COMPARISON OF FLIGHT GUIDANCE SYMBOLOGIES FOR HELICOPTER-LOW-LEVEL-FLIGHT

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ABBREVIATIONS

EVATO	Evaluation Tool
FMS	Flight Management System
FOV	Field of View
H/C	Helicopter
HMS/D	Helmet Mounted Sight and Display
IAS	Indicated Airspeed
LLF	Low-Level Flight
MCHR	Modified Cooper Harper Rating
MFD	Multi Function Display
MMI	Man-Machine-Interface
OAGT	Obstalce Avoidance and Guidance Tunnel
OWS	Obstacle Avoidance System
PID	Pilot ID
RH	Radar Height
SL	Safetyline
UCQ	Uncertainty Questionnaire
WT	Wire & Tree Mode

1. ABSTRACT

Obstacle warning and avoidance is a challenging issue for current and future helicopter developments with the object of extending the operational area.

Up to now different guidance symbology proposals have been presented to detect obstacles and present guidance aids to the pilots to avoid collisions especially in low-level-flights.

At Eurocopter Deutschland in co-operation with the Institute for Aerospace Technology of the Technical University of Munich an investigation has been performed to analyze different flight guidance symbologies regarding their specific philosophy. To evaluate the diverse symbologies an evaluation methodology was established to find out advantages and disadvantages and to derive requirements as well as suggestions for improvement.

This paper is separated in two parts. The first part describes the different guidance symbologies „wire & tree mode“, „safety line“ and „guidance tunnel“ explaining the relating flight guidance symbology and their individual objectives and functional range.

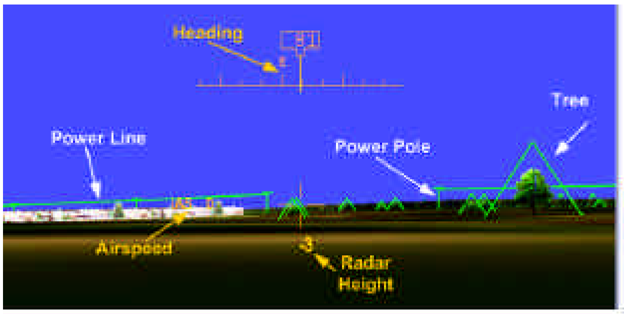
The second part presents the setup and the approach of the evaluation methodology. Due to the fact that each symbology aims at a particular guidance philosophy it is necessary that the assessment takes this into account. The assessment is a combination of already existing methodologies like the Cooper-Harper Rating and the Eurocopter Crew Workload Assessment of the NH90 program and allows to rate the MMI according to nine independent topics like workload, expectance conformity, and so on. EVATO, a MS Excel Tool, is used to perform the evaluation that eases data input, analysis and storage. The methodology also considers influences from the simulation environment (e.g. simulation scenario and flight mechanics) which may affect the assessment.

2. FLIGHT GUIDANCE SYMBOLOGIES

There are several methods possible to provide the information of the Obstacle Avoidance System (OWS) to the pilot like acoustical, haptical or optical information in a MFD or even a HMS/D. The study is limited to the examination of three different optical flight guidance symbologies which support detection, identification and avoidance of obstacles in low-level-flights. All of them (Wire & Tree, Safety Line, Guidance Tunnel) have been designed for a HMS/D application.

2.1. Wire & Tree Symbology

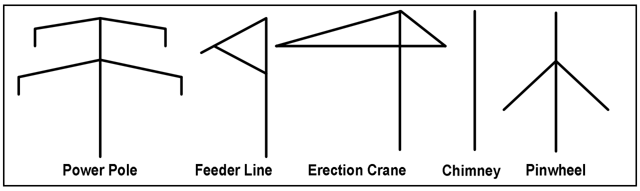
The Wire & Tree symbology (WT) was developed to detect stand-alone obstacles like pinwheels, erection cranes or trees. Its main feature is to detect power lines, the most dangerous type of obstacles for helicopter pilots in good as well as poor visibility conditions.



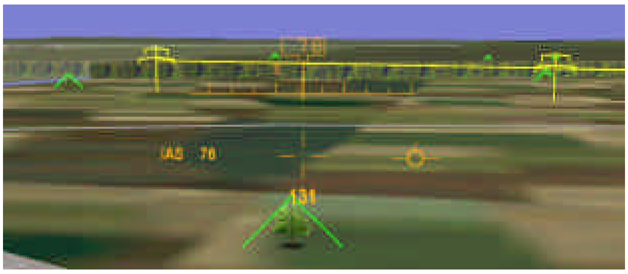
picture 1: Simple Wire & Tree Symbology

In addition to the obstacle overlay symbology, several flight guidance aids for navigational support are displayed in the pilot's FOV. The WT-symbology as shown in picture 1 only allows a differentiation between three types of obstacles, trees, power lines and poles. The underlying sensor model is based on current developments like the HELLAS OWS from EADS Dornier using a laser-based obstacle sensor.

