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Comparison of anthropometry of Brazilian and US Military population for flight deck design

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ABSTRACT

A valid anthropometric dataset is essential to optimize the design of personal equipment and aircrafts. Until recently there were no anthropometric data available for the Brazilian Air Force (FAB) pilot population, and hence international military data have often been used in Defense procurement specifications. Currently, the Brazilian Aeronautical Industry is designing military aircraft using legacy U.S. military anthropometric data. Some accommodation problems have been identified among FAB pilots, highlighting the necessity to investigate this possible issue.

The anthropometric data of the six critical body measurements indicative of cockpit design from the U.S military legacy databases were compared one at a time to the FAB corresponding anthropometric data in three ways: *F*-test, *t*-test, and 5th - 95th percentile limits. This study aimed to verify whether the U.S. Military Personnel legacy databases are applicable to the Brazilian pilot population for aircraft cockpit design purpose.

Brazilian pilots were significantly ($p < 0.05$) different in body size when compared to the U.S. military personnel in legacy databases. The dimension that differ the most was Thumbtip Reach, demonstrating a difference in body proportion beyond that illustrated by the difference in body size.

The reported anthropometric analyses can be used as relevant consideration in product, workplaces, and system design. The U.S. legacy databases were considered inappropriate for ergonomic cockpit design for the Brazilian Air Force pilots.

Relevance to industry: When designing complex workplaces, systems, and personal protective devices, designers and ergonomists should use anthropometric data from a sample population that represents the body size variation expected in the target population. The anthropometric comparisons presented in this study are useful to design an ergonomic flight deck layout for both genders.

1. Introduction

Up-to-date anthropometric data play a key role in design of environments and equipment used by people. The importance of anthropometric data for product efficacy and safety has been recognized by various industries worldwide (Guan et al., 2012; Hsiao, 2013; Lars et al., 2009; Nadadur and Parkinson, 2013; Parkinson and Garneau, 2016; Sadeghi et al., 2015).

Anthropometric data of pilots have been used for cockpit design purposes mainly in the military field, since it can improve the pilots comfort as well as the mission fulfillment (Lee et al., 2013). Nevertheless, the bulk of military aircraft in use worldwide are built around the anthropometry of western aviators, predominantly from the United States. Most developing countries buy these aircraft off the shelf, and then go about trying to fit their aviators into a machine not designed for their users (Singh et al., 1995).

The ergonomic design process requires that we know the body dimensions relevant to the function of the equipment as well as whom it should fit (Sadeghi et al., 2015). However, these body dimensions are only helpful if they are taken from a sample population that represents the body size variation expected in the target population (HFES 300 Committee, 2004; Parkinson and Garneau, 2016). Thus, when designing for a specific population, we need to verify that anthropometric data from one group apply to another

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(Coleman and Blanchonette, 2011). In this sense, Marklin et al. (2010) reinforced the importance of developing anthropometric reference database for specific work groups.

Currently, the Brazilian Air Force (in Portuguese, **F**orça **A**érea **B**rasileira - FAB) is designing its military aircraft using some historical U.S. Male and Female Anthropometric Databases (USAF Male 1950, USAF Male 1967, US ARMY 1988, USAF Female 1968), which in this study will be referred to as the U.S. military legacy databases. The FAB has used statistics from the aforementioned military databases compiled in the Military Handbook of Anthropometry of US Military Personnel – MIL-HDBK-743A (Department of Defense, 1991) and used the percentile approach to estimate the cockpit accommodation dimensions. Although, this usage is based upon the presumption that U.S. and Brazilian military populations are anthropometrically similar, a dangerous presumption given the lack of evidence to support it and the known consequences resulting from poor ergonomic fit (Coleman and Blanchonette, 2011; Kennedy, 1982; Lee et al., 2013; Singh et al., 1995). Thus, using the U.S. data may be an inadequate approach for determining accommodation requirements for a population of Brazilian pilots.

Several studies corroborate this rationale, Lee et al. (2013) report that the anthropometric differences found between Korean helicopter pilots and US ARMY personnel justify the necessity to use specific Korean anthropometric data to develop an optimal and customized design for helicopter cockpit. Ziolek and Wawrow (2004) verified that a North American population database was not applicable to an Asian American population. In fact, several studies show that using regional databases in other non-related regions will generally cause problems (Marklin et al., 2010; Singh et al., 1995; Ziolek and Wawrow, 2004). Since each population consists of a unique mix of users, simply using information from an available database rather than obtaining the relevant information from the intended user population will probably result in suboptimal ergonomic design. Additionally, existing surveys may be lacking data on certain body measures that are critical to the design task (Nadadur and Parkinson, 2013). However, if to get anthropometric data from the target population is not feasible it is possible to minimize the poor ergonomic effects by using a statistical validity to get the appropriate proportions of user groups in a combined sample.

Two possible explanations for problems with physical accommodation cited by Parkinson and Garneau (2016) are the use of inappropriate data (e.g. anthropometric data from a population other than the target one) or the use of outdated sources of anthropometric data.

