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TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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No. 646

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MEASUREMENT OF VISIBILITY FROM THE PILOT'S COCKPIT  
ON DIFFERENT AIRPLANE TYPES

By Gerhard Kurz

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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MEASUREMENT OF VISIBILITY FROM THE PILOT'S COCKPIT  
ON DIFFERENT AIRPLANE TYPES\*

By Gerhard Kurz

I. Purpose of the Investigation

Among the numerous fields of postwar airplane construction in which a more thorough development is being undertaken, there remains an important field concerning practical flight. This field is the investigation of the pilot's view from the airplane and its numerical determination and representation, which has been almost overlooked up to the present time. Good visibility, however, is one of the main requirements for safe flying.

On an airplane, in which motion is possible in three dimensions, the pilot must have an unobstructed view in the direction of flight, as also in any other direction to which he might change the flight path. An airplane pilot requires therefore not only visibility forward and laterally, like the driver of a land vehicle but, since a change in the flight path is possible for him in any direction, he also requires the greatest possible forward range of vision both upward and downward. Of course, the visibility requirements differ according to the different uses of the airplanes. The visibility requirements would therefore be different for a transport airplane than for an airplane used in stunt flying. In the case of a photographic airplane, the pilot requires, above all, vertical visibility downward, so that he can keep in view the portion of the landscape to be photographed, until the instant of flying over it.

On account of these various requirements of visibility, it is desirable for one who attempts to obtain numer-

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\*"Messung der Sicht vom Führersitz verschiedener Flugzeugmuster." Zeitschrift für Flugtechnik und Motorluftschiffahrt, March 28, 1931, pp. 167-176.

ical data, to know to what degree and in what direction visibility is necessary for a given purpose.

At the present time, the predetermination of visibility in new construction is largely guesswork based on the results of experiments with previously built airplanes, and on the use of mock-ups. It often happens that the visibility is neglected for the sake of other structural advantages, without this error being discovered by practical flight tests. It is also evident that, with such a haphazard method, the views on the excellence of the visibility may differ greatly even among specialists. For all these reasons, it seems opportune to determine the visibility on airplanes in as simple and exact a manner as possible.

## II. Purpose

The purpose of this problem is to develop methods and apparatus for the measurement of visibility and to investigate the possibility of the representation and numerical determination of visibility.

The methods, as well as the apparatus required for the measurements, should be as simple as possible to use and should enable the representation of the visibility without much computation. The determination of the visibility, by means of the apparatus, must be possible on existing airplanes, as well as on mock-ups. The representation of the test results should be easily understandable. Furthermore, it should be possible for the purchaser of an airplane to express his particular desires regarding visibility with sufficient accuracy by means of charts and numerical values. On the other hand, the manufacturer should be given the means of representing the visibility in a simplified manner by means of charts or numerical data.

The utility of the developed methods and apparatus had to be tested by visibility measurements on different types of airplanes. Moreover, the minimum requirements for visibility, as well as the judgment of the excellence of the visibility, had to be established by comparison of the experimental results with practical flight tests.

## III. Principle of the Method

In order to develop a method for the measurement of visibility, it is first necessary to explain the concept of "visibility." "Visibility," with respect to any object, signifies very generally the ability to see this object from a given viewpoint. The object may be more or less concealed by opaque obstructions between the observer and the observed object, i.e., the "visibility" with respect to the object is more or less good. In order to ascertain the "visibility" from the pilot's cockpit of an airplane, we must determine to what degree the pilot is prevented by parts of the airplane from recognizing external objects. It is necessary to determine the limits of the pilot's field of vision due to the opaque parts of the airplane.

The eye of the pilot is assumed to be the center of a sphere of any convenient radius. The boundary lines of the field of vision are plotted on the surface of this sphere. (Fig. 1.) If the portions of the surface of the sphere which represent the field of the obstructed view are darkened or hatched to differentiate them from the field of unobstructed view, a diagram of the visibility is obtained. Furthermore, if the surface of the sphere is provided with degree lines similar to the cartographic representation of the earth's surface, a numerical representation of the boundaries of vision is obtained. The angles are referred to a horizontal plane and to a plane perpendicular to it, both planes being parallel to the flight path. Since, at first, only the visibility in that half of the sphere lying in the direction of flight was to be investigated, the lines of intersection of the reference planes with the surface of the sphere were used as the coordinate axes and their point of intersection served as the origin.

It is possible to determine the total visibility from a point in all directions by this method of angular measurement. The present investigation of the visibility was limited, however, to that half of the sphere of visibility lying in front of the airplane, i.e., the "field of visibility" was limited by a plane passing through the eye of the pilot at right angles to the flight path and to the horizon. The field of visibility behind this plane was not investigated because, owing to the forward motion of the airplane, everything lying behind this plane had been already flown over and therefore no longer presented a source of danger. In spite of this fact, the visibility

in that region can also be of some importance to the pilot, although to a lesser degree.

Thus far the visibility from a point has been discussed. Actually, however, the pilot has views from two points, owing to the distance between his eyes. It is therefore necessary for the visibility to be measured from these two points separately, in order to obtain the complete chart of the field of visibility by plotting one over the other. Approximate measurements, however, can be made with sufficient accuracy from a single point midway between the eyes of the pilot, which is designated as the "observation point."

The selection of the location for the observation point is difficult. The pilot can move his head within certain limits and thus change the observation point. Since complete allowance for this movability is not possible, it only remains to undertake the measurement of the visibility from various points corresponding to the most important positions of the pilot. Only those positions will be considered which the pilot normally assumes when flying cross-country in fair weather. He then sits in the airplane in the most restful position. This attitude of the pilot will be designated as the "position of rest." A second point corresponds to the position assumed by the pilot while landing or while flying cross-country in bad weather, when he must see in the direction of flight. This point will be designated as the "landing position" of the pilot. During the landing process the pilot looks to the front and left and bends his head toward the left. The "observation point" which is thus comfortably attained with the body firmly strapped in, was found on the basis of numerous experiments, to be about 17 cm (6.7 in.) to the left of the point marked "position of rest." The visibility was measured from these two points on all the airplanes.

The attitude of the airplane is also of importance in the measuring process. The method of representation is chosen in such a manner that the horizontal axis of the system corresponds to the actual horizon. The position of the airplane with respect to the horizon must therefore be established. The most important position to be considered is that of horizontal rectilinear flight.

