Human Pilot Performance during Boost and Atmosphere Reentry

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TO simulate the acceleration histories for boost and extreme emergency re-entries of an X-15 altitude mission, a centrifuge program was conducted during the months of March and April, 1957, by North American Aviation, and the U.S. Navy, in cooperation with the U.S. Air Force and the National Advisory Committee for Aeronautics. Its purpose was to provide information regarding complex, oscillating, variable-direction acceleration patterns. The accelerative conditions were predicted from analogical computer studies accomplished at North American Aviation.

The specific objectives of the program were to (1) compare and evaluate pilot performance, using center and right-hand stick configurations, in controlling the air vehicle during varied accelerations; (2) evaluate the proposed X-15 armrest and other design configurations to reduce involuntary pilot input to either control system due to the acceleration environment; and (3) evaluate integrated harness, head restraint, and general physiological tolerance aspects during the special and unusual accelerative conditions.

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METHOD

The aircraft motions programed in the centrifuge were those predicted for boost and emergency re-entry conditions. The reentries represented the maximum predicted accelerations induced by the conditions of (1) complete failure of the control augmentation system, (2) gross disturbance and/or out-of-trim at start of the re-entry maneuver, (3) design load factor pullout, and (4) dive to maximum dynamic pressure.

The centrifuge may be considered as having three degrees of freedom, viz., the angular motion of the arm and the motions of two gimbals about two axes with reference to the arm.[1] Each of the three degrees of freedom was programed by a cam, cut in accordance with the acceleration history. The cam provided an electrical signal to an amplidyne which, in turn, was fed to the rotational speed control or to one of the gimbals depending on the cam in question. In this manner, oscillatory accelerations along the three axes of the airplanes were simulated.

A standard center stick and an experimental right-hand stick were used for comparative purposes in this program. The right-hand stick was designed so that the pilot's wrist would serve as the pivot point of the control system. The force gradients used with each of these sticks were decided upon during early simulator tests in order to provide realistic control systems for this program.

The tracking task display consisted of a horizontal line on the face of a cathode ray oscilloscope which moved vertically to indicate pitch, and rotated about its center to indicate roll. This line was driven by a combination of random disturbances, programed normal accelerations, and pilot inputs. The subject was required to hold the display at zero degrees in pitch and roll angles, and any deviation from the horizontal-center position would represent a tracking error. The subject, therefore, was able to see his own tracking error on the scope face. The task, however, was synchronized so that the line on the scope would closely follow the accelerations being simulated.

There were two control ratios between stick and display displacements used for these tests. The first was a "direct" ratio between stick deflection and display response; and the second incorporated an approximation of the aircraft aerodynamics. The latter was termed the "dynamic" ratio and had an approximate 0.2-second delay in the display response. For the purposes of this paper, only the dynamic results will be discussed. It should be noted that the results were similar for the "direct" ratio tests.

PROCEDURE

Two predicted X-15 missions, each combining boost and extreme emergency conditions of reentry, were chosen for centrifuge simulation. In reentry A, the pilot made a normal pull-up maneuver with a resulting positive acceleration of 6.5 G. In the reentry B, the pilot first slowed the vehicle by using speed brakes causing a back-to-front acceleration of 3 G followed by a normal pull-up resulting in a combined back-to-front, head-to-seat acceleration of 9 G. In each case oscillatory motions were superimposed to represent more fully the extreme emergency conditions noted earlier.

The boost condition was a typical rocket acceleration build-up to about 4.5 G in the front-to-back direction. Each test run consisted of a time-based mission profile with the boost, weightless period, and emergency reentry in proper sequence. During weightless period subject was seated in normal 1 G position for proper time interval.

Each of the five subjects was scheduled for sixteen test runs which included four with right hand stick (condition A); four with center stick (condition A); four with right hand stick (condition B); and four with center stick (condition B).

