ANTHROPOMETRIC ACCOMMODATION IN AIRCRAFT COCKPITS:

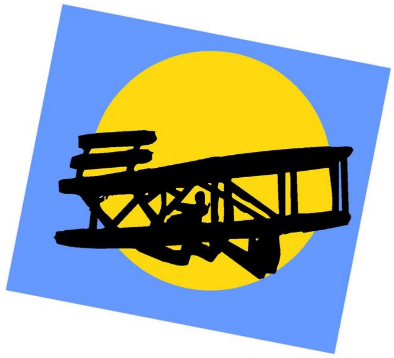
METHODOLOGIES FOR EXAMINATION

1 June 2001

Kenneth W. Kennedy, Ph.D.
Yellow Springs, OH

ENTER HERE

GO TO CONTENTS



ANTHROPOMETRIC ACCOMMODATION IN AIRCRAFT COCKPITS:

METHODOLOGIES FOR EXAMINATION

1 June 2001

For a Review of this web site, see the June 2003 edition of ***The Ergonomist***.

PURPOSE

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RESUMÉ

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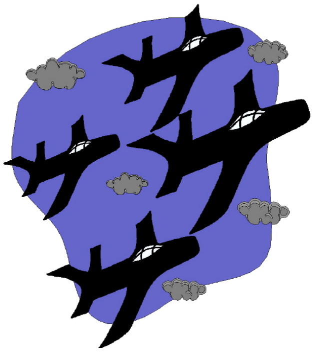
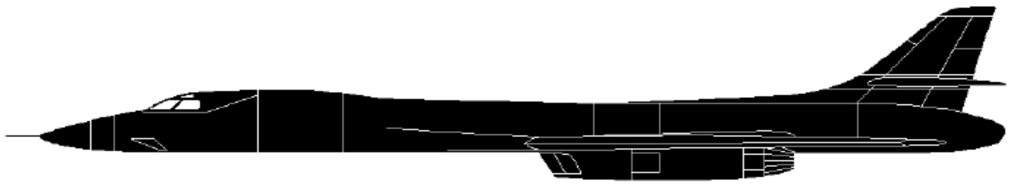


GO TO CONTENTS



HOME
Contact

TABLE OF CONTENTS

Just click on "GO."

HOME
BACK TO CONTENTS

F-117A Stealth Fighter

Contact

PURPOSE

The purpose of this site is to serve as a gathering place of techniques for examining aircraft cockpits in terms directly related to optimum aircraft operation. The focus is limited to accommodation, or lack thereof, to the variability in body sizes and proportions of the potential pilot populations - his/her anthropometrY.

Engineers and Human Factors specialists from the military and governmental agencies, industry and academia interested in the design and evaluation of aircraft cockpits are invited to participate by offering additional, supplemental and alternative methods of evaluation and critiques.

PROVISO

The author acknowledges that the United States Government, its agencies and military services, specifically the United States Air Force, do not necessarily condone or support the techniques of cockpit examination and evaluation described herein. This document is a compilation of the techniques developed and reported by the author and by personnel of the Cockpit Accommodation Facility, AFRL, Wright-Patterson AFB, OH.

HOME

RESUMÉ

July 2007

KENNETH W. KENNEDY, Ph.D.

Yellow Springs, OH

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ENGINEERING ANTHROPOMETRY -- CREW STATION GEOMETRY -- HUMAN MECHANICS

EDUCATION:

Ph.D. Engineering Anthropometry, Union Graduate Institute (1976)
M.A. Human Anatomy, University of Michigan (1965)
Graduate Study, Physical Anthropology and Zoology, University of Michigan (1956-1958)
Graduate Study, Chemistry, Wayne State University (1955)
B.S. Area in Science, Murray State University (1952)

SPECIAL COURSES:

Introduction to Robotics, Institute of Industrial Engineers, Norcross, GA (1982)
Human Factors Engineering, University of Michigan Summer Conference, Ann Arbor, MI (1975)
Physiological Systems Analysis for Engineers, University of Michigan Summer Conference (1971)
Computer Graphics for Designers, University of Michigan Summer Conference (1969)
Engineering Graphics, University of Dayton, Dayton, OH (1963)

HONORS AND AWARDS:

Sustained Superior Performance Award, Aerospace Medical Research Laboratory (AMRL), Wright-Patterson AFB, OH (1983)
Certificate of Merit, AMRL, W-PAFB, OH (1979)
Human Engineer of the Year, AMRL, W-PAFB, OH (1968)
Scholarship, Graduate Study at the University of Michigan, Awarded by AMRL, W-PAFB, OH (1964-65)

EXPERIENCE:

1990 – Present: Consultant: Engineering Anthropometry
Crew Station Geometry
Human Mechanics

Anthropometric and Biomechanical analyses of aircraft crew stations. Most recent: co-development of techniques to evaluate Anthropometric accommodation in aircraft cockpits, including vertical clearance under overhead: operational and ejection leg and torso clearances: internal and external visual fields of view: control stick/wheel clearance: rudder pedal operation: and hand reach to and actuation of controls. Participated in the examination and analyses of USN T-34C, T-44A, TA-4J, and T-45A and the USAF T-37B, T-38A, T-1A, F-16A/C/D, F-15C/D/E, and C-141A: Enhanced Flight Screener (EFS) and Joint Primary Aircraft Training System (JPATS) competing aircraft. Instrumental in obtaining grant from USAF to examine inventory aircraft.

1986 – 1990: Senior Research Scientist
Universal Energy Systems, Inc.
Dayton, OH 45433

Anthropometric and Biomechanic analyses of all-terrain vehicles for Consumer Products Safety Commission: Presented Industrial Ergonomics Seminars to Ford Co.: Consulted with United States Air Force, Ford Motor Co., Stouffers Foods, Industrial Biomechanics, Inc. and other management and research personnel regarding solution of specific ergonomic problems: Provided legal consultation, analysis, discovery, and other investigative activities in product liability issues: Evaluated proposed spacing for a family of new commercial airline passenger seats for Northwest Airlines and Military Airlift Command: Collated and organized anthropometric data from 5 major surveys to serve as basis for computerized data base for the USAF:

Designed and marketed 2-D engineering design manikins: derived 2- and 3-D kinematic human link models.

1958 – 1986: Research Physical Anthropologist, (Civilian)
Armstrong Aerospace Medical Research Laboratory
United States Air Force
Wright-Patterson Air Force Base, OH

Designed and proofed 2-D male and female Engineering Design Manikins representing U.S. Air Force pilots: Accepted by USAF and Aerospace Industries Association as aerospace industry standard: Recommended by NATO and ASCC (Commonwealth) member nations: Patented. Performed Anthropometric and Biomechanical Evaluations of cockpits of a wide range of inventory and experimental military aircraft, ground support equipment, tanks and ordinance handling vehicles. Derived conventional, variable and low profile aircraft crew station design geometries to achieve body size accommodation for a very high percent of USAF pilots.

Analyzed motion characteristics of the human vertebral column and limbs: Served as basic "skeleton" of USAF Armstrong Laboratory Combiman computer model and USAF and UES/Kennedy 2-D engineering design manikins.

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"Anthropometric Accommodation in Aircraft Cockpits, Methodologies for Examination," An Internet Publication, http://CockpitEval.home.att.net, FrontPage 2000, 1 June 2001.

"Anthropometric Accommodation in Aircraft Cockpits, A Methodology for Examination," with D. Dixon, G. Zehner, P. Files, and J. Hudson, Instructional Compact Disc, Air Force Research Laboratory (AFRL), Crew Systems Interface Division, Cockpit Accommodation Facility, Wright-Patterson Air Force Base, OH, 2000.

"T-38 Cockpit Accommodation: Analytical Techniques," with J.A. Hudson, G. F. Zehner, and D.A. Dixon, Poster Session, SAFE Association 1997 Annual Symposium, Phoenix, AZ, 8-10 September 1997.

"Anthropometric Accommodation in Training Aircraft," with G.F. Zehner, J.A. Hudson, L. Ivey, and J. Anderson, paper presented to 1997 SAFE Association 1997 Annual Symposium, Phoenix, AZ, 8-10 September 1997.

"Assessment of Anthropometric Accommodation in Aircraft Cockpits," with G.F. Zehner, SAFE Journal, Vol. 25, No. 1, January, 1995, pp. 51-57.

"Engineering Anthropometry in Vehicular Design," with J.M. Christensen and J.M. Howard, in Peters, G.A. and Peters, B.J., Editors, Automotive Engineering and Litigation, Vol. 3, Garland Law Publishing, New York & London, 1990.

Derivation of Low Profile and Variable Cockpit Geometries to Achieve 1st to 99th Percentile Accommodation, AAMRL-TR-86-016, Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, OH, March 1986.

A Collation of United States Air Force Anthropometry, AAMRL-TR-85-062, Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, OH, January 1986.

"Workspace Evaluation and Design: USAF Drawing Board Manikins and the Development of Cockpit Geometry Design Guides," Proceedings of a NATO Symposium on Anthropometry and Biomechanics: Theory and Application, 7-11 July 1980, Queens College, Cambridge, England, NATO Conference Series 111, Vol. 16, Edited by R. Easterby, K.H.E. Kroemer, and D.B. Chaffin, Plenum Press, New York and London, 1982.

"Workspace Evaluation and Design: USAF Drawing Board Manikins and the Development of Cockpit Geometry Design Guides," Workload and Ergonomics Branch, Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH, 1979.

Reach Capability of Men and Women: A Three Dimensional Analysis, AMRL-TR-77-50, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, OH, July 1978.

"International Anthropometric Variability and Its Effects on Aircraft Cockpit Design," NATO Advisory Committee on Human Factors Symposium on National and Cultural Variables in Human Factors Engineering, Oosterbeek, The Netherlands, June 1972 and in Ethnic Variables in Human Factors Engineering, Edited by A. Chapanis, The Johns Hopkins University Press, Baltimore and London, 1975.

Visibility Toward the Ground from Selected Tactical Aircraft, with D. McKechnie, AMRL-TR-69-123, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, OH, October 1970.

Development of Design Standards for Ground Support Consoles, with C. Bates, Jr., AMRL-TR-65-163, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, OH, December 1965.

Reach Capability of the USAF Population, Phase 1, The Outer Boundaries of Grasping-Reach Envelopes for the Shirt-Sleeved, Seated Operator, AMRL-TDR-64-59, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, OH, September 1964.

HOME

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"Anthropometric Accommodation in Aircraft Cockpits: A Methodology for Evaluation," with G. F. Zehner, 8th Annual Interservice/Industry Acceleration Colloquium, I-675 Holiday Inn, Dayton, OH, 22 July 1994.

"Human Morphometrics, Motion, and Performance Research," (Final Report for the period March 1990 to September 1993, Contract F33615-89-C-0572) with Bruce Bradtmiller, et al, AL/CF-TR-1994-0038, Armstrong Laboratory, Human Engineering Division, Air Force Materiel Command, Wright-Patterson AFB, OH, June 1994.

"An Evaluation of Body Clearances Offered by the PTC Aerospace XL-C940-01-4C Airline Tourist Class Passenger Seat at Pitch Distances of 30 and 31 Inches," Universal Energy Systems, Inc., Dayton, OH, August 1989.

"Anthropometric and Biomechanic Evaluation of Varian Ximatron, Clinac Softpot and Standard Clinac Pendants for Single Hand/Hold and Control/ Operation of Radiation Therapy Equipment," Universal Energy Systems, Dayton, OH, (Report to Industrial Biomechanics, Inc., Oak Ridge, NC), 4 January 1988.

"All Terrain Vehicle Driving Skills: Anthropometric Considerations," Universal Energy Systems, Inc., Dayton, OH, (Report to the Consumer Products Safety Commission, Washington, DC), November 1987.

"Anthropometric Evaluation of Selected All Terrain Vehicles," Universal Energy Systems, Inc., Dayton, OH, (Report to Consumer Products Safety Commission, Washington, DC), November 1987.

"A Collation of United States Army and Air Force Anthropometry," Universal Energy Systems, Inc., Dayton, OH, final product Contract F33615-85-C-0541 (USA), September 1987.

"Repetitive Trauma Disorders: Job Evaluation and Design," with Armstrong, T.J., Radwin, R.G., and Hansen, D.J., Human Factors, 28:3,325-336, June 1986.

"The Effects of Inflation of Antishock Trousers on Hemodynamics in Normalvolemic Subjects," with T. Jenning, J. Seaworth, L. Tripp, L. Howell, and C. Goodyear, Journal of Trauma, April 1985.

"Some Effects of Increasing the Range of Body Sizes to be Accommodated in High Performance Aircraft," USAF Multi-Disciplinary Workshop, Pilot Selection and Flying Physical Standards for the 1980s, Air Force Medical Service Center, Brooks Air Force Base, TX, 3-5 April 1979.

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"New USAF Drawing Board Manikins for Crew Station Design," Proceedings of the 46th Annual Scientific Meetings of the Aerospace Medical Association, San Francisco Hilton, San Francisco, CA, 30 April 1975.

"Paths of Movement of Body Members in the Aircraft Cockpit," with S.

Deivanayagam and M.M. Ayoub, Proceedings of the Annual Meeting of the Human Factors Society, October 1974.

"Using Two-Dimensional Drawing Board Manikins in Crew Station Design," 90th Meeting of the Aircrew Station Standardization Panel (ASSP), Missouri Athletic Club, St. Louis, MO, 13 March 1974.

"Anthropometry and Kinematics in Crew Station Design," Crew System Design, ANACAPA Science, Inc., Santa Barbara, CA, pp. 67-79, July 1973.

Involuntary Head Movements and Helmet Motions During Centrifuge Runs of Up to 6Gz, with K.H.E. Kroemer, AMRL-TR-72-40, Proceedings of the 43rd Annual Scientific Meetings of the Aerospace Medical Association, May 1972: and in Aerospace Medicine, 44:6, June 1973.

"A Device to Evaluate the Reachability of Aircraft Hand-Operated Controls," Proceedings of the 44th Annual Scientific Meetings of the Aerospace Medical Association, Las Vegas Hilton, Las Vegas, NV, 10 May 1973.

"Sizing the Aircraft Crew Station for the Foreign User," SAE International Engineering Congress and Exposition, Cobo Hall, Detroit, MI, 11 January 1973.

Displacements of a Helmet-Attached Reticle Under Gz Forces, with K.H.E. Kroemer, AMRL-TR-72-39, 43rd Annual Meeting of the Aerospace Medical Association, May 1972.

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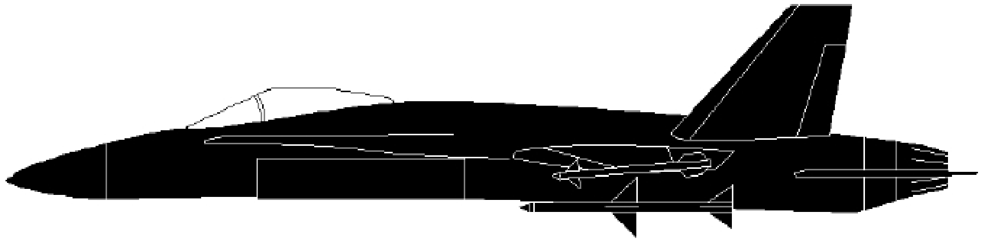
Aperture Sizes and Depths of Reach for One- and Two-Handed Tasks, with B. Filler, AMRL-TR-66-27, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, OH, October 1966.

"Physical and Geometric Aspects of Air Force Anthropometry," with C.E. Clauser, symposium titled "Applied Physical Anthropology - A Survey of Prospects and a Call for Increased AAPA Activity," Proceedings of the 1966 Annual Meeting of the American Association of Physical Anthropologists, University of California, Berkeley, CA, 6 April 1966.

"Relaxed Posture Without Motion," Chapter 2, "An Introduction to Surface-Free Behaviour," by J.C. Simons, Ergonomics 7:1, January 1964.

HOME

TOP OF PAGE



F-18 Hornet

HOME

REVISIONS

November 30, 2001

In "Hand Reach to Controls:"

Addition of a list of example emergency controls for consideration to include in an evaluation. Examples are taken from the F-15A, BF, C, and DF aircraft.

Discussion of a procedure by which questionable reach data may be corrected or removed and the addition of a smoothing chart for reach data for the left hand for subjects in the right cockpit of the T-37B.

Addition of discussion of regression plots and the inclusion of such plots reporting Zone 1 reach data to selected controls in the F-16A, T-1A, T-37B, T-38, and C-141A.

December 16, 2001

Replacement of and additional figures in: "Anthropometric Dimensions," "Operational Leg Clearance with Control Stick/Wheel Motion Envelopes," "Operational Leg Clearance with the Main Instrument Panel," and "Hand Reach to Controls."

January 25, 2002

Replacement of ***X-to-Fingertip***, ***X-to-Grip***, ***X-to-Hook***, and ***X-to-Thumb*** illustrations.

February 5, 2002

Extensive revision of the annotation of "Anthropometric Accommodation in the T-38," ZEHNER, G.F., K.W. Kennedy and J.A. Hudson, ***SAFE Journal***, Vol. 29, No. 1, 1999.

June 20, 2002

Annotation of: ***Prediction of "***Anthropometric Accommodation in Aircraft Cockpits," by G.F. Zehner, Crew Systems Interface Division, Wright-Patterson AFB, OH, AFRL-HE-WP-TR-2001-0137, June 2001.

September 3, 2002

Annotation of the first of a series of important older sources in the areas of aircraft evaluation and design.

January 13, 2003

Annotations of: "Body Size Accommodation in USAF Aircraft," by Zehner, G.F. and J.A. Hudson, AFRL-HE-WP-TR-2002-0118, United States Air Force Research Laboratory, Human Effectiveness Directorate, Wright-Patterson AFB, OH and "Flying Machine Safety Device," Patent No. 1,874,237, by Bruno, N. P., United States Patent Office, August 30, 1932.

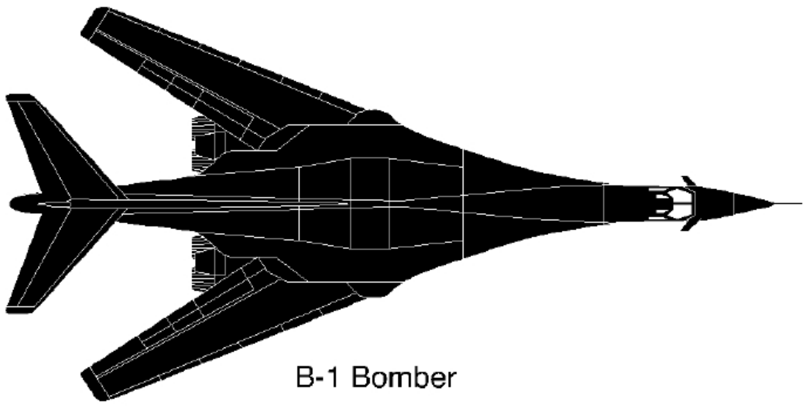
January 26, 2003

Extensive revision of Preface.

June 2007

Standardized font, font size and layout throughout. Added to Annotations.

BACK TO CONTENTS



B-1 Bomber

CONTACT

PREFACE

The documentation on which this web site is based consists of the manuscript of a proposed United States Air Force technical report to be authored by the author of this web site and G.F. Zehner, Air Force Research Laboratory, Wright-Patterson Air Force Base, OH. As with this site, its title was to have been "Anthropometric Accommodation in Aircraft Cockpits, A Methodology for Examination." It was completed and delivered to the Air Force in September 1998. In part because of the severe reduction of Laboratory emphasis and interest in technical reports, it languished. For that reason, it was retrieved in April 2001 by the intended first author and prepared for web publication. The proposed second author was not permitted to participate as an author of a web site. However, he and others, are listed as contributors.

A second source was the script, also prepared by this author, for an instructional compact disc also of the same title. This effort has been completed and is authored by D.A. Dixon, G.F. Zehner, K.W. Kennedy, P.S. Files, and J.A. Hudson. It was released in 1998. Reference to it can be found in the Annotated Bibliography section of this site.

Personnel of the Design Technology Branch AL/CFHD, Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio participated, as did the staffs of Anthropology Research Project, Inc., Yellow Springs, Ohio, and Sytronics, Inc., Dayton, Ohio. The former under USAF contract F33615-89-C-

0572, "Human Morphometrics, Motion, and Performance Research." The latter, beginning in the Fall of 1993, participated under USAF contract # F41624-93-C-6001, "Scientific Visualization of Anthropometry for Research and Design:" K.M. Robinette, of the Design Technology Branch, Armstrong Laboratory, was contract manager for both contracts.

The author of this web site was a consultant to the Air Force as a subcontractor from 1991 through 1999, first through Anthropology Research Project, Inc. and, later, to Sytronics, Inc.

Initial financial support for this effort came from the Design Technology Branch and the Flight Training Systems Project Office, ASD/YT, Wright-Patterson Air Force Base, Ohio. Initially, then Maj. Julie Cohen, ASD/YTE, was the responsible officer. Mr. Larry Ivey, of the same organization, became the responsible officer in late 1992.

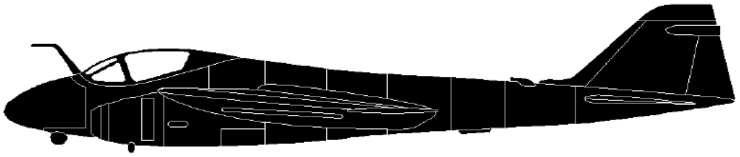
I extend my appreciation to the many people at Wright-Patterson Air Force Base, Randolph Air Force Base, Air Force Academy, Patuxent River NAS, Corpus Christi NAS, for making available several aircraft for our examination and to the several domestic and foreign aircraft companies participating in the EFS (Enhanced Flight Screener) and JPATS (Joint Primary Aircraft Training System) development programs for making their candidate aircraft available for our examination.

I also extend my appreciation to Ilse Tebbetts, Anthropology Research Project, Inc. for editing the original manuscript for this effort, and to Jennifer Schinhofen, also of Anthropology Research Project, Inc. and Tina Brill, of Sytronics Inc., Dayton, Ohio for preparing the many early drafts.

K.W. Kennedy prepared this internet publication.

BACK TO CONTENTS

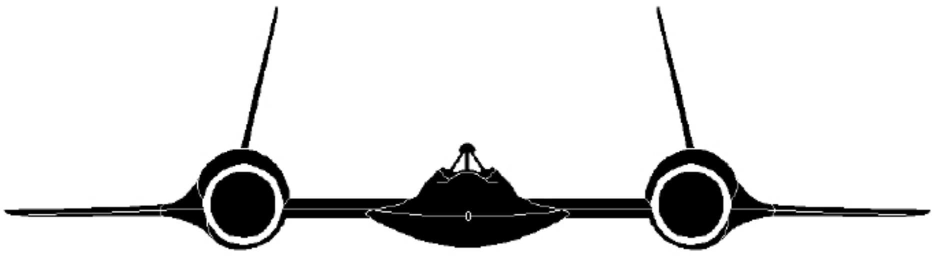
Back to CONTENTS



LIST OF FIGURES

Back to CONTENTS

BACK TO CONTENTS



SR-71 Blackbird

LIST OF TABLES

BACK TO CONTENTS

F-117A Stealth Fighter

F-117A Stealth Fighter

CONTACT THE AUTHOR

INTRODUCTION

This report is intended to serve as a guide to procedures for examining anthropometric accommodation offered in aircraft cockpits. The development of these examination procedures was an evolutionary process. Between 1990 and 1995 we tested them in a variety of aircraft and cockpit mockups. Included were the USAF F-16A, and C-141A aircraft at Wright-Patterson Air Force Base; the T-37B and T-38A at Wright-Patterson Air Force Base and Randolph Air Force Base; the T-1A and F-22A at the contractors' facilities; the USN T-34C, T-44A, T-45A, and the TA-4J at Corpus Christi and Patuxent River Naval Air Stations; the eight Enhanced Flight Screener (EFS) competing aircraft at Wright-Patterson Air Force Base, contractors' facilities, and the Air Force Academy; and the ten Joint Primary Aircraft Training System (JPATS) competing aircraft and cockpit mockups at Wright-Patterson and at the contractors' facilities.

Appropriate body size accommodation in aircraft cockpits is still being sought in the military services in spite of the many years of experience gained by aircraft crewstation designers. At the root of the problem are the methods traditionally used to specify and test new aircraft. For many years, cockpit design was based on the concept of accommodating the 5th through 95th percentile for a limited number of critical anthropometric dimensions of the male pilot. Within the aircraft industry, this concept was inappropriately extended as the "percentile man" concept and included an excessive number of dimensions.

As a result of the inherent restrictions of the 5th to 95th "percentile man" approach, considerable numbers of pilots have experienced difficulty operating or escaping from their aircraft. To correct these deficiencies, multivariate alternatives to the percentile approach were developed to describe body size variability to be accommodated in new USAF aircraft. An unwitting attempt at partial multivariate representation was incorporated in the two-dimensional drawing board manikins developed by the USAF in the mid 1970s. With the move toward accommodating a greater percentage of potential women pilots, a much more sophisticated and complete multivariate analysis was developed in the late 1980s, again by the USAF, in which a number of body size combinations or "multivariate cases" are calculated. These not only described small and large pilots, as the percentile approaches attempted to do, but take into detailed account the variability of body proportions found in many individuals who are not uniformly "large" or "small." The multivariate models found in the table below are typical of those now used by the USAF to evaluate accommodation in aircraft cockpits.

ANTHROPOMETRIC MULTIVARIATE MODELS

		Model 1	Model 2	Model 3
		Generalized Small Female	Small Female Short Reach Higher Shldrs	Male Short Torso Long Limbs
1.	Sitting Height	34.0	35.5	34.9
2.	Sitting Eye Height	28.9	30.7	30.2
3.	Sitting Acromion Height	21.3	22.7	22.6
4.	Sitting Knee Height	19.5	19.1	23.3
5.	Buttock-Knee Length	22.1	21.3	26.5
6.	Thumbtip Reach	28.3	27.6	33.9

		Model 4	Model 5	Model 6

		Generalized Large Male	Male Longest Limbs	Male Long Torso Short Limbs
1.	Sitting Height	40.0	38.0	38.5
2.	Sitting Eye Height	35.0	32.9	33.4
3.	Sitting Acromion Height	26.9	25.0	25.2
4.	Sitting Knee Height	24.7	24.8	20.6
5.	Buttock-Knee Length	27.4	27.9	22.7
6.	Thumbtip Reach	35.6	36.0	29.7

This issue is more important than ever in today's Air Force because the demographics of the pilot population are changing. In the 1950s and 1960s, when most current aircraft were being designed, the USAF pilot population was almost exclusively white and male. Anthropometric databases reflected these demographics and, as a result, so did body size descriptions in aircraft specifications. The current mix of males and females of all races has significantly changed the anthropometric profile of the population.

In addition, the Air Force body size restrictions for entry into undergraduate flight training have changed. More large pilots are being admitted than ever before - and consideration is being given to changing body size restrictions to allow smaller people into pilot training as well. These changes, however, should not be made before carefully assessing the consequences of allowing individuals to fly aircraft not designed to accommodate their particular body sizes. The only reasonable way to make these decisions is through the use of data that describe the anthropometric limits a given cockpit imposes on the flying population. If there is a high probability, for example, that the long-legged pilot will strike the canopy bow during ejection, or that the short-legged pilot will not be able to reach full rudder throw, then consideration should be given to disallowing persons in those size categories to fly specific aircraft.

Describing anthropometric accommodation in cockpits is far from an exact undertaking. It is well known, for example, that there are important differences between the body postures required by anthropometrists to ensure repeatable body measurements and the actual postures and the ways in which pilots position themselves in the seat to operate their aircraft. The most common discrepancies occur in determining Sitting Height and Sitting Eye Height, for which the anthropometrist requires that the subject sit very erect and look straight ahead. The head is positioned in the Frankfurt Plane. * Few tasks, if any, require that the body be so positioned. However, we need reliably measured Sitting Heights and Sitting Eye Heights to determine accommodated under the cockpit overhead and lines of sight over the nose of the aircraft. Similarly, for an understanding of operational knee and shin clearances, interference with control stick movement, knee clearance during ejection, leg reach to rudder pedals, and hand reach to controls, we must concern ourselves with such dimensions as Buttock-Knee Length, Sitting Knee Height, Sitting Shoulder Height, Thumbtip Reach, Thigh Circumference, and Sitting Abdominal Depth.

* Frankfurt Plane: The Frankfurt Plane is a standard plane of reference of the head, realized when the lowest point on the bony margin of the eye socket (orbit) and the left tragion (top of the tragus or “flap” which forms the forward margin of the “ear-hole” are in a common horizontal plane.

The approach taken in developing these procedures is to use a number of test subjects representing as well as possible the body sizes found within the potential flying population, as represented by the multivariate cases. Since it is next to impossible to find subjects whose body sizes duplicate the cases, we were required to develop techniques of analysis by which we could predict the accommodation of the appropriate cases. In a very real sense we use the subjects as human "tools" to establish the upper and lower limits of body size accommodation.

In this effort we concerned ourselves with the seven aspects of anthropometric accommodation listed below. They are arranged in increasing order of complexity.

1. Maximum Sitting Height accommodation.

2. Vision from the cockpit to the outside and toward the instrument panel.

3. Static ejection clearances of the knee, leg, and torso with cockpit structures.

4. Operational leg clearances with the main instrument panel.

5. Operational leg clearance with control stick/wheel motion envelope.

6. Rudder pedal operation.

7. Hand reach to and actuation of controls.

In some aspects of accommodation, overhead and ejection clearances and vision for example, anthropometric relationships are rather straightforward. Overhead clearances are directly related to Sitting Height. Ejection clearances are related to Buttock-Knee Length, Shoulder Breadth, and Elbow to Elbow Breadth, separately.

Vision out of the aircraft, primarily vision over-the-nose, is directly related to Sitting Eye Height.

Other aspects of accommodation are more complex. Operational leg clearances, for example, are influenced not only by measures of leg length, especially Buttock-Knee Length, but also frequently by seat position. If interference is found, it is usually between the areas around the knees and the main instrument panel or side consoles as well as hand controls that are mounted on these surfaces. Since it is usually the large pilot who experiences these interferences, the seat is usually at or near the full down position. Relief can sometimes be gained by raising or further lowering the seat. Whether or not the pilot can raise the seat, of course, depends on the existence of sufficient head room. If the top of the helmet quickly encounters the underside of the canopy or other overhead, or if visual access to critical displays is lost under the glare shield, it may be unwise to raise the seat.

Operational leg clearance with the control stick or wheel motion envelope is driven by seat position, Thigh Circumference, Buttock-Knee Length, and sometimes Abdominal Depth. The upper seat positions and Thigh Circumference seem to be the most critical. With regard to the control stick, we can readily visualize this when we appreciate that the motion of the upper end of the control grip is around the base of an inverted cone. As the seat is raised, the greater the possibility of interfering with its motion - especially if the pilot has large thighs. For the same reason, the potential of interfering with control wheel motion is also increased. If the pilot can retain adequate vision, it might be possible to move the seat downward to relieve interference. Since the large pilot will typically use the full down seat position, the control stick grip/wheel is usually above the thighs and interference may not occur. Also the legs are often sufficiently long as to cause the knees to rise high enough to clear the seat side fence and side consoles, permitting greater space between them for control stick movement. Occasionally full aft motion of the control stick or wheel is interfered with by the pilot's belly. Again, if adequate vision over the nose can be maintained, this can sometimes be relieved by lowering the seat.

The ability to reach and actuate rudder pedals is also effected by seat position. The pilot who is small in Sitting Eye Height may have to raise the seat to achieve adequate vision. If the legs are not disproportionately long, the pedal carriage may have to be adjusted aft to have access to the full range of pedal motion and to be able to actuate the brakes. If the pilot has disproportionately short legs, he or she may not be able to actuate full rudder and brakes, even though the carriage is adjusted full aft. If the seat can be lowered and minimally acceptable vision out of the aircraft maintained, access to rudder pedals can be improved - along with reach to hand controls below shoulder level. Under no circumstances, however, should the pilot sacrifice vision.

Reach with the arm and hand is not only influenced by the dimension Thumbtip Reach, or, as some have called it, "Functional Reach," but also by Sitting Eye Height, Sitting Shoulder Height and the length of the legs. Sitting Eye Height plays a decisive role in seat adjustment, since the pilot must seek at least minimally adequate vision not only over the canopy, but also to the instrument panel. The seat may have to be moved to still a different position to obtain full control of the rudder pedals. The level of the shoulders in the cockpit, which directly influences hand reach, is heavily influenced by attempts to meet vision and rudder pedal requirements. Finally, any factor that effects mobility at the shoulder and elbow, such as design, fit, and adjustment of harnesses and personal protective and survival gear, body strength, and motivation as well, come into play in the act of reaching.

It is typical for pilots to change seat positions to achieve optimum accommodation to a variety of needs. It follows that several subjects with the same arm length will achieve different levels of reach accommodation, depending on his/her other body dimensions. If only one subject is used in the evaluation of operational leg clearance, access to rudder pedals, and hand reach to controls and other aspect of accommodation, the results will be relevant only to that individual.

Examinations of overhead, operational and ejection clearances were usually performed using subjects at the upper ends of the ranges for relevant body size dimensions such as Sitting Height, Buttock Knee Length, Sitting Knee Height, Shoulder Breadth, and Thigh Circumference.

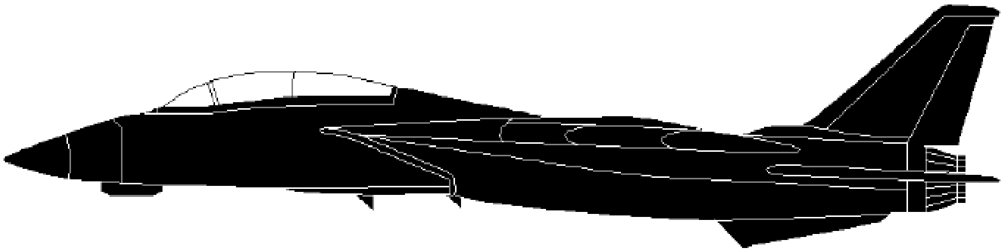
Examinations of internal and external vision were performed on subjects throughout ranges for Sitting Eye Height and Sitting Height.

Measurements of rudder pedal operation and hand reach to controls are most effectively examined using subjects at the smaller ends of the required ranges for dimensions such as Buttock-Knee Length, Sitting Knee Height, Thumbtip Reach and a range of Sitting Shoulder Heights.

The procedures described here concentrate on high performance aircraft with single, side by side, and tandem cockpits with transparent canopies. The procedures will necessarily vary for use on flight decks without transparent overheads.

BACK TO CONTENTS

BACK TO CONTENTS



F-14 Tomcat

CONTACT

PRELIMINARY MEASUREMENTS

Several anthropometric dimensions were measured on all subjects. Click on ANTHROPOMETRY for descriptions of these body dimensions. These, and some additional reach-related measurements, were made on smaller subjects. All measurements were made on semi nude subjects to standardize results. They were made before proceeding with measurements of cockpit accommodation.

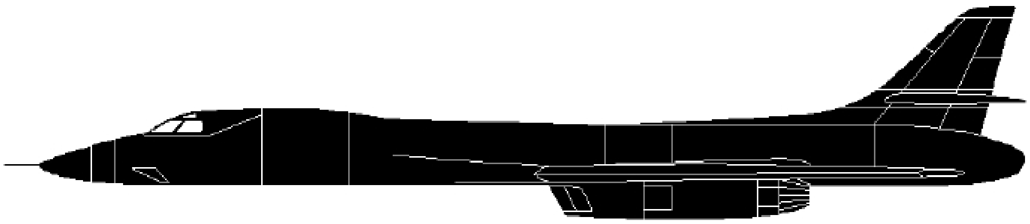
GO TO ANTHROPOMETRY

Early in the development of these procedures, it was discovered that, in any given aircraft model, especially older ones, ejection seats do not necessarily adjust to the same full-up or full-down position relative to the rest of the cockpit. Apparently, as maintenance is performed on the seat, there are adjustments that can be made that affect where the seat stops on the rails. After taking seat/cockpit measurements on 12 T-38A aircraft, it was discovered that up to one inch of variability existed in the relationship between the seat and the canopy. Pilots, then, with large Sitting Heights might strike their heads on the canopy with the seat full-down in some aircraft, but not others of the same model. For pilots with small Eye Height Sitting values, vision over the nose would be better in some aircraft than others. To ensure against the inadvertent use of a "worst case" cockpit to establish accommodation limits, selected measurements should be taken in a number of aircraft of the same model. A data form for taking cockpit geometry dimensions can be found in the Appendix.

Each of the following sections begins with a statement of Purpose and a Discussion to provide background information for the Procedure section. An Analysis and Results section frequently includes selected accommodation values obtained by the investigators on USAF aircraft.

BACK TO CONTENTS

BACK TO CONTENTS



B-1 Bomber

CONTACT

MAXIMUM SITTING HEIGHT ACCOMMODATION

PURPOSE

The purpose of these measurements is to determine the threshold value for Sitting Height at which the bare head contacts the underside of the canopy or other overhead.

DISCUSSION

At least 4 subjects in the upper ranges of Sitting Height should be used to determine the maximum Sitting Height that can be accommodated under the canopy or other overhead. The ranges of values for Sitting Height and other body dimensions can be found in the table, Anthropometric Multivariate Models, at TABLE.

Measurements should be made parallel to the angle of seat adjustment. Accuracy can be difficult if that part of the canopy or overhead immediately above the head varies much from the horizontal. For this reason, measurements are usually made with the seat at or near full-up.

PROCEDURE

1. Subjects representative of the largest Sitting Height expected to be accommodated should be used as subjects. The subject is installed into the aircraft seat. The harnesses are cinched up and the lab belt is buckled. The seat should initially be full-down.

2. The canopy is then closed. The subject raises the seat to the top of its range, or until the head contacts the underside of the canopy. The subject nods his head forward and back, and side to side to be sure there is clearance. If the overhead interferes with head motion, the seat is lowered until there is no interference. The distance, if any, above the head is measured. In the latter case, the seat is considered to be the highest it should be raised for this subject - bare headed.

3. The space between the head and the underside of the canopy can be measured either with a carpenter's retractable tape or with soft, non-abrasive, measuring pads, depending upon the distance. If measured with a tape, it must be oriented parallel to the seat adjustment trajectory. An assistant can provide hand signals to the subject from in front of the aircraft to assure that the head is held vertically. The measurer can do the same from the side to be sure that the head is oriented in the Frankfurt Plane. In side-by-side cockpits and flight decks clearance measurements can usually be made by the investigator from the other cockpit.

Click on FIGURE for a data form* for recording maximum Sitting Height accommodation with vertically adjusting seats.

*This and all other data forms are available by hyper-link. They are not included in the text.

4. For non-ejection seats adjusting in both vertical and fore-aft directions, examine at the full-down/full-forward, full-down/mid-forward, and full-down/full-aft seat positions. Seats adjusting along an up-and-forward ramp should be examined at full-up and forward, midpoint, and full-down and aft positions.

ANALYSIS AND RESULTS

Because helmets are subject to periodic design changes, accommodation for Sitting Height is examined with the subject bare headed. When applying the results, the increase in functional Sitting

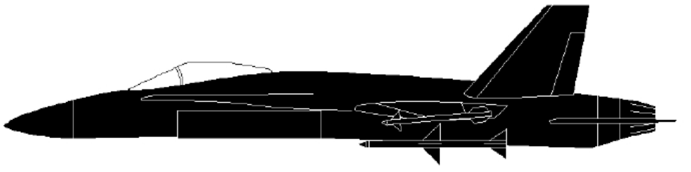
Height due to the helmet is subtracted from the bare head accommodation values. For the HGU-55/P this increase is 1.5 inches. This value, of course, may be different for other helmets. An additional amount, ranging from the diameter of the fist to the thickness of the hand, depending upon Service policy, is also subtracted to provide adequate clearance for head and torso motion. This latter policy adds to the indecisiveness of Maximum Sitting Height accommodation.

If the subject is able to raise the seat to the full-up position without interfering with head motion, we know that the cockpit will accommodate this given Sitting Height, plus the distance the seat has been raised, plus the space above the head below that at which head motion is compromised. The distance between the top of the head and the top of the helmet is subtracted, as is the distance from the top of the head and the canopy for the subject who encounters motion interference in the first example under Procedures.

The maximum Sitting Height accommodated in both cockpits of the T-37B is 40.0 inches. This value allows 1.5 inches for the HGU-55/P helmet and one inch of free space clearance above the helmet.

BACK TO CONTENTS

BACK TO CONTENTS



F-18 Hornet

CONTACT

VISION FROM THE COCKPIT TO THE OUTSIDE AND TOWARD THE INSTRUMENT PANELS

PURPOSE

The purpose of these measurements is to determine selected visual angles through the windscreen, canopy, and side windows of the cockpit and visual access to controls and displays on the instrument panels.

DISCUSSION

We measured several aspects of vision from the cockpit, including vision over the nose, upward under the overhead or canopy bow, over the canopy bow and over the side of the cockpit. We also measured vision out of side windows when appropriate. Because of its obvious importance in approach and landing and the fact that it is in the direction of flight, the principal measure of vision out of the cockpit is the maximum depressed line-of-sight over the nose. Since the over-the-nose and the under- and over-the-canopy bow measurements are within the vertical fore and aft (X-Z cardinal) plane of the aircraft, they are easily associated with pitch. Vision directly over the side of the cockpit is usually within or close to the vertical side-to-side (Y-Z cardinal) plane and equally easy to associate with aircraft roll. Other measures at intermediate angles between these two cardinal planes are more difficult to associate with aircraft attitude.

Since all measurements of vision are tied to aircraft attitude, they are easily altered, inadvertently or by intention, by changing aircraft attitude. To make operational sense out of all the various measures of vision, therefore, aircraft pitch, roll and yaw attitudes must be known. We used a carpenter's inclinometer to determine pitch. Since the aircraft cockpits were examined on the ground, roll was always assumed to be zero. Yaw is irrelevant to our examination of vision.

In the examination of vision inside the cockpit, special attention is given to those controls potentially obscured by the glare shield, control stick or wheel, throttle, and knees. Using line drawings of the instrument panels, the outlines of visual obstruction are drawn as the subject sees them. This procedure is described in detail further on.

The Design Eye Point is the basic reference around which the cockpit is designed. It is the point on the Horizontal Vision Line to which the crew station designer specifies that the pilot should adjust his eyes. The geometry of the cockpit is laid out around this point. The amount of seat adjustability is dictated by the design range for Sitting

Eye Height. If seat location and adjustment range is appropriate then all pilots within the design range should be able to adjust the seat such that his or her eyes are at the Horizontal Vision Line. They may or may not coincide with the Design Eye Point. If it was always possible to adjust the eyes to the Design Eye Point, characteristics of vision would not vary among pilots. In practice, however, pilots do not, or may not be able to, adjust their eyes to these design landmarks. For that matter, there usually isn't a commonly known or convenient procedure for locating them. While subjects throughout the range for Sitting Eye Height are used to examine vision outside the cockpit, emphasis is given to the short Sitting Eye Heights for over-the-nose vision. Larger subjects are emphasized for evaluations of vision under the overhead and canopy bow. The larger subjects are also emphasized in examinations of potential obstructions by the glare shield toward the upper part of the main instrument panel, since they are the most likely to experience visual problems of this kind. The smaller subjects tend to experience visual obstructions produced by the control wheel or stick, throttle and the knees.

PROCEDURE

Initially, we used a carpenter's inclinometer fitted with a sight tube to measure visual angle. The sight tube is equipped with cross-hairs at each end. Later we used an Abney Level.

The examination proceeds as follows:

The subject, dressed in full flight gear minus helmet, is installed into the seat. Parachute and inertia reel harnesses are buckled and adjusted.

External Vision

Forward Cockpit

Part of the examination of vision from the cockpit is conducted with the canopy open - part of it with the canopy closed. We usually begin with the canopy open to permit the subject to gain experience using the measuring instruments before isolating him under a closed canopy.

a. The subject adjusts the seat full-up, as illustrated in the figure below, with the head in the Frankfurt Plane. He/she sights straight ahead over the nose of the aircraft to the ground at the lowest attainable visual angle. Click on FIGURE for a proposed data blank to use in recording vision data.

b. The subject then thrusts his/her head upward and aft to gain additional vision over the nose and the angle of the line of sight is measured again.

c. With the subject's head again in the Frankfurt Plane, measure the angle of vision straight ahead upward under the windscreen bow. See an illustration of this measurement, see the the second figure below.

d. Lines of sight over the nose and upward under the canopy bow are repeated typically at one-inch intervals from full-up to full-down. Care should be taken to ensure that intervals begin at the full-up seat position, even though the subject's head may strike the canopy when the seat is full-up with the canopy closed, or that the initial seat position studied may not be adjusted precisely to one of these intervals.

e. The canopy is then closed. The subject raises the seat to full-up or until appropriate head motion clearance is attained. With the head oriented in the

Frankfurt Plane, the subject sights through the sight tube or Abney Level straight ahead over the canopy bow (as appropriate).

f. With the subject's head oriented level, measure and record the angles of vision out of the lowermost left corner of the windscreen, just forward of the root of the canopy bow as well as aft of the canopy bow at its junction with the side sill, as appropriate.

g. A measurement is also taken of the maximum depressed line of sight over the side of the cockpit, perpendicular to the long axis of the fuselage.

h. These measures of vision are modified as appropriate for flight decks and other side-by-side cockpits.

i. The canopy is then opened. Without disturbing the position of the seat, examine vision to display surfaces in the cockpit.

OVER-THE-NOSE VISION, HEAD IN FRANKFURT PLANE. With the head oriented in the Frankfurt Plane, the subject sights through a sight tube/inclinometer or other appropriate sighting device straight ahead over the nose of the aircraft. The angle from horizontal is recorded.

OVER-THE-NOSE VISION, HEAD TILTED UP AND AFT. The subject rotates his/her head upward and aft to gain additional vision over the nose. Using an appropriate sighting device, the angle from horizontal is measured and recorded.

VISION UPWARD, UNDER THE CANOPY, HEAD IN FRANKFORT PLANE. With the head oriented in the Frankfurt Plane, the subject sights through a sight tube/inclinometer or other appropriate sighting device straight ahead and upward under the canopy frame. The angle from horizontal is recorded.

Aft Cockpit

a. Measures of vision is taken in the forward cockpit are repeated, as appropriate, in the aft cockpit.

b. To offer realistic visual field to the test subject, another subject or assistant, wearing a helmet, is seated in the forward cockpit and the seat adjusted, with the canopy closed, so that the helmet appropriately clears the underside of the canopy. The subject in the aft seat, which has been similarly adjusted to obtain similar, but bare headed clearance, sights along the long axis of the aircraft, over the helmet of the forward occupant or the head box, whichever dominates in the obstruction to vision, in an attempt to sight over the nose of the aircraft. In addition, the subject should move his/her head to the side to look beside the head box or helmet and above the shoulder of the forward occupant and attempt to obtain a view over the nose. If and when the subject achieves this, it is important for the investigator to establish a visual reference point in the forward cockpit to ensure that all subjects establish a comparable line of sight.

Internal Vision

Visual access to internal displays potentially obscured by cockpit structures and body parts is evaluated with the seat adjusted upward until appropriate head clearance with the canopy is obtained, or full-up, whichever occurs first. With the head oriented in the Frankfurt Plane, the subject visually examines the instrument panel to determine if any displays are obscured. The glare shield, control column and wheel, as well as the knees, should receive special attention. Using a line drawing of the instrument panel, the subject should diagram those portions of the panel, if any, that are obscured. Seat position should also be recorded.

ANALYSIS AND RESULTS

When there are adequate numbers of subjects representing the specified minimum Sitting Eye Height, analysis can be as simple as averaging the line-of-sight values for each seat position. For complete understanding of Sitting Eye Height and vision relationships, however, regression equations should be prepared and regression plots made. Table 2 presents data regressed from such an equation for the T-37B.

Visual angles over the nose, especially, must be differentiated in terms of the aircraft structure over which the lowest visual angle is obtained. For the higher seat positions and eye heights, this will likely be the actual nose of the aircraft. For lower seat positions and shorter eye heights, it may be the glare shield, or some intermediate structure. As the eye is lowered (for whatever reason) in the T-38A, for example, the "aircraft structure horizon" changes from the nose to the base of the windscreen and, immediately thereafter, to the glare shield.

VISION FROM THE LEFT COCKPIT OF THE T-37B.

Sitting Eye Height = 28.9", the Small Generalized Female, Table 1.

Lines of Sight in Degrees

(Rounded off to the nearest whole degree)

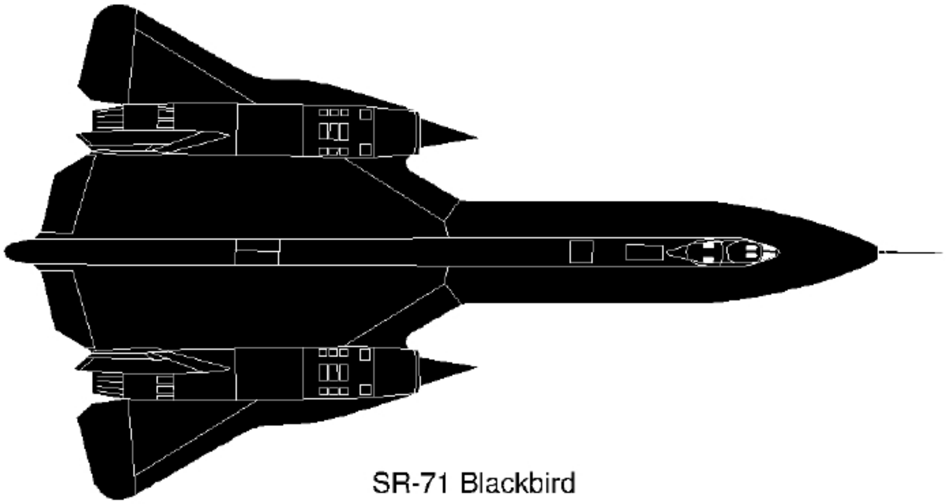
SEAT POSITION	O'NOSE*	O'NOSE HEAD UP/AFT	OVER BOW*	UNDER BOW*
FULL-UP	- 10 Degrees	- 12 Degrees	+23 Degrees	+11 Degrees
- 5/8"	- 10	- 12	+24	+12
- 1 1/4"	- 9	- 11	+26	+14
- 1 7/8"	- 9	- 11	+27	+15
- 2 1/2"	- 8	- 10	+29	+17
- 3 1/8"	- 8	- 10	+30	+18

- 3 3/4"	- 8	- 10	+31	+19
- 4 3/8"	- 7	- 9	+33	+21
FULL-DOWN	- 7	- 9	+34	+22

* Head in Frankfurt Plane.

BACK TO CONTENTS

BACK TO CONTENTS


SR-71 Blackbird

CONTACT

STATIC KNEE, LEG AND TORSO EJECTION CLEARANCES

PURPOSE

The purpose of these measurements is to determine the largest values of Buttock-Knee Length and body breadth, usually at the shoulders, to clear cockpit structures during ejection.

DISCUSSION

Interference between the legs and torso and cockpit structures such as the main instrument panel, controls and structures extending aft of the instrument panel, the canopy bow, and cockpit side-sills and centerline canopy braces during ejection, is associated almost exclusively with the upper ends of the ranges for Buttock-Knee Length and Shoulder Breadth. There can be an association between seat location and leg clearances, since seat adjustment can occur along an angle other than that of the ejection rails. In such ejection systems, the pilot can drift fore and aft to positions of greater and lesser possible interference depending on seat adjustment. Contact by the feet, shins and elbows is related less to torso size and more to leg and arm placement at the onset of the ejection process.

Static dimensions tell us little about leg and foot trajectories and submarining during ejection and only very crudely approximate the violence of the ejection process. The seat and its occupant are sometimes pulled up the ejection rails to simulate the effects of knee depression and, to a minor extent, submarining. However, this also has not been shown to be a completely adequate technique for simulating the ejection sequence, and will yield little additional information beyond that obtained with the seat in the cockpit.

