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# **NextGen Final Report: Data for Updating 14 CFR Part 25.143 and Potential Reference Standards for Part 23, 27, and 29 Aircraft: An Evaluation of Muscular Force That can be Applied to Flight Controls**

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Final Report

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16. Abstract  <p>The Code of Federal Regulations (14 CFR 25.143) contains maximum limitations on the force that a pilot can be expected to exert on manual controls. There are currently no reference standards contained in Parts 23 (General Aviation; rewritten in 2017), 27, and 29 (rotorcraft). A number of recent previous studies suggested that the CFR reference forces were too high to allow a significant portion of the population to attain them. In an attempt to obtain a reasonably large contemporary sample to update knowledge on this topic, human-performance data were collected, at several sites, for both pilots and nonpilots using stratified sampling for age, gender, and pilot status to achieve a comprehensive sample. The criterion values in the CFR were compared with data from these samples to determine what proportion of both potential (nonpilot) and actual pilot populations could apply the maximum forces allowed by the present rule. Results are presented in the form of both success/failure rates and distributions of obtained performance. Significant portions of the females' samples were not able to achieve the short-term reference values for the various controls (over 60% for all controls). Between 15% and 65% of the males' samples, depending upon the control type, were unable to meet the reference short-term force values. The complete distributions by percentiles are provided so that policy makers can determine, based upon the percentage of the overall population to be accommodated, what the appropriate reference values should be. This will inform an update of 14 CFR 25.143 and the formulation of industry-consensus standards to support NextGen in safely accommodating the current pilot population in the next generation of aircraft.</p>					
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## EXECUTIVE SUMMARY

Sections of the Code of Federal Regulations (14 CFR 25.143) contain maximum limitations on the force that a pilot can be expected to exert on manual controls. The origins of the data, used for testing and certification of aircraft, are unclear. Several sources suggest they were derived from the testing of young male U.S. Air Force recruits in the 1950s and possibly as late as the early 1960s (Joslin, 2014; Beringer, 2006). The continued applicability of these standards is questionable because of the lack of information regarding their origin, changing pilot demographics (a higher percentage of female pilots, an aging pilot population and possible changes in the overall population), changing aircraft-control environments, and limited data regarding the simultaneous activation of multiple controls (i.e., yoke plus rudder). As the next generation of aircraft are designed, and existing aircraft are retrofitted with advanced (newer) NextGen controls, an update to the force limitation standards will be a valuable resource.

Previous examinations of the forces that users could apply to flight controls suggested that the CFR reference forces were, in fact, too high, particularly for female pilots and nonpilots (Karim et al., 1972; Leeper, Hasbrook, and Purswell, 1973; Beringer, 2006, 2008, 2009; Beringer, Ball, and Haworth, 2007). These samples were of various sizes and compositions, but all combined to suggest that updates to the CFR reference values were needed if those values were to truly allow a majority of users to be capable of manipulating aircraft controls up to the values specified.

Thus from these archival data, it was clear that there were portions of the female-pilot population that could not achieve the reference-force levels, and from the additional data in the Beringer series of studies, that much of the general nonpilot population could not achieve the reference values. As such, a follow-on study was designed to use a larger sample size (300 participants) using stratified sampling (male/female, pilot/nonpilot, 5 age categories) and sampling performance of force exertion against a variety of types and locations of flight controls. These included sticks (left, center, right), yoke, rudder pedals (left, right), and helicopter collective. Performance was measured for short-term “maximum” force exertion (at 3 seconds) and a subjective prolonged-force estimation after that. The data were collected at three sites including The University of Oklahoma Westheimer Airport (Norman, OK), FAA Southwest Regional Headquarters (Ft. Worth, TX), and the FAA Civil Aerospace Medical Institute (Oklahoma, OK).

The results for the short-term application of force indicated that, on average, more than half of the sample could not achieve the reference-value forces. This was most prevalent for the stick control (over 80% not compliant) and least prevalent for the yoke roll axis (roughly 45% not compliant). A further division of the data by male/female and pilot/nonpilot indicated a large difference between the male and female participants, with roughly an average of 40% difference in compliance, favoring the males (e.g., yoke pitch, one hand) and a lesser separation between the pilots and nonpilots dependent upon the category (anywhere between 8% and 14% difference, favoring the pilots). However, both were consistent differences.

Initial findings for the application of prolonged force (smaller sample, supplemental trials) indicated that the successful maintenance of the reference-value force was dependent upon the control examined. Specifically, for the subsample of female pilots (42), approximately 90% of the participants could maintain the reference force for rudder input for 4 minutes or more, and approximately 87% could maintain the reference yoke-roll force for 4 minutes or more. However, yoke pitch and stick pitch could only be maintained for that duration by between 60 and 70% of the sample. In the worst case, reference stick-roll force could only be maintained for over 4 minutes by about 16% of the sample. Values for a smaller

subsample of males (17) showed a higher percentage holding for 4 minutes or more, all controls with between 60 and 90%.

In examining the application of force to two controls simultaneously, as would be expected during an engine-out situation for a normally configured (engines mounted in wing nacelles) twin-engine aircraft (worst possible case for adverse yaw and roll), the two items of interest were how force applications fared against reference individual-control values (there being no references specified for this condition), and how exerting force on two might affect the force applied to either when compared with single-control applications. Yoke-roll short-term reference forces could be met by about 50% of the sample. Short-term stick reference forces could be met by less of the sample (between 15 and 25% of the sample). However, in all cases rudder-force application for the short-term reference force could only be met by 5% of the sample. In addition, there was over a 50% drop in applicable force from the rudder-only condition to the dual-control condition, accounting for the failure of most to meet the criterion. Stick and yoke input forces, however, were largely unaffected by going from single- to dual-control input.

It is recommended that the entries in the current CFR table be revised to be consistent with the inclusion of an appropriate percentage of the user population, determined as a function of the research reviewed, the present data set, and defined policy. It is also recommended that entries for forces appropriate for dual-control activations and for entries that differentiate between different placements and configurations of flight controls be considered for inclusion, and all should be considered for the establishment of industry-consensus standards.

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# **NEXTGEN FINAL REPORT: DATA FOR UPDATING 14 CFR PART 25.143 AND POTENTIAL REFERENCE STANDARDS FOR PART 23, 27, AND 29 AIRCRAFT: AN EVALUATION OF MUSCULAR FORCE THAT CAN BE APPLIED TO FLIGHT CONTROLS**

## **BACKGROUND**

A significant number of compilations have been created over the last 60 years detailing both static (dimensions) and dynamic (force/strength) anthropometric data for various applications. Some of them have been more general in nature, while some of them have been specifically targeted towards application areas (aviation environment and pilots, for example). A listing of some of the well-established reference sources can be found, collectively, in a series of publications by Beringer (Beringer, 2006; Beringer, Ball, & Haworth, 2007; Beringer, 2008; Beringer, 2009, page 431). Joslin (2014) presents a listing of additional and some later sources, ranging from 1972 through 2013. It is worth noting here some of the more frequently used and well-known references from which data have been excerpted (and from which the later ones extracted data to reproduce from the earlier reports), which include Ahlstrom & Longo, 2003; Diffrient, Tilley, & Bardagjy, 1974; Diffrient, Tilley, & Harman, 1981; Diffrient, Tilley, & Harman, 1982; FAA, 1996; MIL-STD-1472F, 1999; NASA, 1978; NASA, 1995; Van Cott and Kinkade, 1972; Woodson, Tillman, & Tillman, 1992. Additionally, some sources contain data specific to particular types of controls (Foot controls – Hertzberg & Burke, 1971, and Kroemer, 1971; aircraft flight controls by location – Thorsden, Koremer, & Laubach, 1972; helicopter flight controls – Hewson, McNair, & Marshall, 2000). One feature of a number of these databases is that many are reiterations of earlier data captures (e.g., Morgan, Chapanis, Cooke, & Lund, 1963, as one source) and thus, despite later publication dates, the data actually predate the date of the compilation, and one must be aware of the original sources of the data to thus be able to determine its applicability.

The availability of relatively current anthropometry data is important so that design efforts can be appropriate to accommodating a reasonable proportion of the expected user population, for any system, both now and in the immediate future, to align with NextGen. Beringer (2006) pointed out that as compared with much earlier periods in aviation, a greater proportion of the aircraft user (pilot) population is both female and older, either of which would justify a revisiting of the capabilities of the expected user population relative to the criteria expected to be met according to the aircraft certification rules, particularly those that were instituted in the 1960s and/or 1970s but were based upon data obtained in the 1950s and 1960s. Joslin (2014) reports that documented justification exists that demonstrates how the time-based changes in the overall-population anthropometric measures, both static (e.g. stature, static reach envelope) and dynamic (range of motion, strength), call for a periodic and regular updating of these measures. Changes in stature had been, for a number of decades, generally in the direction of “taller” (see Laubach & McConville, 1969, for strength/body size relationship), but that trend appears to have leveled off currently. Most recent trends have indicated an increase in average weight and a slight reduction in average muscular strength, as well as a continuing increase in the proportion of older individuals in the population.

Previous relevant inquiries had focused, specifically, on what performance could be anticipated from female pilots as contrasted with the reference values found in tables in the Code of Federal Regulations (CFR), specifically those in 14 CFR 23.143 and 14 CFR 25.143, which specified the allowable forces a pilot can experience in aircraft controls. Table 1, excerpted and modified from Beringer (2009), shows the participant types, control types, sample sizes and age ranges where available for a number of the most relevant prior samples collected for comparisons with the extant reference values in the CFR.



**Table 1.** Sample compositions showing authors, group, controls examined, sample size, mean age, and age range where available for studies using female participants and aircraft controls. Groups of fewer than 4 individuals have been omitted. (Adapted from Beringer, 2009, pg. 432).

Sample	Group	Controls <sup>+</sup>	n	Age	
				Mean	Range
Karim et al. (1972)	Female Part 91 pilots	Y, RP	25	35.4	18 to 58
Leeper et al. (1973)	Female pilots	Y, RP	24*	34.4	20 to 64
McDaniel (1981)	Males & Females, w/in USAF pilot candidate height/weight criteria	S, RP	61 each	NA	NA
Beringer (2006) Beringer, Ball & Haworth (2007)	Male Part 121 pilots	Y, RP	32	49.7	38 to 58
	Female Part 91 pilots	Y, RP	12	45.7	21 to 64
	Female nonpilots	Y, RP	12	49.5	17 to 71
Beringer (2008, 2009)	Female Part 121 pilots	Y, RP, CS, SS	11	40.8	32 to 54
	Male Part 121 pilots	Y, RP, CS, SS	6	39.5	32 to 52
	Female nonpilots (flight attendants)	Y, RP, CS, SS	10	39.9	24 to 57
	Male nonpilots (flight attendants)	Y, RP, CS, SS	6	32.5	22 to 47

<sup>+</sup>Abbreviations: Y=Yoke, RP=Rudder pedals, CS=Center Stick, SS=Side Stick, S=stick (unspecified).

\*Sample approximated distribution of female pilot population of that time by age, height, and body type.

Additional assessments were performed by Meyer, Pokorski, and Ortel (1996), Schopper & Mastroianni (1987, referred to later), and Thorsden, Kroemer, and Laubach (1972; males only and stick and collective controls). Others examined male/female differences but were not specific to aircraft controls, including Laubach (1976a), Laubach (1976b), and Diffrient, Tilley, & Harman (1981).

Of the reference tables containing specific data for control-force limits previously found in 14 CFR 23 and 14 CFR 25, only the Part 25 table remains in the CFR. The Part 23 table was replaced in the 2017 rewrite of that part [see 14CFR 23.2135 (Amendment 64) Controllability] by reference to a to-be-determined industry-consensus standard. For reference in this report, a combination of the two reference tables is reproduced immediately below, the only difference between this one (Table 2) and the Part 25 table still in force being that the latter does not contain the “stick” reference row. Parts 14 CFR 27 and 14 CFR 29 (rotorcraft) contain no specific quantitative performance values. For simplicity, all following uses of “CFR reference” will refer to the values presented in Table 2.

**Table 2.** Force-exertion limitations (lbs.) in 14 CFR 25.143 with “Stick” row (shaded) reproduced from the table previously in 14 CFR Part 23.143(c). (While “wheel” appears in the table, virtually no contemporary aircraft actually have a literal “wheel.” Thus this report will use “yoke” as the referent for “wheel.”)

Force, in pounds, applied to the control wheel or rudder pedals	Pitch	Roll	Yaw
For short term application for pitch and roll control – two hands available for control	75	50	
For short term application for pitch and roll control – one hand available for control	50	25	
For short term application for yaw control			150
For long term application	10	5	20
<i>Short term Stick, center position [previously from 23.146(c)]</i>	60	30	

## **Context and Purpose**

Given the scarcity of very recent documentation, with moderate sample sizes, of the force applications of interest, a study was designed to collect data on the application of force by a sample representative of a cross section of the expected population of users and of a reasonable size to support generalization. The intent was to update our knowledge in this area and determine to the extent possible if performance for this population might have changed since the reporting of earlier results in the literature, and to generate a basis for recommendations to modify the CFR reference values. We now have more female and older pilots flying (see Laubach, 1976a, for differences in strength between males and females; see Stoll et al., 2002, for the decrease of muscular strength with age).

Knowing the distribution of muscular strength in the pilot population is critical to ensuring that pilots can generate adequate forces to control aircraft. Therefore the primary intent of this study was to gather strength data to determine whether the values contained in the companion tables formerly in Part 23 and currently in Part 25 of 14 CFR were appropriate to a user population whose demographics have likely changed enough to warrant a reevaluation. Additionally, differences between some flight controls (also referred to as “inceptors” in SAE, 2013 and 2018) that are known to influence the force a pilot can exert (center-stick versus side-stick controls, for example, and direction for force application; specifically adduction versus abduction motions) are not noted in the existing tables. Part of the current effort was to document the influence of particular gross differences in usual stick placement, along with the effects of a rotated yoke on applied force. Finally, the tables do not differentiate between activating a single control (i.e., yoke) and activating multiple controls (eg., yoke and rudder) simultaneously. This is important because data from helicopters (Schopper & Mastroianni, 1987; reference “multiple controls”) and studies of dynamic anthropometry (Beringer, et al., 2006, 2007, 2008, 2009) have demonstrated applicable forces will be lower when activating multiple controls simultaneously.

## **METHOD**

### **Participants and Sampling**

Initial overall sample size was selected as 300 individuals. Some additional samples were taken in some cells to compensate for possible attrition due to incomplete or unusable data files. The participants were chosen based upon a stratified-sampling approach whereby 15 individuals were selected to fill each of 20 cells defined by a full crossing of gender (2), pilot status (2), and age group (5). This systematic sampling was intended to cover the expected range of user (and potential user) types to include representative samples of females and older individuals. The resulting distribution of sampling cells is depicted in Table 3. Age brackets were used as a sampling variable to equate age distributions across the four major subsamples. Overall, the sample closely replicated the distribution of hand preference found in the general population (sample, 11.2% left-hand preference; population, 10% left-hand preference).

**Table 3.** Cells contained in stratified-sampling design. The planned total is followed by (actual total) if the two are different.

	<b>Pilot</b>		<b>Nonpilot</b>	
<b>Age (years)</b>	<b>Male (M)</b>	<b>Female (F)</b>	<b>Male (M)</b>	<b>Female(F)</b>
<b>18-29</b>	15 (19)	15 (16)	15	15 (16)
<b>30-39</b>	15	15	15	15
<b>40-49</b>	15	15 (16)	15 (16)	15 (17)
<b>50-59</b>	15 (16)	15	15 (16)	15 (18)
<b>60-69</b>	15	15	15 (16)	15 (17)

Participants were recruited from a number of organizations and data collected at several sites. FAA employees at two of the sites participated as volunteers as part of their regularly scheduled FAA employment. Individuals who were not FAA employees were compensated for their participation time. Data were collected at three sites: (1) FAA Southwest Region Headquarters, Ft. Worth, TX, (2) the University of Oklahoma Westheimer Airport, Norman, OK, and (3) the Civil Aerospace Medical Institute, Oklahoma City, OK.

### **Apparatus**

A cockpit-seating mockup was constructed similar to that used by Beringer (2006). An adjustable (fore/aft, up/down) seat with a lap belt was mounted on rails on the platform and positioned such that its adjustable range relative to the yoke and rudder pedals plane was comparable to that found in aircraft. A representative (simulated) yoke was mounted on a shaft in the same position as that found in the aircraft, and precision force transducers were used to measure applied force in pitch and roll. Precision force transducers were also mounted in two rudder dead pedals (fixed, no movement) such that application of foot force could be measured at the plane of the rudder pedals for either foot. Three positions were used for stick controls: left, center, and right, all with precision force transducers. The yoke was removable, using a quick-release mechanism, and was removed when the center stick was put in place for center-stick-force measurements. This same splined mechanism also allowed the yoke to be installed in discrete incremental rotations in the roll axis to simulate a displaced control. A simulated helicopter collective was installed on the left side of the seat, again with precision force transducers for up and down force. The apparatus was designed with lockable wheels so that it could be moved easily for transportation to remote sites and secured in place when the wheels were locked. The apparatus can be seen in Figure 1, which shows the yoke installed.



**Figure 1.** The force-measurement apparatus.

## Procedure

When participants arrived at the testing location they were asked to sign an informed consent form, which contained a description of the tasks they were to perform. They then filled out a demographic profile to record their age, gender, pilot status, hand preference, and to document any regular exercise that might contribute to their performance of the tasks. Additionally, height and weight of each participant were measured and recorded in their profile.

Following this initial preparation activity, each participant was seated in the apparatus and the seat was adjusted to offer the best compromise, for that individual, between rudder pedal access and stick/yoke access. Knee angles were measured as a covariate. Participants then performed 43 force-application tasks using the various simulated flight controls and following one of two counter-balanced orders of presentation. Each order carefully sequenced the force applications used in each trial so that there was the maximum amount of time possible that passed between repeated use of the same appendage, in a specified direction, in a trial. There were also six strategically placed breaks to provide both additional muscle-recovery time in the course of the trials (Stoll, Huber, Seifert, Stucki, & Michel, 2002; Karim et al., 1972; Leeper et al., 1973; Beringer, 2009) and to allow for the interchanging of the yoke and the center stick when necessary. Additional references used for determination of measurement procedures included Chaffin (1975), Chaffin, Andersson, & Martin (2006a, 2006b), and Kromer (1970).

Trials were distributed by control type and direction of force application as shown in Table 5, which shows only the primary variables and the conditions thus generated. Each of the stick controls had force applied to it in each of the four cardinal directions (left, right, forward, aft), the yoke had force applied to it in both directions of roll and both directions of pitch with either one hand or with both hands, the collective had force applied in the up and down dimensions, and each rudder pedal was pressed. There were eight rotated-yoke trials where the yoke was installed rotated approximately 36 degrees to the left (counter-

clockwise) and 36 degrees to the right (clockwise) to provide a comparison point with the nominal control position. Finally, there were three multiple-control tasks (Schopper & Mastroianni, 1987), which we will refer to specifically as “dual-control” tasks here because only two controls at a time were manipulated/measured, to simulate activation of yoke/rudder or stick/rudder simultaneously as one would be required to do in an engine-out situation in a twin-engine aircraft (left stick/left foot, yoke/left foot, center stick/right foot), and these trials were distributed across the orders to provide maximum separation between their occurrences.

**Table 4.** Listing of tasks by control, hand/foot used, and direction of force applied.

Control	Position	Hand (or foot) used	Pitch		Roll	
			Push	Pull	Left	Right
Stick	Left	Left				
	Center	Left				
		Right				
	Right	Right				
Yoke		Left				
		Right				
		Both				
Rudder	Left	Left				
	Right	Right				
			Up	Down		
Collective	Left	Left				

**Table 5.** Eight rotated-yoke trials as defined by hand used, direction of yoke rotational offset, and direction in which force was exerted (cell entries indicated general direction in which force was actually exerted).

	Direction of Yoke Rotational (36 deg) Offset			
	Counter-clockwise		Clockwise	
	Left Hand	Right Hand	Left Hand	Right Hand
	Force counter-clockwise	Force clockwise	Force counter-clockwise	Force clockwise
	(Down)	(Up)	(Up)	(Down)
	(Up)	(Down)	(Down)	(Up)

**Task performance procedure.** For each trial, participants were instructed to exert as much force as they could on the designated control and in the direction specified, and to apply smoothly increasing force to the control rather than jerk it. They were required to hold this force for 3 seconds (the “temporary” duration, term to be used interchangeably in this document with “short-term”), after which they were to “step down” to a lower force application that they believed that they could hold for several minutes (the “prolonged” period, to be used interchangeably with “long-term” in this document): a subjective self-estimation of prolonged-force ability (Beringer, 2009). The complete trial length was 9 seconds as it had been determined in earlier research and validated during pretest that stable plateaus were reached by that time for the reduced-force portion of the trial. Note that Mil-Std 1472 G §5.1.4.3.1 defines sustained force as being *longer* than 3 seconds, and thus the choice of 3 for the short-term duration (see AC 25-7D §5.1.1.2 for a qualitative definition; value also used by Beringer in previous studies).

A set of three supplemental trials (sustained-force application) was added to those performed by a subset of participants late in the data collection to parallel the earlier method used by Leeper et al. (1973) whereby participants held a specified level of force for as long as they could, the dependent measure then being duration of hold. This additional procedure was implemented due to the step-down portions of the original procedure not producing acceptable and consistent results across the various subsamples. The initial target, based upon discussions/calculations of length of time it might take for the pilot of a low-performance GA aircraft to complete an approach and landing, was 5 minutes duration. In practice, participants either held the requested force for the entire 5 minutes, in which case the trial was terminated, or they terminated the trial themselves when they determined they were no longer able to maintain the force or the experimenter saw the applied force drop more than 10% below the target force level and remain there. This was expected to generate an objective measure of how long the CFR reference forces could be maintained in contrast with the subjective measures used in the interim studies and in the initial data collection herein. The initial session length was approximately one-half hour. Depending upon the lengths of hold for the three individual supplemental trials, this procedure added between 9 and 18 minutes to the session length.

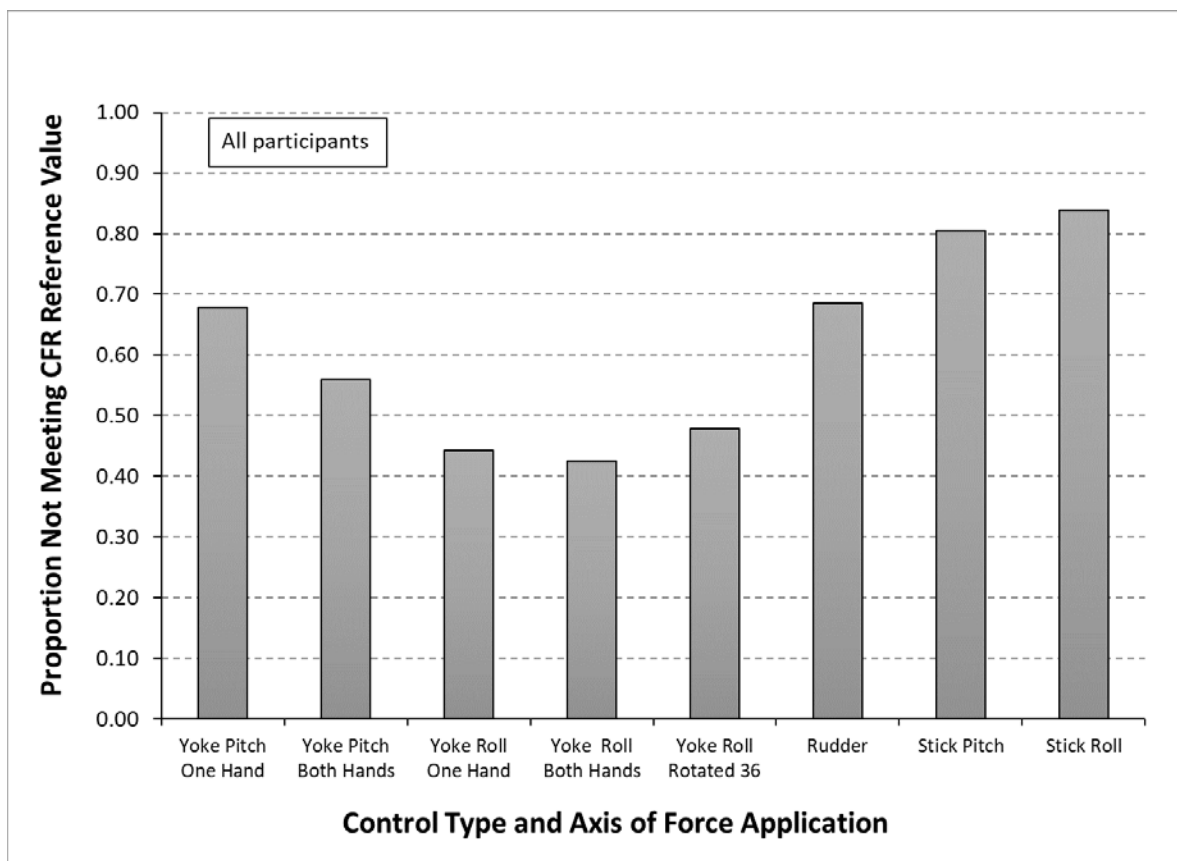
## **RESULTS AND DISCUSSION**

The primary concern in this study was to determine the distribution of force-application capabilities in the populations of interest. The question of immediate interest was what percentage of the participants would be able to achieve the reference forces for short-term application, as evidenced by the obtained distributions, which is to address the question of whether or not the present reference values are too high, and comparisons are presented following between the obtained force values and the CFR reference values. Not only can the distributions demonstrate how much of the population is likely to achieve the reference values, but they can also allow the examination of “average” (50<sup>th</sup> percentile) and low-end percentiles (5<sup>th</sup>, 10<sup>th</sup>, etc. for the weaker individuals; 5<sup>th</sup> percentile and below would be the weakest 5% of the population) that can be used according to subsequently defined policy that might be established concerning what proportion of the population of users should be accommodated.

