The trials at these two heights were extended to find the effects of using the Mk.9 autopilot and also to determine any changes caused by the pilot leaving the rudder free and controlling the heading by ailerons alone.

5. Results of tests

5.1 General. Photographic reproduction of the Hussenot trace recordings are given in figures 3 to 9; they have been reduced from life-size in the ratio 2.45 to 1, except for figure 7 which was reduced by 2.62 to 1. It should be noted that at the start of each record, the trace of aircraft heading is above that of angle of bank.

The traces show that there was a fundamental short-period oscillation in both heading and bank, each cycle occupying some 2 to 4 seconds. In addition there were more random movements in heading and bank, which will be referred to subsequently as general directional wander and general lateral wander respectively. It should be noted that, in giving the magnitudes of these wanders, the short-period oscillation has been excluded.

/The....

* At the foot of each record are dots which are made at 1 second intervals; every tenth dot is omitted so that 10-second time periods are readily discernible.

✓ To obtain true Mach numbers from indicated Mach numbers for the speeds tested, add 0.005 at 10,000 feet, 0.01 at 25,000 feet and 0.02 at 45,000 feet.

The tests were made in nominally calm air conditions. However patches of clear air turbulence were met, even at 45,000 feet, and the corresponding small sections of individual records have accordingly been omitted from the analysis. Any values given below can therefore be taken as applying to calm air conditions.

It is emphasized that the conclusions drawn in the report are derived by visual interpretation of the various curves obtained from the Hussenot trace records. No rigorous analysis by statistical methods has been made, nor has any level of significance been ascribed to the conclusions.

5.2 <u>Short-period directional oscillation.</u> The magnitudes of the oscillation in the various conditions of flight are given in Tables 1 and 2. Two values are given, one the average as assessed visually, the other the maximum occurring within the 2-minute period of the record. Figure 10 summarises the information for the condition when the pilot was controlling the aircraft by ailerons, rudder and elevator in an attempt to maintain level flight on a constant heading. It will be seen that there was an increase in the magnitude of the oscillation with increasing Mach number presumably because of the associated increase in airframe buffeting.

The main details of figure 10 are reproduced in the following table, the values being given to the nearest quarter of a degree. The Mach numbers shown do not represent the limits tested but are chosen as being values tested at all altitudes (slight extrapolation is however required in one instance).

Wing tip tanks.	Height (feet)	Indicated Mach number	Double-amplitude of oscillation (degrees)	
			Average	Maximum
OFF	10,000	0.72	0	$\frac{1}{4}$
		0.79	$\frac{1}{2}$	$\frac{3}{4}$
	25,000	0.72	0	$\frac{1}{4}$
		0.79	$\frac{1}{4}$	$\frac{3}{4}$
	45,000	0.72	$\frac{1}{4}$	$\frac{1}{2}$
		0.79	$\frac{1}{2}$	$\frac{3}{4}$
ON	25,000	0.72	0	$\frac{1}{4}$
		0.79	$\frac{1}{2}$	$1\frac{1}{2}$
	45,000	0.72	$\frac{1}{4}$	$\frac{1}{4}$
		0.79	$\frac{3}{4}$	1

The corresponding values obtained with other forms of control have not been included in this figure 10. Nevertheless from table 2, concerning flight with tip-tanks fitted, it may be seen that when the pilot was controlling the aircraft heading by ailerons only, leaving the rudder free, there appeared to be no appreciable change in the magnitude of the oscillation at either 25,000 or 45,000 feet, the only two altitudes tested in this configuration. When the autopilot Mk.9 was used, there was little change in the magnitude of the oscillation at 25,000 feet but there was apparently some reduction at 45,000 feet. At 0.785 indicated Mach number the reduction actually obtained was from $\frac{3}{4}^\circ$ to $\frac{1}{4}^\circ$ in average value and 1° to $\frac{1}{2}^\circ$ in maximum value, and at 0.74 and 0.715 indicated Mach numbers the oscillation was eliminated (originally $\frac{1}{4}^\circ$ average and $\frac{1}{2}^\circ$ maximum value at each speed).

/The.....

The effect of air turbulence upon the oscillation can be clearly seen from the Hussenot traces, the corresponding periods being indicated by the letters T.A. When turbulence was met, there was an immediate increase in the amplitude of the oscillation, amounting in some instances (for example figure 5(c)), to a doubling of the original amplitude. After the turbulence stopped,* it seemed that it took some 5 to 10 seconds (2 to 3 cycles) for the oscillation to return to its original level.

The period of the oscillation varied with height and Mach number. The values are given in figure 11 for all the configurations tested. At 10,000 feet the period per cycle varied from 2.3 seconds at 0.77 I.M.N. to 2.6 seconds at 0.70 I.M.N.; at 25,000 feet from 2.6 seconds at 0.81 I.M.N. to 3.1 seconds at 0.71 I.M.N.; at 45,000 feet from 3.5 secnds at 0.805 I.M.N. to 4.5 seconds at 0.715 I.M.N.

5.3 <u>General directional wander.</u> From each record a new trace was prepared by eliminating the short period oscillation. The general directional wander was then assessed by the variation of heading, as shown by this modified trace, within a time period dependent upon the camera photographing interval.

Indicated Mach numbers of 0.70 to 0.80 correspond to true airspeeds of approximately 445 to 515 knots at 10,000 feet, 425 to 485 knots at 25,000 feet, and 410 to 465 knots at 45,000 feet. To reduce the computational work, mean speeds of 480, 455 and 440 knots have been considered at the three heights respectively, giving appropriate camera intervals of 8, 17 and 34 seconds for the F.49 camera fitted with the 6 inch lens. (for convenience in analysing, 18 seconds was used at 25,000 feet instead of 17 seconds).

The value of the heading was taken at 2 - second intervals of the record and the change of heading then found for each period appropriate to the camera operating interval. Thus at 10,000 feet, the change of heading was found for each 8 - second period, namely 0 to 8 seconds, 2 to 10 seconds, 4 to 12 seconds and so on; similarly for each 18 - second period at 25,000 feet and 34 - second period at 45,000 feet. Each record treated in this way gave some 50 separate periods.

The average change of heading between successive photographs is shown in tables 1 and 2 and figure 12. In addition, figure 13 shows the maximum change of heading likely to occur on about 5% of occasions; this was found by taking the average of the maximum three values occurring within the approximately 50 intervals considered in each record.

The figures do not indicate any increase in directional wander with increasing Mach number. Indeed, it might be inferred that in several of the conditions tested there was a decrease in wander, though the number of tests was insufficient for definite conclusions to be drawn. There also seemed to be an increase in wander with height but again the evidence is inconclusive.

The main details of figures 12 and 13 relating to normal pilot control are summarised in the following table, the values being given to the nearest ¼ degree. The mach numbers shown do not represent the limits tested.

/Table.......

* As assessed by the aircrew from the buffeting.

Wing tip tanks.	Height (feet)	Indicated Mach number	Change of heading (degrees) between successive photographs*	
			Average	Maximum
OFF	10,000	0.72	$\frac{1}{4}$	$\frac{1}{2}$
		0.77	$\frac{1}{4}$	$\frac{1}{2}$
	25,000	0.72	$\frac{3}{4}$	$1\frac{3}{4}$
		0.79	$\frac{1}{2}$	1
	45,000	0.72	1	$1\frac{3}{4}$
		0.79	$\frac{3}{4}$	2
ON	25,000	0.72	$\frac{1}{2}$	$1\frac{1}{4}$
		0.79	$\frac{1}{4}$	$\frac{3}{4}$
	45,000	0.72	$\frac{3}{4}$	$1\frac{1}{2}$
		0.79	$\frac{1}{2}$	1

It can also be seen from figures 12 and 13 that when the pilot allowed the rudder to trail free, the directional wander was in general no worse and was usually somewhat better than when the pilot attempted to hold the rudder fixed. On the other hand, when the autopilot Mk.9 was controlling the aircraft, the wander was generally somewhat worse than in either of the other two conditions considered.

5.4 <u>Short-period lateral oscillation.</u> The short period lateral oscillation was more difficult to analyse than the corresponding directional oscillation. This was primarily due to the fact that the movements of the aileron by the pilot, either in steering or maintaining his wings level, gave changes in angle of bank of the first order of response and magnitude but changes in heading of only a second order. The short-period lateral oscillation was accordingly overlaid by the changes in angle of bank deliberately applied by the pilot and, to a certain extent, was obscured by them.

Nevertheless an assessment has been attempted and the values are given in tables 1 and 2 and in figure 14. It will be seen that, as for the directional oscillation, the amplitude increased with increasing Mach number. Furthermore, leaving the rudder free did not materially change the magnitude of the oscillation at 25,000 feet though it may have given higher maximum values at 45,000 ft. Use of the autopilot caused no change at 25,000 feet, but gave a marked improvement at 45,000 feet, where at 0.785 I.M.N. the average and maximum values of the double amplitude were reduced from $\frac{1}{2}^{\circ}$ and $1\frac{1}{2}^{\circ}$ respectively to zero.

The main details of figure 14 have been summarised in the table below:

/Table..........

* Excluding short-period oscillation.

Wing tip tanks	Height (feet)	Indicated Mach number	Double amplitude of oscillation (degrees)	
			Average	Maximum
OFF	10,000	0.72	0	½
		0.77	½	½
	25,000	0.72	0	-
		0.79	½	1½*
	45,000	0.72	½	1½
		0.79	[illegible]	2½
	25,000	0.72	0	-
		0.79	½	-
	45,000	0.72	½	-
		0.79	½	1½

5.5 General lateral wander. The analysis to obtain the general lateral wander was carried out in the same way as for the directional wander. The values are given in tables 1 and 2 and in figures 15 and 16, the former figure giving the average change of angle of bank between successive photographs and the latter the maximum change likely to occur on 5% of occasions.

As with the general directional wander, when the pilot was controlling there was no evidence of an increase in wander with increasing Mach number, nor in this case was there any noticeable increase with height. Average wanders of about 1° were common to all heights, Mach numbers and configurations, and the maximum values were in general between 2° and 4°. Whilst it is difficult to draw definite conclusions owing to the scatter of the test results, nevertheless it appears that when the rudder was left free, there was no marked change in the magnitude of the wander at any given height and speed, but there was a noticeable reduction when the autopilot was controlling the aircraft (roughly a reduction from 1° to ½° in average wander and from 2½° to 1° in maximum wander).

6. Discussion of results

6.1 Effect of Mach number on the lateral and directional disturbances.

The amplitudes of the lateral and directional short-period oscillations increased with increasing Mach number over the speeds tested (approximately 0.7 to 0.8 indicated Mach number). It is possible that the increase is associated with the development of airframe buffeting which becomes noticeable at about 0.76 I.M.N., though there is little evidence in figures 10 and 14 to substantiate this theory. The period of the oscillation decreased with increasing Mach number (see figure 11).

/The........

* Only value analysed in this configuration.

The general wanders (excluding these short-period oscillations) seemed to be independent of Mach number. Probably because of insufficient test data, some of the relevant figures show an apparent increase in wander with increasing Mach number, whilst other figures show the reverse.

6.2 Effect of altitude. The amplitudes of the short-period disturbances appeared to increase slightly with increasing altitude.

The increase with altitude was more apparent with the general directional wander but it should be remembered that the interval between successive photographs increased considerably with altitude, from 8 seconds at 10,000 feet to 34 seconds at 45,000 feet. There was thus much more time for a divergence in heading to develop. On the other hand there was little difference in the lateral wander with altitude; in this case, of course, the ~~time~~ period considered would not be expected to affect the wander appreciably since the pilot would in general be much more conscious of changes from a correct lateral level than from a correct heading.

6.3 Effect of fitting wing-tip tanks. The fitting of wing-tip tanks did not appear to alter the amplitudes or periods of the short-period oscillations or affect noticeably the magnitudes of the lateral and directional wanders. It is important to note, however, that the pair of tip-tanks used in the present trials did not appear to cause any material deterioration in the buffeting characteristics at high Mach number, whereas the original pair of tanks used on the photographic trials at Castel Bonito caused an appreciable deterioration. On occasions the buffet with the original tanks was as bad at 0.75 I.M.N. as it was at 0.79 to 0.80 I.M.N. with the later tanks. It may well be that, should the tanks in service deteriorate to such a level, the degree of buffeting might materially exceed that found at a particular Mach number during the present trials and accordingly the magnitude of the short-period oscillation might also be increased.

