VOL. 16, NO. 11, NOVEMBER 1979 J. AIRCRAFT

ARTICLE NO. 78-1573R

Effects of Helmet Loader Cues on Simulator Pilot Performance

B. R. Ashworth* and B. T. McKissick†
NASA Langley Research Center, Hampton, Va.

In high-performance aircraft, the *g* forces on the pilot's helmet provide important feedback concerning the aircraft's dynamic state, as well as limiting the pilot's ability to move his head when the *g* forces are high. A helmet loader has been designed to provide the effects of these forces in aircraft simulators. The design is such that the forces applied to the helmet are independent of the pilot's head and shoulder position. The device is easily installed in a simulator cockpit, quickly attaches to the pilot's flight helmet, and is safe for use in simulators. The helmet loader has been installed in Langley Research Center's differential maneuvering simulator (DMS) and subjectively rated as providing realistic forces on the head and shoulders during high *g* simulator tasks. In order to determine the effect of the helmet loader on a pilot's performance, an experiment was performed in the DMS, consisting of a tracking task using an F-14 aircraft simulation. Pertinent system states were recorded and analyzed using univariate and multivariate statistical algorithms. Analysis of the data indicates that pitch control increases significantly during the transition phases of the task when the helmet loader is activated. Overall, the variation in the performance measures are reduced under the helmet loader activated condition, indicating more precise control of the aircraft simulator for this task.

Introduction

PROVIDING the motion-induced (kinesthetic) cues which the pilot uses in control of the aircraft has always been a concern in piloted-aircraft simulations. This concern is magnified in high-performance aircraft simulations where the pilots tend to rely more heavily on these motion-induced cues. Simulator engineers have historically used various devices in an effort to provide realistic cues to the simulator pilot. At Langley Research Center such devices have included *g*-suits, arm harnesses, *g*-seats, control loaders, blackout/grayout controls, and cockpit buffet as well as motion-based cockpits. Another very important kinesthetic cue to the pilot is the increased load on the neck and shoulders, due to the increased weight of the head/helmet combination.[1] Helmet loaders have had very little utilization to date, primarily due to the problem associated with providing the proper cue without other false cues, such as the restriction of head motion.

A helmet loader has been designed and tested in Langley's differential maneuvering simulator (DMS), which provides the proper cues without restricting the pilot's movement or requiring cumbersome attachments. The loader follows the pilot's movement, while providing the proper forces, and requires only two small strings to be snapped to the helmet. An experiment was conducted to determine the effect of the loader on both Langley test pilots and operational F-15 pilots. Both the objective and subjective data from the experiment was used to determine the effect of the helmet-provided acceleration cues on the simulator pilot's performance.

Presented as Paper 78-1573 at the AIAA Flight Simulation Technologies Conference, Arlington, Texas, Sept. 18-20, 1978; submitted Dec. 18, 1978; revision received April 26, 1979.

Index categories: Simulation; Research Facilities and Instrumentation; Human Factors.

*Aero-Space Technologist, Analysis and Simulation Branch, Analysis and Computation Division. Member AIAA.

†Aero-Space Technologist, Analysis and Simulation Branch, Analysis and Computation Division.

Helmet Loader Design

The helmet loader is designed utilizing force feedback in order to follow the pilot's movements while providing proper helmet forces. Figure 1 shows the helmet system, as installed in the DMS cockpit, and Fig. 2 shows the design in schematic diagram form. The two small pulleys attached to the pilot's shoulder straps provide loosening of the straps as force is exerted downward on the helmet for positive *g*. The excess cable between the helmet and the force transducer allows for unrestricted turning of the head, while the torque motor has sufficient cable wound on its reel to allow for all body and head movements of the pilot.

The helmet loader is essentially a 0.4 damped second-order system with a 20 ms steady-state time delay. Full amplitude sine and triangular response data are plotted in Figs. 3 and 4 for commands representative of changes in normal acceleration of 1-6 *g* in 1 s, which is representative of current high-performance aircraft. Figure 5 shows a 50% step with a 0-90% response time of approximately 50 ms.

The helmet loader has been initially scaled to exert 40 N (9 lb) of force at the selected full-scale command of 6 *g*. The loader uses breakaway snaps on the helmet, current and voltage limiting, and small torque motors to insure that the pilot does not experience excess forces.

