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**TITLE**

Integrating direct voice input in a helicopter crew environment

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# Integrating Direct Voice Input in a Helicopter Crew Environment

**Philip S. E. Farrell[1], Laura Lynne Churchill[2], Michael Wellwood[*], Chris M. Herdman[3]**
**[1]Defence and Civil Institute of Environmental Medicine, Toronto, Canada**
**[2]BAE Systems Canada, Ottawa, Canada**
**[3]Centre for Applied Cognitive Research, Carleton University, Ottawa, Canada**

## Introduction

Integrating alternative control technologies into complex systems presents many challenges. Direct Voice Input (DVI) is one such technology being considered for operations within the complex Canadian Forces tactical helicopter domain. Most DVI research focuses on improving recognition rates by incorporating noise cancellation, adaptive speech algorithms, vocal chord sensors, and lip reading (Jennings & Rucker, 1995). Studies have reported over 99% recognition (Swail & Kobierski, 1997), which is better than humans in some circumstances.

In contrast, DVI performance may be sub-optimal in operational environments due to syntax and grammar issues (Farrell, Ebbers, & Sarkar, 1998), multiple task interference (Cain et al., 2001), inappropriate feedback (Farrell, Perlin, & Ho, 2001), as well as improper crew coordination procedures. If these challenges are not addressed, the crew may turn the DVI system off. This study looks at the impact of DVI on helicopter crew coordination procedures.

The Control Display Unit (CDU) is one onboard system targeted for DVI. The CDU has a screen and keyboard. It is the interface for the flight management system that allows the crew to tune radios, change flight plans, calculate fuel consumption, etc. The CDU has context sensitive keys, a nested menu structure, and is aft of the center console. These aspects of the CDU make it difficult to maintain eyes out-the-window (OTW), which is critical for helicopter operations.

DVI seems to be a natural solution for keeping eyes OTW, potentially reducing workload and increasing situational awareness. However, it also provides another way of conducting business in the cockpit. Since DVI allows hands-free control, it is possible to distribute tasks between the Flying Pilot (FP) and Non-Flying Pilot (NFP). The purpose of this study is to solicit crews' opinions on the operational impact of a proposed crew coordination procedure using DVI.

## Crew Coordination Procedures

During a mission, the crew must aviate, navigate, and communicate. A typical mission has transit, reconnaissance, contact, observe, report, and re-tasking phases. Needless to say, the helicopter environment is demanding and complex, and crews must decide how to divide up specific duties before each mission. The current CH146 Griffon Helicopter Standard Operating Procedures (SOPs) divide the cockpit duties in the following manner. The FP flies the aircraft, maintaining Hands On Cyclic And Collective (HOCAC) and the NFP performs the remaining cockpit tasks such as configuring radios, monitoring aircraft systems, and managing the tactical mission. The pilots switch roles throughout the mission. The SOPs dictate that the FP must ask the NFP to perform any CDU operations (e.g. change a radio frequency). However, with the

[*]Now at The HFE Group, Ottawa, Canada.

proposed DVI crew coordination procedures, it is possible to allocate some tasks to the FP. That is, the FP is asked to maintain radio communications with the squadron and cycle through navigational points (or waypoints) from the flight plan as well as flying the aircraft (maintaining HOCAC). The NFP performs the remainder of cockpit tasks.

Two benefits are anticipated by modifying the crew coordination. First, the NFP's workload, which often exceeds human performance limits, may be reduced. Second, cockpit communication will be reduced. Instead of the FP asking the NFP to perform a DVI task and the NFP having to repeat the command, the FP could speak the command once to the DVI system. This would significantly decrease the intercom traffic in an already busy cockpit.

**Theoretical Framework for Interacting Agents**

A theoretical framework for interacting agents is used to make predictions about the proposed crew coordination. The interaction model is developed from Perceptual Control Theory (PCT) concepts. PCT is a framework for human information processing developed by William Powers in the late 50's (Powers et al., 1960). It describes human perception, cognition, behavior, and external interaction in terms of a control loop. The advantage of this framework is that all the power of classical control theory may be applied to the model. Thus, it is possible to analyze human-machine or human-human interactions in terms of stability, optimal control strategies, error minimization, and goal achievement. From a PCT perspective, the pilots are modeled as intelligent agents who influence common variables within a complex environment. DVI itself may be considered as a third agent, or as part of the work domain that both pilots may access. In this case, we consider the latter.