The lack of accurate and specific anthropometric data for Brazilian military populations has been causing aircrew accommodation problems in the FAB, leading to the conclusion that the body size and body proportions of U.S. legacy databases and Brazilian military personnel are indeed different (da Silva, 2013). Despite being designed and manufactured with an accommodation envelope of 3rd/97th percentile using Anthropometry of USAF Flying Personnel, 1950 – WADC TR 52–321 (Hertzberg et al., 1954), it has been observed that the T-27 Tucano's cockpit does not adequately fit Brazilian pilots at the same anthropometric range for which it was designed (da Silva, 2013). The most commonly observed accommodation problems in the FAB for large pilots are a lack of overhead clearance to the canopy and inadequate clearance for legs in case of ejection. For small pilots, problems include a reduced external visual field and the inability to reach and execute some critical commands including inflight engine relight, fuel pumps, and radios – using arms and full rudder and brakes – using legs. One of the most critical problems detected due to lack of arm reach was the incapacity to actuate the elevator trim override switch (da Silva, 2013). It was estimated by da Silva (2010) that about 20% of the current military male pilot population do not fit into the cockpit of the current FAB trainer aircraft (T-27 Tucano). This issue has forced the FAB to select trainee pilot candidates by size, and consequently, a large number of candidates have been excluded based upon the Tucano's anthropometric limitations – estimated an exclusion rate of about 30% for males and 85% of the female candidates, when considering the Brazilian general population (da Silva, 2010). Since at that time there was no up-to-date anthropometric database from Brazilian population, the estimated exclusion rate for both males and female candidates was calculated by using the Brazilian population height and weight range distribution from the 2010 National Demographic Census database (IBGE, 2010; da Silva, 2010).

This problem of poor accommodation has been exacerbated since 2004 by the inclusion of female trainees and pilots in the Brazilian Air Force Academy (AFA). Because the presence of female pilots is a relatively recent phenomenon in military history, starting in the 70's and only in 1993 they were allowed to fly combat aircraft, the majority of military aircraft worldwide have been designed on the basis of male anthropometric data. Since females are, in general, shorter and lighter than males, the use of only male data for designing and constructing cockpits has made it difficult for the female population to operate most aircraft. Thus, as can be seen in Brazilian Air Force, they face higher exclusion rates (about 85%) in the selection process due to their anthropometric dimensions (da Silva, 2010).

Designing aircraft cockpits to accommodate the wide range of body sizes and shapes existing in the U.S. population has always been a difficult problem for crew station engineers (Zehner, 2001). The difficulty can be explained by the physical attributes of the target population (great variability in body size and in proportions is observed), as well as by the multiple dimension domains that must be taken into consideration in the design of an aircraft cockpit. Zehner et al. (1993) stated that the critical dimensions which determine cockpit accommodation and that must be considered simultaneously are: sitting height; eye height, sitting; thumbtip reach; acromion height, sitting; buttock-knee length; and knee height, sitting; which is corroborated by others researches (Blanchonette, 2013; Department of Defense, 2008; Hudson and Zehner, 1998; Kennedy and Zehner, 1995; Zehner, 1996).

Some authors (Blanchonette, 2013; Coleman and Blanchonette, 2011; Lee et al., 2013; Singh et al., 1995; Zehner, 1996) suggest that a customized anthropometric survey and an in-depth analysis of collected data are needed to develop an ergonomic cockpit design that properly accommodates a designated user population.

The objective of this study was to compare the anthropometric data recently collected on the Brazilian Air Force with corresponding anthropometric data reported in anthropometric surveys of the U.S. military (legacy databases). It is important to point out that the U.S. military legacy databases have been selected for comparison because the Brazilian Air Force and the Brazilian Aeronautical Industry are currently using such databases for cockpit design purposes.

Comparison between these databases are necessary in order to verify any significant morphological differences or similarities in order to determine whether cockpit design based upon legacy U.S. military anthropometric databases are appropriate for the FAB. The results can then be used for improvement in Brazilian product design both in military and general use.

2. Methods

2.1. Brazilian Air Force data

The lack of current, accurate data describing the body dimensions of FAB aircrew prompted the Brazilian Air Force Command Staff (EMAER) to initiate a large-scale anthropometric survey of FAB aircrew. The survey recruited a total of 2339 FAB aircrew (2133 males and 206 females) aged 16–52 years, representing 70% of the entire FAB pilot population, which was large enough to accurately reflect the variability in this population and truly represent the overall FAB pilot population in size, geographic and age distribution. A total of thirty nine (39) critical anthropometric dimensions (using traditional measures of the body) were taken.

These 39 dimensions (see Table 1) were selected since they relate to cockpit design, protective gear design, and digital human modeling, in accordance with the literature review (Department of Defense, 2008; Hudson and Zehner, 1998; Kennedy and Zehner, 1995; Lovesey, 2006; Zehner, 1996, 2002; Zehner et al., 1993). Definitions used were those published in Natick TR-11/017 – Measurer's Handbook: U.S. Army and Marine Corps Anthropometric Surveys, 2010–2011 (Hotzman et al., 2011).

