A Comparison of Active Sidestick and Conventional Inceptors for Helicopter Flight Envelope Tactile Cueing

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This paper will compare the results of two ground-based piloted simulation studies of helicopter flight envelope tactile cueing. The objective of these trials was to develop methods of assisting the pilot in respecting flight envelope limits in a high workload environment. Both trials looked at the same aggressive hover and forward-flight tasks, the difference being that in the first trial, large-displacement programmable force-feel inceptors were used while in the second programmable short active sidesticks were used. An overview of each of the major elements of the paper is given below:

Background

The complex flight envelope limits of helicopters are often difficult for the designer to predict and difficult for the pilot to detect. For example, fatigue load limits in control linkages are highly sensitive to transient flight conditions, and even in steady flight high loading conditions are often masked by only subtle changes in the general vibration levels. Vehicle parameters for which limits are specified, such as transmission torque, can be highly dynamic and only indicated to the pilot using a cockpit gauge. Consequently, conservative restrictions are imposed on the maneuvering envelope, and only indirect and simplified pilot cueing of the envelope limits, such as a maximum allowable speed, are used. As an additional factor, fly-by-wire control systems can decrease a pilot's awareness of control actuator authority limits, as well as eliminate control force "feel". Therefore, to enhance safety, exploit the full potential of helicopters, and reduce pilot workload, it is appropriate that methods for providing control margin cues and flight envelope cues be developed.

Tactile Cueing

It has been shown previously that tactile cueing is an effective means of signaling the pilot of an impending flight envelope exceedance (ref. 1). Tactile cues via the control inceptors are immediate, unambiguous, and require no interpretation as to what control response is required to remedy the situation. However, close attention must be paid to the detailed implementation of tactile cueing and how it interacts dynamically with the limit variable of interest. Figure 1 shows a graphical representation of a typical "softstop" tactile cue in combination with shaking at higher limit thresholds.

Providing tactile cueing of impending envelope exceedances often requires significant lead estimation due to the dynamic nature of limit variables. Polynomial neural networks (PNNs) have been shown to be an effective means of providing the necessary lead estimation (ref. 2). PNNs provide a concise means to express the complex space defined by the helicopter limit variables. Using a PNN estimate of the future value of a limit variable in combination with a simple feedback loop one can adequately estimate the inceptor location associated with the limit of interest. Figure 2 shows a block diagram representation of this approach.

Active Sidesticks

Recent development of active sidestick controllers has made it possible to provide tactile cueing in a lightweight compact form suitable for integration into fly-by-wire helicopter flight control systems. Under a NASA Phase II Small Business Innovative Research contract, Stirling Dynamics Inc. (SDI) has developed a two-axis active sidestick suitable for use in the simulation environment (Figure 3) as well as a three-axis active sidestick suitable for use in the flight environment.

Trial Objectives

Two simulation trials were conducted to look at tactile cueing using PNNs to drive both conventional inceptors and active sidesticks. The objectives of the piloted simulation trials can be summarized as follows:

1. to implement collective tactile cueing of time-varying drivetrain limits using a softstop

2. to implement cyclic tactile cueing for mast bending moment including using a step change in cyclic damping in flight and a softstop when in contact with the ground

3. to implement cyclic tactile cueing for blade stall and the associated increase in pitch link load using an aft cyclic softstop

4. to implement two-axis active sidesticks in place of a conventional cyclic and collective and test the same tactile cues described above

Trial Conduct

Two piloted simulation trials were conducted on the Ames Research Center Vertical Motion Simulator (Figure 4) to look at tactile cueing driven using PNNs for both conventional inceptors and active sidesticks. The GenHel representation of the UH-60A Black Hawk was used as the math model. The basic UH-60A SAS and flight path stabilization (FPS) was used for both simulation trials.

