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# AN EVALUATION OF PERCEPTUAL-MOTOR WORKLOAD DURING A HELICOPTER HOVER MANEUVER

By

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May 1978

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Stability augmentation systems are purported to reduce pilot workload during hover, nap-of-the-earth, and IFR maneuvers. The current research project examines a method of aiding the MEDEVAC pilot in performing a hover maneuver while perhaps reducing workload. A modular, four-axes stability augmentation system (Ministab) with integrated rate attitude and heading retention was installed on the USAARL JUH-1H helicopter. Participating personnel for the project were nine US Army aviators with a total average of 1172 flight hours. The aviators hovered at 30 feet above ground level for five

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20. ABSTRACT (Cont)

minutes under each of the three following flight control conditions: (1) Unaided--"normal" hover with visual flight rules conditions, (2) using Force Trim, and (3) using the Ministab. Continuous information from twenty pilot and aircraft monitoring points was recorded on an incremental digital recorder for all flights. Multivariate analyses were performed on both aircraft status variables and control input workload/activity measures. Under the conditions tested, the stability augmentation system evaluated did not provide a clear-cut improvement in flight performance and workload across all flight parameters.

## SUMMARY

Stability augmentation systems are purported to reduce pilot workload during hover, nap-of-the-earth, and IFR maneuvers. The current research project examines a method of aiding the MEDEVAC pilot in performing a hover maneuver while perhaps reducing workload. A modular, four-axes stability augmentation system (Ministab) with integrated rate attitude and heading retention was installed on the USAARL JUH-1H helicopter. Participating personnel for the project were nine US Army aviators with a total average of 1172 flight hours. The aviators hovered at 30 feet above ground level for five minutes under each of the three following flight control conditions: (1) Unaided--"normal" hover with visual flight rules conditions, (2) using Force Trim, and (3) using the Ministab. Continuous information from twenty pilot and aircraft monitoring points was recorded on an incremental digital recorder for all flights. Multivariate analyses were performed on both aircraft status variables and control input workload/activity measures. Under the conditions tested, the stability augmentation system evaluated did not provide a clear-cut improvement in flight performance and workload across all flight parameters.


STANLEY C. KNAPP
Colonel, MC
Commanding

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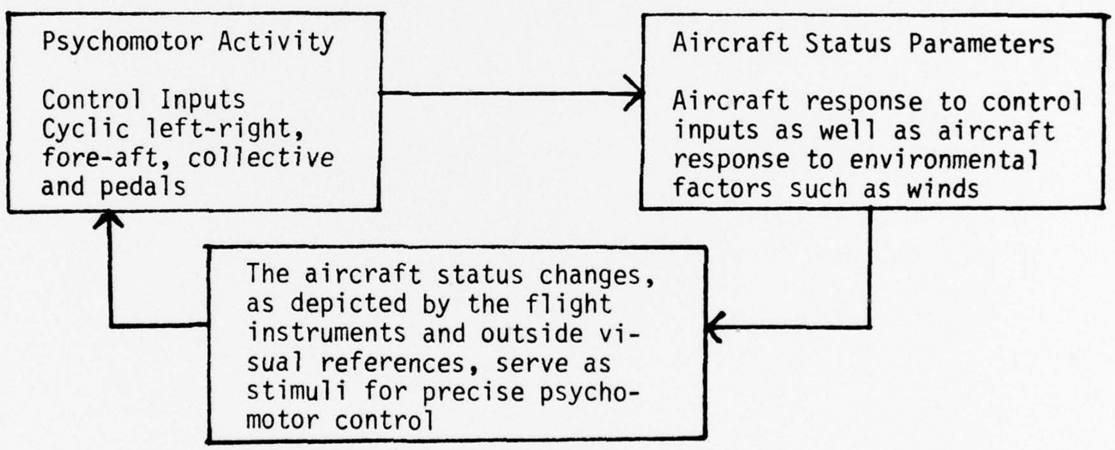
## INTRODUCTION

Successful completion of the Army medical mission often requires that the MEDEVAC helicopter pilot be capable of performing precise stabilized hovers during the extraction of injured personnel. The precision hover, required for hoist extractions, is one of the most difficult and taxing flight maneuvers. The potential severity of this mission-essential maneuver, when high altitudes, adverse weather and immediate threat factors are considered, requires efficient execution. Thus, the "out-of-ground effect" hover maneuver contains two primary elements of concern--a need for a high degree of precision and a concomitant potential for excessive workload. These two areas also reflect the input and output of a multidimensional tracking task which is another way of describing the precision hover. A schematic of the control loop involved might be described as follows:




In a study by Anderson and Toivanen (1970),[1] pilot workload was evaluated relative to varying levels of autopilot assistance during an IFR formation flight using a UH-1 flight simulator. This evaluation "revealed that the increased autopilot capability enabled the pilot to perform considerably better under the highest workload condition tested." As well, "pilot control inputs and aircraft responses required for position control were significantly lower when the outer loop [heading, altitude, and heading and altitude] hold modes of the autopilot were engaged."