The position of the airplane in landing is also important. While gliding toward the ground the pilot may

improve his view by slight changes in the attitude of the airplane. In leveling off, however, the airplane must regain its normal attitude and squarely face the wind. During the rest of the descent, the airplane remains horizontal. The pilot then improves his view by leaning his head out. He maintains this position of the head until the end of the landing process. In landing the wheels and tail skid usually touch the ground simultaneously. The longitudinal inclination of the airplane gradually increases before contact from the horizontal attitude to its attitude when resting on the ground. The airplane turns about its lateral axis so that the forward portions move upward and obstruct the downward view. Since, however, the airplane still has a high speed at the instant of landing, and since good visibility is of particular importance in the landing run on unfavorable ground, the latter position of the airplane will be chosen for judging the visibility while landing. All the airplane types were tested in this position.

The difference between the two positions of the airplanes tested was only in the longitudinal inclination. The measurement for one of the two positions could be replaced by calculation. A repeated measurement leads more quickly, however, to the goal than a point-by-point calculation, which must be carried through with the aid of rather complicated formulas. The most important positions of an airplane for judging the visibility are therefore its position in space where the engine axis is horizontal, and the position which the airplane assumes at the instant of landing. The latter will be designated as the "ground position."

Two different positions of the pilot, or of the "observation point," were chosen for each of these two attitudes, one of which will be designated as the "position of rest," and the other as the "landing position." Four different visibility charts are therefore required for each airplane.

#### IV. Description of Measuring Apparatus

1. Thread angle-indicator.— The first-developed measuring device (fig. 2) is designated as a "thread angle-indicator." A plate with degree divisions whose mid-point is the "observation point" serves as the horizontal refer-

ence plane. Another plate, likewise divided into degrees, is arranged to turn about an axis passing through the "observation point" perpendicular to the first plate. At the bottom of the turn axis, therefore at the "observation point," the end of a thread is fastened which may be drawn toward the different points of the airplane. The complete apparatus is mounted on a stand whose base plate may be clamped to the pilot's seat. The stand is extensible and is provided with universal joints at the points of attachment to the base plate and to the apparatus itself, for easier adjustment. Moreover, the apparatus may be turned horizontally on the stand, in order that it may be placed parallel to the longitudinal axis of the airplane.

The visibility measurements are then made with this apparatus, after fastening the base plate to the pilot's seat, by bringing the starting point of the thread to the chosen observation point. Then with the aid of a water level, the reference plane is made horizontal and is rotated in such a way that the zero direction of the angular scale is parallel to the longitudinal axis of the airplane. The measurements then follow, in which the thread is applied point by point to the parts of the airplane limiting the view, so that the boundary lines of the field of vision may be determined. For reading the angle, the vertical plate is turned until it touches the thread. Then the vertical angle may be read directly and the horizontal angle may be read from the scale on the bottom plate.

The measurements cannot be made by one person alone, because one person is required for stretching the thread and another for reading the angles. Furthermore, a sagging of the thread was unavoidable when measuring distant points on the airplane (e.g., the wing tips), which affected the accuracy of the measurements. No measurement of the points seen by the pilot through transparent objects (for example, the engine housing seen through the windshield) was possible with this apparatus. Lastly, this apparatus was only capable of measuring the field of vision above the horizon, and had to be inverted for the rotatable angle scale to be read vertically downward in order to determine points below the horizon.

2. Bearing angle-indicator.-- The defects in the first apparatus were the cause of building an apparatus designated "bearing angle-indicator." (Fig. 3.) It resembles a theodolite in construction and operation. On a horizon-

tal circular base plate divided into degrees there is placed a second rotatable circular plate, on which a bearing pedestal is mounted for supporting a vertical semicircular plate arranged to turn about a horizontal axis. This vertical plate is likewise divided into degrees and is provided with the true bearing device. This consists of cross hairs and a head mounted on the end of an outrigger. The cross hairs, which represent the "observation point," lie at the intersection of the extended axes about which the horizontal and vertical plates may be turned, so that the position of the cross hairs is unchanged by the rotation. A mirror is mounted on a universal joint behind the cross hairs in order to obtain the bearing of a desired point conveniently. This mirror has the advantage of not requiring the eye of the observer to be placed behind the apparatus in the extension of the bearing direction, which is inconvenient and not always possible when taking a bearing. The stand used for the first apparatus serves for mounting this apparatus on the airplane. Only one person is required for its operation, and bearings of parts of the airplane lying in front of the windshield can be easily obtained. It is also possible, with the same position of the base plate, to measure vertical angles below the horizon to  $-58^{\circ}$ , which has been found to be ample. Moreover, quicker work may be done with this apparatus, so that only about 3 hours were required to measure a field of vision, while 5 to 6 hours were required for the first apparatus. Lastly, its compactness renders it easier to mount and operate.

3. Photographic measuring apparatus.— Since the measurement of fields of vision with apparatus of the described construction requires a relatively large amount of time, and since taking exact bearings is a strain on the eyes, it was attempted to determine the field of vision photographically. The difficulty of this method consists in trying to obtain sharp definition of parts of the airplane far removed from the observation point, and as large a photographic angle as possible. A pinhole camera was therefore used. (Fig. 4.) This gave an optical angle of  $150^{\circ}$  with a plate  $9 \times 12$  cm ( $3.54 \times 4.72$  in.) and a focal length of 18.5 mm (0.73 in.). The diameter of the hole was about 0.2 mm (0.008 in.) and gave a sufficiently sharp picture. The camera was mounted on the previously described stand and was provided with a water level.

Figure 5 shows a photograph of the field of vision of

a Junkers F 13 airplane. The exposure for this photograph was 30 seconds. The outer portions of the picture are underexposed, due to the great distance from the shutter. The outlines of the vision-limiting portions of the airplane nevertheless show with sufficient distinctness.

A diagram corresponding to the degree divisions of the proposed sphere of vision was plotted for interpreting the photograph, as shown in Figure 6. This diagram may be determined graphically as well as mathematically, if the distance of the plate from the shutter is known.

About an hour is required for taking the photograph and plotting the diagram. However, still greater accuracy and saving in time may be effected by improving the camera and the scale.

#### V. Description of the Methods of Representation

Visibility may be illustrated best by imagining a sphere of convenient diameter with the eye of the pilot at its center and with the visibility boundaries projected on the outer surface from the observation point. This surface of the sphere should be represented in a plane. The problem corresponds to the production of maps of the earth's surface. The aim should be clearness and intelligibility even for nontechnical persons. Care was taken not to represent as equal in silhouette all vision obstructing and overlapping parts. They were, instead, separated from one another by boundary lines, so that the different parts of the airplane could be recognized. Moreover, windshields which, when made of cello, are practically opaque, were also treated as such in the representation. They were simply made somewhat lighter than the remaining parts.

