STUDY OF CONTROL FORCE LIMITS FOR FEMALE PILOTS

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University of Oklahoma, College of Engineering, and Federal Aviation Administration, Office of Aviation Medicine, Civil Aeromedical Institute, Oklahoma City, Oklahoma. **STUDY OF CONTROL FORCE LIMITS FOR FEMALE PILOTS** by Robert C. Leeper, A. Howard Hasbrook and Jerry L. Purswell, Ph.D., December 1973, 30 pp. Report No. **FAA-AM-73-23.**

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Female Pilots
Aviation Safety

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16. Abstract

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STUDY OF CONTROL FORCE LIMITS FOR FEMALE PILOTS

I. Introduction.

During flight a pilot experiences a number of different conditions under which he must apply forces to the aircraft controls. In some instances an application of force for only a few seconds is necessary to perform a maneuver or to bring the aircraft under control. In others it may be necessary for the pilot to exert forces over an extended period of several minutes in order to maintain control of the aircraft. These forces may be exerted on one control alone or on various combinations of controls simultaneously. At certain times they may be small while in other situations applications of very large forces close to the limits of the pilot's maximal strength may be required.

The present regulation specifying control force limits for the type of light aircraft flown by general aviation pilots is given in Part 23, Subpart B, Section 23.143, of the Federal Aviation Regulations (FAR 23.143). This regulation uses the words "temporary" and "prolonged" to designate the two time periods of force application, but does not specifically define them, nor does the regulation state whether one or two hands are to be used on the controls to maintain the specified forces. Some critical flight situations require the use of only one hand on the controls. No information is available concerning the origin of the control force limits specified by this regulation, thus we cannot judge their validity with respect to the physical capacity of the general aviation pilot population or to a realistic flight situation.

Previous studies by VanOosterom (1959) have shown that a pilot's ability to exert force on an aircraft control decreases with the amount of time he is required to maintain that force. In a previous study of female pilot endurance by Karim (1972), "temporary" forces were measured in terms of each subject's maximal effort on any given control. However, the term "temporary" has since been clarified by a memorandum (15 February 1972) from the Flight Test Branch, Flight Standards Service of the Federal Aviation Administration as a period of up to 20 seconds for control of pitch and roll and up to 30 seconds for control of yaw. In the present study selected levels of force were presented to each subject and the subject attempted to maintain the aircraft in a safe attitude for as long as possible. These levels of force were based on the findings of Karim (1972) and chosen to provide periods of force application from several seconds to seven minutes.

The lack of clarity and validity in the present FAR 23.143 requirement was recognized by the Flight Standards Service of FAA and the need was expressed to develop a program of strength tests that would accurately measure the strength endurance capabilities of a pilot in flight. Data from preliminary in-flight studies by Paul (1970) and ground-based studies by Karim (1972) suggested that maximal forces specified by FAR 23.143 were too high for most female pilots. Paul compared FAR 23.143 with two similar regulations: the British Civil Airworthiness Regulation, BCAR K2–6 3.4, and the U.S. Military Regulation, MIL–F–8785 B, "Flying Qualities for Piloted Airplanes," and found that the control forces specified in FAR 23.143 are generally higher. The control forces specified by BCAR K2–6 3.4 and MIL–F–8785 B are substantially lower than those specified by FAR 23.143 for aileron and elevator; rudder forces are approximately equal for the three regulations. All three regulations are shown in Appendix B of this report.

The need for a study of strength endurance capabilities of pilots while maintaining an aircraft in a safe attitude has been recognized for many years. However, most work specifying control force limits used male subjects who were tested for maximum static strength (no movement of controls possible). This work is described in reports by Hertel (1930), Gough and Beard (1936), McAvoy (1937), Morgan and Thomas (1945), and Watt (1963). Their results are of rather small value here because the subjects were not required to hold a force for any extended time interval as would a pilot executing a maneuver in an aircraft. Others have tested male subjects for static strength over varying periods of time while the subject was required to maintain the force he was exerting between two force limits. This work is described in reports by Scheffer and Marx (1941) and Van-Oosterom (1959). These reports are discussed in detail in a previous OAM report by Karim (1972).

By testing the strength endurance of subjects in a flight simulator, it was possible to give them flight-related tasks to perform while they were opposing a specific load on a specific control. Birmingham and Taylor (1954) stated that in piloting an aircraft the human acts as an error detector. When an error is detected on a display, the human applies a force to one or more controls to reduce that error. All displays used in this study offered the subject continuous feedback information which should result in the least tracking error and the most quickly stabilized learning curve as reported by Hunt (1961). Rogers (1970) reported that control operators quickly learn the "feel" of a control; that they balance its spring loading, damping, and inertia against the excursion they wish to make. The subjects in this study were given practice in tracking with the displays and controls in the simulator, and before the first strength endurance trial began each subject was able to keep the display deviations to less than 50 percent of the limits of a safe attitude as defined in this study.

At present there are approximately 29,000 female pilots: 7 percent of the total of U.S. general aviation pilots. With the exception of a study by Karim (1972) no data have ever been taken which would accurately represent the strength endurance capabilities of female pilots, yet they form a significant percentage of the pilot population. In addition, none of the previous data applies to actual flight conditions or reflects a pilot's ability to exert large forces for a prolonged period of time. Further research is definitely needed in order to specify realistic control force limits for light aircraft.

II. Method.

A flight simulator and a strip chart recorder were used as the basic equipment in this study to monitor outputs from the simulator, and were housed in the simulator building of the FAA Aeronautical Center in Oklahoma City, Oklahoma. The flight simulator was an analog simulator of a Convair–340, a twin-engine passenger plane with a normal passenger capacity of approximately 40. The simulator, Manufacturer's Serial Number 103, was built by Curtiss-Wright and included all controls and instruments to which a pilot and co-pilot are exposed in a real aircraft. All controls and instruments were the same size and in the same position as in a real aircraft. The simulator included variable engine sounds based on simulated flying conditions, but did not provide cockpit movement capabilities nor any visual cues from outside the cockpit. The seat, wheel, and rudder pedals were modified as explained below to put the subject in a position similar to her normal flying position. The cockpit interior of the modified Convair–340 is shown in Figure 1.

Cockpit Model.

Pilot's Seat. The subject's seat was that normally found in a Convair–340. A 3″ thick cushion mounted to a ¾″ plywood board was permanently installed against the original seat-back to move the subject closer to the controls. The seat allowed horizontal seating position adjustments in 1″ and ½″ increments, based on its position on the tracks attached to the floor. The subject was asked to adjust the horizontal seat position before the practice periods of the test to the position closest to her normal flying position. Some of the smaller pilots found it necessary to use cushions to provide adequate seat adjustment as they normally do in the aircraft they usually fly. The standard Convair–340 lap safety belt and a shoulder harness were used by each subject.

The floor of the simulator was raised 4″ by placing a wooden box under the rudder pedal and the seat was raised 2½″ to make vertical height from the floor to the top of the seat-bottom and the top of the seat-bottom to the center of the grip on the wheel representative of those found in general aviation aircraft. The rudder bars were also raised 4″ to maintain a typical 5″ vertical distance from the floor to the point of application on the rudder pedals. The pedals were in a neutral position of 19″ measured horizontally from the plane of the wheel, again

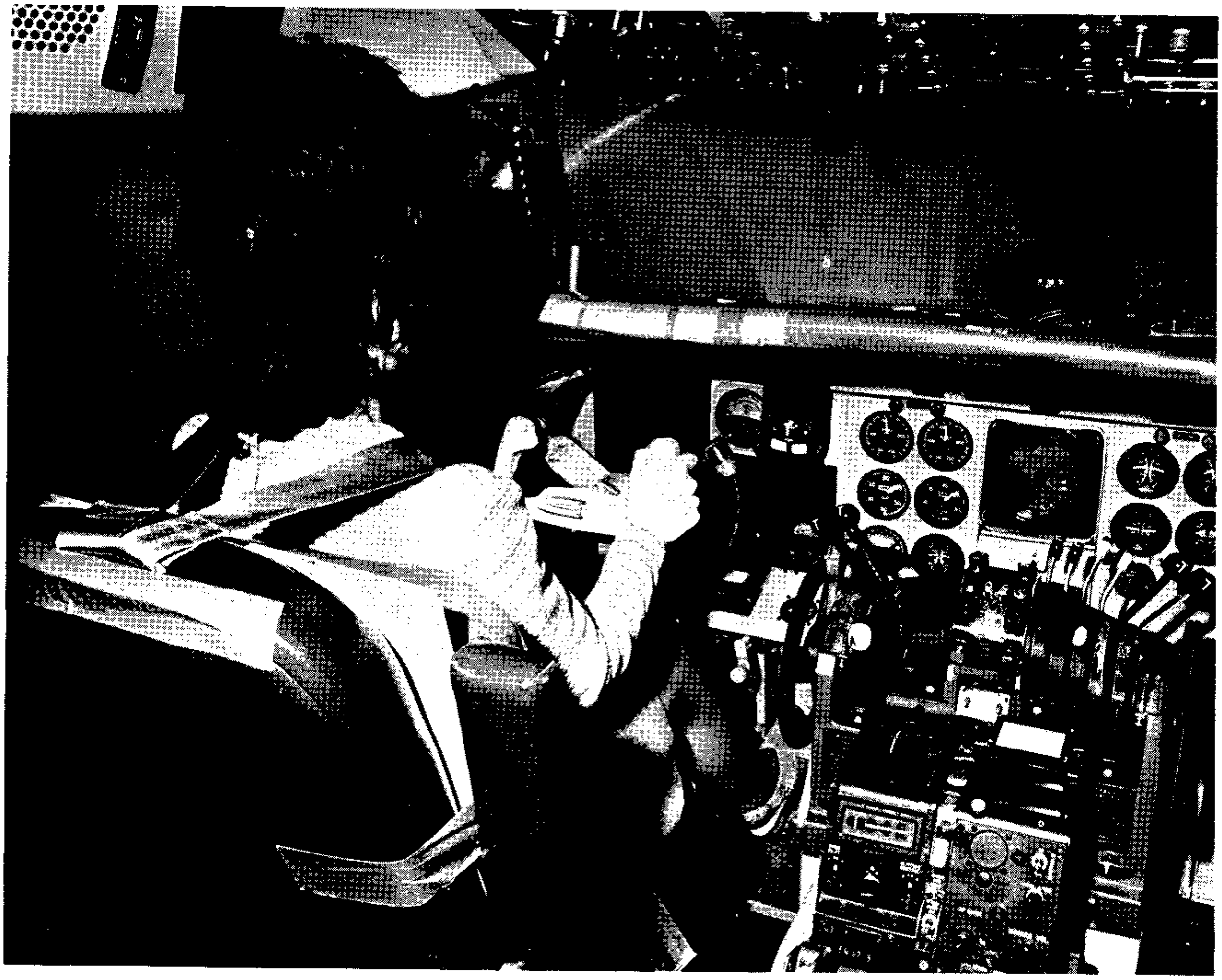


FIGURE 1. Cockpit interior of modified Convair–340 simulator.

representative of that dimension found in light aircraft. The modified rudder pedal configuration is shown in Figure 2.