A four axes stability augmentation and altitude retention system (Ministab) was installed on the USAARL JUH-1H test vehicle for a comparative evaluation with other standard flight control conditions (Kaiser, 1976). The intent of the system was to augment the pilot's performance in pitch, roll, heading and altitude hold. The fourth axis (altitude hold) was not operated during the current evaluation. The objective of the current study was to evaluate aviator workload and aircraft status maintenance capability when using the stability augmentation and attitude retention system as compared to more typical flight control conditions.[2]

## METHOD

### Subjects

Participating personnel for the project were nine US Army aviators with an average age of 27.7. Their rank varied from Chief Warrant Officer to Captain and their average total flight hours were 1172.2. The UH-1 helicopter was reported to be the aircraft in which they had logged the most flight time. The subjects were all currently in assignments which required flying and had been on flight status for an average of 3.8 years.

### Apparatus

The Ministab was made available for testing by the US Army Air Mobility Laboratory at Fort Eustis, Virginia. The Ministab is a "modular stability augmentation system with integrated rate attitude and heading retention that can be applied to any helicopter having boosted flight controls." A computer with an integral rate gyro which senses motions of less than 1/100 of a degree/second is dedicated to each axis.

The test vehicle was a JUH-1H helicopter instrumented to measure and record pilot control inputs and aircraft position, rates and acceleration. This Helicopter In-Flight Monitoring System (HIMS) measures aircraft position in six degrees of freedom while simultaneously recording cyclic, collective and pedal inputs and aircraft status values. These data were recorded in real time on an incremental digital recorder. Continuous information from twenty pilot and aircraft monitoring points was recorded for all flights. Table 1 provides a list of these parameters along with a partial listing of measures that can be derived from the directly recorded information.

Pilot inputs to controls were generally defined in the following manner. Control inputs on the cyclic fore-aft, cyclic left-right, and pedals were required to have the following characteristics: (1) seven successive samples of data (the data were sampled 20 times per second; therefore, .05 seconds per sample) were compared to data sampled .25 seconds later; (2) differences were obtained between these data occurring .25 seconds apart; (3) the average for three consecutive differences had to exceed .075 inches; (4) this difference had to be in the same direction for five consecutive comparisons. The same general requirements were made of the collective control inputs with the exception that six consecutive comparisons were required at .09 inch movements per comparison.

TABLE 1

PARAMETERS MEASURED AND DERIVED

| Parameters Measured | Derived Measures |
|---|---|
| Pitch | Pitch Rate |
| Roll | Roll Rate |
| Heading | Rate of Turn |
| Position X | Constant Error, Average Absolute Error, RMS Error |
| Position Y | Ground Speed, Constant Error Average Absolute Error, RMS Error |
| Acceleration X | |
| Acceleration Y | |
| Acceleration Z | |
| Roll Rate | Roll Acceleration |
| Pitch Rate | Pitch Acceleration |
| Yaw Rate | Yaw Acceleration |
| Radar Altitude | Rate of Climb, Average Absolute Error, Constant Error, RMS Error |
| Barometric Altitude | Rate of Climb |
| Airspeed | |
| Flight Time | |
| Rotor RPM | |
| Throttle | |
| Cyclic Stick (Fore/Aft)<br>Cyclic Stick (Left/Right)<br>Collective<br>Pedals | Control Position, Absolute Control Movement Magnitude, Positive Control Movement Magnitude, Negative Control Movement Magnitude, Absolute Average Control Movement Rate, Average Positive Control Movement Rate, Average Negative Control Movement Rate, Control Reversals, Instantaneous Control Reversals, Control Steady State, Control Movement |