The anthropometric survey reported here was the first large-scale survey in the entire history of the FAB and creates a starting point from which the FAB may choose to initiate further investigations. Detailed anthropometric data collection methods and the full summary statics have been reported separately in da Silva et al., 2017.

2.2. Comparison databases

The primary objective for this procedure was to verify the validity of using U.S. military legacy statistics data for FAB cockpit design purposes.

Since the FAB target population may be somewhat different in body shape and/or body size from the U.S. military personnel who were part of the legacy databases, the anthropometric characteristics of the Brazilian Air Force pilots were compared to U.S. military legacy databases. These specific military databases were chosen since they have been recently used for designing some of the Brazilian military aircraft such as T-27 “Tucano” (used USAF Male 1950), A-29 “Super Tucano” (used US ARMY 1988), and KC-390 – so far unnamed (used USAF Male 1967 and USAF Female 1968).

It is important to note that considering the U.S. legacy databases, all the anthropometric values used in this study were obtained from the DoD-HDBK 743A (Department of Defense, 1991), since this document is the main source for cockpit design of aircraft used by FAB and the Brazilian Aeronautical Industry.

Before starting the database comparison the dimensions were evaluated first for comparability across studies, based on published dimension descriptions, in order to delineate which body dimensions could, in fact, be fairly compared (see Table 2). The procedures used for assessment of dimension comparability are outlined in Gordon et al. (2013). It is important to note that both dimension descriptions and measurement methods used in FAB anthropometric survey were exactly the same used in US anthropometric surveys for the selected comparable dimensions.

For the purposes of this paper, a subset of six critical measurements indicative of cockpit design was used (see Table 1). Stature

Table 1
Relevant measurements for cockpit design and its applications.

Dimension	Design Relevance/Applications
Abdominal depth, sitting	Sets clearance above the knee height and for stick control envelope of motion
[a]Acromial height, sitting	A reference point for control location, as well as shoulder harness height
Biacromial breadth	A reference point for shoulder harness breadth
Biceps circumference, flexed	Important for designing uniforms and protective equipment
Bideltoid breadth	Sets minimum lateral clearance in workplace (cockpit)
Buttock circumference	A reference point for designing uniforms and protective equipment
[a]Buttock-knee length	Sets clearance of knee height obstructions
Buttock-popliteal length	Important for ejection seat manufacturer for designing seat pan
Calf circumference	A reference point for designing uniforms and protective equipment
Cervicale height	Important for designing uniforms and protective equipment
Chest circumference	Important for designing uniforms and protective equipment
Chest depth	Important for designing uniforms and protective equipment
Elbow rest height	Sets height of keyboard, the arm rest adjustments and other important controls
[a]Eye height, sitting	Sets the lines of sight for displays and windows
Foot breadth, horizontal	Sets minimum size of foot pedals and foot pedals pathway/room
Foot length	Sets minimum size of foot pedals and foot pedals pathway/room
Forearm circumference, flexed	Important for designing uniforms and protective equipment
Forearm-forearm breadth	Sets clearance range of motion envelope and is a reference for designing arm rests
Forearm-hand length	Sets maximum forward reach of controls and elbow ejection clearance
Functional Leg length	Sets minimum clearance of underside the main panel, as well as set the pedal reach
Hand breadth	Sets sizes of handles, handgrips, and aperture sizes
Hand length	Sets range of gloves and handle sizes
Head circumference	A reference point for designing uniforms and protective equipment
Hip breadth, sitting	Sets width of the seat
[a]Knee height, sitting	Sets minimum clearance of underside of equipment, such as the main panel
Overhead fingertip reach, sitting	Sets maximum overhead reach of controls
Palm Length	A reference point for designing uniforms and protective equipment
Popliteal height	For ejection seat estimation of seat height from the floor and height adjustment
Shoulder-elbow length	Sets maximum forward reach of controls and elbow ejection clearance
[a]Sitting height	Sets the minimum seat to roof clearance
Span	Sets the pilots reach and clearance
Stature (Height)	Determine the minimum floor to roof clearance in a stand up workstation
Thigh circumference	Sets the stick clearance range of motion envelope
Thigh clearance	Sets minimum clearance between seat top and underside of equipment
Thigh max circumference, sitting	Sets the stick clearance range of motion envelope
[a]Thumbtip reach	Sets maximum forward reach of controls
Waist circumference (narrower)	A reference point for designing uniforms and protective equipment
Waist circumference (*omphalion*)	A reference point for designing uniforms and protective equipment
Weight	Influences the design of supporting structures and establishes ejection seat's limits

[a] Six critical body dimensions for cockpit design and pilot accommodation – Zehner et al. (1993).

Table 2
Body Dimension Comparability results between FAB 2014 and U.S. legacy databases.

