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A Four-Axis Hand Controller for Helicopter Flight Control

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ABSTRACT

A proof-of-concept hand controller for controlling lateral and longitudinal cyclic pitch, collective pitch and tail rotor thrust was developed. The purpose of the work was to address problems of operator fatigue, poor proprioceptive feedback and cross-coupling of axes associated with many four-axis controller designs. The present design is an attempt to reduce cross-coupling to a level that can be controlled with breakout force, rather than to eliminate it entirely. The cascaded design placed lateral and longitudinal cyclic in their normal configuration. Tail rotor thrust was placed atop the cyclic controller. A left/right twisting motion with the wrist made the control input. The axis of rotation was canted outboard (clockwise) to minimize cross-coupling with the cyclic pitch axis. The collective control was a twist grip, like a motorcycle throttle. Measurement of the amount of cross-coupling involved in pure, single-axis inputs showed cross-coupling under 10% of full deflection for all axes. This small amount of cross-coupling could be further reduced with better damping and force gradient control. Fatigue was not found to be a problem, and proprioceptive feedback was adequate for all flight tasks executed.

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INTRODUCTION

A major factor in the design of conventional helicopter controls was the need to provide the pilot sufficient mechanical advantage to overcome aerodynamic and mechanical forces that resist the movement of control surfaces. The conventional control design uses long, large displacement levers as control manipulanda. Cyclic pitch and roll control are on a lever between the pilot's legs. Collective pitch control is on a lever on the pilot's left side, along with a twist grip throttle. Anti-torque control is on pedals.

New technology has provided an impetus to change the conventional control arrangement. Increased pilot tasking associated with new mission equipment requires greater use of the pilot's hands for tasks other than flight control. The development of new flight control technologies has allowed redesign of the flight controls to support this need. For example an automatic throttle can eliminate or greatly reduce the need for the pilot to make inputs through the mechanical throttle twist grip.

The development of servo-actuated control surfaces has permitted significant change in the pilot-control interface. In fly-by-wire systems the pilot's control input consists of a change in line voltage which is interpreted by a logic circuit or computer in order to drive a control surface servo. Fly-by-wire systems offer a number of advantages over mechanical systems. These advantages include more sophisticated input schedules (e.g., variable gain, automatic coordination) and reduction in the size and travel of the control manipulanda, themselves.

The improvements that come from fly-by-wire allow a number of changes in the control manipulanda in the cockpit. Fly-by-wire control systems can support compact, small displacement controllers. They also permit the combining of control axes on a single manipulandum. Three- and four-axis controller configurations have been implemented with varying degrees of success. Common designs have been cascaded, that is, the multiple axes have been placed one atop the other (see Figure 1). In the most usual designs cyclic pitch and roll have been placed at the bottom of the controller in a configuration analogous to the conventional cyclic controller. Yaw, or anti-torque, control has been placed on a rotational axis of the grip. In four-axis designs collective input has been made through a translational movement of the grip.

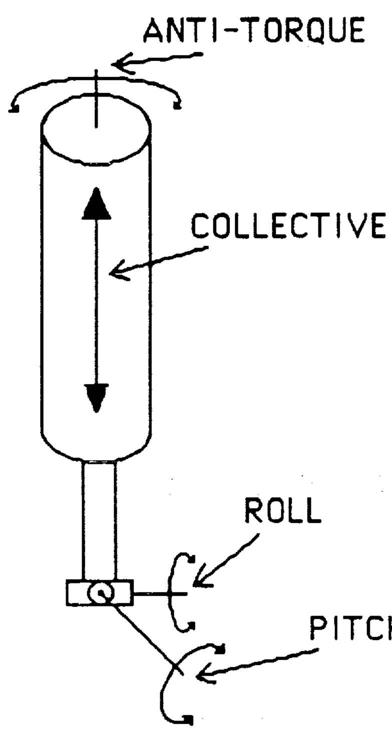

Figure 1. Cascaded Multi-axis Controller

Multi-axis controllers have had a number of problems with interface to the pilot. The quality of feedback on the size and direction of inputs has been poor. A related problem has been fatigue associated with sustained use. Also cross-coupling between axes has led to inadvertent control inputs (Prouty, 1992).

The usual approach to addressing these problems has been to attempt to minimize them by adjusting breakout force and force/input schedules. This approach has had limited success. The RAH-66 Comanche program has proposed 4-axis controller (Harvey, 1992), but this approach is now questionable.

