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ARMSTRONG LABORATORY

COMPUTER MODELS FOR ERGONOMICS (U)

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Kenneth R Boff

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This final report of Computer Models for Ergonomics describes the work on this contract. There has been enhancements to the COMBIMAN and CREW CHIEF programs. CREW CHIEF is a computer model of an Air Force maintenance technician, and may be used to evaluate maintainability of aircraft, as well as equipment in general. COMBIMAN is a computer model of an aircraft pilot, and may be used to evaluate cockpit accommodation, for a seated operator, in general. Both models are interfaced directly to commercial CAD systems.

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SUMMARY

Under previous efforts, Armstrong Laboratory developed two human models, COMBIMAN and CREW CHIEF. CREW CHIEF is a computer model of an Air Force maintenance technician, and may be used to evaluate maintainability of aircraft, as well as equipment in general. COMBIMAN is a computer model of an aircraft pilot, and may be used to evaluate cockpit accommodation, as well as accommodation for a seated operator, in general. Both models are interfaced directly to commercial CAD systems, and execute as third-party applications under these CAD systems.

CREW CHIEF simulates the non-trivial physical activities of the Air Force maintenance technician, including working with hand tools, hand controls, and manual materials handling activities in various postures. These activities are modeled as a function of body size, strength, and encumbering personal protective equipment. Special attention is given to the evaluation of visual and physical accessibility of the system being maintained. The question answered by the CREW CHIEF model is "Can the maintenance technician perform a specified physical activity?"

COMBIMAN simulates the non-trivial physical activities of an Air Force pilot or, more generally, of a seated operator, and include such activities as reaching and actuating aircraft controls, in-flight ejections, and monitoring read-outs and displays in the cockpit. Similar to CREW CHIEF, the emphasis of a COMBIMAN analysis is on physical and visual accessibility.

These computer models are CAE tools used by a designer to evaluate some aspect of human physical performance. The object of the analysis-- the aircraft or cockpit being analyzed-- is usually in the preliminary design phase, which is to say, that it is still "on the drawing board," and does not yet exist in a prototype form. By performing such human factors in this phase of development, designers have more latitude to make meaningful changes to improve ergonomics in their designs, as opposed to waiting until a prototype exists, and even minimal changes become much more costly.

The work on this contract relates to enhancements to, support for, and additional data collection for these two computer models. Some of the enhancements were dictated by the Statement of Work (SOW), while others were developed based on input from current users. Support includes such things as software management, distribution, and promotion. And human physical performance data were collected in support of enhancements or to refine existing data

models used in COMBIMAN or CREW CHIEF. Section 1 gives an executive overview of the final report. Section 2 describes the enhancement and update of CREW CHIEF. Section 3 describes the enhancement and update of COMBIMAN. Section 4 discusses the general support to software development. Section 5 discusses the ergonomics research.

PREFACE

The research documented in this report was performed between 26 December 1989 and 31 March 1994 by the University of Dayton Research Institute (UDRI) under USAF Contract F33615-89-C-0575, "Computer Models for Ergonomics," sponsored by the Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL) and the Air Force Human Resources Laboratory (AFHRL). The project number for this contract is 718408. AAMRL is the monitoring laboratory and Dr. Joe W. McDaniel of the AAMRL Design Technology Branch is the project engineer. The principal investigator is Mr. Philip J. Krauskopf (UDRI).

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SECTION I - INTRODUCTION

U.S. Air Force contract F33615-89-C-0575, "Computer Models for Ergonomics," was issued for exploratory development and research to enhance maintainability and workstation effectiveness of future Air Force weapons systems through the application of biomechanical engineering data and techniques. The research aspect of this effort was the expansion of the databases describing maintenance technician and crew member limitations, such as physical strength and endurance characteristics of male and female Air Force workers; body size limitations for fit and reach accommodation; limitations on tool and equipment manipulations due to restricted workplaces; personal protective equipment and clothing (including appropriate space suits and clothing); visual degradation due to personal protective equipment and restricted workplaces; and the duration of manual activities. The development aspect of this effort included enhancements to computer models of the maintenance technician and air crew members; the creation of data models and algorithms relating these ergonomic limitations and capabilities to specifications for weapon system maintainability; design specifications, standards and handbooks; and the creations of Computer-aided Engineering (CAE) software tools to support design, evaluation, source selection, and trade-of studies for system acquisition.