Aside from clearness, sufficient accuracy is required to make it possible for the purchaser of an airplane to sketch on the chart his wishes regarding visibility with sufficient accuracy to make them clear to the manufacturer. The manufacturer must likewise be able to embody the desired visibility requirements in a simple manner in his designs. These requirements may be regarded as fulfilled, if they can be read from the chart with an accuracy of  $\pm 0.5^\circ$ , because any greater accuracy in construction is

hardly possible. Lastly, it should be possible to determine the visibility of different airplane types from the charts. Since only the ratio of the unobstructed to the obstructed portions of the surface of the sphere enter into the question of the visibility, a true plane chart of the surface area of the sphere must be required.

A chart with rectangular coordinates (fig. 7) was tried as the simplest kind. This is called a "square chart" in the case of land maps. An exact plotting of the points thereon is possible, because the divisions are equal in every direction and intermediate values may be easily estimated or measured. This representation yields a fairly accurate development of the surface of the sphere in the region of the horizon, while toward the top and bottom there is an over-increasing distortion. This method is therefore very imperfect.

In Figure 8 an attempt was made in order to increase the clearness of the chart, to emphasize the portions lying in the main direction of vision by making the degree divisions according to a sine function. This chart also yields no clear representation of the field of vision and therefore has no great advantage over the first.

The method of representation shown in Figure 9 fulfills the requirement of true surface area and is therefore suitable for an evaluation of the field of vision. The horizon of the proposed hemisphere of vision is here developed as in the first method of representation and yields uniform divisions. In order to obtain true surface areas, the distance between the horizontal lines must be so chosen that the areas between them equal the corresponding spherical zones. The method is likewise very simple, but also yields no good representation.

Representing the surface of the sphere as a circular area yields a more plastic picture. In Figure 10, the true azimuthal equatorial projection, like that generally used in making land maps is used for the representation. Aside from its clearness, this method is suitable for the representation of fields of vision, because of the true surface areas.

Another very clear method of representation is shown in Figure 11. The degree network of the sphere of vision is turned forward  $90^\circ$ , so that the pole lies in the direction of the zero ray of vision.

## VI. Visibility Measurements on Airplanes of Different Types

Visibility measurements were conducted on the following airplanes:

1. Dornier Merkur (fig. 12): an old high-wing transport monoplane; pilot's cockpit on the left side under the wing (not in the plane of symmetry of the airplane).
2. Junkers F 13A (fig. 13): low-wing transport monoplane; pilot's cockpit on the left side (not in the plane of symmetry).
3. Junkers W 33 (fig. 14): low-wing freight monoplane; pilot's cockpit on the left (not in the plane of symmetry).
4. Heinkel H.D. 44 (fig. 15): freight biplane; pilot's cockpit on the left behind the upper wing (not in the plane of symmetry).
5. Junkers A 35 (fig. 16): two-place, low-wing monoplane; pilot's cockpit in the plane of symmetry.
6. Albatross L 75 (fig. 17): sport and training biplane; pilot's cockpit in the plane of symmetry under the trailing edge of the upper wing.

Besides these airplanes, the field of vision of an automobile, a 1930 Opel Cabriolet, with a 4-cylinder 20 hp engine, was tested for comparison.

The location of the "observation point" was determined, with the assistance of a trial device, for a person of medium height.

Jacking up the airplane is not necessary for making the measurements in the flight position. It is only necessary to establish the angle of longitudinal inclination which the airplane takes at rest, as compared with its attitude in flight.

A chart of the field of vision of an airplane in which the pilot's cockpit is not on one side in the plane of symmetry, can be made, for a movement of the head toward ei-

ther side, with the help of the four charts of the field of vision obtained according to part III, without making a new measurement. (Thereby the unobstructed areas are increased toward each side. This chart of the field of vision is therefore a combination of two symmetrical halves of visibility fields, of which the left corresponds to a motion of the head toward the left, and the right corresponds to a motion toward the right.) It contains therefore two positions of the head and therefore shows the greatest attainable improvement in the visibility. In the case of airplanes with the pilot's cockpit located on one side, charts of the field of vision were dispensed with, because no essential improvement in visibility for the pilot is possible by moving his head toward the opposite side.

The charts of the fields of vision of the six airplanes tested are represented in the described manner in Figures 18 to 23. The simple quadratic method was used in the representation because of its clearness. In order to obtain a criterion for judging the visibility while landing, it was established by various tests on several airplane types as to which direction the pilot mainly looks while landing. Several airplane pilots of various heights indicated, from the pilot's cockpit of an airplane resting on the ground, the direction in which they were accustomed to look while landing. The various directions were marked on the ground and subsequently measured with an angle-measuring instrument. A direction of view with very little scattering was thus found, which had a horizontal angle of  $-20^{\circ}$  and a vertical angle of  $-10^{\circ}$ . This direction of view is also drawn in the charts of the fields of vision of the other airplane types, to show whether the visibility is adequate for landing.

Figure 24 compares the fields of vision of all of the tested airplane types, as well as that of the automobile. A true surface representation was used, in order to compare the visibilities by areas. The charts of the fields of vision correspond to the flight attitude of the airplane and to the position of rest of the pilot.

In comparison with the field of vision of the automobile, the fields of vision of the airplanes show considerably more free-vision areas, especially in the upper center and lower left. The downward view in the center is naturally better in the case of the automobile. The down-

ward angle, required for visibility when driving an automobile on the ground, is not so great, however, that it cannot be attained on an airplane. The view in this direction is of very great importance, especially for forced landings and for long runs on the ground.

In Figures 25 to 28, representations of the visibility are shown for special observation points. They may be derived in a simple manner from the charts of the fields of vision. Figures 25 and 26 were drawn to illustrate the visibility while flying. They show the airplane, as seen from above, and indicate how much of the visibility required for orientation is present. An altitude of 500 m (1640 ft.) above the ground is assumed. Figure 25 shows the visibility from an Albatross L 75 airplane in one case with the pilot's head at rest, and in the other case with the movement of the pilot's head to both sides to the fixed limit of 17 cm (6.7 in.). The different positions of the pilot are indicated by different hatchings. Figure 26 shows the visibility on the ground from a Junkers F 13 airplane for the pilot's positions of rest and of landing. The airplane itself is likewise shown in the flight position as in the above drawings. The altitude is again assumed to be 500 m (1640 ft.). Conclusions with respect to the visibility ratios in the case of definite ranges of vision may be drawn on the basis of these illustrations. If, for example, the range of vision amounts to only one or two kilometers on account of inclement weather, then only a small unobstructed area extending to the boundary circle will be found for both of the airplanes. The pilot must therefore fly lower in such weather, so that he may have adequate possibilities of orientation at his disposal.

Furthermore, diagrams of the lateral visibility can be drawn, as shown in Figures 27 and 28. Here the vertical angles of vision are drawn for the same airplane types with a horizontal angle of  $-20^{\circ}$ . This horizontal angle corresponds approximately to the main direction of view while flying cross-country and while landing. The two positions of the pilot are differentiated in the illustrations.

