# EXPANDED ACCOMMODATION ANALYSIS AND RAPID PROTOTYPING TECHNIQUE FOR THE DESIGN OF A CREW STATION COCKPIT

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## Abstract

This paper presents a PC based mathematical and rapid prototyping technique for anthropometric accommodation in the design of crew station cockpits using the principle of simulation based design. The developed technique, called “Expanded Accommodation Analysis Technique” (EAAT), is capable of analyzing anthropometric data using multivariate Principal Component Analysis (PCA) approach to describe the body size variability existing in a given flying population. A number of body size representative cases are established which, when used properly in specifying and designing any cockpit, will ensure the accommodation of a desired level of the population.

The technique evaluates the percentage accommodation of a given population in a cockpit that is to be designed using specific manikin cases as boundary conditions. The data on the manikins is used to design the cockpit in order to ensure the accommodation of the established percentage. In the case where any of the manikins cannot be accommodated, the technique has the capability of informing the designer why the manikin(s) is not accommodated. The technique is interactive and user friendly, requiring little or no training from a new user.

## 1 Introduction

In 1977, the Air Force began accepting women into pilot training, but limited them to trainers, transports, tanker and other non-combat aircraft. Early 1993, shortly after the Congress rescinded the combat exclusion law, the Secretary of Defense rescinded the combat exclusion policy, and first woman began training as a fighter pilot. This event also marked a major change in ergonomic design practices. This period saw design standards undergo an evolutionary change to include additional requirements for the expanded accommodation.

In the spring of 1993, the Department of Defense formed a working group to expand the accommodation of females and smaller males in the Joint Primary Aircraft Training System (JPATS). The working group specified new anthropometric requirements in the design of aircraft.

This wider accommodation requirement presents a number of challenges such as:

a. Provide adequate access to controls for small pilots without compromising the ejection clearance requirement for the large pilots.
b. Provide adequate seat adjustment for small pilot visual access to the Head Up Display (HUD) eye box.

It is for this purpose that it is necessary to provide forehand to the designer the percentage of the population that will be accommodated in all future alternative designs in order to ensure adherence to accommodation specifications.

## 2 Design Approach

A major problem with computing such percentage accommodation comes from the methods used traditionally to specify and test new aircraft accommodation. For many years, cockpit designs have been based on the concept of accommodating a typical percentile range, for example, 3rd to 98th percentile for a limited number of critical anthropometric dimensions. This concept was inappropriately extended to larger numbers of dimensions and eventually evolved into the "*percentile man*" concept in which essentially all body dimensions were included.

Percentiles are univariate (one variable) statistics that indicate the relative location of a variable with respect to a distribution of a value for that variable. Percentile values from one variable are unrelated to those of other variables. The percentile approach failed to consider flyers that had varying combinations of anthropometric dimensions (e.g. short torso and long trunk). As has been shown by Robinette, K.M. and J.T. McConville [1], no single individual within a population can have all his/her anthropometric dimensions on any single percentile value. Thus, bringing about a lot of uncertainties as to the actual percentage of the population accommodated within these percentile ranges. Zehner et al. [2-4] have shown that the range of people accommodated with percentiles is much less than the desired.

The errors inherent in this procedure lead to great difficulties for some flyers in the operation and escape from their aircraft. It is to correct these deficiencies that previous work in this area identified the multivariate approach as suitable in describing body size variability, and thus prompted the introduction of such method by the United States Air Force (USAF).

Multivariate method deals with the simultaneous relationships among the anthropometric variables. Here, attention is drawn away from the mean and variance of one or two variables (univariate and bivariate methods), and focuses on the covariance or correlation of a set of variables. This describes a composite population that considers the variability of the data.

By utilizing the method of multivariate data analysis, a 3-D mathematical and graphical analysis tool that can provide population accommodation estimates for a given population in the design of cockpits has been developed [5]. Necessary inputs into the tool include the sample population database, and the boundary limits of accommodation, which may include a desired percentile limit or specific manikin case representations (e.g. JPATS manikins)[6]. In this approach, designers will be able to calculate the actual percentage accommodation values from their percentile limits.

## 3 Principal Component Analysis (PCA)

Principal Component Analysis is a suitable technique that describes the multivariate structure of a sample population. It is a data reduction method that reduces a large number of variables to a smaller number of principal components, without any loss in the analytical objectives.

In PCA, new linear combinations of the original $p$ variables provide $d$ orthogonal (mutually independent) principal components.

