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The U.S. Navy initiated a tri-service effort in 1994 to agree on a population data set representative of the future Department of Defense aviator pool, map current Naval aircraft crew stations, and standardize methods to evaluate crew member accommodation. The Joint Primary Aircraft Training System (JPATS) is specified to accommodate a much wider range of pilot body sizes than any other aircraft in USN/USAF history. Based on the jointly-selected JPATS population, the USN anticipated a concern for this expanded range of pilots to safely fly subsequent aircraft and a need to reengineer those aircraft to better meet a Congressional mandate for female accommodation.

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Safety of Flight and Anthropometry in United States Navy Aircraft

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ABSTRACT

The US Navy initiated a tri-service effort in 1994 to agree on a population data set representative of the future Department of Defense aviator pool, map current Naval aircraft crew stations, and standardize methods to evaluate crew member accommodation. The Joint Primary Aircraft Training System (JPATS) is specified to accommodate a much wider range of pilot body sizes than any other aircraft in USN/USAF history. Based on the jointly-selected JPATS population, the USN anticipated a concern for this expanded range of pilots to safely fly subsequent aircraft and a need to reengineer those aircraft to better meet a Congressional mandate for female accommodation.

To address this safety concern, the USN initiated the cockpit mapping effort to quantify safe pilot fit in all operational aircraft. The USN performs three-dimensional computer aided drafting (CAD) based cockpit measurements of the accommodation provided by each aircraft and measures the clearances, reaches, and field of view for a range of individuals. The end products are prediction equations that are used to determine a percentage of the target population (JPATS) that is expected to be accommodated in a particular aircraft. Aircrew candidate selections for a training pipeline and final operational assignments are based on achieving a suitable seat position.

INTRODUCTION

Cockpits in military aircraft prior to the Joint Primary Aircraft Training System (JPATS) have traditionally been designed to the most recent anthropometric survey of Naval aviators collected in 1964 (8). This survey and previous analyses consisted primarily of white males and evaluated only one body dimension at a time. A serious problem has presented itself due to this limiting design criteria since the introduction of smaller statured ethnic groups and females into the Navy's aviation community. Crew systems engineers have sought to devise design criteria alleviating most of the conflicting cockpit geometry and aviator anthropometric restrictions.

The Aircrew Accommodation Expansion Program (AAEP), based at the Naval Air Warfare Center Aircraft Division (NAWCAD) in Patuxent River, Maryland, is a team comprised of crew systems engineers tasked to perform aircrew accommodation evaluations of existing Naval aircraft. Aircrew accommodation is defined as satisfying all anthropometric requirements from an optimum seat position in order to achieve combat readiness, mission effectiveness, and safety of flight. Multivariate cockpit accommodation criteria ensures that an aviator can see effectively outside the aircraft, reach and operate crucial controls under appropriate harness locked conditions, and fit within the crew station design envelope.

The accommodation evaluations serve multiple purposes for the US Navy. Aviator suitability is determined based upon the differing anthropometrics of individuals, which will assist in determining the training and career pipelines future aviators should follow. Accommodation criteria contained in the detail specifications for procurement of Naval aircraft have historically called for the accommodation of individuals in the 5th to 95th or 3rd to 98th percentile ranges (8, 10). The current USN aviator screening process uses a set of anthropometric restriction codes (ARCs) (3, 5). The primary purpose of these accommodation evaluations is to provide a revision of the ARCs based upon new criteria.

AAEP also assesses the Navy's current capabilities in aircrew accommodation to provide a baseline for comparison between current aircraft and future accommodation expansion designs. Potential problem areas in safety of flight and/or operational requirements are identified, and engineering analyses with design recommendations are provided for crew station modifications of existing and future aircraft to accommodate the anticipated and anthropometrically expanded aviator population (2).

ANTHROPOMETRY AND THE JPATS DATABASE

Anthropometry is the science of measuring the human body. The AAEP team collects anthropometric measurements on prospective subjects using the methods prescribed in the 1988 Anthropometric Survey of Army Personnel (9). AAEP compares the subjects' measurements to the Joint Primary Aircraft Training System (JPATS) database for selection purposes.

The JPATS database, derived from the 1988 Army Survey, was created by the US Air Force. It is a tri-service agreement to satisfy a Congressional mandate for an accommodation of 80 percent of females in military aircraft, striving for 95 percent as a goal. The measurements collected on the subjects are compared to cases one through seven of the JPATS database. These cases represent the different combinations of anthropometric dimensions to be accommodated by the JPATS aircraft (12). AAEP selects test subjects that closely compare to the JPATS cases.

