ICAS-80-8.4 ON THE POSSIBILITIES OF PILOTS TO GET INFORMATION FROM OUTSIDE BY VISION

H.-E. Hoffmann
DFVLR, Germany

Abstract

When flying according to visual flight rules a pilot gets a part of the informations necessary for navigation by observing the air space respectively by observing to the ground. During the last years in the DFVLR investigations are carried out on that point in which distances aircraft and visual references to the ground are visible and how their visibility is influenced by different parameters. Depending on discerning details in the visual object there are distinguished different degrees of visibility ranges: Maximum detection range and maximum recognition range. The parameters the influence of which on these ranges were investigated during the field experiments were inter alia: Size, shape, and inherent contrast of aircraft; type of background; degree of the turbidity of the atmosphere; type of visual reference on the ground (vehicle, mast, cable marker, obstacle beacon); adaptation brightness.

I. Introduction

In the last years a number of investigations have been conducted in the DFVLR concerning the range of observation sensors. The intention was also to determine the range of the natural observation sensor, namely that of the human eye. The aim was to obtain data regarding how the range of the human eye is influenced by various environmental parameters. The units of measure for the range in these investigations were the maximum detection range and the maximum recognition range:

> The maximum detection range is the distance at which an object can just still or just already be seen. It then just stands out from its background.
>
> The maximum recognition range is the distance at which certain details of the object can just still or just already be distinguished. It is then possible to say whether it is e.g. an aircraft.

In this paper the maximum detection range or, in some cases, the maximum recognition range for observing aircraft are equated to the flight visibility while the maximum detection range or the maximum recognition range in observing ground targets are equated to visibility to the ground respectively "visual reference to the ground". The terms flight visibility and visibility to the ground are contained in § 28 and 29 of the German Rules of Air Traffic Control in the section on visual flight rules. While the term flight visibility is also commented on, no explanation is given for the term visibility to the ground.

After a brief description of the test procedure in the 2nd section of this paper, sections 3 and 4 provide information by means of diagrams as to the way the various parameters influence flight visibility or visibility to the ground. The influence of the following parameters is shown:
Horizontal standard visibility

(measure for the degree of turbidity of the atmosphere), colour of an aircraft, size of an aircraft, environmental brightness prior to and after sunset, altitude, nature of the background and intensity of an obstacle beacon.
The results presented here were obtained in field tests - i.e. not in simulation tests in the laboratory. It was necessary to design the tests in such a way as to ensure that a limited number of tests would provide information regarding the influence of a particular parameter on flight visibility or visibility to the ground despite the constantly changing test conditions in the field. The test results apply to observers with normal vision, however, in contrast to an aircraft pilot, to observers who

- were employed only with observing
- had to scan only a very limited field of view
- were not tired
- did not have to switch constantly from close-up to long-distance accommodation.

The results presented in sections 3 and 4 thus represent optimum values compared to those for the flight and visibility to the ground of a pilot. It would be necessary to multiply these values with factors less than one in order to obtain more relevant values for aircraft pilots.

II. Test Procedure

The method used in the tests to determine flight visibility and visibility to the ground was to continually reduce the distance between the observers and the objects being observed until it was possible to detect or recognize the objects. The observers were either people trained for specific observation tasks or they were briefed in their task in preliminary trials. Flight visibility was determined from the ground. The task of the groups of observers consisting of 6 - 8 persons was to determine and register the moment in time in which they just saw the aircraft approaching them in a direct line emerging from the haze (maximum detection range) or in which they were able to recognize the aircraft (maximum recognition range). The distance between the observers and the approaching aircraft was constantly measured by a radar unit. The maximum detection ranges or recognition ranges were determined by allocating the times for detection and recognition to the trajectories of the aircraft registered by the radar set.
To determine visibility to the ground, observations were made from a helicopter approaching a particular target on the ground. In this case, the groups of observers were made up of 3 - 4 persons. The maximum detection range or maximum recognition range was then determined in the same way as for the flight visibility. The size of the sector which the observers had to scan was limited in the vertical direction to approx. 1^{o} and in the horizontal direction to approx. 30^{o}. In only one case (see Fig. 5) they were exactly briefed on the aircraft to be detected. The environmental parameter "horizontal standard visibility" as a measure for the degree of cloudiness of the atmosphere was derived from contrast measurements of natural visual targets. (1, 2, 3, 4) The photometer set up on the ground for this purpose was also used to measure the brightness of the sky. To enable various test parameters to be measured from the air, a second photometer was installed in a helicopter. (5, 6) More precise details of the test procedure, the methods used to determine the observation and measured values and the processing and evaluation of these values can be obtained from the literature stated in the following two sections.

