24th EUROPEAN ROTORCRAFT FORUM
Marseilles, France - 15th - 17th September 1998

Flight testing of a binocular, bisensor HMD for helicopter: Some human factors aspects

Réf. : OP06

A. LEGER*, C. ROUMES***, J.M. BERGEAUD**, P. DAREOUX**,C. GARDELLE

* SEXTANT AVIONIQUE /IHM , BP91, 33166-St- Médard-en-Jalles CEDEX, France
** Centre d'Essais en Vol, Base d'Essais d'Istres (France), 13800 Istres Air, Franc
*** Institut de Médecine Aérospatiale du Service de Santé des Armées, BP73-91223 Brétigny sur Orge France

ABSTRACT

The need for night vision systems in military helicopter has been recognized for many years now. Besides fixed FLIR an night vision goggles, helmet-mounted systems coupled with head-slaved IR sensors have been introduced during the last decade in modern attack helicopters. Monocular HMDs have been fielded on the AH-64 and used in operation. Human factors aspects pertaining to such night vision devices has been extensively reviewed and published. Though, full scal flight tests of binocular HMDs with integrated I^2 and head coupled IR sensors have rarely been reported. A binocular helmet, with a 40 degree full overlap FOV has been developed under a contract of the French DGA. Two Image Intensifiers tubes (I^2) located on each side of the head are integrated on the helmet, which also has full raster and strok capacity. Both images are projected on the visor of the helmet and collimated to infinity. IR sensor imagery and navigation system are coupled to the helmet using an electro-magnetic head-tracker. Test flight of the helmet have been conducted by the French Flight Test Center (CEV) on specially equipped Puma test-bed aircraft. Approximately 150 flight hours have been devoted to testing of the helmet, either with I^2 and IR sensors.

Along with more technical issues, major human factors concerns can be summarized as follow: visor projection, effects of increased interocular separation due to I^2 sensor location, I^2 and IR image usability for piloting tasks and transitions between sensors. In addition to classical test flight methodology basically used by CEV, specific human factor methodology was introduced in ground and flight trial. After adequate training, increased interocular separation with I^2 was found not to be a problem for piloting the aircraft. Errors in speed, altitude and distance are in the same direction as those encountered with NVG and pilots rapidly built (10 hours) their own internal metrics to compensate. Both I^2 and IR image were found usable for piloting the aircraft. The visor projection concept was validated and found extremely agreeable by most pilots. Distortions with off-axis design need to be carefully corrected. Piloting with IR requires more training (20 h) and, in some flight conditions, velocity of head movements was found to exceed the peak velocity of sensor platform. A good complementarity was found between the two sensors. Due mainly to image luminance difference, transition from IR to I^2 raised difficulties. Adjustments time from 5 to 45 seconds were found necessary (following night level) and the change in piloting strategies (switch in internal metrics) requires additional time to be achieved.

1. INTRODUCTION

For many years now, military helicopters have been flying night missions relying on various night vision aids, as Forward Looking Infra-Red (FLIR) or Night Vision Goggles (NVG). Fighters Helicopters have further enhanced the requirement for night vision devices, introducing head-slaved sensors and weapons, associated with head-out symbology displays. Most modern Fighter Helicopter programs and some tactical transport (Tiger, Rooivalk, Commanche, NH90) include the requirement for bisensor (ie: display capability of I^2 and IR images), binocular Helmet Mounted Displays (HMD).

Integrated HMDs, with I^2 and full raster and stroke capability, offer substantial advantages in regard of operational potentialities, but also in term of equipment ergonomy. Compared to NVG based systems, they achieve a lower mass, better Center of Gravity, and minimal encumbrance, which is of considerable interest in usually narrow Fighter

Helicopters cockpit. Optically-coupled I^2 tubes are currently the only technical solution to reach the required performance and safety level for tactical flight, the current generation of I^2 CCD offering far too low performance to be useable in suc situations as NOE flights. It remains quite unclear if significant improvement could be introduced at short or mid term. Should improvement be achieved in this area, it would allow further gain in term of mass reduction and fully open the door for fused imagery displayed in the helmet, which underline the growth potential of HMDs versus NVG based systems.