Ejection clearance subjects should be near the top of the range for Buttock-Knee Length, Sitting Knee Height, and Bideltoid (Shoulder) Breadth.

PROCEDURE

Knee Clearance

Our procedure for examining ejection knee clearance assumes that the canopy has been blown off the aircraft. It is the first choice procedure and the easier procedure to measure since it can be done with the canopy open. A through-the-canopy ejection, however, represents the worst-case. We found that the most accurate measurements can be made directly to the forward transverse part of the canopy frame. This does not account for shards of canopy material remaining in the canopy frame in a through-the-canopy ejection.

1. The subject, dressed in full flight gear, including boots, is installed in the seat. Using an inclinometer, the thighs should be set at right angles to the ejection rails. To do this, the feet may have to be withdrawn aft and the seat adjusted. An inclinometer can be used to set thigh angle. If the seat adjustment and ejection angles differ, the seat should be adjusted to either full-up or full-down, whichever causes the pilot to drift farthest forward. The knees are set 12" apart - centerline to centerline.

2. A rigid straightedge (usually two sections of an anthropometer), equipped with an inclinometer, is held against the forward surface of the left knee (Typ.) in single cockpits (or the outboard knee in side-by-side cockpits) and held in the vertical (X-Z) fore-aft plane. By viewing an attached inclinometer, the top end of the

straightedge is adjusted forward or aft until the angle of the straight edge is equal to that of the ejection rails.

3. Using a carpenter's retractable tape, the distance is measured perpendicular from the <u>aft</u> surface of the straight edge to the nearest structure or other threatening surface or edge forward of the knee, usually the canopy bow, windscreen bow, or glare shield. The procedure is illustrated below.

Click on FIGURE for a proposed form for recording ejection clearance data.

Shoulder/Elbow Width Clearance

1a. Single Crew Station. Measure the distance across the crew station between the sills at the shoulder-elbow station line forward of the seat back.

1b. Side-by-side Crew Stations. Measure the distance between the outboard sills across both cockpits and to the centerline of each cockpit at the shoulder-elbow station line. Where there is a centerline longitudinal canopy brace, measure the width of the brace. By calculation, the extent to which the centerline brace may encroach into the ejection envelopes can be determined. Data forms to record these measurements are not included in this report.

2. The subject, dressed in appropriate flight gear, is installed in the seat and instructed to simulate hand and arm positions appropriate for ejection. In the case of a D-ring, the subject should grasp the D-ring with three fingers of each hand or by one whole hand with the second hand grasping the first's wrist. In the case of side seat-mounted ejection handles, the subject should simulate a full hand grasp with the handles hinged upward.

3. Measure the distance from the most lateral body part, the shoulder, elbow or hand to the inside of each side-sill. Clearance with a centerline canopy brace between side-by-side cockpits can be calculated.

ANALYSIS AND RESULTS

There is a direct relationship between increases in Buttock-Knee Length and reduced knee clearance with the glare shield and canopy bow during ejection. It must be remembered, however, that this is a static measurement. While it cannot be relied upon to pinpoint true clearances associated with ejection, during which the total body is under severely dynamic loading, it is the only technique available for general use in the field.

Since Buttock-Knee Length is the body dimension most closely associated with ejection clearance, data analysis consists of adding the clearance between the knee and canopy or windscreen bow and glare shield to the subject's Buttock-Knee Length to obtain the threshold contact values. Averages of such values were calculated. It is understood that, ideally, there should be adequate free space between the knees, shins and feet and the windscreen bow, canopy frame and glare shield. For most aircraft, there is insufficient information regarding the amount of space forward of the knees to account for the effects of submarining.

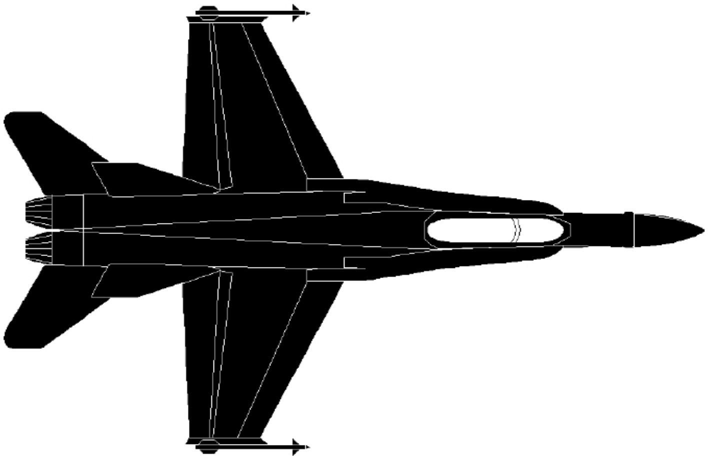
Ejection Clearances

Differentiation should be made between canopy-open and canopy-closed ejections. For the former we need be concerned with the potential interference offered by the windscreen bow. Since through-the-canopy ejection can be either the first or second alternative, clearance with the canopy frame (and canopy shards remaining in the frame) must also be considered - thus the measurement of the additional potential interference offered by the canopy bow and frame. The maximum static Buttock-Knee Length accommodated for ejection clearance with the canopy bow in the T-37B (both cockpits) was found to be 26.4 inches.

Lateral clearance in the T-38A appears to be ample. The T-37B has limited side-to-side clearance. On ejection, the pilot may experience interference between the inboard hand and the centerline canopy brace.

BACK TO CONTENTS

BACK TO CONTENTS



F-18 Hornet

CONTACT

OPERATIONAL LEG CLEARANCES WITH THE MAIN INSTRUMENT PANEL

PURPOSE

The purpose of these measurements is to determine the longest leg lengths to obtain operational knee and shin clearances with the main instrument panel.

DISCUSSION

Interference with the main instrument panel and switch guards, controls, and other structures extending aft of the instrument panel, are associated almost exclusively with the upper ends of the range for Buttock-Knee Length. However, total leg length also has an effect. For that reason data should be gathered on a range of values for combined Buttock-Knee Length and Sitting Knee Height ("combined" leg length or "ComboLeg"). If subjects representing the maximum values for these leg dimensions are not available, larger Buttock-Knee Lengths can be simulated by blocking to a maximum of one inch behind the buttocks. A corresponding maximum of one inch of aft adjustment in the rudder pedal carriage can be used to simulate larger values for ComboLeg. Caution must be exercised so that these artificial means of simulating larger body dimensions do not exceed the maxima for these dimensions in the population.

Interference with the main instrument panel may be found to occur with the feet on neutral rudder pedals as well as during the extremes of rudder pedal motion. All of these conditions are examined.

PROCEDURE

The subject, dressed in flight suit and boots, is installed in the seat, the harnesses are snuggly adjusted and the inertia reel locked with the subject firmly back into the seat.

Data are first gathered at the full-down seat position. The rudder pedal carriage is adjusted to the most forward position that permits the subject full-forward throw at maximum leg reach - usually with the knee fully extended. The subject should be able to operate the rudders and brake without squirming either hip forward. If the pedal carriage is thereby adjusted to its full-forward position, this fact should be noted.

The subject is instructed to engage the rudder pedal bar at neutral rudders with the balls of the feet, rather than with the heel catch. This gives the subject a small amount of additional reach.

Measure the distance between the leg (at the knee or shin) and the main instrument panel, and/or protruding controls and control guards. Measurements are made on both the active and passive legs with full rudder throw.

Measurements are repeated with the seat at one-inch intervals to full-up. The measurement procedure is illustrated below.

MEASURING SHIN CLEARANCE WITH THE MAIN INSTRUMENT PANEL.

Click on FIGURE for a proposed data form.

ANALYSIS AND RESULTS

Generally, there is a direct relationship between increases in Buttock-Knee Length and reduced leg clearance to the main instrument panel. Sitting Knee Height has been found to have only a minor role in affecting such clearance.

Since Buttock-Knee Length is the body dimension most closely associated with leg clearance, data analysis consists of adding the clearance forward of the knees or shins to the subject's Buttock-Knee Length to obtain the threshold clearance value. The worst-case rudder pedal position, neutral or full right or left rudder, is reported. The averages of all such values are calculated. The maximum Buttock-Knee Length to clear the instrument panel in the T-37B is 29.0 inches.

BACK TO CONTENTS

BACK TO CONTENTS

F-117A Stealth Fighter

CONTACT

OPERATIONAL LEG CLEARANCE WITH CONTROL STICK/WHEEL MOTION ENVELOPES

PURPOSE

The purposes of these measurements are to identify areas of interference with control stick or wheel motion at the subject's preferred seat position, and to locate the highest seat position, if any, at which interference does not occur.

DISCUSSION

Interference with control stick/wheel motion appears to be associated with smaller values for Sitting Eye Height and larger values for Thigh Clearance or Circumference and Abdominal Depth. Sitting Eye Height becomes important when the pilot has to raise the seat toward the top of its range to gain adequate vision out of the cockpit. In raising the seat, the space available between the thighs for side to side stick motion is sometimes not adequate. The upper seat positions bring the thighs closer to the base of the inverted cone of stick motion and increases the likelihood of interference. Similarly, the thighs are also brought closer to the control wheel as the seat is raised and can interfere with its motion.

Short heavy subjects, particularly those with heavy thighs, are most prone to encroaching on stick and wheel movement. An example of wheel interference is presented below.

OPERATIONAL LEG CLEARANCE WITH CONTROL STICK

AN EXAMPLE OF CONTROL WHEEL INTERFERENCE.

Sometimes it is necessary to determine the accuracy with which the size and shape of the stick motion box, as specified in engineering drawings, has been rendered in the cockpit or mockup.

PROCEDURE

OPTION A, STICK CONTROLLED AIRCRAFT.

Before subjects are installed in the cockpit, measure the full range of side-to-side stick motion (in inches) from a convenient location on the stick, such as the tip of the trim button, to convenient locations on the right and left sides of the cockpit. These locations should be marked to assure that they can be easily identified when subsequent measurements are made with the subject in the seat. Measurements should be made at least at full-forward, at neutral, and at full-aft. Also, measure full right and left aileron movement (in degrees) on the left wing, using an inclinometer. (Aileron and pitch trim should be set at neutral for these measurements.) These data will serve as baseline measurements from which potential interference is evaluated. Click on FIGURE for a data form for baseline data.

The subject, dressed in flight suit and boots adjusts the seat to the full-up position. The rudder pedal carriage is adjusted to the most forward position that permits the subject full forward pedal throw, usually the balls of his feet, without squirming either hip forward. It will be found in some aircraft, that, with the seat full-up, some small subjects cannot obtain full pedal throw, even with the pedal carriage adjusted full-aft. In such a case, adjust the seat downward until full pedal use can be obtained in the full-aft pedal adjustment, record this seat position, and begin the examination there.

The subject moves the control stick side to side at full-forward, neutral, and at full-aft positions within its envelope, attempting to obtain full excursion - first with the feet on neutral rudders and again when holding full right or left rudder. If interference is found between the control stick and the subject's legs at any seat position, the measurement(s) of stick positions (i.e., the distance between the points measured to obtain baseline measurements) and aileron angles are made and recorded. The seat is then lowered in one-inch increments and the measurements are repeated until interference is no longer encountered or until the seat reaches full-down. If and when a seat position is found at which no interference occurs, that position is recorded.

Data are recorded on a form such as that in FIGURE.

OPTION B, WHEEL CONTROLLED AIRCRAFT

The full and unimpeded range of control wheel rotation is measured with an inclinometer or other suitable measuring instrument. Measurements are made in degrees right and left from neutral.

End points of full right and left aileron movement on the left wing are also measured in degrees. These data serve as baseline measurements and are recorded on the data form.

The subject adjusts the seat to the full-up position. The rudder pedal carriage is adjusted to the most forward position that permits the subject full forward pedal throw, using the balls of his feet, without squirming either hip forward. The subject rotates the control wheel to the right or left, with the feet on neutral rudders and again toward the passive leg when holding full right or left rudder, whichever causes the greatest potential interference by the passive leg.. The object is to attempt full rotation. Full forward and aft yoke positions are examined.

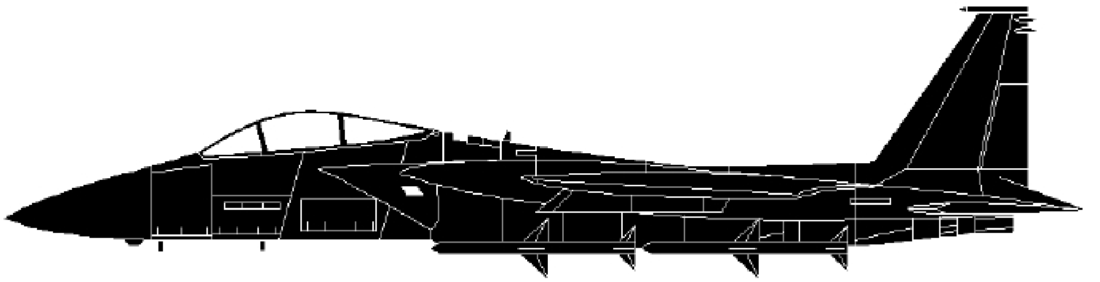
If interference is found at any column or leg position, measurements of wheel rotation and aileron angles are made. Just as for control stick interference procedures, the seat should then be lowered in one-inch increments and the exercise repeated until the seat is full down or until interference is no longer encountered. The seat position and interference data can be recorded on the form illustrated in FIGURE.

ANALYSIS AND RESULTS

Two wheel-controlled aircraft were examined. Legs were found to interfere with wheel rotation in an early version of the T-1A. Discovery resulted in correction prior to production.

BACK TO CONTENTS

BACK TO CONTENTS



F-15C Eagle

F-15-A

CONTACT

RUDDER PEDAL OPERATION

PURPOSE

The purpose of these measurements is to determine the smallest leg length able to achieve full rudder pedal throw and brake operation with the carriage adjusted to its aft-most position. Leg length is expressed in terms of the combined values for ComboLeg, the sum of Buttock-Knee Length and Sitting Knee Height. While this is not a conventional measure of leg length, it is a measure of total leg length and is directly related to the ability to reach and actuate rudder pedals.

DISCUSSION

Because ejection rails are sloped up and aft, ejection seats typically move the operator away from foot controls when adjusted upward, and, of course, closer to foot controls when adjusted downward. Since reach to the rudder pedals is so closely associated with seat position, access is examined at one-inch, or other small, intervals throughout the range of seat adjustment.

Subjects measuring as close as possible to the bottom of the accommodation range for the combined values for ComboLeg are used for this assessment. The smallest combined leg length in the current USAF population is about 40.6".

This assessment is based on the following assumption. If maximum leg reach is necessary for one pilot to achieve full rudder depression when the rudders are adjusted to the full-aft position, another pilot with a one-inch longer ComboLeg will be able to achieve full rudder depression when the rudders are adjusted one inch forward from full-aft.

The F-16 series of aircraft present a cockpit geometry in which the knee is usually not fully extended to obtain full rudder. The seat pan in these aircraft is set typically at +30 degrees, potentially causing the underside of the thigh to press into the forward edge of the seat cushion when thrusting the feet forward. Actual compression of the thigh and the seat is reduced, however, by the near-isometric nature of pedal operation.

PROCEDURE

Prior to examination, it is necessary to establish the position of the fully depressed rudder pedal with the carriage adjusted full-aft. This is done by measuring its distance from a mark made on the outboard wall of the pedal well, aft and upward from the pedal toward the subject's hip joint as he/she sits in the seat. The location of neutral rudder is not used because of uncertainty as to its exact location. By comparing this distance with a corresponding distance obtained when the subject adjusts the carriage to his/her maximum forward position, we can calculate the minimum combined leg length necessary to actuate the pedals in each seat position. The minimum leg length needed to fully actuate the pedals and attain braking with the carriage full-aft will be the minimum leg length that can safely operate the aircraft from any given seat position.

1. The subject, wearing flight suit and appropriate flying boots, is seated in the cockpit. The seat is raised to the full-up position.

2. The subject adjusts the rudder pedal carriage forward until he/she can just obtain full left rudder and actuate the left brake with the leg comfortably straight and knee extended, but without hip rotation. After the subject has adjusted the pedal carriage, the left foot should

be moved inboard while holding the pedal full down to make space for the measurement to be made. Measure the distance between the contact surface of the depressed left rudder pedal aft and upward to the point marked on the outboard wall of the pedal well. FIGURE illustrates a data form for these data.

3. Repeat at one-inch intervals through the range of seat adjustment.

The minimum combined leg length needed to obtain full forward rudder throw and brake for a given seat position is equal to the subject's combined leg length minus the remaining aft carriage adjustment. See the discussion at the beginning of this section.

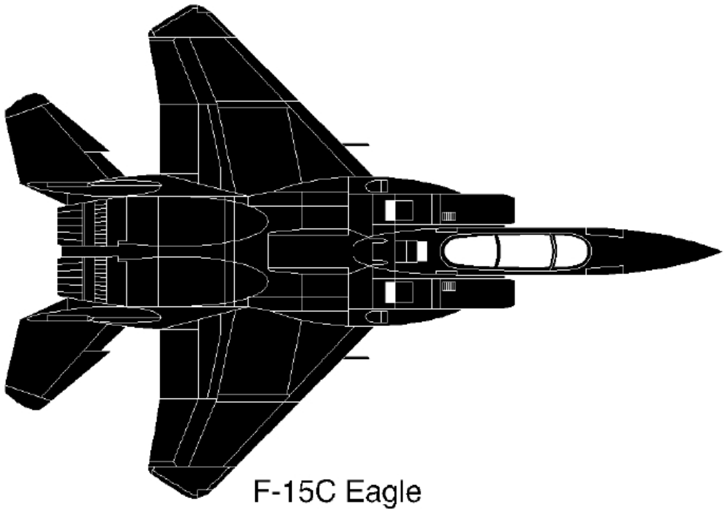
ANALYSIS AND RESULTS

Analysis of the data consists of averaging values for ComboLeg required to actuate the rudder pedals and brake in the full-aft carriage adjustment, for each seat position. The minimum combined leg lengths to obtain full forward rudder and brakes in the T-37B was found to be 41.9 inches, seat full-down, and 42.3 inches, seat full-up.

Since the smallest ComboLeg in the current USAF population is about 40.6 inches, some prospective pilots can expect to have difficulty obtaining full rudder throw in most seat positions in both cockpits of the T-37B. These pilots would have to rotate their hips forward away from the seat back to fully depress the pedals. The T-1A, F-16A, and C-141A all accommodate to the minimum 40.6" combined leg length.

BACK TO CONTENTS

BACK TO CONTENTS



CONTACT

HAND REACH TO CONTROLS

PURPOSE

The purpose of these measurements is to determine the minimum Equivalent Thumbtip Reach necessary to reach and actuate selected hand controls under Zones 1, 2, and 3 restraint as described in Mil-Std-1333B, ***Aircrew Station Geometry for Military Aircraft***.

DISCUSSION

Thumbtip Reach, frequently referred to as "Functional Reach," is a familiar body dimension. Although difficult to obtain good repeatability, it is the most commonly used dimension when attempting to understand reach capability with the hand.

The manner in which hand controls in cockpits are operated can be classified into four general types:

- those that are operated typically with the tip of the forefinger (push buttons and toggle switches).* These will be designated as "F" type controls.

- those that are operated with the thumb and forefinger (locked toggle switches, knobs, and most circuit breakers): "T" type controls.

- those gripped with the whole hand (control stick grip or wheel): "G" type controls. **

- those operated by using the fingers as a hook (T-handles): "H" type controls.

* Obviously, in an ultimate stretch, if the reach cannot be made with the forefinger, the third (medial) finger can be attempted. For this reason, we measure to the latter.

** A case can be made for the elimination of the "G" measurement for some controls and substitute the "H" measurement. It can be argued that, in reaching for some "Grip" type controls, it would be possible to pull the hand around the controller if the pilot can initially "crawl" around it using a "hooking" action. If, however, as in the case of the stick grip of the primary controller, the control is undesirably displaced in the process, the true "G" type measurement must be used.

To completely understand accommodation it is not sufficient to merely make a can/can't appraisal of a series of subjects' abilities to reach and actuate hand operated controls. Such determinations do not yield information on the actual reach capability necessary to access controls. We only know that that particular subject could or could not reach. We also may not know how much farther the subject might have been able to reach or that he/she was performing an excessively extended reach. Also, if the subject cannot reach a given control, we will not know how much longer his/her arm must be so as to reach it.

It is essential, therefore, to determine the minimum arm length necessary to reach controls. Initially, we attempted to measure reach miss-distances between the control and the appropriate interface of the hand, with the hand in the operating attitude. It was very quickly found that such measurements are both difficult and unreliable. A much more convenient procedure was developed and is recommended for use here. It consists of marking a short line on the thumb side of the lower forearm perpendicular to the axis of the forearm. The distances from this line to the interface points on the hand are measured in advance of the examination session. These special dimensions are referred to as "X-to" dimensions and are described and illustrated in the section "Anthropometric Dimensions" in Contents.

When gathering reach data, rather than attempt to measure from the interface point on the hand to a control, we measured from the line on the lower forearm (the"X" point) to the control. This made it possible to express reach capability, regardless of the method of control actuation, in terms of the familiar "Thumbtip Reach." We referred to this as "Equivalent Thumbtip Reach," since it included not only reaches to "T" type controls, but to "G," "F," and "H" controls as well. The logic of the Equivalent Thumbtip Reach calculation is discussed in the Analysis and Results section.

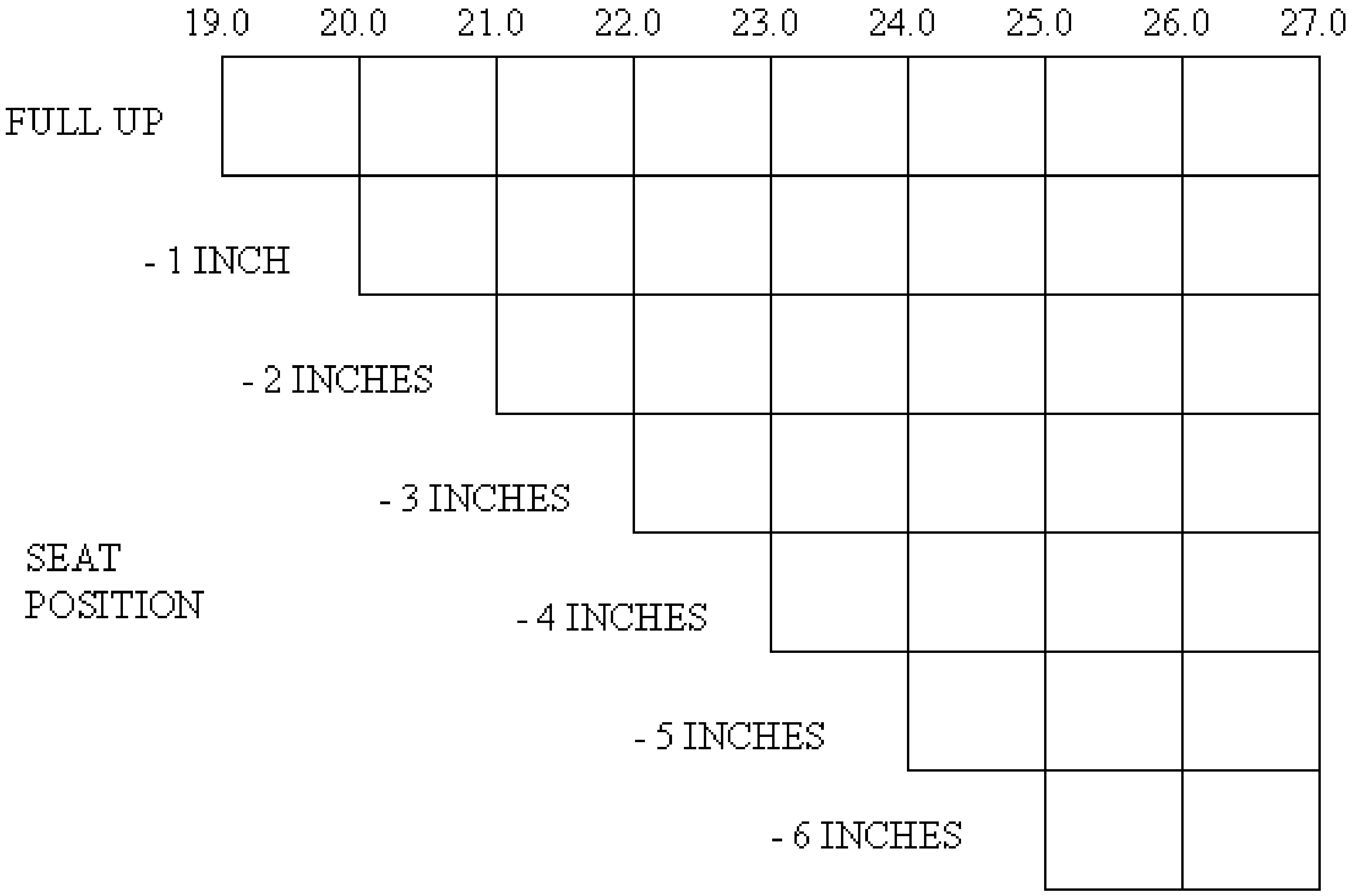
For any given seat position it is obvious that, all other factors being equal, controls that can be reached and actuated by subjects with short arms can also be reached and actuated by those with longer arms. In the vertically adjusting ejection seat, this relationship is somewhat complicated, since seat position is strongly influenced by the requirement to gain adequate vision out of the cockpit. Pilots with lower Sitting Eye Heights need to adjust the seat toward the upper end of its range and invariably farther away from hand controls to gain adequate vision over the nose of the aircraft. The worst case, insofar as reach to controls below shoulder level is concerned, is the pilot with short Thumbtip Reach and Sitting Eye Height, and relatively high shoulders. Such a pilot may have to adjust the seat full-up, moving the shoulders the greatest possible distance away from all such controls. In high performance aircraft, this constitutes most controls.

The Figure below illustrates a Seat Position Selection Chart which can be used to ensure that reach data are obtained on subjects representing an appropriate range of shoulder levels within the cockpit. The logic of its construction and use is based on the following discussion.

SEAT POSITION SELECTION CHART FOR EXAMINATION OF REACH CAPABILITY

AIRCRAFT I.D.________________________COCKPIT ___________

SITTING SHOULDER HEIGHTS



SEAT POSITION SELECTION CHART. This chart is used as a guide to assure that reach data are obtained at an appropriate range of shoulder levels within the cockpit. Ideally, all combinations of Sitting Shoulder Height and Seat Position should be used. Short of that, those for the full-up seat should be emphasized. If it is impossible to obtain subjects for every Sitting Shoulder Height, those of up to 1 inch larger or smaller can be used with seat positions adjusted to simulate the desired shoulder height.

In the cockpit, the seat can usually be adjusted upward or downward to produce different elevations of the shoulder in the cockpit. For example, the shoulders of a pilot with a 22.0" Sitting Shoulder Height and in the full-up seat adjustment will be at essentially the same level as another pilot with a 23.0 inch Sitting Shoulder Height in the seat adjusted 1 inch down from full-up, and a third pilot with a 24.0" shoulder in the seat at -2.0". It follows, then, that the Equivalent Thumbtip Reach required to access a given control will be essentially equal for such shoulder heights and seat adjustment combinations. In selecting subjects to be representative of those who will potentially experience difficulty in reaching controls, it is necessary to target the uppermost seat position. That is, to examine subjects in the full-up seat or simulated for the full-up seat. Because of the above relationships, then, a subject with a Sitting Shoulder Height of 22 inches in the seat adjusted to 2 inches down from full-up can simulate the subject with a 20 inch Sitting Shoulder Height in the full-up seat. Evidence for the validity of this assumption will be discussed further on. This eases the persistent problem of finding subjects who are of the exact sizes needed for the examination of reach. Simulation probably should not be attempted to Sitting Shoulder Heights more than two inches less than that of the subject. We reached this conclusion only after a large number of simulations were attempted. It is rare that a larger shoulder height has to be simulated.

When it is necessary to determine if controls have been located appropriately to accommodate to specific values for Sitting Shoulder Height and Thumbtip Reach, using subjects to simulate a target value for Sitting Shoulder Height can be quite useful. If, for example, a cockpit must accommodate to a minimum Sitting Shoulder Height of 22.7 inches and a Thumbtip Reach of 27.6 inches (see TABLE), we can simulate the small shoulder height with subjects as large as 24.7 inches. Since the worst case seat position for pilots meeting the target value of 22.7 inches would be full-up in order to gain adequate over-the-nose vision, we can simulate this shoulder height by lowering the seat by an amount equal to the difference between the subject's Sitting Shoulder Height and 22.7 inches. Again, we recommend that subjects not be more than two inches larger than the target value. Using the reach measuring procedures described in the previous paragraphs, the minimum necessary Equivalent Thumbtip Reach can be determined and compared to the 27.6-inch minimum target value.

Three reach zones specifically for use in aircraft cockpits have been defined in Mil-Std-1333B, ***Aircrew Station Geometry for Military Aircraft***. Although this Mil-Std is no longer recognized by the military services, the guidance it offers as regards reach zones is still followed by the majority of aircraft companies and many agencies of the Department of Defense.

Reach Zone 1 requires that the operator's shoulders be relaxed, but "fully restrained and equipped without stretch of arm or shoulder muscles." The harnesses are snugged and the pilot is held back against the seat back with the inertia reel locked. Forward and side-to-side motions of the torso and shoulders are not permitted, and should not be required. Zone 1 controls are defined as "critical and emergency controls," further, that all controls specifically related to "takeoff, landing, low altitude high speed flight, weapons delivery, and escape should be located within Zone 1." Many crew station engineers and pilots feel that Zone 1 should include, at the most, only the control stick or wheel at neutral, seat ejection grips and handles, and ignition and fuel controls. These categories of controls are not universally agreed to and reach requirements vary with aircraft type.

Zone 2 reaches are defined as those requiring the restraint system to remain as described for Zone 1, but the operator is free to move his/her shoulders and torso forward and to the sides to the maximum limit permitted by the total restraint system. Mil-Std-1333B calls for "essential" controls to be placed within Zone 2.

Reach Zone 3 specifies that the inertia reel be unlocked and the shoulders and torso permitted to move forward and to the sides as necessary for a maximum reaches. Mil-Std-1333B specifies these controls as "non-critical" or "non-essential."

A convenient way to contain shoulder and torso motion for Zone 1 measurements is to attach a cord to the seat or cockpit structure aft of each shoulder, stretching it forward, and with the hand, holding it firmly against the bony prominence at the tip of the shoulder (acromial process). If motion of the shoulder occurs during the reach measurement, it can be readily detected through disturbance of the shoulder/cord contact. This is illustrated below.

CONTROLLING SHOULDER AND TORSO MOVEMENT.

There is no set formula for selecting controls to which measurements will be made. Since there can be a very large number, however, only a sampling of them is attempted. The examiner should always be mindful of primary, safety-of-flight, emergency controls and contractually binding controls from the RFP or SOW, etc., and include them among those examined. Additional controls spaced at regular intervals over the surfaces and at the boundaries of the main instrument panel, sub-panels, pedestals, side consoles, overhead, and bulkhead panels should also be selected. Where there are groups of related controls within a relatively small area, an attempt should be made to select those that represent the variety of types and spatial distribution within the group. If a large area is found to contain only displays, or is vacant, landmarks on the surface of the panel, such as screw heads, can be selected to represent the area. For consistency, we assumed all such latter landmarks to be thumbtip interfaces. If, at a later date, such panel spaces are considered for the location of controls, information regarding reach will be available.

Examiners must designate which of the selected controls will be operated by the right and left hands, and which can conveniently be operated by either hand. In the latter case, reach measurements are made on each arm. Since primary control grips are designed to be grasped in the right hand and usually located between the knees, it should be assumed that, in such aircraft, controls on the main instrument panel to the left of the centerline of the cockpit will generally be operated exclusively with the left hand. Since the right hand is assumed to be preoccupied with the control stick, controls on the main instrument panel to the right of the crew station centerline and all those on a center pedestal may be operated by either hand. Controls on left and right sub and side panels will be operated only with the corresponding hand. Occasionally, a control will be found on the bulkhead just to the side of the shoulder. Such controls are sometimes more conveniently reached with the opposite hand. In wheel controlled aircraft, the pilot should never be expected to operate a control on one side of the yoke with the opposite hand.

Go to C-5A, C-141B, F-15A,BF,C&DF and F-16A/B,C/D,CG/D&CJ/D for complete lists of emergency controls for each model of each aircraft as well as a proposed list of hand controls for these aircraft to which reach measurements should be made.

PROCEDURE

To determine the shortest arm length necessary to reach a control, it is necessary that the test subject's elbow be fully extended and locked during the reach. Some controls are close enough that they do not require the elbow to be fully extended, indeed some are so close that the elbow cannot be extended. To obtain a measurement for such controls, subjects can often compensate and obtain a fully extended elbow by hyper-flexing the wrist.

Because measurements can be made only when the subject's elbow is fully extended and we want to obtain reach values for as many controls as possible, subjects with Thumbtip Reaches as close as possible to the minimum value should be used. A control too close to obtain a valid measurement, and therefore easily reached by such subjects, virtually assures that it can be reached by the full range of subjects.

The examination proceeds as follows.

1. Record Sitting Shoulder Height and Thumbtip Reaches on a Reach Data Forms Cover Page such as that illustrated in FIGURE.

2. Wearing typical flight gear less helmet, the subject is installed into the seat. In high performance ejection cockpits, the seat is adjusted to a position based upon the subject's Sitting Shoulder Height. The Seat Position Selection Chart above can be used to assure that a range of actual and simulated values for this dimension are represented. If a specific minimum accommodation value for Sitting Shoulder Height has been designated, the seat is adjusted down by an amount equal to the difference between his/her shoulder height and the target value to a maximum of 2 inches. In cockpits and flight decks with seats with both fore and aft and vertical adjustability and those that adjust along a ramp, the seat should be full-forward and full-up. Record seat position on the Reach Data Forms Cover Page.

3. All torso and shoulder harnesses are buckled and appropriately snugged up. The subject should lean forward, lock the inertia reel, and then settle comfortably against the seat back, allowing the reel to take up the slack in the restraint system. The inertia reel should remain locked for all Reach Zones 1 and 2 measurements. It is important to determine that both shoulders are equally restrained. This can be checked by selecting a point or control located in the centerline of the main instrument panel and taking right and left hand Zones 1 and 2 reach measurements to it. Equivalent Thumbtip Reaches that agree in correspondence with the differences in the subject's right and left Thumbtip Reaches, if any, will indicate equivalent restraint for both shoulders. Zone 1 measurements can be simulated in aircraft not equipped with manual locking inertia reels, but Zone 2 measurements cannot.

4. With the back resting comfortably against the seat-back and the forearms and hands resting in his/her lap, the shoulder cord for the left shoulder is brought forward over the bony prominence at the tip of the shoulder and held against the shoulder to encourage the maintenance of contact with the seat back while measuring Zone 1 reaches.

5. Ask the subject to extend the hand toward each of the controls to be examined,

in turn, usually beginning with the extreme left and proceeding around to the right. All Zone 1 reaches for a given hand are usually completed before beginning Zone 2 measurements.

6. Measure and record the distances measured from the "X" mark on the forearm to the interface points on the controls. An example of such a measurement is illustrated below.

MEASURING REACH CAPABILITY IN THE COCKPIT. Measurement is made between the mark on the thumb-side of the lower forearm to the interface of the control.

In the case of the control grip, toggle switch, or pushbutton, for instance, the interface point is the near surface of the control. In the case of a T-handle, ejection D-ring or handle, the interface point is the back side of the "T", strap, or handle. Most measurements will have positive values. That is, the mark on the forearm will be on the near side of the control. Occasionally the arm will be extended far enough that the mark on the forearm will be found on the far side of the interface point. If it is possible to make such measurements, the values are recorded and analyzed as negative values. Record results on the data forms shown in the below hyper-links.

GO TO FIGURE to data form for left handed reaches, left and right handed reaches and for right handed reaches.

GO TO FIGURE for left and right handed reaches.

GO TO FIGURE for right handed reaches.

7. Steps 5 and 6 are repeated for left hand Zone 2 reach - that is, without containing the shoulder and allowing the subject to lunge forward against the

restraint system. The subject should not be expected to obtain absolute maximum reach.

8. After all Zone 2 measurements have been made, those potentially reachable only under Zone 3 restraint are measured. For Zone 3 measurements the harness is unlocked. The subject, in attempting to reach the control, is permitted to lunge or lean the torso in the direction of the control to a comfortable maximum permitted by the unlocked restraint system.

ANALYSIS AND RESULTS

Analysis of reach data requires the use of both left and right Thumbtip Reaches, the "X" to hand interface measurements for both hands, "X" to control interface measurements, Sitting Shoulder Height, and seat position. Examples of left and right Thumbtip Reaches and "X" to hand interface measurements can be found in the first table below: examples of "X" to control "F" type interface in the second.

SAMPLE VALUES FOR THUMBTIP REACH AND "X-TO-INTERFACE" POINTS ON THE HAND.

THUMBTIP REACH (R) __29.0"__ , (L) __29.0"__

LEFT X TO G _3 5/8"_ , X TO F _8 3/8"_ , X TO H __7"__ , X TO T __6"__

RIGHT X TO G __4"__ , X TO F _8 7/8"_ , X TO H _7 1/2"_ , X TO T _6 1/4"_

- - - - - - - - - -

SAMPLE DATA FOR ONE SUBJECT REACHING WITH EACH HAND TO AN "F" TYPE CONTROL.

CONTROL ________________

(LOCUS) (HAND) (MODE)	MEASUREMENTS	EQUIVALENT THUMBTIP REACH
		ZONE 1 ___33.5"___
(MIP)(L)(F)	Z-1 __12 7/8"__, Z-2 __8 5/8"__	ZONE 2 ___29.3"___
	Z-3 ___7____	ZONE 3 ___27.6____

- - - - - - - - - -

ZONE 1 ___31.6"___

(MIP)(R)(F) Z-1 __11_1/2"__, Z-2 __7_1/2"___ ZONE 2 ___27.6"___

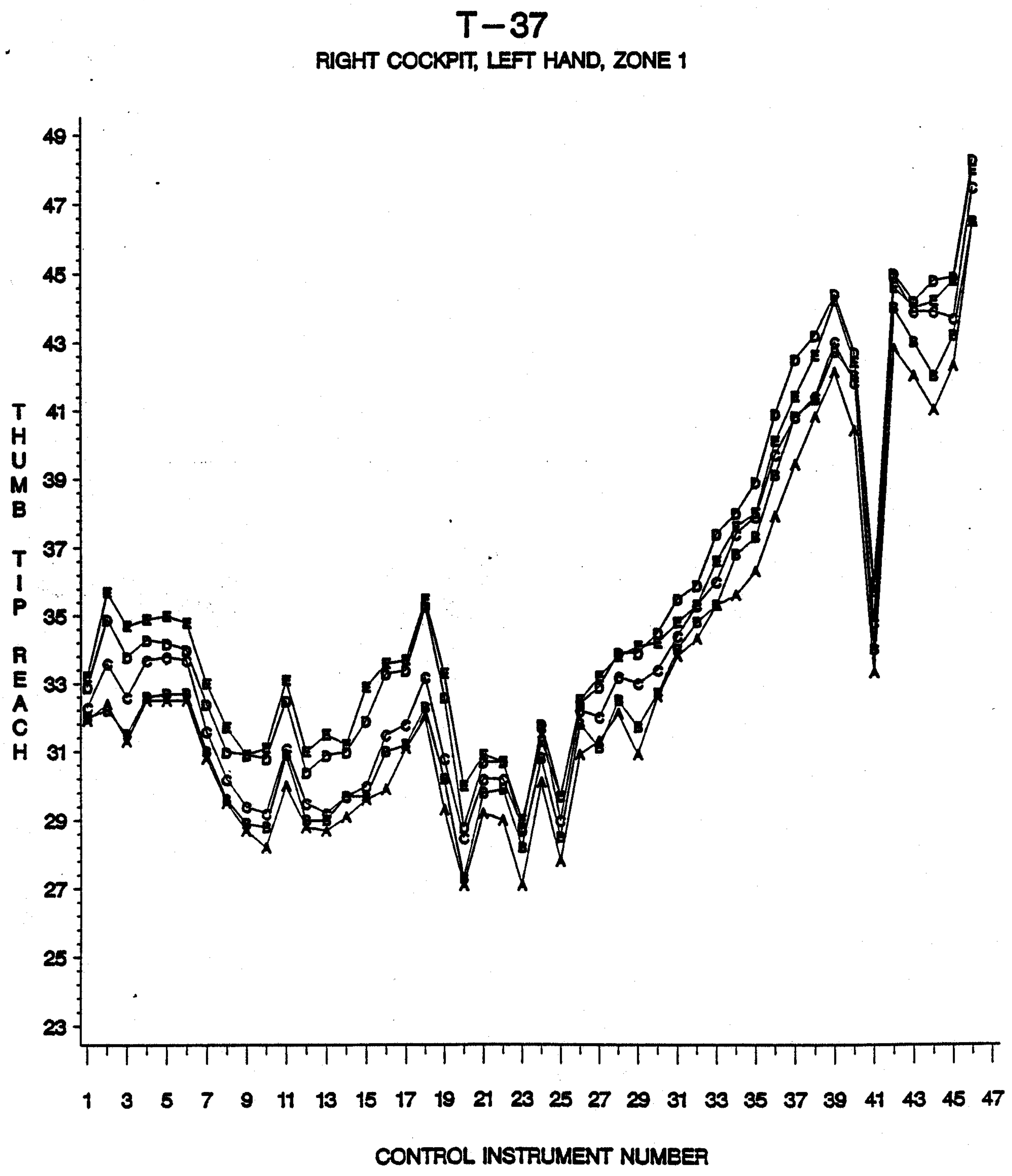
Z-3 ___5.5____ ZONE 3 ___25.6____

Analysis proceeds as follows. The distance from "X" to the control minus the distance from "X" to the interface point on the hand is equal to the distance between the interface point on the hand to the control. If the "X"-to-control distance is greater than the "X" to hand interface distance, the subject cannot be expected to reach the control under the specified reach conditions. If less, the subject should be able to reach to and likely beyond the control.

Using the sample subject whose data are shown in these first two tables above, the values for the minimum Equivalent Thumbtip Reaches necessary to access this control under Zones 1 and 2 restraint are calculated in a straightforward manner as follows. The subject's Thumbtip Reaches, both left and right, were measured at 29" each. The distance from "X" to fingertip was 8 3/8 inches for the left arm. The distance from "X" to the control interface on the main instrument panel (MIP) for the left arm was 12 7/8 inches. Therefore, this control would require a Zone 1 left hand Equivalent Thumbtip Reach equal to 29 + (12 7/8 - 8 3/8) or 33.5 inches. Equivalent Thumbtip Reach, Zone 2, equals this value (33.5) minus the difference between Zone 1 and Zone 2, or 33.5 - (12 7/8 - 8 5/8) or 29 1/4 (29.3) inches.* The minimum Zone 1 and 2 Equivalent Thumbtip Reaches for the right hand (given this subject's Sitting Shoulder Height and seat position) to this control were found to be 31.6 and 27.6 inches, respectively.

* All data were rounded off to the nearest 0.1 inch.

Reach data can be examined to correct or remove questionable data. This is a straightforward process of arranging the data by control and individual Equivalent Thumbtip Reaches. In the below table, reach data for the left hand for subjects "A" through "E" in the right cockpit of the T-37B are reported. Subject "A" had the lowest shoulder level in the cockpit and subject "E" the highest. Since higher shoulders are farther away from controls below shoulder level, we would expect an increasing progression of values for Equivalent Thumbtip Reach for those subjects when reaching to such controls. As expected, subject "A" consistently needed the least Equivalent Thumbtip Reach and subject "E" the greatest. The order of values for subjects "B" through "D," also generally reflects this pattern. Outliers and values that significantly depart from the established relationships are questioned. Decisions to eliminate values are made only after consideration of the pattern of values for controls near the one in question. Only minor departures from the expected order of values are accepted. Those that depart by an amount that is obviously misrepresentative can be altered to agree more closely with those located nearby. For controls above shoulder level, a decreasing progression of values would be expected, although a severe aft angle of seat travel can complicate this relationship.



REACH DATA SMOOTHING GRAPH FOR THE LEFT HAND, ZONE 1, RIGHT COCKPIT OF THE T-37B. Subject "A" had the lowest shoulder level in the cockpit and subject "E" the highest. For controls below shoulder level we would expect an increasing progression of values of Equivalent Thumb-Tip Reach, subject "A" reporting the smallest, subject "E" the largest.

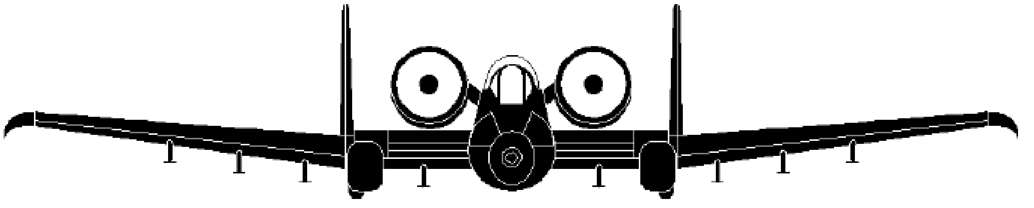
Reach data can be analyzed in at least two ways, depending upon the purpose of the examination. If the purpose is to provide an extensive mapping of reach capability, or if values are to be used in the pilot candidate selection process, regression plots can be developed. The variables in the regression plots are Sitting Shoulder Height, Equivalent Thumbtip Reach and seat position. If regression plots are to be prepared, as many subjects as possible should be used, not so few as are presented here for the purpose of illustration. Sitting Shoulder Height/seat position combinations should be selected so as to obtain a distribution of shoulder levels within the cockpit that is representative of the smaller pilots. Therefore, if subjects at the lower end of the range for Sitting Shoulder Height are not available, they may sometimes be simulated by lowering the seat. Lowering the seat by 1 inch, therefore, would simulate a pilot with 1 inch lesser Sitting Shoulder Height than the subject in the seat. Otherwise, measurements of reach are typically made with the seat full up. Regression plots can be seen at: F-16A, T-1A, T-37, T-38, C-141A, and T-37(a).

"To eliminate the need for a regression requiring three predictive variables, we substituted the variable Span for Thumb-Tip Reach and Biacromial Breadth, and created a two variable regression using Span and Sitting Shoulder Height. For some controls, particularly those overhead or on the aft portion of the side consoles, Shoulder Height is a significant variable in the regression equations. However, most of the controls . . . are forward of the shoulder, and the height of the shoulder was not significant in the resulting equation. Therefore, most of the time, only arm span is necessary to predict reach capability." (From Zehner, G.F. and J.A. Hudson, ***Body Size Accommodation in USAF Aircraft***, AFRL-HE-WP-TR-2002-0118, United States Air Force Research Laboratory, Human Effectiveness Directorate, Wright-Patterson AFB, OH.)

If the purpose of the evaluation is to decide compliance with a requirement for body size accommodation, it is usually sufficient to calculate average minimum Equivalent Thumbtip Reaches for each control and compare these with the anthropometric accommodation requirements detailed in the specification documents.

BACK TO CONTENTS

BACK TO CONTENTS



A-10 Thunderbolt II

CONTACT

USING THE DATA

There are several uses for accommodation data, the most straightforward of which is the verification of design specifications. If a cockpit is required to accommodate a given range of body sizes, the techniques described here make it possible to validate compliance. This is done by comparing the anthropometric dimensions in the specification to the results of the evaluations. Test subjects who are close to the body size requirements set forth in the specification can be selected. In that way, the acceptability of proposed clearance, vision, reach, and operability can be observed directly as opposed to being inferred. For reach to controls it is important to have a list of the critical controls which must be reached in under Zone 1 restraint and those under Zone 2 restraint. These lists should be compiled by the System Program Office and test pilots since its composition will vary depending on the aircraft's mission requirements.

Another use for these data is to predict the fit of a range of body sizes in a crewstation. Data can also be used to assess the effects of expanding the ranges of body sizes permitted to enter pilot training.

(The following is from Zehner, G.F. and J.A. Hudson, Body Size Accommodation in USAF Aircraft, AFRL-HE-WP-TR-2002-0118, United States Air Force Research Laboratory, Human Effectiveness Directorate, Wright-

Patterson AFB, OH.and contributed by the authors.) ***"Software has been written and distributed which accepts input of an individual's anthropometric dimensions and gives [an] output of all aircraft in which that individual is accommodated. In the event that this document must be used for the same purpose, the procedure is as follows: First, small candidates must be measured for Sitting Eye Height, Shoulder Height Sitting (Acromion), Buttock-Knee Length, Knee Height Sitting, and Arm Span. First, compare the Sitting Eye Height measurements with the data in Table 3.2. If the candidate's Sitting Eye Height is less than 29.6 inches, this individual will not have adequate external vision in the T-38 or T-1. There would be no follow-on Trainer for this individual to fly. However, given the variability in anthropometric measurements, and the variability due to posture in the cockpit accommodation measurements, those who are close to 29.6 inches for Sitting Eye Height may be classified as marginal and given a "fit-check" in those aircraft. If the Sitting Eye height is greater than 29.6 inches, then it is important to calculate the amount greater and apply the adjustment listed in column three of Table 3.2. If for example, the candidate has a Sitting Eye Height of 30 inches, that value is 2.5 inches greater than the minimum requirement for the T-37. Since that seat adjusts in 0.625-inch notches, the candidate could lower the seat 4 notches and still see the minimum vision requirement. This will place the candidate much closer to rudders and hand controls. However, the candidate is only 0.4 inches larger than the minimum requirement in the T-1. The seat in this aircraft adjusts in 0.8-inch intervals. Therefore the candidate must remain in the full-up seat position for rudder and reach calculations. Those aircraft listed as 1/1 in Table 3.2 are continuously adjustable, so any amount of excess Sitting Eye Height can be subtracted directly from the seat position. At that point, classify the candidates as pass/fail (and possibly marginal) for each aircraft in Table 3.2. Next, using the seat position data, classify the candidate in each aircraft for reach to rudders using Table 4.2. The minimum Comboleg required for reaching full rudders from the full-up seat position is 40.5 inches. However, (using our candidate with a 30-inch Sitting Eye Height as an example) this person could sit 4 notches down, the minimum Comboleg from this position would be 39.5 inches. The last step is to again apply the seat position information, this time to Table 5.3 arm reach to controls. We will assume our candidate pilot has an arm Span of 63 inches and a Shoulder Height [Sitting] of 22 inches. The most restrictive reach requirement in [the] T-37 is full-forward stick with locked harness inertial reels. The equation for calculating miss distance to this control is miss distance = (.38603 X Shoulder Height Sitting (22 inches)) - (.70890 X Arm Span (63 inches)) + 34.4 inches. This equals -1.77 inches. A negative miss distance means the candidate went beyond the control by 1.77 inches and is a pass.* In addition, since the seat could be lowered 4 notches, the candidate would be 0.28 X 4 = 1.12 inches closer to the control. The final excess reach capability would be -2.89 inches. Once again it must be pointed out that there is variability (called statistical error) in this process and the numbers are best estimates. Those close to the minimum limits could be characterized as marginal and given live fit-tests.***

Large pilots must be measured for Sitting Height and Buttock-Knee Length . . . . Seat

effect is irrelevant because the seat will travel up the rails during ejection, and we assume that if a candidate has overhead clearance problems the seat will have been adjusted full-down. Table 7.2 and Table 8.1 can be used directly. The same variability caveat applies to large candidates. Those very close to these limits could be classified as marginal and given a fit-check."

* The convention would be to consider a "plus" value as one ***greater*** than that necessary to reach a given control. Multiplying the result by (-1) would satisfy this convention.

We have only limited ability to predict the individual's level of accommodation. This is true of all measures but especially hand reaches to controls. When regression equations are used, they must be based on large samples. Such predictions produce "average" values expected for a population of individuals of that body size. There can be a good deal of variation around the average. If examination indicates some question regarding an individual's ability to safely operate the aircraft, a trial in the cockpit may be warranted.