III. Flight visibility as a function of various parameters

The degree of turbidity of the atmosphere is one of the environmental parameters subject to wide fluctuations regarding location and time and which exerts considerable influence on flight visibility. To what extent flight visibility is influenced by the degree of turbidity of the atmosphere is shown in Fig. 1 where the maximum detection range for observations of a dark-green Do 27 is plotted as a function of the horizontal standard visibility. A point to mention here is that the horizontal standard visibility corresponds roughly to the ground visibility as commented on in the air traffic control rules. The Do 27, the subject of the observations on which the values in Fig. 1 are based, is a single-engined, 4-seater aircraft with a wing span of 12 m. Such a large number of values have been obtained from the tests conducted over several years into the maximum detection range for observing a Do 27 that it was possible to represent the dependence of this maximum detection range on the horizontal standard visibility by means of a curve for horizontal standard visibility ranges of between 8 and 60 km. The data for plotting this curve of the maximum detection range below a horizontal standard visibility range of 8 km are not reliable enough and this is expressed in Fig. 1 by the fact that the path of the maximum detection range curve of the horizontal standard visibility is represented by a broken line at low horizontal standard visibility ranges.

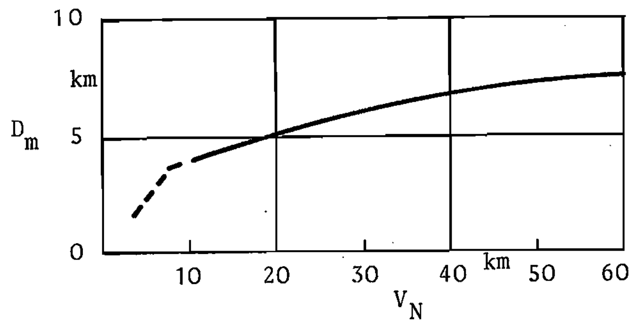

Fig. 1. The maximum detection range D_m when observing a darkgreen Do 27 in dependence on horizontal standard visibility V_N

The curve of Fig. 1 shows that flight visibility, represented here by the maximum detection range, is considerably less than the horizontal standard visibility or ground visibility. A maximum detection range of 5 km corresponds e.g. to a horizontal standard visibility range of 20 km and when the horizontal standard visibility range is 60 km the Do 27 is detected only at a distance of approx. 7.5 km. Fig. 1 further shows that changes in the horizontal standard visibility range at low standard visibility levels have a greater influence on the maximum detection range than changes in the horizontal standard visibility range at large horizontal standard visibility ranges. With a horizontal standard visibility range of 20 km, a 10 km change in the horizontal standard visibility range results in changes in the maximum detection range of approx. 1 km. On the other hand, changes in the horizontal standard visibility range when this is 60 km have scarcely any effect on the maximum detection range.

For the next illustration 2 the maximum detection ranges of Fig. 1 have been converted into the times which would elapse between the detection of a dark-green Do 27 and a possible collision if 2 aircraft are on collision course at the time they are detected and remain on this course following detection. These times have been plotted for 3 different approach velocities, again as a function of the horizontal standard visibility.

