<table>
<thead>
<tr>
<th>UNCLASSIFIED</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD NUMBR</td>
</tr>
<tr>
<td>AD000001</td>
</tr>
<tr>
<td>CLASSIFICATION CHANGES</td>
</tr>
<tr>
<td>TO:</td>
</tr>
<tr>
<td>FROM:</td>
</tr>
<tr>
<td>LIMITATION CHANGES</td>
</tr>
<tr>
<td>TO:</td>
</tr>
<tr>
<td>FROM:</td>
</tr>
<tr>
<td>AUTHORITY</td>
</tr>
<tr>
<td>DRDS, BDS memo., 22 Jul 1070; DRDS, BDS memo., 22 Jul 1070</td>
</tr>
</tbody>
</table>
NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.
NOTICE: WHEN GOVERNMENT OR OTHER DRAWINGS, SPECIFICATIONS OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY RELATED GOVERNMENT PROCUREMENT OPERAION, THE U. S. GOVERNMENT THEREBY INCURS NO RESPONSIBILITY, NOR ANY OBLIGATION WHATSOEVER; AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED, OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE AS IN ANY MANNER LICENSING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.
MINISTRY OF SUPPLY

AEROPLANE AND ARMAMENT EXPERIMENTAL ESTABLISHMENT

BOSCOMBE DOWN

LATERAL AND DIRECTIONAL BEHAVIOUR AND THE EXTENSION OF THE STABILISING EFFECT

by

R.J. KEYES, R.A.

ATTENTION IS CALLED TO THE PENALTIES ATTACHING TO ANY INFRINGEMENT OF THE OFFICIAL SECRETS ACT.

THE DOCUMENT IS THE PROPERTY OF THE GOVERNMENT.

It is intended for the use of the officers only, and for communication to such officers under them as may require to be acquainted with the contents of the report in the course of their duties. The officers exercising this power of communication will be held responsible that such information is imparted with due caution and reserve. Any person other than the authorised holder, upon obtaining possession of this document, by finding or otherwise, should forward it, together with his name and address, in a sealed envelope to—

THE SECRETARY, MINISTRY OF SUPPLY,
THAMES HOUSE, MILBANK, LONDON, S.W.1.

Letter postage need not be prepaid; other postage will be refunded.

All persons are hereby warned that the unauthorised retention or destruction of this document is: a offence against the Official Secrets Act, 1911-1930.
Lateral and directional behaviour and the effect on survey photography

by

H.J. Kayes, B.A.

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 wanderings in heading and angle of bank. The average magnitudes 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 were of the order of 1 degree. Though maximum values of 2 degrees and above were measured, the effects of freezing the rudder and also of using the standard autopilot Mk 9 are described in the report.

The effects of the oscillations and wanderings 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 those 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 air office

SECURITY INFORMATION

RESTRICTED
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 rough air conditions, would require further improvements in control. Such improvement may be given by a modified autopilot Mk.3 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 R.A.S. for the elimination of rocking, but it seems probable that gyroscopic stabilisation of the camera may be required.

This Report is issued with the authority of

[Signature]
Air Commodore
Commanding, A.E.F.A.S.

SECURITY DESIGNATION

RESTRICTED

List of Contents......
List of Contents

1. Introduction ................................................................................................................. 4
2. Problems involved in survey photography ................................................................. 4
3. Condition of aircraft relevant to tests ........................................................................... 5
4. Scope of tests ............................................................................................................... 6
5. Results of tests ............................................................................................................. 6
   5.1 General ................................................................................................................... 6
   5.2 Short-period directional oscillation ........................................................................ 7
   5.3 General directional wander .................................................................................... 8
   5.4 Short-period lateral oscillation ............................................................................... 9
   5.5 General lateral wander .......................................................................................... 10
6. Discussion of results .................................................................................................... 10
   6.1 Effect of Mach number on the lateral and directional disturbances ...................... 10
   6.2 Effect of altitude .................................................................................................. 11
   6.3 Effect of fitting wing-tip tanks ............................................................................ 11
   6.4 Effect of leaving the rudder free ......................................................................... 11
   6.5 Effect of using the autopilot No. 9 ..................................................................... 12
   6.6 Effect of the oscillations and wander on survey photography ............................... 12
7. Conclusions .................................................................................................................. 14
8. Further developments ..................................................................................................... 15