Transmission torque, retreating blade stall, and mast bending moment were used as representative limits. The transient and do-not-exceed (DNE) limits for the limit variables were set conservatively to ensure sufficient operation in the region of the limits. The transmission torque limit was time-varying depending on the length of time that had been spent in the transient torque region (80-90 percent). Softstop tactile cueing of transmission torque was keyed to the transient/DNE boundary. Blade stall was approximated using the calculated quantity termed equivalent retreating indicated tip speed (ERITS). A comparison of ERITS to the UH-60A handbook limit is shown in Figure 5. Lead estimation of the limits was achieved using PNNs as described previously. Tactile cueing was implemented as described in the trial objectives. The force and displacement characteristics of the active sidestick are summarized in table 1. Head up display (HUD) cueing, as shown in Figure 6 was used to reinforce the tactile cueing.

Four configurations were evaluated: 1) no HUD or tactile cueing, 2) HUD cueing only, 3) tactile cueing only, and 4) both HUD and tactile cueing. Three tasks were performed: a bobup, an acceleration-deceleration and a maximum performance turn. In total, over 1600 runs were performed by a combination of nine pilots (4 NASA, 2 US Army, 3 US industry).

Detailed descriptions of the PNN and tactile cueing algorithms will be disclosed in the full paper.

Preliminary Results

Figure 7 shows a sample time histories of torque and collective for the bobup task. The time-varying nature of the torque limit can be seen as the torque value transitions above and below the transient limit. It can be seen that the pilot's input tracked the moving softstop as torque decreased in accordance with the decreasing limit.

Figure 8 shows a summary of Handling Qualities Ratings (HQRs) and integrated torque and blade stall exceedances for the three tasks. The error bars indicate the ninety-five percent confidence of the mean. It can be seen that pilot opinion improves and limit exceedances decrease with the tactile cueing present. The best results were achieved with both tactile and HUD cues present.

Pilot commentary regarding the active sidestick was quite favorable. No force "ripple" or force-feel granularity was detectable by the pilots in performing the tasks. Using the full available displacement (±25 degrees) was found to yield a satisfactory stick gain when a direct linear mapping of the UH-60A control authority was used. It is also noteworthy that this high level of acceptability was achieved using only the UH-60A rate-damped SAS with altitude-hold trim system (FPS). The ergonomic benefits associated with the upright posture that dual sidesticks affords was also evident.

In the results shown for the bobup task, it can be seen that without any tactile cueing the pilots were unable to avoid torque exceedances as well with the active sidestick as the conventional. This is also reflected in their HQRs for the same. However, with the tactile cueing added, the two devices yielded equivalent results. In the acceleration/deceleration task the results were nearly equivalent for the conventional inceptors and the active sidesticks. In the maximum performance turn task the active sidestick exhibited an advantage in both HQRs and exceedances.

Detailed discussion of all trial results will be included in the full paper.

Preliminary Conclusions

The following major points were noted :

1. Tactile cueing reinforced by HUD symbology yielded significant handling qualities benefits and reduced exceedances.

2. The active sidesticks yielded quite favorable commentary from the evaluation pilots in terms of feel, comfort, and controllability.

3. Results indicate that for the tasks evaluated, nearly equivalent performance is achieved with the conventional inceptors and the active sidesticks when the tactile cues are present.

References

1. M. Whalley and M Achache, "Joint U.S./France Investigation of Helicopter Flight Envelope Limit Cueing", American Helicopter Society 52nd Annual Forum, Washington D.C., June 1996.

2. A. Bateman, D. Ward, R. Barron, and M. Whalley, "Piloted Simulation Evaluation of a Neural Network Limit Avoidance System for Rotorcraft," AIAA Atmospheric Flight Mechanics Conference, Portland, Oregon, August, 1999.

Table 1. Active stick force characteristics

	Longitudinal Cyclic	Lateral Cyclic	Collective
Displacement (deg)	±25	±25	±25
Breakout (lb)	1.12	1.12	0
Gradient (lb/deg)	0.270	0.225	0
Damping ratio (nd)	1.0	1.4	0.7
Friction (lb)	0	0	1.35
Softstop breakout height (lb)	8.99	4.50	4.50
Softstop breakout width (deg)	0.5	0.5	0.5
Gradient above softstop (lb/deg)	0	0	2.25
Shaking frequency (hertz)	20	20	20
Shaking magnitude (lb)	31?	31?	9