BACK TO CONTENTS

BACK TO CONTENTS
BACK TO PRELIMINARY MEASUREMENTS

A-10 Thunderbolt II

CONTACT THE AUTHOR

ANTHROPOMETRIC DESCRIPTIONS

"X" TO DIMENSIONS

"X" refers to a mark placed on the thumb side of the forearm and from which the distances to the Hand Grip, Finger-Tip, Hook, and Thumb-Tip interfaces on the hand are measured. The most convenient location of the "X" mark was found to be on the distal third of the forearm. Measurements are taken from both arms. It is not necessary that the locations of marks on both arms be identical.

"X" TO GRIP

With the elbow flexed to 90 degrees and the forearm and hand horizontal and forward, a 1 inch diameter dowel is held in the grip of the hand and oriented vertically. The distance between the "X" mark and the near surface of the dowel, parallel to the axis of the forearm, is measured.

"X" TO HOOK

The arm and hand are oriented as with "X" to Fingertip. The distance between the "X" mark and the most distal crease in the index finger is measured.

"X" TO FINGERTIP

The arm is oriented as with "X" To Grip, but the hand is flattened and thrust forward. The distance between the "X" mark and the tip of the index finger is measured.

"X" TO THUMB

The arm and hand are oriented as with "X" to Hook, but with the thumb flattened along the palmar edge of the palm at the base of the forefinger. The distance between the "X" mark and the tip of the thumb is measured.

CONVENTIONAL ANTHROPOMETRIC MEASUREMENTS

BUTTOCK-KNEE LENGTH

Subject sits erect, feet resting on a surface adjusted so that the knees are flexed to about right angles and thighs horizontal. Measure the horizontal distance from the rearmost surface of the right buttock to the forward surface of the right kneecap.

SHOULDER (BIDELTOID) BREADTH

Subject sits erect, head in the Frankfort plane, upper arms hanging relaxed, elbows flexed to about 90 degrees, forearms and hands extended forward horizontally. Measure the horizontal distance between the maximum lateral protrusions of the right and left deltoid muscles.

SITTING ABDOMINAL DEPTH

Subject sits erect, upper arms hanging relaxed, forearms and hands extended forward horizontally. Breathing is normal. Measure the horizontal depth of the abdomen at its greatest above the upper surface of the thighs.

SITTING EYE HEIGHT

Subject sits erect, head in the Frankfort plane, upper arms hanging relaxed, forearms and hands extended forward horizontally. Measure the vertical distance from the sitting surface to the right external canthus (outer "corner" of eye).

SITTING HEIGHT

Subject sits erect, head in the Frankfort plane, upper arms hanging naturally at sides, elbows flexed to 90 degrees, forearms and hands directed forward. Measure the vertical distance from the sitting surface to the top of the head.

SITTING KNEE HEIGHT

Subject sits with feet resting on a surface adjusted so that the thighs are horizontal and the knees are flexed to about 90 degrees. Measure the vertical distance from the footrest surface to the superior margin of the right knee cap.

SITTING SHOULDER (ACROMION) HEIGHT

Subject sits erect, head in the Frankfort plane, upper arms hanging relaxed at sides, and forearms and hands extended forward horizontally. Measure the vertical distance from the sitting surface to the right Acromion - the bony landmark at the tip of the shoulder.

STATURE (STANDING HEIGHT)

Subject stands erect, head in the Frankfort plane, heels together, and weight distributed equally on both feet. Measure the distance from the floor to the top of the head.

THIGH CIRCUMFERENCE

Subject stands erect with feet separated by about 15 inches. Measure the circumference of the right thigh with the tape as high as possible in the crotch.

THUMBTIP REACH

Subject stands erect with heels, buttocks, and back in contact with a wall or other vertical surface. The right arm is rotated forward to the horizontal, thumb and forefinger tips opposed in a fingertip grasping attitude, thumb extended and parallel to the axis of the arm and forearm. Measure the distance from the wall to the tip of the thumb.

WEIGHT

Subject is wearing shorts and top as appropriate.

BACK TO CONTENTS
BACK TO PRELIMINARY MEASUREMENTS

Back to CONTENTS

F-117A Stealth Fighter

CONTACT THE AUTHOR

ANNOTATED BIBLIOGRAPHY

NOTE: The following is a list of references that have been annotated (indicated by "GO") and some scheduled for annotation. Others will be added as time permits. Sources selected for annotation not only represent the most recent efforts, some published and some unpublished "in-house" reports, but also some that are relatively ancient and represent important work of pioneers in the area of aircraft evaluation and design. The latter are indicated by #.

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Back to CONTENTS

BACK TO FIGURES
BACK TO MAXIMUM SITTING HEIGHT
GO TO CONTENTS

MAXIMUM SITTING HEIGHT ACCOMMODATION

AIRCRAFT I.D. ______________________ CREW STATION ______________________

TOTAL VERTICAL SEAT ADJ. __________ , TOTAL HORIZONTAL SEAT ADJ. ________

CANOPY/OVERHEAD TANGENT ANGLE ____________

SEAT ADJUSTED UP TO TOUCH OR FULL- UP

	SUBJECT	HEAD TO CANOPY DISTANCE *1		REMAINING DOWNWARD SEAT ADJ.		SITTING HEIGHT		HEAD TO CANOPY DISTANCE **2		MAXIMUM SITTING HEIGHT ACCOMMODATED (BARE HEADED)
1)	________	________	+	________	+	________	-	________	=	____________
2)	________	________	+	________	+	________	-	________	=	____________
3)	________	________	+	________	+	________	-	________	=	____________
4)	________	________	+	________	+	________	-	________	=	____________
5)	________	________	+	________	+	________	-	________	=	____________
6)	________	________	+	________	+	________	-	________	=	____________

7) ________ ________ + _________ + ________ - ________ = ____________

8) ________ ________ + _________ + ________ - ________ = ____________

9) ________ ________ + _________ + ________ - ________ = ____________

10) ________ ________ + _________ + ________ - ________ = ____________

DATA FORM FOR RECORDING MAXIMUM BARE HEADED SITTING HEIGHT ACCOMMODATION UNDER THE CANOPY OR OTHER OVERHEAD. To obtain an applicable helmeted accommodation value, the distance from the top of the bare head to the top of the helmet and an appropriate clearance must be subtracted from bare headed accommodation.

* Measured on subjects who can raise the seat full up without encountering head motion interference.
** Measured on subjects who encounter head motion interference.

BACK TO FIGURES
BACK TO MAXIMUM SITTING HEIGHT
GO TO CONTENTS

BACK TO FIGURES
BACK TO VISION
GO TO CONTENTS

DATA FORM FOR RECORDING MEASUREMENTS OF VISION FROM THE COCKPIT.

EXTERNAL VISION

AIRCRAFT I.D. ________________ CREW STATION ___________ AIRCRAFT ATTITUDE ___________

NAME ____ DATE ________________

LINES OF SIGHT

	HEAD IN	HEAD UP			
	FRANKFURT PLANE	AND BACK	__________	__________	__________
SEAT					
MAX UP	_______	_______	_______	_______	_______
- 1 " *	_______		_______		

- 2 "	________		________		
- 3 "	________		________		
- 4 "	________		________		
- 5 "	________		________		
FULL DOWN	________	________	________	________	________

* From Full Up.

BACK TO FIGURES
BACK TO EJECTION
GO TO CONTENTS

EJECTION CLEARANCES: KNEES AND BODY BREADTHS

AIRCRAFT ____________________ CREW STATION ______________

ANGLE OF EJECTION RAILS ______ DEGREES.

SUBJECT	KNEE TO NEAREST THREATENING STRUCTURE	TO OTHER STRUCTURE (I.D. ??)	SHOULDER/ARM TO COCKPIT SIDE-SILL
1. ____________	______________	______________	______________
2. ____________	______________	______________	______________
3. ____________	______________	______________	______________
4. ____________	______________	______________	______________
5. ____________	______________	______________	______________
6. ____________	______________	______________	______________
7. ____________	______________	______________	______________

8. ______________ ________________ ________________ ________________

9. ______________ ________________ ________________ ________________

10. ______________ ________________ ________________ ________________

DATA FORM FOR RECORDING KNEE AND BODY BREADTH EJECTION CLEARANCES.

BACK TO FIGURES
BACK TO LEG CLEAR W/MAIN
GO TO CONTENTS

OPERATIONAL LEG CLEARANCE WITH THE MAIN INSTRUMENT PANEL

AIRCRAFT __________ CREW STATION __________

SUBJECT __________ BUTTOCK-KNEE LGTH. _______ SITTING KNEE HT. ________

LEG (SHIN/KNEE) CLEARANCES

SEAT POSITION (CHECK IF CARRIAGE IS FULL- FWD)	NEUTRAL RUDDER	FULL RT RUDDER ACTIVE LEG	FULL RT RUDDER PASSIVE LEG	FULL LT RUDDER ACTIVE LEG	FULL LT RUDDER PASSIVE LEG	1” BUTT BLOCK (CHECK)	1” RUDDER ADJ (CHECK)
FULL- DOWN	( )_____	_____	_____	_____	_____	_____ /	_____
+ 1 INCH	( )_____	_____	_____	_____	_____	_____ /	_____
+ 2 INCHES	( )_____	_____	_____	_____	_____	_____ /	_____
+ 3 INCHES	( )_____	_____	_____	_____	_____	_____ /	_____
+ 4 INCHES	( )_____	_____	_____	_____	_____	_____ /	_____
+ 5 INCHES	( )_____	_____	_____	_____	_____	_____ /	_____
+ 6 INCHES	( )_____	_____	_____	_____	_____	_____ /	_____
FULL- UP	( )_____	_____	_____	_____	_____	_____ /	_____

DATA FORM FOR OPERATIONAL LEG CLEARANCES.

BACK TO FIGURES
BACK TO LEG CLEAR W/CONTROL
GO TO CONTENTS

DATA FORM FOR UNIMPEDED CONTROL STICK/WHEEL AND AILERON MOTION: BASELINE MEASUREMENTS.

Baseline Measurements

AIRCRAFT ________________ COCKPIT _________ (No Pitch or Aileron Trim)

LEFT FORWARD RIGHT

<-______|______-> ________________________________<-______|______->

<-______|______-> <----- NEUTRAL STICK -----> <-______|______ ->

<-______|______-> ________________________________<-______| ______->

LEFT AFT RIGHT

DISTANCE FROM MIP TO FULL- FWD STICK _______

DISTANCE FROM MIP TO NEUTRAL STICK _______

DISTANCE FROM MIP TO FULL- AFT STICK _______

DISTANCE FROM FULL- FWD TO FULL- AFT STICK _______

- -

AILERON POSITIONS AT 1 INCH INTERVALS FROM CENTER TO FULL LEFT AND RIGHT STICK

FULL 4" 3" 2" 1" CTR 1" 2" 3" 4" FULL

LEFT **RIGHT**

_____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____

____

UNIMPEDED CONTROL WHEEL AND AILERON MOTION - Baseline Measurements

AIRCRAFT I.D. _______________________ CREW STATION __________________

	ANGLE OF LEFT WING AILERON	WHEEL ROTATION FROM NEUTRAL
FULL LEFT	______Degrees	_______Degrees
FULL RIGHT	______Degrees	_______Degrees

AILERON POSITIONS AT 10 DEGREE INTERVALS FROM CENTER TO FULL LEFT AND RIGHT

FULL 40 30 20 10 CTR 10 20 30
40 FULL
LEFT **RIGHT**

_____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____

BACK TO FIGURES
BACK TO LEG CLEAR W/CONTRO
GO TO CONTENTS

DATA FORM FOR CONTROL STICK INTERFERENCE AND AILERON MEASUREMENTS

FEET ON NEUTRAL RUDDERS AND FULL RIGHT OR LEFT RUDDER

AIRCRAFT ______________ COCKPIT ________

Neutral Rudders ____ Right Rudder ____ Left Rudder ____

NAME _______________ SEAT POSITION ________

No Pitch or Aileron Trim

```
LEFT       LEFT                                        RIGHT      RIGHT

STICK      AILERON                                     STICK      AILERON

(INCHES)   (DEGREES)                                   (INCHES)   (DEGREES)



<- ______   ______      <----- FORWARD STICK ----->     ______   ______ ->
            |                                                    |
            |                                                    |
            |                                                    |
<- ______ | ______      <----- NEUTRAL STICK ----->      ______  | ______ ->
            |                                                    |
            |                                                    |
            |                                                    |
<- ______ | ______      <--------- AFT STICK -------->    ______  | ______ ->

LEFT                                                                  RIGHT
```

DISTANCE FROM MAIN INSTRUMENT PANEL TO SUBJECTS AFT-MOST STICK

____

HIGHEST SEAT POSITION AT WHICH INTERFERENCE IS NO LONGER FOUND ________

COMMENTS:

BACK TO FIGURES
BACK TO LEG CLEAR W/CONTROL
GO TO CONTENTS

DATA FORM FOR CONTROL WHEEL INTERFERENCE AND AILERON MEASUREMENTS.

SUBJECT ____________________________ SEAT POSITION __________

RUDDER POSITION (CIRCLE)

NEUTRAL RUDDER - FULL LEFT RUDDER - FULL RIGHT RUDDER

SEAT POSITIONS	CONTROL COLUMN FORWARD		NEUTRAL		AFT	
FULL- UP	WHEEL LEFT	WHEEL RIGHT	WHEEL LEFT	WHEEL RIGHT	WHEEL LEFT	WHEEL RIGHT
	_____	_____	_____	_____	_____	_____
AILERON	_____	_____	_____	_____	____	_____
- 1 IN	WHEEL LEFT	WHEEL RIGHT	WHEEL LEFT	WHEEL RIGHT	WHEEL LEFT	WHEEL RIGHT
	_____	_____	_____	_____	_____	_____

AILERON

	______	______	______	______	______	______
- 2 IN	WHEEL LEFT	WHEEL RIGHT	WHEEL LEFT	WHEEL RIGHT	WHEEL LEFT	WHEEL RIGHT
	______	______	______	______	______	______

AILERON

	______	______	______	______	______	______
- 3 IN	WHEEL LEFT	WHEEL RIGHT	WHEEL LEFT	WHEEL RIGHT	WHEEL LEFT	WHEEL RIGHT
	______	______	______	______	______	______

AILERON

	______	______	______	______	______	______
- 4 IN	WHEEL LEFT	WHEEL RIGHT	WHEEL LEFT	WHEEL RIGHT	WHEEL LEFT	WHEEL RIGHT
	______	______	______	______	______	______

AILERON						
	_____	_____	_____	_____	_____	_____
- 5 IN	WHEEL	WHEEL	WHEEL	WHEEL	WHEEL	WHEEL
	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT
	_____	_____	_____	_____	_____	_____
AILERON						
	_____	_____	_____	_____	_____	_____
FULL DOWN	WHEEL	WHEEL	WHEEL	WHEEL	WHEEL	WHEEL
	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT
	_____	_____	_____	_____	_____	_____
AILERON						
	_____	_____	_____	_____	_____	_____

BACK TO FIGURES
BACK TO RUDDERS
GO TO CONTENTS

DATA FORM FOR RECORDING RUDDER PEDAL OPERATION (MINIMUM ACCOMMODATION)

AIRCRAFT I.D. ____________________ CREW STATION ______________

SUBJECT ____________________

SEAT	SUBJECT ADJUST POINT		FULL- AFT ADJUST POINT		SUBJECT'S COMBOLEG		MIMIMUM ACCOMMODATED COMBOLEG
FULL- UP	_________	-	_________	+	________	=	________
- 1	_________	-	_________	+	________	=	________
- 2	_________	-	_________	+	________	=	________
- 3	_________	-	_________	+	________	=	________
- 4	_________	-	_________	+	________	=	________
- 5	_________	-	_________	+	________	=	________

- 6	____________	-	____________	+	____________	=	____________
FULL- DN	____________	-	____________	+	____________	=	____________

BACK TO FIGURES

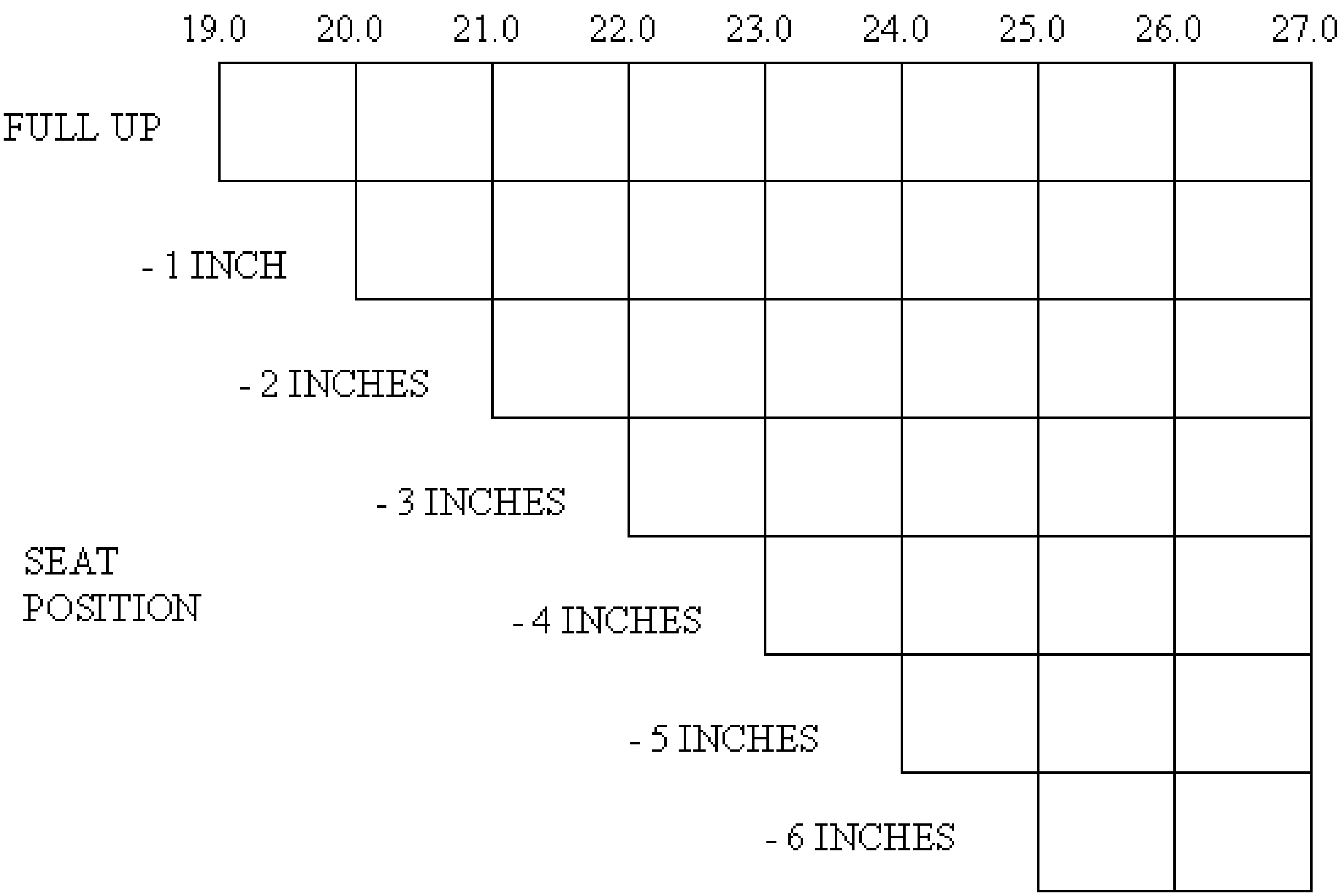
BACK TO REACH

GO TO CONTENTS

SEAT POSITION SELECTION CHART FOR EXAMINATION OF REACH CAPABILITY

AIRCRAFT I.D. ________________________ COCKPIT ___________

SITTING SHOULDER HEIGHTS



SEAT POSITION SELECTION CHART. This chart is used as a guide to assure that reach data are obtained at an appropriate range of shoulder levels within the cockpit. Ideally, all combinations of Sitting Shoulder Height and Seat Position should be used. Short of that, those for the full-up seat should be emphasized. If it is impossible to obtain subjects for every Sitting Shoulder Height, those of up to 1 inch larger or smaller can be used with seat positions adjusted to simulate the desired shoulder height.

BACK TO FIGURES

BACK TO REACH

SEAT POSITION SELECTION CHART FOR EXAMINATION OF REACH CAPABILITY

GO TO CONTENTS

BACK TO FIGURES
BACK TO REACH
GO TO CONTENTS

REACH DATA FORMS COVER SHEET

AIRCRAFT I.D. ________COCKPIT _____________SEAT POSITION ___________

SUBJECT ____________________ SITTING SHOULDER HEIGHT _____________

LEFT THUMBTIP REACH _______,

X TO GRIP _______, X TO FINGER _______

X TO HOOK _______, X TO THUMB _______

RIGHT THUMBTIP REACH ______,

X TO GRIP _______, X TO FINGER _______

X TO HOOK _______, X TO THUMB _______

CENTERLINE CONTROL OR TARGET

Left Z-1 ________, Z-2 ________

Right Z-1 ________, Z-2 ________

HAND REACH TO CONTROLS COVER SHEET

BACK TO FIGURES
BACK TO REACH
GO TO CONTENTS

LEFT HAND REACHES

AIRCRAFT I.D. ____________ COCKPIT ___________ PAGE ____OF____

SEAT _____ IN./STOPS DOWN FROM FULL-UP.

CONTROL	(LOCUS) (HAND) (MODE)	MEASURED REACH VALUES	EQUIVALENT CALCULATED TH-T REACHES
			ZONE 1 _______
_________________	( )(L)( )	Z-1 _____ Z-2 _____	ZONE 2 _______
		Z-3 _____	ZONE 3 _______
			ZONE 1 _______
_________________	( )(L)( )	Z-1 _____ Z-2 _____	ZONE 2 _______
		Z-3 _____	ZONE 3 _______

ZONE 1 ________

__________________ ( )(L)( ) Z-1 ______ Z-2 ______ ZONE 2 ________

Z-3 ______ ZONE 3 ________

ZONE 1 ________

__________________ ( )(L)( ) Z-1 ______ Z-2 ______ ZONE 2 ________

Z-3 ______ ZONE 3 ________

ZONE 1 ________

__________________ ( )(L)( ) Z-1 ______ Z-2 ______ ZONE 2 ________

Z-3 ______ ZONE 3 ________

ZONE 1 _______

_________________ (   )(L)(   ) Z-1 _____ Z-2 _____ ZONE 2 _______

Z-3 _____ ZONE 3 _______

REACH DATA FORM - LEFT HAND REACHES. "LOCUS" indicates the location of the controller. Examples include "MIP" (Main Instrument Panel), "LSP" and "RSP" (Left and Right Sub Panels), and "PED" (Pedestal). "HAND" refers to hand used by pilot to reach. "MODE" refers to type of reach required - i.e., thumb and forefinger (T), grip (G), finger (F), and hook (H). Measured Reach Values are the dimensions measured from a mark on the lower forearm to the interface point on the control.

BACK TO FIGURES
BACK TO REACH
GO TO CONTENTS

REACH DATA FORM - LEFT AND RIGHT HAND REACHES.

AIRCRAFT I.D. ____________ COCKPIT ___________ PAGE ____OF____

SEAT _____ IN./STOPS DOWN FROM FULL-UP.

CONTROL	(LOCUS) (HAND) (MODE)	MEASURED REACH VALUES	EQUIVALENT CALCULATED TH-T REACHES
			ZONE 1 _______
_________________	( )(L)( )	Z-1 _____ Z-2 _____	ZONE 2 _______
		Z-3 _____	ZONE 3 _______
			ZONE 1 _______
_________________	( )(R)( )	Z-1 _____ Z-2 _____	ZONE 2 _______
		Z-3 _____	ZONE 3 _______

- -

ZONE 1 ________

__________________ (   )(L)(   ) Z-1 ______ Z-2 ______ ZONE 2 ________

Z-3 ______ ZONE 3 ________

ZONE 1 ________

__________________ (   )(R)(   ) Z-1 ______ Z-2 ______ ZONE 2 ________

Z-3 ______ ZONE 3 ________

- -

ZONE 1 ________

__________________ (   )(L)(   ) Z-1 ______ Z-2 ______ ZONE 2 ________

Z-3 ______ ZONE 3 ________

ZONE 1 _______

_________________ (   )(R)(   ) Z-1 ______ Z-2 ______ ZONE 2 _______

Z-3 ______ ZONE 3 _______

BACK TO FIGURES
BACK TO REACH
GO TO CONTENTS

REACH DATA FORM - RIGHT HAND REACHES

AIRCRAFT I.D. ____________ COCKPIT ___________ PAGE ____OF____

SEAT _____ IN./STOPS DOWN FROM FULL-UP.

CONTROL	(LOCUS) (HAND) (MODE)	MEASURED REACH VALUES	EQUIVALENT CALCULATED TH-T REACHES
			ZONE 1 _______
________________	( )(R)( )	Z-1 _____ Z-2 _____	ZONE 2 _______
		Z-3 _____	ZONE 3 _______
			ZONE 1 _______
________________	( )(R)( )	Z-1 _____ Z-2 _____	ZONE 2 _______

Z-3 ______ ZONE 3 ________

ZONE 1 ________

__________________ ( )(R)( ) Z-1 ______ Z-2 ______ ZONE 2 ________

Z-3 ______ ZONE 3 ________

ZONE 1 ________

__________________ ( )(R)( ) Z-1 ______ Z-2 ______ ZONE 2 ________

Z-3 ______ ZONE 3 ________

ZONE 1 ________

__________________ ( )(R)( ) Z-1 ______ Z-2 ______ ZONE 2 ________

Z-3 ______ ZONE 3 ________

ZONE 1 ________

__________________ (   )(R)(   ) Z-1 ______ Z-2 ______ ZONE 2 ________

Z-3 ______ ZONE 3 ________

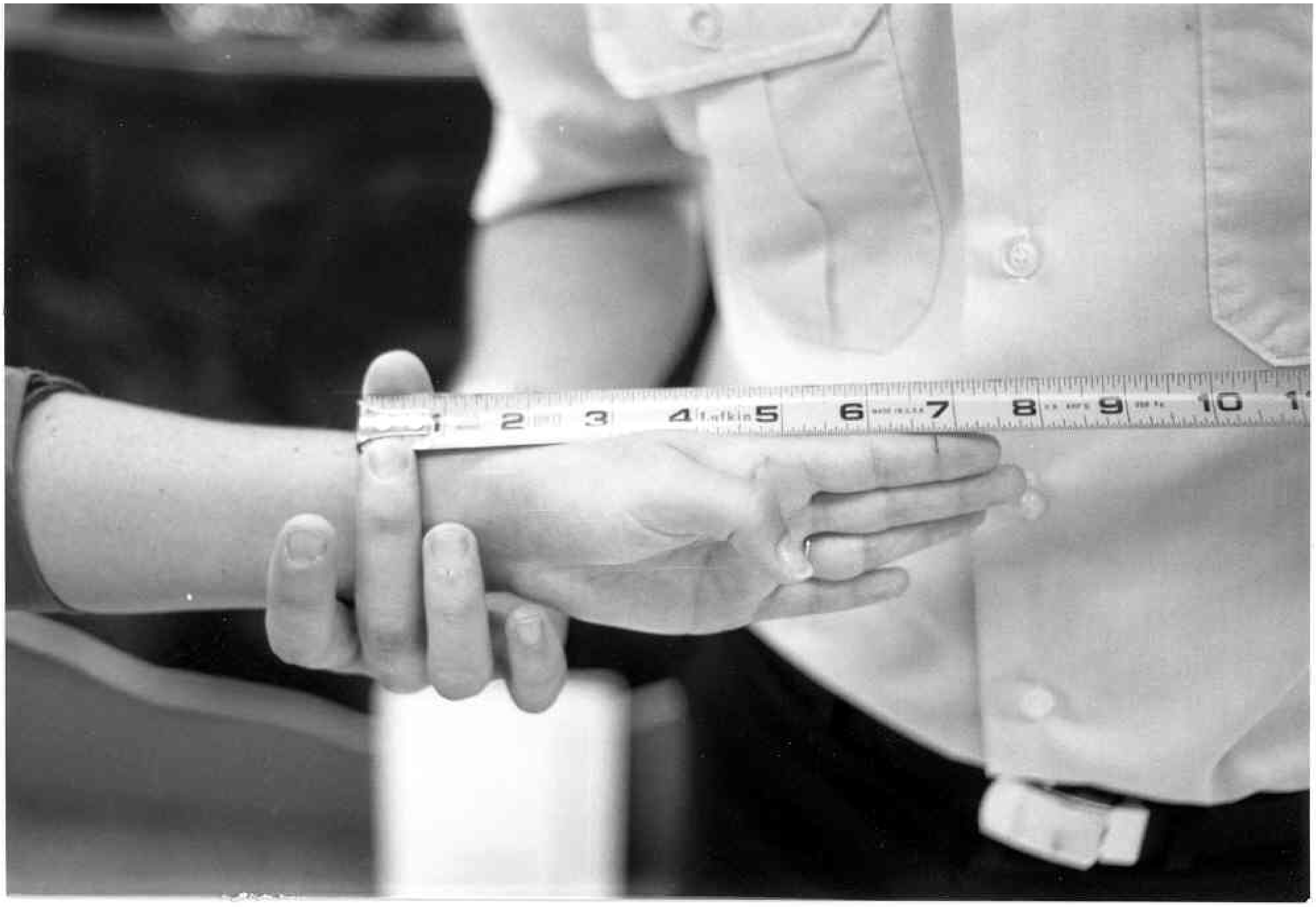
BACK TO FIGURES
BACK TO REACH
BACK TO ANTHROPOMETRY
GO TO CONTENTS

DIMENSION "X" TO FINGERTIP.

BACK TO FIGURES
BACK TO REACH
BACK TO ANTHROPOMETRY
GO TO CONTENTS

DIMENSION "X" TO GRIP. "X" refers to a mark placed on the thumb side of the forearm and from which the distances to the Grip, Hook, Fingertip, and Thumbtip interfaces on the hand are measured. The most convenient location of the mark was found to be in the distal third of the forearm near the wrist. It is not necessary that the location of the mark on both arms be identically located.

BACK TO FIGURES
BACK TO REACH
BACK TO ANTHROPOMETRY
GO TO CONTENTS



DIMENSION "X" TO HOOK.

BACK TO FIGURES
BACK TO REACH
BACK TO ANTHROPOMETRY
GO TO CONTENTS

DIMENSION "X" TO THUMB.

BACK TO TABLES

BACK TO REACH

GO TO CONTENTS

ANTHROPOMETRIC MULTIVARIATE MODELS

		Model 1	Model 2	Model 3
		Generalized Small Female	Small Female Short Reach Higher Shldrs	Male Short Torso Long Limbs
1.	Sitting Height	34.0	35.5	34.9
2.	Sitting Eye Height	28.9	30.7	30.2
3.	Sitting Acromion Height	21.3	22.7	22.6
4.	Sitting Knee Height	19.5	19.1	23.3
5.	Buttock-Knee Length	22.1	21.3	26.5
6.	Thumbtip Reach	28.3	27.6	33.9

		Model 4	Model 5	Model 6
		Generalized Large Male	Male Longest	Male Long Torso

			Limbs	Short Limbs
1.	Sitting Height	40.0	38.0	38.5
2.	Sitting Eye Height	35.0	32.9	33.4
3.	Sitting Acromion Height	26.9	25.0	25.2
4.	Sitting Knee Height	24.7	24.8	20.6
5.	Buttock-Knee Length	27.4	27.9	22.7
6.	Thumbtip Reach	35.6	36.0	29.7

BACK TO TABLES

BACK TO VISION

GO TO CONTENTS

VISION FROM THE LEFT COCKPIT OF THE T-37B.

Sitting Eye Height = 28.9", the Small Generalized Female.

LINES OF SIGHT IN DEGREES

SEAT POSITION	O'NOSE*	O'NOSE HEAD UP/AFT	OVER BOW*	UNDER BOW*
FULL UP	- 10 Degrees	- 12 Degrees	+23 Degrees	+11 Degrees
- 5/8"	- 10	- 12	+24	+12
- 1 1/4"	- 9	- 11	+26	+14
- 1 7/8"	- 9	- 11	+27	+15
- 2 1/2"	- 8	- 10	+29	+17
- 3 1/8"	- 8	- 10	+30	+18
- 3 3/4"	- 8	- 10	+31	+19
- 4 3/8"	- 7	- 9	+33	+21
FULL DOWN	- 7	- 9	+34	+22

* Head in Frankfurt Plane.

BACK TO TABLES

BACK TO REACH

GO TO CONTENTS

SAMPLE VALUES FOR THUMBTIP REACH AND "X-TO-INTERFACE" POINTS ON THE HAND.

THUMBTIP REACH (R) ___29.0"___ , (L) ___29.0"___

LEFT X TO G _3_5/8"_ , X TO F _8_3/8"_ , X TO H ___7"___ , X TO T ___6"___

RIGHT X TO G __4"___ , X TO F _8_7/8"_ , X TO H _7_1/2"_ , X TO T _6_1/4"_

BACK TO TABLES

BACK TO REACH

GO TO CONTENTS

SAMPLE DATA FOR ONE SUBJECT REACHING WITH EACH HAND TO AN INTERFACE "F" TYPE CONTROL.

CONTROL _________________

(LOCUS) (HAND) (MODE)	MEASUREMENTS	EQUIVALENT THUMBTIP REACH
		ZONE 1 ___33.5"___
(MIP)(L) (F)	Z-1 __12 7/8"__, Z-2 __8 5/8"___	ZONE 2 ___29.3"___
	Z-3 ___7____	ZONE 3 ___27.6____

- - - - - - - - - - -

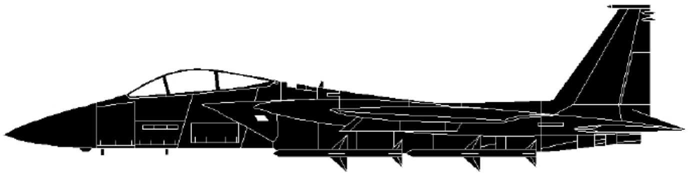
(LOCUS) (HAND) (MODE)	MEASUREMENTS	EQUIVALENT THUMBTIP REACH
		ZONE 1 ___31.6"___
(MIP)(R) (F)	Z-1 __11 1/2"__, Z-2 __7 1/2"___	ZONE 2 ___27.6"___

Table 4

Z-3 ___5.5____

ZONE 3 ____25.6____

Back to HAND REACH TO CONTROLS



F-15C Eagle

F-15A, BF, C AND DF EMERGENCY CONTROLS

A list of emergency controls, followed by "boldface" and "non-boldface" incidents justifying their classification as emergency controls. "L" indicates operation, typically with the left hand, "R" the right. The manner in which the control is usually operated is indicated by "F" for forefinger, "T" for thumb and forefinger, "G" for grip, and "H" for hook, followed, in parenthesis, by location in the cockpit.

AIR SOURCE KNOB – R – T (Right Console, Fwd)
- Bleed Air Malfunctions
  - Uncommanded Fuel Venting

AIR-FRAME MOUNTED ACCESSORY DRIVE (AMAD) LIGHT – L – F (MIP, Extreme Left)
- Airframe Mounted Accessory Drive (AMAD) Fire/Overheat

ANTI SKID SWITCH – L – F (Left Console, Fwd)
- Blown Tires
- Anti-Skid Malfunction
- Landing Gear Unsafe

ARRESTING HOOK SWITCH – L – F (Left Subpanel)
- Abort during Takeoff
- Blown Tires
- Landing Gear Unsafe
- Arrestment

Back to REACH

CABIN TEMPERATURE CONTROL KNOB – R – T (Right Console, Fwd)
Extreme Cockpit Temperature

CABIN TEMPERATURE CONTROL SWITCH – R – F (Right Console, Fwd)
ECS Malfunction

CANOPY CONTROL HANDLE – R – G (Right Bulkhead)
Canopy Unlocked Inflight/Loss of Canopy

CANOPY EMERGENCY JETTISON – L – G (Left Bulkhead, Fwd)
Smoke, Fumes or Fire in Cockpit

CONFORMAL TANK EMERGENCY TRANSFER SWITCH – L – F (Left Console, Fwd)
Fuel Transfer System Malfunction

CONFORMAL TANK FUEL CONTROL SWITCHES – L – F (Left Console, Fwd)
Fuel Transfer System Malfunction
Uncommanded Fuel Venting
Inflight Fuel Leak

CONTROL STICK FULL FWD – R – G (Forward)
Out of Control Recovery (Control Stick Neutralize and Release)

CONTROL STICK FULL FWD & LEFT – R – G (Forward-Left)
Out of Control Recovery (Control Stick Neutralize and Release)

CONTROL STICK FULL LEFT – R – G (Forward-Left)
Out of Control Recovery (Control Stick Neutralize and Release)

EJECTION HANDLES – L – H (Left and Right Seat)
Out of Control

EMERGENCY BRAKE/STEER HANDLE – L – H (MIP, Center)
Hydraulic Failure

EMERGENCY GENERATOR SWITCH – R – F (Right Console, Fwd)
Airframe Mounted Accessory Drive (AMAD) Fire/Overheat
Smoke, Fumes or Fire in Cockpit
Uncommanded Fuel Venting
Inflight Fuel Leak

EMERGENCY LANDING GEAR HANDLE – L – H (Left Subpanel)

Back to REACH

Fuel Transfer System Malfunction
Landing Gear Emergency Extension

EMERGENCY STORES JETTISON – L – F (MIP, Center)
External Stores Jettison on Takeoff

EMERGENCY VENT HANDLE – R – H (Right Subpanel)
Smoke, Fumes or Fire in Cockpit
Canopy Unlocked Inflight/Loss of Canopy
Extreme Cockpit Temperature
ECS Malfunction

*ENGINE CONTROL SWITCH (L & R) – R – F (Right Console, Fwd)
Restart (F100-PW-220 Engine)
Air Inlet System Malfunction (PW-220 Engine)
Engine Electronic Control Malfunction/Nozzle Failure (PW-220)

*ENGINE ELECTRONIC CONTROL (EEC) SWITCH (L & R) (Right Console, Fwd)
Air Inlet System Malfunction (PW-100 Engine)
Engine Electronic Control Malfunction/Nozzle Failure (PW-100)

*Engine Control Switch (F100-PW-200) and EEC Switch (PW-100) are in same location.

ENGINE FIRE WARNING LIGHTS (L & R) – L – F (MIP, Upper Left)
Engine Fire/Overheat
Inflight Fuel Leak

ENGINE MASTER SWITCHES (L & R) – R – T (Right Console, Fwd)
Inflight Fuel Leak

ENGINE START FUEL FLOW SWITCH (L & R) (Right Console, Aft)
Restart (F100-PW-100 Engine)

ENGINE START SWITCH – R – F (Right Console, Fwd)
JFS Assisted Restart

EXTERNAL TANK SWITCH – L – F (Left Console, Fwd)
Fuel Transfer System Malfunction
Uncommanded Fuel Venting
Inflight Fuel Leak

EXTERNAL TRANSFER SWITCH – L – F (Left Console, Fwd)
  Fuel Transfer System Malfunction

FINGER LIFTS – L – H (Throttle)
  JFS Assisted Restart

FIRE EXTINGUISHER/FIRE WARNING TEST SWITCH – L – T (MIP, Extreme Left)
  Engine Fire/Overheat
    Airframe Mounted Accessory Drive (AMAD) Fire/Overheat
  Bleed Air Malfunctions

FUEL DUMP SWITCH – L – F (Left Console, Fwd)
  Fuel Transfer System Malfunction
  Uncommanded Fuel Venting

INERTIA REEL LOCK – L – T
    Approach-end Arrestment

INLET RAMP SWITCH (L & R) – L – F (Left Console, Fwd)
  Air Inlet System Malfunction

GENERATOR SWITCHES (L & R) – R – F (Right Console, Fwd)
  Airframe Mounted Accessory Drive (AMAD) Fire/Overheat
  Smoke, Fumes or Fire in Cockpit
  Generator Failure

JET FUEL STARTER (JFS) HANDLE – R – H (MIP, Extreme Right)
  JFS Assisted Restart

LANDING GEAR CIRCUIT BREAKER – L – T (Pedestal, Right)
  Landing Gear Fails to Retract on Takeoff
  Fuel Transfer System Malfunction
  Landing Gear Emergency Extension

LANDING GEAR HANDLE – L – F (MIP, Extreme Lower Left)
  Landing Gear Fails to Retract
  Out of Control Recovery
    Fuel Transfer System Malfunction
    Hydraulic Failure
  Landing Gear Emergency Extension

MAIN GENERATOR SWITCHES (L & R) – R – F (Right Console, Fwd)

Uncommanded Fuel Venting
Inflight Fuel Leak

OXYGEN REGULATOR – 100% - R – F (Right Console, Fwd)
Smoke, Fumes or Fire in Cockpit
Loss of Cabin Pressure

PITCH RATIO SWITCH – L – T (MIP, Extreme Left)
Flight Control System Malfunction

ROLL RATIO SWITCH – L – F (Left Console, Fwd)
Flight Control System Malfunction

SELECT JETTISON BUTTON – L – T (MIP, Extreme Left)
External Stores Jettison on Takeoff
JFS Assisted Restart
Fuel Transfer System Malfunction
Flight Control System Malfunction
Approach-end Arrestment

SLIPWAY SWITCH – L – T (Left Console, Fwd)
Fuel Transfer System Malfunction
Uncommanded Fuel Venting

SPEEDBRAKE CIRCUIT BREAKER – L – T (Pedestal, Left Side)
Speed Brake Failure

SPEEDBRAKE SWITCH – L – T (Inboard Throttle)
Control Stick Neutralize and Release (Out of Control Recovery)
Controlled Ejection

THROTTLE (RETARD) – L – H
Abort during Takeoff
Engine Failure/Loss of Thrust/Afterburner Failure on Takeoff
Engine Fire/Overheat
Out of Control Recovery
Engine Stall/Stagnation
Restart
JFS Assisted Restart
Engine Electronic Control Malfunction/Nozzle Failure (PW-100-PW-220)
Afterburner Burnthru
Airframe Mounted Accessory Drive (AMAD) Fire/Overheat/Failure

- Smoke, Fumes or Fire in Cockpit
- Canopy Unlocked Inflight/Loss of Canopy
- Bleed Air Malfunctions
- Oil System Malfunction
- Internal Tank Fails to Transfer
- Inflight Fuel Leak
- Flight Control System Malfunction
- Blown Tires
- Arrestment
- Controlled Ejection

The selection of hand controls to which to take reach measurements is made from the above list of emergency controls, with an eye toward representation of those grouped in clusters as well as the manner in which they are operated. These emergency controls are then supplemented with additional controls selected to represent otherwise unrepresented clusters of non-emergency controls and areas where non-emergency controls or no controls are located. Where there is a cluster in which all controls can be represented by one or a few controls, the control(s) requiring the greatest arm length to operate are given priority. In the list below, they are listed in order of measurement, left to right in the cockpit for both hands. Emergency controls are in BOLD. Others are fillers to assure that all areas of the instrument panels are represented. Controls that are represented, but to which it is not necessary to measure, are indented.

F-15A, BF, C AND DF PROPOSED CONTROL MEASUREMENT ORDER

LEFT HAND

CANOPY EMERGENCY JETTISON – L – G (Left Bulkhead, Fwd)

ARMAMENT SAFETY SWITCH – L – F (Left Console, Aft)

EMERGENCY A/R – L – F (Left Console, Aft)

AVIONICS SELECT KNOB – L – T (Left Console, Aft)

RADIO MODE SELECT KNOB – L – T (Left Console, Mid)

RADAR MODE SELECT KNOB – L – T (Left Console, Mid)

FUEL DUMP SWITCH – L – F (Left Console, Fwd)

Back to REACH

SLIPWAY SWITCH – L – T
EXTERNAL TRANSFER SWITCH – L – F
CONFORMAL TANK EMERG TRANSFER SWITCH – L – F

LEFT INLET RAMP SWITCH (L & R) – L – F (Left Console, Fwd)
RIGHT INLET RAMP SWITCH
ROLL RATIO SWITCH – L – F
ANTI SKID SWITCH – L – F
WING/CTR/CONFORMAL TANK FUEL TRANSF SWITCHES – L – F

THROTTLES - RETARD – L – H
FINGER LIFTS – L – H (Throttle)
SPEEDBRAKE SWITCH – L – T (Inboard Throttle)

INERTIA REEL LOCK – L – T

EJECTION HANDLES – L – H

EMERGENCY LANDING GEAR HANDLE – L – H (Left Subpanel)
ARRESTING HOOK SWITCH – L – F

LANDING GEAR HANDLE – L – F (MIP, Extreme Lower Left)
PITCH RATIO SWITCH – L – T

SELECT JETTISON KNOB – L – T (MIP, Extreme Left)

AIR-FRAME MOUNTED ACCESSORY DRIVE (AMAD) LT – L – F (MIP, Extreme Left)
ENGINE FIRE WARNING LIGHTS (L & R) – L – F
FIRE EXTINGUISHER/FIRE WARNING TEST SWITCH – L – T (MIP, Extreme Left)

MASTER CAUTION LIGHT – L – F (MIP, Center Top)

EMERGENCY STORES JETTISON – L – F (MIP, Center)

EMERGENCY BRAKE/STEER HANDLE – L – H (MIP, Center)

LANDING GEAR CIRCUIT BREAKER – L – T (Pedestal, Right)
SPEEDBRAKE CIRCUIT BREAKER – L – T (Pedestal, Left Side)

RIGHT HAND

CONTROL STICK FULL FWD (MOVE TO NEUTRAL) – R – G

CONTROL STICK FULL FWD & LEFT (MOVE TO NEUTRAL) – R – G

CONTROL STICK FULL LEFT (MOVE TO NEUTRAL) – R – G

LANDING GEAR CIRCUIT BREAKER – L – T (Pedestal, Right)

FUEL QUANTITY SELECT KNOB – R – T (MIP, Extreme Right)

JET FUEL STARTER (JFS) HANDLE – R – H (MIP, Extreme Right)

EMERGENCY VENT HANDLE – R – H (Right Subpanel)

OXYGEN REGULATOR – 100% - R – F (Right Console, Fwd)

*RIGHT ENGINE CONTROL SWITCH (L & R) – R – F (Right Console, Fwd)
*ENGINE ELECTRONIC CONTROL (EEC) SWITCHES (L & R)
EMERGENCY GENERATOR SWITCH – R – F
GENERATOR SWITCHES (L & R) – R – F
ENGINE MASTER SWITCHES – R – F
ENGINE START SWITCH – R – F

*Engine Control Switches (F100-PW-200) and EEC Switches (PW-100) are in same location.

ANTI-FOG SWITCH – R – F (Right Console, Fwd)

AIR SOURCE KNOB – R – T (Right Console, Fwd)
CABIN TEMPERATURE CONTROL KNOB – R – T
CABIN TEMPERATURE CONTROL SWITCH – R – F

STORM/FLOOD CONTROL KNOB – R – T (Right Console, Mid)

ENGINE START FUEL FLOW SWITCH (L & R) (Right Console, Aft)

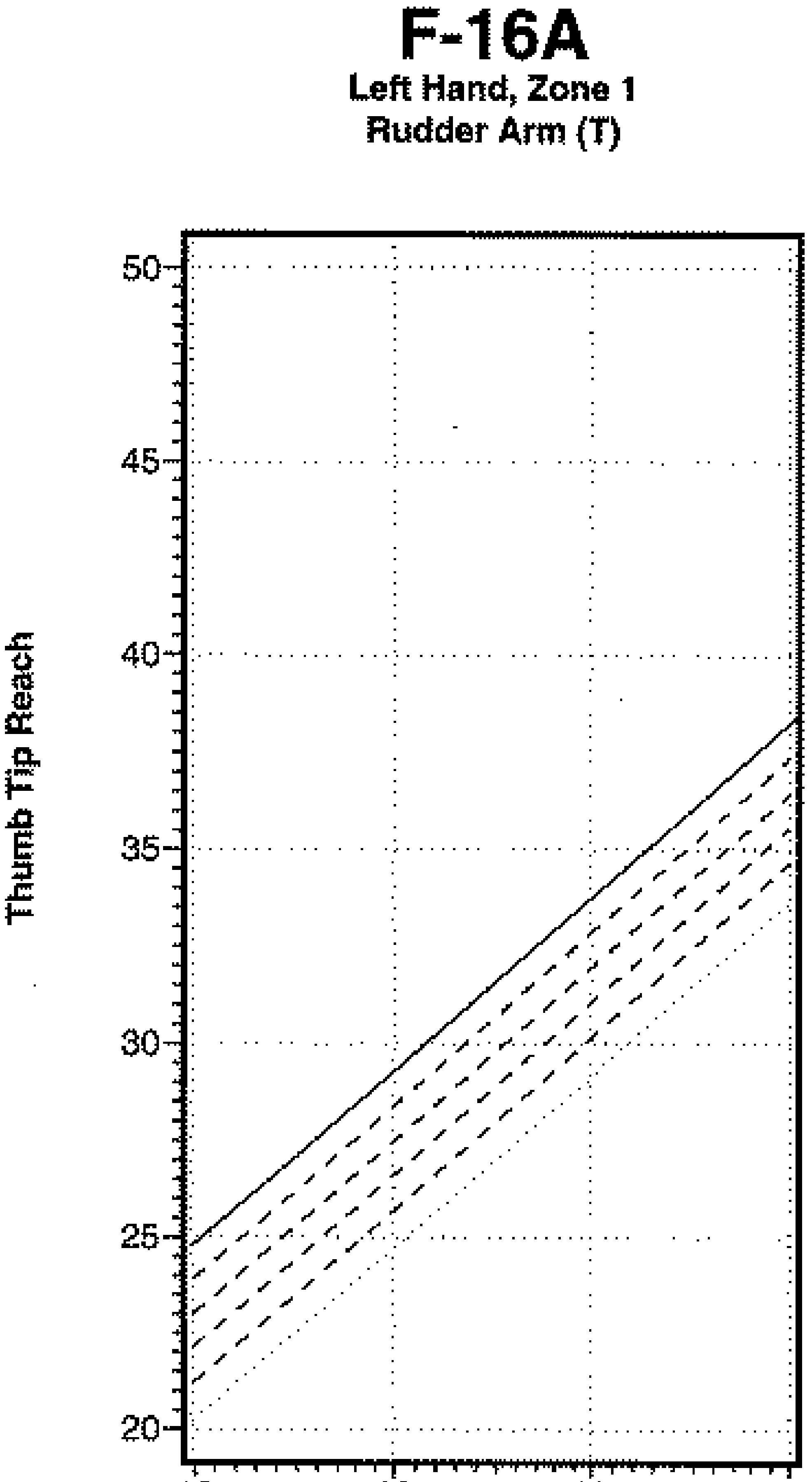
CANOPY CONTROL HANDLE – R – G (Right Bulkhead)

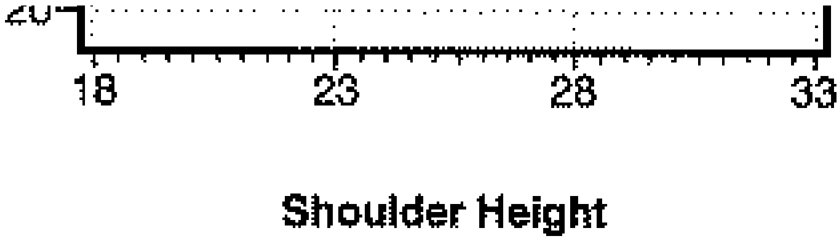
Back to TOP

Back to REACH

Back to HAND REACH TO CONTROLS

Back to REACH



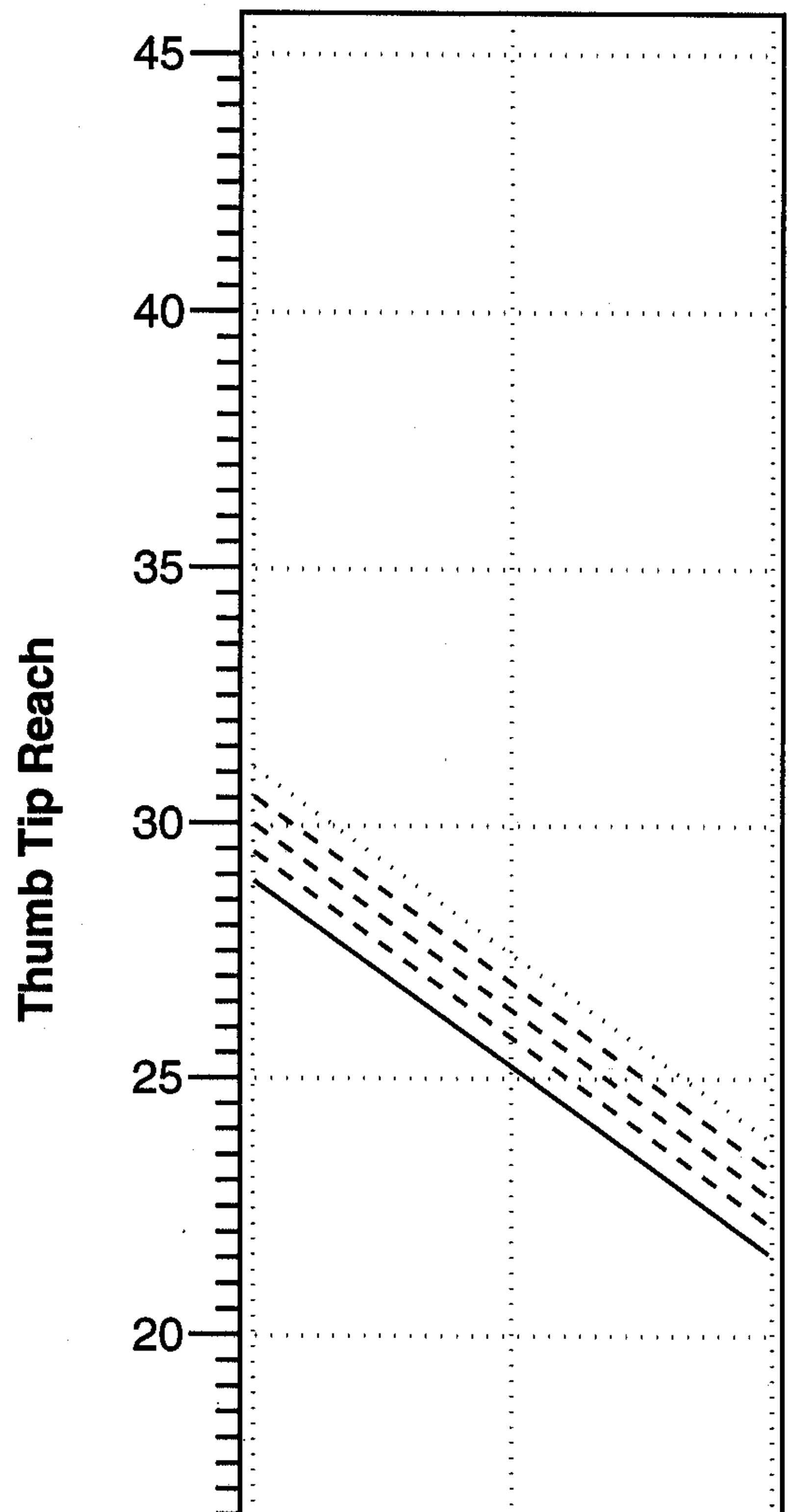


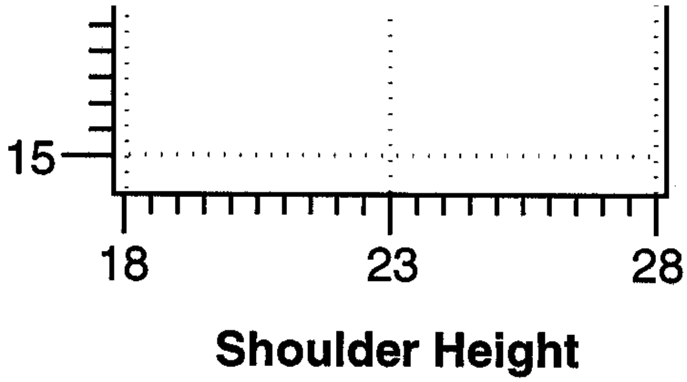
Regression Plots, Zone 1 Equivalent Thumbtip Reaches with the Left Hand to the Rudder Arm Switch, a Thumb Operated Control in the F-16A. The full-up seat position is represented by a solid line. Each successive line represents one inch down from the previous seat position. The full-down seat position is represented by the dotted line. To derive Zone 2 Equivalent Thumbtip Reaches, subtract 2.2 inches from Zone 1 values. Zone 1 Equivalent Thumbtip Reach (full-up seat) = Sitting Shoulder Height X 0.908 + 8.463, r = 0.68. N = >10.

