

**HELICOPTER PILOT PERFORMANCE  
FOR DISCRETE-MANEUVER FLIGHT TASKS**

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# HELICOPTER PILOT PERFORMANCE FOR DISCRETE-MANEUVER FLIGHT TASKS

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## Introduction

In order to address effectively the topics of aircraft handling qualities, pilot workload assessment, or aircrew training, it is sometimes necessary to describe and quantify adequately the associated flight tasks. Traditionally only labels have been used to do this (e. g., "landing", "climb", "turn", ...), but labels are insufficient to portray the level of aggressiveness, the amplitude of maneuvering, the degree of closed-loop damping, and other features of task execution crucial to success.

This paper describes a current study of several basic helicopter flight maneuvers. This is part of an effort sponsored by the U. S. Army Aeromechanics Laboratory under the Reference 1 contract. The data base consists of in-flight measurements from instrumented helicopters using experienced pilots. The analysis technique is simple enough to apply without automatic data processing, and the results can be used to build quantitative math models of the flight task and some aspects of the pilot control strategy. In addition to describing the performance measurement technique, some results are presented which define the aggressiveness and amplitude of maneuvering for several lateral maneuvers including turns and sidesteps.

## Analysis Approach

The main purpose of this paper is to outline a general procedure for interpreting and analyzing pilot performance of certain discrete-maneuver flight tasks. The scope is limited to a few basic roll-axis helicopter maneuvers with emphasis on the inner-loop control of bank angle. Nevertheless, this permits useful connections to be made with the topics of pilot workload, handling qualities, pilot skill development, and vehicle performance.

One important concept is the recognition of the task as being an integral part of the man-machine system. As the piloting task varies, so must the control strategy and the closed-loop interactions between pilot and aircraft. In fact, the dynamics of task execution should be and usually are the dominant response modes of the pilot-vehicle combination. In addition, it is important to note how quickly a task is executed with respect to the time or space available. In short, there are several dimensions to task performance which are involved in the formula for success besides the more traditional precision metrics (such as tracking or trajectory errors, for example).

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Discrete maneuvers represent an important class of piloting tasks. Most tasks, in fact, are composed of a series of several discrete commands of attitude and power. These commands may not be either very periodic or numerous. Thus classical spectral analysis techniques requiring long record lengths and normally applied to long-term continuous tracking tasks may be of only limited use.

The analysis of discrete maneuver tasks is not necessarily more difficult than continuous tasks. Discrete tasks can be portrayed using conventional feedback control block diagrams and Laplace transforms as shown in Figure 1. This formulation is more thoroughly described in Reference 2.