1. Forces measured at center of grip; 5.6 inches from pivot.
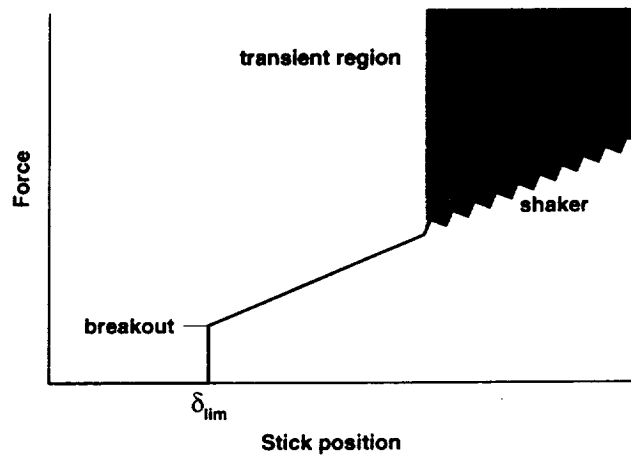
Figure 1. Typical collective softstop
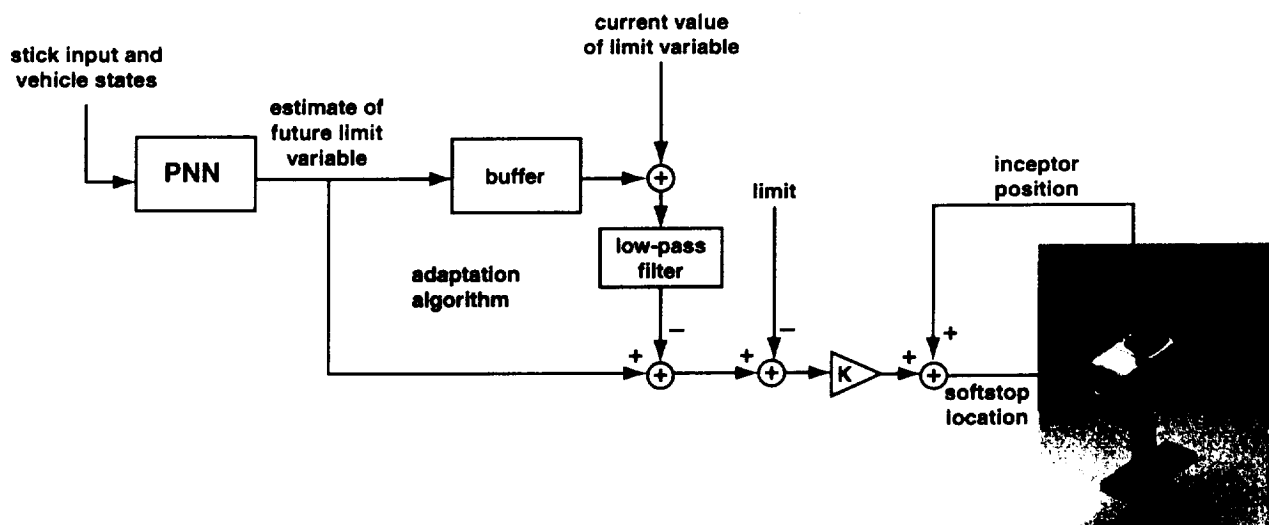
Figure 2. Softstop location calculation using PNN.
