TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 222

AIR FLOW INVESTIGATION FOR LOCATION OF ANGLE OF ATTACK HEAD ON A JN4h AIRPLANE.

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Summary

The technical staff of the National Advisory Committee for Aeronautics at Langley Field, has made a series of free flight tests with a JN4h airplane in order to find the best place for an instrument for measuring the angle of attack.

A "neutral zone" was found where the air remains either at rest relative to the undisturbed air beyond the influence of the airplane, or is set in motion parallel to the motion of the airplane. This zone is about midway between the two wings and slightly in front of, or at the vertical plane through the leading edges of the wings but the exact position as well as the outlines of the zone varies considerably as the conditions of flight change.

However, there is a restricted area at the section under investigation where the air flow remains, within the limits of plus or minus .5 degree, parallel to the direction of flight throughout the entire flying range. Such a permanently neutral zone has been observed both in level flight and in one condition

of climb, and the number of observations warrants the statement that such a neutral zone exists under all conditions of steady flight.

Introduction

It has been the practice in the past to attempt to measure angle of attack in flight by placing some device on the end of a long boom as far in front of the wing as practicable. Other investigators used similar methods, all of which involve inherent errors of considerable magnitude due to the influence of the airplane itself on the air flow in the immediate neighborhood. The elimination of these errors required laborious calibrations which were not entirely reliable except where many check flights had been taken. Such procedure would be obviated for any work on a particular airplane if a region could be located in reasonable proximity to the airplane where a suitable instrument would indicate the correct values of angle of attack throughout the flying range (Reference 1).

The existence of such a region in front of a biplane cellule has been indicated from theoretical considerations, and some investigations made on model airfoils have actually shown a "neutral zone" in front of two superposed airfoils (Reference 2). The present article deals with the investigation of the air flow at several points in front of a two-bay biplane in flight in a vertical-longitudinal plane near the outer strut.

Methods and Apparatus

This investigation had for its object the determination of a relation between the angle of the direction of air flow and the angle of attack and hence a precise measurement of the latter was necessary at the outset. The measurement was made by flying the airplane in steady level, and steady climbing flight with a special long trailing bomb suspended about 25 feet below the lower longeron, and at certain airspeeds the arrangement was photographed from another airplane flying alongside. A picture so obtained is shown in Fig. 1. The angle between the axis of the bomb and the longerons was measured on the photographs and the true geometric angle of attack was directly obtained by adding the average angle of incidence of the wings.

Airspeed was recorded by means of an N.A.C.A. swiveling pitot-static head as shown in Fig. 1, connected to an N.A.C.A. continuous recording instrument. The two airplanes were flown near enough to each other that the observer in the test plane could see when the photographer made an exposure and at that instant could close an electric circuit to mark the point on the airspeed record when the picture was taken. Thus the records on the two airplanes were synchronized and the angle of attack for different airspeeds was obtained.

This method of measuring angle of attack does not require a knowledge of the attitude of the airplane and the flight-path angle. The essentials to its success are steady piloting and good flying conditions in the air.

Having measured the angle of attack of several airspeeds for both climbing and level flight, no further use was made of the bomb. Successive flights were made at approximately the same airspeeds as before with an angle of attack head located at various points near the outer strut of the wing as indicated in Fig. 3. This measuring head was an N.A.C.A. yaw-head as illustrated in Fig. 2. Instead of measuring yaw the head was set up to measure air flow direction in the vertical-longitudinal plane by merely rotating it about the axis of the shank 90° from the position in which it was used to measure yaw.

The head itself consists mainly of a hollow shaft through which two tubes are run and to which is attached a short cylindrical cross-tube closed at both ends. Eight holes, .03 inch in diameter drilled in this tube, are so arranged that two groups of four each are angularly displaced by 45° from, and on either side of the plane containing the axes of the cross-tube and the shaft. One such group can be seen in the figure. Each group of holes passes to an inner space of half the cross-tube closed to the other half, and each such portion of the cross-tube is connected to one of the tubes which lead off through the shaft. Rubber tubing connects these tubes to either side of a diaphragm of a pressure recording instrument. Thus an air flow directed against the cross-tube parallel to the shaft axis produces equal pressures on each side of the diaphragm. Any change in direction of the air flow in the plane normal to the axis of the cross-tube produces an increased or decreased pressure on one side or the other of the diaphragm of the recording instrument (Reference 3). This pressure change is recorded as in the recording airspeed meter. The recorded pressures are a function of the angle of air flow and of the dynamic pressure. By a simple calibration in the wind tunnel these relations are obtained directly in terms of impact pressures which necessitated the measurement of airspeed on the airplane in flight with a pitot-static head as heretofore mentioned.