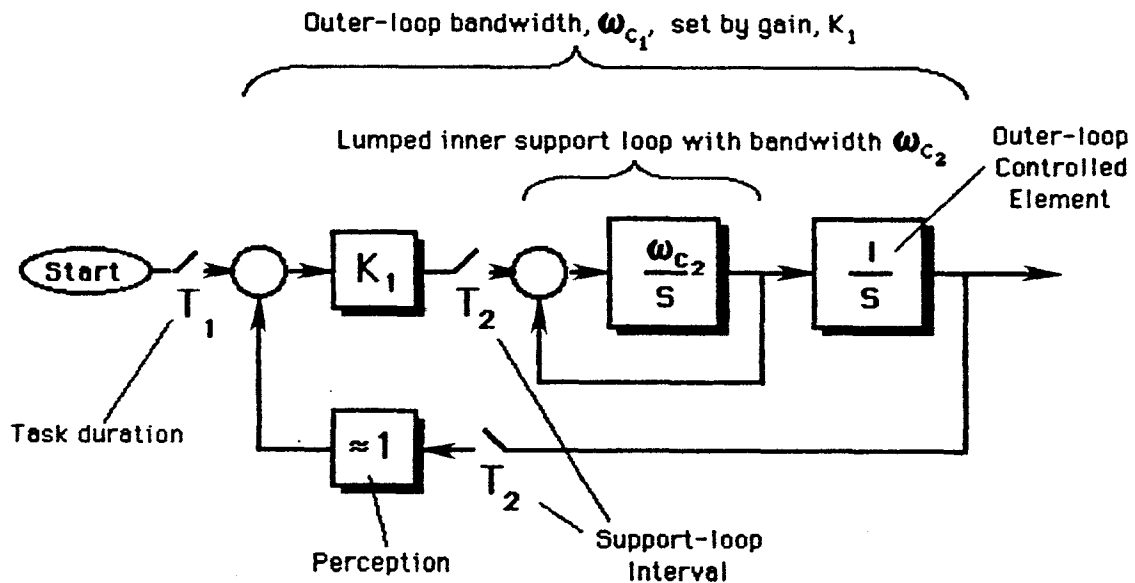


Figure 1. Block Diagram Structure for a Discrete Maneuver Task and Support Loop

One factor which can complicate effective task performance measurement is the sometimes short, transitory nature of task execution. For example, a simple sideward translation of a helicopter might span only a dozen seconds and involve one quick bank to start, a second one to stop, and perhaps a third for fine adjustment of the final position. Each command might typically occur every three or four seconds, and the closed-loop response to a command need be only about one half cycle of the dominant mode of the bank angle task. Finally, bank angle commands may not be very periodic. Some of these features are illustrated in a timing diagram of an actual sidestep maneuver as shown in Figure 2. The term "timing diagram" is used because of the resemblance of the sequence of commands to a digital computer software timing sequence. The outer-loop lateral position commands correspond to a