Another approach to minimizing the negative characteristics of multi-axis controllers has been to alter the flight control laws to reduce the need for the pilot to make cross-coupled or fatiguing inputs. This approach has also been used to some extent on helicopters with conventional or hybrid control systems. Examples are the AH-64 Apache, command trim switch, and the OH-58 Kiowa, intermixing bell crank. The command trim switch allows the pilot to "center" the cyclic and pedals at the current position at the time of switch depression. This reduces pilot fatigue by eliminating the need for the pilot hold inputs. The intermixing bell crank is a mechanical system that trims cyclic pitch to compensate for the pitch up moment induced by increasing collective pitch, again reducing pilot fatigue.

Fly-by-wire allows even greater adjustment of the flight control laws because the flight control computer can interpret a single pilot input to command coordinated movement of several control surfaces. For example the Advanced Digital Optical Control System (ADOCS, Landis and Glusman, 1986) interprets a "cyclic roll" input to mean either commanded side slip rate or commanded coordinated turn rate, depending upon airspeed. This approach does not directly address the controller design problem, but it could reduce their effects by reducing the need to make or sustain certain inputs. In practice this approach has experienced difficulty in defining control laws that are comfortable and intuitive to pilots and that support the full aircraft performance envelop.

THE TEST CONTROLLER

The problems of fatigue, poor precision and cross-coupling associated with cascaded multi-axis arise because the geometry of the controller is incompatible with that of the wrist. This incompatibility can cause cross-coupling within the wrist during multi-axis movements. The twisting anti-torque input is particularly prone to cross-coupling. Also certain input motions can place an excessive load on muscle groups that are easily fatigued. The lifting collective input is particularly fatiguing.

The design objective for the test controller was to minimize the negative characteristics of a cascaded, multi-axis controller design by orienting the axes in a way more compatible with the geometry of the wrist. Two aspects of the design supported this goal. The first aspect was a change in the orientation of the grip to place the hand in a more relaxed and natural position. The second aspect was to allow the hand to be positioned on the grip in a way that would facilitate isolated inputs.

A design drawing for the controller is shown in Figure 2. The cyclic pitch and roll were placed in the usual configuration on a universal joint at the base. Anti-torque ("pedals") is on a pivot atop the cyclic control. Two adjustments were provided at this point to allow for optimum ergonomic configuration. A rotational adjustment (not shown) allowed the grip to pivot in the plane of cyclic roll. This adjustment changed the position of the hand and wrist from horizontal to 45 deg. from horizontal. The second adjustment let the grip translate relative to the anti-torque pivot. This adjustment positioned hand over the roll/pitch pivot. The thrust (collective pitch) control was a motorcycle-type twist grip. Twisting the grip forward increased thrust. There was no separate throttle control.

The actual device was both simple and inexpensive. Centering was accomplished by means of opposite acting coil springs. Force gradient could be adjusted by replacing the springs. No damping was provided. A friction lock on the thrust control could be adjusted so that an input could be held or the control would return to the null position. The thrust control adjusted both forward and aft from the null, so that inputs could be either commanded thrust (forward only) or deltas from the current value (fore and aft).

CONTROLLER EVALUATION

Two evaluations were performed. One evaluation consisted of making full deflection inputs on one axis and measuring the cross-coupled output on the other axes. The second evaluation consisted of installing the controller in a limited fidelity flight simulator and evaluating it subjectively.

The controller was installed in a limited fidelity flight simulator at McDonnell Douglas Helicopter Company for both evaluations. For evaluation of cross-coupling the virtual prototyping computer system for generating flight instrumentation was programmed to simulate a four-channel oscillograph. The display in the cockpit was masked to prevent the subject's seeing his input. After data collection began, the subject made a full deflection input on one control axis. This input consisted of a movement from the null position to one stop back to the other stop and finally to the null position. Output of all four axes was recorded.

Typical controller output is shown in Figures A1 through A8. Two recordings are shown for each control axis. One shows an example of a small cross-coupled controller response, and one shows a relatively large cross-coupled response. In the worst cases cross-coupling is about 10% of full deflection output. Typically it is under 5%, and in the best cases it is around 1% or less. The worst cross-coupling appears in cyclic pitch response to thrust inputs.

Interestingly, cross-coupling between roll and pitch axes is of about the same size as other cross-couplings. Roll and pitch are not problem axes in this type of controller configuration. The observed cross-coupling was very likely a result of the limited engineering design of the proof-of-concept device. Centering, control of breakout force and force displacement schedule were imprecise and the was no control of damping. Improvements in these areas should greatly reduce cross-coupling.