Further, to facilitate the goal of selecting appropriate reference values, distributions of the various percentile values for force application were generated and are contained in the Appendices. In an attempt to succinctly highlight these outcomes, distributions of the raw data as grouped by the entire sample, males, females, pilots, and nonpilots are presented, illustrating the performance of the entire sample and its component subsamples. Examination of subsamples/groupings having less than 75 data points is generally avoided because of the effect the smaller size has on the shape and reliability of the distribution. It should also be noted that there were cases, for a small number of trials, where the data did not exhibit a clearly interpretable stabilized plateau at the end of the initial three seconds of the trial. In these cases, the distributions and percentiles were determined with the slightly smaller samples (no more than two cases where there were 67 of the intended 75 for a subsample, and usually between 72 and a few more than 75 where additional participants were obtained in a cell).

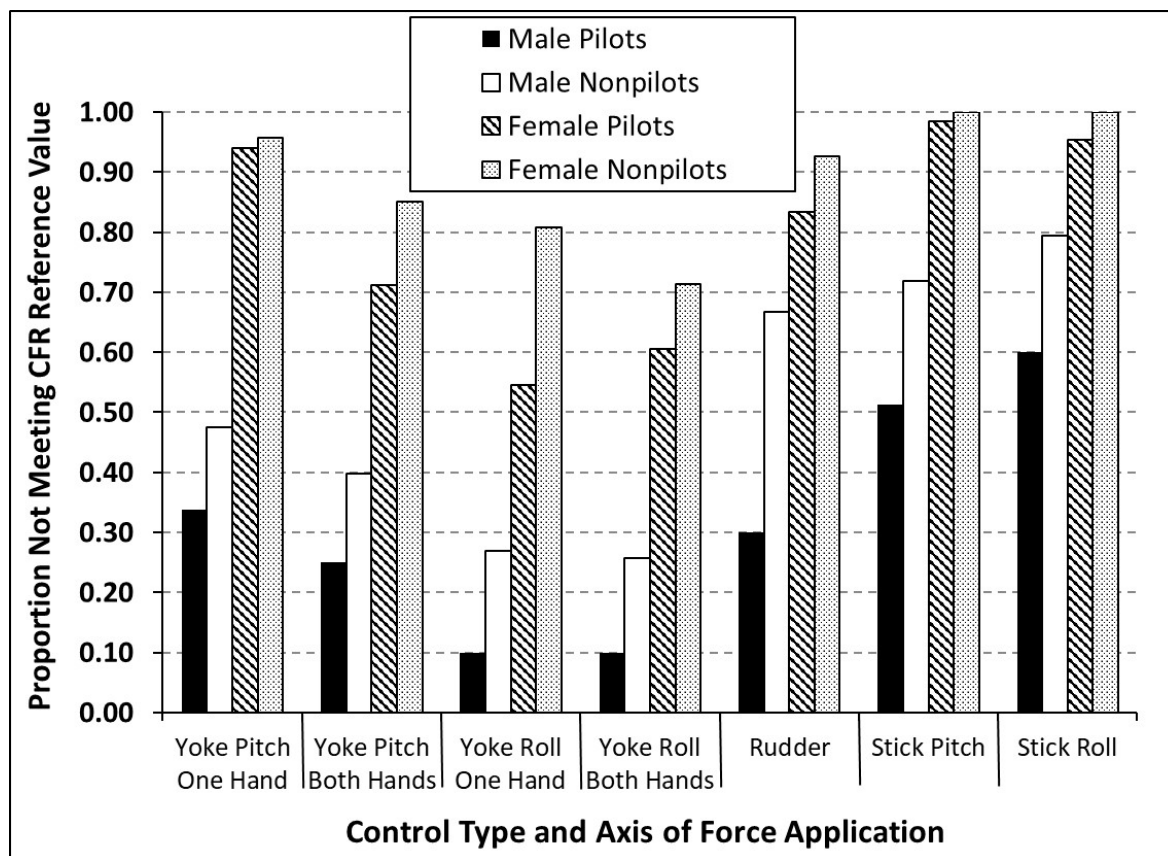
### Short-term force application: Pass/fail comparison

A first-cut examination of how the participants performed was to use the percentiles from the obtained distributions as a representation of the “failure” rates to reach the reference-force values. Figure 2 presents the distribution of all individuals in the sample by their failure rates in achieving the reference-force values by the various controls and axes of force application. The “proportion not meeting CFR reference values” is based upon the first 5-percentile increment at which the reference force was met. Thus, if the criterion reference value could only be met by people at the 95<sup>th</sup> percentile and above (very strong individuals), then anyone *below* that strength level could *not* satisfy it (95% of sample) and anyone *at or above* that level *could* meet it (5% of the sample). This was an attempt to recognize that although the true value could have been between 90% and 95%, the more conservative approach would take the higher value. In figure 2 one can see that “failure” rates for the overall sample ranged from .45 (just under half) on the “yoke roll both hands” task to roughly .85 (just over three quarters) on the “stick roll” task, with the stick fairing worst overall for both pitch and roll. This separation of proportions and percentages is kept throughout the reporting of results so that there will be no confusion between “percentage,” which is the whole-number representation of the ratio/proportion, and “percentile,” which is a division point in the distribution of scores.



**Figure 2.** Distribution of the proportions of the sample failing to meet criterion force levels (noncompliance rates) for short-term application by flight-control type and input axis.

Figure 3 depicts the task outcomes in more detail, showing the data in Figure 2 broken into the four categories of participants: male pilots, male nonpilots, female pilots, or female nonpilots. One can immediately see that there is an ordered and consistent relationship between the four sub samples, indicating that the order of force application progresses from highest average for male pilots, followed, in order, by male nonpilots, female pilots, and female nonpilots. The average difference between the male compliance rate with the reference forces and that of the females was roughly .40 favoring the males (e.g., yoke pitch, one hand) with a lesser separation between the pilots and nonpilots dependent upon the category (anywhere between .08 and .14 difference, favoring the pilots; a replication of earlier findings by Beringer). However, both were consistent differences. Again, as seen in the all-participants summary, all subsamples met with the same difficulty in meeting the criteria for the stick-type control. A finer-grained examination of stick-control position and direction of applied force will follow in a later section. Appendix A contains the detailed distributions, by each type of trial, for the sample as a whole and by the various subdivisions (pilots, nonpilots, and those groups divided by males and females).

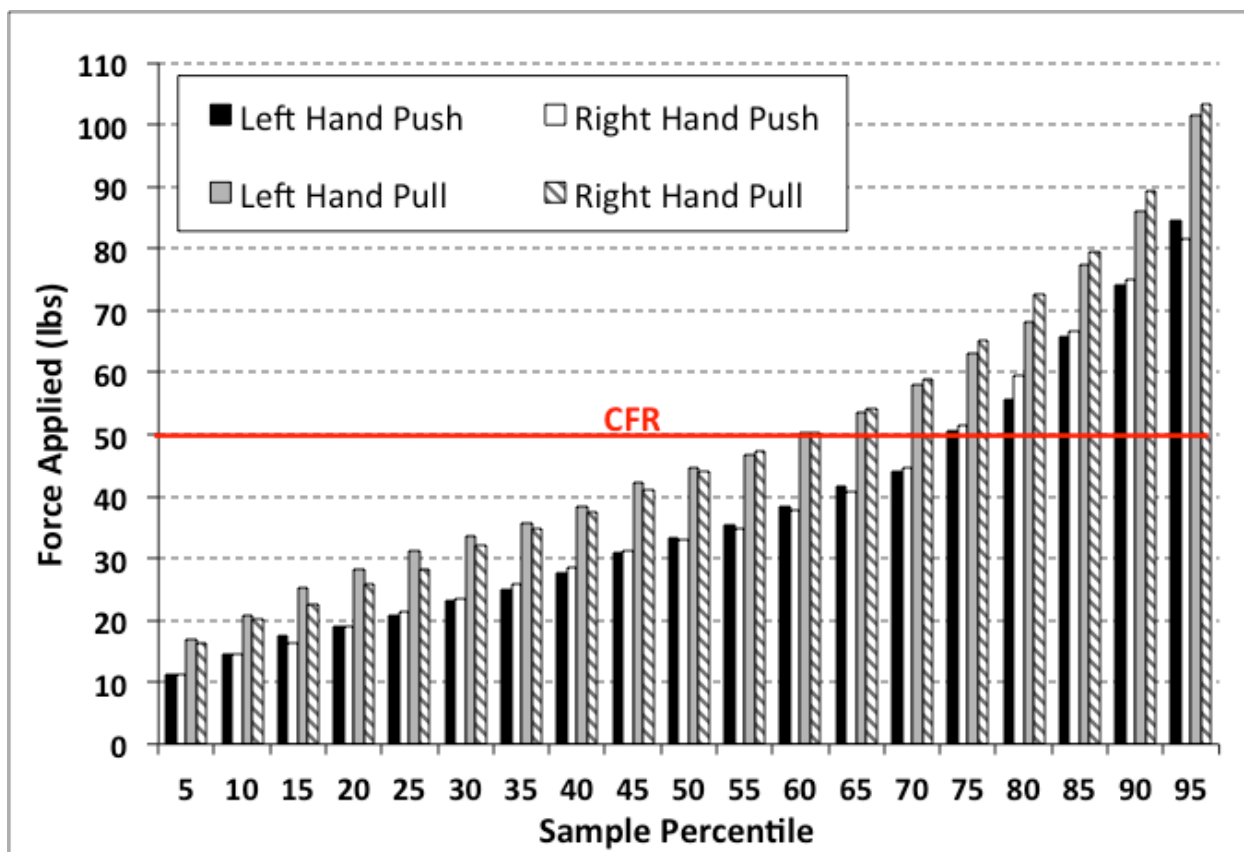


**Figure 3.** Noncompliance rates relative to CFR reference short-term forces by control type/axis and subsample.

An alternative graphical representation, which mimics the summary tables presented in Appendix A, is shown in Figure 4. This graph, which shows only the results for yoke pitch, presents the force values that correspond to 5-percentile increments from the 5<sup>th</sup> to the 95<sup>th</sup> percentile, for all participants, sorted by hand and direction of applied force. As can be seen here, and in Table A1 in Appendix A, the yoke-pitch criterion force (50 pounds) is not reached in the complete sample for the pull direction until we go to the 60<sup>th</sup> percentile individuals, indicating that 60% of the sample could not attain the CFR reference force. If

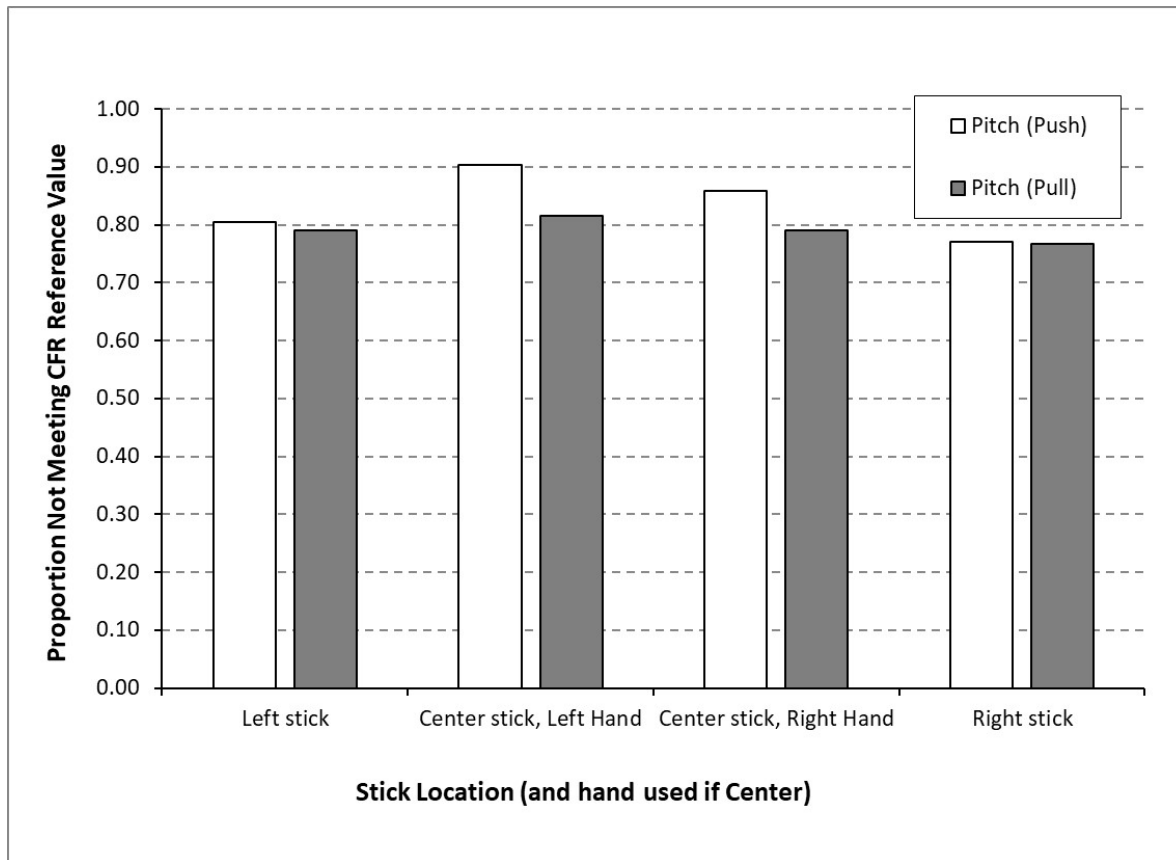


one wished to adopt a policy, for example, to try to accommodate 90% of the population (by inference), one would then choose the force level attained by the 10<sup>th</sup> percentile individuals, which is roughly 20 pounds. For pushing in the pitch axis, the criterion is not met until the 75<sup>th</sup> percentile individuals, meaning 75% of the sample could not attain the reference value for pitch push. Again, to accommodate 90% of the overall population, one would need to go to roughly 15 pounds of force. Data can be extracted in the same way from the tables in Appendix A.



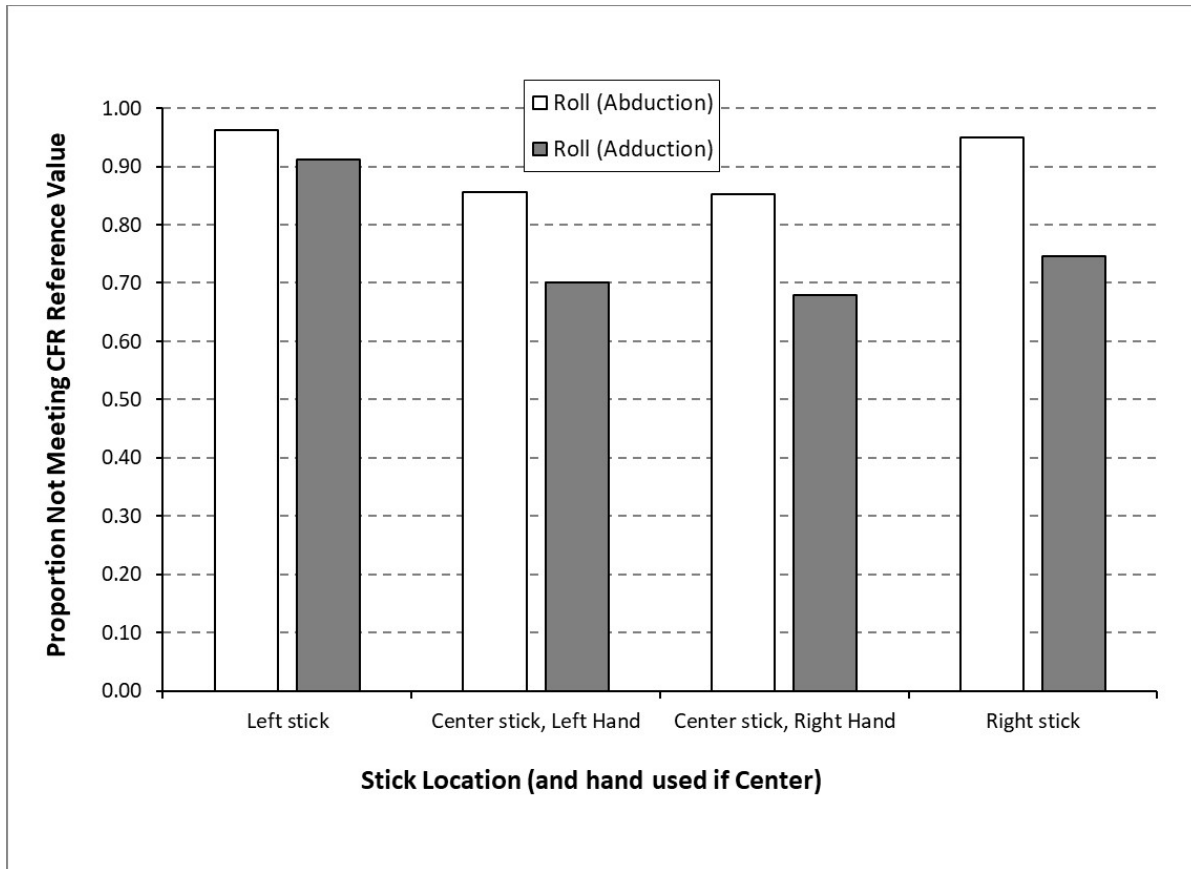
**Figure 4.** Graphical representation of attained short-term force values for the complete sample by hand, direction of force, and 5-percentile increments for yoke pitch.

**Separation of stick data by location.** One can further differentiate between the three stick locations used in this study and by the direction of force to be applied in a given axis. If we look at the pitch axis first, it would be expected, from much previous data, that more force could be exerted in pull than in push, and thus that compliance would be higher for pitch push (lower nonconformance). Figure 5 shows the noncompliance rates (proportion of sample not able to reach reference-value forces) differentiated by stick location. This is based upon the application of the reference values to the left and right locations of the stick (despite some discussion that has occurred about side-stick forces; that, however, was more related to fly-by-wire considerations). It is clear that, for the complete sample, the results follow expectations, with both the left- and center-stick positions producing higher noncompliance in pitch push than in pitch pull, with only the right-stick position having equivalent rates for push and pull. Noncompliance was slightly higher in the center location, most likely because of the change in orientation of the arm to the control, resulting in the change putting the vector of applied force out of alignment with the pitch axis.



**Figure 5.** Noncompliance rates for relative to CFR reference short-term forces by stick-control location and hand used in center location for applying pitch force.

Roll-force application must be examined by the directionality of the applied force relative to the body midline to be interpreted correctly. Adduction is in the direction towards the body midline (left hand moving to the right or right hand moving to the left) and abduction is away from the body midline (left hand moving to the left and right hand moving to the right). It is generally expected that more force can be applied towards the body midline than away from the midline. Figure 6 illustrates exactly this outcome, as, in every case, the noncompliance rates were higher for abduction (away from midline) than for adduction (towards midline). These differences ranged from 10% at the lowest to nearly 20% at the highest, in each case favoring adduction. Note that only .038 (3.8%) of the sample could achieve compliance for the left-stick-left-roll condition and only .05 could achieve compliance for the right-stick-roll-right condition, and that overall there was *no* situation in which there was anything better than .30 (just under a third) compliance (center stick, right hand, left roll; adduction). To look ahead to what this could mean for selecting force levels that would be allowable, one would be wise to look at the values for abduction as setting the lower bound. Again, the specific force levels applied can be seen in the tables in Appendix A.



**Figure 6.** Noncompliance rates for all participants relative to CFR reference short-term forces by stick-control location and hand used in center location for applying roll force.

*Comparison of CFR reference with performance obtained for females.* A closer examination of one part of the sample, female pilots, can give us some additional insight into how that segment of the current system users with which we would be most concerned was able to perform. Summary data are presented in Tables 6, 7, and 8. In the interest of brevity, directions of roll and directions of pitch have again been collapsed across/averaged to present simple comparisons between the obtained data and the CFR reference data. Each entry presents the obtained data for that percentile followed by the CFR reference data in parentheses. Examination of these three tables makes it clear that even for the current user population of female pilots, those that would be considered “average” (the 50th percentile), and those below the 50th percentile would not be able to apply the forces presently required in the reference table. The closest that any percentile got to a reference value was the 50<sup>th</sup> percentile for yoke roll, 1 hand (24 obtained versus 25 specified) and 2 hands (44 obtained versus 50 specified). These findings are consistent with the many previous studies, performed over the last 47 years, that have focused on this particular subpopulation.

**Table 6.** Short-term applied forces (lbs), 5<sup>th</sup> percentile female. In tables 5 through 7, (na) indicates that there is no reference value for that flight control in the CFR, entries are of the format “obtained (CFR reference)”, and all obtained applied-force values are rounded to the nearest pound.

Flight Control	Pitch	Roll	Yaw	Coll.
Center stick/cyclic	13 (60)	7 (30)		
Left stick	13 (na)	11 (na)		
Right stick	14 (na)	6 (na)		
Yoke, 1 hand	17 (50)	9 (25)		
Yoke, 2 hands	20 (75)	18 (50)		
Rudder pedal			34 (150)	
Collective				15 (na)

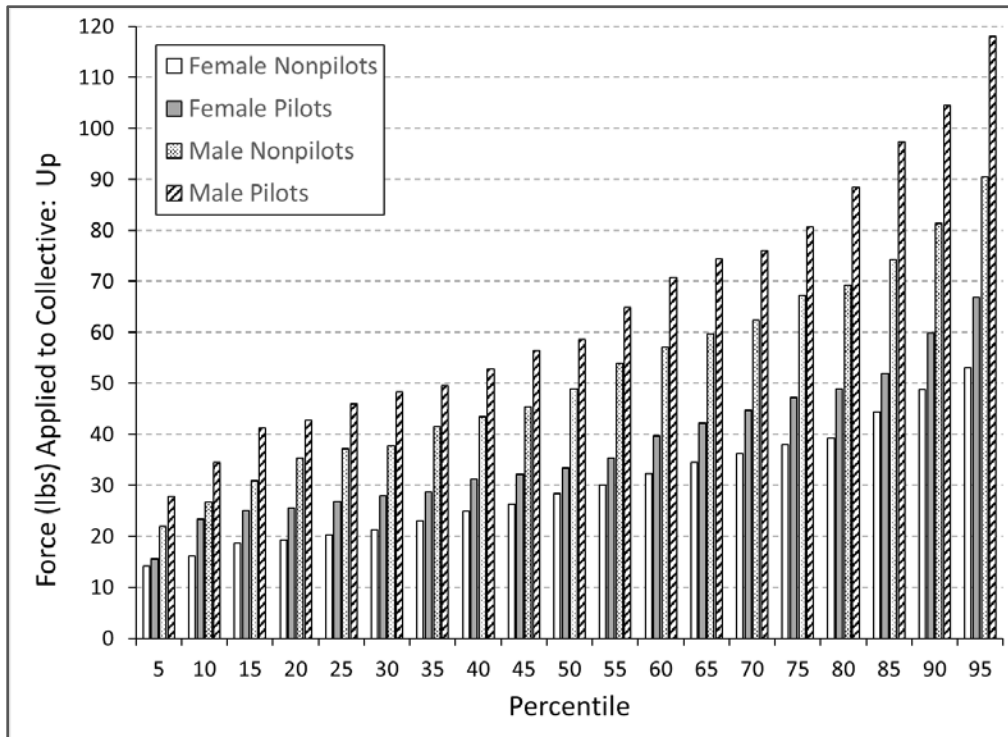
**Table 7.** Short-term applied forces (lbs), 25<sup>th</sup> percentile female.