Back to REACH

T-1A

Left Cockpit, Right Hand, Zone 1
Horiz Stab De-Ice Backup Man Norm (F)



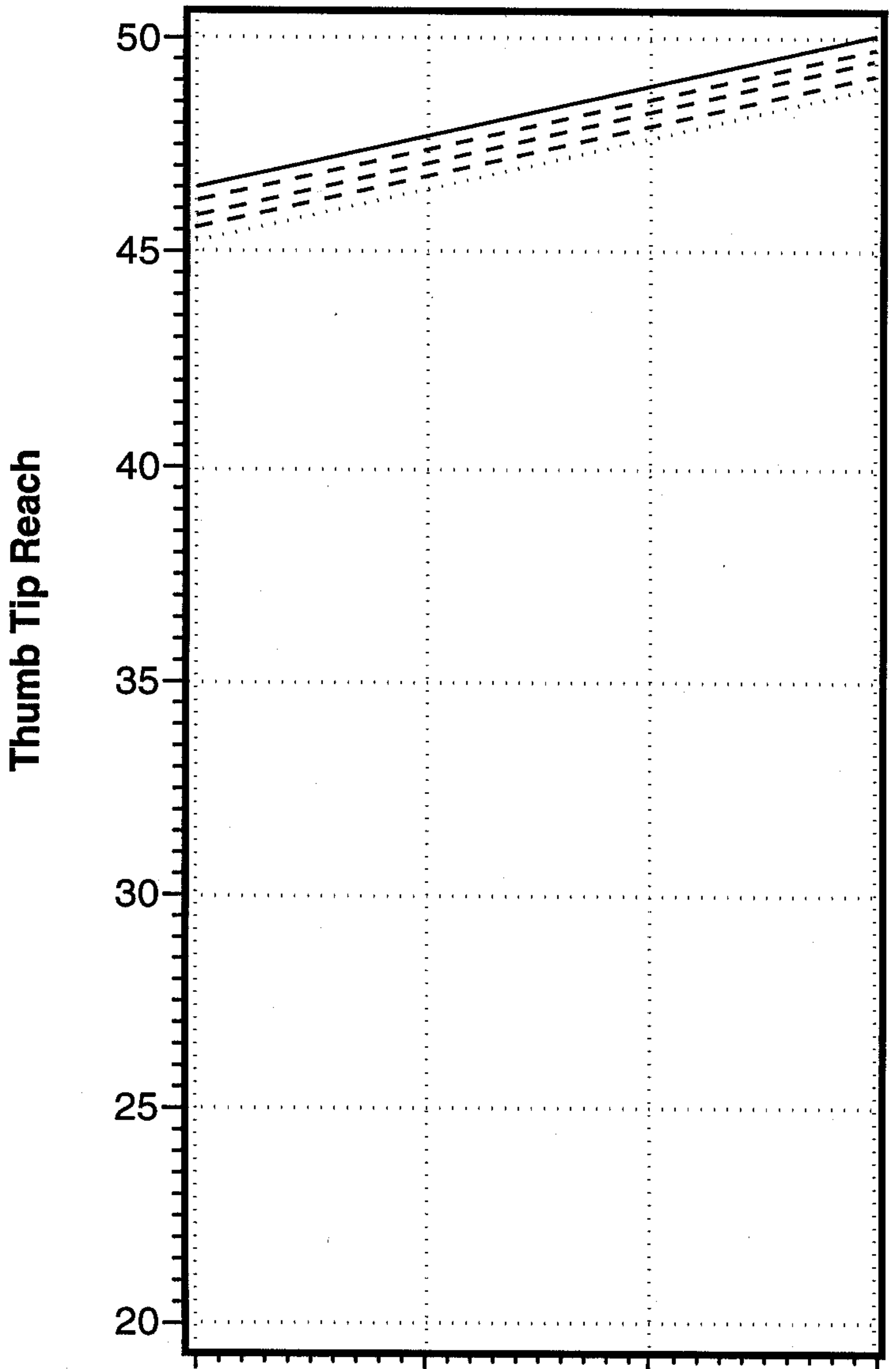


Regression Plots, Zone 1 Equivalent Thumbtip Reaches with the Right Hand to the Horizontal Stabilizer De-Ice Backup Switch, a Thumb Operated Overhead Control in the Left Cockpit of the T-1A.
Since this control is located overhead, subjects with higher shoulders can have shorter reaches to access it. This is illustrated by the reverse slope of the regression lines. Zone 1 Equivalent Thumbtip Reach (full-up seat) = Sitting Shoulder Height X -0.78 + 43.318, r = -0.94. N = <10.

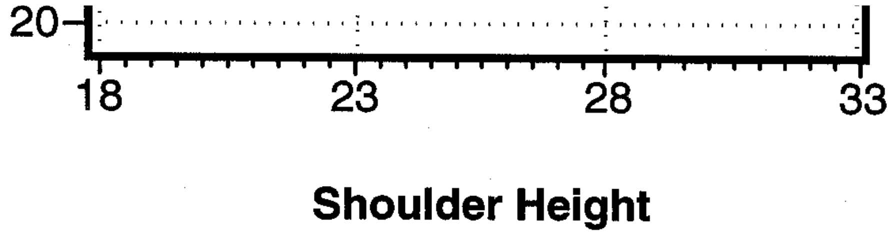
Back to REACH

T-37

Right Cockpit, Left Hand, Zone 1
Canopy Emergency Jettison T-Handle (H)



Back to REACH

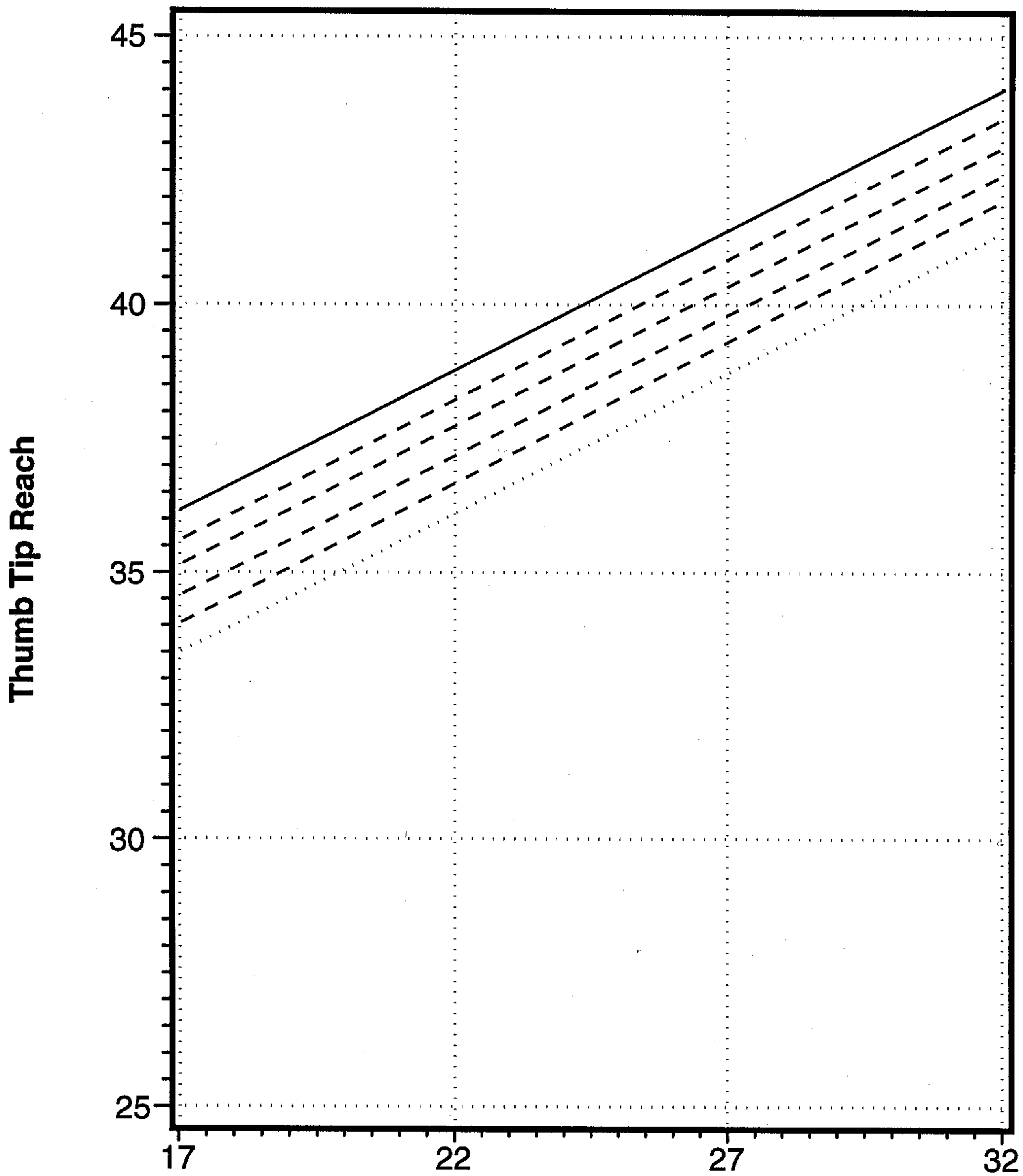


Regression Plots, Zone 1 Equivalent Thumbtip Reaches with the Left Hand from the Right Cockpit to the Canopy Emergency Jettison T-Handle, a Hook Operated Control in the Left Cockpit of the T-37B. This control is mounted in the left bulkhead. These data apply if the occupant of the right cockpit must, in an emergency, reach through the left cockpit to actuate this control under Zone 1 reach conditions. The values are clustered, since this control is not only close to shoulder level, but at a great distance. The purpose in reporting reaches to this control is to illustrate an impossibly large reach capability requirement that would be necessary in an emergency if the copilot must have his shoulder harness tight and locked - admittedly, an impossibly large reach under an unlikely condition. Zone 1 Equivalent Thumbtip Reach (full-up seat) = Sitting Shoulder Height X 0.235 + 42.155, r = 0.069. N = <10.

Back to REACH

T-38

Forward and Aft Cockpit, Left Hand, Zone 1
UHF Command Radio Control Panel, Preset (T)

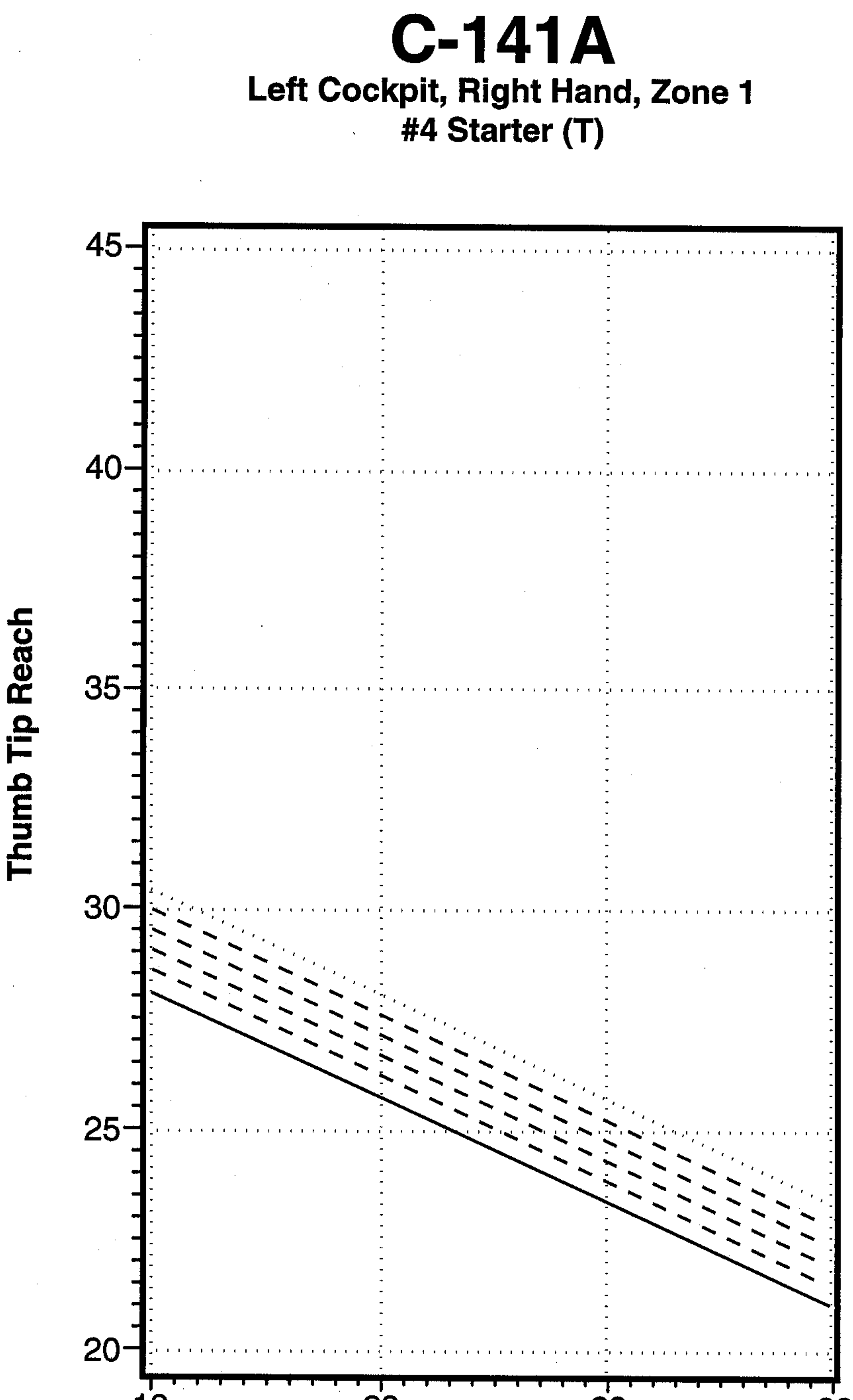


Back to REACH

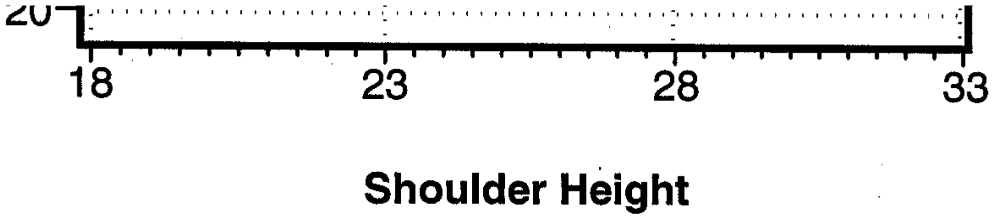
Shoulder Height

Regression Plots, Zone 1 Equivalent Thumbtip Reaches with the Left Hand to the UHF Command Radio Control Panel Preset Switch, a Thumb Operated Control Examined in Both Cockpits of the T-38A. Data for the two cockpits have been combined. Zone 1 Equivalent Thumbtip Reach (full-up seat) = Sitting Shoulder Height X 0.450 + 28.727, r = 0.50. N = <10.

Back to REACH



Back to REACH

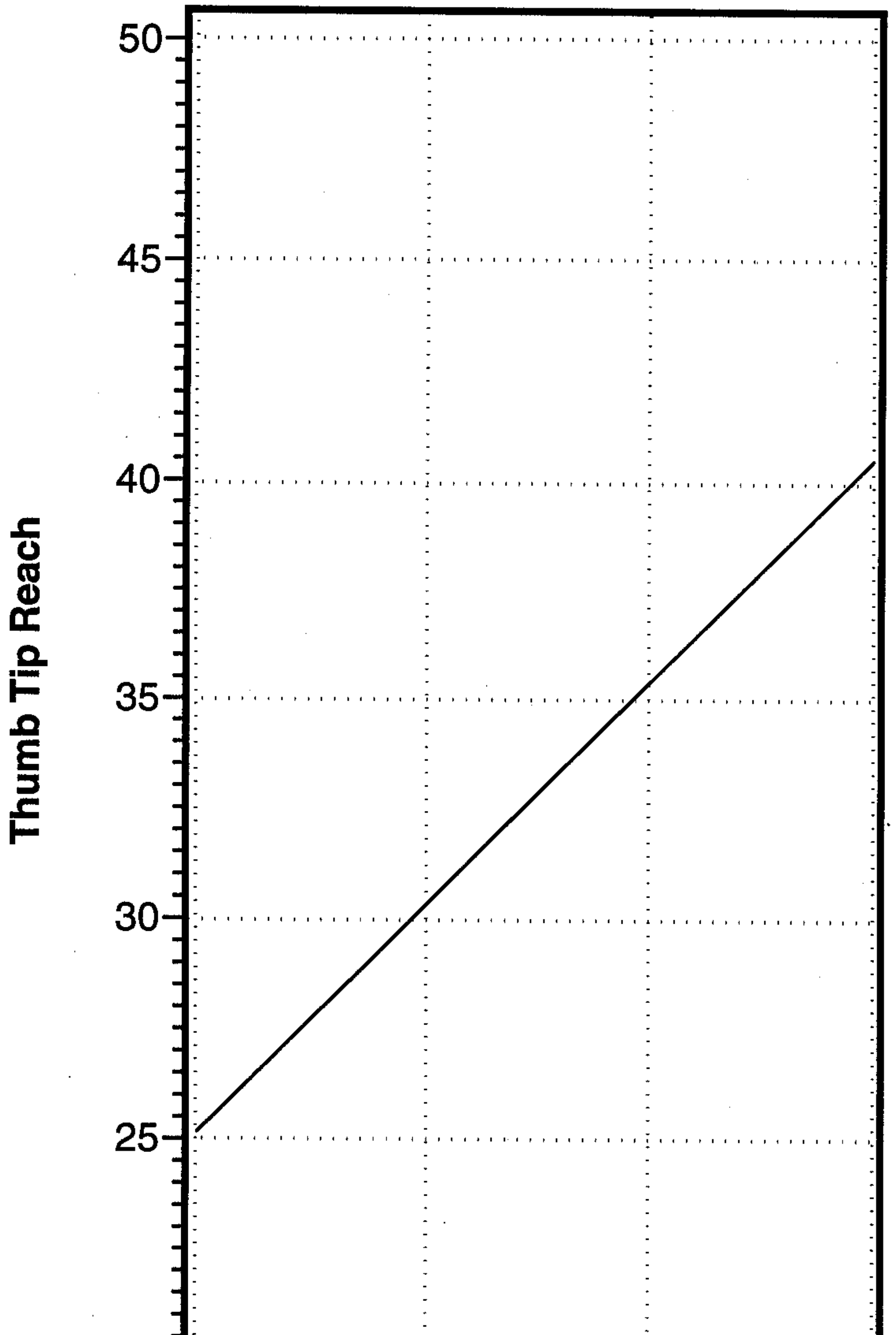


Regression Plots, Zone 1 Equivalent Thumbtip Reaches with the Right Hand to Actuate Starter #4, a Thumb Operated Control, from the Left Cockpit of the C-141A. Starter #4 is located on the overhead panel. Because this control is well above shoulder level, the slope of the regression lines is reversed. Zone 1 Equivalent Thumbtip Reach (full-up seat) = Sitting Shoulder Height X -0.467 + 36.538, r = -0.83. N = <10.

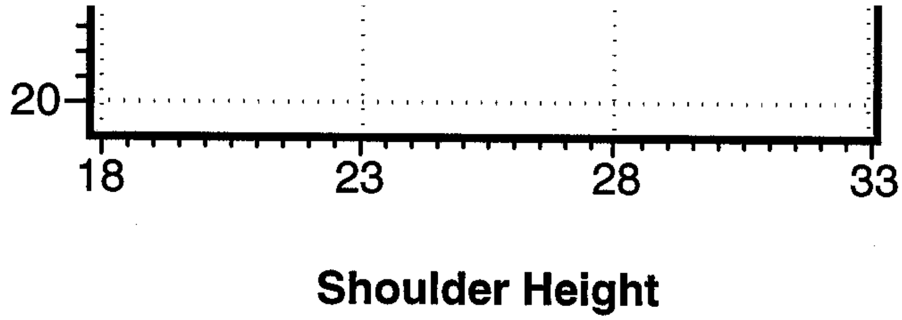
Back to REACH

T-37

Both Cockpits, Both Hands, Zone 1
Ejection Seat Hand Grips (H)



Back to REACH



Regression Plot, Zone 1 Equivalent Thumbtip Reaches with Both Hands to the Ejection Seat Hand Grips, Hook Operated Controls in Both Cockpits of the T-37B. Data for both hands and both cockpits are combined. Because this control is attached to the seat and, therefore, its position relative to the pilot's shoulders does not change as the seat is adjusted, only one regression line is needed. Zone 1 Equivalent Thumbtip Reach (full-up seat) = Sitting Shoulder Height X 1.024 + 6.593, r = 0.91. N = >10.

Back to [Body Size in USAF Aircraft]

Table 3.2. Inventory Aircraft Minimum Vision Data

Aircraft	Minimum. Sitting Eye Height	Additional Eye Height (in.) required to move the seat down	USAF Females	Female Pilots	USAF Males	Male Pilots
T-37	27.5	.625 per notch	93.8	100.0	99.9	100.0
T-6	25.0	1/1 *	100.0	100.0	100.0	100.0
T-1	29.6	.80 per notch	47.1	91.2	91.4	96.2
T-38	29.75	1/1	41.7	85.7	89.6	94.3
F-16	30.2	1/1	30.5	65.6	82.8	87.6
F-15	30.5	1/1	22.4	50.4	77.6	82.0
A-10	29.0	1/1	64.9	99.4	96.7	99.8
F-117	29.6	1/1	47.1	91.2	91.6	96.2
F-22	29.0	1/1	64.9	99.4	96.8	99.8
TH-67	30.0	Fixed seat	36.1	76.3	86.0	90.9
UH-1	26.6	.75 per notch	99.3	100.0	100.0	100.0
MH-60	27.8	.5 per notch	91.2	100.0	99.9	100.0
MH-53J	27.0	.625 per notch	98.2	100.0	100.0	100.0
B-1B	27.0	1/1	98.2	100.0	100.0	100.0
B-2	28.5	1/1	78.7	100.0	98.8	100.0
B-52	30.0	1/1	36.1	76.3	86.3	91.1
C-21	26.1	1.5 per notch	99.9	100.0	100.0	100.0
C-130J	28.0	.5 per notch	88.0	100.0	99.8	100.0
C-5	28.9	.47 per notch	66.5	100.0	97.1	99.9
C-17	29.2	1/1	58.8	98.6	96.0	99.8
KC-10	26.1	1/1	99.9	100.0	100.0	100.0

KC-10	26.1	1/1	99.9	100.0	100.0	100.0
KC-135	27.3	.5 per notch	95.9	100.0	100.0	100.0
C-141	28.1	.625 per notch	86.5	100.0	99.6	100.0

Back to Body Size in USAF Aircraft

Back to Body Size in USAF Aircraft

Table 4.2. Rudder Reach Requirements for USAF Aircraft

Aircraft	Minimum Comboleg	If Sitting Eye Height is larger than minimum, reduce Comboleg by this amount	USAF Females	Female Pilots	USAF Males	Male Pilots
T-37	40.5	1 notch (.625") / 0.25	90.4	100.0	99.9	100.0
T-6	40.0	1" / 0.67	99.6	100.0	100.0	100.0
T-1	38.6	1 notch (.8") / 0.2	99.4	100.0	100.0	100.0
T-38	43.0	1" / 0.5	45.3	81.3	95.2	96.6
F-16	38.5	1" / 0.65	99.4	100.0	100.0	100.0
F-15	38.75	1" / 0.7	99.2	100.0	100.0	100.0
A-10	42.5	1" / 0.8	60.8	97.0	98.3	99.5
F-117	36.25	1" / 0.5	100.0	100.0	100.0	100.0
F-22	40.0	1" / 0.5	93.2	100.0	99.9	100.0
TH-67	41.4	Seat Fixed	74.4	98.6	98.7	99.3
UH-1	40.75	1 notch (.75") / 0.3	90.8	100.0	99.9	99.3
MH-60	40.6	1 notch (.5") / 0.2	88.8	100.0	99.9	100.0
MH-53J	43.5	1 notch (.625") / 0.4	59.6	97.2	98.3	99.5
B-1B	37.5	1"/ 0.5	100.0	100.0	100.0	100.0
B-2	41.6	1"/ 0.7	76.4	100.0	99.5	100.0
B-52	42.7	1"/ 0.75	51.2	87.3	96.3	97.6
C-21	38.1	1 notch (1.5") / 0.3	99.9	100.0	100.0	100.0
C-130J	38.75	1 notch (.5") / 0.2	99.4	100.0	100.0	100.0
C-5	39.0	1 notch (.47") / 0.125	98.2	100.0	100.0	100.0
C-17	40.6	1" / 0.4	87.5	100.0	99.8	100.0
KC-10	38.9	1" / 0.4	99.8	100.0	100.0	100.0

KC-10	38.9	1" / 0.4	99.8	100.0	100.0	100.0
KC-135	35.6	1 notch (.5") / 0.175	100.0	100.0	100.0	100.0
C-141	41.4	1 notch (.625") / 0.15	76.6	99.7	99.3	99.9

Back to Body Size in USAF Aircraft

Back to Body Size in USAF Aircraft

Table 5.3. Arm reach requirements for remaining USAF aircraft

Aircraft	Regression Equation. (Acromion Height = acrht)	If Sitting Eye Height is larger than minimum, reduce miss distance by this amount.	USAF Females	Female Pilots	USAF Males	Male Pilots
T-37	Stick = .38603 * acrht-.70890 * span + 34.4	1notch (.625") / 0.28 less miss	96.8	100.0	100.0	100.0
T-6	Stick= Min Span 60.1"	1" / 0.5	98.6	100.0	100.0	100.0
T-1	Throttle = .5468 * span – 31.6	1notch (.8") / 0.5	99.5	100.0	100.0	100.0
T-38	Throttle = .3239 * span – 21.6	1" / 0.9	37.3	75.2	97.1	98.7
F-16	Throttle = .5328 * span – 32.5	1 / 0.77	92.8	100.0	100.0	100.0
F-15	Ebrake/Steer = .3318 * span – 22.6	1 / 0.66	17.2	36.9	91.1	93.3
A-10	Canopy Jettison .39154*span – 26.8	1 / 0.67	28.1	61.4	94.9	97.3
F-117	Drag Chute = .6256 * span – 39.7	1 / 0.5	67.7	96.4	99.7	99.8
F-22	Gear ovrd = 14.8 + .83939 * acrht - .515 * span	1 / 0.7	62.2	87.3	99.1	99.3
TH-67	Min Span = 60"	Seat fixed	96.5	100.0	100.0	100.0
UH-1	Collective = 6.8 +0.7 * acrht -.334 * span	1notch (.75") / 0.5	80.8	98.1	99.8	99.8
MH-60	Throttle = 24.8 - .412 * span. Add 1.3" to miss if wearing body armor	1notch (.5) / 0.3 further away	67.3	95.3	99.2	99.4
MH-53	Collective = 55.43 + .41327 * acrht – 1.0 * span	1notch (.625) / 0.4	69.7	97.8	99.8	99.9

	span					
B-1	Stick FFL = 16.0 +.5396*acrht - .41974 * span	1 / 0.5	63.5	95.0	99.4	99.7

Back to Body Size in USAF Aircraft

Back to Body Size in USAF Aircraft

Table 7.2. Maximum Sitting Heights for all USAF aircraft studied

Aircraft	Max Sitting Height With HGU 55/P Helmet (1.5")	USAF Females	Female Pilots	USAF Males	Male Pilots
T-37	40.9	100.0	100.0	100.0	100.0
T-6	41.5	100.0	100.0	100.0	100.0
T-1	43.4	100.0	100.0	100.0	100.0
T-38	40.0 (aft cockpit)	100.0	100.0	99.8	100.0
F-16	39.7 (includes 2.25" clearance space)	100.0	100.0	99.5	99.8
F-15	44.1	100.0	100.0	100.0	100.0
A-10	43.6	100.0	100.0	100.0	100.0
F-117	43.5	100.0	100.0	100.0	100.0
F-22	43.4	100.0	100.0	100.0	100.0
TH-67	40.0	100.0	100.0	99.8	100.0
UH-1	42+	100.0	100.0	100.0	100.0
MH-60	42+	100.0	100.0	100.0	100.0
MH-53J	41.5	100.0	100.0	100.0	100.0
B-1	44.4	100.0	100.0	100.0	100.0
B-2	55.3	100.0	100.0	100.0	100.0
B-52	53	100.0	100.0	100.0	100.0
C-21	39	100.0	100.0	98.2	98.4
C-130J	42+	100.0	100.0	100.0	100.0

C-130J	42+	100.0	100.0	100.0	100.0
C-5	42+	100.0	100.0	100.0	100.0
C-17	42+	100.0	100.0	100.0	100.0
KC-10	42+	100.0	100.0	100.0	100.0
KC-135	42+	100.0	100.0	100.0	100.0
C-141	42+	100.0	100.0	100.0	100.0

Back to Body Size in USAF Aircraft

Back to Body Size in USAF Aircraft

Table 8.1. Maximum Buttock-Knee Length for all USAF aircraft studied.

Aircraft	Maximum Buttock-Knee Length to Contact	USAF Females	Female Pilots	USAF Males	Male Pilots
T-37	27.3	100.0	100.0	99.9	100.0
T-6	29.7	100.0	100.0	100.0	100.0
T-1	27.4	100.0	100.0	99.9	100.0
T-38	30.8	100.0	100.0	100.0	100.0
F-16	27.1	100.0	100.0	99.9	100.0
F-15	27.2	100.0	100.0	99.9	100.0
A-10	26.7	100.0	100.0	99.4	99.4
F-117	28.2	100.0	100.0	100.0	100.0
F-22	27.9	100.0	100.0	100.0	100.0
TH-67	27.9	100.0	100.0	100.0	100.0
UH-1	28+	100.0	100.0	100.0	100.0
MH-60	26.9	100.0	100.0	99.5	99.6
MH-53J	28+	100.0	100.0	100.0	100.0
B-1	28	100.0	100.0	100.0	100.0
B-2	30.6	100.0	100.0	100.0	100.0
B-52	28.4	100.0	100.0	100.0	100.0
C-21	26.3	100.0	100.0	97.8	97.8
C-130J	28+	100.0	100.0	100.0	100.0

C-130J	28+	100.0	100.0	100.0	100.0
C-5	28+	100.0	100.0	100.0	100.0
C-17	28+	100.0	100.0	100.0	100.0
KC-10	28+	100.0	100.0	100.0	100.0
KC-135	28+	100.0	100.0	100.0	100.0
C-141	28+	100.0	100.0	100.0	100.0

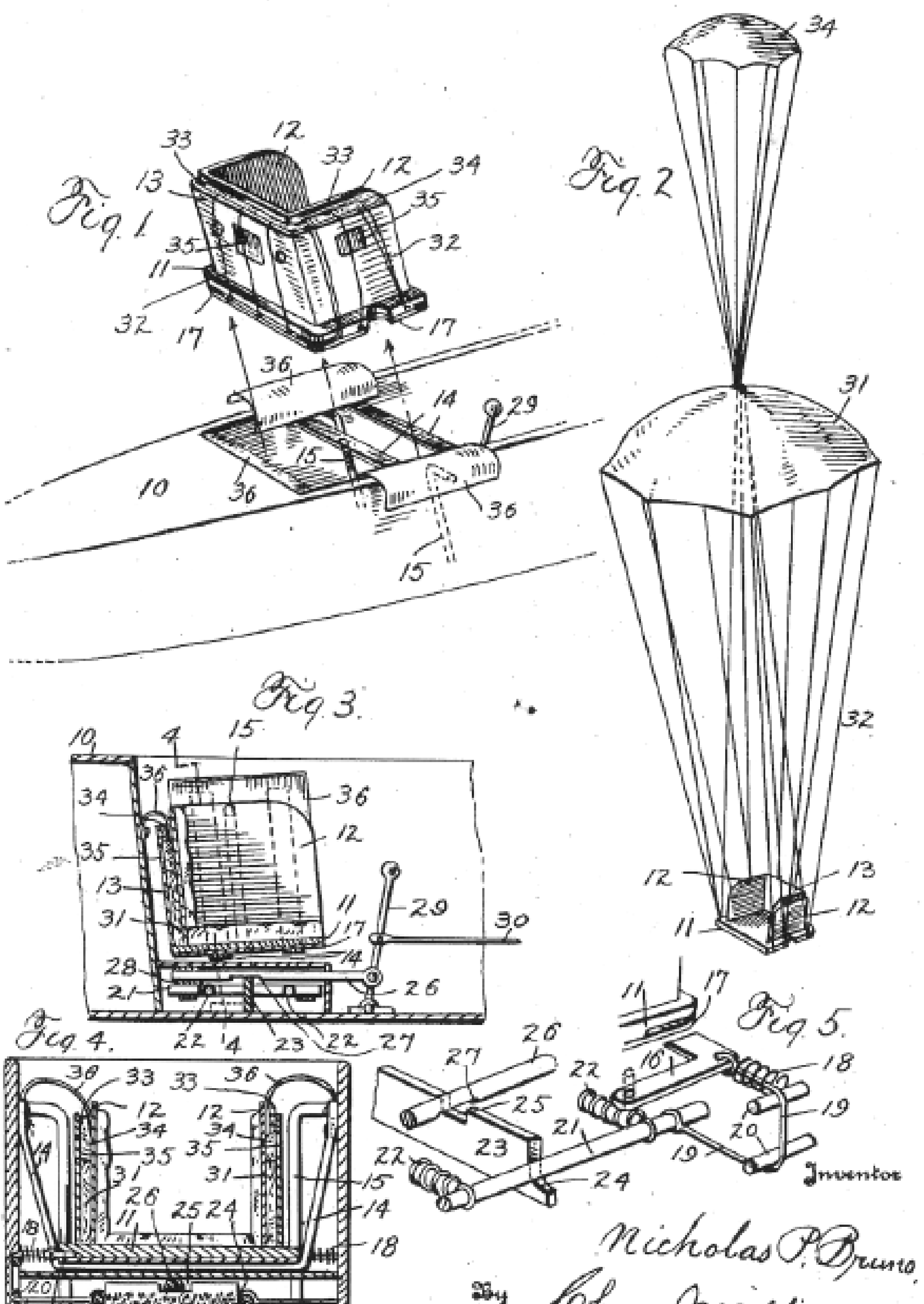
Back to Body Size in USAF Aircraft

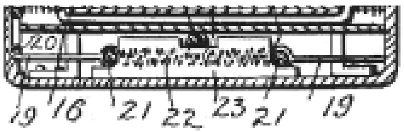
Back to Annotated Bibliography

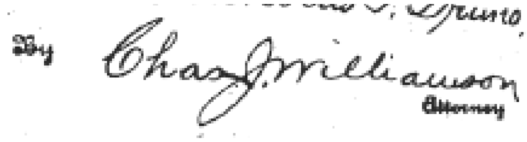
Aug. 30, 1932. N. P. BRUNO 1,874,237

FLYING MACHINE SAFETY DEVICE

Filed July 22, 1930







Excerpts from the Patent: " . . . Describing in detail what is shown in the drawing, within the fuselage 10, is placed any desired number of chairs each including a seat or bottom, 11, with sides, 12, and back, 13, the seat on the underside being engageable by an upward and outward expelling device against the action of which the chair is normally held by a releasable latch device, which remains in chair-locking position until the emergency arises for the expulsion of the chair with its occupant from the machine. Such expelling device may consist as shown, of one or more spring or elastic bands or straps, 14, which extend transversely of the fuselage beneath the seat and with their opposite ends secured to the frame work at a sufficiently high point that when the chair is in normal position, the bands are stretched and placed under tension extending beneath the seat and upwards along the sides of the chair. Upon opposite sides the seat engages vertically extending guide bars, 15, over which the seat slides when the expelling device acts and which serves to position the seat when in normal position for use. Said vertical bars preferably inclined upward and rearward so that when the chair is acted upon by the expelling device, the chair will move not only upward but rearward for the purpose of contributing to the clearance of the airplane by the chair when expelled therefrom . . .

The chair as has been explained is equipped with a parachute 31, the suspending cords, 32, of which are suitably attached to the side and rear edges of the chair seat, 11 and which is so associated with the chair in a folded or collapsed state that when the chair is projected out into the air and begins to descend, the parachute will automatically open. As a convenient way of storing the parachute ready for use, I make the side and back walls of the chair hollow or double to provide a storage space, 33, in which the parachute may be stored. I preferably equip the parachute with a supplemental or auxiliary small parachute, 34, which initiates the removal of the main or supporting parachute. Said auxiliary small parachute, 34, is stored in the upper part of the chamber in the side and back walls of the chair and the outer section of the double wall is provided with perforations, 35, to allow the free and ample flow of air into contact with the auxiliary parachute when the chair begins to descend, to at once force the auxiliary parachute out of the chamber and to initiate the opening thereof. . . ."

Back to Annotated Bibliography

Back to Annotated Bibliography

FLIGHT DECK DESIGN AND PILOT SELECTION: ANTHROPOMETRIC CONSIDERATIONS*

Buckle, P.W., G.C. David, and A.C. Kimber,
Aviation, Space, and Environmental Medicine, 61:12,1079-1084, December 1990.

* Reprints may be obtained from Peter W. Buckle, Ph.D., Lecturer, University of Surrey, Guildford, Surrey GU2 4XH, England.

ABSTRACT

"Safe and successful operation of flight displays and controls is, in part, dependent on the anthropometric characteristics of the pilots with respect to the design of a particular aircraft. This paper describes the approach required to optimise this fit and provides guidelines for both those responsible for design and those who select pilot recruits. The major results reported are those for a British population, although the aircraft considered (Boeing 737-200, 747, 757 and Lockheed TriStar) are used by airlines throughout the world. The study shows that limitations in design considerably reduced the pool of potential recruits with the appropriate anthropometric characteristics. The selection criteria, based on functional seated eye height, might exclude 73% of the British 19-65-year-old female population and 13% of the male population."

"The following study described how we have derived anthropometric criteria for trainee pilot selection. The paper also examines how anthropometric selection criteria and design criteria for flight decks are related. Finally, it considers the implication of these anthropometric criteria for the different populations from which civil aircraft pilots are recruited.

If population differences have not been fully accounted for in the design process, then selection of users is required and generally takes one of two forms. The first is "trial and error," in which users find they are unable to achieve certain tasks at some point during training. The second approach, and that described here, relies on a considered and scientific use of available data sources ..., complemented by a study of the operational tasks required of pilots with respect to anthropometric dimensions, including reach demands.

Back to Annotated Bibliography

The latter approach was adopted to provide selection criteria for a major international airline which was about to start a recruitment programme for trainee pilots. The airline was operating a fleet which included Boeing 737, 747, and 757 aircraft as well as the Lockheed TriStar. It was considered desirable that all those individuals who were recruited could meet the anthropometric requirements of flying any aircraft in the fleet.

In the course of the research, we were unable to ascertain the anthropometric criteria used by the plane manufacturers in designing cockpit layout, although these must exist. The airline that commissioned the study was similarly unable to locate the manufacturers' guidance in this area. As a result, our criteria have been derived without prior knowledge or expectation of the manufacturers' criteria. Further, although anthropometric criteria have been published by a number of authorities, including the U.S. Federal Air Regulations ..., the functional dimensions used to establish them are not clearly defined.

The aims of this study were therefore to 1) examine the critical clearance and reach requirements for the satisfactory operation of the flight deck equipment; and 2) use these data to propose anthropometric selection criteria for trainee pilot recruitment."

METHODS

Measurements in Training, Full Flight Simulators

Definition of Measurements

Fitting Trial

Derivation of Design and Selection Criteria

RESULTS

Generation of Stature Criteria

DISCUSSION

"It is important for both employers and candidates that anthropometric selection criteria should be established scientifically if they are to be used as an initial selection technique. This will allow ineligible candidates to be

Back to Annotated Bibliography

excluded with and acceptable degree of confidence. It will also prevent the unnecessary rejection of those who are otherwise capable of meeting the recruitment specification.

The results of this study have shown that effective flight deck operation will be beyond the capabilities of a much greater proportion of the female population than of the male population.

Design stature limitations can be related to stature data for most national groups. In this way the group having a 50% probability of meeting the operational requirements can be established. In calculating the minimum and maximum percentiles, it is apparent that the closer together they are, the greater are the problems of design transfer. When the range of the population accommodated appears to restrictive, further anthropometric research is advisable.

An additional factor which must be considered and reviewed regularly, is that of secular trends in stature. Such studies have shown that the mean stature of young adults in developed countries has increased by approximately 10 mm per decade during the past 30 years ... .

This study has shown that an increase in the available selection pool could be effected if further consideration were given to functional dimensions during the design process. In view of this, the impact of transfer of the design to other national groups requires further consideration.

The methodology for establishing anthropometric selection criteria may be used in the evaluation of new aircraft types to ascertain if effective operation will be limited to individuals of particular anthropometric dimensions. If the requirements of the new aircraft are too restrictive or its implications for future recruitment are too severe it could result in the need for remedial changes being identified and requested of the manufacturer."

CONCLUSIONS

APPENDIX

REFERENCES

There are 7 references.

Back to Annotated Bibliography

Back to Annotated Bibliography

AIRCREW/COCKPIT COMPATIBILITY: A MULTIVARIATE PROBLEM SEEKING A MULTIVARIATE SOLUTION

Keith C. Hendy
Defence and Civil Institute of Environmental Medicine
North York, Ontario, Canada M3M 3B9

AGARD Conference Proceedings No. 491, North Atlantic Treaty Organization, 1990.

NOTE: The following are selected extracts from and/or annotations regarding the subject publication.

"Aircrew/cockpit compatibility depends on an interaction between the anthropometry of individual aircrew members and the geometry of the cockpit. Selection criteria in the past have attempted to deal with this interaction, but the model was too simple. This is a multi-variate problem which requires a multi-variate solution. Essentially the problem is one of charting the region of intersection between the anthropometric data domain and a set of rules or criteria which define 'operability'. The nature of this problem was demonstrated through computer simulated fitting trials of subjects in a number of cockpit-like geometries. The simulations clearly demonstrate that membership in a particular category of 'fit' depends on interactions between workspace and anthropometry which are geometry specific. Further, the simulations show that the establishment of analytical expressions to define class membership is complex and appears to require a non-linear approach. The consequences of these results are discussed in terms of establishing selection standards and determining design criteria for cockpits which are compatible with these standards. It is argued that cockpit design must be based on an extensive sampling of human characteristics in order that the full range of interactions, between various anthropometric dimensions and the workspace, is represented.

" ... This paper examines the effects of interactions between individual anthropometry and workspace geometry with a view to establishing the consequences of these interactions in developing selection strategies and guidelines for design. The problem of defining physical compatibility in the workspace, is essentially one of charting the region of intersection between an anthropometric data space and a set of rules or criteria which define 'operability' in a workspace. The non-linear multi-variate nature of this problem is demonstrated through computer simulation fitting trials of subjects in a number of cockpit-like geometries. The computations make use of a simple sagittal plane manikin to represent the human skeletal form."

There are 23 references.

Back to Annotated Bibliography

Back to Annotated Bibliography

SAFE ASSOCIATION 1997 ANNUAL SYMPOSIUM

T-38 Cockpit Accommodation: Analytical Techniques

Hudson, Jeffrey A.
Sytronics, Inc.
Dayton, OH

Kennedy, Kenneth W., Ph.D.
Consultant
Yellow Springs, OH

Zehner, Gregory F.
Air Force Research Laboratory
Wright-Patterson AFB, OH

Dixon, David A.
LTSI
Dayton, OH

POSTER SESSION

Abstract:

"New training aircraft are being designed to accommodate 97% of the potential pilot population. This will allow entrance to pilots with statures ranging from 4' 10" to 6' 5". Given body sizes of these extremes, determining their accommodation in subsequent aircraft assignment is essential. While the entire Air Force inventory is slated to be evaluated (and is in progress) the accommodation analysis for the first aircraft, the T-38, has been completed. Subjects were placed in both fore and aft cockpits to evaluate the following: 1) ability to reach and operate controls, 2) vision over the nose, and 3) shin-panel, thigh-stick, and head-canopy clearance distances. The results were used to generate regression models, using anthropometric measures, to predict the ability of cases in a potential pilot population to simultaneously assure adequate vision and reach to controls.

A series of regression models to predict reach, each with different combinations of anthropometric measures, were tested against one other. A regression model using Span and Sitting Acromion Height proved to have the best combination of simplicity and predictive accuracy. To determine accommodation for a case, an algorithm was designed that finds the lowest seat position possible that still allows adequate vision. From this position the ability to operate rudders and reach other critical controls is determined. Originally, the accommodation results were startling low for females (5%), and for males only about one half were accommodated (55.3%). The draft requirements of, 1) Stick Positions - Full Forward and Left, - Full Forward, and 2) the reach to the Canopy Jettison T-handle were primarily responsible for this disaccommodation. AETC, however, has since evaluated and removed them from the requirement list. Without the extreme stick positions and reach to canopy jettison the accommodation increases to 69.4% for females and to 94.1% for males in the front cockpit.

Figures:

· Detailed flow chart for Accommodation Algorithm: 1) adequate vision, 2) adequate reach to rudders, 3) adequate reach to controls.

· Body diagram showing anthropometric measures used

Tables:

· Control Requirement List and their Predictive Regression Equations (to determine Pass/Fail for each control)

· Minimum anthropometric measures for each control interface

· Gender specific accommodation percentages using a potential pilot population

Graphs:

. Regression: T-38 Over the Nose Vision vs. Eye Height Sitting

· Regression: T-38 Rudder Miss/Excess vs. ComboLeg (Buttock Knee Length + Knee Height Sitting)

· Span vs. Sitting Acromion Height (gender specific, showing accommodate disaccommodated cases of potential pilot population)"

Back to Annotated Bibliography

Back to Annotated Bibliography

THE DERIVATION OF LOW PROFILE AND VARIABLE COCKPIT GEOMETRIES TO ACHIEVE 1ST TO 99TH PERCENTILE ACCOMMODATION

Kenneth W. Kennedy
AAMRL-TR-86-016
Harry G. Armstrong Aerospace Medical Research Laboratory
Wright-Patterson AFB, Ohio 45433-6573
March 1986

ABSTRACT: "This study was undertaken to serve three objectives: (1) to derive new cockpit geometries in which the techniques of vertical aircraft ejection seat adjustment move the small pilot toward his/her controls and the large pilot away from them, thus avoiding the incompatibilities associated with adjusting the small pilot up and aft, away from hand controls, and the large pilot down and forward, toward hand controls [the situation found in most high performance aircraft]; (2) to demonstrate the relative ease with which the engineer can accommodate to the 1st to 99th percentile range of male body sizes within the USAF, including reach capability; and (3) to demonstrate appropriate techniques in using the AAMRL Drawing Board Manikins in the derivation of basic geometries of ejection seats and of cockpits. Design requirements are: (1) vertical seat adjustment should be for the purpose of bringing the pilot's eyes to a 15 degree Down Vision Line; and (2) all pilots within the anthropometric design range should be able to avoid thrusting their knees forward of the Ejection Clearance Line by assuming the correct ejection posture, even though they might have adjusted the seat to a considerably different position than recommended for their body size. Low Profile and Variable Cockpit Geometries are derived in detailed step by step demonstrations."