Because future sensor technology might be able to distinguish between different types of poles the Wire & Tree Mode is equipped with an additional option. Besides the detection of trees and power lines, the sensor can differ between five different kinds of poles, power lines, train feed lines, erection cranes, chimneys displaying a different symbol for each of them (see picture 2 and 3). To keep pilot's mental workload for interpretation at an adequate level, the number of different symbols got limited to a maximum of seven.



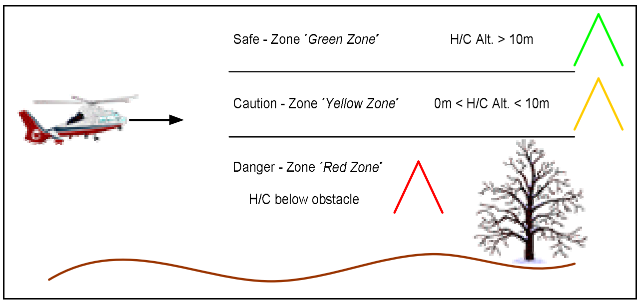
picture 2: Pole symbologies used for type specific Wire & Tree MMI-Mode



picture 3: Type specific Wire & Tree Symbology showing a tree and two power poles in the back

Using the simple Wire & Tree symbology the pilot is able to derive distance and height of the obstacles. Using the type specific symbology, the pilot gets additional information about the obstacle type which is very helpful for planning the lateral safety distance to avoid any collisions.

The pilot does not get any information about the vertical distance between his helicopter and the obstacle. Thus he doesn't know if he can fly over it without changing his current altitude. Therefore he mostly passes the obstacles too high which may lead to severe situations (enemy radar contact) especially in military low-level missions. Because of this fact an altitude sensible color concept was implemented. Dependant to the H/C altitude the obstacle overlay changes its color (comparable to a traffic light, see picture 4) and indicates if the pilot has to climb or is even able to descent to stay on a safe route.



picture 4: Operation mode of the altitude sensible color concept

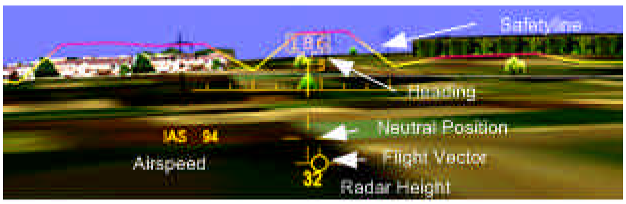
Compared to a monochrome display the color concept confers the Wire & Tree symbology some kind of dynamic gets direct information to control his altitude. Furthermore the color concept declutters the pilot's field of vision because a polychrome display is much better to interpret than a monochrome one.

The number of displayed overlays is adaptable to the pilots needs. However, for the evaluation campaign it got limited to 30 (maximum 100) to guarantee an identical simulation environment to all test pilots and to avoid a congestion of the pilot's field of vision.

The Wire & Tree symbology represents a static flight guidance philosophy that supports obstacle detection but does not provide the pilot with proposals concerning a safe route to the destination. The pilot has to react on the displayed information and has to decide the kind of avoidance maneuver (horizontal, vertical) by himself. Thus he keeps his unrestricted decision freedom on the one hand and has to perform all flight tasks (navigation, obstacle avoidance, communication…) on the other hand which may lead to an increased workload level.

2.2. Safety line Symbology

The safety line symbology for obstacle avoidance during low-level flights (LLF) is displaying the terrain elevation together with obstacle information in a specified distance in front of the helicopter. The distance is adaptable to the pilots needs.



picture 5: Safety line with additional flight guidance symbology (altitude sensible color concept)

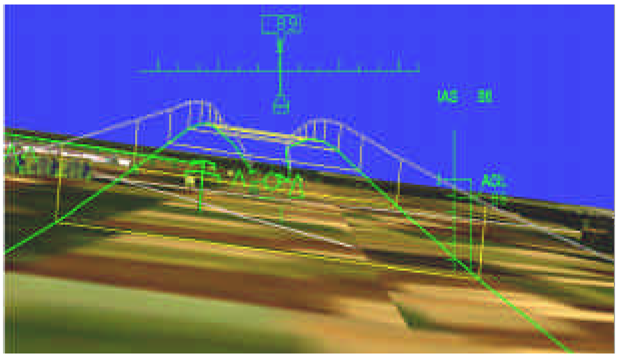
In addition to the safety line a flight vector, which is also displayed in the pilot's Field of View (FOV) indicates, whether the H/C is able to pass the terrain safely by maintaining the current altitude. Therefore flight vector position above the safety line means ´safe flight´, flight vector below the SL denotes that the pilot has to react and bring it back up. Due to decreasing pitch angle with increasing H/C airspeed both, the flight vector and the neutral position cross move upwards towards the heading indicator (airspeed dependant) to keep reference with the horizon and the safety line.

