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AN INVESTIGATION OF SPINAL INJURY POTENTIAL FROM THE USE OF THE ACES II EJECTION SEAT BY LOWER WEIGHT FEMALE PILOTS

THESIS

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AFIT/GSM/LSY/84S-1

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DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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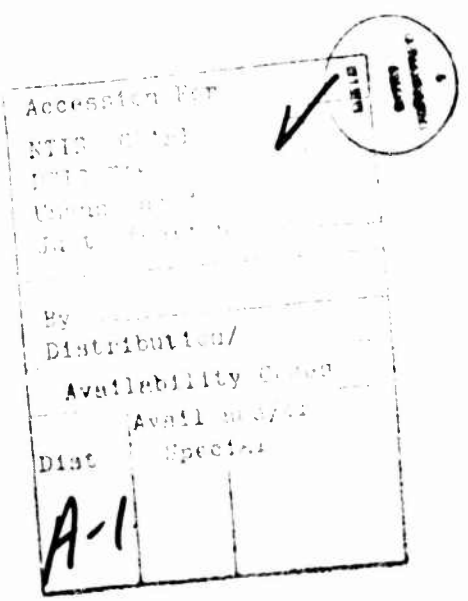

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THESIS

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Systems Management

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AN INVESTIGATION OF SPINAL INJURY POTENTIAL FROM THE USE OF THE ACES II EJECTION SEAT BY LOWER WEIGHT FEMALE PILOTS

I. Introduction

Background

In November 1973, The Chief of Staff, United States Air Force, approved a proposal to establish a test program to train women pilots (22:67). Since the initial test program of ten female pilots began in September 1976, the population of female rated officers has increased substantially. A 1982 report by Bragg et. al. of the Escape Seat Test Track Division at Holloman AFB noted that in 1982 there were over 109 female pilots in Air Training Command alone (11:1).

One of the major assignment restrictions on female rated officers is they cannot be assigned to aircraft that "engage in a combat mission" (22:83). It is in these types of aircraft (i.e., fighter/attack aircraft) that most incidents involving emergency crew ejection occur. Because females do not fly in combat aircraft there has been limited attention rendered to the female flying population regarding injury potential during ejection. However, it is significant to note that all female pilots and navigators must go through Undergraduate Pilot Training (UPT) or Undergraduate Navigator Training (UNT), which involves

flight training in ejection seat equipped aircraft. Additionally, several women are assigned to fly ejection seat equipped test aircraft. It is quite possible that with the increasing number of female pilots the restriction banning women from combat aircraft may sometime be rescinded.

Several studies have addressed the issue of anthropometric differences between male and female flyers; however, none of them have demonstrated significant justification for performing separate ejection seat tests based on female data. In 1977, L.C. Rock of the Aeronautical Systems Division determined that injury potential for female aviators in the T-37 and T-38 ejection seats was minimal (22:47-55). Specifically, the T-37 ejection seat presented the highest probability of injury, which was only 4 percent for a person weighing 98.7 pounds (22:49). It was determined that because this probability was so low it was acceptable for females to fly in ejection seat aircraft with no necessary corrective actions or ejection seat test track data (22:49).

Up to this point, the discussion has centered on why separate ejection tests have not been performed for the female flying population. At the time of the Rock study it made sense not to test, since the population, as well as the probability for injury, were so small. However, as

noted earlier, the female flying population has increased substantially since 1977. Also, on the horizon is a new trainer aircraft (T-46A) which uses an ejection seat which was not previously utilized by female aviators.

In this study, the effects of physical characteristics, such as weight and height, will be examined in order to determine if the potential for injury when using an ejection seat for emergency escape is significant for female aviators. Studies have been performed to determine potential injuries to females with the T-37 and T-38 ejection seats. This study will examine the injury potential for female aviators with regard to the ACES II ejection seat. The ACES II is currently installed in the A-10, F-16, and F-15; has been delivered for use in the B-1B; and is designated for use in the T-46A, which will replace the T-37 aircraft. All female aviators will be required to fly the T-46A aircraft while undergoing initial flying training.

Statement of the Problem

Various experts in the field of emergency crew egress have stated that the potential for injury when using the ACES II Ejection Seat may be different for a certain class of light weight individuals than it is for heavier personnel (5,8,9,12,13,25). The major problem in

confronting this issue is that relatively few aviators who fall into the lower weight classes have been involved in emergency egress situations requiring the use of the ACES II (8,9). Furthermore, the ACES II ejection seat has never been tested for the lower weight class in question (7). This means that the potential for injury to flyers in the lower weight category may be significant, but will go undetected if not tested in some manner.

The fact that there may be an increased population of flyers (e.g., female aviators) in the lower weight class who will be required to use the ACES II as standard safety equipment further compounds this problem.

Objectives

The purpose of this study is to determine the statistical distribution of physical characteristics (i.e., age, weight, height, and sitting height) for the current population of female pilots. Also, the study is designed to determine if lower weight class female aviators are susceptible to higher than normal spinal injury potential if required to use the ACES II ejection seat for emergency egress. In order to accomplish these objectives and establish a guide for this study, three research questions were developed. These questions are presented following the justification for this study.

Justification

In September 1963, Headquarters Air Training Command (ATC) querried the T-46A System Program Office (SPO) as to what the minimum and maximum body weights were that could be safely ejected in the ACES II ejection seat (2:1). The main concern was for personnel in the lighter weight categories. ATC personnel desired an engineering analysis to establish suitable weight limits and also to determine whether ballast (extra compensating weight attached to the seat) is necessary to enhance seat performance for light weight personnel (2:1).

For the T-46A SPO personnel, the questions raised by Headquarters ATC were already being investigated because the ACES II had been qualified for only the 5th through 95th male body weights. The SPO was aware of the possibility that light weight individuals, such as female aviators, may be susceptible to a higher injury potential than heavier personnel when using the ACES II ejection seat (3). This injury rate pertains to those spinal injuries which are associated with the positive G forces experienced during an actual ejection (18:12).

When distinguishing between "lighter" and "heavier" personnel, the category of interest is the 5th percentile nude male body weight, which is 140.2 lbs. Below this

weight, ejection tests are not conducted (17:7). Specifically, Military Standard 9479B states that ejection seats shall be designed to "comfortably accommodate variations in anthropometric dimensions of crewmembers between the 5th and 95th percentile sizes" (18:4). These figures are based on "A Review of Anthropometric Data of German Air Force and United States Air Force Flying Personnel 1967-1968" (22:7).

The 1967-1968 anthropometric survey was completed considering only male flying personnel (there were no female USAF or German Air Force pilots at the time). This survey provided the anthropometric data used in formulating Military Standard 846C and Military Standard 9479B; therefore, no consideration for a female flying population is given when designing USAF aircraft ejection systems.

When the initial female UPT program began, Aerospace Medical Research Laboratories (AMRL) conducted a comparison of male and female anthropometry. They used the 1967-1968 male anthropometry study and compared it to a "1972 Anthropometry of Air Force Women" (22:7). Table I illustrates that with regard to these two studies a 1967 5th percentile male (140.2 lbs) is comparable to a 1972 80th percentile female (140.15 lbs) in terms of weight. This statistic must be viewed with caution with regard to weight differences between male and female aviators because

the female anthropometric survey was conducted on Air Force women when there were no female flyers. The weight distribution among female aviators may differ from United States Air Force women as a whole.

Table I

Male/Female Anthropometry

	1967-68 Data 5th percentile (A)	Comparable Percentile (B)	5th Percentile Female (B)
Stature (Height) inches	65.90	66.07-80th	60.21
Weight pounds	140.20	140.15-80th	102.29
Gluteal Furrow (leg length) inches	29.40	29.41-70th	26.16
Seated Height inches	34.70	34.77-80th	31.66
Hip Breadth Seated inches	13.45	13.50-40th	12.42
Spine to wrist (arm length) inches	33.50	33.51-95th	29.20

Adapted from ASD-TR-77-32 (22:8)

(A) NATO Agrograph-205/AD No. N75-26635, Summary of USAF & German Anthropometric Survey Descriptive Data.
(B) AMRL TR 70-5, Anthropometry of Air Force Women.

The Test Track Division at Holloman AFB established a more representative anthropometric survey of female flyers in 1982. The population consisted of 109 female Air

Training Command instructor and student pilots (11:3). Over 70 percent of the females weighed below 140.2 lbs (11:7).

As previously mentioned, ejection seat testing does not include tests for individuals below the 5th percentile male body weight. The results of the Gragg survey indicate that a majority of female flyers have not been accounted for in ejection systems tests. It is for this reason that the T-46A SPO is interested in probing the matter. Also, it is the opinion of T-46A SPO personnel that the issue could possibly involve more aircraft than just the T-46A.

Research Questions

In order to assist the T-46A SPO in responding to the Headquarters ATC query regarding the use of the ACES II ejection seat by lower weight pilots, the following questions will be addressed in this study:

1) What are the statistical distributions of the characteristics of age, weight, height, and sitting height for the current population of female pilots within the United States Air Force?

2) What percentage of female pilots weigh less than 140.2 pounds, this being a characteristic which places the female pilot in a category where injury potential to the spine has not been investigated?

3) Using an ejection system model, what is the potential for spinal injury to lower weight class female pilots using the ACES II ejection seat?

Literature Review

Crew Escape Systems. A brief literature review is presented to provide background information on the initial problems of crew escape from high speed aircraft, development stages of ejection systems in general, and the operating characteristics of the Advanced Concept Ejection Seat (ACES II).

Initial Problems. Military aircraft became instruments of war during World War I and were greatly improved during World War II. If it was necessary for a crewmember to abandon these early aircraft in flight, the process simply involved opening any barriers to exit (e.g., canopies, hatches, or bomb bay doors) and jumping or falling from the aircraft. This procedure was quite adequate based upon the aircraft types and speeds. However, with the advent of high speed jet aircraft, this procedure was no longer acceptable. Wind tunnel tests proved that at speeds above 250 knots, it was nearly impossible for a crewmember to physically force himself from an aircraft. This was due to the aerodynamic forces which hindered opening exits and inhibited him from exiting

into the airstream (5). A suitable system to forcefully remove or eject the aircrewmember from the aircraft became mandatory.

Ejection Seat Development. Early ejection system designs were based upon a ballistic catapult (charge) which forced the ejection seat up a set of guiderails out of the aircraft. The force applied was very short in duration. The main drawback to these systems was that the force required to clear the tail of the aircraft during high speed ejections exceeded human tolerance levels and resulted in substantial injuries (4:74).

An improvement to the initial designs was the addition of a rocket catapult which ignited as the ejection seat cleared the set of guiderails. The rocket was mounted to aim the seat slightly forward to increase the tail clearance of the ejectee during high speed ejections. The force applied during the ejection was much greater in this design, but because it was spread over a longer duration, it did not exceed human tolerance levels (4:74). This system worked fine for high speed ejections; however, during low altitude and low airspeed ejection situations, a shortcoming surfaced. The slightly forward thrust vector of the rocket induced severe instabilities which resulted in occupant fatalities due to man-seat separation delays (6). Another improvement was needed.

The addition of vernier rockets (a small rocket system which sensed and counteracted rotation) to the seat solved the rotation problem (4:75). These improved ejection systems provided for safe ejections throughout a wider range of ejection conditions (i.e., aircraft speed, altitude, and attitude) at the time the ejection was initiated. The ejection seats had only one mode of operation (the ejection sequence was fixed) and did not react to different ejection conditions. The current generation of aircraft ejection seats, including the ACES II, takes into account initial ejection conditions and modifies its performance accordingly.

ACES II. In order to provide optimum performance throughout the ejection envelope and to enhance aircrew survivability, an ejection seat must be designed for maximum flexibility. The ACES II ejection seat is the current state of the art equipment which meets these criteria and is installed in high performance U. S. Air Force Aircraft (1:1). Developed by Douglas Aircraft Corporation, The ACES II is standard equipment in the F-15A/B, F-16A/B, A-10, and B-1B aircraft (1:1). Weber Corporation under contract with Fairchild-Republic Corporation provides this seat for the T-46A trainer.

The ACES II system was designed to meet the requirements of Military Standard 9479 B (1:1). Therefore,

when testing was conducted, data pertinent to lower weight classes (i.e. below the 5th percentile male - 140.2 pounds) was not used.

Table II

ACES II Advanced Technology Characteristics

1.	Multiple operating modes to optimize performance over the 0 to 600 KEAS escape range.
2.	Self-contained sensing of escape conditions for recovery mode selection.
3.	Electronics for sequencing and precision timing in each mode.
4.	Gyro controlled vernier rocket for posture stabilization at slow speeds.
5.	Hemisflo drogue parachute for stabilization and deceleration at high speeds.
6.	Mortar deployed recovery parachute for consistent, positive operation.
7.	Parachute canopy reefing to optimize recovery performance over full 0 to 600 KEAS range.

Compiled from Report MDCJ-4576B (1:1)

As was previously mentioned the ACES II is designed for optimum performance. It is configured to perform throughout the 0 to 600 knots equivalent airspeed (KEAS) escape envelope (1:1). It is flexible enough to allow for changes in time delays to optimize high speed performance

for aircraft such as the T-46A, whose maximum ejection velocity is less than 600 KEAS (1:1). Table II represents a list of the advanced technology characteristics provided in the ACES II.

The theory behind the operation of the ACES II is that it provides an automatic ejection sequence for the crewmember (23:4-1). This means that once the ejection is initiated by the crewmember pulling the ejection handles, no further action is required on the part of that crewmember to safely complete the ejection up through and including parachute deployment.

Table III

ACES II Event-Time Sequence

Typical Event Timing — time (seconds)

	mode 1	mode 2 (A-10)	mode 2 (F-15) (F-16)	mode 3
1. Rocket catapult fires	0.0	0.0	0.0	0.0
2. Drogue deploys	N/A	.17	.17	.17
3. Stapac ignites	.18	.18	.18	.18
4. Parachute deploys	.20	.97	1.17	*
5. Drogue releases from seat	N/A	1.12	1.32	*
6. Seat releases from crewman	.45	1.22	1.42	*
7. Parachute inflates	1.8	2.6	2.8	*
8. Survival equipment deploys	5.5	6.1	6.3	*

* sequence is interrupted until seat crosses mode 3 boundary, then deploys parachute after .82-second delay (A-10) or 1.0-second delay (F-15/16).

Reprinted from report MDCJ-4576B (1:1)

There are three modes of operation for the ACES II. These modes depend on the aircraft speed and altitude at the time of ejection (23:4-1). Optimal performance is obtained through multiple modes of operation combined with electronic sequencing, and use of recovery and drogue parachutes (1:7). The event and time sequence for the various modes of operation is presented in Table III. Also, Figure 1.1 illustrates a graphical plot of the mode envelopes.

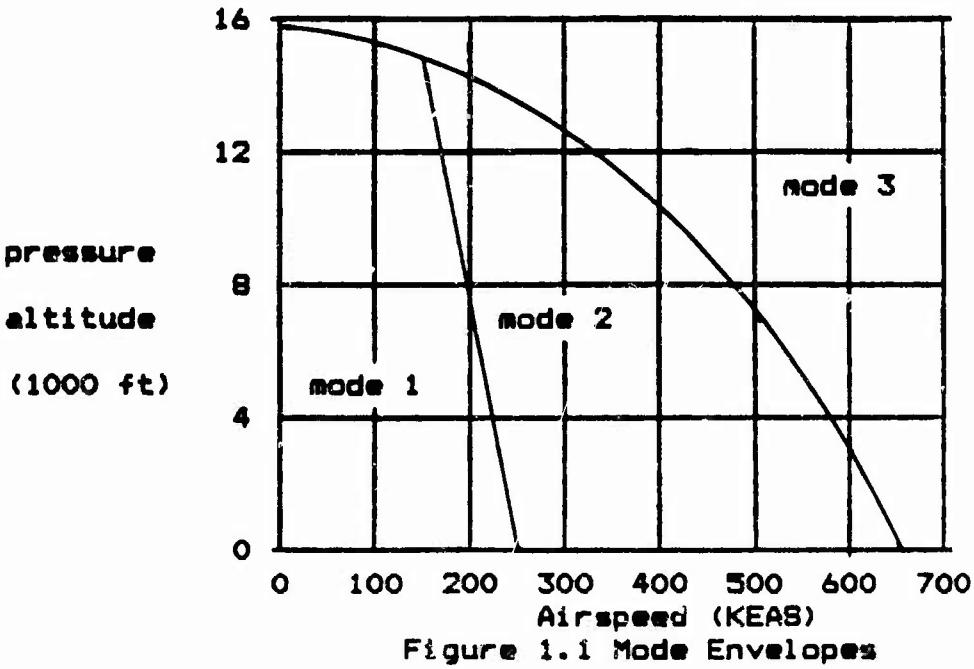

Figure 1.1 Mode Envelopes

Reprinted from report MDCJ-4576B (1:1)

The ACES II has been statically tested at the Douglas Long Beach facility. Also, over 130 complete system tests were performed at government test t acks (1:20). These

tests were conducted in order to meet the 5th through 95th anthropometric design requirements of Military Standard 9479B.

It remains to be seen what the results of complete systems testing will yield for the T-46A aircraft. These tests will begin in August of 1984 and are presently programmed in accordance with current ACES II requirements and therefore will not address the increasing population of flyers below the 1967 5th percentile male. Even if the ACES II is successfully tested according to the current military specifications, it still remains to be seen what the test results would be if lower weight class criteria were included in these tests.

Summary

Since the advent of female aviators in the United States Air Force, there has been a steady increase in the female segment of the flying population. Based on historical anthropometric data, it is evident that women are generally smaller in stature and weight than men (11:6-7).

Because there have been no formal ejection seat safety tests for lower weight class individuals (i.e., below the 5th percentile male)(17:7), the possibility for higher injury to these people has not been fully examined. A

current survey of the female flying population and the use of an ejection system model should provide a determination whether or not female aviators have a higher than normal spinal injury potential if required to use the ACES II ejection system.

II. Methodology and Survey Results

Overview

The first objective of this study was to determine the statistical distributions of female pilot physical characteristics. From this first objective, the percentage of female pilots in the lower weight class for which ACES II ejection seat testing has not been accomplished can be determined. The second objective was to determine the potential for spinal injury during an ACES II ejection for these lower weight class female pilots.

In order to meet these objectives the following methodology was employed:

1. Obtain actual physical characteristic data from the current population of female pilots.

2. Use the actual physical characteristic data to determine what percentage of female pilots are in a weight class for which ejection seat tests are not conducted.

3. Analyze actual ACES II ejection data to determine the percentage of lower weight individuals (i.e., below 140.2 pounds) that sustained spinal injuries during aircraft ejections.

4. Establish a representative sample of inertial and center of gravity properties for the lower weight class females.

5. Simulate actual ACES II ejections using the inertial properties obtained in step 4 as input parameters to the 232ACES2 ejection model.

6. Calculate Dynamic Response Index (DRI) for several simulated ejections using a computer program designed for this purpose.

This chapter describes in detail the methodology employed in meeting the first research objective. By following the first two steps of the overall methodology, guidelines were established in order to answer the research questions associated with the first objective. Also included in this chapter are the results of the survey, which are presented following each subsection of the overall methodology.

Presented in chapter III is the methodology, as well as the results associated with that methodology, employed in meeting the second research objective. The last four steps of the overall methodology are the guidelines for meeting this objective.

Physical Characteristics Data Collection

Physical characteristics data on female pilots includes the individual's age, weight, height, and sitting height. This information was necessary to determine the distribution of these characteristics among the current female pilot population.

To obtain this data, The Air Force Manpower and Personnel Center's (AFMPC) ATLAS data base was queried to identify the current population of female pilots. AFR 36-1 was used to identify Air Force Specialty Codes (AFSC) associated with aircraft and duty positions to which women

can be assigned for flying duty. Combat aircraft (e.g., F-15, B-52) AFSC's were not used since females, by Law, cannot be assigned to combat aircraft. AFR 36-1 was also consulted to identify flight surgeon AFSC's. All applicable AFSC's were used so that there was a point of reference to begin the information search. This inquiry provided a listing of all USAF female pilot's and USAF flight surgeon's names and current duty locations. The information provided by the AFMPC ATLAS included:

1. Names of all women who are currently assigned to the requested AFSC's.
2. Duty locations of these women.
3. Names of all USAF flight surgeons.
4. Duty locations of the flight surgeons.