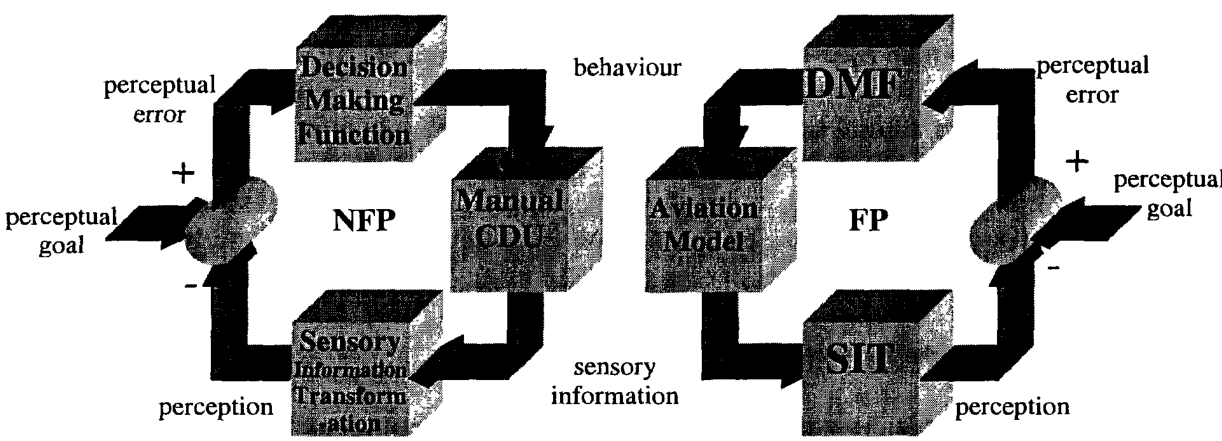


Figure 1. Current crew coordination model in terms of PCT information processing signals and transformations.

Figure 1 models crew coordination where the NFP and the FP influence separate parts of their world. The NFP influences navigation and communication CDU states. The world produces sensory information that is transformed into perceptions. These perceptions are compared to internal goals. The perceptual error becomes the impetus to make decisions and to act. These behaviors influence the world, thus closing the loop. The FP has an identical framework except aviation states are influenced. This crew coordination model shows the case where each loop is independent.

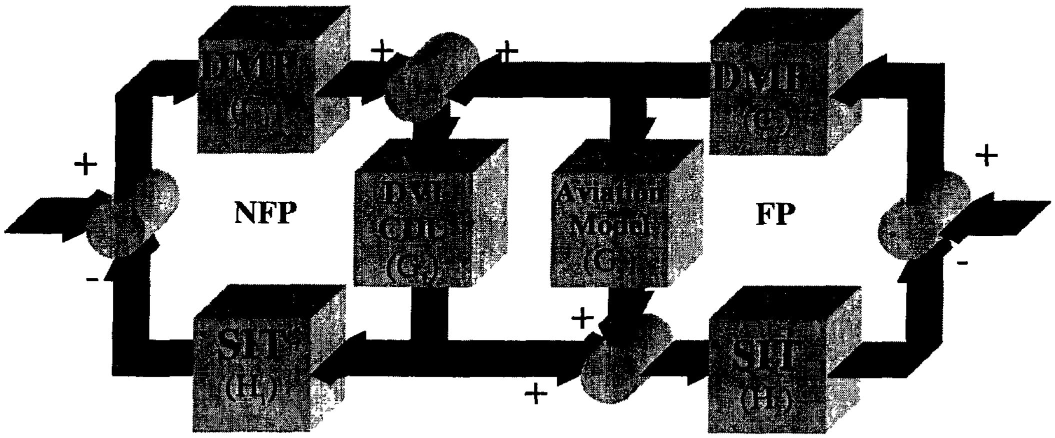


Figure 2. Proposed crew coordination model where the FP has access to navigation and communication states using DVI.

On the other hand, Figure 2 depicts the proposed crew coordination model. All the functions (letter names used for analysis) and signals remain the same except that the FP influences some CDU states using DVI, and has the ability to perceive their output. The interaction manifests itself as disturbances on the individual loops. The loops are tightly coupled and the system stability is not intuitively obvious without analyzing the system.

A stability analysis was performed for multiple agent interaction (Farrell, 2001). The analysis yielded three human factors principles that may be exploited in order to ensure safe operation and effective performance. The condition for stability for interaction models as in Figure 2 was that the determinant of the loop gain function matrix is not equal to zero as follows:

$$\mathrm{Det}\left[I + H_1G_1C_1 + H_1(G_1 + G_2)C_2 + H_1G_1C_1H_2G_2C_2\right] \neq 0 \qquad (1)$$

Equation 1 implies that all transformations are linear. It is likely that humans make continuous and discrete (nonlinear) behaviors. Theoretically, linear models can be fitted to the nonlinear model, and equation 1 can be applied to the linearized model. Assuming, for example, that each transformation is a linear first order differential equation, the loop gain may be sixth order, thus increasing the potential for an unstable system. These assumptions are yet to be validated.