Besides the monochrome safety line design two additional color concepts have been implemented. In the first mode (type specific mode) the color complies with the hazardousness of the detected obstacles. For example power lines lead to a red, whereas stand-alone obstacles lead to a yellow coloring of the safety line. For this reason the pilot does not only get a picture of the obstacle position but also needful information about the type of the obstructions.
The second color mode is comparable to the altitude sensible color concept of the Wire & Tree mode. The safety line is made up of several points with a distance of 30m between each other. For each point is examined, in which color zone it is currently located (green, yellow or red zone). Because of this each point can have a different color. This color concept does not provide information about the obstacle type anymore but is indicating a safe flight direction and altitude instead.

The safety line can be seen as a semi-dynamic flight guidance aid. It indicates the pilot a safe route of flight with helpful altitude information. The pilot still keeps full decision freedom but already gets safe direction and altitude proposals provided by the safety line and flight vector symbology.

2.3. Obstacle Avoidance & Guidance Tunnel

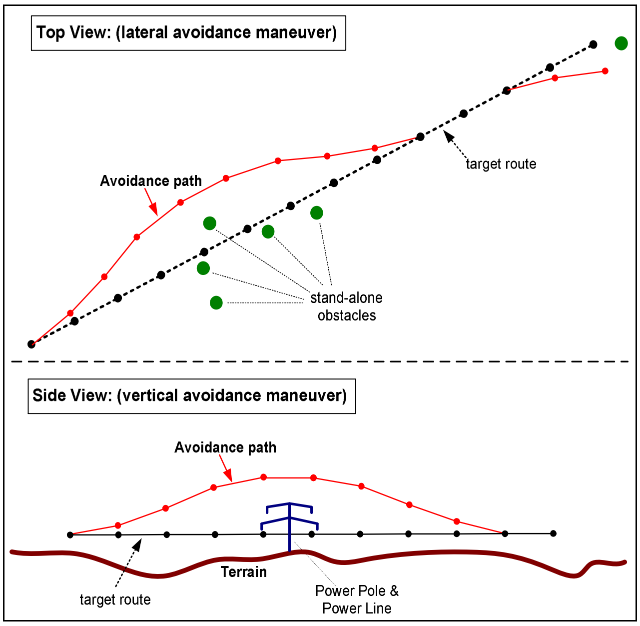
The third developed symbology is the so-called Obstacle Avoidance & Guidance Tunnel (OAGT). The OAGT is generated for a preplanned route (via H/C FMS). The tunnel is showing a safe route to his destination in terms of a channel displayed in the FOV of the pilot (see picture 6). The OAGT enables the pilot to perform low-level flights at constant ground clearance with automatic obstacle detection and avoidance which reduces pilot workload especially in bad weather conditions.



picture 6: : Obstacle Avoidance and Guidance Tunnel Symbology

As apparitional the guidance tunnel acts as a flight path indicator. The tunnel always shows about 1km of flight path in advance and for that reason the time between realization and execution of course alterations respectively obstacle avoidance maneuvers can be increased significantly. Thus the course of the flight is discernable at an early stage and relieves the pilot, because permanent course rechecking with the digital map on the Navigation Display is not necessary any more.

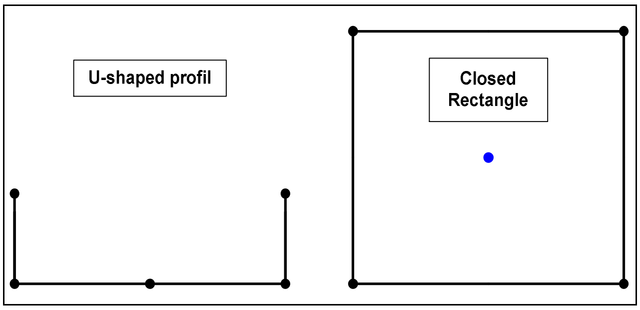
The obstacle avoidance algorithm independently plans its maneuvers dependant on the type of obstacles. As soon as obstacles underrun predefined safety areas along the tunnel trajectory, a type specific avoidance maneuver is planned automatically. This means, a power line initiates a vertical, a stand-alone obstacle a lateral avoidance maneuver (see picture 7).



picture 7: Type specific obstacle avoidance algorithm

Due to the fact that the tunnel symbology takes over flight tasks as navigation and obstacle detection as well as avoidance, the pilot's workload level decreases and he has more time to perform other mission tasks (i.e. communication).

