SEVENTH EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM

Paper No. 54

EXPERIMENTAL INVESTIGATION OF VISUAL AIDS FOR HELICOPTERS LOW LEVEL FLIGHT AT NIGHT AND POOR VISIBILITY

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September 8 - 11, 1981

Garmisch-Partenkirchen
Federal Republic of Germany

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Summary

Recent investigations have shown that helicopters may be operated at night efficiently in low level flight if the crew is provided with appropriate visual aids. The question is, however, what system fulfills the operational and human requirements best with respect to performance, cost and reliability.

As a result of increasing user interest in this field the DFVLR Institute for Guidance and Control has launched an R & D programme some years ago designed to identify the potential and the limitations of advanced display systems for visual aids in helicopters. In the course of this programme some hundred flight hours of experience have been accumulated already with a combination of the sensor image and computer generated instrument displays in a head-down display, helmet mounted sight/display and night goggles.

The layout of the instrument display was considered assuming a transport mission and various display modes were implemented. The visual aids were flight tested in Bo 105 and Bell UH-1D helicopters with particular emphasis on the usefulness of the display modes on flight performance and low level flight performance.

1. Introduction

In the last 10 to 15 years the number of civil and military helicopters has increased considerably. The well known flexibility of helicopters and the achieved technical reliability are the main reasons for also increasing requirements regarding helicopter operation. The maximum requirements result from the military point of view: nap of the earth flight at speeds between hover and 100 kts 24 hours a day at any weather condition.

Today helicopter operation at night and poor visibility is normal above a safety high of about 500 ft under Visual Flight or Instrument Flight Conditions.

But the flexibility of helicopter operation in low level flight is reduced significantly under the conditions of bad weather and darkness. This is because most of the respective missions require the helicopter to be flown at relatively low hight employing terrestrial navigation as the main guidance aid. Rather than relying on radio frequency, inertial or doppler navigation systems alone the pilot must recognize the structure and very often the fine detail of the terrain ahead, too, in order to maintain orientation and to avoid obstacles. For a more flexible helicopter operation under the mentioned conditions one of the most important aspects, therefore, is how the pilot's vision capability can be enhanced without affecting the ordinary cockpit and flight procedures to an unacceptable extent.

2. Objectives

Various components are available for the specification and for the design of appropriate systems.

- low light level and infrared cameras on a gimballed platform

- electronic head-up, head-down and helmet mounted devices

- electronic symbol generators for the generation of instrument displays on the display devices

- night goggles

The question is, however, which combination of these components will serve the requirements of night vision and helicopter guidance in low level flight at night and poor visibility best.

In order to study the suitability of these components for future helicopter night vision/display systems the DFVLR Institute for Guidance and Control started a series of experiments some years ago. The order of the components being investigated was largely determined by their respective availability. However, in the mean-time most types of sensors and displays relevant to helicopter night vision/display systems were tested in the laboratory and inflight and several hundred flight hours were accumulated in Bell UH-1D and MBB Bo 105 helicopters. The tests included ordinary TV/Low Light Level/infrared sensors, a head-down display of sensor and instrument information, night goggles, and a Helmet Mounted Sight/Display (HMS/D).

The objectives of these studies are fairly straight forward and may be classified as follows:

1. Study the characteristics of various components which may be part of a future helicopter night vision/display system regarding operational requirements, performance and human factors.

2. Compare the ins and outs of these components relative to each other.

3. Specify helicopter night vision/display systems for the different modes of application.

In the past the programme of work was directed to reach objectives 1 and 2 while the present and future activities are focussed on objectives 2 and 3. The mode of application being investigated in the course of the current programme is "quasi-VFR low level flight" at night. An appropriate combination of terrestrial navigation employing visual aids and artificial navigation aids (RF, inertial, doppler) and/or weapon aiming by means of night vision/display systems are other modes of application to be investigated next.

3. Important aspects

All flight tests regarding visual aids and displays for helicopter are flown in an area and over tracks which are identifical for most of the experiments. Over the years a knowledge of the terrain and its peculiarities has been accumulated which has turned out to be most useful in order to compare 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. A relative comparison of visual aids and displays under identical conditions of flight is made possible by this approach and a considerable amount of experience has been gained in this respect in the past regarding head-down and head-up displays, the helmet mounted sight/display and various electro-optical sensors including night goggles.

Another aspect which must be emphasized is the close cooperation with the end-user - the military. Right from the beginning in the mid 70's the sharing of scientific methods on one hand and operational experiences/requirements on the other and a mutual support regarding test vehicles and personel has led to an effiency of the research programme which otherwise could not have been achieved.