PREFACE: ". . . This paper was presented as part of the Symposium of the 26th meeting of the Air Standardization Coordinating Committee (ASCC), Working Parting 61, 'Aerospace Medical and Life Support Systems,' 5 November 1985, at the RAF Institute of Aviation Medicine, Farnborough, Hant, England. It also appears in the Report of that meeting, Volume IV, 'Symposium Proceedings.'"

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"The 1st to 99th percentile ranges of body sizes to be accommodated are listed below. This is a typical example of the manner in which anthropometric percentile range accommodation is best applied to design. The 1st to 99th percentile accommodation range is applied only to the key dimension(s).

Eye Height, Sitting	1st to 99th Percentile
Thumb-Tip Reach	1st Percentile to Top of Range

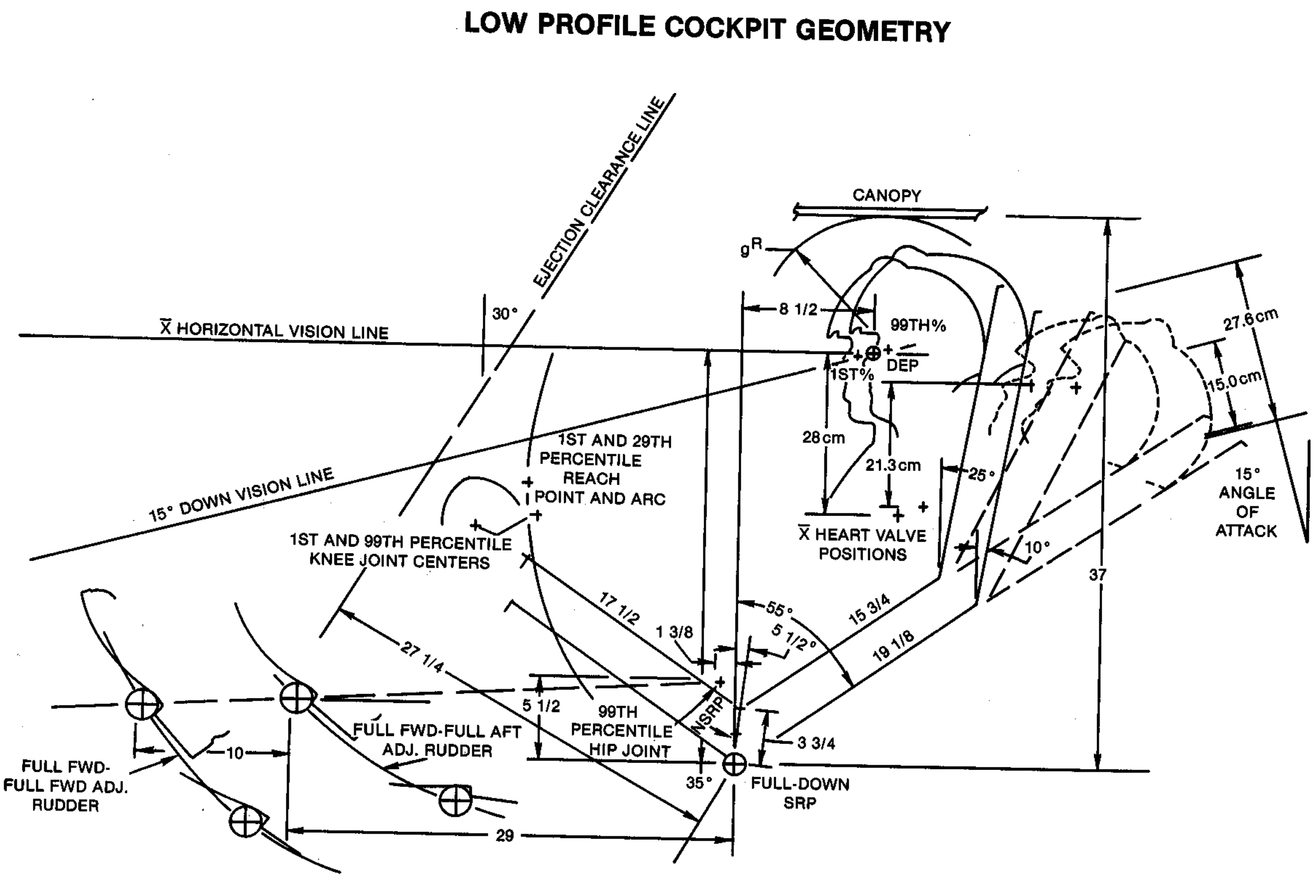
Buttock-Knee Length	Bottom of Range to 99th Percentile
Buttock-Popliteal Length	1st Percentile to Top of Range
Knee Height, Sitting	1st Percentile to Top of Range
Popliteal Height, Sitting	1st Percentile to Top of Range
Bideltoid Breadth	Bottom of Range to 99th Percentile
Hip Breadth, Sitting	Bottom of Range to 99th Percentile

First and 99th percentile limits are specified only for Eye Height, Sitting . . . This dimension plays a decisive role in determining vertical seat adjustment range and, therefore, the total depth of the cockpit. Contrary to the apparent belief in may airframe companies and military agencies, Sitting Height is not the most critical body dimension in cockpit layout, since it is taken into account by the military services' convention in calling for a 9- to 13-inch arc originating at the Design Eye Position and to which the underside of the canopy or overhead fuselage must be tangent."

THE LOW PROFILE COCKPIT GEOMETRY

"The impetus for developing the Low Profile Geometry can be traced to conversations with members of the original cadre established at Wright-Patterson Air Force Base, Ohio, to initiate studies leading to what is now known as the Advanced Tactical Fighter (ATF). Drawing on these conversations, as well as from lessons learned in the AAMRL Hight Acceleration Cockpit (HAC) experience and from work done by the author, a basic low profile geometry was developed. It was driven by the following design requirements . . .It was specified . . . that the frontal area of the fuselage of a low profile aircraft be . . . approximately 80 percent of that of the F-16A. . . . A seated posture must be produced that would passively resist submarining during ejection, but would not result in the pilot's knees encroaching on the 15 degree Down Vision Line."

The Low Profile Cockpit Geometry is offered as a potential solution to the accommodation of a large range of body sizes in the reduced aircraft frontal area.

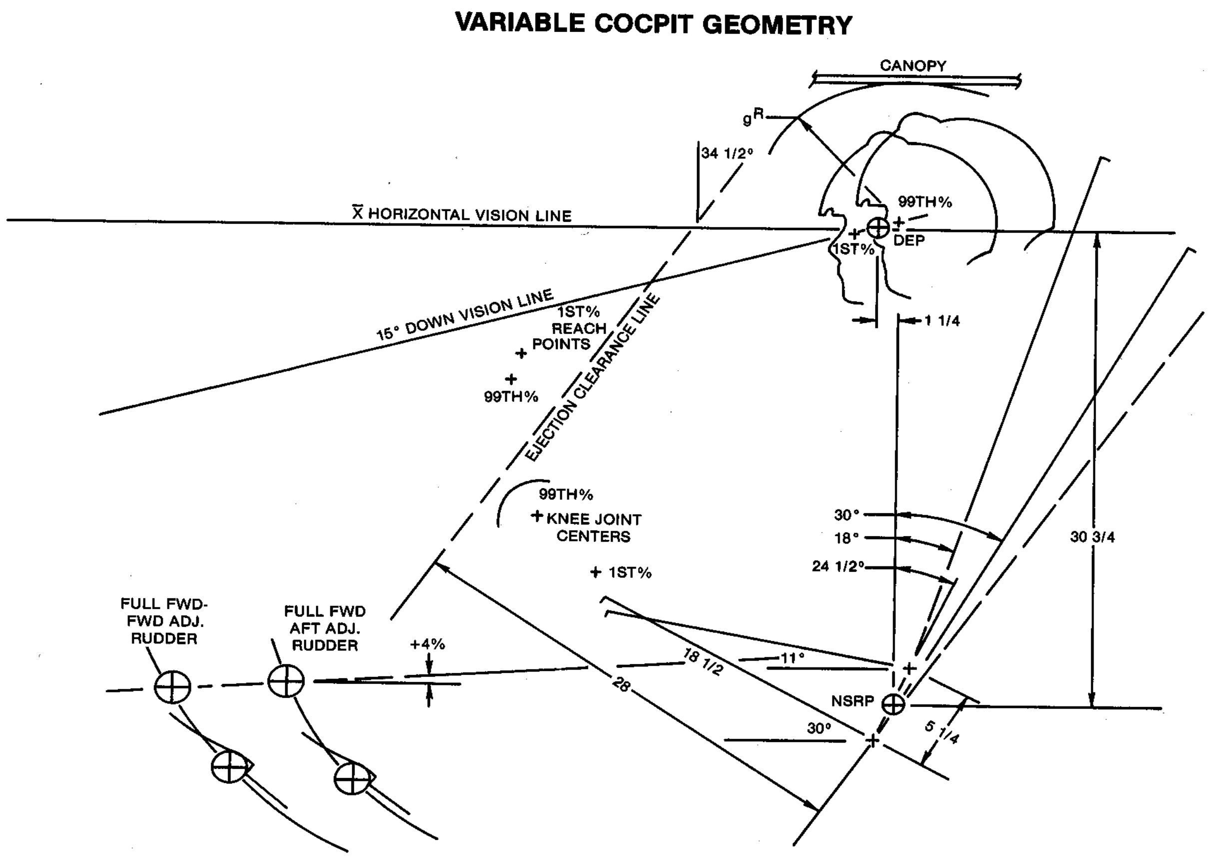


Low Profile Cockpit Geometry

THE VARIABLE COCKPIT GEOMETRY

"Unfortunately, ejection seat design technology has been such that we have been required to accept what is, in the Human Factors sense, an unacceptable characteristic of ejection seats: namely, the adjustment of the smaller pilot up and aft, away from his controls, and the larger pilot down and forward, toward his controls."

The Variable Cockpit Geometry offers a solution to this incongruity.



Variable Cockpit Geometry

The author discusses the development of the Low Profile and Variable Cockpit Geometries as well as mockups to demonstrate the viability of each.

Back to Annotated Bibliography

Back to Annotated Bibliography

A COLLATION OF UNITED STATES AIR FORCE ANTHROPOMETRY

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AAMRL-TR-85-062

Harry G. Armstrong Aerospace Medical Research Laboratory
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January 1986

ABSTRACT: "Four major anthropometric surveys of United States Air Force personnel have been conducted since the end of World War II: that of male rated and non-rated flying personnel in 1950, of male recruits, enlisted and non-rated officers in 1965, of male rated officers and cadets in 1967, and of female officers and enlisted in 1968. Only two surveys have been adequately published: those of 1950 and 1968. For the purposes of this collation, four USAF subpopulations have been distinguished: (1) non-rated male officers and enlisted, (2) rated male officers and cadets, (3) non-rated female officers and enlisted personnel, and (4) rated female officers and cadets. The latter is an artificial subset of women taken from the 1968 survey and who meet the Air Force body-size criteria for entry into Undergraduate Pilot Training and retention as a rated officer. Dimension titles and descriptions are listed alphabetically and cross referenced such that the user can be quickly directed to the desired or to related body size data. Summary statistics consist of the number of subjects measured, the Mean, Standard Deviation, and the 1st, 5th, 50th, 95th and 99th percentile values for each dimension."

The sources of these anthropometric data are as follows.

"Survey: 1965 survey of United States Air Force male officers and enlisted personnel [USAF.MEN].

The survey of USAF male personnel conducted during the spring and summer of 1965 was planned and supervised by H.T.E. Hertzberg and later by M. Alexander and C.E. Clauser of the Aerospace Medical Research Laboratory at Wright Patterson Air Force Base, Ohio, and by L.L. Laubach of the Anthropology Research Project then at Webb Associates, Yellow Springs, Ohio. The measuring team was composed of students from Antioch

College, Yellow Springs, Ohio. In the first portion of the survey, 683 enlisted men were measured, along with 549 officers and 4 warrant officers. In the second half 106 enlisted men were measured, along with 2,632 basic trainees. All subjects were measured at Lackland Air Force Base, Texas. Data measured on the basic trainees are not included in this Collation."

"Surveys: Primary: 1967 survey of United States Air Force male rated officers [USAFLY.MEN].
Secondary: 1950 survey of United States Air Force male flying personnel.

The 1967 survey of United States Air Force male rated officers was conducted during the first three months of 1967. It was planned and conducted under the direction of C.E. Clauser, then Chief of the Anthropology Branch of the Aerospace Medical Research Laboratory (AMRL), Wright-Patterson Air Force Base, Ohio, with the collaboration of M. Alexander, K.W. Kennedy, J. Henninger, and J.W. Garrett of the AMRL, and E. Churchill and L.L. Laubach of the Anthropology Research Project, then at Webb Associates, Yellow Springs, Ohio. Subjects were measured at 17 Air Force bases across the contiguous United States. A total of 182 dimensions were taken on 2420 Air Force personnel between 21 and 50 years of age. Of these, 1187 were rated pilots, 505 were rated navigators, 505 were student pilots, and 188 were student navigators. Thirty-five were found to have AFSCs other than those sought. The measuring team consisted of trained students primarily from Antioch College, Yellow Springs, Ohio. Summary statistics and descriptions of dimensions and measuring techniques for most of the variables are reported in A REVIEW OF ANTHROPOMETRIC DATA OF GERMAN AIR FORCE AND UNITED STATES AIR FORCE PERSONNEL, 1967-1968, edited by H.J. Grunhofer and G. Kroh, and published as [NATO] AGARD-AG-205, 1975. . . . Brief summary statistics on 58 selected body dimensions also have been reported in Chapter III, "Anthropometry," by J.T. McConville and L.L. Laubach, in ANTHROPOMETRY SOURCE BOOK, VOL. I, ANTHROPOMETRY FOR DESIGNERS, NASA Reference Publication 1024, 1978 . . ..

The 1967 survey of USAF flying personnel was the second such major survey of this population. The first was conducted during the spring and summer of 1950. It was organized and directed by H.T.E. Hertzberg and G. Daniels and reported in ANTHROPOMETRY OF FLYING PERSONNEL - 1950, WADC TR 52-321 (AD 47 953), by H.T.E. Hertzberg, G.S. Daniels, and E. Churchill. . . . Subjects were measured at 14 Air Force bases in 7 states. The measuring team consisted of Antioch College students. The original statistical analysis was the initial activity of the Anthropology Research Project contract staff, then located at Antioch College. The data were analyzed and reported prior to the availability of modern computer facilities. Since this survey was first published, the data have been thoroughly reanalyzed using modern electronic computers. This has made it possible to include actual measured values to the nearest millimeter in the analyses, rather than notating the range within which each value was placed and analyzing the range data rather than the actual. Millimeter figures for most variables originally recorded but not punched on cards were incorporated into the reanalyzed data. Some 63 of the original 4063 subjects with missing body size values have been deleted. The entire body of data has been thoroughly reedited for errors."

"Survey: 1968 survey of United States Air Force female officers and enlisted personnel [USAF.WOM].

The survey of women of the Air Force was made in the spring of 1968 by the Anthropology Branch, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio and the Anthropology Research Project, then at Antioch College, Yellow Springs, Ohio. A description of the survey and the results are published in . . . [ANTHROMETRY] OF AIR FORCE WOMEN by C.E. Clauser, et al., AMRL-TR-70-5 (AD 746 113), Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, 1972 . . .. Data for age, 123 body size measurements, and grip strength were obtained from a sample of 1,905 women. Thirteen measurements were repeated on 1,513 subjects with the subjects wearing foundation garments. Age is reported in tenths of years. Weight is reported in pounds. All other variables were recorded in millimeters."

"1968 Subset of female USAF personnel meeting the body size requirements for entry into USAF Undergraduate Pilot Training and retention as a rated officer [USAF.MEN].

The subset to represent women pilots was extracted by selecting from the 1968 USAF survey only those women who meet the Air Force body size criteria for entry into Undergraduate Pilot Training and retention as a rated officer. Specifically, only those women 18 years of age . . . or older and between 34 and 39 inches, inclusive, in Sitting Height were eligible. In addition, all members of the subset had to meet one of the following Height-Weight relationships.

Back to Annotated Bibliography

Height inches	Weight Minimum	Maximum
64	103	139
65	106	144
66	108	148
67	111	152
68	114	156
69	117	161
70	119	165
71	122	169
72	125	174
73	128	179
74	130	185
75	133	190
76	136	196"

"Dimension titles are listed alphabetically and cross referenced such that if a user knows a dimension only by a common name, such as "Height." he can be quickly directed to the title used by the Air Force anthropologists, "Stature," where the description and summary statistics are stated. There are many such cross references. References to dimensions similar to the one of primary concern are also included, the purpose being to alert the user to alternative and related dimensions.

The summary statistics reported here consist of the number of subjects (n), Mean . . ., Standard Deviation (SD), and the 1st, 5th, 50th, 95th, and 99th percentiles. Convenient allotment of space did not permit the inclusion of additional data, such as Coefficient of Variation (CV) and additional percentiles. . . . Additional percentiles can be approximated through the addition and subtraction of multiples of the Standard Deviation to and from the Mean. Listed in Table 1 are multipliers that can be applied to the Stantdard Deviation and used to calculate estimates of selected percentiles based on the normal distribution. Their accuracy will be a function of the closeness with which the distribution of the specific dimension approximates normal or symmetry.

Table 1. Factors for Estimating Selected Percentiles . . .

1st and 99th Percentiles = Mean ± 2.33 X SD

Back to Annotated Bibliography

2nd and 98th Percentiles = Mean ± 2.06 X SD
3rd and 97th Percentiles = Mean ± 1.88 X SD
5th and 95th Percentiles = Mean ± 1.65 X SD
10th and 90th Percentiles = Mean ± 1.28 X SD
15th and 85th Percentiles = Mean ± 1.04 X SD
20th and 80th Percentiles = Mean ± 0.84 X SD
25th and 75th Percentiles = Mean ± 0.67 X SD
30th and 70th Percentiles = Mean ± 0.53 X SD
35th and 65th Percentiles = Mean ± 0.39 X SD
40th and 60th Percentiles = Mean ± 0.25 X SD
45th and 55th Percentiles = Mean ± 0.13 X SD"

A sample page follows.

	"MEAN	SD	1%	5%	50%	95%	99%
SOURCE	in	in	in	in	in	in	in
n	cm	cm	cm	cm	cm	cm	cm

<u>ACROMION HEIGHT, SITTING</u> - see also Acromion Height, Standing and Midshoulder Height, Sitting.

Subject sits erect, head in the Frankfort plane, arms hanging relaxed, and forearms and hands extended forward horizontally - the vertical distance from the sitting surface to the right Acromiale.

USAFLY.MEN	24.04	1.12	21.4	22.2	24.0	25.9	26.7
n = 2420	61.05	2.85	54.4	56.5	61.0	65.9	67.7

<u>ACROMION HEIGHT, STANDING</u> - see also Acromion Height, Sitting and Midshoulder Height, Sitting.

Subject stands erect - the vertical distance from the standing surface to the right Acromiale.

USAF.MEN	56.82	2.45	51.2	52.8	56.8	60.9	62.8
n = 1236	144.32	6.22	130.0	134.2	144.3	154.7	159.5

Back to Annotated Bibliography

USAF.WOM	51.91	2.16	47.3	48.4	51.9	55.6	57.0
n = 1905	131.86	5.48	120.1	123.0	131.7	141.1	144.7
USAFLY.WOM	54.00	1.47	51.3	51.8	53.9	56.7	57.9
n = 455	137.16	3.74	130.3	131.6	136.8	143.9	147.0

ACROMION-RADIALE LENGTH - see also Shoulder-Elbow Length

Subject stands erect (Typ.) with arms hanging at sides - the straight-line distance between the right Acromion and the right Radiale.

USAFLY.MEN	12.97	.67	11.4	11.9	13.0	14.1	14.6
n = 2420	32.95	1.70	29.1	30.2	32.9	35.8	37.0
USAF.WOM	12.21	.64	10.8	11.1	12.2	13.2	13.7
n = 1905	31.01	1.63	27.4	28.3	31.0	33.6	34.7
USAFLY.WOM	12.61	.54	11.3	11.7	12.6	13.5	14.0
n = 455	32.02	1.36	28.7	29.6	32.1	34.2	35.5

ACROMION-TO-BICEPS CIRCUMFERENCE LEVEL

Subject stands erect (Typ.) with arms hanging at sides - the straight-line distance between the right Acromiale and the indentation at the distal margin of the deltoid muscle.

USAFLY-MEN	7.48	.59	6.1	6.5	7.5	8.5	8.9
n = 2420	19.01	1.50	15.6	16.5	19.0	21.5	22.6"

The Report concludes with a GLOSSARY OF SELECTED TERMS.

Back to Annotated Bibliography

Back to Annotated Bibliography

WORKSPACE EVALUATION AND DESIGN: USAF DRAWING BOARD MANIKINS AND THE DEVELOPMENT OF COCKPIT GEOMETRY DESIGN GUIDES

Kenneth W. Kennedy, Ph.D.

in

Anthropometry and Biomechanics: Theory and Application
Easterby, R.K., K.H.E. Kroemer, and D.B. Chaffin (Eds.)

pp. 205 - 213

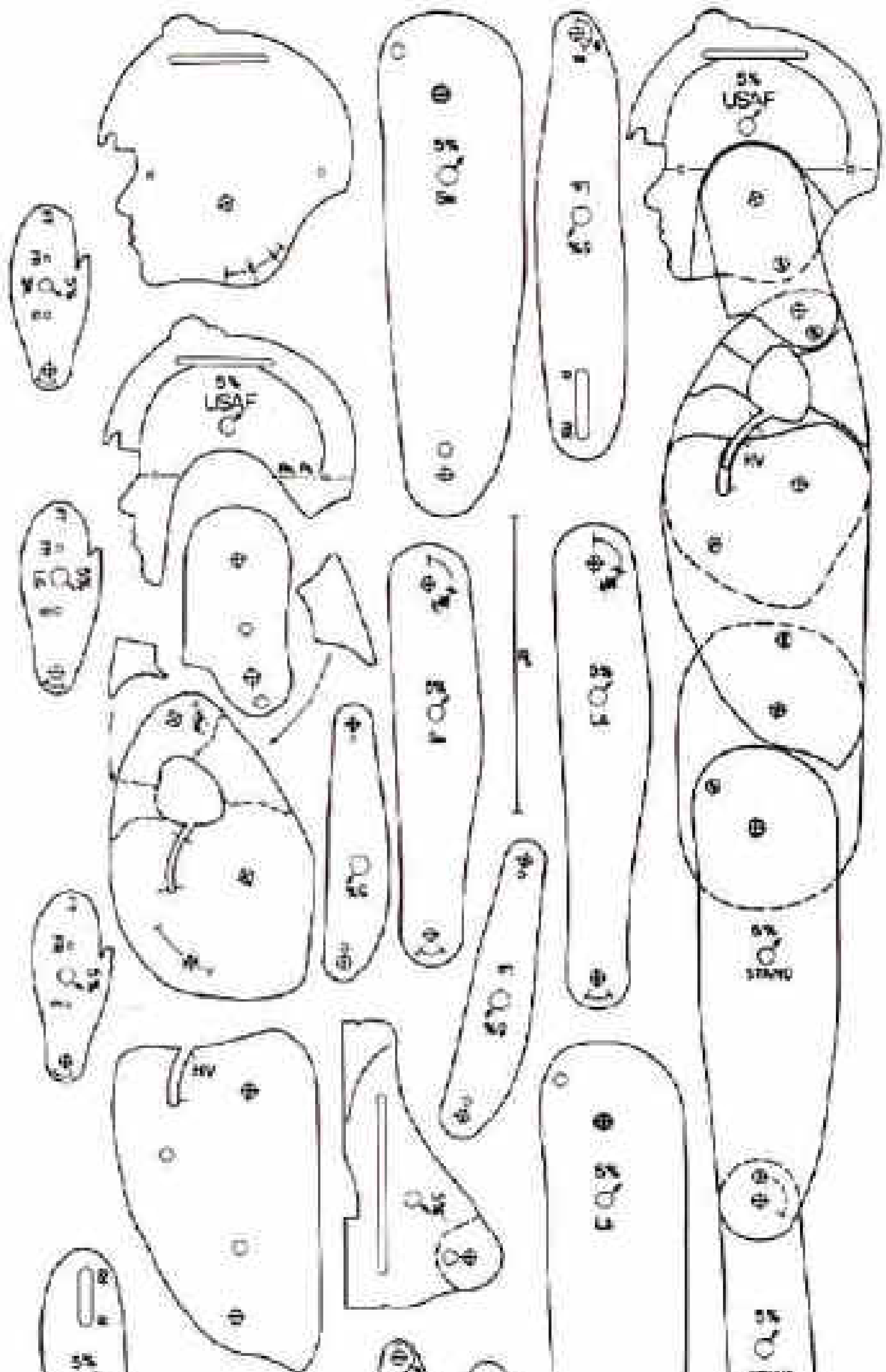
NATO Conference: Series III, Human Factors

Plenum Press, New York, USA

1982

1. USAF DRAWING BOARD MANIKINS

"One of the more recent design tools developed from anthropometric data is the series of USAF Two-Dimensional Drawing Board Manikins - USAF Patent 4,026,041, May 31, 1977. They were designed by the author primarily for use in the design and evaluation of seated work and crew stations, although with the use of appropriate limb parts they are of essentially equal usefulness in standing workstation design. Fifth, 50th, and 95th percentile male manikins were designed in accordance with the anthropometry of the USAF rated pilots projected to the 1980-90 time period. The procedures used in making these projections are included in Churchill and McConville (1976). A plan for the 5th percentile male manikin is illustrated in Figure 1. A 5th percentile female manikin was designed primarily after the current USAF anthropometric data on women from Clauser, et al (1972). An abbreviated list of body-size data after which the manikins were designed is found in Table 1.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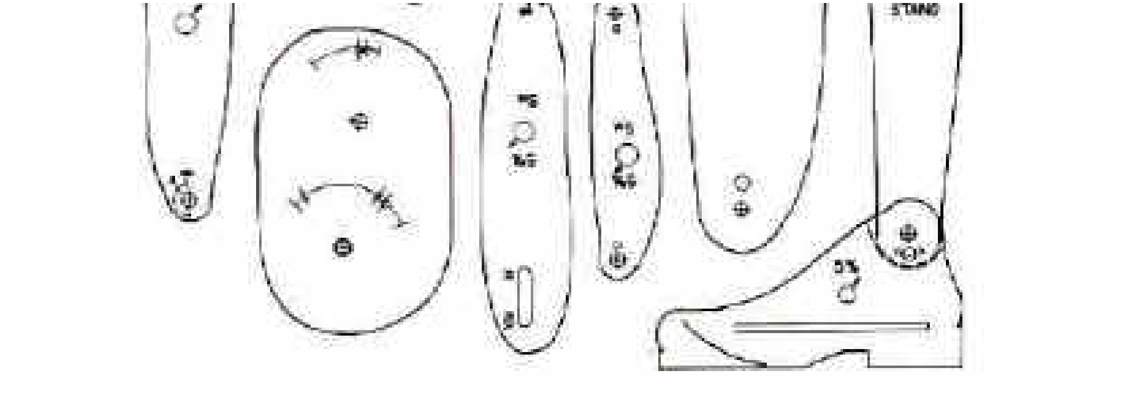

Figure 1. Parts layout and assembly view of the 5th percentile USAF male manikin. Scale line, when increased to 16 inches will yield full scale, 8 inches for half scale, and 4 inches for quarter scale.

Back to Annotated Bibliography

TABLE 1. Anthropometric data after which the USAF manikins were designed - an abbreviated list.

DIMENSION[1] (All values in centimeters)	AF WOMEN 1968 5TH%	USAF MALE, RATED OFFICERS 1980-1990 ESTIMATES 5TH%	50TH%	95TH%
Stature	152.4	168.2	178.4	188.6
Sitting Height	80.4	88.5	93.6	99.0
Eye Height (Sitting)	68.7	76.4	81.3	86.5
Thumb-Tip Reach[2]	71.0	78.0	86.0	93.0
Thumb-Tip Reach, Extended	76.0	82.9	90.1	97.7
Forearm-Hand Length	40.0[3]	44.6[4]	47.9[4]	51.2[4]
Elbow-Grip Length	29.6[3]	32.8	35.4	38.1
Hand Length	16.9	17.9	19.2	20.6
Buttock-Knee Length[5]	51.3	54.1	60.8	67.6
Knee Height[5]	44.5	49.9	56.1	62.4

[1] Unless otherwise indicated, female data are from Clauser, et al (1972). Male data were projected from Grunhofer and Kroh (1975).
[2] From Kennedy (1978).
[3] From Churchill, et al (1977).
[4] From Hertzberg, et al (1954).
[5] For seated work stations - most-used values.

[NOTE: As indicated above, this is an abbreviated list. These manikins are classified according to their percentiles for Sitting Height, that is, the combined length of the torso, neck and head. Equivalent total arm (upper arm, forearm and hand) lengths to produce those same percentiles for Thumb-Tip Reach are provided as are alternative total arm lengths to reflect 95 percent of the predicted ranges for Thumb-Tip Reach that are compatible with the designated percentile for Sitting Height. Similarly with total leg length, i.e., combined Buttock-Knee Length and Knee Height.]

"Considerable additional anthropometric data were used to establish the overall sizes and mobility of the manikins. Several dimensions, derived from Snyder, et al (1972), were used to establish the relationships between and the mobility limits of the major segments of the torso. The centers of rotation of the head, neck, and torso correspond to the atlanto-occipital joint, the interspaces between the 7th cervical and 1st thoracic vertebrae, 8th and 9th thoracic vertebrae, 3rd and 4th lumbar vertebrae, and the hip joints. Joint range data for the limbs were taken from Barter, et al (1957).

"Information regarding the position of the base of the heart (aortic) valves was taken from Eycleshymer and Schoemaker (1911). Tracking the position of the base of the heart is accounted for by using overlapping arcuate slots and engraved indices on the overlapping parts of the upper torso. The position of the valves can, therefore, be estimated as the torso flexes and extends. By tracking the positions of the eye and aortic valves, changes in tolerance to +Gx and +Gz accelerations can be appreciated.

"Located close to the center of rotation of the manikin segments are adjustment holes and indices indicating ranges of motion. Near the centers of rotation within the head, neck and torso, the letters "E" (Erect) and "S" (Slumped) are engraved. Adjacent segments may be aligned such that the adjustment holes will overlay indices so lettered. When all are overlaying "E", the head, neck, torso, and thigh are in the erect, seated (or standing) position - when overlaying "S", a typical slumped orientation of the torso is achieved.

"Additional upper and lower limbs were designed to allow the user to consider variability in body proportions as well as in body size. Using regression equations based on Eye Height, Sitting, and Weight, and an appropriate factor of the Standard Error of the Estimate, the ranges of limb lengths that can be expected to be associated with the various percentile torso sizes, i.e., 5th, 50th, and 95th percentiles, were determined. The ranges necessary to include the central 90 percent were calculated and alternate limbs were designed accordingly. In practice, the small limbs associated with the 5th percentile torso usually see more use than the others. As will be seen later, however, special design situations require the use of other body/limb combinations to represent the extremes of capability and, therefore, accommodation. To facilitate the use of the manikins for standing work stations, a lower limb of appropriate length was designed.

2. COCKPIT GEOMETRY DESIGN GUIDES

"Cockpit geometry design guides have the general appearance of the familiar U. S. Department of Defense Military Standards 33574, -5, and -6, which specify the basic cockpit geometries of stick and wheel controlled, fixed wing aircraft and helicopters, and the USAF Design Handbook 2-2, "Crew Stations and Passenger Accommodations." They differ from these documents, however, in that they permit a great deal more flexibility in design. These military standards specify single values for the seat back angle, seat angle, vertical seat adjustability and the location and movement envelopes of the throttle, control stick, and rudder pedals. They strongly imply, thy their lack of any alternative guidance, that aircraft of the same generic type must all meet the same standard geometric requirements. The design guides, however, have been developed specifically to portray ranges of acceptable dimensions and relationships. They also will make available more extensive anthropometric and geometric data not found in military standards and handbooks. It is hoped that they will provide the much needed anthropometric data base to permit flexibility in cockpit design.

"There are several critical elements basic to any aircraft cockpit geometry design guide. They are: (1) back angle, (2) seat angle, (3) in the ejection cockpit, the angle of the path along which vertical seat adjustability is achieved, and (4) also in the ejection cockpit, the angle of ejection - the ejection clearance line. The range of body size accommodation is always 5th to 95th percentile for Eye Height, Sitting, although 1st to 99th for this dimension is easily achieved. The ranges of accommodation for all other body dimensions is 1st to 99th percentile, minimum. To achieve these ranges of accommodation, the USAF 5th and 95th percentile male drawing board manikins were used, along with their alternate limbs. Since hard mock-ups and live subjects were not used to verify accommodation, the recommended values must be perceived, as their name implies, to be Guides.

"In the brief space of this paper, only selected guides for an ejection type cockpit can be presented. The first portrays geometric information for cockpits with a 15º seat-back and 10º seat combination and in which vertical seat adjustability and ejection are parallel to the back. Adequate adjustability for 5th to 95th percentile accommodation to Eye Height, Sitting can be obtained with 4.6 cm movement parallel to the back, above <u>and</u> below NSRP: 6.6 cm above <u>and</u> below NSRP [Neutral Seat Reference Point] will accommodate 1st to 99th percentile for this body dimension.

"To help guide the placement of hand operated controllers in the forward direction, the guide contains information showing the relationship between minimum reach capability and the minimum space needed for fore and aft ejection clearance. Obviously, in an ejection-seat cockpit, it is necessary that hand operated controls in front of the pilot be located beyond the ejection clearance line. This requirement is crucial in attempting to achieve accommodation to large ranges of hand reach and Buttock-Knee Length. Back angle and direction of seat adjustment play critical roles in achieving useful, reachable space forward of the ejection clearance line.

"Another important consideration is the range of lower leg (shank) lengths. These values, expressed as arcs originating from expected knee centers, determine the maximum thrust of the foot in the forward direction. It is in this manner that the position of full forward throw of the rudder from its full forward (99th percentile leg) and full aft (1st percentile leg) adjustments. The throw and adjustability dimensions can be developed from these data. For the purpose of comparison, all examples of possible rudder location, throw, and travel in this short paper, are along a horizontal line at NSRP level. This should not be taken as a recommendation. A wide variety of approaches to provide rudder travel and throw can be derived.

"Several other useful data points are included. They include range of eye positions, catapult/ejection eye position, position of the base of the heart, the highest expected knee position during full rudder thrust with the opposite leg, position of the knee of the large pilot and clearance needed for safe ejection, minimum head clearance under the canopy, and others. Although not illustrated in this paper, dimensional information has been developed to provide the designer with several alternatives for locating the maximum full pitch down - full left aileron control stick position: ranges of reference points for the throttle, sidearm control, and forearm rests: a selection of fixed side-stick orientations so as to be centered in the range of forearm pronation/supination: and reach contours in front of the pilot.

"Although not presented here, similar information is also presented regarding another 15º back angle - 10º seat geometry in which, to achieve vertical seat adjustment, the seat is moved forward and upward along an angle established so as to achieve equivalent reach capability for the 1st to 99th percentile range. Using this procedure to obtain vertical adjustability, the smaller pilot is moved upward and forward. This is entirely logical from a human factors standpoint since the smaller pilot should be located higher and farther forward in the cockpit to achieve equivalent general accommodation as

Back to Annotated Bibliography

the larger pilot.

"The up and forward seat adjustment introduces an interesting and instructive set of design considerations. In the conventional case of vertical seat adjustability upward and aft parallel to the seat back, the pilot with a short torso and with arms shorter than usual - less than 1st percentile - as expected, will represent the minimal reach capability that must be accommodated. With up-and-forward seat adjustability, a pilot with different body and limb proportions produces minimal reach capability. The seat adjustability angle and length are such that the pilot with a long torso and relatively short arms - 45th percentile minimum - will have the least reach forward. This body proportion, then, unexpectedly produces the minimum reach capability from the recommended seat position. Although this direction of seat adjustment appears to result in a slight enlargement of the accessible space forward of the ejection clearance line, another problem is created, that of assuring adequate knee clearance during ejection.

"If there could be certainty that all pilots would adjust to the horizontal vision line, no problems related to safe knee clearance during ejection would be anticipated. However, since pilots often adjust themselves as high as possible, the probability of a clearance problem must be considered. This probability is increased if and when the pilot with a large torso and large Buttock-Knee Length raises the seat up and forward. In an attempt to control the maximum to which the larger pilots can raise the seat upward and forward, a minimal canopy clearance is indicated - 4 cm., approximately the thickness of the hand. It is unlikely that other, better procedures to control knee protrusion can be developed for this method of raising the seat.

"In another variant of the up-and-forward seat adjustment approach, the seat is moved along a 71º angle for the purpose of achieving equivalent positioning of essentially all pilots' eyes. An adjustment of 5.2 cm. along this angle above <u>and</u> below NSRP will accommodate from 5th to 95th percentile Eye Height, Sitting - 7.6 cm. above <u>and</u> below NSRP will accommodate 1st to 99th. The seat adjustment angle and length are such that the body proportions that produce minimum reach capability are the small torso/short reach pilots. The up-and-forward seat travel angle at which the changeover from small torso/short reach to large torso/short reach is between 43º and 71º. The point to which the pilot with 95th percentile torso and 45th percentile reach can be expected to reach, is further forward than that with a 55th percentile torso and 1st percentile reach. It appears that a small amount of additional space for manual control location is made available forward of the ejection line when using a 71º seat travel line. Again, to limit the upward travel of the seat, for the primary purpose of controlling forward knee protrusion, a minimal head/canopy clearance might be required."

There are 9 references.

Back to Annotated Bibliography

Back to Annotated Bibliography

REACH CAPABILITY OF MEN AND WOMEN: A THREE-DIMENSIONAL ANALYSIS

Kenneth W. Kennedy, Ph.D.
AAMRL-TR-77-50
Aerospace Medical Research Laboratory
Wright-Patterson Air Force Base, Ohio 45433-6573

July 1978

ABSTRACT: "This report contains descriptions of the outer and inner boundaries of the 5th, 50th, and 95th percentile grasping-reach envelopes of men and of women. The reach envelopes are intended to guide the placement of critical hand operated controls for the seated operating and working body positions. The most important envelope is the 5th percentile, since it describes that past which 95 percent of the using population can reach. Thus, a controller located at the boundary of this envelope can be reached by an equivalent percentage of the male or female adult populations. A critical review of previous investigations of arm reach and a description of the Aerospace Medical Research Laboratory's Grasping-Reach Measuring Device are presented. The data-gathering procedures and the methods of analyses are included. Applications of the data are also discussed. Data are presented in both graphic and tabular form. Vertical (X-Z) and (Y-Z) planes, and horizontal (X-Y) planes through the various percentile envelopes are presented.

Appendices are included, reporting (1) comparisons between original and final data, (2) reach envelopes for a 50/50 mixed adult male and female using population, and (3) anthropometric data on subject populations."

REVIEW OF THE LITERATURE:

Eighteen sources are reviewed.

APPARATUS: "To derive information on reach capability, the Aerospace Medical Research Laboratory Reach and Strength Measuring Device was used. It includes a rotatable hard seat mounted on a platform beneath an arch so that the Seat Reference Point (SRP) of the seat lies in the plane of the arch. . . . One side of the arch contains friction held measuring rods radiating at 15° intervals, so that each points to the center of the arch. Each rod is calibrated to indicate the distance from the center of the arch to the mid-point of the knob at the inside ends of the rods. . . . The seat's axis of rotation runs vertically through its SRP and the center of the arch. the SRP is 24 inches . . . below the center of the arch. . . . This design permits the subjects to push the scaled rods along lines radiating from the shoulder level, regardless of the orientation of the seat. . . .

Two large button switches, lightly spring-loaded, were installed in the back of the seat, 18 inches above SRP and 3 inches to the right and left of the seat-back centerline. When the subject is seated, the weight of [the] back against the switches energizes two lights at his feet. . . . Should a light . . . go off during reach measurements, the subjects know they are out of position and must repeat the measurement. The right light is the most important, since all reaches are made with the right hand. The lights function as a warning, primarily during establishment of the forward and left sectors of the reach envelope, when loss of contact between the subject's back and the seat back is most likely to occur."

Reach capability obtained with the use of the back switches is intended to be equivalent to Reach Zone 1, as defined in Mil Std 1333, ***Aircrew Station Geometry for Military Aircraft***, 9 January 1987.

Measurements were taken throughout vertical planes at 15° intervals from that corresponding to the mid-sagital plane, or 0°.

"Twelve anthropometric dimensions were measured on each subject. These are listed below.

Age	Acromion Height, Sitting
Height	Buttock-Knee Length
Weight	Biacromial Diameter
Functional Reach	Shoulder Breadth
Sitting Height	Shoulder-Elbow Length
Eye Height, Sitting	Forearm-Hand Length

The means and standard deviations for these dimensions, as well as comparable data from military and civilian populations are given . . .."

Back to Annotated Bibliography

Back to Annotated Bibliography

ASSESSMENT OF ANTHROPOMETRIC ACCOMMODATION IN AIRCRAFT COCKPITS

Kenneth W. Kennedy, Ph.D. and Gregory F. Zehner
SAFE Journal, Vol. 25, No. 1, January, 1995.

ABSTRACT: "This paper focuses on aspects of anthropometric accommodation in aircraft cockpits and anthropometric multivariate models as accommodation criteria. Appropriate body size accommodation in aircraft cockpits is still being sought in military services despite the many years of experience logged by designers. This issue is more important than ever in today's Air Force because the demographics of the pilot population are changing. Larger pilots are currently being admitted and the probability that much smaller pilots will be in flight training in the near future is very high. For that reason, a set of evaluation procedures has been developed to assess the anthropometric accommodation limits of cockpits. Seven aspects of accommodation are examined: 1) overhead clearance, 2) operational leg clearances, 3) control stick/wheel operation clearance, 4) ejection clearances, 5) rudder pedal operation, 6) visual field, and 7) hand reach to controls."

INTRODUCTION: ". . . For many years, cockpit design was based on the concept of accommodation the 5th through 95th percentile for a limited number of critical anthropometric dimensions of the male pilot. Within the aircraft and automotive industries, this concept was inappropriately extended to larger numbers of dimensions, and eventually evolved into the "percentile man" concept in which essentially all body dimensions are included. As a result of errors inherent in this "percentile man" approach, considerable numbers of pilots have experienced difficulty operating or escaping from their aircraft. To correct these deficiencies, multivariate alternatives to the percentile approach have been developed to describe body size variability in the USAF flying population. An attempt at partial multivariate representation was incorporated in the two-dimensional drawing board manikins developed by the USAF in the mid 1970s. . . . A much more sophisticated and complete multivariate analysis has now been developed, again by the USAF, in which a number of body size combinations or "multivariate cases" were calculated. These not only describe "typical" small and large pilots, as the percentile approaches attempted to do, but take into account the variability of body proportions found in many individuals who are not uniformly "large" or "small." The multivariate models . . . are typical of those used by the USAF to evaluate accommodation in aircraft cockpits."

". . . In most aspects of body size accommodation - overhead and ejection clearances and vision, for example - anthropometric relationships are rather straightforward. Others are considerably more complex. The ability to reach hand controls, for example, is not only influenced by the length of the arm, but also by Sitting Eye Height, Sitting Shoulder Height, and the length of the legs. Sitting Eye Height plays a decisive role in seat adjustment, since the pilot must seek optimum vision both inside and outside the cockpit. the seat may have to be moved to a different position to obtain full control of the rudder pedals. The level of the shoulders in the cockpit, which directly influences reach capability, can thus be influenced by attempts to meet vision and rudder pedal access requirements. Finally, not only the length of the arm, but any factor that influences mobility at the shoulder and elbow, such as design, fit, and adjustment of harnesses and personal protective and survival gear, strength, and motivation come into plan in the act of reaching. It is typical behavior for a pilot to shift seat positions to achieve optimum accommodation for a variety of needs. It follows that several pilots with the same arm length can have different reach capabilities in the cockpit, depending on his/her other body dimensions. If only one subject is used in the evaluation of reach, or any other aspect of accommodation, the results will be relevant only to that individual."

USING THE DATA: ". . . There are several uses for accommodation data, the most straightforward of which is the verification of design specifications. If a cockpit is required to accommodate a given range of body sizes, these techniques make it possible to validate compliance. . . . Another use for these data is to predict the fit of a range of body sizes in a crewstation. Data can also be used to assess the effects of expanding the ranges of body sizes permitted to enter pilot training. . . ."

Back to Annotated Bibliography

Back to Annotated Bibliography

LETTER REPORT: "JPATS MULTIVARIATE CASES 1 AND 7 ACCOMMODATION IN SELECTED AIRCRAFT"

Kenneth W. Kennedy, Ph.D.
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Yellow Springs, Ohio 45387

To:

Design Technology Branch
AL/CFHD - Mr. G.F. Zehner
Human Engineering Division
Armstrong Laboratory
Wright-Patterson Air Force Base, Ohio 45433

10 January 1994

Joint Primary Aircraft Training System (JPATS) Anthropometric Multivariate Cases 1 and 7 have been examined in light of the accommodation they are offered in the USAF T-37B, T-38A, F-16A, and C-141A cockpits. Parameters considered include: maximum Sitting Height accommodated (set full down), minimum combined leg length to access rudder pedals (seat full up), leg clearance with the main instrument panel (seat full down), maximum Buttock-Knee Length to clear cockpit structure during ejection (all seat positions), vision over the nose and under windscreen bow (seat full up), and minimum reaches necessary to access a selection of hand controls (seat full up). All information except reach regression charts were taken from your Aircraft Accommodation Database.

Since multivariate cases 1 and 7 report anthropometric data on small female subjects we do not find accommodation problems associated with maximum Sitting Height accommodated, leg clearance with the main instrument pane, and maximum Buttock-Knee Length to clear cockpit structure during ejection.

We do find potential accommodation problems with these cases in minimum combined leg length to access rudder pedals, vision over the nose, and minimum reaches necessary to access hand controls.

Back to Annotated Bibliography

ANTHROPOMETRY

	Case 1 Generalized Small Pilot (Female)	Case 7 Objective (Female)
Thumbtip Reach	27.0"	26.1"
Buttock-Knee Length	21.3	20.8
Knee Height, Sitting	18.7	18.1
Sitting Height	32.8	31.0
Eye Height, Sitting	28.0	26.0
Shoulder Height, Sitting	20.6	19.5

OVERHEAD CLEARANCE

Aircraft	Seat Position	Case 1	Case 7
F-16A	Full Up	4.4" (Incl. Helmet)	6.2" (Incl. Helmet)
C-141A (Left)	Full Up & Fwd	7.3" (Bare Head)	10.1" (Bare Head)
T-37B (Left)	Full Up	5.2" (Incl. Helmet)	5.0" (Incl. Helmet)
T-38A (Fwd)	Full Up	8.7" (Incl. Helmet)	11.5" (Incl. Helmet)
T-38A (Aft)	Full Up	3.2" (Incl. Helmet)	5.0" (Incl. Helmet)
T-1A (Left)	Full Up & Fwd	6.3" (Bare Head)	8.1" (Bare Head)

KNEE/SHIN CLEARANCE WITH MAIN INSTRUMENT PANEL

Aircraft Seat

Back to Annotated Bibliography

	Position	Case 1	Case 7
F-16A	Full Up	5.7"	6.2"
C-141A (Left)	Full Up & Fwd	Surplus	Surplus
T-37B (Left)	Full Up	5.4"	5.7"
T-38A (Fwd)	Full Up	NA	NA
T-38A (Aft)	Full Up	NA	NA
T-1A (Left)	Full Up & Fwd	NA	NA

EJECTION CLEARANCE WITH GLARE SHIELD

Aircraft	Seat Position	Case 1	Case 7
F-16A	All Pos	8.2"	8.7"

EJECTION CLEARANCE WITH WINDSCREEN BOW

Aircraft	Seat Position	Case 1	Case 7
T-37B (Left)	All Pos	5.1"	5.6"
T-38A (Fwd)	All Pos	9.5"	10.0"
T-38A (Aft)	Full Up	11.5"	12.0"

VISION OVER THE NOSE - IN DEGREES

F-16A	Full Up	-10.0º	-5.0º
C-141A (Left)	Full Up & Fwd	-9.1º	-

Back to Annotated Bibliography

6.0º

T-37B (Left)	Full Up	-9.2º	-7.0º
T-38A (Fwd)	Full Up	-4.5º	-1.7º
T-38A (Aft)	Full Up	NA	NA
T-1A (Left)	Full Up & Fwd	-10.0º	-6.0º

VISION UNDER CANOPY BOW - IN DEGREES

C-141A (Left)	Full Up & Fwd	+25.6º	+27.0º
T-37B (Left)	Full Up	+14.2º	+21.2º
T-38A (Fwd)	Full Up	+ 8.0º	+10.0º
T-38A (Aft)	Full Up	+ 8.8º	+12.0º
T-1A (Left)	Full Up & Fwd	+18.4º	+22.0º

ACCESS TO RUDDER PEDALS - CARRIAGE FULL AFT

F-16A	Full Up	1.6" Excess*	0.5" Excess*
C-141A (Left)	Full Up & Fwd	0.6" Short**	1.7" Short**
T-37B (Left)	Full Up	0.8" Short**	1.1" Short**
T-38A (Fwd)	Full Up	3.0" Short**	4.1" Short**

T-38A (Aft) Full Up 2.8" Short** 3.9" Short**

T-1A (Left) Full Up & Fwd 0.4" Short** 0.7" Short**

* Cases #1 and #7 could reach with their legs these amounts beyond that necessary to fully depress pedals.

** Cases #1 and #7 would need to have legs these amounts longer to fully depress pedals.

HAND REACH CAPABILITY TO CONTROLS - REACH ZONE 2 MISS DISTANCES AND RIGHT OR LEFT HAND ARE INDICATED. (Only those controls that could not be reached by more than 1.0 inch are listed. Those not reached under the more stringent Zone 1 reach requirement are not included and would add significantly to the list.)

PLEASE NOTE: ONLY SELECTED HAND CONTROLS WERE EXAMINED. THEREFORE, THE ABSENCE OF A CONTROL IN THE FOLLOWING LISTS DOES NOT NECESSARILY IMPLY THAT IT COULD BE REACHED. THE APPEARANCE OF A HAND CONTROL ON THESE LISTS DOES NOT NECESSARILY IMPLY DISACCOMMODATION. SOME SHOULD BE REACHED UNDER ZONE 1 REQUIREMENTS, OTHERS UNDER ZONE 3.

REACH ZONE 2 MISS DISTANCES - SUBJECTS REQUIRED THESE AMOUNTS OF ADDITIONAL REACH TO ACCESS CITED CONTROLS.

NOTE: When it is feasible that a given control might be reached with either hand and neither can reach it, miss distances for both are given - the greatest first.