The results of these flights are shown in Fig. 3, where the true geometric angle of attack for the section, along with the directions of air flow obtained at the various points as shown, is plotted against airspeed. Figs. 4-8 show the air flow through a biplane cellule at different airspeeds. The zone where the direction of air flow agrees within one-half a degree with the direction of flight is shown by the shaded area and the smaller "permanently neutral" area is expressly indicated in each figure. Considerable extrapolation was necessary in determining the shaded area when it extended any considerable distance ahead of the leading boundary of the cellule. Interference of brace wires prevented investigation of more points in the cellule at that particular section but it is believed that sufficient data was obtained for locating and confining the "neutral zone" to fairly definite and well-defined limits.

Precision

In the measurement of angle of attack by the direct photographic method, it was necessary to make sure that the plane of the camera plate was parallel to the plane of the suspended bomb and longeron. Among other things this required very steady piloting which, one is pleased to state, was to be had from the test pilots of the National Advisory Committee for Aeronautics.

A 5-inch by 7-inch graflex camera was used, on which was mounted a bubble level by which the lens axis was held in a horizontal plane. Insurance of parallel conditions between the plane of the camera plate and the plane of the bomb and its supporting wire (which plane was considered vertical) was obtained by releasing the shutter when the bubble indicated a level condition of the top of the camera. Since there might be an angle in the horizontal plane (a mutual angle in yaw between the two airplanes) only those photographs were used where the leading edge of the wing appeared in the center of the picture and showed itself perpendicular to the plane of the camera. This condition is shown in Fig. 1. A mathematical analysis of this method, included as an appendix to this report, indicates that the inherent errors are practically negligible. The influence of the air flow about the airplane on the flight-path bomb when suspended 25 feet below the fuselage may be neglected as it was drawn up to within 15 feet, and several photographs of it in that location showed no appreciable effects of its proximity to the airplane (Reference 4).

As the measurement of angle of attack required the accurate measurement of the airspeed it was thought that a universal swiveling pitot head mounted in the position shown in Fig. 1 would give the desired results. This is substantiated by the conclusions of others (Reference 5). Impact pressures at the different positions at which the angle of attack head was located were obtained by separate flights with a swiveling pitot-static head replacing the angle of attack head. As much as 10 per cent variation from the airplane's indicated impact pressure, as obtained from the swiveling pitot-static head in front of the wing, was found at the different points inside the cellule. These local pressures were used in computing the angle of air flow in conjunction with the angle of attack head, and these angles are plotted against the airspeed of the airplane.

Results

The results of the investigation are shown graphically in Fig. 3. In this figure airspeed is plotted against "angle of attack" as obtained by the photographic method and by the angle of attack measuring head as placed at the various locations. Attention is called to the maximum angles as obtained at the two points in front of the leading edges of the two airfoils, and the decrease from these values as the position in front of the middle of the gap is approached. This decrease is noticeable at all airspeeds. It would appear that these angles of "upwash" vary with the lift coefficient in some such manner as does the angle of "downwash."

The neutral zone, as indicated by the shaded areas in Figs. 4-8, is found at the same location indicated by work done on model airfoils. Compared to these its unusual shape and the different shifting in position with change of angle of attack was to be expected since every biplane of different gap-chord ratio and different stagger would be expected to induce a different air flow peculiar to its dimensions and arrangements. There is found to be a very restricted area where all the neutral zones of Figs. 4-8 are common to one another. It is considered that this is the point at which angle of attack instruments can be located to the best advantage of this airplane, it being relatively close to the strut, 2.7 feet and 3.35 feet from the upper and lower leading edges, respectively. It is noted, however, that it exists only on the edge of these zones in several of the figures, and consequently it cannot be said that the flow at this point is strictly neutral. It is only that point which approaches most nearly to it.

The flights for the determination of impact pressures at the various points where the angle of attack head was located indicated that this point is also advantageous for the measurement of impact pressures for airspeed. The air flow there not only is parallel to the airplane motion but the pitot-static pressures at this point agree with pitot-static pressures obtained from the reference swiveling pitot-static head. This would indicate that the impact pressures measured at this point would more closely approach the true impact pressure corresponding to the speed of the airplane than at any other point so near the structure.

Conclusions

Viewing the tests from the standpoint of finding an area of undisturbed flow near the structure for all angles of attack at which the airplane will usually be flown, the results cannot be considered entirely satisfactory. If an accuracy of not greater than plus or minus .5 degree is wanted, then the point indicated will satisfy those conditions. Moreover, for convenience this location for instruments is excellent.