1.1 Background

Under previous efforts, Armstrong Laboratory developed two human models, COMBIMAN and CREW CHIEF. CREW CHIEF is a computer model of an Air Force maintenance technician, and may be used to evaluate maintainability of aircraft, as well as equipment in general. COMBIMAN is a computer model of an aircraft pilot, and may be used to evaluate cockpit accommodation, as well as accommodation for a seated operator, in general. Both models are interfaced directly to commercial CAD systems, and execute as third-party applications under these CAD systems.

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These computer models are CAE tools used by a designer to evaluate some aspect of human physical performance. The object of the analysis-- the aircraft or cockpit being analyzed-- is usually in the preliminary design phase, which is to say, that it is still "on the drawing board," and does not yet exist in a prototype form. By performing such human factors in this phase of development, designers have more latitude to make meaningful changes to improve ergonomics in their designs, as opposed to waiting until a prototype exists, and even minimal changes become much more costly.

The work on this contract relates to enhancements to, support for, and additional data collection for these two computer models. Some of the enhancements were dictated by the Statement of Work (SOW), while others were developed based on input from current users. Support includes such things as software management, distribution, and promotion. And human physical performance data were collected in support of enhancements or to refine existing data models used in COMBIMAN or CREW CHIEF.

1.2 Enhance and Update CREW CHIEF

Over the course of the previous contract, CREW CHIEF users and potential users were surveyed and questioned concerning enhancements to the CREW CHIEF model that they would find useful. The two major enhancements most often cited by these customers called for explicitly in the contract. In addition, since CREW CHIEF interacts directly with commercial CAD systems and databases, customers were queried concerning their current and projected CAD development platforms, with the intention of porting the CREW CHIEF model to those particular platforms. During this contract, versions 3 and 4 of CREW CHIEF were released.

Since the Air Force is beginning to require that weapons systems manufacturers consider maintenance times in their designs, and since no method existed for the accurate and standard estimation of these times, the single most requested enhancement to the CREW CHIEF model was the development of an objective Time-to-Repair estimation capability. Most of the experimentation performed under this contract went towards collecting data to support development of this capability. Even so, because of the immense quantity of data required, and because of unexpected funding cuts experienced throughout the life of the contract, not all aspects of this capability were fully developed under this contract. An initial capability was developed, with some time estimation capabilities. However, there are still data needed in particular areas; and flight-line validation was not possible under this effort.

With the construction of the Space Station Freedom, and as people venture further out into space for more extended periods of time, equipment will, of necessity, become more reusable, and extra- and intra-vehicular maintenance activities will become more prevalent. Consequently, designers need to begin to consider human physical capabilities in space, and the way they differ from earth-bound capabilities. So, the other major enhancement to the CREW CHIEF m was the development of a model for performing maintenance in space. The unique conditions and requirements of micro-gravity and working in a vacuum dictate a whole new set of capabilities and limitations for a human model. Just as human physical capabilities change, so too the personal protective equipment worn by maintainers, the actual maintenance tasks required, and even the tools required by and available to the space-bound maintainer are different.

According to the CREW CHIEF users, one of the most desirable characteristics of the model is the fact that it interacts directly with the user's CAD drawing, and completely avoids any need to translate the drawing from one format into another. Indeed, changes in the design of a major weapons system are more the rule than the exception, and fifty or more changes in a single subsystem each week are not at all unusual. Under these conditions, designers do not have time to reformat their electronic drawings. Consequently, the CREW CHIEF-CAD interfaces were evaluated under this effort, with the intention of ensuring that the aircraft designers' CAD systems be directly supported by the model. While the original SOW required rehosting CREW CHIEF to three IBM- and three VAX-based CAD systems, the aerospace community does not appear to use many VAX-based CAD systems, so only one such interface was developed. In addition, there were additional interfaces developed that do not fall into either of the categories mentioned above.