The tunnel is available in two different geometries, the U-shaped bar and the closed rectangular geometry (see picture 8).



picture 8: OAGT geometry alternatives

The evaluation campaign should also verify which geometry is preferred by the pilots.

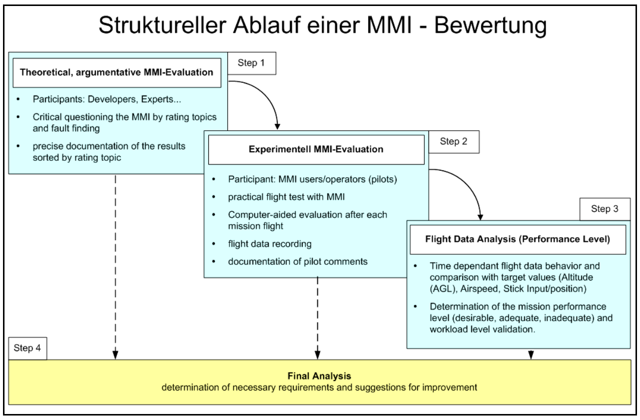
The guidance tunnel represents a dynamic flight guidance aid and acts as a command display. This guidance aid shows the pilot a precise route to his destination and therefore pilot's own initiatives get suppressed. Tasks like navigation, obstacle detection and avoidance are performed by the OAGT and relieve the pilot who can fully concentrate on his mission.

All in all, the guidance tunnel allows safe flights under all visibility conditions even in no view conditions because this guidance symbology does not rely on the periphery like the safety line or the wire & tree mode. The OAGT allows emergency rescue services like the German ADAC to fly under almost all weather conditions. Thus the guidance tunnel probably represents the best possibility to enlarge the operational area and to increase the economic efficiency of helicopters.

3. MMI-EVALUATION METHODOLOGY

3.1. Process and structure of the evaluation methodology

Nowadays avionic manufacturers try in large-scale to relieve pilots whose cockpit function changes to a more and more cognitive one. New systems (MMI) are very complex and afford a lot of concentration and memorizing effort. Thus the performance of the MMI is limited by the operator and his non-expandable capacities. To evaluate MMI-components the use of special assessment methodologies which are tailored for MMI-evaluation purposes are mandatory. There already exist a lot of approaches how an evaluation needs to be made up but none of them is really complete. For the assessment of the described obstacle avoidance symbology a new methodology has been designed, that combines already existing procedures completed by new and missing aspects. (i.e Cooper Harper Rating (CHR), NH90 Crew Workload Assessment (CWA), ISO 8241/10…). The evaluation process is shown in picture 9. To determine requirements or suggestions for improvement three sources of data are available.



picture 9: Evaluation methodology process

The first step is a theoretical and argumentative assessment with experts and engineers who critically scrutinize the MMI. The results get documented precisely for later analysis. The second step is an experimental assessment with future users of the MMI (here: pilots). Simulation flight tests impart knowledge and functional range of the MMI-components. Questionnaires or pilot comments are used to assess the systems. An important fact is, that the participants are not all part of one operational area (i.e. military pilot) but cover all areas for which the MMI is designed. This makes sense to avoid the development for only one group of later users. Flight data analysis, the last part of the evaluation methodology is used to determine the degree of mission performance which the pilots achieve by using the different kinds of obstacle avoidance aids. These three sources of information are used to work out necessary or needful requirements for the MMI.

The experimental evaluation takes place in two segments, through questioning (commentaries and questionnaires) and through observation (pilot behavior and flight data recording). Questionnaires are subjective and consider the pilot as a participant of the development process. In the observation part the user acts in a passive way with reduced personal influence on the test results. The questioning as a part of the experimental assessment is based on three already existing methods. The ergonomic standard (ISO 9241/10) describes a criteria rating system which should be used for MMI-development and assessment, too. The final criteria system consists of nine independent rating tasks, namely:

- requirement appropriateness
- workload level
- expectance conformity
- controllability
- memorize ability
- failure robustness
- self-descriptiveness
- customizability
- security and confidence

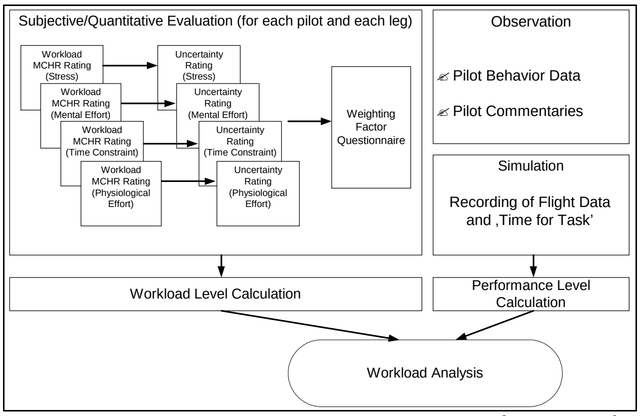
Because of their self-contained character it is possible to choose what rating topics are necessary to achieve the defined evaluation goal in the run up to the assessment campaign. For the evaluation of the guidance symbology i.e. the rating topic ´failure robustness´ stayed unconsidered because there is no interaction between the pilot and the MMI possible and therefore no failures can occur.