All flight tests were conducted with a three crew: experimental pilot, safety pilot and test engineer. Both test vehicles (Bell UH-1D, Bo 105) were equippped with an airborne experimental system. It consists of a computer for

- data acquisition, processing and storage
- software symbol generation
- driving the electronically generated instrument displays
- driving the gimballed platform

Additional systems to be investigated like Infrared Cameras, Low Light Level TV or Helmet Mounted Sight/Display respectively can be integrated in the airborne experimental system.

4. Results

4.1 Flight tests under simulated night conditions

During the first years of our research and development programme a Bell UH-1D helicopter was used. The flight tests were conducted under simulated night conditions, which means: the experimental pilot had no direct outside view. He was forced to use his visual aid only whereas safety pilot and test engineer both had a normal outside view. The experimental helicopter was equipped with a normal TV-camera as simulated sensor (Fig. 1). The camera had a field of view of 28° in azimuth and 22° in elevation. It was fixed under the cabin nose with a depression angle of 6° down. The camera image was displayed on a monitor with 23 cm diagonal field of view, which was integrated in the left cockpit panel in front of the experimental pilot (Fig. 2).

Right from the beginning on it was obvious that only the superimposition of sensor image and instrument information on a display could meet the requirements for helicopter guidance at night and bad weather. Therefore the first task was the purport and design of the electronic instrument information on the display. The final instrument information layout for the flight tests is shown on Fig. 3.

Employing the described system (fixed camera and head down display) the pilots were able to meet the requirements of a helicopter transport mission, which means: average radio altitude of about 220 ft at an indicated airspeed of 80 kts along well known routes. The comparable normal visual flights were conducted 4 kts faster and 40 ft lower (84 kts and 180 ft). If the mission routes are known from map briefing only, the average radio height increased to 340 ft and the airspeed decreased to 72 kts employing the simulated night vision system.

The performance of visual flights and quasi-VFR-flights (using night vision systems) differed considerably regarding the lateral deviation if the pilots had to follow an given track with a great number of bends as accurately as possible. (The test route was a part of the river Weser). This happened because in quasi-VFR-flight the experimental pilot could only look via the camera in the direction of the helicopter's longitudinal axis.

Therefore in another series of experiments the sensor platform was driven in such a mode, that enables the camera to look into the turn when the helicopter banked for turning [3]. In flight tests and computer simulations an optimum factor of 0.9 was found, which means: 1° helicopter bank angle produces 0.9° sensor deviation angle in azimuth. Additional to this mode a roll compensation was necessary to prevent the sensor to look "into the ground" when the helicopter banks. So the sensor remained even in turns at a depression angle of 6° down in relation to the ground plane. The desired comparison of flight performance under different conditions, VFR flight and quasi-VFR-flight with fixed and "looking into the turn" camera, required the development of a special airborne measuring equipment which could record the lateral deviation from a given curved track without the aid of any ground stations [3].

It could be found that employing the "looking into the turn" camera in quasi-VFR-flight, the lateral deviation to a given track could be reduced significantly as against the fixed camera. The average values were 45 m using the "looking into the turn" camera and more than 109 m lateral deviation using the fixed camera. More than 109 m because the measuring equipment reached its maximum value several times so that a record of the greater actual values was not possible. The lateral deviation in normal VFR-flight was approximately zero, respectively, below the accuracy of measurement, 5 - 10 m.

The pilots range of vision was extended significantly by the "looking into the turn" camera as against the fixed camera. The pilots gave a corresponding positive opinion about this mode and no desorientation was reported as result of the moving camera, because in turns the camera motion was very similar to the normal pilots scanning behaviour.

Nevertheless it became obvious that using the described techniques and procedures the improvement of helicopter operation at night and poor visibility came to a limit. Especially low level flight at about 50 - 100 ft depending on the terrain or hovering among obstacles was not possible.

When the Bell helicopter went back to the German Air Force after 2 1/2 years of experimental work in night vision/display systems the DFVLR got a Bo 105 helicopter at its disposal. So the previous experimental work could be continued with a type of helicopter whose agility is very suitable for low level flight.