The wheel used was a standard Beechcraft Bonanza wheel from the current 1972 model. This wheel was chosen because its grip and diameter are typical of plastic molded wheels used in current model general aviation aircraft. It was mounted to the center of the Convair wheel so the movement of the Bonanza wheel caused a proportional movement of the control linkage attached to the Convair wheel. When the seat was in the most forward position, the wheel was 17″ measured horizontally from the cushion attached to the seat back. The modified seat and wheel are shown in Figure 3. All dimensions in the modified simulator were within the range of dimensions found in five general aviation aircraft measured by the experimenters.

Monitoring Equipment. Each subject's performance during the test was recorded on a strip chart recorder. The recorder used was a Sanborn 850, 6 channel recorder. The subject performed tracking tasks on two instruments: the artificial horizon (attitude indicator) and the vertical pointer (needle) of the turn and bank indicator. On the artificial horizon she saw the two variables of pitch angle and roll angle; and on the vertical pointer of the turn and bank indicator she saw the variable of rate of turn. During any one trial the subject tracked on two of these displays while the third display remained fixed in the null position. In this simulator a change in the force applied to any control surface caused an angular displacement of the servo attached to that control. The resultant change in voltage was viewed by the subject as a movement on the appropriate dis-

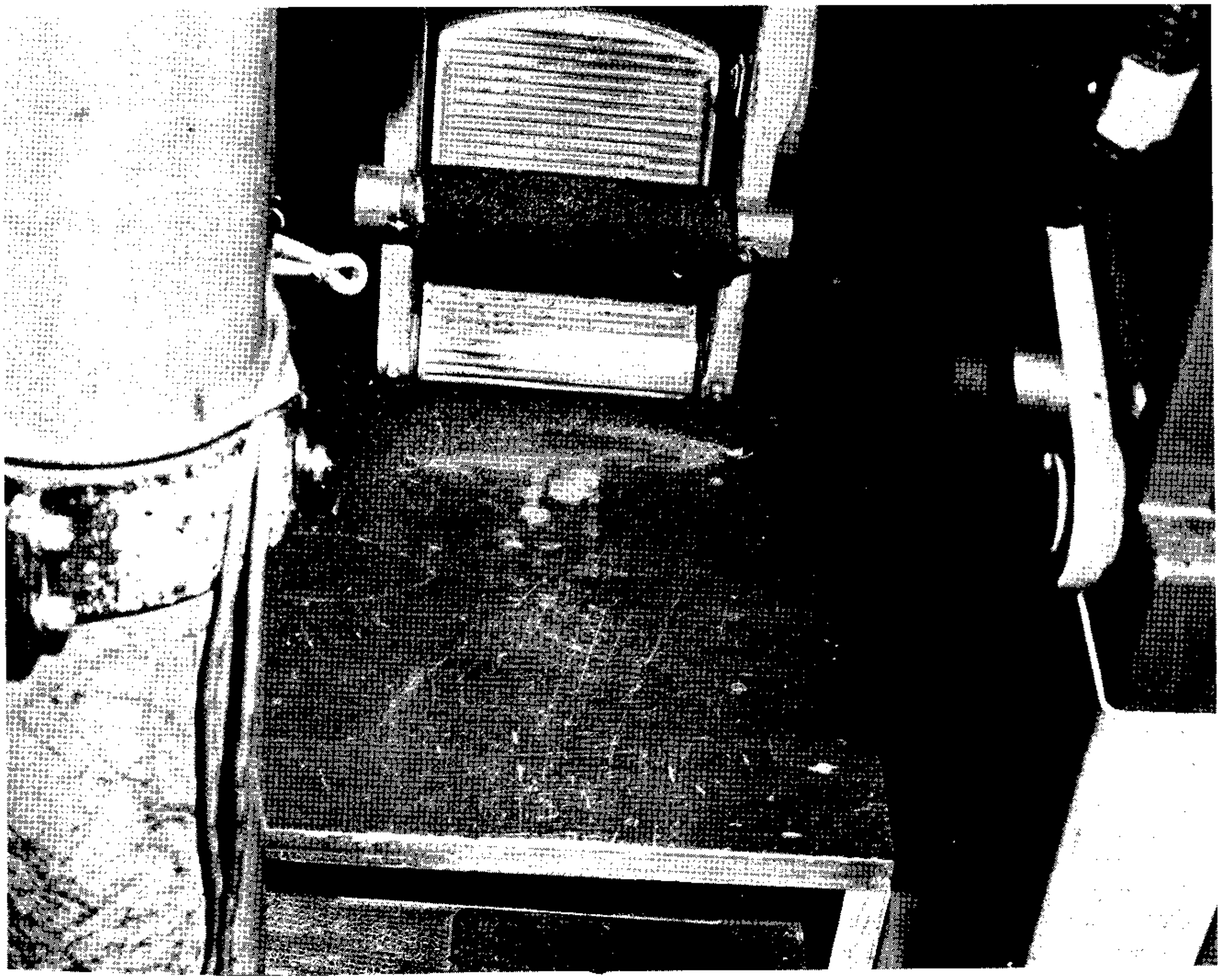


FIGURE 2. Rudder pedal modification; subject's heel rested on wooden platform, ball of foot on horizontal bar.

FIGURE 3. Modified seat and wheel; note permanent seat cushion, shoulder harness and subject's grip on Bonanza wheel.

play, and was recorded on the appropriate channel of the strip chart. The resulting lines on the individual channels recorded what the artificial horizon and turn bank vertical pointer indicated to the subject. The subject's task was to apply enough force to the controls to center the two active displays and keep them as close to center as possible.

The artificial horizon and the turn and bank indicator were located on the control panel directly in front of the subject. The artificial horizon showed an aircraft symbol which was superimposed over a horizontal line when the aircraft was at zero degrees pitch and roll. When the wheel was pulled toward the subject, the aircraft symbol moved to a position above the horizon, indicating a positive (nose up) pitch of the aircraft. When the wheel was turned clockwise, the horizontal line rotated counterclockwise, indicating the right wing was lower than the left and that the aircraft was in a roll to the right. Scales over the aircraft symbol and at the top of the indicator showed pitch in 5 degree increments and roll angle in 10 degree increments. The vertical pointer in the turn and bank indicator showed the aircraft was on a straight course when it was vertical and superimposed over the center marker. When the right pedal was pushed, the top of the pointer moved to the right, indicating a right turn of the aircraft. When the pointer was over one of the conventional "doghouse" indicators, to either side of the center marker, the aircraft was turning in that direction at a rate of three degrees per second. The two instruments used are shown in Figure 4. In this picture the artificial horizon indicates a pitch

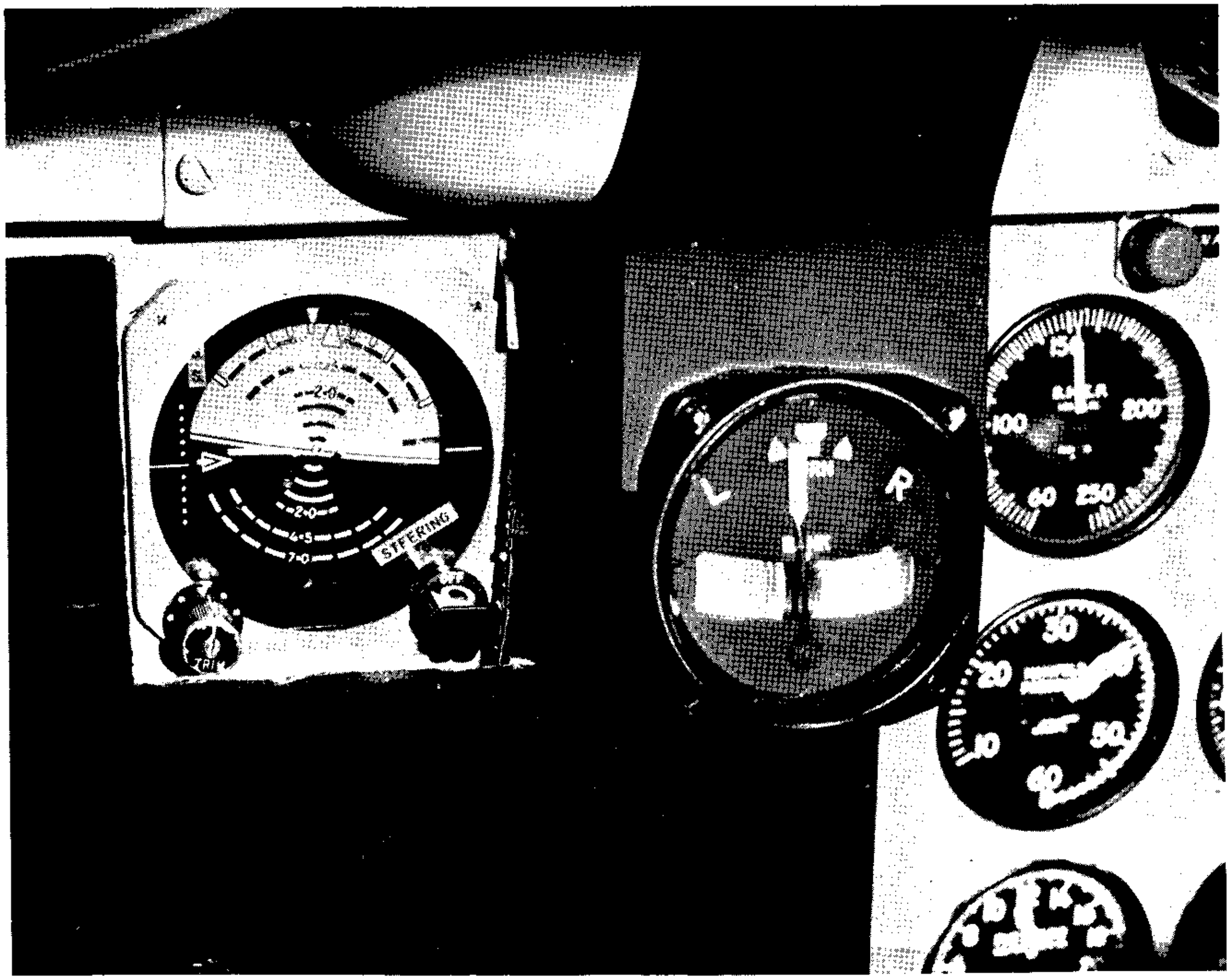


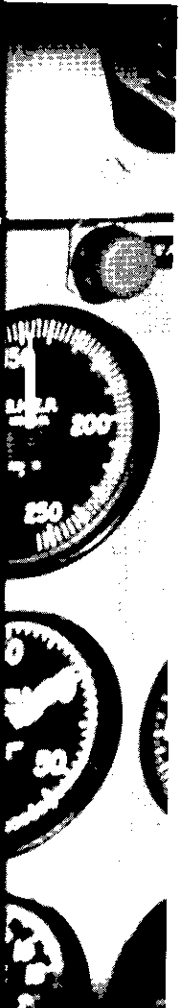
FIGURE 4. Flight instruments used for control of simulator; attitude indicator (left), turn and bank indicator (right).

angle of about two degrees nose up, a roll angle of about nine degrees to the left, and the turn and bank pointer indicates a turn to the left at a rate of about 1½ degrees per second. To bring these indicators to a null position the wheel should be moved forward and turned clockwise, and the right rudder should be pushed forward.