SCOPE OF TESTS

Evaluations of aircrew anthropometric accommodation in all the trainer aircraft (T-34C, T-45A, TA-4J, T-2C, T-44A, and TH-57C) were conducted at NAS Patuxent River, MD, and NAS Meridian, MS. Each of the evaluations typically required thirty hours of ground tests conducted over a three-day period. Subsequent ground tests for data verification were conducted at NAS Pensacola, FL, and NAS Patuxent River, MD. Aircrew accommodation data were collected in both crew stations with test subjects attired in the full complement of summer flight gear as specified for each aircraft (1). Evaluation of aircrew anthropometric accommodation includes the following five functional parameters:

a. External field of view (EFOV).
b. Functional arm reach (operation of critical flight and time-critical emergency controls).
c. Functional leg reach (operation of rudder pedals).
d. Cockpit volume clearances, including ejection clearances (where applicable).
e. Overhead/canopy clearance.

This evaluation does not address either additional accommodation limitations due to the effects of flying aggressive flight profiles or any limitations based on individual aircrew strength.

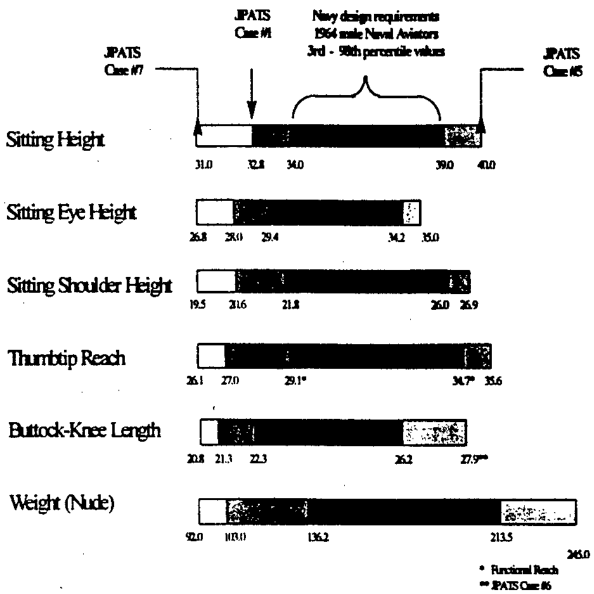
METHODS

Drawings of the cockpit, including NATOPS pull-outs, are used to identify the location of controls and clearance issues. Blueprint diagrams identify the aircraft coordinate system with respect to the butt, water, and fuselage station lines. These data are used in conjunction to establish a CAD drawing of the cockpit aligned to the aircraft coordinate system.

This effort requires the use of a portable Coordinate Measurement Machine (CMM). The CMM records data such as points, lines, and planes in a 3D space, and saves this data as an AutoCAD file. In addition to providing precise data collection, it allows digital storage and downloading of test data to the appropriate software programs for data reduction and analysis. The positions of all prescribed hand operated controls, rudder pedals, glare shield, overhead obstructions, and the knee cut-outs on the instrument panel are recorded and saved in this CAD file.

A minimum of ten subjects are brought to the aircraft after the initial cockpit geometry has been taken. The subjects represent diverse anthropometric dimensions and capture the extremes of the JPATS specification accommodation cases (see Figure 1). Each subject is evaluated in four seat positions ranging from full up to full down in the T-34C, T-45A, TA-4J, and T-2C. The T-44A had fore/aft seat movement as well as vertical movement; it was evaluated in the four extreme corners of seat positions. The TH-57C cockpit seats were non-movable.

Figure 1



A specific AnthroCAM computer routine is developed for each aircraft prior to the subject evaluations. The routine interfaces with the CMM, and prompts the evaluator to take data in the form of each subject's miss or over reach to controls, and clearance distances. Explicit measurement criteria are as follows:

- Clearance measurements are taken between the top of the helmet and the overhead/canopy surface or the canopy breakers in aircraft so equipped while the head is stationary and upright. The independent anthropometric variable for the equation is sitting height (SH).

- Lower leg clearance distances are measured between the shin line and the line along the lower edge of the main instrument panel. The independent anthropometric variable for the equation is buttock knee length (BKL).

- Rudder control capability is measured between the sole of the subject's boot and a nominal point on the rudder pedals while full throw of the pedals is attempted. The independent anthropometric variable for the equation is functional leg length (FLL).

- The ability of each subject to reach and operate the most remote essential or emergency control in each crew station is evaluated. Functional reach is evaluated in the Zone 2 condition (shoulder harness locked with maximal stretching of arm and shoulder). Sitting acromial (shoulder) height plus seat adjustment height establishes the discrete shoulder position of each subject as the origin of functional reach. The independent anthropometric variables for the equation are functional reach (FR) and sitting shoulder height (SAH).

- Vertical field of view is evaluated by determining whether the subject can establish a horizontal vision line through the design eye point (DEP). The independent anthropometric variable for the equation is sitting eye height (SEH).

Multivariate regression analysis is performed and accommodation prediction equations are produced where:

Dependent variable = miss/over reach or clearance distance

Independent variables = subjects' anthropometric measurements and recorded seat positions

The data generated by the routine are organized into a Microsoft Excel worksheet. The data are reduced into accommodation prediction equations using the software package Statistica and a series of outlier analyses. The final accommodation prediction equations are entered into a software package which delivers the predicted available seat adjustment range specific to the individual based upon his/her anthropometric dimension inputs for each completed aircraft. A percentage of the JPATS population is expressed by dividing the successful number of accommodated individuals by the total number of individuals in the JPATS population data set.

