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Executive summary

A simulation environment for helicopter flight in degraded visual environments

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Problem area
Helicopter brownout is a hazardous and challenging type of degraded visual environment (DVE). Due to the loss of outside world visual references, combined with disorientation caused by moving dust particles, the pilot may lose situational awareness. These phenomena are particularly challenging during operations close to the ground such as landings and cargo pick-ups. During landings, for example, brownout may result in touch down with unintended drift of the aircraft and related risks such hard landings and even aircraft loss.

Description of work
This paper describes the development, possibilities and application of a real-time simulation environment for helicopter flight in DVE at NLR. The environment enables evaluation and assessment of potential DVE aids and equipment by objective pilot-in-the-loop measurements.

This is enabled by integrating several hardware facilities such as a reconfigurable helicopter pilot station, a research helmet mounted display, and software simulation tools.

This report is based on a presentation held at the RAeS Conference “Operating Helicopters Safely in a Degraded Visual Environment”, London, June 16 - 17, 2010.

Results and conclusions

A representative real-time simulation model of brownout dust clouds and several brownout-related systems and aids were developed and implemented. A number of tests have been performed with pilots to evaluate the simulation environment and it is now ready to perform assessments of aiding systems intended to compensate for the loss of situational awareness of pilots in brownout conditions.

Applicability

The simulation environment is currently being applied in the 'Helicopter Brownout Technology Watch' project for the Netherlands' Ministry of Defence. It will be of help in other DVE-related pilot-in-the-loop evaluations.

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Contents

A SIMULATION ENVIRONMENT FOR HELICOPTER FLIGHT IN DEGRADED VISUAL ENVIRONMENTS

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Abstract

This paper describes the development, possibilities and application of a *real-time* simulation environment for helicopter flight in a degraded visual environment (DVE) at NLR, enabling evaluation and assessment of potential DVE aids and equipment by objective pilot-in-the-loop measurements. This is enabled by integrating several hardware facilities such as a reconfigurable helicopter pilot station; a research helmet mounted display and software simulation tools such as flight vehicle modeling and analysis software; rapid display development and image generating software. Current activities focus on what is considered a severe form of helicopter flight in DVE: brownout. A representative real-time simulation model of brownout dust clouds and several brownout related systems and aids were developed and implemented. A number of tests have been performed with pilots to evaluate the simulation environment and it is now ready to perform assessments of aiding systems intended to compensate for the loss of situational awareness of pilots in brownout conditions.

Introduction

Background

Helicopter flight in degraded visual environments (DVE) is gathering significant and increasing attention among helicopter operators and in the helicopter industry.

Helicopter brownout is a hazardous and challenging type of DVE since spatial disorientation occurs due to the (sudden) degraded visibility. Also, the strong multi directional motion of particles in the cloud surrounding the helicopter effects the perception a pilot has of the position, motion and attitude of the aircraft he controls. Due to loss of (visual) references with the outside world combined with disorientation due to false cues, the pilot may lose situational awareness.

During operations close to the ground such as landings and cargo pick-ups, these phenomena may result in touch down with unintended drift of the aircraft and related risks.

Dutch brownout activities

The Royal Netherlands' Air Force (RNLAF) has a vast amount of experience with transport helicopters operating in brownout (and whiteout) conditions and has encountered the effects of this phenomenon (*Figure 1*). Based on this experience, flight crew procedures and standard operating procedures, including related training, have been optimized. Also, helmet-mounted systems such as the Optical Display Assembly (ODA) on the Chinook and the ANVIS-HUD on the Cougar [1] are in use to support the pilot in limiting conditions such as brownout.

Figure 1. A CH47-D RNLAF Chinook helicopter descending into a dust cloud.

The RNLAF is looking into preferably type-independent systems that can be implemented in the helicopter fleet. This system has to increase safety margins of helicopter operations in DVE, such as brownout, and consequently to expand the operational availability of the fleet. Therefore, the Netherlands National Aerospace Laboratory (NLR) in concert with the RNLAF, is investigating the employability and viability of aiding systems intended to compensate for the loss of situational awareness of pilots in brownout conditions.

This ‘helicopter brownout technology watch’ project consists of three main phases. In the first phase users (pilots and other crew members) are questioned about their experience and opinions on aids or solutions for the problem. The aim is to reveal what information is essential and how it should be presented to effectively compensate for situational awareness shortage occurring in DVE.

In the second phase, a detailed inventory is made of solutions and aids that are available on the market or are still under development. This is intended to give an overall picture of technological readiness levels.

