

Design and Evaluation of a Constraint-Based Helicopter Display to Support Safe Path Planning

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EXTENDED ABSTRACT

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1 Introduction

This paper is part of the project “Understanding the Use of Automation in Helicopters”, which in turn is a part of NITROS, a European Joint-Doctorate project which aims to increase helicopter safety by addressing critical aspects of their design. Improved automation in the helicopter cockpit can support pilot decision making and situation awareness, and therefore, improve safety. After analysing short-term hover tasks [1] and medium-term obstacle avoidance [2], this paper represents the final analysis of the project. It will focus on long-term mission management and path planning, and how these tasks can be supported by existing and novel automation systems in order to improve safety.

Examples of current developments in helicopter pilot navigation support can often be found in the form of Electronic Flight Bags (EFBs), for example as described by De Bernardi and Ferroni [3]. An EFB can cover a broad range of functions, from pre-mission performance calculation and trajectory planning, to warnings about restricted airspace and terrain proximity. However, it has been found by Rood and de Reus [4] that tablet-based EFBs could only be used in low-workload mission phases like cruising, somewhat limiting their usefulness in more workload-intensive mission phases.

Digital maps, with a variety of possible overlays and functions, have been described in many publications, for example by Guillanton and Germanetti [5], Haisch et al. [6], or Lueken et al. [7]. Data about a prospective flight plan, weather, airspace restrictions, and terrain elevation information can be visualised. This paper, however, does not aim to develop an “optimal” navigation display, or describe the most desirable functions. Rather, it investigates the effect of utilising different design philosophies during display and automation development, and how these philosophies impact the pilots’ decision-making process.

To develop novel automation systems for helicopters, this paper takes inspiration from the Ecological Interface Design (EID) methodology, which is based on Cognitive Work Analysis. An existing Ecological Display (the “Travel Space Representation” as described and analysed by Klomp et al. [8]) is adapted to incorporate the specific requirements of helicopter control and mission path planning. The most important change is the transition from a “4D trajectory” tool, which postulates a fixed arrival time, to a “3D trajectory” tool, which provides information about the (now flexible) expected travel time, dependent on the chosen path.

Through a human-in-the-loop experiment with helicopter pilots in TU Delft’s SIMONA Research Simulator, this paper will investigate the effect of different display design methodologies during a simulated helicopter mission that includes repeated path planning and arrival time estimation tasks for the pilots. A **Baseline Navigation Display**, which only provides basic information about the expected mission structure and the location of mission targets and obstacles, will be compared with an **Automatic Path Planning Display**, which automatically calculates a mission trajectory and the expected arrival times, and with a **Constraint-Based Path Planning Display**, which provides the pilots with additional information about time- and manoeuvre-constraints during the mission.

The dependent measures of this experiment consist of

- workload,
- situation awareness,
- performance (mission time, path planning efficiency, estimation accuracy),
- safety (distance to obstacles, out-of-fuel situations),
- control strategy (re-plan frequency, deviation from suggested solutions), and
- pilot preference.

The results of this experiment are expected to give an insight into the effect of employing design methodologies based on EID in the helicopter domain, and whether these displays can improve safety when applied to a long-term path planning task. While the automatic path planning display might be easier to use, which would lead to a lower workload and possibly higher pilot acceptance, the constraint-based display provides more information to the pilots and might therefore lead to an increase in situation awareness and more varied control strategies. Some unexpected events (e.g., undetected obstacles) will be inserted into the experiment to analyse the robustness of the human-vehicle system in each display configuration towards system malfunction and off-nominal situations. Previous results of this project [2] suggest that in these cases, pilot preference might shift to constraint-based displays.

2 Display Design

The pilots are tasked to complete a predetermined flight plan which includes three target way-points per experiment run. At each target, the pilots are asked to hover in place for ten seconds. The path to the target way-points can be obstructed by circular bad weather areas, which have to be evaded by the pilots. They are asked to approach each target way-point with a maximum speed of 100 kt, but as fast as possible otherwise. I.e., they need to find the shortest route, evading all bad weather pockets, from their position to the next target.