Flight Control	Pitch	Roll	Yaw	Coll.
Center stick/cyclic	29 (60)	12 (30)		
Left stick	23 (na)	18 (na)		
Right stick	23 (na)	12 (na)		
Yoke, 1 hand	24 (50)	18 (25)		
Yoke, 2 hands	36 (75)	29 (50)		
Rudder pedal			54 (150)	
Collective				25 (na)

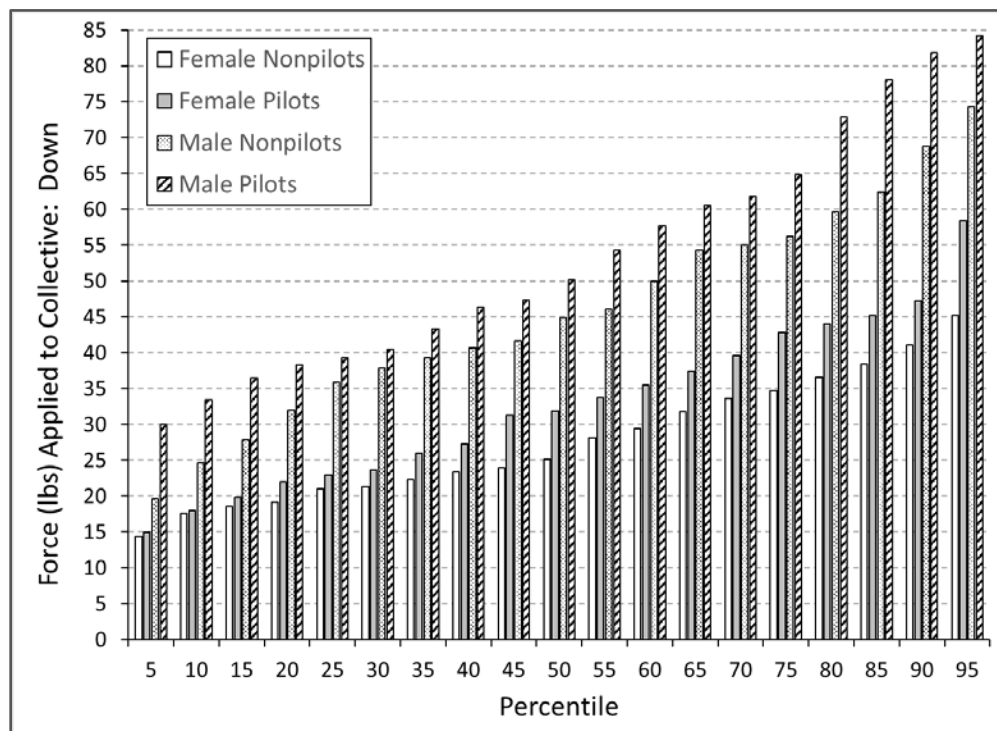
**Table 8.** Short-term applied forces (lbs), 50<sup>th</sup> percentile (“average”) female.

Flight Control	Pitch	Roll	Yaw	Coll.
Center stick/cyclic	29 (60)	17 (30)		
Left stick	29 (na)	23 (na)		
Right stick	32 (na)	15 (na)		
Yoke, 1 hand	32 (50)	24 (25)		
Yoke, 2 hands	52 (75)	44 (50)		
Rudder pedal			91 (150)	
Collective				33 (na)

***Distribution of values for the collective.*** As regards rotorcraft controls, we have already seen the data for rudder pedals (an analog of torque pedals) and for the center stick (analog of cyclic). The one additional control for which data were collected for short-term force was the helicopter collective. As there is no rule-based reference value, Figures 7 and 8 present, respectively, the distributions in five-percentile increments, for force exerted in the up direction (7) and force exerted in the down direction (8) by the four major subgroups of participants without reference lines. We again can see that the ordering of force applied, least to most, is in the order of female nonpilots, female pilots, male nonpilots, and male pilots. The separation between the groups is least at the lower percentiles (5<sup>th</sup>, 10<sup>th</sup>, 15<sup>th</sup>) and greatest at the higher percentiles (85<sup>th</sup>, 90<sup>th</sup>, 95<sup>th</sup>). On average, more force could be applied in the up direction (pull) than in the down direction (push), but the differences, again, were most notable at the higher percentile levels. Tables 9 and 10 present a brief summary of applied collective forces, by participant group and direction of force application, for the 5<sup>th</sup> (8) and 50<sup>th</sup> (9) percentiles.



**Figure 7.** Distribution of short-term Force (lbs) applied to the collective in the up direction by percentile and participant group.



**Figure 8.** Distribution of short term Force (lbs) applied to the collective in the down direction by percentile and participant group.

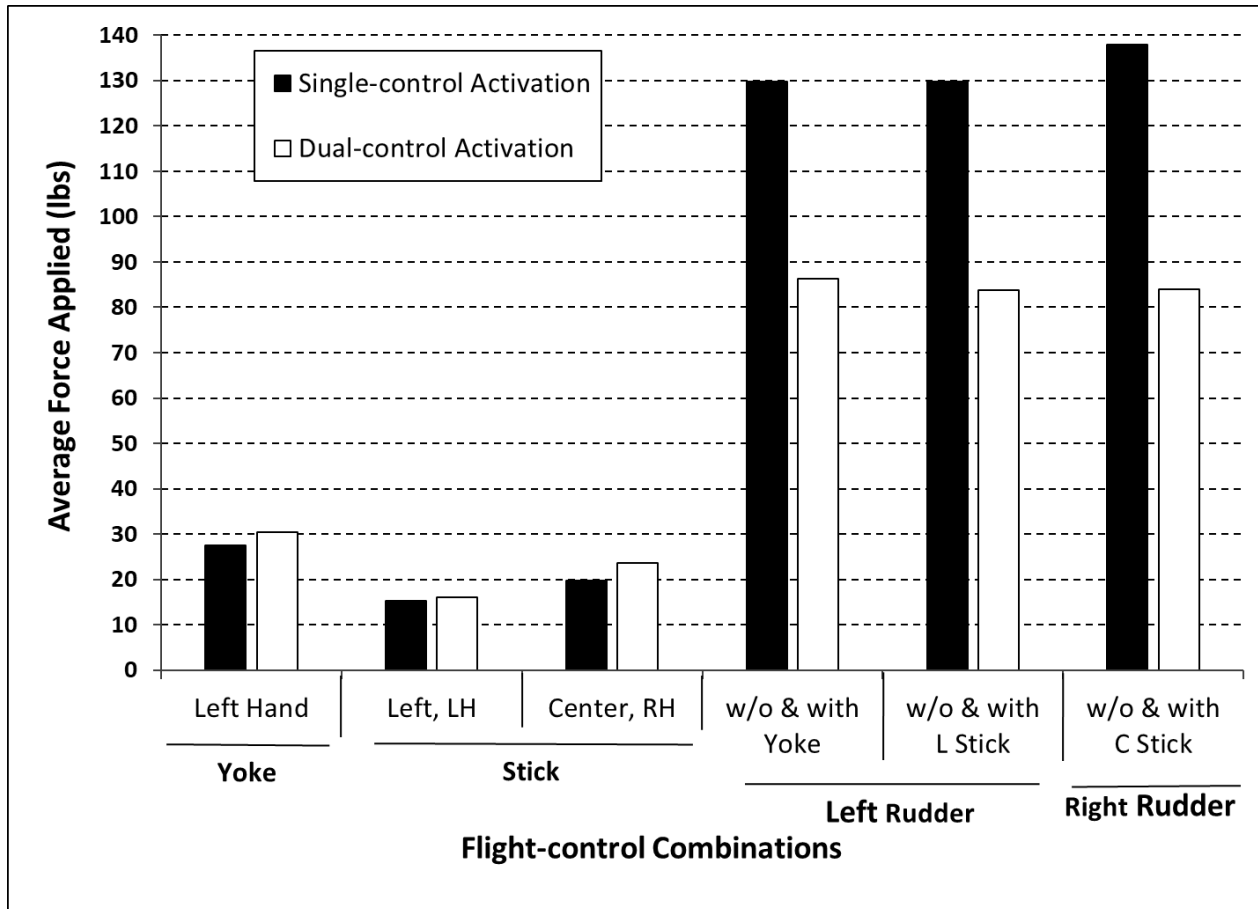
**Table 9.** Short-term force in pounds applied to collective for the 5<sup>th</sup> percentile by direction and participant group.

<b>Direction of Force</b>	<b>Female</b>		<b>Male</b>	
	<i>Nonpilot</i>	<i>Pilot</i>	<i>Nonpilot</i>	<i>Pilot</i>
<i>Up</i>	14	16	22	28
<i>Down</i>	14	15	20	30

**Table 10.** Short-term force in pounds applied to collective for the 50<sup>th</sup> percentile (average) by direction and participant group.

<b>Direction of Force</b>	<b>Female</b>		<b>Male</b>	
	<i>Nonpilot</i>	<i>Pilot</i>	<i>Nonpilot</i>	<i>Pilot</i>
<i>Up</i>	28	33	49	59
<i>Down</i>	25	32	45	50

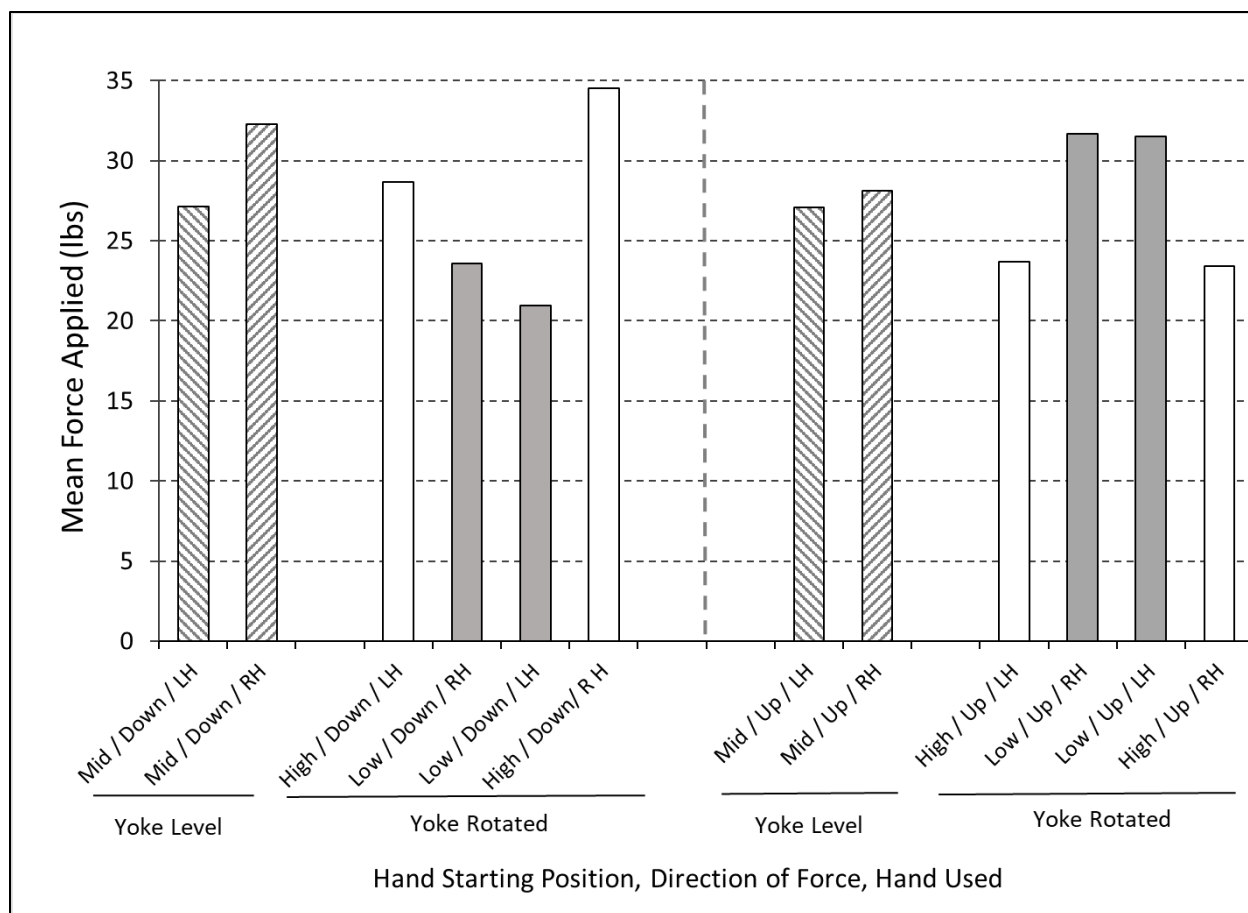
**Single- versus dual-control control application.** It is also of definite interest to verify how the application of forces changes from a single-control input to a dual-controls input, mentioned earlier as representative of real-world engine-out aircraft control tasks. To reiterate what was found by Beringer (2009), and which reflected (for fixed wing) what was found by Schopper et al. (1987) for helicopters, Beringer found that while the average applicable roll force for his sample was constant at 31 pounds from the single to the dual-controls trials, the average application of rudder force dropped from 182 pounds in single mode to 100 pounds in dual mode, thus showing a 44% drop. Figure 9 illustrates the differences found in the present study, across the entire sample, for the single-control applications that matched the components of the dual-controls applications in this examination. One can see that the average forces (50<sup>th</sup> percentile) applied for the yoke, in roll, were very close to that found by Beringer (2006 – 2009) at about 30 pounds in both instances. The left-stick roll was also unaffected between single and dual, being consistent at about 17 pounds. The center-stick values were also quite consistent, ranging from about 20 pounds in the single task to about 24 pounds in the dual task. However, the case for the rudder was quite different, and the drops were very consistent regardless of the hand control used in conjunction with the rudder. In all three cases, the values for single-control rudder application were near 130 pounds, while the dual-controls values all dropped to very near 60 pounds (a decrease of approximately 54%). Note that these are both below the CFR reference value of 150 pounds. This finding directly replicates the earlier findings of Beringer, and clearly suggests that the single-control values need to be reexamined for applicability in the more interesting cases where dual-control inputs would be necessary to maintain control of the aircraft.



**Figure 9.** Applied-force (short-term) values (average - 50<sup>th</sup> percentile) for the complete sample by task and control type.

### Rotated Yoke trials: Comparison with nominal position

Referring back to Figure 2, we can see that, as averaged across the three variables used in sampling (direction of yoke offset rotation, hand used, direction of force application) to make an overall comparison with the nominal-position yoke CFR values (which are not indexed by hand used or direction of roll force), a rotated yoke resulted in a failure-to-achieve rate of about 48%, whereas one-handed yoke roll in the nominal position (level) showed a rate of about 44%. As such, the overall (average) effect of applying force to a yoke rotated approximately 35 degrees was very small. However, there are some expected effects that one can see in examining the data presented in Figure 10. The most obvious one is that less force can be exerted in the “upwards” direction in roll when the grip of the yoke being used is already elevated (i.e., “High/Up/LH” on the right-hand side of the figure) as compared with force exerted in the same direction when the yoke is in the level position. On the other hand, as it were, one can see that slightly more force can be exerted in the upwards direction when the yoke is rotated so that the hand being used is low to start with (“Low/Up/RH” and “Low/UP/LH” on the right-hand side of the figure). Thus, these results simply confirm how biomechanical advantage changes, as expected, with rotational offsets of the yoke. A complete plot, located in the Appendix, across all calculated percentiles for the 12 conditions shown in Figure 8, shows that the disparities are extremely small for the percentile values, which would be of interest (5<sup>th</sup>, 10<sup>th</sup>, 15<sup>th</sup>, 20<sup>th</sup>), but tend to spread as one reaches the highest end of the strength distribution (90<sup>th</sup>, 95<sup>th</sup> percentile), from which revised reference values would *not* be selected.



**Figure 10.** Mean roll force (short-term) applied as a function of yoke rotation, hand used, and direction of force application.

### Ratio of short-term forces, female to male

Previous studies had examined the ratio of force input values from female and male participants for upper body strength and had found values of between .66 and .67. The 50th percentile values, short-term force, for the present dataset were examined to determine what these values might be for the “average participant” across the various controls. Collapsed across all yoke values, the average ratio was .55 (range, .47 to .62). The average across all stick tasks was .57 (range, .49 to .63). For the collective, the average was .60 (range, .58 to .62). Although not a measure of upper-body strength, the average ratio for rudder force was .50 (range, .47 to .53).

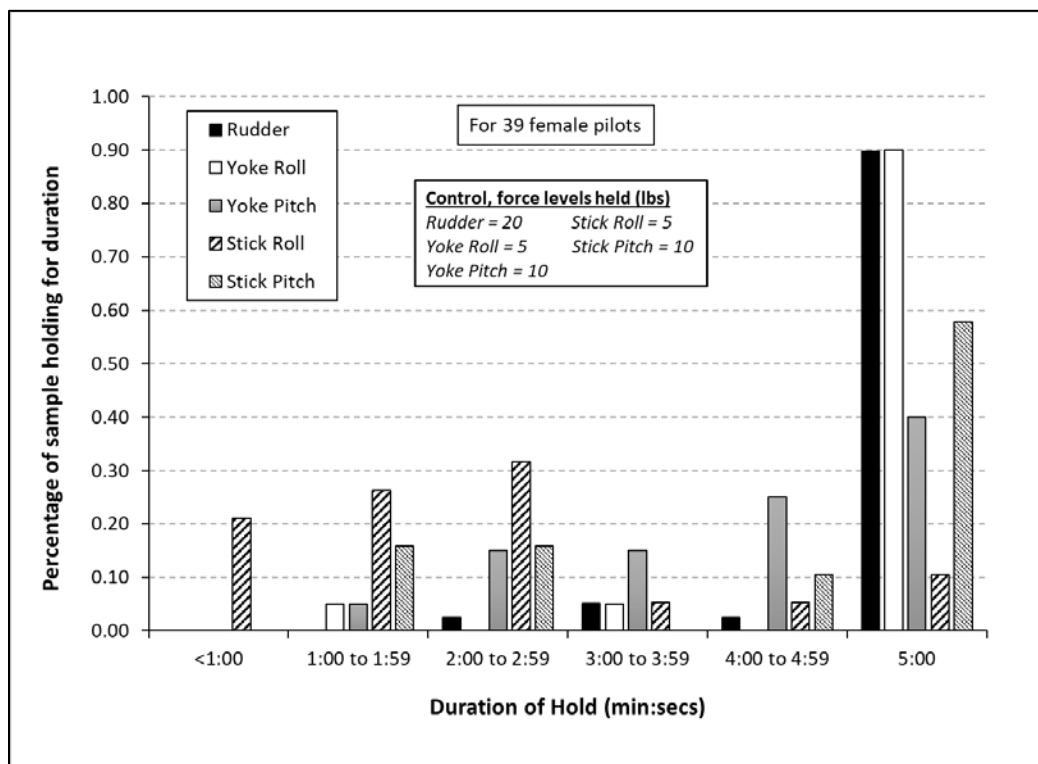
### Supplemental trials – Prolonged-force application

As mentioned previously, it was determined upon evaluation of the second phase of the trials (the subjective self-estimate of prolonged force that could be maintained) that they were not producing the type of data that could be relied upon. As such, three additional trials that mimicked the earlier Leeper et al. (1973) work were added for 56 individuals near the end of the data collection. All of the participants in this sample were right-handed. The manual control used was alternated between participants as only one set of legitimate long-term trials could be conducted for each participant using manual input. Thus, approximately half in each subsample used the yoke and the other half used a stick. Hand used was split between trials for the same reason, so that one hand was used for pitch and the other for roll. The directions

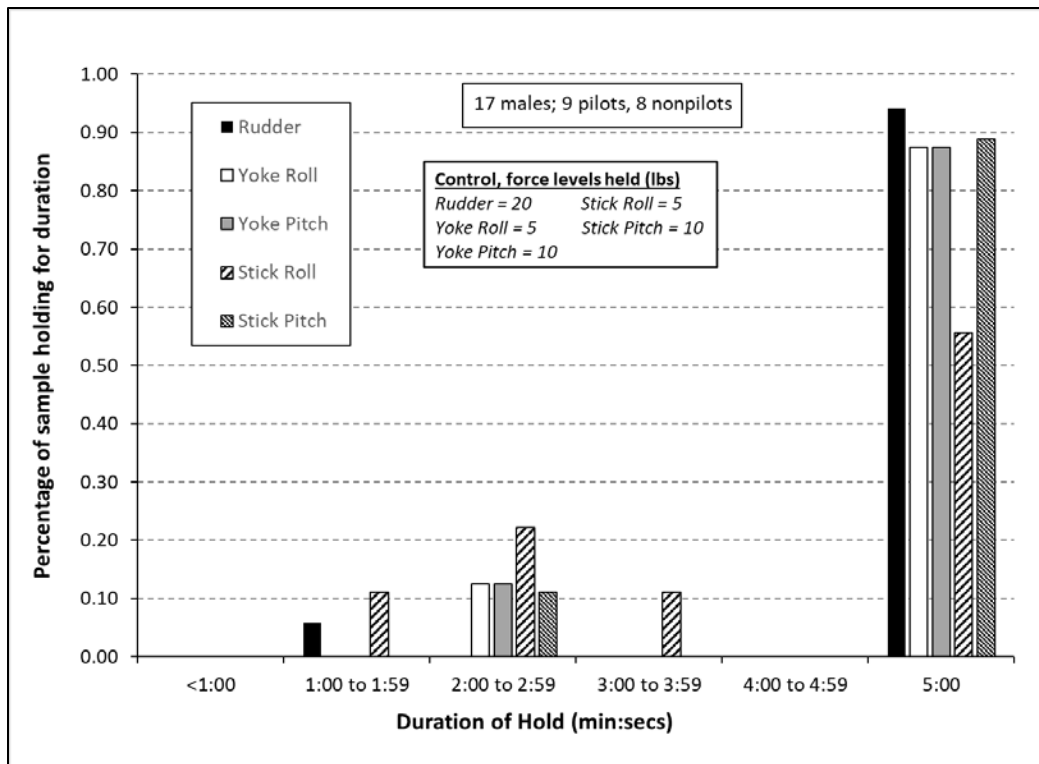


used were selected because they represented a category of expected lesser force application: yoke pitch push, yoke roll/hand up (i.e., left-hand roll right), stick push, and stick roll away from body centerline. As such the data constitute a generalizable sampling across hand used (both preferred and nonpreferred) and do not favor preferred hand, which would bias the values slightly higher.

Figure 11 presents the results for these supplemental trials by hold-duration category (one-minute brackets) and type of control for 39 female pilots, a population of concern. One can see from this graph that over 80% of the sample was able to maintain the reference rudder and yoke-roll forces for 5 minutes (the higher end of the required-length estimate) and that climbed to close to 90% for rudder when 4 minutes was used as the length of time. The lowest percentage was for stick roll, where only 16 % of the sample could hold the force for 4 minutes or better. Stick pitch and yoke pitch fell in the middle of these. The smaller sample of males included 9 pilots and 8 nonpilots, and did somewhat better as expected, with a higher overall percentage of 5-minute holds (Figure 12). Inasmuch as the two subsamples of males did not differ markedly in their distribution of scores, the two are combined to provide a better base for the distribution. Taken together, they provide some idea of the length of holds likely to be expected for male system users. Cumulative frequency plots for these data, for determination examination of what lengths of hold could be expected for what additive percentage of the samples, are shown in Appendix B. Regarding both sets of data (short-term and sustained), no systematic relationship was found in any of the supplemental trials between the demographic variables sampled (age, height, weight) and the length of time the participant could hold the prescribed force. This was particularly true for the smaller sample due to the potential number of covariates and the sample size.



**Figure 11.** Distribution of hold times for fixed-force trials for 42 female pilots by control type and hold-time category.



**Figure 12.** Distribution of hold times for fixed-force trials for 17 males, 9 pilots and 8 nonpilots, by control type and hold-time category.

## CONCLUSIONS AND RECOMMENDATIONS

It is evident from this examination that significant portions of the samples of pilots and nonpilots were unable to attain the criterion-performance levels called for in the CFR table. This was most prevalent for the female samples, and in each case for pilots and nonpilots, the males, not unexpectedly, had somewhat higher compliance rates with the CFR reference values than the females. However, none of the subsamples achieved very high compliance rates, with the full-sample compliance rates ranging from 55% at a high (yoke roll) to 17% at a low (stick pitch/roll). It should be noted that the lower-percentile values obtained were, in many cases, even lower than those obtained in some earlier studies. Some of these values, however, may not have a significant impact in some systems, particularly in fly-by-wire side-stick aircraft where proportional force feedback may not be felt as readily or, in some cases, at all. It would appear necessary, given the results of this study and multiple studies over the last two decades, to reevaluate the force values contained in the CFR table, in advisory guidance, and those to be incorporated into projected industry-consensus standards in the light of these data. A prudent approach would be to adopt lower values that are both consistent with measured human performance and with policy determining what percentage of the pilot population should be accommodated by the subsequently determined revised reference values. However, it is not within the scope of this inquiry to set policy and thus that activity is left to those who may be involved in the modification of the existing and planned reference values.

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## APPENDIX A: TABLES SHOWING DISTRIBUTIONS OF RESPONSES

NOTE: For all tables in Appendix A, green cells indicate percentiles at which the group met the CFR reference values for specific controls in specific axes. There is no such marking in the “collective” rows as this control is not listed in the CFR reference table. For example, in the first row of Table A1, “Yoke Pitch, LH Push,” the criterion level of force, 50 pounds, was not met until the first green cell (the 75<sup>th</sup> percentile, value being 50.46). Thus 75% of the sample could not attain the criterion level of force. Dependent upon the population-accommodation policy one wished to adopt, one would choose how much of the population one wanted to accommodate (for example 90% accommodated, 10% not), and then choose the 10<sup>th</sup> percentile as the value that would allow for this accommodation. In the example, the entry under the 10<sup>th</sup> percentile in the first row is “14.43” pounds.