1.3 Enhance and Update COMBIMAN

COMBIMAN development began in the mid-1970s, and includes many data models, as well as many analytical models. This is a relatively mature product, but there are still enhancements that could improve the model significantly. The contract describes in detail two major enhancements to be performed on the COMBIMAN model. In addition, since COMBIMAN interacts directly with commercial CAD systems and databases, customers were queried concerning their current and projected CAD development platforms, with the intention of porting the COMBIMAN model to those particular platforms.

When COMBIMAN was first developed, 3-D commercial CAD systems did not yet exist. Consequently, since COMBIMAN requires 3-D digitized data, it was developed as a stand-alone CAD system. As mentioned earlier, though, systems designs today change so rapidly that designers do not have the time required to reformat these design data just to perform CAE analysis. Therefore, one of the major enhancements required under this contract was to develop a host-independent COMBIMAN, using the host-independent CREW CHIEF model as a basis for development.

The COMBIMAN model was first developed assuming a specific seatpan and seatback angle. However, many of today's high-performance aircraft use reclined seats. Modifying COMBIMAN to accurately simulate these reclined seats was possible, but the procedure was tedious, and required the COMBIMAN user to modify both his geometry, as well as the sitting posture used for analysis. Because of this, the second major enhancement spelled out in the contract was to develop seat models and a conform-to-seat capability for COMBIMAN.

Similar to CREW CHIEF, COMBIMAN interacts directly with the user's CAD drawing, so it needs to be hosted to those CAD systems used by cockpit designers. This contract required that these CAD systems be identified, and that COMBIMAN be hosted to them.

1.4 General Support for Software Development

Besides all the direct development work already mentioned, there are many activities required for supporting the models in general. These activities cover a wide range of topics, including distribution, training, configuration management, documentation, validation, and software and hardware acquisition and maintenance. Minor enhancements, those requiring significantly less effort than those mentioned earlier, are also covered under this heading.

The contract SOW required that two video tapes be produced. The first video tape, which was to be approximately 10 minutes long, was to display an overview of CREW CHIEF and its capabilities. The second video tape was to be instructional, and was to last approximately 30 minutes. Because the contract was under-funded, however, the effort on the first video tape had to be reduced, and the second tape had to be eliminated altogether.

Many potential users visit the Computer-Aided Workplace Design Facility (CWDEF) throughout the year, to evaluate the utility of CREW CHIEF and COMBIMAN for their needs. Consequently, demonstrations of each program must be available at all times. To make the most efficient use of these visitors' times, these demonstrations must be prepared and rehearsed before hand.

Sometimes users will visit the CWDEF to obtain training in the use of one or both programs. These users are often times not well versed in the use of the CAD system, itself. Thus UDRI developed and maintained training procedure and used these procedures to teach customers how to use correctly COMBIMAN and CREW CHIEF.

Under the subject SOW, UDRI was required to use COMBIMAN and CREW CHIEF to provide solutions for applied design problems, and to perform statistical analysis as necessary for these design problems. Problems in several workplace designs were analyzed and improved under this contract.

In order to help disseminate the models and information developed under this effort, UDRI intended to develop and conduct an off-site workshop on human modeling technology. However, limitations in funding also prevented the successful development of this workshop.

Periodic communication with current users of both COMBIMAN and CREW CHIEF are critical for maintaining tools that are both useful and easy to use. UDRI conversed with several users to elicit both future enhancements and information of problems encountered while using these programs. This information was used to improve the models when possible.

Because of the size and complexity of the CREW CHIEF and COMBIMAN models, strict procedures must be followed to ensure that enhancements merge as seamlessly as possible with existing code and functionality. In addition, since any corrections required in the program core modules must be distributed across several hardware and CAD platforms, strict procedures must be in place to ensure the corrections get added everywhere. UDRI employed a waterfall software development method to ensure these goals.

Each hosting of the human modeling programs must be configured to allow it to be ported to systems outside the Air Force. It must be configured to allow easy installation, while not violating CAD vendor copyrights. It must be configured to allow easy installation of updates. And it must be configured to support more than one version of a particular CAD host. UDRI configured each hosting for distribution using these criteria.