Since the IHADSS was initially fielded on the AH 64, human factors aspects pertaining to HMDs have been extensively reviewed in the literature by many (see Newman, 5). Despite claims by some pilots that they are able to take advantage of the monocular design of the IHADSS, problems associated with monocular HMDs have been clearly identified (1). It is now quite well recognized that, though inducing increased design complexity and challenges, binocular HMDs are better responding to human factors requirements than monoculars (7). A core of experimental studies and guidelines are available in the literature regarding the human factors design issues of binocular HMDs. So far, little reports of flight testing of such helmets coupled with sensors platforms have been made, specially in regards of human factors aspects. The purpose of this article is to present some test flights results of the TOPOWL helmet. Two Flight test phases were successively conducted at the Flight Test Base of Istres. The first one was mainly devoted to testing of the I^2 channel, while the second one focused on head-slaved IR imagery and compatibility/complementarity of the I^2 and IR channels. It is not intended here to report exhaustively results of these test flights, but to focus on some human factors issues evaluated during the flight trials. Results presented hereby mainly belong to the second phase of testing (2), even though some aspects have been initially identified during the first period of test.

2. METHODOLOGY

From the very origin of the development, the importance of human factors issues was clearly recognized in regard of design, but also in terms of evaluation methodology. In regard of issues such as Increased Inter Ocular Separation (I^2OS), improperly referred as « hyperstereopsis », the need for adequate evaluation techniques was quite obvious. More generally, it was decided that test flight plans would be jointly elaborated by the Flight Test Center (CEV) and SEXTANT Avionique with help of the Aerospace Medical Institute (IMASSA) for specific human factors methodologies.

2.1. Test-Bed aircraft

Various aircraft were used during the first test flight phase. A large part of the testing was carried out on the SA 330 (Puma) « Helios », test-bed platform for the TIGER program, which was fitted with a HUD and head tracker system. The second phase of the testing was conducted on the Puma « PVS » which was fitted with all functionalities of the HAC-TIGER night vision platform (PVS).

2.2. HMD

Two different prototype versions of the TOPOWL helmet were used following the test phase considered. The differences between the two versions (HMSH and HMSD-B) was only that miniature CRTs were mounted on the HMSD-B instead of a LED module displaying fixed symbology. Main characteristics of the helmet are as follows:

- Day/ night display module: Visor projection, 40 ° Field of View, full overlap, collimated to infinity
- Integrated display capabilities: Stroke symbology, Raster image, Intensified Image
- Modular Integrated I^2 tubes on each side of the helmet (240 mm distance)
- AC Magnetic Head-Tracker
- Head supported mass: 2.2 kg (night configuration
- NBC kits compatibility (EPHES, ARH, TAERS)

TOPOWL Helmet

2.3. Specific Human Factors methodologies

Specific methodologies for distance and Above Ground Level (AGL) altitude evaluation were based on previous laboratory studies and results obtained at IMASSA. Their objective was to overcome difficulties in subjective direct verbal estimation of distance and altitude and introduce more objective metrics. The bisection technique originally used was adapted to flight test constraints to become a « double distance », « double height » technique, which was then validated during preliminary test flights. A similar attempt to develop a « natural » metrics for aircraft velocity estimation was rejected, due to possible impact on flight safety.