Key to row identifiers in Appendix A tables:

Yoke Pitch	LH Push	Yoke pitch left-hand push
Yoke Pitch	RH Push	Yoke pitch right-hand push
Yoke Pitch	LH Pull	Yoke Pitch left-hand pull
Yoke Pitch	RH Pull	Yoke pitch right-hand pull
Yoke Pitch	BH Push	Yoke pitch both hands push
Yoke Pitch	BH Pull	Yoke pitch both hands pull
Yoke Roll	LH Lft (straight)	Yoke roll, left-hand, roll left (yoke level)
Yoke Roll	LH Rt (straight)	Yoke roll, left-hand, roll right (yoke level)
Yoke Roll	RH Lft (straight)	Yoke Roll, right-hand, roll left (yoke level)
Yoke Roll	RH Rt (straight)	Yoke roll, right-hand, roll right (yoke level)
Yoke Roll	BH Lft	Yoke roll, both hands, roll left
Yoke Roll	BH Rt	Yoke roll, both hands, roll right
Yoke Rotated 36 Roll	LH Lft R (rot)	Yoke rotated, left-hand, roll left, offset 36 degs Right (clockwise)
Yoke Rotated 36 Roll	LH Rt R (rot)	Yoke rotated, right-hand, roll right, offset 36 degs Right
Yoke Rotated 36 Roll	RH Lft R (rot)	Yoke rotated, right-hand, roll left, offset 36 degs Right
Yoke Rotated 36 Roll	RH Rt R (rot)	Yoke rotated, right-hand, roll right, offset 36 degs Right
Yoke Rotated 36 Roll	LH Lft L (rot)	Yoke rotated, left-hand, roll left, offset 36 degs Left (counterclockwise)
Yoke Rotated 36 Roll	LH Rt L (rot)	Yoke rotated, right-hand, roll right, offset 36 degs Left
Yoke Rotated 36 Roll	RH Lft L (rot)	Yoke rotated, right-hand, roll left, offset 36 degs Left
Yoke Rotated 36 Roll	RH Rt L (rot)	Yoke rotated, right-hand, roll right, offset 36 degs Left
Rudder Pedal	Left Foot	Left rudder pedal, press left foot
Rudder Pedal	Right Foot	Right rudder pedal, press right foot
Collective	Down	Collective, push down
Collective	Up	Collective, pull up
Left Stick	LS LH Pull	Left side stick, left-hand, pitch pull
Left Stick	LS LH Push	Left side stick, left-hand, pitch push
Center Stick	CS LH Pull	Center stick, left-hand, pitch pull
Center Stick	CS LH Push	Center stick, left-hand, pitch push
Center Stick	CS RH Pull	Center stick, right-hand, pitch pull
Center Stick	CS RH Push	Center stick, right-hand, pitch push
Right Stick	RS RH Pull	Right side stick, right-hand, pitch pull
Right Stick	RS RH Push	Right side stick, right-hand, pitch push
Left Stick	LS LH Lft	Let side stick, left-hand, roll left
Left Stick	LS LH Rt	Left side stick, left-hand, roll right
Center Stick	CS LH Lft	Center stick, left-hand, roll left
Center Stick	CS LH Rt	Center stick, left-hand, roll right
Center Stick	CS RH Lft	Center stick, right-hand, roll left
Center Stick	CS RH Rt	Center stick, right-hand, roll right
Right Stick	RS RH Lft	Right side stick, right-hand, roll left
Right Stick	RS RH Rt	Right side stick, right-hand, roll right
Multi, Yoke	LH Left	Dual-control, yoke, left-hand, roll left (yoke-force component, dual #1)
Multi, Rudder Pedal	Left Foot	Dual-control, left rudder pedal (rudder-force component, dual #1)
Multi, Left Stick	LH Left	Dual-control, left stick, left-hand, roll left (stick-force components, dual #2)
Multi, Rudder Pedal	Left Foot	Dual-control, left rudder pedal (rudder-force component, dual #2)
Multi, Center Stick	RH Rt	Dual-control, center stick, right-hand, roll right (stick-force component, dual #3)
Multi, Rudder Pedal	Right Foot	Dual-control, right rudder pedal (rudder-force component, dual #3)

**Table A1.** Distributions for all participants by five-percentile increments for momentary (short-term) force application by control and direction of exerted force.

Control/axis	Hand/direction	n	Min	Max	Avg	STD	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Yoke Pitch	LH Push	308	4.96	109.91	38.36	22.74	11.38	14.43	17.44	18.88	20.86	23.18	25.11	27.79	30.98	33.24	35.48	38.24	41.59	43.99	50.46	55.74	65.75	74.25	84.66
Yoke Pitch	RH Push	306	4.04	119.83	38.65	22.94	11.25	14.40	16.46	19.10	21.48	23.50	25.93	28.42	31.11	33.04	34.91	37.79	40.61	44.60	51.46	59.57	66.66	75.10	81.68
Yoke Pitch	LH Pull	306	6.32	135.69	49.50	25.53	16.91	20.85	25.27	28.20	31.25	33.53	35.59	38.50	42.32	44.72	46.67	50.37	53.68	58.04	62.96	68.27	77.35	86.11	101.41
Yoke Pitch	RH Pull	302	6.95	142.67	49.66	27.30	16.21	20.07	22.54	25.82	28.34	31.99	34.75	37.54	41.00	44.10	47.33	50.23	54.23	58.94	65.20	72.69	79.61	89.32	103.21
Yoke Pitch	BH Push	315	7.91	266.18	74.58	50.79	19.01	25.31	30.22	33.44	38.23	42.80	46.22	50.58	57.37	61.16	65.72	72.46	79.36	86.54	93.35	105.08	123.03	147.32	174.41
Yoke Pitch	BH Pull	307	11.16	333.24	86.36	56.41	22.13	29.68	34.58	39.52	44.96	50.02	55.40	59.44	66.22	69.93	77.37	86.87	95.97	103.44	115.18	122.35	139.96	169.77	206.93
Yoke Roll	LH Lft	308	1.90	70.23	27.47	13.15	9.39	13.36	15.25	16.83	18.56	19.73	21.24	22.42	23.36	24.66	26.57	27.52	29.78	32.32	34.41	37.28	42.00	43.85	57.51
Yoke Roll	LH Rt	310	2.80	76.42	27.67	14.82	8.42	11.22	13.27	14.73	16.69	18.57	20.04	21.39	22.99	24.60	25.58	27.83	29.99	33.77	36.54	40.13	43.99	49.26	55.46
Yoke Roll	RH Lft	306	3.51	75.98	28.60	14.20	10.30	12.92	14.86	16.19	17.35	19.17	21.00	22.75	24.08	25.96	27.28	29.72	31.24	33.12	37.73	41.74	45.35	48.84	54.69
Yoke Roll	RH Rt	306	2.31	95.82	32.83	16.21	11.09	13.83	17.10	19.13	22.49	24.02	25.60	27.69	28.84	30.09	31.41	32.83	35.11	37.92	40.80	45.27	49.60	56.16	64.21
Yoke Roll	BH Lft	303	3.54	145.48	56.84	28.77	20.85	25.55	28.65	32.21	34.99	37.60	42.69	45.98	49.31	51.30	54.39	58.21	62.70	66.77	72.79	79.66	86.74	100.00	114.29
Yoke Roll	BH Rt	307	4.85	196.32	64.26	35.04	18.96	25.84	29.61	33.96	37.73	41.93	45.92	49.72	54.15	58.55	62.59	66.13	70.78	76.03	84.27	90.84	98.72	112.58	136.85
Yoke Rotated 36 Roll	LH Lft R	308	2.37	86.07	29.15	13.58	11.09	13.94	16.04	17.20	19.47	21.01	22.58	24.01	25.06	26.88	29.14	30.48	31.99	33.72	36.06	40.29	42.51	47.50	55.30
Yoke Rotated 36 Roll	LH Rt R	305	1.40	65.32	24.15	13.26	7.36	9.35	11.08	12.70	14.25	15.72	17.44	18.61	20.10	21.08	21.83	24.30	26.41	29.20	32.67	35.36	38.39	43.76	50.98
Yoke Rotated 36 Roll	RH Lft R	308	1.27	77.83	32.20	15.77	12.09	14.70	16.33	18.61	19.69	21.49	23.58	25.54	27.56	28.87	30.39	32.62	34.48	37.38	41.94	47.32	51.39	55.24	62.85
Yoke Rotated 36 Roll	RH Rt R	309	0.55	63.62	24.02	12.26	7.82	10.06	11.92	14.23	15.54	16.55	18.00	19.15	20.27	21.90	22.90	24.35	26.28	27.90	30.52	34.16	37.43	42.02	47.01
Yoke Rotated 36 Roll	LH Lft L	309	3.03	64.86	21.32	10.25	7.24	10.21	11.58	13.30	14.60	15.16	16.15	16.84	17.94	19.59	20.51	22.37	23.62	25.08	26.99	29.29	32.25	35.01	40.64
Yoke Rotated 36 Roll	LH Rt L	310	1.35	85.17	31.99	16.66	9.98	13.46	15.37	18.01	19.85	21.37	22.97	25.47	27.31	29.53	31.07	32.80	35.43	38.41	41.04	43.95	49.70	55.83	66.86
Yoke Rotated 36 Roll	RH Lft L	307	2.23	81.15	23.96	12.80	8.31	10.47	12.14	13.24	14.92	15.98	17.05	18.68	20.26	21.04	22.53	23.84	25.70	27.44	30.37	34.43	36.92	42.27	49.36
Yoke Rotated 36 Roll	RH Rt L	304	0.25	105.13	35.06	17.71	11.92	14.93	17.22	19.19	21.82	23.47	25.94	28.59	30.38	32.49	34.60	36.88	39.36	40.91	45.21	50.16	53.70	58.49	70.17
Rudder Pedal	Left Foot	302	0.81	610.90	129.82	97.32	28.92	40.43	46.45	52.03	58.90	66.69	75.57	82.57	90.05	99.95	112.41	121.84	132.26	149.35	174.57	192.62	238.13	270.11	327.96
Rudder Pedal	Right Foot	304	15.93	536.20	137.95	91.89	38.61	49.46	58.01	64.62	71.62	78.11	86.24	92.96	102.75	114.57	126.62	136.71	147.31	158.05	180.70	196.21	228.83	261.04	316.65
Collective	Down	309	7.20	101.93	40.23	18.04	16.99	19.58	21.53	23.36	25.29	29.36	31.66	33.91	35.83	37.94	39.61	41.50	44.10	46.14	50.16	54.78	59.82	64.17	77.96
Collective	Up	306	10.51	138.14	46.43	24.00	16.88	20.78	23.44	25.88	28.32	31.10	33.44	36.16	38.66	42.22	44.60	47.43	49.90	54.05	58.43	64.18	70.87	80.18	97.09
Left Stick	LS LH Pull	312	6.52	128.23	44.08	23.88	14.14	18.75	22.30	25.34	27.33	29.72	31.07	32.49	35.82	38.35	40.70	43.67	47.62	51.86	54.74	61.62	69.44	78.66	95.89
Left Stick	LS LH Push	311	2.14	131.05	42.24	23.47	15.41	17.80	21.62	23.40	25.80	27.11	28.64	31.77	33.97	36.13	37.94	41.17	44.84	48.56	53.89	59.50	68.41	77.74	89.45
Center Stick	CS LH Pull	310	5.54	126.40	43.34	22.24	15.45	18.75	22.45	24.05	26.11	29.46	32.12	34.92	36.87	38.80	42.20	44.61	47.47	51.69	56.30	59.35	66.42	72.17	88.56
Center Stick	CS LH Push	306	4.12	113.01	35.42	17.86	12.45	14.55	18.28	19.65	21.36	24.20	25.83	28.31	29.73	31.57	34.54	37.07	39.96	42.54	46.79	51.38	56.18	59.55	68.05
Center Stick	CS RH Pull	314	4.02	137.27	44.49	23.42	15.15	19.18	21.41	23.00	27.96	30.89	32.94	35.74	37.20	39.99	42.86	45.66	48.50	51.95	55.62	61.19	68.56	79.39	92.05
Center Stick	CS RH Push	300	2.97	120.28	37.60	19.66	12.34	14.82	18.51	20.09	21.75	23.70	26.54	29.17	31.83	34.78	36.84	40.62	42.99	46.69	49.40	53.37	59.43	65.94	72.73
Right Stick	RS RH Pull	307	5.82	150.60	48.15	26.99	14.94	20.38	22.22	25.28	27.25	31.77	34.04	37.71	40.45	43.20	45.10	48.19	50.77	54.42	58.26	67.48	77.43	91.40	101.50
Right Stick	RS RH Push	308	3.72	139.26	44.25	25.31	14.69	18.43	20.95	23.77	26.21	27.67	29.83	32.15	34.94	37.39	40.15	43.30	47.30	52.14	57.31	64.55	70.79	82.37	98.02
Left Stick	LS LH Lft	301	3.88	36.84	15.18	6.54	6.00	7.74	8.77	9.94	10.55	11.23	11.97	12.64	13.27	14.09	14.89	16.18	16.77	17.77	18.87	20.42	21.92	23.68	28.32
Left Stick	LS LH Rt	302	2.07	56.68	19.92	9.04	7.22	10.63	11.97	12.70	13.41	14.52	15.52	16.73	17.79	18.47	19.71	20.48	21.61	22.73	24.07	25.90	29.22	31.47	35.61
Center Stick	CS LH Lft	310	1.89	58.32	19.47	10.28	6.68	8.53	9.93	11.09	12.17	13.21	14.23	15.41	16.45	17.41	18.53	19.81	20.88	22.11	24.54	26.78	29.26	33.81	39.64
Center Stick	CS LH Rt	308	1.99	72.85	25.07	13.34	8.48	10.47	12.11	13.77	15.37	16.41	17.74	19.57	20.75	21.84	23.82	25.80	27.31	29.90	31.60	35.30	39.79	44.95	50.58
Center Stick	CS RH Lft	313	3.29	73.39	25.30	13.22	8.69	10.69	12.32	14.34	15.82	16.74	18.50	19.71	20.86	22.07	23.35	25.47	27.93	31.02	33.65	35.35	37.02	44.62	51.62
Center Stick	CS RH Rt	309	2.35	52.05	19.64	10.27	7.03	8.16	9.67	10.92	12.09	13.80	14.73	15.32	16.67	17.45	18.67	19.59	20.97	22.89	24.34	26.55	29.60	36.59	41.35
Right Stick	RS RH Lft	305	2.22	78.16	24.05	12.50	8.82	11.10	12.62	13.98	15.11	16.58	17.54	18.77	20.40	21.36	23.12	23.12	24.71	25.73	27.85	30.36	32.50	39.63	51.06
Right Stick	RS RH Rt	307	3.21	40.18	16.28	7.00	6.00	8.55	9.85	10.75	11.68	12.18	12.78	13.70	14.42	15.13	15.75	16.54	17.34	18.30	19.66	22.30	23.82	26.47	30.10
Multi, Yoke	LH Lft	302	2.16	75.25	30.43	15.26	9.56	12.93	14.81	17.02	19.09	21.19	23.03	24.16	24.95	28.14	30.34	31.63	34.04	36.81	39.95	43.70	47.51	51.54	59.78
Multi, Rudder Pedal	Left Foot	304	9.39	553.99	86.26	68.21	23.41	29.20	33.44	37.59	43.17	45.66	50.42	55.82	60.93	65.60	71.15	78.46	84.27	97.78	108.08	124.52	143.15	178.03	207.12
Multi, Left Stick	LH Lft	286	1.20	38.85	15.96	7.12	6.08	7.71	8.93	9.92	10.69	11.40	12.21	13.05	13.89	14.92	15.79	16.98	18.01	19.20	20.06	21.58	24.05	25.72	29.68
Multi, Rudder Pedal	Left Foot	291	11.13	341.63	83.70	60.92	20.00	28.14	35.25	38.46	41.29	45.37	48.63	53.97	63.54	67.18	72.74	78.89	85.19	93.36	102.91	122.49	138.27	159.06	212.86
Multi, Center Stick	RH Rt	302	5.27	69.79	23.61	10.98	9.73	11.41	13.17	14.58	16.03	17.48	18.57	19.35	20.24	20.95	21.94	23.11	25.22	27.43	29.85	32.43	34.29	38.76	46.83
Multi, Rudder Pedal	Right Foot	292	9.01	393.93	84.06	53.47	27.90	33.40	38.46	44.24	49.22	52.65	56.90	62.22	66.30	70.17	76.17	82.86	87.04	95.91	102.79	114.92	128.20	148.52	195.52



**Table A2.** Distributions for all males by five-percentile increments for momentary (short-term) force application by control and direction of exerted force.

Control/axis	Hand/direction	n	Min	Max	Avg	STD	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Yoke Pitch	LH Push	155	7.74	109.91	51.13	23.96	17.48	20.30	25.26	29.15	32.90	35.49	38.29	41.58	43.87	47.44	51.45	54.56	60.29	65.50	69.36	74.22	79.79	84.60	91.96
Yoke Pitch	RH Push	153	10.60	119.83	51.50	24.08	15.38	21.97	27.57	30.63	32.36	35.00	36.50	39.54	43.51	47.42	53.31	58.04	64.84	66.66	70.45	75.10	78.86	81.68	89.36
Yoke Pitch	LH Pull	155	12.62	135.69	63.51	26.86	22.94	29.92	33.68	39.68	43.28	46.46	50.07	55.46	58.80	61.43	64.13	65.15	71.84	76.63	81.24	86.08	91.70	101.07	115.00
Yoke Pitch	RH Pull	152	13.97	142.67	65.19	28.28	21.26	28.37	35.65	40.14	42.86	49.41	51.62	56.16	58.94	63.12	67.19	72.16	74.16	79.54	82.55	89.29	95.69	102.87	118.53
Yoke Pitch	BH Push	157	13.11	266.18	100.25	56.69	29.09	34.58	45.64	51.87	59.80	64.31	71.05	75.17	83.42	86.55	92.38	99.14	110.18	122.49	135.99	145.18	162.42	174.57	226.06
Yoke Pitch	BH Pull	154	17.97	333.24	117.59	60.54	36.17	47.57	56.07	65.12	72.94	78.64	87.80	95.98	100.23	105.71	115.73	121.82	129.69	139.85	151.96	169.65	183.29	206.64	228.51
Yoke Roll	LH Lft	154	7.75	70.23	34.63	13.19	16.07	20.01	22.18	23.18	24.60	26.59	27.39	29.40	30.85	33.58	34.17	35.36	37.63	39.21	42.59	43.44	48.10	57.51	59.10
Yoke Roll	LH Rt	154	7.77	76.42	36.37	14.85	15.49	19.68	21.51	23.61	24.71	25.51	27.47	30.04	33.13	35.31	37.12	39.75	42.00	44.13	46.65	49.34	50.99	55.50	63.46
Yoke Roll	RH Lft	153	6.86	75.98	36.69	14.38	16.06	17.69	21.80	24.10	25.97	27.19	29.71	30.71	32.82	36.23	37.99	40.93	42.30	45.27	47.04	48.84	52.03	54.69	61.26
Yoke Roll	RH Rt	151	5.68	95.82	41.95	16.60	18.21	23.73	26.72	28.93	30.32	31.56	33.29	36.40	37.73	39.36	40.99	44.32	47.54	49.25	53.54	56.34	59.20	64.53	71.04
Yoke Roll	BH Lft	151	19.98	145.48	73.08	28.55	34.49	40.15	44.80	49.29	51.39	53.80	56.95	62.20	64.35	69.90	73.75	78.17	82.33	86.17	88.97	100.02	103.57	114.46	128.23
Yoke Roll	BH Rt	156	16.30	196.32	83.73	35.62	34.49	41.99	45.71	48.99	56.13	65.28	69.43	71.41	74.72	80.63	84.61	89.00	92.76	98.03	102.50	111.41	122.95	136.61	148.46
Yoke Rotated 36 Roll	LH Lft R	156	10.87	86.07	36.55	13.42	18.00	21.04	23.71	25.65	27.56	29.07	30.46	31.28	32.88	33.79	35.61	37.76	40.48	41.51	44.13	46.11	49.66	55.13	61.08
Yoke Rotated 36 Roll	LH Rt R	152	4.32	65.32	31.85	13.50	11.14	15.64	17.89	19.89	20.98	22.99	24.60	27.17	29.46	31.58	33.17	34.32	36.42	38.42	40.71	43.77	47.41	51.01	54.69
Yoke Rotated 36 Roll	RH Lft R	157	8.92	77.83	41.00	15.31	18.84	21.99	24.38	26.77	29.38	31.53	32.93	34.56	37.18	39.59	41.44	45.29	47.88	49.10	52.33	54.02	58.90	62.72	67.58
Yoke Rotated 36 Roll	RH Rt L	153	7.37	63.62	30.64	12.71	11.53	13.46	17.63	19.88	21.53	22.58	24.87	26.22	27.81	29.36	31.18	32.44	34.85	36.57	38.69	41.87	43.25	47.16	56.10
Yoke Rotated 36 Roll	LH Lft L	154	3.35	64.86	26.67	10.58	12.03	14.46	15.33	16.94	18.86	20.34	22.82	24.04	24.81	25.97	26.84	28.45	29.80	31.26	32.59	34.90	36.70	39.75	43.96
Yoke Rotated 36 Roll	LH Rt L	156	10.36	85.17	41.82	16.36	19.58	22.30	25.43	27.32	29.67	31.37	33.43	35.68	37.95	39.30	41.05	43.04	44.89	49.45	53.18	55.77	60.82	66.85	72.83
Yoke Rotated 36 Roll	RH Lft L	154	5.20	81.15	30.96	13.39	12.50	15.81	18.91	20.56	21.04	22.22	23.21	25.12	26.73	28.77	30.60	33.12	35.62	36.72	38.58	42.17	44.51	49.35	54.72
Yoke Rotated 36 Roll	RH Rt L	154	0.25	105.13	44.36	18.06	17.33	22.41	24.44	28.79	32.76	35.75	38.01	39.39	40.10	42.11	44.59	46.40	51.10	53.31	54.35	57.86	60.75	69.99	78.43
Rudder Pedal	Left Foot	146	0.81	610.90	178.62	111.67	42.39	61.29	74.26	83.62	93.77	100.22	112.75	122.81	143.81	155.35	168.16	187.51	204.02	225.04	255.26	272.80	287.78	328.80	386.60
Rudder Pedal	Right Foot	149	21.50	536.20	183.28	101.93	62.70	72.84	84.89	95.17	109.94	118.41	133.03	138.20	146.86	158.22	177.81	188.04	198.24	217.07	237.35	257.52	272.11	320.05	394.76
Collective	Down	157	11.99	101.93	50.02	17.92	22.63	28.98	32.92	36.00	38.24	39.31	40.53	42.49	45.13	46.96	50.03	54.23	55.54	59.11	61.08	62.93	71.24	77.42	82.09
Collective	Up	153	15.08	138.14	59.18	25.25	23.06	30.06	35.26	37.48	41.47	43.20	45.90	48.54	51.24	54.84	58.27	61.82	66.60	70.03	74.35	80.18	85.25	97.09	105.59
Left Stick	LS LH Pull	156	11.92	128.23	57.82	24.72	26.91	29.77	31.69	35.48	37.91	42.07	44.69	47.89	49.50	52.72	55.92	59.96	65.57	69.44	75.39	78.66	86.72	95.89	101.79
Left Stick	LS LH Push	156	14.43	131.05	55.69	24.39	24.61	27.99	29.96	34.44	36.33	37.91	41.02	43.79	47.92	52.27	54.21	58.32	63.26	68.41	73.00	77.61	82.83	89.40	98.94
Center Stick	CS LH Pull	157	11.80	126.40	55.57	22.96	23.61	27.43	32.76	35.15	37.25	40.27	44.60	48.76	51.42	54.07	56.34	57.79	60.73	65.79	68.38	72.10	78.24	88.53	99.85
Center Stick	CS LH Push	153	12.18	113.01	45.49	17.73	19.91	24.33	26.34	29.52	30.98	33.60	36.25	39.41	41.09	44.73	47.59	50.33	52.83	55.39	57.87	59.47	61.72	68.05	72.90
Center Stick	CS RH Pull	158	9.35	137.27	57.41	23.89	23.79	31.58	34.47	37.18	40.99	43.20	45.35	48.14	49.85	52.76	55.57	58.05	61.90	67.70	72.58	79.26	83.79	91.99	101.20
Center Stick	CS RH Push	152	11.88	120.28	49.05	19.06	19.25	23.83	30.65	34.74	36.22	38.08	40.80	42.40	45.16	47.32	49.42	52.03	55.37	58.04	60.82	65.15	70.63	72.68	81.68
Right Stick	RS RH Pull	155	14.39	150.60	63.46	28.16	26.46	31.26	33.93	39.77	42.63	44.81	48.26	50.46	53.66	56.64	61.37	66.55	72.71	76.70	85.84	91.02	95.36	101.50	111.89
Right Stick	RS RH Push	153	12.22	139.26	59.10	26.39	20.85	28.85	32.07	35.39	39.25	41.51	43.59	47.73	51.76	56.31	59.54	62.98	67.36	70.99	78.14	82.49	90.90	98.25	108.53
Left Stick	LS LH Lft	149	3.88	36.84	18.88	6.61	8.31	10.97	12.10	13.21	14.22	15.23	16.42	17.08	17.74	18.46	19.24	20.16	21.03	21.91	22.46	23.45	24.78	28.33	30.83
Left Stick	LS LH Rt	152	7.21	56.68	24.57	9.15	12.48	15.03	16.45	17.33	18.42	19.10	20.13	21.08	21.93	22.65	23.32	24.82	25.84	27.92	29.81	31.35	33.58	35.59	42.73
Center Stick	CS LH Lft	154	1.89	58.32	24.32	10.98	10.22	12.70	14.01	15.41	17.12	18.09	18.90	19.56	20.53	21.64	22.77	25.10	26.33	28.20	30.20	33.47	36.48	39.66	45.93
Center Stick	CS LH Rt	155	5.35	72.85	31.67	13.96	12.18	15.37	17.48	19.55	21.46	22.55	24.40	26.45	27.57	29.13	30.99	32.29	35.73	38.29	40.29	43.55	48.64	50.53	58.04
Center Stick	CS RH Lft	157	6.66	73.39	32.08	13.80	14.19	15.73	17.94	19.46	20.93	22.46	23.82	27.15	29.60	31.40	32.92	34.27	35.12	36.74	39.78	43.80	46.53	51.61	61.03
Center Stick	CS RH Rt	156	6.21	52.05	24.67	10.75	9.98	13.42	14.80	16.29	16.85	17.51	19.23	19.77	20.49	22.24	23.38	24.44	26.36	28.37	30.41	35.97	39.15	41.33	44.97
Right Stick	RS RH Lft	150	7.56	78.16	31.32	13.11	13.90	16.78	18.42	20.72	23.23	24.63	25.28	26.72	27.70	29.22	31.27	32.29	33.72	36.14	37.95	39.66	42.61	51.12	59.81
Right Stick	RS RH Rt	153	4.33	40.18	20.19	7.23	8.69	12.18	13.02	14.20	14.61	15.83	16.85	17.57	18.21	19.41	20.75	22.05	22.87	23.91	25.10	26.49	27.76	30.12	33.53
Multi, Yoke	LH Lft	152	8.46	75.25	39.21	14.59	17.18	19.91	23.00	26.61	29.26	30.70	32.01	33.99	35.83	38.32	39.80	42.23	45.38	47.30	48.70	51.21	53.59	59.69	67.25
Multi, Rudder Pedal	Left Foot	151	14.68	553.99	117.28	80.10	31.02	43.60	47.95	54.95	61.89	67.54	75.78	83.54	93.08	100.97	106.98	113.54	124.90	134.38	161.88	177.02	186.32	205.33	249.32
Multi, Left Stick	LH Lft	143	6.13	38.85	20.02	7.02	9.14	10.89	12.73	14.33	15.34	15.92	17.11	17.96	18.62	19.31	20.10	21.47	22.48	24.05	24.78	25.72	27.13	29.68	31.86
Multi, Rudder Pedal	Left Foot	143	17.15	341.63	113.56	69.52	33.09	40.24	46.56	58.09	65.34	71.25	77.26	84.11	88.78	95.69	103.56	117.82	127.05	133.57	147.51	152.72	179.76	213.38	271.31
Multi, Center Stick	RH Rt	150	9.27	69.79	29.07	11.48	13.73	16.41	17.79	19.02	20.14	21.38	22.19	24.13	25.30	27.49	28.70	30.99	32.41	33.19	35.20	37.69	42.59	46.83	50.97
Multi, Rudder Pedal	Right Foot	147	9.18	393.93	106.76	61.66	37.15	45.01	54.53	59.20	63.68	69.21	75.48	79.33	85.58	93.77	101.37	106.00	115.18	119.95	132.29	140.51	160.57	194.11	227.31