6.4 Effect of leaving the rudder free. As noted earlier in the report, the oscillations and wanders with the rudder free (that is, the pilot's feet off the rudder pedals) were in general no worse, and in fact may have been somewhat smaller, than when the pilot clamped hard on both rudder pedals. This is contrary to the pilots qualitative assessment as the pilot was convinced that he was achieving some improvements by applying continuous firm pressures to both rudder pedals.

It may have been that there was some sympathetic movement of the rudder during the short period oscillations and that this was apparent to the pilot as slight rudder bar movement. In fact, the pilot could detect arhythmic change of pressure in the two rudder pedals. When however he applied firm pressure to the rudder pedals and prevented this pedal movement (as in fact he could since the rudder was fairly light about its mean position and, because of its spring-tab, had no incompressible connection with the rudder pedals), the rudder was still capable of movements against the restraint of the spring tab torque tube. Although some change in amplitude and period of oscillation might be expected from freeing the rudder, no change could be seen from the evidence so far presented.

It would appear however that in any future work on this subject a continuous recording of the rudder position is desirable. This would provide evidence to decide whether the short-period oscillation is materially affected by the known lightness of the rudder over small displacements.

/6.5......

6.5 Effect of using the autopilot Mk.9. As mentioned previously in the appropriate sections, the use of the autopilot Mk.9 had little effect on the lateral or directional short period oscillations at 25,000 feet but gave some improvement at 45,000 feet, when compared with the corresponding conditions under pilot control. The general directional wander with the autopilot in use was rather worse at both altitudes but the general lateral wander was noticeably less.

It is interesting to note that during the photographic survey trials at Castel Benito (see 6th part of this Report for handling aspects) the aircraft was fitted with a standard autopilot Mk.9. This was criticised on two counts. Firstly it was difficult to steer accurately onto a course as the aircraft could easily settle on to a course some 5° off that intended; this can be partially eliminated when the pilot has had considerable practice with and experience in the use of the autopilot. Secondly, when the aircraft was finally running on course, any disturbance of the aircraft away from its initial conditions of bank and heading was more serious when the autopilot was controlling than when the pilot was controlling. After a disturbance, the pilot applied corrective action as quickly as possible, sufficient only to restore laterally level flight on the original heading; the autopilot however usually overcorrected and the original required conditions were only regained after two or three damped cycles of oscillation about those conditions.

Subsequent conversations with the Autopilot Section of R.A.E. have shown that they are fully aware of certain deficiencies in the standard Mk.9 autopilot for the high-altitude survey role of the Canberra. For instance, the rudder spring-tab has a natural frequency of vibration that induces movement of the roll datum pendulum, thereby leading to imperfect stabilising in bank. The spring-loaded knob of the autopilot controls has also been criticised as giving insufficiently precise control of the actuation. Modifications have been made and further tests are being carried out to assess their value. In the meantime work is continuing on the Mk.10 autopilot which is intended for use in the P.R. Canberra; this will embody a pre-set pointer and a follow-up mechanism so that a course can be pre-selected and the unit will then follow up and lock onto the chosen conditions of heading and bank.

In addition, R.A.E. subsequently stated that the particular autopilot used on the trials at Castel Benito was sluggish about the roll datum and affirmed that this might well cause the over-correction that was found. It was also stated that a fully serviceable unit should not suffer from that defect and should be capable of detecting and suppressing all short period oscillations, including the short period one of this report.

The present series of measurements were made with a standard Mk.9 autopilot. It is interesting to note that, despite the claims made, the autopilot did not eliminate the short period oscillation (see the first paragraph of this sub-section). Nor was the period of the oscillation changed (so far as can be seen from present evidence) as might have been expected from the introduction of the autopilot into the control circuits.

6.6 Effect of the oscillations and wanders on survey photography. Informal discussions have been held with members of the Directorate of Military Survey and the Colonial Survey. These have shown that it is difficult to ascribe simply an upper acceptable limit to the tilt of the camera from the vertical. Whereas 2° is usually regarded as the limit under peace-time conditions, when time is not an over-riding factor and corrections for tilt can accordingly be incorporated with some loss of time and effort, no such limit can be readily ascribed to similar photography under war conditions. It may well be necessary to accept photographs that are below the normal usable standard because weather conditions or enemy reaction make it unlikely that better ones will be

/obtained......

obtained within a useful time; on the other hand a higher standard may be demanded if usable maps are to be produced in time for their military use.

Certain requirements were laid down in "War Office Policy Statement No. 33 (Air Survey)" dated 3rd August, 1951, namely that it should be possible to stabilise the camera to within 15 minutes of tilt from the vertical and preferably to within 1 minute, such angles of tilt to be recorded by an automatic observer when each photograph was taken. The American view on this requirement, given in their "Comments on draft revised War Office Policy Statement" issued by the Engineer Research and Development Laboratories, Fort Belvoir, Virginia on 16th April, 1951, was that camera stabilisation should be within 3 minutes for precise photogrammetric plotting without ground control (that is without any supplementary ground survey measurements), but that ± 1 degree was considered sufficient for general mapping coverage.

There are then three standards against which the lateral and directional steadiness of the aircraft is to be measured, namely the ± 2 degrees of tilt at present tolerated by the map preparers, the ± 1 degree considered good enough by the Americans for general map coverage, and the ± 1 or 3 minutes considered as a desirable target for future developments. The angle of tilt is of course a combination of the angle of bank and the angle of pitch, the change of heading merely displacing the centre of the photograph further from the mean track of the aircraft. In the particular case where the camera setting for fore-and-aft vertical alignment is correct, the angle of tilt is correctly represented by the angle of bank. Unfortunately, as explained in section 3.2., the limitations of the measuring system prevented the direct establishment of the angle of bank from the horizontal and the concept of change of angle of bank between successive photographs had to be used instead. It is then no longer possible to assess the aircraft's behaviour directly against the angle of tilt requirements, but some assessment can be made if it is assumed that the first photograph is taken with zero bank, when the change of angle of bank to the next photograph represents the tilt at that second instant. (This method gives, of course, an optimistic result when the aircraft is banked in one direction at the first photograph and banks further in that direction for the second photograph; likewise a pessimistic result will be given when the aircraft between photographs reduces the initial angle of bank towards zero, possibly reaching opposite bank.)

To help in this assessment, figure 17 has been prepared to show the total changes in angle of bank that can be expected between successive photographs from a combination of the short-period oscillation and the general wander. The figure gives four bands or zones within which the change of bank may be expected to lie, the upper and lower limits of each band representing the cases where the short-period oscillation respectively augments and reduces the general wander. The band A in the figure gives the combination of the average values of short-period oscillation and general wander, and accordingly represents the limits of change of angle of bank that can be expected for the majority of the survey photographs. Occurring less frequently will be the cases covered by bands B and C, formed by combining the average value of one movement with the maximum value of the other movement. Even less frequently will occur cases represented by band D, where the maxima of both movements combine.

The figure was prepared for the aircraft fitted without wing-tip tanks, but, from the evidence already given, any conclusions should apply equally for the aircraft with wing-tip tanks. It can be seen that, when the pilot was controlling the aircraft by normal use of aileron and rudder, the average change of bank (band A) did not exceed 2 degrees within the speeds and heights tested. On the other hand, changes of bank materially in excess of 2 degrees could be expected, particularly at the higher

/altitudes....

altitudes, though such occurrences would be relatively infrequent. On this evidence, it appears that most of the survey photographs could be used satisfactorily by the map preparers working under peace-time conditions and probably also under war-time conditions but occasional excessive angles of tilt might make several groups of photographs unusable, thereby demanding a repeat sortie. This is much more probable if it should be decided that only 1 degree of tilt can be accepted, as the average change of bank could be equal to or greater than 1 degree at all speeds tested at 25,000 and 45,000 feet and only slightly below 1 degree at 10,000 feet. Considerable improvement was obtained at 45,000 feet by use of the standard autopilot Mk.9 and on the evidence given it seems probable that the average tilt could be kept within the 1 degree limit. Further improvement is also expected by R.A.E. as a result of modification to the gyroscope and the autopilot control (see section 6.5) and later by the introduction of the autopilot Mk.10. Unless considerable improvement is obtained however it is probable that the 15 minute limit of tilt will be exceeded even under calm air conditions. It may well be necessary to use some device such as the auto-stabiliser now being developed at R.A.E. for the elimination of snaking, but whilst this might materially reduce the short-period oscillation it is not certain that it would have any effect on the long-term general wander or the sudden changes of bank and heading that would occur due to gusts. Improvement might well be obtained with gyroscope stabilisation of the camera, though this would necessarily be a considerable complication.

It seems desirable therefore that an investigation be made into the limits of tilt as laid down by the War Office Policy Statement No. 33 (Air Survey). If its requirements are accepted as realistic it may be necessary to formulate new requirements on the damping of the lateral and directional short-period oscillations.

In conclusion, it must be pointed out that there is no reason to suppose that, so far as general wander is concerned, the Canberra aircraft is any worse than any other aircraft for survey photography at high speeds and altitudes. No similar measurements by the methods of this report have been made at this establishment on other aircraft at high altitude, where difficulties in maintaining chosen courses are to be expected because of the low indicated airspeeds and low damping.

7. Conclusions

The present trials showed that even under calm air conditions there was a short period oscillation in heading and angle of bank. Both the period (some 2 to 4 seconds) and the magnitude varied with Mach number and altitude. In addition there were general wanders in heading and bank that appeared to be independent of Mach number and, in the case of angle of bank, also independent of altitude when considered over periods equal to the time intervals between successive photographs of the F.49 survey camera fitted with a 6 inch lens. At Mach numbers near 0.8, the average magnitudes of each of the oscillations and wanders was of the order of 1 degree, though maximum values of 2° and above were measured, all under calm air conditions whilst the pilot was attempting to maintain the aircraft on a constant heading with wings level by normal use of the three flying controls. The effects of freeing the rudder and also of using the standard autopilot Mk.9 are described in the report.

The effects of the oscillations and wanders on the aircraft's usefulness in the survey role have been discussed in the report. From the evidence provided, it would seem that most of the photographs obtained under calm air conditions could be used by a survey mapping section under peace-time conditions, and probably also under war conditions when the time allowed for map preparation may well be curtailed. It is probable that the closer limits of flying implied by the restriction of

/the.....

the permissible angle of camera tilt to 1 degree could be met under calm air conditions by using the standard autopilot Mk.9, but any further reduction in this angle of tilt, either to meet War Office policy requirements or to allow a margin for flight under non-calm air conditions, would require further improvements in control. Modifications to give improvements in the standard autopilot Mk.9 are being developed by R.A.E., pending completion of the autopilot Mk.10 intended for the aircraft. Nevertheless if, despite the known behaviour of aircraft at high altitude the War Office persist in their requirements to restrict the camera tilt to 15 minutes and ultimately to 1 minute, then it is probable that gyroscopic stabilisation of the camera will be required, possibly coupled with the use of some such device as the auto-stabiliser now being tested at R.A.E. for the elimination of snaking.

8. Further developments

(a) Arrangements are being made for the Directorate of Military Survey to study the photographs obtained with the aircraft on the trials at Castel Benito and prepare maps from them. This will help directly in the assessment for peacetime photography in the survey role.

(b) Tests should be made with the autopilot Mk.9 in its modified form, if there are indications that it is any better than the standard Mk.9.

(c) An investigation into the limits of tilt as laid down by the War Office Policy Statement No. 33 (Air Survey) should be undertaken to determine whether the requirements are realistic in the light of the known behaviour of aircraft.

(d) It may be necessary to formulate new requirements on the damping of the short-period oscillation.