The ATLAS data contained the names of 261 female pilots assigned to 52 different duty locations. The ATLAS flight surgeon data identified the specific flight surgeon(s) assigned at each of the 52 duty locations. A flight surgeon from each identified duty location was contacted to explain the nature of this study and the reason the physical characteristics data was required to complete this research. A letter (see Appendix A) was then sent to each contacted flight surgeon identifying female pilots assigned to his/her wing. The flight surgeon was

requested to provide the age, weight, height, and sitting height (physical characteristics) of each female pilot which was identified in the letter. In addition, they were requested to provide the same characteristics for female pilots not identified by the ATLAS data base search, but who had recently been assigned to that wing. Each flight surgeon was explicitly requested to return the data in a different order from the list of names provided so that the physical characteristics data could not be associated with a specific person. The identity of the individuals was not required in the research.

Physical Characteristics Data Collection Results

Of the 52 requests for information that were mailed out, 48 were returned. This means that 92 percent of the flight surgeons contacted responded to the request. The information returned contained data on 215 female pilots. The ATLAS search (February 1984) identified 261 female pilots on active duty, a difference of 46 pilots exists. This difference can be represented by the following categories:

```
 1 - Separated from the service.
 1 - Eliminated from UPT.
14 - TDY or PCS, medical records unavailable.
15 - Flight surgeon failed to respond.
15 - Unknown - no explanation provided.
--
46 - Total
```

Based on the given categories, the actual female pilot population was no higher than 259 and may have been as low as 244 effective February 1984. Using the higher of these two figures, the physical characteristics data collected represents 83 percent of all female pilots on active duty.

Appendix B contains a table showing the response from the bases and how we arrived at these percentages. The following section discusses the statistical analysis of the data collected.

Physical Characteristics Data Analysis

Descriptive statistics were used in order to determine the actual distributions of the physical characteristics data. Also, by using this method, the percentage of female pilots in the untested lower weight class (i.e., below 140.2 pounds) was determined. The volume of data obtained was too cumbersome to manually calculate the various statistics. For this reason the Statistical Package for the Social Sciences (SPSS) was applied to analyze the data. SPSS is an integrated system of computer programs designed for the analysis of social science data (19:1).

SPSS allows the user to compute descriptive statistics by using two subprograms entitled CONDESCRIPTIVES and FREQUENCIES (19:181). For the purpose of analyzing the female physical characteristic data the subprogram

FREQUENCIES was used. It enables the user to compute the following descriptive statistics: mean, standard error, median, mode, standard deviation, variance, kurtosis, skewness, range, minimum and maximum values of the data. Also, the FREQUENCIES subprogram is capable of generating histograms on any designated variable (19:200-201).

When analyzing the female physical characteristic data all capabilities of the FREQUENCIES subprogram were not utilized. The following paragraphs briefly discuss the various descriptive statistics that were used to analyze the data. Each characteristic (i.e., age, weight, height, and sitting height) was evaluated on an individual basis.

Evaluation of the data was accomplished in both grouped and ungrouped form. Grouping was used so that individual characteristics could be separated into equal size classes. For example, the weight data was separated into classes such as 100 to 110 lbs, 110 to 120 lbs, 120 to 130 lbs, and so forth. The use of grouping also eased the burden of evaluating a large number of finite data points. It also aided in the development of more precise histograms.

The first statistic used with each variable (i.e., age, weight, height, and sitting height) was the range. The range is calculated by determining the maximum and minimum value of the variables encountered and then

subtracting the minimum from the maximum (19:182).

The arithmetic mean was the second descriptive statistic used. It is a measure of central tendency for the variables of interest (19:183). For ungrouped data the mean is simply the sum of all values for each case divided by the total number of cases (16:184). For grouped data the formula for calculation of the mean is revised as follows:

$$\bar{X} = \frac{\sum_{k=1}^{c} m_k f_k}{n}$$

where: $\bar{X}$ = the grouped mean
c = the number of classes
m = the class mark (middle value of each class k)
f = the frequency of values falling into each class k
n = the total number of cases.

Calculation of the mean for the female's age, height, weight, and sitting height determined the point of central tendency for each of the variables.

Another descriptive statistic which was used to evaluate the data was the median. The median, like the mean, is a common measure of location (16:186). It is the numerical value of the middle case or the case lying exactly on the 50th percentile (19:183). This means that half of the cases lie above the median and half below the

median. Once again, the calculation for the median for the female pilot physical characteristic data was accomplished using both grouped and ungrouped data.

It is important to note that the median may or may not be a unique value, and the median may or may not be one of the actual data values (16:186). For the physical characteristics data the median demonstrated the 50th percentile value for each of the variables (age, weight, height, and sitting height).

Unlike the mean and medium, the next two descriptive statistics that were utilized are measures of dispersion rather than location. The first one used in analyzing the data was the variance. This statistic measures the dispersion of the data about the mean of the variable. It is one way of measuring how closely the individual values of the variable cluster around the mean (19:184). By using the variance, the measure of dispersion for ages, weights, heights, and sitting heights about their respective grouped means for the female pilot population was determined.

The second measure of dispersion and the last of the descriptive statistics used in analyzing the female pilot physical characteristic data was the standard deviation. It is simply the square root of the variance. The reason it was used here and in general is to provide a more intuitive interpretation of the data in relation to the

mean (19:183). The basis for this intuitive interpretation is the fact that the standard deviation is expressed in the same units as the original values of the variables.

Before concluding this section of the methodology it is necessary to briefly discuss one more descriptive method which aided in analyzing the female pilot physical characteristics data. This method was the use of histograms.

Construction of the histograms was based on the grouped data. The relative frequency for each class was then plotted as a bar extending upward (vertically) from the horizontal axis of the graph. The horizontal axis (x-axis) is the plot of the data values which are separated by class size. The vertical axis (y-axis) is a plot of the frequency. Unlike the previously discussed measures of location and dispersion, the histogram provides a visual display of the range of the data, the central tendency, and the character of dispersion throughout the range of values (16:201).

For the female pilot physical characteristic data, each of the individual characteristics (i.e., age, weight, height, and sitting height) were plotted using histograms. In this way, visual presentations of the data were provided to reinforce the previously measured descriptive statistics.

By using the methodology described in this section, an adequate answer to the first two research questions was obtained and the first objective of this research met. First, by using descriptive statistics the statistical distributions of the physical characteristics for the current population of female pilots in the United States Air Force was determined. This will enable interested users of this type of data to further examine anthropometric differences that exist among female pilots.

Secondly, from analysis of the data, the percentage of female pilots who weigh less than 140.2 lbs was identified. Recall that below 140.2 lbs is the weight class for which ejection seat testing is not conducted and therefore spinal injury potential is not known. The number of female pilots who fly United States Air Force Aircraft and whose physical characteristics have caused them to be excluded from ejection seat testing have been identified. Results of this data analysis follow in the next section. A detailed analysis and comparison of these results with regard to other anthropometric surveys is discussed in Chapter IV.

Physical Characteristics Data Analysis Results

The results from the SPSS computer runs are presented in order of ungrouped statistics followed by the grouped statistics. Also, each of the physical characteristics are

presented in order of age, weight, height, and sitting height.

Table IV represents the statistics associated with female characteristics data obtained in the current survey. The statistics presented are those obtained from the ungrouped data.

Table IV

Physical Characteristics Statistics

STATISTIC	AGE (years)	WEIGHT (pounds)	HEIGHT (inches)	SITTING HEIGHT (inches)
range	14	95	11	8.75
- maximum	35	198	73	38.75
- minimum	21	103	62	30.00
Mean	25.433	133.271	66.579	35.233
Median	24.737	131.938	66.086	35.043
Variance	8.265	216.824	3.934	1.116
Standard Deviation	2.875	14.725	1.983	1.056

The FREQUENCIES subprogram calculated the absolute, relative, and cumulative frequency distribution for each of the physical characteristics. The appropriate computer printouts pertaining to these frequency distributions are contained in appendix F.

For the ungrouped data the frequency distributions were used as a basis for developing graphical depictions of the physical characteristics cummulative distributions. The following figures, Figures 2.1 thru 2.4, are the graphical representations of the distributions for age, weight, height, and sitting height respectively.

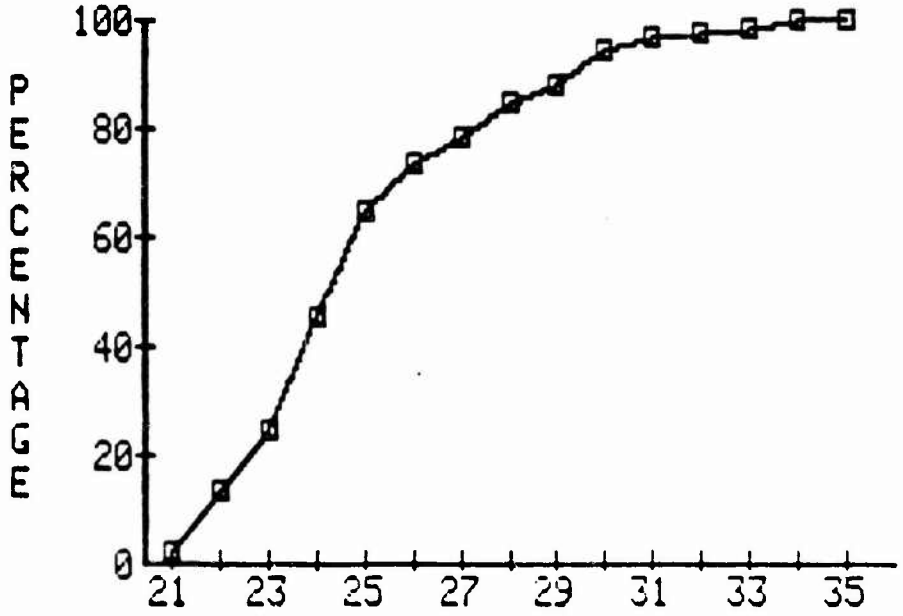

FIGURE 2.1
FEMALE PILOT AGE
DISTRIBUTION (CUMULATIVE)

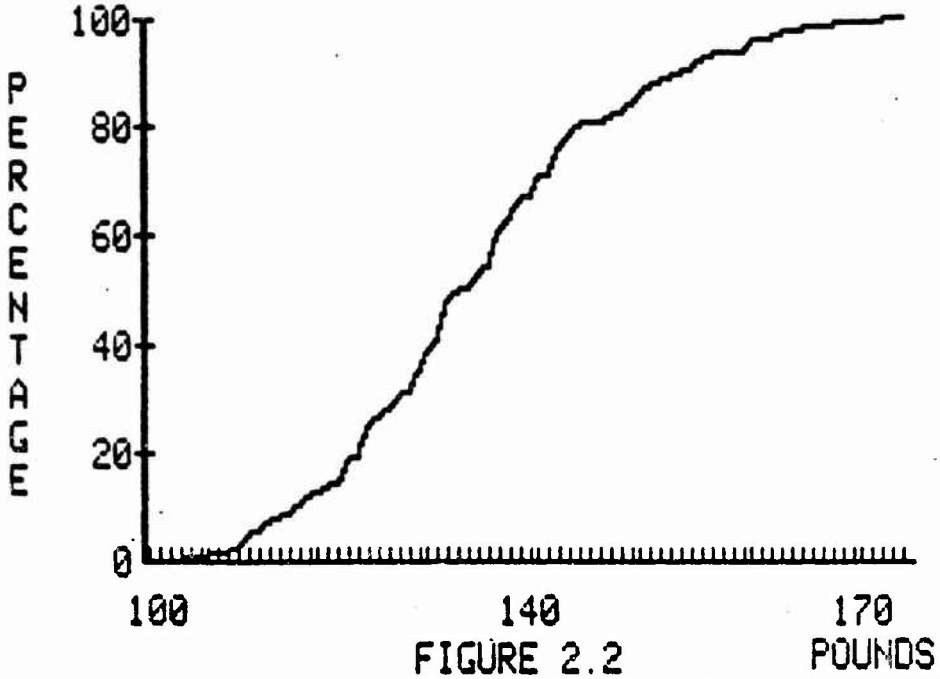

FIGURE 2.2
FEMALE PILOT WEIGHT
DISTRIBUTION (CUMULATIVE)

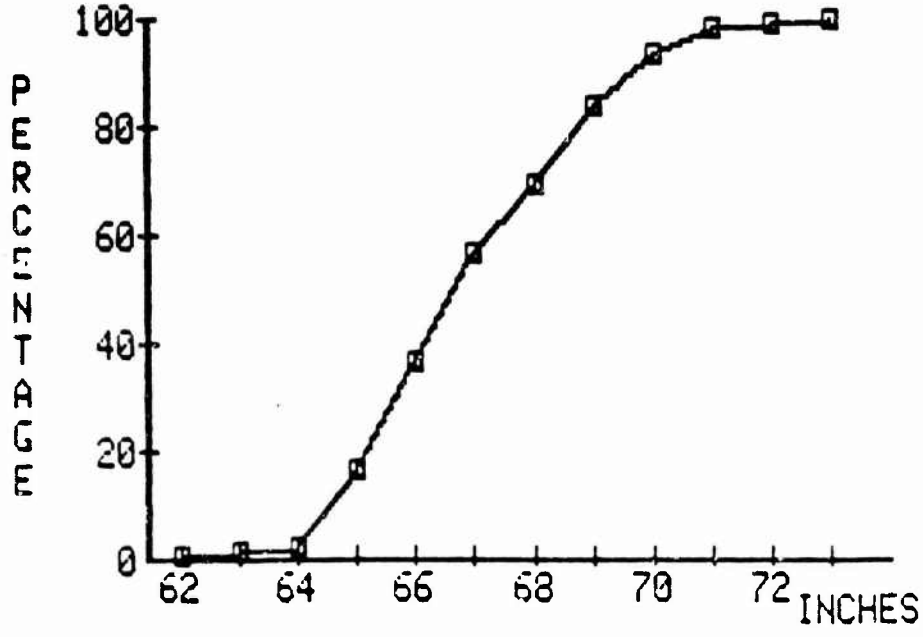

FIGURE 2.3
FEMALE PILOT HEIGHT
DISTRIBUTION (CUMULATIVE)

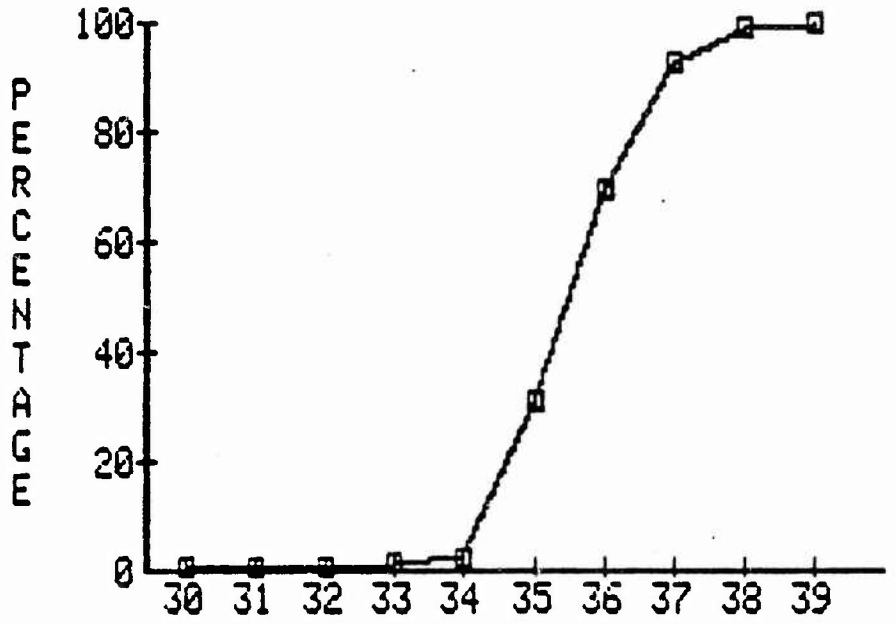

FIGURE 2.4
FEMALE PILOT SITTING HEIGHT
DISTRIBUTION (CUMULATIVE)

These cumulative distributions are a means of identifying a measurement (e.g., 145 lbs) with a specific percentile (e.g., 80.5) of the female population. Using these graphs along with the raw data from the computer printout, a precise answer to the second research question was obtained.

The second research question in abbreviated form is: "What percentage of female pilots weigh less than 140.2 pounds?" The answer to this question, based upon the previously discussed results, is 73.3 percent of the 215 females pilots surveyed weigh less than 140.2 pounds. This

means that approximately 190 pilots of the current female pilot population are in a category (i.e., below the fifth percentile male weight) where ejection seat tests are not conducted.

Along with the cumulative distributions depicted, another representation of the physical characteristics data, histograms of the grouped data, is provided to better answer the first research question. Figures 2.5 thru 2.8 are the tabular, as well as graphical, depictions of the grouped physical characteristics data distributions.