Dimensions	USAF 1950	USAF 1967	US ARMY 1988	USAF 1968 Female
Acromial Height, Sitting*	C	C	C	NA
Buttock-Knee Length*	NC	NC	C	NC
Eye Height, Sitting*	C	C	C	C
Knee Height, Sitting*	C	C	C	NA
Sitting Height*	C	C	C	C
Stature	C	C	C	C
Thumbtip Reach*	PC	PC	C	PC
Weight	**NC	C	C	C

*Critical dimensions for cockpit design. ** Subject determined his own weight on standard military scales.
C = Comparable; NC = Non-comparable; PC = Probably Comparable; NA = Non-acquired.

and weight were added to the six cockpit critical dimensions for general body size comparison.

The selected anthropometric data from the U.S military legacy databases were compared one at a time to the present study in three ways (*F*-test, *t*-test, and 5th - 95th percentile limits). To identify how much of a difference exists between the target population and the U.S. military legacy databases, all comparable measurements were analyzed by *F*-test to compare variances, and paired *t*-test to compare mean values.

Since the formula for the *t*-statistic changes if the variances are not assumed equal, it is a good practice to perform an *F*-test prior to the *t*-test to check for the equality of variances within samples to be compared. Thus, the combination of these both tests increases the quality of the comparison.

For the *F*-Test, the null hypothesis was that these populations have the same variance for each of the body dimensions compared. For the *t*-test, the null hypothesis was that no difference exists between the means of each of the body dimensions compared between the databases. T-tests were conduced on only those comparisons for which samples did not have statistical different variances. Since most design requirements make use of extreme percentiles, rather than the mean, comparisons of the 5th - 95th percentile values were also performed, following the procedure used by Gordon et al. (2013) and Hotzman et al. (2011). The 5th and 95th percentiles were compared to the allowable error found during survey as indicated by Hsiao et al. (2014). If the differences in both 5th or for the 95th percentile values were smaller than or equal to the allowable error, the differences were considered to be of no practical significance. These comparisons also allowed us to evaluate whether the current practice of using historical (1950, 1967, 1968, 1988) U.S. anthropometric data to design the Brazilian aircraft' flight deck is adequate for contemporary Brazilian pilots.

Since the *F* and *t*-test were performed for many dimensions simultaneously it is necessary to follow the Bonferroni correction in order to reduce the probability of rejecting the null hypotheses when it is true (type I error). Therefore, the procedure is to test each individual hypothesis at a statistical significance level of $1/n$ times what it would be if only one hypothesis was tested; the Bonferroni correction would then test each individual hypothesis at a significance level of α/n.

The statistical software used for these analyses included Minitab® (version12, Minitab Inc., State College, PA) and SPSS® (Released, 2010. IBM SPSS Statistics Standard Grad Pack Shinkwrap, version19.0 for Windows. Armonk, NY: IBM Corp.).

3. Results

After used the criteria outlined by Gordon et al. (2013) to check comparability of FAB dimensions to other survey dimensions, some measurements were not comparable (NC), some were probably comparable (PC) and some were not acquired (NA) at the studied surveys. As a result, the following number of measurements was considered comparable to the 39 taken during the FAB Anthropometric Survey: 28 from USAF 1950, 24 from USAF 1967, 18 from USAF 1968 (females), and 36 from U.S. ARMY 1988.

However, since the scope of the present study is cockpit design, it is advisable to focus on those body dimensions known as critical to cockpit design plus stature and weight as biological parameters (see Table 2).

3.1. Variances and mean values

Since many comparisons were being done simultaneously, the Bonferroni correction was applied (significance level of α/n). Considering that 6 dimensions were examined in USAF 1950 database, to obtain an overall significance level of $\alpha = 0.05$, the significance for any individual comparison using the Bonferroni correction is 0.05 divided by the number of dimensions being compared ($0.05/6 = 0.008$). Therefore, the p value used for the USAF 1950 comparison was 0.008. The same Bonferroni correction procedure was done for all other database comparison. Table 3 presents the male *F*-test results for comparison between FAB 14 and U.S. military legacy databases.

Shaded cells representing dimensions from each legacy database for which samples did not present statistically different variances when compared to FAB 2014 database with Bonferroni correction.

Since weight is not normally distributed in mammal populations, a *t*-test was performed only on the other shaded cell dimensions, which are assumed to have equal variances (see results on Table 4).

For those body dimensions with unequal variances, a nonparametric test should be used. However, since the author only had access to the published data instead of the raw data, it was not possible to conduct a non-parametric test. Otherwise, the use of *F*-test previously the *t*-test improves the test validity.

For the male USAF 1950/FAB 2014 comparisons, Table 4 shows that differences in the means of 4 out of the 6 comparable dimensions were not found to be significantly different and only the means of Knee Height, Sitting and Stature were found to be statistically similar with the Bonferroni corrections ($p \le 0.008$). In the comparison between FAB 2014 and a USAF 1967, after the *F* and *t*-test, all dimensions presented mean values that were statistically different. When comparing the FAB 14 database with the U.S. ARMY 88 database, the *t*-test result shows only Acromion Height, Sitting was not statistically significant with the Bonferroni corrections.

For females, F-test and individual t-tests were conducted only between the USAF 1968 database and the FAB 2014 database (see Table 5), since it is the only female database used in Brazil for cockpit design purposes.

Table 3
F-test results comparing male dimensions between databases.