A clamp was attached at a point halfway from the pivot point of the column to the center point of the grip. The spring scale and winch were used to position the clamp precisely so that a load applied to the column at the point of the clamp was twice the force required at the center of the grip to keep the column from moving away from the subject. The load applied to the column was in the form of lead weights suspended from a low friction pulley in front of the simulator. The amount of weight attached to the cable equaled the load applied perpendicular to the column. Figure 5 shows 80 pounds attached to the column, meaning the subject would be required to pull the wheel toward her with 40 pounds of force to keep it from moving away from her and causing the aircraft to pitch downward.

A similar cable and pulley arrangement was attached to the left rudder pedal so that a load applied to that pedal required an equal horizontal force applied by the subject to the right pedal to keep that pedal from moving toward the subject.

A bracket and cable were attached to the copilot's wheel so that the load applied by adding weights to the cable was half the force required to be applied to the grips of the wheel to keep it from turning clockwise.



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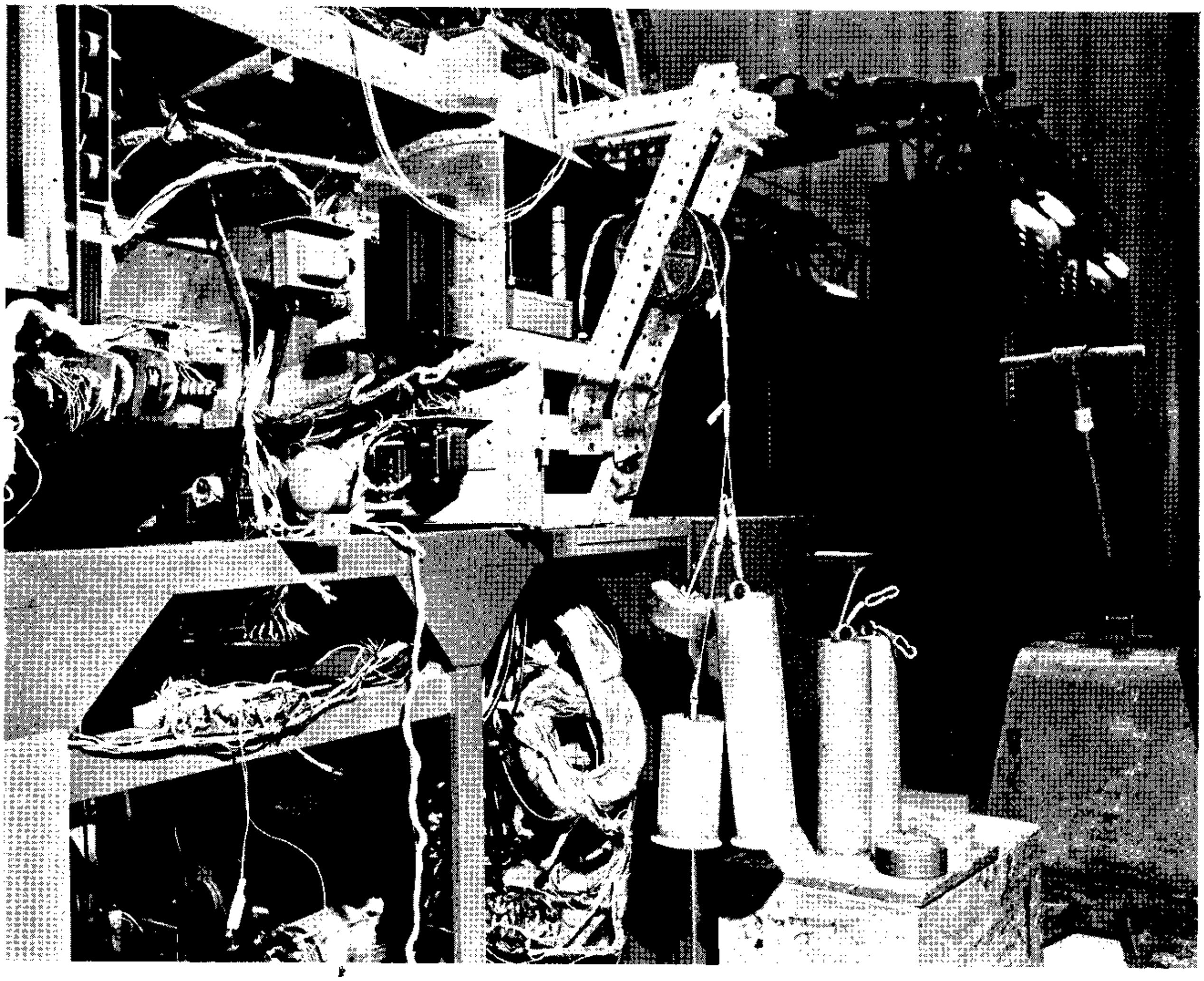

FIGURE 5. Equipment used to load controls.

The supplementary trim box included potentiometers for varying the simulator's force system from zero to 150 pounds. The elevator potentiometer provided force pulling the wheel toward the subject, the rudder potentiometer provided force pulling the left pedal toward the subject, and the aileron potentiometer provided force turning the wheel counterclockwise. There were 10 turn linear potentiometers which provided a given force when turned to a specific point on the revolution counter.

An AC digital voltmeter was used by the experimenter to ensure that all trim controls in the simulator were in the same position at the start of each trial. The voltmeter and the supplementary trim box are shown in Figure 6.

Measurement. Previous studies by VanOosterom (1959), Caldwell (1964), Rohmert (1960), and others indicate that the ability to exert force on a control decreases with the amount of time the force is required to be maintained. In order to investigate this relation for pilots operating aircraft controls, nine measurements were taken for each subject.

Each subject was asked to keep two displays as perfectly centered as possible while exerting either a high, medium, or low level of force on one of two controls. During a preliminary study it was found that in most cases the subject could keep the displays close to centered up to a certain point, but at this point or shortly thereafter she released the control. Subjects reported that they would attempt to keep the displays as perfectly centered as possible in an actual emergency, and reported little boredom in attempting to keep both displays perfectly centered. These tests

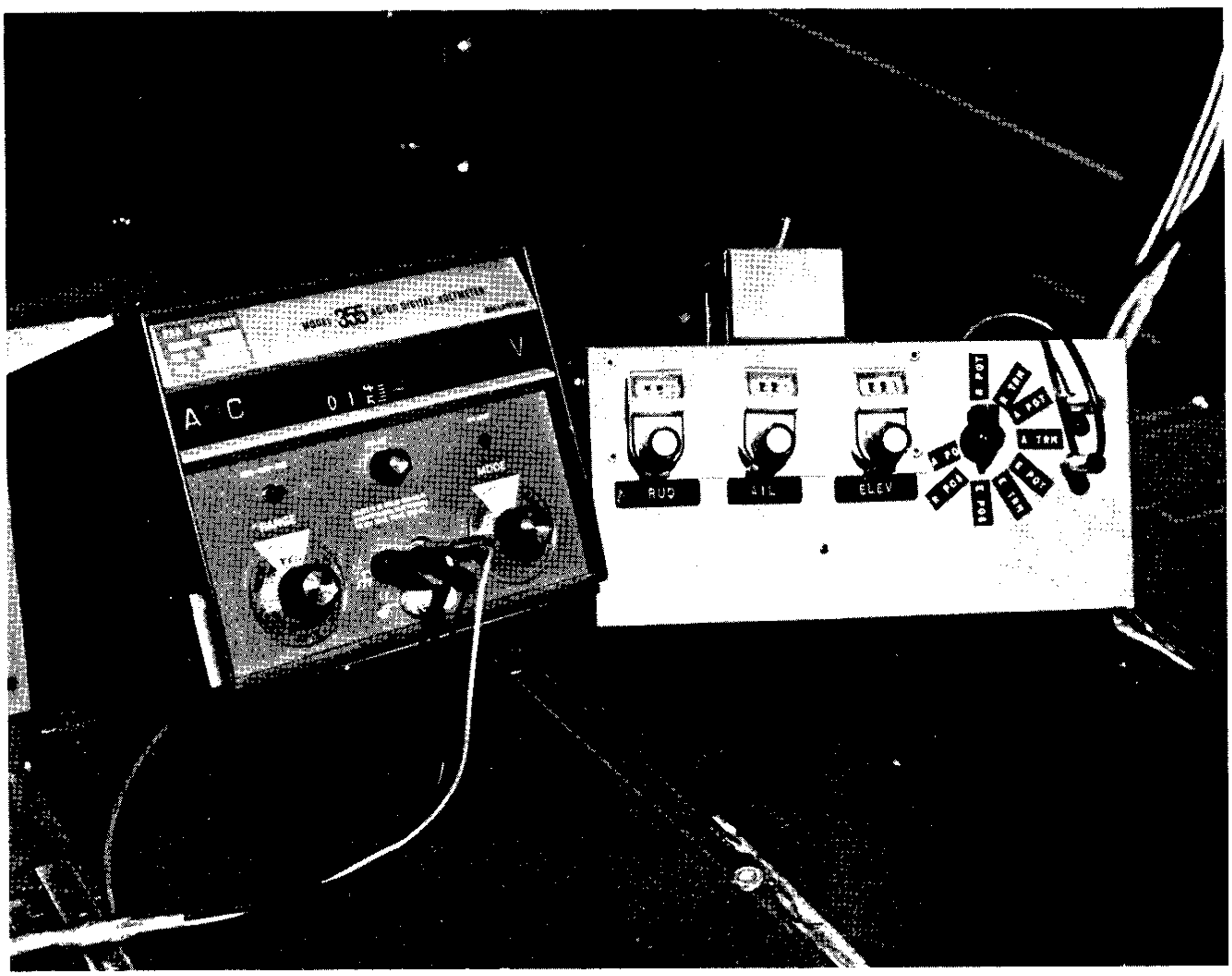

FIGURE 6. Accessory equipment, AC voltmeter (left) and supplementary trim box (right).

continued until the subject gave up or until the display representing the control requiring the subject to endure a specific force went outside the limits of a safe attitude. None of the subjects succeeded in bringing the aircraft back within the defined limits once they had been exceeded. These limits were chosen to reflect an aircraft grossly deviating from a straight and level course, and were set at 10 degrees roll and pitch, and a rate of turn of 2 degrees per second. When the subject reached a deviation of half the control limit, she was reminded to center the display. At any time the display showed a deviation of half the control limit or more, the experimenter kept up a strong, verbal encouragement to the subject to re-center the display. A seven minute limit was used: two minutes more than Monod (1956) and others have suggested as the point where strength endurance can be continued indefinitely.

Experimental Design. The test equipment was designed to represent a typical general aviation aircraft from the standpoint of dimensions and placements of controls. Each control was kept near the neutral position and each subject made small movements of the control around that position to keep the appropriate displays centered. A horizontal adjustment of the seat was provided to allow for differences in pilot size. Each subject was asked to adjust the seat to her usual flying position. She used either the cushions she brought or a 1½″ thick cushion provided by the experimenter to make adjustments. No attempt was made to restrict a subject to any given position because this would not have reflected her actual flight posture.