The rating topics get complemented by Modified Cooper Harper Ratings (MCHR). The original Cooper Harper Rating (CHR) is used to assess handling qualities of aircrafts. Therefore it is designed very generic and does not allow an assessment of single aircraft components like avionic MMIs. Due to this fact the CHR got modified and adapted to use it for evaluating some of the discussed rating topics. (i.e requirement appropriateness, memorize ability…).

For evaluating the pilot workload level the so-called NH90 Crew Workload Assessment Methodology was taken and slightly modified.

The original CWA was developed by Eurocopter France in 2002 to assess the crew workload level during NH90 missions. The methodology breaks down workload in four subclasses [6]:

- Workload through time constraint, to evaluate the time-induced pressure generated by the time allowed to complete the required mission tasks and the speed with which one task follows the next.
- Workload through stress to express a lack of confidence, a feeling of subjective constraint and nervous tension.
- Workload through mental effort expresses the mental activities by means of quantifying the difficulties in finding information, data processing and decision making.
- Workload through physiological effort evaluates the induced physiological activity and tiredness generated by the MMI while performing the required mission tasks



picture 10: Process of the assessment topic *´Workload´*

Each of the four subclasses is evaluated by a MCHR and an Uncertainty Questionnaire (UCQ). Due to the fact, that simulations can only be compared with real flights in a restricted manner, the danger exists, that external factors influence the evaluation in either a positive or a negative way. Uncertainties can lead from the simulation environment (cockpit configuration, underlying helicopter model), the mission scenario (unrealistic events, too much simplified/complicated scenario) as well as the pilot's knowledge and training for the simulation campaign. The pilot takes those uncertainties into account which may lead to an under- or even an over-estimation of the four workload subclasses. The UCQ evaluate these uncertainties and allow a modification of the workload component rating results.

As already mentioned, an evaluation using a questionnaire is a subjective assessment method which supplies abstract user statements with which the user is influencing the MMI design process. In addition to this summative method the developed evaluation methodology consists of two more data sources, pilot comments and flight data (log files) analysis. During the simulation flight it is possible to record different flight data, like H/C position, flight time, altitude (radar height) and airspeed, With the aid of those data it is possible to completely reconstruct the flight and the MMI user operation after the campaign. These data allow the determination of the performance level of the pilot that is defined as the difference between conceptual formulation and task performance of the mission flight. Further on the flight data permit a conclusion of the pilot's workload during the test flight. The performance level criterion is also used for the workload evaluation to verify the acceptability of the pilot's workload rating.

´Noisy thinking´ (pilot commentaries) helps to verify the results of the questionnaires and are one of the major sources for suggestions for improvements. During the flight test and the assessment, the pilot's are forced to enunciate all their thoughts concerning the MMI, the simulation environment, the tactical mission scenario and the evaluation methodology itself. The comments are recorded and analyzed later on to verify the answers of the pilots given during the questionnaire.

3.2. Computer-Aided Evaluation with EVATO

To offer a computer-aided evaluation, EVATO (Evaluation Tool), a MS Excel application was developed. The tool allows an individual choice of rating topics in advance of each assessment campaign. In addition the number of questions, answers and MCHRs is individually changeable and completable as required to evaluate different MMI-components. In the future EVATO will also be featured with automatic data analysis functionality for an easy and fast way to receive results right after the questioning. This allows pilot answer validations in the debriefing session, the last part of the assessment campaign.

3.3. Implementation of the assessment

The assessment is mission task related and therefore has to be adapted in advance of each campaign. For the evaluation of the guidance aid symbology a LLF mission of about 10 to 15 minutes was designed. The primary mission objective was a collision-free flight to the destination. Secondary mission tasks were the compliance with the predetermined airspeed and radar height.

For the evaluation of the flight guidance symbologies the following flight data have been recorded to determine the performance level:

- Mission time t in [s]
- Altitude (radar height) RH in [ft]
- Airspeed IAS in [kt]

Table 1 is showing the declared performance level for the symbology evaluation campaign.