The analysis also demonstrated that interacting systems are error-limiting. That is, the error may be limited from going out of range due to the partner's ability to intervene if they think the system is becoming unstable. Unfortunately, the NFP and FP may end up playing a type of "tug-o-war" with the CDU and not achieve any of their goals. Currently in an emergency there is nothing to stop the FP from accessing the CDU, however, the proposed model would see the FP accessing the CDU as a matter of course. *The model would predict that although there is control redundancy (error-limiting) it is less likely that the crew will achieve their goals.*

The PCT/IP model asserts that workload is directly related to the amount of information to be processed (Hendy & Farrell, 1997), which increases with the number of control loops attended to. In Figure 1, the NFP deals with the CDU related loops while in Figure 2 the FP relieves the NFP of some of the information load. *Therefore, the model predicts that the overall workload will be redistributed rather than reduced with the proposed crew coordination procedure.*

## Subjective Workload Ratings and Questionnaire

As part of an experimental series, participants were asked to comment on the impact of DVI in a crew helicopter environment. The experiments involved the development of a composite mission scenario, appropriate DVI syntax, feedback for the DVI system, and the modified crew coordination procedure. Two experiments were performed in a virtual environment called the Aircraft Crewstation Demonstrator (ACD). The ACD is a rapidly reconfigurable fixed-based human-in-the-loop simulator. It was converted into a helicopter cockpit with instrument panels, helicopter controls, two CDUs and Verbex™ speech recognition units. The OTW view was generated by Silicon Graphics™ machines and projected on a single, 8'x10' screen.

The first experiment investigated the impact of DVI on flight safety using the head position as a metric for flight safety (Herdman et al., this issue). The second experiment looked at the interaction between DVI and attentional demands by incorporating visual and auditory detection tasks while performing the mission (Johannsdottir et al., this issue). Participants were regular forces helicopter pilots with operational CDU experience. Participants provided subjective ratings of workload and answered open-ended questions after completing a Manual Input (MI) CDU session, and a DVI CDU session.

The workload ratings were categorized by mission segment, crew position, and workload dimensions. The dimensions were the NASA TLX, plus visual, audio, and global workload (Cain et al., 2001). The scale was from 0 (low) to 10 (high). Unlike NASA TLX, a simple t-test was performed on each workload dimension. The open-ended questions were organized in terms of feedback, simulator realism, syntax, and crew coordination. Subjective data related to crew coordination are reported below and compared to the theoretical predictions.

## Results

The workload ratings are summarized in Figure 3. The bars represent the difference between the DVI and MI rating scores. A positive value indicates that the workload was perceived as greater in the MI than in the DVI condition. NFP participants rated workload as generally being less in the DVI than the MI condition. Individual t-tests showed that for Segment #1, the advantage for DVI over MI was significant in the visual ($t(11) = 3.56$, $p < .005$), time ($t(11) = 2.20$, $p < .05$), anxiety ($t(11) = 2.16$, $p < .055$), and global ($t(11) = 2.66$, $p < .023$) indices. For Segment #2, a DVI workload advantage over MI was perceived in the visual ($t(11) = 2.80$, $p < .018$), physical ($t(11) = 2.60$, $p < .026$) and time ($t(11) = 1.75$, $p = .10$) indices. The only significant workload advantage of DVI over MI in Segment #3 was in the visual index ($t(11) = 1.87$, $p = .089$). FP participants rated workload as less in the DVI than the MI condition only in mission Segment #3 and only for the visual workload index ($t(11) = 4.10$, $p < .002$).

Participants commented on the current crew coordination procedure in question 8 of the MI condition. Four of 12 pilots stated that in reality the FP can operated a radio when the workload of the NFP is excessive. Without DVI, this would require the FP to remove one hand from the flight controls. In the DVI condition (question 8), participants agreed that the division of duties between the NFP and the FP was appropriate. Participants noted that NFP and FP duties were rarely mixed up or inappropriately taken over by the other crewmember.