The third phase consists of assessing systems that meet user requirements on feasibility, employability and possible extendibility. To perform this final phase, an effective pilot-in-the-loop simulation environment is needed.

The need for a DVE simulation tool

The principles and mechanisms behind potential solutions and aids need to be understood to successfully implement and use these systems. It is important to obtain performance measures and feedback from end-users. For this reason, a real-time pilot-in-the-loop simulation environment is a valuable tool.

Compared to existing pilot-in-the-loop helicopter flight simulators, challenging aspects are reproducing the effects of flight in brownout conditions as experienced by the pilot. It is also challenging to find a proper method to objectively measure effectiveness and employability of a system that is under assessment. The main point of the first aspect is to build up the dust cloud in a realistic way, based on helicopter parameters and wind conditions. This is highly dependent on the specific type of helicopter and on the inputs the pilot provides. With respect to the second aspect, assessment should preferably be based on predefined objective criteria, so objective measures are needed. These are usually restricted to pilot inputs on cyclic, collective and pedals, and on the resulting helicopter parameters such as position, attitude, speed, and rotation. However, to understand pilot control inputs and task load, it is helpful to objectively measure the information that is being used by the pilot. For a large part, this is visual information, coming from the outside world, cockpit instruments and the helmet mounted display (HMD). The scanning pattern and the resulting control inputs are assumed to be influenced by the information presented. Thus, the ability to record the pilot’s visual scanning pattern is a valuable addition to the other measures.

Approach

Our method to achieve a suitable, realistic and reconfigurable simulation environment is based on integrating several high-end hardware and software simulation and research facilities. The flexible and reconfigurable simulation set-up offers a suitable environment to objectively study the effectiveness of symbology, imagery and other forms of information, presented to the pilot on an HMD. This can be achieved while bringing the pilot into a realistic DVE during simulated flight.

Besides gathering pilot opinions, measurement of pilot eye and head-movement is applied to objectively assess viewing habits and to deduce the effectiveness of the provided information. Pilot flight performance during the use of different aids is evaluated by monitoring control inputs, aircraft stability and other aspects such as the number of successful landings.

This paper focuses primarily on operations related to landing in brownout conditions. Take-off might require a slightly different approach because of the more dynamic maneuvers to get away from the cloud.

Simulation environment

Two key elements form the basis for the DVE simulation environment: a reconfigurable pilot station and a research helmet-mounted display (HMD). The specific DVE elements are built on top of them. Both the pilot station and the research-HMD have previously been used in several studies and demonstrations. For example, a demonstrator was built for night-time helicopter flight with infrared imagery and colour-coded symbology on the HMD visor. The set-up was also used to develop and assess new HMD symbology for flight test purposes before implementation on an actual helicopter [2].

Helicopter Pilot Station

The NLR Helicopter Pilot Station (HPS) is a fixed base, reconfigurable helicopter pilot station with realistic control forces for real-time pilot-in-the-loop simulations. A large field-of-view visual system with a fully programmable outside world provides the pilot with a virtual operational environment (*Figure 2*).

The cockpit is equipped with six reconfigurable touch screens (*Figure 3*), representing Multi-Function Displays (MFD). The displays provide the pilot with primary flight and navigation information. They can also be configured to serve as displays and/or control panels for onboard systems like sensors or auto pilots. This is performed by using the in-house developed rapid prototyping tool for graphical cockpit displays 'Vincent' [3].

A control loading system drives the cyclic and collective stick as well as the pedals, to provide the pilot with realistic control forces. Functions can be assigned to buttons and switches on the sticks.

The FlightLab development and analysis environment, integrated into the HPS, drives the rotorcraft flight simulation. Flightlab is a multi-body code dedicated to rotorcraft analysis [4]. Flight control system (FCS) design is an important aspect of FlightLab and this feature is employed to model helicopter FCSs. In addition to high fidelity flight mechanics of several helicopter types, it supplies information to the control loading system and provides the rotor wake features with ground interaction.

A number of rotorcraft simulation models have been implemented and validated by NLR, in recent years. They can be simulated real-time in the HPS to a high fidelity level. Some are validated and fine tuned based on dedicated flight test data according to the method described in [5].

The visual system with four projectors offers the cockpit occupants a field of view of 180 × 70 degrees (horizontal × vertical), approaching a common helicopter field of view. The virtual world in which simulated helicopter flights are performed is driven by EuroSim [6] and Vega Prime software [7]. Besides time and space, also visual conditions and weather types can be defined and controllable objects can be added. Settings to simulate typical DVE conditions such as fog, precipitation and darkness, can be applied. The open structure of the visual system offers opportunities to implement new conditions, such as interactive particle clouds that are driven by the rotor wake originating from the helicopter flight mechanics simulation (FlightLab).