**Table A3.** Distributions for all females by five-percentile increments for momentary (short-term) force application by control and direction of exerted force.

Control/axis	Hand/direction	n	Min	Max	Avg	STD	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Yoke Pitch	LH Push	153	4.96	58.54	25.43	11.32	9.25	11.93	13.84	15.85	17.45	18.52	19.64	21.03	22.04	23.38	24.83	27.14	29.66	31.66	33.59	34.99	38.00	41.42	44.03
Yoke Pitch	RH Push	153	4.04	62.47	25.79	11.98	9.26	11.32	13.56	15.65	16.84	18.94	19.40	21.29	22.40	23.66	25.58	27.08	29.30	32.44	33.41	34.67	39.25	41.29	47.03
Yoke Pitch	LH Pull	151	6.32	73.03	35.13	13.19	14.33	17.68	20.38	22.65	25.74	27.60	28.81	31.21	33.01	34.36	35.93	38.14	40.05	43.73	45.16	46.62	50.35	52.26	56.54
Yoke Pitch	RH Pull	150	6.95	72.83	33.91	14.13	14.12	16.58	18.63	21.45	22.55	24.71	26.37	28.33	31.33	32.86	33.97	35.98	39.58	41.97	44.54	46.45	48.57	53.27	57.76
Yoke Pitch	BH Push	158	7.91	157.89	49.07	25.53	15.60	21.64	24.82	27.91	30.36	32.77	34.72	38.91	42.62	44.39	46.83	50.09	55.53	59.55	61.48	69.16	75.69	86.06	94.43
Yoke Pitch	BH Pull	153	11.16	124.67	54.94	27.12	18.04	24.51	27.74	30.95	33.57	37.10	39.79	44.27	46.28	50.51	55.24	57.05	61.08	66.47	69.49	76.48	85.26	95.78	112.64
Yoke Roll	LH Lft	154	1.90	47.39	20.32	8.36	7.44	10.12	11.76	13.76	15.15	15.79	17.15	18.12	18.77	19.45	20.86	21.87	22.44	23.48	25.34	26.50	27.54	30.34	35.25
Yoke Roll	LH Rt	156	2.80	40.42	19.08	8.40	7.51	8.78	10.05	11.85	12.94	13.99	14.52	15.77	17.32	18.45	19.21	20.10	21.12	22.38	24.28	26.08	28.16	30.27	35.10
Yoke Roll	RH Lft	153	3.51	45.15	20.51	8.15	9.43	10.90	12.09	13.68	14.60	15.53	16.26	17.17	17.90	19.90	20.82	22.28	22.98	24.10	25.64	27.28	29.50	32.47	33.89
Yoke Roll	RH Rt	155	2.31	54.76	23.95	9.54	8.63	11.52	13.11	14.85	17.06	18.39	20.17	22.19	23.07	24.48	25.44	26.52	28.17	28.90	29.88	31.22	32.71	34.41	38.99
Yoke Roll	BH Lft	152	3.54	99.45	40.71	17.88	13.93	21.76	24.56	26.91	28.42	29.67	31.39	33.66	35.56	37.52	40.80	43.29	46.80	49.32	52.20	55.51	58.89	65.69	71.21
Yoke Roll	BH Rt	151	4.85	106.38	44.15	19.80	15.10	19.83	23.99	27.29	28.88	30.46	33.16	36.67	39.37	41.24	46.61	49.63	53.12	55.60	58.52	60.67	64.11	66.60	80.26
Yoke Rotated 36 Roll	LH Lft R	152	2.37	47.79	21.55	8.67	9.90	11.22	12.86	14.09	15.41	16.45	17.16	18.13	19.63	20.91	21.63	23.12	23.94	24.74	25.65	28.66	30.41	32.97	37.95
Yoke Rotated 36 Roll	LH Rt R	153	1.40	37.57	16.50	7.22	5.81	7.86	8.81	9.76	11.06	12.11	12.80	13.62	15.04	16.13	17.24	18.28	19.48	20.20	21.12	21.67	23.57	25.58	28.99
Yoke Rotated 36 Roll	RH Lft R	151	1.27	60.49	23.04	9.99	11.11	12.21	14.01	14.84	15.54	16.53	18.35	19.09	20.07	21.10	23.10	24.32	26.21	28.12	28.79	30.13	32.12	33.44	43.82
Yoke Rotated 36 Roll	RH Rt R	156	0.55	44.02	17.53	7.40	5.87	8.18	9.70	10.93	12.73	14.30	15.05	15.64	16.38	17.47	18.41	19.12	19.71	20.75	22.61	23.29	24.18	26.41	28.34
Yoke Rotated 36 Roll	LH Lft L	155	3.03	40.78	16.00	6.48	5.66	8.22	9.62	10.68	11.55	12.75	13.99	14.61	14.87	15.77	16.17	16.72	17.49	19.15	20.00	20.65	21.91	23.58	27.45
Yoke Rotated 36 Roll	LH Rt L	154	1.35	48.08	22.05	9.56	8.04	9.91	12.21	14.01	15.01	16.10	17.66	18.80	20.14	20.85	21.61	23.19	25.22	27.23	29.11	30.61	32.06	35.02	40.28
Yoke Rotated 36 Roll	RH Lft L	153	2.23	41.85	16.90	7.02	6.83	8.65	10.15	11.00	11.85	12.61	13.77	14.77	15.37	15.99	16.77	17.44	18.62	20.00	21.21	22.81	24.40	26.63	29.54
Yoke Rotated 36 Roll	RH Rt L	150	3.51	58.78	25.52	11.02	10.13	12.47	14.42	15.73	17.20	18.46	19.69	21.60	23.07	24.93	26.41	28.56	29.39	30.81	32.03	33.61	35.12	39.22	47.08
Rudder Pedal	Left Foot	156	18.57	254.03	84.14	48.80	25.95	35.29	39.60	44.42	47.48	51.00	55.72	58.86	65.03	72.43	78.37	82.59	89.93	103.31	113.15	123.15	132.68	150.94	179.92
Rudder Pedal	Right Foot	155	15.93	276.06	94.36	52.22	31.40	38.88	47.67	51.12	55.92	62.46	67.45	71.78	74.82	83.41	88.29	93.05	102.14	108.67	121.45	132.33	149.60	158.86	200.12
Collective	Down	152	7.20	64.99	30.12	11.37	14.95	17.81	19.00	20.81	21.42	22.56	23.37	24.32	26.53	29.35	31.18	32.34	34.19	35.41	37.73	40.43	43.01	44.93	50.00
Collective	Up	153	10.51	78.95	33.67	13.82	14.84	17.91	19.65	21.35	23.61	25.12	26.25	28.21	29.43	31.55	32.55	34.66	36.53	39.28	43.17	46.45	48.55	52.52	58.24
Left Stick	LS LH Pull	156	6.52	66.06	30.33	12.38	12.54	14.31	17.02	19.14	21.28	22.88	24.67	26.12	27.67	29.60	30.58	32.15	34.17	35.88	38.72	40.55	42.22	46.72	53.27
Left Stick	LS LH Push	155	2.14	66.95	28.70	11.91	11.49	15.63	16.61	18.78	20.65	21.98	22.72	24.90	25.89	26.78	27.78	29.94	31.85	33.54	36.12	37.76	41.43	45.23	48.99
Center Stick	CS LH Pull	153	5.54	63.69	30.80	12.31	12.84	15.52	16.98	19.77	22.25	22.86	23.97	24.95	27.89	30.02	31.91	33.45	36.17	38.17	40.01	42.37	44.38	46.04	49.15
Center Stick	CS LH Push	153	4.12	65.10	25.36	11.05	9.62	12.54	13.30	15.11	17.87	19.10	19.63	21.15	22.40	24.12	25.63	27.56	28.99	29.93	31.74	35.45	37.57	40.68	43.46
Center Stick	CS RH Pull	156	4.02	72.65	31.41	13.68	12.96	15.87	17.51	20.33	21.03	21.66	22.85	26.20	29.05	30.59	32.13	33.40	35.86	37.18	39.61	42.71	45.72	48.87	55.20
Center Stick	CS RH Push	148	2.97	62.96	25.84	11.77	10.43	12.49	13.53	16.74	18.18	19.40	20.18	20.75	22.46	23.51	24.59	26.87	28.65	30.40	32.52	34.51	38.58	44.02	48.54
Right Stick	RS RH Pull	152	5.82	66.55	32.55	13.49	13.58	14.97	18.07	20.88	21.72	23.08	24.43	25.84	27.29	32.29	33.98	37.18	39.36	40.47	42.83	45.28	48.06	51.95	55.47
Right Stick	RS RH Push	155	3.72	66.46	29.58	12.40	12.20	15.17	16.92	19.23	21.11	22.45	23.93	25.38	26.60	27.67	28.43	29.97	32.24	34.90	36.68	39.37	42.67	47.44	52.23
Left Stick	LS LH Lft	152	3.94	24.61	11.55	3.90	5.23	6.91	7.55	8.14	8.84	9.58	10.05	10.33	10.90	11.38	11.84	12.33	12.92	13.28	13.91	14.68	15.55	16.54	18.18
Left Stick	LS LH Rt	150	2.07	34.23	15.21	5.98	5.64	7.35	9.62	10.93	11.79	12.31	12.70	13.27	13.87	14.31	14.71	15.71	16.90	17.94	18.58	19.98	21.08	23.64	26.37
Center Stick	CS LH Lft	156	2.21	34.46	14.68	6.71	5.62	7.50	8.36	8.74	9.63	10.55	11.29	11.87	12.40	13.54	14.33	15.49	16.29	17.21	18.21	20.58	21.50	23.19	28.00
Center Stick	CS LH Rt	153	1.99	48.70	18.38	8.49	7.35	9.13	9.95	11.06	11.94	13.08	14.30	15.33	15.83	17.28	18.08	19.88	20.73	21.55	22.09	24.57	27.00	30.23	34.49
Center Stick	CS RH Lft	156	3.29	47.50	18.49	8.19	8.01	8.74	10.04	11.21	12.07	13.35	14.70	15.86	16.29	17.37	18.76	19.76	20.63	22.01	23.28	24.33	26.02	29.17	35.39
Center Stick	CS RH Rt	153	2.35	39.14	14.51	6.59	6.08	7.08	8.03	8.99	9.59	10.34	10.98	11.62	12.67	14.09	14.68	15.03	15.81	17.22	18.24	18.87	21.57	23.61	27.27
Right Stick	RS RH Lft	155	2.22	36.38	17.01	6.39	7.54	9.37	10.67	11.89	12.62	13.39	14.20	14.65	15.45	16.67	17.16	18.15	19.10	20.37	20.90	21.85	23.51	24.94	29.53
Right Stick	RS RH Rt	154	3.21	22.33	12.39	3.96	4.84	6.65	8.53	9.39	10.06	10.37	11.15	11.58	12.05	12.18	12.61	13.37	13.98	14.62	15.26	15.73	16.50	17.15	18.62
Multi, Yoke	LH Lft	150	2.16	55.71	21.54	9.82	7.72	9.75	11.54	13.15	14.41	15.62	17.02	18.73	20.08	21.82	23.01	23.37	24.24	24.78	26.73	28.87	30.99	34.13	41.28
Multi, Rudder Pedal	Left Foot	153	9.39	252.99	55.65	32.28	20.20	26.10	28.76	31.02	33.65	35.88	39.60	43.18	45.07	46.71	53.35	57.18	60.50	63.94	68.66	75.14	78.98	90.45	118.16
Multi, Left Stick	LH Lft	143	1.20	22.64	11.91	4.40	4.79	6.08	7.52	8.04	8.83	9.71	10.31	10.67	10.98	11.47	12.14	12.75	13.11	13.84	14.44	15.51	16.93	18.22	19.95
Multi, Rudder Pedal	Left Foot	148	11.13	205.90	54.84	30.79	18.08	22.25	26.00	29.86	36.43	38.40	39.70	42.42	45.46	48.33	50.39	53.16	61.72	66.78	68.90	73.45	81.28	89.15	104.18
Multi, Center Stick	RH Rt	152	5.27	41.22	18.22	7.17	8.56	9.98	10.69	11.94	12.63	13.72	14.86	15.47	17.28	18.30	18.95	19.58	20.45	20.76	21.68	22.63	25.11	27.39	32.67
Multi, Rudder Pedal	Right Foot	145	9.01	175.12	61.03	29.38	23.94	29.25	32.24	35.72	39.31	44.26	46.78	49.22	50.87	55.18	59.90	63.73	68.05	70.22	78.82	84.16	91.10	97.87	109.80

**Table A4.** Distributions for all pilots by five-percentile increments for momentary (short-term) force application by control and direction of exerted force.

Control/axis	Hand/direction	n	Min	Max	Avg	STD	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Yoke Pitch	LH Push	150	4.96	109.91	41.92	23.75	13.02	17.31	19.46	21.47	23.99	25.97	29.67	31.09	32.91	34.96	37.25	41.23	43.87	48.11	55.50	65.92	73.68	80.97	85.57
Yoke Pitch	RH Push	151	4.04	119.83	42.89	23.49	13.55	18.75	20.32	23.57	25.31	26.97	30.50	33.67	35.18	37.81	40.59	45.28	52.04	61.62	67.19	72.91	77.97	83.75	
Yoke Pitch	LH Pull	150	15.68	135.69	56.16	26.95	19.15	27.86	29.74	32.58	35.59	38.24	40.95	45.32	46.69	50.41	53.63	57.70	61.95	64.71	71.41	79.62	85.31	97.22	113.47
Yoke Pitch	RH Pull	148	11.11	142.67	56.20	28.93	20.47	25.18	27.48	31.14	33.18	38.70	41.58	44.57	46.41	49.73	53.52	57.22	60.77	67.39	73.25	79.93	86.63	98.69	117.37
Yoke Pitch	BH Push	155	9.78	266.18	86.71	56.88	23.69	32.85	36.06	43.92	45.41	49.82	55.58	60.10	64.08	70.87	74.59	83.97	87.71	93.87	111.21	128.04	150.01	170.80	218.88
Yoke Pitch	BH Pull	151	11.16	333.24	99.88	63.61	27.87	34.74	39.66	44.99	54.05	59.31	64.01	66.56	75.20	86.09	91.95	97.84	106.19	117.09	129.19	152.35	177.12	190.65	228.35
Yoke Roll	LH Lft	150	1.90	70.23	30.55	14.35	11.12	15.13	17.50	19.16	21.52	22.46	23.46	25.10	26.55	27.14	29.45	31.46	33.54	35.22	36.66	42.33	43.93	50.22	58.95
Yoke Roll	LH Rt	152	2.80	76.42	31.61	15.59	8.76	14.13	15.68	18.40	19.89	21.19	23.14	25.26	25.97	28.05	30.02	33.79	36.25	39.45	41.96	44.65	49.05	52.64	59.83
Yoke Roll	RH Lft	148	5.19	75.98	32.06	14.47	12.24	15.59	17.17	18.98	21.23	23.24	24.29	25.87	27.27	29.07	30.78	32.92	35.53	39.04	44.02	46.27	48.48	52.22	55.15
Yoke Roll	RH Rt	150	2.31	95.82	36.52	17.37	12.29	17.13	20.95	23.09	25.46	27.77	28.92	29.62	30.67	32.38	33.75	37.03	39.13	41.79	47.28	49.68	55.97	61.24	68.57
Yoke Roll	BH Lft	148	3.54	145.48	63.34	30.73	24.38	26.77	32.60	35.50	40.97	44.53	48.11	50.58	53.95	56.61	63.09	66.64	70.32	77.32	83.55	88.07	99.61	106.44	125.44
Yoke Roll	BH Rt	151	11.26	196.32	71.40	38.96	20.21	25.57	29.71	36.14	41.59	46.76	54.71	58.17	61.28	65.19	69.94	73.47	80.57	85.21	95.38	99.15	110.34	129.73	145.54
Yoke Rotated 36 Roll	LH Lft R	153	2.37	86.07	31.31	15.06	11.60	13.78	15.62	17.81	20.18	22.93	24.33	25.91	27.58	29.80	31.07	32.49	34.53	37.51	40.11	42.40	45.92	53.35	60.29
Yoke Rotated 36 Roll	LH Rt R	146	5.51	65.32	27.89	13.93	8.35	10.98	13.05	15.21	17.86	20.26	21.14	21.69	23.61	25.39	27.19	29.53	32.29	34.32	36.05	39.07	42.76	48.95	54.42
Yoke Rotated 36 Roll	RH Lft R	150	7.04	77.83	34.88	16.19	12.37	15.59	17.49	19.56	22.18	24.71	26.89	28.76	30.35	31.89	33.37	35.59	39.56	44.55	47.33	49.10	53.11	58.70	63.22
Yoke Rotated 36 Roll	RH Rt R	153	1.46	63.62	27.23	13.52	8.40	11.32	14.48	15.67	17.52	18.80	20.27	22.57	23.78	25.02	26.39	27.53	28.56	31.87	36.07	39.22	42.19	46.09	56.10
Yoke Rotated 36 Roll	LH Lft L	153	3.20	64.86	23.94	10.93	8.61	11.58	13.98	14.96	16.16	16.96	17.84	19.60	20.64	22.56	23.88	24.90	26.42	29.02	31.10	32.90	35.42	38.34	43.08
Yoke Rotated 36 Roll	LH Rt L	150	3.24	84.24	35.02	17.37	12.35	14.90	17.44	19.79	21.26	23.30	26.00	27.78	30.23	32.47	35.06	36.43	39.36	41.69	44.18	49.04	55.30	62.04	69.31
Yoke Rotated 36 Roll	RH Lft L	151	2.23	81.15	26.99	13.52	10.65	12.00	14.15	15.92	17.71	18.87	20.53	21.03	22.79	24.15	25.47	27.19	29.31	32.33	35.45	36.72	41.31	44.51	53.78
Yoke Rotated 36 Roll	RH Rt L	147	3.51	90.89	38.56	18.64	13.65	15.51	19.22	22.79	24.64	27.05	29.32	32.06	33.63	35.90	39.13	40.10	42.34	46.22	50.81	54.36	58.32	62.76	74.57
Rudder Pedal	Left Foot	150	19.46	610.90	159.18	108.46	36.28	45.74	56.99	66.35	84.47	90.26	103.99	112.38	119.50	126.88	136.81	159.09	173.51	186.88	213.87	254.65	273.37	302.13	368.16
Rudder Pedal	Right Foot	153	15.93	521.32	161.28	99.33	42.94	55.55	64.59	75.34	90.16	98.97	108.37	119.30	130.10	139.48	149.56	158.96	180.83	190.90	207.67	235.58	259.74	281.07	383.21
Collective	Down	151	8.24	101.93	43.99	19.04	18.20	21.48	23.30	27.01	31.22	33.16	35.43	37.54	39.06	41.13	43.36	45.05	46.95	50.01	55.34	60.13	62.73	73.03	81.99
Collective	Up	150	12.25	138.14	52.08	25.98	21.87	25.18	27.46	28.90	32.09	33.79	39.03	42.23	44.73	47.03	48.55	51.02	54.84	59.38	67.04	73.27	78.95	89.98	104.66
Left Stick	LS LH Pull	152	6.52	128.23	49.34	26.13	18.44	22.83	25.39	27.77	29.78	31.11	34.11	36.48	40.46	43.06	46.43	49.81	53.21	57.16	62.30	71.11	77.76	87.85	100.60
Left Stick	LS LH Push	153	2.14	131.05	46.77	26.03	15.32	20.01	22.19	25.45	27.14	29.50	32.47	34.99	36.77	39.02	44.04	46.61	52.30	54.84	60.98	69.21	77.14	82.95	96.96
Center Stick	CS LH Pull	152	5.54	126.40	47.63	23.71	16.42	22.06	23.43	25.85	29.67	32.72	36.34	38.02	41.64	44.08	46.13	49.58	55.04	57.05	59.67	66.43	70.81	79.66	97.25
Center Stick	CS LH Push	149	4.12	113.01	38.41	19.77	13.30	17.18	19.14	20.10	21.21	24.65	26.86	29.64	32.58	35.85	38.32	40.75	44.15	48.32	51.55	57.28	59.26	65.07	70.42
Center Stick	CS RH Pull	154	4.02	137.27	49.71	25.94	16.22	20.88	22.45	26.51	30.60	32.89	36.30	38.85	43.32	45.74	48.42	51.93	54.77	58.37	63.58	71.02	79.58	89.94	100.42
Center Stick	CS RH Push	144	2.97	120.28	40.74	21.30	13.03	16.76	19.94	21.33	23.18	26.64	28.80	31.18	34.82	37.06	38.92	42.66	45.95	49.68	55.25	58.96	66.65	71.55	76.34
Right Stick	RS RH Pull	149	7.25	150.60	54.71	29.77	19.04	22.04	25.66	27.30	32.11	36.40	40.36	43.25	44.58	47.76	49.63	54.50	58.00	64.03	71.26	83.45	91.71	96.11	112.89
Right Stick	RS RH Push	152	3.72	139.26	47.39	27.31	15.23	19.10	22.15	24.86	27.21	29.91	31.72	34.10	36.43	39.25	42.38	48.12	51.95	56.20	62.76	67.58	76.80	93.72	103.04
Left Stick	LS LH Lft	150	3.88	36.84	16.24	7.03	6.79	8.10	9.58	10.17	10.56	11.52	12.76	13.51	14.80	15.67	16.45	16.90	18.19	18.74	21.02	22.07	22.73	25.11	30.31
Left Stick	LS LH Rt	146	3.82	54.89	21.27	9.58	9.87	11.56	12.50	13.91	14.69	15.85	16.71	17.45	18.46	19.19	20.33	21.17	22.21	23.36	25.82	28.78	31.09	34.15	42.44
Center Stick	CS LH Lft	152	1.89	58.32	21.58	11.30	6.76	9.46	10.86	12.07	13.15	14.23	15.61	17.21	18.42	19.50	20.91	21.86	22.89	25.63	27.55	30.55	34.23	38.14	44.42
Center Stick	CS LH Rt	152	1.99	72.85	27.68	14.74	9.96	11.60	12.92	15.22	16.25	18.24	19.86	20.90	21.86	24.04	26.98	28.65	30.38	32.28	37.11	40.32	44.95	49.72	57.83
Center Stick	CS RH Lft	153	3.29	65.51	27.89	13.73	10.09	12.58	14.59	16.03	17.82	19.28	20.36	21.60	23.22	23.83	27.57	29.34	32.06	33.77	35.37	39.64	43.44	47.55	55.22
Center Stick	CS RH Rt	150	2.35	52.05	21.77	11.15	7.02	9.67	11.20	12.08	13.81	14.63	15.60	16.76	17.40	18.99	20.62	23.05	24.04	25.33	28.45	31.10	34.85	39.64	43.14
Right Stick	RS RH Lft	149	2.22	67.79	26.50	13.51	10.08	12.63	14.60	15.41	16.66	17.53	18.80	21.30	23.16	24.46	24.90	26.24	29.44	31.44	32.72	34.30	39.11	44.09	58.70
Right Stick	RS RH Rt	147	3.21	40.18	17.62	7.67	5.82	9.20	10.19	11.15	12.08	13.18	14.28	15.01	15.75	16.79	17.13	17.83	18.84	21.05	22.34	24.95	26.63	28.61	32.65
Multi, Yoke	LH Lft	149	4.46	75.25	33.78	16.32	10.68	14.35	16.70	19.58	21.81	23.20	24.57	27.23	29.77	31.84	33.80	35.72	38.35	41.66	44.19	47.23	51.22	58.21	67.05
Multi, Rudder Pedal	Left Foot	152	15.82	553.99	104.73	81.80	29.51	35.11	39.96	44.56	47.18	53.52	60.29	66.45	74.23	78.89	84.72	97.28	105.74	118.01	130.40	164.36	182.12	199.60	252.65
Multi, Left Stick	LH Lft	140	1.20	38.85	17.27	7.73	6.04	7.90	9.72	10.53	11.25	12.68	13.83	14.70	15.78	16.68	17.78	18.64	19.67	20.48	21.66	23.30	25.54	27.24	31.55
Multi, Rudder Pedal	Left Foot	145	13.86	341.63	99.68	71.09	28.28	36.58	38.97	41.74	46.36	51.90	58.83	64.71	69.72	79.02	85.25	94.54	102.12	119.64	130.28	150.65	161.01	205.90	244.21
Multi, Center Stick	RH Rt	143	5.27	69.79	26.21	12.05	10.57	12.56	14.37	15.15	17.11	18.87	19.72	20.49	22.16	23.51	25.39	27.53	30.56	32.19	33.20	35.13	38.46	44.26	50.22
Multi, Rudder Pedal	Right Foot	139	9.01	393.93	98.98	64.83	24.88	37.25	42.88	48.36	53.14	60.14	67.38	72.80	77.73	85.14	92.20	98.87	102.73	109.05	119.84	138.66	158.27	188.21	232.15