Aileron strength endurance trials were conducted using the left hand alone so that the subject had the right hand free to activate the throttles, radio, landing gear, and other controls as she would do in flight. Elevator strength endurance testing was conducted with the right hand only to avoid fatigue buildup resulting from using the left hand in both aileron and elevator trials. The right leg was chosen arbitrarily to test leg strength endurance on the rudder pedals.

Each subject was shown the proper hand grip on the wheel at the beginning of the session. The Bonanza wheel had an inward projection from the rim on which all subjects placed their thumbs. This placed the fingers in the four identations formed on the back of the wheel. Each subject was asked to dry any perspiration from the wheel and from her hand with a paper towel before each trial. The subject was not allowed to regrasp the wheel if it began to slip out of her hand because the act of regrasping the wheel required either temporary use of the other hand to stabilize the wheel or a momentary loss of contact between the wheel and the proper hand, which allowed the airplane to go beyond the limits of a safe attitude as defined in this study. The subjects were also instructed to place the ball of the foot on the steel pipe attached to the surface of the pedal. This placed the heel of the foot on the wooden box under the pedals.

Subjects. Previous anthropometric studies have shown that strength is dependent on age, sex, height and body type. The Aeromedical Certification Branch, Civil Aeromedical Institute of FAA has available data on age, height, and weight for all active airmen including the female pilot population. The sample of 24 female pilots used in this study approximates the active female pilot population closely for each of the three parameters mentioned above. Age, height, and weight statistics for the subjects tested are listed in Table 1 of Appendix A, along with other anthropometric data.

Each of the 24 subjects was tested on the three control axes at the three levels of force. The order of presentation of these nine trials was counterbalanced so as to minimize the effects of fatigue buildup in the data.

Experimental Routine. Experimental sessions began at 9:00 a.m. or 1:00 p.m. and lasted from 2 to 2½ hours. Upon arrival, the subject's height and weight were measured. She was seated in the left seat of the simulator and the seat belt and shoulder harness were adjusted to give a snug comfortable fit. She was then asked to slide the seat forward to the position closest to her normal flying position. At this point the purpose of the experiment was explained and the proper grip on the wheel and proper foot position on the rudder pedals were demonstrated.

Two short practice sessions were successfully completed before the control force testing began. These sessions allowed the subject to practice the tracking task while applying a low force. The nine trials were then given in a counterbalanced order as described earlier.

III. Results and Discussion.

The presentation of results has been divided into four sections:

1. Recorded data from the test subjects.
2. Correlation analysis to determine the relationship between endurance time and anthropometric and other variables.
3. Stepwise multiple linear regression to develop prediction equations for endurance time based on anthropometric and other variables.
4. Polynomial and exponential regression analysis for each control to examine the relationship between force exerted and endurance time.

Recorded Data. Tables 2, 3, and 4 shown in Appendix A present the data recorded for the time each subject maintained each of the three levels of force on the elevator, rudder, and aileron trials, as well as a summary of endurance times recorded for each of the nine test conditions. From these tables some comparisons can be made between the test data and the control limits contained in FAR 23.143 now in effect for general aviation aircraft.

The term "temporary" in FAR 23.143 has been recently clarified by the Flight Test Branch as a period of up to 20 seconds in control of pitch and roll, and up to 30 seconds in control of yaw. Because the ability of a pilot to exert force on a control diminishes over time, the "temporary" forces specified in FAR 23.143 should then be compared to forces capable of being maintained for a full 20 seconds in the case of pitch and roll, and for a full 30 seconds in the case of yaw.

In the elevator strength endurance tests the highest level of force maintained was 55 pounds, compared to a force of 75 pounds specified in FAR 23.143 for "temporary" application. In these tests 14 of 24 subjects, or 58 percent, could not maintain a 55-pound pull on the wheel for 20 seconds. This compares with data from Karim (1972) in which study 7 of 25 subjects, or 28 percent, could not maintain an elevator push for 20 seconds at the 45-pound force level. These studies suggest that this current control limit is too high for a sizeable portion of female pilots.

In the rudder strength endurance tests the highest level of force maintained was 150 pounds, the same as that specified in the regulation. In these tests 5 of 24 subjects, or 21 percent, could not maintain a 150-pound force on the right pedal for 30 seconds. However, all 24 subjects were able to maintain the 130-pound force for 30 seconds. These results compare to the results from Karim (1972) in which study 3 of 25 subjects, or 12 percent, could not maintain a left rudder force of 105 pounds for 30 seconds. Subjects who participated in both studies reported that the seat in this study offered more support than that used in the 1972 study. Also, subjects in this study were allowed to lift the buttocks from the seat while pushing on the rudder; this was not allowed in the study by Karim.

In the aileron strength endurance tests the highest level of force maintained was 22 pounds, considerably below the force of 60 pounds specified in the regulation. In these tests 4 of 24, or 17 percent, could not maintain a 22-pound downward pull with the left arm for 20 seconds. These data compare with data from Karim (1972): 17 of 25 subjects, or 68 percent, could not maintain a 25-pound left aileron force for 20 seconds, although all 25 subjects did maintain a 15-pound force for 20 seconds. Since 17 percent of the subjects in this study were unable to maintain a force less than half the current control force limit, this control force limit seems to be far too high for a sizeable portion of female pilots.

Correlation Analysis. Correlation analysis was used to determine what effect the anthropometric and other parameters had on the data obtained from the nine test conditions. Correlation coefficients were computed for the time a force was maintained in each of the nine test conditions versus the anthropometric parameters of age, height, weight, elbow angle, angle of the lower arm above horizontal, knee angle, foot angle, seat-back height, and seat-bottom length. The results of this analysis are presented in Table 5 of Appendix A. A correlation coefficient greater than 0.271 was required for significance at the 10 percent level of confidence; a correlation coefficient greater than .347 was needed for significance at the 5 percent level of confidence.

It should be remembered that each subject in this experiment adjusted her seated position in the simulator to that closest to her normal flying position. In most of the past research on maximum strength the subject's seated position was adjusted by the experimenter to achieve certain predetermined angles at the elbow, knee, and foot. Since the present study was conducted to measure the strength endurance capabilities of a pilot in flight, each subject in this study determined her own seated position which put her in a different position relative to the controls than that of any other subject. This means the subjects had different strength endurance capabilities in terms of the biomechanics of force exertion. The data in this study represent the strength endurance capabilities of female pilots in the posture in which they normally fly and not their capabilities in any given optimal or minimal posture. It should be noted that all the test subjects adjusted their seat position so they could achieve full control of the rudder pedals, their normal practice in the airplanes they fly. Their arm position relative to the wheel was determined by the seat position chosen for proper rudder control. This position was often disadvantageous for force exertion on the wheel, especially for short subjects who used pillows against the seat-back in order to reach the pedals and then found the wheel, even when in the neutral position was very close to their abdomen. In response to a question on the personal data form, all subjects replied that during the tests they were in a seated position very similar to that in which they normally fly. They also stated that any problems of control placement encountered in the simulator were similar to those they encounter in general aviation aircraft.

Age, height, and weight all had a significant effect on elevator pull endurance. Since age was positively correlated with endurance for all three trials, this means that older subjects maintained a given force longer than younger subjects. This result is contrary to the expected result that age and endurance time would be negatively correlated since aging after the middle 20's generally reduces muscular strength, as reported by Asmussen and Heebol-Nielson (1962). In this study no reason can be given for the observed positive correlations. Height and weight were positively correlated at the 5 percent level for the low and the high force levels, meaning that at these levels, taller and heavier subjects were able to maintain a force longer than short and light subjects.

The seated positions of the subjects placed them in disadvantageous positions for exertion of a large pull force on the wheel. With an average elbow angle of 91 degrees and an average lower arm angle above horizontal of 27.8 degrees, the subjects' biceps and latissimus dorsi muscles were already partially contracted, making exertion of a large force difficult. Hunsicker and Greey (22) found that a subject with an elbow angle of 90 degrees was weaker in pull than with any other elbow angle except 60 degrees. In these tests elbow angle was not determined to be a significant variable in determining elevator pull endurance, but lower arm angle was significant for the highest force level. The negative correlation means that the greater the lower arm angle the shorter the endurance time. A large lower arm angle indicates a subject had to grasp the wheel several inches above her elbow height. This put more of the load on the biceps and thereby shortened endurance time.

There were no significant correlations between age and endurance time, although small positive correlations were observed. Height and weight were observed to be important variables in determining how long a subject could maintain a force. Knee angle and foot angle were not found to be significant variables, probably because these measured angles reflect the subject's seated position while at rest. When a subject was exerting a force, she often found an improvement in her endurance by lifting the buttocks from the seat, pushing the knee downward, and pushing the heel forward, thus increasing the knee angle and decreasing the foot angle. The height of the buttock elevation was limited by the lap seat belt, but the subjects were able to increase knee angles to an approximate range of 130–170 degrees and decrease foot angles to an approximate range of 70–90 degrees. These changes in knee and foot angles occurred as subjects attempted to "stand on the rudder," as they would do in an aircraft in an emergency which required the exertion of a large force on the rudder. Data presented by Morgan, et al. (1963) indicate a knee angle of 135–150 degrees provides optimal force application on a pedal. In an effort to maintain a rudder force as long as possible, each subject in this study found her endurance capability increased as she moved her knee toward the locked position and then used her back muscles against the seat-back to provide a push force on the pedal. This technique on the part of the subjects agrees with the suggestions of

Morgan, et al. on control placement. The working angles of these subjects reflect the true posture of a pilot required to maintain an abnormally high rudder force; but since each subject varied her knee and foot working angles over a wide range of values during each trial, working angles were not measured.

Seat-back height and seat-bottom length were measured to determine what effect the support characteristics of a seat have on endurance. Positive correlations between the height of the seat-back, expressed in percentage of seated shoulder height and endurance time, indicate that perhaps taller seat-backs may give better support and therefore increase endurance time since the only significant correlation at the 10 percent level was for the 150-pound force. Seat-bottom length, in percentage of thigh supported, varied from 60 to 70 percent in this study and was positively correlated with endurance time at the 5 percent level for the 110- and 130-pound forces, although the correlation was not significant for the 150-pound force. This indicates that within the range of 60 to 70 percent, a longer seat-bottom gives more support to the thigh and this increases endurance time.

Again the significant positive correlations between age and endurance times in this study cannot be explained by any of the measured variables. Height was an important variable in aileron endurance at the low and middle force levels, while weight was the most highly correlated variable with endurance time at all three levels. These correlations indicate taller and heavier subjects could maintain a force longer. Elbow angle correlation with endurance time increased as the required force increased and was significant for the highest force level, indicating that subjects with larger elbow angles maintained the aileron force longer. Lower arm angle was also increasingly important as the force requirements increased and was significant at both the medium and high levels of force. The negative correlations indicate that subjects whose elbows were considerably below the level of the grip on the wheel were able to maintain the aileron force for a shorter time than those with higher elbow positions. Seat-back height was important at the 22-pound level, indicating a higher seat-back offered the subjects more support and thereby increased endurance times.