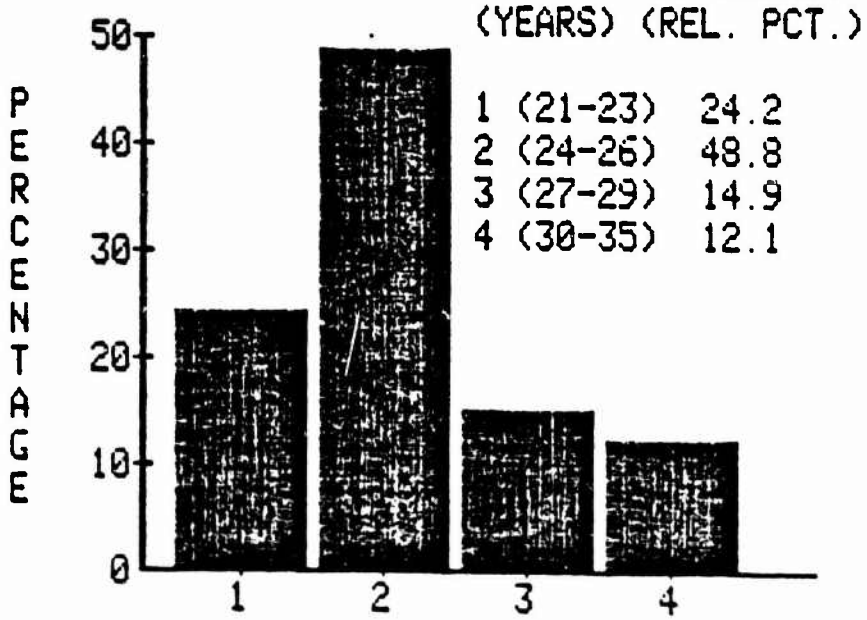

FIGURE 2.5
FEMALE PILOT
AGE DISTRIBUTION

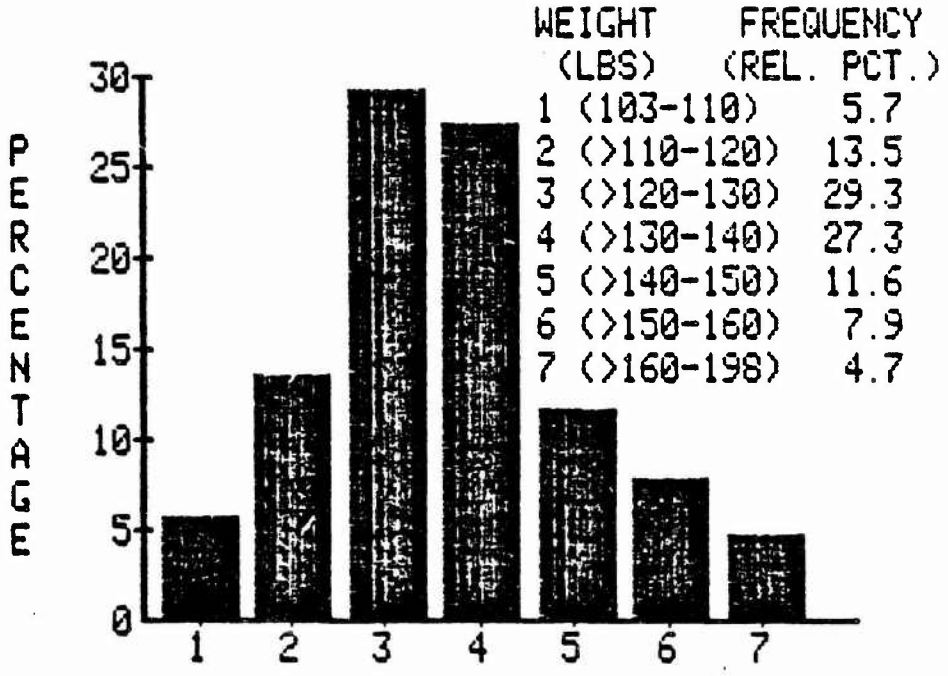

FIGURE 2.6
FEMALE PILOT
WEIGHT DISTRIBUTION

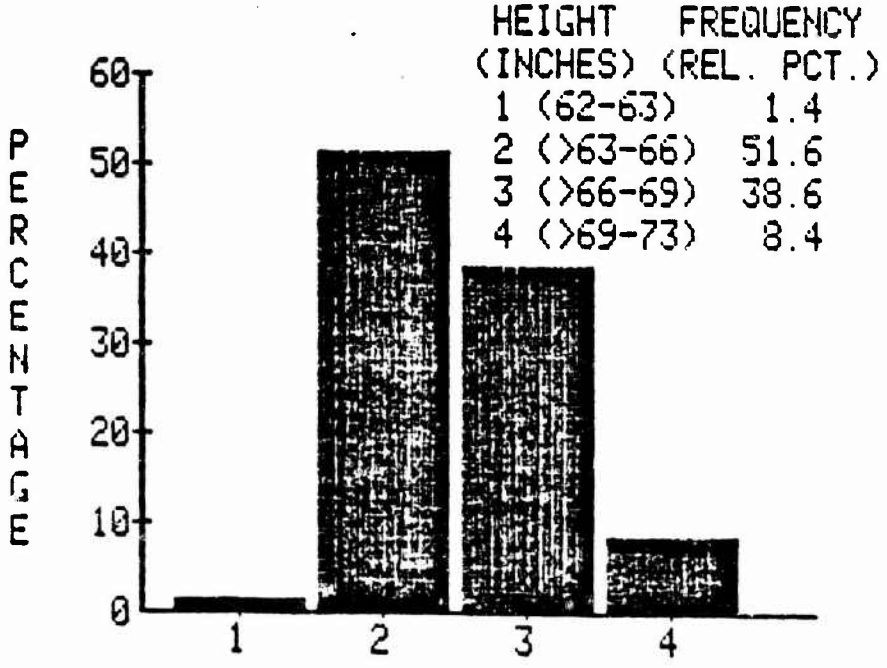

FIGURE 2.7
FEMALE PILOT
HEIGHT DISTRIBUTION

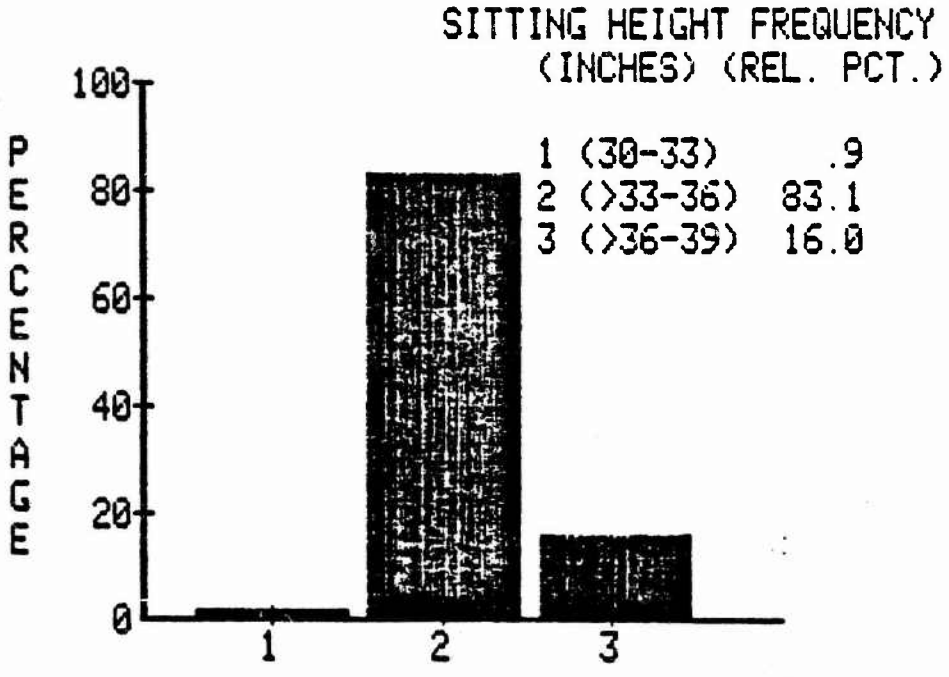

FIGURE 2.8
FEMALE PILOT SITTING
HEIGHT DISTRIBUTION

Summary

The results of the statistical analysis of the female pilot physical characteristics data provided the answers to the first two research questions. In Chapter IV, an analysis of these statistics is discussed with regard to identification of the fifth, fiftieth, and ninety-fifth percentile female categories, comparison with the Gragg Study, and finally a comparison of these statistics with

the associated male pilot statistics (i.e., A Review of Anthropometric Data of German Air Force and United States Air Force Personnel 1967-1968 (22:6)).

The next chapter focuses on the second research objective. As such, the discussion in that chapter pertains to steps three through six in the methodology and the results associated with that objective.

III. Spinal Injury Investigation Results

Overview

Presented in this chapter is a detailed discussion of the various methods used in meeting the second research objective. As was previously mentioned, this objective was to assess the spinal injury potential for lower weight female pilots required to use the ACES II ejection seat. Only one research question, which essentially asks what the spinal injury potential is, was used to meet this objective.

Similar in format to chapter II, this chapter addresses the last four steps of the overall research methodolcgy along with the specific results. Analysis and discussion pertaining to those results, and the answer to the third research question are reserved for chapter IV.

The major impetus in this chapter revolves around the use of an ejection system model which incorporates a subprogram designed to assess spinal injury potential. All aspects of the methodology, except the examination of actual ACES II ejection data, are related to the use of this ejection system model.

Presented, once again, are steps three through six of the overall methodology.

3. Analyze actual ACES II ejection data to determine what percentage of lower weight individuals (i.e.,

below 140 pounds) that sustained spinal injuries during aircraft ejections.

4. Establish a representative sample of inertial and center of gravity properties for the lower weight class females.

5. Simulate actual ACES II ejections using the inertial properties obtained in step 4 as input parameters to the 232ACES2 ejection model.

6. Calculate Dynamic Response Index (DRI) for several simulated ejections using a computer program designed for this purpose.

These steps provide a guide to answer the last research question and thus meet the second research objective.

Actual Ejection Data

An analysis of ejection statistics was accomplished with respect to the A-10, F-15, and F-16 aircraft. These USAF aircraft are the only aircraft in the current inventory that utilize the ACES II ejection system for emergency aircrew escape. The Norton Safety Center Ejection Seat/Egress Manager provided data on more than 40 emergency ejections involving the identified aircraft (9). The major area of concern in analyzing this data was whether or not there were a significant number of instances in the data that demonstrated an increased spinal injury rate as weight decreased. In other words, did light weight individuals experience spinal injuries at a greater rate than heavier individuals when actually using the ACES II ejection seat? Prior to discussing the actual analysis of

the data, a list of significant definitions describing the types of injuries sustained is provided for familiarization.

Definitions. The following definitions are used to insure a common understanding of the injury severities and injury types during the analysis. The injury types are broken into two areas: first, the injury types caused by factors other than ejection forces; and second, the injuries caused by ejection forces. Many of these definitions are the same as defined in a technical report written by Walker and Mehaffie (24:xi,xii). These definitions are important because they constitute the coding conventions used by the Norton Flight Safety Center.

1. Injury Severities (In Order of Increasing Severity).

a. None - No injuries were sustained by the ejectee.

b. Minimal - Injuries sustained by the ejectee resulted in a week or less before being physically qualified to return to flight duty.

c. Minor - Injuries sustained by the ejectee resulted in more than a week before the person was physically qualified to return to flight duty (note: physical qualification to return to flight status expected within a reasonable period).

d. Major - Injuries sustained by the ejectee resulted in a doubtful or extended period before the person was physically qualified to return to flight status.

e. Fatal - ejectee did not survive the ejection or died from injuries related to the ejection.

2. Injury Due to Factors Other Than Ejection Forces.

a. Contact injuries - injuries resulting from ejectee contacting a structure or object. These injuries are listed in the time sequence of most likely occurrence beginning from the initiation of the ejection sequence. The injuries result from: cockpit contact, canopy contact, external aircraft structure contact, contact with debris from wreckage, contact with seat after seat separation, and contact with survival gear (seat kit).

b. Environmental factor injuries - injuries resulting from environmental factors. These injuries result from windblast (force of airstream acting on ejectee prior to seat separation), air deceleration (deceleration of the ejectee relative to the air mass after seat separation), and descent exposure (e. g., frostbite due to extreme cold temperatures at high altitudes).

c. Parachute injuries - injuries involving the parachute system. These injuries are due to parachute opening shock, and ejectee entanglement in the parachute shroud lines.

d. Ground impact - injuries resulting from landings. These injures included unchecked fall either from a malfunctioning parachute or due to ejection too close to the ground without enough time for parachute deployment.

e. Miscellaneous injuries - injuries due to other factors. Injuries in this category would include ejection rocket burns where one aircraft occupant ejects and the second aircraft occupant is burned by the first's ejection seat rocket blast.

3. Injury due to ejection forces.

a. Injuries due to excessive force - injuries related to force applied by the ballistic

catapult or the rocket catapult. These injuries generally result in major to fatal injuries. The injuries are categorized as spinal compression injuries.

After reviewing these definitions it is quite evident that there is a large number of recorded injury types and injury severities. Of interest to this study are the ejection force related injuries (i.e., injury due to ejection force).

Ejection Data Analysis. The analysis of the ejection data first required an investigation of all the cases to identify those which resulted in spinal injury to the ejectee. The next portion of the analysis required that the physical characteristics of the ejectee who sustained the spinal injury be recorded. In this manner, it was possible to note whether or not there were any trends with respect to the physical characteristics of those sustaining spinal injury (i.e., a trend could be identified if the spinal injury rate increased as the ejectees' weight decreased).

To identify those individuals who sustained spinal compression injuries during aircraft ejections, the time sequence of sustaining injuries and ultimate survival of the individual is important. The injuries resulting in spinal compressions occur within the first .2 seconds after the ejection sequence has been initiated. Therefore, in

the many possible instances where ejection force is listed as one of several causes of injury, it is most probable, because of the time sequence involved, that the spinal compression injury was the first to occur. Other injuries most likely could not have caused the spinal injury; however, spinal injuries may have complicated other types of injuries. For the purposes of this study, a listing of ejection force related injury in the Norton Safety Center data will be categorized as an ejection resulting in spinal compression injuries.

The ultimate survival of the ejectee was another factor which was treated carefully. It is possible that death could have been caused by a spinal compression injury which left the occupant physically incapable of survival. Because of the difficulty of determining spinal compression injuries, especially during an autopsy, those ejection cases resulting in fatalities were not considered in determining whether or not the ejectee suffered a spinal compression injury.

In recording the physical characteristics of the ejectees, care was taken to ensure that the data on a specific accident was kept together. In addition, a check on the physical characteristics was made. During this check, any obvious unusual entries such as an 8 foot tall

or a 450 pound individual were the basis for eliminating a specific case from the data base.

As was previously mentioned, the goal of this analysis was to determine if there are any trends relating the physical characteristic of weight with the possibility of sustaining spinal injuries during an ejection emergency.

The information derived from this analysis must be viewed from the standpoint that each of these ejections involved only male pilots. Billiam, Gragg, and Adam completed a study considering a proposed change to the A/T 37 aircraft ejection seat. The test dummies included as the low-end of the investigation a fifth percentile male anthropometric dummy. Their conclusion was that the proposed modification was unsafe and they stated, "Since a 5th percentile male is heavier than a 70th percentile female, the female population would fare even worse" (10:22). The information in the last section, although it may provide trend information, is concerned only with the male flying population.

Following the discussion of the results, the 232ACES2 ejection model is described and also the methodology employed in collecting inertial and center of gravity properties on female subjects is presented. This is the first time that this type of data on female personnel has been incorporated in an ejection system model (6).

Actual Ejection Data Results

Mr. Rudy Delgado from Headquarters Air Force Inspection and Safety Center provided the requested information on actual aircraft ejections in which the ejectee used the ACES II ejection seat. This information covered every ACES II ejection from early in 1978 through February 1984. As was previously mentioned, the aircraft involved were the A-10, F-15, and F-16. Since these are designated as combat aircraft, it is not surprizing that every pilot that has ejected utilizing the ACES II was a male.

In addition to the above information, Mr. Delgado also provided a summary of mishaps involving female aircrews. This information contained ejection as well as non-ejection type mishaps from 1980 through February 1984.

In examining the data, the major concern was to determine if there were any recognizable trends with regard to ejection forces, spinal injuries, and weight. This was the case for both the male ejections and the female ejections.

Examination of the data revealed that there were a total of 43 actual ejections using the ACES II. The severity of injuries ranged from none to fatal. Also, injuries included those that were due to ejection forces as well as those that were not.

Of the 43 ejection cases examined, there were only 8 which had injuries that were attributed to ejection forces. Of these eight, only one case resulted in spinal injury to the ejectee. The injury in this cases was classified as being major. The weight of the ejectee was 158 pounds which places him in a weight category above the fifth percentile male.

Various types of injuries were attributed to ejection forces for the remaining seven cases. The most prevalent type was neck injury, which was present in six of the cases. In only one of these six cases was the individual's weight below the fifth percentile male and in that case his weight (135 pounds) was very close to the fifth percentile male.

Examination of the summary of mishaps involving female aircrews revealed that only two cases involved ejections. One was from a T-37 and the other from a T-38 (note: neither aircraft incorporates the ACES II ejection seat). The ejection from the T-37 aircraft resulted in fatal injuries to the pilot. However, the T-38 female pilot ejection resulted in several minor injuries of which one was to the back. The individual in this case weighed 153 pounds, once again above the fifth percentile male weight.

In light of the above findings from both the ACES II ejections and the female mishap summary, it was determined

that inadequate data existed with regard to identifying any recognizable trends. It is not possible to say that lower weight female pilots have a higher potential for spinal injury based on only two ejections that resulted in spinal injury. Also, in both these cases the individuals were not in the lower weight class.

Further investigation of the spinal injury potential was accomplished using an ejection seat computer model. Discussion of this model follows in the next section.

232ACES2 Computer Model

In the preceding chapter and section the discussion centered on using descriptive statistics to analyze the current female pilot population, and the analysis of the actual ACES II ejection data from the A-10, F-15 and F-16 aircraft. In addition, the results of these analyses were presented. This section reviews the 232ACES2 computer model, which was used in an attempt to assess the spinal injury risk potential for lower weight class female pilots.

The 232ACES2 computer model is a simulation model for the ACES II ejection seat. This computer program is a commercial version of the Air Force Flight Dynamics Laboratory's (AFFDL) Simulation and Analysis of In-Flight Escape System Techniques (SAFEST) computer model (6). Using various subroutines, both programs are designed to

compute the trajectory dynamics of an ejection seat and crewperson as it is catapulted into free flight along a set of rails constrained to translate and rotate with the aircraft (14:8). Mathematical computations of the forces and the moments upon the seat and the crewperson during the ejection are used to obtain trajectory dynamics (14:8).

Since the 232ACES2 model is highly complicated and designed to obtain various outputs, such as parachute performance, it is not necessary to present every aspect of the model. The major output of interest in this study is the Dynamic Response Index (DRI), which is the indicator of spinal injury potential specified by MIL-STD 9479B for USAF ejection seat design.

The DRI is, in itself, the model currently used by the USAF and USAF Contractors to determine the probability of spinal compression injury (4:77). It is calculated by mathematically describing the human body in terms of an analogous lumped parameter mechanical model consisting of a mass, spring, and damper (18:27). The following equations are used to determine DRI:

$$\frac{d^2\delta}{dt^2} + 2\zeta\omega_n\frac{d\delta}{dt} + \omega_n^2\delta = \frac{d^2z}{dt^2}$$

$$DRI = \frac{\omega_n^2\delta_{max}}{g}$$

where:

δ = compression of the spring in feet
ζ = 0.224 (damping ratio of the model)
ω_n = 52.9 radians per second (undamped natural frequency of the model)

$\frac{d^2 z}{dt^2}$ = z axis output acceleration from the seat bucket in feet per second squared.

t = time in seconds
g = 32.2 feet per seconds squared (acceleration due to gravity)

Substituting the above values the equation becomes:

$$\frac{d^2 \delta}{dt^2} + 23.7 \frac{d \delta}{dt} + 2789 \delta = \frac{d^2 Z}{dt^2}$$

$$DRI = 86.9 \ \delta_{max}$$

(note: Equations Extracted from Mil-S-9479B (18:27))

The equations above are used in a subroutine of the 232ACES2 model to compute the DRI. In terms of DRI allowed by military specification in designing ejection systems, the maximum value is 18.0 with a standard deviation of 1.0 (18:12). This equates to a 5 percent probability of spinal injury due to ejection system forces (18:12).

The most critical phase of the ejection sequence in which DRI is an appropriate measure for spinal injury potential is approximately the first two tenths of a second time period after ejection initiation (20). To accurately determine DRI, the forces (i.e., the thrust from the

catapult motor) must be parallel to the spine of the ejectee (not to exceed five degrees from this axis). Beyond the first two tenths of a second time period, the ejection seat has departed the aircraft and is no longer constrained to the guiderails. This is when the last of three ejection seat rollers departs the guiderails and is commonly referred to as strip-off (20). Therefore, the forces acting upon the ejectee are no longer limited to the five degree cone about the spinal axis and DRI can no longer be used as an accurate measure of spinal injury potential.

The two tenths of a second time period results from the length of time it takes the CKU-5/A catapult to eject the crewperson/seat combination from the aircraft. (Note: The CKU-5/A consists of a solid-propellant rocket motor which is integrated with a solid-propellant cartridge catapult (1:13)). According to a Douglas Aircraft report, the thrust of the catapult cartridge which is in excess of 4000 pounds of thrust results in an acceleration of approximately 14 G's. If the acceleration can be determined, it can be used to compute DRI's (the measurement used to determine spinal injury potential) for any specific individual.

As part of the method of assessing spinal injury potential to lower weight class female pilots, it was

necessary to obtain inertial and center of gravity properties data which was collected on a representative cross section of female test subjects. This data was one of the necessary inputs for the 232ACES2 computer program to compute DRI's.

Each test subject's weight, center of gravity, and inertial information (see Appendix B) was input to the computer program in order to simulate an actual ACES II ejection. With the contractor's consent, a simulation of the three ejection modes was performed using the inertial and center of gravity properties established for each test subject (i.e., this required 3 simulation runs for each test subject's data).

An analysis of the resulting DRI's for each ejection simulation was performed. The results of this analysis was used in an attempt to determine the spinal injury potential for lower weight class female pilots. Prior to discussing the results, the following section addresses the methodology employed in establishing the inertial and center of gravity properties which were required as an input to the 232ACES2 computer model.

Center of Gravity and Inertial Properties

Inertial and center of gravity data on lower weight female pilots was an input required in this study for use

of the 232ACES2 computer model. The moments of inertia and the center of gravity are physical characteristics, in this case of female test subjects, which affect how a body (mass) will react when acted upon by outside forces. In evaluating the ACES II ejection system, the moments of inertia and center of gravity of the test subjects must be accurately measured if the 232ACES2 computer model is expected to provide reliable results. This section discusses the theory behind the device used to determine this information and then the procedure followed in the selection of test subjects/collection of data.