List of Tables

Table

| Level flight with flaps and undercarriages up; air brakes in. Wing tip tanks not fitted. | 1 |
| Level flight with flaps and undercarriages up; air brakes in. Wing tip tanks fitted. | 2 |

List of Illustrations

Figure

| Survey photography | 1 |
| Displacements of aerial photograph in pitch, yaw, and roll | 2 |
| Hussong records of aircraft heading and angle of bank | 3 - 9 |
| Double-amplitude of short period directional oscillation | 10 |
| Period of directional oscillation | 11 |
| Average change of heading between successive photographs | 12 |
| Maximum change of heading between successive photographs | 13 |
| Double-amplitude of short-period lateral oscillation | 14 |
| Average change of angle of bank between successive photographs | 15 |
| Maximum change of angle of bank between successive photographs | 16 |
| Total change of angle of bank between successive photographs | 17 |

SECURITY INFORMATION

/1. Introduction...
1. Introduction

In the 4th part of Anzare/Report No. 861/2, it was stated that the lateral and directional behaviour of the Canberra P1 3 VX197 without wing-tip tanks was worse than on Canberra P2 aircraft previously tested and precluded the flying of an accurate compass course. It was suggested that the following 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 Bonito appeared on preliminary analysis to confirm this view. The pilot reported that at high altitudes 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 Bonito, 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 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 B₁ B₂ B₃ B₄ or C₁ C₂ C₃ C₄ is photographed instead of A₁ A₂ A₃ A₄. 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 B₁ B₂ B₃ B₄ of figure 2(b) is photographed instead of A₁ A₂ A₃ A₄ and the object O, originally on the fore-and-aft centre line L₁ L₂, is displaced.

It will be appreciated that if the aircraft 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 $X_2Y_3$. 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 such photographs may be present whenever the aircraft is flying in a cross-wind relative to the 'track-maneuverable' as the fore-aft line through the aircraft will then be at an angle to the track, though on the Canberra FR.5 aircraft means are provided on two of the three survey camera installations for a rotation of the camera into the direction of the 'track-maneuverable'.

(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 $B_4 B_5 B_6 B_7$, for example, is photographed instead of $A_2 A_3 A_4 A_5$. The difficulties introduced are those already given in paragraph (c), namely the complication of the corrections to distance. but there is also the confusion likely to arise with the yawing case considered in paragraph (b).

Difficulties due to diversions 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 measuring of both the 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 inadquate 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 diversions (a) to (d) above might be expected to occur together, attention has been concentrated on the lateral and directional diversions which had already been the objects of criticism by the pilots. To help in getting the correct perspective of these diversions, 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.

<table>
<thead>
<tr>
<th>Ground speed (knots)</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (feet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time interval (seconds)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10,000</td>
<td>18</td>
<td>19</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>20,000</td>
<td>36</td>
<td>24</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>40,000</td>
<td>72</td>
<td>48</td>
<td>36</td>
<td>32</td>
</tr>
</tbody>
</table>

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 6500 (Port) and 6506 (Starboard).

3.2 Instrumentation. A Humonot (A 20) recorder was used to give continuous traces of the changes in the aircraft 'pitch angle' of bank indicated by a Quten M 1.8 gyroscope (for further details see 3rd part...
of Report AAL/66). The recording was set to give a trace length of approximately 1 millimeter per second, and transverse scale displacements of 2½ millimeters 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 QSV 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 Hussonot recordings did in fact correspond to zero angle of bank and zero change of heading, even if there were means of measuring these angles accurately in the initial carefully trimmed conditions.

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

3.3 Aircraft Loadings. The aircraft weight at take-off when tip-tanks were fitted was 38,070 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 (M.M.) of 0.7 to 0.84.

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 10-9 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 Hussonot trace recordings are given in figures 3 to 9; they have been reduced from lifesize 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 wander, the short-period oscillation has been excluded.

* 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.

/ The...

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 not, even at 45,000 feet, and the corresponding small sections of individual records have accordingly been omitted from the analysis. Any values given below are therefore to 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 Hussonot trace records. No rigorous analysis by statistical methods has been made, nor has any level of significance been ascribed to the conclusions.