It is not to be expected that the results of these tests can be applied to another airplane with any useful degree of accuracy. Both the lift coefficient and the arrangement of the structure affect the results to a considerable degree. It would be very interesting to investigate the air flow about this airplane along with another with the same airfoil and same weight but with different stagger or different gap-chord ratio. It would also prove of interest to investigate the circulation of the air flow about two similar airplanes differing only in the wing section.

Appendix I.

The following is a mathematical analysis of the photographic method of finding the angle of attack of an airplane in flight. It is prepared by Mr. Paul E. Hemke of the technical staff of the National Advisory Committee for Aeronautics.

In this method a vane or bomb is suspended by means of a single wire from an airplane. This bomb is so arranged that it will point along the true flight path. A second airplane flying alongside the first carries a camera which records the image of the first airplane and the bomb. The angle between the axis of the bomb and the axis of the airplane is measured from the photograph.

There are several possible sources of error:

(1) The change of distance between the airplanes.

(2) The roll of one airplane relative to the other.

(3) The yaw of one airplane relative to the other.

(4) The pitch of one airplane relative to the other.

It is at once evident that (1) and (4) do not affect the size of the angle recorded by the camera, i.e., they do not change the size of the angle as we usually understand that term.

Let us consider then the effect of rolling (Fig. 9). Let plane M be the vertical plane determined by the axis of the bomb and the axis of the airplane. Let α be the angle of attack.

If O, the origin of a system of rectangular coordinates, is taken in the lens of the camera, then the image E D F of angle A B C is α when N, the plane of A B C is also vertical. Suppose now that rolling changes the position of N to N' through an angle Φ. Using the orientation of axes shown in Fig. 9, we see that the equation of the plane N' is

$Z - d = m(y - b)$, $m = \tan\beta = \cot\Phi$ and d, b are intercepts on the Y and Z axes. The equation of the plane D E C B is $Z = nX$ where $n = \tan\alpha$. The intersection of N' and D E C B is the line B C',

$$\frac{X}{1/n} = \frac{y - b + \frac{d}{m}}{1/m} = \frac{Z}{1} \qquad (1)$$

The directions of B C' are then $\frac{1}{n} : \frac{1}{m} : 1$. A B is in the X Y plane and its direction cosines are 1,o,o. Then,

$$\cos\gamma = \frac{1/n}{\sqrt{1 + \frac{1}{m^2} + \frac{1}{n^2}}} = \frac{1}{\sqrt{1 + n^2 + \frac{n^2}{m^2}}} = \cos(\alpha + \epsilon) \qquad (2)$$

where $\gamma = \angle$ A B C'. Let ϵ represent the difference between γ and α. Squaring (2), putting $n = \tan\alpha$ we have,

$$\tan^2\alpha \tan^2\Phi = \mathrm{Sec}^2(\alpha + \epsilon) - \mathrm{Sec}^2\alpha .$$

This reduces further to

$$\tan(\alpha + \epsilon) = \pm \frac{\tan\alpha}{\cos\Phi} \quad ; \quad \cos\Phi = \pm \frac{\tan\alpha}{\tan(\alpha + \epsilon)} \qquad (3)$$

We may neglect the negative sign since it does not introduce any changes in the final analysis. From (3) we see that $\epsilon > 0$.

This means that the image as recorded will be smaller by an amount ϵ than the angle itself. When $\Phi = 0$, $\epsilon = 0$ and when $\Phi = \frac{\pi}{2}$. $\gamma = \alpha + \epsilon$ * is $\frac{\pi}{2}$. If we assume some numerical cases we see what change is produced in γ by a given change in Φ.

$\alpha = 2^\circ$		$\alpha = 6^\circ$	
Φ	$\gamma = \alpha - \epsilon$	Φ	$\gamma = \alpha - \epsilon$
0°	2°	0°	6°
5°	1° 59' 33"	5°	5° 59' 30"
10°	1° 58' 10"	10°	5° 54' 30"
20°	1° 52' 20"	20°	5° 37' 5"
30°	1° 41' 30"	30°	5° 4' 45"

Since precautions are taken to level the camera, it is hardly possible that errors will occur in the measurement due to mutual rolling of the planes.

The conclusions then are as follows:

(1) The relative distance alone does not cause an error.

(2) The roll causes a slight error which is probably negligible. This error is the same for either direction of roll and it is of such a character that the measured angle will be smaller than the true angle.

(3) The yawing causes an error numerically the same as that due to rolling but opposite in sign. The two should tend to offset each other.