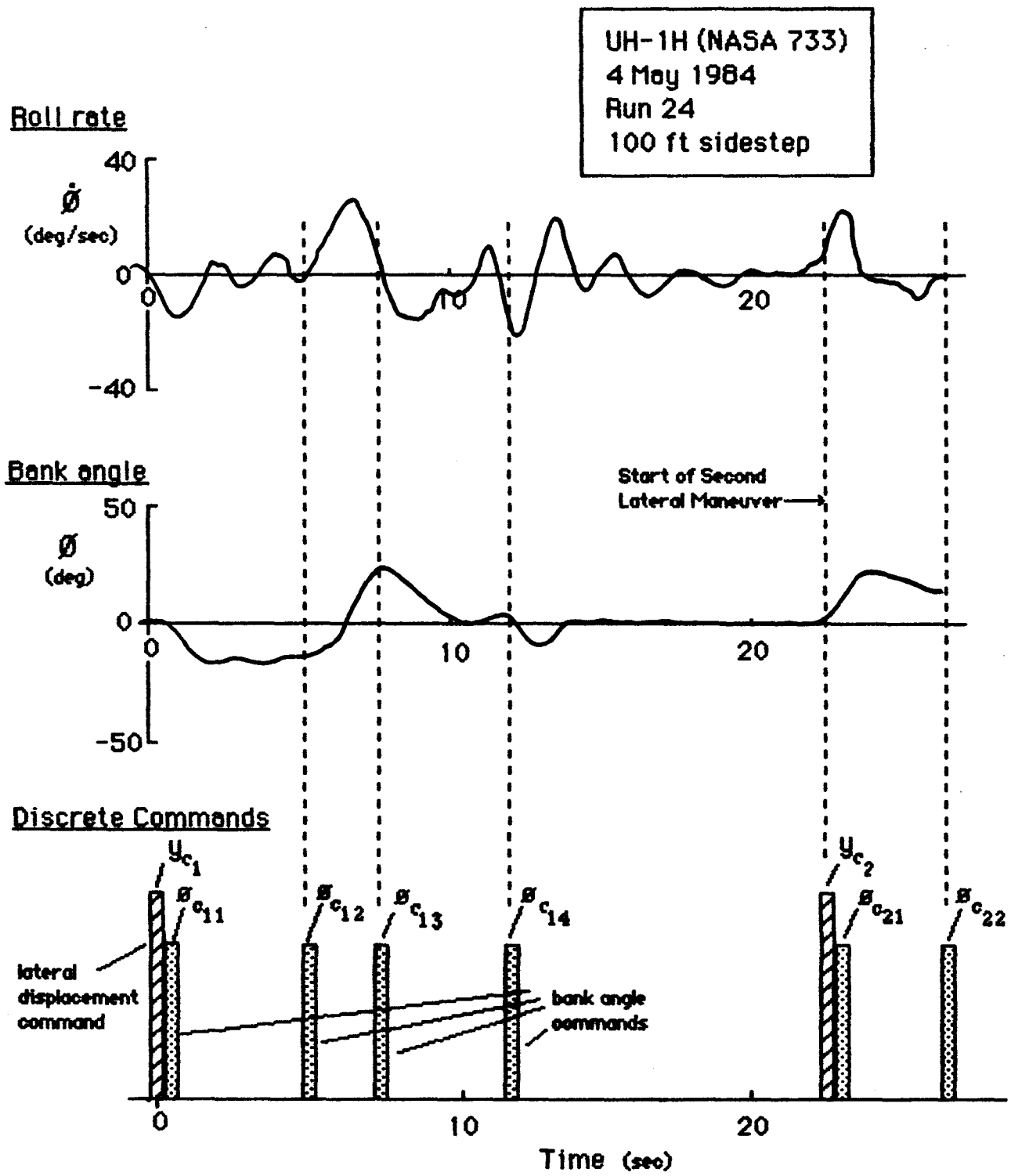


Figure 2. A Timing Diagram for a Typical Helicopter Sidestep Maneuver

kind of slow duty cycle while the inner-loop bank angle commands occur much more frequently. However, a typical flight task may involve only a few cycles of commands, and it is therefore necessary to use response identification techniques which will work over a fairly short sample.

One method for handling individual short-term discrete maneuvers is illustrated in Figure 3. If the features of a roll maneuver are to be studied, the first step is simply to obtain time history information which indicates the magnitudes of roll rate and corresponding bank angle change. Alternatively, this can be expressed on a phase-plane portrait in which case two important features can be clearly seen: (1) The net bank angle change and (2) the peak roll rate during that change. Finally these two features can be cross-plotted.

Roll rate versus net bank angle change can be interpreted in at least two ways. First, as explained in Reference 3, the proportion of peak rate to the net change in displacement is proportional to closed-loop natural frequency or bandwidth:

$$\omega_c \approx \frac{\text{peak rate} \times 2.4}{\text{net change in displacement}}$$

A detailed explanation of this relationship is given in Reference 4 using general second-order system phase plane plots. The valid range of damping ratios is about 0.4 to 1. A more exact determination of closed-loop frequency could be made using standard system identification techniques.

The second important facet of the roll rate versus incremental bank angle change is the magnitude of the maneuver in terms of either roll rate or bank angle. It was found that the former is perhaps a more significant parameter to use in connection with handling qualities since it can be directly compared with the vehicle roll rate capability. This will be discussed further at a later point.

It should be noted that the main purpose in applying the above analysis technique is to permit rapid assessment of flight or simulator data quickly and with minimal dependence on complicated data analysis techniques and complex data processing equipment. It is possible to examine on-line strip chart records of roll rate, bank angle, and lateral control and extract data points within a few moments of the actual generation of data. This permits better correlation of data with the conditions surrounding the data collection and factors affecting the pilot and aircraft.

## Examination of Flight Data

Several flight maneuvers have been examined in the above manner. As part of the previously mentioned Army program, two experienced test pilots flew a NASA UH-1H through a series of aggressive turns, slalom courses, lateral sidesteps, and lateral jinking maneuvers. The objective was to observe the magnitude and aggressiveness and possible variations in piloting technique among these various maneuvers. Figure 4 is representative of how the discrete maneuver data appeared for one important class of lateral maneuver, the sidestep from hover. In this case the individual maneuvers combined to form a nearly straight line, i. e., the peak roll rate tended to be proportional to each roll attitude change. By multiplying the slope of the trend line by 2.4, the resultant closed-loop bandwidth appeared to be slightly in excess of 3 rad/sec—a fairly high value for a multiloop/multi-axis flight task. A typical value for routine approach and landing bank angle regulation would be about one half as much.