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CANBERRA PR 3 V X 181

Level flight with flaps and undercarriage up; air brakes in wing-tip tanks not fitted

Height (feet)	Camera Interval (Secs.)	Type of Control	Approx. I.A.S. (knots)	Indicated Mach number.	Double-amplitude of short period oscillation (degrees)				Wander between successive Photographs (Degrees)				Fig Number	Remarks
					Directional		Lateral		Directional		Lateral			
					Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum		
10,000	8	Pilot	390	0.70	0	1/4	1/4	1/2	0.2	0.5	0.6	1.4	3a	
			400	0.72	0	1/4	0	1/2	0.3	0.7	0.5	1.7	3b	
			410	0.74	1/4	1/2	1/4	1/2	0.2	0.4	0.7	2.3	3c	
			420	0.76	1/4	1/2	1/4	1/2	0.2	0.5	0.6	1.8	3d	
			425	0.77	1/4	1/2	1/4	3/4	0.2	0.6	0.7	1.8	3e	
			440	0.795	1/2	3/4	-	-	-	-	-	-	3f	Heavy Buffet; Test Stopped.
25,000	18	Pilot	290	0.71	0	0	0	-	0.5	1.2	1.0	2.8	4a	
			300	0.73	0	1/2	0	-	0.9	1.7	0.9	1.7	4b	
			310	0.75	1/4	1/2	0	-	0.6	1.9	1.2	3.9	4c	
			325	0.79	1/2	1	1/2	1 3/4	0.3	0.5	0.5	1.3	4d	
			330	0.81	1/2	1/2	1	-	0.5	1.1	0.9	3.0	4e	
45,000	34	Pilot	190	0.725	1/4	1/2	3/4	1 1/4	0.8	1.7	1.1	3.0	5a.	
			190	0.73	1/4	1	1/2	2 3/4	1.1	2.0	1.3	3.3	5b.	
			200	0.75	1/4	1/2	1/4	1 1/4	0.5	0.9	0.6	1.6	5c.	
			205	0.77	1/4	3/4	1/2	1 1/4	1.1	2.3	1.4	3.1	5d.	
			210	0.785	3/4	1	1	2 1/4	0.8	2.2	1.0	2.9	5e.	
			220	0.805	3/4	1 1/2	1 1/4	2 1/2	0.6	1.6	0.8	2.2	5f.	

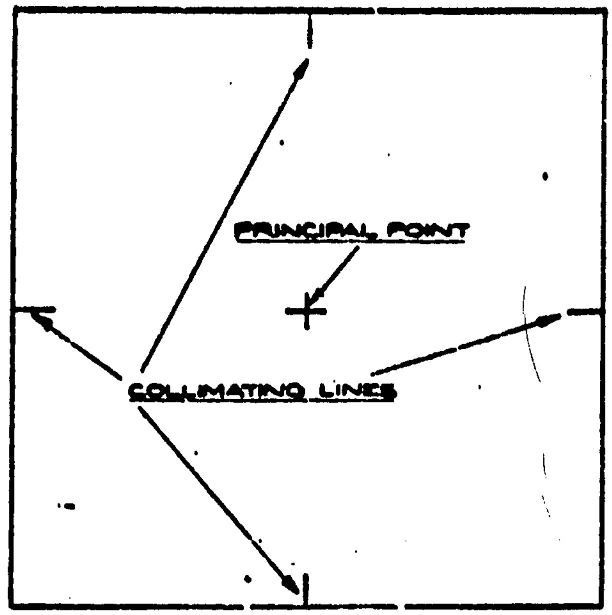
/Table 2......

Canberra PR 3 VX 181.

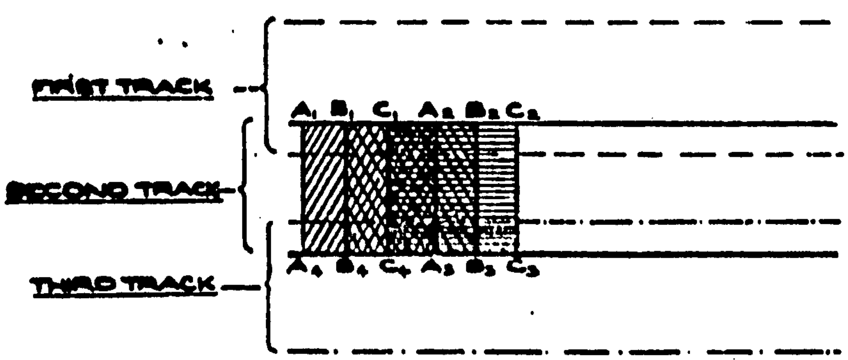
Level flight with flaps and undercarriage up; air brakes in. wing-tip tanks fitted.

Height (feet)	Camera Interval (Secs.)	Type of Control	Approx. I.A.S. (knots)	Indicated Mach Number	Double Amplitude of short-period oscillation (Degrees) Directional Average	Directional Maximum	Lateral Average	Lateral Maximum	Wander between Successive Photographs (Degrees) Directional Average	Directional Maximum	Lateral Average	Lateral Maximum	Fig. Number	Remarks
25,000	18	Pilot	290	0.715	0	½	0	-	0.4	0.7	0.9	2.4	6a	
			300	0.73	0	½	0	-	0.4	0.8	1.2	3.7	6b	
			310	0.75	0	½	0	-	0.5	1.1	1.0	2.5	6c.	
			315	0.77	½	½	0	-	0.4	0.9	1.1	3.7	6d.	
			325	0.79	¾	1½	½	-	1.3	2.1	1.0	2.3	6e	
		Pilot, but rudder free.	300	0.73	0	0	0	0	0.7	1.3	0.7	1.8	7a	
			310	0.75	½	½	0	½	0.3	0.8	1.0	2.2	7b	
			325	0.795	½	1	¼	-	0.3	0.6	0.8	1.9	7c	
		Autopilot Mk.9	300	0.73	0	½	0	½	0.6	0.8	0.2	0.6	7d	
			310	0.75	¼	½	0	½	0.8	1.2	0.6	1.7	7e	
			315	0.77	0	½	0	¼	1.4	1.7	0.7	1.4	7f.	
45,000	34	Pilot	185	0.715	½	½	¼	-	0.7	1.4	0.8	1.9	8a	
			195	0.735	½	½	¼	1	0.7	1.6	1.0	2.5	8b	
			200	0.75	½	½	-	-	2.1	3.0	1.3	4.8	8c	
			205	0.77	½	1	½	1	0.5	0.9	0.8	2.0	8d	
			210	0.785	¾	1	½	1½	0.9	1.5	1.2	2.3	8e	
			220	0.805	1	1	½	1½	0.4	0.9	0.7	1.8	8f.	
		Pilot, but rudder free.	195	0.74	0	½	0	-	0.5	0.8	0.9	2.4	9a	
			205	0.77	¾	1	½	2½	0.4	0.9	0.9	2.5	9b	
			220	0.805	1¼	1½	¾	3	0.6	1.1	1.4	2.8	9c	
		Autopilot Mk.9.	185	0.715	0	½	0	0	2.0	2.6	0.4	0.9	9d	
			195	0.74	0	0	0	0	0.5	0.9	0.3	0.6	9e	
			210	0.7[illegible]	¼	¼	0	0	2.4	2.8	0.5	1.5	9f	

FIG. 1



1(a) REFERENCE MARKS ON SURVEY PHOTOGRAPHS



1(b) OVERLAPPING OF PHOTOGRAPHS (DIAGRAMMATIC ONLY).

SURVEY PHOTOGRAPHY.

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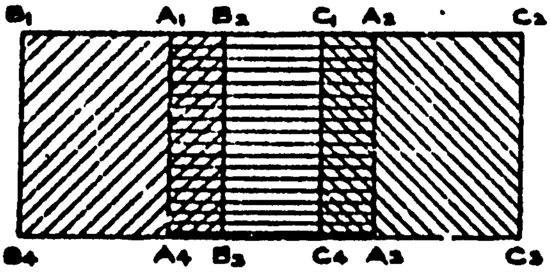
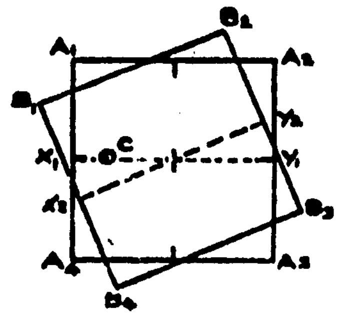
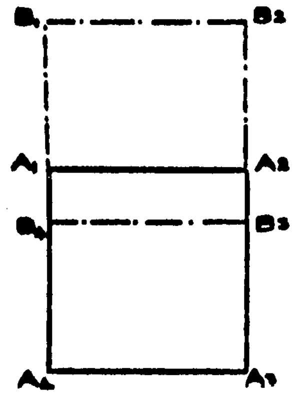


2(a) DISPLACEMENT IN PITCH.



2(b) DISPLACEMENT IN YAW.



2(c) DISPLACEMENT IN ROLL.

DISPLACEMENTS OF AERIAL PHOTOGRAPH IN PITCH, YAW, AND ROLL.

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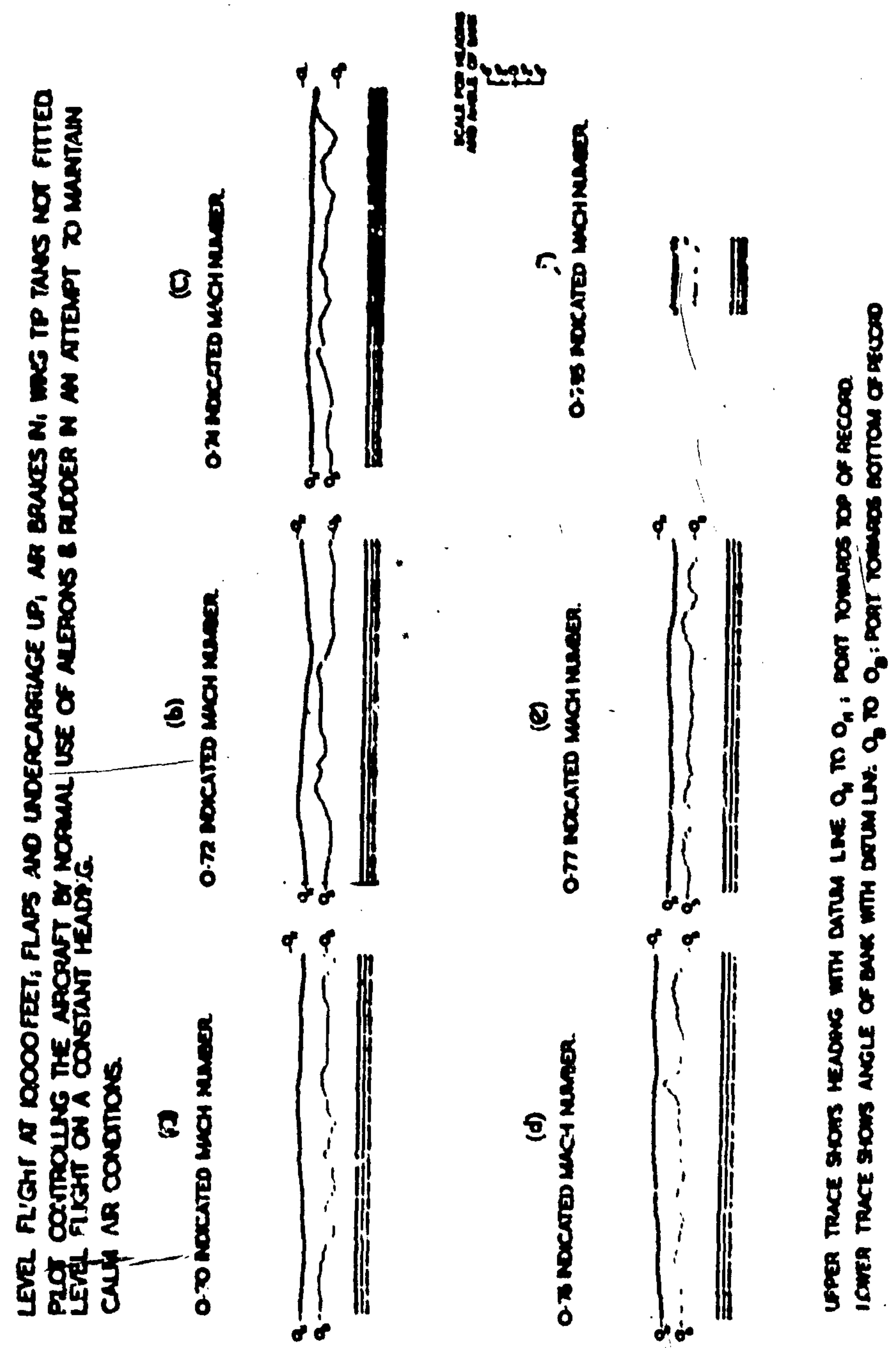
FIG. 3.



HUSSENOT RECORDS OF AIRCRAFT HEADING AND ANGLE OF BANK.

