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FLYING WITH NIGHT-GOGGLES AND HEAD-DOWN DISPLAY AT NIGHT

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Abstract

Modern helicopters must have the ability to operate at night flying at low level. This requirement exists in the military case regarding transport, search and rescue and tank attack missions under conditions of low ambient illumination. But it is of equal importance in the civil case for search and rescue.

Recent investigations have shown that helicopters may be operated at night efficiently in low level flight if the crew is provided with appropiate visual aids. The question is, however, what system fulfills the operational and human requirements best with respect to performance, cost and reliability.
Within the last 10 years DFVLR Institute for Guidance and Control has conducted a rather comprehensive R & D program on components and systems suitable to achieve helicopter operation at night. Particular emphasis was placed on the role of the pilot in the system, on pilot workload and on the human engineering aspects of the interface between pilot and helicopter. Components and systems investigated for this purpose included electronic head-down display, helmet mounted display, night goggles, low light level TV and forward looking infrared cameras.

List of symbols

EKG - Electrocardiogram
EOG - Electrooculogram
HDD - Head down Display
h - Radio altitude
IAS - Indicated airspeed
IFR - Instrument Flight Rules
LDNS - Light Doppler Navigation System
r - product-moment coefficient of correlation
VFR - Visual Flight Rules
φ - bank angle
ω_z - yaw rate

1. Introduction

Helicopter operation at night is presently possible above a safety height of about 500 ft under Visual Flight or Instrument Flight Conditions. But this is not the typical mission for helicopters. The flexibility of helicopters can be utilized better. The requirements of the military are: nap-of-the-earth flight at speeds between hover and 100 kts, 24 hours a day. Visual aids must be provided for recognizing the structure and very often the fine detail of the terrain ahead, in order to maintain orientation and to avoid obstacles. For a more flexible helicopter operation under the above-mentioned conditions one of the most important aspects, therefore, is how the pilot´s visual capability can be enhanced without affecting the ordinary cockpit and flight procedures to an unacceptable extent.

Many considerations affect the overall performance of night vision systems. The optimum night vision design, for the ultimate performance, will always leave the light amplifier or image intensifier as the limiting factor in the system. If, however, the system cost is of prime considerations, then a certain amount of caution should be exercised, to ensure the optics or the tubes are not over-designed for the intended application.
The state-of-the-art in image intensifier tube performance has made great advances in recent years, and is now at the point where the image intensifier should really be considered a major optical component in the system design phase.

To achieve the desired system performance under a multitude of conditions, it may be necessary, due to the lighting environment, to reject part of the standard image tube sensitivity spectrum. The appropiate selection of the display lighting and the associated spectral filtering is an important consideration and can be constructively used to reject unwanted reflections while still permitting the night vision system to function in the prescribed manner.

2. Objectives

In several investigations at DFVLR during 1980/81, the night goggles in combination with a Head down Display (HDD) with associated spectral filtering turned out to be a very suitable and relatively simple equipment for helicopter low level guidance at night. The pilots were able to perform the required tasks with a feeling of safety nearly as good as under ordinary VFR-conditions. Therefore, it seemed to be convenient to continue the investigations with these night systems.

Today the German Army is flying helicopters at night using helmet-mounted night goggles (Fig.1).

In this case the pilots are able to look at the instruments underneath their goggles. In addition, the pilot must switch on a helmet-mounted lamp in order to locate and read the instruments. To improve this procedure, DFVLR proposed the combination of night-goggles and Head-down Display (Fig.2). Flight tests, which started in autumn 1982 in co-operation with the German Army, were made in order to learn more about pilot's workload and flight performance using the combination of Head-down Display and night goggles.

3. Important aspects

DFVLR has always placed great emphasis on testing visual aids under realistic conditions. This means that visual aids are tested at that mission height where they should overcome pilot's lack of vision. Technical aids for low-level flight can't be tested at heights of about 500 ft. The visual impressions at heights of about 500 ft are quite different from those of 100 ft. Moreover, it is very important to determine a suitable test route. The route must have obstacles requiring changes in altitude. It is useless to test technical visual aids under conditions where there are no obstacles.