Because of the complexity of these programs, one must develop user's guides that provide both quick reference for procedural questions, as well as detailed reference for proper application of the software. These user's guides must be tailored for each CAD host, since the software is tailored thusly. Under previous contracts, UDRI developed a format for user's guides that met these goals to a large extent. The effort under the current both applied this format to individual CAD hostings, and provided improvement to the format, as a whole.

In addition to user documentation, UDRI was required to document the source code for both models, so that future enhancements to the software can be done expeditiously. As a matter of course, UDRI incorporates this type of documentation into any source code we develop. Because of this, and because of funding shortfalls, this documentation was not set down onto paper, and the deliverable items were deleted.

One of the most important tasks required under this contract is the validation of all software and models. Validation of the CREW CHIEF and COMBIMAN models included validation of the models, themselves, as well as validation of the software. For the models both experimental and real-life tasks were used. The software was generally validated using 100% testing on the databases.

1.5 Ergonomics Research

The amount of data required to support the CREW CHIEF and COMBIMAN models is immense. Some of the data exist already, and are maintained in an ergonomics library located on-base. Much of the data need to be collected; these experiments must be carefully planned to ensure that enough and correct data are collected. Much of this experimentation requires custom or new laboratory equipment.

Whenever possible, UDRI used existing data for the COMBIMAN and CREW CHIEF models. However, the requirements of these models are often so stringent that data either do not exist, or are entirely inadequate for their needs. In these cases, UDRI designed, performed, and reported experimentation to fulfill these data needs. Experimentation was performed measuring human physical and visual characteristics as they relate to workplace accommodation. In addition, a large portion of the ergonomic research performed during this contract was to satisfy data requirements for the Task Time Estimator.

UDRI also provided support to the Air Force by using the COMBIMAN and CREW CHIEF programs to solve applied design problems. UDRI personnel created electronic mockups of the designs being evaluated, by either translating and simplifying existing electronic mockups, or by creating these mockups from scratch using paper-based technical drawings. The programs were then exercised to evaluate the human-workplace interaction.

During the course of this contract, UDRI developed, acquired, and maintained equipment for the Physical Ergonomics Laboratory. Most of the fabrication was performed in the workshop facilities available to the Physical Ergonomics Laboratory. High-precision equipment was calibrated at the USAF PMEL facility. Records for all new and existing equipment were maintained.

UDRI maintained and improved the library facilities during this contract. Several new items were acquired for it. And a new organizational structure was developed for it.

The work performed under this contract was planned using an integrated research plan. This plan covered all aspects of the effort, including CAD system interfaces, program enhancements, major mathematical models, and major research thrusts. In addition, each individual research study was fully planned and approved.

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SECTION 2 - ENHANCE AND UPDATE OF CREW CHIEF

The contract SOW contained three major areas of enhancement for the CREW CHIEF model. The first was the development of a task time estimation capability for aircraft maintenance tasks. The second was the development of models of maintenance in space. And the third area was the rehosting of CREW CHIEF on additional IBM- and Vax-based CAD systems. In addition, all of the CREW CHIEF software and documentation had to be maintained.

2.1 Develop Time-to-Repair Computation

UDRI's continued development of the Task Time Estimator computations included the following:

1. Study methods for task time prediction.
2. Study Industry Requirements.
3. Revise development plan.
4. Perform research.
5. Develop TTE capabilities for CREW CHIEF
6. Validate Time-to-Repair estimates.
7. Hosts for enhancements

Study Methods for Task Time Prediction. During the initiation of the Task Time Estimator UDRI studied numerous methods of collecting and predicting task time data. The most commonly used methods are:

1. Occurrence Sampling - used to measure activities and delays of workers or machines,
2. Time Study - used to determine a time standard for performing a given task, and
3. Predetermined Time Systems - used to predict task time by assigning predetermined times to basic motions.