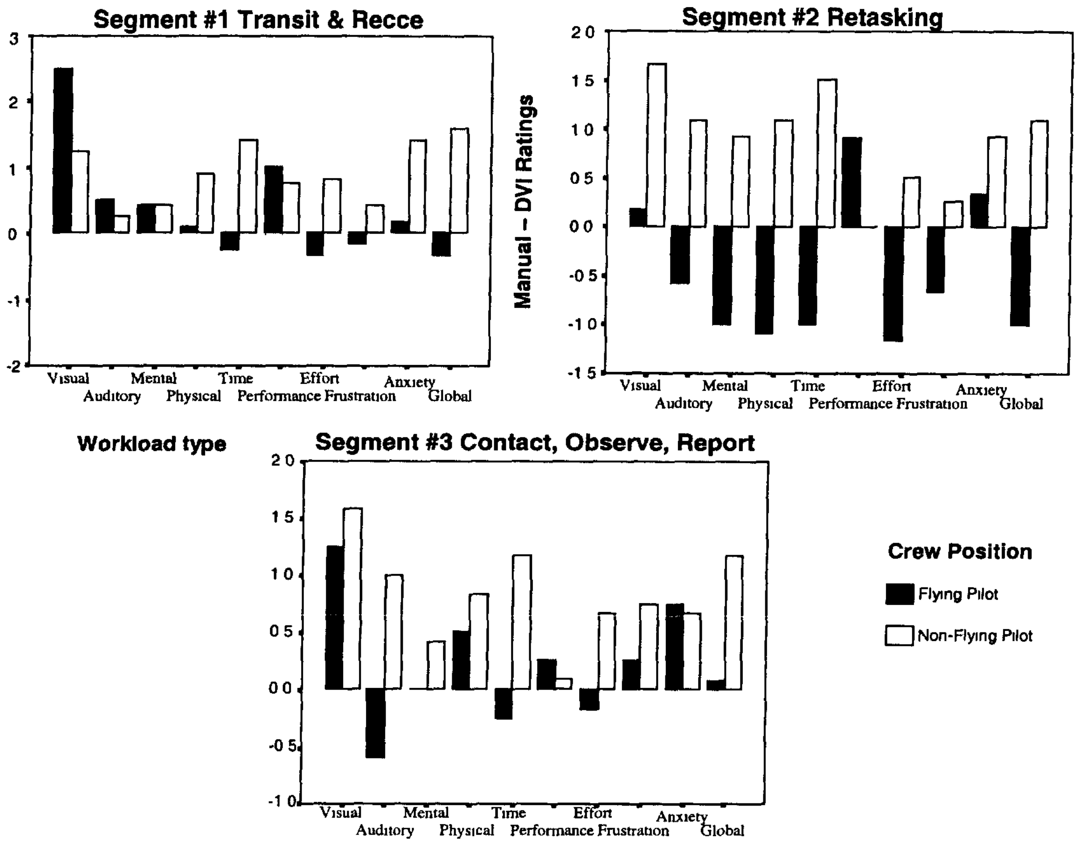


Figure 3. MI minus DVI Workload Ratings For Mission Segments, Crew Position, and Workload Type

## Discussion

The model predicted that the workload would be redistributed rather than reduced with DVI. Segment #2 of Figure 3 shows a trend that the NFP perceives less workload during the proposed crew coordination (DVI condition) than the current crew coordination (MI condition). In contrast, the FP perceived the exact opposite. Overall, the NFP workload favors the DVI condition while the FP workload is fairly neutral, although the majority of scores are not statistically significant. This implies that the FP may have spare capacity to deal with any additional tasks during these phases.

The model also predicted that the proposed crew coordination procedure would not always provide goal achievement. The responses to the open-ended questions showed that conflicts (i.e., no goal achievement) rarely occurred for the new crew coordination procedure. Goals were achieved by carving off specific CDU states and letting the FP influence those states only. That is, the proposed crew coordination procedure defaulted to a version of Figure 1 in order to ensure goal achievement. In order to fully investigate this hypothesis, a novice crew would be allowed to evolve a crew coordination procedure as they attempt to accomplish the mission objectives. The resultant procedure would be compared to the theoretical models.

## Conclusion

The alternative control technology, Direct Voice Input, provided an opportunity to investigate a modified crew coordination procedure in a complex helicopter environment. The current and proposed crew coordination procedures were described and modeled using a Perceptual Control Theory framework for multiple agent interaction. A mathematical analysis yielded a condition for stability. With the model, two predictions were made related to the redistribution of workload and the goal achievement of the DVI system.

An experiment was conducted that yielded subjective workload ratings and responses to open-ended questions. The workload ratings verified that the workload was redistributed and that the FP might have had spare capacity during some segments to absorb the load. The responses to the open-ended questions did not capture the dynamics of multiple agent interactions because the proposed crew coordination procedure still yielded independent control of CDU states.

DVI will change the way we interact with systems and care must be taken to ensure successful integration into complex systems.

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