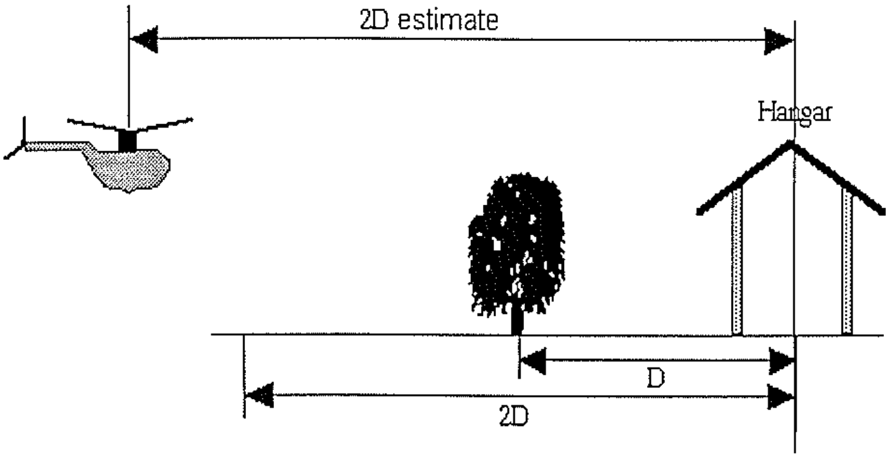

Figure 1: Double distance estimation

The double distance technique is illustrated in figure 1. The pilot flies along a straight line joining two landmarks, maintaining a constant aircraft velocity. He reports and hover when he feels that the current position is at double distance of the farther landmark, taking as reference the estimated distance between the two landmarks. On pilot's report, the distance of the aircraft to the farther landmark is measured. The measure obtained is referred as « double distance estimate », directly derived of the estimated distance between the two landmarks. Different distances between landmarks were used, ranging from 10 to 180 meters.

A similar technique was use for AGL altitude estimation and is illustrated in figure 2. Hovering above a landmark, the pilot is asked to take the aircraft at an altitude double of the landmark estimated height. A radioaltimeter measure is then recorded, giving a « double height estimate ». Different landmarks heights were used, ranging from 15 to 100 feet.

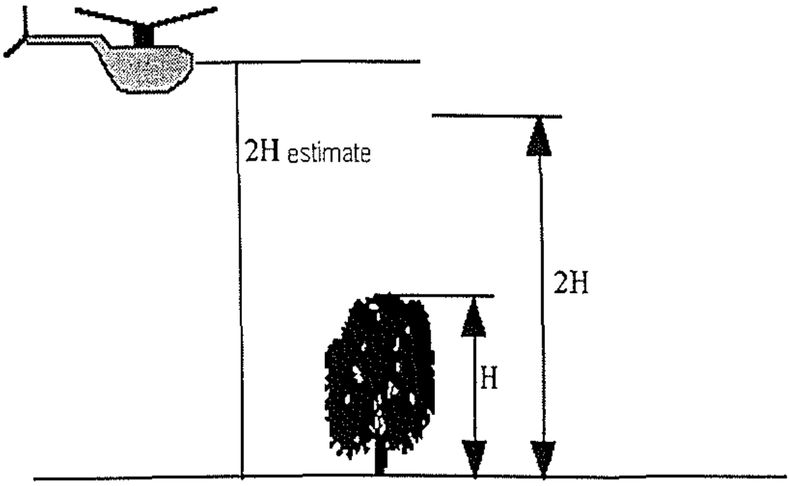

Figure 2: Double height estimation

In addition to the distance and height estimation techniques, classical metrics were use for image quality ratings; Questionnaires were also elaborated to investigate subjective aspects of image quality and explore the impact of various characteristics of the displayed images on pilot perception and aircraft handling quality obtained.

2.4. Flight test scenarios

Numerous features of the equipment tested were completely new in regard of NVG classical characteristics. It was therefore recognized that training issues were of paramount importance in the testing process and that scenarios must take this fact into account. A basic scheme was observed for the two test phases, build on a gradual difficulty approach with three major step:

- Training phase, circuits flights where the pilots were asked to perform different exercise, including distance and height estimation
- Transition and tactical flight in known areas
- NOE flights

Pilots changed from one step to the next when performance was considered as satisfying and when they felt they have build enough self-confidence to carry on new exercises. A safety pilot wearing NVGs was monitoring all flights. A test Flight engineer was systematically monitoring the evaluation process and recording the data.

3. FLIGHT TEST RESULTS

66 hours of test flight (40 hours at night) were realized during phase 1 from may 1995 to April 1196. Several pilots from different organization participated in the tests, though only one pilot crossed the threshold of 10 hours which was considered « a priori » necessary to adjust to the new features of the helmet. During the second flight test phase, 77 hours (45 at night) were flown, mainly by three pilots who acquired a substantial experience on both the I^2 and IR channels. For the two phases together, the total of flight hours comes to 143.

Data presented hereby are addressing three points which were clearly identified as specific objectives from the beginning of the study: Effects of Increased Interocular separation, pilotability of I^2 and IR images and visor projection of imagery and symbology. Other issues with strong human factors implications appeared, sometimes quite unexpectedly, during the course of the flight tests. Among these miscellaneous issues, three points deserve a particular attention from a human factors standpoint, as they all have implications on flight safety and pilot performance.