Over the years a knowledge of the terrain and its peculiarities has been accumulated which has turned out to be most useful for comparing the performance of visual aids and displays and pilot's reaction, respectively, under varying environmental conditions. Important factors are, for example, the structure and the shape of the terrain, visual and thermal contrast between different objects on the ground and between these objects and a low ceiling, the appearance of streets, railroads, rivers, edges of forests and firebreaks etc. and their effect on flight strategy for the visual aid/display being tested. In cooperation with the end-user - the military - flight tests were always made under realistic operational conditions.

All flight tests were conducted with a three-man crew: experimental pilot, safety pilot and test engineer. The test vehicle (BO 105) was equipped with an airborne experimental system. It consisted of a computer which provided

- data acquisition, processing and storage
- software symbol generation
- drive for the electronically-generated instrument displays

Flights were made over both a familiar route as well a new route, never flown before. This was necessary in order to check for training effects and to determine whether a simple transformation of the familiar-route data would suffice to describe the data from the unfamiliar route. On flights over the unfamiliar route the pilots had only a map briefing and support of LDNS (Light Doppler Navigation System) which was integrated in the helicopter.

Flight time of the investigations in 1982/83 was:

Total flight time	: 84,5 h
Preparation and training	: 32,5 h
Flight tests	: 52,0 h

Three pilots, two from the military and one from DFVLR, flew the flight tests over the familiar route (ca. 15 minutes) for a total of 70 times. Some flights were made under average ambient light of 1,5 mlux. The pilots had to fly either with night-goggles and standard-instrumentation, or with night-goggles combined with the HDD. For reference, they also flew the same route during the daytime. Finally, the pilots also flew over the unfamiliar route (ca. 30 minutes) with only a map briefing.

During each flight test 17 parameters were recorded. These included, for example, all flight control movements, pilot`s reaction time to a warning signal, and the time spent looking at the instruments.

In the case of pilot workload some medical investigations were made; for example, EKG, EOG and urine analysis.

In addition to the recorded parameters, pilots´ comments were gathered by means of inquiry and specially designed rating scales.

4. Results

Due to the volume restrictions of this paper, only selected portions of the results will be presented.

Design of the HDD-Symbology

The design of the HDD-Symbology was based on the instrument information layout used in former studies. However, for this study the symbology was extended due to the special requirements of an operational low-level flight at night (Fig. 3-5).

For this paper, a detailed comparison of flying with HDD versus the standard instrumentation will not be made. From the results, it can be concluded that the layout of the display is good and the pilots were able to fly with a better feeling of safety than with conventional instrumentation.

Table 1 presents, for example, two parameters of flight guidance obtained from flights at various ambient light levels with night-goggles combined with a HDD. From this table it can be seen that the data of the flights with average ambient light under

5 mlux are very different from those above 5 mlux. This result can also be derived from all other parameters. These results were quite unexpected. As can also be seen, different results were obtained from flights over the familiar route, compared to the unfamiliar one. But they are not that much different. That is, a simple transformation of the familiar-route data with respect to pilot`s training would suffice to interpret the data from the unfamiliar route.

Helicopter pilots are trained to fly coordinated with respect to bank and yaw. Less coordinated flying may be caused by turbulence, but also by a distraction of the pilot`s attention from the flight task, if other tasks have become more demanding. Therefore the squared product-moment coefficient of correlation (r) between bank angle φ and yaw rate ω_z was determined, because r^2_{φ,ω_z} represents the proportion of coordinated flying, i.e. the proportion of the total variation of yaw rate ω_z which is correlated with a variation of bank angle φ. The parameter r may serve as an indirect measure, then, to indicate a variation of pilot`s attention in this respect if other influencing factors as, for example, turbulence or a variation of torque, are within normal tolerances.

Table 1 also presents a comparison of r^2-values obtained from flights at different ambient light levels. It can be seen that the values from flights at a light level of about 5 mlux are comparable with those at daylight. Below 5 mlux the pilots were flying more coordinated. This means the pilots were flying more carefully and with more concentration, which was also verified by the variance of the stick-movements. The data show that, as the light level increased, the control coordination decreased (lower r^2). Due to the better out-of-the-cockpit visual information, the pilot was able to fly closer to the terrain, but at the cost of increased control movement, as described next.

Figs. 6 and 7 show the variance of the pilot`s stick movements for pitch and bank as a function of ambient light level. Taking the variance of stick-movements at daylight as 100% it can be seen that the variance was on the same order for flights at light levels of about 5 mlux. Flights at average light levels below 5 mlux and also over the unfamiliar route show much less vigorous control activity. This is due to the increased difficulty of the flight task under these conditions, with the resulting conservative control behavior.