Dimensions	FAB 2014	USAF 1950	USAF 1967	ARMY 1988	FAB 2014/USAF 1950 F-test Results			FAB 2014/USAF 1967 F-test Results			FAB 2014/ARMY 1988 F-test Results		
	SD	SD	SD	SD	Delta	F	p_1	Delta	F	p_2	Delta	F	p_3
Acromion Height, Sitting*	29.8	28.5	28.5	29.6	1.3	1.0918	0.0431	1.2	1.0918	0.0371	0.2	1.0122	0.7888
Buttock-Knee Length*	27.5	NC	NC	29.9	NC	NC	NC	NC	NC	NC	−2.4	1.1796	0.0002
Eye Height, Sitting*	31.1	31.9	32.1	34.2	−0.8	1.0487	0.2141	1.0	1.0639	0.1424	−3.1	1.2054	0.0000
Knee Height, Sitting*	25.0	24.8	24.9	27.9	0.2	1.0170	0.6602	0.1	1.0088	0.8348	−2.9	1.2445	0.0000
Sitting Height*	32.4	32.3	31.8	35.6	0.1	1.0049	0.8998	0.6	1.0368	0.3920	−3.2	1.2088	0.0000
Stature	62.0	61.6	61.9	66.8	0.4	1.0130	0.7361	0.1	1.0032	0.9395	−4.8	1.1608	0.0010
Thumbtip Reach*	40.4	40.3	39.8	39.2	0.1	1.0039	0.9274	0.6	1.0293	0.4932	1.2	1.0611	0.1924
Weight	11.7	NC	9.80	11.1	NC	NC	NC	1.9	1.4412	0.0000	0.6	1.1051	0.0278

*Critical dimensions for cockpit design. Shaded cells assume equal variances with Bonferroni correction ($p_1 < 0.008$; $p_2 < 0.007$; $p_3 < 0.006$). Values in mm and kg. NC = Non-comparable. Delta = absolute difference in Standard Deviation.

Table 4
T-test results comparing male dimensions between databases.

DIMENSIONS	FAB 2014	USAF 1950	USAF 1967	ARMY 1988	FAB 2014/USAF 1950 T-test Results			FAB 2014/USAF 1967 T-test Results			FAB 2014/ARMY 1988 T-test Results		
	Mean	Mean	Mean	Mean	Delta	t	p_1	Delta	t	p_2	Delta	t	p_3
Acromion Height, Sitting*	598.4	590.9	610.5	597.8	7.5	−9.50	0.0000	−12.1	13.95	0.0000	0.6	−0.62	0.2684
Buttock-Knee Length*	605.7	NC	NC	–	NC	NC	NC	NC	NC	NC	–	–	–
Eye Height, Sitting*	802.0	799.6	809.5	–	2.4	−2.88	0.0020	−7.5	8.15	0.0000	–	–	–
Knee Height, Sitting*	552.0	550.4	557.6	–	1.6	−2.34	0.0096	−5.6	7.58	0.0000	–	–	–
Sitting Height*	919.3	913	931.8	–	6.3	−7.27	0.0000	−12.5	13.03	0.0000	–	–	–
Stature	1755	1756	1773	1757	−1	0.24	0.4048	−18.2	9.88	0.0000	−2	–	–
Thumbtip Reach*	779.6	820.5	803.1	800.8	−40.9	37.67	0.0000	−23.5	19.68	0.0000	−21.2	16.57	0.0000
Weight	79.2	74.1	78.7	78.5	5.1	–	–	0.5	–	–	0.7	–	–

*Critical dimensions for cockpit design. Shaded cells indicate no statistical significance with the Bonferroni correction ($p_1 = 0.008$; $p_2 = 0.008$; $p_3 = 0.025$). Values in mm and kg. Cells with dashes indicate that these dimensions presented not equal variance in the *F*-test (Table 1). Delta = absolute difference in means.

Table 5
F-test and *T*-test results comparing female dimensions USAF 1968 and FAB 2014.

DIMENSIONS	FAB 2014	USAF 1968	FAB 2014/USAF 1968 F-test Results			FAB 2014	USAF 1968	FAB 2014/USAF 1968 T-test Results		
	SD	SD	Delta1	F	p_1	Mean	Mean	Delta2	t	p_2
Eye Height, Sitting*	29.1	30.6	−1.5	1.1035	0.4858	751	737	14	−6.46	0.0000
Sitting Height*	31.1	31.7	−0.6	1.0409	0.7762	865.8	856	9.8	−4.26	0.0000
Stature	54.3	60	−5.7	1.2209	0.1548	1642	1621	21	−5.28	0.0000
Thumbtip Reach*	36.2	38.8	−2.6	1.1482	0.3269	709.5	741.3	−31.8	11.83	0.0000
Weight	10.1	7.5	2.6	1.8168	0.0000	62.9	56.9	6	–	–

*Critical dimensions for cockpit design. Shaded cells in the *F*-test assume equal variances with Bonferroni correction ($p_1 < 0.01$; $p_2 < 0.0125$). Values in mm and kg. Delta1 = absolute difference in Standard Deviation and Delta2 = absolute difference in Means. Cells with dashes indicate that weight presented not equal variance in the *F*-test.