5.2 Short-period directional oscillation. 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 airflow 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).

<table>
<thead>
<tr>
<th>Wing tip tanks</th>
<th>Height (feet)</th>
<th>Indicated Mach number</th>
<th>Double-amplitude of oscillation (degrees)</th>
<th>Average</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10,000</td>
<td>0.72</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>25,000</td>
<td>0.72</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>45,000</td>
<td>0.72</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OFF</td>
<td>25,000</td>
<td>0.72</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>45,000</td>
<td>0.72</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ON</td>
<td>25,000</td>
<td>0.72</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>45,000</td>
<td>0.72</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 0.705 indicated Mach number the reduction actually obtained was from 1° to 0° in average value and 1° to 0° in maximum value, and at 0.74 and 0.715 indicated Mach numbers the oscillation was eliminated (originally 2° average and 3° maximum value at each speed).
The effect of air turbulence upon the oscillation can be clearly seen from the Hussonot traces, the corresponding periods being indicated by the letters T.A. When turbulence was cut, there was an immediate increase in the amplitude of the oscillation, amounting in some instances (for example, figure 5(a)), 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 L.M.N. to 2.6 seconds at 0.70 L.M.N.; at 25,000 feet from 2.6 seconds at 0.81 L.M.N. to 3.1 seconds at 0.71 L.M.N.; at 45,000 feet from 3.5 seconds at 0.805 L.M.N. to 4.5 seconds at 0.715 L.M.N.

5.3 General directional wander. 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 450, 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 17-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 ½ degree. The Mach numbers shown do not represent the limits tested.

As assessed by the aircrew from the buffeting.
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 No. 9 was controlling the aircraft, the wander was generally somewhat worse than in either of the other two conditions considered.

### Table

<table>
<thead>
<tr>
<th>Wing tip</th>
<th>Height (feet)</th>
<th>Indicated Mach number</th>
<th>Change of heading (degrees) between successive photographs</th>
</tr>
</thead>
<tbody>
<tr>
<td>tank no.</td>
<td></td>
<td></td>
<td>Average</td>
</tr>
<tr>
<td>OFF</td>
<td>40,000</td>
<td>0.72</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>25,000</td>
<td>0.77</td>
<td>1</td>
</tr>
<tr>
<td>ON</td>
<td>25,000</td>
<td>0.72</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>45,000</td>
<td>0.79</td>
<td>1(\frac{1}{2})</td>
</tr>
</tbody>
</table>

5.4 Short-period lateral oscillation. The short period lateral oscillation was more difficult to analyze 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 wing 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 L.M.N., the average and maximum values of the double amplitude were reduced from \(\frac{1}{3}\) and \(\frac{1}{2}\) respectively to zero.

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

Table......

* Excluding short-period oscillation.
5.5 General lateral wander. The analysis to obtain a 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 wander of about 0.7° 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 0.5° in average wander and from 2° 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 0.75 M.M., though there is little evidence in figures 10 and 11 to substantiate this theory. The period of the oscillation decreased with increasing Mach number (see figure 11).

Only value analyzed in this configuration.
The general wander (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 wander. 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 buffeting with the original tanks was as bad at 0.75 L.M.N. as it was at 0.79 to 0.80 L.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 wander 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 an rhythmic 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 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 Costel Bonito (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 damp 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 preset 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 Costel Bonito 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 subsection). Nor was the period of the oscillation altered (as 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 wander on survey photography. Several discussions have been held with members of the Directorate of Airway 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 peacetime 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 another conditions or enemy reaction make it unlikely that better ones will be
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 ± for 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, the 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 banks.)

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 maximum 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 rudder 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 generally in excess of ± 2 degrees would be expected, particularly at the higher
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 most-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 report aortis. 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 altitudes, 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 wander 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 P.49 survey camera fitted with a 6 inch lens. At Mach numbers near 0.8, the average magnitudes of each of the oscillations and wander was on the order of 1 degree, though maximum values of 20 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 wander 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 most-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 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 shaking.

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 in the damping
of the short-period oscillation.