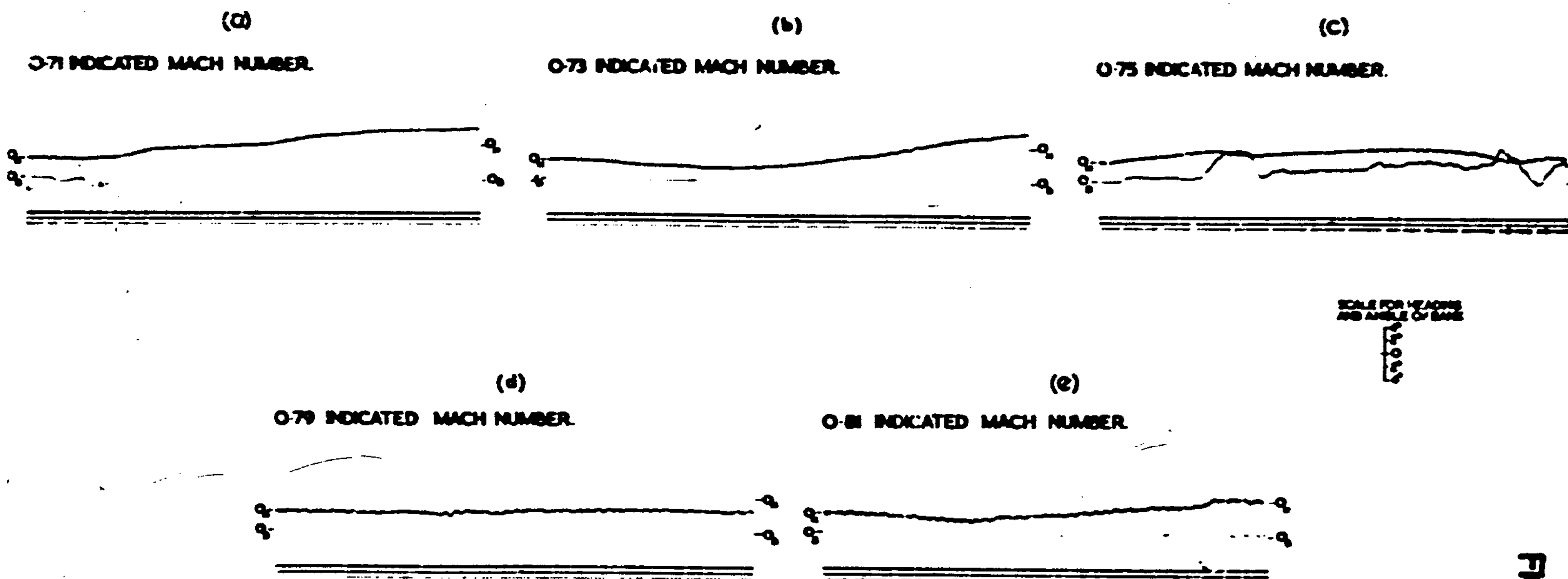
A.& A.E.E. NEG. No 19819

CANBERRA PR3 VX 181

LEVEL FLIGHT AT 25,000 FEET, FLAPS AND UNDERCARRIAGE UP, AIR BRAKES IN, WING TIP TANKS NOT FITTED.

PILOT CONTROLLING THE AIRCRAFT BY NORMAL USE OF AILERONS & RUDDER IN AN ATTEMPT TO MAINTAIN LEVEL FLIGHT ON A CONSTANT HEADING.

CALM AIR CONDITIONS.



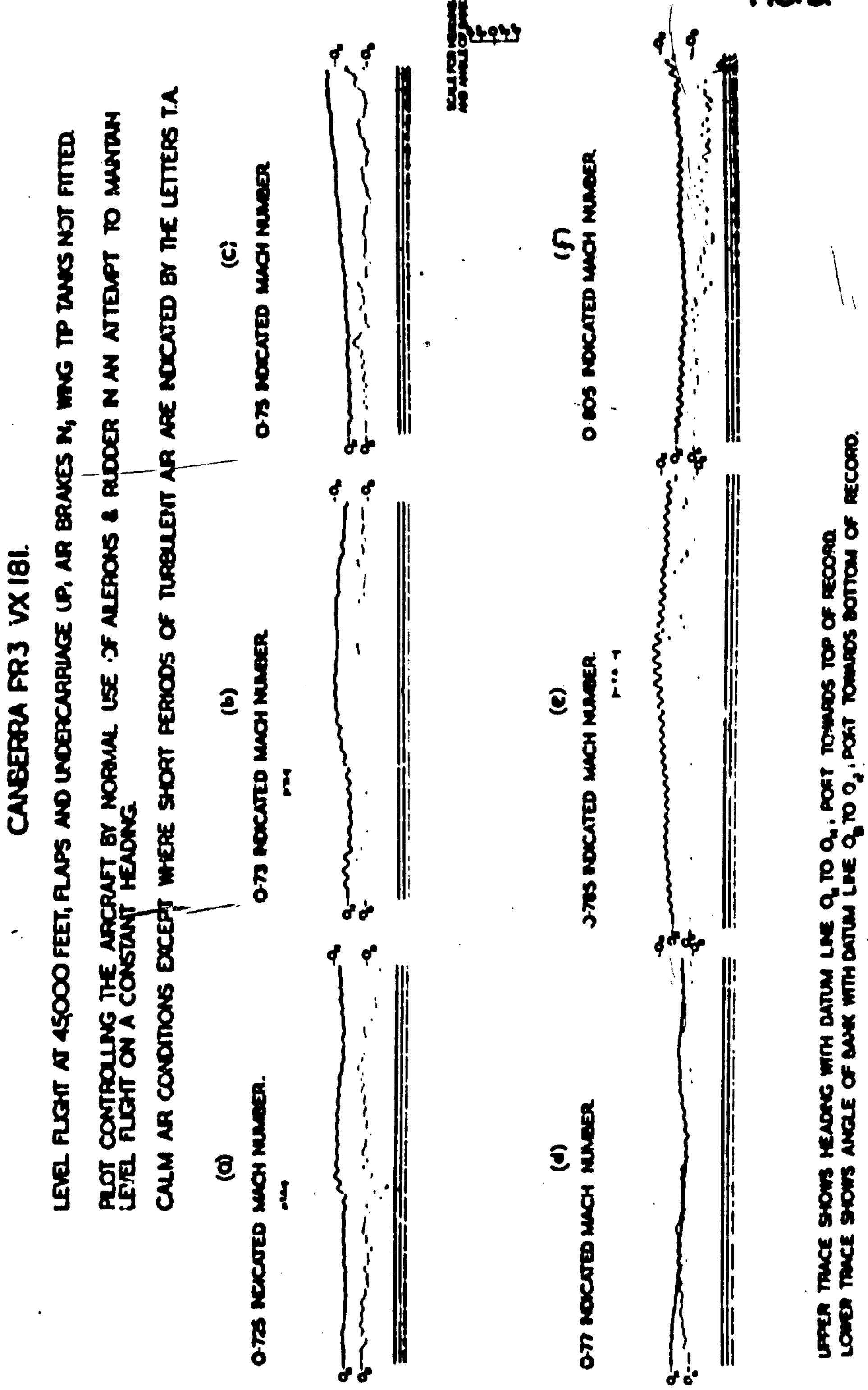
UPPER TRACE SHOWS HEADING WITH DATUM LINE O_H TO O_H ; PORT TOWARDS TOP OF RECORD.
LOWER TRACE SHOWS ANGLE OF BANK WITH DATUM LINE O_B TO O_B ; PORT TOWARDS BOTTOM OF RECORD.

FIG. 4.

HUSSENOT RECORDS OF AIRCRAFT HEADING AND ANGLE OF BANK.

A.& A.E.E. NEG. No. 16518.

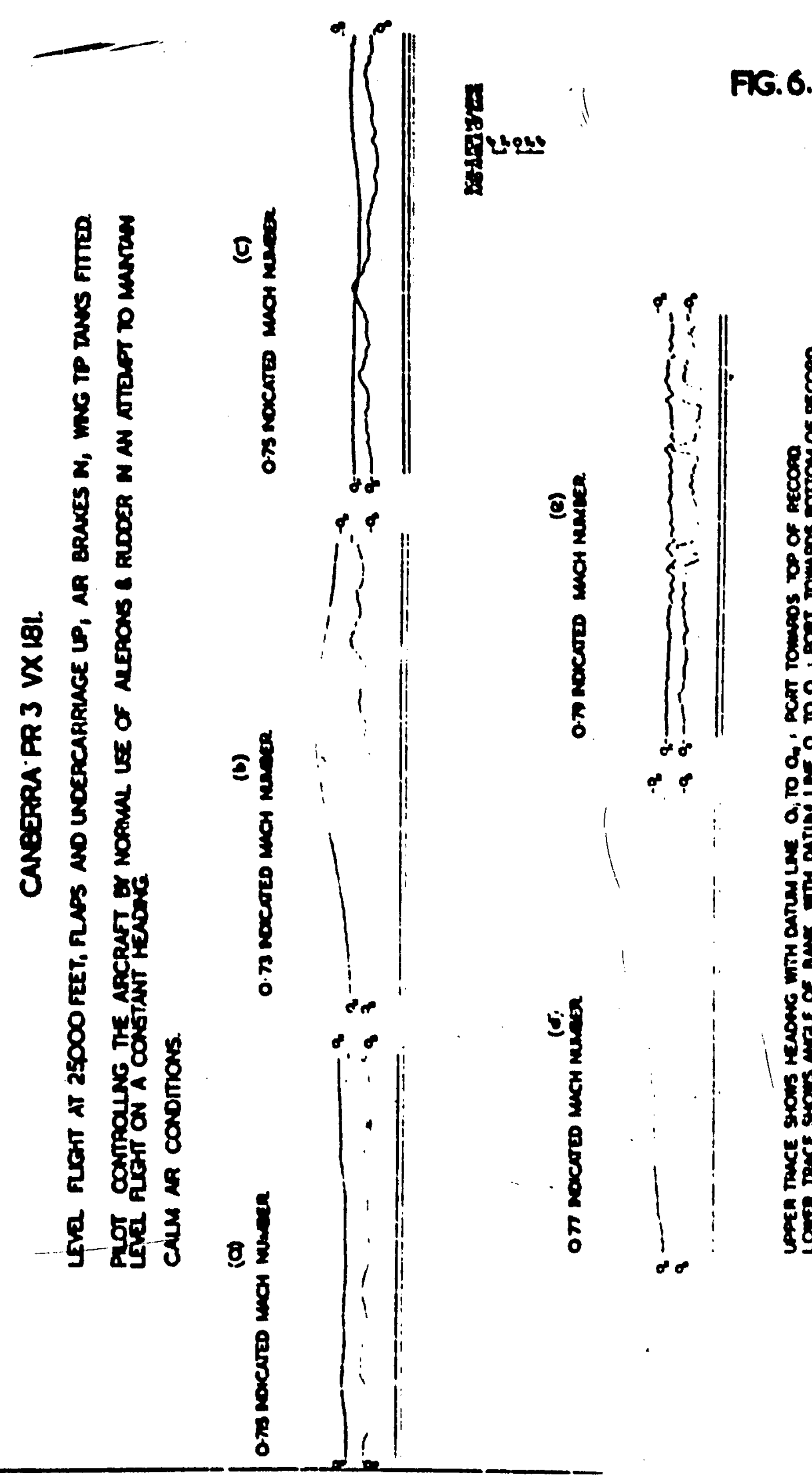
FIG. 5.



HUSSENOT RECORDS OF AIRCRAFT HEADING AND ANGLE OF BANK.

A.& A.E.E. NEG. No 15919.

FIG. 6.



HUSSENOT RECORDS OF AIRCRAFT HEADING AND ANGLE OF BANK.

CANBERRA PR3 VX181.

LEVEL FLIGHT AT 25,000 FEET. FLAPS AND UNDERCARRIAGE UP; AIR BRAKES IN, WING TIP TANKS FITTED.
CALM AIR CONDITIONS.

(i) PILOT CONTROLLING THE AIRCRAFT WITH AILERONS ONLY (LEAVING RUDDER FREE) IN AN ATTEMPT TO MAINTAIN LEVEL FLIGHT ON A CONSTANT HEADING.

(a) 0·73 INDICATED MACH NUMBER.

(b) 0·75 INDICATED MACH NUMBER.