F-16A, MULTIVARIATE CASE 1, SEAT FULL UP:

Airspeed Mach Ind. 6.0", Left Hand
Altimeter Select Knob 7.3", LH
Course Select 5.5", LH
DIS/LTS 5.0", LH
Emergency Stores Jettison 2.6", LH
Fuel Quantity Select 5.5", RH
HUD Filter 2.2", LH

HUD DISP MILS DEPR 4.2", LH
HSI Pull to Cage 8.6", LH
IFF Ident 2.9", LH
ILS Volume 1.9", RH
Pitch Alt Hold 2.4", LH
Select Jettison 4.6", LH
Shift Multiple Function Display 3.8", LH
TACAN Heading 4.1", LH

F-16A, MULTIVARIATE CASE 7, SEAT FULL UP:

All of the above by greater values, plus the following:

Down Lock Release 1.8", Left Hand
Storage Config CAT 1 1.5", LH

C-141A, MULTIVARIATE CASE 1, LEFT COCKPIT, SEAT FULL UP AND FWD:

ADI LT 2.2", Left Hand
Anti Skid Toggle 11.8", LH
BDHI Set Index Left 1.8", LH
Brake T-Handle 1.9", LH
Cargo Doors - All Doors 1.5", LH
Chute Release Off 1.9", LH
Circuit Breaker Panel, XMTR-1, 11.4", LH
Co Pilot Side Console Lights 11.1", RH
Emergency Cabin Depressurize T-Handle 2.3", RH
Emergency Oxygen Shut-Off 6.2", LH
Emergency Pressure LH Toggle 6.5", LH
Engine Fire Test-4 8.7", RH
Fire Extinguisher T-Handle #4 3.2", RH
Flaps Landing Aft 3.1", RH
HSI Course Set Knob-Left 2.3", RH
Instrument Power Toggle 1.1", RH
Landing Gear Handle 9.1", RH
Mach Incr Toggle 1.2", RH
Rudder Hi Pressure O'Ride 5.6", RH
Thrust Reverse Limiter 6.2", RH
Weather Radar Slew Toggle 2.6", RH
Windshield Heat 4.1", RH

C-141A, MULTIVARIATE CASE 7, LEFT COCKPIT, SEAT FULL UP AND FWD:

All of the above by a greater value plus the following:

ADF Control Transfer 2 1.2", Right Hand
BDHI VOR 2 Left 1.3", LH
Trim Reset Toggle 1.1", RH

T-37B, MULTIVARIATE CASE 1, LEFT COCKPIT, SEAT FULL UP

AC Fuses Lowermost Right 14.4", Right Hand
AC Fuses Uppermost Right 12.4", RH
AN-APX 72 Transponder Control Panel - MA 3.7", RH
Battery Switch 3.2", LH
Cockpit Air Lever 4.4", RH
Cockpit Air Temp Control Rheostat 3.2", RH
Control Stick Grip, Full Fwd Left 2.1", RH
DC Circuit Breaker L'most Right 11.1", RH
DC Circuit Breaker U'most Right 10.8", RH
Left Fuel Shutoff T-Handle 1.9", LH
Right Fuel Shutoff T-Handle 2.8", LH
Left Generator Switch 3.1", LH
Right Generator Switch 4.2", LH
Inverter Switch 1.4", LH
NAV DME Control Panel Sel Switch 3.6", RH
UHF Command Radio ARC 164 3.4", RH

T-38B, MULTIVARIATE CASE 7, LEFT COCKPIT, SEAT FULL UP:

No additional controls.

T-1A, MULTIVARIATE CASE 1, LEFT COCKPIT, SEAT FULL UP AND FWD:

Cabin Controller 4.3", Right Hand
Cabin Dump 5.4", RH
Climb-Dive Pull to Cage 1.6", RH
Defog Lever 1.6", LH
Emergency Brake 1.6", RH
Landing Gear Downlock Release 1.5", RH
Temperature Control Panel - Man-Press-Cntrl 8.9", RH

T-1A, MULTIVARIATE CASE 7, LEFT COCKPIT, SEAT FULL UP AND FWD:

Back to Annotated Bibliography

All of the above by a greater value plus the following:

Landing Gear Lever 1.5", Right Hand

T-38A, MULTIVARIATE CASE 1, FORWARD COCKPIT, SEAT FULL UP:

AIMS Control Panel Master Knob 2.8", Right Hand
Airspeed Mach Inc 2.3", LH
Altimeter Set Knob 4.3", LH and 2.9", RH
AOA Index Lights Dimmer 2.2", LH
Battery Switch 3.5", RH
Boost Pump Left, Switch 1.9", RH
Boost Pump Right, Switch 2.1", RH
Cabin Air Temp Switch 5.6", LH and 2.4", RH
Cabin Pressure Switch Ram Dump 3.3", LH and 2.3", RH
Cabin Temp Control Knob 8.2", LH and 3.9", RH
Cabin Defog Knob 8.3", LH and 4.2", RH
Canopy Jettison T-Handle 3.1", RH
Canopy Locking Lever 4.1", RH
Circuit Breaker Panel ARC 164 11.1", RH and 8.9", LH
Circuit Breaker Panel Caution Warning 10.9", RH and 9.6", LH
Clock Set Button 1.6", LH
Comm Antenna Switch 2.2", LH
Compass Switch 4.3", LH
Control Stick Full Fwd Left 4.4", RH
Crossfeed Switch 2.3", RH
Engine Anti Ice Switch 5.6", LH and 2.7", RH
HSI Heading Set Knob 3.6", RH and 1.8", LH
ILS Control Panel Frequency Knob 8.0", RH and 6.0", LH
ILS Control Panel Power 7.3", LH and 7.3", RH
Inertia Reel Locking Lever 1.9", LH
Intercom Switch Comm 4.3", LH
Intercom Switch ILS 4.5", LH
Landing Gear Alt Rel Handle 1.9", LH
Landing Taxi Light Switch 2.2", LH
Master Caution Light 3.4", LH and 2.4", RH
NAV Mode Switch TACAN 1.8", LH
Oxygen Supply Switch 100%-Norm 4.1", RH
Oxygen Supply Switch Emergency Norm Test 3.1", RH
Oxygen Supply Switch On-Off 4.8", RH
Pitot Heat Switch 4.6", LH and 2.8", RH
Radio Transfer Switch Comm 2.0", LH

Back to Annotated Bibliography

Radio Transfer Switch NAV 2.3", LH
Rudder Pedal Adjust T-Handle 7.1", RH and 5.7", LH
Seat Adjust Switch 1.5", RH
Standby Attitude Ind 1.1", LH
TACAN Control Panel A/A-T/R 6.5", LH and 6.4", RH
TACAN Control Panel Channel Knob 7.0", RH and 4.8", LH
UHF Command Radio Control Panel - Main 7.1", RH and 4.3", LH
UHF Command Radio Control Panel - Preset 6.0", RH and 5.3", LH

T-38A, MULTIVARIATE CASE 7, FORWARD COCKPIT, SEAT FULL UP

All of the above by a greater value plus the following:

Throttle, Full Forward 1.1", Left Hand

T-38A, MULTIVARIATE CASE 1, AFT COCKPIT, SEAT FULL UP:

Airspeed Mach Ind 3.8", Left Hand
Altimeter Set Knob 4.0", LH and 2.7", RH
AOA Indexer Lights Dimmer 3.1", LH
Canopy Jettison T-Handle 3.4", RH
Canopy Locking Lever 3.7", RH
Clock Set Button 2.7", LH
Command & NAV O-Ride Switch 3.2", LH
Control Stick Full Fwd Left 5.1", RH
Downlock O'Ride Button 1.1", LH
Engine Start Button-L 4.6", LH
HSI Course Select Knob 2.9", LH and 2.6", RH
HSI Heading Set Knob 4.1", RH and 3.5", LH
ILS Control Panel Frequency Knob 7.8", RH and 7.4", LH
ILS Control Panel Power 8.1", LH and 7.1", RH
Inertia Reel Locking Lever 1.9", LH
Intercomm Switch Comm 4.2", LH
Intercomm Switch ILS 4.6", LH
Intercomm Switch Inter 4.3", LH
Intercomm Switch NAV 4.3", LH
Landing Gear Warning Light Silence Button 1.3", LH
Lighting Control Panel Cockpit Floods 3.2", RH
Master Caution Light 3.7", LH and 1.7", RH
NAV Mode Switch TACAN 2.9", LH
Oxygen Supply Switch 100%-Norm 5.3", RH
Oxygen Supply Switch Emergency Norm Test 4.0", RH
Oxygen Supply Switch On-Off 5.7", RH

Rudder Pedal Adjust T-Handle 7.4", RH and 6.6", LH
Seat Adjust Switch 3.3", RH
Standby Attitude Ind 2.6", LH
TACAN Control Panel A/A-T/R 7.0", LH and 5.8", RH
TACAN Control Panel Channel Knob 6.6", RH and 5.7", LH
UHF Command Radio Control Panel - Main 6.2", RH and 5.3", LH
UHF Command Radio Control Panel - Preset 6.1", LH and 5.3", RH

T-38A, MULTIVARIATE CASE 7, AFT COCKPIT, SEAT FULL UP:

All of the above by a greater value plus the following:

Steering Mode Switch Norm-Manual 1.5", Left Hand

Back to Annotated Bibliography

Back to Annotated Bibliography

COCKPIT STUDIES - The Boundaries of the Maximum Area for the Operation of Manual Controls

Barry G. King, Dorothy J. Morrow, and Erwin P. Vollmer

Report No. 3, Project X-651
Naval Medical Research Institute
National Naval Medical Center
Bethesda, Maryland

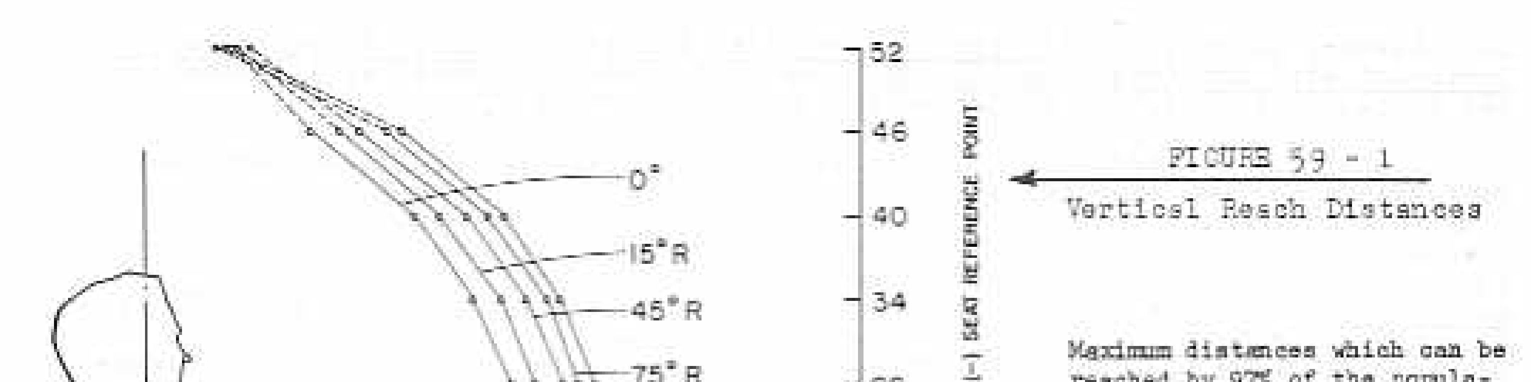
15 July 1947

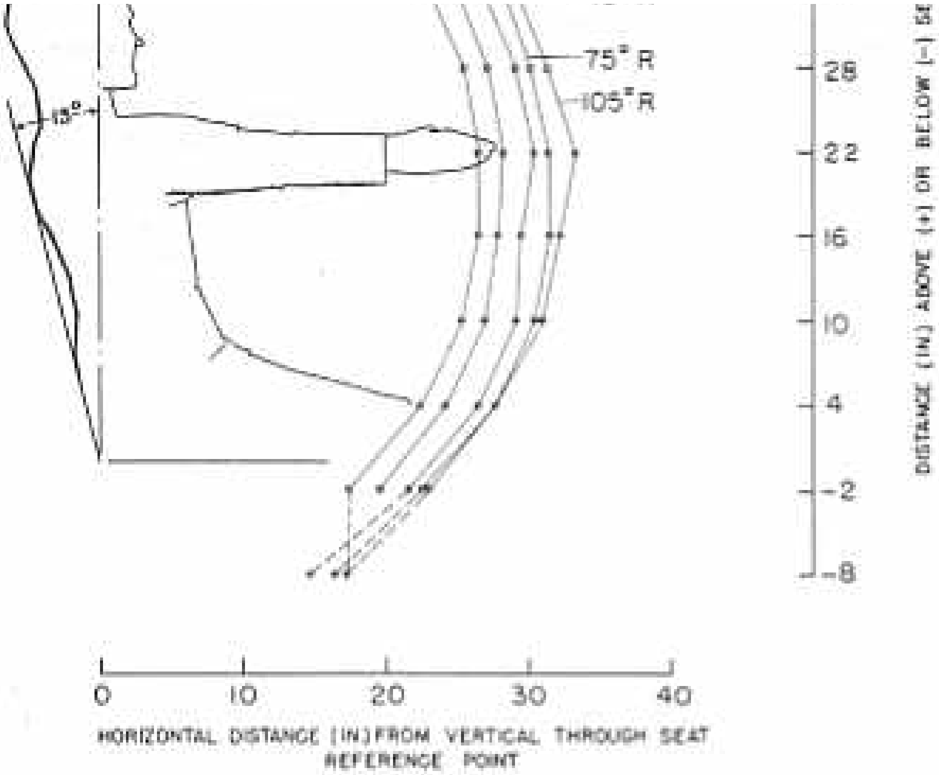
This annotation is taken from: ***Annotated Bibliography of Applied Physical Anthropology in Human Engineering***, by Robert Hansen and Douglas Y. Carnog, H. L. Yoh Company, Philadelphia, PA, Aero Medical Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, May 1958.

"The boundaries of the maximum working area for operation of manual controls may be represented by a segment of the shell of an ellipse; the shell is about five inches thick. The maximum dimension to the periphery of this shell is found at approximately shoulder height at 105° to the right or left; dimensions diminish as the arm is brought to the zero position and as the arm is raised or lowered.

'Average reaches for 139 subjects varied between 36.8 inches and 13.1 at various points on the elliptical segments; dimensions within 0° and 75° satisfactory for 93 per cent of the sample varied from 31.6 to 11.6 inches when seat back was 13° from vertical.' Anthropometric measurements are given for a large number of subjects. The problem of representative samples f the military population is discussed. A simple rapid method for further testing of dimensions, selection of pilots and studying placement of controls is described.

The report is 47 pages long, including 12 tables, nine figures, and three appendices. The bibliography contains eight references. Two figures are included with this annotation."

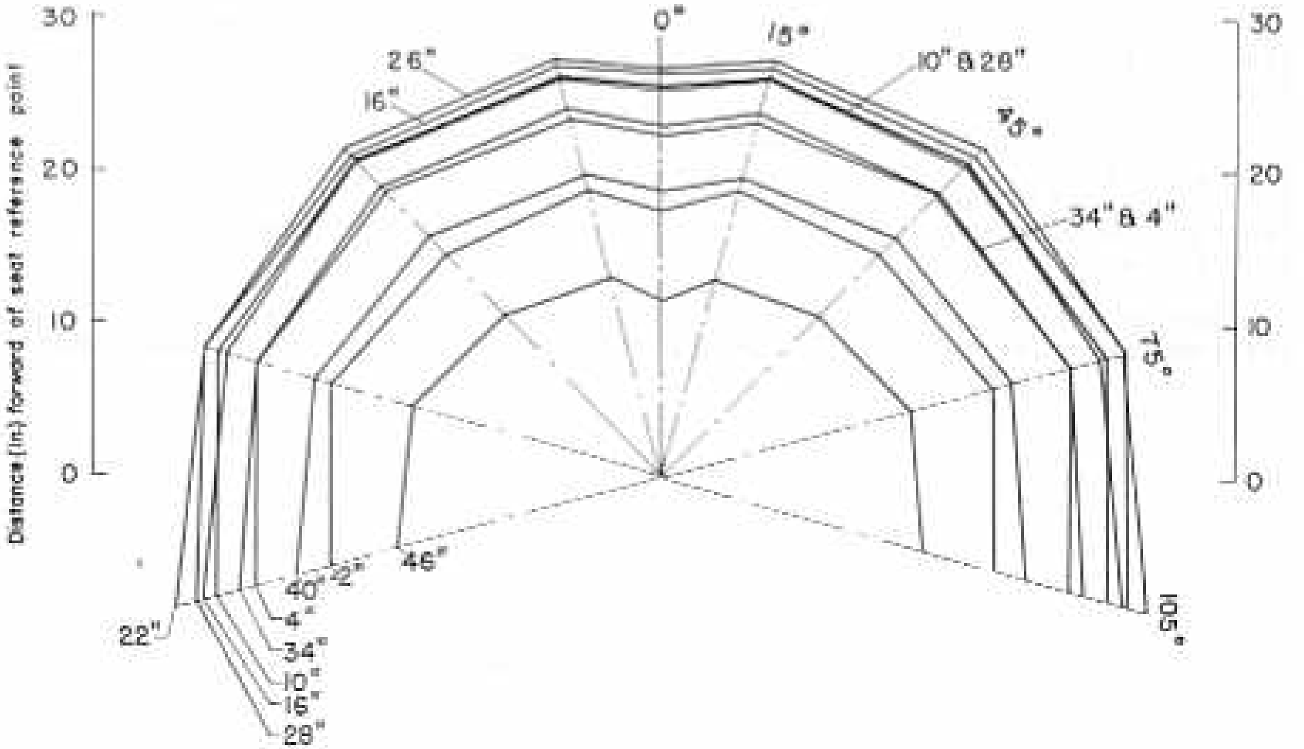




Maximum distances which can be reached by 97% of the population at each position. The elliptical arcs indicate the maximum boundaries of the working area for operation of manual controls (at right angles from 0° to 105° to the right) for this group. Seat back angle 13°.

FIGURE 59 - 2

Horizontal Reach Distances



Maximum distances which can be reached by 97 per cent of the population at each position. The eliptical arcs indicate maximum boundaries for this group for operation of manual controls at various horizontal levels. Seat back 13° from vertical

Back to Annotated Bibliography

Back to Annotated Bibliography

FUNCTIONAL COCKPIT DESIGN

Barry G. King

Aeronautical Engineering Review
Vol. 11, No. 6, June 1952, pp. 32 - 40.

This annotation is taken from: ***Annotated Bibliography of Applied Physical Anthropology in Human Engineering***, by Robert Hansen and Douglas Y. Carnog, H. L. Yoh Company, Philadelphia, PA, Aero Medical Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, May 1958.

"This article emphasizes the need for the human engineering of the airplane cockpit and stresses the fact that classical or standard anthropometry is often inappropriate to the determination of the most desirable cockpit dimensions. The author stresses that what is needed for functional cockpit design is an anthropometry of 'natural' cockpit situations. By natural' the author means body conditions that parallel those of normal operation or function, as distinguished from the posed body conditions dictated by standard anthropometric techniques. For example, King states, 'Values for both eye level and sitting height when maintaining a natural easy sitting position are about one-and-one-half to two inches less than when measured under the standardized (and sometimes artificial) postures used by anthropologists for comparison of races and groups.'

The report is eight pages long. It contains seven tables and three figures. The data presented are from the report.

TABLE 58 - 1

Sitting Height and Eye Level (in Inches) of Men Measured in Anthropometric and Natural Sitting Postures (N = 100)

	$\bar{x}$***	$\pm s_{\bar{x}}$	$\pm s$
Anthropometric* sitting height	36.20	0.132	1.32
Natural** sitting height	34.79	0.125	1.25

Back to Annotated Bibliography

Anthropometric* eye level	31.32	0.126	1.26
Natural** eye level	29.66	0.124	1.24

* Standard anthropometric technique.
** Measured in natural easy sitting postures

*** $\bar{x}$ = mean, $\pm s\bar{x}$ = standard deviation of mean, and ±s = standard deviation.

TABLE 58 - 2 *

Reach Measurements: The Maximum Distance at Which a Large Percentage of a General Pilot Population[1] Will Be Able To Reach and Operate Manual Controls Located at Various Points in the Work Area

Level (Inches) Above Seat Reference Point	Angle (Degrees) 0	R15	R45	R75
46	11.6"	13.7"	15.0"	17.0"
40	18.9	20.5	22.4	24.1
34	22.9	24.9	26.6	28.0
28	25.5	27.1	29.1	30.1
22	26.7	28.2	30.3	31.4
16	26.6	28.0	29.7	31.6
10	25.3	27.0	29.3	30.4
4	22.6	24.2	26.4	27.9
- 2	17.5	19.7	21.8	22.8

* Distances for right arm reach are measured from the vertical line through the reference point with the subject's shoulders touching the back cushion; seat back 13° from the vertical. The [Seat] [R}eference [P]oint is taken as the [center of the] upper level of the seat cushion at its line of intersection with the small lower cushions of the back pad (Warren McArthur seat). R15° stands for 15° to right. Reach for left arm can be outlined by using above measurements at corresponding points to the left of 0°.

[1] These distances were suitable for 97.7 per cent of the 139 subjects studied at each position, and suitable for 94 per cent of the group at all positions.

TABLE 58 - 3

Mean Distances for Forward Head Movement of Seated Subjects Restrained by Lap Safety Belt *

	3-In. Belt, N = 100			2-In. Belt, N = 96		
	$\bar{x}$	$\pm s_{\bar{x}}$	$\pm s$	$\bar{x}$	$\pm s_{\bar{x}}$	$\pm s$
Test Condition	In.	In.	In.	In.	In.	In.
* Natural	31.04	0.16	1.632	32.09	0.16	1.592
Static-suspended weight	34.00	0.15	1.509	34.11	0.16	1.600
Dynamic-drop weight	37.05	0.17	1.712	36.66	0.20	2.012

* Natural refers to maximum forward position of head which can be voluntarily assumed without action of suspended or drop weights."

Back to Annotated Bibliography

Back to **Annotated Bibliography**

A MULTIVARIATE ANTHROPOMETRIC METHOD FOR CREW STATION DESIGN (U)

AL-TR-1993-0054

Richard S. Meindl
Jeffrey A. Hudson

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School of Biomedical Sciences
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pp. i - viii and 1 - 33

ABSTRACT:

"Body size accommodation in USAF cockpits is still a significant problem despite all the years of experience and the many aircraft designs that have been developed. Adequate reach to controls, body clearances (particularly during escape), and vision (internal and external), are all functions of pilot body size and position in the cockpit.

One of the roots of this problem is the way cockpit accommodation is specified and tested. For many years the percentile pilot has been used. This paper describes the errors inherent in the "percentile man" approach, and presents a multivariate alternative for describing the body size variability existing in a given flying population. A number of body size "representative cases" are calculated which, when used properly in specifying, designing, and testing new aircraft, should ensure the desired

level of accommodation.

The approach can be adapted to provide anthropometric descriptions of body size variability for a great many designs a=or for computer models of the human body by altering the measurements of interest and/or selecting different data sets describing the anthropometry of a user population."

INTRODUCTION:

"The recent development of computer models of the human body for describing dimensional variability of military personnel has advanced beyond current methods to describe and use available anthropometric data. In fact, anthropometric data are generally used to estimate only the extremes of univariate (single variable) distributions of a few gross dimensions, with little provision for individuals with unusual anthropometric proportions (Roebuck et al.,1975). Since extreme ratios (e.g. long buttock-knee length coupled with short sitting height) present the most difficult design problems for accommodation in workstations or for protective equipment, univariate percentile rankings for user populations are inappropriate, except for the most general description of international anthropometric variability.

Subgroup methods, which identify and select individuals atypical in combinations of two or more variables, partly address this issue. However, the severe sample truncations used in this method require initially massive data bases. This is especially true if subgroups are defined by the outermost regions of joint distributions of more than two variables.

Regression methods predict body proportions that are realistic as well as segment sizes that are additive (Robinette and McConville, 1981). These approaches require that one or two "key" dimensions be chosen as independent variables. Yet all human body measures are "free to vary" in an experimental sense, and therefore serve poorly as regressors. This problem can be particularly pronounced in those instances in which standard deviations from regression are large (or bivariate correlations are low). For example, the statistical assumptions necessary for the application of least-squares regression designs are approximated poorly in workstation dimension studies, owing to moderate intercorrelations (McConville et al., 1978), and not at all in the analysis of mask fit/seal accommodation, because the correlations among human facial measurements are extremely low. The typical results of these analyses are extreme values for the independent variables (regressors), and considerably less extreme values for the dependent variables (regressands) (those predicted)."

Additional segments include the following.

THE MULTIVARIATE DESCRIPTION OF AN ANTHROPOMETRIC SAMPLE: METHODS

ANALYSIS OF A TWO-COMPONENT MODEL

A THREE-COMPONENT MODEL: A COMBIMAN APPLICATION

THE PROBLEM OF MULTIPLE POPULATIONS

CONCLUSION

"A preliminary attempt was made, at the conclusion of this analysis, to reduce six critical cockpit dimensions to two new measures (principal components), and to disaccommodate extreme anthropometric combinations as symmetrically as possible, while still applying the sitting height restrictions for the current population of Air Force flying personnel. It was also found appropriate to equally weight the anthropometric information of the three "derived" populations (68AF white females, 65AF black males, and 65AF white males), or to consider each population separately and combine the results. The issue of designing a workstation based on the anthropometrics of a composite user population is an important one. It requires a multivariate approach, additional survey data, and of course some reliable estimates of the actual proportions of males, females, Whites, Blacks, and others in future user populations. Depending on the extent of international application, some analysis of the anthropometrics of additional populations may also be required."

There are six Figures, 7 Tables and 10 references.

Back to **Annotated Bibliography**

Back to Annotated Bibliography

MILITARY STANDARD 1333A

AIRCREW STATION GEOMETRY FOR MILITARY AIRCRAFT

DEPARTMENT OF DEFENSE
Washington, D.C. 20301

30 June 1976

THE FOLLOWING ARE EXTRACTS.

1. PURPOSE AND SCOPE

1.1 Purpose - This standard establishes the design requirements for aircrew station geometry in military aircraft. Compliance assures a design that is efficient, safe and comfortable for operation by aircrew personnel for the ranges of body sizes specified by the procuring activity.

1.2 Scope - The requirements defined herein apply to all piloted aircraft procured by the military departments."

2. REFERENCED DOCUMENTS

Seventeen Specifications, Standards and other publications are cited as part of this standard to the extent specified herein.

3. DEFINITIONS

3.1 Design eye position - The design eye position is a reference datum point based on the eye location that permits the specified vision envelope required by MIL-STD-850 [***Aircrew Station Vision Requirements for Military Aircraft***], allows for posture slouch and is the datum point from which the aircrew station geometry is constructed.

3.2 Horizontal vision line - The horizontal vision line is a reference line passing through the design eye position (3.1) and parallel to the fuselage reference line.

3.3 Back tangent line - The back tangent line is established by a vertically inclined plane tangent to the back of the seated man at the thoracic region and buttocks.

3.4 Bottom tangent line - The bottom tangent line is a horizontal line coincident with the reference line of the seat.

3.5 Seat reference point (SRP) - The seat reference point is the intersection of the back tangent line and the bottom tangent line."

Back to Annotated Bibliography

3.6 Neutral seat reference point (NSRP) - The neutral seat reference point is the seat reference point with the seat in the nominal mid-position of the seat adjustment range. This seat position will place the 50th percentile (seated height) man with his eye in the design eye position.

3.7 Buttock reference point - The buttock reference point is the most forward limit of the bottom tangent line and represents the body pressure points located 5.75 inches forward of the seat reference point. This represents the area of the lowest seat cushion compression under a static vertical load of 1-g.

3.8 Thigh tangent line - The thigh tangent line is the average line of the aircraft seat when occupied by a crewmember with the maximum weight as specified by the procuring activity. The thigh tangent line originates at the buttock reference point and extends upward and forward from that point to the forward edge of the seat.

3.9 Control grip reference point - The control grip reference point is the point at which the crewman's second finger (middle digit) is in contact with the forward or downward face of any grip-type control such as control stick, control wheel, collective stick, or throttle.

3.10 Efficient, safe, and comfortable aircrew operation - Efficient, safe, and comfortable aircrew operation is defined by the dimensions, size, and adjustments of an aircrew stations that will allow the aircrew to: reach and actuation all controls, have external vision in accordance with MIL-STD-850, have unobstructed internal view of all critical controls and displays, be able to function effectively without undue fatigue or discomfort, and escape without injury.

4. GENERAL REQUIREMENTS

4.1 Selection of geometry Aircrew station geometry shall take into consideration all aspects of control and display requirements associated with safe flight, execution of the mission, and safe emergency egress and shall conform to the requirements specified herein. A description and explanation of the proposed geometry determined on the basis of the requirements contai8ned herein shall be approved by the procuring activity. This description shall contain a rationale for the proposed geometry and shall delineate the accommodation limitations, if any, for a specified aircrew population. _

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4.1.1 Basic geometry guide - A basic geometry guide for this document is presented as Figure 1. _

4.1.2 Seating geometry - The seating geometry shall conform to the requirements of Figure 2.

Back to Annotated Bibliography

4.2 External vision - The external vision for aircrew stations shall conform to the requirements of MIL-STD-850.

4.3 Internal vision - The internal vision of all controls and displays shall conform to the requirements of MIL-STD-203 [***Aircrew Station Controls and Displays for Fixed Wing Aircraft***] and MIL-STD-250 [***Cockpit Controls, Location and Actuation of for Helicopters***].

4.4 Ejection clearance dimensions - The ejection clearance dimensions for aircrew stations shall conform to the requirements of Figure 3.

Back to Annotated Bibliography

4.5 Anthropometric considerations - The aircrew station geometry shall be based on the anthropometric percentile range specified by the procuring activity and employing the factors outlined in MIL-STD-1472 [***Human Engineering Design Criteria for Military Systems, Equipment and Facilities***] and/or obtained from studies conducted in accordance with the requirements of MIL-H-46855.

4.5.1 Body dimensions - The requirements for all body dimensions shall conform to the following documents for each Service, as applicable:

Army

USANL TR 72-51-CE [***The Body Size of Soldiers, Anthropometry*** 1966]
USANL TR 72-52-CE [***Anthropometry of U.S. Army Aviators*** 1970]

Navy

NAEC ACEL Report No. 533 [***Anthropometry of Naval Aviators*** 1964]

4.5.1.1 Functional body data - Figures 4, 10, 11, 12, 13, 14, and 15 present arm and leg link values derived from cockpit work space studies and functional considerations of anthropometric data. (PMTC Report TIP-75-1 [***A Program to Compute the Range of Leg Reach from the Seat-Reference-Point,*** June 1975] provides the computation method employed.) [Because of space limitations, these figures are not reproduced here.]

4.5.1.2 Reach zones - Applicable data of reach/grasp capability defined in USAF Report AMRL-TDR-64-59 [KENNEDY, K. W., ***Reach Capability of the USAF Population, Phase 1, The Outer Boundaries of Grasping-Reach Envelopes for the Shirt-Sleeved, Seated Operator***, AMRL-TDR-64-59, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, OH, September 1964] shall be considered for reach zones illustrated in Figure 4 and defined as follows: [Figure 4 does not add substantial information for the understanding of reach zones and is not included here.]

ZONE 1 Restraint Harness Locked - Functional Reach
This zone includes the area that can be functionally reached with the seat in the full up (two-way seat) position and/or in the full up and forward (four-way) seat adjust position by the fully restrained crew-member without stretch of arm or shoulder muscles. Controls placed in this zone shall include those frequently used during operation of the aircraft in flight phases which required full restraint. This would include such flight phases as takeoff, landing, low altitude-hi-speed flight, weapons delivery, and escape. This zone defines the maximum limit allowed for the placement of emergency (escape system) controls and establishes the forwardmost operation limit of primary flight and propulsion controls (except for helicopters).

ZONE 2 Restraint Harness Locked - Maximum Functional Reach
This zone includes the area that can be functionally reached with the seat in the full up (two-way seat) position and/or in the full up and forward (four-way) seat adjust position by the fully restrained crew- member with maximum stretch of shoulder and arm muscles. This zone defines the maximum limit allowed for the placement of helicopters primary flight and propulsion controls and the placement of emergency controls other than escape controls.

ZONE 3 Restraint Harness Unlocked - Maximum Functional Reach
This zone includes the area that can be functionally reached with the seat in full up (two-way seat) position and/or full up and forward (four-way) seat adjust position by the crewmember with the shoulder restraint fully extended and the arms stretched full length. Only non-critical flight controls and ground operated controls shall be placed in this zone. For helicopters, emergency controls may be placed in this zone subject to the procuring activity approval."

4.6 Effects of personal and survival equipment - All geometry requirements specified herein are based upon nude body dimensions and to not include any tolerance for clothing or equipment, except flight boots and basic headgear. Many items of personal and survival equipment significantly alter the crewman's position in the aircrew station.

All such equipment specified by the procuring activity shall be considered at the earliest point in design, and adjustments made to the geometry to accommodate required equipment for the anthropometric range specified by the procuring agency. A check list of most frequently used items is contained in NAVAIR 13-1-6 Series Manuals [***Aviation-Crew Systems Manual***] and as otherwise specified by the procuring activity.

4.7 Accessibility of controls - Crewstation controls shall be accessible and usable by the entire anthropometric range of percentiles specified by the procuring activity.

4.7.1 Selection of controls - Selection of controls for the respective crewmembers shall be based upon the analyses and data derived from the studies required by MIL-H-46855 [***Human Engineering Requirements for Military Systems, Equipment and Facilities***] or by other techniques specified by the procuring agency.

4.7.2 Location and actuation of controls - The location and actuation of controls shall conform to MIL-STD-203 or MIL-STD-250, as applicable. Specific control locations and arrangements shall be established with the specified reach zones in accordance with the designated aircraft mission requirements.

5. CONTROL AND DISPLAY REQUIREMENTS

5.1 Controls

5.1.1 Pitch and roll controls

5.1.1.1 Stick type - The vertical location of the handgrip reference point shall be located from 11 to 15 inches above the neutral seat reference point, as required for the particular aircraft. The maximum envelope of stick throw shall be based on Zone 1 reach as defined in . . . paragraph 4.5.1.2. A minimum clearance of 1.5 inches . . . shall be maintained between the stick and all structures when the stick is in any extreme position. Special consideration shall be given to the effect of personal and survival equipment . . . when establishing stick envelope.

(a) For helicopters the vertical distance from the cyclic reference point to the neutral seat reference point shall not exceed 12 inches to permit supporting the forearm against the leg.

5.1.1.2 Control wheel type - The height of the handgrip reference point above the neutral seat reference point shall be based upon the specified wheel configuration and upon maintaining a 1.5 inch clearance . . . between the bottom surface of the wheel through its full forward, aft, and rotational travel and the leg of the crewmember of maximum specified percentile with the seat in the full up position and yaw control pedals in full aft adjustment. The maximum wheel throw envelope shall be based on Zone 1 reach as defined in . . . paragraph 4.5.1.2. The minimum clearance between wheel and structure shall be 1.5 inches as shown . . . while a minimum clearance of 0.5 inch shall be maintained between the crewmembers' hand and body.

5.1.2 Propulsion controls

5.1.2.1 Single throttle - The location of the forwardmost position of the throttle

Back to Annotated Bibliography

shall be based on Zone 1 reach as defined in . . . paragraph 4.5.1.2. The aft position shall be based on the aft structural clearance of the maximum specified arm . . . .

5.1.2.2 Multiple throttle - Locate the same as for single throttle, except the geometry of all throttles shall be based upon the forwardmost position of the throttle furthest from the crewman laterally.

5.1.3 Collective lever

5.1.4 Yaw control pedals - The yaw control shall consist of two pedals of the configuration conforming to MIL-B-8584. Differential braking as defined by MIL-B-8584 [***Brake System, Wheel, Aircraft, Design of***] shall be provided by these pedals. The most forward adjustment position of the yaw controls shall be based upon the specified percentile leg length seated with the seat full aft and full down, and yaw controls on, full forward throw, with the brake fully depressed . . . . The most aft adjustment position of the yaw controls shall be based on the minimum specified percentile leg length seated with seat full forward and full up and full forward yaw control throw, with the brake fully depressed . . . . Yaw control pedals forward and aft range requirements shall be based on the functional leg throw data . . . . These requirements have been obtained for various seat positions with respect to a horizontal reference line (referred to as the heel reference line in PMTC Report, TIP-75-1) which is located 4.75 inches below the brake fulcrum point on the yaw controls (shown in Figure 2) and parallel to the horizontal vision line. A minimum clearance . . . of 1.5 inches above and 0.75 inches on either side of the pedal shall be maintained over the maximum specified percentile foot in a flight boot, throughout the full pedal travel. Throughout the range of yaw control adjustment and travel, the distance from the brake fulcrum to the nearest point on the crewstation floor shall be between 4.75 to 6.0 inches. Pedal length shall be the minimum required to satisfy braking requirements. With normal braking procedures, a 1.5 inch clearance between maximum size footwear and all adjacent instruments and structure shall be maintained . . . .

5.2 Displays

5.2.1 Lower surface consoles

5.2.2 Overhead consoles

5.2.3 Instrument panel - The instrument panel shall be located so as to provide a 1.5 inch clearance with the crewmembers' legs through the full range of leg movement . . . . On aircraft equipped with ejection seats, clearance shall be provided as shown in Figure 3. The panel shall provide the most normal viewing angle as practicable from the design eye position.

5.3 Seats - Aircrew seats conforming to the requirement of MIL-A-81815 [***Aircrew, Automated Escape System***], MIL-S-58095 [***Seat System, Crashworthy, Non-Ejection, Aircrew, General Specifications for***], MIL-S-81771 [***Seat, Adjustable, Aircraft, General Specification for***], and MIL-A-23121 [***Aircrew Environmental Escape and Cockpit Capsule System, General Specifications for***] shall provide the body positioning capability in accordance with the requirements specified herein.

6. MULTI-CREW STATION REQUIREMENTS

6.1 Tandem arrangement

6.1.1 Dual control -

(a) The single crew station geometry specified herein shall be duplicated for both crew stations unless otherwise specified by the procuring activity.

(b) Minimum fore and aft spacing between the crew stations shall be based on the minimum space required to accommodate the largest specified percentile crew member in each station while maintaining full control movements in both stations.

(c) The external vision for the forward and aft crew stations shall conform to MIL-STD-850.

6.1.2 Single control

6.2 Side-by-side arrangement

6.2.1 Dual control

(a) . . .

(b) Both crew positions shall be on the same level, unless otherwise specified. The lateral centerline spacing between crewmembers shall be a minimum of 26 inches and a maximum of 42 inches centerline to centerline for configurations with displays and controls common for both crewmembers. In rotary wing aircraft, the dimensions shall be a minimum of 26 inches and a maximum of 50 inches.

(c) Minimum lateral spacing shall be based upon minimum clearances between seat and structure or controls, and providing for no interference between crewmembers in performance of their flight tasks. The absolute minimum clearance between seats shall be 3 inches for non-ejection seats and 6 inches for ejection seats.

6.2.2 Single control - The flight control station geometry shall conform to the requirements herein and the other crew station geometry shall be configured for the specific aircraft mission.

7. NOTES

7.1 International interest

Back to Annotated Bibliography

Back to Annotated Bibliography

HUMAN BODY SIZE IN MILITARY AIRCRAFT AND PERSONAL EQUIPMENT

Francis E. Randall, Albert Damon, Robert S. Benton, and Donald I. Patt

AAF Technical Report No. 5501
Army Air Force
Air Materiel Command
Wright Field, Dayton, OH

10 June 1946

THE FOLLOWING ARE EXTRACTS.

SUMMARY:

"The functional aircraft must include its crew members. The flight potential of an aircraft can never exceed that of its crew members.

The present report deals with the relation of human body size to military aircraft and equipment. It contains the necessary data and instructional material to guide the designers of aircraft and associated flying equipment in the proper use of anthropometry, as it applies to AAF flying personnel. The functional man is fully described and the spatial requirements of his personal equipment are evaluated. Finally, the complete functional man is considered in his air crew position and as an integral part of the functional aircraft."

CHAPTER I - INTRODUCTION

"From the time the Wright brothers constructed their first airplane and flew it in 1903, the problem of adapting aircraft design to all the high technical requirements has met with unlimited attention. The requirements established by air flow characteristics, by air speeds, altitudes, temperatures, as well as the other mechanical problems which must be considered, such as the size ***of*** instruments, the stress of metals and other materials, have occupied almost to the fullest extent the attention of designers. With all due credit to the highly developed techniques which have been, and continue to be, applied to aircraft design, it is the purpose of the data presented on the following pages to try to aid in some degree the consideration of the designers in so far as the problems presented by human body size are concerned.

The concept of writing specifications on the man, which are as definite and demanding as any of those written on any type of material or equipment otherwise used in an airplane, has been attempted many times. It is certainly realized by any sincere designer that his potential airplane is not really complete until a man actually enters the plane and engages it in flight. It should be quite apparent that the operational behaviour of an airplane of unlimited potentialities is actually no better than the behaviour characteristics imposed upon it by the physiological capabilities of the human being involved. It has been the experience of the Army Air Forces during the progress of World War II that many problems relating to inefficiencies on the part of the flight personnel could have been eliminated had the designers of the planes been fully cognizant of some of the implications of human biology.

The data discussed later in this report are not presented in an effort to try to sell engineers on the idea that an airplane should be considered only from the standpoint of the human being, but rather that it should be considered as a functional unit combining both the aircraft and the human being under flight conditions. Therefore, it shall be constantly stated that these data are actually specifications and should receive as much attention as do those specifications relating to any other type of equipment.

One ***of*** the most interesting historical facts which has been brought to our attention has been the one of the condition in which the original flights were made. It will be recalled that these occurred with the pilot flying in what is termed the "prone" position and that our so-called conventional positions for the pilot now are actually the opposite, historically speaking. It would be interesting to speculate upon what progress aircraft would have made had the man been retained in his original prone status. Recent developments along this line which are usually considered radical, are actually a continuation ***of*** stories which the Wright brothers initiated, and we shall gain much information from flight tests which will be conducted on this position. Aerodynamically it is probably the best possible position in which the pilot can be installed in the aircraft because it permits the minimum thickness to be designed into the plane.

The first Army Air Forces attempt made to write a specification on the human being for use in aircraft was made about 1926, at which time Mr. Hugh Lippman constructed from meager data available a profile scale manikin which was used up to the time Captain (now Colonel) Harry G.

Armstrong prepared data derived from Randolph Field Aviation Cadets in such a manner as to illustrate that the Medical Corps and Air Corps physical size requirements were permitting acceptance of unnecessarily large individuals. At that time 6'7" and 250 pounds were acceptable. It was Armstrong's recommendation that these maximum limits be dropped to 6'4" and 200 pounds, and that almost as large a population would be obtained inasmuch as only a very small percentage of individuals falls above that value. It was also Armstrong's recommendation that fighter pilot sizes should be limited to 70" and 180 pounds, in order to gain as much performance as possible from fighter aircraft. This recommendation was accepted with certain reservations. For some period the fighter stature was held at 5'8" instead of the 5'10" recommended by Armstrong. This acceptance limit was adequate so long as peacetime requirements remained. However, with the advent of stepped-up military requirements in 1942, such a large number of men was required for pilot training that a 5'8" limit actually prevented full use of the potentials available. The greatest defect which appeared in this regard was due to the fact that the fighter-type aircraft available for military use at that time had been designed around the 5'8" average and, without due regard to this fact, the limits were stepped up to 5'10" again, irrespective of the abilities ***of*** the planes to accommodate these higher statures.

This situation would not have been too disastrous had the original design requirements remained in use. That is to say, that these aircraft had been designed to fly not more than 3 and 1/2 hours. However, it is easily recognizable that this situation did not remain, inasmuch as long range requirements entered in and wing tanks and belly tanks were added to these same aircraft to enable them to fly as much as seven to eleven hours. There could be no modifications of the cockpit to provide any comfortable conditions for the pilots of the large stature who would be trained to fly these planes. This situation subsequently developed into probably the most difficult problem from the human operational standpoint encountered in World War II. The fact that high priorities were assigned by Army Air Force Headquarters to every aspect of problems relating to the alleviation of fatigue of pilots is alone sufficient proof of its importance. Therefore, from the standpoint ***of*** operational requirements of the Army Air Forces, every preliminary design should incorporate to the fullest extent the consideration of the size of human beings, and, also, that every consideration should be made in a cockpit design to provide for every eventuality possible regarding the possible ranges of this aircraft. It will, therefore, be the purpose of all the discussions to follow to try to instruct the designers in the best known way to provide adequate functional and comfort installations in cockpit designs in such a manner that the aircraft will not be limited in its performance by the poor functioning of the human beings involved."

CHAPTER I I - THE FUNCTIONAL MAN

"The concept of the functional man is of such a nature as to complicate the entire picture in the design of aircraft. Historically, the man has been regarded too frequently as a constant and a more or less static piece of equipment. This is probably the factor which has contributed more than anything else to the failures in operational aircraft so far as the performance of the human being is concerned. It will be well to keep in mind the general problems presented in this concept.

. . . the "man" is not of a single size. . . . In fighter air craft the stature is allowed to vary from 5'4" to at least 6', and in some cases actually exceeds this value. The weight may vary from 120 to 180 pounds. In bombardment type aircraft commissioned officers may vary from 5' to 6'4", and in weight from 120 to 200 pounds. . . .

In addition, functionally speaking, this "man" may vary in the amounts of equipment worn, from very light clothing, including a small quick-attachable parachute, to the large bulky total of the equipment consisting of heavy flying clothing, emergency survival vests, life rafts, flak suits. and heavy parachutes. . . . This total amount of equipment may in certain conditions add as much as 117 pounds of weight to the nude weight of the individual. . . .

Next, and of no less importance, is the factor involved in the space requirements of the aircrew as they go through the motions of performing their duties. Minimum dimensions will avail us nothing if they must be greatly exceeded in the operational requirements of the individual. . . .

. . . In addition to the engineering requirements which are imposed by the human being and which can be adequately met if early consideration is given to them, there is a strong indication that the actual work of the flight surgeons and the Medical Corps in general would be reduced considerably if the man received a greater amount of attention.

Let us begin then with the nude man in the more or less static sense of the word and develop him throughout the whole range of requirements which have been established for his use in aircraft. . . . This is the man sent to the aircraft for installation from a training center. He already has certain inherent characteristics in him which can in no way whatsoever be modified. . . . He must be taken as he stands upon "delivery" and installed effectively in an airplane. It is the responsibility of the designer and the

Back to Annotated Bibliography

manufacturer to have provided tolerances in the plane in order to insure efficient installation of the equipment.

We can well imagine the difficulties which are encountered in some subassemblies when one item has been delivered with certain fixtures which are over-sized compared to their original requirements. It takes little time in the ordinary processes to see that this matter is corrected, yet it has been common procedure to ignore equally glaring inadequacies and tolerances in con ditions involving the man. . . ."

CHAPTER III - PERSONAL EQUIPMENT

HELMET SIZING
OXYGEN MASKS
FLYING CLOTHING
- Coverall Type
- Two-Piece Type
- Electrically-Heated Suits
- Gloves
- Footgear
- Clothing, Female
- Flak Clothing
- Parachutes

CHAPTER IV - AIRCREW POSITIONING

PRINCIPLES OF COCKPIT SEATING
- Stick Type Control
- The Center of Gravity of the Seated Fighter Pilot
- Body Size Considerations for Ejection Seats

"In fighter-type aircraft, and possibly in certain type of heavier planes, it must be kept in mind that speeds in excess of three hundred and fifty miles per hour render emergency escape very dangerous, and consideration must be given to the provision of ejection of the man under some form of power other than his own. The Germans attained this by providing a charge of powder which would eject both the seat and the man, following which the man could release the seat and proceed through the ordinary parachute maneuvers.

Attempts have been made to modify existing aircraft in such a manner as to incorporate installation of an ejection-type seat, but it has been found extreme ly difficult to gain fully satisfactory means. Therefore, the designer should make every effort to incorporate the full installation for his aircraft before the mock-up stage is reached.

The primary requisite for the consideration of the human body as it relates to the cockpit is the degree of assurance which can be guaranteed for the positioning of the body in the seat. A definite example will serve to demonstrate this point.

In the type of seat figured, it will be seen that the toes of the feet serve to define the maximum [fore and aft dimensional] requirement. The position of the instep in relation to the hip will also define the extent of radius through which the thigh must go to attain a fixed position. It may be that lower dimensional requirements might be attained if pans rather than stirrups could be provided, perhaps holding the toes down and back from their present position. However, the degree to which this could be attained will be determined by the clearances offered when the seat is at full-down adjustment. In addition, if there is a possibility that the feet might slip off the stirrups. the thighs might very well be describing a radius as the knees pass the windshield, and thereby present a maximum dimensional requirement of about 28 inches, even with the feet falling farther back.

There are certain aerodynamic requirements which must be considered if deviations from the 13° angle used by the Germans on this particular seat are indicated. They went to great length to design the head rest in such a manner as to protect the face in the slip-stream, and . . . that the relative position of [the top of] this head rest will change from a position somewhat in line with the top of the head of a tall man, down to a position about level with his ears if the angle of ejection is dropped back to 30° from the vertical. If the ejection angle should be this great, the head rest must be elongated and this elongation may require such an increase in the sitting position of the seat structure, at 13°, that it will be too long to fit under the canopy of the aircraft.

If ejection at angles in excess of 13° is considered, the man must be moved from the 13° back to the ejection angle, requiring time. If he is not moved back, but stays at the 13°[stet] while ejection is occurring, then the difference in angles may be sufficient to apply transverse "g" to the man's head and produce instability in amounts great enough to break the neck. A small difference may be inconsequential, but extreme care should be taken to insure this before full installation is considered.

Frontal areas must also be considered in relation to the angles of ejection and the trajectories which must be maintained to clear the rudder. . . . The total frontal area drops from 5.0 sq. ft. at 13° down to 4.5 sq. ft. at 30°, so may offer some advantage to compensate for the lower trajectory inherent in ejection at the 30° angle.

Finally, in consideration of frontal areas, it is absolutely imperative that no less than 25 inches be provided laterally for clearances at the shoulders and elbows."

Back to Top of Page

Back to Annotated Bibliography

Back to Annotated Bibliography

ANTHROPOMETRIC ACCOMMODATION IN USAF TRAINING AIRCRAFT: A COMPARISON OF OPERATIONAL REQUIREMENTS

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ABSTRACT: "Pilot trainees much smaller and slightly larger than ever before will be accommodated in the Department of Defense's newest trainer, but will they be able to fly the advanced trainers, such as the T-38 and the T-1, that they will encounter later in their training?

To determine an aircraft's body size pass/fail criteria, we first establish its "operational requirements," the tasks a pilot must be able to carry out to safely and effectively fly the aircraft.

This paper describes the process of defining operational requirements. It will also compare the operational requirements of all USAF trainers and examine the difference in trainer requirements."

INTRODUCTION: "The Air Force Research Laboratory is determining body size accommodation pass/fail criteria for United States Air Force (USAF) inventory aircraft. The first phase of this project focuses on trainers, particularly on the new training aircraft that will be used as the primary trainer for both the USAF and the Navy. The new trainer will accommodate at least 95% of the potential pilot population. This trainer was designed to accommodate sizes from 58" in stature and 31" sitting height, up to 77" in stature and a 40" sitting height (Zehner, 1996). This high level of accommodation contrasts sharply with other aircraft in the USAF inventory, which accommodates a more limited body size range.

When finishing Undergraduate Pilot Training (UPT), pilots have two choices: continue training in the T-38 Fighter/Bomber track or the T-1 Tanker/Transport track.

Pilot trainees will be accommodated in the new trainer, but will they be able to fly the advanced trainers, such as eh T-38 and the T-1? Can the USAF expand (if even slightly) the body size standard for the T-38 and the T-1?

To determine an aircraft's body size pass/fail criteria, we first establish its "operational requirements," the tasks a pilot must be able to carry out to safely fly the aircraft. As the basis for the pass/fail criteria, the operational requirements must be as thorough and correct as possible. Old military standards (such as the [Mil Std]1333) listed numerous controls that had to be accessible by pilots under emergency or restrained conditions. These requirements are too restrictive and were developed before most of the aircraft were ever flown. We developed a more accurate procedure for defining operational requirements based on pilots' experiences with the specific aircraft. Our methods for operational requirements include:

a) Review of a particular aircraft's technical order[, the "dash one"] . . ..
b) Simulator flights.
c) Actual aircraft sorties. [Study flights]
d) Pilot interviews.
e) Pilot questionnaires.