It was noted during the aileron endurance trials that when a subject tried to pull downward on the left grip, she also had a strong tendency to pull on the wheel toward her body, causing a nose up attitude of the aircraft. There was no way to record this tendency in the wooden mock-up, but in the simulator the effect of this incidental back pressure on the wheel could be seen on the artificial horizon. Subjects were continuously instructed to keep the aircraft level in pitch as well as roll during these trials, as they would have to do in an aircraft in an emergency in which the pilot must maintain an abnormally high aileron force. Many subjects reported that by keeping the airplane level in pitch, their endurance capabilities were reduced. The aileron endurance times recorded in this study are based on a more realistic flying situation than those recorded in the wooden mock-up of Karim (1972) and should more closely reflect the actual strength endurance capabilities of a female pilot in an airborne aircraft.

Stepwise Multiple Linear Regression Analysis. The previous correlation analysis revealed the individual effects of each of the anthropometric and other variables on endurance time.

The first three stepwise multiple linear regression subproblems predicted elevator pull endurance at the 25-, 40-, and 55-pound force exertion levels. At the highest force tested weight and age explained 29.6 and 5.8 percent of the variance in elevator pull endurance times for the 55-pound force level; seat-back height and lower arm above horizontal angle explained 3.2 and 2.4 percent; and elbow angle and height added another 2.0 and 2.3 percent. A variance in endurance times of 54.7 percent could not be explained in terms of these six anthropometric variables and must be attributed to other variables not included in this analysis. The final prediction equation for right-hand pull strength at the 55-pound force level was:

(endurance time,
secs.) = −.83.68
\+ .40 (age, yrs)
\+ .48 (height, cms)
\+ .20 (weight, lbs)
\+ .43 (seat-back ht, % of seated shoulder ht.)
− .34 (elbow angle, °)
− .83 (lower arm angle, °)

and the standard error of the estimate was 11.89 seconds.

A similar analysis was performed for the right rudder endurance data by using stepwise multiple linear regression to predict endurance time. One subproblem was analyzed for each of the three rudder force exertion levels (110, 130, and 150 pounds) used in the study. At the highest force tested height explained 21.8% of the variance in right rudder endurance times for the 150-pound force level; foot angle and seat-bottom length accounted for 13.5 percent; and weight, seat-back height, and age explained an additional 6.5 percent of the variance. A variance in right rudder endurance times of 58.2 percent was unexplained by the anthropometric variables mentioned here. The final prediction equation for right rudder endurance time at the 150-pound force level was:

(endurance time,
secs.) = −2031.95
+ 2.44 (age, yrs)
+ 9.73 (height, cms)
+ 1.32 (weight, lbs)
+ 5.98 (seat-back ht, % of seated shoulder ht)
+ 6.65 (seat-bottom ln, % of seated thigh ln)
− 6.92 (foot angle, °)

and the standard error of the estimate was 133.16 seconds.

The stepwise multiple linear regression analysis for left aileron included one subproblem for each of the 14-, 18-, and 22-pound force levels. At the highest force tested weight and lower arm angle explained 39.0 and 9.9 percent of the variance in the endurance times recorded for the 22-pound left aileron test; height and elbow angle accounted for an additional 6.0 percent of the variance. A variance in endurance times of 45.1 percent could not be explained by the anthropometric variables listed here and must be attributed to the effects of other anthropometric variables or to other factors which were not studied here.

The final prediction equation for left aileron endurance time at the 22-pound force level was:

(endurance time,
secs.) = +116.59
− 1.15 (height, cms)
+ .62 (weight, lbs)
+ .49 (elbow angle, °)
− .45 (lower arm angle, °)

and the standard error of the estimate was 16.96 seconds.

Polynomial and Exponential Regression Analysis. One purpose of this study was to define the relationship between control forces and the time they can be maintained by a pilot flying an aircraft. Polynomial and an exponential regression analysis were performed on each of the three controls studies; elevator pull, right rudder, and left aileron. The independent variable was the amount of force required and the dependent variable was the length of time a force could be maintained. On each control there were 24 subjects tested at each of three force levels, resulting in 72 data points on each control axis. Prediction equations were then obtained from these analyses for endurance time in terms of the force exerted for each of the control axes.

It should be remembered that the three levels of force on each control in this study were absolute values, not percentages of maximal force as studied by Karim (1972). This means that a given force might be very near one subject's maximal strength and yet might be a relatively light force compared to another subject's maximal strength. This explains some of the wide variation in endurance times recorded for any one force level. In some cases such as the highest rudder force level, times ranged from 1 second to 420 seconds. This is not unexpected since Karim (1972) reported maximal rudder strength ranged from 81 to 250 pounds in the aircraft mock-up she used for testing the strength of female pilots. The regression equations in this study do not explain endurance times in terms of maximal strength, but do reflect the capabilities of a representative sample of female pilots for maintaining a specific control force while keeping an airplane in a safe attitude.

The polynomial regression program used in this analysis was designed to compute linear, quadratic, and cubic equations for each set of data points. Since there were only three levels of the independent variable, the cubic equations were not relevant and were therefore not calculated. A linear regression on the logarithmic transform of a negative exponential curve of the form $Y=ae^{-bx}$ was also performed in an effort to determine a prediction equation for control force endurance times. For each control axis studied the linear, quadratic, and exponential prediction equations were compared on the basis of variance explained by the regression divided by variance unexplained by the regression. After comparison of the effects of these three equations the polynomial prediction equation containing the significant term or terms and the exponential prediction equation were plotted with the 72 data points.

The prediction equations presented in this section for each of the three control axes were found to be significant at the 5 percent level. The power of the tests and the probability of rejecting a false hypothesis were also calculated, with the result that the tests based on the exponential equations were much more powerful than those computed for the linear and quadratic equations. The results of the polynomial and exponential regression analyses are presented in three parts: one each for elevator pull, right rudder, and left aileron.

All three prediction equations for elevator pull were significant at the 5 percent confidence level. They are presented below, with Y equal to endurance time in seconds and X equal to force maintained in pounds.

Linear	$Y=366.944-6.676\ X$
Quadratic	$Y=727.968-26.595\ X+0.249\ X^2$
Exponential	$Y=1901.103\ e^{-.0902X}$

Since the quadratic term in the polynomial regression analysis was significant at the 5 percent level ($F=12.9$), the quadratic prediction equation and the exponential prediction equation are plotted with the 72 elevator pull and data points in Figure 7. It was determined that the exponential curve fits the data better than the quadratic equation in the range of tested values from 25 to 55 pounds.

All three prediction equations for right rudder were significant at the 5 percent level. However, the quadratic term in the polynomial regression was not significant ($F=0.2$). For this reason only the linear and exponential prediction equations are presented below, with Y equal to endurance time in seconds and X equal to force maintained in points.

Linear	$Y=229.486-3.944\ X$
Exponential	$Y=12677.754\ e^{-.0388X}$

These two prediction equations are plotted with the 72 right rudder data points in Figure 8. It was found that the exponential equation fits the data slightly better than the linear equation, but the difference in fit is quite small. However, the levels tested in this study varied over a rather small range of 110 to 150 pounds. By testing rudder endurance at higher and lower force levels the quadratic and exponential equations would be expected to become more useful in predicting right rudder endurance times.

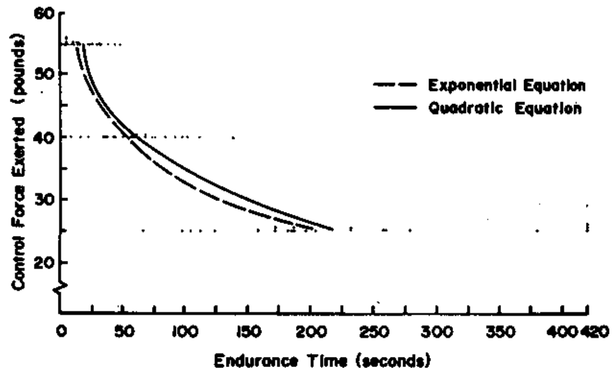

FIGURE 7. Plot of elevator pull endurance.

All three prediction equations for left aileron were significant at the 5 percent level. The quadratic term, however, was not significant in the polynomial regression ($F=0.5$). Because of this fact only the linear and exponential prediction equations are presented below, with Y equal to endurance time in seconds and X equal to force maintained in pounds.

Linear	$Y=378.128-15.516\ X$
Exponential	$Y=1714.61\ e^{-.1769X}$

These two prediction equations are plotted with the 72 left aileron data points in Figure 9. It was found that the exponential equation fits the data considerably better than the linear equation in the range of force levels tested. By recording left aileron endurance times at a force level above 22 pounds and at a level below 14 pounds, the authors believe the quadratic and exponential equations would be more useful in predicting left aileron endurance times.

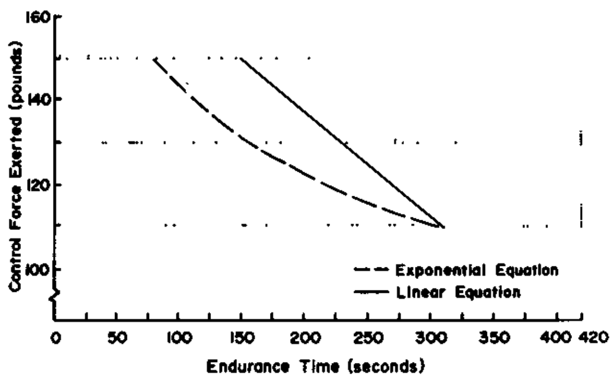

FIGURE 8. Plot of rudder endurance.

IV. Summary.

The correlation analysis between anthropometric and other variables and endurance times revealed, as expected, several significant linear relationships. The stepwise multiple linear regression analysis revealed the combined effects of various anthropometric variables on endurance times recorded at three force levels for elevator pull, right rudder, and left aileron. Prediction equations were also obtained for predicting endurance time based on control force exerted. Polynomial and exponential regression analyses were performed to calculate linear, quadratic, and exponential equations to determine prediction equations for control force endurance times based on control force exerted. These equations were then compared and the calculated negative exponential regression equations were determined to be the best predictors for endurance times.

The data showed that the current FAR 23.143 control force limits for general aviation aircraft are too high for a sizeable portion of the U.S. female pilot population.

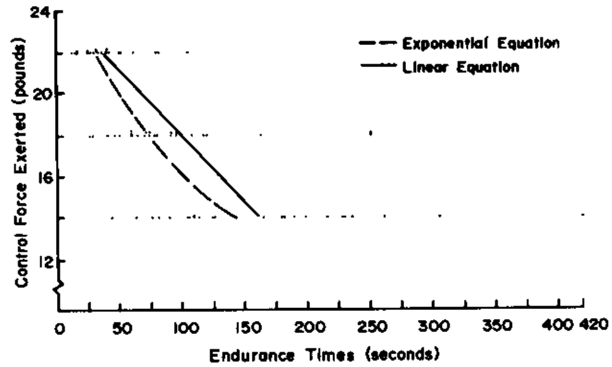

FIGURE 9. Plot of aileron endurance.