(4) The pitching of the airplanes causes no error.

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Fig. 1
Method of determining the angle of attack

Fig. 2 Yaw head

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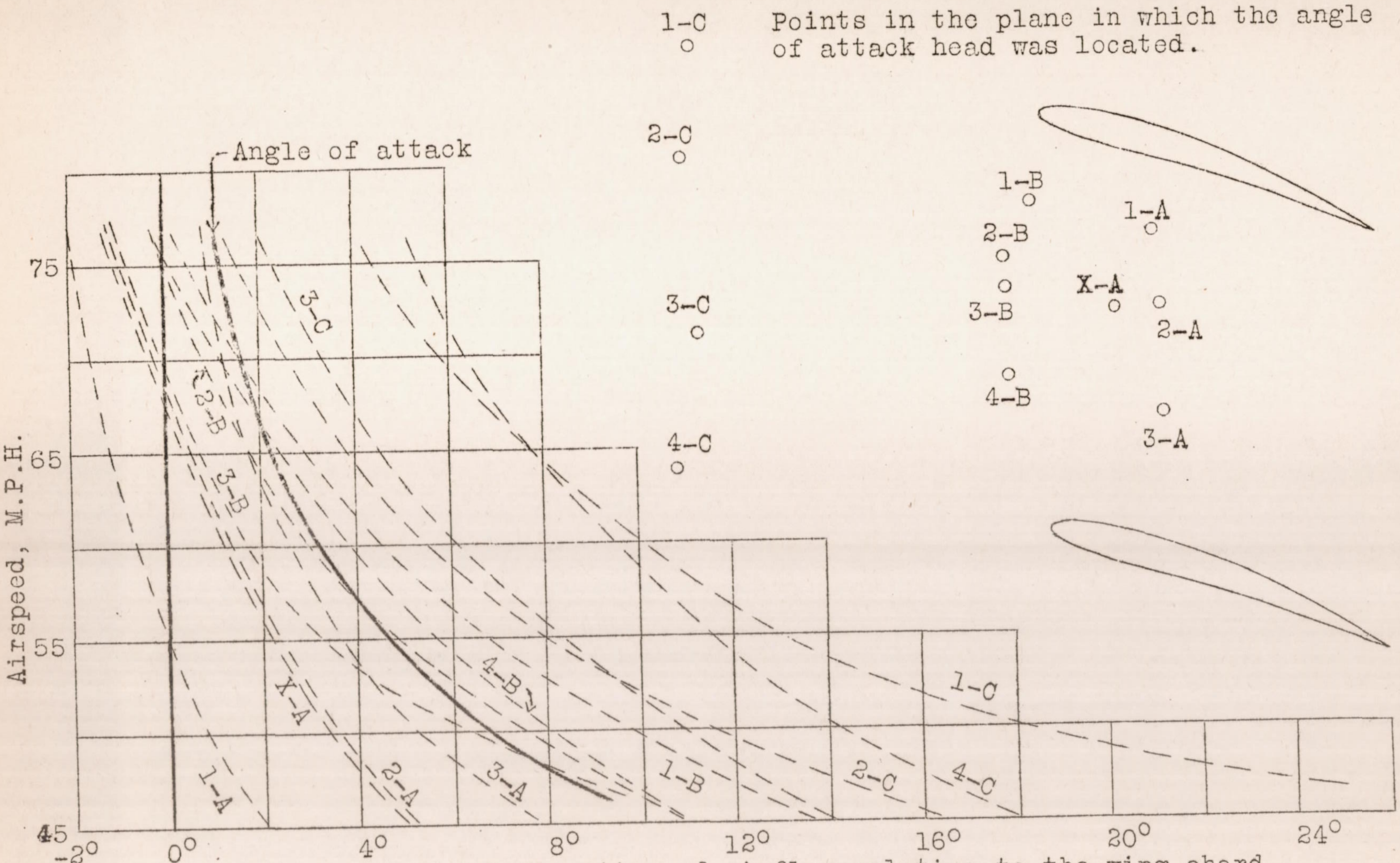
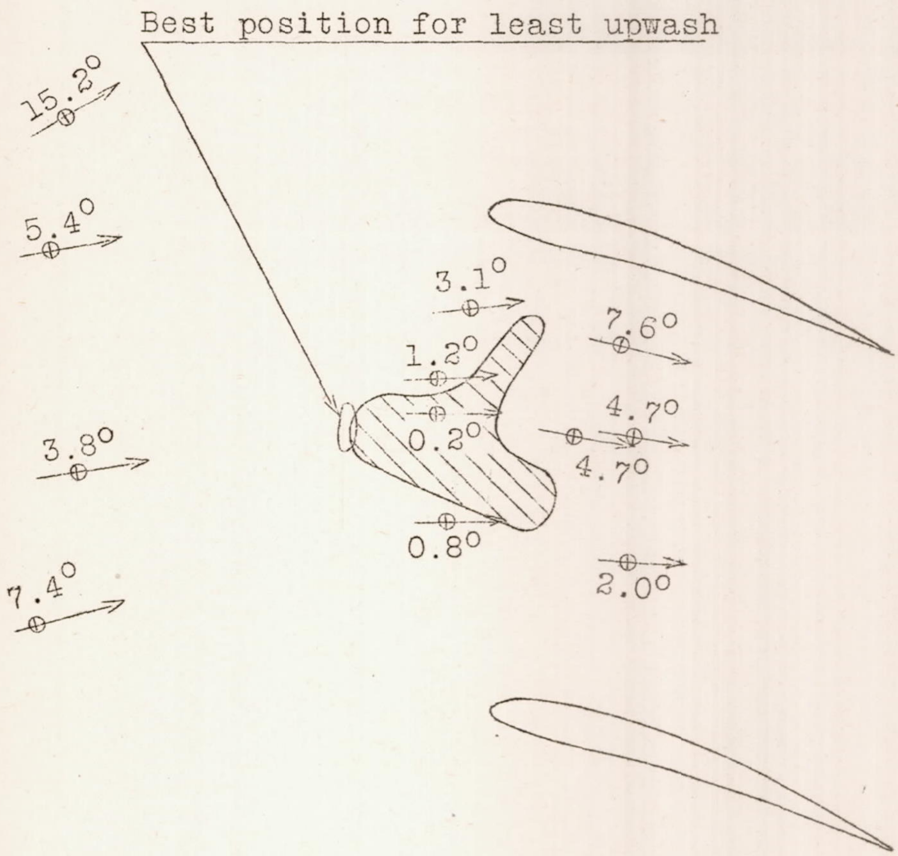