Performance Level	Time Constraint	Airspeed	Radar Height
DESIREABLE	< +10% von t	90 – 100 kts ++	0ft < 60ft
ADEQUATE	+10% < +20% t	85– 90 kts	60ft < 75ft
INADEQUATE	> +20% t	< 85 kts	> 75 ft

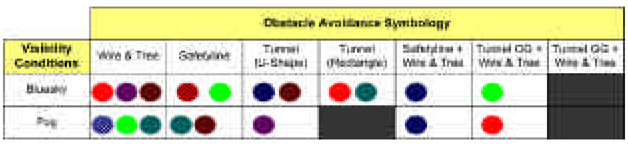
Table 1.: Performance Level Classification

As already mentioned above, pilots from different operational areas were invited to take part in the evaluation campaign. The next table gives an overview about the operational area, education, training and flight hours of the participants.

Operational Area	Educational Background	Annual Flight Hours
Airport Police	EC 120, EC 135	150
ADAC	BK 117 IFR/VFR EC 135	300
Lufthansa	ATPL A300/310	750
EADS	*expired*	*Former AlphaJet instructor*
Army (TBM)	MFS-H CHPL	100
Army (TBM)	IFR, IP, BIV	100

Table 2.: Information of invited test candidates

The symbology need to be tested under different visibility conditions (i.e. fog or blue sky) to get clear results. Therefore a trial matrix was made up to schedule the participants.



picture 11: Trial matrix for the evaluation of the different obstacle avoidance symbologies

To guarantee plausible results each combination of the matrix should be flown at least three times. Because of insufficient available test pilots every symbology was flown not less than four times under different visibility conditions.

3.4. Data analyzing process

The data analysis takes place in three steps:

- Analyzing the questioning results (pilot answers) and visualizing the MCHR results in diagrams. Each rating topic is examined separately to derive clear requirements.
- Analyzing the pilot commentaries to verify their given answers during the computer-aided assessment and find out needful suggestions for improvement for all future operational areas.
- Analysis of the recorded flight data and determination of the performance level to verify the degree of mission performance and the acceptability of the workload level.

4. RESULTS OF THE SYMBOLOGY EVALUATION CAMPAIGN

This part presents the most important conclusions that resulted from the evaluation campaign.

4.1. Requirement Appropriateness

The rating analysis of the topic ´requirement appropriateness´ showed that the safety line symbology is voted as the best concept to perform low-level flights in obstacle sceneries because of its low information density in the pilot's FOV. Some terrain collisions relativize this result. The pilots explained that they had not enough information about their current radar height in form of acoustic warnings as soon as a defined minimum altitude (decision height) gets undershot.

The altitude sensible multicolor concept of both, the Wire & Tree mode and the safety line mode is very useful because the pilots can easily estimate the distance between the H/C and the terrain/obstacles. In addition the color concept helps to declutter the FOV, because multicolor information can be interpreted more easily compared to a monochrome display.

Especially the WT and the SL guidance aids improve obstacle cognition and therefore increase the time between obstacle detection and initiation of necessary avoidance maneuvers.

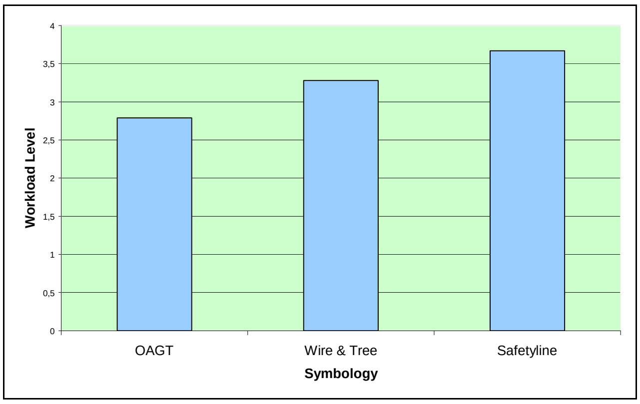
The advantages of the flight tunnel OAGT can be found at missions under restricted visibility conditions, because it takes over the most important flight tasks as navigation and obstacle avoidance which leads to a reduced workload level of the pilot. A disadvantage is the loss of reference to the outside world. Due to the high line density in the FOV the pilots loose eye contact to the outer world. This may also be a consequence of the limited FOV of the simulation and should be re-tested in real flight conditions. A positive feature of the OAGT is the flight prediction feature which allows to foresee course alterations and to plan steering maneuvers at an early stage.

The WT allows an excellent estimation of obstacle direction, height and type, whereas the SL-symbology only enables the pilot to recognize height and direction of those. The OAGT as a command display does not provide the pilot with any obstacle information that cause avoidance maneuvers of the tunnel.

None of the presented guidance aids allowed an estimation of the distance between the obstacles and the H/C and therefore additional display information need to be implemented.