These representations, derived from the actual pictures of the fields of vision, naturally show only certain parts of the visibility conditions, but contribute to their understanding.

## VII. Conclusions with Regard to the Minimum Visibility Requirements

It is worth while, from the standpoint of safety in travel, to try to establish general minimum requirements of visibility for all airplanes. This problem may be solved in two ways: either by actual measurements and their comparison with practical experience, or on the basis of purely theoretical considerations. In the second case, requirements may arise which undoubtedly are desirable with respect to safety, but which can hardly, or only with great difficulty be fulfilled in the present state of knowledge. The next practicable way should accordingly be entered upon with the endeavor to establish mutual criteria from the results of measurements on airplanes whose visibility is recognized as satisfactory. It is promised, however, that the number of airplanes thus far investigated is too small to give conclusive results. The utility of the indicated criteria must rather be demonstrated first by measurements of other types.

With the setting up of the minimum requirements, the establishment of only certain parts in the chart of the field of vision can be treated, which parts must be vision-free or at least partially so. The most important region to be examined is in the vicinity of the point illustrated in section VI, which considers the direction of view while landing. It was required that, in the field of vision, a region in the vicinity of these points should be entirely free from obstructions. For the flight position of the airplane, a minimum angle of about  $-20^{\circ}$  downward, the zero vertical axis on the right,  $-40^{\circ}$  on the left, and  $+10^{\circ}$  upward may be established as the limits. This range must be completely free for the usual positions of the pilot (lateral movements of the head permitted).

The minimum field of vision here proposed is indicated by hatchings in the visibility charts. It should be noted that the field of vision is almost entirely free in the case of airplanes having good visibility in practice. If windshields lie within this region, care must be taken to make them of really transparent material with narrow frames. The windshields should not cover an angle of more than  $4^{\circ}$  to  $5^{\circ}$  in the field of vision. Besides these requirements, a free zone of at least  $90^{\circ}$  is required on

the left side of the field of vision. The upward and downward limits, in particular, may still be made dependent on the purpose for which the airplane is to be used.

If the minimum requirements are developed purely on logical considerations without giving heed to the results of the measurements, then they would certainly have to be very much greater than represented above. It is, of course, desirable, from this viewpoint, for no obstructions to be placed in the way of the pilot in the direction of flight. He should be able to see the whole path before him in flight, as also in landing and particularly, in taxiing. If one thinks, in this connection, of land vehicles, e.g., automobiles, street cars, etc., the need of such a view along the path of travel is obvious. The fact that these requirements in the case of the airplane have not yet become pressing, is to be attributed mainly to the still small density of traffic in the air. The collisions which have already occurred, however, could have nearly all been avoided with better visibility.

#### VIII. Conclusions with Respect to Judging the Excellence of Visibility

A purely experimental evaluation of the visibility of the individual types can be undertaken on the basis of the illustrations shown. It is possible, by comparison of the fields of vision, to make a more or less complete picture of the visibility conditions of an airplane and, with a little practice, to arrive at a worthwhile judgment in comparison with the others. It is nevertheless desirable not to make the measure of the excellence of visibility dependent on subjective estimates, but to establish numerical values therefor.

Such a numerical value may be obtained in a simple manner if the free-vision area on the surface of the hemisphere of vision is put in proportion to the total surface area of the hemisphere. The best value of excellence of 1.0 is then obtained for completely unobstructed vision, and values smaller than 1.0 according to the size of the free-vision areas, down to value of zero, in which case there is no visibility. This evaluation may be very easily performed by planimetering the given areas in a true

surface representation of the field of vision. The series, according to the values 0.44, 0.15, and 0.22 was obtained in this manner, for the Junkers F 13, Dornier Merkur, and Albatross L 75.

Such a judgment, however, has the disadvantage that the visibility areas lying in the direction of motion of the airplane, which are of much greater importance than those lying to the side or above, appear of equal importance with the latter in the excellence of visibility. A false picture of the excellence of the visibility will therefore be obtained from such an evaluation. Hence an attempt was made to emphasize the more important parts of the field of vision by corresponding valuations.

The total areas of visibility represented in true surface projections were divided from the center into four circular or annular zones. (Fig. 29.) The evaluation of the individual zones I to IV, stands in the respective ratios of 1:0.8:0.6:0.2. This relationship is shown in Figure 29.

It follows that visibility is most important in the direction of flight, and that it loses in importance in all directions from the central line. If the sum of the unobstructed areas, which have previously been multiplied by factors corresponding to the valuation ratios, is put in proportion to the sum of the total areas of the individual zones which have likewise been multiplied by these factors, then a coefficient of excellence is obtained that again reaches the value of 1.0 for entirely unobstructed vision. Excellence coefficients computed in this manner for the three given types have the values 0.43, 0.17, and 0.20. These values differ very little from those determined first.

From the few examples, no final judgment can be pronounced regarding the possibility of such an evaluation of visibility. Perhaps the visibility of an airplane cannot be fully expressed by a single coefficient. Perhaps a better picture can be obtained by dividing the field of visibility into single zones in certain important directions of view and then determining the coefficients of excellence for these zones. This method has the advantage of separate values for the individual visibility requirements, e.g., with regard to landing, orientation, or the danger of collisions.

### IX. Suggestions for the Further Investigation

Further measurements should be made on the greatest possible number of airplane types, in order to learn more about the general and particular requirements of visibility.

The measurements by means of angle-measuring instruments may be superseded by improved photographic apparatus and a considerable simplification of the task may be thus effected.

### X. The Most Important Results

1. A process was developed, with the help of which it is possible to determine in a simple manner the visibility of an airplane from the pilot's cockpit.
2. A suitably constructed angle-measuring instrument was used for determining the visibility. It was also found possible to measure the field of vision with an improved photographic camera. The latter method may be further improved and will then constitute a very quick and simple process.
3. No one method for representing the results of the measurements could be found which equally satisfied all the requirements. There is, rather, the choice between several methods, according to the purpose to be fulfilled.
4. A unified main direction of view resulted from the comparison of the measurements on the different airplane types, which direction is of decisive importance for cross-country flying as well as for landing. Obstructions to the view in the neighborhood of this direction are very objectionable in flight and especially in landing.
5. A region roundabout this particularly important direction of view is proposed as the minimum requirement for visibility, which region should be free from all obstructions on every airplane. The limits are established by the angles.
6. The proposal is made for an evaluation of visibility of an airplane to express the visibility relations according to the extent of the unobstructed or obstructed

areas and by different valuations of the visibility in different directions by a numerical coefficient. Its utility can be demonstrated, however, only after the investigation of more airplane types.