Each of these principal components explains different amounts of variation contained in the sample space. These new axes show no correlation within the population. For instance, for any two principal components $PC_i$ and $PC_j$:

$$PC_i = f_{i1}Z1 + f_{i2}Z2 + \ldots + f_{ip}Z_p \qquad (1)$$

and

$$PC_j = f_{j1}Z1 + f_{j2}Z2 + \ldots + f_{jp}Z_p \qquad (2)$$

In which the ($f_{i1}$, $f_{i2}$, … $f_{ip}$) represent the weights (eigenvectors) of the standardized variables $Z_1$, $Z_2$, …$Z_p$ (Z scores) on principal component i, $PC_i$ and $PC_j$ are completely orthogonal

Where,

$$Z_p = (X_p - \mu_p)/\sigma_p \qquad (3)$$

Some of the principal components represent major axes of variation, while some are much less important. Those principal components that account for minimal variation are discarded.

PCA may reveal that some of the original variables are needless redundancies. The subsequent elimination of a variable can only be justified after its careful consideration in a truly multivariate context.

## 4 Use of PCA in the Development of the Tool

The computational steps for the PCA-based numerical solution of a multivariate problem is as given below:

1. Choose the anthropometric data (X) to analyze.
2. Compute the mean (μ) and the standard deviation (σ) of each variable in the original data.
3. Compute the Z-score matrix of the original data.
4. Compute the correlation matrix or co-variance matrix of the Z-score matrix.
5. Compute the eigenvalues and the eigenvectors from the correlation matrix or co-variance matrix
6. Use the eigenvectors and the Z-sores to compute the principal components.
7. Plot a graph of the principal components.
8. Compute percentile levels of accommodation using "confidence level"
9. Compute percentage accommodation of the original data using predetermined manikins cases (under the assumption of a similar means and variance to the population data) as the accommodation limit.

The tool developed consists in path components for environment and cockpit modeling, cockpit and environment prototyping, and accommodation analysis [7].

## 5 Accommodation Analysis

The Graphical User Interface (GUI) of the tool developed is as shown in Figure 1.

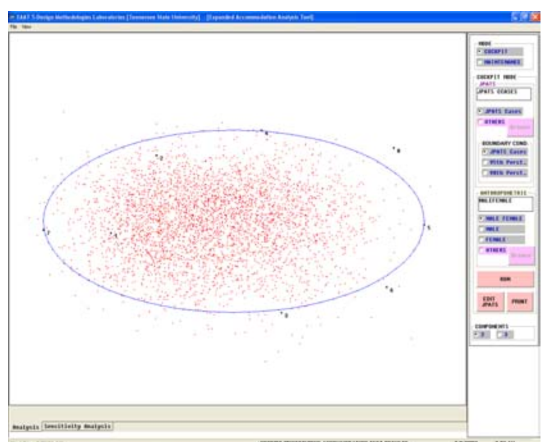

Figure 1: GUI for percentage accommodation analysis

The interface gives the designer options to select the design variables to use in the analysis, the population data, the boundary conditions (JPATS in this case), and the type of analysis to perform (2 or 3 components analysis). The status window gives the percentage accommodation for the population and the variance computed by imposing the chosen options. Other advance features include options to view data for manikin that are not accommodated. This data can be transferred to prototyping environment to view their performance on the design.

## 6 Modeling

The Modeling tool is in two parts

- Cockpit modeling
- Environment Modeling

### 6.1 Cockpit Modeling

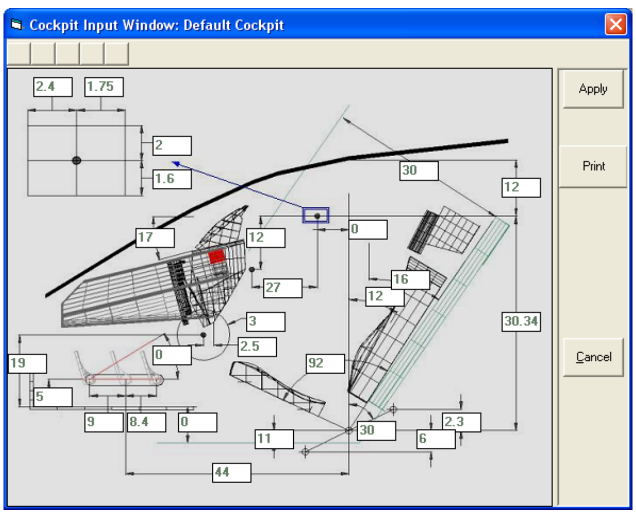


Figure 2: Cockpit Input Window

The cockpit-input window (Figure 2) allows a designer to configure any cockpit design into the prototyping tool. This is achieved by setting the dimensions and location definition of the basic cockpit components like the control panel and seat move distances. The model generated is then stored in a database.

### 6.2 Environment Modeling

The environment modeler (Figure 3) is used to generate models of task environment. The environment modeler uses collection of primitives objects to compose any maintainer environment. All generated environment models are stored in model database.