Circulation List

AIR/12 2 Copies 1 for Action
TPA/TMB 25 Copies
O.C. Headland Sqn. 1 Copy
R.T.O. English Electric 2 Copies
<table>
<thead>
<tr>
<th>Height (feet)</th>
<th>Camera Interval (Secs.)</th>
<th>Type of Control</th>
<th>Approx. L.A.S. (knots)</th>
<th>Indicated Mach number</th>
<th>Double-amplitude of short period oscillation (degrees)</th>
<th>Wander between successive Photographs (Degrees)</th>
<th>Fig Number</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Directional Average</td>
<td>Directional Maximum</td>
<td>Lateral Average</td>
<td>Lateral Maximum</td>
</tr>
<tr>
<td>10,000</td>
<td>8</td>
<td>Pilot</td>
<td>390</td>
<td>0.70</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>400</td>
<td>0.72</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>410</td>
<td>0.74</td>
<td>1/2</td>
<td>4</td>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>420</td>
<td>0.76</td>
<td>1/2</td>
<td>4</td>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>425</td>
<td>0.77</td>
<td>1/2</td>
<td>4</td>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>440</td>
<td>0.795</td>
<td>1/2</td>
<td>-</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>25,000</td>
<td>18</td>
<td>Pilot</td>
<td>290</td>
<td>0.71</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>300</td>
<td>0.75</td>
<td>1/2</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>310</td>
<td>0.75</td>
<td>1/2</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>325</td>
<td>0.79</td>
<td>1/2</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>330</td>
<td>0.81</td>
<td>1/2</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>45,000</td>
<td>34</td>
<td>Pilot</td>
<td>190</td>
<td>0.725</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1 1/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>190</td>
<td>0.73</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1 1/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>200</td>
<td>0.75</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1 1/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>205</td>
<td>0.77</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1 1/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>210</td>
<td>0.785</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1 1/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>220</td>
<td>0.805</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1 1/2</td>
</tr>
</tbody>
</table>

/Table 2......
<table>
<thead>
<tr>
<th>Height (feet)</th>
<th>Camera Interval (Secs.)</th>
<th>Type of Control</th>
<th>Approx. I.A.S. (Knots)</th>
<th>Indicated Mach</th>
<th>Double Amplitude of short-period oscillation</th>
<th>Wander between Successive Photographs (Degrees)</th>
<th>FIG. Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Directional Average/Maximum</td>
<td>Lateral Average/Maximum</td>
<td></td>
</tr>
<tr>
<td>25,000</td>
<td>18</td>
<td>Pilot</td>
<td>290</td>
<td>0.715</td>
<td>0/1 0</td>
<td>0.4/0.7 0.9/2.4</td>
<td>6a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>300</td>
<td>0.73</td>
<td>0/1 0</td>
<td>0.4/0.8 1.2/3.7</td>
<td>6b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>310</td>
<td>0.75</td>
<td>0/1 0</td>
<td>0.5/1.1 1.0/2.5</td>
<td>6c</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>315</td>
<td>0.77</td>
<td>1/1 1</td>
<td>0.4/0.9 1.1/3.7</td>
<td>6d</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>325</td>
<td>0.79</td>
<td>1/1 1</td>
<td>1.3/2.1 1.0/2.3</td>
<td>6e</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pilot, but rudder free</td>
<td>300</td>
<td>0.73</td>
<td>0/1 0</td>
<td>0.7/1.3 0.7/1.9</td>
<td>7a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>310</td>
<td>0.75</td>
<td>1/1 0</td>
<td>0.7/0.8 1.0/2.2</td>
<td>7b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>325</td>
<td>0.755</td>
<td>1/1 1/2</td>
<td>0.6/0.8 0.8/1.9</td>
<td>7c</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Autopilot, Nk.9</td>
<td>300</td>
<td>0.73</td>
<td>0/1 1/2</td>
<td>0.6/0.8 0.2/0.6</td>
<td>7d</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>310</td>
<td>0.75</td>
<td>0/1 0</td>
<td>0.3/1.2 0.6/1.7</td>
<td>7e</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>315</td>
<td>0.77</td>
<td>0/1 0</td>
<td>1.4/1.7 1.4/1.4</td>
<td>7f</td>
</tr>
<tr>
<td>45,000</td>
<td>34</td>
<td>Pilot</td>
<td>185</td>
<td>0.715</td>
<td>1/1 1/2</td>
<td>0.7/1.4 0.8/1.9</td>
<td>8a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>195</td>
<td>0.735</td>
<td>1/1 1/2</td>
<td>0.7/1.6 1.0/2.5</td>
<td>8b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>200</td>
<td>0.75</td>
<td>1/1 1/2</td>
<td>2.1/3.0 1.3/4.8</td>
<td>8c</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>205</td>
<td>0.77</td>
<td>1/1 1/2</td>
<td>0.5/0.9 0.8/2.0</td>
<td>8d</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>210</td>
<td>0.785</td>
<td>1/1 1/2</td>
<td>0.9/1.5 1.2/2.3</td>
<td>8e</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>220</td>
<td>0.805</td>
<td>1/1 1/2</td>
<td>0.4/0.9 0.7/1.8</td>
<td>8f</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pilot, but rudder free</td>
<td>195</td>
<td>0.74</td>
<td>0/1 0</td>
<td>0.5/0.8 0.9/2.4</td>
<td>9a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>205</td>
<td>0.77</td>
<td>1/1 1/2</td>
<td>0.4/0.9 0.9/2.6</td>
<td>9b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>220</td>
<td>0.805</td>
<td>1/1 1/2</td>
<td>0.6/1.4 1.4/2.8</td>
<td>9c</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Autopilot, Nk.9</td>
<td>185</td>
<td>0.715</td>
<td>0/1 0</td>
<td>2.0/2.6 0.4/0.9</td>
<td>9d</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>195</td>
<td>0.74</td>
<td>0/1 0</td>
<td>0.5/0.9 0.3/0.6</td>
<td>9e</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>210</td>
<td>0.765</td>
<td>0/1 0</td>
<td>2.4/2.8 0.5/1.5</td>
<td>9f</td>
</tr>
</tbody>
</table>
**FIG. 1**

