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Extending helicopter operations to meet future integrated transportation needs

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A B S T R A C T

Helicopters have the potential to be an integral part of the future transport system. They offer a means of rapid transit in an overly populated transport environment. However, one of the biggest limitations on rotary wing flight is their inability to fly in degraded visual conditions in the critical phases of approach and landing. This paper presents a study that developed and evaluated a Head up Display (HUD) to assist rotary wing pilots by extending landing to degraded visual conditions. The HUD was developed with the assistance of the Cognitive Work Analysis method as an approach for analysing the cognitive work of landing the helicopter. The HUD was tested in a fixed based flight simulator with qualified helicopter pilots. A qualitative analysis to assess situation awareness and workload found that the HUD enabled safe landing in degraded conditions whilst simultaneously enhancing situation awareness and reducing workload. Continued development in this area has the potential to extend the operational capability of helicopters in the future.

1. Introduction

In most cities the dominant car-road transport system is already reaching a saturation point (Tibbs, 1998). This issue is going to be exacerbated when we consider that by 2040 the world's population is expected to reach nine billion, with 64% of the world living in urban areas (Ministry of Transport (2013)). Therefore, the future transport environment is an issue that concerns us all, whether a car owner or a regular user of public transport, increased demands on the current transport infrastructure means that the future transport system will look very different from today. Tibbs (1998) argued that scenarios for future transport systems need to address the likelihood of a fundamental shift away from the car-road system. In the 1950s it was predicted that rotorcraft would be essential in the transport systems of overly populated countries before the end of the 20th century, but they have not realised their full potential in industrialised countries (British Helicopter Association, BHA, 2014). There are more helicopters in military service than civilian operation and commercial passenger-carrying operations are generally confined to corporate or offshore domains. The unique characteristics of helicopters means that they have the potential to result in radical changes to the urban transport environment (Dodge and Brooks, 2013). Increased helicopter transport is already evident in a recent review by the National Transport Safety Board (NTSB, 2011) which reported that in relation to air taxi operations between 2004 and 2010 helicopter flight activities increased by 97 percent while fixed wing flight activity decreased by 28 percent. Currently, one of the biggest limitations on rotary wing flight is their inability to fly safely in degraded visual environments (DVE) during critical phases of flight (such as approach and landing). This paper presents a study that developed and evaluated a Head up Display (HUD) concept to assist rotary wing pilots landing in DVE. The HUD was developed with the assistance of Work Domain Analysis phase of the Cognitive Work Analysis method as an approach for analysing the cognitive work of landing the helicopter in order to identify the critical information requirements associated with this task.

1.1. Rotary wing aviation

The current operational environment for helicopters varies greatly with role, but helicopters generally operate outside of direct air traffic control, at low altitudes and under visual flying conditions (BHA, 2014). This means that helicopters are used in operational contexts that are not suitable for fixed wing aircraft, including medical

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rescue over land, search and rescue over water or mountains, rapid corporate passenger transfer, oil platform transfer, police search, television broadcasting and firefighting. Helicopters tend to perform take-off and landing manoeuvres that are unlike fixed wing aircraft, generally being steep and with greatly reduced landing distances at both managed and unmanaged landing sites (Dodge and Brook, 2013). This benefit of helicopter flight is also the helicopter's greatest hazard as these manoeuvres can be dangerous and in remote locations. So unless this phase can be made safer and more consistently enabled the risk has the potential to negate the benefit of helicopter flight (Nascimiento et al., 2014).

Helicopters are to aeroplanes, what motorcycles are to automobiles; there are fewer of them but they have disproportionately higher accident rates. Estimates suggest that accident rates for helicopters are ten times higher than for fixed wing operations (Nascimiento et al., 2014). A primary cause of rotary wing accidents is degraded visibility caused by poor weather. A DVE is one in which ocular visibility is reduced due to light levels (e.g. night), weather phenomena (e.g. fog) or atmospheric conditions (e.g. dust) (Hart, 1988). Baker et al. (2011) found that bad weather was the second most common precipitating factor (after mechanical failure) for fatal and nonfatal crashes in their analysis of 178 Gulf of Mexico helicopters accidents. Furthermore, the bad weather accidents resulted in the largest number of deaths (40 percent of all deaths). Due to the nature of helicopter operations, in remote locations and in emergency operational contexts, the likelihood of encountering DVE can be significant. Accident data has suggested that inadvertent Instrument Meteorological Conditions (IMC) flights (i.e. starting in visual flight conditions and unintentionally entering instrument flight rules) is one of the major causes of helicopter accidents, particularly when pilots are not trained to IMC level (Hart, 1988). These accidents are caused by spatial disorientation and subsequent loss of control and commonly lead to controlled flight into terrain. Aside from the increased safety risk, DVE presents one of the most disruptive factors in civil aviation and is a leading contributing factor to flight delays at major commercial airports (Allan et al., 2001; Pejovic et al., 2009).