Theory for Center of Gravity and Inertial Properties Determination. Technology Incorporated designed and produced a device which is capable of making the necessary measurements and subsequently computing the center of gravity, moments of inertia, and products of inertia of a test subject for the Air Force Flight Dynamics Research and Technology Division (AFWAL/FIER). The main component of the system is a large platform which either rests on three scales for center of gravity information or swings as a pendulum for inertial measurements (see Figure 3.1)(26:1). In addition, there is associated measuring equipment which measures the period of oscillation when the platform is swinging and a computer program that translates the measured values (period of oscillation and weights) into

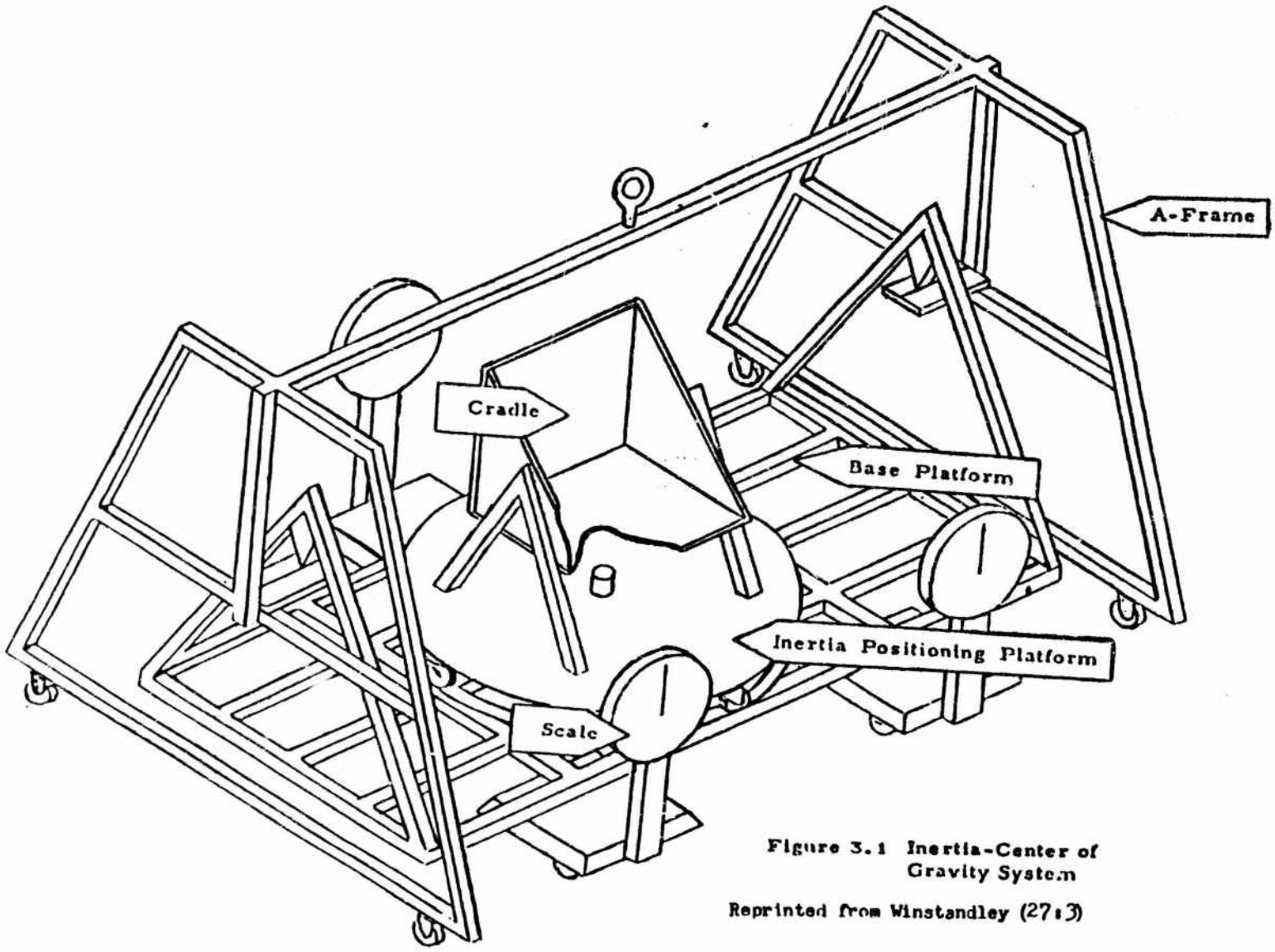

Figure 3.1 Inertia-Center of Gravity System

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center of gravity and moments/products of inertia. When utilizing this apparatus, the first procedure is to secure the test subject into the cradle and lower the apparatus onto the scales and measure the weight. The cradle is repositioned and the weight is again measured. After the first two measurements are completed, the apparatus is lifted from the scales and set into a swinging motion. A series of five measurements are then taken with the cradle in six different positions (a total of 30 measurements)(27:6-7,10-12,22).

The first two measurements in the sequence are to determine the center of gravity of the test subject. The platform is lowered onto three scales that measure the test subject's weight (note: the weight of the platform/cradle structure is removed prior to beginning this procedure by zeroing the scales before inserting the test subject). The total weight of the subject can be determined from the following equation (see Figure 3.2 for orientation (26:7)):

$$W = w_1 + w_2 + w_3$$

where: w_1, w_2, & w_3 = the weight measurements on the three scales.

These measurements determine the center of gravity for the X, Y plane (the plane defined by the X-axis (from the test subject's back through chest) and the Y-axis (from the test

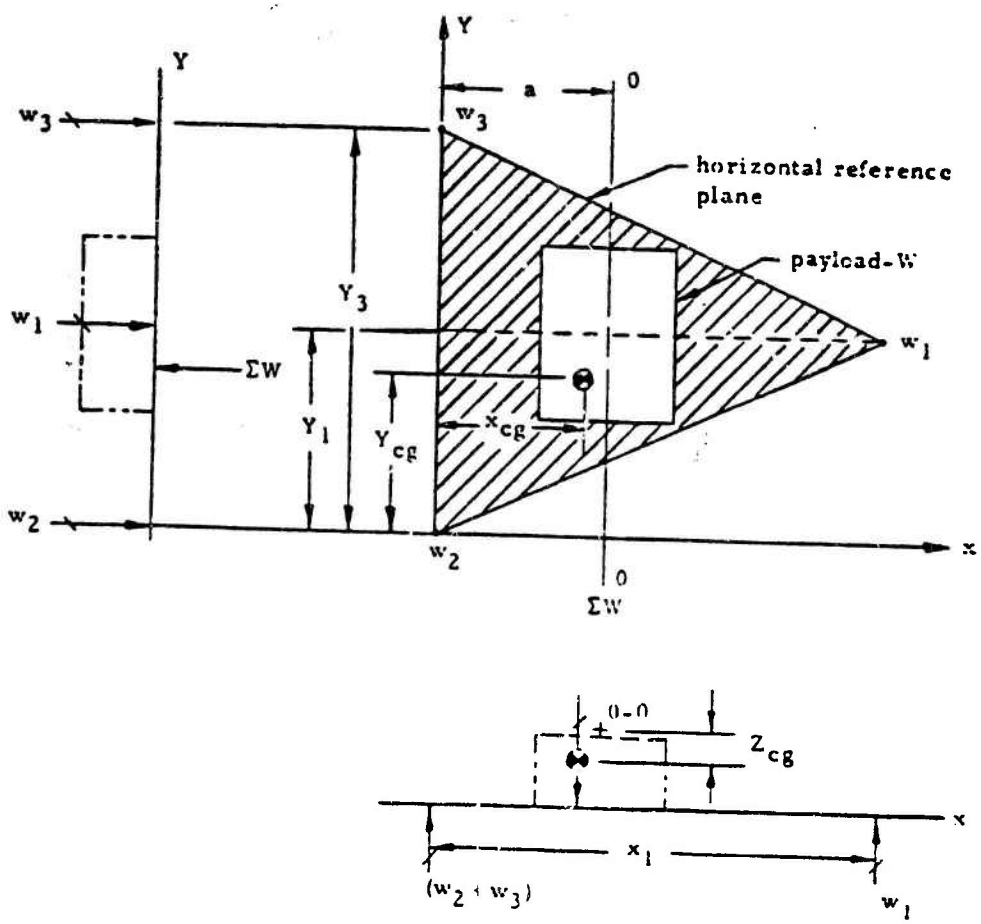


Figure 3.2 Horizontal Reference Plane Projection to Illustrate Method of Locating Center of Gravity by Weighing Test Object in a Single Plane

Reprinted from Winstandley (26:8)

subject's right through left shoulder)). The center of gravity in the X, Y plane can be determined from the following equations:

$$Y_{cg} = \frac{y_1 w_1 + y_3 w_3}{W}$$

$$X_{cg} = \frac{x_1 w_1}{W}$$

where: x_1, y_1 & y_3 = feet (see Figure 3.2)

w_1, w_3 & W = pounds

The test subject is then rotated in the cradle to a reclining position on her back. A second set of scale readings is taken to determine the center of gravity in relation to the subject's Z-axis (the axis extending from the subject's feet through the subject's head). The center of gravity can be established by the following equation:

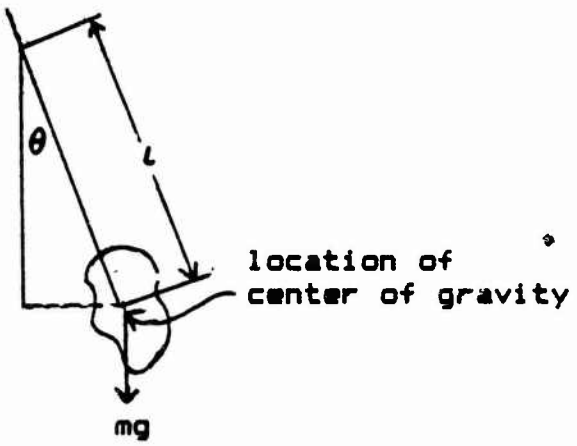
$$Z_{cg} = a - \frac{x_1 w_1'}{W}$$

where: a & x_1 = feet (see Figure 3.2)

w_1' & W = pounds

The next procedure is to measure the moments of inertia of the test subject. This discussion will cover finding the moment of inertia in the simple case. In a

similar manner, the three moments of inertia and three products of inertia can be calculated for any fixed set of axes (this will be required in the 232ACES2 model because the ejection seat is in fact mounted in the aircraft with about a 14 degree tilt back for crew comfort). A simple pendulum system is sketched below which represents the inertial properties measurement apparatus (26:8).



$$I \frac{d^2\theta}{dt^2} = - mg\iota \sin\theta$$

where:
- I = mass moment of inertia of the pendulum
- m = mass of the pendulum
- θ = angle of motion
- ι = distance from the axis of rotation to the center of gravity of the pendulum

This is the simple case for the moment of inertia of the complete test subject apparatus combination. The input for the model will only include the moments of inertia for the test subject. This can be accomplished with the knowledge of the moment of inertia of the apparatus alone (this has already been determined), and then manipulating the variables according to the following equation:

$$I_{2cg} = \frac{w_c \ell_c T^2}{4\pi^2} - I_1 - \frac{w_2 \ell_2^2}{g}$$

where: I_{2cg} = moment of inertia of the test subject about its center of gravity on a parallel axis to the pendulum axis

w_c = weight of test subject and apparatus

c = distance of axis of rotation to center of gravity of test subject and apparatus

T = period of oscillation

I_1 = moment of inertia of the apparatus

w_2 = weight of the test subject

ℓ_2 = distance of axis of rotation to center of gravity of the test subject

g = 32.2 feet per second squared (acceleration due to gravity)

(note: for the complete derivation of these formulas and the computations to determine the products of inertia see Winstandley (26:9-20)).

Test Subjects / Collection of Data. Once having attained a basic understanding of the theory for determining the inertial and center of gravity properties, the next step was to locate appropriate test subjects. Female personnel assigned to the Air Force Institute of Technology were contacted to determine if they would voluntarily participate in this program. To be qualified for this test, the test subjects selected had to meet the following criteria:

1. Weight near or below 140.2 pounds (this is the category of interest).

2. Physically qualified to attend Undergraduate pilot training in terms of height and weight.

   a. Weight at or above 103 pounds.

   b. Height not less than 64 inches or more than 76 inches (note: this restriction was relaxed to not less than 63 inches because female pilots have received similar waivers to this restriction).

   c. Sitting Height not less than 34 inches or more than 39 inches (note: this restriction was relaxed to not less than 33 inches for the same reason stated above).

   d. Weight in relation to height in accordance with AFR 160-43 (15:44,87).

In addition, the test subjects' weight should range from at or above 103 pounds to at or near 140.2 pounds because this is the weight category of interest in this study. Seven test subjects meeting the above criteria were identified

and scheduled for the testing procedure. See Appendix D and E for a comparison of the seven test subjects' weight/height and weight/sitting height with the population of female pilots identified earlier.

Center of Gravity and Inertial Properties Results

The testing of the seven test subjects occurred at the Aircrew Escape Group's (AFWAL/FIER) test facility. Mr. Jim Peters, Aerospace Engineer, agreed to supervise the testing and provided the necessary personnel to conduct the tests. The testing was conducted in accordance with User's Manual for Mechanical and Dynamic Properties of Crew Escape Systems Apparatus (27). After the tests were completed and the run data was collected, Mr. Peters provided manual computations of the inertial and center of gravity properties of the test subjects. Manual computations were accomplished due to a computer program malfunction. Appendix G contains the results of the manually computed center of gravity and inertial properties that were forwarded to the contractor for use in the ACES II computer simulation. Appendix H contains computer calculated center of gravity and inertial properties based on the same raw data for future users of this information. The following section discusses the actual results of the ejection simulations using the 232ACES2 computer model.

232ACES2 Computer Model Results

In addition to the three requested computer simulation runs on each of the test subjects' data, and computer runs for thirty degree climbs and dives on selected test subjects' data, the contractor voluntarily provided some additional computer runs. These computer runs included the use of a heavier than normal seat kit (i.e., a 66.7 pound seat kit rather than the normal 25.4 pound seat kit), and elevated grain temperatures (i.e., a 165 degree fahrenheit CKU-5A temperature simulating a heat-soaked propellant charge prior to ejection) for selected test subjects' data. In all, thirty-nine computer simulation runs were completed.

Table V is a summary of the 39 computer simulation runs with the associated maximum DRI (at or prior to strip-off) for each test subject. The DRI values for every test subject in each flight condition grouping either did not vary or had just slightly minor variations (note: a flight condition grouping would be runs 1 thru 10 where airspeed, altitude, and attitude remain constant between runs). A slightly higher variation (maximum of 2.097 DRI) exists between flight condition groupings.

Table V - 232ACES2 Computer Runs Summary

Run Number	Test Subject	Total Ejected Weight*	DRI Maximum	Flight Condition
1	One	309.25	8.343	
2	One	350.55	8.343	
3	Two	287.25	8.343	5000 feet
4	Three	278.90	8.343	AGL
5	Four	301.75	8.343	Straight
6	Five	288.05	8.343	& Level
7	Five	329.35	8.343	200 KEAS
8	Six	302.15	8.343	70 Degree
9	Seven	273.00	8.343	F. Grain
10	Seven	314.30	8.343	Temperature
11	One	309.25	7.799	
12	One	350.55	7.704	
13	Two	287.25	7.704	8000 feet
14	Three	278.90	7.704	AGL
15	Four	301.75	7.704	Straight
16	Five	288.05	7.704	& Level
17	Five	329.35	7.704	350 KEAS
18	Six	302.15	7.704	70 Degree
19	Seven	273.00	7.704	F. Grain
20	Seven	314.30	7.704	Temperature
21	One	309.25	7.507	
22	One	350.55	7.490	
23	Two	287.25	7.520	15,000
24	Three	278.90	7.532	feet AGL
25	Four	301.75	7.508	Straight
26	Five	288.05	7.518	& Level
27	Five	329.35	7.503	450 KEAS
28	Six	302.15	7.504	70 Degree
29	Seven	273.00	7.536	F. Grain
30	Seven	314.30	7.520	Temperature
The remaining runs at 5000 ft AGL, 350 KEAS				
31	One	309.25	7.873	30 Degree
32	Five	288.05	7.873	Climb
33	Seven	273.00	7.873	70 F gr.t.
34	One	309.25	7.873	30 Degree
35	Five	288.05	7.873	Dive
36	Seven	273.00	7.873	70 F gr.t.
37	One	309.25	9.577	30 Degree
38	Five	288.05	9.579	Dive
39	Seven	273.00	9.587	165 F gr.t.

* Note: Total ejected weight includes crewperson, flight clothing (flight suit, boots & helmet), seat kit (either 25.4 or 66.7 pounds) and prototype ACES II ejection seat.

Although all of the DRI's were considerably less than the maximum allowable of 18, the fact that there was little variation between runs caused the research team to question the validity of these results. Figure 3.3 graphically demonstrates the lack of variation in DRI's for different individuals as computed by the 232ACES2 model. Consultation and discussion of these results with crew escape experts from AFWAL/FIER confirmed that a problem appeared to exist with respect to catapult cartridge thrust in the 232ACES2 computer simulated ejections.

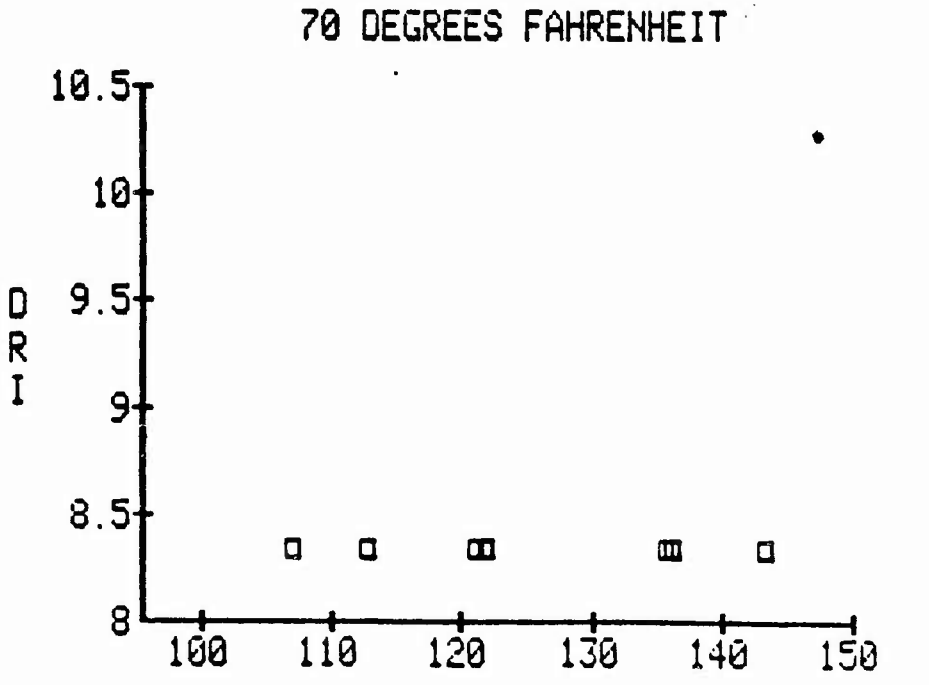


FIGURE 3.3
232ACES2 COMPUTER RUN DRI
RELATIONSHIP TO TEST SUBJECT WEIGHT

The fact that all DRI's were nearly the same for each test subject indicated the most likely cause was a constant Gz (vertical acceleration) profile during the catapult phase for all test subjects during a specific flight condition grouping. Discussion with the contractor's personnel confirmed these findings. It was stated that the reason for using the constant Gz profile was an assumption that the total difference in weight between the heaviest total ejected weight (i.e., female pilot, seat kit, and seat) of 350.55 pounds and the lightest total ejected weight of 273.00 pounds was negligible (77.55 pounds) and therefore need not be accounted for in calculating DRI's during the catapult phase.

The assumption that the differences in weight are negligible is contrary to the whole purpose of this research effort. Therefore, for the purpose of this study, the DRI's calculated during the catapult phase of the 232ACES2 ejection simulations are of little, if any, value.

At this point, it was necessary to locate a suitable computer program capable of calculating DRI's for the lower weight class test subjects. Experts at AFWAL/FIER were able to provide the required program. Discussion of the methodology incorporated in using this computer program, as well as the results of the computer runs, are presented in the next two sections.

DRI Computer Program

As was previously discussed, DRI is the measure accepted by the Air Force to demonstrate the probability of spinal injury during an ejection. A computer program designed by Mr. Richard Dobbek, one of the resident aeronautical engineers at AFWAL/FIER, was used to calculate DRI's for this study. This program is essentially the subroutine used in the SAFEST and 232ACES2 ejection programs to compute DRI's. The only two inputs required for this program are time and the applicable Gz at that time. The total ejected weight of the test subjects and actual thrust curves were used to calculate the Gz's at specific time intervals. Gz is calculated by dividing the actual thrust at a given instant of time by the total ejected weight. A Hewlett-Packard 85 micro-computer was used for running the AFWAL DRI program.

In order to calculate Gz it was necessary to obtain valid thrust-time curve data for the CKU-5/A cartridge catapult. An initial thrust-time curve (quantic catapult firing #37, 19 Sept 1969, ambient temperature, 300 pound mass) for a CKU-5/A was used to calculate Gz for all seven test subjects. Gz's were calculated for test subjects using both the heavy (66.7 pound) and the light (25.4 pound) seat kits. The resulting time and Gz's were used as inputs for the AFWAL DRI program.