3.1. Increased Interocular Separation

Location of I^2 tubes on each side of the head, with a separation between sensors of approximately 240 mm, introduce a noticeable change in pilot perception of the intensified scene. Quite fortunately, basic aspects of this kind of issues have been investigated in laboratory studies (3). On the basis of literature data and some in-house investigations, it was assumed that some kind of physiological adjustments would take place and allow the pilot to operate normally after a few hours of exposure to the situation.

Inflight results show that, on initial exposure, some perceptual differences with NVGs were consistently reported by all pilots. The « double distance » and « double height metrics » demonstrated that there was a systematic under-estimation of distance and height, pilots feeling closer and lower than they were really. Flight results are matching quite closely some laboratory results reported elsewhere (8). It is of importance to note that initial misperception is going in a « safe » direction. After a few hours of flight (estimated between 5 and 10 for most pilots) adjustment of the internal model was realized, as predicted, and pilots returned to nominal performance obtained with NVG. Quite likely, the adjustment mechanisms imply neural plasticity more than a purely cognitive process, which allow to expect a good retention and robustness of the model.

Effect of I^2OS on velocity was more difficult to assess, due to lack of a reliable metrics. The main effect on velocity is clearly related to FOV size. Some underestimation effects with I^2OS were anecdotally reported, but did not seem to induce more comments or difficulties after few flight hours. Another effect reported with I^2 OS, due to test-bed aircraft characteristics, was the vision of struts through the I^2 tubes. This was considered as disturbing by some pilots, though others would rapidly adjust their head-movements strategies and, as reported later on, even take advantage of the location of the I^2 tubes.

3.2. Image pilotability

Except for I^2OS effect, there was little question about the pilotability of I^2 images. Aspects linked to the I^2 channel performance will not be reported here. Specific issues related to I^2 channel in the prototype helmet will be reported in the miscellaneous section. Otherwise, with appropriate training (see above paragraph), NOE flights were performed with velocity up to 70Kts and over in night 3-4.

Results obtained with IR images displayed in the helmet show some noticeable differences with NVG flights. Some the human factors issues pertaining to the thermal imager have been reviewed by rash and Coll. (6). The performed Flights allowed to explore a large domain in regard of the use of IR images.

- At night with images rated from very poor to excellent following night and weather conditions
- During day, with degraded weather conditions.

The recovery of an adequate safety level for night Flights with thermal imagery requires an extensive training. 20 Flight hours at least appear necessary to elaborate a usable internal model with IR imagery. Some exercise remain excessively difficult, as landings on a slanting area. As reported by others depth perception is affected. Results obtained with the distance and altitude estimation techniques have demonstrated that initial misperception goes at the opposite of safety consideration as overestimation was quite systematically found. Pilots feel:

- further than reality
- higher than reality

Once training was acquired and depending on weather conditions, the IR imagery displayed in the HMD allowed to perform NOE tactical flights with satisfactory safety and efficacy conditions. This point was considered as very positive as tests showed that the IR image is really « flightworthy » and, in appropriate weather condition, can be fully exploited to pilot the aircraft as well as NVG images.

During day conditions, the IR was found of little use for piloting purpose. In Bad weather conditions (fog), a slight visibility improvement was observed with the IR imagery. This improvement was evaluated to 200-300 m in horizontal visibility and 20 to 50 ft in vertical. At any rate, the image could not be used alone to fly the aircraft and had to be used in conjunction with appropriate symbology.

3.3. Visor projection

Using visor projection for an helicopter HMD was by many aspects a challenge, initially eliciting some reserve among the test pilots community. Besides minimizing transmission problems, one of the reason to introduce this concept was expectation of a better spatial situation awareness due to an unobstructed peripheral vision.

The excellent unobstructed vision of the cockpit and outside world was clearly identified from the very first test flight. Some pilots, mostly on their first flight, reported a « tunnel vision » effect, feeling that FOV was smaller than 40° and that they were looking at « a TV set ». Such perceptual effects, classically observed initially in simulators with visor projection HMDs, can probably be linked to border effects between the collimated image and the peripheral perception of the cockpit structures. Perception of being « outside of the scene » usually fades out after few minutes and the pilots feel then fully immersed in the helmet image.

In addition to the improvement of peripheral vision, a quite significant advantage was found during test flight. Compared to night vision goggles, an increased visual comfort at night was observed with an increased tolerance to ambient illumination level. Providing a good registration of images, this was particularly clear when flying over urban areas, where intensified image, direct vision of the outside scene and cockpit illumination appeared quite harmoniously melted.