Simulation Facility

The helmet loader was installed in NASA Langley's DMS in order to carry out this study. The DMS provides a realistic means of simulating two aircraft or spacecraft operating in a differential mode and has a wide field of view visual display where all servos involved in projecting the visual scene are synchronized with a 0.7 damped, 25 rad/s second-order transfer function. An F-14 simulation was used as the test aircraft. A more detailed description of the DMS is given in Ref. 2.

Statistical Analyses and Experiment Design

Experimental Task

A tracking task (approximately 70 s in length) was used in performing the experiment. The target aircraft was driven by a taped maneuver consisting of a 3 *g* windup turn at a constant airspeed of 325 knots. The pursuit aircraft was required

Fig. 1 Helmet loader installed in DMS.

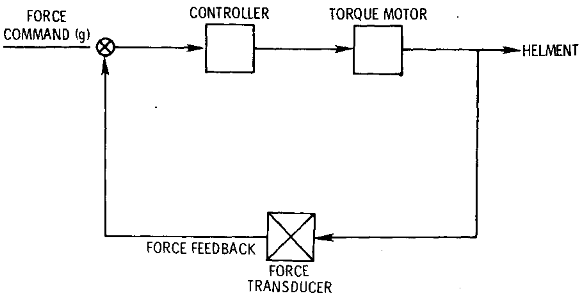

Fig. 2 Helmet loader controller.

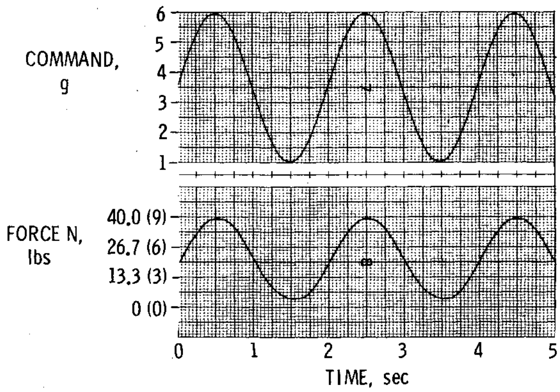

Fig. 3 Sine response.

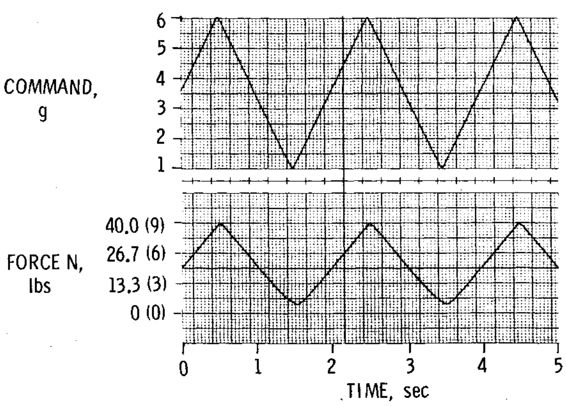

Fig. 4 Triangular response.

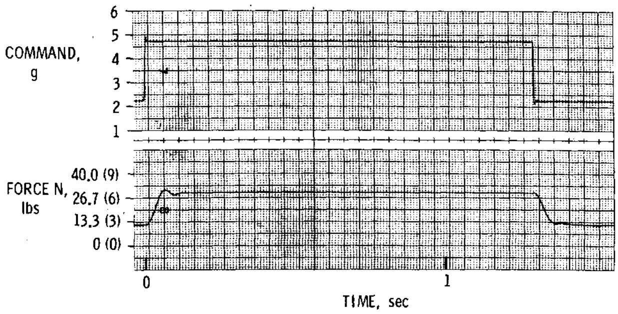

Fig. 5 Step response.

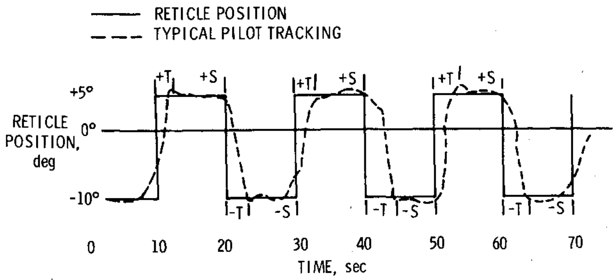

Fig. 6 Structure of one computer run.