Eye-movement-recordings

Pilot`s viewing angle in elevation during flights with night goggles is comparable with the viewing angle during daylight flight. Two factors are dominant: the vision range with night goggles and the requirements of the task.

Eye-movement-recordings during daylight flights with a similar field-of-view as that of night goggles showed that the pilot`s average viewing angle in elevation is between 0° (looking for navigation point) and -15° (flying over an obstacle) (Fig. 8) Normally his viewing angle is approximately -6°. During flight tests at operational limits at night, for example at 50 ft and with 80 kts at an ambient light level below 1 mlux, the pilots reported that, flying over an obstacle, the HDD came into their field of view, while following the obstacle with their eyes. That means that, in this case it would be better to integrate the HDD in the lower part of the instrument panel. But the responses to the inquiry showed that the pilots agreed that the integration of the HDD as shown in fig.8 was suitable for most missions. The result is considered important for future helicopter cockpit design.

Flight tests over the unfamiliar route

As already described above, the data from flight tests over the unfamiliar route are different from those of the familiar one. Moreover the results also showed that night flights under operationally demanding conditions with visual aids can only be conducted by two pilots in team work. The pilot is fully engaged in flying, while the copilot is involved in navigation. Only by continuous communication and data exchange were the pilots able to get the vital information to perform their tasks. Analysis of the intercom data showed that, during a total flight time of 25 minutes, a verbal data exchange occured on the average of every 8 seconds.

5. Summary

The knowledge about application and performance of night vision systems and their components regarding helicopter low-level flight has increased considerably. The task demands of a transport in low level flight were fulfilled, with a good feeling of safety reported by the pilots, using night goggles in combination with a HDD. Moreover, the results showed different levels of control activity, depending on the flight conditions, but especially as a function of light level.

Recent experiences, however, have shown that in the future more emphasis should be placed on the human element - the pilot. But more generally, there is a lot of research yet required to achieve a better adaptation of the helicopter, the helicopter cockpit layout and the airborne equipment to the special requirements of low-level operation at night.

6. References

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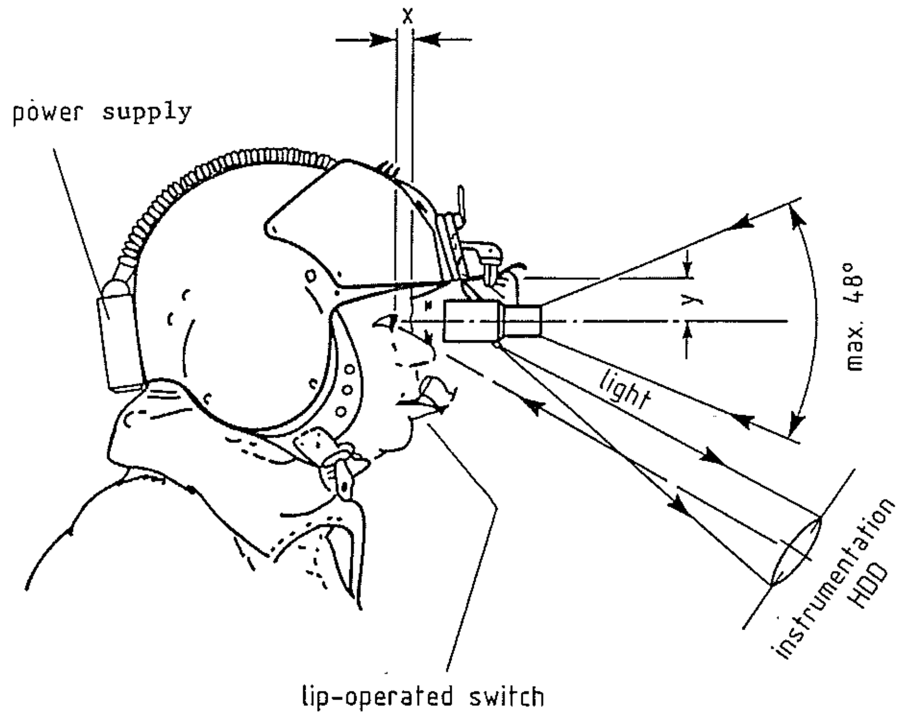

Figure 1 Pilot with helmet-mounted night goggles (optical and geometrical relations).

Figure 2 Pilot with helmet-mounted night goggles and Head-down Display in DFVLR Bo 105.