In the meantime a Helmet Mounted Sight/Display (HMS/D) became available. The system is shown schematicly in Fig. 4. A camera is mounted on a moving platform under the cabin of a Bo 105 helicopter. The image of the terrain is fed to a mixer where it is superimposed by electronicly generated instrument displays produced by the electronic symbol generator. The output of the mixer is fed to a helmet mounted cathod ray tube where the combined image is transmitted to the pilot's right eye by means of a semireflective mirror. Furthermore the pilots angular head position is determined by a computer on the basis of the phase relationship between infrared light transmitted from the surveying units and the light received by the helmet sensors. The azimuth and elevation signals are in turn fed to the moving platform in a way that the pilot's line of sight and that of the camera are in close agreement. An infrared sensor (FLIR) and the Helmet Mounted Sight/Display were provided by Honeywell Inc. while the platform, electronic symbol generator and mixer where built at DFVLR. For the laboratory investigations a platform made by Dornier GmbH was employed, too (Figure 5 and Figure 6). It was the first time that a Helmet Mounted Sight/Display was used for flight guidance purposes. So prior to the flight tests detailed investigations were made in the laboratory and on a moving simulator. Main points of the ground tests were:

- Visibility of the display area for the test persons, because 40° field of view is very unusual for normal eyeball rotation alone.

- Quality of an infrared sensor image.

- Legibility of the display with several levels of ambient illuminations.

- Display symbology.

- Special display modes like:
  Virtual head-up display
  Off-axis display
  Roll-stabilized display

- Tracking accuracy of stationary and non stationary targets.

- Tracking accuracy monocular and binocular.

A detailed description of the results is given in [2].

A transport mission at night was assumed for the flight tests along well known routes with a demanded altitude of 200 ft at 80 kts very similar to the previous tests with the UH-1D. Under simulated night conditions the system to be tested mainly consisted of the HMS/D, the camera fixed to a gimballed platform, and the superimposition of the image of the terrain and instrument information in the Helmet Mounted Display.

It turned out very soon that flight performance could be improved significantly employing the camera driven by the pilot's head movement as against employing the "looking into the turn" mode or even the fixed camera. Along given tracks with multiple bends (river Weser) the tracking accuracy regarding lateral deviation became comparable to normal VFR-flights. Beyond this helicopter operation employing visual aids could be extended again. It became possible to make fullstop landings out of 400 ft radio altitude and 80 kts airspeed, low level flights between 20 and 60 ft average height at 15 to 40 kts, and low level hovering manoeuvres with and without yaw movement of the helicopter.

In addition to flight performance pilot's eye movement, respectively, head movement could be registered by means of a video recorder in connection with an eye mark recorder and in terms of angular deviations in azimuth and elevation. It became obvious that the pilot's maximum head-movements in a transport mission were about $\pm$ 45° in azimuth and in elevation between 20° down and 15° up as well in VFR-flights as in quasi VFR-flight employing the Helmet Mounted Sight/Display. The average direction of the pilot's line of sight in the vertical plane was about 6° down in a transport mission, while during landing approaches the average direction was between 7° and 5° down in the whole range of height between 400 and zero ft (Fig. 7). This is a very interesting result because in the past sometimes a sensor depression angle of 90° down for landing approaches has been required.

4.2 Flight tests under real night conditions

Flight tests under real night conditions were the next step in our research and development programme. The experimental system with the HMS/D was fitted with an infrared camera from Honeywell (Mini-FLIR) and a Low Light Level TV from AEG, respectively. Safety pilot and experimental engineer were provided

with night goggles. The experimental pilot was able to use HMS/D and night goggles as well (Fig. 8).
The flight tests were conducted in close cooperation with the German Army helicopter force.

As the first important result of these flight tests the main findings of the previous flight tests under simulated night conditions could be verified.

The data analysis showed that for flights with the HMS/D the helicopter was flown at a higher but more constant barometric altitude and with lower and less variable airspeed in comparison to ordinary VFR-flights. This corresponds well with the observation that the pilots tried to maintain a more constant flight profile by controlling the helicopter in a more gentle rather than abrupt fashion. Nevertheless, the pilots reported higher strain and stress - although acceptable - for flights with the HMS/D with respect to VFR-flights and particularly in comparison to flights employing night goggles. On the other hand they were able to follow a given track with multiple bends and obstacles very accurately at night which is a demanding task under daylight conditions, already. The average radio altitude along these tracks was about 150 ft (standard deviation 50 ft) at an average airspeed of 78 kts (standard deviation 10 kts). The pilots were able to achieve a fairly constant performance in the course of the experiment. Their visual scanning behaviour was in good agreement with corresponding results obtained from VFR-flights at higher altitudes (200 ft). Performance measures were radio altitude, airspeed, angular motion of the helicopter and their derivative as well as azimuth and elevation of the pilot's line of sight.