Before leaving the starting position or each target, the pilots are asked to estimate the travel time to the next target. To fulfil this task, they need to incorporate the travel speed of the helicopter, the time of acceleration and deceleration, and the travel distance to the following target, taking into account all bad weather pockets on the way. The navigation display provides information to support this task, based on its configuration. During each experiment run, the helicopter only possesses a certain amount of reserve fuel (measured in travel distance, 4km per run). If the pilots expect to run out of reserve fuel before reaching the next target, they need to detect this and abort the mission (by telling “mission control”, i.e., the experiment conductor).

The three different navigation display variants are: a **Baseline Display**, which shows minimal information, and two extensions to it: an **Advisory Display**, which provides course suggestions, and a **Constraint-Based Display**, which enables the pilot to manually set a desired course.

The baseline navigation display is shown in Figure 1a. It provides a top-down view of the mission area, with the ownship helicopter position at its lower centre. All targets are presented as a small white square. Targets that still need to be reached are marked with a cyan way-point, and are connected with a magenta flight path. The shortest flight path, ignoring bad weather areas, is shown in magenta. The shortest distance to each way-point is shown in cyan next to each way-point. These distances do not update automatically, but only when the pilots press the “initialise” button, which is the trigger on the cyclic stick. The displays can be re-initialised as often as the pilots desire.

Figure 1b shows the advisory display, the second display variant investigated in this experiment. When initialising the display, an intermediate way-point is placed between targets to avoid any bad weather areas at minimum additional travel distance, and the additional travel distance of this path is shown in magenta next to each way-point. At most one intermediate way-point is placed per leg.

Figure 2 shows the constraint-based display, the third display variant of this experiment. At the press of the “select” button on the cyclic stick, it shows the location of all intermediate way-points that result in a safe trajectory to the next target as a green area. The pilots can estimate the additional travel distance of intermediate way-points through the shown ellipses. If the way-point lies on the first ellipses, the trajectory is one kilometre longer than the direct route. If it lies on the second ellipses, it is two kilometres longer, etc.

This display allows the pilots to manually choose and set an intermediate way-point. By pressing the “select” button, the pilots can cycle through the ellipses, as shown in Figure 2b: the selected ellipse is highlighted in cyan. To choose an intermediate way-point on this ellipse, the pilots need to orient the nose of the helicopter towards the chosen ellipse (shown as a cyan line). Now, holding the “select” button for one second will set the intermediate way-point at the crossing of the heading and the chosen ellipse, see Figure 2c. The additional travel distance of this way-point is now shown in magenta next to every future way-point.

For legs 2 and 3, the remaining reserve fuel is visualised as a white ellipse. This can support the pilots in estimating whether the remaining reserve fuel is sufficient to complete future legs: if there is no safe intermediate way-point, the remaining reserve fuel might be insufficient.

3 Preliminary Results

Up to this point, three pilots participated in this experiment. The ongoing restrictions posed by the pandemic limit the number of participants. By the end of the experimental period, we hope to have gathered data of five or