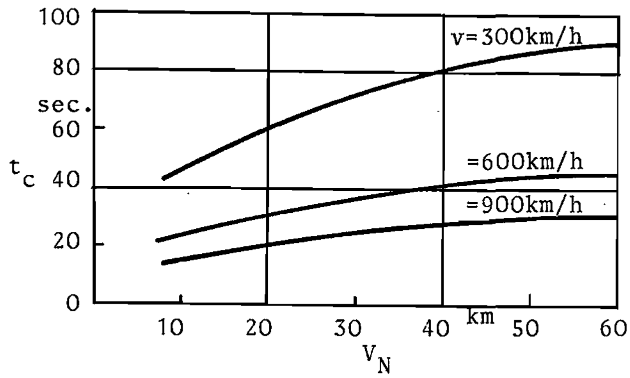

Fig. 2. The time t_c between detecting a darkgreen Do 27 and collision for different velocities of approach v in dependence on horizontal standard visibility V_N

At an approach velocity of 300 km/h the time which elapses between the detection of a dark-green Do 27 and a possible collision at a horizontal standard visibility range of 8 km is 41 seconds, increasing at long standard visibility ranges to a time of 85 seconds. With an approach velocity of 900 km/h, the time which elapses until the moment of collision with a standard visibility range of 8 km is approx. 13 seconds and when the standard visibility range is greater than 60 km, approx. 30 seconds.

Fig. 3 is intended to provide information on what influence a different colour may have on flight visibility. In this diagram the top continuous curve represents the maximum detection range when observing a dark-green Do 27 and the bottom curve the maximum detection range for the same type of aircraft, in this case, however, painted white and yellow. The maximum detection ranges for both aircraft were determined with direct approach and with the sky as a background. The part of the curve determined in tests for the maximum detection range as a function of the horizontal standard visibility when observing a yellow-white Do 27 has been shown with a continuous line while the extended part based on theoretical considerations is shown as a broken line.

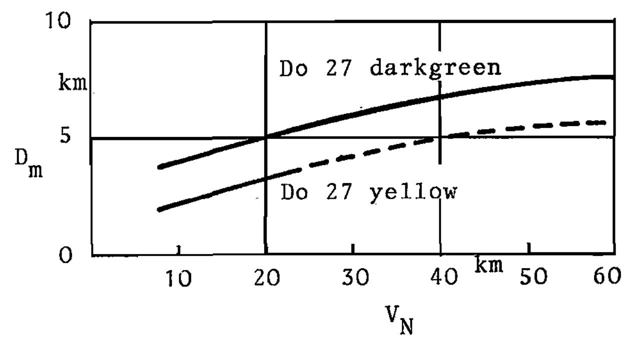

Fig. 3. The maximum detection range D_m when observing a darkgreen and a yellow Do 27 in dependence on horizontal standard visibility V_N

The result of the plottings of Fig. 3 can be stated as being that the maximum detection range for observing a yellow-white Do 27 is approx. 1.8 km less than for observing a dark-green Do 27 provided a Do 27 is observed against the sky.

While Fig. 3 showed what influence a different colour of aircraft may have on the maximum detection range, Fig. 4 illustrates what influence a different colour and, in addition, a different size may have on the maximum detection range. The top curve of Fig. 4 reflects the maximum detection range of a medium-sized brightly painted commercial aircraft with a wing span of approx. 30 m as a function of the horizontal standard visibility. The maximum detection range was determined in tests at a horizontal standard visibility range of approx. 15 km. The remaining part of the curve was got mathematically.

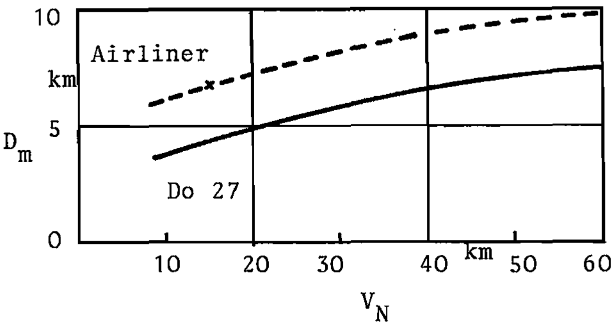

Fig. 4. The maximum detection range D_m when observing a darkgreen Do 27 and a white airliner in dependence on horizontal standard visibility V_N

A comparison of the values for the maximum detection ranges when observing a dark-green Do 27 reveals that the brighter colour of the commercial airline and its different size increase the maximum detection range when observing the commercial airline by approx. 2.5 km.