RESULTS

This analysis is based on an expanded range of anthropometric measurements reflecting the current candidate aviator population. Analyses of the accommodation data collected in each aircraft yield sets of accommodation prediction equations for each anthropometric dimension being investigated. These equations are then employed to determine fit/no-fit ranges for each anthropometric dimension in each completed aircraft. The fit/no-fit ranges are then mapped to the aircraft anthropometric restriction codes (ARCs) using the relationships shown in Table 1.

Table 1

CODE	SH (in)	FR (in)	BKL (in)	FLL (in)
9	40.0-41.0	</= 27.9	> 28.0	49.0-50.0
8	39.5-39.9	28.0-28.4	27.0-28.0	48.0-48.9
7	39.0-39.4	28.5-28.9	26.5-26.9	47.0-47.9
6	38.5-38.9	29.0-29.4	26.0-26.4	46.0-46.9
5	38.0-38.4	29.5-30.4	25.5-25.9	45.0-45.9
4	35.0-37.9	30.5-30.9	25.0-25.4	43.0-44.9
3	34.0-34.9	31.0-31.4	24.0-24.9	40.0-42.9
2	33.0-33.9	31.5-32.4	23.0-23.9	39.0-39.9
1	32.5-32.9	32.5-33.9	22.0-22.9	38.0-38.9
0	32.0-32.4	>/=34.0	</=21.9	36.0-37.9

The regression equations exhibit coefficients of determination (R^2) of 0.7 or above. Uncertainty introduced by the standard error associated with each regression equation is accounted for by the inclusion of a fit check range. The revised ARCs, derived as described above for the T-34C, T-45A, TA-4J, T-2C, T-44A, and TH-57C, are presented in Table 2 (10). Those codes listed within parentheses indicate personnel with specific dimensions that require a fit check. Codes not contained between a set of parentheses should not be assigned for flight duty in the corresponding aircraft. In the case of the T-45A aircraft, no official ARCs were previously available. This was in part due to a cancellation of an instruction which delegated responsibility for developing the ARCs (4).

Table 2

	SH	FR	BKL	FLL
T-34 Front			9 (8)	(9)
T-34 Rear	(0)		(9)	(9)
T-45 Front	0 8-9 (1-3) (7)	(9)	8-9 (7)	9 (7-8)
T-45 Rear	0-1 8-9 (2) (7)	(9)	8-9 (7)	9 (7-8)
TA-4 Front and Rear	(0-1)	8-9 (5-7)		
T-2 Front	0-1 (2)	7-9 (4-6)	0 (1) (8-9)	(0-3) (9)
T-2 Rear	0-1 (2)	7-9 (4-6)	0 (1) (8-9)	(0-3) (8-9)
T-44 Right	(0-1)	7-9 (4-6)	(0-1)	(0-2)
T-44 Left	(0-1)	9 (5-8)	(0-1)	(0-2)
TH-57 Right and Left	(0-1) (7-9)		9 (8)	(0) (9)

AIR 4.6 has recommended revisions to instructions (3, 5) to reflect the aircraft anthropometric restriction codes contained in Table 2. It is also recommended that Table 1 eliminate the open ended dimensions and cap all codes 0 and all codes 9 as absolute boundaries (6, 7).

CONCLUSIONS

Accommodating the anthropometrically expanded aviator population of today's Navy poses quite a challenge for both aircraft manufacturers and crew systems engineers. It requires a well-balanced combination of teamwork, technology, skill, and persistence. Obtaining accurate anthropometric data is crucial in assessing existing aircraft accommodation and providing reengineering recommendations. Newly developed ARCs and software packages will aid in this process in order to bring together the best mix of aircrew and aircraft. These tools will be delivered to the fleet, the final customer, and will assist in saving time and money when deciding which career path a future aviator will follow. Most importantly, however, is these tools will also aid in protecting the lives of those future aviators.

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BIOGRAPHIES

Heather D. Tucker has been employed by the Naval Air Warfare Center in Patuxent River, Maryland, since 1996. She is a project engineer assigned to the Aircrew Accommodation Expansion Program. She is responsible for data collection and analysis of anthropometric assessments of Navy aircraft, and creating a software program to analyze aviator accommodation in all existing aircraft and predict aviator candidate pipeline assignments. Ms. Tucker received a Bachelor of Science in Industrial Engineering from West Virginia University, and is currently pursuing a Master of Science in Systems Management/Operations Research from Florida Tech University.

Jennifer J. Crawford provides support to the Aircrew Accommodation Expansion Program which is located at the Naval Air Warfare Center in Patuxent River, Maryland. She has been a member of this team for two years performing duties such as data collection and analysis on anthropometric assessments of Naval cockpits and test preparation and coordination. She is certified to operate the FaroArm™, a coordinate measurement machine, and is also certified to take anthropometric measurements on humans. Ms. Crawford received her Bachelor of Science in Industrial Engineering from West Virginia University.