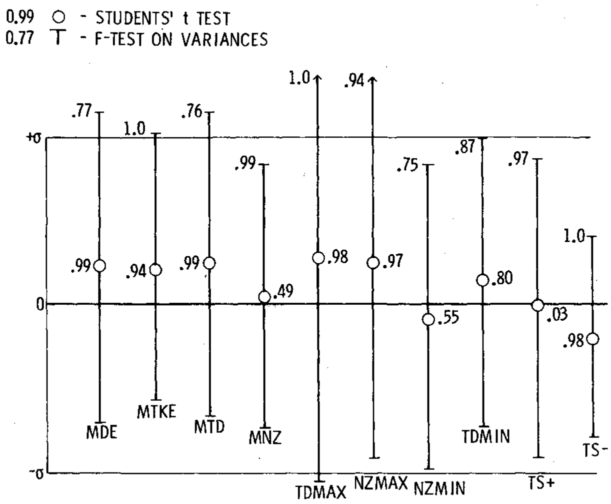

Fig. 7 Normalized longitudinal measures for negative transition.

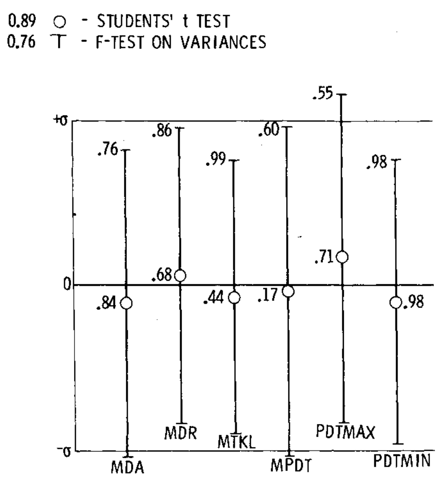

Fig. 8 Normalized lateral measures for negative transition.

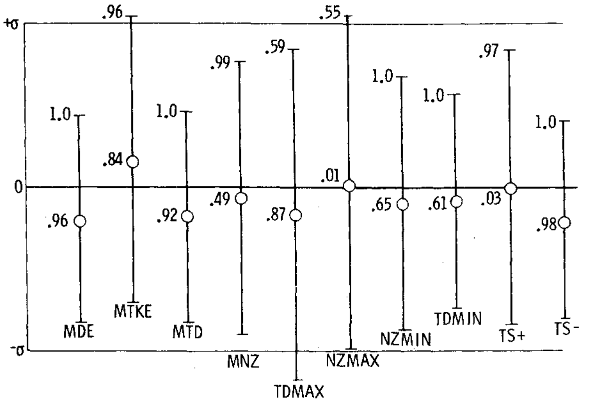

Fig. 9 Normalized longitudinal measures for positive transition.

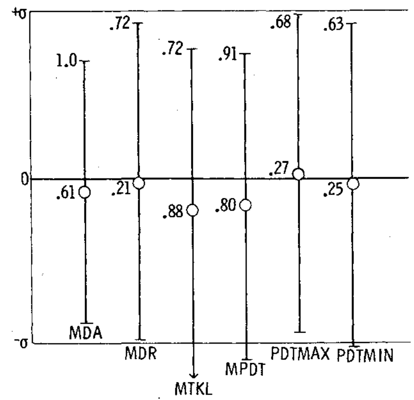

Fig. 10 Normalized lateral measures for positive transition.

to track the target while maintaining a 457 m (1500 ft) range. During the task, the pursuit pilot's tracking reference (reticle) was switched from a 10 deg lead position to a 5 deg lag (decreasing *g*) back to a 10 deg lead (increasing *g*). These changes in reticle position (occurring every 10 s) forced the pilot to reacquire the target after each change in the tracking reference (Fig. 6), thus increasing and decreasing "*g*" from the nominal 3 *g* point. Range information was provided by a standard reticle range analog bar scaled for 914 m (3000 ft). This caused the required 457 m (1500 ft) range to appear at the 6 o'clock tab.