## XI. Summary

A process for the measurement of the visibility of airplanes from the pilot's cockpit is developed in the foregoing work. The apparatus necessary for the measurements was suitably constructed and measurements of the fields of vision were made with it. The visibilities of six airplanes of different types of construction and use were measured, as well as the visibility of an automobile for comparison. Various methods of representation for illustrating the fields of vision were examined with regard to their suitability for the foregoing purposes. The results are compared with those obtained in practice by means of charts of the fields of vision. The attempt was made to establish minimum visibility requirements and to express the excellence of visibility by means of a numerical coefficient.

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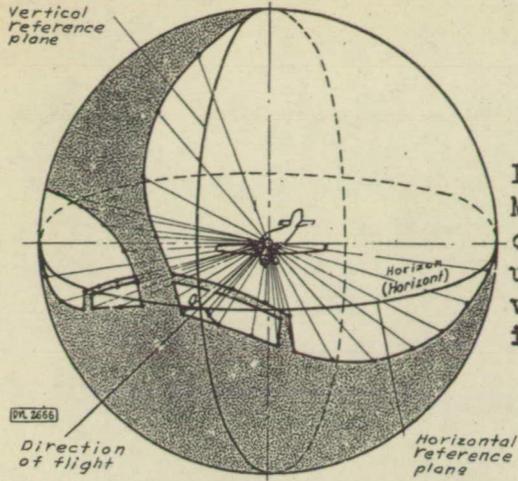


Fig. 1 Method of measuring visibility.

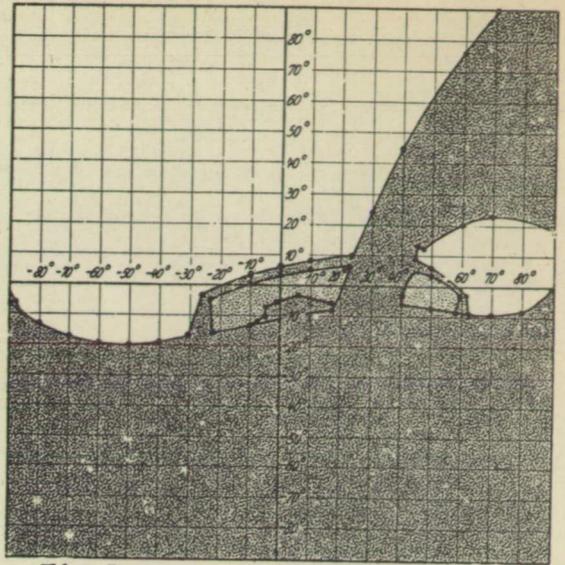


Fig. 7 "Square chart" of field of vision.

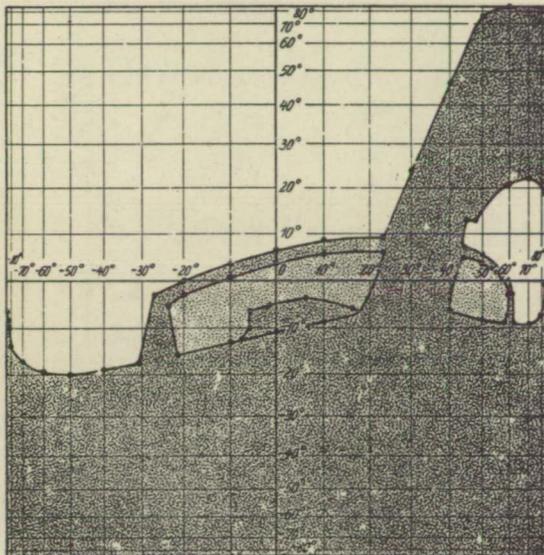


Fig. 8 Visibility chart with degree divisions according to a sine function.

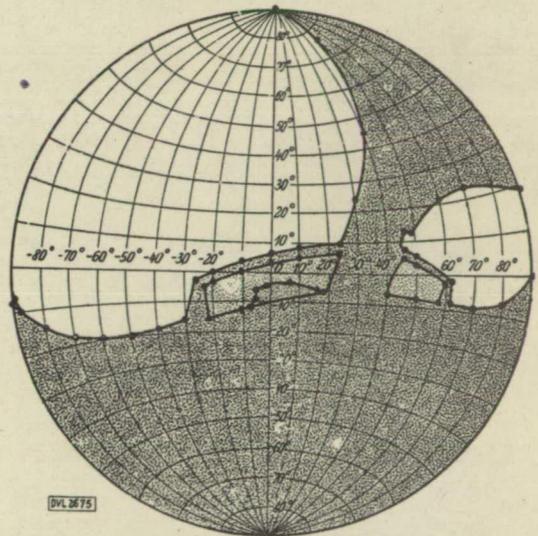


Fig. 10 True-surface azimuthal equator projection.

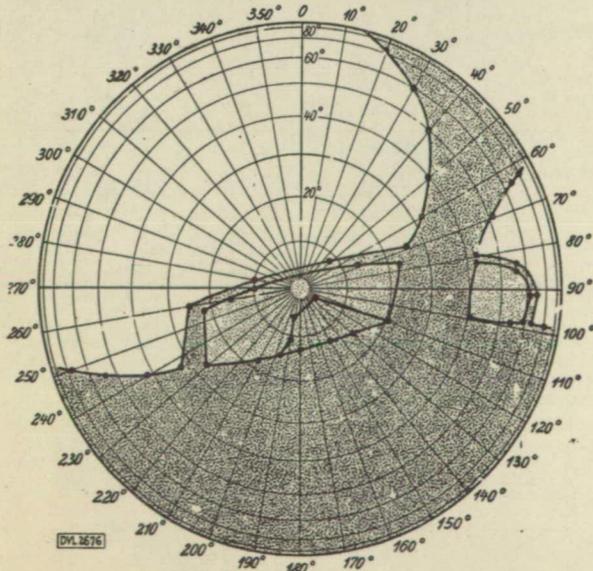


Fig. 11 Orthogonal azimuthal polar projection.

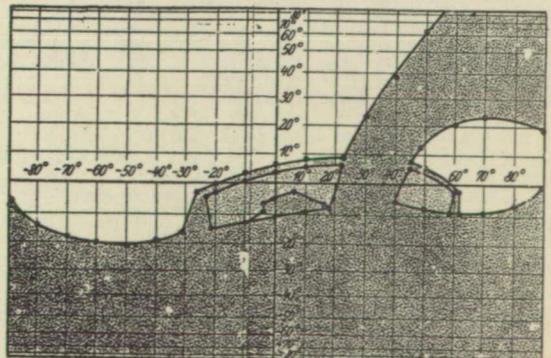


Fig. 9 True-surface diagram of field of vision. (Cylinder projection)



Fig.2 Angle indi-  
cator with thread.