Globally, at the end of the test flights, the concept of visor projection was considered as fully validated for an operational use in fighter or tactical transport helicopters. Some human factors concerns were originally raised about he dimorphic shape of the visor. In the frame of these tests flights, it was showed that dimorphic visor shape did not cause specific perceptual problems, neither during night nor day flight.

3.4. miscellaneous

Three points will be considered here: Effects of I^2 image distortion, issues related with head-slaved platforms and complementarity and transition issues of I^2 and IR images.

3.4.1. I^2 image distortion

A serious I^2 image distortion was identified from the very first flight and considered as susceptible to impact flight safety. Distortion effects were initially so bad that pilot were seriously desoriented just by moving their head around. Some corrections were rapidly introduced in the optical system, though residual distortion was still considered as unacceptable to perform certain tasks with the required level of safety. Optics of the HMD had been designed on the basis of NVG specifications (tolerance of 5%). To take a « safe » margin, a value of 3% maximum distortion was retained for the design and was effectively obtained, following the reception protocol adopted.

The literature relating the effects of distortion on the ability to perform piloting tasks is pretty sparse. Some authors (9) mention that shape of distortion is a factor of influence, but, with exception of a 2% orthogonality requirement found in SAE standards, little attention is paid to distortion shape in most HMD specification. As a matter of facts, distortion generated by off-axis design falls usually in the parabolic type (a rectangular shape becomes trapezoidal). Of course, distortion can be almost totally eliminated by adding the appropriate combination of lenses, inducing then additional weight on the head. The head supported mass generated by binocular HMDs with integrated I^2 tubes is a constant worry in the design process. Recent results from crash modelisation (4) show that mass limit could be as low as 2.3 kg for the 50th percentile male population and probably lower for small females. It is therefore of interest to specify precisely

« acceptable » residual tolerance as a function of distortion shape and task to be performed. Till now, very few data are available in the literature and only « rule of the thumb » can be applied.

Following these results, a redesign of the optics of the helmet was decided for the production model. Thanks to the data obtained during the test flights, the trade-off between optical complexity and residual distortion requirement is now satisfactorily achieved.

3.4.2. Head and sensor platform movements

Two issues have to be considered under this heading: compensation of head roll movements and adequation of platform peak velocity in azimuth to head velocity during horizontal scanning movements.

On most helicopters, thermal imager platform have only two degrees of freedom: azimuth and elevation. During large rotational movements on the head in the horizontal plane, a variable amount of roll component is naturally introduced in the movement. In the absence of roll compensation, the image provided by a two DOF platform has been shown during the test flights to generate spurious sensations leading to what pilots refer as « vertigo ». This desorientation was particularly pronounced on rapid head movements and looking downward on the side. Results of the test flight demonstrated that introduction of electronic roll compensation suppressed the spurious effects. Such compensation appears therefore as absolutely necessary to flight safety in case of a two DOF sensor platform.

It is usually assumed, following AH-64 experience, that a platform peak velocity of 120°/s is appropriate for piloting. Head movements naturally performed by human beings, especially in the horizontal plane, can reach largely superior values up to 600-700°/s. There is, however, reasonable doubts that such rapid head movements could be used while piloting with a reduced field of view. Laboratory results have shown that velocity of head orientation movements in the horizontal plane while wearing a visual field restriction device could largely exceed the current characteristics of sensor platforms (10). These results were confirmed during test flights, with peak head movements of 240°/s when flying high speed NOE in a canyon. In this case, head velocity is paced by the information need on lateral clearance and directly proportional to aircraft ground speed. Due to the lag generated by the sensor platform limitations, pilots could not take full advantage of the possibilities offered by the HMD and had to reduce speed.

3.4.3. I^2/IR images :Complementarity and transition issues

Encouraging results were obtained during these test flights on operational complementarity of the IR an I^2 channels. Though, the limited number of flight hours and of encountered visibility conditions do not allow to give reliable quantitative features on the gain which could be obtained from such complementarity. One point emerging quite clearly is the need expressed by pilots to be able to choose « real time » the sensor most adapted to the outside conditions.