Further investigation revealed the existence of "The Final Report on CKU-5/A Rocket Catapult 1983 Quality Evaluation" which included the measured thrust-time curves obtained during lot acceptance testing (21). The data from three actual firings (CKU-5/A sn49 - 165 degrees F, CKU-5/A sn27 - 70 degrees F, and CKU-5/A sn849 - 70 degrees F) were used for this study (note: by using the thrust and Gz curves from these runs, it was determined that approximately a 370 pound mass was used for these firings which equates to a 218 pound individual). Once again, the test subjects' total ejected weights were used to calculate Gz from the three thrust-time curves.

For this program, it was not necessary to use inertial and center of gravity properties. Therefore, it was possible to simulate the lowest-weight female pilot in the current female pilot physical characteristics data survey and to determine her spinal injury potential if required to eject using the ACES II ejection seat. Only the two lightest weight individuals (i.e., 103 pounds from the current survey and the 107 pound test subject) were used with the heavy seat kit.

A total of 44 computer runs were made using the AFWAL DRI program. The data from these runs was used to provide a more realistic answer to the third research question (note: the answer is addressed in Chapter IV).

The results of the AFWAL DRI program runs are discussed in the following section.

DRI Computer Program Results

For the quantic catapult firing #37 all seven test subjects were run with both the lightweight and heavyweight seat kit. This accounted for fourteen total runs in all based on this catapult's thrust-time curve. Figures 3.4 and 3.5 are the graphical plots of the resultant DRI's versus the female test subjects weight. Each graph corresponds to a different seat kit configuration.

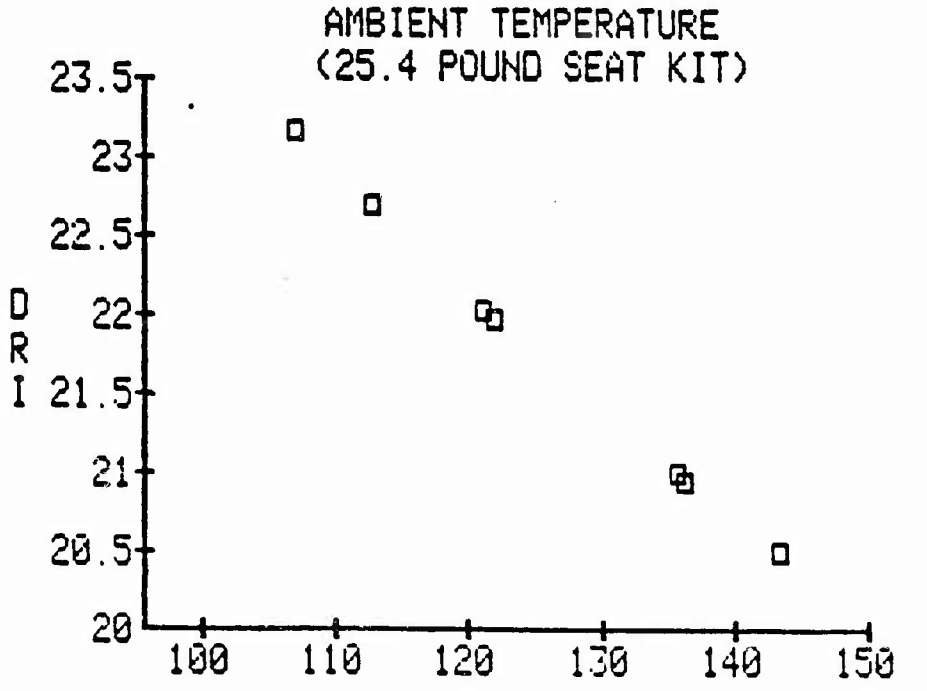


FIGURE 3.4
1969 QUANTIC CATAPULT FIRING #37 DRI
RELATIONSHIP TO TEST SUBJECT WEIGHT

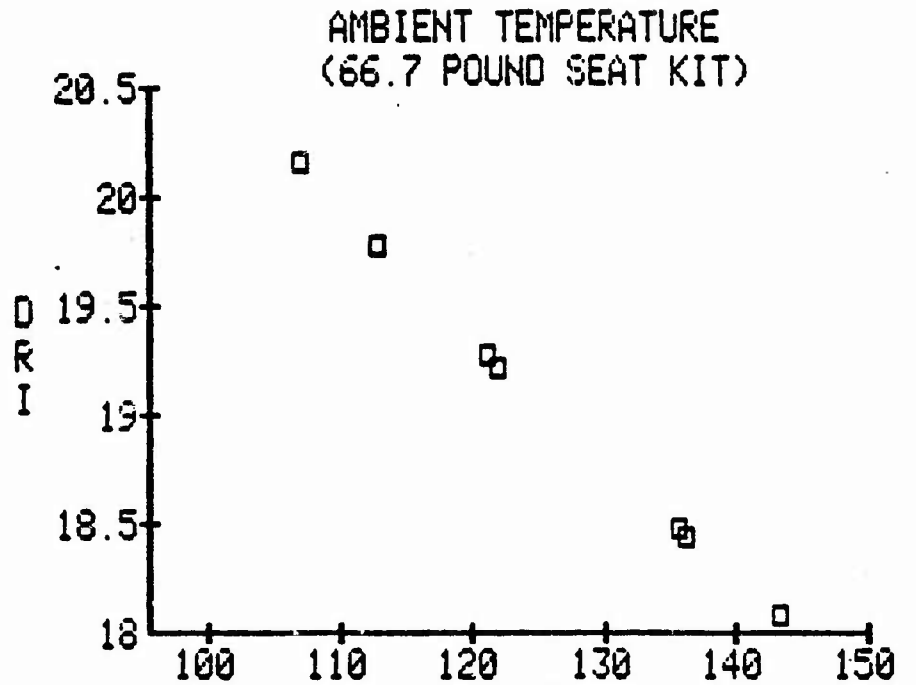


FIGURE 3.5
1969 QUANTIC CATAPULT FIRING #37 DRI
RELATIONSHIP TO TEST SUBJECT WEIGHT

The resultant DRI's were high. In the case of calculations using the lightweight seat kit all DRI's exceeded the maximum allowable '18.0 $\pm$ 1.0). With the heavyweight seat kit four of the seven test subjects' DRI's exceeded the maximum allowable.

Due to the fact that this data was based on a catapult firing which took place nearly fifteen years ago, the research team felt a more realistic DRI plot would be found using current CKU-5/A catapult firing data. As was previously mentioned, three such firings were used.

For all three catapult firings the DRI's were calculated for the seven test subjects plus the 103 pound individual from the current survey. Because DRI's were well within limits for the heavier female subjects when the heavy seat kit was used, only the two lightest weight individuals required computation of DRI using this heavy seat kit.

Figures 3.6 through 3.8 are the graphical plots of the resultant DRI's versus the female test subjects weights. Each one represents a different catapult firing with only the lightweight seat kit in use.

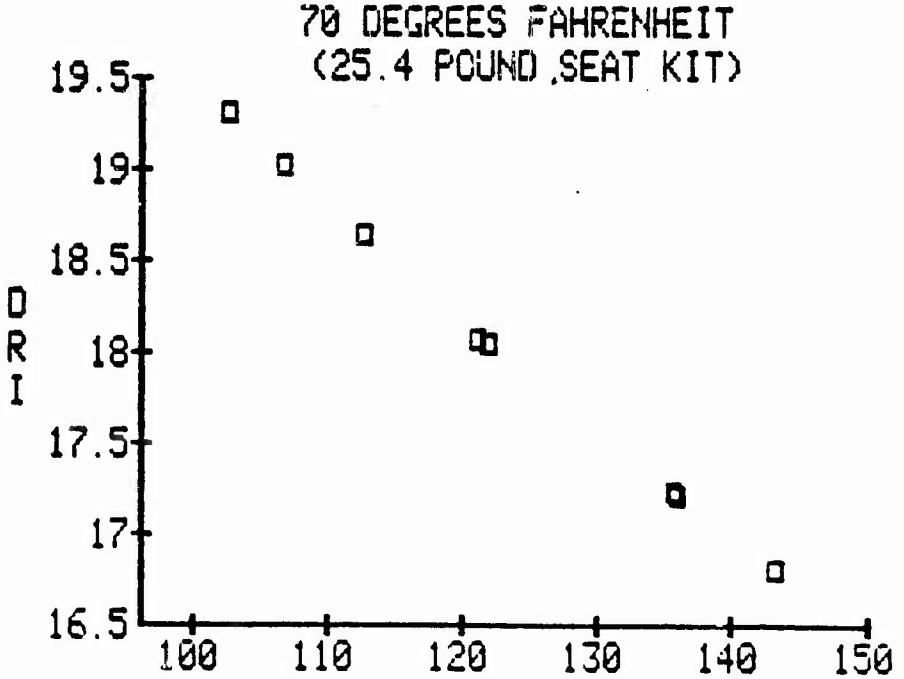


FIGURE 3.6
CKU 5/A SERIAL NUMBER 27 DRI
RELATIONSHIP TO TEST SUBJECT WEIGHT

70 DEGREES FAHRENHEIT

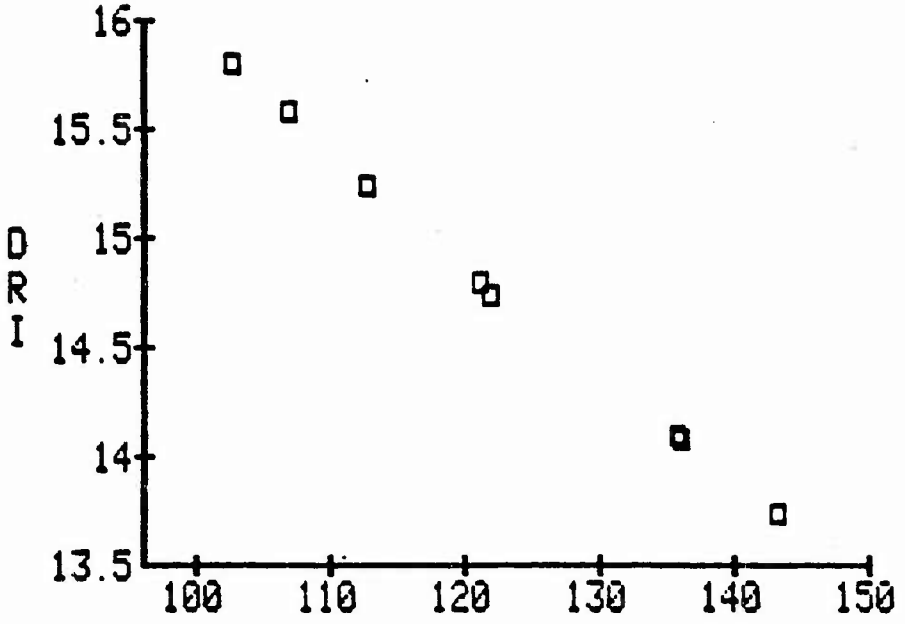


FIGURE 3.7

CKU 5/A SERIAL NUMBER 849 DRI
RELATIONSHIP TO TEST SUBJECT WEIGHT

165 DEGREES FAHRENHEIT

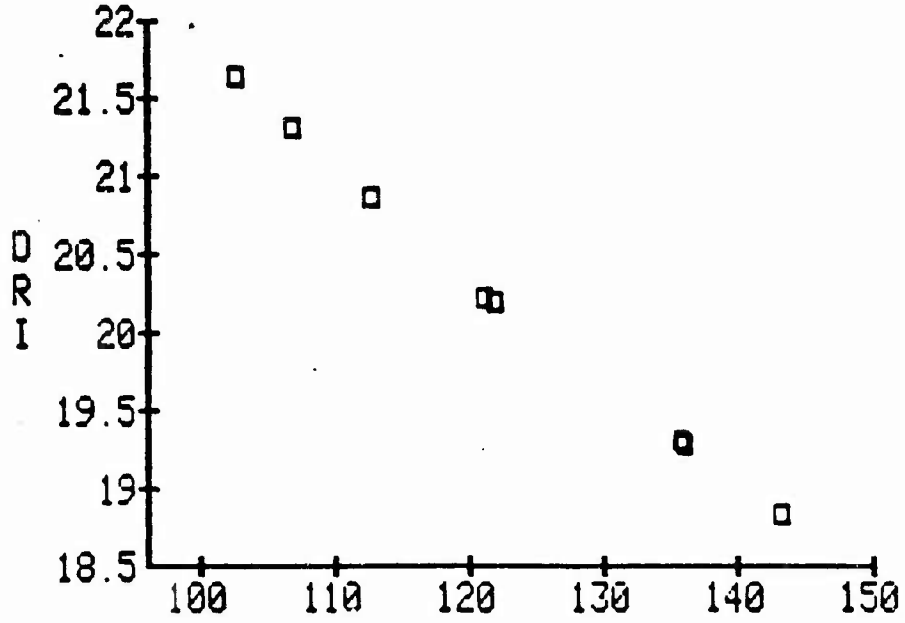


FIGURE 3.8

CKU 5/A SERIAL NUMBER 3 DRI
RELATIONSHIP TO TEST SUBJECT WEIGHT

As can be seen from the figures the highest resultant DRI was slightly over 21.5 (23.68). This occurred to the lightest individual using the catapult firing with the highest grain temperature (165 degrees Fahrenheit). The lowest DRI was slightly above 13.5 (13.74). This occurred to the heaviest individual using the catapult firing with the lowest grain temperature (70 degrees Fahrenheit) and lowest thrust-time curve.

For the runs (6 total) using the heavyweight seat kit with the two lightest weight individuals the highest DRI was 18.76, which occurred for the 103 pound female using highest grain temperature firing. The lowest DRI was 13.52, which occurred for the 107 pound test subject using the lowest grain temperature and lowest thrust-time curve.

This concludes the results section with respect to the AFWAL DRI program. Analysis of these results is reserved for Chapter IV.

Summary

This concludes the methodology employed in determining the physical characteristics of the current population of female pilots (chapter II) and in assessing spinal injury potential for lower weight class female pilots. By obtaining actual physical characteristic data of the female pilots, the percentage of female pilots below 140.2 pounds

was determined. This percentage demonstrates that segment of the female pilot population for which ejection seat testing has not been conducted. It is this segment of the female pilot population for which spinal injury potential has not been assessed.

A cross section of female test subjects representing lower weight class female pilots were identified to determine inertial and center of gravity properties for use in the contractor's 232ACES2 computer model. An attempt was made to use the 232ACES2 ejection model to assess the spinal injury potential for lower weight female pilots. Unfortunately, assumptions made by contractor personnel made this information inappropriate for use in this study.

An alternative to the 232ACES2 model, the AFWAL DRI program, was available. Using this program, DRI's were calculated using the test subjects' weights and the weight of the lightest female pilot identified in the current female physical characteristics survey along with actual CKU-5/A cartridge catapult thrust curves. The AFWAL DRI program provided realistic calculations of the DRI's for lower weight female pilots.

The results of each of the areas addressed in chapter II and chapter III were provided following the methodology

employed. Several areas require further analysis. This analysis is provided in the next chapter.

IV. Analysis

Overview

The purpose of this chapter is to discuss, in depth, the results of the research areas presented in chapter II and chapter III. All aspects of this research did not lend themselves to a detailed analysis. In some cases, the pure results were sufficient to answer the specific research questions. In other cases it was necessary to accomplish further analysis of the results in order to provide a better understanding of the significance and implications of the findings.

The following are the major areas of analysis and discussion presented in this chapter:

1. Identification of Female Pilot Physical Characteristics Data Percentiles.
2. Anthropometric Survey Comparisons.
3. Analysis of Female Test Subjects' Physical Characteristics.
4. Thrust-time curve analysis.
5. DRI results comparisons and implications.

By addressing these areas a better understanding of the results are possible.

Physical Characteristics Data Percentiles

Although the results of the female pilot physical characteristics survey demonstrate that approximately 73.3

percent of the female pilot population is in a weight class below that of the fifth percentile male pilot, the discussion of the results did not address the percentile breakdowns of all female pilot physical characteristics data. In reviewing other anthropometric surveys it was found that most surveys identified at least the fifth, fiftieth, and ninety-fifth percentile categories. Therefore, these percentiles are identified with respect to the current survey of female pilot physical characteristics data in order to provide researchers with a comparison to other surveys.

Table VI is a tabular summary of the percentile breakdowns of the female pilots physical characteristics data. Once again these figures are based on a survey of 215 female pilots.

Table VI

Female Pilot Physical
Characteristics Percentiles

Percentile	Age (years)	Weight (pounds)	Height (inches)	Sitting Height (inches)
5TH	21.4	109.6	64.2	34.3
50TH	24.4	131.2	66.4	35.4
95TH	30.4	159.8	70.3	37.3

For those interested in obtaining percentiles other than the ones presented in the table, Appendix F contains the computer printout from which the percentiles can be calculated. These percentiles provide a basis for identifying the lower end of the spectrum of physical characteristics that might be considered for ejection seat testing.

Anthropometric Surveys Comparison

This section demonstrates the overall relationship between the physical characteristics of the female pilot population and those of the male pilot population's fifth percentile. The male pilot fifth percentile figures are based on a survey conducted in 1967/1968. Also contained in this section is a comparison of the current survey results with those of the 1982 Gragg survey. With this comparison it is possible to identify whether or not the distributions generated by the Gragg and current surveys are the same.

The area of interest once again is the fifth percentile male. Recall that it is below this percentile where ejection seat tests are not conducted. Table VII is a representation of the relationship between the fifth percentile male data from the 1967-68 survey and the female data from the current survey.

Table VII

Male/Female Pilot Physical Characteristics Comparison

Characteristic	Male Pilot 5TH Percentile	Female Pilot Comparable percentile	Female Pilot 5TH percentile
Weight (pounds)	140.2	73RD	109.6
Height (inches)	65.9	36TH	64.2
Sitting Height (inches)	34.7	17TH	34.3
Age (years)	N/A	N/A	21.3

There was no data available for age with respect to the fifth percentile male in the 1967-68 male anthropometric survey. This is most likely due to the fact that the relationship of age to injury potential during an ejection was not a focus in that survey. Age information is included in the current survey to satisfy the needs of any person who may desire this information for future research.

It can be seen from Table VII that in all cases, the comparable percentiles for female pilots is larger than that of the male fifth percentile data. The largest percentile difference being in the weight characteristic.

The method used in comparing the current survey with the Gragg survey was the Chi-Square Goodness of Fit test.

This method is a means of testing to see if the sample data (current survey) agrees with some specified distribution (Gragg survey) (16:334). Observed frequencies are compared with the expected frequencies for the same categories to check if the null hypotheses (i.e., the physical characteristics distributions in the current survey are the same distributions as in the Gragg survey) are true (16:334). Rather than manually calculate the Chi-Square values, the SPSS program was utilized once again.

The physical characteristics data distributions for weight, height, and sitting height were compared. Age distribution comparison was not performed because the Gragg survey did not require age as a response. The following are the results of the Chi-Square analysis in order of weight, height, and sitting height:

1) Weight Distribution Comparison
   Ho: Dab = Dg
   Ha: Dab $\neq$ Dg

   (Note: Dab is the current distribution, and Dg is the Gragg distribution)

   Level of Significance: Alpha = .05

   Chi-Square = 31.144
   Degrees of Freedom = 5
   Significance = .000

   Reject Ho and conclude that the distribution of weights obtained by surveying the existing population of female pilots in the Air Force is significantly different from the distribution of weights obtained in the 1932 Gragg ATC survey.

2) Height Distribution Comparison

Ho: Dab = Dg
Ha: Dab ≠ Dg

Level of Significance: Alpha = .05

Chi-Square = 4.257
Degrees of Freedom = 3
Significance = .235

Fail to reject Ho and conclude that there is no evidence to suggest that the distribution of heights obtained by surveying the existing population of female pilots in the Air Force is different from the distribution of heights obtained in the 1982 Gragg ATC Survey.

3) Sitting Height Distributions

Ho: Dab = Dg
Ha: Dab ≠ Dg

Level of Significance: Alpha = .05

Chi-Square = 62.516
Degrees of Freedom = 4
Significance = .000

Reject Ho and conclude that the distribution of sitting heights obtained by surveying the existing population of female pilots in the Air Force is significantly different from the distribution of sitting heights obtained in the 1982 Gragg ATC survey.

The results of the Chi-Square Goodness of Fit test indicate that, except for height, significant differences do exist between the distributions obtained from current survey and those obtained from the Gragg survey. Figures 4-1 through 4-3 are graphical comparisons of the distributions. Each figure is a side by side histogram depicting the distributions from both surveys in one graph.