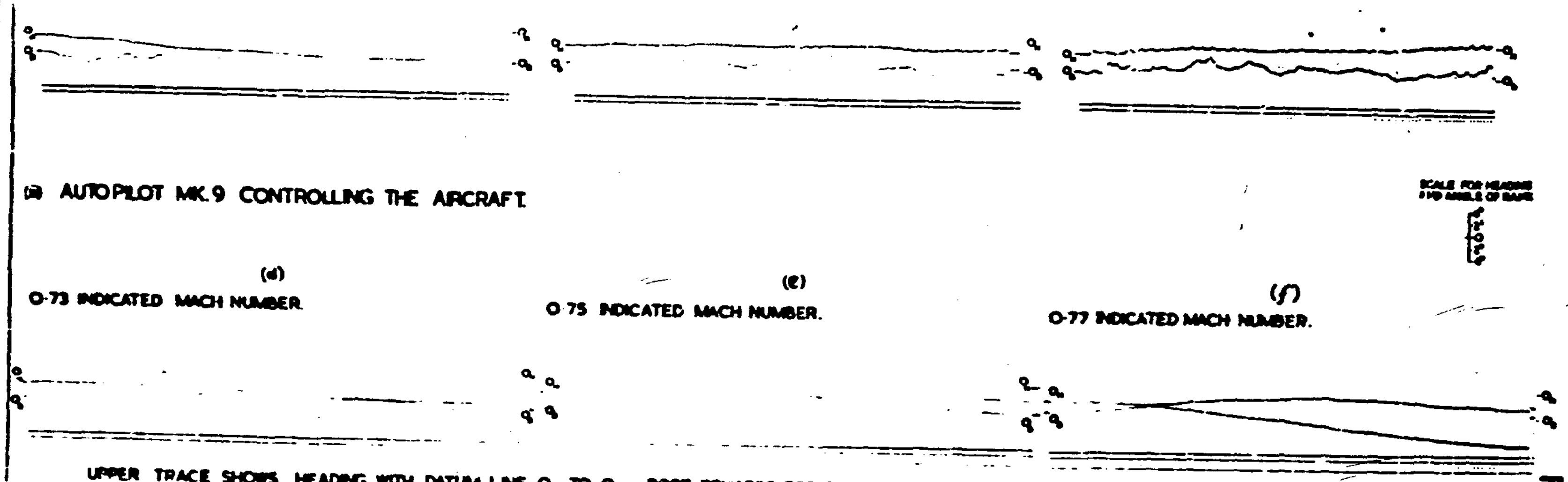
(c) 0·795 INDICATED MACH NUMBER.

(ii) AUTOPILOT MK.9 CONTROLLING THE AIRCRAFT.

(d) 0·73 INDICATED MACH NUMBER.

(e) 0·75 INDICATED MACH NUMBER.

(f) 0·77 INDICATED MACH NUMBER.

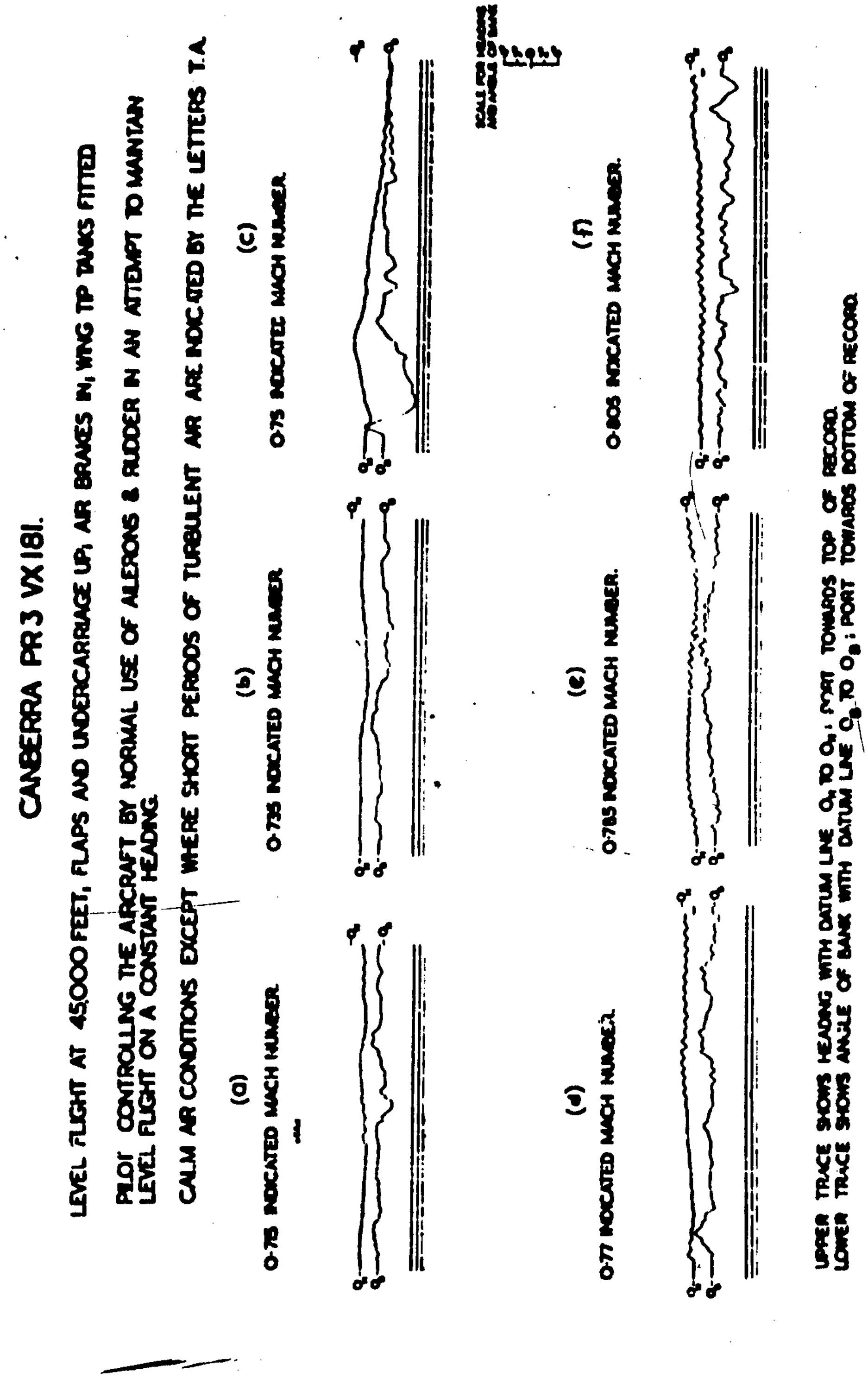


UPPER TRACE SHOWS HEADING WITH DATUM LINE O_H TO O_H, PORT TOWARDS TOP OF RECORD.
LOWER TRACE SHOWS ANGLE OF BANK WITH DATUM LINE O_B TO O_B, PORT TOWARDS BOTTOM OF RECORD.

FIG. 7.

HUSSENOT RECORDS OF AIRCRAFT HEADING AND ANGLE OF BANK.

FIG. 8.



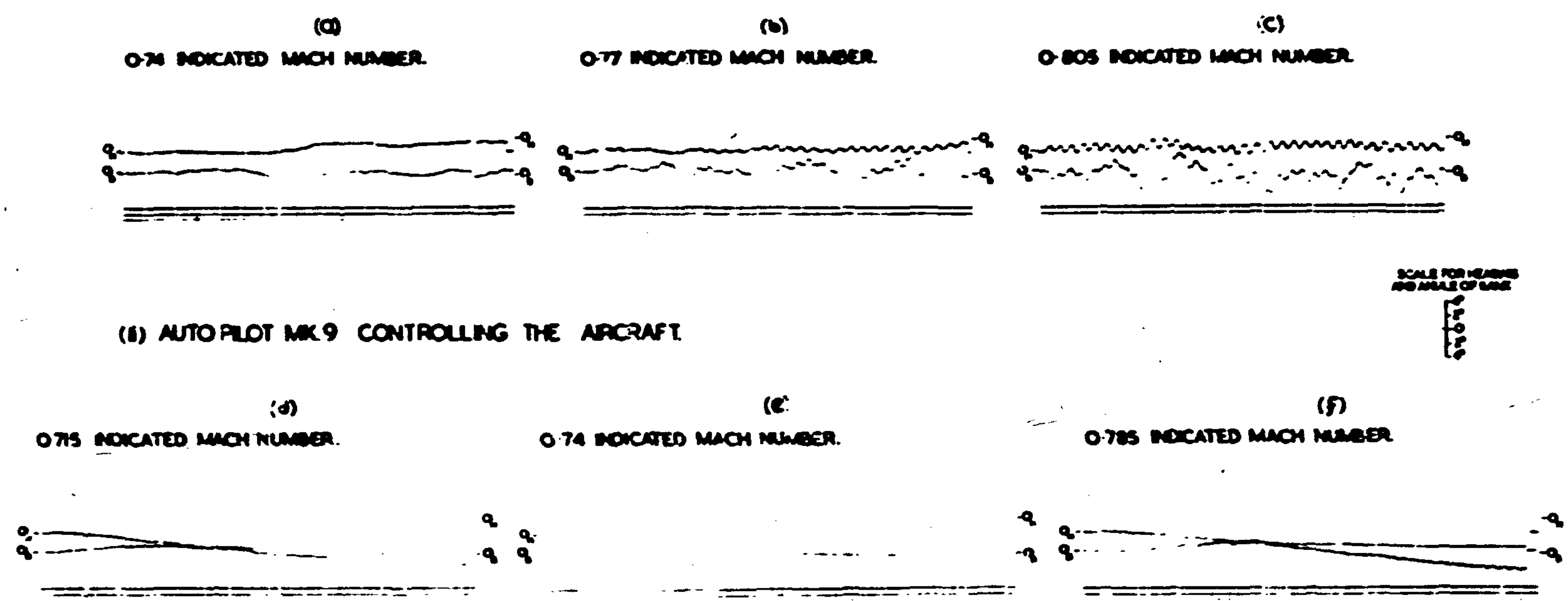
HUSSENOT RECORDS OF AIRCRAFT HEADING AND ANGLE OF BANK.

CANBERRA PR 3 VX 181

LEVEL FLIGHT AT 45000 FEET; FLAPS AND UNDERCARRIAGE UP; AIR BRAKES IN; WING TIP TANKS FITTED. CALM AIR CONDITIONS.

(I) PILOT CONTROLLING THE AIRCRAFT WITH AILERONS ONLY (LEAVING RUDDER FREE) IN AN ATTEMPT TO MAINTAIN LEVEL FLIGHT ON A CONSTANT HEADING.

(II) AUTO PILOT MK 9 CONTROLLING THE AIRCRAFT.



UPPER TRACE SHOWS HEADING WITH DATUM LINE O_H TO O_H; PORT TOWARDS TOP OF RECORD.
LOWER TRACE SHOWS ANGLE OF BANK WITH DATUM LINE O_B TO O_B; PORT TOWARDS BOTTOM OF RECORD.

FIG. 9.

HUSSENOT RECORDS OF AIRCRAFT HEADING AND ANGLE OF BANK.

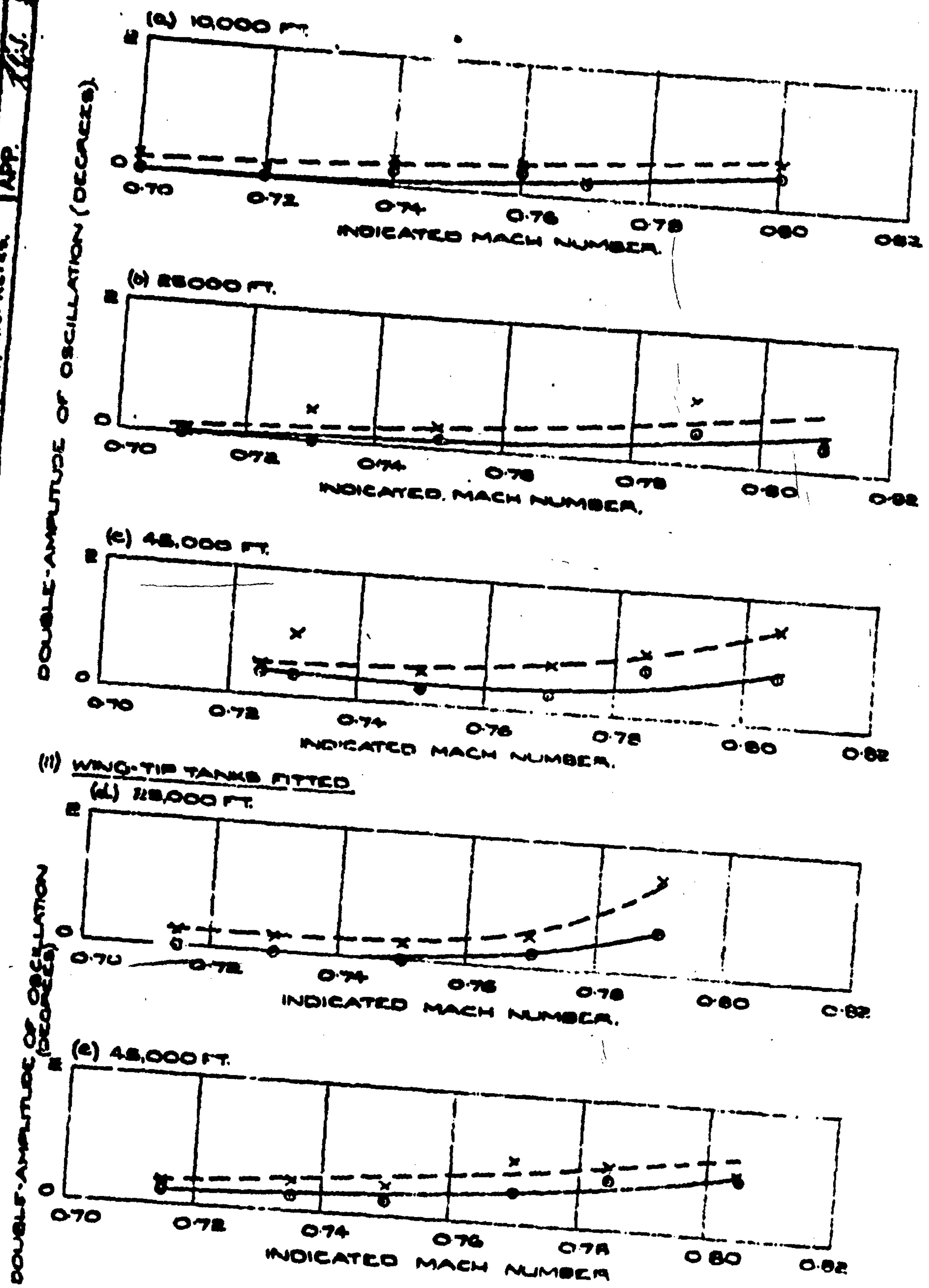
FIG. 10.