## Flight Testing

A Ministab training program of instruction used for system familiarization is provided in Appendix A. All in-flight evaluations took place at the Highfalls stagefield. A one-minute period was allotted just prior to the actual testing on each condition for practice on that condition. The aviators were tested under each of the three flight control conditions: (1) Unaided--"normal" hover during visual flight rules (VFR) conditions; (2) using Force Trim; (3) using Ministab. "Force Trim or Force Gradient enables the pilot to trim the control as desired for any condition of flight by means of springs and magnetic brake release assemblies. The Force Trim can be activated on the cyclic controls and the pedal controls. These devices are electromechanical units used to induce artificial control feeling and returns the cyclic to the desired initial position" (Operator's Manual, 1971).[3]

The aviators hovered at 30 feet above ground level (AGL) in essentially the same location (over the stagefield runway) for five minutes under each condition. Table 2 indicates the three flight conditions evaluated and controls (Con) required. The order of testing for the three experimental conditions was counterbalanced to minimize order effect bias. The direction of the wind was determined before the test of each flight condition and based on this information a heading was chosen that allowed the aircraft to face into the wind during the hover.

TABLE 2

FLIGHT CONTROL CONDITIONS EVALUATED

| Flight Conditions | Flight Parameters | | | |
|---|---|---|---|---|
| | Pitch | Roll | Heading/Yaw | Altitude |
| 1. Unaided--"Normal" VFR Hover Conditions | Manual Con With Cyclic Fore-Aft | Manual Con With Cyclic Lateral | Manual Con With Pedals | Manual Con With Collective |
| 2. Force Trim | Force gradients on with manual override for control changes with the cyclic. | | Force gradients on with manual override for control with the pedals. | Manual control with collective. |
| 3. Stability Augmentation Attitude Retention System (Ministab) | Monitor & make manual control inputs when conditions exceed the 10% control authority of the system. | | Monitor & make manual control inputs when conditions exceed the 10% control authority of system. | Manual control with collective. |

## Subjective Evaluation

After each flight condition was completed, a Cooper-Harper Handling Qualities Rating Scale was filled out by the subject (Cooper and Harper, 1969).[4] Post flight, the subjects completed a biographical data form and a questionnaire concerning aspects of their flight under the different experimental conditions.

## RESULTS AND DISCUSSION

Three primary analyses were performed on the data collected during the evaluation of the stability augmentation system. The first analysis to be reported concerned an examination of the existing wind conditions relative to the research helicopter during the evaluation. Again, the order of testing of the three flight conditions was counterbalanced across subjects to minimize order effect bias. Testing was continuous in that each condition evaluated was immediately followed by the next condition (approximately five-minute separations). The wind information collected during the testing periods was evaluated with the Versatile MANOVA program (Schori, 1976)[5] to determine if the wind direction, velocity, or aircraft heading relative to wind direction (crosswind component) varied among the three flight conditions. The results of this analysis are reported in Table 3.

An examination of these data reveals that no significant differences were observed either univariately on any of the variables or overall in the multivarite test of significance. Indeed, the means listed in Table 3 indicate that very little difference did exist in wind direction variability, velocity and crosswind component across the three flight conditions. Therefore, performance and/or aircraft status differences found can be attributed to the flight conditions being evaluated and not extraneous wind variables impinging upon performance.

The second analysis pertained to an evaluation of aircraft status or stability variables. These variables are listed in Table 4 along with the findings of the analysis. It is indeed noteworthy that none of the variables examined (aircraft axis variation and rate measures) proved to be different to a significant degree across the three flight conditions. That is, the aircraft position variability and rate variability about each of the four axes did not change significantly when the stability augmentation system was activated as compared to the force trim and unaided flight conditions.

The third analysis to be described concerns the control input data which could relate to the activity requirements or workload of the operator. Table 5 contains the flight control variables which describe performance along each of the four primary flight control channels. The magnitude of control inputs was examined along with the number of inputs per second.

TABLE 3

MULTIVARIATE ANALYSIS OF VARIANCE WITH DISCRIMINANT ANALYSIS
SUMMARY WIND DATA

| Variable | Flight Condition Means | | | | |
|---|---|---|---|---|---|
| | Unaided | Force Trim | Ministab | F[1] | Standardized Canonical Wts |
| Crosswind Component[2] | 13.75 | 12.12 | 14.95 | 0.23 | -0.278 |
| Wind Direction Mean[2] | 195.28 | 229.01 | 201.42 | 0.66 | 0.034 |
| Wind Std Deviation[2] | 15.78 | 10.40 | 16.33 | 0.97 | -0.171 |
| Wind Velocity Mean[3] | 8.85 | 9.50 | 9.07 | 0.29 | -0.129 |
| Wind Velocity Std Deviation[3] | 1.72 | 1.47 | 1.90 | 2.97 | -0.367 |