The F-test shows that the differences in the variances of 4 out of 5 dimensions are not statistically significant with the Bonferroni correction ($p < 0.01$). Thus a *t*-test was performed for the dimensions in the shaded cells (see results on Table 5).

These 4 dimensions were significantly different in means, showing that the FAB 2014 female population was taller than their 1968 U.S. counterparts, but with shorter arms. A particularly noteworthy statistic was observed for Thumbtip Reach, where the arms of the FAB 14 females were more than 30 mm shorter than the arms of USAF 68 females.

3.2. Extremes 5th –95th percentile

For FAB 2014/USAF 1950 comparison, Table 6 shows that for the 5th percentile differences, Eye Height, Sitting; Knee Height, Sitting and Stature were below their respective allowable observer error. For the 95th percentile differences, Acromion Height, Sitting; Eye Height, Sitting; and Sitting Height presented no significant difference (see Table 7). Thus, only Eye Height, Sitting was simultaneously not different for both the 5th and 95th percentiles. In general, the FAB 14 population was shown to be larger for the lower

Table 6
5th percentile comparison male and females dimensions between databases.

DIMENSIONS	FAB Male 2014	FAB Female 2014	USAF 1950	USAF 1967	ARMY 1988	USAF Female 1968	FAB 2014/ USAF 1950	FAB 2014/ USAF 1967	FAB 2014/ ARMY 1988	FAB 2014/ USAF 1968
	5th %ile	5th %ile	5th %ile	5th %ile	5th %ile		Delta	Delta	Delta	Delta
Acromion Height, Sitting*	550	520	543	565	549	NA	7	−15	1	NA
Buttock-Knee Length*	563	544	NC	NC	569	NC	NC	NC	−6	NC
Eye Height, Sitting*	750	698	747	762	735	687	3	−12	15	11
Knee Height, Sitting*	511	478	510	517	514	NA	1	−6	−3	NA
Sitting Height*	865	813	860	881	855	804	5	−16	10	9
Stature	1651	1547	1654	1672	1647	1524	−3	−21	4	23
Thumbtip Reach*	715	650	755	739	739	677	−40	−24	−24	−27
Weight	62.7	50.4	60.1	63.6	61.6	46.4	2.59	−0.91	1.09	4

*Critical dimensions for cockpit design. Shaded cells indicate no difference or values below the allowable observer error. Values in mm and kg. NC = Non-comparable; NA = Non-acquired.
Delta = absolute difference in 5th Percentile.

Table 7
95th percentile comparison male and females dimensions between databases.

DIMENSIONS	FAB Male 2014	FAB Female 2014	USAF 1950	USAF 1967	ARMY 1988	USAF Female 1968	FAB 2014/ USAF 1950	FAB 2014/ USAF 1967	FAB 2014/ ARMY 1988	FAB 2014/ USAF 1968
	95th %ile	95th %ile	95th %ile	95th %ile	95th %ile	95th %ile	Delta	Delta	Delta	Delta
Acromion Height, Sitting*	649	610	646	659	637	NA	3	−10	12	NA
Buttock-Knee Length*	653	630	NC	NC	644	NC	NC	NC	9	NC
Eye Height, Sitting*	853	801	848	861	852	788	5	−8	1	12.65
Knee Height, Sitting*	594	551	606	599	591	NA	−12	−5	3	NA
Sitting Height*	972	918	972	986	966	909	0	−14	6	8.7
Stature	1857	1729	1867	1877	1857	1721	−10	−20	0	8.1
Thumbtip Reach*	848	770	867	870	888	805	−19	−22	−40	−35.2
Weight	100.2	83.9	98.1	95.6	91.2	70.9	2.1	4.6	9	13.06

*Critical dimensions for cockpit design. Shaded cells indicate no difference or values below the allowable observer error. Values in mm and kg. Delta = absolute difference in 95th Percentile. NC = Non-comparable; NA = Non-acquired.

limit and smaller for the higher limit than the USAF 50 population.

For FAB 2014/USAF 1967 comparison, all cockpit critical dimensions (Tables 6 and 7) presented practical significance at the extremes (5th – 95th percentile). The FAB 2014 population was shown to be smaller and heavier than the USAF 67.

Considering the lower limit (5th percentile), the FAB 2014 population had a relatively long torso (Acromion Height, Sitting, Eye Height, Sitting, Sitting Height) and short limbs (Buttock-Knee Length, Knee Height, Sitting, Thumbtip Reach) when compared to the ARMY 88 database. For the upper limit (95th percentile), the FAB 14 population data showed subjects have a relatively larger torso and legs and shorter arms.

Comparing the female data from the USAF female 68 survey with the current FAB database for 5th – 95th percentile values (Tables 6 and 7), all the selected dimensions presented significantly practical design differences. In both extremes, the FAB 14 population reported longer torsos and shorter arms than the 68 USAF female subjects.