The night goggles which were used in this period of flight testing also turned out to be a very suitable and relativ simple equipment for helicopter low level guidance at night. The pilots were able to perform the demanded tasks with a good feeling of safety nearly as well as under ordinary VFR-conditions. For example they were able to assess some critical situations during HMS/D-flights correctly by means of their night goggles.

Nevertheless a direct contrast between the performance of night goggles and Helmet Mounted Sight/Display was not possible, because of the different scope of both systems and the quality of the sensor images which affects directly the performance of the HMS/D.

During the tests it became obvious that some system limits were reached sometimes. For example, while the angular response of the moving platform of $25^{\circ}/s$ was adequate for a transport mission difficulties were experienced in low level flight at altitudes of less than 100 ft. Higher rates of turn in the order of $100^{\circ}/s$ are considered adequate for this flight regime. Furthermore, contrast and resolution of the sensor image need to be increased and a low persistence

CRT phosphor would be desirable in order to prevent ghosting of bright targets at high turn rates of the camera.

5. Conclusions

The knowledge about application and performance of night vision systems and their components regarding helicopter low level flight has encreased considerably. It is felt that for more demanding missions than a transport only and with regard to experiences gained from other flight tests with head-up/head-down displays, night goggles and various electro-optical sensors a single system would be inadequate to satisfy all possible needs. Rather a combination of sensors and display can be foreseen as an optimum solution.

Beside the knowledge about helicopter night vision systems a series of unsolved problems remains. For example, no equipment is known for the discovery of powerlines. It is also necessary to adapt the helicopter cockpit layout and the airborne equipment to the special requirements of helicopter night operation. The extent of automatic control regarding flight mechanics in connection with navigation and weapon systems has to be investigated as well as methods and procedures for comprehension and evaluation of flight performance and work load.

6. Schrifttum

[1] Beyer, R., Kohnen, E., Schick, F.V., Stolzke, U.: Demonstration eines Head-up Displays in einem Hubschrauber Bell UH-1D. DFVLR-IB 153-76-07 (1976).

[2] Beyer, R.: Untersuchung einer kombinierten Darstellung von Umweltbild und Instrumentenanzeigen in einem Hubschrauber Bell UH-1D. DFVLR-IB 153-76-11 (1976).

[3] Beyer, R., Kohnen, E.: Untersuchung unterschiedlicher Ausrichtungen des Elektro-optischen Sensors für eine kombinierte Darstellung von Umweltbild und Instrumentenanzeigen in einem Hubschrauber Bell UH-1D. DFVLR-IB 153-77-24 (1977).

[4] Beyer, R., Kohnen, E.: Untersuchung einer kombinierten Darstellung von Umweltbild und Instrumentenanzeigen für den Anflug von Hubschraubern unter Instrumentenflugbedingungen. DFVLR-IB 153-78-13 (1978).

[5] Dierke, R., Erdmann, F., Biertümpel, E., Ehlers, R., Löhr, H.: Ein Versuchsaufbau zum Ausmessen eines "Helmet Mounted Sight/Display" mit nachgeschaltetem Kameraschwenkrahmen im Forschungsflugsimulator der DFVLR. DFVLR-Mitt. 80-04 (1980).

[6] Kohnen, E.: Beschreibung der Versuchseinbauten im Hubschrauber Bo 105, Kennzeichen D-HDDP zur Durchführung von Displayuntersuchungen. DFVLR-IB 153-78-44 (1978).

[7] Stein, H.: Untersuchungen zum Einsatz eines Helmet Mounted Sight/Display (HMS/D) für die Flugführung von Hubschraubern. DFVLR-IB 153-80/16.

[8] Danneberg, E., Kohnen, E., Stein, H., Stolzke, U.: Untersuchungen des Zusammenwirkens von "Helmet Mounted Sight/Display" und Sensorschwenkrahmen unter Einschluß eines Piloten. DFVLR-IB 112-81/06.