Overall Multivariate Test of Significance

| Wilks Lambda | F-Ratio | df(Num) | df(Den) | Prob |
|---|---|---|---|---|
| 0.580 | 0.750 | 10 | 24 | 0.67 |

Total Discriminatory Power (Estimated Omega Squared) = 0.369

Significance Test, Individual Canonical Variables
Root I--88.64% Variance
Chi-Square = 6.11, df = 6, $p < 0.41$
Root II--11.36% Variance
Chi-Square = 0.96, df = 4, $p < 0.91$

[1] Univariate F-Ratio, df = 2/16. These F-Ratios were also not significant at the .05 level of probability.
[2] Unit of measurement--degree.
[3] Unit of measurement--knot.

TABLE 4

MULTIVARIATE DISCRIMINANT ANALYSIS OF VARIANCE
WITH DISCRIMINANT ANALYSIS

| Variable | Flight Condition Means | | | $F^1$ | Standardized Canonical Wts |
|---|---|---|---|---|---|
| | Unaided | Force Trim | Ministab | | |
| Pitch Std Deviation[2] | 0.69 | 0.80 | 0.83 | 2.05 | 0.069 |
| Roll Std Deviation[2] | 0.74 | 0.83 | 0.76 | 1.89 | 0.091 |
| Heading Std Deviation[2] | 2.70 | 3.55 | 2.44 | 1.82 | 0.058 |
| Radar Altitude Std Deviation[3] | 2.28 | 2.18 | 2.32 | 0.20 | -0.051 |

Overall Multivariate Test of Significance

| Wilks Lambda | F-Ratio | df(Num) | df(Den) | Prob |
|---|---|---|---|---|
| 0.48 | 1.41 | 8 | 26 | 0.23 |

Total Discriminatory Power (Estimated Omega Squared) = 0.46

Significance Test, Individual Canonical Variables
Root I--74.8% Variance
Chi-Square = 6.97, df = 5, p = 0.22
Root II--25.1% Variance
Chi-Square = 2.76, df = 3, p = 0.56

[1]Univariate F-Ratio, df = 2/16. These F-Ratios were not significant at the .05 level of probability.
[2]Unit of measurement--degree.
[3]Unit of measurement--feet.

TABLE 5

MULTIVARIATE ANALYSIS OF VARIANCE WITH DISCRIMINANT ANALYSIS
CONTROL INPUT PARAMETERS

| Variable | Flight Condition Means Unaided | Force Trim | Ministab | F[1] | Standardized Canonical Wts |
|---|---|---|---|---|---|
| Cyclic Fore-Aft (CFA) Control Movement Magnitude[3] | 0.35 | 0.38 | 0.27 | 11.71** | 0.037[2] |
| CFA Control Movements No of Occurrences/Sec | 0.78 | 0.75 | 0.50 | 9.63** | 0.018[2] |
| Cyclic Left-Right (CLR) Control Movement Magnitude[3] | 0.33 | 0.34 | 0.32 | 0.32 | -0.025[2] |
| CLR Control Movement No of Occurrences/Sec | 0.73 | 0.68 | 0.74 | 0.40 | -0.008 |
| Collective Control Movement Magnitude[3] | 0.27 | 0.34 | 0.43 | 0.98 | 0.007 |
| Collective Control Mov No of Occurrences/Sec | 0.02 | 0.06 | 0.04 | 2.40 | -0.013 |
| Pedals Control Movement Magnitude[3] | 0.25 | 0.30 | 0.20 | 6.57** | 0.012 |
| Pedals Control Mov No of Occurrences/Sec | 0.29 | 0.38 | 0.19 | 5.09* | -0.008 |

Overall Multivariate Test of Significance

| Wilks Lambda | F-Ratio | df(Num) | df(Den) | Prob |
|---|---|---|---|---|
| 0.084 | 2.73 | 16 | 18 | 0.02 |

Total Discriminatory Power (Estimated Omega Squared) = 0.90

Significance Test, Individual Canonical Variables
Root I--75.5% Variance
Chi-Square = 18.7, df = 9, p = 0.02
Root II--24.4 Variance
Chi-Square = 9.6, df = 7, p = 0.20

[1] Univariate F-Ratio, df = 2/16.
[2] Primary Contributor.
[3] Unit of measurement--inch.
* p = .05
** p = .01

Four of the variables examined univariately showed significant differences across the flight conditions ($p < .05$) and are so designated in Table 5. Individually, the cyclic fore-aft flight control channel demonstrated that the Ministab did indeed reduce perceptual-motor workload in that 35% fewer inputs were required during the Ministab hovers as compared to the Unaided flight condition. As well, 33% fewer inputs were required during the Ministab hover as compared to the Force Trim hover. The average magnitude of cyclic fore-aft control inputs was also smaller for the Ministab hover as compared to the control inputs during the Unaided and Force Trim flight conditions.