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APPENDIX A

TABLE 1

ANTHROPOMETRIC DATA

Item	Age	Height		Weight	Seat Back Ht./ Shoulder Ht.	Seat Bottom Ln./ Thigh Length
Subj. No.	yrs.	cm.	in.	lbs.	%	%
1	42	159.0	62.6	119	89	70
2	42	169.7	66.8	131	82	61
3	35	161.1	63.4	134	96	63
4	55	152.0	59.8	104	66	60
5	42	166.3	65.5	132	87	64
6	64	161.2	63.5	140	90	66
7	28	166.7	65.6	117	94	64
8	33	167.3	65.9	134	91	63
9	42	169.6	66.8	205	83	63
10	37	171.6	67.6	150	87	63
11	26	167.1	65.8	160	84	63
12	29	174.4	68.7	154	89	60
13	32	165.5	65.2	133	89	66
14	29	163.4	64.3	125	93	64
15	31	165.7	65.2	92	94	63
16	45	157.1	61.9	134	91	67
17	21	161.2	63.5	122	95	64
18	25	156.5	61.6	102	91	60
19	24	154.9	61.0	108	83	62
20	20	165.6	65.2	109	88	64
21	43	165.1	65.0	114	83	60
22	29	167.2	65.8	124	84	65
23	28	165.7	65.2	127	94	64
24	24	153.3	60.4	114	87	64
Subj. Summary						
Mean	34.4	163.64	64.2	128.5	87.9	63.5
Std. Dev.	10.8	5.81	2.29	23.2	6.3	2.4
Max.	64	174.4	68.7	205	96	70
Min.	20	152.0	59.8	92	66	60
Range	44	22.4	8.9	113	30	10

Item	Foot Angle	Knee Angle	Elbow Angle	Lower Arm Angle	Seat Position Vertical	Seat Position Horizontal
Subj. No.						
1	90°	113°	88°	27°	1	1
2	85	120	117	14	1 + 2" cushion	3
3	93	125	106	18	1	4
4	88	131	94	30	1	1 + 2" cushion
5	94	128	98	21	1	4
6	74	131	94	23	1	3
7	81	135	95	35	1	4
8	88	116	84	29	1	1
9	92	130	110	16	1	3
10	88	118	94	27	1	3
11	81	112	82	34	1	2
12	92	117	79	34	1	3
13	95	133	108	25	1	3
14	91	117	85	32	1	2
15	90	122	88	33	1	2
16	89	118	86	33	1	1
17	80	117	87	33	1	1
18	84	121	72	37	1	1 + 1½" cushion
19	84	126	72	32	1	1 + 1½" cushion
20	90	125	95	28	1	3
21	81	111	74	28	1	1 + 1½" cushion
22	94	130	118	13	1	5
23	85	126	87	33	1	3
24	90	129	71	32	1	1 + 1½" cushion
Subj. Summary						
Mean	87.5	123.0	91.0	27.8		
Std. Dev.	5.3	7.0	13.5	6.9		
Max.	94	135	118	37		
Min.	74	111	71	13		
Range	20	24	47	24		

TABLE 2

ENDURANCE DATA FOR ELEVATOR PULL

Item	Time Force Maintained (secs.) 25 lb.	40 lb.	55 lb.
Subj. No.			
1	185	43	5
2	231	36	4
3	123	41	24
4	257	74	2
5	379	49	37
6	420	148	45
7	185	67	31
8	231	84	11
9	171	62	48
10	420	101	34
11	259	55	14
12	420	112	15
13	216	59	14
14	195	37	11
15	97	15	4
16	182	92	10
17	104	8	4
18	176	68	8
19	203	58	21
20	65	36	10
21	184	62	32
22	278	98	26
23	157	75	28
24	111	21	4
Subj. Summary			
Mean	218.7	62.5	18.4
Std. Dev.	102.2	32.5	13.8
Max.	420	148	48
Min.	65	8	2
Range	355	140	46

TABLE 3

ENDURANCE DATA FOR RIGHT RUDDER

Item	Time Force Maintained (secs.) 110 lb.	130 lb.	150 lb.
Subj. No.			
1	420	420	178
2	375	70	8
3	420	320	146
4	152	38	1
5	420	277	36
6	420	420	420
7	285	272	204
8	242	181	386
9	420	234	96
10	420	420	420
11	391	290	249
12	420	420	420
13	420	420	134
14	374	130	82
15	154	65	49
16	268	169	124
17	271	88	39
18	219	111	66
19	170	64	43
20	238	59	25
21	95	62	25
22	420	420	165
23	420	272	420
24	90	39	2
Subj. Summary			
Mean	313.5	219.2	155.8
Std. Dev.	118,2	146.4	150.1
Max.	420	420	420
Min.	90	38	1
Range	330	382	419

TABLE 4

ENDURANCE DATA FOR LEFT AILERON

Item	Time Force Maintained (secs.) 14 lb.	18 lb.	22 lb.
Subj. No.			
1	190	91	45
2	75	52	15
3	125	78	50
4	109	74	39
5	215	164	80
6	167	60	41
7	113	107	39
8	179	96	39
9	420	251	105
10	124	91	52
11	261	74	32
12	305	251	28
13	236	96	82
14	103	70	31
15	44	27	12
16	181	117	50
17	89	59	13
18	81	25	24
19	110	46	23
20	63	40	15
21	106	79	35
22	200	119	61
23	227	59	34
24	230	64	31
Subj. Summary			
Mean	164.7	91.3	40.7
Std. Dev.	87.8	58.2	23.0
Max.	420	251	105
Min.	44	25	12
Range	376	226	93

TABLE 5

CORRELATION COEFFICIENTS FOR ENDURANCE TIME

VERSUS NINE ANTHROPOMETRIC AND OTHER PARAMETERS

	Elevator Pull 25 lb.	40 lb.	55 lb.
Age	.4754**	.4984**	.3480**
Height	.3725**	.2023	.3794
Weight	.3797**	.3319*	.5442**
Elbow Angle	.1172	.0614	.2690
Lower Arm Angle	-.1944	-.0947	-.4010
Lower Back Ht.	-.2505	-.1402	.0464
	Right Rudder 110 lb.	**130 lb.**	**150 lb.**
Age	.1645	.2082	.1297
Height	.5507**	.4504**	.4666**
Weight	.6284**	.4829**	.4101**
Knee Angle	.0644	.1112	-.1081
Foot Angle	.2293	.1802	-.1856
Seat Back Ht.	.2341	.2252	.2992*
Seat Bottom Ln.	.3783**	.4504**	.1403
	Left Aileron 14 lb.	**18 lb.**	**22 lb.**
Age	.0999	.1693	.3520**
Height	.2987*	.4882**	.2034
Weight	.7970**	.7312**	.6244**
Elbow Angle	.1412	.2433	.4980**
Lower Arm Angle	-.2208	-.2769	-.5298*
Seat Back Ht.	.1726	-.0210	.2952*

*Significant at 10% level .271
** Significant at 5% level .347

APPENDIX B

COMPARISON OF CONTROL FORCE LIMITS

Excerpts from FAR 23.143, BCAR K2-6 3.4 and MIL-F-8785 B are presented here for comparison of maximal control force specifications. FAR 23.143 lists the following control force limits under the section on controllability and maneuverability.

FEDERAL AVIATION REGULATIONS
PART 23, SUBPART <u>B - FLIGHT</u>

CONTROLLABILITY AND MANEUVERABILITY 23.143 General.

(c) If marginal conditions exist with regard to required pilot strength, the "strength of pilots" limits must be shown by quantitative tests. In no case may the limits exceed those precribed (sic) in the following table:

Values in pounds of force as applied to the control wheel or rudder pedals	Pitch	Roll	Yaw
(a) For temporary application			
Stick	60	30	-
Wheel (applied to rim) .	75	60	-
Rudder Pedal			150
(b) For prolonged application	10	5	20

In contrast the British Civil Air Regulation lists the following maximal control force specifications for temporary application.

BRITISH CIVIL AIRWORTHINESS REQUIREMENTS
SECTION K SUB-SECTION K 2 - FLIGHT

K2-6 HANDLING - GENERAL

3.4 Excessive Control Forces. The assessment of whether a control force is excessive, apart from a maximum figure which may be prescribed, may be influenced by the ease of applying it and the general level of control forces for the aeroplane. In the case of the aileron and elevator control, forces will, in any case, normally be regarded as excessive if, at the specified air speed, they cannot readily be applied with one hand for the appropriate period without retrimming.

NOTE: The maximum forces likely to be accepted for short period application, with the controls in a favourable position, are:---

(a) for elevator control, 50 lb. for a wheel control, or 35 lb. for a stick control;
(b) for aileron control, 20 lb. for a stick control, or 30 lb. applied at the rim of a wheel control;
(c) for rudder control, 150 lb.

MIL-F-8785 B has four separate classifications of airplanes. Class 1 airplanes are small light airplanes similar to those covered under FAR 23.143. The control force specifications for military aircraft are listed according to class, flight maneuver and level of performance.

The following excerpts from MIL-F-8785 B apply to similar conditions as the control force specifications listed under FAR 23.143.

ELEVATOR FORCES. For nose-wheel aircraft at take-off, 20 pounds pull to 10 pounds push. For tail-wheel airplanes at takeoff, 20 pounds push to 10 pounds pull; par. 3.2.3.3.2. Elevator force for landing, 35 pounds pull; par. 3.2.3.4.1. For spin recovery, 75 pounds; par. 3.4.3.

AILERON FORCES. For climb, cruise, and loiter, 40 pounds; for takeoff, approach, and landing, 20 pounds; par. 3.3.4.2. For spin recovery, 35 pounds; para. 3.4.3.

RUDDER FORCES. For speed change, go-around and cross winds, 100 pounds; par. 3.3.5, 3.3.7. For dives and assymetric thrust 180 pounds; para. 3.3.8, 3.3.9. For spin recovery, 250 pounds; par. 3.4.3.

TABLE 6

CONTROL FORCE REQUIREMENTS FOR TEMPORARY APPLICATION SPECIFIED UNDER FAR 23.143, BCAR K2-6 3.4 AND MIL-F-8785.B

	Elevator	Aileron	Rudder
FAR 23.143	75 lb.	60	150
BCAR K-26 3.4	50	30	150
MIL-8785B	10-75	20-40	100-250