**Table A5.** Distributions for all nonpilots by five-percentile increments for momentary (short-term) force application by control and direction of exerted force.

Control/axis	Hand/direction	n	Min	Max	Avg	STD	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Yoke Pitch	LH Push	158	5.67	104.68	34.99	21.26	9.44	13.76	15.80	17.84	18.88	20.61	21.96	23.99	27.09	29.26	33.78	35.88	39.04	41.96	44.56	50.65	56.70	66.87	77.54
Yoke Pitch	RH Push	155	5.72	111.04	34.52	21.68	10.61	11.96	14.50	16.27	17.55	19.39	21.76	23.51	27.44	29.96	32.00	34.63	37.08	40.82	43.84	51.58	57.67	66.50	80.90
Yoke Pitch	LH Pull	156	6.32	122.59	43.10	22.36	14.20	18.71	21.80	23.44	26.49	29.53	32.42	34.20	35.80	39.61	42.86	44.54	47.58	50.44	54.51	58.57	63.23	75.68	88.17
Yoke Pitch	RH Pull	154	6.95	120.08	43.37	24.12	14.19	17.32	20.06	22.50	23.98	26.39	29.77	33.87	35.43	37.23	40.77	43.20	48.55	51.67	57.70	63.13	71.07	77.02	93.51
Yoke Pitch	BH Push	160	7.91	229.04	62.83	40.98	16.49	22.41	25.57	29.65	31.74	34.64	39.20	42.64	47.54	51.49	59.00	63.80	69.71	76.20	84.68	92.80	100.97	120.75	144.55
Yoke Pitch	BH Pull	156	14.86	228.97	73.29	44.90	19.90	25.16	30.50	34.29	39.37	44.97	46.78	52.90	56.81	60.36	69.47	73.26	80.41	92.28	100.03	106.86	121.29	132.40	159.23
Yoke Roll	LH Lft	158	4.37	62.69	24.55	11.18	9.33	11.93	14.27	15.26	16.09	18.20	19.31	19.99	21.15	22.41	23.43	24.59	26.72	27.83	29.97	33.97	37.41	41.77	44.22
Yoke Roll	LH Rt	158	3.89	74.74	23.88	12.99	7.94	9.67	11.77	12.77	14.18	15.77	17.34	18.90	20.13	21.48	22.87	24.12	25.20	27.93	30.53	33.75	36.98	42.02	50.42
Yoke Roll	RH Lft	158	3.51	71.14	25.35	13.19	9.98	11.28	13.01	14.56	15.73	16.55	17.69	19.80	20.95	22.62	23.76	26.01	27.68	30.10	31.90	36.12	38.83	42.04	50.94
Yoke Roll	RH Rt	156	5.68	77.65	29.29	14.19	10.33	12.42	14.82	17.20	18.45	20.49	22.96	24.77	25.72	27.36	28.68	30.72	32.36	34.24	36.63	38.94	42.44	49.41	58.01
Yoke Roll	BH Lft	155	3.78	141.01	50.64	25.34	17.96	23.10	27.78	29.71	31.64	34.49	37.42	40.46	43.78	47.46	50.41	52.56	55.89	59.99	62.62	69.68	77.17	83.16	100.56
Yoke Roll	BH Rt	156	4.85	154.93	57.35	29.28	16.46	26.72	29.57	33.15	36.36	39.33	43.13	45.86	49.04	51.82	54.13	58.99	64.64	69.11	71.98	82.90	87.98	98.53	114.72
Yoke Rotated 36 Roll	LH Lft R	155	6.18	73.39	27.02	11.59	11.06	14.16	16.30	17.16	19.15	20.32	21.08	22.25	23.52	24.74	25.34	28.66	30.09	31.31	33.41	35.00	40.51	43.70	49.26
Yoke Rotated 36 Roll	LH Rt R	159	1.40	59.03	20.71	11.62	6.04	8.81	9.85	11.15	12.69	13.36	15.25	15.95	17.44	18.32	19.48	20.10	21.11	23.51	25.27	29.21	33.86	38.29	45.09
Yoke Rotated 36 Roll	RH Lft R	158	1.27	75.27	29.65	14.98	11.86	14.44	15.26	17.47	18.90	20.17	21.38	23.40	24.35	26.80	28.15	29.50	32.02	33.36	37.14	40.82	47.20	52.85	61.33
Yoke Rotated 36 Roll	RH Rt R	156	0.55	50.63	20.88	9.98	6.55	9.62	10.97	12.55	14.22	15.31	16.34	17.50	18.70	19.52	20.34	21.61	22.60	23.82	25.86	29.01	31.90	35.62	41.75
Yoke Rotated 36 Roll	LH Lft L	156	3.03	54.62	18.74	8.84	6.22	8.70	10.28	11.74	13.14	14.21	14.64	15.20	16.13	16.74	18.43	19.28	20.42	22.33	23.57	25.55	27.88	30.13	34.40
Yoke Rotated 36 Roll	LH Rt L	160	1.35	85.17	29.16	15.49	8.99	11.76	14.18	15.83	18.18	20.45	21.58	23.09	24.96	27.30	29.40	30.29	31.80	33.40	36.35	39.98	43.73	50.24	60.00
Yoke Rotated 36 Roll	RH Lft L	156	2.32	63.01	21.02	11.35	7.60	9.42	10.43	12.34	13.08	13.94	15.27	16.45	16.98	18.72	20.15	21.45	22.44	23.39	26.10	27.99	32.10	37.55	46.16
Yoke Rotated 36 Roll	RH Rt L	157	0.25	105.13	31.78	16.16	10.59	13.30	16.68	18.24	19.61	21.60	22.69	25.05	27.44	29.47	31.49	32.90	35.01	38.61	39.70	42.94	50.10	53.50	58.57
Rudder Pedal	Left Foot	152	0.81	454.77	100.84	74.63	25.52	35.72	42.65	47.25	51.85	56.54	60.92	66.85	74.21	78.89	82.57	89.52	98.11	112.80	125.01	144.81	175.06	203.28	249.12
Rudder Pedal	Right Foot	151	21.50	536.20	114.30	77.07	30.90	44.59	50.78	60.72	65.06	68.60	73.96	80.52	85.56	89.84	99.49	110.46	122.15	133.98	142.46	154.82	179.34	208.49	263.92
Collective	Down	158	7.20	87.69	36.63	16.29	15.96	18.50	20.93	21.83	23.51	24.87	27.74	29.68	32.54	34.72	37.25	39.04	40.48	42.36	45.72	50.38	54.73	59.55	67.84
Collective	Up	156	10.51	112.44	40.98	20.59	15.76	18.90	20.73	22.53	25.00	27.20	30.06	32.82	35.99	36.86	38.70	42.33	44.62	48.56	53.10	56.11	62.28	69.15	81.23
Left Stick	LS LH Pull	160	7.98	102.24	39.07	20.38	12.74	16.38	18.93	21.79	25.19	27.31	29.56	31.00	32.18	35.32	36.75	39.40	41.52	44.18	48.83	52.84	60.31	68.92	82.15
Left Stick	LS LH Push	158	6.70	107.38	37.86	19.80	15.56	17.07	19.33	22.16	24.00	25.87	27.09	28.39	30.31	33.37	35.83	37.48	39.94	42.65	46.49	51.19	58.20	68.29	81.78
Center Stick	CS LH Pull	158	7.46	104.32	39.22	19.95	14.83	17.12	20.26	22.67	24.19	26.50	29.38	31.92	33.73	35.35	37.54	40.11	42.95	45.49	48.71	53.67	58.30	66.42	79.07
Center Stick	CS LH Push	157	5.62	79.50	32.59	15.37	11.37	13.15	17.15	19.39	21.56	23.83	25.24	27.58	29.03	29.87	30.98	33.24	36.05	38.84	41.30	44.75	51.47	55.39	61.23
Center Stick	CS RH Pull	160	8.08	115.92	39.47	19.51	14.00	17.37	20.60	21.64	24.86	28.65	31.58	33.09	35.32	36.61	38.31	41.03	42.98	45.39	48.92	52.28	57.60	64.89	79.15
Center Stick	CS RH Push	156	5.79	93.96	34.70	17.59	11.04	13.38	17.18	19.07	20.51	22.34	24.40	26.62	29.81	32.64	34.94	36.81	40.87	43.33	47.15	48.80	52.31	60.20	66.49
Right Stick	RS RH Pull	158	5.82	108.96	41.98	22.48	13.75	16.06	21.14	22.97	24.74	26.83	30.61	33.79	36.11	38.36	40.58	43.45	46.13	49.36	52.00	54.50	62.12	74.31	91.97
Right Stick	RS RH Push	156	6.44	109.39	41.18	22.87	14.48	17.05	20.17	21.84	24.51	26.74	28.34	29.79	32.61	36.14	39.30	41.15	43.40	45.80	53.38	58.96	65.14	78.74	90.61
Left Stick	LS LH Lft	151	4.03	32.51	14.13	5.84	5.54	7.20	8.25	9.24	10.43	10.99	11.60	12.17	12.61	13.09	13.60	14.18	14.94	16.46	17.71	19.19	20.15	21.82	24.62
Left Stick	LS LH Rt	156	2.07	56.68	18.66	8.33	6.56	9.22	11.23	12.21	12.94	13.39	14.46	15.19	17.04	17.92	18.49	20.01	21.05	22.15	23.40	24.83	27.21	29.93	33.69
Center Stick	CS LH Lft	158	4.03	54.43	17.44	8.75	6.71	7.99	8.66	10.07	11.60	12.24	13.33	14.27	15.02	16.12	17.12	18.01	19.00	20.45	20.94	22.85	26.01	28.34	33.69
Center Stick	CS LH Rt	156	4.21	66.53	22.52	11.28	7.73	9.73	11.60	13.12	14.53	15.46	16.55	17.59	18.92	20.71	21.74	23.77	25.03	26.55	28.46	31.11	33.90	38.29	44.95
Center Stick	CS RH Lft	160	4.40	73.39	22.83	12.26	8.33	9.35	10.88	12.32	14.24	15.60	16.38	17.85	19.30	20.49	21.46	22.89	24.42	26.11	30.38	33.71	35.50	36.75	46.80
Center Stick	CS RH Rt	159	3.65	51.60	17.63	8.95	7.04	7.78	8.41	9.77	10.84	12.36	13.86	14.76	15.22	16.65	17.47	18.28	19.18	20.05	21.88	22.86	25.05	28.20	37.51
Right Stick	RS RH Lft	156	6.14	78.16	21.71	11.00	8.35	10.03	11.55	12.74	13.84	14.38	16.59	17.61	18.77	19.81	20.62	21.50	23.49	25.23	27.15	28.80	31.85	36.62	40.61
Right Stick	RS RH Rt	160	4.04	35.10	15.04	6.09	6.17	8.03	9.55	10.51	11.40	12.05	12.31	12.74	13.21	13.97	14.55	15.20	15.88	16.61	18.10	19.28	21.43	23.85	26.41
Multi, Yoke	LH Lft	153	2.16	69.39	27.17	13.42	8.50	11.83	13.68	15.55	17.12	18.97	21.12	22.69	23.57	24.22	26.26	28.93	30.47	31.50	35.37	39.38	43.10	47.73	52.09
Multi, Rudder Pedal	Left Foot	152	9.39	245.29	67.79	44.24	19.29	24.00	28.46	31.02	34.28	41.51	45.16	47.64	53.52	58.41	62.09	64.22	69.42	78.04	83.83	98.39	112.36	125.95	166.55
Multi, Left Stick	LH Lft	146	4.09	31.99	14.71	6.25	6.10	7.20	8.66	9.51	10.36	10.90	11.45	12.06	12.79	13.12	14.10	15.17	16.05	17.61	18.41	19.40	21.60	24.68	26.31
Multi, Rudder Pedal	Left Foot	146	11.13	266.36	67.82	43.54	18.03	24.60	27.95	33.78	38.06	40.78	44.15	48.29	51.34	60.48	66.31	69.03	73.84	78.57	85.20	91.91	105.35	127.37	150.99
Multi, Center Stick	RH Rt	159	5.61	56.82	21.27	9.36	8.92	10.71	12.09	13.57	15.03	17.01	17.81	18.53	19.21	20.04	20.59	21.27	22.11	23.15	25.26	27.58	29.67	33.03	41.43
Multi, Rudder Pedal	Right Foot	153	9.18	203.32	70.49	35.63	29.27	31.96	36.07	40.90	45.03	50.14	52.64	56.16	60.01	62.92	66.22	69.94	75.48	81.75	86.69	93.91	107.08	119.65	141.45

**Table A6.** Distributions for male pilots by five-percentile increments for momentary (short-term) force application by control and direction of exerted force.

Control/axis	Hand/direction	n	Min	Max	Avg	STD	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Yoke Pitch	LH Push	79	9.56	109.91	55.39	24.23	19.32	25.06	30.33	32.13	33.89	37.32	41.40	44.54	47.70	53.67	58.26	64.59	67.01	70.49	77.06	80.42	83.17	85.48	92.19
Yoke Pitch	RH Push	78	11.92	119.83	57.09	23.16	24.25	31.24	32.51	35.14	36.35	37.82	41.60	46.19	53.21	59.26	63.76	66.74	69.24	72.87	75.13	77.60	79.75	83.17	88.84
Yoke Pitch	LH Pull	78	15.88	135.69	71.70	27.15	30.57	38.07	41.26	45.99	50.27	58.57	61.85	64.44	64.71	69.70	74.57	78.09	81.84	85.22	88.98	94.95	103.11	111.97	117.46
Yoke Pitch	RH Pull	77	14.50	142.67	72.87	29.28	26.83	39.02	42.07	44.87	49.84	53.94	58.08	64.11	68.56	72.93	74.29	79.87	81.61	86.39	91.51	98.04	105.08	116.14	125.57
Yoke Pitch	BH Push	80	18.62	266.18	117.29	60.45	45.06	52.60	59.59	64.73	71.06	74.94	82.73	85.82	89.99	95.32	112.75	122.51	136.19	146.13	155.84	169.11	173.65	216.19	239.15
Yoke Pitch	BH Pull	77	34.89	333.24	138.10	64.61	51.51	64.38	69.42	78.87	88.82	96.00	99.99	106.06	116.34	128.40	135.98	148.18	167.81	176.77	181.38	190.47	212.33	228.16	259.69
Yoke Roll	LH Lft	77	7.75	70.23	37.90	14.31	20.51	22.56	24.40	26.16	26.82	29.43	31.02	32.37	33.76	34.86	35.36	37.43	39.80	43.11	47.20	50.06	58.06	58.94	67.76
Yoke Roll	LH Rt	79	7.77	76.42	40.48	15.29	16.63	22.07	24.93	25.66	27.34	30.15	33.28	36.20	39.46	41.08	43.35	44.54	46.60	49.00	49.80	51.41	55.93	59.22	67.55
Yoke Roll	RH Lft	76	8.50	75.98	40.46	14.08	18.21	23.84	24.95	26.91	29.24	30.44	34.56	37.47	38.56	42.43	44.93	46.10	47.23	48.30	49.91	51.92	53.64	54.99	63.35
Yoke Roll	RH Rt	76	8.52	95.82	46.04	17.50	24.35	27.28	29.46	30.35	31.41	33.93	36.99	39.04	40.66	44.31	47.40	49.06	51.37	55.65	57.23	60.82	65.60	68.56	80.02
Yoke Roll	BH Lft	77	24.95	145.48	80.44	28.94	41.13	45.24	49.02	53.25	56.38	62.07	64.59	68.00	72.99	77.52	82.42	86.75	88.64	95.56	101.22	104.11	113.06	125.18	131.37
Yoke Roll	BH Rt	80	20.20	196.32	92.85	38.10	37.25	45.00	55.66	64.94	66.22	70.71	74.53	77.85	83.12	88.36	92.04	97.13	100.54	106.69	116.85	128.86	139.56	145.52	160.65
Yoke Rotated 36 Roll	LH Lft R	80	12.36	86.07	38.92	14.66	19.57	23.11	25.87	26.63	28.62	29.73	31.21	31.84	34.43	36.32	38.14	40.40	41.40	44.13	46.20	52.64	55.90	59.14	66.28
Yoke Rotated 36 Roll	LH Rt R	76	6.04	65.32	35.94	13.37	15.52	20.32	21.34	23.93	25.55	28.51	30.62	32.32	33.46	35.36	36.09	38.29	39.72	42.04	45.82	48.58	52.63	54.33	57.68
Yoke Rotated 36 Roll	RH Lft R	80	14.12	77.83	43.03	15.19	18.75	23.68	26.87	29.90	31.66	33.18	34.43	37.23	39.62	42.67	46.19	47.92	48.69	50.21	53.17	55.88	60.81	63.05	69.16
Yoke Rotated 36 Roll	RH Rt R	79	8.28	63.62	34.97	12.96	15.73	20.24	21.66	23.73	26.14	27.09	27.96	30.50	31.40	32.49	35.87	36.70	39.20	41.33	43.09	45.82	51.18	56.02	58.59
Yoke Rotated 36 Roll	LH Lft L	80	4.18	64.86	29.43	11.01	13.24	16.41	18.24	20.05	23.27	24.33	24.82	26.02	26.97	28.94	30.39	31.89	32.67	34.40	36.13	37.58	40.08	42.66	46.82
Yoke Rotated 36 Roll	LH Rt L	79	11.76	84.24	45.10	16.37	21.65	25.15	28.02	30.89	33.17	35.18	36.53	38.70	41.05	42.83	44.17	46.59	50.22	53.92	55.96	61.61	66.24	69.24	73.00
Yoke Rotated 36 Roll	RH Lft L	79	9.80	81.15	34.18	13.69	16.21	20.15	20.74	21.91	23.39	25.22	26.83	28.83	31.13	33.19	35.47	36.12	36.97	38.91	43.01	43.84	47.63	53.04	59.75
Yoke Rotated 36 Roll	RH Rt L	78	13.31	90.89	48.42	17.85	21.57	25.64	32.79	35.03	36.33	39.35	40.04	41.00	43.63	45.76	49.18	51.71	54.13	56.24	59.72	61.57	69.46	73.37	81.33
Rudder Pedal	Left Foot	77	59.69	610.90	220.23	112.71	77.87	91.53	107.90	112.86	122.53	147.90	160.95	169.89	186.46	193.49	215.71	247.65	262.19	272.88	284.84	299.24	328.89	367.53	428.53
Rudder Pedal	Right Foot	78	56.28	521.32	214.96	101.92	79.22	106.70	114.35	129.87	139.48	146.18	158.17	178.99	187.74	194.02	204.94	223.35	237.52	251.88	260.67	275.50	312.35	379.90	426.64
Collective	Down	80	19.94	101.93	53.87	18.47	30.00	33.41	36.48	38.34	39.29	40.47	43.31	46.31	47.37	50.15	54.29	57.67	60.47	61.77	64.84	72.88	78.03	81.86	84.20
Collective	Up	78	15.08	138.14	65.42	27.01	27.88	34.49	41.15	42.71	45.88	48.24	49.62	52.81	56.42	58.64	64.85	70.74	74.32	76.00	80.67	88.49	97.40	104.48	117.95
Left Stick	LS LH Pull	78	11.92	128.23	64.15	26.86	28.19	32.33	35.78	39.45	43.69	47.37	49.18	51.81	54.88	58.20	62.93	70.53	75.65	77.75	84.50	87.50	97.55	100.35	110.90
Left Stick	LS LH Push	79	14.43	131.05	61.57	26.30	26.78	29.64	34.78	36.89	39.34	44.96	46.91	52.19	53.38	56.97	62.57	68.22	71.50	76.89	80.11	82.58	90.05	96.26	110.37
Center Stick	CS LH Pull	80	11.80	126.40	60.50	23.57	26.66	32.11	35.76	37.43	44.13	47.88	50.90	54.49	56.21	57.41	59.67	63.55	67.18	70.62	73.24	77.73	84.96	94.92	101.72
Center Stick	CS LH Push	77	13.64	113.01	49.33	19.40	19.51	24.65	27.06	32.51	35.66	38.35	40.43	44.40	47.35	49.55	52.07	55.34	57.72	58.62	60.23	61.86	67.93	70.37	83.85
Center Stick	CS RH Pull	80	15.07	137.27	64.29	25.30	27.98	35.32	37.84	42.94	45.58	48.34	51.20	54.75	56.95	58.71	63.05	69.18	73.00	78.23	82.15	89.24	93.02	99.42	106.43
Center Stick	CS RH Push	78	11.88	120.28	52.13	20.55	17.78	28.87	33.72	36.14	37.70	38.97	42.16	44.07	46.74	49.55	52.94	56.94	58.70	64.00	69.70	71.28	72.45	74.11	86.02
Right Stick	RS RH Pull	79	16.53	150.60	71.84	29.67	31.76	37.87	42.71	44.16	48.11	50.30	54.53	58.53	64.31	67.71	73.91	81.43	85.92	89.22	93.07	95.75	100.63	109.55	126.89
Right Stick	RS RH Push	78	12.96	139.26	62.81	28.06	23.53	30.32	33.06	36.40	39.70	42.23	47.74	50.97	54.06	59.38	63.86	67.38	70.77	74.75	82.87	92.44	97.70	102.97	110.07
Left Stick	LS LH Lft	77	3.88	36.84	20.13	7.17	7.23	11.04	12.45	14.01	16.33	16.86	17.79	18.45	18.84	20.49	21.28	22.02	22.30	22.67	23.51	24.73	28.24	30.29	32.98
Left Stick	LS LH Rt	78	7.21	54.89	25.22	10.22	12.22	15.19	16.42	16.95	18.06	18.61	19.64	20.60	21.84	22.60	23.26	25.09	26.31	29.20	31.35	31.78	35.39	41.28	46.69
Center Stick	CS LH Lft	79	1.89	58.32	26.88	11.67	12.17	14.09	16.67	17.63	18.62	19.48	19.93	21.58	22.27	25.11	25.67	27.04	30.36	31.79	35.76	37.84	39.73	43.82	47.77
Center Stick	CS LH Rt	79	5.35	72.85	34.80	15.28	13.28	17.08	19.56	21.48	22.64	24.18	26.86	28.12	29.93	31.38	35.42	38.24	40.26	42.32	47.14	49.64	51.55	57.25	60.52
Center Stick	CS RH Lft	79	9.98	65.51	34.77	13.92	14.46	17.91	20.46	21.60	23.21	26.69	29.09	30.59	31.86	32.66	34.18	35.50	39.84	42.41	45.10	46.51	50.20	54.68	61.75
Center Stick	CS RH Rt	79	6.21	52.05	27.12	11.32	10.90	14.23	16.25	16.81	17.20	19.68	21.19	23.19	23.93	24.54	25.58	28.31	30.44	33.87	36.60	39.41	41.32	43.02	45.63
Right Stick	RS RH Lft	77	8.16	67.79	34.03	13.74	15.69	17.57	21.29	23.61	24.70	25.42	26.57	29.21	31.44	32.10	32.67	33.76	36.49	38.67	40.41	43.81	51.22	57.50	61.41
Right Stick	RS RH Rt	76	4.33	40.18	21.98	7.70	7.04	14.07	14.57	16.19	17.01	17.67	18.33	19.53	21.11	22.12	22.60	23.45	25.04	26.44	27.57	28.33	30.08	32.60	34.21
Multi, Yoke	LH Lft	77	14.09	75.25	42.98	15.19	19.26	24.69	27.28	29.38	31.73	33.15	34.51	37.31	39.51	41.67	43.79	45.93	47.84	49.95	53.11	57.87	61.64	66.77	69.58
Multi, Rudder Pedal	Left Foot	80	34.46	553.99	143.96	91.74	45.25	50.56	60.84	69.23	80.08	86.00	98.70	106.39	110.88	120.55	130.63	150.59	168.21	178.37	183.94	193.93	210.88	247.22	319.18
Multi, Left Stick	LH Lft	72	6.85	38.85	22.16	6.82	11.29	14.55	15.83	16.69	18.00	18.55	19.25	19.83	20.22	21.31	22.01	23.01	24.02	25.37	26.00	27.14	30.46	31.46	34.65
Multi, Rudder Pedal	Left Foot	74	38.37	341.63	137.93	76.41	44.82	47.51	62.97	72.91	80.32	88.36	99.47	102.39	115.18	122.44	133.32	145.30	152.41	155.86	170.01	197.25	214.28	236.95	319.68
Multi, Center Stick	RH Rt	74	9.27	69.79	32.11	12.13	15.51	17.24	19.61	20.72	22.56	24.27	25.49	27.99	30.71	31.99	32.55	33.52	34.70	35.57	39.59	44.06	47.02	50.05	51.68
Multi, Rudder Pedal	Right Foot	72	21.45	393.93	129.96	71.61	53.03	57.73	66.26	73.55	76.66	85.02	94.24	100.55	102.82	112.35	119.04	134.03	138.37	147.18	160.61	168.12	214.62	229.12	259.65



**Table A7.** Distributions for female pilots by five-percentile increments for momentary (short-term) force application by control and direction of exerted force.