Study Industry Requirements. As part of our background research, UDRI contacted several major aircraft manufacturers to gain a better perspective on the current methods of predicting aircraft maintenance times. UDRI spoke with representatives of the aircraft companies' Maintainability Divisions to ascertain the current methods of predicting aircraft maintenance times, to present the current capabilities of CREW CHIEF, and to determine the desired capabilities of the Task Time Estimator. The five aircraft manufacturers visited to define requirements for the task time estimator were: Boeing Commercial Aircraft Co., Seattle, WA; Douglas Aircraft Co., Long Beach, CA; General Dynamics, Fort Worth, TX; Lockheed Aeronautical Systems Corp., Burbank, CA; and Rockwell International, Lakewood, CA.

Revise Development Plan. Throughout the development of the Task Time Estimator, UDRI continued to revise and update the TTE development plan as a result of experimentation and discussions with the Air Force, and our sub-contractors at Anthropology Research Project, and Texas Tech University. Development plans and revisions were presented to the Air Force during a Preliminary Design Review (PDR) {Attch 1, CDRL Sequence 3}, a Critical Design Review (CDR) {Attch 1, CDRL Sequence 3}, and the final Research Program Plan, Volume I {Attch 1, CDRL Sequence 5}.

Perform Research. UDRI planned and conducted numerous time and motion studies during this contract employing nearly 500 subjects logging over 1100 hours of actual data collection.

Develop TTE Capabilities for CREW CHIEF. The Task Time Estimation (TTE) function calculates the time required to remove and replace individual components and subsystems within a proposed design. This function takes into account such things as obstruction cased by other parts of the system, body posture, clothing, fatigue, and also the tools being used (if any).

Validate Time-to-Repair Estimates. UDRI performed time study research to validate existing data and developed a plan for validating the Task Time Estimator time-to-repair estimates.

2.1.1 Study Methods for Task Time Prediction

During the initiation of the Task Time Estimator UDRI studied numerous methods of collecting and predicting task time data. The most commonly used methods are:

1. Occurrence Sampling - used to measure activities and delays of workers or machines,
2. Time Study - used to determine a time standard for performing a given task, and
3. Predetermined Time Systems - used to predict task time by assigning predetermined times to basic motions.

The following is a brief description of those three methods.

<u>Occurrence Sampling</u> is exactly what its name implies. Sample observations are made at random over a period of time to detect the occurrence of the activity under study. Occurrence Sampling has three main uses: (1) to determine the percentage of the day that a person is working and the percentage that he or she is not working, (2) to establish a performance index or performance level for a person during his or her working time, and (3) to establish a time standard under certain circumstances. Establishing a time standard using Occurrence Sampling is done by simply dividing the number of work units produced by the time the person was performing work. For example, it is determined over the course of a two-week-long Occurrence Sampling study that a person is working 85% of the time, and that he or she produc( ) work units during that time; the time for a single unit would be:

$$80 \text{ hours} \times .85 = 68 \text{ hours}$$

$$100 \text{ units}/68 \text{ hours} = 1.47 \text{ units/hour}$$

Although Occurrence Sampling can be used in some cases to determine time standards, it is generally agreed that time study and the use of Predetermined Time Systems (PTSs) are superior for that purpose. Therefore, occurrence sampling was not used as a data collection method.

<u>Time study</u> is a technique of establishing an allowed time for performing a given task based upon measurement of the work content of the prescribed method. The objective of time study is to determine reliable time standards for all work both direct and indirect. (Indirect work involves such things as machine time which is beyond the control of the worker.) The exact procedure for performing a time study may vary depending upon the type of operation being studied. However, there are four fundamental steps:

Step 1: Define task method

The first step is to accurately define the task and the exact method for performing the task. This is done by partitioning the task into task elements and recording the complete description of each element and the sequence in which the elements are performed.

Step 2: Measure task time

Once the task method has been defined and divided into elements, the next step in performing a time study is to actually measure the time required to perform each element of the task.

Step 3: Rate the operator's performance

The next step in conducting a time study is to rate the operator's (or technician's) performance. The pace, or rate of speed at which the operator performs a task, directly influences the measured time.