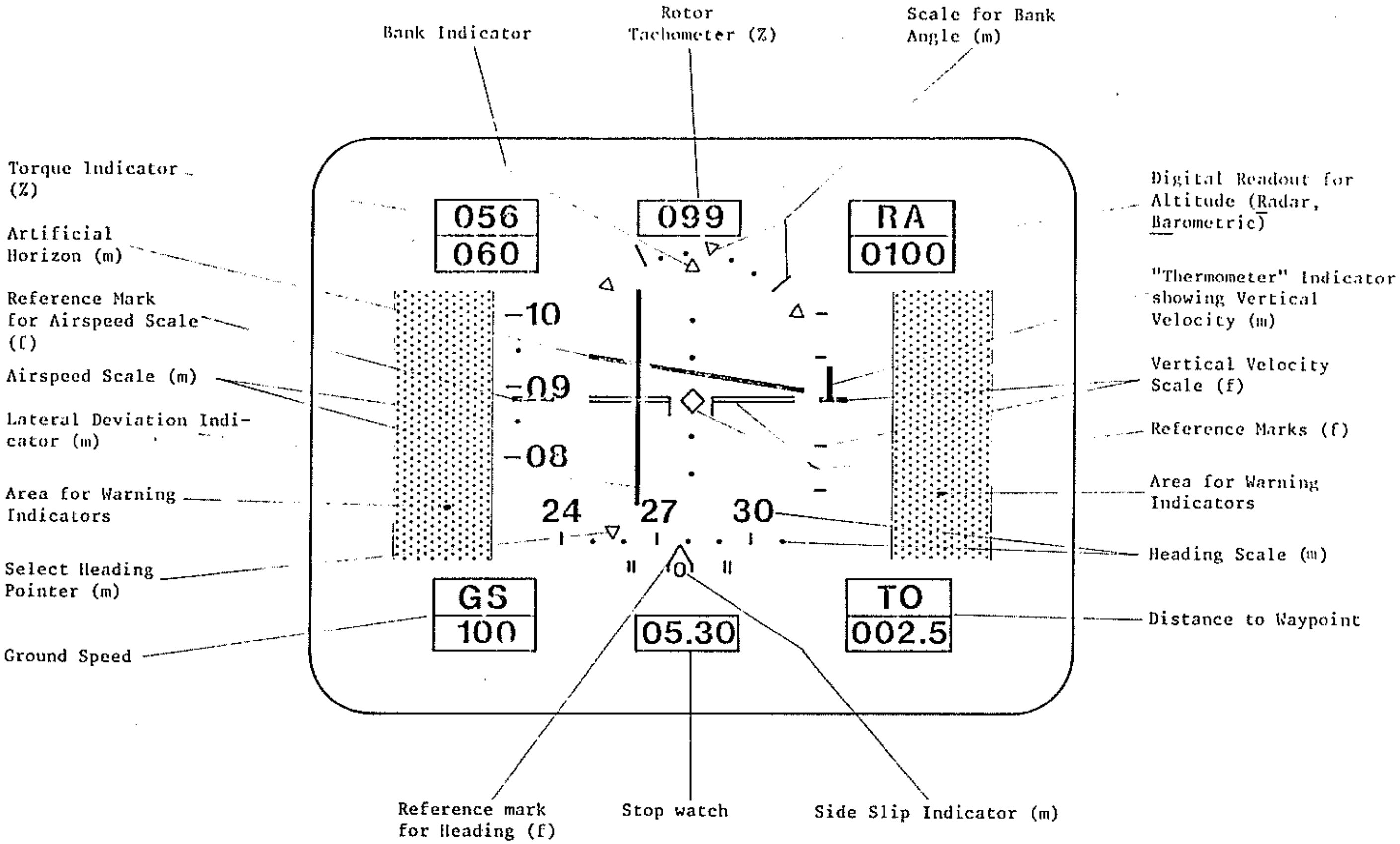

Figure 3 Instrument displays.