LEVEL FLIGHT WITH FLAPS & UNDERCARRIAGE UP, AIR BRAKES IN. PILOT CONTROLLING.

O———O AVERAGE.

X— — —X MAXIMUM WITHIN 2 MINS.

(i) WING-TIP TANKS NOT FITTED.

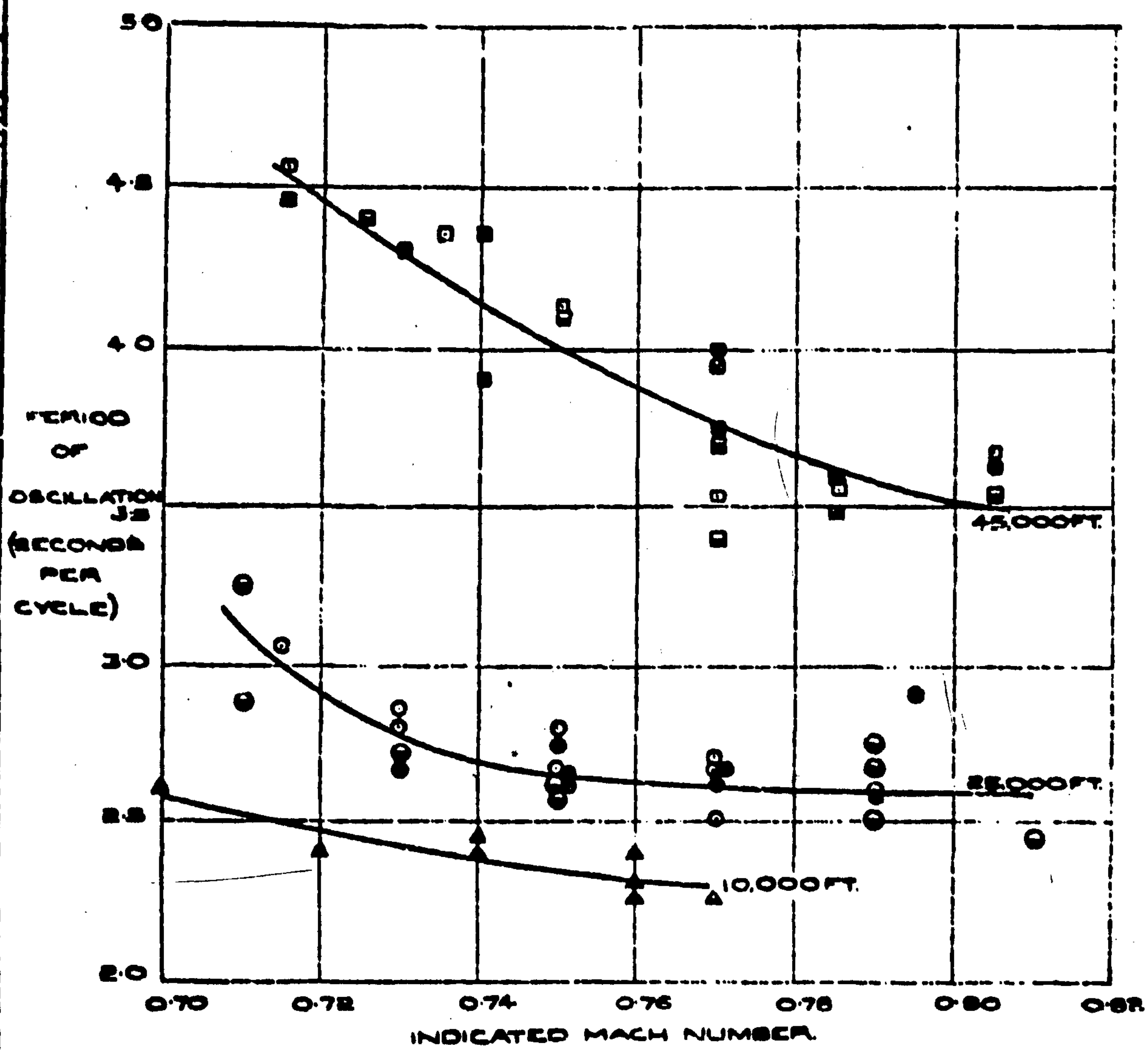


DOUBLE-AMPLITUDE OF SHORT PERIOD DIRECTIONAL OSCILLATION

K.No A396a T.O. PART OF REPORT No. A&AEE/881/2 TR. CH. H.T. KEYES. APP.

FIG. 11.

LEVEL FLIGHT WITH FLAPS & UNDERCARRIAGE UP
AIR BRAKES IN



HEIGHT (FEET)	WING-TIP TANKS ON	WING-TIP TANKS OFF	DESCRIPTION.
10,000		▲	PILOT CONTROLLING.
25,000	⊙ ◉ ⊕	⊖	PILOT CONTROLLING. PILOT CONTROLLING, BUT RUDDER FREE. AUTOPILOT MK.9 CONTROLLING.
45,000	⊡ ▣ ■	⊟	PILOT CONTROLLING. PILOT CONTROLLING BUT RUDDER FREE. AUTOPILOT MK.9. CONTROLLING.

PERIOD OF DIRECTIONAL OSCILLATION.

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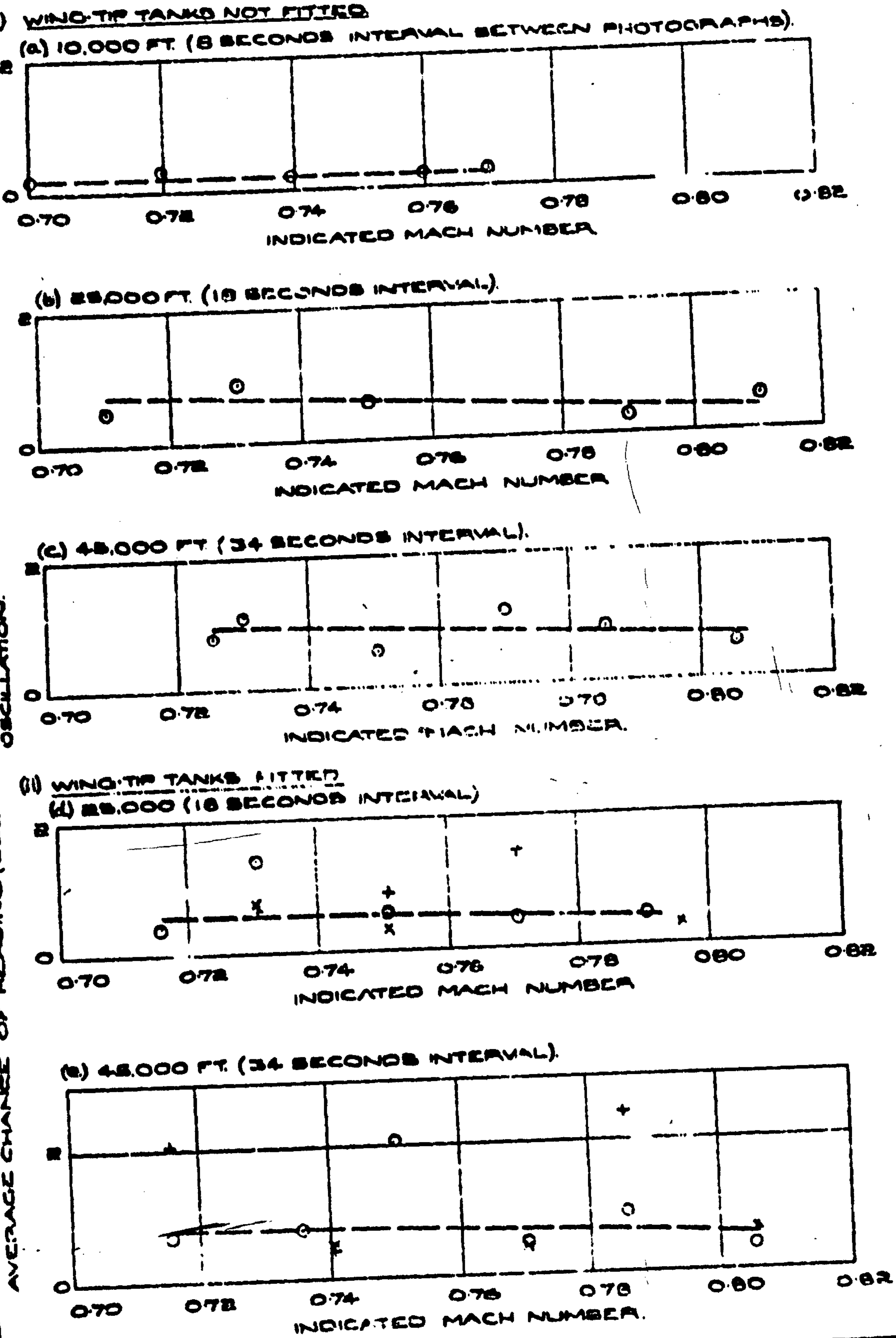
FIG. 12

LEVEL FLIGHT WITH FLAPS & UNDERCARRIAGE UP, AIR BRAKES IN.

⊙ PILOT CONTROLLING THE AIRCRAFT BY NORMAL USE OF AILERON AND RUDDER IN ATTEMPTING TO MAINTAIN LEVEL FLIGHT ON A CONSTANT HEADING.

× AS ABOVE, BUT RUDDER LEFT FREE

+ AUTOPILOT MK 9 CONTROLLING.