Step 4: Determine the number of samples to measure

The time required to perform the elements of an operation may vary slightly from one time to the next. Variations in time may result from such things as a difference in the exact position of the parts and tools used by the operator, or from possible differences in determining the exact end points by the analysts. Time study is a sampling process; thus the greater the number of task cycles timed, the more closely the results will represent the activity being measured.

The formula show below can be used to estimate the number of samples needed to estimate the true average time values.

Let N = actual number of readings of an element.

and

X = individual readings of an element.

Then

$$\bar{X} = \frac{\sum X}{N} \quad = \text{ average of sample mean of all readings of that element.}$$

Now N' represents the required number of observations to predict the true time within ±5% precision and 95% confidence level (i.e., the chances are at least 95 out of 100 that the sample mean will be in error more than ±5% of the true element time) is given by:

$$N' = \left(\frac{40\sqrt{N\sum X^2 - \left(\sum X\right)^2}}{\sum X} \right)^2$$

If a 90% confidence level and a precision of ±10% are used as the criteria, then the formula will be:

$$N' = \left(\frac{20\sqrt{N\sum X^2 - \left(\sum X\right)^2}}{\sum X} \right)^2$$

The first **Predetermined Time System** (PTS) was developed to establish motion time values. In the original research, the operations were filmed and then analyzed frame-by-frame. The researchers defined the basic motions, such as reach and move. The time values for these motions could then be determined by counting the number of elapsed frames of film.

The procedure for determining standard times using a PTS is relatively straightforward, but requires a high degree of precision and skill by the analyst to produce accurate and consistent results. To compute a total time for a task, the task must first be divided into the specific motions recognized by the particular PTS. Predetermined Time Systems have divided motions into classes of motions such as reach, grasp, select, position, search, etc. Each class of motions is further subdivided into specific categories. For example, a reach can be divided by the different lengths of reach (i.e., 1, 2, 3, . . . 30 in.), and types of reach (i.e., reach to object in fixed location, reach to object whose general location is known, reach to object jumbled in a group with other objects, reach to a small object, etc.). Once the task has been divided into its basic motions, the times for each motion are obtained from the

PTS database. To determine the normal time estimate, the time values associated with each motion of the task are summed.

Predetermined Time Systems can be defined as functional, specific, or generic. A functional system is one that has been adapted for use in a particular type of work (i.e., clerical). A specific PTS is one that has been developed for a particular industry or organization. Generic systems are systems that can be used in a variety of different activities. The defined motions of a generic system can be used to describe almost any type of task.

Predetermined Time Systems also differ in the complexity of their basic elements. A basic-level system is a system whose elements consist mostly of single motions that cannot be further subdivided. Second-level systems combine two or more of the single elements of a basic system into a multi-motion element. Third- and fourth-level systems combine even more elements of a basic system to form their basic elements. As the system level increases the work content of each element increases.

In our study of existing methods of predicting aircraft maintenance task time, UDRI investigated over 25 Predetermined Time Systems. Two of those systems included Boeing's Airplane Maintenance Engineered Time Standards (AMETS) and a system developed by the Navy called Elemental Standard Data System (ESD). Both of these systems were developed specifically for use with aircraft maintenance. Boeing's AMETS system is a direct application of the Navy system. The Navy's ESD system is a multi-level system composed of Methods-Time Measurement (MTM) and the Naval Aviation Logistics Center (NALC)-developed data.

Methods-Time-Measurement. Methods-Time-Measurement (MTM) is the most widely used Predetermined Time System. The MTM system is a basic level, generic PTS originally developed from the study of industrial operation and first published in 1948. MTM consists of 12 categories of basic motions: reach; move; turn; apply pressure; grasp; position; release; disengage; eye travel and eye focus; body, leg, and foot motions; secondary engage; and crank. Analysis of a task using MTM involves breaking down the task into the systems basics motions, determining the nature of the motions and the conditions under which the motions are performed. Additionally, some basic motions can be performed simultaneously and some cannot. Once the motion patterns have been determined, time values can be assigned to each motion and summed for a total task time.