Fig. 5 plots the maximum detection range when observing a military aircraft in comparison to the maximum detection range when observing the dark-green Do 27. The military aircraft, an F 104, was provided with a camouflage coat. The test on which the maximum detection ranges of the F 104 are based, was conducted at a horizontal standard detection range of approx. 18 km. (see x in top and bottom curve of fig. 5). The top curve for the F 104 derived from theory and represented by a broken line applies for the event that the F 104 approaches the observers with the afterburner switched off, i.e. with a smoke plume. The result was that the observers were precisely directed to the point in the sky at which the F 104 was bound to emerge out of the haze. The bottom curve spplies for the event that the observers had to scan a sector of approx. 30° in a method similar to that used for determining the maximum detection range for the other aircraft.

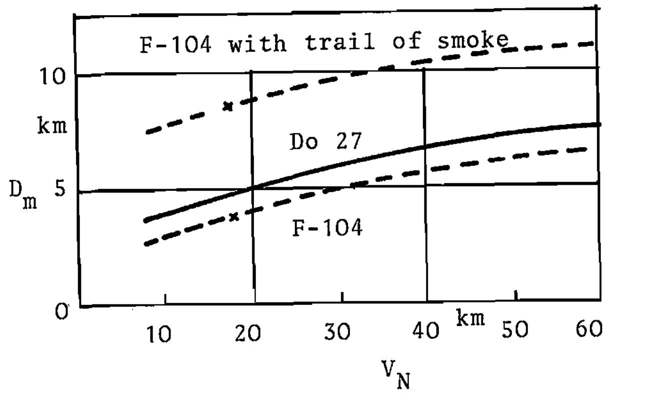

Fig. 5. The maximum detection range D_m when observing a darkgreen Do 27,a F-104 and a F-104 with trail of smoke in dependence on horizontal standard visibility V_N

The F 104, somewhat smaller than the Do 27 in direct approach, is detected approx. 1 km later than the dark-green Do 27. This applies for the event that the sector to be scanned when observing both aircraft is equal in size. If the observers are directed precisely to the approaching F 104 due to the plume caused by switching off the afterburner, the F 104 is detected almost 4 km sooner than the dark-green Do 27.

A further parameter affecting flight visibility is the environmental brightness. (9, 10). The values for the maximum detection range given in Fig. 6 were again obtained when observing the darkgreen Do 27 prior to and after sunset. The top curve applies to a horizontal standard visibility range of 13 km. The sky luminance in $^{cd}/m^2$ has been plotted on the abscissa of this diagram as a measure for the brightness of the sky.

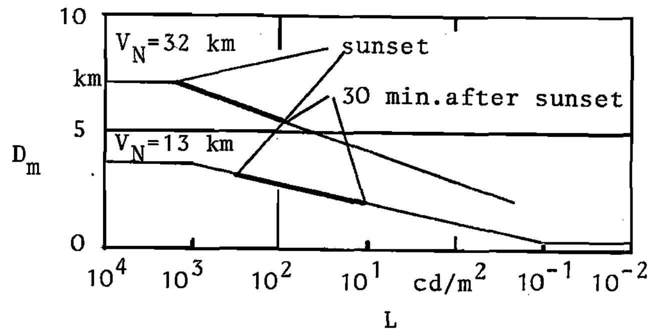

Fig. 6. The maximum detection range D_m when observing a darkgreen Do 27 in dependence on sky luminance L before and after sunset

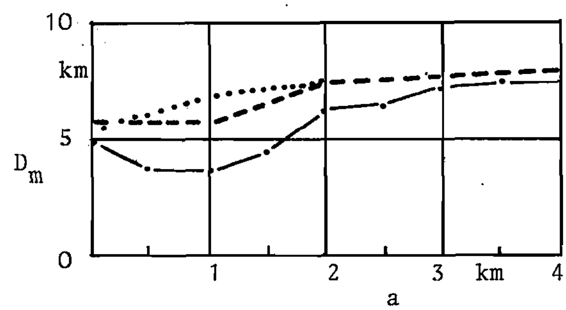

Fig. 7. The maximum detection Range D_m when observing a darkgreen Do 27 in dependence on flight altitude a at 3 different times (calculated from (11) and (12))

The maximum detection range, when observing a dark-green Do 27, of approx. 7 km at a horizontal standard visibility range of 32 km with a daytime brightness (i.e. at brightnesses of 10^3 cd/m²) is reduced up to 30 minutes after sunset by approx. 1.5 km to 5.5 km. At a horizontal standard visibility range of 13 km the maximum detection range already begins to decrease before sunset. 30 minutes after sunset, the maximum detection range has also fallen by 1.5 km compared to the maximum detection range in daytime brigthness.