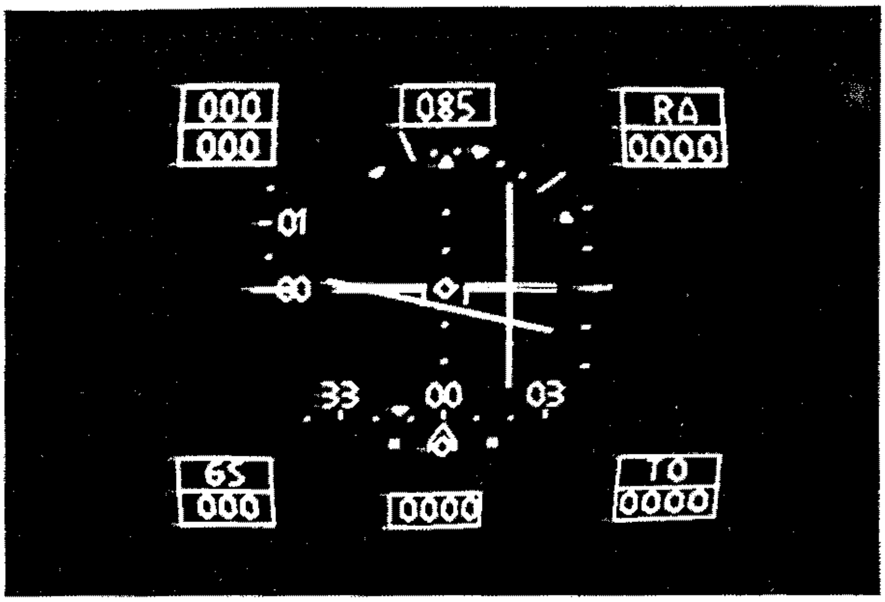

Figure 4 Instrument display without warning indicators.

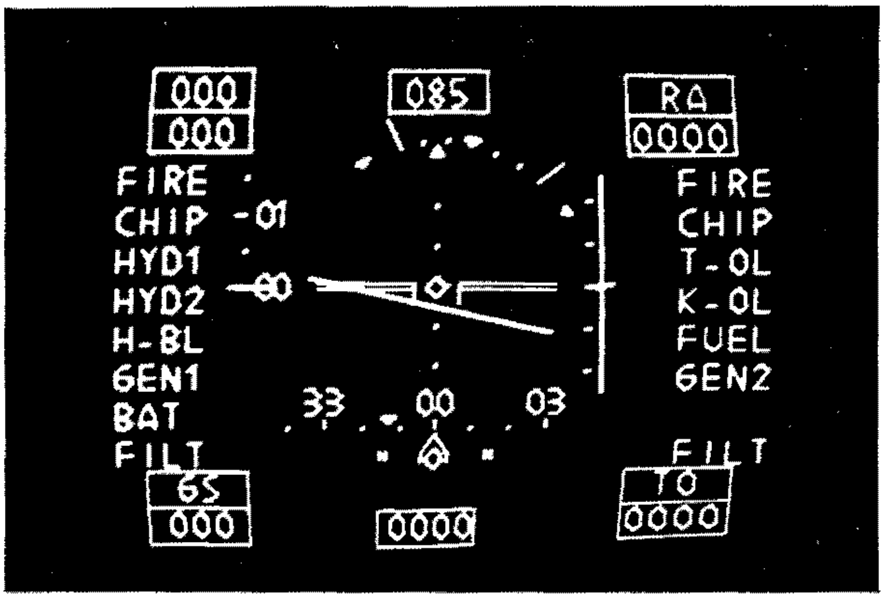

Figure 5 Instrument display with warning indicators.