Upon recommendation of the project medical officer, tests were made in series of four test runs per experimental session. Conditions were alternated for each subject every four test runs,[2] two subjects starting with condition A, three subjects with condition B. The use of control sticks was scheduled as follows: R, right hand stick; C, center stick; (a), RCCR; and (b), CRRC. Three subjects started with (a) and two subjects started with (b). This procedure was repeated throughout the four experimental sessions. Data were recorded for static (1 G) tracking performance for each control configuration and each experimental condition.

RESULTS

The ten subjects included four test pilots, two flight surgeons, two aviation physiologists, and two psychologists. A total of 168 runs were made, 70 of which were completed by five subjects using the "dynamic" control ratio. The remaining runs were utilized by a total of ten subjects for "direct" control ratio, orientation and safety-type runs.

Figure 1 summarizes the mean integrated error in millimeters per second, as recorded for roll. Note that there is consistently more error when using the center stick both at 1 G and during acceleration and, for reentry A, there was less error with the right-hand stick during acceleration than with the center stick at 1 G.

Figure 2 summarizes the mean integrated error in millimeters per second, as recorded for pitch. Note, as was shown for roll, that there is consistently more error when using the center stick both at 1 G and during acceleration and, for reentry A, there was less error with the right-hand stick during acceleration than with the center stick at 1 G. Tape recordings were made of pilot comments after each run, for qualitative evaluation. Examples of these comments are as follows:[2,3]

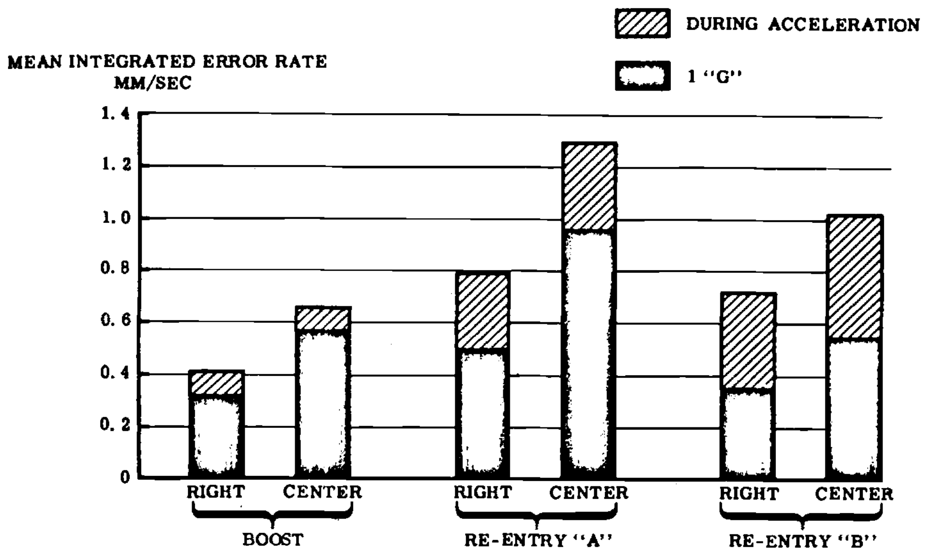

Fig. 1. Tracking error for control sticks and experimental conditions as measured in roll.

1. The force gradients, friction, breakout, and throws of the center stick showed need for further optimization. The right-hand stick, however, was generally better in these respects.

2. The work required to hold the arm against the G-load when using the center stick was tiring and difficult. Moreover, there were more occurrences of "tingling," when using the center stick, and stabilizing the arm against the knee was difficult with the throws required.

3. All subjects agreed that there was less work to control with the right-hand stick,

but that some modifications were required on the armrest configuration.

4. All subjects agreed that the right-hand stick provided a support to "hold on to" during acceleration, and felt more secure in the seat when using it.

A statistical analysis of performance measures, by the analysis of variance method, revealed no statistically significant differences between control sticks as measured in pitch for either reentry condition. A significant statistical difference, at the .01 level, was found for subjects and control sticks as measured in roll. It was determined from visual inspection of the data that the roll variability was due to the non-pilot members of the subject sample. As an overall observation, therefore, it would appear that for a test pilot sample there was no statistically significant differences in tracking performance between the two control configurations or two reentry conditions. As was noted earlier, however, there was a small but consistent difference in favor of the right hand stick.