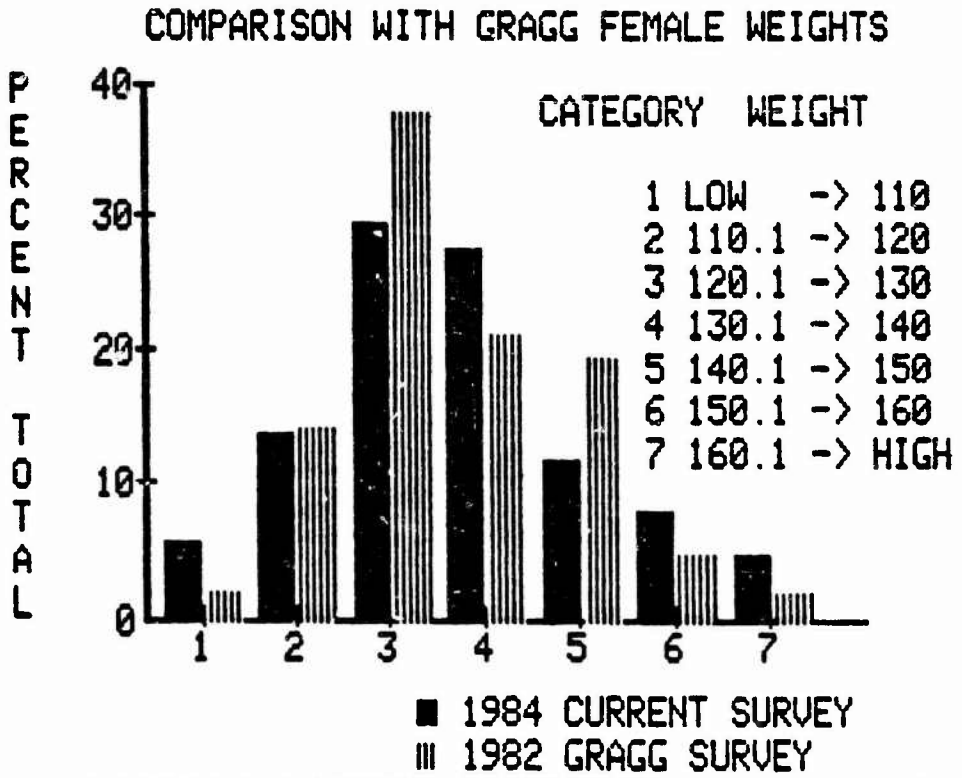


FIGURE 4.1 WEIGHT DISTRIBUTIONS COMPARISON

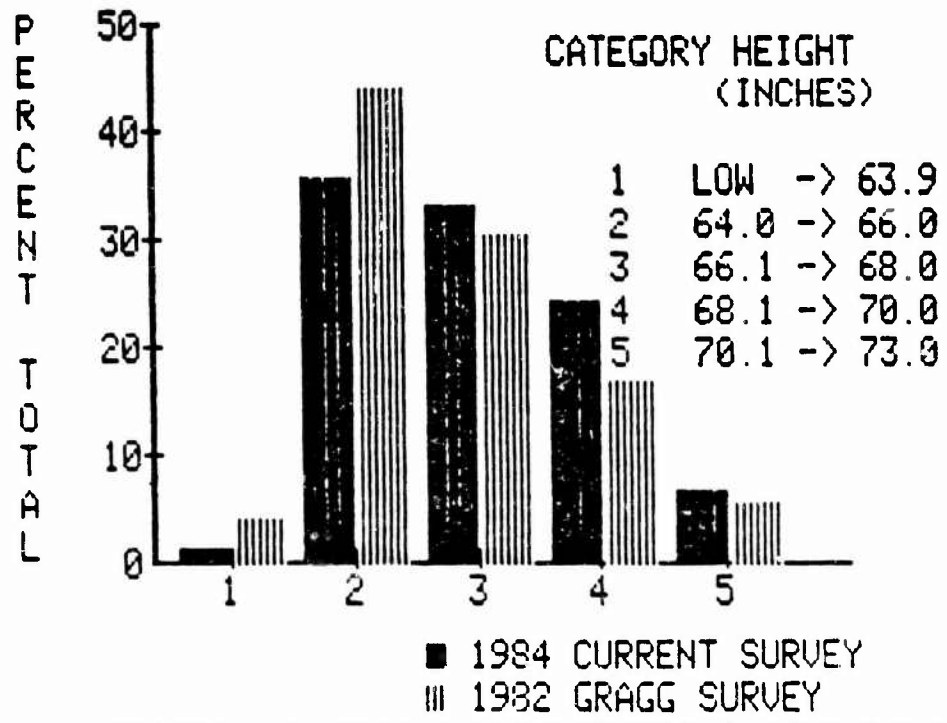


FIGURE 4.2 HEIGHT DISTRIBUTIONS COMPARISON

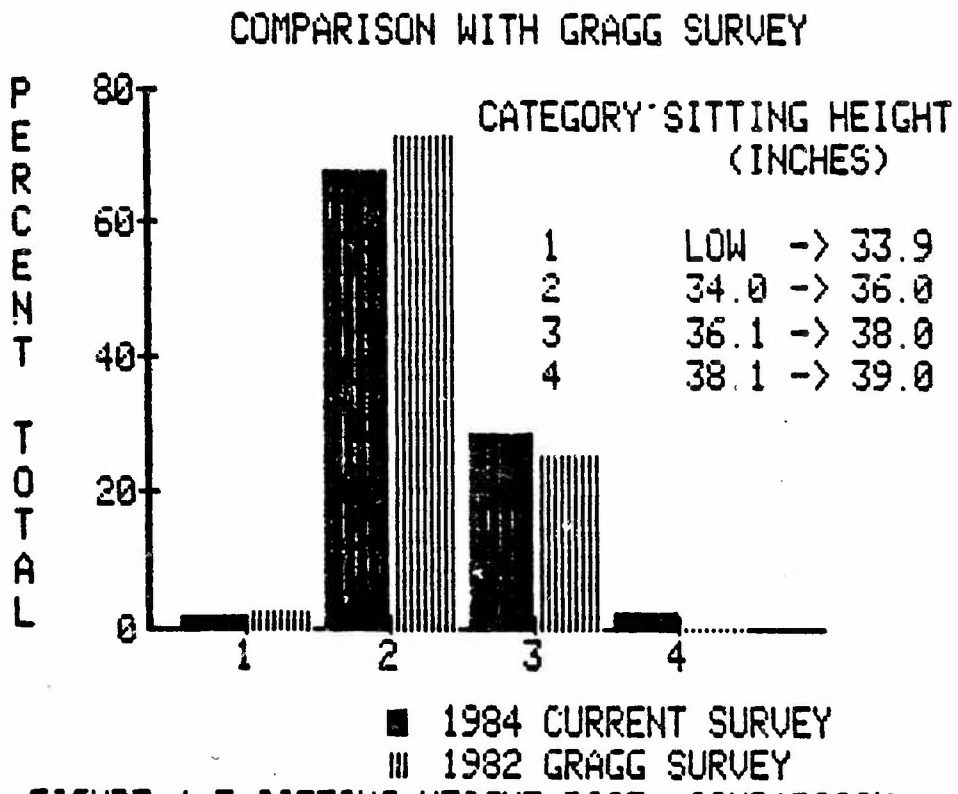


FIGURE 4.3 SITTING HEIGHT DIST. COMPARISON

This concludes the comparison of anthropometric surveys. Recommendations regarding the use of this data are provided in Chapter V.

Analysis of Female Test Subjects' Physical Characteristics

As was previously mentioned, an effort was made to select female test subjects whose basic physical characteristics were compatible with AFR 160-43, Medical Examinations and Medical Standards (15). Realizing that occasionally waivers are granted for either being higher or being below a specific standard, test subjects were retained if their measurements fell slightly below those standards required by the regulation.

The sitting and standing height limits were relaxed by one inch (i.e., to 63 inches standing, 33 sitting height). Investigation of the actual data of female pilot physical characteristics did indeed reveal that several pilots were below the 64 inch minimum height (maximum of 2 inches) and several other pilots were below the 34 inch sitting height limit (maximum of 4 inches).

At the time the female test subjects were required to gather the center of gravity and inertial properties data, the results of the physical characteristics data survey were unknown. It was desired that the test subjects were representative of the female pilots at or below 140.2 pounds.

Analysis of this matter occurred after the results of the survey were known. This was accomplished by plotting a scattergram of weight versus height and weight versus sitting height of the female pilot physical characteristics data. The weight versus height and weight versus sitting height of the female test subjects were then plotted on these scattergrams to determine if the test subjects' data was evenly spread across the female pilot data below 140.2 pounds (see appendicies D and E).

The results of this analysis suggest that the test subjects are indeed representative of the female pilot

population with respect to the physical characteristics surveyed.

Thrust-Time Curve Analysis

Because of the problem mentioned in Chapter III of the constant Gz curves used in the 232ACES2 computer simulations, a comparison was completed of the 232ACES2, the Quantic Catapult #37, and the CKU-5/A SN 27 thrust time curves. This section discusses why the cartridge catapult thrust-time curve used in the 232ACES2 computer is not considered representative of a CKU-5/A cartridge catapult thrust-time curve and then covers the comparison of the three identified thrust-time curves.

The thrust-time curves printed in the 232ACES2 computer runs were calculated from a constant series of Gz values within each flight condition group during the catapult phase of the ejection sequence. This was confirmed by contractor personnel during the investigation of why the DRI values for each test subject either were the same or only varied slightly for each flight condition group before strip-off (6). For this study, Gz should have been calculated by dividing cartridge catapult thrust by the total ejected weight. In addition, the maximum Gz's used in the 232ACES2 computer runs were inconsistent with information published in a Douglas Aircraft report. This report states, "the peak catapult acceleration is

approximately 14 g's (1:13)." The maximum Gz for the test subjects during the catapult phase of the 232ACES2 computer simulation ranged from about 4 to 7 g's lower than that stated in the Douglas report. These lower than expected constant Gz curves forced the DRI to test subject weight relationship to be a constant (note: DRI can be computed from the Gz curve). The thrust-time curve printed in the ninth 232ACES2 computer run is compared to the thrust-time curves of the Quantic Catapult firing #37, and the CKU-5/A SN 27 in Figure 4.4.

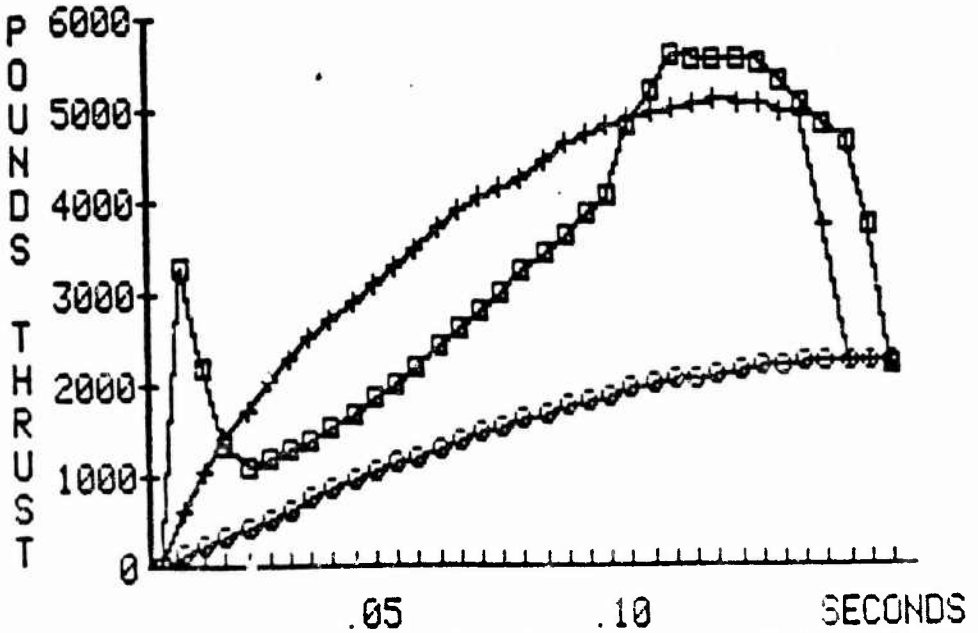


FIGURE 4.4
THRUST-TIME
CURVES COMPARISON

By examining these thrust-time curves, it is readily apparent that the thrust-time curve used in the 232ACES2 model was approximately one-half that measured during actual CKU-5/A cartridge catapult thrust-time curves. The significant difference in thrust time curves existing between the 232ACES2 model and actual test firings is the major basis for rejecting the use of the 232ACES2 computed DRI's to determine the spinal injury potential of lower weight female pilots. Therefore, it was necessary to use the AFWAL DRI program to determine this spinal injury potential.

DRI Results Comparisons and Implications

Recall that the maximum allowable DRI is 18.0 with a standard deviation of 1.0. This is for a grain temperature of 70 degrees Fahrenheit (18:12). Also, for a grain temperature of 165 degrees Fahrenheit, the maximum allowable DRI value for CKU-5/A lot acceptance increases to 22.0 with a standard deviation of 1.0 (18:13). This is just slightly in excess of a 25 per cent probability of spinal injury. In essence, the higher the grain temperature for a CKU-5/A, the larger the acceptable risk level.

Table VIII is a summary of all 44 computer runs done with the AFWAL DRI program. Columns A and B represent the results based on the 1969 CKU-5/A firing. These

Table VIII

DRI Results
(Based upon Actual CKU-5/A Test Firings)

Column ->	A	B	C	D	E
Test Subject	Quantic Catapult #37 (1969) Kit A	Quantic Catapult #37 (1969) Kit B	SN 849 (1983) Kit A	SN 27 (1983) Kit A	SN 3 (1983) Kit A
1	20.48	18.06	13.74	16.81	18.82
2	22.04	19.27	14.78	18.07	20.23
3	22.71	19.77	15.24	18.64	20.86
4	20.98	18.46	14.08	17.23	19.29
5	21.98	19.20	14.74	18.04	20.20
6	20.95	18.44	14.06	17.20	19.26
7	23.18	20.15	15.56 13.52**	19.04 16.54**	21.32 18.51**
8*	N/A	N/A	15.79 13.70**	19.33 16.75**	21.64 18.76**

Kit A - 24.5 pound seat kit
Kit B - 66.7 pound seat kit
* - Hypothetical 103 pound test subject
** - DRI value with 66.7 pound seat kit

Note: Tests Subjects are not listed in order of decreasing weight.

results show the maximum DRI being exceeded in all cases; however, there was not another thrust curve available to average DRI's to determine if the average exceeded 18.0. Also, the consensus among crew escape engineers (Bailey, Santi, Britton, Peters) is that the instrumentation used to

determine the thrust-time curve has improved, thus providing a more reliable thrust-time curves. Therefore, because of these factors, as well as the length of time since this firing took place, the resultant DRI's were not used in the assessment of spinal injury potential for female pilots.

Columns C and D of Table VIII identify those DRI's associated with the 1983 CKU-5/A catapult firings. Both were fired at 70 degrees Fahrenheit grain temperature, however, Column C represents the lowest thrust-time curve available and Column D represents the highest thrust-time curve available. by averaging the DRI's associated with these two firings the following mean DRI is obtained:

Test Subject	DRI
1	15.28
2	16.43
3	16.94
4	15.66
5	16.39
6	15.63
7	17.30/15.03
8	17.56/15.23

The highest mean DRI (17.56), which is for the hypothetical 103 pound test subject is still slightly below the maximum allowable DRI. In essence the probability for spinal injury for the lowest weight female pilot using the mean DRI is just slightly below 5 percent.

Although this appears to be right at the acceptable level of risk, these findings must be tempered by the fact that the data has been based on only two firings of a CKU-5/A catapult at 70 degrees Fahrenheit. Also, the thrust generated by these firings was based on propelling a 370 pound mass. The thrust generated by propelling a 270 pound mass, which would be equivalent to a 103 pound test subject's total ejected weight, could be different. Thus, Gz and subsequently the DRI values could be considerably different (i.e., they could be higher or lower).

One final comment regarding the analysis of DRI's obtained through these two firings is that with the heavier seat kit the mean DRI for the 107 and 103 pound individuals was 15.03 and 15.23 respectively. This is well within the acceptable level of risk; however, these results are subject to the same factors which were previously mentioned.

The final column, Column E, of Table VIII reflects the DRI's obtained for the test subjects when Gz values were derived from a thrust-time curve of a 165 degree Fahrenheit CKU-5/A. It was initially intended to use a high and low thrust-time curve for two 165 degree Fahrenheit CKU-5/A catapult firings; however, the data on one of the CKU-5/A catapult firings was in error (the tabular and the plotted data for SN 41 was inconsistent). The report indicated SN3

as the low thrust firing and SN41 as the high thrust firing, however, the two thrust-time curve plots were identical (21)(i.e., They both reflected SN3 data). Thus, only one thrust-time curve was used, eliminating the possibility of obtaining a mean DRI for catapults with an elevated initial grain temperature.

The resultant DRI's for the test subjects, as indicated in Column E, demonstrate that for this firing all individuals were within the acceptable risk level for spinal injury (maximum DRI was 21.64). Once again, for the lowest weight individual, the DRI was right at the edge of acceptability. As with the 70 degree Fahrenheit, catapult firings, if other factors are considered, the resultant DRI's could be either higher or lower.

At this point it is possible to provide an answer to the third research question and thus satisfy the requirements of the second objective. Restated in abbreviated form, the third research question is: "What is the spinal injury potential for lower weight class female pilots?"

Based upon the results of this analysis, the spinal injury potential for the lowest weight (103 pound) female pilot is approximately five percent. (Note: for a more detailed explanation of this answer see chapter V). This is for a catapult firing with an initial grain temperature

of 70 degrees fahrenheit. For an initial elevated grain temperature the spinal injury potential is greater than five percent; however, this is acceptable for CKU-5/A lot acceptance by regulation (i.e., the hotter the grain temperature, the higher the acceptable risk for spinal injury).

In summary, analysis of the resultant DRI's generated for female test subjects reveals that, excluding the data based on the 1969 CKU-5/A catapult firing, most DRI's are at or are within acceptable risk limits for spinal injury. In all cases, as the weight of the individual test subjects decreases, the resultant DRI's increased.

Summary

This chapter has been an in depth discussion of the analysis which was performed for the various aspects of this study. In the following chapter the major conclusions and recommendations are presented. Although all three research questions have been answered, chapter V addresses these research questions again by discussing the major conclusions and recommendations as they pertain to those questions.

V. Conclusions, Recommendations, and Summary

Overview

This chapter is a look at the overall accomplishments of this study. Addressed are the major conclusions of the research team with regard to the research questions which were posed in Chapter I. Also, recommendations for new or improved programs, as well as further study areas, are presented. Finally, a summary of the complete study is presented as an end to this chapter.

Conclusions

The conclusions of this study are presented as answers to the three research questions presented in chapter I. Each question is stated again with the answer and discussion to follow. Although the three questions were answered directly from the results in the preceeding chapters, they are again discussed in order to provide a better picture of the course this study has taken.

Research Question 1. What are the statistical distributions of the characteristics of age, weight, height, and sitting height for the current population of female pilots within the United States Air Force?

This is not simply a one line answer. The distributions of the female pilot physical characteristics data are identified in Chapter II through the use of

population this would mean that approximately 190 female pilots weigh less than 140.2 pounds.

Other facts and figures relating to the physical characteristics of female pilots are presented in Chapters II and IV. As the female pilot population grows over the next few years, so will the number of people who go unaccounted for in ejection seat testing.

Research Question 3. Using an ejection system model, what is the potential for spinal injury to lower weight class female pilots required to use the ACES II ejection seat?

Based on the DRI program used for this study and the resulting DRI's, the spinal injury potential for the lowest weight (103 pound) female pilot is approximately 5 percent. In other words, the lowest weight female pilot in the United States Air Force has the possibility of sustaining spinal injuries during an ejection attempt about five percent of the time. This is based on the average of two runs using two different CKU-5/A catapult firings at the same temperature of 70 degrees Fahrenheit. Accordingly, this percentage is an acceptable risk level according to Mil-S-9479B.

However, it would be wrong to categorically state that the spinal injury potential for lower weight class female pilots is at a constant 5 percent level and therefore

population this would mean that approximately 190 female pilots weigh less than 140.2 pounds.

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However, it would be wrong to categorically state that the spinal injury potential for lower weight class female pilots is at a constant 5 percent level and therefore

acceptable. This is because of the many various factors that were not possible to consider in this study (e.g., catapult firings of a different mass). Therefore, for purposes of this study, there is no definitive answer to research question 3.