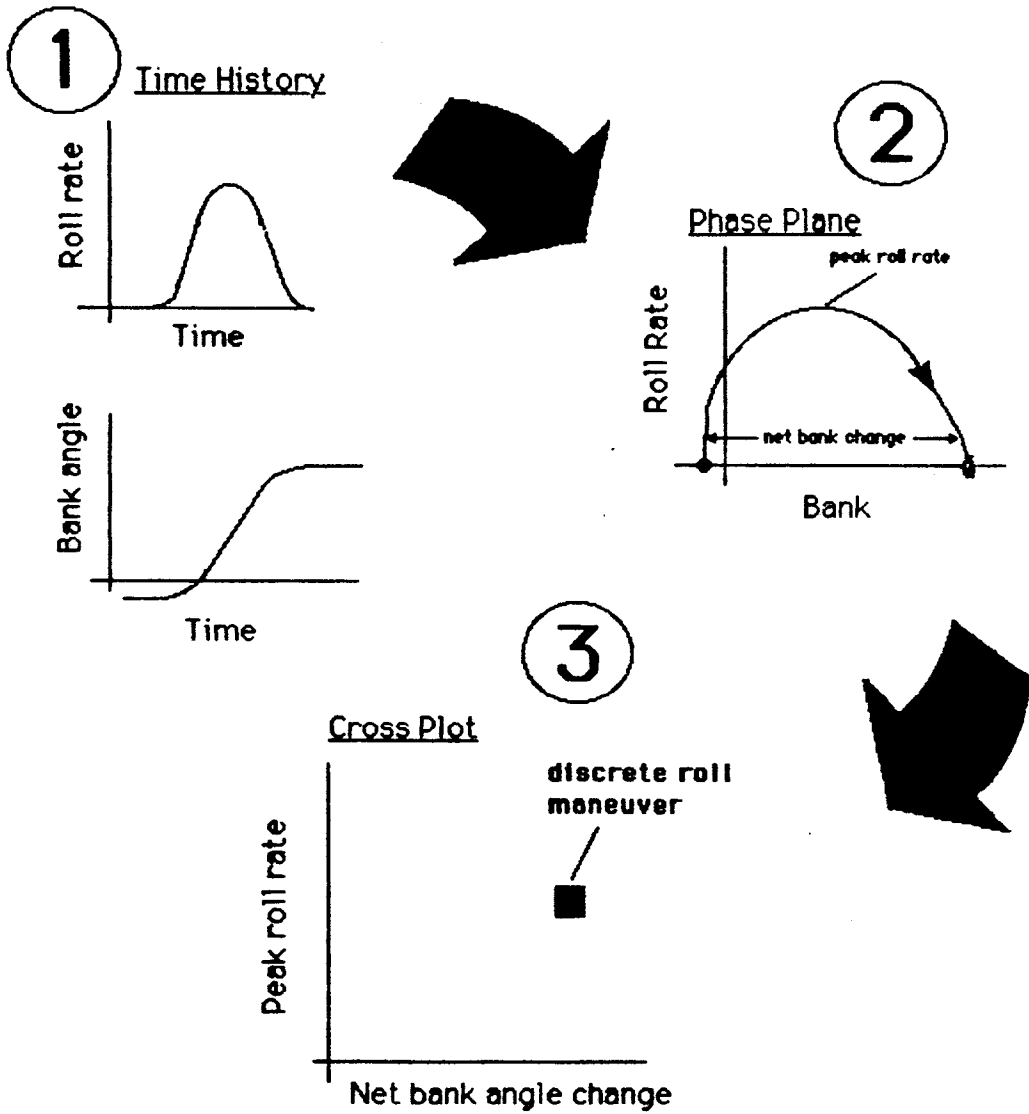


Figure 3. Analysis of Roll Maneuver Data

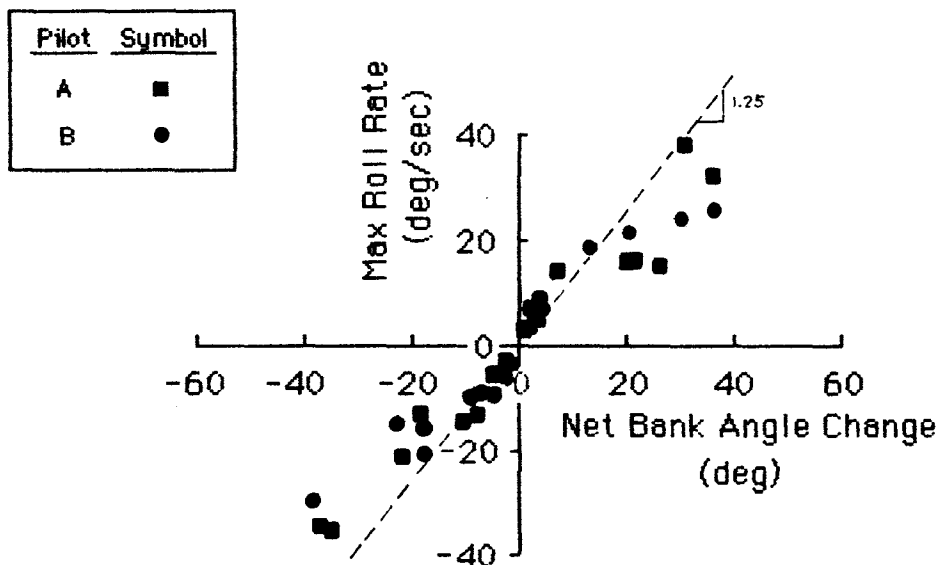


Figure 4. Aggressive Sidesteps from Hover with a UH-1H

Other maneuvers performed in forward flight generally were somewhat less aggressive, involved larger bank angle changes but were limited in the values of peak rollrate to about 40 deg/sec. One aspect being actively studied is why rollrates in excess of this value do not appear to be used by the pilots even though the helicopter may be capable of substantially greater rollrates.

In addition to the flight data that have been obtained in the course of this study, a number of other data bases have also been examined. One set of data involving an interesting comparison of two helicopters was furnished by the DFVLR\* in Reference 5. The aircraft were a UH-1D (teetering rotor) and a Bo-105 (rigid rotor). The UH-1D is characterized by a modest level of roll damping with some quickening provided by a mechanical stabilizer bar. The Bo-105 has considerably faster short-term roll response as a result of the directly applied flapping moment on the rotor hub. A preliminary assessment of the discrete maneuver performance, however, indicates that the two helicopters were operated at comparable levels of aggressiveness in the slalom-type test that were conducted.