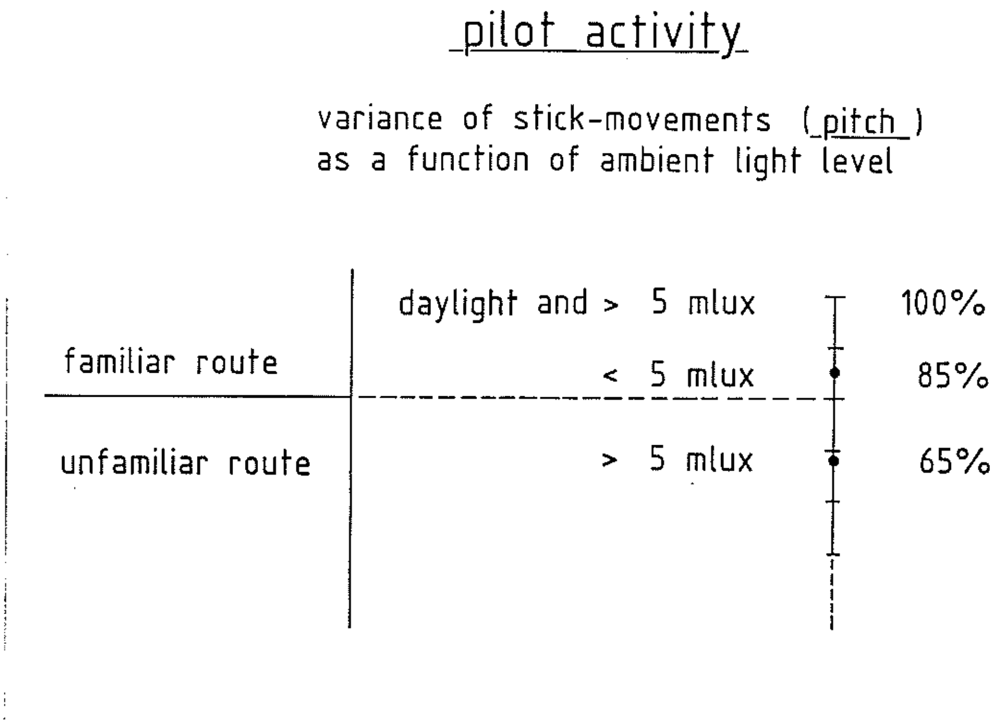

Figure 6 Variance of pilots' stick movements in pitch as a function of ambient light level.

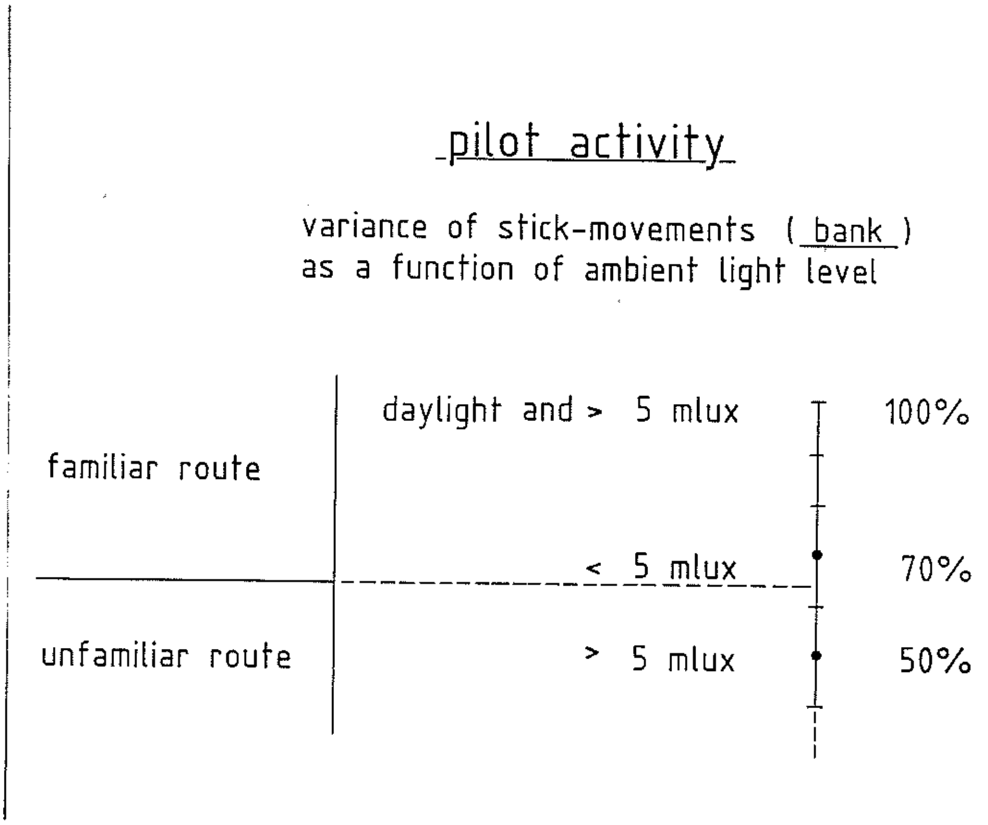

Figure 7 Variance of pilots' stick movements in roll as a function of ambient light level.