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AVERAGE CHANGE OF HEADING BETWEEN SUCCESSIVE PHOTOGRAPHS

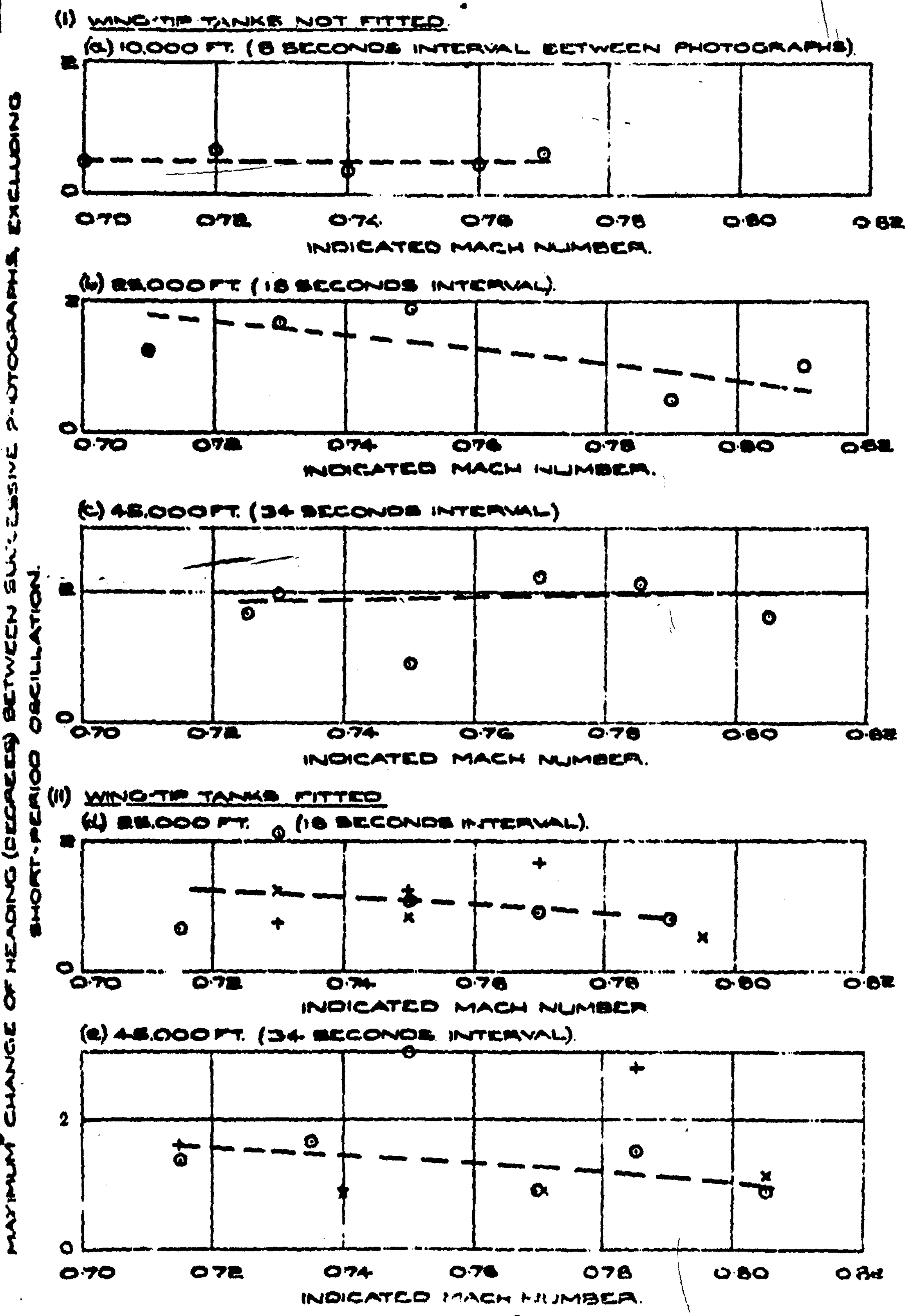
FIG.13.

LEVEL FLIGHT WITH FLAPS & UNDERCARRIAGE UP, AIR BRAKES IN.

O PILOT CONTROLLING THE AIRCRAFT BY NORMAL USE OF AILERON AND RUDDER IN ATTEMPTING TO MAINTAIN LEVEL FLIGHT ON A CONSTANT HEADING.

X AS ABOVE, BUT RUDDER LEFT FREE.

+ AUTOPILOT MK.9 CONTROLLING.



*LIKELY TO BE OBTAINED ON 5% OF OCCASIONS.

MAXIMUM CHANGE OF HEADING BETWEEN SUCCESSIVE PHOTOGRAPHS.

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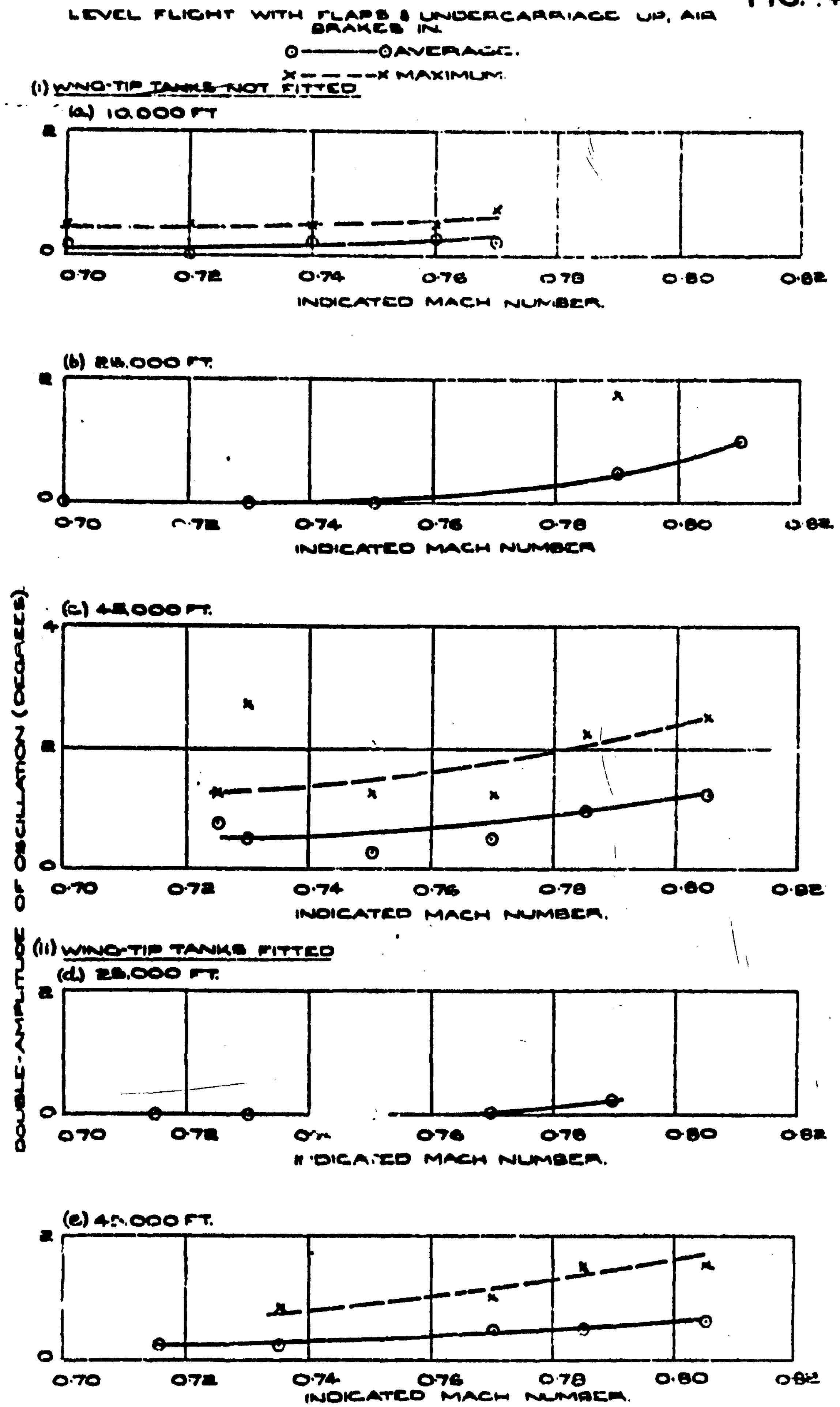
FIG. 14.



DOUBLE-AMPLITUDE OF SHORT-PERIOD LATERAL OSCILLATION.

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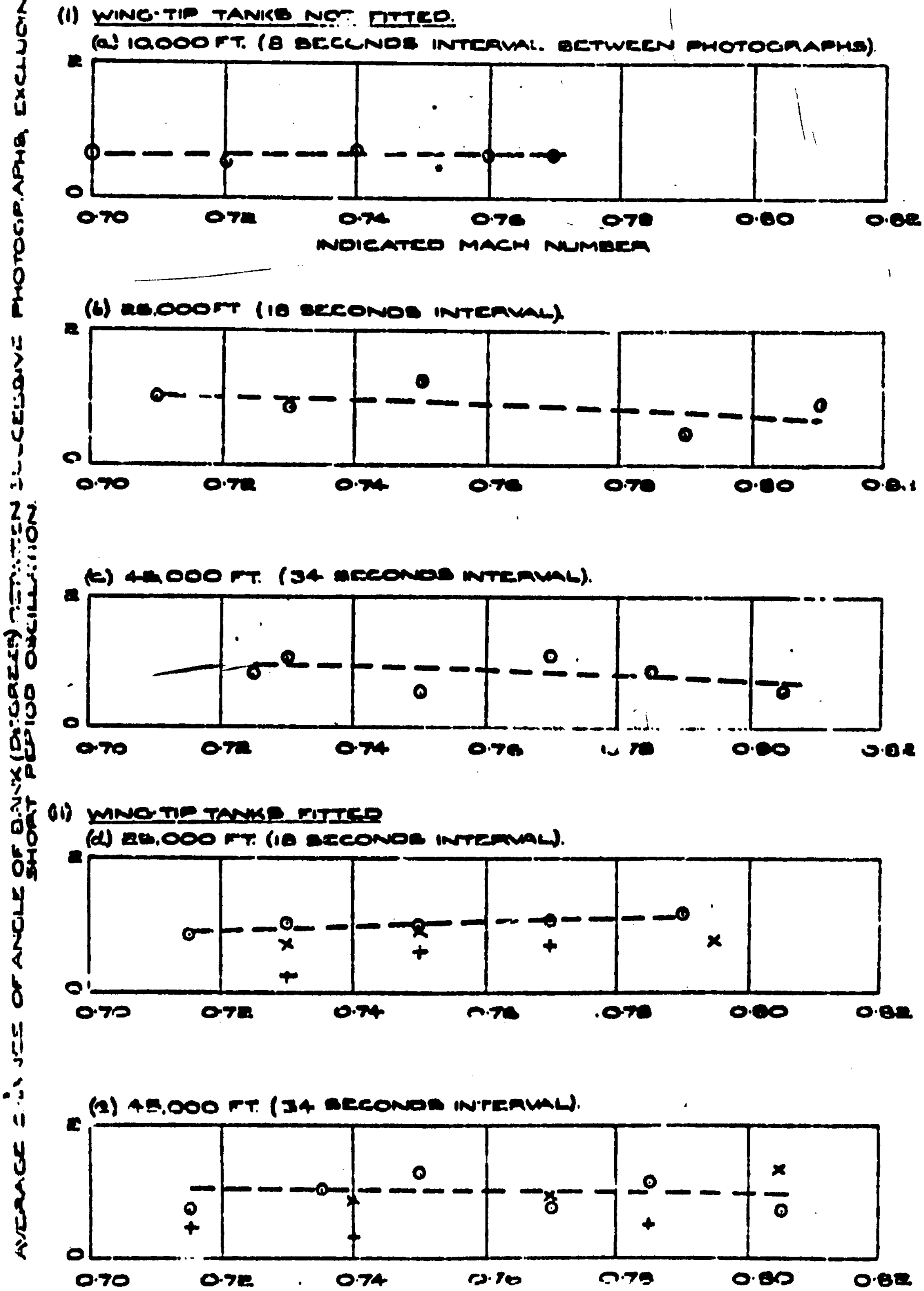
FIG. 15.

LEVEL FLIGHT WITH FLAPS & UNDERCARRIAGE UP AIR BRAKES IN.