The results of this study demonstrate that the lowest weight female pilots are at the edge of the acceptable risk limit. Several more catapult firings and subsequent DRI runs on the model may indicate that the DRI could be over this limit. Thus, the research team concludes that the results indicate an acceptable level of injury risk for the limited information available at this time; but, proper CKU-5/A test firing information must be gathered to clearly establish this fact for all cases.

One other conclusion was made with regard to DRI's and the 232ACES2 computer model which was initially used in this study. It was suggested that before the U.S. Air Force accepts the results of this model, contractor personnel should update their program to include varying Gz curves for different weight conditions during the CKU-5/A catapult phase (i.e., approximately the first .2 second) of the ejection. This would provide realistic DRI's during the phase in which DRI measurement is most valid. As it was, the DRI's provided by the 232ACES2 model were nearly constant for all runs and considerably lower than those

obtained by the research team when using AFWAL's program.

General Recommendations

Recommendation I. Recommend that the U.S. Air Force either contract for, or perform a series of CKU-5/A rocket catapult firings. These firings should use a mass which is equivalent to the total ejected weight of a lower weight class female pilot using the ACES II seat. In this manner, actual thrust-time curves for an appropriate weight can be derived for use in computing the DRI's for lower weight class female pilots.

These catapult firings should include a sufficient number to include varying grain temperatures as well as providing statistically significant results. Recommend that these test firings be accomplished as soon as possible in order to provide data for personnel at the T-46 SPO.

Recommendation II. Recommend that a data base supplemental to the Atlas data base be created for rated officers both male and female. This data base should contain pertinent medical information which would assist in studies similar to this one and for the design of advanced crew escape systems. This data base could be maintained by an agency such as Aerospace Medical Research Laboratories (AMRL). Also, convenient updating could take place when the officer received his/her annual flight physical.

This recommendation requires considerable investigation in terms of feasibility. We recommend that this be considered as a potential research topic.

Recommendation III. Based on the results of this study the research team recommends that no waivers be granted for female pilots weighing less than 103 pounds. Evidence clearly suggests that, below this weight, the maximum DRI would be exceeded using the ACES II ejection seat in its current configuration.

Recommendation IV. Recommend that Weber Aircraft update their 232ACES2 computer ejection model to include varying Gz curves for lower weight class personnel. This is necessary to attain a valid assessment of DRI during the first .2 second of an ejection, the most critical phase for DRI.

Recommendations for Further Study

Recommendation I. Recommend that the AFWAL's SAFEST computer ejection model be used to investigate the spinal injury potential for lower weight class female pilots. This was the original intent of this study; however, software problems with the SAFEST model precluded its usage.

If this model is used for further research, it is recommended that additional test subjects be incorporated

in order to get a larger representation of the population. Also, recommend that lower weight class males be used as test subjects and that the data obtained from their runs be used as comparison data with the lower weight class females.

Recommendation II. Recommend that investigation of injury potential to lower weight class female pilots be expanded beyond the catapult phase of ejection with the capabilities of the SAFEST ejection model and/or the 232ACES2 ejection model (provided it is properly validated). Full trajectory analysis should be possible. Inquiries into areas such as wind blast and parachute opening shock effects are possibilities for investigation.

Another computer model, the Mcdonnell-Douglas model, could possibly be made available to further the efforts of a study in this area. By using all models available, validation of the results would be more statistically significant.

Recommendation III. Recommend that a feasibility study be conducted on the development of a lower weight class (e.g., first or fifth percentile) female ejection dummy. The study would need to address the establishment of a first through fifth percentile center-of-gravity profile for lower weight female pilots. Also, cost considerations need to be taken into account. This

ejection dummy would aide in assessing injury potential because it would be used in actual sled tests.

Recommendation IV. A complete examination of female center-of-gravity and inertial properties should be conducted to determine if current ejection seat designs do not preclude safe ejection by female pilots. A preliminary investigation using the test subjects' centers-of-gravity by Mr. Vic Santi, an ejection systems expert, indicate that five of the test subjects had a center-of-gravity more than two inches above the the rocket thrust line. A Douglas Aircraft report (1:13) states that the STAPAC unit in the ACES II ejection seat is designed to compensate for an ejectee's centur of gravity which lies within two inches of the rocket thrust line. If this value of two inches is exceeded, it could lead to serious instabilities during the rocket firing.

Summary

This research has focused on assessing spinal injury potential for lower weight class USAF female pilots required to use the ACES II ejection seat. In assessing this potential, it was necessary to determine the size of the female pilot population, as well as the distribution of physical characteristics for that population. A survey was performed to gather this information. The results of that

survey indicated that the majority of USAF female pilots are in a weight class for which ejection seat testing is not conducted.

Without performing actual ejection seat sled tests, this research project set out to determine spinal injury potential through the use of an ejection system model. The model used was provided by one of the subcontractors that is involved in the development of the T-46A aircraft. Unfortunately, the assumptions made by contractor personnel in running the computer model with the data provided by this research team caused the results to be rejected.

A suitable, but less sophisticated replacement computer program was located and used to assess the spinal injury potential. The results indicated that, although within acceptable limits, the spinal injury potential is right at maximum limit for the lowest weight female pilots as specified in Mil-S-9479B. Recommendations regarding these findings suggested that further study is required to attain a more definitive assessment of spinal injury potential for lower weight female pilots.

Continued investigations regarding female pilots and the ACES II ejection seat, as well as future escape systems, are certainly warranted. As was mentioned early in this report, the female pilot population within the United States Air Force is continually expanding. This

means that appropriate emphasis must be rendered these aviators, especially from a physiological standpoint.

Appendix A: Letter to USAF Flight Surgeons

AFIT/LS (Capt Abati/AV 785-7212) 23 Mar 84

Request for age, height, weight, and sitting height of female pilots at your location.

Dr. Sammy Smith

1. This is a request for information in support of an Air Force Institute of Technology (AFIT) master's degree thesis. The T-46A (follow-on primary jet trainer) System Program Office is sponsoring this investigation to determine the spinal injury risk potential for female aviators who may be required to use the ACES II ejection seat. In order to assess the risk factors for women, it is necessary to obtain data on the current population of female flyers. This information is vital to the completion of this research.
2. Because your wing has been identified as one which has female pilots assigned for flying duty, we believe your office has the information required for this research. The specific information needed is the most recently recorded age, weight, height and, if available, sitting height of each female pilot assigned to your wing. Please note that no individuals or bases will be identified in the study, and all information will be treated as confidential.
3. Attached to this letter is a format designed to allow for convenient entry of the information. We have provided the names and, in many cases, the last four SSAN's of the female pilots we believe are assigned at your location to assist in records searches. The list of female pilots may have some omissions. If possible, please provide the information on those individuals. To further ensure the anonymity of the individuals, vary the order of entries so that it is different from the list of names and SSAN's provided. However, ensure that each line pertains to only one individual. Please include any additional entries on a separate sheet if necessary. After recording this information, please return it in the enclosed addressed envelope as soon as possible, but no later than 15 April 1984.
4. In order to complete this research before actual testing of the T46-A ejection seat begins, we need this information at your earliest convenience. Your help in this research is greatly appreciated. Should you have any questions concerning either the information requested or the specific nature of this research, please contact Capt David Abati or Capt Michael Belcher at AV 785-7212. Thank you in advance for your cooperation.

DAVID W. ABATI, Captain, USAF
AFIT School of Systems and Logistics

4 Atch
1. Indorsement
2. Privacy Act Statement
3. Information Entry Sheet
4. Return Envelope

Appendix B: Responses from the Flight Surgeon Letters

The following table gives a breakdown of the responses received from each flight surgeon by individual bases.

BASE	EXPECTED	ACTUAL	DIFFERENCE	REASON
1	3	3	-	
2	3	3	-	
3	2	0	-2	Did not report.
4	2	3	+1	New arrival.
5	3	3	-	
6	3	3	-	
7	3	3	-	
8	5	5	-	
9	3	0	-3	Did not report.
10	3	3	-	
11	1	0	-1	DOS.
12	1	2	+1	New arrival.
13	1	1	-	
14	4	3	-1	records unavailable.
15	3	2	-1	TDY SOS.
16	2	2	-	
17	1	1	-	
18	2	2	-	
19	2	2	-	
20	1	1	-	
21	1	1	-	
22	1	1	-	
23	2	2	-	
24	2	0	-2	Did not report.
25	5	3	-2	PCS.
26	2	1	-1	PCS.
27	6	6	-	
28	2	2	-	
29	5	5	-	
30	12	9	-3	2 TDY, 1 PCS.
31	4	4	-	
32	17	12	-5	2 TDY, 1 PCS, 2 Unknown.
33	4	5	+1	New arrival.
34	4	4	-	
35	1	1	-	

Responses from the Flight Surgeon Letters

BASE	EXPECTED	ACTUAL	DIFFERENCE	REASON
36	6	5	-1	Unknown.
37	1	1	-	
38	4	4	-	
39	3	3	-	
40	3	3	-	
41	1	1	-	
42	6	4	-2	Unknown.
43	3	0	-3	Did not report.
44	1	6	+5	New arrivals.
45	2	2	-	
46	4	3	-1	Unknown.
47	19	18	-1	Unknown.
48	16	15	-1	Unknown.
49	7	0	-7	Did not report.
50	20	16	-4	3 PCS, 1 Eliminated from UPT.
51	16	11	-5	Unknown.
52	33	25	-8	Unknown.
Totals	261	215	-46	

The above breakdown shows that 48 out of 52 flight surgeons responded to the request, or 92 % of the total number of letters were returned with the requested data.

The ATLAS search identified 261 female pilots are currently on active duty. Taking away the DOS pilot and the eliminated student pilot, this figure becomes 259. Data was received on 215 female pilots, or 83 % of the total female pilots on active duty as of February 1984.

Appendix C: Current USAF Female Pilot Characteristic Survey

WEIGHT	HEIGHT	SITTING HEIGHT	AGE
103.00	64.00	34.00	24
106.00	65.00	34.50	29
107.00	66.00	36.37	30
107.50	65.50	34.00	23
108.00	65.00	35.00	23
110.00	63.00	34.00	23
110.00	64.00	34.50	24
110.00	64.00	34.50	24
110.00	64.50	35.50	29
110.00	65.00	33.75	24
110.00	65.00	35.00	25
110.00	65.50	34.50	25
111.00	66.00	35.75	26
112.00	64.00	36.00	24
112.00	65.00	35.50	25
112.00	66.00	36.50	22
113.00	64.00	35.00	24
113.00	65.00	34.75	23
114.00	64.50	34.50	29
114.00	65.00	34.50	22
114.50	66.00	36.25	25
115.00	64.00	34.00	27
115.00	67.25	35.50	23
116.00	64.50	34.00	22
116.00	65.00	34.00	27
116.00	69.00	35.50	22
117.00	65.50	35.00	30
117.25	65.00	34.25	24
118.00	64.50	34.50	33
118.00	66.00	34.50	31
119.00	64.75	35.25	31
120.00	63.50	34.25	26
120.00	64.00	33.50	25
120.00	64.00	34.50	24
120.00	64.00	35.25	25
120.00	64.50	34.00	31
120.00	65.00	34.00	21
120.00	65.00	34.50	25
120.00	65.00	34.50	25
120.00	65.00	35.00	26
120.00	65.50	34.00	24
121.00	64.00	30.00	25

Current	USAF	Female	Pilot	Characteristic	Survey
121.00	65.50	36.50	24
122.00	64.00	34.00	23
122.00	64.00	34.00	26
122.00	64.50	35.50	33
122.00	65.00	34.00	24
122.00	65.00	35.00	30
122.00	67.00	35.25	34
122.00	68.00	34.50	25
122.00	68.00	35.50	24
122.00	68.00	36.75	24
122.00	68.00	36.75	25
122.00	69.00	35.00	30
123.00	64.00	34.50	24
123.00	64.50	35.00	24
123.00	66.00	35.25	26
124.00	64.00	35.75	34
124.00	65.00	35.00	27
124.00	65.50	35.00	24
124.00	66.00	34.75	22
124.00	67.00	36.00	26
125.00	65.00	35.00	25
125.00	66.00	34.00	25
125.00	66.00	34.25	23
125.00	66.00	35.00	29
126.00	65.00	35.25	24
127.00	63.50	34.50	28
127.00	65.00	34.50	25
127.00	66.00	35.00	24
127.00	66.00	35.50	24
127.00	66.00	36.00	24
127.00	67.00	34.50	26
127.00	67.00	35.00	25
127.00	68.00	35.00	24
127.00	69.00	36.50	30
128.00	64.50	35.75	25
128.00	65.00	35.00	23
128.00	66.00	34.50	23
128.00	66.00	34.50	28
128.00	66.00	36.00	30
128.00	66.25	34.50	23
128.00	68.00	36.00	25
128.00	68.00	37.00	27
129.00	64.00	34.75	25
129.00	64.00	35.00	28
129.00	65.00	34.50	26
129.00	66.00	34.00	26

Current USAF Female Pilot Characteristic Survey

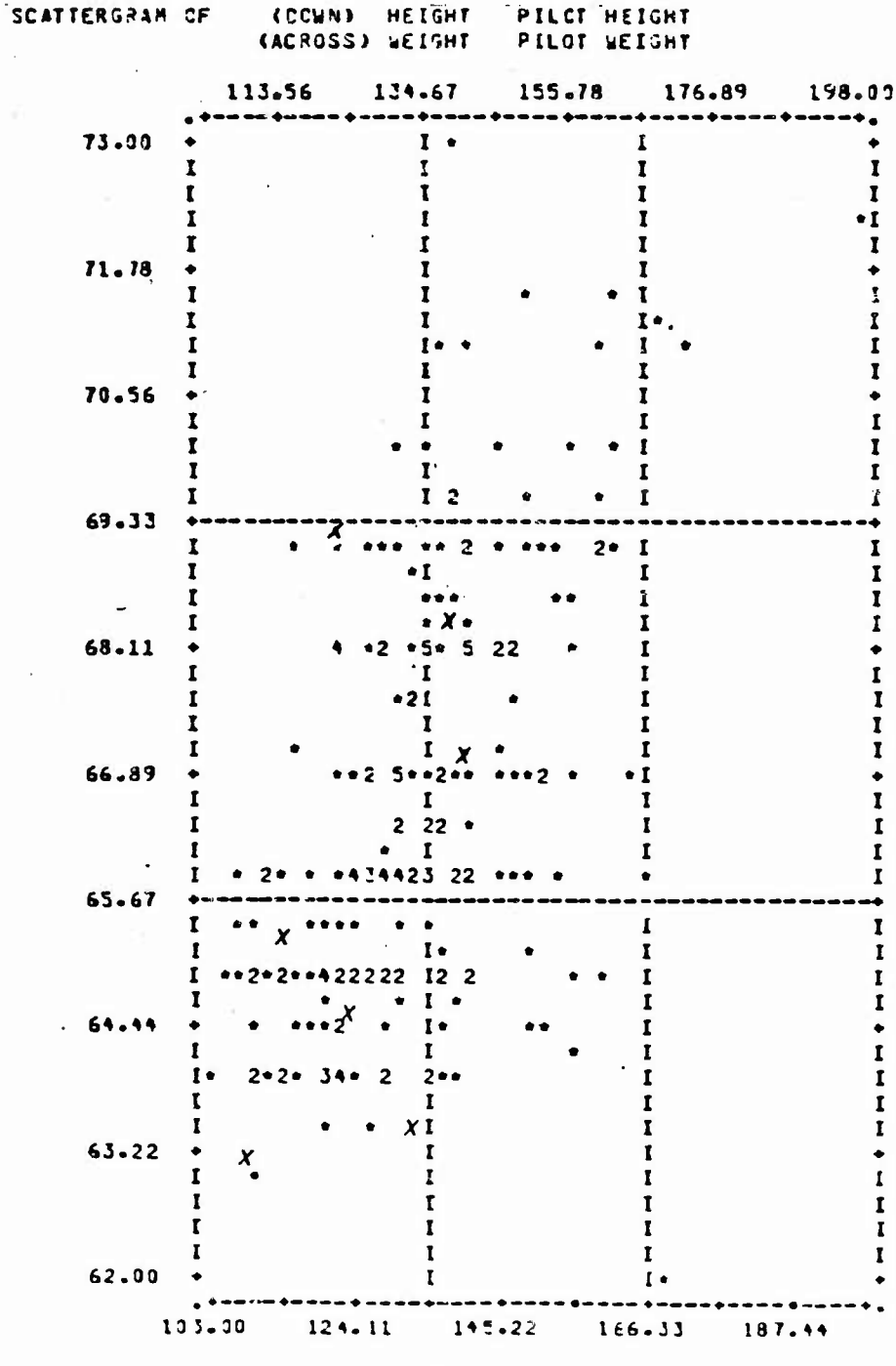
129.00	69.00	36.00	26
130.00	64.75	34.50	22
130.00	65.00	34.00	23
130.00	65.50	34.25	23
130.00	66.00	34.75	22
130.00	66.00	35.00	29
130.00	66.00	35.25	34
130.00	66.50	35.50	23
130.00	67.00	35.00	24
130.00	67.00	35.00	26
130.00	67.00	35.00	28
130.00	67.00	35.25	25
130.00	67.00	35.25	27
130.00	67.50	35.50	22
130.00	69.00	35.50	25
130.00	70.00	34.50	22
131.00	65.00	34.50	27
131.00	66.00	35.25	32
131.00	66.50	34.50	22
132.00	67.50	34.00	30
132.00	68.75	36.25	24
133.00	66.00	35.75	30
133.00	66.00	36.00	24
133.00	67.00	34.75	25
133.00	67.50	35.00	24
133.00	68.00	37.00	22
134.00	64.00	34.50	25
134.00	65.50	35.75	23
134.00	66.00	36.00	24
134.00	68.00	34.75	31
135.00	64.00	34.00	24
135.00	66.00	35.00	22
135.00	66.50	35.50	23
135.00	66.50	36.00	29
135.00	67.00	36.50	26
135.00	68.00	34.00	21
135.00	68.00	35.00	22
135.00	68.00	35.25	24
135.00	68.00	36.25	25
135.00	68.25	34.50	22
135.00	68.50	38.75	22
135.00	69.00	36.00	26
135.00	70.00	36.00	24
135.25	66.00	36.00	23
136.00	67.00	35.00	28
136.00	67.00	35.50	24

Current	USAF	Female	Pilot	Characteristic	Survey
136.00	68.00	36.00	32
136.00	68.50	35.50	22
136.00	69.00	37.00	25
137.00	64.00	34.75	29
137.00	64.50	34.25	22
137.00	65.00	35.00	24
137.00	65.00	35.25	22
137.00	66.50	35.00	24
137.00	66.50	35.00	24
137.00	71.00	36.50	25
137.50	65.25	35.00	24
138.00	64.00	35.25	29
138.00	66.00	34.00	23
138.00	67.00	35.00	25
138.00	73.00	38.75	28
139.00	66.00	35.50	26
139.00	68.50	35.75	22
139.00	69.50	34.50	23
139.00	69.50	37.00	24
139.50	64.75	36.25	24
140.00	65.00	35.25	25
140.00	66.00	35.00	27
140.00	66.00	36.00	25
140.00	68.00	34.25	23
140.00	68.00	34.75	24
140.00	68.00	35.00	25
140.00	68.00	36.50	25
140.00	69.00	35.50	24
140.00	69.00	37.00	27
141.00	68.00	35.00	28
141.00	68.25	35.75	22
142.00	65.00	35.50	28
142.00	66.50	34.75	23
142.00	67.00	33.25	25
142.00	71.00	36.50	22
145.00	67.25	35.75	22
145.00	68.00	35.00	25
145.00	69.00	35.00	22
145.00	70.00	36.25	30
146.00	66.00	35.75	21
146.00	67.00	36.00	25
146.00	68.00	35.75	34
147.00	67.00	34.50	28
147.00	68.00	35.50	26
148.00	66.00	35.50	27
148.00	67.50	37.50	28