The degree of turbidity of the atmosphere, i.e. the horizontal standarf visibility, is usually dependent on altitude. This means again that flight visibility may also change with altitude. The work of DUNTLEY (11) contains results of flight measurements in which the scattering coefficient was measured as a function of altitude over a particular location at the ground at various times. These values have been converted into horizontal standard visibilities and, using the data from (12), into maximum detection ranges when observing a dark-green Do 27 as a function of altitude.

Fig. 7 shows the different behaviour which flight visibility may display as a function of altitude in the lower section of the atmosphere. During the one test period (bottom curve of Fig. 7) the maximum detection range at extremely low altitudes is 5 km, dropping at altitudes of between 0.5 and 1 km by approx. 1.2 km to 3.8 km to then climb to a maximum detection range of 7 km at altitudes higher than 1 km. The two other curves of Fig. 7 show in the one case a constancy of the maximum detection range of not quite 6 km in the lower section of the atmosphere up to 1 km altitude, in the other case an immediate rise in maximum detection range as the altitude increases. Investigations into the dependence of flight visibility on altitude and the connection with meteorological parameters are being conducted in the DFVLR. (13).

As mentioned already at the beginning, not only the maximum detection range but also the maximum recognition range may be used as a measure for flight visibility. In the tests which provided the values forming the basis of Fig. 8, 3 different aircraft of approx. the same size but each painted differently, approached the observers in irregular order. The task of the observers was to recognize which of the 3 approaching aircraft was the dark-green Do 27.

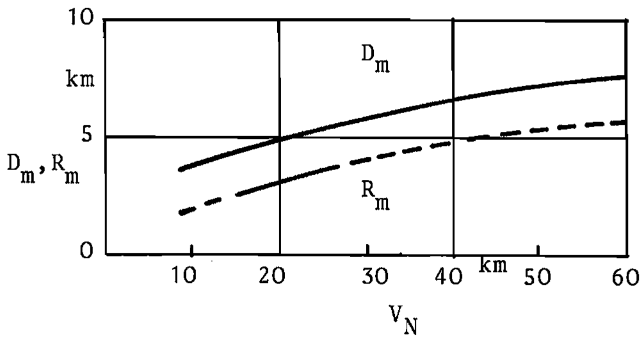

Fig. 8. The maximum detection range D_m and the maximum recognition range R_m when observing a darkgreen Do 27 in dependence on horizontal standard visibility V_N

Under the conditions just described, the maximum recognition range for recognizing a dark-green Do 27 is almost 2 km less than the maximum detection range, thereby indicating that, if the maximum recognition range and not the maximum detection range is taken as the measure for flight visibility, all the ordinate values shown in Figs. 1-7 require to be reduced by a particular amount.

Further results regarding the maximum detection range or maximum recognition range when observing aircraft and thus the flight visibility are contained in the references. (7-10)

IV. Visibility to the ground as a function of various parameters

Widely varying optical reference points on the ground may be taken as criteria for visibility to the ground when carrying out observations form the air. This involves the size and shape of the reference points, their illumination or brightness and the background against which they are observed. One of the principal reference points on the ground in the tests conducted by the DFVLR was a 1.5 t truck. This reference point is therefore used in the following figures 9 - 13 to illustrate the influence of different parameters on visibility to the ground. The last 2 diagrams then provide values for the maximum detection range when observing obstacle beacons.