Figs. 1 and 2 graphically summarize male findings from the FAB 2014 and the US legacy databases comparison using box-plots and whisker in order to allow a direct visual differentiation of the means and 5th – 95th percentile extremes as well as the degree of dispersion for each dimension across the selected anthropometric databases. In place of minimum and maximum of all the data the whisker representing the 5th percentile and the 95th percentile.

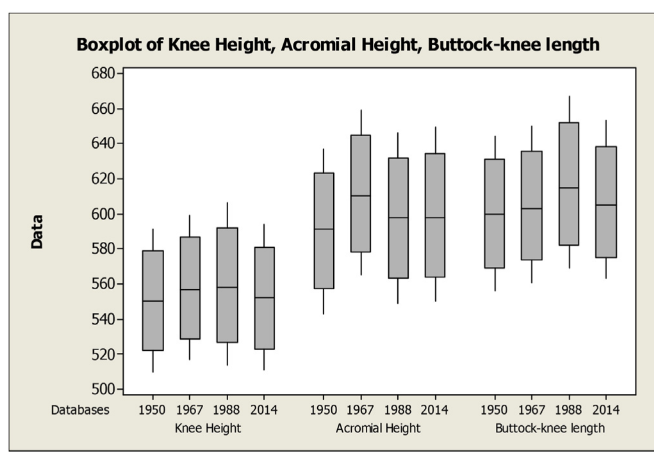

Fig. 1. Means and 5th – 95th percentile extremes comparison across the databases for Knee Height, Acromial Height, and Buttock-knee Length.

4. Discussion

Anthropometric data developed for males and females of military age in the 1950s and 1960s in the U.S. are still in use today and form the only comprehensive body of information available on this subject in Brazil. There has long been a concern about the applicability of the U.S. military legacy data on cockpit design for Brazilian pilots. An aircraft designed for a U.S. military population or using a U.S. military anthropometric database may not provide the same fit characteristics for Brazilian pilots due to differences in body size and shape from those of U.S. population. The operational and safety impacts of T-27 Tucano's cockpit fit problems for both

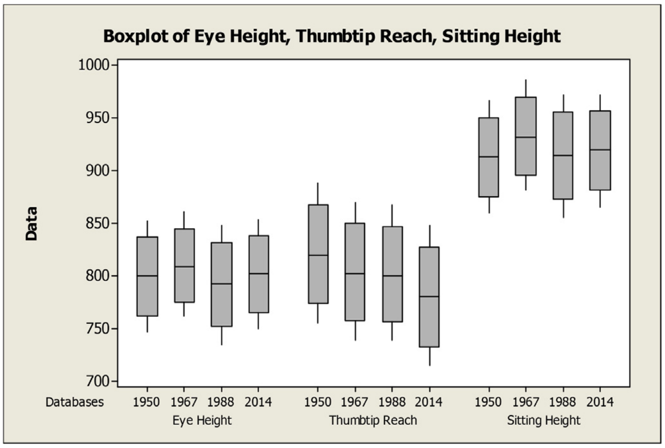

Fig. 2. Means and 5th – 95th percentile extremes comparison across the databases for Eye Height, Thumbtip Reach, and Sitting Height.

large and small pilots (da Silva, 2013) as well as a 20% estimated exclusion rate of Brazilian current military pilots identified by da Silva (2010) raised this issue and made the FAB authorities concern about that.

Having recognized the potential problems inherent in using legacy databases from the U.S. military, the FAB initiated a study to develop an anthropometric database of its current pilots. This specific anthropometric database can now be used to develop a new generation of FAB aircraft in the near future.

In order to elucidate this apparent accommodation problem, the newly created FAB database was compared with U.S. military legacy databases (USAF, 1950, USAF, 1967, ARMY, 1988 for men, and USAF, 1968 for women) and *F*-Tests and *t*-tests revealed that Brazilian pilots were significantly ($p < 0.05$) different in body size when compared to the U.S. military personnel in legacy databases, being Knee Height Sitting from USAF 1950 and Acromion Height Sitting from ARMY 1988 the only two dimensions that can be used for cockpit design purposes for FAB pilots.

The dimension that differ the most between the new database and the U.S. military legacy databases was Thumbtip Reach or Functional Reach, demonstrating a difference in body proportion beyond that illustrated by the difference in body size. The mean arm length of the FAB population was found to be significantly shorter than that described in both USAF 1950 and 1967 databases. However, this result should be interpreted with caution, since the measurement technique used was not quite the same and had been considered “Probably Comparable” by Gordon et al. (2013); and maybe it cannot be really compared. In the same way, similar difference in proportion was also found when comparing to ARMY 1968 database, but in that case the Thumbtip Reach dimension was stated as “Comparable” by Gordon et al. (2013).

These findings considering difference in arm length between FAB 2014 and legacy databases can be associated with T-27 Tucano's accommodation problems, mainly regarding the inability of the Brazilian military pilots to reach and operate some controls in the cockpit, as described by da Silva (2013).

Consequently, the results also confirmed initial suspicions that using U.S. military legacy databases would be inadequate for designing aircraft cockpit or for representing the anthropometric variability of the current FAB pilots.