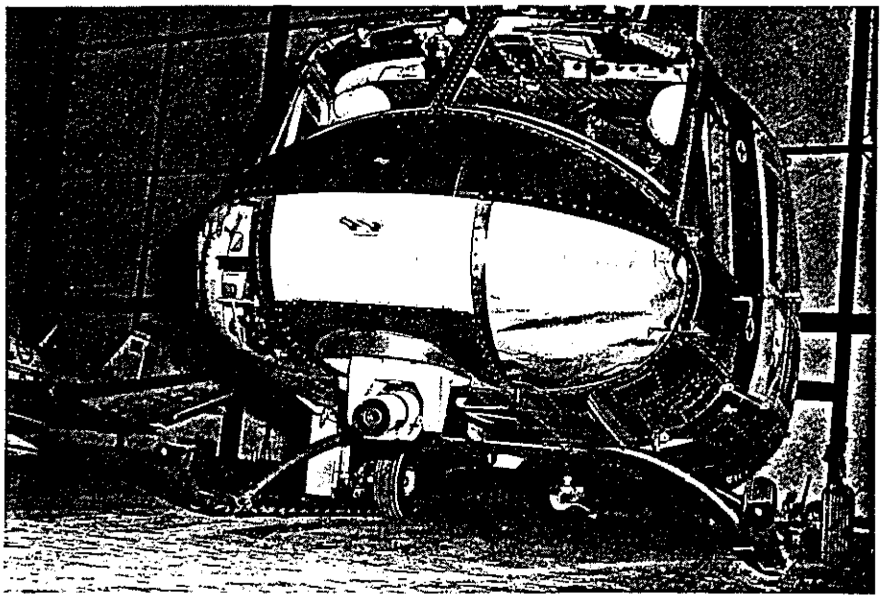

Fig. 1 Bell UH-1D experimental helicopter equpped with Low Light Level TV (LLLTV).

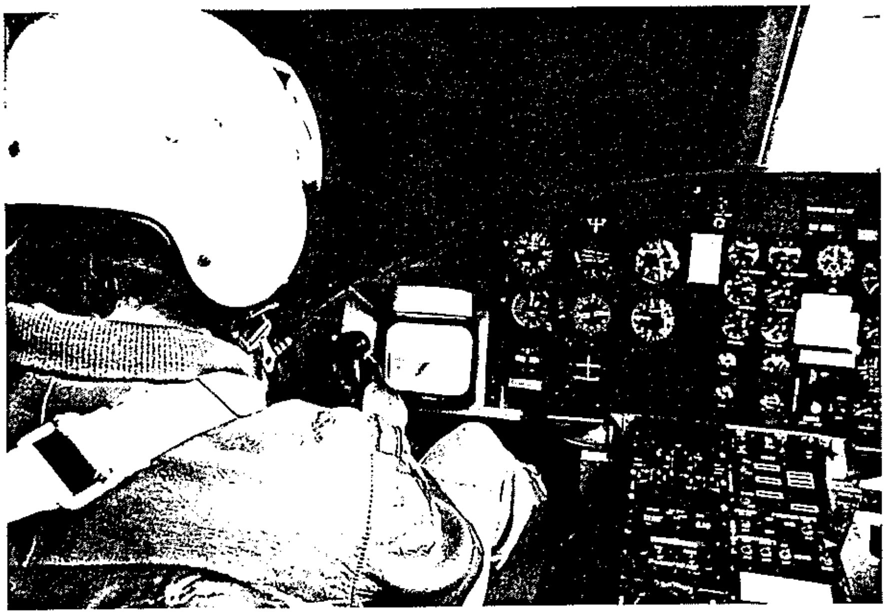

Fig. 2 Experimental head-down display integrated in the left cockpit panel of a Bell UH-1D helicopter.