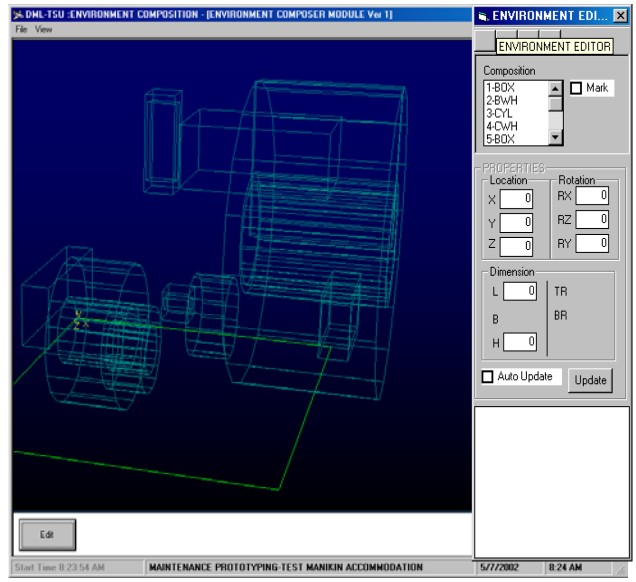


Figure 3: Environment Modeler

## 7 Prototyping

Prototyping in EAAT is a means of investigation of how a pilot or a maintainer will perform different task in new design environment before an investment in actual construction.

### 7.1 Cockpit Prototyping

The cockpit developed using the modeler can be prototyped. To achieve this, the EAAT uses the anthropometric database of manikins used as the design boundary to generate a computer model of the manikin. The generated manikin is inserted in the developed environment model for investigation. A visual representation of the manikins can be viewed in 2-D (Figure 4) and 3-D (Figure 5). The user can switch the views from 2-D to 3-D into an orientation

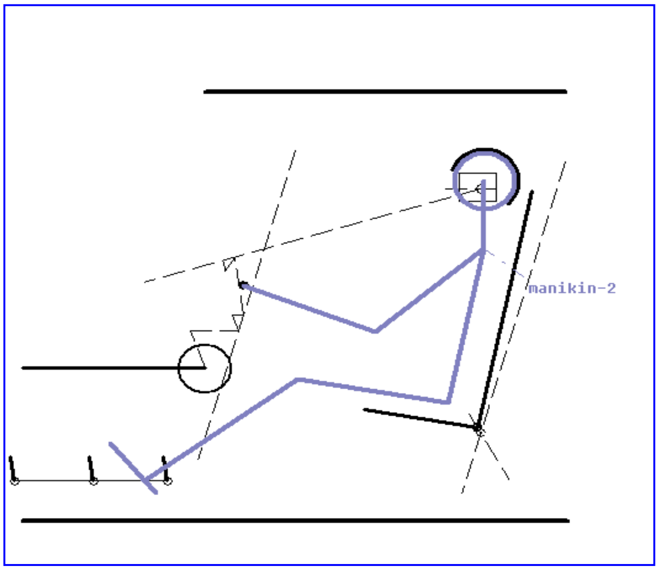


Figure 4: 2-D Cockpit Prototyping - Manikin 2

The prototyping feature has the ability of showing 9 manikins generated from the database.

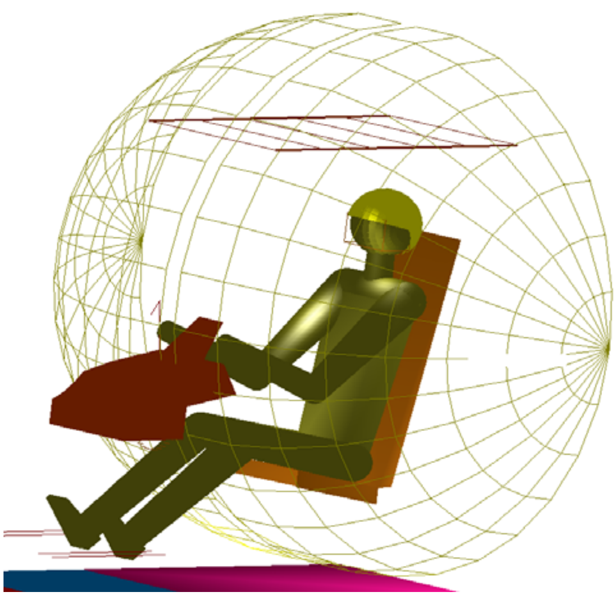

Figure 5: 3-D Cockpit with Reach Envelope

Analysis ability of EAAT includes giving the accurate task miss distance outputs, point-to-point distance analysis.