1(a) Reference marks on survey photographs

1(b) Overlapping of photographs (diagrammatic only)

Survey photography.
DISPLACEMENTS OF AERIAL PHOTOGRAPH IN PITCH, YAW, AND ROLL.
**CANBERRA PR.1 V/181**

LEVEL FLIGHT AT 10,000 FEET; FLAPS AND UNDERCARRIAGE UP; AIR BRAKES IN; WING Tips 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.**

(a) 
0.70 indicated mach number.

(b) 
0.72 indicated mach number.

(c) 
0.74 indicated mach number.

(d) 
0.76 indicated mach number.

(e) 
0.77 indicated mach number.

(f) 
0.78 indicated mach number.

Upper trace shows heading with datum line O₃ to O₄: Port towards top of record.

Lower trace shows angle of bank with datum line O₅ to O₆: Port towards bottom of record.
FIG. 4.

CANBERRA PR3 VX 181

LEVEL FLIGHT AT 25000 FEET; FLAPS AND UNDERCARRIAGE UP; AIR BRAKES IN; WING TP 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.

(a) 0.71 INDICATED MACH NUMBER.

(b) 0.73 INDICATED MACH NUMBER.

(c) 0.75 INDICATED MACH NUMBER.

(d) 0.79 INDICATED MACH NUMBER.

(e) 0.81 INDICATED MACH NUMBER.

SCALE FOR HEADING AND ANGLE OF BANK

UPPER TRACE SHOWS HEADING WITH DATUM LINE O_0 TO O_n: PORT TOWARDS TOP OF RECORD.
LOWER TRACE SHOWS ANGLE OF BANK WITH DATUM LINE O_0 TO O_n: PORT TOWARDS BOTTOM OF RECORD.
CANBERRA PR.3 VX 181.

LEVEL FLIGHT AT 45000 FEET, FLAPS AND UNDERCARRIAGE UP, AIR BRAKES IN, WING TIP TANKS NOT FITTED.

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

CALM AIR CONDITIONS EXCEPT WHERE SHORT PERIODS OF TURBULENT AIR ARE INDICATED BY THE LETTERS T.A.

(c) 0.725 INDICATED MACH NUMBER.

(d) 0.77 INDICATED MACH NUMBER.

(e) 0.785 INDICATED MACH NUMBER.

(f) 0.805 INDICATED MACH NUMBER.

HUSSENOT RECORDS OF AIRCRAFT HEADING AND ANGLE OF BANK.