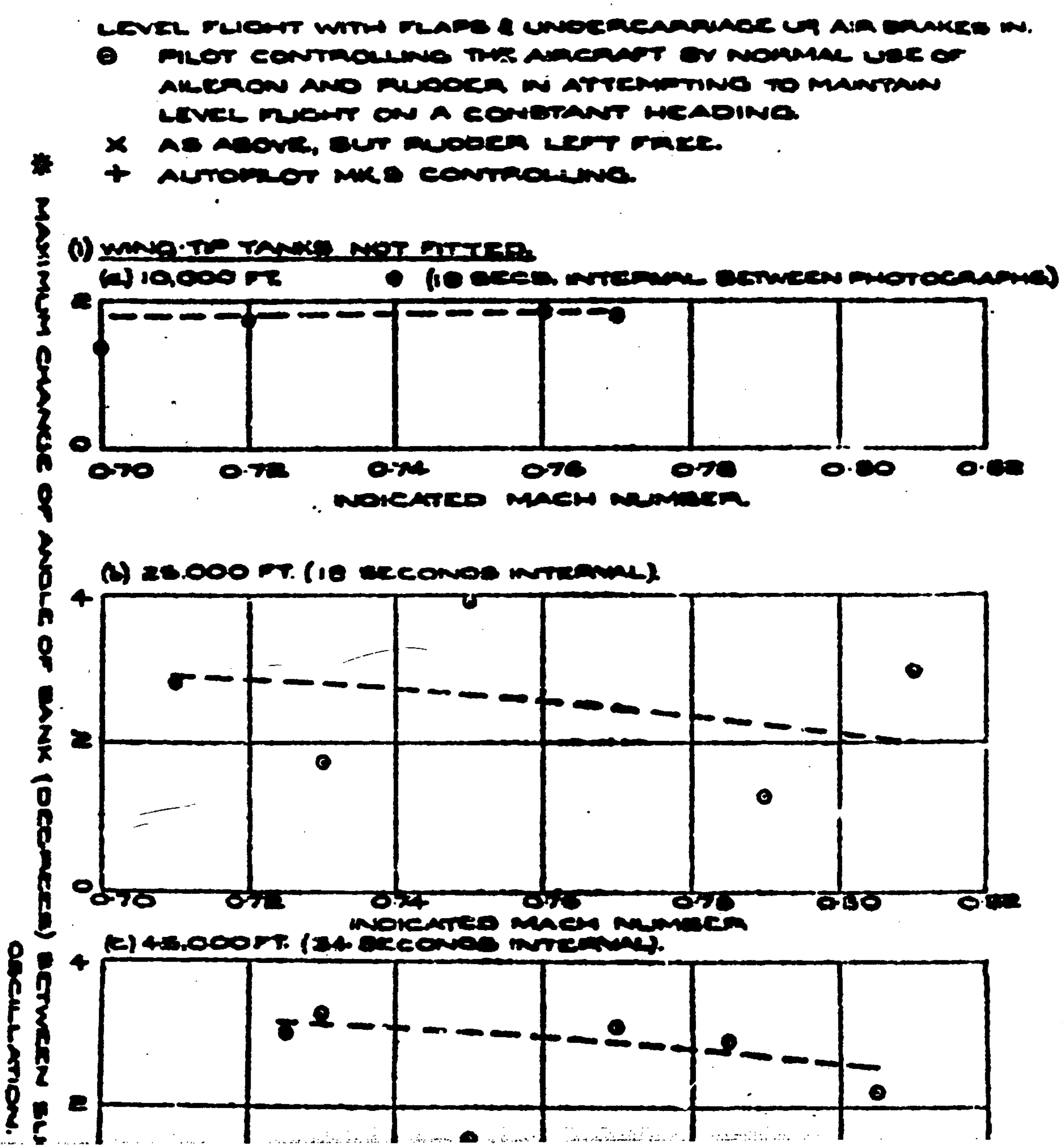
⊙ PILOT CONTROLLING THE AIRCRAFT BY NORMAL USE OF AILERON AND RUDDER IN ATTEMPTING TO MAINTAIN LEVEL FLIGHT ON A CONSTANT HEADING.

× AS ABOVE, BUT RUDDER LEFT FREE.

+ AUTOPILOT MK.9 CONTROLLING.

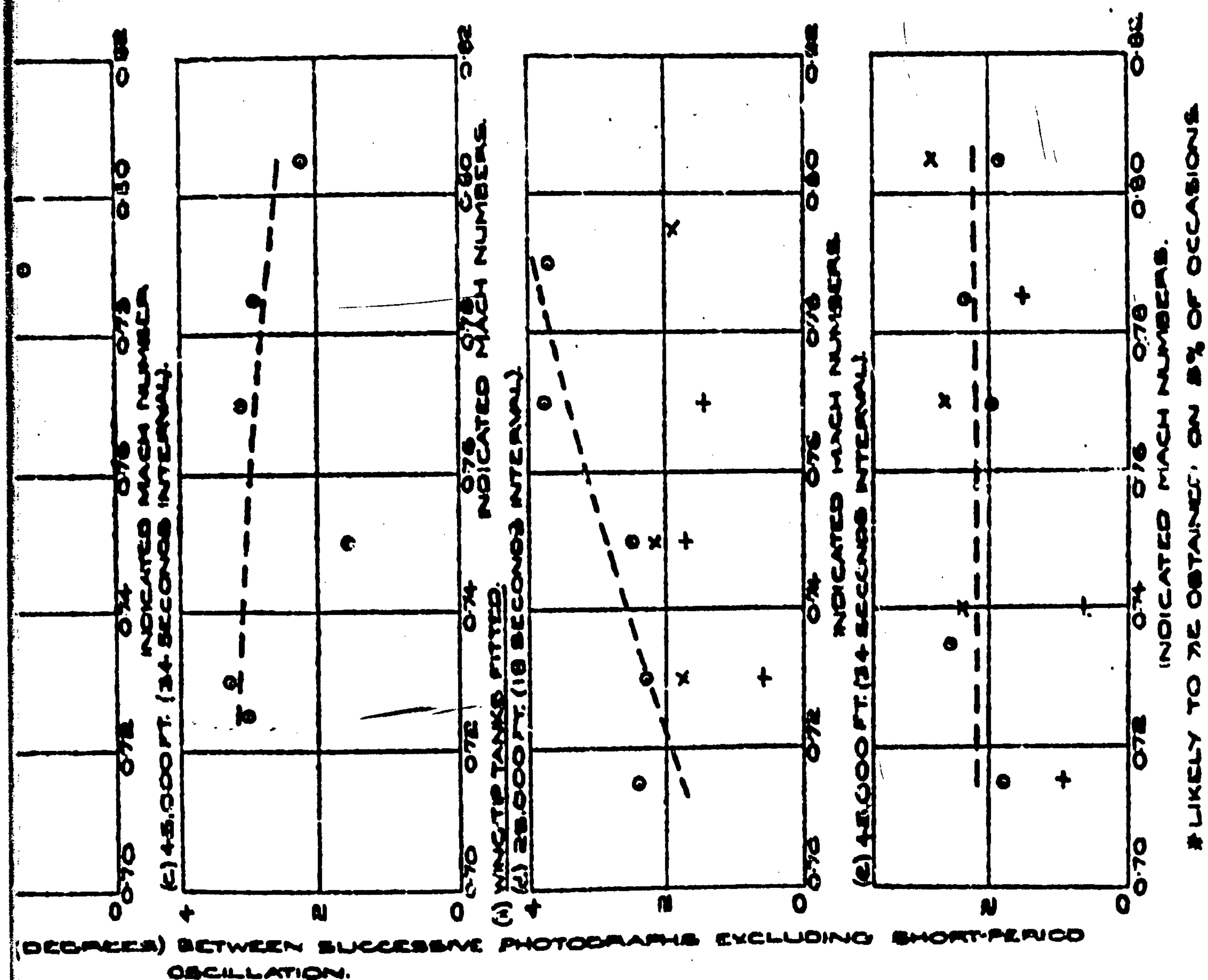


AVERAGE CHANGE OF ANGLE OF BANK BETWEEN SUCCESSIVE PHOTOGRAPHS


LEVEL FLIGHT WITH FLAPS & UNDERCARRIAGE UP, AIR BRAKES IN.
⊙ PILOT CONTROLLING THE AIRCRAFT BY NORMAL USE OF AILERON AND RUDDER IN ATTEMPTING TO MAINTAIN LEVEL FLIGHT ON A CONSTANT HEADING.
X AS ABOVE, BUT RUDDER LEFT FREE.
+ AUTOPILOT MK.9 CONTROLLING.
(i) WING-TIP TANKS NOT FITTED.
(a) 10,000 FT.
(10 SECS. INTERVAL BETWEEN PHOTOGRAPHS)
0·70
0·72
0·74
0·76
0·78
0·80
0·82
INDICATED MACH NUMBER.
(b) 25,000 FT. (10 SECONDS INTERVAL).
INDICATED MACH NUMBER.
(c) 45,000 FT. (34 SECONDS INTERVAL).
* MAXIMUM CHANGE OF ANGLE OF BANK (DEGREES) BETWEEN SU[...] OSCILLATION.

MAX[...]
BETW[...]

FIG. 16.



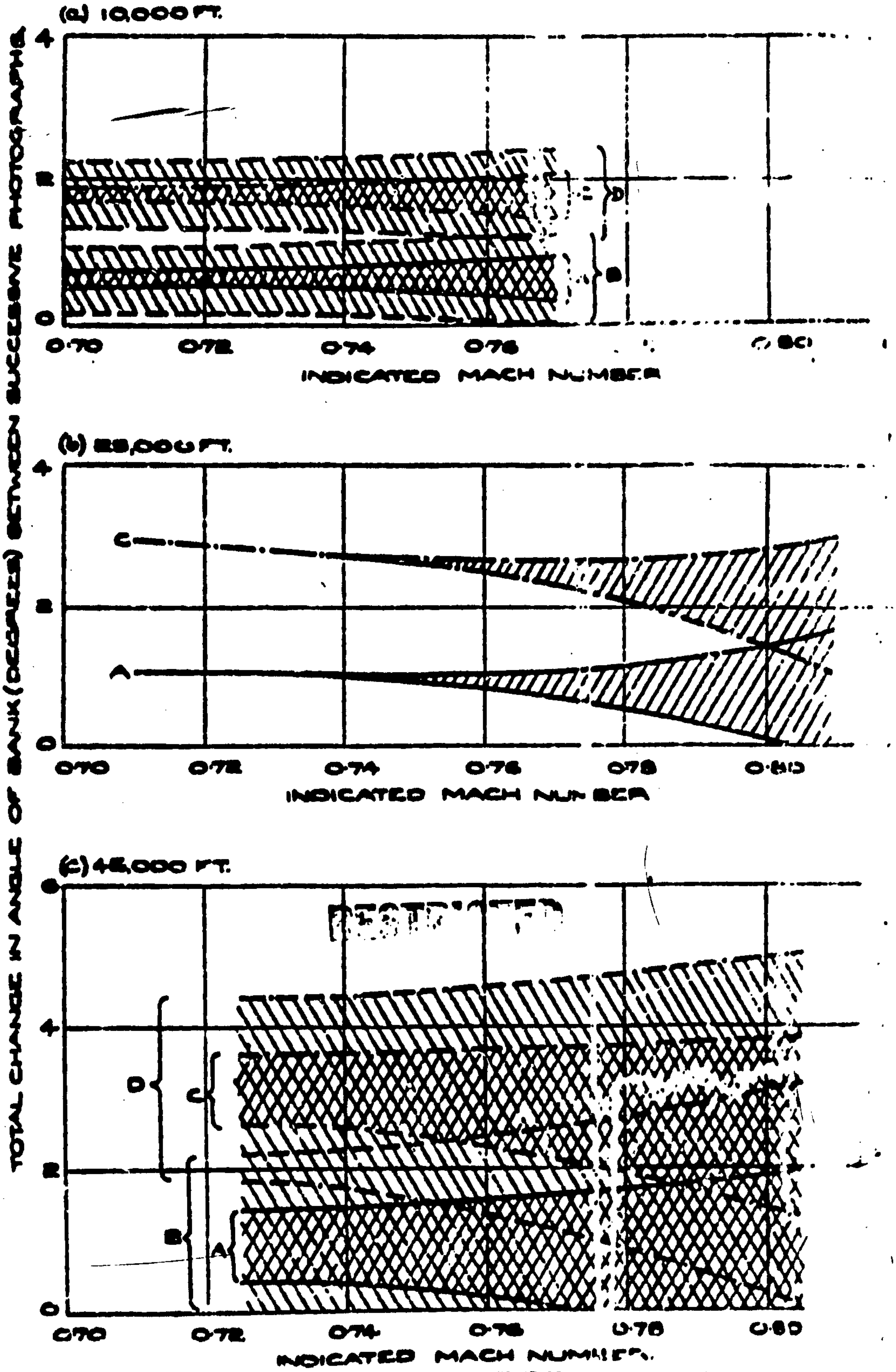
MAXIMUM CHANGE OF ANGLE OF BANK BETWEEN SUCCESSIVE PHOTOGRAPHS.

RESTRICTED

LEVEL FLIGHT — UNDERCARRIAGE UP, AIR BRAKES IN, WING TIP TANKS NOT FITTED.

PILOT CONTROLLING THE AIRCRAFT BY NORMAL USE OF AILERONS & RUDDER IN ATTEMPTING TO MAINTAIN LEVEL FLIGHT ON A CONSTANT HEADING.

A - AVERAGE WANDER ± AVERAGE SHORT-PERIOD OSCILLATION.
B - AVERAGE WANDER ± MAXIMUM SHORT-PERIOD OSCILLATION.
C - MAXIMUM WANDER ± AVERAGE SHORT-PERIOD OSCILLATION.
D - MAXIMUM WANDER ± MAXIMUM SHORT-PERIOD OSCILLATION.



TOTAL CHANGE IN ANGLE OF BANK BETWEEN SUCCESSIVE PHOTOGRAPHS.

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