The maneuvers from this study along with the flight results from the DFVLR tests are listed in Table 1.

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Table 1. Summary of Lateral Maneuver Flight Data

Source	Aircraft	Maneuver	Airspeed (kt)	$\omega_c$ (rad/sec)	$\dot{\phi}_{PK}$ (deg/sec)
Hindson/ Wilson	UH-1H	Straight-line slalom	60	1.5	40
		" " "	80	2.4	40
		50° Intersection turn	60	2.4	46
		130° " "	60	2.4	30
		30 ft Lateral jink	30	2.4	40
		Sidestep	Hover	3.1	37
DFVLR	UH-1D	Straight-line slalom	60	2.4	25
		" " "		1.7	23
	Bo-105	'German slalom'		1.6	47
		" "		1.8	32
	UH-1D/ Bo-105	High-g turn		-	33

The above performance data are valuable in gauging the demands of a given maneuver against the capability of the aircraft—a fundamental handling qualities aspect. Figure 5 shows how maneuver requirements and aircraft capabilities can be expressed on a common scale. One aircraft characteristic is the maximum roll rate available. For a helicopter this is dependent upon basic rotor design parameters including rotor rpm, Lock number, and swashplate deflection angle. A second essential characteristic is the effective bandwidth or short-term roll response. For an augmented helicopter this is directly related to the roll damping stability derivative.

## Conclusions

The analysis of discrete-maneuver task performance from flight data has been found to be feasible using simple, easy-to-apply techniques.