4.2. Pilot Workload

All symbologies contributed to reduce pilot workload in a great manner. The best result (desirable) achieved the OAGT (see picture 12), because some important flight tasks (i.e. navigation, obstacle detection and avoidance) are conducted by this guidance aid. Another fact for workload reduction is the low amount of information of the OAGT (compared to the WT and SL-modes) which lead to a reduced interpretation effort.



picture 12: Result of the Workload Level Analysis

Especially in turns, the pilots criticized the steerability through the OAGT that affords a lot of concentration to stay inside the tunnel. The tough steerability through the tunnel is mainly a result of the fix geometry (const. tunnel width). Solving this problem would lead to a further workload level reduction.

4.3. Controllability

As already mentioned the tunnel affords a lot of concentration to navigate the helicopter through it. Thus the OAGT geometry needs to be reworked.

Nevertheless all symbologies improve navigation through the obstacle scenery in LLF. In addition to the fix tunnel geometry H/C flight mechanics have to be considered especially for calculating the turn radii, i.e. implementation of velocity dependant, dynamic trajectory planning and indication.

4.4. Memorize Ability

Every symbology was seen as an easy-to-use and learn system that only afford a minimum effort to get to know all provided features. Additionally, they can be understood unaided and without special training.

Concerning memorize ability, the tunnel is the best possibility to guide pilots through an obstacle scenario in LLF due to the low amount of displayed information. Especially for inexperienced pilots this fact is very important and helpful.

4.5. Safety and Confidence

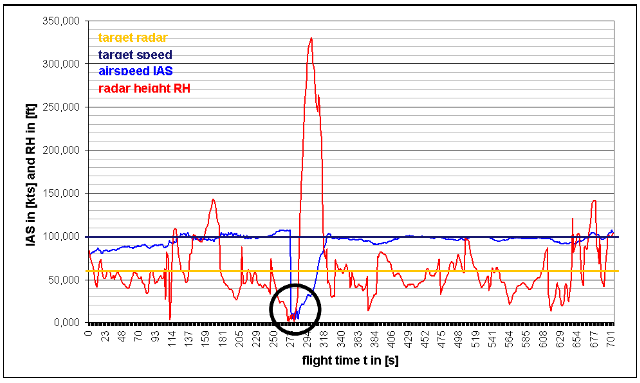
All presented flight guidance aids are conducive to improve both, flight safety and subjective safety feeling. On the one hand, personal confidence is highest by using the WT-symbology because the pilot has a complete situation report and he can detect and classify all obstacles at an early stage. On the other hand, the WT affords an own situation analysis of the pilot which increases workload level during the flight.

The altitude sensible color concept of the WT and the SL-mode induce an additional feeling of safety and confidence, because the pilots can estimate the distance between their H/C and the terrain/obstacle.

Due to the fact that the OAGT does not provide any obstacle information to the pilot, this symbology needs to be improved to increase subjective safety and confidence feeling. The pilots' suggestion is to have an obstacle indication near the displayed tunnel trajectory

4.6. Performance Data Analysis

The following picture illustrates an example of the flight data analysis, showing a mission with Wire & Tree symbology under restricted visibility conditions.



picture 13: Example of a performance diagram

The run of the curves airspeed and radar height show, that the pilot had a terrain collision (see white circle). For the rest of the flight time the candidate was able to hold a const. speed above the required 95-100kts. The pilot's explanation to the collision was a short time of excessive demand due to a high information density at this point of flight that resulted in a disregard of his flight instruments (radar height indicator). Due to the terrain character the radar height curve fluctuates especially when crossing forest and city areas. After calculating the average value of all flight data, the result shows an adequate performance level (see table 3).

Performance Data	Target Value	Actual Value	Performance Level
flight time t	< 630s	703 s	adequate
Average IAS	> 95 kts	92,10 kts	adequate
Averaget RH	< 60 ft	65,93 ft	adequate

Table 3.: Performance Level Results

A collision is tantamount to non-obtaining the declared primary flight goal, to perform a collision-free flight to the destination. Therefore a collision leads automatically to the performance level ´inadequate´ because a terrain collision is basically always the result of false interpretation of the presented guidance information or a disregard of the primary flight displays. The only obstacle avoidance symbology which did not cause any collisions is the OAGT and thus this concept achieved the best performance result (´desirable´) after analyzing all mission data.

5. DERIVATION OF REQUIREMENTS

The data analysis allowed to derivate requirements whereas only the most important ones will be discussed in the following part sorted by the type of symbology.