Pedal control inputs also indicated a significant reduction in perceptual-motor workload by aviators when hovering with the Ministab. Thirty-four percent and forty-nine percent fewer pedal control inputs were made during the Ministab hover than during the Unaided and Force Trim flight conditions respectively. As well, the average magnitude of the control movements was smaller for the Ministab flight condition.

An evaluation of the results of the control input multivariate analysis indicates that performance varied significantly across the three flight conditions ($f = 2.73$, $df = 16/18$, $p = .02$). One root accounted for the significant discrimination (chi square = 18.7, $df = 9$, $p = 0.02$) and accounted for 75% of the variance. The total discriminatory power or estimated omega squared was 0.90. A review of the primary contributors among the standardized canonical scores depicted in Figure 1 that the flight performance displayed under the Ministab condition is characterized by fewer and smaller cyclic fore-aft control movements along with slightly smaller cyclic left-right control inputs as compared to the Unaided and Force Trim flights. Statistically, the variables utilized in the control input analysis produced a significant separation between the Ministab flight condition and the Unaided and Force Trim flights as witnessed by Figure 1. The scores plotted in Figure 1 represent mean canonical scores or a composite group mean for each flight condition.

## Subjective Evaluations

The questionnaire utilized to obtain subjective/pilot opinion information about the flight evaluation provides several important points which impact the results of the study. The most important point made by several of the pilots was that the familiarization or instruction period given the pilots before flight testing (Appendix A) was not adequate for full proficiency with the system. This implies: (1) the stability augmentation system either requires greater experience than that described in Appendix A for adequate proficiency or the system is not automatically easy to master and may or may not be adequately understood and controlled with more experience with the system, and (2) the outcome of evaluation is more dependent upon level of experience with the system than was initially considered. It should be pointed out that the program of instruction received by each test subject was along the lines of that recommended by the system developers. The subjects were also equivocal about whether or not the Ministab aided or interfered with normal precision control while hovering. Five subjects stated that the system aided their hover while four considered the system an interference.

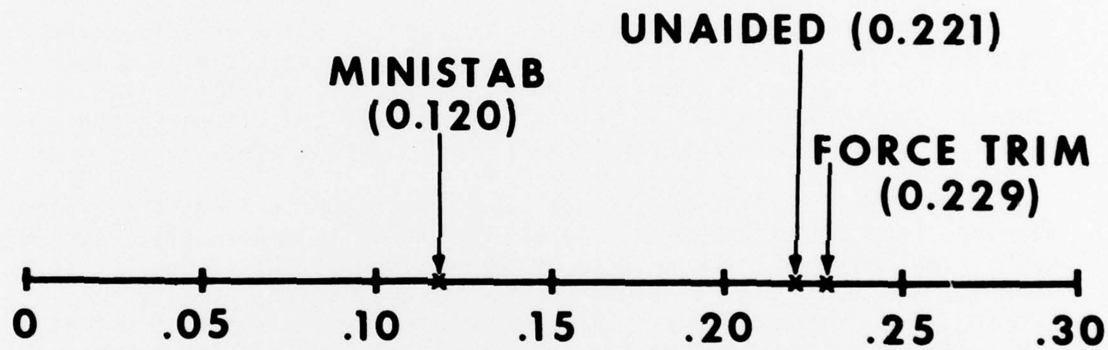



FIGURE 1 **CONTROL INPUT DATA**

**MEAN CANONICAL SCORES**

The three flight conditions were ranked by the subjects as to which gave them their best hover performance. The outcome indicated that the Ministab provided the best hover performance (mean rank = 1.44) followed by 1.78 for the Unaided condition and 2.78 for the Force Trim hover condition. The Force Trim flight condition was not the familiar or normal mode of hover for the subjects and was considered undesirable because of control stiffness and reduction in control "touch."