Angle of attack and direction of airflow relative to the wing chord at a section near the outer strut

Fig. 3

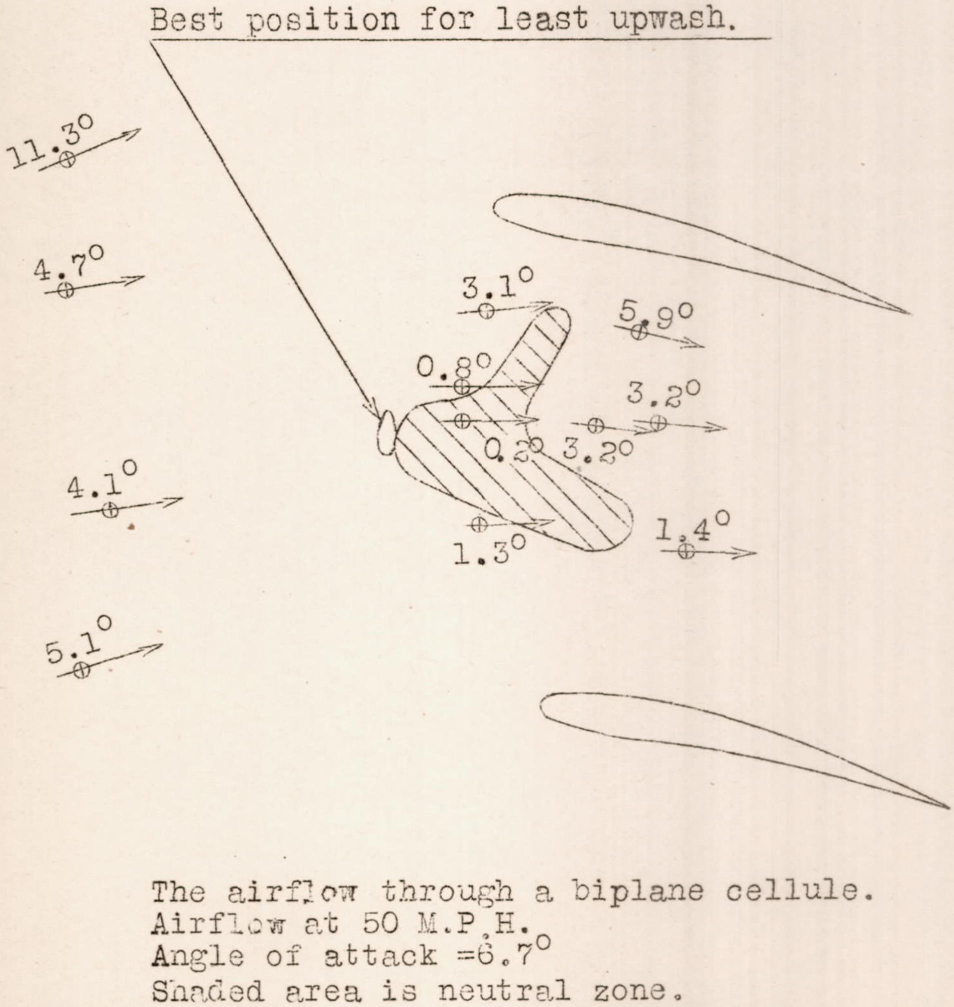


The airflow through a biplane cellule.
Airflow at 46.5 M.P.H.
Angle of attack = 9.2°
Shaded area is neutral zone.

Note: Angles are graphically exaggerated 2 times actual value.

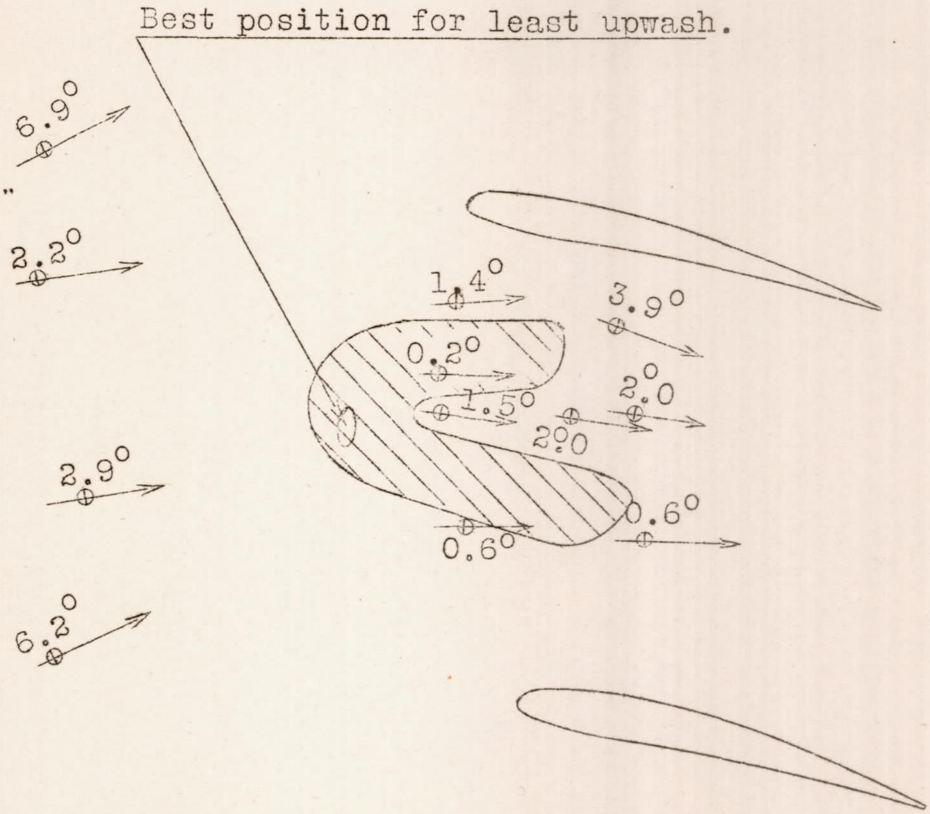
Scale: 1 inch = 2 feet.