Control/axis	Hand/direction	n	Min	Max	Avg	STD	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Yoke Pitch	LH Push	71	4.96	55.77	26.93	10.68	11.63	13.18	15.27	17.63	18.96	20.23	21.93	23.28	24.15	25.30	27.78	29.85	31.01	32.30	34.81	36.45	38.15	41.49	43.81
Yoke Pitch	RH Push	73	4.04	62.16	27.72	11.15	11.16	14.53	17.13	18.92	19.65	22.05	23.13	24.26	25.34	25.95	27.58	29.40	32.37	33.28	33.86	35.82	40.00	41.59	46.82
Yoke Pitch	LH Pull	72	15.68	73.03	39.33	13.12	16.80	21.37	27.35	28.15	29.27	30.88	33.29	34.04	36.42	38.17	40.35	44.39	45.50	46.65	50.17	51.24	53.20	56.51	59.25
Yoke Pitch	RH Pull	71	11.11	69.33	38.13	13.76	16.57	20.97	22.24	25.76	27.59	28.90	31.56	32.91	33.69	36.62	39.77	42.37	44.87	45.86	47.37	52.35	54.08	56.56	61.33
Yoke Pitch	BH Push	75	9.78	157.89	54.09	27.23	19.92	24.72	29.70	32.88	34.13	38.28	42.71	44.28	45.34	47.33	50.94	55.55	59.97	61.48	67.73	73.26	84.24	92.53	101.04
Yoke Pitch	BH Pull	74	11.16	124.67	60.11	28.72	20.26	27.77	30.82	35.09	37.53	39.94	44.22	48.57	53.91	56.20	59.67	63.21	65.72	67.92	77.00	88.92	92.87	105.65	117.41
Yoke Roll	LH Lft	73	1.90	47.39	22.80	9.54	7.42	11.14	13.90	16.31	17.18	17.69	18.82	19.71	21.58	22.30	23.07	23.78	25.41	26.48	27.41	28.32	31.47	35.65	42.59
Yoke Roll	LH Rt	73	2.80	40.42	22.02	8.79	8.38	11.31	13.30	14.42	15.52	17.51	18.41	19.10	19.88	20.73	21.69	23.06	25.17	25.77	27.89	29.81	33.09	35.39	38.52
Yoke Roll	RH Lft	72	5.19	45.15	23.20	8.31	10.53	13.90	14.77	16.21	17.05	17.63	18.65	20.04	21.24	23.14	24.07	24.63	26.13	27.26	28.55	30.88	32.56	33.51	37.56
Yoke Roll	RH Rt	74	2.31	54.76	26.75	10.50	9.27	12.79	16.05	17.89	20.88	21.81	23.03	23.81	26.16	27.77	28.77	29.08	30.28	31.22	32.46	33.26	36.38	39.19	44.56
Yoke Roll	BH Lft	71	3.54	99.45	44.79	20.10	19.56	24.03	25.67	26.86	28.88	32.64	34.42	35.56	37.90	41.79	46.87	49.41	50.55	53.95	55.36	60.30	66.89	70.48	82.83
Yoke Roll	BH Rt	71	11.26	106.38	47.24	22.27	16.24	20.16	22.67	26.07	28.20	30.50	33.96	37.69	41.55	46.51	51.13	55.62	56.77	59.22	60.73	61.89	70.61	76.98	89.31
Yoke Rotated 36 Roll	LH Lft R	73	2.37	47.79	22.97	10.38	9.96	11.44	12.72	13.92	14.63	16.05	17.20	17.83	19.46	21.81	23.35	24.25	25.63	27.93	30.30	32.41	34.18	38.09	42.39
Yoke Rotated 36 Roll	LH Rt R	70	5.51	37.57	19.16	8.06	7.77	8.45	9.35	11.27	12.25	13.70	14.57	16.66	18.46	20.02	20.78	21.42	21.69	23.22	24.40	25.87	27.30	29.14	34.69
Yoke Rotated 36 Roll	RH Lft R	70	7.04	60.49	25.56	11.70	11.43	12.33	13.99	15.59	16.41	17.91	19.68	20.44	22.18	24.09	25.70	27.74	28.70	29.74	30.39	32.80	34.94	44.55	51.22
Yoke Rotated 36 Roll	RH Rt L	74	1.46	44.02	18.96	8.20	7.14	8.98	9.91	11.52	14.47	14.79	15.62	16.11	17.23	18.29	19.01	20.01	22.77	23.19	23.97	25.04	26.48	27.61	33.77
Yoke Rotated 36 Roll	LH Lft L	73	3.20	40.78	17.94	7.00	8.31	10.75	11.56	12.09	13.75	14.62	14.95	15.67	16.33	17.11	17.33	18.92	19.66	20.47	21.26	22.53	23.60	27.19	32.66
Yoke Rotated 36 Roll	LH Rt L	71	3.24	48.08	23.80	10.06	8.74	12.85	14.65	14.98	16.26	18.01	19.00	19.84	20.77	21.35	22.81	25.54	26.65	28.64	31.29	32.72	35.83	38.68	42.87
Yoke Rotated 36 Roll	RH Lft L	72	2.23	41.85	19.10	7.70	7.63	10.80	11.47	12.28	13.91	15.08	15.83	16.11	17.08	18.20	18.98	20.47	21.25	22.74	24.20	25.19	26.83	29.69	32.30
Yoke Rotated 36 Roll	RH Rt L	69	3.51	58.78	27.43	12.17	7.77	14.18	15.32	16.15	18.06	19.99	22.49	24.33	25.38	26.79	28.35	29.14	30.01	32.11	33.74	35.74	39.19	44.99	51.44
Rudder Pedal	Left Foot	73	19.46	254.03	94.79	52.39	29.53	36.07	41.79	45.50	47.52	53.85	59.35	71.27	83.03	88.18	100.24	106.39	113.96	121.79	126.73	132.46	138.57	164.71	182.23
Rudder Pedal	Right Foot	75	15.93	276.06	105.46	57.10	38.31	42.18	49.54	54.94	60.86	64.81	73.13	79.68	90.66	94.67	101.08	107.96	120.47	127.92	139.32	149.19	159.53	180.85	214.07
Collective	Down	71	8.24	64.99	32.85	12.42	14.95	18.02	19.87	21.99	22.99	23.62	26.02	27.30	31.27	31.83	33.76	35.44	37.43	39.57	42.82	43.99	45.14	47.21	58.40
Collective	Up	72	12.25	78.95	37.64	14.75	15.59	23.31	25.06	25.54	26.85	28.02	28.70	31.10	32.11	33.33	35.32	39.71	42.20	44.69	47.17	48.85	51.87	59.86	66.90
Left Stick	LS LH Pull	74	6.52	66.06	33.74	13.05	14.66	19.52	22.10	23.00	23.97	25.56	27.32	29.35	30.14	30.76	31.45	34.06	36.58	40.17	41.96	45.19	51.39	53.22	57.14
Left Stick	LS LH Push	74	2.14	66.95	30.96	13.47	11.98	15.60	18.63	20.66	21.98	22.70	25.02	25.98	26.88	28.04	30.67	32.68	34.25	36.16	37.13	41.83	45.64	49.25	57.10
Center Stick	CS LH Pull	72	5.54	63.69	33.32	13.52	14.46	16.45	20.17	22.28	22.86	23.53	24.72	28.29	29.87	32.62	36.17	37.66	39.02	41.64	42.91	44.88	45.97	50.36	58.45
Center Stick	CS LH Push	72	4.12	65.10	26.74	12.02	12.20	13.22	14.50	17.49	18.72	19.49	20.17	20.94	21.36	24.49	25.98	27.86	29.89	32.05	35.68	37.93	40.46	43.24	47.62
Center Stick	CS RH Pull	74	4.02	72.65	33.95	15.27	12.50	16.51	20.01	21.02	21.66	22.80	25.53	28.18	30.60	32.03	33.14	36.18	37.87	42.27	44.88	48.12	51.85	53.18	63.37
Center Stick	CS RH Push	66	2.97	62.96	27.27	12.57	12.42	13.34	16.15	18.68	19.93	20.07	20.96	21.75	22.79	23.74	26.37	27.33	29.07	30.59	32.68	36.76	39.36	45.62	52.74
Right Stick	RS RH Pull	70	7.25	66.55	35.38	13.80	14.71	20.00	21.68	22.21	24.46	25.74	26.20	27.31	32.14	33.98	37.72	40.04	41.34	44.52	46.08	48.00	50.68	55.62	59.38
Right Stick	RS RH Push	74	3.72	66.46	31.13	13.79	12.49	15.67	17.48	19.53	21.48	23.66	24.68	26.38	27.63	29.41	30.23	32.11	33.86	36.05	37.75	40.30	47.72	52.19	57.07
Left Stick	LS LH Lft	73	3.94	21.31	12.14	3.86	5.46	7.73	8.21	8.86	9.58	9.99	10.21	10.34	10.98	11.67	12.80	13.27	13.85	14.75	15.28	16.12	16.45	16.75	18.18
Left Stick	LS LH Rt	68	3.82	34.23	16.73	6.30	7.02	10.11	11.16	12.01	12.47	13.28	14.04	14.21	14.75	15.67	16.66	17.58	18.55	19.92	20.42	21.13	22.70	25.49	29.85
Center Stick	CS LH Lft	73	2.21	34.46	15.85	7.49	5.32	8.42	9.04	9.94	10.53	11.22	11.92	12.32	13.19	13.86	14.61	16.02	17.25	18.95	21.03	22.14	24.14	27.22	30.49
Center Stick	CS LH Rt	73	1.99	48.70	19.98	9.35	8.66	10.01	11.05	11.74	12.77	14.05	15.23	15.79	17.64	18.76	20.23	20.73	21.76	22.04	26.63	28.66	30.28	32.14	38.84
Center Stick	CS RH Lft	74	3.29	47.50	20.55	8.90	8.94	10.35	11.74	12.95	14.51	15.60	16.22	17.32	18.82	19.53	20.02	20.82	22.85	23.37	24.29	27.75	30.35	34.87	36.27
Center Stick	CS RH Rt	71	2.35	39.14	15.82	7.32	6.14	8.14	9.15	10.21	11.03	11.44	12.08	13.07	14.11	14.48	15.01	15.71	17.15	18.40	18.83	20.74	23.87	26.95	30.53
Right Stick	RS RH Lft	72	2.22	36.38	18.43	7.11	7.68	10.80	11.97	12.86	14.23	14.70	15.16	15.65	16.80	17.38	17.94	19.12	20.45	21.72	23.52	24.63	25.20	29.01	31.39
Right Stick	RS RH Rt	71	3.21	22.33	12.96	4.07	4.54	7.44	9.29	9.89	10.34	11.07	11.59	11.94	12.18	12.73	13.75	14.38	14.87	15.55	15.91	16.63	17.10	17.54	18.33
Multi, Yoke	LH Lft	72	4.46	55.71	23.94	10.86	8.73	10.39	12.52	14.57	15.75	17.67	19.27	20.31	21.82	22.79	23.36	24.41	26.17	28.39	31.25	33.20	35.60	39.65	43.57
Multi, Rudder Pedal	Left Foot	72	15.82	252.99	61.15	34.74	26.88	29.03	33.31	35.18	37.26	41.81	43.30	45.07	46.40	52.61	57.69	61.37	67.85	72.74	77.10	79.54	88.09	99.92	115.72
Multi, Left Stick	LH Lft	68	1.20	21.14	12.09	4.66	4.34	6.02	7.38	7.94	8.55	9.75	10.12	10.66	10.98	11.92	12.80	13.35	13.99	14.51	15.10	16.47	16.94	18.79	20.32
Multi, Rudder Pedal	Left Foot	71	13.86	205.90	59.81	33.86	19.85	28.14	32.34	36.56	37.82	39.01	40.83	43.89	48.29	51.90	56.58	60.06	65.93	68.52	71.52	80.68	87.97	100.33	125.18
Multi, Center Stick	RH Rt	69	5.27	41.22	19.88	8.15	10.34	10.60	12.28	12.84	13.94	14.64	14.99	16.14	17.25	19.11	19.44	20.39	21.51	22.57	25.12	26.26	29.86	32.29	35.40
Multi, Rudder Pedal	Right Foot	67	9.01	175.12	65.69	33.15	23.14	25.80	33.33	37.37	42.08	45.08	47.60	49.38	50.50	59.87	67.46	70.09	77.73	83.85	88.05	94.08	99.08	104.54	116.51

**Table A8.** Distributions for male nonpilots by five-percentile increments for momentary (short-term) force application by control and direction of exerted force.

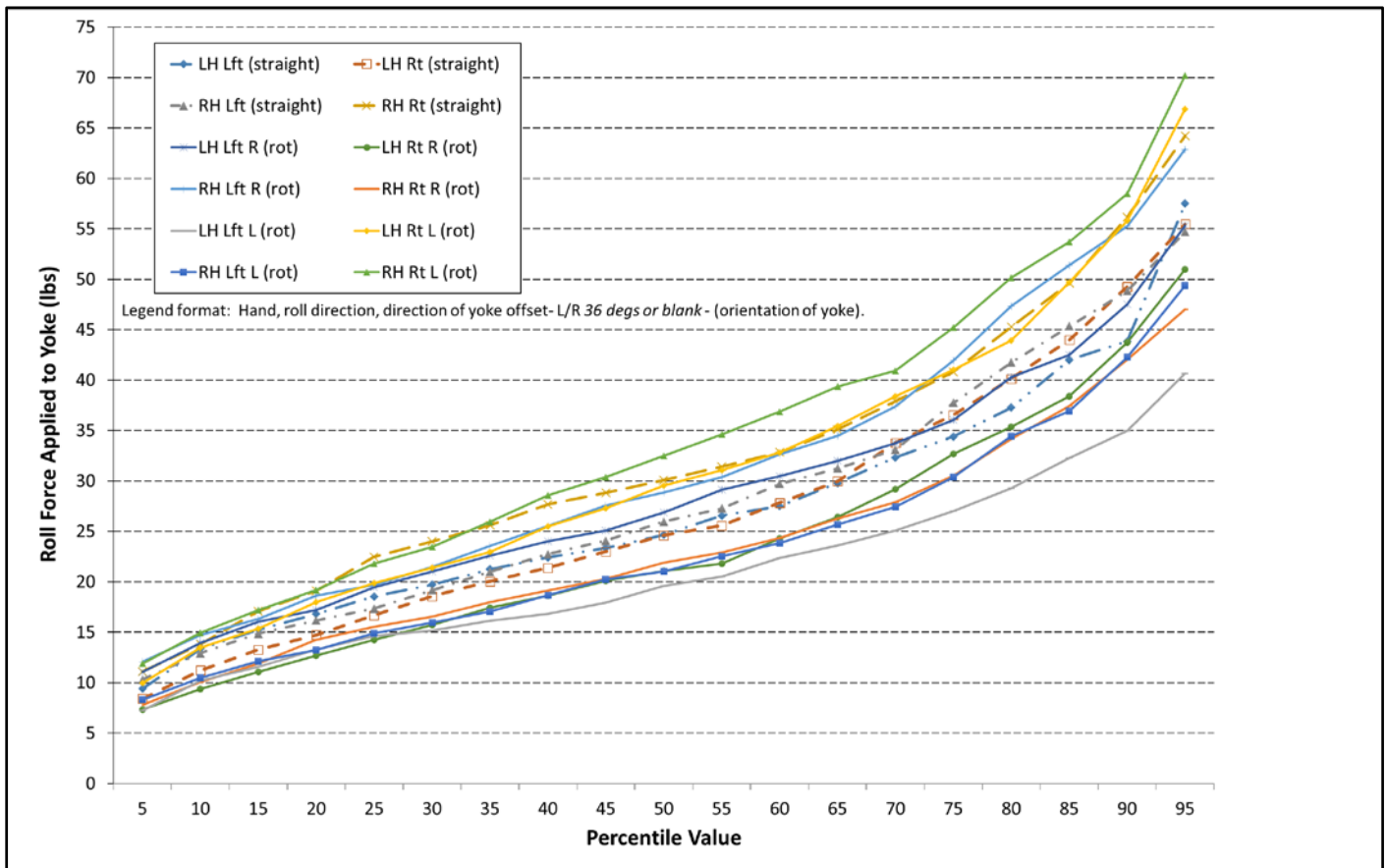
Control/axis	Hand/direction	n	Min	Max	Avg	STD	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Yoke Pitch	LH Push	76	7.74	104.68	46.70	23.00	14.81	18.70	21.46	25.02	28.93	34.77	35.90	38.60	41.59	43.41	44.82	50.53	52.52	56.65	62.07	67.64	73.05	77.70	91.77
Yoke Pitch	RH Push	75	10.60	111.04	45.70	23.79	13.73	16.30	21.65	23.67	28.69	30.49	31.95	34.89	36.92	40.84	43.84	48.19	53.18	56.62	64.36	66.59	75.04	81.12	89.85
Yoke Pitch	LH Pull	77	12.62	122.59	55.21	24.00	21.20	24.59	30.02	33.05	36.37	41.90	44.01	48.07	49.60	54.35	56.52	58.92	60.38	63.42	70.00	75.77	80.68	88.46	100.29
Yoke Pitch	RH Pull	75	13.97	120.08	57.32	25.05	20.06	24.06	29.15	35.41	36.92	40.47	43.05	50.15	53.10	56.84	60.84	62.72	65.24	70.91	72.90	77.65	84.83	94.26	101.42
Yoke Pitch	BH Push	77	13.11	229.04	82.56	46.64	22.06	30.27	33.67	39.75	45.24	50.21	58.74	64.25	70.70	75.46	83.62	88.66	93.81	101.79	108.08	122.41	135.41	144.73	174.29
Yoke Pitch	BH Pull	77	17.97	228.97	97.07	48.49	27.08	38.39	46.84	52.83	57.27	67.69	73.00	78.24	87.43	94.73	100.26	105.15	112.96	121.49	123.30	132.61	141.84	160.27	200.50
Yoke Roll	LH Lft	77	11.64	62.69	31.35	11.12	15.83	16.88	20.06	21.44	22.87	23.78	25.40	26.83	27.86	29.19	30.78	34.00	35.15	37.69	38.76	41.96	43.10	44.47	50.17
Yoke Roll	LH Rt	75	8.03	74.74	32.05	13.13	13.99	18.12	20.00	21.03	23.14	23.62	24.67	25.05	27.45	29.74	31.97	34.24	36.34	37.30	40.02	42.76	45.59	50.72	53.17
Yoke Roll	RH Lft	77	6.86	71.14	32.97	13.77	15.69	16.80	17.72	20.91	23.38	25.10	26.46	27.72	29.97	30.94	32.58	34.42	37.82	39.47	41.34	42.15	45.93	51.62	59.33
Yoke Roll	RH Rt	75	5.68	77.65	37.82	14.63	14.14	19.55	22.76	25.77	28.17	30.09	31.88	32.87	34.70	36.81	37.98	39.67	41.22	44.24	47.25	50.69	54.14	58.42	61.61
Yoke Roll	BH Lft	74	19.98	141.01	65.43	26.21	26.15	34.60	38.05	44.54	49.42	50.68	52.51	54.23	56.86	61.62	63.15	71.07	75.08	78.28	80.36	83.68	90.74	100.94	117.88
Yoke Roll	BH Rt	76	16.30	154.93	74.14	30.18	33.84	37.19	44.17	45.78	47.20	51.78	56.98	67.95	70.27	71.98	74.57	83.94	84.96	88.62	92.51	98.72	105.74	114.99	131.32
Yoke Rotated 36 Roll	LH Lft R	76	10.87	73.39	34.06	11.54	17.40	20.34	21.69	24.31	25.30	28.07	29.60	30.48	31.75	33.15	33.74	34.31	36.33	40.58	41.51	44.01	46.05	49.29	51.39
Yoke Rotated 36 Roll	LH Rt R	76	4.32	59.03	27.76	12.42	10.18	13.10	15.74	16.79	18.32	19.79	20.75	21.46	23.93	25.56	28.69	29.93	32.73	33.93	37.22	38.54	43.28	45.10	49.42
Yoke Rotated 36 Roll	RH Lft R	77	8.92	75.27	38.89	15.25	18.86	21.68	22.49	24.28	26.58	27.56	30.26	32.64	34.71	37.11	39.24	40.98	44.20	47.70	51.98	52.97	57.51	61.51	66.56
Yoke Rotated 36 Roll	RH Rt R	74	7.37	50.63	26.03	10.74	10.43	11.86	13.14	16.24	17.53	19.44	21.52	22.15	23.70	25.00	26.65	28.84	30.14	32.01	34.26	35.70	37.83	41.98	43.74
Yoke Rotated 36 Roll	LH Lft L	74	3.35	54.62	23.68	9.26	12.03	13.15	14.36	14.88	15.48	17.70	18.90	20.54	22.35	23.27	24.36	25.87	26.73	28.17	28.97	30.73	32.37	34.92	39.45
Yoke Rotated 36 Roll	LH Rt L	77	10.36	85.17	38.44	15.75	16.58	20.84	23.01	26.12	27.31	29.40	29.92	32.36	33.73	35.96	38.33	39.75	40.82	44.22	47.35	50.87	55.62	60.46	68.47
Yoke Rotated 36 Roll	RH Lft L	75	5.20	63.01	27.57	12.27	11.54	12.92	15.76	17.46	19.50	20.88	21.50	22.20	22.72	24.47	26.61	28.36	30.55	32.22	35.78	38.08	41.24	47.42	50.70
Yoke Rotated 36 Roll	RH Rt L	76	0.25	105.13	40.19	17.42	16.73	20.09	22.41	23.19	25.67	29.43	32.75	37.08	38.63	39.41	40.31	42.94	45.43	49.71	52.47	53.49	55.67	58.46	70.27
Rudder Pedal	Left Foot	69	0.81	454.77	132.19	90.81	28.77	41.58	50.87	61.48	72.30	77.77	82.39	88.67	97.24	103.18	118.28	124.33	143.98	151.85	182.95	203.43	216.21	258.26	292.71
Rudder Pedal	Right Foot	71	21.50	536.20	148.48	90.52	49.36	63.41	66.88	79.24	84.98	89.57	98.16	109.49	121.61	133.50	137.46	143.05	153.59	172.25	187.71	206.55	230.15	267.15	330.48
Collective	Down	77	11.99	87.69	46.01	16.51	19.65	24.67	27.89	32.01	35.92	37.83	39.30	40.66	41.63	44.85	46.01	49.95	54.22	55.04	56.26	59.68	62.34	68.69	74.30
Collective	Up	75	16.59	112.44	52.69	21.59	22.02	26.77	30.82	35.37	37.22	37.68	41.46	43.42	45.43	48.89	53.91	57.02	59.77	62.32	67.24	69.26	74.20	81.37	90.42
Left Stick	LS LH Pull	78	16.72	102.24	51.49	20.67	25.34	29.06	30.19	31.71	32.06	36.90	39.83	42.87	45.39	48.33	50.02	52.79	57.00	60.98	66.32	69.18	74.71	82.57	91.98
Left Stick	LS LH Push	77	15.98	107.38	49.66	20.75	24.12	26.34	28.45	30.37	33.97	35.95	37.33	38.55	41.54	43.70	48.62	53.04	55.25	58.61	65.24	68.63	73.39	82.88	88.14
Center Stick	CS LH Pull	77	16.11	104.32	50.44	21.26	21.38	24.84	27.70	33.30	34.95	36.09	38.24	41.09	44.67	48.86	51.88	53.99	56.89	58.80	62.29	66.88	72.01	80.22	96.48
Center Stick	CS LH Push	76	12.18	79.50	41.60	15.00	19.97	24.14	25.13	29.08	29.90	30.86	32.11	35.79	36.92	40.98	42.71	44.75	47.72	51.33	54.28	55.38	58.01	61.70	66.96
Center Stick	CS RH Pull	78	9.35	115.92	50.36	20.19	21.86	26.30	32.11	34.40	36.55	38.94	41.08	43.07	44.78	46.86	49.21	51.05	54.02	57.28	61.21	64.71	72.52	79.43	88.13
Center Stick	CS RH Push	74	12.65	93.96	45.80	16.88	19.44	22.01	25.08	31.56	34.75	36.36	39.55	41.40	43.15	46.09	48.06	49.37	51.60	53.68	56.98	60.53	62.23	67.27	74.17
Right Stick	RS RH Pull	76	14.39	108.96	54.75	23.71	25.37	28.59	30.63	33.28	35.65	39.74	42.38	44.82	47.87	50.46	52.06	54.65	56.65	63.37	69.37	74.89	84.84	92.77	102.48
Right Stick	RS RH Push	75	12.22	109.39	55.24	24.13	18.86	25.81	31.12	32.59	37.34	40.18	42.79	44.19	47.58	54.63	56.52	59.27	62.31	65.39	71.10	79.10	82.12	90.88	99.62
Left Stick	LS LH Lft	72	6.13	32.51	17.56	5.72	9.19	10.86	11.94	12.59	13.45	14.23	14.82	15.30	16.39	17.21	17.74	18.52	19.76	20.08	20.72	21.82	23.34	25.34	28.30
Left Stick	LS LH Rt	74	8.33	56.68	23.88	7.89	13.10	15.00	16.77	17.81	18.51	19.85	20.55	21.18	22.18	22.67	23.41	24.59	25.35	26.45	28.92	30.12	31.19	33.73	35.53
Center Stick	CS LH Lft	75	5.26	54.43	21.63	9.56	10.04	11.91	12.84	13.90	14.74	15.88	17.25	18.19	18.89	19.84	20.53	21.67	22.95	24.95	27.34	28.27	29.35	33.93	38.65
Center Stick	CS LH Rt	76	6.51	66.53	28.42	11.69	12.15	14.96	16.28	17.77	19.19	20.97	22.49	24.95	26.34	27.03	28.63	30.03	31.65	32.95	35.92	38.13	40.33	45.31	50.13
Center Stick	CS RH Lft	78	6.66	73.39	29.35	13.20	13.00	15.50	16.51	18.24	19.38	20.45	21.72	23.58	24.51	27.48	30.73	33.27	34.32	35.00	36.18	36.79	38.97	46.93	53.63
Center Stick	CS RH Rt	77	7.07	51.60	22.16	9.56	8.41	13.36	14.23	14.88	16.16	16.97	17.71	18.74	19.30	19.79	20.21	21.70	22.35	24.03	26.88	28.41	30.21	37.61	42.31
Right Stick	RS RH Lft	73	7.56	78.16	28.46	11.84	11.30	15.38	17.85	18.86	20.28	22.05	23.68	25.23	26.67	27.21	27.80	29.00	31.10	32.37	35.01	37.42	38.01	40.90	46.59
Right Stick	RS RH Rt	77	6.34	35.10	18.42	6.29	9.90	11.96	12.79	12.99	13.67	14.28	14.74	15.49	16.42	17.30	17.96	18.66	20.24	21.77	22.94	24.18	25.50	26.47	30.93
Multi, Yoke	LH Lft	75	8.46	69.39	35.33	12.93	16.42	18.44	20.50	22.32	23.65	29.02	30.21	30.98	32.18	35.34	36.37	39.33	40.25	43.68	46.15	47.98	48.89	52.10	55.14
Multi, Rudder Pedal	Left Foot	71	14.68	245.29	87.23	50.22	21.18	28.74	38.44	45.92	49.86	55.67	61.91	66.46	70.74	78.59	83.85	93.82	101.06	105.64	112.53	124.82	134.09	155.61	196.29
Multi, Left Stick	LH Lft	71	6.13	31.99	17.84	6.57	6.97	9.43	9.99	11.79	13.07	14.22	14.90	15.58	16.42	17.21	17.88	18.96	19.50	21.51	24.07	24.71	25.25	26.78	28.83
Multi, Rudder Pedal	Left Foot	69	17.15	266.36	87.42	49.84	25.55	31.55	36.56	42.62	48.89	60.12	66.31	70.05	74.64	78.88	84.65	88.45	93.85	104.40	118.86	127.23	132.80	146.38	195.34
Multi, Center Stick	RH Rt	76	9.98	56.82	26.11	10.02	13.57	15.46	17.26	17.93	18.98	19.64	20.32	21.47	22.06	24.13	25.42	26.41	27.61	29.51	31.61	33.11	36.32	42.22	46.17
Multi, Rudder Pedal	Right Foot	75	9.18	203.32	84.50	39.43	33.11	40.34	43.22	51.57	55.93	61.94	63.44	68.91	73.37	78.06	81.97	86.73	91.41	102.20	108.04	117.91	124.37	131.85	167.49