From the time history data recorded on strip charts, the inner-loop task performance features readily obtained included measures of pilot aggressiveness, amplitude of maneuvering, and inner- or support-loop command intervals. This was adequate for portrayal of the task demands versus aircraft capabilities.

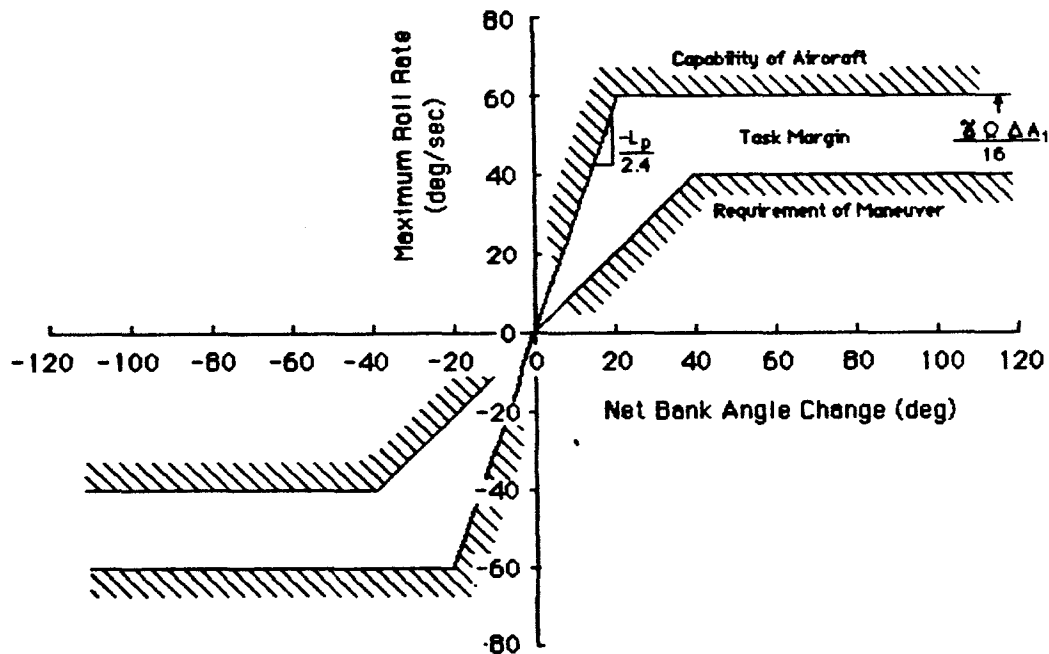


Figure 5. Interpretation of Discrete Maneuver Performance

In general, performance of several helicopter flight tasks varied between quick, small-amplitude discrete maneuvers and slower (lower bandwidth), large-amplitude maneuvers. In both cases, the peak roll rates observed were comparable.

Two modes of pilot operating conditions seemed to be involved over the range of discrete maneuvers. For small-amplitude maneuvers, the magnitude of peak roll rate was about proportional to the magnitude of the bank angle command. Hence a linear, fixed-gain pilot model generally applies. For large-amplitude maneuvers, the peak roll rate was fairly independent of the bank angle command, thus a contactor-type control model is a better representation (i. e., a "saturated" or "limited" control). Both these operating modes—linear or contactor—can simultaneously be expressed by a simple linear gain in series with a limiter.

Sidestep maneuvers involved the highest level of pilot aggressiveness observed. Closed-loop bandwidths in excess of 3 rad/sec were typical. Peak roll rates as high as 40 deg/sec were employed by the pilots. These values tended to represent the most critical demands placed on this helicopter of any of the tasks explored.

Forward flight maneuvers such as turns or slalom maneuvers involved large amplitude bank angle commands with maximum peak rollrates of about 40 deg/sec. However for the inner loop, the maximum closed-loop bandwidths were typically about 2.5 rad/sec.

Further analyses of outer-loop task performance are yet to be done. Typically this is more difficult only because of the data processing needed to handle translational position and velocity states. The same simple bandwidth and timing measurement techniques used for the inner loops are applicable, however.

The ultimate objective of this work is to catalog pilot performance parameters on a task-by-task basis and relate them to specific handling qualities features required.

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