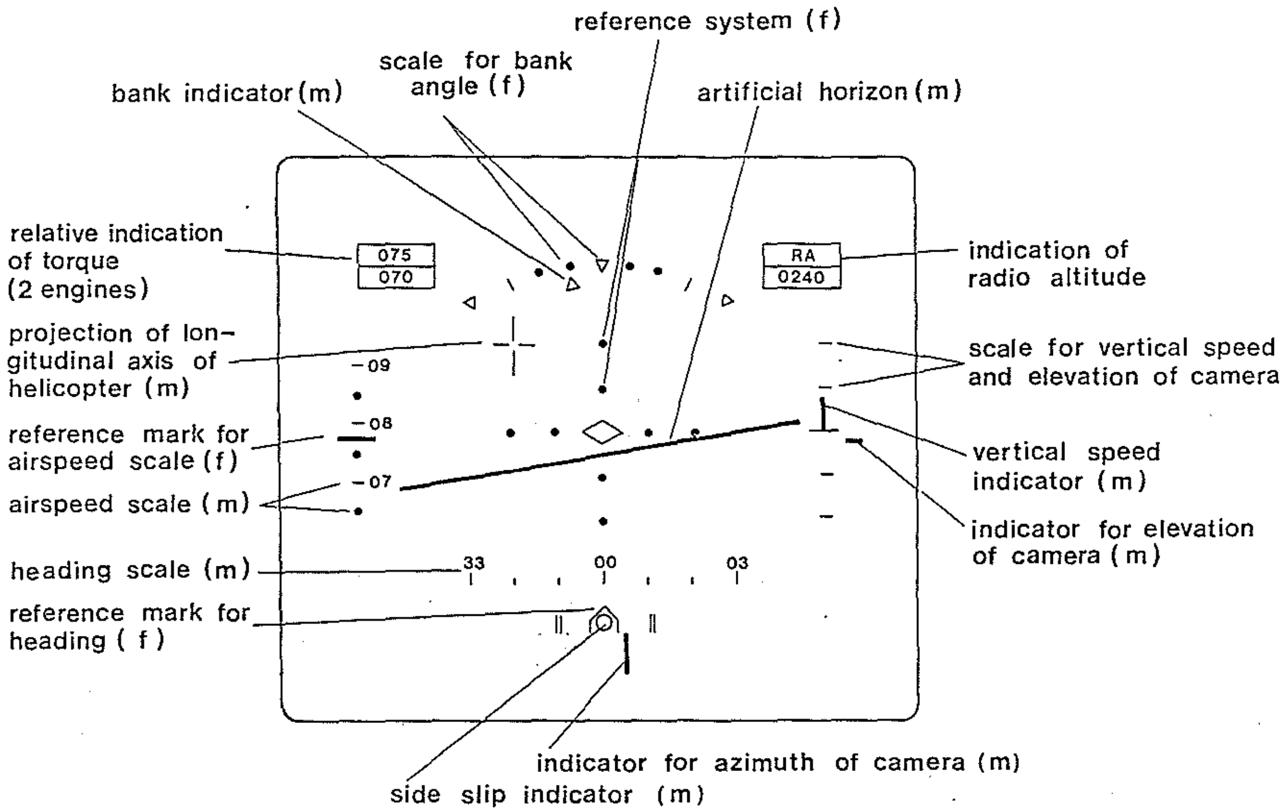

Fig. 3 Instrument displays.