Fig. 4



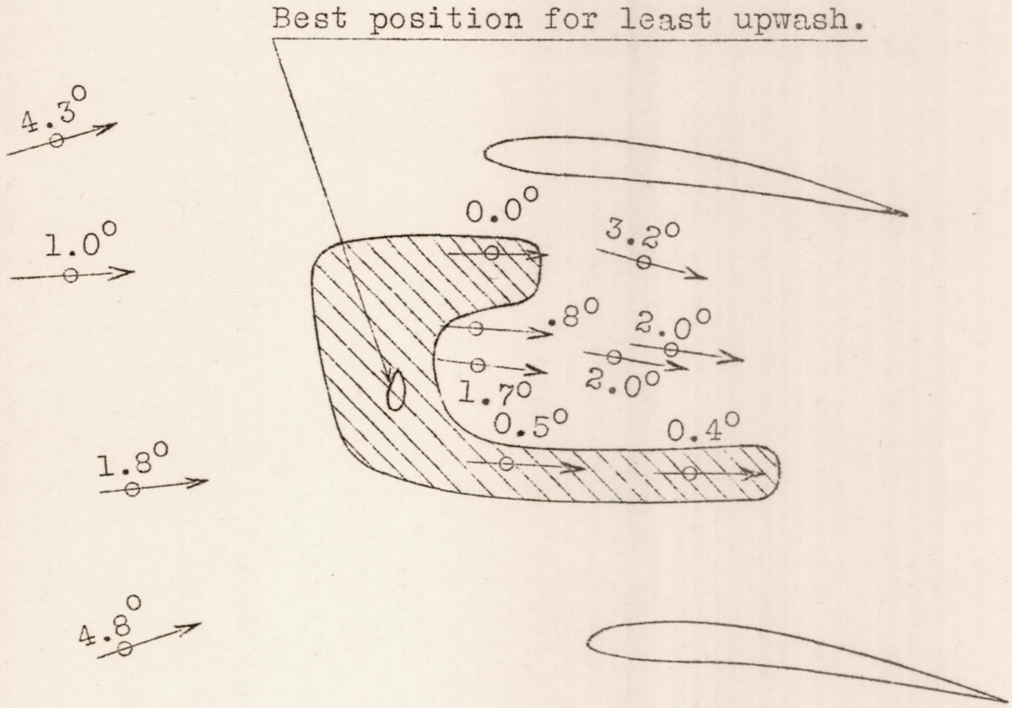
The airflow through a biplane cellule.
Airflow at 50 M.P.H.
Angle of attack =6.7°
Shaded area is neutral zone.
Note: Angles are graphically exaggerated twice the actual value.
Scale: 1 inch = 2 feet.

Fig.5



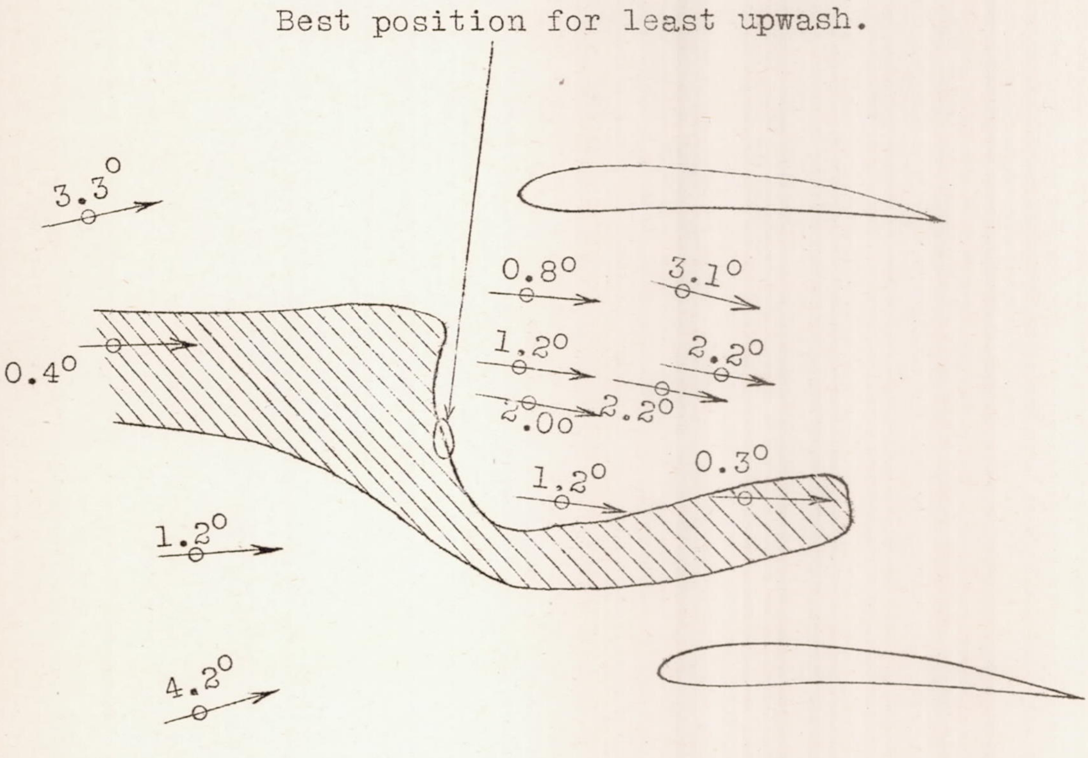
The airflow through a biplane cellule.
Airflow at 60 M.P.H.
Angle of attack = 3.2°
Shaded area is neutral zone.
Note: Angles are graphically exaggerated 4 times actual value.
Scale: 1 inch = 2 Feet.