The next step involves static anthropometric measurements of subjects in [sic] the aircraft. The combination of these two steps indicates the body size necessary for a pilot to be able to perform the operational requirements, and therefore be accommodated in the aircraft (Kennedy & Zehner, 1995)."

DETERMINING OPERATIONAL REQUIREMENTS: ". . . The general list of requirements for each aircraft includes: vision requirements (what a pilot needs to see to fly and land this aircraft.); reach requirements (what controls are necessary to reach in the aircraft in a worse case "emergency" scenario); clearance for legs with the yoke/stick envelope."

CONCLUSIONS: ". . . Each training aircraft has a uniquely defined mission, as do the operational aircraft in the USAF inventory. It is important that each aircraft be studied in all phases of this research project. The operational requirements for each aircraft are unique and equally important."

Back to Annotated Bibliography

Back to ANNOTATED BIBLIOGRAPHY

EFFECTS OF PRESSURE SUIT AND RACE ON

FUNCTIONAL REACH, STATIC AND DYNAMIC STRENGTH

A Thesis

Submitted to the Graduate Faculty of the
Louisiana Sate University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science in Industrial Engineering

in

The Department of Industrial and Manufacturing Systems Engineering

b y

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B.E. (Mechanical Engineering)
Madras University, India, 2000
December, 2004

pp. i - xi and 1 - 109

ABSTRACT

"In the design of any manual workspace, it is important for the designer to have access to data that can illustrate reach capabilities under real-time work situation. Wearing bulky clothing (pressure suit) and protective restraints (seat or shoulder harness belts) is often mandatory in high acceleration work environments. Clothing and personal equipment worn can influence the functional reach and strength values since they add to the

body size. The present study was conducted to investigate the effect of wearing a VKK-6M pressure suit on functional reach limitations and strength values.

The technology of incorporating body dimensions into cockpit design primarily evolved in western countries and therefore the only datasets available is of Caucasians. When designing equipment for populations other than westerners, western anthropometric data is inappropriate. In this thesis a representative sample of Caucasian and Asian Indian population are chosen and their reach envelopes are compared. Subjects reach and strength data are collected with and without-suit and analyzed to see the effect of pressure suit on reach and strength.

The study concludes that wearing pressure suit reduces the average reach significantly (at ***a*** = 0.05). The 5th percentile Asian Indian and Caucasian reach envelopes are derived for placement of critical cockpit controls. Race-reach study showed a significant difference in shoulder breadth of Caucasians and Asian Indians (at ***a*** = 0.05), but no apparent relationship between bideltoid breadth and thumb tip reach was found. The study on significance of wearing pressure suit on strengths (at ***a*** = 0.05) concluded, suit does not affect static or dynamic strength.

INTRODUCTION

[The] Aviation industry, in achieving its aim of optimizing use of space and weight for an aircraft, has the utmost need for applying anthropometric data into design. Functional anthropometric data can be used in improving pilot's performance by minimizing stretching and over extension from the seated position. Care should be taken to incorporate anthropometric measurements fro a wide variety of users while in the design stage of the equipment. This allows not only an average individual but also the extremes of a population, being able to operate the equipment equally effectively. It is important to realize that there is no average individual and designing for the average user is often seen as bad design, as it only accommodates 50% of a population (Pulat, 1997). An ideal cockpit design controls should be within the reach of the smallest operator while on the other hand, the cockpit should be able to accommodate 95 percentile of headroom for the tallest operator. In some situations, the dimensions of a workspace may become a limiting factor that may restrict its usage. For the aviation industry, this limitation on workspace eliminates a pool of potential recruits based on their stature and eye height, although they have appropriate anthropometric characteristics.

If population differences are not been accounted during the design process, then the selection of users is required. The selection criteria are based on one of the two methods. The first is the trial and error, in which all the users who are unable to perform certain tasks at some point during the training are eliminated. The second approach relies on use of available data sources from various studies on reach demands of users performing different operational tasks (Usher and Aghazadeh, 1988). A person with 5% stature doesn't mean the reach of that person falls in the 5% of population. Hence, before designing a workplace, designers must look into anthropometric and reach data of the people from different age, gender, race and work groups. This process of collecting data deals with physical measurements of a person's size and form for developing engineering drawings and preparing mock-ups. The data thus obtained accounts for the selection criteria based on the reach, clearance and visibility requirements for that particular workplace.

While designing an experimental setup, it is important to simulate the experimental conditions most likely prevailing in the work situations. For example, while studying a pilot flying a high altitude aircraft, an Anti-G suit (Anti Gravity suit) which protects him during rapid accelerations and fast turns, has to be considered. Most of the design data collected on functional reach is gathered under light clothing and under earth's gravitational field which does not affect the reach measurement. The length of functional arm reach is dependent on the kind of task or operation to be performed. As shown in Table 1.1, sustained high-G accelerations can significantly influence the functional reach capability or range of motion of an articulation.

Table 1.1: Influence of high-G accelerations on reach capability

Acceleration Level	Reach Motion Restricted To
Up to 4 G	Arm
4 to 5 G	Forearm
5 to 8 G	Hand
8 to 10 G	Fingers

Source: Webb Associates (1978)

Factors affecting reach can broadly be classified as functional requirement, protective equipment worn and race. Functional requirements include wearing protective restraints (e.g. seat or shoulder harness belts) that are often required in vehicles or other work environments where unexpected acceleration or deceleration may occur. Restraints can significantly alter reach measurements. Thus, use of anthropometric datasets developed using similar restraint systems is required. Sustained high-G accelerations can significantly influence the reach capability or range of motion of an articulation (Table 1.1: Webb Associates, 1978). Normal reach tasks that people perform in day to day activity require coordination of multiple body segment rather than maximum effort. A task requiring only a finger grip pressure (push button) can be located at the outer limits of the arm reach, as defined by the finger tip reach would be the maximum functional reach attainable. Where as, other tasks that may include rotation of a control knob between thumb and forefinger which would result in reduction of functional reach. Tasks like full hand grip of a control level would reduce maximum functional reach further. Jobs where precision or continuous operation of an equipment or tool is required, the controls should be located further close to the operator (Pulat, 1997).

When designing reachable controls, one should consider any potential restraint caused by the persons clothing. Clothing and personal equipment worn on the body can influence functional reach measurements significantly. The effect is mostly a decrease in reach, but this decrease has to be considered if clothing or equipment is bulky and cumbersome. This empathize [emphasizes ?] the point that most design data collected on functional reach is gathered under light clothing and under earth's gravitational field which does not affect the reach measurement. One of the neglected areas in equipment and workplace design is optimization of the matching of equipment with the specific characteristics of the operators and users (Lamey, Aghazadeh and Nye, 1991). Hence when designing for a set of users, the anthropometric characteristics of the users has to be considered. Caucasian population generally has wide shoulders and large stature than Asian Indians. When designing equipment for Asian Indians, western anthropometric data is inappropriate and equipments designed considering the anthropometry of western people would not be suitable (Viren et al., 2002).

Back to ANNOTATED BIBLIOGRAPHY

Back to Annotated Bibliography

PREDICTION OF ANTHROPOMETRIC ACCOMMODATION IN AIRCRAFT COCKPITS

AFRL-HE-WP-TR-2001-0137

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NOTE: The following are selected extracts from or annotations regarding the subject publication.

PREFACE

"This project was presented as a dissertation to Ohio State University. However, it was a group effort. A number of people helped in various stages of its' completion. Ken Kennedy, who has been my friend and mentor at AFRL, helped develop the aircraft measurement methods, and assisted me in gathering the T-38 data. Jeff Hudson also helped gather and organize data, and was one of the team that developed the Multivariate Models program discussed in Chapter 5. Richard Meindl also helped develop that technique. Joyce Robinson has helped me assemble databases for many years, and continued her kind and patient support on this project. Finally, Patrick Files did the initial editing of the manuscript and Tina Brill helped with formatting.

ABSTRACT

Designing aircraft cockpits to accommodate to wide range of body sizes existing in the US population has always been a difficult problem for Crewstation Engineers. The approach taken in the design of military aircraft has been to restrict the range of body sizes allowed into flight training, and then to develop standards and specifications to ensure that the majority of

Back to Annotated Bibliography

the pilots are accommodated. Accommodation in this instance is defined as the ability to:

- Adequately see, reach, and actuate controls;
- Have external visual fields so the pilot can see to land, clear for other aircraft, and perform a wide range of missions (ground support/attack or air-to-air combat); and
- Finally, if problems arise, be able to escape safely. Each of these areas is directly affected by the body size of the pilot. The USAF is considering relaxing body size entrance requirements so that smaller and larger people could become pilots. Existing accommodation problems will become much worse.

This dissertation describes a methodology for correcting this problem and demonstrates it by predicting pilot fit and performance in the USAF T-38A aircraft based on anthropometric data. The methods described can be applied to a variety of design applications where fitting the human operator into a system is a major concern. A systematic approach is described which includes: defining the user population, setting functional requirements that operators must be able to perform, testing the ability of the user population to perform the functional requirements, and developing predictive equations for selecting the future users of the system.

To each of these people I offer my thanks and a cold one the day this dissertation is accepted.

CHAPTER 1

INTRODUCTION

Two recent policy decisions by the U.S. Government have created an immediate need for anthropometric data and accommodation performance data for people of extreme body size in USAF cockpits. In addition, the ability to predict accommodation levels based on an individual's anthropometric data has become very important.

The first of these policy changes occurred when the Secretary of Defense (Aspin Memorandum, Apr 93) and Congress expressed the need for the services to expand opportunities for military women by opening career paths that had previously been restricted to males. This has resulted in a small number of women being trained in and assigned to Fighter Aircraft.

This policy change has created a problem. All existing USAF aircraft were designed to accommodate a male pilot population with a minimum Stature of 64 inches and a minimum Sitting Height of 34 inches. Traditional cockpit design practice was to perform anthropometric surveys on the existing pilot population and to use summary statistics from those surveys as design requirements for aircraft. On the small end of the design range, 5th percentile male pilot values for critical body dimensions were used as minimum design points. Those members of the population smaller than the minimum design values sometimes had to stretch in order to be accommodated. Unfortunately, of those females meeting the minimum [pilot training] entry requirements (~45% of military women) a very large percentage fall below 5th percentile male values. On the large end, 95th percentile male values were used as design limits. Larger pilots may have clearance and escape problems.

Previous experience has shown that assignment of individuals to aircraft in which: they are too small to adequately reach switches and controls, see over the nose to land, achieve full rudder throw with brakes, move the control stick to the full range of it's capability, or have escape clearance problems, are at increased risk for mishap.

The second policy change occurred when Congress and the Department of Defense directed the Joint Primary Air Training System (JPATS) to accommodate a much wider range of body sizes than are currently allowed to enter flight training. The JPATS aircraft will be the primary trainer for both the USAF and Navy for the next 30 or so years. This change in design philosophy was necessary because body size restrictions for becoming a pilot prevent the majority of women from entering flight training. While smaller males will also benefit from a change in design philosophy, the largest impact will be felt in the female military population. Unfortunately, this policy change has the potential to dramatically increase body size fit problems.

The JPATS aircraft was designed to accommodate 97% of the "general female military population." While this group must meet all of the other criteria for entry into flight training, it is not subjected to the 34 inch Sitting Height and 64 inch Stature limitation. It appears that individuals of 31 inches in Sitting Height and 58 inches in Stature will be able to fly the JPATS aircraft. For that reason, the US Air Force is now considering expansion of the body size entrance requirements (AFI 48-123) for Undergraduate Pilot Training (UPT). This change is intended to provide essentially equal opportunity for both genders for entry into flight training.

At the same time, larger pilots are also being allowed to enter flight training. The current maximum size for pilots is 40 inches in Sitting Height, and 77 inches in Stature. While the large body size restriction has been in place for several years, some individuals have had the size requirements waived, and been permitted to become USAF pilots.

While it will be possible for pilots of extreme body size to operate the JPATS aircraft when it is completed, these pilots must continue training in either the T-1 (Tanker/Transport trainer) or the T-38 (Fighter/Bomber trainer). After that training they will be assigned to one of the other 40 or so types of aircraft in the USAF fleet. Our previous experiences in evaluating accommodation in some of these aircraft indicated pilots smaller than the 5th percentile or larger than the 95th percentile design requirements could have difficulty operating them. Therefore, a much larger percentage of the population will be at even greater risk if entrance requirements are relaxed.

While currently only a few accident investigations have reported body size as a cause of the mishap, we appear to be very near the limits of current aircraft accommodation. A change to pilot entrance requirements could create a very dangerous situation.

This research project focuses on the T-38 aircraft. This aircraft was selected since it is the next step (after JPATS) in flight training for pilots headed to the Fighter/Bomber track of Specialized Undergraduate Pilot Training. Five questions related to accommodation are addressed in this research.

Anthropometric Samples

1) What are the anthropometric profiles of the ***current*** male and female pilot populations, and, the ***potential*** pilot populations if size restrictions are removed?

Chapter 2 addresses sample construction. That is, the creation of several anthropometric datasets. These datasets must be representative of current male and female pilots as well as those individuals who could be pilots if anthropometric restrictions for entry into flight training were not in place. The USAF has not performed an anthropometric survey on female members since 1968 or male pilots since 1967. Because those surveys are now outdated, a sample representative of the current population is needed.

To create current datasets [representative of USAF flying populations], the 1988 U.S. Army Anthropometric Survey (Gordon et al, 1989) 'datapool' was used. In the Army survey, researchers used a stratified sampling

Back to Annotated Bibliography

strategy for age categories and over-represented specific ethnic/racial groups. This was done so that in the future if there are demographic shifts in the Army population, restructured subsets could be constructed which keep the "working database" current. The datapool includes over 200 measurements on more than 5,000 subjects. Using a similar philosophy, . . . [the] Army datapool is restructured to match USAF demographic profiles.

This was accomplished by selecting subjects from the Army datapool representative of the age, race, and height/weight profiles of the USAF population. In doing so, the significance of each of these parameters on anthropometric dimensions was studied. Age was examined since growth is not always complete in the military population, and because pilots must be college graduates. This cuts the lower end of the pilot age distribution off at 21 years. Younger subjects may need to be excluded from the dataset due to incomplete growth. Age categories of 5 years were compared to check for secular and growth differences within the datapool. Similar statistical approaches were then applied to examine ethnic differences in anthropometric distributions.

The results of these tests indicate that it may be improper to combine African-American and European-American samples in the same dataset in the proportions existing in the current USAF pilot population (~85% European-American) because significant differences in body type may be hidden in the summary statistics. It may be necessary to separate these groups for statistical analysis because the accommodation problems each group encounters may be quite different.

Next, since Height and Weight restrictions for the Air Force are different from those of the Army, comparisons of their effect on the resulting samples are necessary. Weight differences obviously effect many well correlated anthropometric dimensions (such as Waist Circumference or Hip Depth). A key examination was to assure that all of these restrictions have not resulted in a violation of the multivariate normality assumption used in other analyses. Bimodal distributions may result from combining two very different samples.

Operational Requirements

2) What tasks must be performed in an aircraft to safely and effectively operate it?

Chapter 3 addresses the establishment of the "operational requirements" for the T-38. These requirements establish the pass/fail criteria which pilots must perform to safely operate that particular aircraft. While it is obvious that all controls must be reachable in an aircraft, which ones must be reached in an emergency condition? In an emergency, the inertial reel restraint system may lock, or, due to adverse G forces, the pilot may be pushed into a difficult position from which to reach a particular control. For these reasons, critical reaches as well as minimum visual fields (to see the landing zone, or other aircraft in a formation) were defined. This research was done at the Instructor Pilot Training School at Randolph Air Force Base, Texas. This school is a unique resource since it is where instructor pilots are trained. The entire syllabus of training maneuvers as well as student errors and emergency procedures for recovery from them are the focus of this training. A panel of Instructor Pilots and Safety Officers was assembled to discuss and define the operational requirements for the aircraft.

The areas defined are: minimum external visual field, the "critical controls list" (which controls need to be accessible during emergency situations where the pilot may have a locked inertial restraint system or be unable to reach a long distance), adequacy of rudder pedal and brake reach, the necessary range of stick/yoke mobility, and adequate clearance space for control operation and ejection.

Cockpit Mapping

3) By using "cockpit mapping" techniques, can the performance of an individual in a particular cockpit be accurately predicted from anthropometric measurements, and, can these data be used to predict accommodation percentages for the population?

Chapter 4 describes the anthropometric evaluation used to determine which body sizes are able to meet the minimum accommodation criteria once the operational requirements set has been defined. Cockpit Mapping is the technique used to make measurements on a sample of subjects performing the operational requirements in a crewstation. Regression equations based on sample data are then used to predict performance levels for the population. The methods which will be used in this research require at least 20 test subjects representing as well as possible the extremes of body size within the potential user population. Samples of roughly this size were decided upon based on previous experience with these types of data. Typically, some data editing is required. If fewer than 20 subjects are used it becomes difficult to determine which subject data should be considered outliers.

When combined with the critical tasks list discussed earlier, these data

Back to Annotated Bibliography

can be used to assess the impact of accommodation limits on the entire population in terms of the percentage which can or cannot operate a particular aircraft safely. By applying the results of the performance evaluation in the cockpit to the datasets constructed to represent the pilot population, the severity of the non-accommodation problem that exists for the current pilot population as well as the severity of the problem if anthropometric entrance requirements are changed can be determined.

Future Design Criteria

4) What anthropometric statistical methods should be used to design future cockpits so that accommodation levels can be increased?

Chapter 5 presents the creation of new statistical techniques for the design of future aircraft. The traditional method of design uses lists of 5th and 95th percentile values for a large number of dimensions. Primarily body segment lengths. Nearly all current USAF aircraft were designed in this way. Unfortunately, this method leads to many errors and misconceptions since percentiles are not additive, and do not describe variability in body proportions. A multivariate technique for describing body size variability should be used to specify new aircraft design and existing aircraft modifications.

Using a Principal Components technique developed by Meindl, Hudson, and Zehner (1993), several small subsets of body types which exhibit the range of size and proportional variability existing in the larger population will be constructed. If the body size variability exhibited by these subsets is accommodated into a new aircraft design, then the target percentage of the total population will. This system is now in place for the design of new USAF aircraft.

Crewstation Design Methodology

5) Using the data information described above, what methodology should be used to incorporate anthropometric information into the design of an aircraft?

Chapter 6 describes a step-by-step methodology for using these data in the design of a cockpit. This methodology should be used in place of outdated Military Design Standards such as 1333 C (Aircrew Station Accommodation Criteria For Military Aircraft). This Standard uses the traditional "percentile man" philosophy as well as a number of seemingly arbitrary design rules in crewstation designs.

Back to Annotated Bibliography

While this dissertation addresses a very specific design problem, the methodologies described can be applied to a variety of design applications where fitting the human operator into a system is a major concern. A systematic approach which includes: defining the user population, setting functional requirements that operators must be able to perform, testing the ability of the user population to perform the functional requirements, and where necessary, developing new design criteria and methods that assure accommodation, is the key to a successful human engineering design.

CHAPTER 2

ANTHROPOMETRIC SAMPLES

Dataset Construction
Age Structure
Race/Ethnicity
Combined Samples
Body Fat
Conclusions

CHAPTER 3

OPERATIONAL REQUIREMENTS

T-38 Operational Requirements
External Vision Requirements

CHAPTER 4

COCKPIT MAPPING

... Each area of accommodation ... involve different numbers of subjects, depending on the amount of variability we expect. For example, overhead clearance is a straightforward measure in which clearance above the head is added to the subject's Sitting Height. When the seat is positioned full down, the subject's Sitting Height plus the clearance space sum to the largest Sitting Height that could be seated with no head clearance. Because there is little variability in results, just four large subjects are averaged to arrive at the final value. For reach to controls however, subject results vary a great deal because of harness fit, strength, motivation, and a number of anthropometric variables. We use a larger number of subjects and perform multiple regression analysis to produce the final results for this area of accommodation. ...

For the T-38, we examined seven aspects of anthropometric accommodation:

1. Overhead clearance.
2. Rudder pedal operation.
3. Internal and external visual field.
4. Static ejection clearances of the knee, leg, and torso with cockpit structures (i.e. canopy bow).
5. Operational leg clearances with the main instrument panel.
6. Operational leg clearance with the control stick motion envelope and pilot's ability to attain the full range of stick travel.
7. Hand reach to controls.

In aspects of accommodation (overhead clearance and vision, for example), anthropometric relationships are obvious and fairly simple. Overhead clearances are directly related to Sitting Height. Vision out of the aircraft, primarily ONV [Over the Nose Vision], is directly related to Sitting Eye Height. For these measures, multiple anthropometric dimensions are unnecessary to explain accommodation levels.

Other measures of accommodation are more complex. For example, operational clearance of the body with the control stick motion envelope can be restricted as the stick is pulled aft. There often is not room between the thighs to roll the aircraft ... . Limitation of stick motion is influenced by Sitting Eye Height, Thigh Circumference, and Buttock-Knee Length. The relationship between the upper seat positions (used by pilots with small Sitting Eye Height) and Thigh size seems to be the most critical. ... .

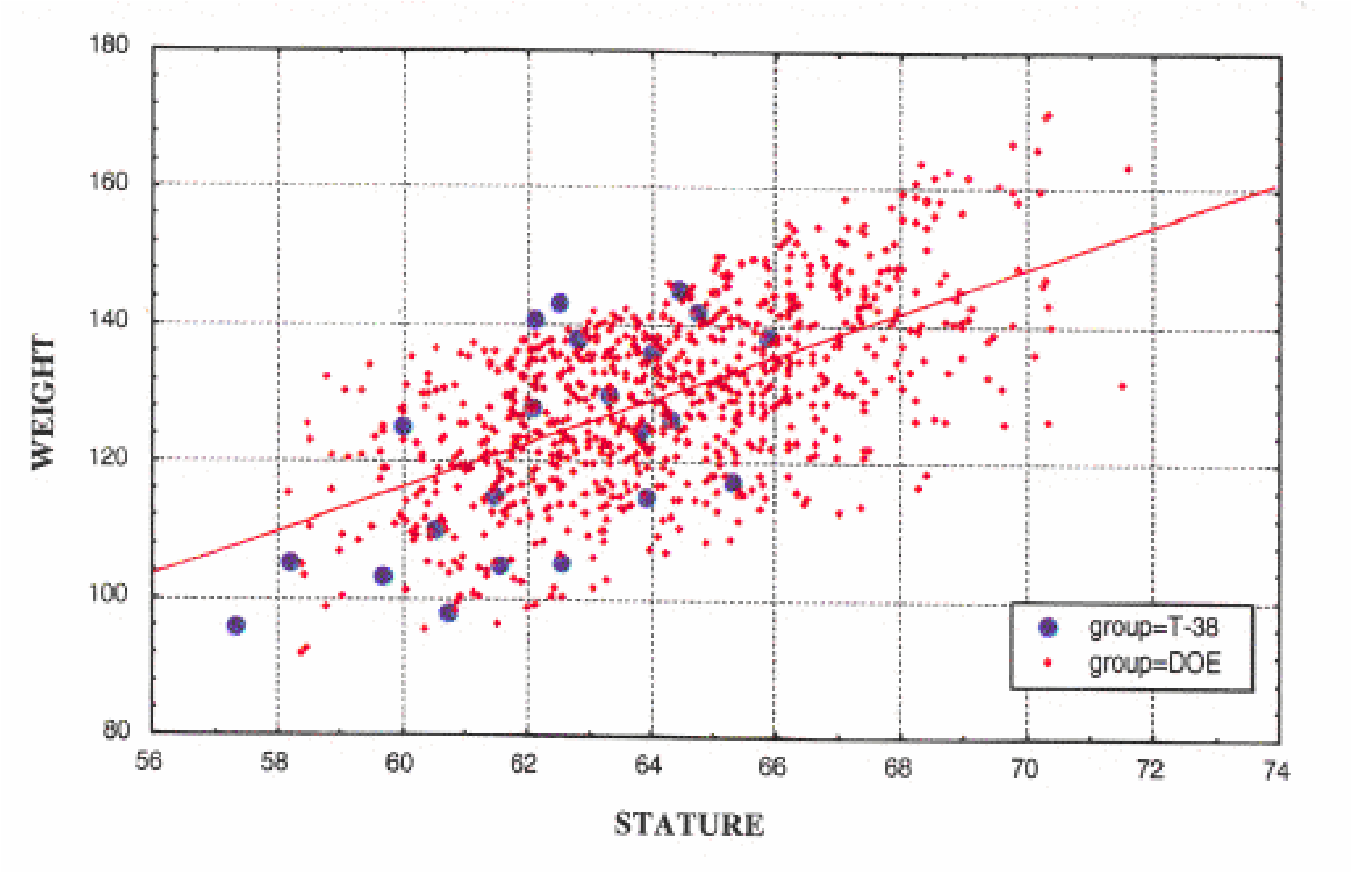
As the seat is raised to improve external vision, the range of stick travel side-to-side increases ... . large pilots will typically use the full-down seat position, and the control stick is usually so far above the thighs that interference does not occur. However, small pilots are typically adjusted as high in the seat as possible to gain adequate over-the-nose vision. In this seat position, the stick often contacts their thighs. Also, pilots with long legs are typically able to spread their knees apart, making a greater space available between the thighs for control stick movement. Small pilots may not be able to spread their legs while keeping their feet on the rudder pedals"

[There appears to be an oversight at this point in the outline of this report. Whereas, further on, there is a section entitled "LARGE PILOT

ACCOMMODATION," there is no corresponding and necessary section entitled "SMALL PILOT ACCOMMODATION." The latter title should logically appear at this point.]

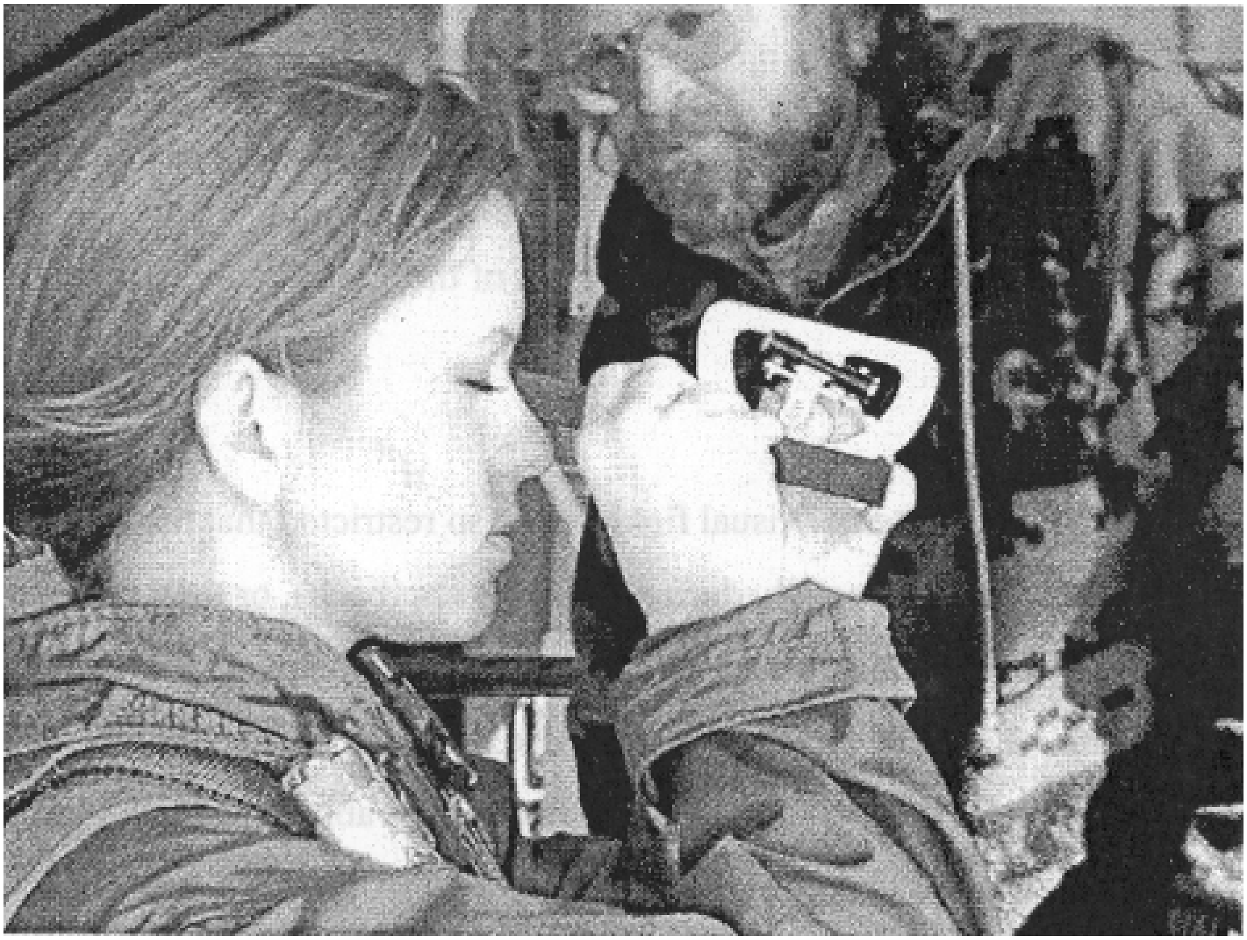
"Test Sample

The T-38 study of small pilot accommodation included 22 small test subjects, each equipped in the full complement of flight gear used by the Air Education and Training Command. Prior to measurement of their capabilities in the cockpit, each subject was measured on 18 traditional anthropometric dimensions ... . subjects were selected to represent the small size extremes of the population while retaining a reasonably normal distribution for each measure. [The Figure below] compares this sample ... to the USAF baseline population ... .



Forward Vision Over the Nose

... Vision ... was measured in two body postures in the front cockpit and one in the rear. In the front crewstation, ONV was measured with the subjects looking straight ahead over the nose of th4e aircraft. Subjects were instructed to keep their heads level (i.e. in the Frankfort Plane). An Abney Level ... [see below] was used to measure the depressed elevation angle to the ground over the nose of the aircraft." [Unfortunately, in this photograph, the Abney Level is not adjusted properly for final reading.]



Reach to Rudders

Like ONV, the ability to reach and actuate rudder pedals and brakes is affected by seat position. A pilot with very short legs may lower the seat to reach the rudder pedals. However, minimum vision levels (and, therefore, seat position) must be maintained throughout a mission. Under normal circumstances pilots should not be allowed to excessively sacrifice external vision. The pilot who is small in Sitting Height will have to adjust the seat [upward] to achieve adequate vision. This moves the pilot farther away from the rudder pedals. If the seat can be lowered and acceptable vision out of the aircraft maintained ..., the pilot can improve access to the rudder pedals.

[Many aircraft require] ... very little rudder input when in the air except during slow flight "gun jinks". These radical maneuvers are used when trying to avoid enemy fire. The pilot slams full rudder and quickly pushes the stick in various directions causing extreme movements of the aircraft. In addition to jinks, maneuvering on the ground and maintaining control in case of a blown tire on landing or takeoff require the ability to apply full rudder and brake simultaneously. Measurements were made in a number of seat positions so that the effect of seat movement could be calculated.

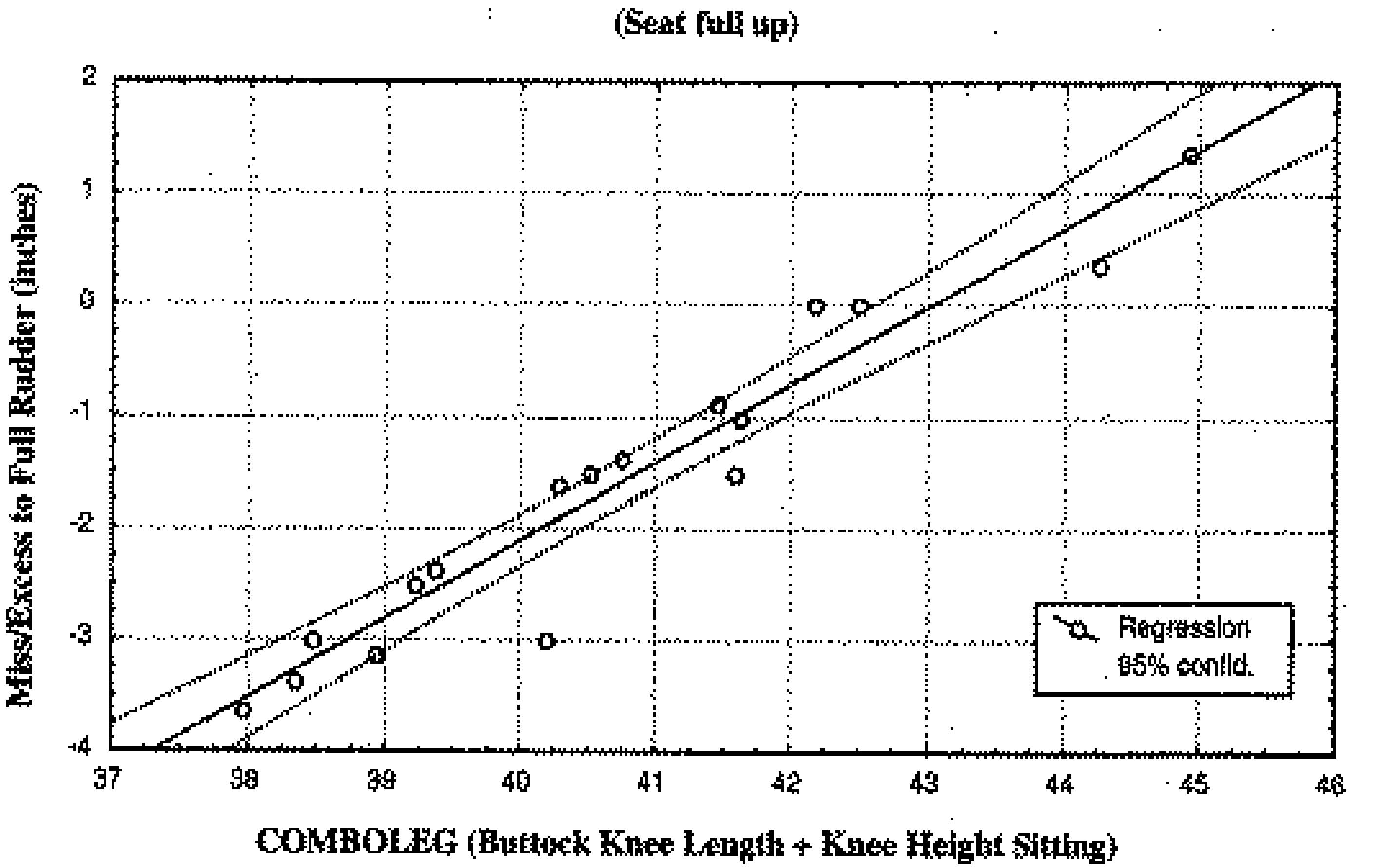
In this analysis subjects placed their feet on the rudders with their toes [forward part of the shoe sole] on the brakes. Full ruder throw was defined as full rudder input, and full brake, with the knee fully extended. The subject was tightly restrained and not allowed to slide forward in the seat. This method of positioning the foot is an intentionally conservative estimate: under certain flight conditions, a great deal of strength is required to hold the pedal in.

Measurement was made to the rudder adjust position where the subject could just actuate the rudder and brake. A regression equation was developed using rudder position and leg length, and the leg length equated to a full aft rudder adjustment was calculated.

The measurement which best identifies the minimum leg length required to reach full rudder throw is a combined leg length. Buttock-Knee Length and Knee Height Sitting are summed to arrive at a new [artificial] measure called Comboleg. For example, if a [minimal] 42-inch combined leg length [Comboleg] is required to obtain full rudder throw, it does not matter if an individual has a 23-inch Buttock-Knee Length and 19-ing Knee Height Sitting or a 22-inch Buttock-Knee Length and 20-inch Knee Height Sitting. Their reach to rudders ... will be the same. The correlation between Comboleg and rudder adjust position is .96.

The graph below shows miss distance (negative numbers) [and excess reach] to full rudder and brake for a variety of leg lengths. With the seat in the full-up position, a combination leg length [Comboleg] of 43 inches is required to attain full rudder and full brake simultaneously.

Back to Annotated Bibliography



Arm Reach to Controls

Pilots must be able to reach and operate hand controls to safely fly an aircraft. In normal flight conditions, with the inertial reels unlocked, this is not a difficult task. Under adverse-G conditions, however, when there is an inadvertent reel lockup, small pilots will have difficulty reaching many controls. ...

... Several factors other than body size affect reach capability in an aircraft cockpit. The design, fit, and adjustment of harnesses, personal protective equipment, survival gear, body strength, and motivation, all influence the act of reaching. Due to these factors, reach is the most difficult area of accommodation to accurately quantify. For that reason, we liberally edited outlier subjects. Subjects more than 2 standard errors away from the predicted values for a given reach ... were examined for possible deletion.

Reach to controls was based upon two harness configurations ...: first, with the reels locked and shoulders against the seat back. This is referred to as a Zone one restraint condition (MIL STD 1333C). Next, we evaluated reach in Zone two, where the reels are locked but shoulders are allowed to reach out toward the control with a maximum stretch. [Zone 2 is illustrated below.] ... In Zone 3 ... the harness is not locked and the subject is allowed to lean forward to gain access to controls. All subjects were able to reach all controls of interest in a Zone 3 harness configuration.

Figure 4.10. Zone 2 Reach Position.

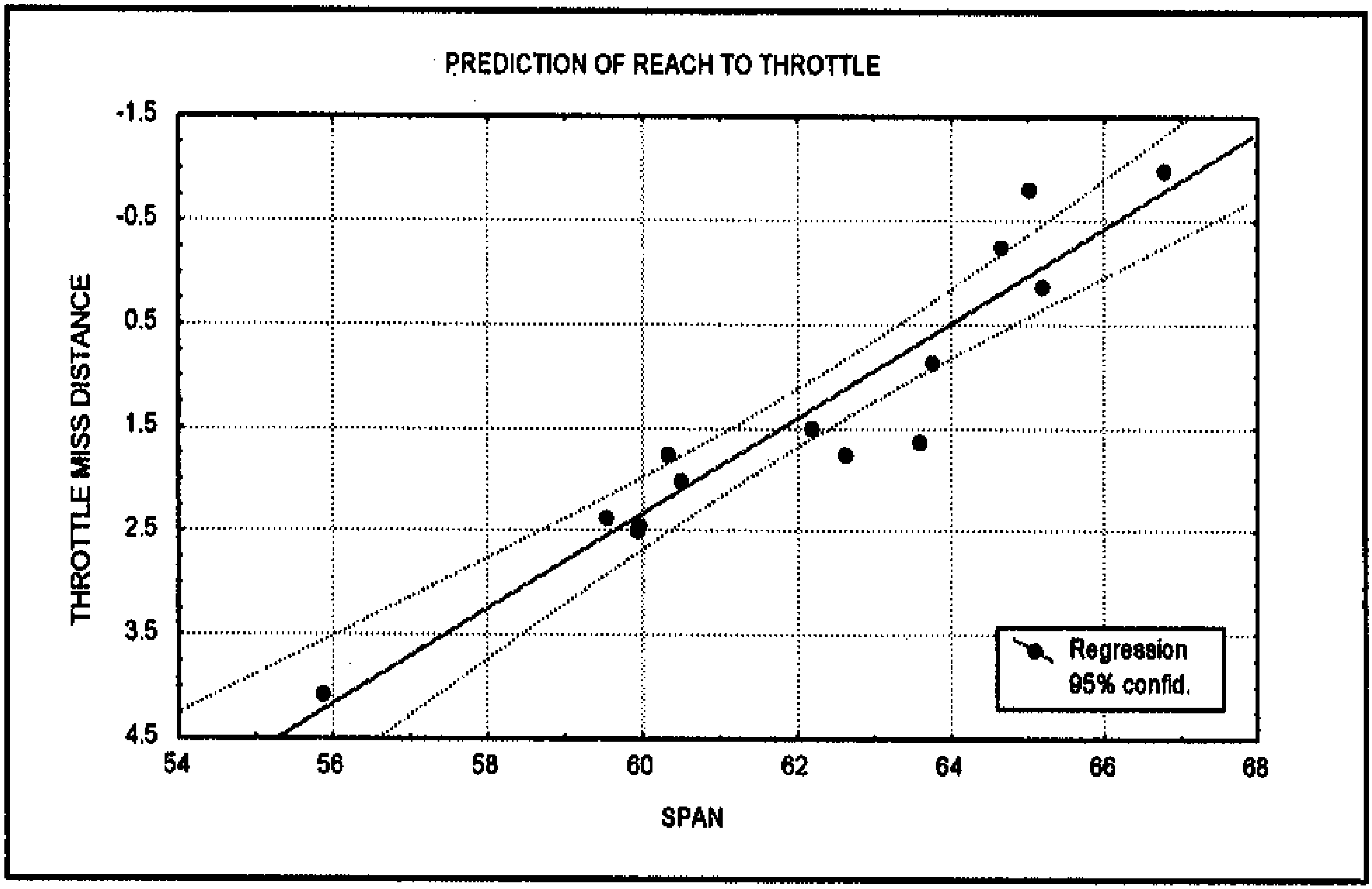
Reach was initially measured in the full-up seat position, and then repeated in a lower seat position to determine the change in reach ability for an increment of seat adjustment. Measurements were taken from the interface point on the body [the hand] to its respective contact point on the control. ... Miss or excess distances were measured and regressed against body dimensions to determine the body sizes and proportions just able to ... [reach].

Reach to a particular control is a function of arm length [as indicated in the measurement] (Span) and torso height. Torso height plays a large role in seat adjustment, since the pilot must seek at least minimally adequate vision. Moving the seat up, however, [typically] moves the pilot further from some controls [i.e., those below shoulder level].

Back to Annotated Bibliography

Arm reach may also be affected by the width of the shoulders, primarily because of the restraint system. ... Wide-shouldered subjects are relatively free to move around the shoulder straps while stretching. ...

Seat position effects were calculated by averaging differences in reaches for each subject between the full-up seat position and the down-one inch seat position. The results indicate that for each inch the subject lowers the seat, miss distance to the throttle is reduced by 0.9 inches (range = .25 to 1.75 inches). A 2.5-inch smaller Span measurement would reduce miss distance by 0.9 inches. [The author gives no evidence here to support this latter conclusion.] ... Again, in the analysis, subjects were ... positioned so that they would see at least the minimum -11 degrees visual angle [over the nose of the aircraft].



Prediction of Reach to Throttle -95% Confidence

[As can be seen in the above chart, negative values are used to report GREATER reach capability. A confusion arises when it is reported, as above, that a SMALLER Span REDUCES miss distance. One must interpret "reduce" to mean a move from more to less negative, and possibly into positive values - or, as is used here, reflecting lesser reach capability. As we saw in the Reach to Rudders section this interpretation is reversed - positive values indicate greater reach with the leg, negative values indicate less.]

... two steps ... [are] necessary to determine the percentage of the various populations accommodated on reach ... . Two steps were required because, if a pilot's arms are too short to reach the controls, he or she may be able to lower the seat to get closer to the controls. Lowering the seat is acceptable if the subject still has adequate (-11 degrees) ONV in the lowered seat position. During data analysis, therefore, we mathematically adjust the seat so that each person ... sees -11 degrees over the nose. From that seat position, we determined if the subject could reach [the control]... .

Total Accommodation Rates for Small Pilots

LARGE PILOT ACCOMMODATION

[The author includes a section titled "Test Sample" within his discussion of small pilot accommodation. Contrary to expectation, however, he did not include a similar discussion here, his discussion of large pilot accommodation.]

Overhead Clearance

Inadequate overhead clearance in an aircraft ... can interfere with pilot performance and can be an ejection hazard. If the pilot is unable to sit erect with his head firmly in contact with the seat headbox, poor spinal positioning could result in an injury during ejection. Also, pilot mobility and his or her ability to check the sky for other aircraft directly behind (the "six o'clock" position) is reduced. Both of the3se problems are exaggerated when the aircraft is under negative G-forces or is inverted. The pilot's head is then forced into the canopy.

During these measurements, the pilot sat erect with the head held in the Frankfort Plane (horizontal line of sight).[*] The space between the top of the head and the underside of the canopy was measured. In addition, clearance space had to be verified in a manner to ensure that the pilot could place his head fully into the head box before ejection and have sufficient side space for checking the sky ... directly behind him ... . We began with the subject in the full down seat position and adjusted the seat upwards until the head contacted the canopy. His or her mobility to turn and "check six" were then tested, and the seat was adjusted down until head mobility was acceptable.

Back to Annotated Bibliography

Seat position was recorded, and the distance from the seat full-down position was added to the subject's Sitting Height. ... [This value, then represented the absolute maximum accommodated Sitting Height.]

[* The definition of Frankfort Plane is unrelated to "the horizontal line of sight. The classical definition is as follows: "The standard horizontal plane of orientation of the head, realized when the lowest point in the margin of the left eye socket (orbit) and the left tragion ([an approximation of the] superior margin of the external auditory meatus) are in a common horizontal plane" - ***from A Collation of United States Air Force Anthropometry (U)***, K. W. Kennedy, AAMRL-TR-85-062, Harry G. Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, OH, January 1986 - and others. A horizontal line of sight may approximate but is independent of the Frankfort Plane and can be horizontal in a great variety of head positions.]

Since helmet designs in the military are subject to change, these measurements were taken two ways: bareheaded for overall clearance, and with the IHGU-55/P (the current flight helmet) to test mobility. When a new helmet comes into the inventory, the HGU-55/P data may become obsolete and will [or may] need to be replaced. ...

Sitting Height is the only anthropometric variable of interest for overhead clearance. The correlation between Sitting Height and Overhead Clearance is -.92. ...

Leg Clearance

Leg Clearance to the Canopy Bow

... Clearances for escape were measured to the Canopy Bow ... to ensure the pilot would not strike this structure during ejection. ...

Operational Shin Clearance

... [O]perational clearance was measured forward from the shin to the bottom edge of the main instrument panel to ensure ejection clearance the pilot has space to operate the rudders. ...

Large Pilot Final Accommodation Percentages

Discussion

Stick Interference with the Thigh

Back to Annotated Bibliography

One final anthropometric accommodation problem [,stick Interference with the thigh,] exists that we were unable to quantify. When the seat is full-up, there is very little space between the thighs for stick roll authority (pulling the stick full aft and moving it left and right all the way to its limits). This problem is made worse if the pilot has short legs. For small subjects, reach to rudders is so difficult that the knee is fully extended and the pilot is unable to spread the thighs apart to make room for ... stick [travel]. However, the relationship between body size measures and stick/thigh interference is unclear. The correlation between body size measures and stick interference problems was near zero. However, 13 of 19 subjects tested with the seat full-up had stick movement restricted by one to two inches. ...

CHAPTER 5

FUTURE DESIGN CRITERIA

Percentile Limitations
Regression Modeling
The USAF Multivariate Accommodation Method
Bivariate Distribution for Accommodation
Principal Component Analysis
Cockpit Accommodation Example
Racial/Ethnic Variability
Male Comparisons
Summary

CHAPTER 6

FUTURE DESIGN METHODS

Background
External Vision
Internal Vision
Overhead Clearance
Reach to Rudders
Shin Clearance
Escape Clearances
Arm Reach to Controls
Control Stick Range of motion

DISCUSSION

REFERENCES

There are 32 references.

APPENDIX A: ANTHROPOMETRIC MEASUREMENT DESCRIPTIONS

APPENDIX B: REACH MEASUREMENTS MADE IN THE T-38A

APPENDIX C: MODEL I AND MODEL II REGRESSION ANALYSIS"

Back to Annotated Bibliography

Back to Annotated Bibliography

BODY SIZE ACCOMMODATION IN USAF AIRCRAFT

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January 20

ABSTRACT

"The USAF is considering relaxing body size entrance requirements for Undergraduate Pilot Training (AFI 48-123 [Air Force Instruction 48-123, Medical Examinations and Standards, 22 May 2001]) to provide equal opportunity for both genders. The research described here was undertaken from 1997 through 2000 to determine the smallest and largest people that can safely and efficiently operate each current USAF aircraft.

In the past, aircraft were measured during the procurement process, to ensure they met the specifications set by the USAF, but not to determine the absolute limits of body size accommodation. Body size limit data for each aircraft will help policy makers determine if a change to AFI 48-123 is in the best interest of the USAF by indicating:

1. If pilots of extreme size are safely accommodated in specific cockpits.
2. If there are adequate career paths available for pilots of extreme body size within the current and future USAF aircraft inventory, and

Back to Annotated Bibliography

3. If there are cost effective modifications that could increase accommodation levels.

This research was carried out using live subject trials N= ~25 in each aircraft, and then used multiple regression to provide the best estimate for a particular accommodation parameter. We examined seven aspects of anthropometric accommodation in each aircraft.

1. Overhead clearance.
2. Rudder pedal operation.
3. Internal and external visual field.
4. Static ejection clearances of the knee, leg, and torso with cockpit structures.
5. Operational leg clearances with the main instrument panel.
6. Operational leg clearance with the control stick motion envelope (the pilot's ability to move the stick through its full range of travel).
7. Hand reach to controls."

1.0 INTRODUCTION

1.1 Background

" . . . With the procurement of the Joint Primary Aircraft Training System (JPATS or T-6)[*] and its eventual introduction into the USAF and USN inventories, it will be possible to train pilots whose body sizes are considerably smaller than ever before. While the original design philosophy for JPATS was to accommodate all potential USAF pilots what meet AFI 48-123 requirements, during source selection this philosophy was modified to require accommodation of 95% of both the male and female military population, including whose who do not meet the restrictions in AFI 48-123.

[* For a description of the JPATS T-6 Texan II click on JPATS.]

It is possible for pilots as small as 58 inches in Stature [Go to Instruction-48-123 for the prescribed Height/Weight Table] and 31 inches in Sitting Height to operate the T-6. However, after the T-6, student pilots must continue training in the T-1 (Tanker/Transport trainer) or the T-38A (Fighter/Bomber trainer). The T-1 and the T-38 were designed to accommodate a specific percentage (98% and 90%, respectively) of a population with a Stature range of 64 to 76 inches, and a Sitting Height range of 34 to 39 inches. (Recently, AETC extended the large size limit to 77 inches and 40 inches, respectively.)

Back to Annotated Bibliography

This [accommodation range] is . . . true for the vast majority of USAF inventory aircraft, especially those designed in the 1950s and 1960s. Nearly all of these aircraft were designed to accommodate the body sizes of an all-male pilot corps. Data gathered on fleet aircraft show the smallest JPATS-eligible pilots (especially those with less than a five foot stature) will not be able to fly them safely.

While the T-6 primarily increases accommodation for smaller pilots, it also accommodates somewhat larger pilots. Maximum Leg Lengths specified in the T-6 requirements documents were several inches larger than the lengths for which inventory aircraft were designed. These large, longer-legged pilots may suffer ejection injuries if they attempt to eject from follow-on aircraft with inadequate clearance space."

1.2 Cockpit Accommodation

2.0 METHODS

"The first step in assessing accommodation in an aircraft was to determine what the pilot ***must*** be able to do to fly the aircraft safely. We call these baseline abilities Anthropometric Operational Requirements. These requirements were established in a six-step process. First, we reviewed T. O.-1 [Technical Order -1, "Dash Ones."] flight manuals for the aircraft and examined all emergency procedures. Next, we interviewed selected instructor and safety pilots to determine a rough set of requirements. At this point, we asked pilots to fly both simulator sorties (to observe emergency procedures) and actual study flights (to determine minimum visual requirements) when possible. Using the results of these initial steps, we created a questionnaire and distributed it to as many experienced pilot as possible. In the case of training aircraft, we attempted to query 40 pilots at the instructor Pilot Training School at Randolph AFB, Texas. We used the results of this questionnaire to validate all earlier steps. The final step in the process was to submit the draft list of operational requirements to the appropriate Command headquarters for review and approval. For AETC, these requirements were signed by AETC/CC. For the other commands, signatures were obtained from AMC/CC, ACC/DO, and AFSOC/CV. Once these requirements were established, we completed the anthropometric portion of the research. . . ."