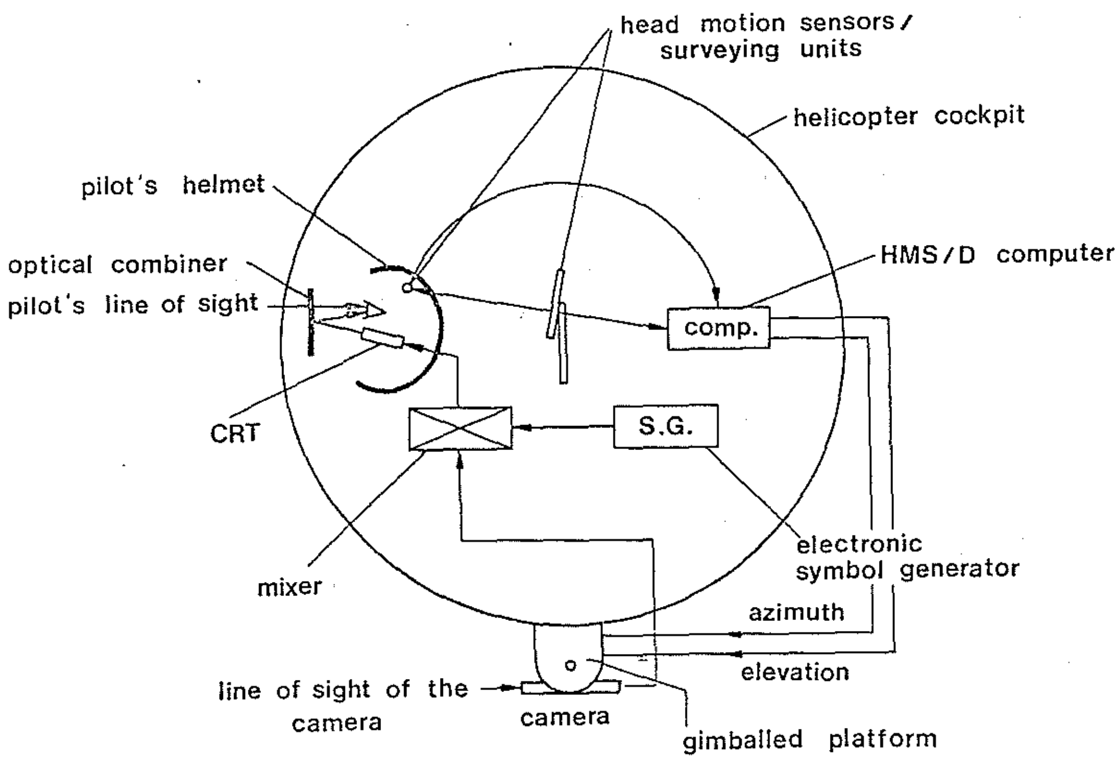

Fig. 4 The Helmet Mounted Sight/Display System.

Fig. 5 Pilot wearing Helmet Mounted Sight/Display.

Fig. 6 Bo-105 experimental helicopter equipped with a sensor on a gimballed platform which is driven by the pilot's head movement.

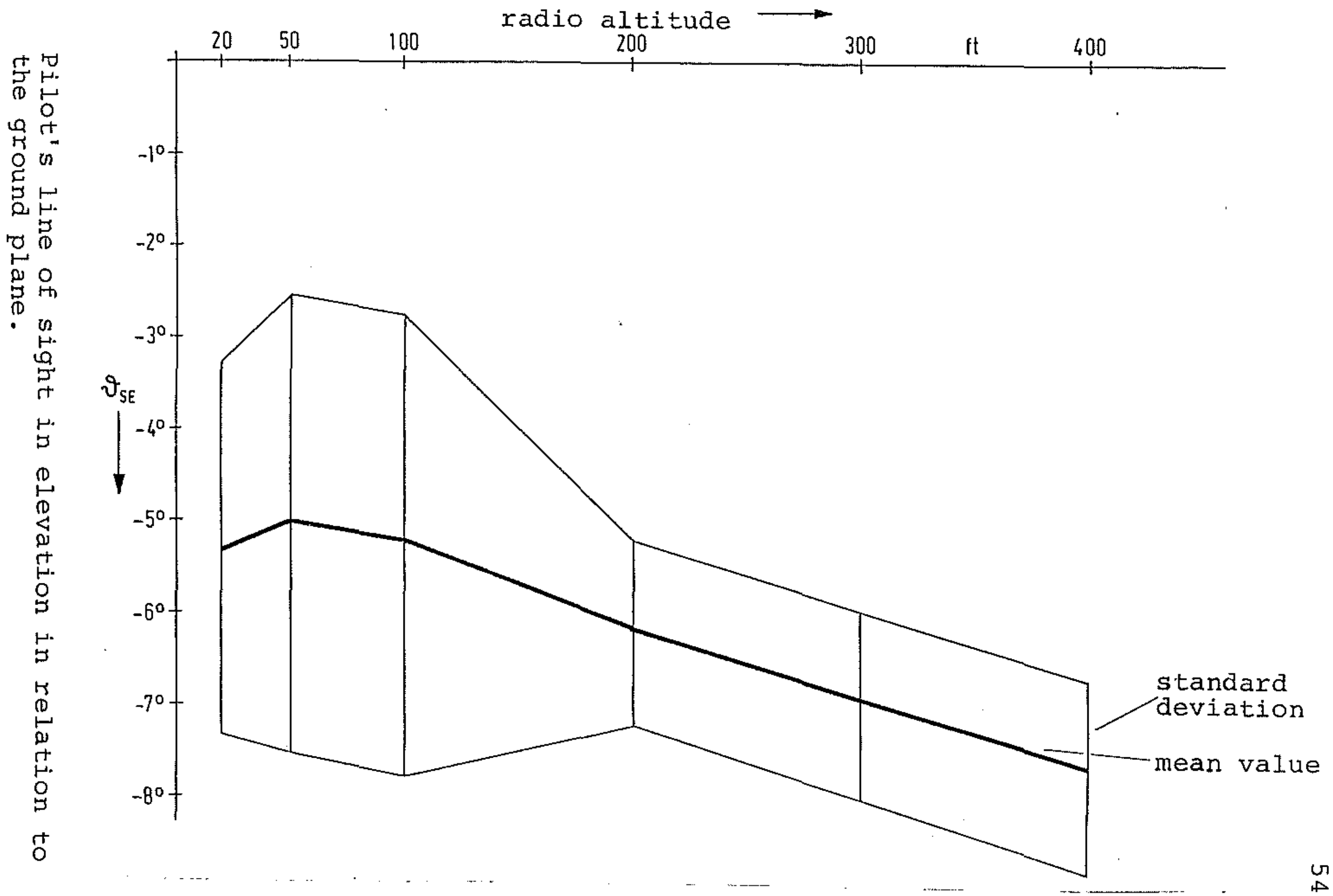

Fig. 7 Pilot's line of sight in elevation as a function of radio altitude during landing approaches.