APPENDIX C

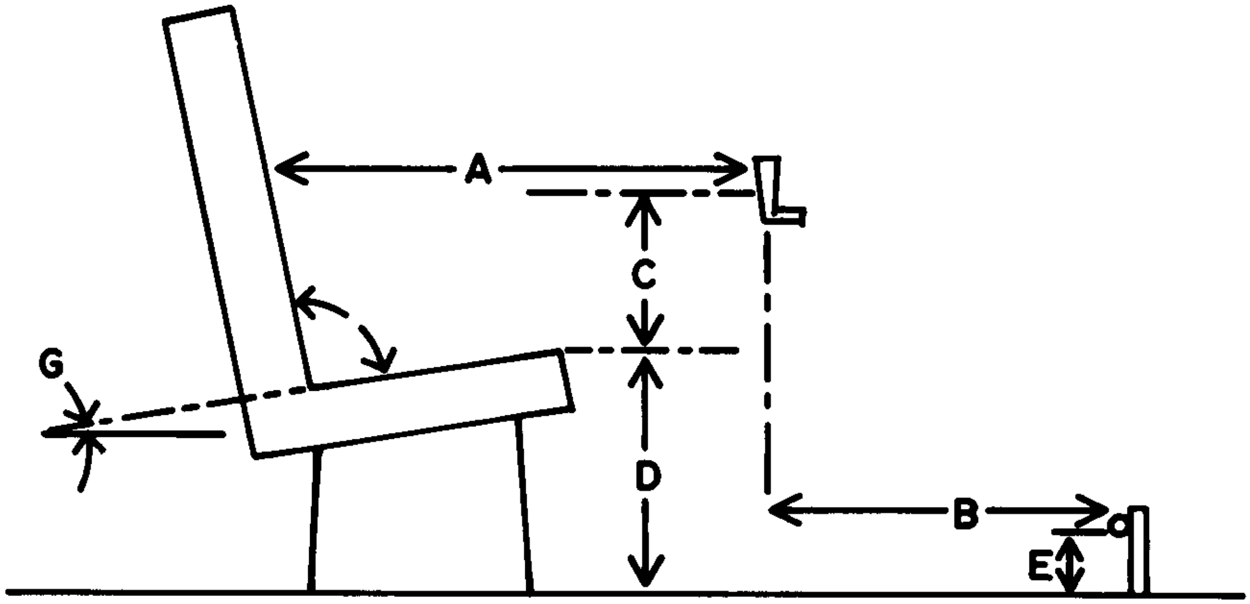
TEST CONDITIONS AND SEATING GEOMETRY

TABLE 7

TEST CONDITIONS IN CONVAIR SIMULATOR

Simulator Flying Conditions	
Flight Engineer Controls	
Gross Weight	42,000 lbs.
Sound Volume	.25
Center of Gravity	.25
Turbulence	0
Wind Speed	0
Fuel	Full
Cockpit Controls	
Cowl Flaps	Open
Panel Lights	Bright
Flap Position	11°*
Landing Gear	Down *
Altitude (locked)	3000 ft.
Manifold Pressure	38 in.
Engine RPM	2350
Brake Horsepower	154
Indicated Airspeed (locked)	130 knot

* These values chosen to simulate an aircraft in initial phase of landing.



A Horizontal Distance--Seat back to wheel

B Horizontal Distance--Wheel to rudder pedal

C Vertical Distance--Wheel to seat edge

D Vertical Distance--Seat edge to floor

E Vertical Distance--Rudder to floor

F Angle--Seat back to seat bottom

G Angle--Seat bottom to horizontal

Note: All dimensions from seat taken with seat cushions uncompressed.

FIGURE 10. Seat dimensions and control placements.

TABLE 8

COMPARISON OF SEATING GEOMETRY OF MODIFIED CONVAIR WITH GENERAL AVIATION AIRCRAFT

	Modified Convair 340	Karim Mock-up	Piper Com.250 1959	Cessna 150, 1968	Beechcraft Bonanza, 1967	Piper Tri-P 1958	Beechcraft Baron, 1967
Vertical Dimensions							
Seat to Floor (")	15	13	14	14	15	12	13
Seat to Grip (")	13	12	13	13½	13	14	12
Pedal to Floor (")	5	5	5½	4½	5	6	5½
Horizontal Dimensions							
Seat to Wheel (")	17-29	19-25	16-23	20-25	22-27	19-22	17-22
Wheel to Pedal (")	19	17½	21	20	19	23	22
Seat Dimensions							
Back Height (")	20	21	19	22	21	21	22
Bottom Length (")	14	16	17	18	19	15	19
Bottom Width (")	18	18	18	17	18	18	18
Seat Angle (°)	95	95	100	105	100	90	95
Bottom Angle (°)	10	10	10	10	10	15	5
Wheel Dimensions							
Diameter (")	10	10	10	10	10	12	10
Rim Diameter (")	7/8	5/8	3/4	3/4	7/8	5/8	7/8

APPENDIX D

APPENDIX D

DATA FOR U.S. PILOT POPULATIONS AND TEST SUBJECTS

TABLE 9

AGE DISTRIBUTION OF ACTIVE AIRMEN BY CLASS AND SEX*
As Of: 31 December 1969
Note: Classes based on class of Medical Certificate

Age	First Class		Second Class		Third Class		Total Airmen	
	Male	Female	Male	Female	Male	Female	Male	Female
Less than 15	2	-	7	-	30	7	39	7
15-19	2,100	34	4,834	243	25,936	2,299	32,870	2,576
20-24	9,176	68	35,316	664	55,048	4,037	99,540	4,769
25-29	19,155	71	48,691	599	50,683	4,530	118,529	5,200
30-34	17,290	53	39,443	524	43,122	3,674	99,855	4,251
35-39	10,957	26	37,831	530	46,039	3,323	94,827	3,879
40-44	6,734	41	25,490	572	49,602	2,928	81,826	3,541
45-49	9,354	27	31,365	468	38,432	2,138	79,151	2,633
50-54	5,054	13	15,990	298	23,306	1,143	44,350	1,454
55-59	1,634	4	5,754	134	12,425	473	19,813	611
60-64	474	1	2,306	60	5,589	165	8,369	226
65-69	57	1	745	22	1,997	47	2,799	70
70-74	5	-	208	2	674	15	887	17
75-79	3	-	37	-	162	6	202	6
80-84	-	-	7	-	30	2	37	2
85 and over	-	-	-	-	3	-	3	-
TOTAL	81,995	339	248,024	4,116	353,078	24,787	683,097	29,242

*Totals are based on active certified airmen within the past 25 months.

SOURCE: Civil Aeromedical Institute, Aeromedical Certification Branch, Medical Statistical Section: RIS: AC 8500-1, Aeromedical Certification Statistical Handbook Computer Run.

TABLE 10

HEIGHT DISTRIBUTION OF ACTIVE AIRMEN BY CLASS AND SEX*
As Of: 31 December 1969

Height in Inches	First Class Male	First Class Female	Second Class Male	Second Class Female	Third Class Male	Third Class Female	Total Airmen Male	Total Airmen Female
Less than 59	411	5	1,173	41	1,615	282	3,199	328
59	106	-	285	21	370	87	761	108
60	117	10	466	96	618	642	1,201	748
61	47	12	221	126	354	853	622	991
62	52	35	223	363	535	2,606	810	3,004
63	75	38	371	461	917	2,857	1,363	3,356
64	223	37	1,323	618	2,410	3,986	3,956	4,641
65	575	54	2,843	640	4,888	3,674	8,306	4,368
66	1,832	45	8,175	637	13,049	3,723	23,056	4,405
67	4,150	48	14,125	473	21,221	2,719	39,496	3,240
68	8,217	27	25,963	346	36,999	1,809	71,179	2,182
69	9,621	12	29,336	160	39,895	840	78,852	1,012
70	13,082	11	38,124	70	53,650	340	104,856	421
71	12,510	3	37,977	27	55,074	165	105,561	195
72	14,621	1	41,760	25	57,013	97	113,397	123
73	6,933	1	19,508	5	27,328	27	53,769	23
74	5,505	-	14,859	3	20,420	22	40,784	25
75	2,432	-	6,425	2	9,130	17	17,987	19
Over 75	1,486	-	4,864	2	7,592	41	13,942	43
TOTAL	81,995	339	248,024	4,116	353,078	24,787	683,097	29,242

*Totals are based on active airmen certified within the past 25 months.

SOURCE: Civil Aeromedical Institute, Aeromedical Certification Branch, Medical Statistical Section; RIS: AC 8500-1, Aeromedical Certification Statistical Handbook Computer Run.

*Totals are based on active airmen certified within the past 25 months.

SOURCE: Civil Aeromedical Institute, Aeromedical Certification Branch, Medical Sta tistical Section; RIS: AC 8500-1, Aeromedical Certification Statistical Handbook Computer Run.

TABLE 11

WEIGHT DISTRIBUTION OF ACTIVE AIRMEN BY CLASS AND SEX*
As Of: 31 December 1969

Weight in Pounds	First Class Male	First Class Female	Second Class Male	Second Class Female	Third Class Male	Third Class Female	Total Airmen Male	Total Airmen Female
Less than 90	120	3	264	10	381	86	765	99
90-99	2	5	3	47	50	387	55	439
100-109	23	22	45	282	394	2,007	372	2,311
110-119	145	77	383	783	1,338	5,166	1,866	6,026
120-129	606	103	1,962	1,057	4,856	6,451	7,424	7,611
130-139	2,106	61	7,257	881	13,800	4,918	23,163	5,860
140-149	5,247	36	16,974	534	27,111	2,707	49,332	3,277
150-159	10,455	13	30,834	242	43,850	1,388	85,139	1,643
160-169	14,908	9	42,644	124	56,888	718	114,440	851
170-179	16,174	4	45,188	70	59,661	405	121,023	479
180-189	13,811	4	40,176	32	52,497	247	106,484	283
190-199	8,696	1	27,884	27	36,729	137	73,309	165
200-209	4,710	-	15,944	13	22,635	72	43,289	85
210-219	2,641	-	9,031	4	14,328	37	26,000	42
220-229	1,306	-	4,753	6	8,282	25	14,341	31
230-239	584	-	2,380	2	4,644	9	7,608	11
240-249	248	-	1,142	-	2,512	8	3,902	8
Over 249	213	-	1,160	2	3,212	19	4,585	21
TOTAL	81,995	339	248,024	4,116	353,078	24,787	683,097	29,242

*Totals based on active airmen certified within the past 25 months.

SOURCE: Civil Aeromedical Institute, Aeromedical Certification Branch, Medical Statistical Section; RIS: AC 8500-1, Aeromedical Certification Statistical Handbook Computer Run.