3.0 SMALL PILOT ACCOMMODATION

Back to Annotated Bibliography

4.0 REACH TO RUDDERS

5.0 ARM REACH TO CONTROLS

"Reach to a particular control is a function of arm length, [sitting] shoulder height, and [sitting] eye height. Sitting Eye Height . . . plays a large role in seat adjustment, since the pilot must maintain at least minimally adequate vision. Moving the set up moves the pilot farther from most controls since the height of the shoulders relative to the control of interest directly influences the pilot's reach ability.

Arm reach is also affected by the width of the shoulders, primarily because of the restraint system. On subjects with narrow shoulders, the torso harness may restrain forward movement of the shoulder. Wide-shouldered subjects, however, are better able to move their shoulders around the outside of the straps while reaching.

To eliminate the need for a regression requiring three predictive variables, we substituted the variable Span for Thumb-Tip Reach and Biacromial Breadth, and created a two variable regression using Span and Sitting Shoulder Height. For some controls, particularly those overhead or on the aft portion of the side consoles, Shoulder Height is a significant variable in the regression equations. However, most of the controls . . . are forward of the shoulder, and the height of the shoulder was not significant in the resulting equation. Therefore, most of the time, only arm span is necessary to predict reach capability.

6.0 STICK INTERFERENCE WITH THE THIGH

7.0 LARGE PILOT ACCOMMODATION

8.0 LEG CLEARANCE

9.0 FINAL ACCOMMODATION PERCENTAGES

10.0 SUMMARY OF RESULTS

11.0 USE OF THE DATA

"Software has been written and distributed which accepts input of an individual's anthropometric dimensions and gives [an] output of all aircraft in which that individual is accommodated. In the event that this document must be used for the same purpose, the procedure is as follows: First, small candidates must be measured for Sitting Eye Height, Shoulder Height Sitting (Acromion), Buttock-Knee Length, Knee Height Sitting, and Arm Span. First, compare the Sitting Eye Height measurements with the data in Table 3.2. If the candidate's Sitting Eye Height is less than 29.6 inches, this individual will not have adequate external vision in the T-38 or T-1. There would be no follow-on Trainer for this individual to fly. However, given the variability in anthropometric measurements, and the variability due to posture in the cockpit accommodation measurements, those who are close to 29.6 inches for Sitting Eye Height may be classified as marginal and given a "fit-check" in those aircraft. If the Sitting Eye height is greater than 29.6 inches, then it is important to calculate the amount greater and apply the adjustment listed in column three of Table 3.2. If for example, the candidate has a Sitting Eye Height of 30 inches, that value is 2.5 inches greater than the minimum requirement for the T-37. Since that seat adjusts in 0.625-inch notches, the candidate could lower the seat 4 notches and still see the minimum vision requirement. This will place the candidate much closer to rudders and hand controls. However, the candidate is only 0.4 inches larger than the minimum requirement in the T-1. The seat in this aircraft adjusts in 0.8-inch intervals. Therefore the candidate must remain in the full-up seat position for rudder and reach calculations. Those aircraft listed as 1/1 in Table 3.2 are continuously adjustable, so any amount of excess Sitting Eye Height can be subtracted directly from the seat position. At that point, classify the candidates as pass/fail (and possibly marginal) for each aircraft in Table 3.2. Next, using the seat position data, classify the candidate in each aircraft for reach to rudders using Table 4.2. The minimum Comboleg required for reaching full rudders from the full-up seat position is 40.5 inches. However, (using our candidate with a 30-inch Sitting Eye Height as an example) this person could sit 4 notches down, the minimum Comboleg from this position would be 39.5 inches. The last step is to again apply the seat position information, this time to Table 5.3 arm reach to controls. We will assume our candidate pilot has an arm Span of 63 inches and a Shoulder Height [Sitting] of 22 inches. The most restrictive reach requirement in [the] T-37 is full-forward stick with locked harness inertial reels. The equation for calculating miss distance to this control is miss distance = (.38603 X Shoulder Height Sitting (22 inches)) - (.70890 X Arm Span (63 inches)) + 34.4 inches. This equals -1.77 inches. A negative miss distance means the candidate went beyond the control by 1.77 inches and is a pass.* In addition, since the seat could be lowered 4 notches, the candidate would be 0.28 X 4 = 1.12 inches closer to the control. The final excess reach capability would be -2.89 inches. Once again it must be pointed out that there is variability (called statistical error) in this process and the numbers are best estimates. Those close to the minimum limits could be characterized as marginal and given live fit-tests.

Large pilots must be measured for Sitting Height and Buttock-Knee Length . . . . Seat effect is irrelevant because the seat will travel up the rails during ejection, and we assume that if a candidate has overhead clearance problems the seat will have been adjusted full-down. Table 7.2 and Table 8.1 can be used directly. The same variability caveat applies to large candidates. Those very close to these limits could be classified as marginal and given a fit-check."

* The convention would be to consider a "plus" value as one ***greater*** than that necessary to reach a given control. Multiplying the result by (-1) would satisfy this convention.

REFERENCES

APPENDIX A. Sorted Reach to Controls by Aircraft

APPENDIX B. Anthropometric Measurement Descriptions

APPENDIX C. Aircraft Functional Anthropometric Requirements

Body Size/Reach Requirements for the A/OA-10, B-1, B-2, B-52, F-117A, F-15, F-16, and HH-60G.
Consisting of: Measurement Assumptions, Vision Requirement, Body Clearances/Size Requirements,
Minimum Reach Requirements with ***Un-Locked Reels***, and Minimum Requirements with ***Locked-Inertia Reels.***

Operational Requirements for the C-130, C-141, C-17, C-21, C-5, H-1, H-53J, KC-10, KC-135, and T-38.
Consisting of: Vision Requirements, Minimum Reach Requirements with ***UN-Locked*** Reels and Minimum Requirements with Locked Inertial Reels

Cockpit Accommodation Operational Requirements for T-1 and T-37.
Consisting of: Vision Requirements, Body Clearances Requirements, Reach to controls with Locked Reels Requirement, and Rudder Requirements.

APPENDIX D. Staff Summary Sheets on Anthropometric Operational Requirements

Back to Annotated Bibliography

Back to Annotated Bibliography

ANTHROPOMETRIC ACCOMMODATION IN THE T-38

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ABSTRACT: "The USAF [United States Air Force] may expand the body size entrance requirements for Undergraduate Pilot Training (UPT). We are now conducting a research project to quantify the smallest and largest people that can safely and efficiently operate all types of USAF aircraft prior to changing these requirements. Our accommodation analysis of the T-38 was based on AETC's [Air Education and Training Command] list of operational requirements (tasks that a pilot must be able to carry out to safely fly the aircraft).

Our results indicate that the T-38 accommodates large pilots quite well, except in the rear cockpit, where pilots with Sitting Heights higher than 39" may have their helmets pressed against the canopy during negative-G flight. Accommodation for small pilots is much worse in both cockpits. Seventy-three percent of the JPATS [Joint Primary Aircraft Training System]-eligible female population and 13% of the JPATS-eligible male population cannot perform one or more of AETC's operational requirements. These pilots would have to stretch to see over the nose, and they either would not be able to reach full rudders or they would have to slide forward in the seat to reach full rudders. With locked inertial reels, they would not be able to reach to retard a full throttle, so they would be forced to unlock the reels or unload restrictive G-forces."

Note: For more information regarding the JPATS program, see http://www.wpafb.af.mil/ascpa/factshts/programs/jpats98.htm.

EXTRACTS:

INTRODUCTION: "With the procurement of the Joint Primary Aircraft Training System (JPATS) and its eventual introduction into the USAF and USN inventories, it will be possible to train pilots whose body sizes are considerably smaller than ever before (Zehner, 1996). The USAF is now considering expanding the body size entrance requirements for Undergraduate Pilot Training (UPT) (AFI 48-123) to take advantage of the increased accommodation offered by the JPATS aircraft and to provide equal access to flight training for both male and female pilot candidates."

"Potential USAF pilots must first fly the T-3 Firefly (the initial "Flight Screener") and then, after JPATS . . . must continue training in either the T-1 Tanker/Transport trainer or the T-38 Fighter/Bomber trainer. If small pilots cannot safely fly existing trainers, it may be pointless to allow them to enter UPT, and unless these [training?] aircraft are modified, there may be no point in designing follow-on aircraft to JPATS-level accommodation limits."

BACKGROUND: "For JPATS, the size range . . . is defined as a series of body size test cases (1-7). Each case represents a separate individual with either extreme size or body proportions. It will be possible for pilots as small as 58" in Stature and 31" in Sitting Height, or as large as 77" in Stature and 40" in Sitting Height, to operate the JPATS aircraft."

". . . the T-38 was intended to accommodate 5th through 95th percentile male anthropometric dimensions based on the 1950 USAF anthropometric survey of pilots (Hertzberg, Daniels, & Churchill, 1954). Because of the improper use of percentiles in the design specifications for the T-38 (Zehner, Meindl, & Hudson, 1992), and the potential for the actual designs to exceed requirements in some areas of accommodation, we had to complete our investigation to determine the real accommodation levels of the aircraft."

"Previous investigations of accommodation in training aircraft have focused on the existing pilot population body size, and the results from these studies indicate that, in some areas, the extreme ends of the size distribution of current pilots are at or very near the limits of accommodation. There is clearly a potential for accommodation problems if even larger and smaller pilots are allowed to fly these aircraft."

COCKPIT ACCOMMODATION: "We examine seven aspects of anthropometric accommodation:

1. Overhead clearance.
2. Rudder pedal operation.
3. Internal and external visual field.
4. Static ejection clearances of the knee, leg, and torso with cockpit structure.
5. Operational leg clearances with the main instrument panel.
6. Operational leg clearance with control stick motion envelope (the pilot's ability to attain the full range of stick travel).
7. Hand reach to controls."

"We test subjects of various sizes with the seat adjusted to numerous positions in the cockpit. This allows us to examine the subject in progress, and . . . to extrapolate measurements for subjects of neighboring sizes and varying proportions."

ANTHROPOMETRY: "We have assembled a pool of over 50 test subjects for these studies. . . . Our sample was not selected to exactly represent the body size distribution of the pilot population. Small subjects were selected to over-represent the extremes of the general USAF population while retaining a reasonably normal distribution for each measure. A small number of large subjects were selected to represent the largest potential pilots in the USAF population."

ANNOTATOR'S ADDENDUM: The following are anthropometric multivariate Cases 1, 5 and 7 values that are critical for the examination of JPATS cockpits. They were derived specifically for the JPATS program, in which potential pilots as small as 58" in Standing Height are specified for accommodation.

JPATS ANTHROPOMETRIC MULTIVARIATE CASES 1, 5 AND 7

Back to Annotated Bibliography

	Case 1 Generalized Small Pilot (Female)	Case 5 Longest Limbs (Male)	Case 7* Objective Small Pilot (Female)
Sitting Height	***32.8"***	***38.0"***	***31.0"***
Sitting Eye Height	***28.0***	***32.9***	***26.8***
Sitting Shoulder Height	***20.6***	***25.0***	***19.5***
Sitting Knee Height	***18.7***	***24.8***	***18.1***
Buttock-Knee Length	***21.3***	***27.9***	***20.8***
Thumbtip Reach*	***27.0***	***36.0***	***26.1***

**** Case 7 was proposed by the USN to target smaller female pilots than the USAF Case 1.***
***** Equivalent to Functional Reach.***

RESULTS FOR SMALL PILOTS

VISION OVER THE NOSE: "The JPATS cases range from 26.8" to 35.0" for Sitting Eye Height, while the range for the current pilot population is 28.9" to 35.4". We measured over-the-nose vision (ONV) with the subject's head held level (in the Frankfurt Plane), and again with the subject's head stretched up for maximum possible downward vision. AETC instructor pilots have insisted that trainees should fly with their heads level, and that the additional degree of vision attained by stretching should be held in reserve as a safety margin."

"The [regression plot] . . . below predicts head-level ONV angles for flyers based on their Sitting Eye Heights, with the seat in the full-up position. The graph shows that people of very small Eye Height Sitting may only be able to see a few degrees over the nose when the aircraft is in level flight. Depending on the aircraft angle of attack during landing, these pilots may not be able to see the runway over the nose of the aircraft."

Back to Annotated Bibliography

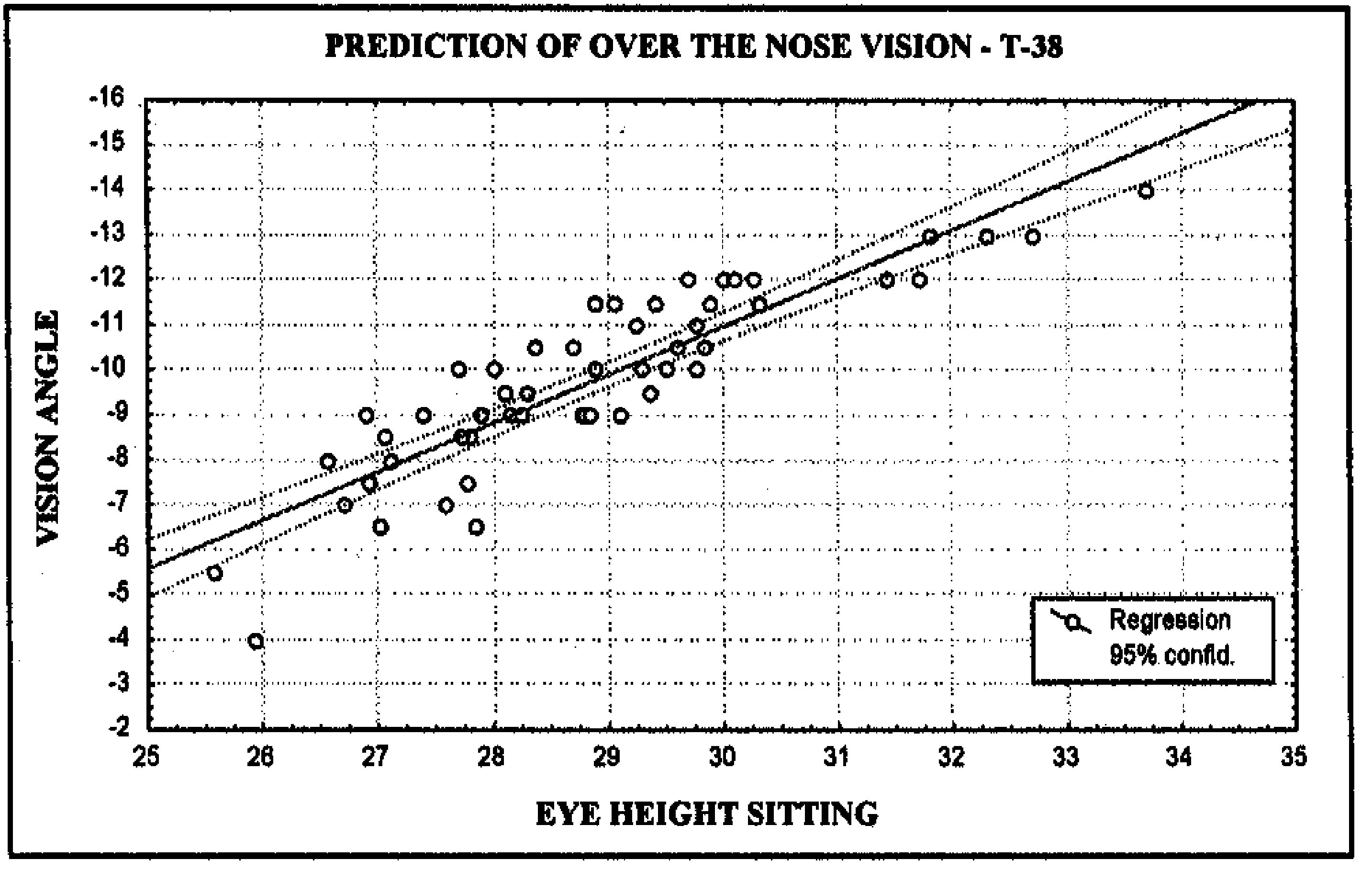

Figure 1. Over the nose vision plot (seat full up)

"Fifty-eight percent of the JPATS female population and 10% of the JPATS male population falls below the size necessary for acceptable ONV. For the current USAF pilots, 14% of females and 6% of males will have an ONV angle worse than -11 degrees."

"For the JPATS smallest sizes (cases 1 and 7, eye heights = 28.0" and 26.8", respectively), external visual field is so restricted that the pilots cannot see the runway during a no-flap approach. . . . Subjects near case 7 size typically have eye positions below the aft edge of the glare shield in the T-38. When the HUD is added, small JPATS cases will see very little of the display."

RUDDER THROW: "The measurement which best identifies the minimum leg length required to reach full rudder throw is a combined leg length. We add Buttock-Knee Lengthy and Sitting Knee Height to arrive at a new measure that we call "Comboleg." . . . Using Coboleg would not be appropriate . . . in aircraft where the pilot cannot fully extend his or her knee. . . . The range of Comboleg measures for current pilots is 40.7" to 52.4". The JPATS range is 38.9" to 52.7". "

"We defined rudder accommodation limit as full rudder input and full brake with the knee fully extended. The subjects were tightly restrained and not allowed to slide forward in the seat. We then measured subject miss or excess reach to rudders for regression analysis. The [regression plot] . . . below shows miss/excess distance (negative numbers for miss distance, and positive numbers for excess distance) to

Back to Annotated Bibliography

full rudder and brake for a variety of leg lengths. With the seat in the full-up position, a Comboleg length of 43" is required to attain full rudder and full brake simultaneously. This applies to both the front and rear cockpits in the T-38." [Miss distances is the additional leg reach that is needed by a given individual to gain full rudder and brake actuation. Excess distance is the leg reach beyond that which is minimal for full rudder and brake actuation.]

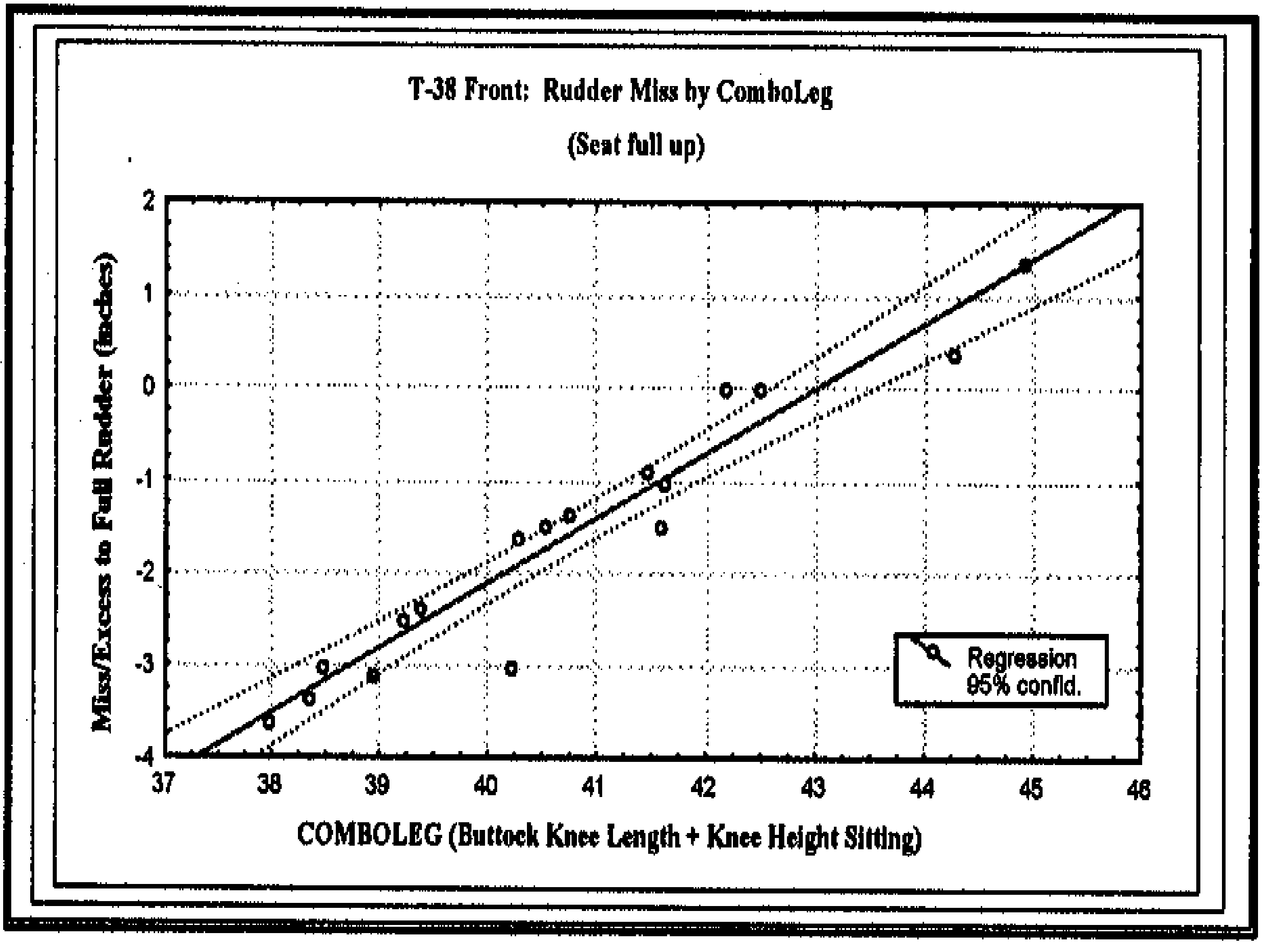

Figure 2. [Regression plot for predicting] Leg reach to rudders (seat full up).

"We used a two-step process to determine the percentage of the various populations accommodated on rudder pedals. Two steps are required because, if a pilot's legs are too short to reach the rudder pedals, he or she may be able to lower the seat to get closer. This is acceptable if the pilot still has equal to or better than -11 degrees over-the-nose vision in the lower seat position. Therefore, we adjust the seat so that each subject in the following calculations sees -11 degrees ONV. From that seat position, we determine if the subject can reach full rudder input and full brake."

"Fifty-four percent of the JPATS female population and 5% of the JPATS male population are too small to both reach the pedals and see -11 degrees out of the cockpit. JPATS Case 7 represents a Comboleg of 38.9 inches, and is the smallest multivariate body size to be accommodated in JPATS. Case 7 would miss full rudder by 4.1" with the seat full-up. This is a misleading figure, however, because Case 7 would need to raise the seat an additional 3.2" beyond full-up to see the minimum -11 degrees ONV. If it were possible to raise Case 7 that much, miss distance to the rudders would be 5.7"."

Back to Annotated Bibliography

"For current USAF pilots, 19% of females and 3% of males cannot apply full rudder and brake while maintaining -11 degrees ONV. All current pilots are within one inch of reaching full rudder and brake while seeing at least -11 degrees ONV. ***All current pilots are within one inch of reach full rudder and brake while seeing at least -11 degrees ONV.***" [Annotator's italics]

ARM REACH TO CONTROLS: "The most difficult area in which to establish pass/fail criteria is reach to [hand] controls. . . . reach to a particular control is a function of arm reach, shoulder height, shoulder width, and seat position. . . . even though two pilots might have the same arm length, their other body measurements will almost certainly be different. Pilots typically select a seat position to optimize external [ONV] vision, and then, if necessary, adjust the seat to improve reach to rudders and [hand] controls. [Typically, in ejection type seats, the large torso pilot, because of minimal clearance above the helmet, must lower the seat.] [Therefore, t]he aft-angled ejection seat moves a large-torso pilot lower and more forward in the cockpit (closer to controls and rudders) and short-torso pilots higher and more aft in the cockpit (further from controls and rudders) [, the opposite that good human factors design]."

"To eliminate the need for three-measurement regression, we substituted the variable Span for Thumb-tip Reach and Biacromial Breadth, and created a two-step regression using Span and Sitting Shoulder Height. The multiple correlation between Shoulder Height, Span, and miss distance to the throttle is .95 with a standard error of .5 inches."

"We based reach to control measurements on the Zone 2 harness configurations as defined in Mil. Std. 1333, with inertial reels locked but shoulders reaching out toward the control."

"While USAF pilots usually do not lock their reels, safety concerns dictate looking at "worst-case" scenarios. Locking the inertial reels is meant to simulate the restricted mobility a pilot experiences during adverse-G conditions, and it also tests whether the pilot can control the aircraft when there is an inadvertent restraint lock."

"AETC determined that, with locked inertial reels, pilots must be able to operate the inertial reel lock, the ejection handles, and retard the throttles. In the T-38, the throttles are the most difficult of this group to reach, so they are the only control[s] discussed here. [The inertia reel lock and the ejection handles are mounted on the seat and, therefore, reach distances to them are not affected by seat position.]"

"Since this is multiple regression, a number of combinations of Shoulder Height and Span [can] equate to zero miss distance. . . . Miss distance rises as span decreases and as shoulder height increases. A two varible [sic] example graph is shown below. The required Span length for reaching throttles is approximately 65 inches." [Without further explanation, announcing that a 65-inch "required," that is, ***minimum*** Span for reaching the throttles is confusing.]

"As with rudders, we used a two-step process to determine the percentage of the various populations accommodated on reach to throttles. Two steps are required because, if a pilot's arms are too short to reach the controls, it may be possible to lower the seat to get closer. This is acceptable if the subject still has adequate (-11 degrees) ONV in the lower seat position. Therefore, we adjust the seat so that each subject in the following calculations sees -11 degrees over the nose. From that seat position, we determine if the subject can reach the throttles well enough to retract them when they are full forward."

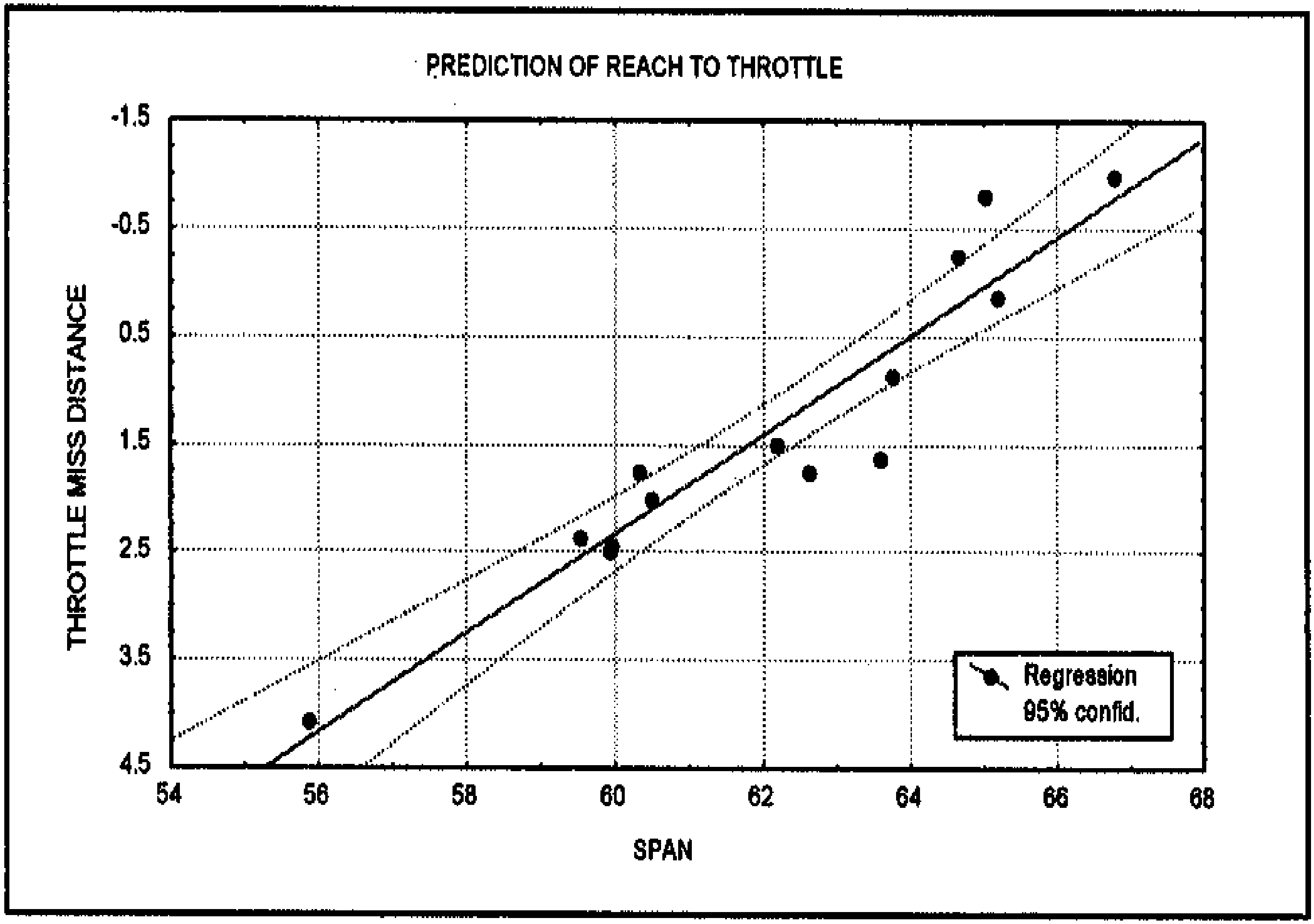

Figure 3. Arm reach to throttles (seat full up).

"Sixty percent of the JPATS female population and 2% of the JPATS male population are too small to reach the throttles and still see -11degrees over the nose. For current USAF pilots, 23% of females and 1% of males will not be able to reach and retract full throttle. ***All current pilots are within one inch of reaching and retracting full throttle while maintaining -11 degrees ONV.*** [Annotator's italics]

SUMMARY FOR SMALL PILOT RESULTS: "The T-38 is not a very accommodating aircraft for small pilots. . . . percentages of pilot populations failing to meet the operational requirements . . . are 73% of the JPATS female population, 13% of the JPATS male population, 36% of the current female pilots, and 8% of current male pilots. It is not surprising that such large percentages of the JPATS population fall outside the T-38 accommodation limits, but it is surprising that over a third of women [currently] eligible to enter UPT do not meet the AETC requirements. These pilots have to stretch to see over the nose, and they either cannot reach full rudders or have to loosen their lap belts and slide forward to reach full rudders. With locked inertial reels, they cannot reach to retract a full throttle, so they must unlock the reels or unload the G forces that are limiting movement."

LARGE PILOT ACCOMMODATION: "The front cockpit of the T-38 can accommodate pilots much larger than the range of Sitting Heights found in the military population . . ."

"In the T-38's rear cockpit, however, the current 40" maximum Sitting Height is only minimally acceptable. [Their helmets] will touch the canopy . . . and will press hard against the canopy during negative-G flight."

"In the T-38, there is a great deal of room in front of the pilot's knees, and the canopy bow and glareshield are well outside the ejection envelope."

"Both small and large subjects found it difficult to pull the control stick full-aft and then roll it to the stops on the left and right sides. This action was most difficult with the seat in the full-up position. The correlation between stick interference and the body measurements we expected to be related to it (thigh circumference, thigh clearance, and buttock-knee length) were around zero."

Back to Annotated Bibliography

Back to Annotated Bibliography

A MULTIVARIATE ANTHROPOMETRIC METHOD FOR CREW STATION DESIGN: ABRIDGED (U)

AL-TR-1992-0164

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FINAL REPORT FOR PERIOD JANUARY 1989 TO DECEMBER 1992

APRIL 1993

ABSTRACT: "Body size accommodation in USAF cockpits is still a significant problem despite all the years of experience and the many aircraft designs that have been developed. Adequate reach to controls, body clearances (particularly during escape) and vision (internal and external), are all functions of pilot body size and position in the cockpit.

One of the roots of this problem is the way cockpit accommodation is specified and tested. For many years the percentile pilot has been used. This paper describes the errors inherent in the "percentile man" approach, and presents a multivariate alternative for describing the body size variability existing in a given flying population. A number of body size "representative cases" are calculated which, when used properly in specifying, designing, and testing new aircraft, should ensure the desired

level of accommodation.

The approach can be adapted to provide anthropometric descriptions of body size variability for a great many designs or for computer models of the human body by altering the measurements of interest and/or selecting different data sets describing the anthropometry of a user population."

[The Abstract is identical to that of the original version under the same title.]

PREFACE: [The Preface does not, as one would expect, contain an explanation regarding the reason for issuing an abridged version of the original Technical Report of essentially the same title and authored by the same investigators.]

INTRODUCTION: "Military personnel of every size and shape much be able to operate complex equipment safely, effectively, and comfortably. Personnel charged with the specification and procurement of complex workstations and personal protective equipment are continually challenged by the need to accommodate and fit very large numbers of an increasingly heterogeneous population. In writing specifications, the goal is to ensure that the body size and proportions of most of the population will be accommodated in each item or system to be procured. Traditionally, this has been done by using percentiles to specify the portion of the population that must be accommodated. Typically, specifications read: "the system shall be designed to allow safe operation by the fifth percentile female pilot through the ninety-fifth percentile male pilot." What is not specified is how the 5th and 95th percentile pilots are defined.

The purpose of this report is to point out the drawbacks inherent in the percentile approach, and the present a more suitable method for describing variability in body size. The proposed method is based on the pioneering work of Bittner et al. (1986). For a detailed statistical description of the technique, see Meindl et al. (in press)."

[The work by Meindl, Hudson and Zehner, cited above as being "in press," has an Armstrong Laboratory technical report number of the 1993 series, thus appearing to have been published later than the abridged version. This is even more confusing since the "abridged" version, appropriately, has a later publication date.]

Percentiles: ". . . while a 5th percentile Stature value can be accurately located, that value tells us little or nothing about the variability of ***other*** body dimensions of individuals with 5th percentile Stature. Consider Weight, for example. Individuals of 5th percentile Stature in the 1967 survey ranged from 125 lbs. (less than 1st percentile Weight) to 186 lbs. (74th percentile Weight). . . . [What might appear to be a] logical next step is to consider the fifth percentile for both measures. It is common for people to assume that the 5th percentile for both Stature and Weight represents a "5th percentile" person. In fact, only 1.3 percent of subjects in the 1967 survey were smaller than the 5th percentile for ***both*** measures, while 9% were smaller for one ***or*** the other. The problem is compounded with each additional measurement used to specify the size of the USAF individual. Thus, at worst, use of percentiles can mean that workspaces or equipment are not suitable for anyone. . . ."

"The pitfalls attendant upon the use of multiple percentiles can be illustrated by considering the body dimensions critical to cockpit design. . . . Sitting Height, Shoulder Breadth, Buttock-Knee Length, Knee Height Sitting, and Functional Reach. Generally a group of measures such as this is listed in a specification or standard along with 5th and 95th percentile values for each. This gives the impression that if these values are used as design criteria, 90% of the population will be accommodated. . . . There is no difficulty in identifying the individuals who constitute 90% of the population in Sitting Height. However, . . . when those same individuals are screened for 5th-95th percentile Buttock-Knee Length values, their numbers drop. With application of each additional cockpit dimension, the group diminishes until, finally, it represents only 67% of the population."

THE MULTIVARIATE ACCOMMODATION METHOD: "The multivariate accommodation method is an alternative to the percentile . . . It corrects the deficiencies of both while retaining the concept of accommodating a specific percentage of the population in the design. Briefly, the multivariate accommodation method is based on principal component analysis, which reduces a list of variables to a small manageable number, and then enables designers to select the desired percentage level of a population to be accommodated. This percentage level is accommodated in a way which takes into account not only size variance but proportional variability as well -- i.e. not only individuals who are uniformly large or small, but those whose measurements combine, for example, small torsos with long limbs, or vice versa.

A number of examples of the approach are given . . . beginning with a very simple two-measurement example, building to a basic cockpit layout, and concluding with a fairly complex 11-variable computer man-model."

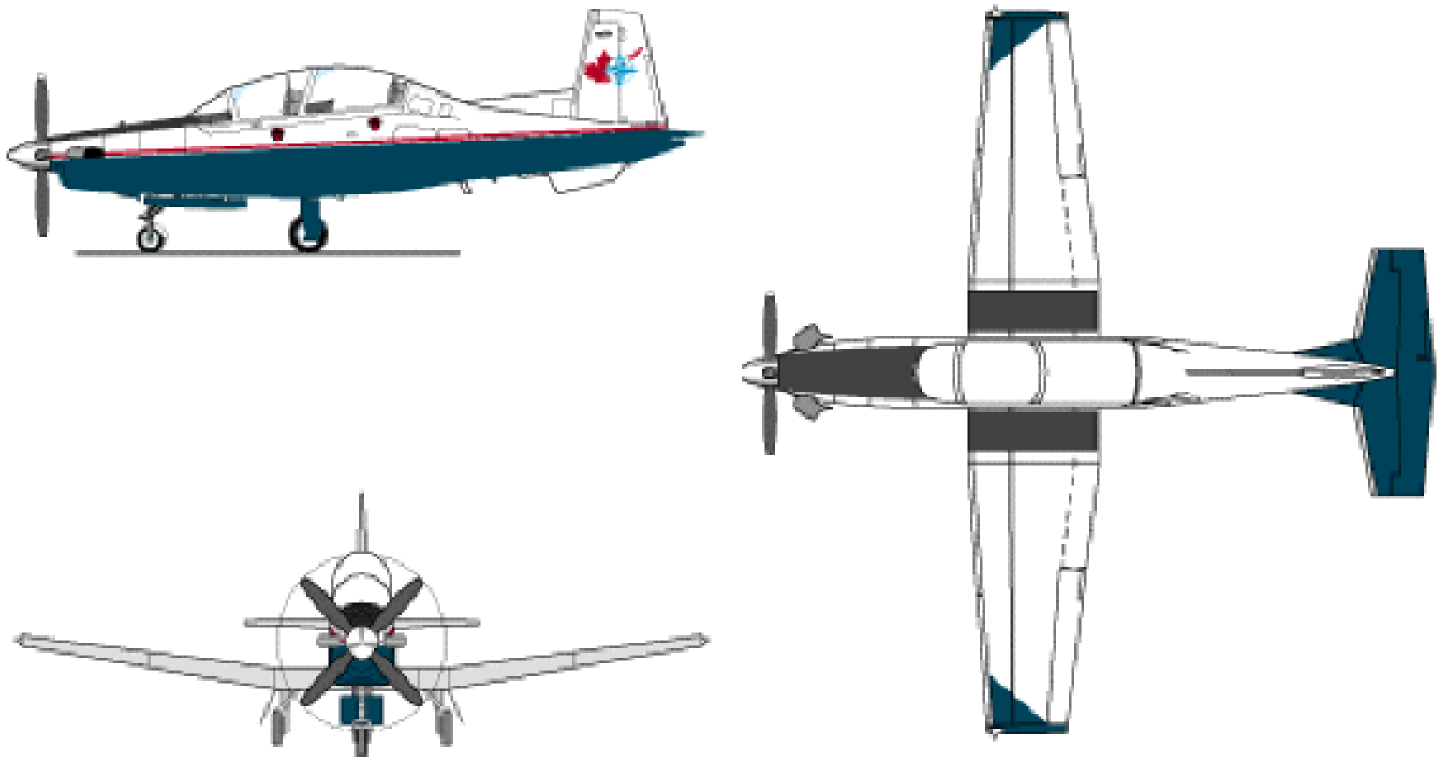
DISCUSSION: "There are a number of multivariate statistical techniques which could be utilized to determine similar combinations of body size test cases. The technique described here, however, when combined with lists of minimum and maximum values, gives a much more accurate description of the body size and proportional variability existing in the population and, if used in designing workspaces, will greatly reduce the accommodation problems experienced by users. This assumes , of course, that the seat, rudder, and other adjustable components can be adjusted in sufficiently small increments. Without such adjustability, it may be necessary . . . to pick many more ***representative cases*** than the numbers suggested here to ensure the desired level of accommodation. However, for the purposes of writing anthropometric specifications, large numbers of ***representative cases*** may overwhelm the designer and thus, be counterproductive."

Back to Annotated Bibliography

Back to Body Size in USAF Aircraft

T-6A JPATS [Texan II / Harvard II] *

Back to Body Size in USAF Aircraft



"The Raytheon Aircraft Company [formerly Beechcraft] T-6A Joint Primary Air Training System (JPATS) turboprop is designed as a dedicated training aircraft possessing jet-like handling characteristics. Replacing the Air Force's T-37 and the Navy's T-34C aircraft, which are 37 and 22 years old, respectively, the T-6A will offer better performance and significant improvements in training effectiveness, safety, cockpit accommodations and operational capabilities. Seven hundred and forty T-6A aircraft will be purchased by the United States Air Force and the United States Navy. The Air Force and Navy transition to the T-6A is expected to take approximately 10 years. The Air Force will steadily replace T-37s with T-6s at all Air Education and Training Command joint specialized undergraduate pilot training bases.

The T-6A Texan II is named after the classic T-6 Texan trainer used by the Navy and Air Force in the 1940s and 1950s. The T-6A will support a variety of joint flight-training programs, including joint primary pilot training for entry-level aviation students. It will provide the skills necessary for pilots to progress to one of five training tracks: a bomber/fighter track (T-38); a strike track (T-45); an airlift/tanker track (T-1A); a maritime track (T-44); or a helicopter track. It also will support joint navigator and naval flight officer training at Naval Air Station Pensacola, Fla. Also slated for use in companion trainer programs for Air Combat Command and Air Mobility Command, the T-6A may support Euro-NATO joint jet-pilot training administered by the Air Education and Training Command, Randolph AFB, Texas.

The T-6A Texan II offers better performance and significant improvements in training effectiveness, safety, cockpit accommodations and operational capabilities than present aircraft. The T6-A TEXAN II is a single-engine, stepped tandem, two-seat primary trainer aircraft. Its Pratt Whitney PT6A-68 engine is flat rated at 1,100 shaft HP. The PT6A-68 engine and the T6-A TEXAN II aerodynamic characteristics result in exceptional performance. Its excellent thrust-to-weight ratio provides an initial rate of climb of more than 4,500 fpm and outstanding short field capability with a takeoff distance of only 1,775 feet at sea level. Its superior aerobatic performance is demonstrated by the aircrafts ability to perform a constant altitude 2g turn at 25,000 feet. The T-6A combines features typical of a primary trainer with the very low fuel consumption and overall economy of a turboprop, while simultaneously providing 50 percent more overall thrust than its predecessor. The T6-A TEXAN II performance is unmatched.

The T6-A TEXAN II cockpit is entered through a side-opening, one-piece canopy/ windscreen that has demonstrated resistance to bird strikes at speeds up to 270 knots. The pressurized cockpit features an advanced avionics package with sunlight-readable, active-matrix liquid crystal displays. It features a stepped-tandem, cockpit configuration, with the instructor's rear seat raised slightly to improve visibility from the rear cockpit; modern avionics; and improved egress systems. Both T-6A cockpits are covered by a single, side-opening, non-jettisoned canopy. The T-6A offers increased birdstrike protection over current training aircraft, and will improve the safety of landing and low-level training at Air Force and Navy bases. The pressurized cockpit permits training at higher, less-congested altitudes and reduce the stress on student pilots. The aircraft is equipped with an onboard oxygen-generating system that reduces the time needed to service the aircraft between flights.

The T-6A is equipped with a through-the-canopy, zero-zero ejection seat, a significant improvement from the seats in the T-37. But the minimum recommended ejection altitude has not changed since the days of rudimentary egress systems—it’s still 2000 feet AGL. This minimum recommended ejection altitude purposely does not take into account the advances in ejection seat technology and the better than “zero-zero” capabilities of today’s egress systems. That’s because 2000 feet gives pilots adequate time to perform all of the required post-ejection actions and steer away from ground hazards, particularly the aircraft impact fireball. By delaying ejection, pilots greatly increase the chances of sustaining significant (or fatal) injuries. The “zero-zero” capability of seats was not designed, and is not intended, to allow pilots to get closer to the ground prior to ejecting—it was designed to permit ejection during all stages of takeoff or landing, something that the old systems could not do. Through-the-canopy ejection systems, like that found on the T-6A, involve an explosive charge fracturing the transparency prior to the pilot ejecting. The necessary explosion occurs very close to the pilot, i.e., less than a foot away. Some shrapnel and molten metal is going to be sprayed inside the cockpit. Common sense and self-preservation dictate that the pilots try to cover every possible piece of skin prior to ejecting. Pilots should leave themselves enough time to be fully prepared to leave the aircraft at the minimal ejection altitude. While the T6-A is a good aircraft and a significant advancement in technology for USAF flight trainers, it does have only one engine. Engine failures will occur, and pilots will eject. The seat is extremely capable, but delaying ejection will reduce or remove any existing safety margin.

The T-6A's tricycle-type landing-gear is hydraulically retracted through electric controls and is equipped with both differential brakes and nosewheel steering. The aircraft is fitted with electrically controlled, hydraulically operated, split flaps, used for takeoff and landing. It also has a single, ventral-plate, speed brake located between the flaps. All flight controls are manually activated, with electrically activated trim controls. The presence of an automatic rudder trim aid device results in a more balanced flight control environment. Flight controls and avionics can be operated from both cockpits. For single-pilot operations, the pilot will fly in the front cockpit. A low-wing, training aircraft approved for night and day Visual Flight Range (VFR) and Instrument Flight Range (IFR) flight, the T-6A Texan II has a cockpit designed to accommodate the widest possible range of pilots, both male and female, and will open flying careers to the largest possible pool of qualified applicants.

The current T-6A Texan II program calls for buying up to 711 production aircraft (372 for the Air Force and 339 for the Navy) from Raytheon Aircraft Co., Wichita, Kan., at an estimated cost of $4 billion. This number may increase to some 860 JPATS aircraft, based on projections of the number of aviators both services need and the number of joint squadrons they must develop. The Flight Training System Program Office at Wright-Patterson AFB is managing the acquisition of the Texan. JPATS is seeking to maximize the benefits of allowing the prime contractor to operate using commercial practices with its subcontractors and vendors. The program will be conducted using commercial style practices to the greatest extent possible; however, due to the nature of the acquisition strategy, current government acquisition, auditing and domestic content policies will continue to be applied to the prime.

In response to FY89 Congressional direction, DoD submitted the 1989 Trainer Aircraft Master Plan which documented the status of USAF and USN pilot training programs. In December 1990 the Joint Requirements Oversight Council validated the JPATS Mission Need Statement, with a need for nearly 900 trainer aircraft to replace the Air Force T-37B and Navy T-34C. Operational requirements were subsequently codified in the JPATS Operational Requirements Document. In January 1992 JPATS was designated a Defense

Acquisition Pilot Program.

The Air Force, as the Executive Service for JPATS, manages the program through the Flight Training System Program Director under a joint agreement with the Navy. The Program Director reports to the AFPEO for Airlift and Trainers (AFPEO/AT). The Milestone Decision Authority is the Air Force Component Acquisition Executive (CAE). From the beginning of the program, JPATS was structured to take advantage of NDI/commercial practices and, thus, quantitative measures of specific regulatory relief unique to commercial items are difficult to quantify. Therefore, the program initially concentrated on three quantifiable measures: number of program office staff, time to deliver the first production aircraft, and program cost. These measures were refined in coordination with the PPCG to develop JPATS-specific metrics.

JPATS experience demonstrates the potential cost (in both dollars and time) of infusing acquisition reform principles into an ongoing solicitation. The JPATS Request for Proposal (RFP) was delayed twice to incorporate aspects of acquisition reform, specifically reductions in the RFP size, reductions in the number of referenced documents, and reductions in the number of contract data requirements. The JPATS source selection was also disturbed by directed program changes while in source selection. Although not the most efficient mechanism for implementation of changes, the revised RFP incorporated value added changes which ultimately resulted in program savings.

The JPATS selection process began formally on May 18, 1994, when the request for proposal was issued by the Aeronautical Systems Center at Wright-Patterson Air Force Base, Ohio. Some of the major requirements in the proposal were advanced ejection seats, increased bird-strike protection, electronic flight instrumentation and digital cockpit display, pressurized cockpit, increased oxygen capacity, and cockpits to accommodate a larger range of individuals with different physical (male and female) dimensions. The source selection process included assessment of each contestant's proposals and flight evaluations of the candidate aircraft. This was one of the longest and most closely scrutinized source-selection competitions ever." The selection process took fourteen months and entailed evaluation of seven aircraft, seven cockpit mockups, and thousands of pages of contractor proposals.

Source selection for the JPATS was completed in the summer of 1995. On June 22, Raytheon Aircraft Company was selected as the JPATS contractor, and contract award was slated to occur in August. However, protest actions were filed with the General Accounting Office in July. On Nov. 22, 1995, and Feb. 5, 1996, the GAO issued rulings that upheld the source selection decision.

Raytheon was awarded the contract Feb. 5, 1996. The US General Accounting Office denied protests lodged by Cessna Aircraft Company against the selection of Raytheon, and an earlier protest, lodged by Rockwell, was also denied. Reported results demonstrate the cost of the protest in terms of government and contractor staffing.

In early 2001 the Navy decided to discontinue acquisition of the Joint Primary Aircraft Training System (JPATS) for fiscal years 2002 through 2007. On 04 December 2001 the Air Force approved full-rate production for the JPATS."

* This material is quoted from: http://www.globalsecurity.org/military/systems/aircraft/t-6.htm

Back to Body Size in USAF Aircraft

Back to Body Size in USAF Aircraft

Attachment 16

HEIGHT AND WEIGHT TABLES

Table 3. Height and Weight Tables.

Height (inches/cm)	**Men**		**Women**	
	Minimum (lb/kg)	Maximum (lb/kg)	Minimum (lb/kg)	Maximum (lb/kg)
58/147.32	98/44.54	149/67.72	88/39.99	132/60.00
59/149.86	99/44.99	151/68.62	90/40.90	134/60.90
60/152.40	100/45.45	153/69.54	92/41.48	136/61.81
61/154.94	102/46.36	155/70.45	95/43.18	138/62.72
62/157.48	103/46.81	158/71.81	97/44.09	141/64.09
63/160.02	104/47.27	160/72.72	100/45.45	142/64.54
64/162.56	105/47.72	164/75.54	103/46.81	146/66.36
65/165.10	106/48.18	169/79.81	106/48.18	150/68.18
66/167.64	107/48.63	174/79.09	108/49.09	155/70.45
67/170.18	111/50.45	179/81.36	111/50.45	159/72.27
68/172.72	115/52.27	184/83.63	114/51.81	164/75.54
69/175.26	119/54.09	189/85.90	117/53.18	168/76.36
70/177.60	123/55.90	194/88.18	119/54.09	173/78.63
71/180.34	127/57.72	199/90.45	122/55.45	177/80.45
72/182.88	131/59.54	205/93.18	125/56.81	182/82.72
73/185.42	135/61.36	211/95.90	128/58.18	188/85.45
74/187.96	139/63.18	218/99.09	130/59.09	194/88.18
75/190.50	143/65.00	224/101.81	133/60.45	199/90.45
76/193.04	147/66.81	230/104.54	136/61.81	205/93.18
77/195.58	151/68.63	236/107.27	139/63.18	210/95.45
78/198.12	153/69.54	242/110.00	141/64.09	215/97.72
79/200.66	157/71.36	248/112.72	144/65.45	221/100.45
80/203.20	161/73.18	254/115.45	147/66.81	226/102.72

Notes: HQ USAF/DP directed policy for Air Force Accessions:

1. If an applicant is weighed and found to be at or below their MAW, a BFM is not required and processing can continue.

1. If an applicant is weighed and found to be at or below their MAW, a BFM is not required and processing can continue.
2. If an applicant is above their MAW, a BFM is required and can only be administered by approved medical personnel.
3. If the applicant passes the BFM, processing can continue, and if during subsequent processing the applicant's weight is found to be at or below his/her MAW, no further BFM is required.

This material is not found in this USAF report. It is from AFI (Air Force Instruction) 48-123 - Medical Examinations and Standards, Attachment 16, ***Height and Weight Tables***, 22 May 2001.

Back to Body Size in USAF Aircraft