MTM-General Purpose Data. MTM-General Purpose Data (MTM-GPD) was developed to simplify the application of MTM by providing single element time values for commonly used MTM motion patterns, thereby eliminating repeated motion-by-motion analysis. MTM-GPD elements are described in non-specific terms to permit the widest possible application. The MTM-GPD data elements were derived from MTM analysis of repetitive motion patterns submitted by members of the MTM Association for Standards and Research, and were officially adopted by the Association in 1963. The principle use of MTM-GPD is as a first level building block in the development of more comprehensive standard data such as the Navy's Elemental Standard Data. MTM-GPD is also commonly used directly as a substitute for detailed MTM analysis.

Elemental Standard Data. ESD is a Predetermined Time System based on MTM-GPD and is composed of two types of data, Universal and Specific. Universal data are composed of three levels of data: basic-purpose, multi-purpose, and omni-purpose. Basic and multi-purpose data are composed of MTM-GPD and supplemented with NALC developed multi-purpose data. The third data level is omni-purpose data which consist of 908 coded data elements, each describing the complete accomplishment of an element of work. Omni-purpose data are composed of MTM-GPD basic and multi-purpose data and/or other Omni-purpose data elements. Each Omni-purpose data element has a time value for installation, removal, or others as may apply. Omni-purpose elements also include times for first piece or additional piece, if appropriate. The first piece is defined as those motions necessary to accomplish the element, as defined in its work content, separate and apart from any other element. The additional piece is defined as only those motions necessary to accomplish the "do" portion of the element.

The ESD Omni-data contain times for the use of most common aircraft tools and fasteners. ESD omni-purpose data elements represent an average of acceptable shop maintenance. During the development of the data, each element was analyzed to incorporate the practical expectations associated with low volume repair and maintenance tasks. Each omni-purpose data element represents an average time value for two or more MTM-GPD analysis of similar units of work. For example, the element time for removing a bolt with a wrench is computed from the average of three MTM-GPD analyses of removing a bolt using different types of wrenched. This method of using an average time for like tasks is similar to the method of bench marking task times used in some time-slotting techniques (a comparative estimation approach of developing maintenance time standards).

The ESD system also includes a procedure for accounting for the difficulty of an omni-purpose data element. ESD defines five levels of difficulty ranging from 1) very easy, to 5) very difficult. Difficulty is defined in terms of three variables which effect the time to accomplishing a data element, weight, distance, and control. Each of these variables are weighted to represent their relative impact on time, with control accounting for 85% of total difficulty, for the majority of omni-purpose data elements.

Although much of the data in the ESD system were developed for shop work, many elements describe maintenance tasks that are performed on the flight line and are well-suited for use in the Task Time Estimator (TTE), such as the installation and removal fasteners. Therefore, UDRI decided to use ESD omni-purpose data as a starting point for building the TTE. Furthermore, the MTM-GPD data upon which the omni elements were constructed, are available and will allow the modification of the elements.

Upon receiving the ESD data from the Navy, UDRI decomposed each of the Omni-level elements into the MTM-GPD elements from which they were constructed. We found numerous errors through out the database. Errors included such things as incorrect multiplication factors, and errors in summation. Most of the errors found in the data were clerical in nature and could be attributed to the fact that the ESD d[illegible]e was created from manual calculation and subsequently entered manually. Much of the data entry was done by inmates in the State of California, and some of the data were never entered into a computerized database at all. UDRI entered that portion of the data which had not previously been entered, then re-computed and recompiled the entire ESD Omni database. We also composed a list of all the errors that we found and corrected, and sent it to the Navy.

Data Collection Procedures. UDRI performed two pilot time study experiments for the purpose of testing our procedures for conducting time studies. The first pilot study was designed to investigate the effects of arm and hand clearance on the time required to perform a simple installation task. The task involved positioning a small, flat, round object (approximately 4 inches in diameter) onto a medal mounting plate and securing it with four 1/4 inch bolts, using a boxed end wrench. The object was positioned transverse to the subject with the bolts installed from the subjects right. A vertical barrier was placed to the right of the object to provide interference with the arms and hands, but not with the tool. Five levels of interference were used between the barrier and the mounting plate: 9, 6, 4, 3, and 2 inches.