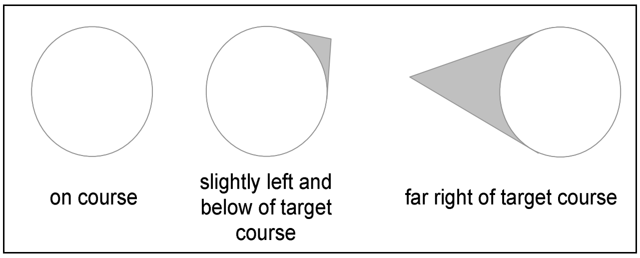
5.1. Wire & Tree Symbology

Due to the fact of occurred terrain collisions and the relatively high pilot workload the information density in the FOV needs to reduce the interpretation effort during flight. A possibility is i.e. the reduction of the displayed overlay symbols dependant to the obstacle distance (currently 30 symbols at one time) to declutter the visual field of the pilot.

Another improvement is the expansion of the color concept that currently only indicates the vertical distance between the H/C and the obstacles. The pilots explained that the color concept should also announce the lateral distance under run which would help to perform straighter and deeper mission flights.

The most important requirement to increase flight safety and avoid terrain collisions is the implementation of an additional altitude warning signal in the form of an acoustic announcement as soon as a minimum radar height is undershot.

The navigation task during a flight with the WT is very demanding and therefore the pilots ask for ancillary course information in their FOV. A possibility illustrates picture 14.



picture 14: Suggestion for additional course information in he pilot's FOV

A horizontal 3D cone could tell the pilot how far his current course deviates from the planned target course. This additional flight guidance information reduces the amount of views to the Navigational Display to check course and current H/C position in the cockpit and the pilot can fully concentrate on his flying tasks.

To allow distance estimation of the obstacles a distance indication below each obstacle symbol would also be useful to reduce the interpretation workload of the user.

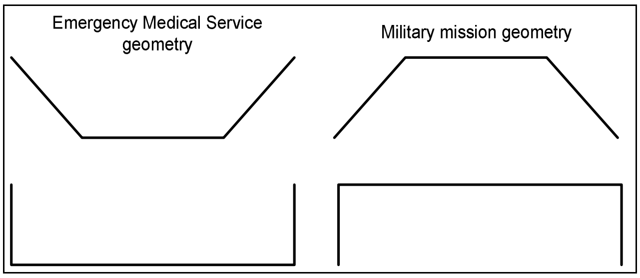
5.2. Safety Line Symbology

To reduce pilot workload through navigation support and to increase flight safety the SL symbology needs to be upgraded with additional course information as well as an altitude announcement as already described for the WT.

The Safetyline only shows the lateral terrain characteristics in a defined distance in front of the H/C. This prevents extreme LLF because the pilots cannot estimate the terrain character between the H/C and the SL and thus run the risk of being detected by hostile radar station especially in military missions.

5.3. Guidance Tunnel OAGT

A major deficiency of the current OAGT geometry is the high line density in the pilot's FOV which prevents to scan the outside world and causes a tunnel vision. Especially for military applications the tunnel geometry must be defined mission specific. For missions in enemy region for example pilots need to have free sight to the ground and a top-closed tunnel is preferred to indicate a maximum allowed flight altitude to stay invisible for hostile radar stations. Emergency Medical Services prefer a bottom-closed tunnel that indicates a minimum allowable altitude for safe terrain crossing (picture 15).



picture 15: Mission specific tunnel geometry suggestion

To ease navigation effort through the tunnel and to reduce physiological workload during flight, two requirements have been allocated. First of all the turn radius calculation has to be performed dynamically and airspeed dependant. A second possibility is an idea called ´stretch-tunnel´. In regions of no danger the tunnel could expand to a higher width and only in situation where obstacles threaten flight safety, the tunnel merges. This add-on gives more flying liberty to the pilot and should also result in an immense reduction of the workload level.

A last requirement is a position indicator that tells the pilot his position in the tunnel. Especially when using the U-shaped tunnel profile, the pilots do not know their exact position in the flight tunnel. An additional signal would help to increase the pilot's situation awareness.

6. CONCLUSIONS

The investigation of the three flight guidance aids showed that all concepts are suitable to perform H/C LLF in obstacle sceneries, but the results also showed, that all of them still have deficiencies that need to be reduced. The flight tunnel is the concept with the lowest skill demand and that leads to the lowest workload level. WT and SL are good alternatives but need to be upgraded with additional flight guidance information to prevent terrain collisions and increase flight safety especially under restricted visibility conditions.

The evaluation methodology was well accepted among the test candidates. The average duration of one evaluation cycle (30 to 50 minutes) is necessary to achieve usable test results which influence the development of such systems. In addition the methodology was rated as structured and transparent. The computer-aided assessment with EVATO was also seen as a good option compared to a paper-based questionnaire.

The next steps are to implement all of the symbol requirements and start new simulation campaigns to assess the influence of those upgrades.

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