Fig.3 Bearing-  
angle indicator.

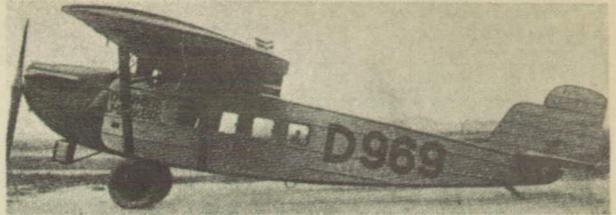


Fig.12 Dornier-Merkur.



Fig.13 Junkers F 13.



Fig.14 Junkers W 33.

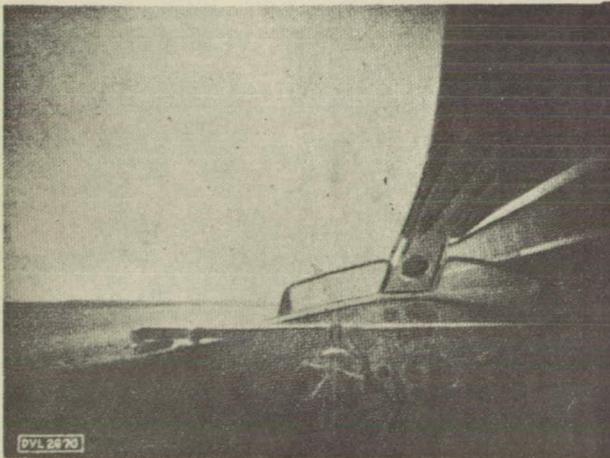


Fig.5 Field of vision of  
Junkers F 13 airplane.



Fig.15 Heinkel HD 44.



Fig.4 Pin hole camera.

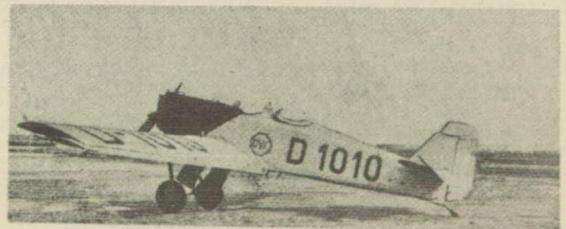


Fig.16 Junkers A 35.



Fig.17 Albatros L 75.

Figs.12 -17 Airplanes whose fields  
of vision were determined.

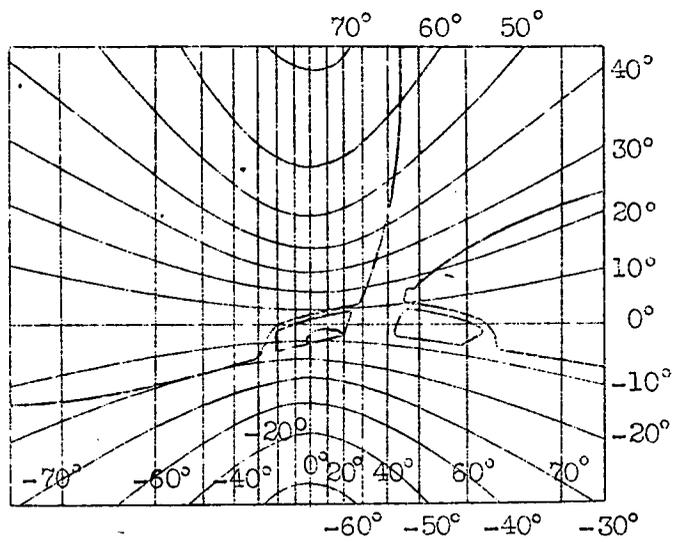
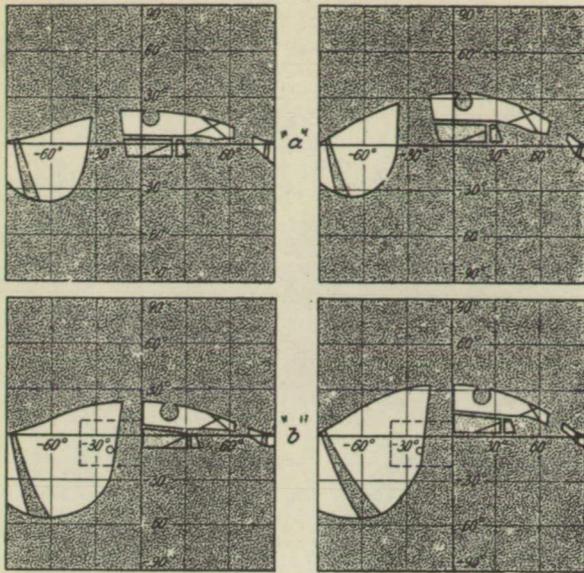
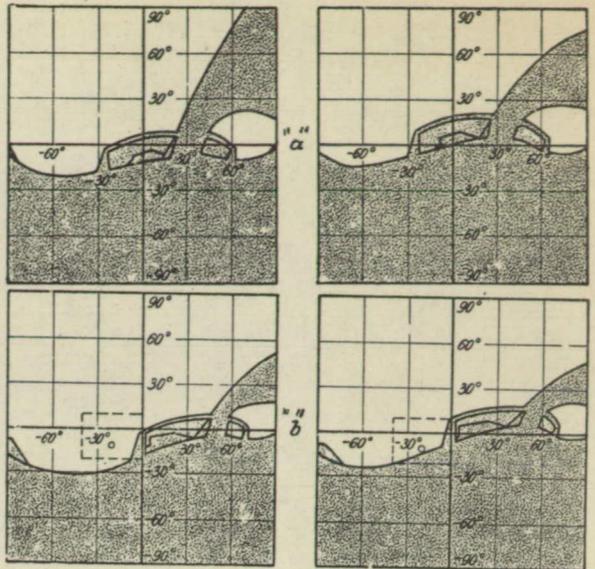


Fig.6 Diagram for determining angular position of any point in Figure 5.



Flight attitude      Ground attitude

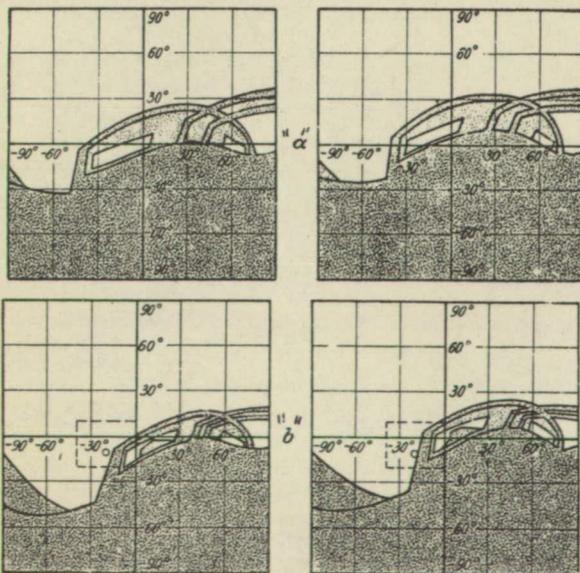
Fig.18 Visibility charts of Dornier "Merkur".