The operational benefits afforded to helicopters and the associated contexts of use have driven an increased demand for their use in DVE in a civilian setting (Baker et al., 2011; BHA, 2014). Furthermore, the ability to fly at low altitudes makes rotary wing aircrafts more susceptible to issues arising from low visibility for greater proportions of flight, not just critical phases. A primary challenge in civil aviation is the creation of safe operational environments for rotary wing aircrafts to operate in DVE. If helicopters are going to become an increasingly viable mode in the future transport system there is a need to increase operational effectiveness and safety. The implementation of HUDs is one way of achieving this.

1.2. Head up display technology

HUDs have been commonly used in military aviation for a number of years but are increasingly being used in commercial flight operations and for other applications such as driving (Harris, 2011; Jakus et al., 2014). A HUD interposes images on a transparent layer between the pilot and windshield, allowing the pilot to simultaneously look at the HUD symbology and the outside world. The images are focused at infinity which means that the pilot does not have to re-focus their eyes when transferring their gaze from HUD symbology to the outside environment. Generally, the content of the HUD includes primary flight information normally found on the primary flight display, additional flight path symbology (e.g. 'Highway in the sky') and conformal, graphical, representations of the outside environment (Alexander et al., 2003; Thomas and Wickens, 2004; Harris, 2011). A HUD allows the pilot to fly 'eyes out' rather than switching attention to head-down displays (HDD) inside the cockpit. The objective of a HUD is to replicate the operational benefits of clear-day flight operations regardless of the actual outside visibility condition, thus increasing operational capacity and reducing accidents caused by low visibility conditions.

One of the most important requirements of a helicopter cockpit is good visual characteristics (Lovesey, 1975). At low altitudes in good visibility, helicopter pilots use visual cues in the immediate surroundings to identify terrain features and determine their orientation, rate and direction of movement, height and distance. In low visibility the spatial and temporal resolution of visual cues are reduced and can result in diminished situation awareness and increased workload (Hart, 1988). The presentation of information via a HUD in a manner that does not require the pilot to divert visual attention and cognitive resources into the cockpit has the ability to optimise workload and enhance situation awareness (Snow & Reising, 1999; Fadden et al., 1998; Snow and French, 2002). Conformal symbology is often included on HUDs to increase the realism of the presented information. Conformal, or scene-linked, symbology allows information to be displayed at a static position relative to the real world; an example of this would be the outline of a helipad displayed on the HUD which remains overlaid on top of the view of the helipad in the outside world, regardless of what part of the HUD the pilot is looking at. Conformal symbology leads to faster detection of changes in symbology and improved flight path tracking accuracy (Fadden et al., 1998; Snow and French, 2002).

HUDs however may cause the detection of unexpected events to be degraded by attention capture when the pilot's attention shifts away from the outside environment and remains too focused on processing information presented by the HUD (Fadden et al., 1998; Thomas & Wickens, 2004; Jakus et al., 2014). An overly cluttered HUD can be detrimental to pilot situation awareness and the overlay of symbology can obscure objects and may disrupt effective scanning (Yeh et al., 2003; Harris, 2011). To optimize the benefits of HUDs, designers must preserve the most useful and unambiguous visual cues pilots naturally use so that information is processed intuitively by pilots (Foyle et al., 1992; Harris, 2011; Fadden et al., 1998).

2. Concept development

2.1. The Work Domain Analysis phase of Cognitive Work Analysis (CWA)

Helicopter flight operations represents a complex socio-technical system made up of numerous interacting parts, both human and non-human, operating in dynamic, ambiguous and safety critical domains. The complexities in these systems present significant challenges for modelling and analysis. CWA is a structured framework for considering the development and analysis of these complex socio-technical systems (Jenkins et al., 2009; Vicente, 1999; Rasmussen, 1986). The framework guides the analyst through the process of answering the question of why the system exists, what activities can be conducted within the domain as well as how this activity can be achieved and who can perform them, identifying competencies required. CWA has been applied in a variety of domains including the military (Jenkins et al., 2008; McIlroy and Stanton, 2011; Stanton and Bessell, 2014), driving (Cornelissen et al., 2013, 2014), aviation (Ahlstrom, 2005; Stanton and Plant, 2010, 2011), rail (Stanton et al., 2013) and nuclear power plants (Walker et al., 2014) and has seen a range of applications including system modelling, training needs analysis, interface design and requirements specification (Walker et al., 2014).

CWA consists of five phases each modelling a different set of constraints. For a detailed description of each phase and the associated tools the reader is directed to additional texts including Vicente (1999), Jenkins et al. (2009) and Read et al. (2015). Whilst each phase of the analysis process builds upon the last, McIlroy and Stanton