Fig.6



The airflow through a biplane cellule.
Airflow at 70 M.P.H.
Angle of attack = 1.6°
Shaded area is the neutral zone.
Note: Angles are graphically exaggerated 4 times actual value.
Scale: 1 inch = 2 feet.

Fig.7



The airflow through a biplane cellule.
Airflow at 75 M.P.H.
Angle of attack = 1.2°
Shaded area is the neutral zone.
Note: Angles are graphically exaggerated 4 times actual value.
Scale: 1 inch = 2 feet.

Fig.8

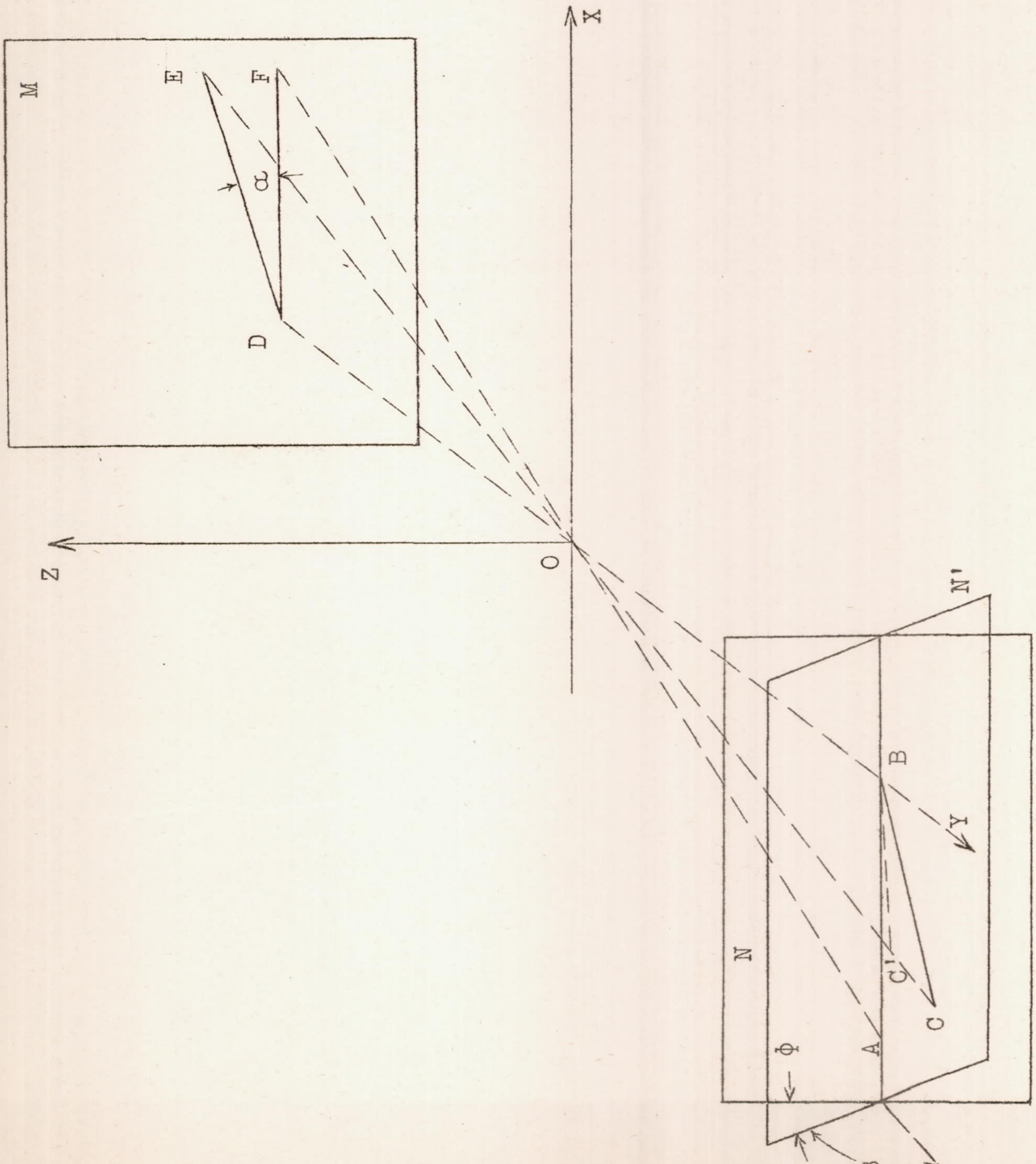


Fig. 9