Flight attitude      Ground attitude

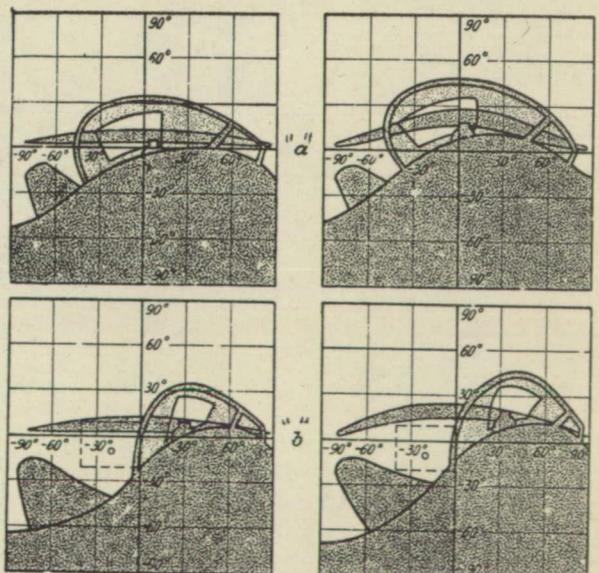
Fig.19 Visibility charts of Junkers F 13.

a, At rest, b, In landing. The dash rectangle indicates direction of view of pilot in flight and in landing.



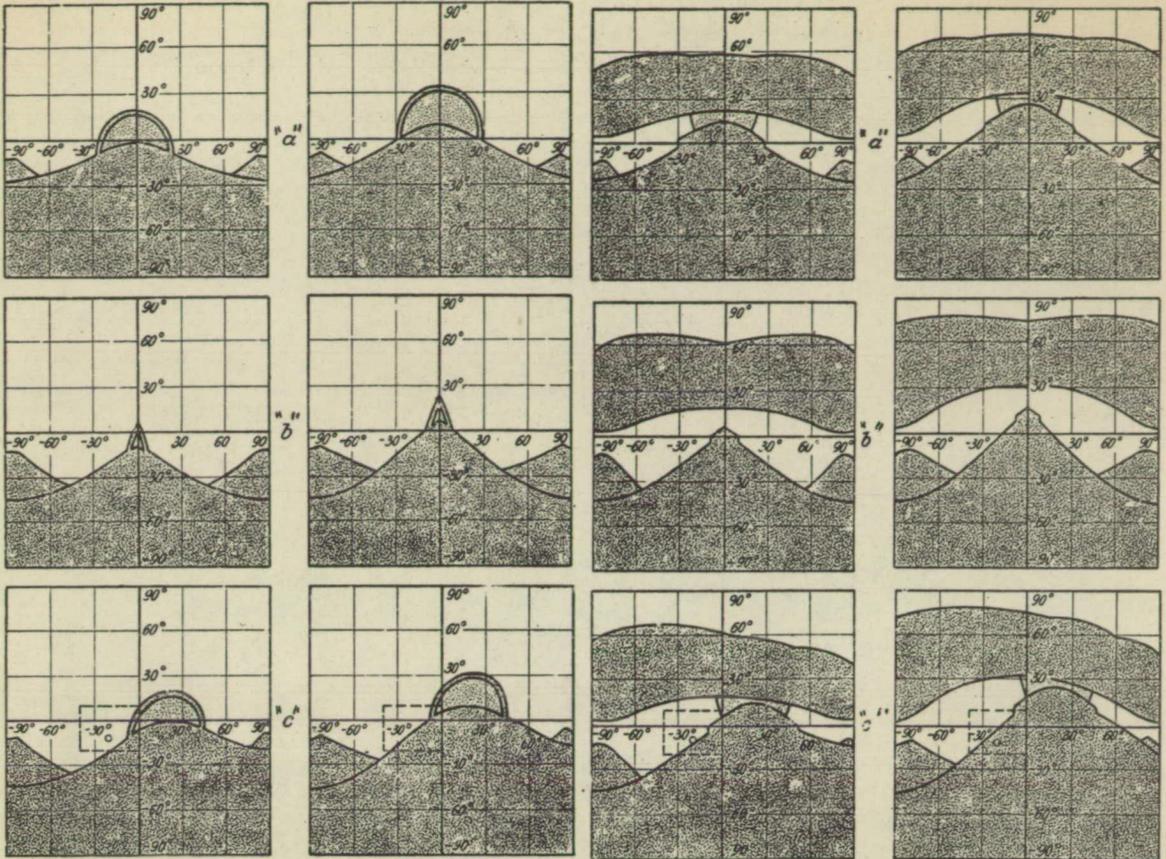
Flight attitude      Ground attitude

Fig.20 Visibility charts of Junkers W 33.



Flight attitude      Ground attitude

Fig.21 Visibility charts of Heinkel HD 44.



Flight attitude      Ground attitude

Fig.22 Visibility charts of Junkers A 20.

Flight attitude      Ground attitude

Fig.23 Visibility charts of Albatros L 75.

a, At rest, b, With head tipped to either side, c, In landing.