**Table A9.** Distributions for female nonpilots by five-percentile increments for momentary (short-term) force application by control and direction of exerted force.

Control/axis	Hand/direction	n	Min	Max	Avg	STD	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Yoke Pitch	LH Push	82	5.67	58.54	24.14	11.76	6.58	10.26	12.28	14.02	16.24	17.50	18.51	19.02	20.47	21.68	22.70	24.09	26.63	29.14	32.22	33.97	37.08	41.42	45.21
Yoke Pitch	RH Push	80	5.72	62.47	24.03	12.51	7.56	10.69	11.84	13.33	15.38	16.27	17.05	19.06	19.38	21.29	21.83	23.59	27.05	29.07	32.60	34.05	38.66	41.17	48.68
Yoke Pitch	LH Pull	79	6.32	56.56	31.30	12.11	11.53	14.89	18.14	20.42	22.12	23.13	25.51	27.15	28.88	32.21	33.19	34.84	35.83	38.73	40.09	42.99	44.72	47.61	52.00
Yoke Pitch	RH Pull	79	6.95	72.83	30.13	13.45	10.41	14.90	16.83	18.49	20.19	22.22	22.98	24.04	26.34	27.74	31.57	32.97	34.63	36.09	39.37	42.04	43.61	48.47	49.98
Yoke Pitch	BH Push	83	7.91	101.13	44.53	23.14	14.28	18.67	22.80	25.21	27.64	29.62	30.52	33.23	35.38	39.22	42.54	46.54	50.15	55.41	59.43	64.41	70.14	77.59	92.73
Yoke Pitch	BH Pull	79	14.86	118.51	50.10	24.75	17.76	20.99	24.78	28.25	31.19	32.13	36.27	39.68	44.36	46.12	46.78	53.43	56.50	58.81	67.80	69.81	75.43	81.12	101.47
Yoke Roll	LH Lft	81	4.37	32.99	18.08	6.40	7.69	9.36	11.06	13.01	13.90	14.64	15.25	15.78	17.45	18.46	18.81	19.52	20.37	21.12	22.33	23.19	24.75	26.95	29.14
Yoke Roll	LH Rt	83	3.89	34.76	16.50	7.15	6.14	8.31	9.53	9.96	11.77	12.04	12.92	13.73	14.31	15.43	16.14	17.47	18.70	19.85	21.30	22.33	24.42	27.17	29.03
Yoke Roll	RH Lft	81	3.51	37.82	18.11	7.24	7.85	10.05	10.96	11.66	12.98	13.83	14.47	15.47	15.97	16.56	17.90	19.76	20.68	21.09	22.65	23.09	25.69	28.20	32.17
Yoke Roll	RH Rt	81	5.84	35.46	21.39	7.79	8.32	11.05	12.31	13.60	14.84	16.40	17.77	18.47	20.21	22.64	23.76	24.76	25.40	26.02	27.21	28.47	29.67	31.75	33.77
Yoke Roll	BH Lft	81	3.78	71.58	37.13	14.90	13.66	18.13	22.96	26.60	28.32	28.86	30.07	31.21	32.94	35.97	37.57	39.78	42.67	44.06	47.53	50.67	55.89	59.05	62.12
Yoke Roll	BH Rt	80	4.85	82.48	41.41	17.00	13.17	17.99	25.33	27.73	29.19	30.38	33.14	36.20	37.87	39.93	43.16	46.89	49.57	52.86	54.26	57.12	60.91	64.77	66.70
Yoke Rotated 36 Roll	LH Lft R	79	6.18	35.36	20.24	6.52	9.45	11.16	13.57	14.82	15.87	16.47	17.16	19.03	19.78	20.33	21.08	21.59	22.96	23.43	24.37	24.97	27.19	29.23	31.82
Yoke Rotated 36 Roll	LH Rt R	83	1.40	27.27	14.25	5.56	5.52	6.69	8.79	9.40	9.84	11.08	12.00	12.72	13.09	14.18	15.27	15.84	17.09	17.77	18.62	19.48	20.12	21.12	23.46
Yoke Rotated 36 Roll	RH Lft R	81	1.27	40.36	20.85	7.65	10.02	12.04	14.00	14.56	15.04	15.64	17.43	18.77	19.10	19.70	20.92	21.48	23.99	24.66	27.27	28.45	29.26	31.10	33.06
Yoke Rotated 36 Roll	RH Rt R	82	0.55	33.94	16.24	6.37	5.49	7.14	9.51	10.47	11.56	13.08	14.29	15.13	15.67	16.53	17.65	18.70	19.23	19.71	20.45	21.85	22.34	23.34	26.32
Yoke Rotated 36 Roll	LH Lft L	82	3.03	27.62	14.28	5.47	5.04	6.68	8.19	9.36	10.18	10.69	12.18	13.57	14.36	14.62	15.04	15.94	16.19	16.64	17.94	19.28	20.08	21.45	23.57
Yoke Rotated 36 Roll	LH Rt L	83	1.35	43.46	20.55	8.91	7.36	9.03	11.48	12.08	13.70	15.28	16.08	17.82	18.72	20.47	21.27	22.11	23.38	25.22	27.84	29.92	30.67	31.92	33.99
Yoke Rotated 36 Roll	RH Lft L	81	2.32	27.40	14.95	5.74	6.47	8.28	9.08	9.89	10.42	11.28	12.38	13.11	13.84	14.65	15.27	15.87	16.73	17.04	18.67	19.61	22.13	23.10	25.83
Yoke Rotated 36 Roll	RH Rt L	81	8.66	58.61	23.89	9.72	10.15	11.64	12.71	14.92	16.88	18.02	18.79	19.70	21.09	22.76	25.04	26.30	28.88	30.28	31.49	32.16	33.41	34.97	39.51
Rudder Pedal	Left Foot	83	18.57	238.21	74.78	43.62	24.30	29.61	37.80	43.41	47.71	50.02	53.44	56.26	58.44	64.60	67.96	74.20	77.18	81.10	85.57	97.58	114.22	136.10	175.51
Rudder Pedal	Right Foot	80	21.60	240.29	83.96	45.11	25.92	34.95	42.83	48.99	53.07	58.59	64.62	67.56	71.10	74.12	76.92	84.52	87.64	92.44	105.13	118.21	126.25	151.19	162.19
Collective	Down	81	7.20	52.20	27.72	9.82	14.36	17.55	18.58	19.20	21.02	21.33	22.32	23.31	23.98	25.12	28.17	29.41	31.72	33.66	34.70	36.54	38.39	41.03	45.19
Collective	Up	81	10.51	56.12	30.15	11.96	14.14	16.17	18.63	19.36	20.35	21.27	23.01	24.94	26.31	28.32	30.10	32.30	34.49	36.13	38.01	39.23	44.47	48.73	53.08
Left Stick	LS LH Pull	82	7.98	53.30	27.26	10.94	11.91	12.79	14.27	16.88	18.13	19.21	21.20	22.83	25.77	27.05	28.63	29.96	32.36	34.24	35.84	37.39	39.45	40.83	44.14
Left Stick	LS LH Push	81	6.70	49.02	26.64	9.93	11.15	15.65	16.34	17.62	18.83	21.08	22.09	22.99	24.85	25.77	26.56	27.81	28.80	30.99	33.43	36.05	38.33	41.44	45.08
Center Stick	CS LH Pull	81	7.46	47.81	28.55	10.73	12.74	14.91	16.06	17.22	19.02	22.25	22.93	24.17	26.10	27.71	30.73	31.81	32.60	35.03	37.22	39.38	41.39	44.15	46.24
Center Stick	CS LH Push	81	5.62	56.10	24.13	10.01	9.26	11.48	12.96	13.94	15.78	18.41	19.39	21.60	22.66	24.11	25.58	27.56	28.53	29.17	30.12	31.92	34.68	36.93	41.03
Center Stick	CS RH Pull	82	8.08	68.33	29.12	11.70	12.98	14.22	16.54	18.40	20.45	21.36	21.81	23.65	26.91	29.13	30.36	32.14	34.25	35.71	37.22	38.67	40.45	43.44	47.38
Center Stick	CS RH Push	82	5.79	48.71	24.69	11.03	9.29	11.07	13.04	14.47	17.17	18.45	19.17	20.41	21.30	23.30	24.53	26.15	28.55	29.50	32.33	33.26	36.88	41.28	46.67
Right Stick	RS RH Pull	82	5.82	55.51	30.13	12.81	12.84	13.82	15.34	17.50	20.66	21.51	22.20	23.68	24.97	27.66	32.88	34.29	37.20	38.33	39.94	41.66	45.38	48.69	52.26
Right Stick	RS RH Push	81	6.44	60.20	28.17	10.86	11.93	14.96	16.23	19.21	20.66	21.78	23.77	24.29	26.22	27.42	28.10	28.42	29.83	33.84	36.13	38.47	40.51	43.07	46.54
Left Stick	LS LH Lft	79	4.03	24.61	11.00	3.88	4.95	5.65	7.03	7.55	8.04	8.88	9.62	10.16	10.88	11.14	11.66	12.12	12.22	12.65	13.05	13.47	14.04	14.69	18.48
Left Stick	LS LH Rt	82	2.07	27.65	13.95	5.42	5.21	6.72	7.91	9.34	10.93	11.80	12.26	12.70	13.10	13.31	13.90	14.50	14.91	16.34	17.91	18.21	19.37	21.22	24.19
Center Stick	CS LH Lft	83	4.03	32.47	13.66	5.80	5.64	7.38	7.89	8.25	8.66	9.34	10.60	11.62	11.87	12.60	13.99	14.90	15.98	16.41	17.26	18.05	20.45	20.84	23.68
Center Stick	CS LH Rt	80	4.21	42.72	16.91	7.38	7.30	8.11	9.49	9.92	11.40	12.21	13.54	14.53	15.44	15.92	16.93	17.63	19.39	20.74	21.52	22.78	24.13	26.02	29.78
Center Stick	CS RH Lft	82	4.40	35.92	16.63	7.04	7.57	8.47	8.70	10.00	10.83	12.01	12.48	13.75	15.09	16.16	16.46	17.86	19.18	20.54	21.52	22.71	24.45	25.58	28.89
Center Stick	CS RH Rt	82	3.65	27.43	13.38	5.70	5.84	7.04	7.68	8.03	8.64	9.40	10.10	10.57	11.21	12.30	14.21	14.73	15.17	16.55	17.34	18.17	19.07	22.05	23.92
Right Stick	RS RH Lft	83	6.14	31.75	15.77	5.43	7.30	9.21	9.70	10.75	12.00	12.45	12.94	13.78	14.23	14.85	16.67	16.97	18.50	19.28	20.32	20.63	21.32	22.07	24.93
Right Stick	RS RH Rt	83	4.04	21.53	11.91	3.82	5.23	6.26	7.78	8.64	9.59	10.11	10.73	11.25	11.64	12.10	12.21	12.54	13.01	13.71	14.55	15.14	15.46	16.51	18.85
Multi, Yoke	LH Lft	78	2.16	41.28	19.32	8.21	3.19	8.94	11.10	12.09	13.27	14.35	15.46	16.90	18.20	19.62	21.89	23.17	23.52	24.22	24.76	25.37	27.43	29.77	31.13
Multi, Rudder Pedal	Left Foot	81	9.39	168.85	50.76	29.28	16.16	21.90	26.03	28.94	30.72	32.12	33.95	37.76	43.10	45.24	48.06	53.58	55.46	59.81	63.87	67.62	71.58	79.07	121.63
Multi, Left Stick	LH Lft	75	4.09	22.64	11.75	4.18	5.27	6.50	7.56	8.21	8.91	9.56	10.42	10.67	10.99	11.43	11.81	12.28	12.72	13.09	13.33	14.39	16.06	18.09	19.73
Multi, Rudder Pedal	Left Foot	77	11.13	177.83	50.26	27.08	17.12	19.44	24.59	25.55	29.82	34.58	38.44	40.78	43.62	47.50	48.41	49.90	52.27	63.54	67.29	71.01	74.99	82.88	94.28
Multi, Center Stick	RH Rt	83	5.61	32.81	16.83	5.94	7.17	9.02	10.01	10.98	11.58	12.58	14.02	15.05	17.28	17.96	18.51	18.97	19.82	20.53	20.73	21.29	22.54	22.80	26.74
Multi, Rudder Pedal	Right Foot	78	17.28	149.95	57.03	25.25	25.42	29.43	31.78	35.37	37.76	42.90	45.72	48.75	51.00	53.96	56.49	60.01	62.38	66.07	69.67	70.93	82.22	86.64	95.56

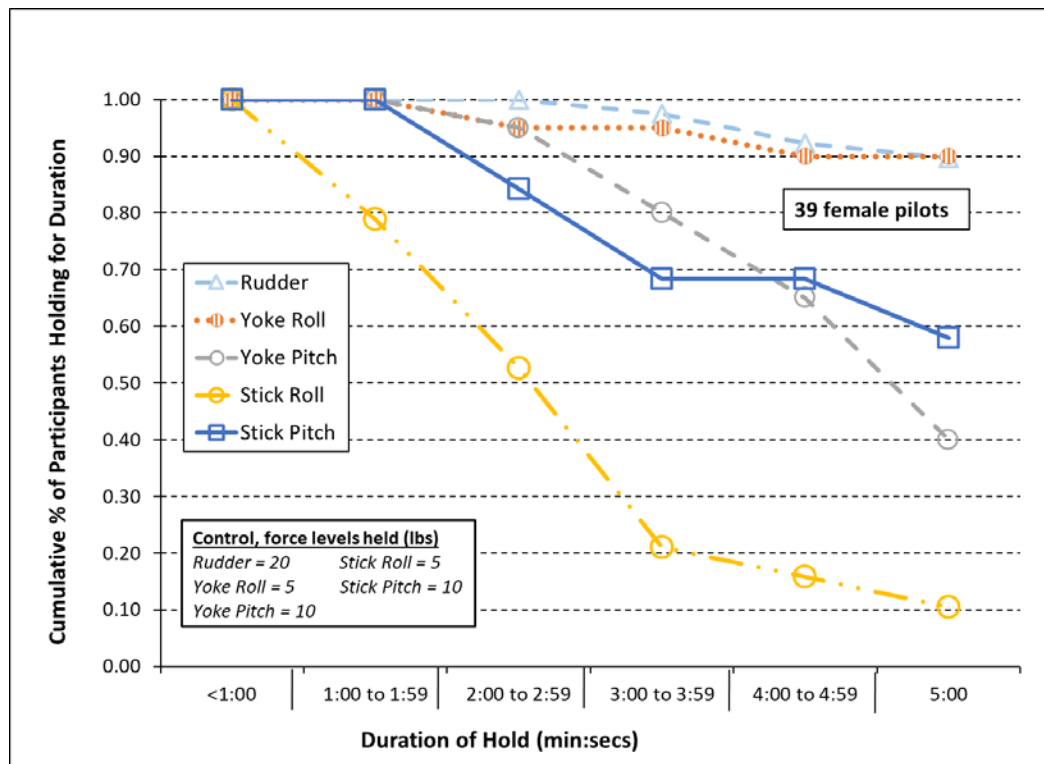


## APPENDIX B: PERCENTILE DISTRIBUTIONS FOR LEVEL-YOKE REFERENCE AND ROTATED-YOKE CONDITIONS

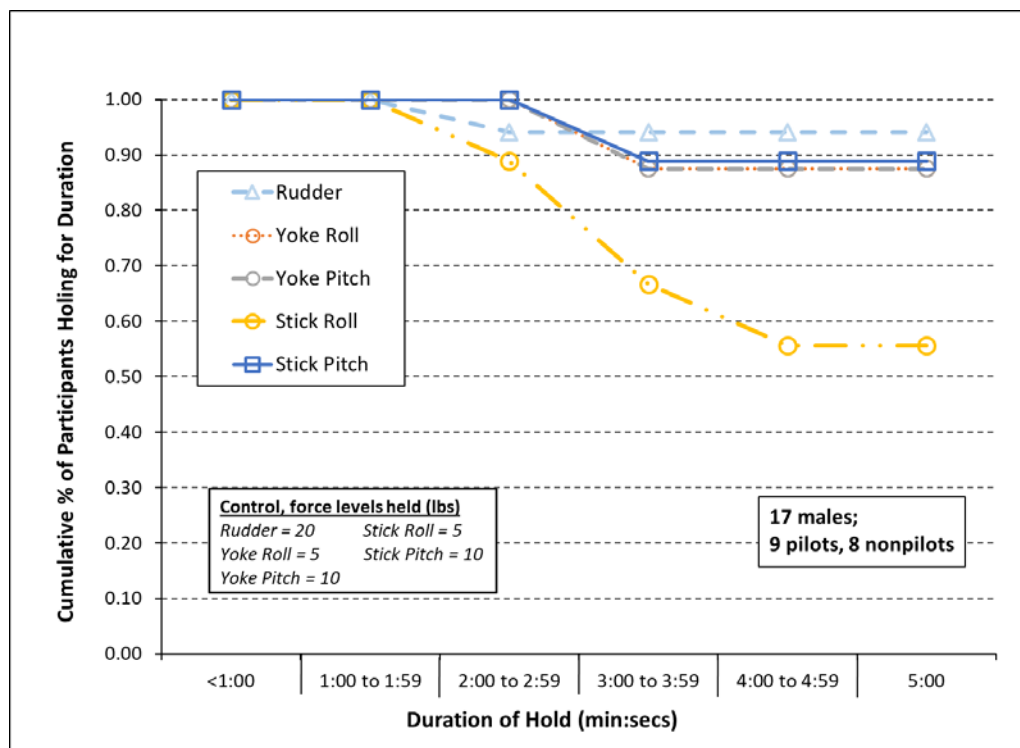


**Figure B1.** Distributions of applied short-term roll force (lbs) for reference (straight) and thirty-six-degree rotated-yoke conditions.

## APPENDIX C: CUMULATIVE FREQUENCY PLOTS FOR LENGTH OF HOLD



**Figure C1.** Cumulative frequency plot for female pilots, hold times, by control type and hold-time category in one-minute intervals.



**Figure C2.** Cumulative frequency plot for males, hold times, by control type and hold-time category in one-minute intervals.