Subjects and Procedure

Two groups of pilots were used as test subjects in this study. The first group considered of two Langley test pilots with many hours in fighters and simulators. These two test pilots were used during the helmet loader developmental phase and, as a result, were very familiar with this simulation. The second group consisted of five F-15 pilots with no experience flying this simulation. The amount of flight time in high-performance fighter aircraft varied from a pilot just out of flight school to those having several thousand hours of flight time.

The experiment was conducted by flying the task in sets of 10 70-s runs. Each set of 10 runs (a session) consisted of 10 randomly chosen runs—5 with the helmet loader actuated, 5 with the helmet loader deactivated. During this experiment,

Table 1 Longitudinal and lateral performance measures

Longitudinal
Mean stick deflection for pitch, MDE
Mean vertical track, MTK
Mean pitch rate, MTD
Mean normal acceleration, MNZ
Maximum pitch rate, TDMAX
Minimum pitch rate, TDMIN
Maximum normal acceleration, NZMAX
Minimum normal acceleration, NZMIN
Positive transition time, TS+
Negative transition time, TS−
Lateral
Mean stick deflection for roll, MDA
Mean rudder deflection, MDR
Mean lateral track, MTKL
Mean roll rate, MPDT
Maximum roll rate, PDTMAX
Minimum roll rate, PDTMIN
NZMAX
NZMIN
TS+
TS−

the *g*-seat and *g*-suit systems were inactive; however, the control loader and cockpit buffet systems were active. Each pilot was allowed three to five practice runs (with the helmet activated) to familiarize himself with the simulator and task. After the practice runs, each pilot flew two sessions per day. Previous experience indicated that two sessions were about the maximum amount of time a pilot could fly this task before his performance started to deteriorate due to fatigue. Each member of the first group flew a total of seven sessions, while each member of the second group flew a total of four sessions. The first two sessions for each pilot were treated as learning sessions and the remaining sessions were used to analyze the experiment.

Performance Measures

During each data run, 11 state variables were recorded every 1/16 s. Variables recorded were vertical tracking error (TKE), lateral tracking error (TKL), total tracking error (TKC), normal acceleration (NZ), pitch rate (TD), roll rate (PDT), range to target (RT), longitudinal stick deflection (DE), lateral stick deflection (DA), rudder pedal deflection (DR), and time (t). In order to calculate the performance measures, the tracking task was broken down into four basic phases, as shown in Fig. 6. These phases are: 1) transitioning from −10 deg (lead) reticle setting to +5 deg (lag) reticle setting (positive transition, denoted by +S), 2) tracking at +5 deg reticle setting (positive tracking, denoted by +S), 3) transitioning from +5 deg reticle setting to −10 deg reticle setting (negative transition, denoted by −T), and 4) tracking at −10 deg reticle setting (negative tracking, denoted by −S). The pilot is considered to have transitioned when the vertical tracking error reaches 80% of the required value (−10 or +5 deg). Four measurement calculations (arithmetic mean, variance, maximum, and minimum) were applied to the four parts of the task to develop the measures as shown in Table 1.

Statistical Analyses

The univariate analyses include *F*-ratio test and the student's t-test for paired data. The multivariate analyses included Hotelling's T^2 and linear discriminant analysis for paired data. In each of the tests, performance measures were tested under the helmet-activated condition vs the helmet-deactivated condition. As previously mentioned, the first group flew five sessions for analysis, while the larger second group flew two sessions for analysis. This resulted in 150 replicates of a performance measure for each of the two helmet conditions.

Results and Discussion

The results for both sets of pilots are similar; therefore, only the data from the five F-15 pilots will be presented.

The performance measures for the helmet-activated data (Figs. 7-14) are normalized with respect to the data for the helmet-deactivated condition. The center horizontal lines of the figures represent the means of the performance measures for the helmet-deactivated condition. The two outer horizontal lines represent the 1σ limits of the performance measures for a deactivated condition. The vertical lines represent the 1σ limits and mean of a performance measure for a helmet-activated condition. The numbers on the figures give the α levels at which the F-test (upper numbers) and paired student's t-test (lower numbers) are significant. Figure 9, for example, indicates that the mean stick deflection for pitch during a positive transition (MDE +T) is significantly lower ($\alpha = 0.96$) when the helmet loader is activated. The variance of this performance measure for positive transition is reduced significantly ($\alpha = 1$) when the helmet loader is activated, as compared to when it is not activated.