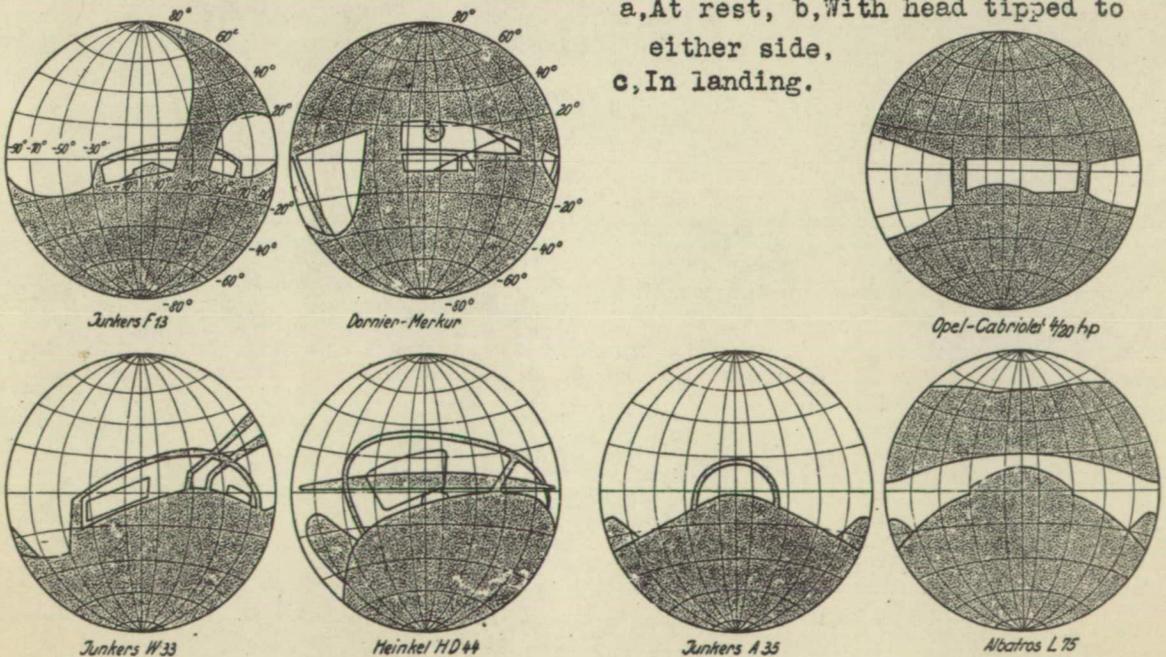


Fig.24 Comparison of visibility charts. True surface azimuthal equator projection.

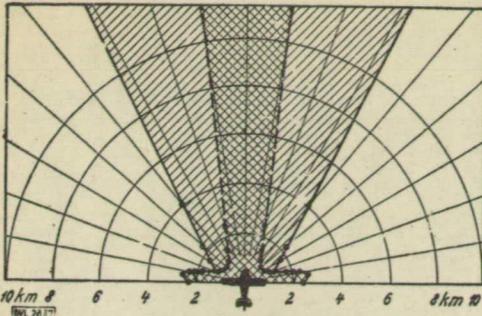


Fig.25 Ground view from 500 m(1640 ft.) altitude (Albatros L 75).

- Airplane in flight attitude, pilot at rest.
- Airplane in flight attitude, pilots head tipped to both sides.

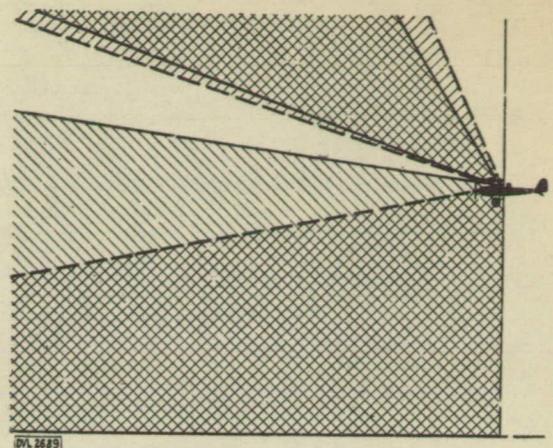


Fig.27 Side view at a horizontal angle of  $-20^{\circ}$ , (Albatros L 75).

- Pilot at rest
- Pilot in landing.

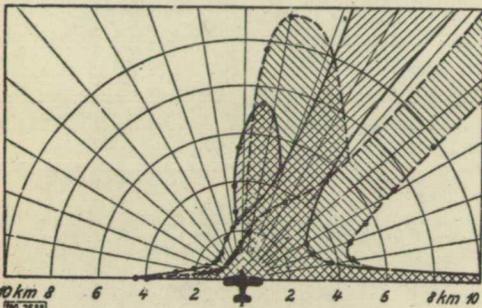


Fig.26 Ground view from 500 m(1640 ft.) altitude (Junkers F 13).

- Airplane in flight attitude, pilot at rest.
- Airplane in flight attitude, pilot in landing position.

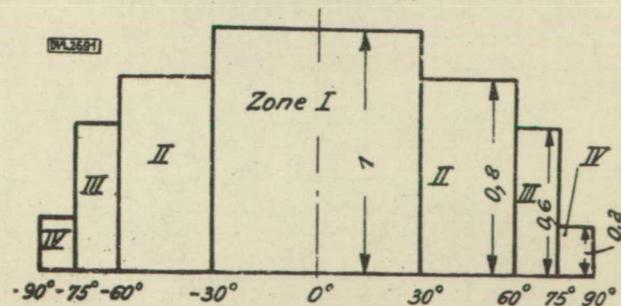
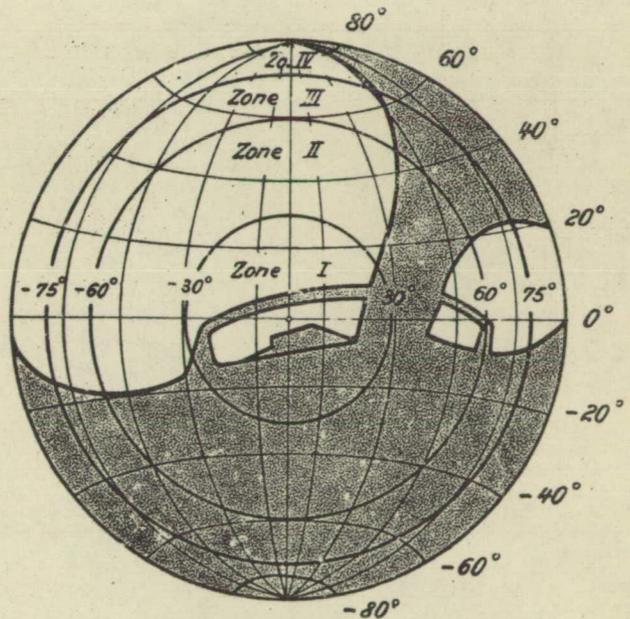


Fig.29 Division of field of view into zones, and diagram for computing degree of visibility. (True-area representation)

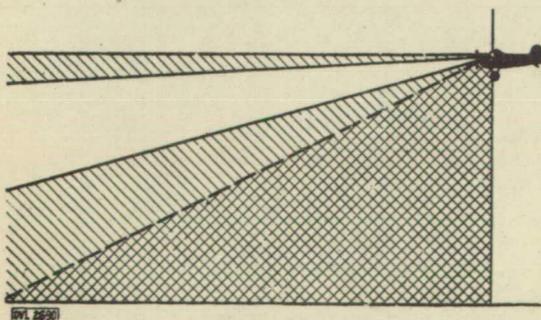


Fig.28 Side view at a horizontal angle of  $-20^{\circ}$ , (Junkers F 13).

- Pilot at rest
- Pilot in landing.