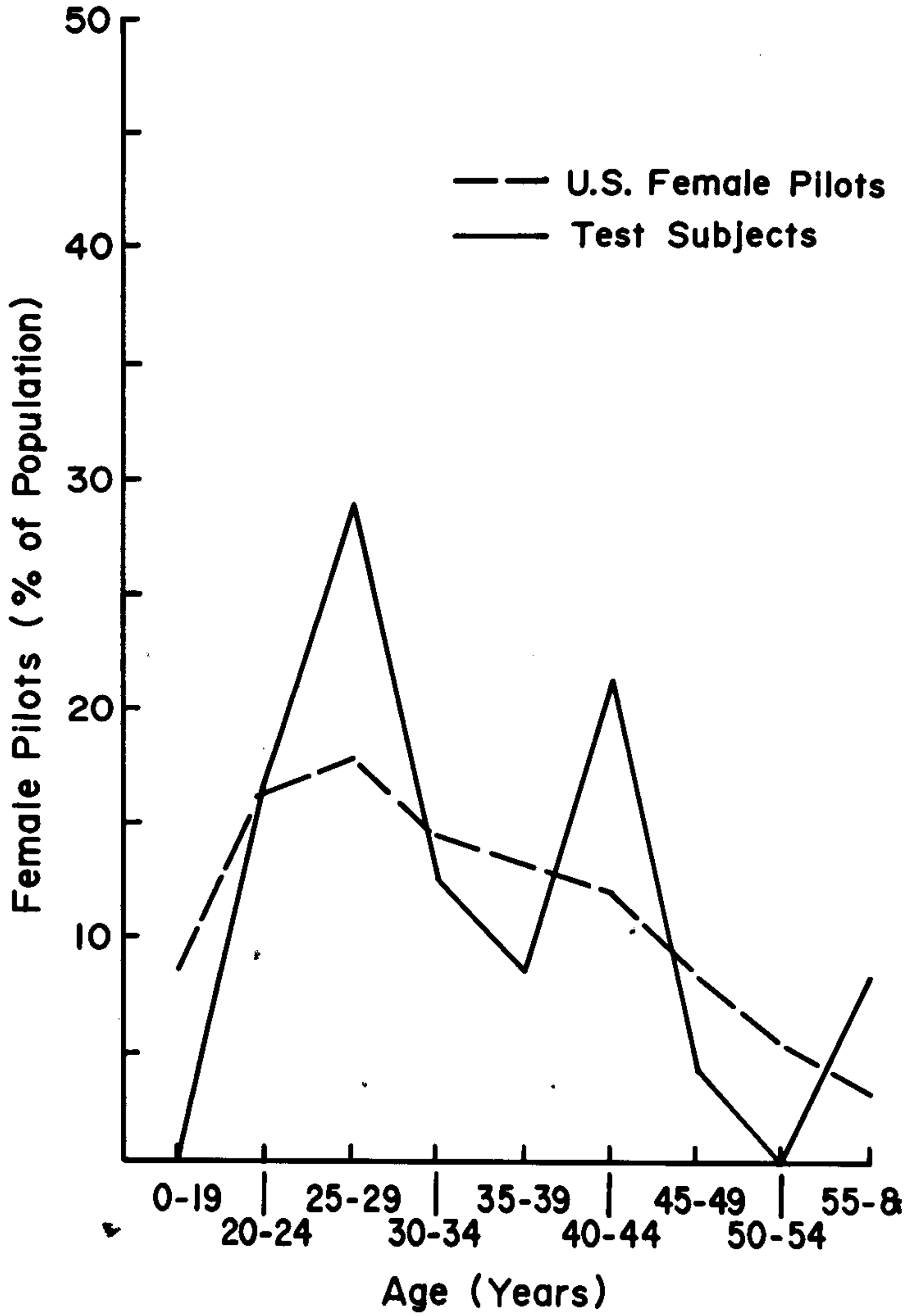


FIGURE 11. Age distribution curves.

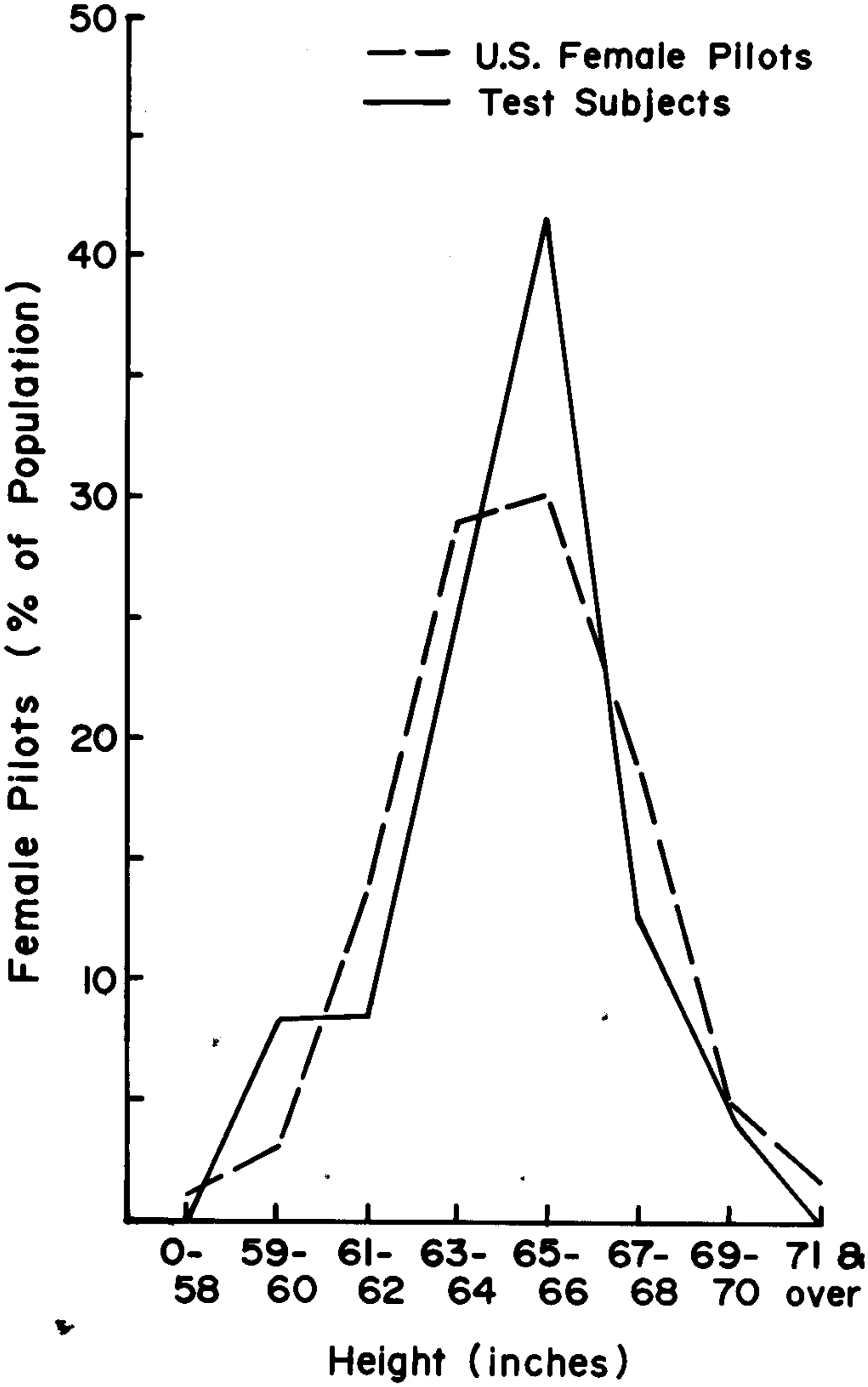


FIGURE 12. Height distribution curves.

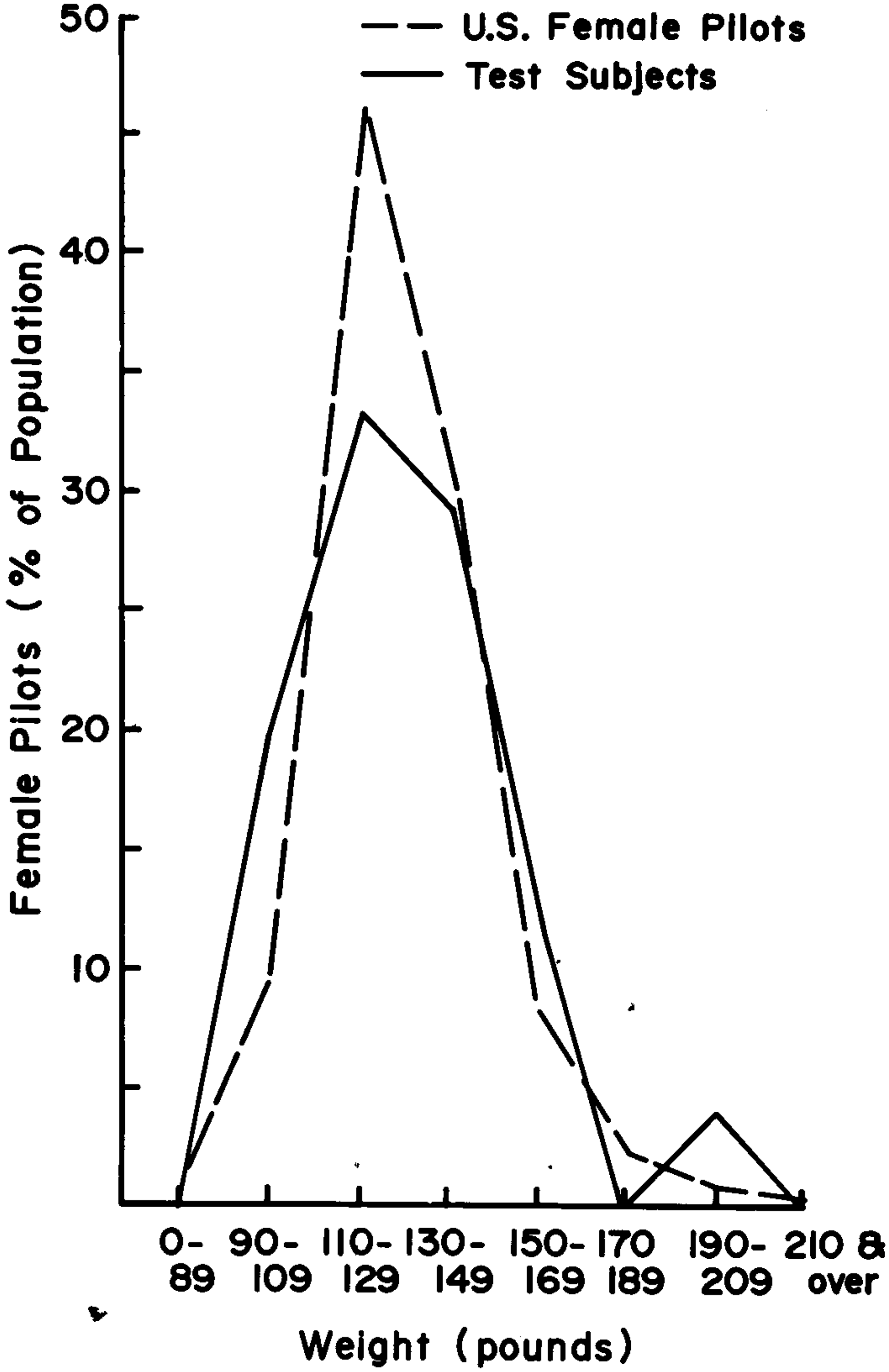


FIGURE 13. Weight distribution curves.

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University of Oklahoma, College of Engineering, and Federal Aviation Administration, Office of Aviation Medicine, Civil Aeromedical Institute, Oklahoma City, Oklahoma. **STUDY OF CONTROL FORCE LIMITS FOR FEMALE PILOTS** by Robert C. Leeper, A. Howard Hasbrook and Jerry L. Purswell, Ph.D., December 1973, 30 pp. Report No. **FAA-AM-73-23.**

The study described in this paper was the second phase in a ground-based control force testing program conducted by the University of Oklahoma and the Civil Aeromedical Institute of the Federal Aviation Administration located in Oklahoma City, Oklahoma. A Convair-340 simulator, modified to conform to a typical civil aviation aircraft, was used for the study. Female pilots were used as subjects.
The data show that the current FAR 23.143 control force limits for general aviation aircraft are too high for a majority of U.S. female pilots. Data on strength capabilities for women for operating aircraft controls are presented in the form of prediction equations for level of control force versus time.

I. Leeper, Robert C.
II. Hasbrook, A. Howard
III. Purswell, Jerry L.

Descriptors
Control Forces
Female Pilots
Aviation Safety

University of Oklahoma, College of Engineering, and Federal Aviation Administration, Office of Aviation Medicine, Civil Aeromedical Institute, Oklahoma City, Oklahoma. **STUDY OF CONTROL FORCE LIMITS FOR FEMALE PILOTS** by Robert C. Leeper, A. Howard Hasbrook and Jerry L. Purswell, Ph.D., December 1973, 30 pp. Report No. **FAA-AM-73-23.**

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