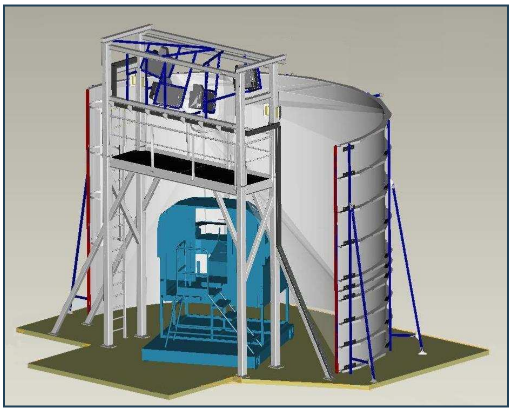

Figure 2. Artist impression of the NLR Helicopter Pilot Station.

Figure 3. Cockpit view of the NLR Helicopter Pilot Station.

Helmet Mounted Display

A fully colour-capable research-HMD with line-of-sight sensor and eye tracking capability (*Figure 4*) is integrated into the HPS cockpit. Imagery and symbology from a colour matrix display is projected on a reflective patch on the transparent visor in front of the pilot's right eye.

The HMD symbology itself can be freely and rapidly defined on a standard personal computer with graphics capabilities, for example using the Vincent tools. This allows creating and updating of symbol sets without significant lead times due to employing external contractors or symbol generator manufacturers. In addition to standard two-dimensional symbology, the Vincent tool allows defining three-dimensional symbology. Several layers of 2D and 3D symbols can be combined. This is a useful feature for prototyping (partly) scene-linked symbol sets.

Figure 4. Research HMD. The optical module with line-of-sight sensor and integrated eye-tracker is mounted on top of a standard flight helmet.

The HMD can also present simulated sensor imagery, either on itself or blended with simulated symbology. For example, it is possible to add sensor data (e.g. infrared) to the database used for the outside world presentation and define a specific sensor channel in the Vega visual software. The characteristics of the simulated sensor output can be tuned to resemble an actual sensor. The simulated viewpoint and viewing direction can be coupled to the HMD position and line-of-sight, and optionally an optical parallax can be introduced to mimic offset sensor placements such as on a turret below the cockpit.

The electro-magnetic head-tracker used for the research-HMD is found in many HMD systems and is a requirement for presenting world-conformal, scene-linked symbology. The built-in optical eye-tracker is a unique research and evaluation tool and allows to monitor and record pilot visual scanning behaviour when using a HMD. Note that an external eye-tracker can not be used for tracking visual scanning on the HMD visor since the visor blocks the view of the eye-tracker. The eye-tracker is important for objectively studying pilot performance in simulated DVE in general and more specifically with supporting cues on the HMD and on multi-function displays (MFDs) in the cockpit.

Current focus

Current activities concentrate on the development of high fidelity models to augment the existing in-flight DVE simulation with brownout simulation capabilities. These activities include graphical rendering of dust and implementation of models for simulation of sensors (e.g. FLIR, dust penetrating radars).

Configuring the simulation environment

The simulation environment must be configured to be able to accommodate for pilot-in-the-loop studies under representative conditions. Key elements of a sufficient configuration include:

- a suitable rotorcraft flight mechanical model including a flight control system and a rotor wake model;
- appropriate simulation of the working principle of the particular brownout aid or system under assessment, including proper reflection of control, symbology and performance;
- representative reproduction of significant elements of the operational environment;
- representative reproduction of significant sensations a pilot experiences during brownout
- pilot and system performance monitoring method and provisions

Landing procedures and techniques as prescribed by the authorities do not contain extreme movements. Based on the procedures the movements may be described as quasi-steady. The resulting vestibular cues are usually too weak for detection of drift during near ground operations. Therefore the HPS, being a fixed based simulator, is well suited for our purposes since no motion cue is necessary.

Rotorcraft model simulation

RNLAF operates with different types of transport category rotorcrafts among which are the CH47-D ‘Chinook’ and the AS532 U2 ‘Cougar’ helicopter. Both types are available in the NLR HPS-model library. During the first series of pilot-in-the-loop brownout simulations, the ‘Cougar’ rotorcraft will be deployed.