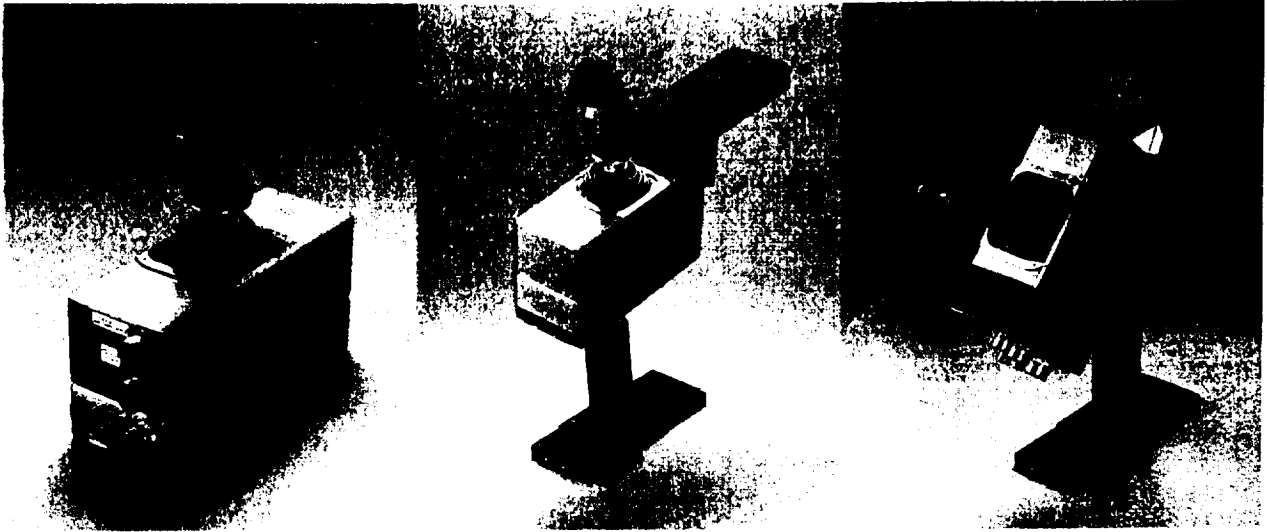
Figure 3. Stirling Dynamics Inc. active sidestick shown unmounted, in cyclic mounting, and in collective mounting.
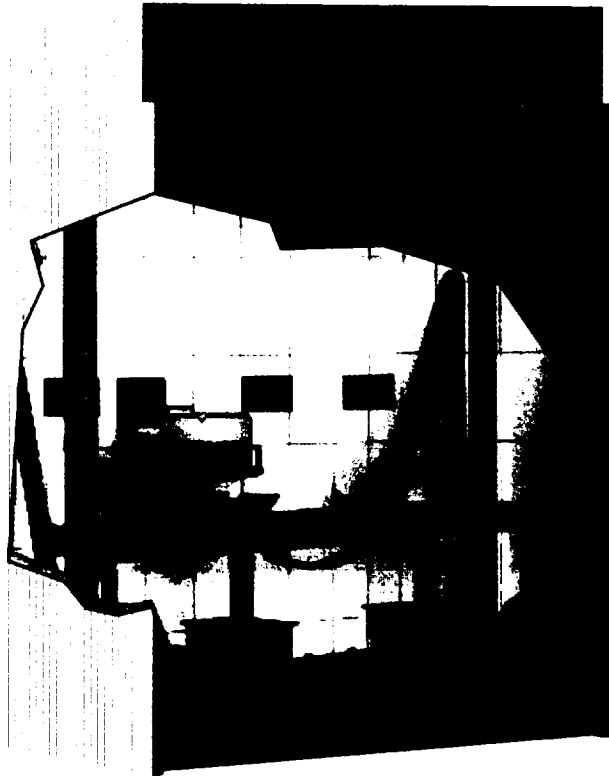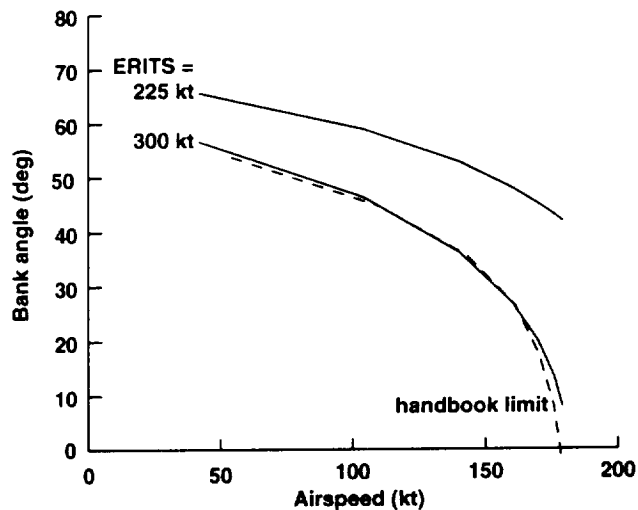