The 3-D view mode allows further analysis into side task reach and reach envelope analysis as shown in Figure 5.

## 7.2 Environment Prototyping

Similar to the cockpit prototyping, the environment prototyping tool can be used to investigate how a maintainer can perform a task in the maintenance environment. The EAAT use four standard postures, standing, squatting, bending and kneeling, to examine how a task will be performed. Figure 6 illustrates a maintainer in a squatting position.

Using models in this manner help to achieve prove of design concept usability, to investigate different design concept and also to manage the process of improving existing designs. All cockpits and environment prototype developed using the modeler can be prototyped. To achieve this the EAAT uses the anthropometric database of the manikins used as the design boundary to generate a computer model of the manikin. This generated manikin is inserted in the developed environment model for investigation.

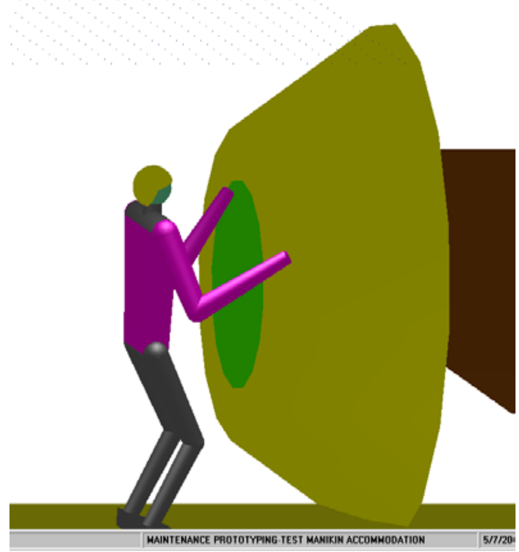


Figure 6: GUI for Maintainer Environment

## 8 Sensitivity Analysis with the EAAT

To fully utilize the EAAT as an aid for proper design accommodation analysis, this tool not only gives percentage accommodation numerically and graphically, but also provides the designer with a sense of the factor(s) bringing about dis-accommodation in the analysis. Thus, necessary changes can be made to meet the design goals.

In order to accomplish this, there is a need to have some information on how each variable affects the percentage accommodation. This is illustrated by a graphical representation of the weight (eigenvectors) of the different variables on each component, as shown in Figure 7. The Figure shows the variables that are dominant on each component. Looking at component 1, it can be observed that variable number 1 is the most dominant. This means that the adjustment of this variable will bring about the most significant change on component 1. This future reduces the occurrence of unnecessary variable changes.

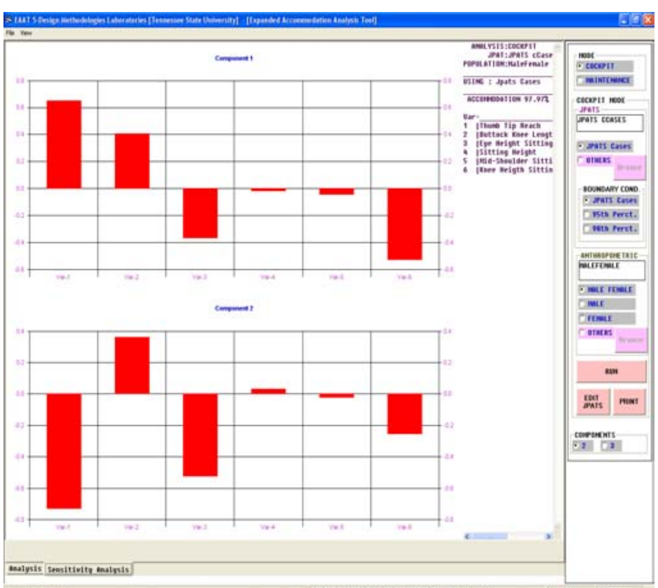

Figure 7: Sensitivity Analysis Plot

## 9 Conclusion

The development of the Expanded Accommodation Analysis Technique makes it very easy and more efficient to assess accommodation of a given population in the design of crew stations and maintainer environment. The technique can also show areas of possible improvement and helps to develop new design manikins cases if necessary

The technique is primary in the rapid prototyping of cockpits in the design of crew station since it enables designers to quantify the percentage of a given population his/her design is going to accommodate. With this technique, accommodation and reached detail is effectively considered in the design process. Hence, adherence to stringent accommodation specifications in the design of the crew stations is ensured.

The technique can also be used in the design of other systems that accommodate human beings e.g. automobiles, sporting equipment etc. where the designer has to design his/her systems to accommodate as many percentage of a given population as possible.

The tool developed is robust and has a friendly user-interface. It was developed using Visual Basic platform for all personal computers.

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