Current USAF Female Pilot Characteristic Survey

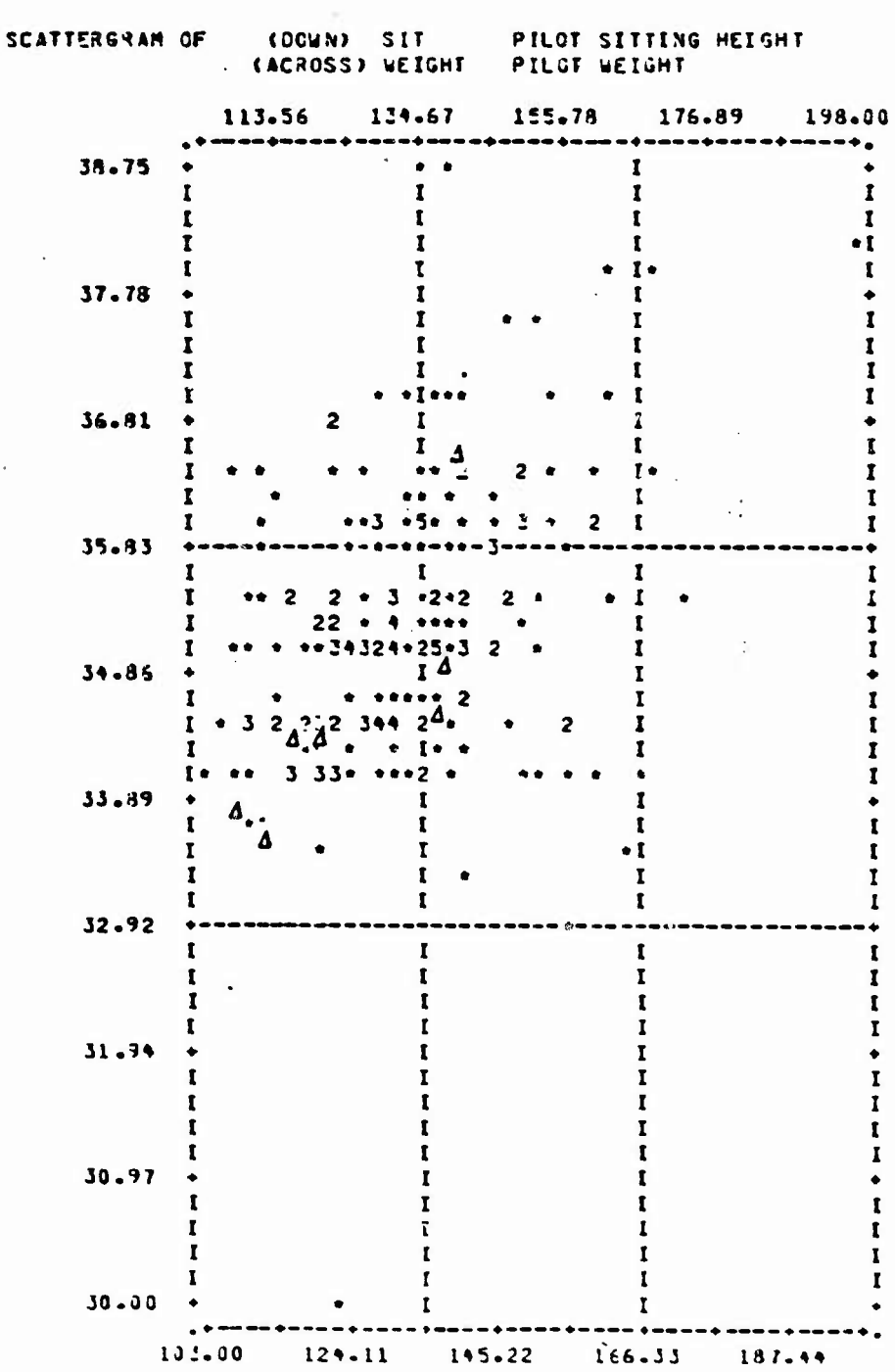
148.00	68.00	*****	24
149.00	65.25	36.00	23
149.00	67.00	36.00	26
149.00	69.00	35.25	26
149.00	71.50	36.50	28
150.00	64.50	34.00	31
150.00	66.00	36.00	26
150.00	69.50	36.50	23
151.00	67.00	34.00	28
151.00	69.00	37.50	30
152.00	64.50	35.50	28
152.00	67.00	35.00	25
153.00	68.50	36.50	24
153.00	69.00	37.00	26
154.00	66.00	36.00	24
155.00	64.25	33.00	27
155.00	67.00	*****	30
155.00	70.00	34.50	23
156.00	65.00	34.00	35
156.00	68.00	34.50	25
156.00	68.50	35.75	24
159.00	69.00	36.00	30
160.00	65.00	34.00	25
160.00	69.00	*****	25
160.00	69.50	36.50	25
161.00	71.00	36.00	23
162.00	70.00	35.50	28
162.00	71.50	38.00	21
163.00	69.00	37.00	24
165.00	67.00	33.50	25
166.00	66.00	34.00	25
168.00	62.00	36.50	30
168.00	71.25	38.00	24
173.00	71.00	35.50	24
198.00	72.25	38.25	22

Appendix D: Weight vs Height



X = Test Subject

Appendix E: Weight vs Sitting Height



Δ = Test Subject

Appendix F: Frequency Distributions Computer Printouts

PILOT AGE

CATEGORY LABEL	CODE	ABSOLUTE FREQ	RELATIVE FREQ (PCT)	ADJUSTED FREQ (PCT)	CUM FREQ (PCT)
	21.	4	1.9	1.9	1.9
	22.	24	11.2	11.2	13.0
	23.	24	11.2	11.2	24.2
	24.	46	21.4	21.4	45.6
	25.	40	18.6	18.6	64.2
	26.	19	8.8	8.8	73.0
	27.	10	4.7	4.7	77.7
	28.	14	6.5	6.5	84.2
	29.	8	3.7	3.7	87.9
	30.	13	6.0	6.0	94.0
	31.	5	2.3	2.3	96.3
	32.	2	.9	.9	97.2
	33.	2	.9	.9	98.1
	34.	3	1.4	1.4	99.5
	35.	1	.5	.5	100.0
	TOTAL	215	100.0	100.0	

Frequency Distributions Computer Printouts

PILOT WEIGHT

CATEGORY LABEL	CODE	ABSOLUTE FREQ	RELATIVE FREQ (PCT)	ADJUSTED FREQ (PCT)	CUM FREQ (PCT)
	103.	1	.5	.5	.5
	106.	1	.5	.5	.9
	107.	1	.5	.5	1.4
	108.	1	.5	.5	1.9
	108.	1	.5	.5	2.3
	110.	7	3.3	3.3	5.6
	111.	1	.5	.5	6.0
	112.	3	1.4	1.4	7.4
	113.	2	.9	.9	8.4
	114.	2	.9	.9	9.3
	115.	1	.5	.5	9.8
	115.	2	.9	.9	10.7
	116.	3	1.4	1.4	12.1
	117.	1	.5	.5	12.6
	117.	1	.5	.5	13.0
	118.	2	.9	.9	14.0
	119.	1	.5	.5	14.4
	120.	10	4.7	4.7	19.1
	121.	2	.9	.9	20.0
	122.	11	5.1	5.1	25.1
	123.	3	1.4	1.4	26.5
	124.	5	2.3	2.3	28.8
	125.	4	1.9	1.9	30.7
	126.	1	.5	.5	31.2

Frequency Distributions Computer Printouts

127.	9	4.2	4.2	35.3
128.	8	3.7	3.7	39.1
129.	5	2.3	2.3	41.4
130.	15	7.0	7.0	48.4
131.	3	1.4	1.4	49.8
132.	2	.9	.9	50.7
133.	5	2.3	2.3	53.0
134.	4	1.9	1.9	54.9
135.	14	6.5	6.5	61.4
136.	5	2.3	2.3	63.7
137.	7	3.3	3.3	67.0
138.	1	.5	.5	67.4
138.	4	1.9	1.9	69.3
139.	4	1.9	1.9	71.2
140.	1	.5	.5	71.6
140.	9	4.2	4.2	75.8
141.	2	.9	.9	76.7
142.	4	1.9	1.9	78.6
145.	4	1.9	1.9	80.5
146.	3	1.4	1.4	81.9
147.	2	.9	.9	82.8
148.	3	1.4	1.4	84.2
149.	4	1.9	1.9	86.1

Frequency Distributions Computer Printouts

150.	3	1.4	1.4	87.4
151.	2	.9	.9	88.4
152.	2	.9	.9	89.3
153.	2	.9	.9	90.2
154.	1	.5	.5	90.7
155.	3	1.4	1.4	92.1
156.	3	1.4	1.4	93.5
159.	1	.5	.5	94.0
160.	3	1.4	1.4	95.3
161.	1	.5	.5	95.8
162.	2	.9	.9	96.7
163.	1	.5	.5	97.2
165.	1	.5	.5	97.7
166.	1	.5	.5	98.1
168.	2	.9	.9	99.1
173.	1	.5	.5	99.5
198.	1	.5	.5	100.0
TOTAL	215	100.0	100.0	

Frequency Distributions Computer Printouts

PILOT HEIGHT	CODE	ABSOLUTE FREQ	RELATIVE FREQ (PCT)	ADJUSTED FREQ (PCT)	CUM FREQ (PCT)
	62.	1	.5	.5	.5
CATEGORY LABEL	63.	1	.5	.5	.9
	64.	2	.9	.9	1.9
	64.	21	9.8	9.8	11.6
	64.	1	.5	.5	12.1
	65.	10	4.7	4.7	16.7
	65.	3	1.4	1.4	18.1
	65.	29	13.5	13.5	31.6
	65.	2	.9	.9	32.6
	66.	8	3.7	3.7	36.3
	66.	35	16.3	16.3	52.6
	66.	1	.5	.5	53.0
	67.	7	3.3	3.3	56.3
	67.	22	10.2	10.2	66.5
	67.	2	.9	.9	67.4
	68.	4	1.9	1.9	69.3
	68.	24	11.2	11.2	80.5
	68.	2	.9	.9	81.4
	69.	5	2.3	2.3	83.7
	69.	1	.5	.5	84.2
	69.	16	7.4	7.4	91.6
	70.	4	1.9	1.9	93.5
	70.	5	2.3	2.3	95.8
	71.	4	1.9	1.9	97.7
	71.	1	.5	.5	98.1
	72.	2	.9	.9	99.1
	72.	1	.5	.5	99.5
	73.	1	.5	.5	100.0
	TOTAL	215	100.0	100.0	

Frequency Distributions Computer Printouts

PILOT SITTING HEIGHT

CATEGORY LABEL	CODE	ABSOLUTE FREQ	RELATIVE FREQ (PCT)	ADJUSTED FREQ (PCT)	CUM FREQ (PCT)
	30.	1	.5	.5	.5
	33.	1	.5	.5	.9
	33.	1	.5	.5	1.4
	34.	2	.9	.9	2.4
	34.	1	.5	.5	2.8
	34.	24	11.2	11.3	14.2
	34.	6	2.8	2.8	17.0
	35.	30	14.0	14.2	31.1
	35.	9	4.2	4.2	35.4
	35.	36	16.7	17.0	52.4
	35.	14	6.5	6.6	59.0
	36.	21	9.8	9.9	68.9
	36.	11	5.1	5.2	74.1
	36.	21	9.8	9.9	84.0
	36.	5	2.3	2.4	86.3
	36.	1	.5	.5	86.8
	37.	12	5.6	5.7	92.5
	37.	2	.9	.9	93.4
	37.	7	3.3	3.3	96.7
	38.	2	.9	.9	97.6
	38.	2	.9	.9	98.6
	38.	1	.5	.5	99.1
	39.	2	.9	.9	100.0
	BLANK	3	1.4	MISSING	
	TOTAL	215	100.0	100.0	

Appendix G: Center of Gravity and Inertial Properties (Manually Generated)

test subject	# 1		# 2		# 3	
standing height	67 inches		69 inches		65 inches	
sitting height	35 inches		34 inches		33 inches	
age	33		29		33	
weight	143.33		121.30		112.95	
flight gear	14.00		14.00		14.00	
kit weight	25.40	66.70	25.40	66.70	25.40	66.70
total weight	309.25	350.55	287.25	328.55	278.90	320.20
Ixx	12.2431	12.9664	12.3118	13.0392	11.6087	12.2945
Iyy	14.6727	14.9431	14.9779	15.2539	13.8525	14.1078
Izz	6.6027	6.3154	4.9775	4.7609	5.3531	5.1202
Ixy	0.0952	0.1010	-0.1455	-0.1372	-0.0041	-0.0039
Ixz	4.3741	4.2132	4.5764	4.4080	3.9755	3.8292
Iyz	-0.2322	-0.4680	0.2024	0.1004	0.2255	0.1119
x	0.8461	0.8773	0.8517	0.8829	0.8081	0.8393
y	0.0756	0.0660	0.0764	0.0668	0.0749	0.0653
z	-1.3535	-1.2453	-1.3474	-1.2392	-1.3272	-1.2190

Notes: center's of gravity and inertial data manually generated from the raw data.

x, y & z center of gravity location units are in feet measured from the lower roller of the ACES II ejection seat.

Ixx, Iyy, Izz, Ixy, Ixz & Iyz units are slug feet squared.

flight gear includes flight suit, helmet, and boots.

Center of Gravity and Inertial Properties (Manually Generated)

test subject	# 4		# 5		# 6	
standing height	63.5 inches		64.5 inches		68.5 inches	
sitting height	34.5 inches		34 inches		36 inches	
age	25		29		25	
weight	133.80		122.10		136.20	
flight gear	14.00		14.00		14.00	
kit weight	25.40	66.70	25.40	66.70	25.40	66.70
total weight	301.75	343.05	288.05	329.35	302.15	343.45
Ixx	12.9330	13.6970	12.3463	13.0757	13.0749	13.8473
Iyy	14.6482	14.9182	13.7836	14.0376	13.3634	15.6465
Izz	6.9038	6.6034	6.1554	5.8876	6.0692	5.8051
Ixy	0.0989	0.1049	-0.2769	-0.2610	-0.0411	-0.0387
Ixz	4.2159	4.0608	3.6277	3.4942	3.8871	3.7440
Iyz	-0.2491	-0.5020	-1.1784	-2.3748	-0.1481	-0.2985
x	0.8365	0.8677	0.7890	0.8202	0.8308	0.8620
y	0.1008	0.0912	0.1568	0.1472	0.0672	0.0576
z	-1.3497	-1.2415	-1.3620	-1.2538	-1.3812	-1.2730

Notes: center's of gravity and inertial data manually generated from the raw data.

x, y & z center of gravity location units are in feet measured from the lower roller of the ACES II ejection seat.

Ixx, Iyy, Izz, Ixy, Ixz & Iyz units are slug feet squared.

flight gear includes flight suit, helmet, and boots.

Center of Gravity and Inertial Properties (Manually Generated)

test subject	# 7	
standing height	63 inches	
sitting height	33.5 inches	
age	36	
weight	107.05	
flight gear	14.00	
kit weight	25.40	66.70
total weight	273.00	314.30
Ixx	10.5589	11.1872
Iyy	12.7028	12.9369
Izz	5.0788	4.8578
Ixy	0.6233	0.6612
Ixz	2.9704	2.8611
Iyz	-0.4030	-0.8122
x	0.7906	0.8218
y	0.0716	0.0620
z	-1.3723	-1.2641

Notes: center's of gravity and inertial data manually generated from the raw data.

x, y & z center of gravity location units are in feet measured from the lower roller of the ACES II ejection seat.

Ixx, Iyy, Izz, Ixy, Ixz & Iyz units are slug feet squared.

flight gear includes flight suit, helmet, and boots.

Appendix H: Center of Gravity and Inertial Properties (Computer Generated)

test subject	# 1		# 2		# 3	
standing height	67 inches		69 inches		65 inches	
sitting height	35 inches		34 inches		33 inches	
age	33		29		33	
weight	143.30		121.30		112.95	
flight gear	14.00		14.00		14.00	
kit weight	25.40	66.70	25.40	66.70	25.40	66.70
total weight	309.25	350.55	287.25	328.55	278.90	320.20
Ixx	12.2273	12.8241	12.2939	12.8778	11.6150	12.1642
Iyy	14.5208	14.7017	14.8028	14.9687	13.7627	13.9121
Izz	6.2396	5.9915	5.0086	4.7598	5.2687	5.0381
Ixy	0.3214	0.3645	-0.0040	0.0385	0.2826	0.3217
Ixz	3.7868	3.6216	3.9100	3.7402	3.5471	3.4096
Iyz	-0.2039	-0.6094	0.2442	-0.1647	0.2535	-0.1539
x	0.8497	0.8707	0.8524	0.8745	0.8106	0.8386
y	0.0683	0.0601	0.0731	0.0637	0.0734	0.0637
z	-1.3515	-1.2569	-1.3475	-1.2471	-1.3294	-1.2287

Notes: center's of gravity and inertial data computer generated from the raw data.

x, y & z center of gravity location units are in feet measured from the lower roller of the ACES II ejection seat.

Ixx, Iyy, Izz, Ixy, Ixz & Iyz units are slug feet squared.

flight gear includes flight suit, helmet, and boots.

Center of Gravity and Inertial Properties (Computer Generated)

test subject	# 4		# 5		# 6	
standing height	63.5 inches		64.5 inches		68.5 inches	
sitting height	34.5 inches		34 inches		36 inches	
age	25		29		25	
weight	135.80		122.10		136.20	
flight gear	14.00		14.00		14.00	
kit weight	25.40	66.70	25.40	66.70	25.40	66.70
total weight	301.75	343.05	288.05	329.35	302.15	343.45
Ixx	12.8797	13.4735	12.2488	12.8765	13.0514	13.6924
Iyy	14.4941	14.8714	13.6754	13.8931	15.1285	15.3626
Izz	6.4374	6.1978	5.7927	5.5898	5.8478	5.6032
Ixy	0.3357	0.3728	-0.2603	-0.1824	0.1946	0.2410
Ixz	3.6911	3.5338	3.3263	3.2127	3.4826	3.3406
Iyz	-0.2207	-0.6484	-1.3431	-1.8217	-0.0917	-0.4802
x	0.8398	0.8625	0.7937	0.8231	0.8345	0.8578
y	0.0933	0.0819	0.1483	0.1295	0.0481	0.0422
z	-1.3485	-1.2522	-1.3612	-1.2593	-1.3781	-1.2783

Notes: center's of gravity and inertial data computer generated from the raw data.

x, y & z center of gravity location units are in feet measured from the lower roller of the ACES II ejection seat.

Ixx, Iyy, Izz, Ixy, Ixz & Iyz units are slug feet squared.

flight gear includes flight suit, helmet, and boots.

Center of Gravity and Inertial Properties (Computer Generated)

test subject	# 7	
standing height	63 inches	
sitting height	33.5 inches	
age	36	
weight	107.05	
flight gear	14.00	
kit weight	25.40	66.70
total weight	273.00	314.30
Ixx	10.5710	11.1934
Iyy	12.6881	12.5678
Izz	5.0538	4.4788
Ixy	0.6296	0.9147
Ixz	2.9310	3.4193
Iyz	-0.4037	-0.8128
x	0.7935	0.8247
y	0.0716	0.0620
z	-1.3721	-1.2639

Notes: center's of gravity and inertial data computer generated from the raw data.

x, y & z center of gravity location units are in feet measured from the lower roller of the ACES II ejection seat.

Ixx, Iyy, Izz, Ixy, Ixz & Iyz units are slug feet squared.

flight gear includes flight suit, helmet, and boots.

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Title: AN INVESTIGATION OF SPINAL INJURY POTENTIAL FROM THE USE OF THE ACES II EJECTION SEAT BY LOWER WEIGHT FEMALE PILOTS

Thesis Advisor: James R. Coakley, Major, USAF

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Historically, ejection seat sled tests conducted to assess injury potential to pilots have only incorporated the 5th through 95th percentile male weights. Since female pilots within the United States Air Force have increased in number during the past seven years, it was estimated that the risks associated with an ejection emergency for female pilots have not been adequately evaluated during ejection seat testing. The objectives of this thesis were to determine the percentage of female pilots who weigh less than the 5th percentile male and then to determine the spinal injury potential for these lower weight females with regards to the ACES II ejection seat. It was determined that the majority of female pilots are in a weight class below the 5th percentile male, and Also, it was determined that, based upon a computer model, the spinal injury potential is right at the acceptable limits. However, the authors caveat this second conclusion with the fact that a critical input to the computer model that was used, the time-thrust curve for the DKU-5/A cartridge catapult, represented the thrust experienced by a 215 pound individual. Actual CKU-5/A test firings are scheduled to be accomplished in September 1984 before the second conclusion can be realistically accepted. Recommendations for further study indicate investigations of the injury potential for lower weight female pilots during the entire ejection sequence are necessary.