Figure 4. NASA Ames Vertical Motion Simulator.

Figure 5. Comparison of ERITS with UH-60A handbook stall limits at 17,227 lb, 4000 ft, 95 degrees.
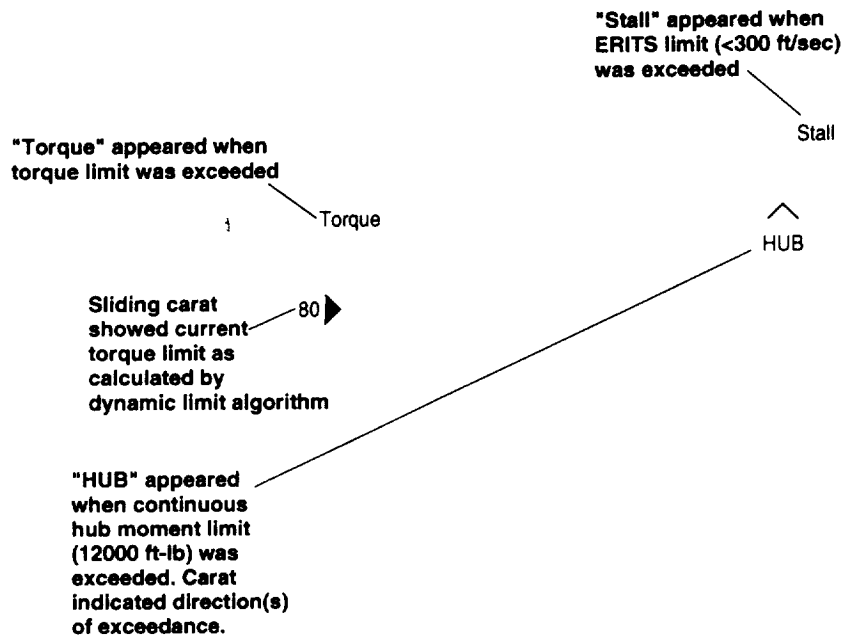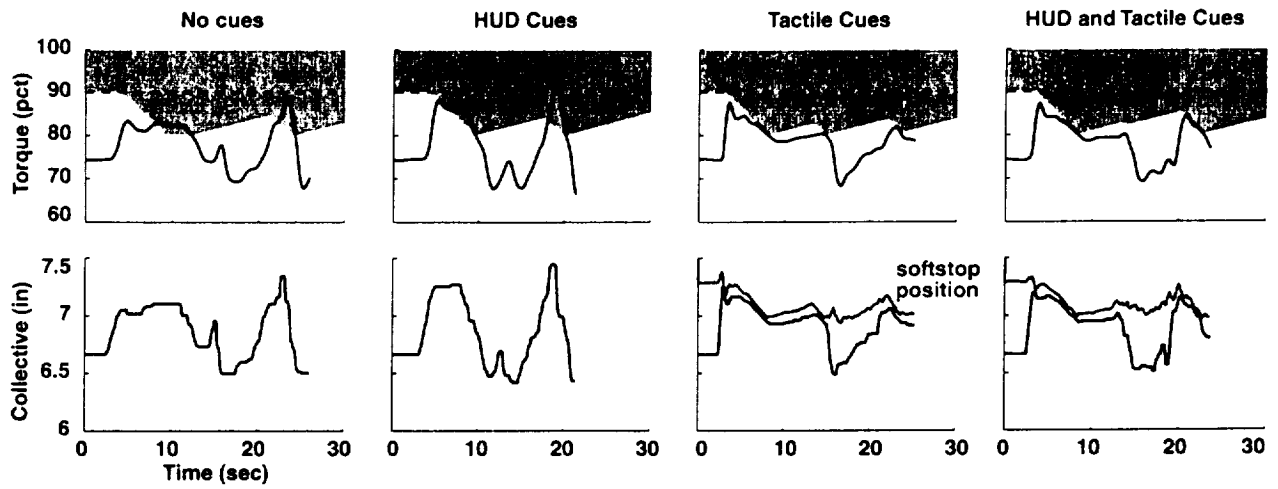

Figure 6. HUD warning cues.