Examination of the univariate analysis (Figs. 7-14) shows that the helmet loader had more effect on pilot performance during the transition periods of the task. In particular, the effect of the helmet loader shows up mainly in the longitudinal axis. Significantly more pitch control (MDE) is applied when the helmet loader is activated (a mean is judged to be significant if $\alpha \geq 0.9$). This results in significantly more pitch rate (MTD) during a negative transition and significantly less MTD during a positive transition. Other measures that show significant mean differences during a negative transition are TDMAX, NZMAX, MTKE, and TS−. The most apparent effect, however, is not the mean differences, but a significant lowering of the variance when the helmet loader is activated. Fifteen out of thirty measures for the transition portion have significantly lower variances. Of the measures that are not significantly lower, only two have significantly higher variances (TDMAX and NZMAX for negative transition) and there is no statistical difference in the remaining measures. Therefore, although more control is used when the helmet is activated, the pilot exhibits less variation in their control inputs during a transition.

A similar trend is evident in the tracking portion of the task. But this time more significant results appear in the lateral axis. The variation in lateral stick input (MDA) is significantly reduced for positive and negative tracking. Other measures that show reduced variance for the lateral axis are MDR, MTKL, and PDTMAX for positive tracking. MDA and MPDT show reduced variances for negative tracking. Hence, with the helmet loader activated, there is less variation in the pilot's roll input while tracking.

While the most important result from the univariate analyses is reduced control variation, the measure that most strongly differentiates between helmet-activated and unactivated is TS−. The pilots performed negative transitions significantly faster on the average (3.05 vs 3.22 s) when the helmet loader was on. There was also reduced variation in the negative transition time. The importance of TS− is also reflected in the multivariate analysis.

In the multivariate tests, two basic groups of ten performance measures were analyzed: one primarily for the longitudinal degree of freedom, the other for the lateral degree of freedom. The performance measures for these groups are given in Table 1. Initially all ten measures were analyzed. Next, based on the discriminant analysis, the dimension (number of measures) was reduced and the remaining measures were reanalyzed. The results of the reduction in dimension is given in Table 2. It can be seen that TS− ranks high in all the groups. The two groups for the negative transition provide the strongest differentiation between helmet loader on the helmet loader off; the probabilities of these two groups (0.971,0.978) are higher than the probabilities for any other group. In the four groups for the transitions, the measures contributing most to

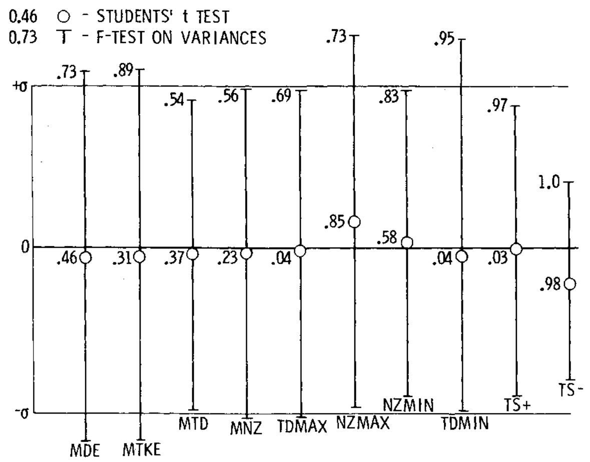

Fig. 11 Normalized longitudinal measures for negative tracking.

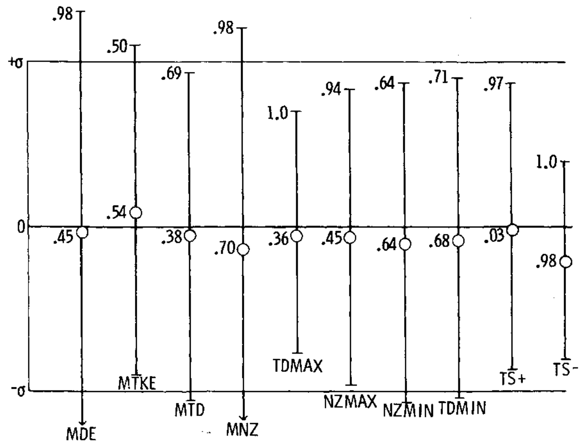

Fig. 13 Normalized longitudinal measures for positive tracking.