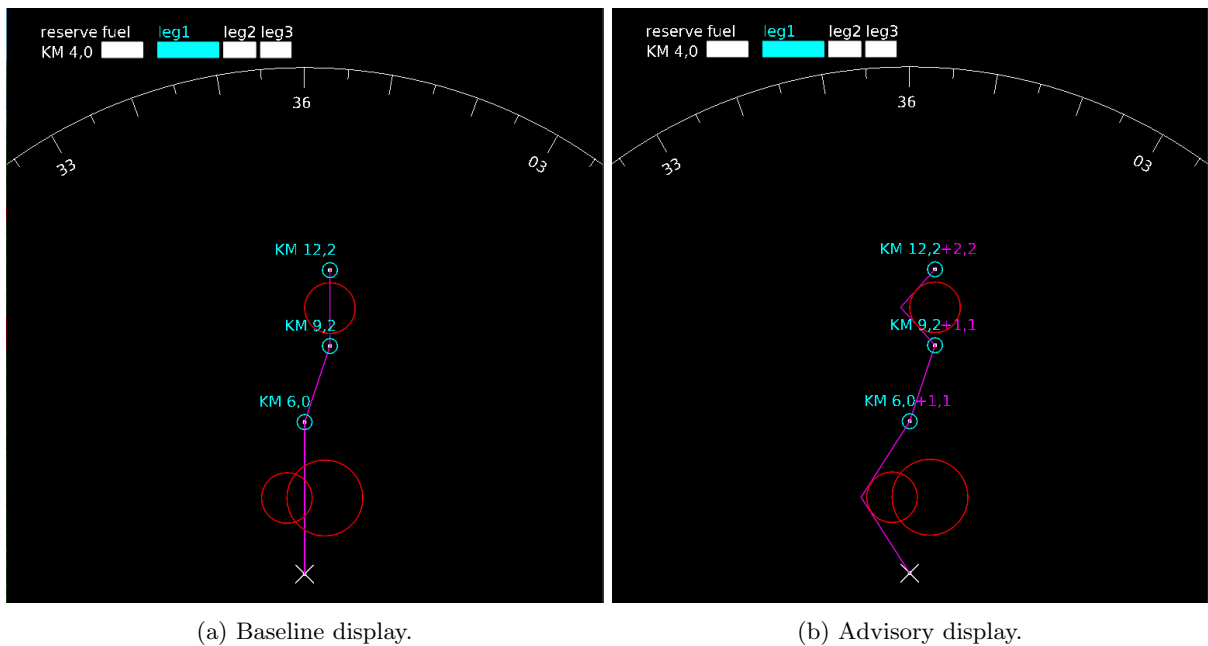


Figure 1: Navigation display variants one and two.

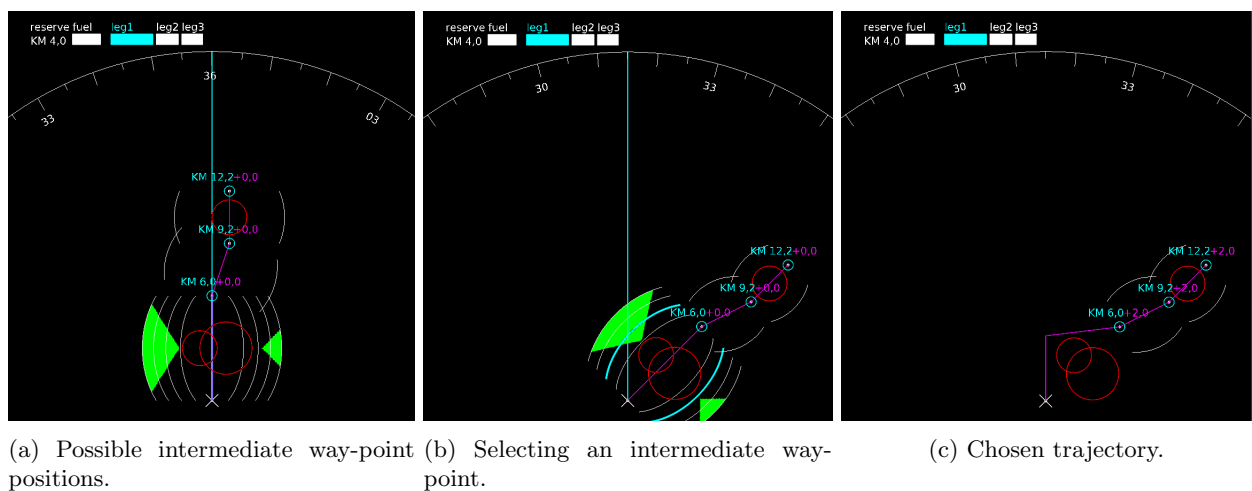


Figure 2: Constraint-based display.

more participants. If possible, the experiment can be performed again later in Spring or Summer 2021, to increase the number of participants and strengthen the significance of results.

Preliminary results of four participants highlight the effect of different display representations on pilot decision-making. The path suggestion of the advisory display, which can be computed easily and presents an easy to follow trajectory, was always followed, and pilots preferred the ease of use of this display. However, the suggestion was also followed in cases when the experimental course could have afforded different, better trajectories that would have saved reserve fuel and time. The additional options were ignored or not discovered, and the nicely presented solution of the advisory display was preferred.

Conversely, using only the baseline display was less preferred by the pilots, as it required more cognitive resources and reasoning. Pilots generally appreciated all the information of the constraint-based display, but some disliked the higher required workload to use it. Beside these points, pilots more often selected optimal routes with these two displays, than with the advisory display. These results suggest that a display that requires active pilot participation can cause an increase in workload and lower pilot preference ratings, but can lead to better trajectory planning decisions. More detailed results of the whole experiment data will be presented at the workshop itself.

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