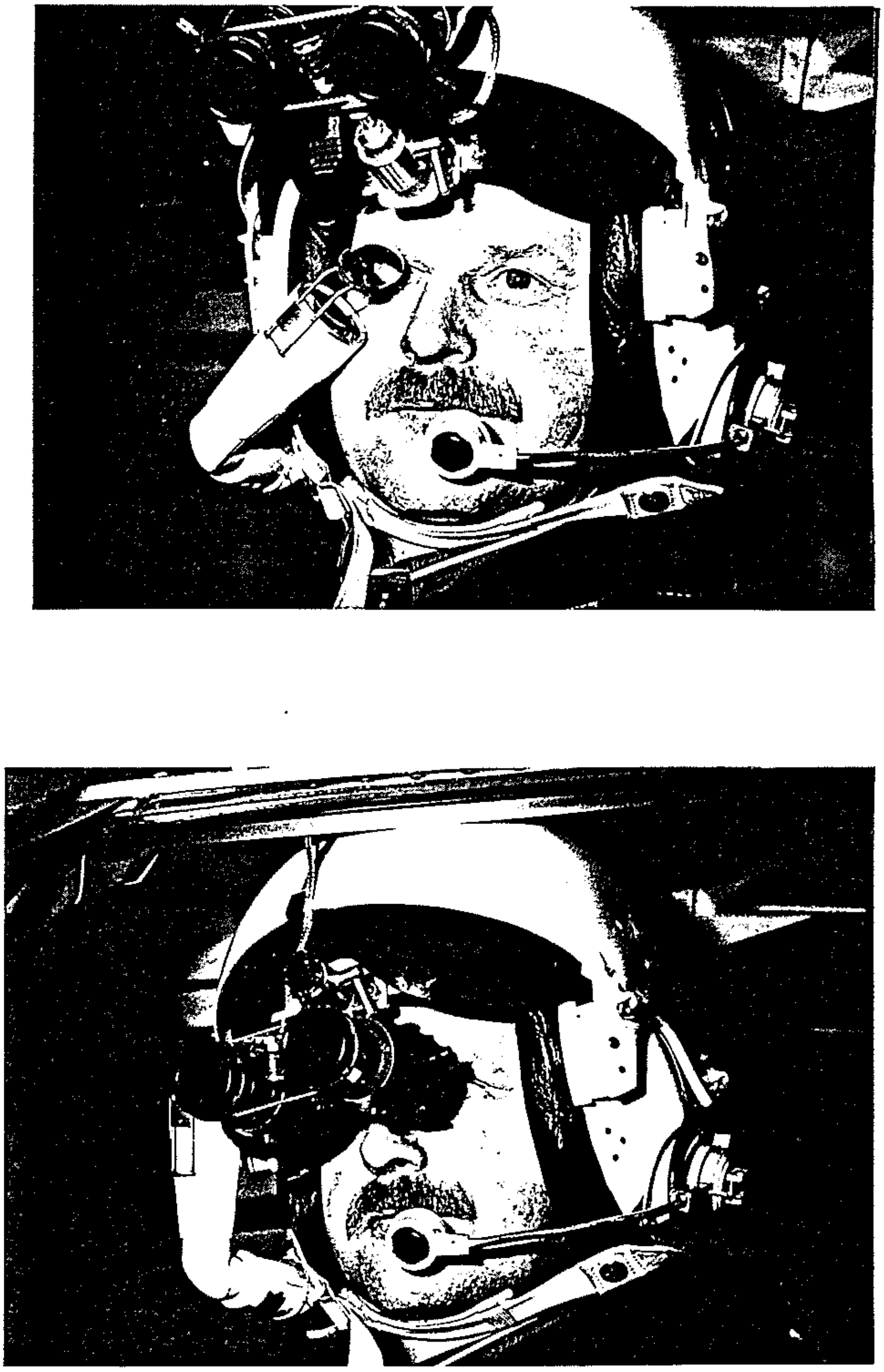

Fig. 8 Alternative utilization of the Helmet Mounted Sight/ Display (above) and night goggles (below).