UPPER TRACE SHOWS HEADING WITH DATUM LINE O₁ TO O₂, PORT TOWARDS TOP OF RECORD.
LOWER TRACE SHOWS ANGLE OF BANK WITH DATUM LINE O₁ TO O₂, PORT TOWARDS BOTTOM OF RECORD.
CANBERRA PR 3 VX 181.

LEVEL FLIGHT AT 25000 FEET, FLAPS AND UNDERCARRIAGE UP, AIR BRAKES IN, WING TIP TANKS 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.

(c) 0.75 indicated Mach number
(b) 0.73 indicated Mach number
(c) 0.75 indicated Mach number

(e) 0.77 indicated Mach number
(f) 0.79 indicated Mach number

Upper trace shows heading with datum line O_1 to O_1: port towards top of record.
Lower trace shows angle of bank with datum line O_2 to O_2: port towards bottom of record.
CANBERRA PR.3 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 O₁ TO O₂, PORT TOWARDS TOP OF RECORD.
LOWER TRACE SHOWS ANGLE OF BANK WITH DATUM LINE O₁ TO O₂, PORT TOWARDS BOTTOM OF RECORD.
CANBERRA PR 3 VX 181.

LEVEL FLIGHT AT 45,000 FEET, FLAPS AND UNDERCARRIAGE UP, AIR BRAKES IN, WING TIP TANKS 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 EXCEPT WHERE SHORT PERIODS OF TURBULENT AIR ARE INDICATED BY THE LETTERS T.A.

(a) 0.78 INDICATED MACH NUMBER
(b) 0.735 INDICATED MACH NUMBER
(c) 0.75 INDICATED MACH NUMBER

(d) 0.77 INDICATED MACH NUMBER
(e) 0.785 INDICATED MACH NUMBER
(f) 0.805 INDICATED MACH NUMBER

SCALE FOR HEADING AND ANGLE OF BANK

UPPER TRACE SHOWS HEADING WITH DATUM LINE O1 TO O2: PORT TOWARDS TOP OF RECORD.
LOWER TRACE SHOWS ANGLE OF BANK WITH DATUM LINE O3 TO O4: PORT TOWARDS BOTTOM OF RECORD.
CANBERRA PR.3 VX 181

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

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

(c) 0.74 INDICATED MACH NUMBER.

(d) 0.745 INDICATED MACH NUMBER.

(e) 0.74 INDICATED MACH NUMBER.

(f) 0.785 INDICATED MACH NUMBER.

AUTOPILOT MK.9 CONTROLLING THE AIRCRAFT.

UPPER TRACE SHOWS HEADING WITH DATUM LINE O, TO O, POINT TOWARDS TOP OF RECORD.
LOWER TRACE SHOWS ANGLE OF BANK WITH DATUM LINE O, TO O, POINT TOWARDS BOTTOM OF RECORD.

FIG. 9.
LEVEL FLIGHT WITH FLAPS & UNDERCARRIAGE UP AIR BRAKES IN PILOT CONTROLLING AVERAGE.

(i) WING-TIP TANKS NOT FITTED.

(a) 10,000 FT.

(b) 25,000 FT.

(c) 48,000 FT.

(d) 115,000 FT.

(e) 48,000 FT.

DOUBLE-AMPLITUDE OF OSCILLATION

INDICATED MACH NUMBER
LEVEL FLIGHT WITH FLAPS & UNDERCARRIAGE UP
AIR BRAKES IN

PERIOD
OF
OSCILLATION
(SEC/2
PER CYCLE)

INDICATED MACH NUMBER

0.7
0.72
0.74
0.76
0.78
0.8
0.82

HEIGHT
(FEET)

10,000
25,000
45,000

WING-TIP TANKS ON

WING-TIP TANKS OFF

DESCRIPTION

PILOT CONTROLLING

PILOT CONTROLLING
PILOT CONTROLLING, BUT
RUDDER FREE.
AUTOPILOT MK 8
CONTROLLING.

PILOT CONTROLLING
PILOT CONTROLLING BUT
RUDDER FREE.
AUTOPILOT MK 8
CONTROLLING.
LEVEL FLIGHT WITH FLAPS UNDERCARRIAGE UP, AIR BRAKES ON.

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 MKS CONTROLLING.