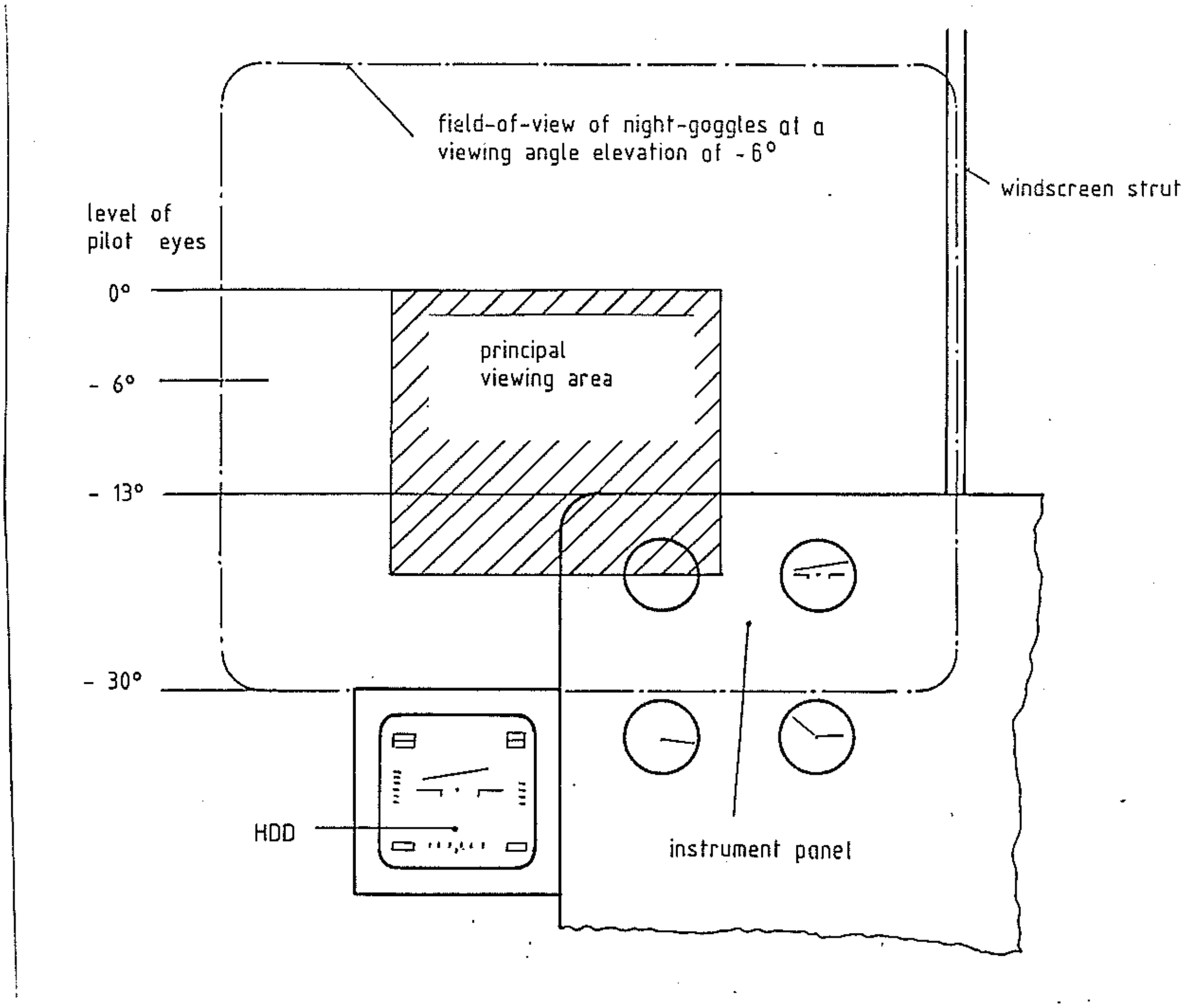

Figure 8 Field-of-view of the night goggles at a pilot's viewing angle of approximately -6° (typical for DFVLR Bo 105).

Parameter	ambient light	IAS	h_R	r^2_{φ,ω_z}	
Dim.	mlux	kts	ft	-	
	< 5	84 (4)	104 (24)	0,66 (0,05)	familiar route
	> 5	90 (2)	84 (7)	0,36 (0,06)	
	daylight	95 (2)	64 (7)	0,4 (0,09)	
	> 5	87 (3)	127 (31)	0,33 (0,07)	unfamiliar route

Table 1 Comparison of parameter means (rounded-off values) obtained in helicopter low-level-flights at night and for reference at day. ( ) = standard deviation.