Once pilots where used to pilot with thermal images, transition from I^2 to IR was considered as quite easy. The reverse (IR to I^2) was found more problematic. Due to difficulties on the test-bed aircraft to finely tune the brightness of the IR image, the luminance of IR images (raster) was usually quite higher than those of the I^2 tube. Subsequently, difficulties linked to retinal adaptation were observed on transition, with adaptation delay reaching 45 seconds in night 5 (with probably a quite high raster image luminance setting). As I^2 image luminance cannot be adjusted and remains function of the night level, these observations stress the need to correctly match the display luminance for the two sensors. The role played by overlaid symbology also deserve some attention.

4. CONCLUSIONS

Human factors considerations constitute a key point for design of testing of helmet mounted displays. The complexity of issues reached by using binocular bisensor helmets calls for an increased attention on these aspects in regard of flight safety and performance. Results obtained during 143 hours of test flight are very satisfying on this points.

The TOPOWL modular concept has been globally validated. Increased Interocular separation generated by I^2 tubes location on each side of the head does not constitute anymore a concern for pilots. Habituation appears to be fast and should be quite robust. Visor projection does not only provide a superior situation awareness, it also brings an increased visual comfort compared to NVGs.

Regarding image pilotability, a major result is that both I^2 and IR image, depending on outside conditions, allow to safely perform tactical flights. Flying thermal images requires quite extensive training before acquiring sufficient proficiency and safety level. these results indicate that pilots should be free to select the piloting sensor as they wish, I^2 or IR, function of prevailing external condition and tasks. Improvement of sensor platform peak velocity is required to fully take advantage of the PVS.

I^2 image parabolic distortion correction was found to be a serious problem. This point should deserve further attention to build comprehensive design guidelines, taking into account task related issues and the need to keep the mass of the helmet in acceptable limits. Brightness matching also constitute a serious issue when switching from a sensor to another, especially from the IR raster image to the I^2 image.

For many years, numerous laboratory studies attempted to address human factors issues related with the use of binocular HMD. Data available from the literature are a precious help to the design of such equipments. These laboratory studies are, however, very far to cover all the issues pertaining to such complex systems as HMDs and PVS. Results obtained during these flight tests give evidence that there is still a long way before design can be done on purely theoritical basis. Risk of overdesign due to arbitrary specification or underdesign due to lack of knowledge remains quite high in advanced technological systems. Comprehensive flight trials using sound human factors methodologies constitute an essential tool for succssful devlopments.

5. REFERENCES

1. Behar, R.W Wiley, R.R. Levine, C.E. Rash, D.J. Walsh, R.L.S. Cornum "Visual survey of Apache aviators (VISAA)," USAARL report No. 90-15, Sept. 1990

2. Bergeaud, « Essais HMS/DB sur le puma PVS », Technical Report N° 3064/BE/IS/SE/VT, 83 pages,1997

3. Fisher, K.J. Ciufffreda, « adaptation to optically increased interocular separation under naturalistic viewing conditions », Perception, Vol. 19, pp 171-180, 1990.

4. Leger, L. Portier, J. Baudou, X. Troseille, « crash survivability and operational comfort issues of Helmet Mounted Displays in helicopters: simulation approach and flight tests results », Proceedings seminar on « te design and integration of helmet systems », additional paper, 1997.

5. Newman, K.W. Greeley, « Helmet-Mounted Display Design Guide », TR-97-11, 400 pages, 1997

6. Rash, R.W. Verona, J.S. Crowley, « human factors and safety considerations of night vision systems flight using thermal imaging systems », USAARL Report N° 90-10, 22 pages, 1990

7. Roumes, J. Plantier, J.P. Menu "L'avenir est-il au visuel de casque binoculaire," AMP panel symposium Helmet Monted Displays and Night Vision Goggles, AGARD CP-517, pp 11-1 to 11-9, 1991

8. Roumes, J. Plantier, A. Leger, « Perception of distance in a binocular HMD: data from helicopter video tapes » Proceedings SPIE vol.3362, 1998

9. Pinkus, H. L. Task, « Display system image quality », AGARD-LS-156, « visual effects in the high performance aircraft cockpit », 8-1 to 17, 1988

10. P.B. Sandor., A. Leger, « Tracking with a restricted field of view: performance and eye-head coordination aspects » Aviat. space Environ. Med; 62 (11), 1026-31, 1991