The results of the Cooper-Harper Handling Qualities Rating Scale which was completed by each of the subjects after each of the flight conditions revealed the following ratings:

| Mean Pilot Rating | Flight Condition |
| --- | --- |
| 3.11 | Unaided |
| 3.33 | Ministab |
| 4.33 | Force Trim |

These subjective rating data again demonstrate the very slight perceived differences between the Unaided and Ministab flight conditions--the Unaided hover condition being the least demanding followed closely by the Ministab with a larger separation occurring between the Ministab and Force Trim conditions.

It should be noted that several months prior to the investigation reported in this article, the Ministab system was evaluated by a test pilot at Fort Rucker, Alabama. Several of the test pilot's written comments about the evaluation seem to support the objective and subjective results of the current investigation (Simon, 1976).[6]

In general, the test pilot made favorable comments about the system; however, it was noted that the "pure SAS [stability augmentation system] gain in the roll axis appeared to be higher than it should be.... This tendency was noted several times during the evaluation, usually occurring in a climbing turn." In addition, the test pilot stated that "the length of time required for the 'automatic fly-through' process or synchronization (where the controls are moved a small amount and held momentarily without depressing the mag brake button) was acceptable for up and away/cruising flights although a little learning was necessary to adapt to the time lag. However, this 'syncro time lag' was excessive in the hover regime probably due to the frequency of control inputs required for holding a position over the ground. It was noticed that a sizable number of corrective control inputs were made which did not cause or allow the system to synchronize itself."

The test pilot suggested a reduction in time lag "which should further reduce pilot workload." It is reported that this time lag reduction was accomplished before the current investigation. However, it is possible that the reduction was not sufficient and coupled with the excessive gain in the roll axis, which was mentioned earlier, these two factors could have produced the reduction in effectiveness of the Ministab (equivalence seen in the number of control inputs per second and magnitude of movement across the three flight conditions) along the cyclic left-right control dimension. No gain problems were noted by the test pilot along the pitch axis which corresponds to the reduced number of control inputs observed in the cyclic fore-aft control dimension for the Ministab condition relative to the Unaided and Force Trim conditions (Table 5).

## CONCLUSIONS

In conclusion, under the set of conditions that existed during the evaluation, the stability augmentation system examined did not provide a significant change in aircraft stability. More completely, aircraft status maintenance was essentially equivalent across all three flight conditions.

The multivariate analysis data indicated that statistically the Ministab did reduce the overall control activity requirements for the aviators. However, performance on the collective control was essentially equivalent across the flight conditions in terms of both movement magnitude and number of inputs. This equivalence should be expected because, as mentioned earlier, the attitude hold mode was inoperative during the study. Although the aviators tested were aware of this, their opinion of the Ministab was based upon the total performance requirement which included collective control activity.

Another factor which could relate to the lack of perceived differences between the Ministab and the Unaided condition was the cyclic left-right control input data which indicated no differences in magnitude and number of inputs across the three conditions. Obviously control inputs made in the helicopter are a vector reflecting both left-right and fore-aft components, but because of measurement requirements the control inputs are described independently in terms of fore-aft and left-right activity. An integration of the fore-aft and left-right information could indicate whether or not more workload is experienced on the cyclic control under one or another of the flight conditions. However, the key issue here is that the stability augmentation sytem evaluation did not, under the conditions tested, provide a clear-cut improvement in flight performance and workload across all flight control parameters. This position is supported by the results of the questionnaire as well as the Cooper-Harper rating data. It is quite possible that given a much higher degree of experience on the part of the test pilots with the Ministab, along with more turbulent conditions, the Ministab could produce a more stable platform for hover operations, medical hoist, weapons delivery, etc., and provide a substantial reduction in control activity requirements for the pilot. Future research at the US Army Aeromedical Research Laboratory will examine state-of-the-art improvements in stability augmentation systems in order to provide information which will enable the pilot to maximize his capabilities, enhance mission accomplishment, and extend the pilot's effective performance range in continuous operations.

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## APPENDIX A

Ministab Training (POI) Time: 30-60 minutes

a. Preflight--Point out basic components of system associated with the preflight of test aircraft (static stops, computers, radar alt).

b. System Description--To familiarize pilot with internal (cockpit) controls of ministab system, i.e., control head, circuit breakers, cyclic, and collective control surfaces (gray control box familiarization).

c. System Operation--To point out system capabilities and limitations. Explanations to include emergency procedures of (1) primary system, (2) yaw axis, and (3) LORAS (low airspeed indicator).

d. Pilot Familiarization and Technique--Purpose is to allow pilot to become comfortable in utilizing system.

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