A Cougar flight mechanics model for real-time simulation has been developed in recent years. The rotor system consists of a fully articulated rotor hub with lag dampers and 4 rigid blades. A non-viscous 3-state Peters/He inflow model is used [10]. The rotor blade consists of six structural and five aerodynamic blade segments. The blades’ aerodynamic and mechanical properties are available through table lookup. Airloads are calculated quasi-unsteady. The flight control system is based on a generic model tuned to Cougar properties. The flight mechanics model has been statically validated using flight test data for stationary flights [9]. Cockpit displays are designed to match the original instruments.

Brownout aid simulation
Primarily based on feedback from the RNLAF, the preferred aids for brownout mitigation are sought in augmenting outside world visual cues with visual cues on a helmet-mounted display.

Market research reveals that there are two main philosophies: (1) two-dimensional symbology that is not head-tracked and (2) scene-linked symbology that does need line-of-sight tracking. Examples of the first kind are the ANVIS-HUD symbology currently in use on the RNLAF Cougar helicopters [1] and the EADS Degraded Vision Landing Aid [10]. An example of the second kind is the DustOff system marketed by Elbit [11]. Both philosophies have their benefits and weaknesses, not only in terms of usability but also in a technical sense or certification-wise. As stated before, the tools are in place to explore these symbologies with pilots in an efficient way (research-HMD, Vincent for symbology).

When mimicking obstacle warning symbology every potential obstacle is known to the computer. It is therefore not needed to precisely simulate the obstacle detection sensors and related processing; it is often sufficient to mimic the output of the sensors. The simulation environment allows for efficiently exploring inaccuracies in symbology such as line-of-sight registration errors and receiver operating characteristics of obstacle detectors (e.g. false alarm rate). Examples of 2d, 3d and combined symbology are presented in *Figure 5*, *Figure* 6.and *Figure 7*.

Operational environment simulation
The existing NLR scenery database offers suitable locations that are representative for the operational environment and landscape in which RNLAF transport helicopter fleet crew generally experience the effects of brownout.

A flat area with sand texture has been selected in cooperation with RNLAF pilots as landing zone. Irregular shaped acre-like fields provide contrast to the pilot. To provide reference to the pilot, a few trees have been added next to the landing zone. The size of the landing zone meets the specifications described in common standard agreements concerning helicopter use in land based operations [12].

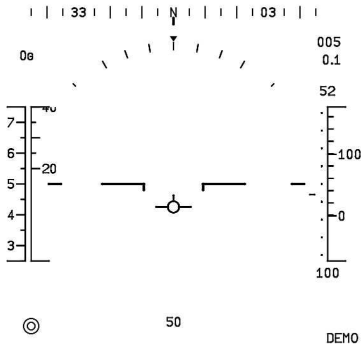

Figure 5. Example of 2d symbology, presenting basic flight information.

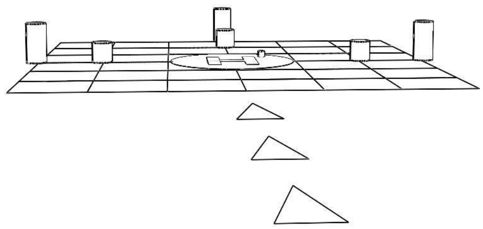

Figure 6. Example of 3d symbology, presenting scene-linked information about the landing zone and the approach flight path.

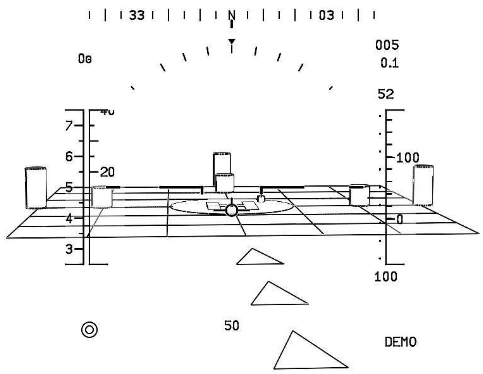

Figure 7. Example of combined 2d and 3d symbology, providing both basic flight information and scene-linked information.

The landing zone is marked with a smoke grenade as commonly used by armed forces to designate a landing spot during tactical operations. The smoke grenade not only enables the helicopter crew to identify the LZ but also serves as a wind indicator. In the simulated environment, the smoke trail can be adjusted interactively by specifying wind direction and speed. If required, controllable obstacles can be added (buildings, vehicles, troops) to simulate more confined areas.

Dust cloud simulation

A key element in dust cloud simulation is a true visual reproduction of disorientating effects as experienced by the pilot. These effects are caused by flight into a dust cloud raised by the rotor wake; this means that timing, rate, direction and appearance of the cloud must be visualized to the pilot as true as possible.