1) WING-TIP TANKS NOT FITTED

(a) 10,000 FT (6 SECONDS INTERVAL BETWEEN PHOTOGRAPHS).

(b) 50,000 FT (18 SECONDS INTERVAL)

(c) 45,000 FT (34 SECONDS INTERVAL).

(d) WING-TIP TANKS FITTED

(e) 50,000 (18 SECONDS INTERVAL)

(f) 45,000 FT (34 SECONDS INTERVAL).

AVERAGE CHANGE OF HEADING BETWEEN SUCCESSIVE PHOTOGRAPHIC recordings.
FIG. 13.

LEVEL FLIGHT WITH FLAPS & UNDERCARRIAGE UP, AILERONS IN.
+ PIVOT 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.3 CONTROLLING.

(i) WING-TIP TANKS NOT FITTED

(a) 10,000 ft. (6 seconds interval between photographs).

(b) 25,000 ft. (16 seconds interval).

(c) 45,000 ft. (34 seconds interval).

(ii) WING-TIP TANKS FITTED

(d) 25,000 ft. (16 seconds interval).

(e) 45,000 ft. (34 seconds interval).

MAXIMUM CHANGE OF HEADING BETWEEN SUCCESSIVE PHOTOGRAPHS.
LEVEL FLIGHT WITH FLAPS & UNDERCARRIAGE UP, AIR BRAKES IN.

FIG. 14.

(a) 10,000 FT

(b) 24,000 FT

(c) 45,000 FT

(d) 28,000 FT

(e) 45,000 FT

WING-TIP TANKS NOT FITTED

WING-TIP TANKS FITTED

DOUBLE-AMPLITUDE OF SHORT-PERIOD LATERAL OSCILLATION.
LEVEL FLIGHT WITH FLAP \& UNDERCARRIAGE UP AIR
SNAKES IN.
(1) PILOT CONTROLLING THE AIRCRAFT BY NORMAL USE OF
AILERON AND RUDDER IN ATTEMPTING TO MAINTAIN LEVEL
FLIGHT ON A CONSTANT HEADING.
(2) AS ABOVE, BUT RUDDER LEFT FREE
+ AUTOPILOT MK.8 CONTROLLING.

FIG. 15.

(1) WING-TIP TANKS NOT FITTED.
(2) 10,000 FT (6 SECONDS INTERVAL BETWEEN PHOTOGRAPHS).

![Graph showing indicated Mach number vs. time.]

(3) 25,000 FT (18 SECONDS INTERVAL).

![Graph showing evolution of angle of attack.]

(4) 45,000 FT (34 SECONDS INTERVAL).

![Graph showing average change of angle of bank.]

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.
- AS ABOVE, BUT RUDDER LEFT FREE.
+ AUTOPilot MK.8 CONTROLLING.

(1) WING-TIP TANKS NOT FITTED.
(2) 10,000 FT. (10 SECS. INTERVAL BETWEEN PHOTOGRAPHS).

MAXIMUM CHANGE OF ANGLE OF BANK (DEGREES) BETWEEN 0-0

INCIDATED MACH NUMBER

0 0.70 0.74 0.76 0.80 0.82

(3) 25,000 FT. (10 SECONDS INTERVAL).

MAX

INCIDATED MACH NUMBER

0 0.70 0.74 0.76 0.80 0.82

(4) 45,000 FT. (34 SECONDS INTERVAL).

MAX

INCIDATED MACH NUMBER

0 0.70 0.74 0.76 0.80 0.82
FIG. 16.

Maximum change of angle of bank between successive photographs.
LEVEL FLIGHT, WIND CARRIED UP, AIR BRAKES:
MAIN-WIND TIP TANKS NOT FITTED.

PILOT CONTROLLING THE AIRCRAFT BY NORMAL USE OF AILERON Rudder in attempting to maintain level flight on a constant heading.

- AVERAGE WANDER: AVERAGE SHORT-PERIOD OSCILLATION
- MAXIMUM WANDER: MAXIMUM SHORT-PERIOD OSCILLATION
- MAXIMUM WANDER: AVERAGE SHORT-PERIOD OSCILLATION
- TOTAL CHANGE IN ANGLE OF BANK BETWEEN SUCCESSIVE PHOTOGRAPHS.