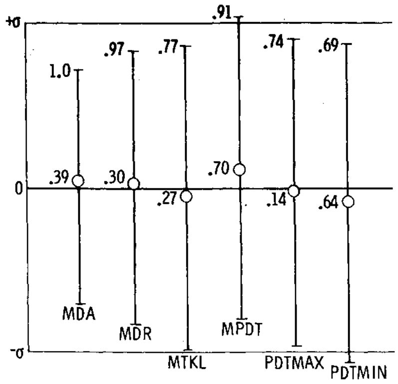

Fig. 12 Normalized lateral measures for negative tracking.

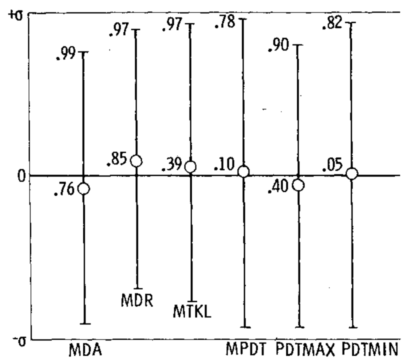

Fig. 14 Normalized lateral measures for positive tracking.

Table 2 Results of multivariate analyses

Group	+ T Task	Probability	Group	+ S Task	Probability
Longitudinal	MTD TDMIN TS – MDE MNZ	0.972	Longitudinal	TS – TDMAX NZMIN TDMIN	0.921
Lateral	TS – PDTMIN PDTMAX	0.930	Lateral	TS – MDR NZMIN	0.956
Group	**– T Task**	**Probability**	**Group**	**– S Task**	**Probability**
Longitudinal	MTD TDMIN NZMIN TS – MTK TDMAX MDE MNZ	0.971	Longitudinal	NZMIN TS – NZMAX TDMAX MNZ TDMIN	0.939
Lateral	TS – PDTMIN NZMIN MPDT	0.978	Lateral	TS – NZMIN MTKL MPDT	0.946

distinguishing between helmet loader activated and helmet loader deactivated are TS –, MTD, TDMIN, and PDTMIN. All of these performance measures, with the exception of TS –, are highly correlated (0.7 or greater) with control activity. TS – indicates that the helmet loader is providing a cue that enables the pilots to transition faster during the negative transition. This is not surprising since the strongest normal acceleration cue should be during a negative transition when the pilots are increasing their *g* loads.

Conclusions

Analysis of the simulation data indicates that the helmet loader does have measurable effect on the pilot/simulator system. The effect is mainly seen in the transition portion of the task. The pilots significantly increase their control outputs for pitch, which causes a significant increase in aircraft pitch rate. This is accomplished while more precise control of the aircraft is being executed. A significant reduction in the variances of 50% of the measures for transition indicates more precise control of the simulator aircraft. An effort is underway to obtain flight data for this same task in order to reference these variations in control to those measured in actual flight. Subjective data indicate that the cue provided through the use of the helmet loader is realistic, and there is not noticeable time delay in the presentation of the cue. However, the pilots had mixed opinions about the effect of the helmet on their performance. Tests to determine the effect of the helmet loader on the linear pilot transfer function and an experiment in which the helmet loader and *g*-seat[3] are used together are planned.

References

[1] Kraemer, K. H. and Kennedy, K. W., "Involuntary Head Measurements and Helmet Motions During Centrifuge Runs With up to + 6 Gz," *Aerospace Medicine*, Vol. 44, June 1973, pp. 639-644.

[2] Ashworth, B. R. and Kahlbaum Jr., W. M., "Description and Performance of the Langley Differential Maneuvering Simulator," NASA TN D-7304, 1973.

[3] Ashworth, B. R., McKissick, B. T., and Martin Jr., D. J., "Objective and Subjective Evaluation of the Effects of a G Seat on Pilot/Simulator Performance During a Tracking Task," Presented at the Tenth NTEC/Industry Conference, Orlando, Fla., Nov. 1977.