Unlike a representation of degraded vision by means of a screen blank out or an upcoming uniform fog, the graphical representation of dynamic behavior of dust was a prerequisite for addressing spatial disorientation and cloud build-up. This requires the use of a physics based rotor wake model. Realistic, real-time and rotor wake-interactive dust cloud simulation and visualization based on physics based mechanisms is challenging [13]. There is a field of tension between computer time limitations and the extensiveness of required calculations such as required for proper (real-time) computation of rotor wake and particle behaviour and realistic graphical rendering of the particle cloud.

The Flightlab helicopter analysis tool offers arbitrary complexity for its physical models. Indeed real-time simulation requires a fairly simple aerodynamic interference model for the flight-mechanics calculations. For detailed off-line aerodynamic analyses, a free vortex wake model is available. This model has been used to generate tables of induced velocity components on a cubed rectangular grid surrounding the helicopter (*Figure 8*). The grid is effectively configured to cover the field of view of the pilot. The tables are generated for combinations of velocity and height above the ground and for stationary forward flight. Based on the momentary helicopter flight condition the tables are interpolated to find the velocity components that are used to generate the movement of particles (*Figure 9*).

Fragments of dust cloud are graphically represented by semi-transparent textures (*Figure 10*). The opacity can be adjusted to account for the severity of brownout from 'light' to a 'heavy'. Clogging of particles affects the opacity and ensures graphical representation of the density of the cloud. Different colors of the textures provide the visual cue for the movement of the dust cloud.

In the current setup the simulation is run on one standard COTS PC running the simulation and four PC's hosting the image generators equipped with mid-range COTS graphic boards. The image generator software of the HPS is configured to draw over 200 controllable objects ('players'). With a carefully chosen grid resolution of 11x11x11 and the number of particles (216) it was possible to provide a realistic dust cloud and to maintain the desired frame rate for the visual and the flight mechanics computation.

Figure 8. Visualization of Cougar helicopter rotor wake stream lines.

Figure 9. Particles tracing the stream lines, with velocity varying along the lines.

Figure 10. Dust textures attached to particles in the grid result in a dust cloud, wrapping the helicopter.

Results

NLR has achieved a simulation environment for real-time assessment of piloting aids for countering the effects of brownout conditions. The basis for the environment is NLR's reconfigurable helicopter pilot station, providing a cockpit environment with realistic controls and flight mechanics and wide field-of-view outside world visual system. A landing site conforming to common standards [12] was realized in a visual system database (*Figure 11*).

A major new element in the set-up is a physics-based dust cloud simulation for 'light' and 'heavy' brownout. Dust cloud build-up is representative for the real-world situation with regard to time, location and geometry. The simulated cloud adequately mimics dust movement due to rotor wake and hinders the pilot's vision of the outside world, while preserving the requirements for real-time computation and memory bounds. It is available for pilot-in-the-loop simulation (*Figure 12* and *Figure 13*).

The research-HMD is integrated in the cockpit, including line-of-sight tracking. We have developed both 2D and 3D symbology. The computations for correctly aligning these symbologies to the outside world are available. Consequently, scene-linked symbology can be shown. The mechanism to present scene-linked obstacle symbols is also in place, as well as the possibility to show simulated FLIR imagery on the HMD visor.

Objective pilot performance data can be collected, not only with respect to the flight path and inputs on the controls, but also visual scanning data as an indicator of pilot behaviour.

Figure 11. Helicopter approaching the landing zone, marked with a smoke grenade, as seen from the pilot viewpoint.

Figure 12. Final approach of the landing zone: the developing brownout cloud is decreasing the HPS pilot's visual reference with the outside world. Illustrative inset: *the dust is wrapping the helicopter as it approaches the ground.*

Figure 13. The dust cloud loses transparency quickly in the last seconds before touchdown, as seen from the HPS cockpit. Illustrative inset: *the helicopter disappears in the dust.*

Concluding remarks

The primary aim of the work was to develop, assess and demonstrate a simulation setup for the assessment of systems that are intended to assist the pilot during DVE operations. The second aim was to create awareness of the risks occurring during DVE operations.

Although no formal validation of the simulation environment has taken place yet, feedback from various pilots indicates that the environment is at least sufficiently mature for the purposes of the 'brownout technology watch' project. The project will provide the first opportunity to take the environment to use, since for the summer of 2010 a first assessment of 2D and 3D symbology, including drift indication and world conformal symbology, is scheduled.

The set-up has potential for extensions such as simulation of different types of dust particles and 'white out' conditions. A development that is currently taking place is the addition of a load master position, to better meet the common RNLAF transport helicopter brownout procedures where the load master plays an important role.

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