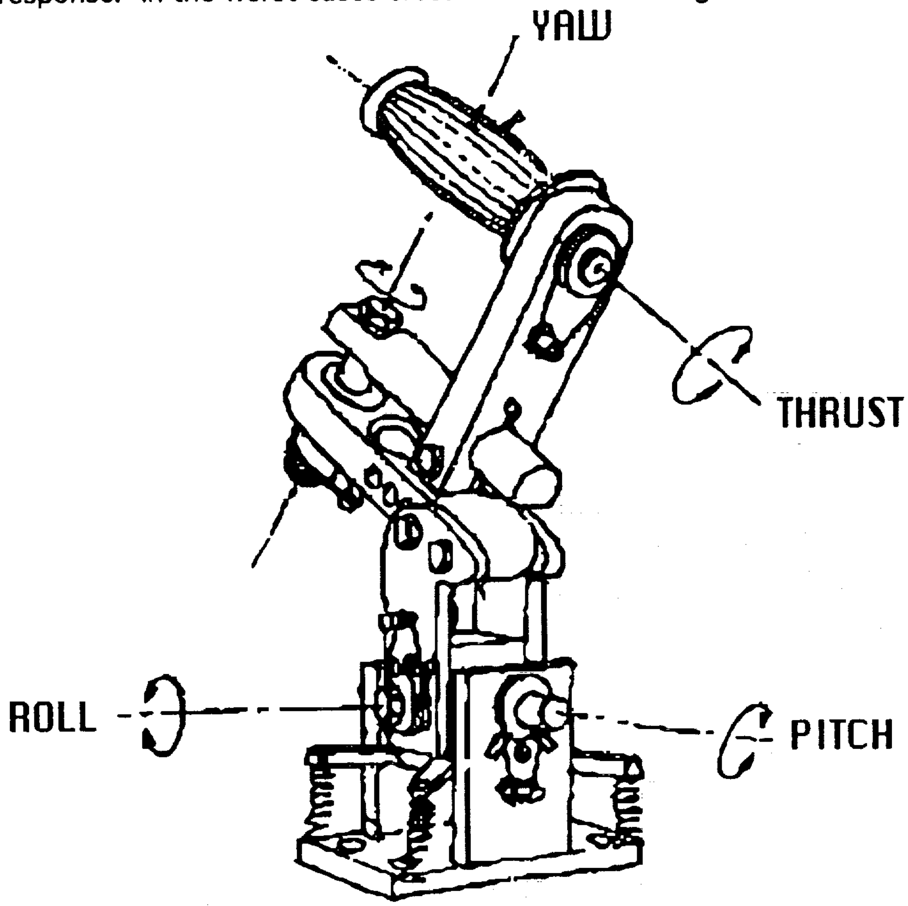

Figure 2. Test Controller

The simulator used for the subjective evaluation was a limited fidelity device having a two channel Sogitec computer generated out-the-window visual scene and a 9 inch CRT panel instrument display. In addition to the test controller, it contained conventional controls from an SH-53. Two aircraft models were used. The AH-64 model had stability augmentation as in the Apache. The MD-500 model had no stability augmentation. Both models had an autothrottle.

Simulation engineers, familiar with both the AH-64 and MD-500 simulated flight characteristics, performed a variety of flight tasks using both the conventional and test controls. These tasks included high speed flight, low speed flight, hover and hovering flight and "pedal" turns. Based on the subjective opinions of the engineer/pilots the test controller was found to be comparable to the conventional controls in all modes of flight.

The most demanding task for the test controller was high speed flight with the MD-500 aircraft model. This model had no stability augmentation, coordination or command trim. Therefore the pilot had to make and hold anti-torque and anti-pitch inputs. The pilots were able to make the inputs as accurately with the test controller as with the conventional controls, but they found them more fatiguing due to the higher force gradients and lack of trim control in the proof-of-concept device.

CONCLUSIONS

The proof-of-concept, cascaded, four-axis controller showed cross-coupling between control axes that was small enough to be potentially applicable for helicopter applications.

While cross-coupling was intrinsic to the cascaded design, the quality of design and fabrication contributed significantly to the amount of cross-coupling. Improvements in breakout, force gradient and damping could greatly reduce cross-coupling.

The device was found to be accurate and easy to use in simulation. Control of the simulated helicopter was subjectively comparable to conventional controls.

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REFERENCES

Harvey, D.S., "Can a computer Fly a Helicopter?", Rotor & Wing International, Aug. 1992.

Landis, K.H. and Glusman, S.I., Development of the ADOCS Controllers and Control Laws. Vol I-II, USAVSCOM Technical Report Number TR-84-A-7, St Louis, MO, Mar 1987.

Prouty, R.W., "The Sidearm Controller: a Few Considerations," Rotor & Wing International, Sep. 1992.