Figure 7. Sample time history results from bobup task with active sidestick including torque transient region (yellow), dynamic torque DNE level (red), and calculated tactile softstop position (blue).
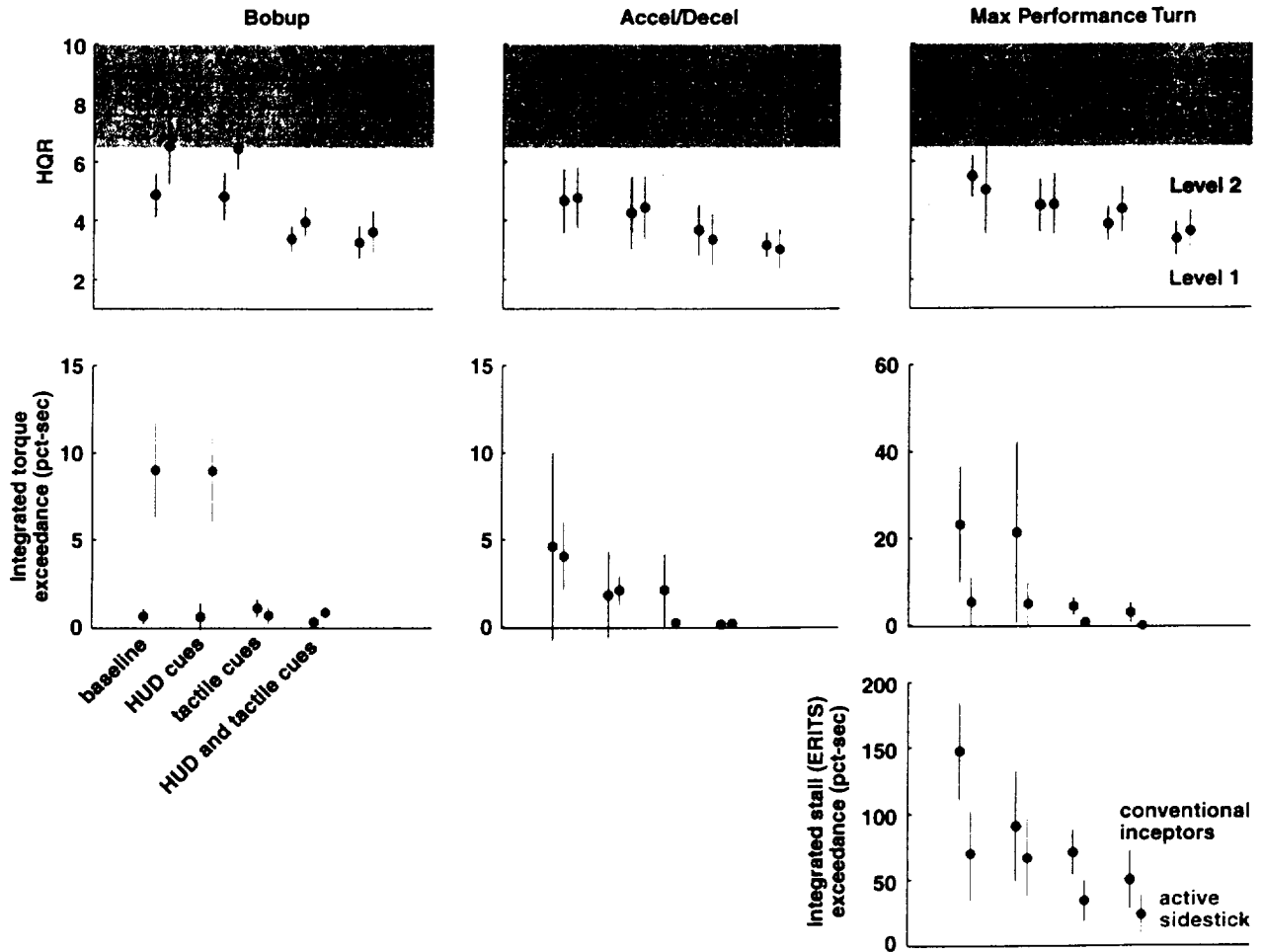

Figure 8. Preliminary results.