The mean Sitting Height in the present study was significantly taller than that observed in the USAF 1950 survey, although the Stature was the same, which suggests that Brazilian pilots have longer torsos than USAF 1950. The FAB 2014 population is statistically smaller than the USAF 1967 population in all five dimensions critical to cockpit design compared by means, since Buttock-knee Length was not suitable for comparison in these studies. Overall, these findings suggest that for cockpit design purposes, the dimensions of the FAB male pilots are different from their counterparts in the USAF legacy database. Similar results were found when comparing female database (FAB, 2014 vs. USAF, 1968).

Since the p-value is influenced by the sample size, it was necessary to analyze the *t*-test results with caution. It is known that small sample sizes could not be enough to perform some statistical tests. On the other hand, when sample sizes are larger, it is easier to find significant p-values when they are not really there (i.e., false positives), because significance gets exaggerated. With a large sample, the *t*-test has so much power that even a small difference can be flagged as statistically significant. Therefore, in order to mitigate this point, the statistical interpretation took into account the deltas as well as the entire tendency and also graphic analyses.

The results of the test extremes (5th - 95th percentiles) for databases comparison also reinforced the validity of the *t*-test findings. Similar to findings comparing the mean and variance, the results derived from comparing the extreme percentiles indicated that the previously used databases were inappropriate for cockpit design for the FAB. Such inference was made since the extreme percentile differences were statistically significant based upon a cutoff of a difference equal to or below the allowable observer errors found during the present study.

In general, the extremes test comparison showed that the FAB 2014 population had a relatively long torso and short limbs in both extremes, for both genders. On that account, this study reveals that besides the body size differences there is also a significant difference in body proportions in the FAB 2014 when compared to U.S. legacy databases, corroborating da Silva (2013). Databases USAF 1950 e ARMY 1988 presented just few dimensions that probably can be used for designing cockpit to Brazilian pilots, since no dimensions appeared in the three tested criteria and only Eye Height, Sitting met the 5th/95th percentile range at the USAF 1950 database and only Stature met the same criteria at ARMY 1988 database. In regard to the USAF databases (male 1967 and female 1968) all critical dimensions presented significantly statistical and practical design differences. The higher the heterogeneity between the compared databases indicates the higher the adjustability required for a cockpit layout design in order to fairly accommodate Brazilians and U.S. military pilots, which probably will increase the cost, the size and the weight required for such a cockpit, consequently affecting the aircraft performance.

These results reinforce the need to use specific target population databases for cockpit design purposes, corroborating several studies (Lee et al., 2013; Singh et al., 1995; Coleman and Blanchonette, 2011) and can help the FAB to better interpret why cockpit fit problems are currently occurring and why exist a large exclusion rate during pilots trainees selection due to their anthropometric measurements. This study also bring up the need of the developing countries reflect about the importance of create their own anthropometric database for design purpose.

In addition, this study has numerous implications for the Aerospace Industry and for FAB, in particular concerning the development and/or acquisition of new aircraft, upgrading existing aircraft, and the design and sizing of uniforms and protective equipment worn by aircrew. This study provides critical data to address cockpit design, space arrangement issues and adjustments.

For better comparison regarding contemporary population difference in body size, more recent U.S. data should be used in future studies.

5. Conclusion

Being the first large-scale anthropometric survey in the Brazilian Armed Forces, the data obtained in the 2014 FAB Anthropometric Survey provide more accurate anthropometric information about the FAB pilots. The information provided was essential to determine the limitations of using U.S. military legacy databases for designing workstations for the contemporary FAB pilots.

The database comparison results showed that body dimensions considered critical for designing cockpits presented significantly statistical and practical differences between FAB 2014 and the U.S. legacy databases used in the design of current FAB aircraft for both body size and body proportion. In general, Brazilian pilot population is smaller and heavier (difference in body size) and has long torsos and short upper-limbs (difference in body proportions) when compared to U.S. legacy databases for both genders.

From the results this study we can confirm that to design an ergonomic cockpit the first and most critical step for optimal anthropometric accommodation is defining the population to be accommodated. The second step is to identify the critical dimensions in accommodation process. The third step is to use anthropometric data from the target population.

The identified anthropometric differences need to be reflected in the design of aircraft cockpit layouts, in order to provide proper reach, comfort, and visibility for the pilots of the Brazilian Air Force.

This study highlights the importance of using anthropometric data from a sample population that represents the body size variation expected in the target population, and that the application of anthropometric data from one country/region or time period to another target population can be inappropriate for the design of specific workplaces, systems, and personal protective devices.

The U.S. military legacy databases are not appropriate sources when designing for actual Brazilian pilots. This finding reinforces the necessity of deriving and using specific databases targeted to the intended user population in order to develop optimal, customized designs.

The anthropometric comparison results presented in this study are useful to design an ergonomic flight deck geometry and layout for both genders. Therefore, it is recommended that the FAB database be used in place of the legacy U.S. databases for procurement and design decisions, in order to maximize safety and comfort, and optimize human performance and mission effectiveness.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.ergon.2018.01.016.

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