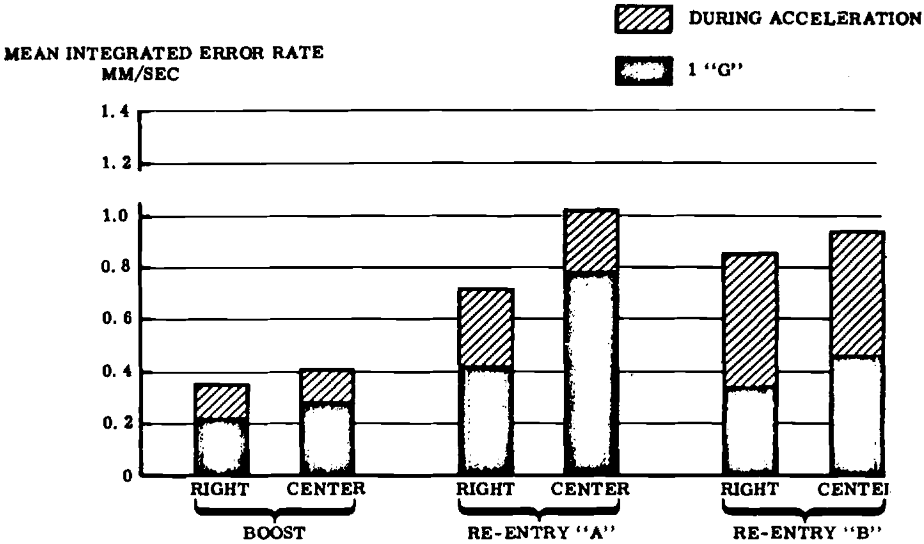

Fig. 2. Tracking error for control sticks and experimental conditions as measured in pitch.

DISCUSSION

A great amount of learning was indicated by the tracking results and by comments of those individuals who took part in the tests. Since there was a combination of three different major accelerative conditions, two different stick configurations, and two different control ratios involved in the program, concise statements regarding learning characteristics are difficult to make. One example, however, can be shown to illustrate these aspects.

Figures 3 and 4 present the tracking results for one subject during reentry conditions A and B, for center and right-hand sticks with dynamic control, as measured in roll and pitch, respectively. Prior to these runs, the subject (a non-pilot) had adequate 1 G experience with both sticks and six accelerative sessions with reentry condition B.

The last four runs shown in Figures 3 and 4 were the first of this type (reentry A) to be experienced by this subject, and therefore, it indicates that there is greater transfer of tracking ability with the right-hand stick when experiencing a different accelerative condition for the first time. To generalize, it might be said that the subject will perform more effectively with the right hand stick during varying or