The number of values for visibility to the ground is not as comprehensive as that for flight visibility. It is therefore not possible to present a curve for the dependence of visibility to the ground on the horizontal standard visibility range but only to provide values for particular ranges of horizontal standard visibility. Fig. 9 plots the maximum detection range when observing a 1.5 t truck for horizontal standard visibility ranges of approx. 7 and 30 km. These values apply to a very particular method of positioning this vehicle in relation to its background and to the nature of its illumination. The results plotted in Fig. 9 are intended to illustrate what influence different horizontal standard visibilities have on the maximum detection range of a particular object seen against a particular background.

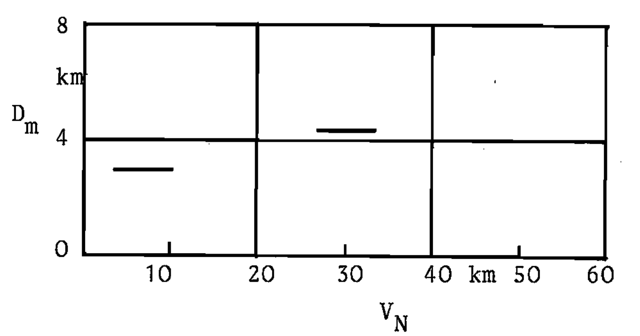

Fig. 9. The maximum detection range D_m for two different horizontal standard visibilities V_N

Whereas a 1.5 t truck is detected from approx. 3 km at a horizontal standard visibility range of approx. 7 km, the maximum detection range increases to 4.3 km at a horizontal standard visibility of approx. 30 km.

The results of other investigations have been plotted in Fig. 10 to show what influence a reducing environmental brightness has on the maximum detection range when observing a truck. This diagram plots the curve of the maximum detection range prior to and following sunset.

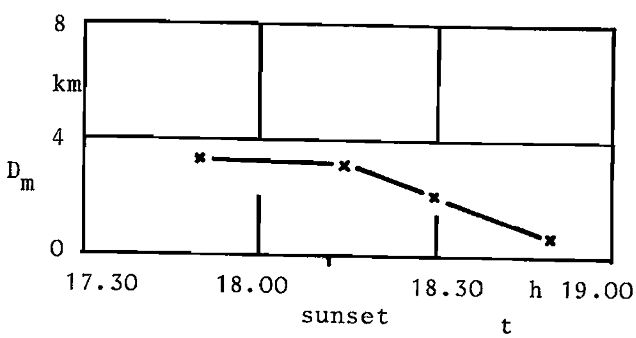

Fig. 10. The maximum detection range D_m when observing a truck in dependence on time t before and after sunset

Whereas the maximum detection range in this case is slightly more than 3 km before sunset, the range 30 minutes after sunset is only approx. 1.2 km.

A further parameter which may have a considerable influence on the maximum detection range when observing an object on the ground is its background. Fig. 11 shows the effect of 3 different types of background on the maximum detection range when observing a 1.5 t truck.

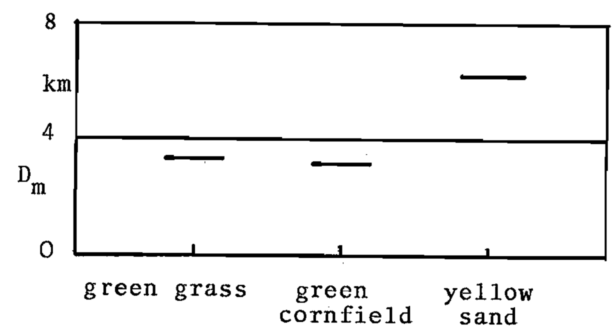

Fig. 11. The maximum detection range D_m when observing a truck for different backgrounds

While no difference was determined in the influence exerted by green grass and a green corn field as a background, yellow sand considerably increases the maximum detection range when used as a background. While the truck could be detected at a range of approx. 3 km when seen against a background of green grass or a green corn field, this range increased to just over 6 km when the truck was viewed against yellow sand.

For a specific case of the dependence of the horizontal standard visibility on altitude (s. the comments on Fig. 7) Fig. 12 illustrates to what extent the maximum detection range changes as a function of altitude when observing a truck.

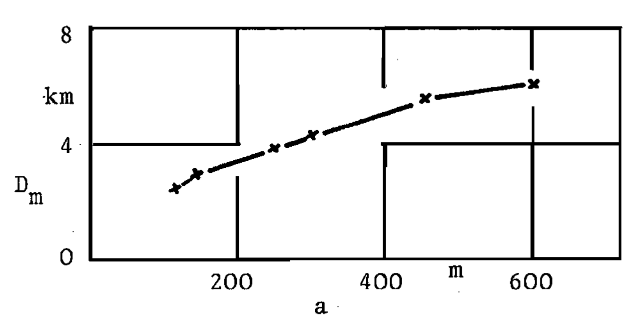

Fig. 12. The maximum detection range D_m when observing a truck in dependence on flight altitude a

While the maximum detection range is approx. 2.5 km at an altitude of approx. 120 m, it increases steadily to approx. 6 km at an altitude of 600 m.

In a similar way as presented in Fig. 8 regarding flight visibility, Fig. 13 is intended to show how much lower visibility to the ground may be when the maximum recognition range and not the maximum detection range is taken as the measure for visibility to the ground. The maximum detection range and the maximum recognition range when observing a 1.5 t truck have been plotted for two horizontal standard visibilities ranges, these being approx. 7.5 and 30 km.

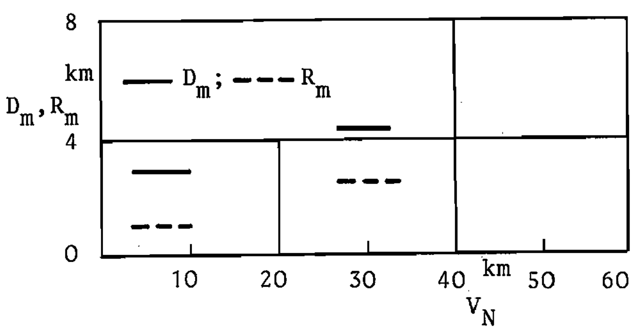

Fig. 13. The maximum detection range D_m and the maximum recognition range R_m when observing a truck for two different horizontal standard visibility V_N

If, in the specific case of Fig. 13, the maximum recognition range and not the maximum detection range is taken as the measure for visibility to the ground, this means a reduction in visibility to the ground by approx. 1.8 km.

The last two diagrams reflect the result of tests in which the criterion used for measuring visibility to the ground was not a 1.5 t truck but an obstacle beacon or the mast on which the beacon was mounted. Fig. 14 shows how the maximum detection range both of the obstacle beacon as well as of the mast on which it was mounted varies as a function of the environmental brightness prior to and following sunset.

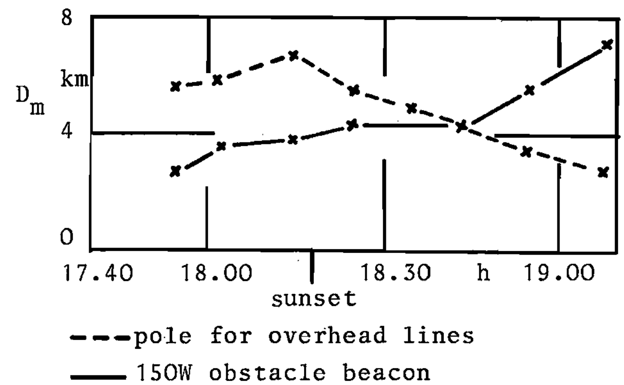

Fig. 14. The maximum detection range D_m when observing a pole for overhead lines and a 150W obstacle beacon in dependence on time t before and after sunset

While at the brightnesses prevailing before sunset and also for some time after sunset the mast was detected from a greater range than the obstacle beacon, the situation approx. half an hour after sunset is different. From this time the obstacle beacon is detected at a greater range than the mast. Whereas before and after sunset the maximum detection range when observing the mast grew less and less, the maximum detection range when observing the obstacle beacon became greater during this period.

While Fig. 14 shows the path followed by the maximum detection range as a function of the environmental brightness wehen observing a 150 watt obstacle beacon, the values plotted in Fig. 15 represent the maximum detection ranges for obstacle beacons of different power for observations conducted at night.