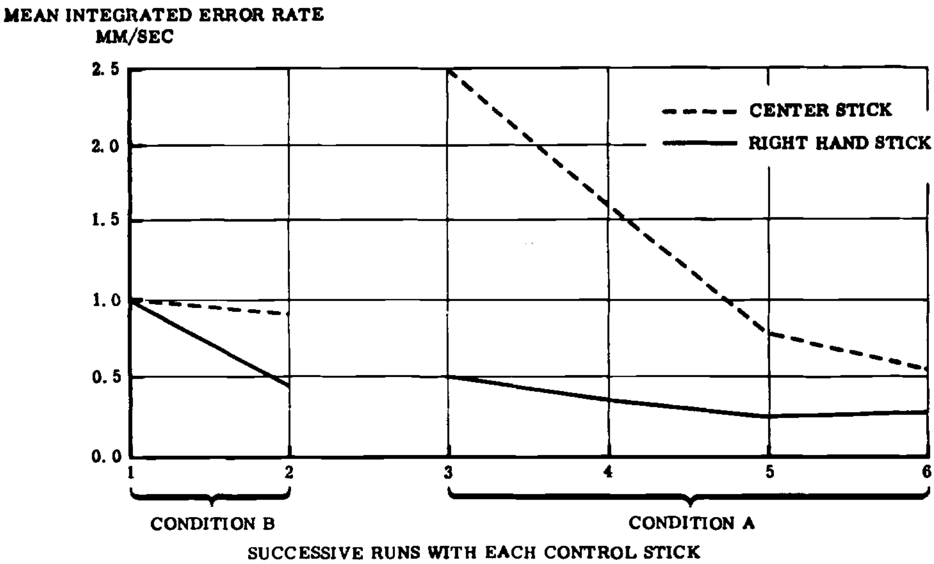

Fig. 3. Transfer of learning as measured in roll.

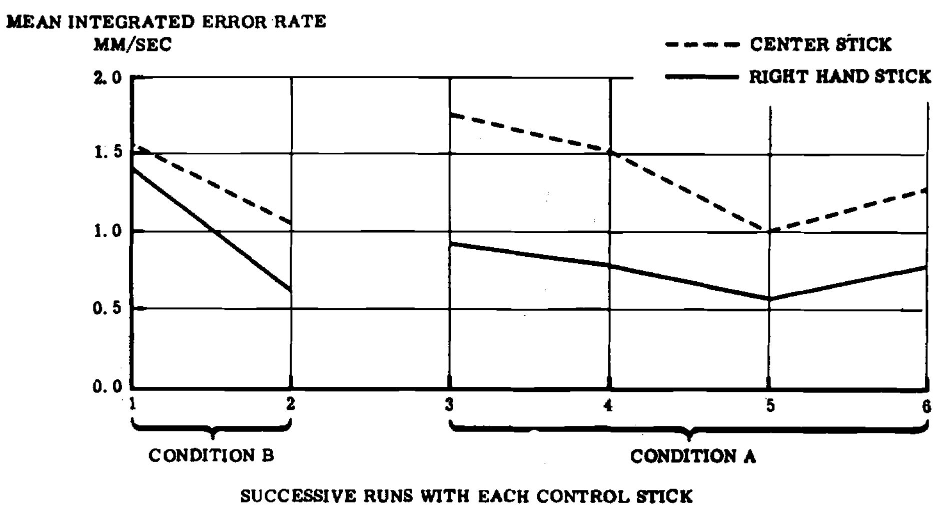

Fig. 4. Transfer of learning as measured in pitch.

unexpected G conditions because of a more positive transfer of learning with that stick. It is also indicated, however, that with sufficient practice a subject is able to track almost, if not equally, as well with the center stick.

For the purposes of this report, the following general conclusions are made:

1. No physiologic limits were encountered during either of the boost or reentry conditions tested. It was demonstrated that "worst condition" accelerations, representing the maximum design limits of the aircraft, are within the physiologic tolerance of a pilot in good physical condition with conventional G protection.

2. The tracking results for both direct and dynamic ratios have shown that performance with the right hand stick is consistently better than that with the center stick although a statistically significant difference between the two was not found.

3. Subject's comments indicated a preference for the right hand stick principally due to the amount of physical effort required to properly operate the center stick under acceleration as compared to the right hand stick.

ACKNOWLEDGMENT

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Weightless Meals

Pre-ingestion truly presents a problem under conditions of weightlessness. When one considers assembling a traditional meal on a plate under conditions of weightlessness, the aspect is awesome. Imagine opening a package of corn flakes and envision each little corn flake suspended between container and bowl, assuming, of course, that the bowl is fastened to something and is not also floating. Can one even predict how milk poured in a container will act? Will it pour or fall as a lump, or remain glued to the container? Consider another meal—lunch. Perhaps a sandwich is the answer, since the filling would be contained between bread and shepherded to the mouth by hand. At any rate, in this situation of weightlessness, meals would certainly not be of the type to which we are accustomed.—Jane C. Ebbs: Space Nutrition, *Journal of the American Dietetic Association*, January, 1959.