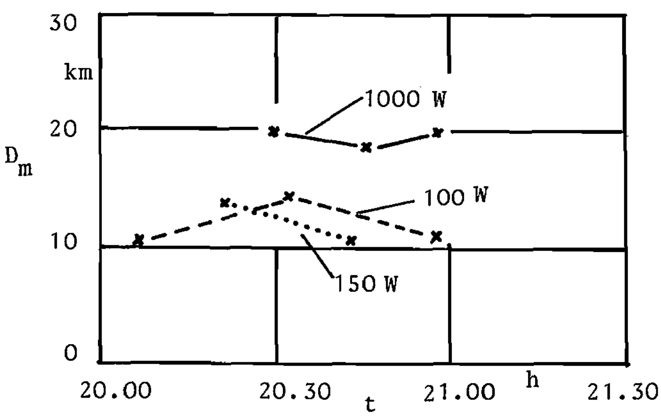

Fig. 15. The maximum detection range D_m when observing obstacle beacons whith different power during one night

Whereas no significant difference is detected in the case of the 100 and 150 watt obstacle beacon, the 1000 watt obstacle beacon can be detected from a 5 to 9 km greater range.

References

[1] Hoffmann, H.-E. Die Bestimmung der horizontalen Normsicht durch Kontrastmessungen an natürlichen Sichtzielen.
Deutsche Luft- und Raumfahrt, Forschungsbericht 67-11 (1967).

[2] Hoffmann, H.-E. Über einige Erfahrungen bei der Bestimmung der horizontalen Normsicht durch Kontrastmessungen an natürlichen Sichtzielen.
Deutsche Luft- und Raumfahrt, Forschungsbericht 71-22 (1971).

[3] Hoffmann, H.-E. Concerning some experiments obtained during the determination of the horizontal standard visibility by contrast measurements of natural targets.
Royal Radar Establishment, Malvern Worcs. RRE. Translation No. 352, 46 pp. (1971).

[4] Hoffmann, H.-E. and Kuehnemann, W. Comparison of the results of two measuring methods determining the horizontal standard visibility with the visual visibility range.
Atmospheric Environment Vol. 13, No. 12, pp. 1629-1634, (1979).

[5] Hoffmann, H.-E. Optische und atmosphärisch-optische Parameter bei Versuchen zur Sichtbarkeit in Norddeutschland 1977.
DFVLR-Mitt. 79-06 (1979).

[6] Hoffmann, H.-E. Optical and Atmospheric Optical Parameters during Visibility Tests in the North of Germany 1977.
Techn. Transl. ESA-TT-615 (1980).

[7] Hoffmann, H.-E. Die maximale Auffaßreichweite bei der optischen Beobachtung tief anfliegender Flugzeuge vom Boden aus.
DFL-Bericht Nr. 0344, Braunschweig (1966).

[8] Hoffmann, H.-E. The visibility range when observing an aircraft with and without field-glasses.
OPTICA ACTA Vol. 19 (1972) No. 5, pp. 463-466.

[9] Hoffmann, H.-E. Ein Überblick über die wichtigsten, ausreichend fundierten Kenntnisse zur Sichtbarkeit (maximalen Auffaßreichweite) von Flugzeugen.
Deutsche Luft- und Raumfahrt, Mitt. 74-33 (1974).

[10] Hoffmann, H.-E. A Review of the most important established Facts about the Visibility (Maxim.Detection Range) of Aircraft.
Royal Aircraft Establishment, Farnborough, Hants, Library Translation No. 1895, 17 pp. (1976).

[11] Duntley, S.Q. Measured Visible Spectrum Properties of Real Atmospheres.
AGARD Conference Proceedings No. 1 on Optical Propagation in the Atmosphere, Lygnby, Denmark, 27-31 October 1975, p. 39-1 - 19-14 (1976).

[12] Hoffmann, H.-E. Influence of the Flight Altitude and Limitation of the Field of View on the Visibility of Targets on the Ground and the Maximum Visibility Flight Altitude.
Techn. Transl. ESA-TT-654 (1980).

[13] Hoffmann, H.-E. The dependence of air-to-ground visibility upon flight altitude and meteorological parameters (in preparation).