The subjects were two male UDRI employees who volunteered to participate. The first subject performed the installation task 10 times for each of the five barrier placements. After the first subject completed the ten trials at the 6 inch barrier placement, it was decided that barrier placement did not cause an increased interference and was omitted for the second subject.

Although the study only employed two subjects, it provided two major findings. The first involved the effects of practice. The first subject tested was very well practiced on the task before the study began, having performed the task approximately 50 times. The second subject was given only five trials practice before the study began. Once the study began, performance of the second subject improved gradually over the first 20 trials, while performance of the first subject remained relatively constant.

Since the proficiency at which the subject performs has a direct effect on the time, it was concluded that subjects should be well practiced before testing begins in future studies in order to accurately determine the effects of the variables under study. (Further studies found this assumption to be incorrect. But more about that later.)

The second major finding in this study was the ability of subjects to adapt to the situation. It was expected that decreasing the distance between the barrier and the object would increase the installation time due to restricted arm and hand clearance. However, the barrier had no effect at the 9, 6, 4, and 3 inch levels. At those levels, the subjects were able to adjust by using more hand and finger motion, so restrictions on arm movements caused no increase in time. Only the 2 inch level showed an increase in time. At the 2 inch level, hand and finger movements were also restricted.

The next pilot study involved a one handed installation task working through an access opening. The object installed was placed on a flat horizontal surface and secured with four 1/4 inch bolts using a boxed end wrench. The variables investigated in this study were access opening size, visibility, object location, and reach interference. Two access opening sizes were used, 5" x 5" and 9" x 9". The fixture used to provide the access opening was a wooden frame which did not obstruct visibility. Three objects were used, a 4 x 4 inch flat metal plate, a 4 x 4 inch flat metal plate with a 3 x 3 x 3 inch solid wooden cube mounted in the center, and a 4 x 4 inch flat metal plate with a 3 x 3 x 3 inch transparent Plexiglas cube mounted in the center. Each of the plates had four mounting holes, one on each side of the square plate. The holes were located 2 inches from the top and bottom of the plate and 1/2 inch from the side. The flat plate was used as a control condition. The plate with the wooden cube in the center caused the subject to reach around the cube in order to install two of the four bolts. The wooden cube also completely obscured vision to those two bolts. The plate with the Plexiglas cube also required the subject to reach around the cube to install two of the bolts, yet did not obscure the subjects vision of those bolts.

Each object was installed at three different locations relative to the access opening, centered directly in front of the opening, and 12 inches to the left and right of the center of the opening. When the object was located to the right of the opening, installation was performed with the left hand. All other installation tasks were performed with the right hand.

The first two subjects in this study were UDRI employees, who were also the study experimenters. From the results of the first pilot study, it was decided that the installation task be very well practiced. So, each subject/experimenter performed each of the task conditions repeatedly until their installation time ceased to decrease with subsequent trials. Analysis of their data showed an astounding absence of any effect between any of the conditions tested. Through repetition, these subjects had become so efficient at performing the task that restricted visual and physical accessibility caused by the apparatus was no longer a hindrance.

From the results of the previous study, it was felt that a maximum level of proficiency was needed in order to prevent the effects of practice from masking the effects of the variables being studied. However, the results of this study showed that maximum proficiency can also mask the variables effects. Therefore, it was decided that a better method of controlling the effects of practice would be through experimental design.

The study was repeated using two UDRI technicians as subjects. These subjects were given limited practice to allow them to become familiar with the task, yet not enough to gain any significant level of proficiency. Once testing began, each subject performed each of the installation tasks in random order. Each task was performed four times in two test sessions, two per session.

Since only two subjects were used, the randomization procedure did not actually control the effects of practice. However, the limitation on the number of repetitions did produce the expected effects of the variables studied. The major finding in this study was not the effects of the variables, but rather the discovery of a better method for designing future time study experiments. The method of controlling the effects of practice through experimental design and procedures, is also more consistent with the way maintenance is actually performed. Maintenance technicians are familiar with the tasks they perform. However, most maintenance tasks are performed infrequently and maximum proficiency is never actually obtained.

2.1.2 Study Industry Requirements

As part of our background research, UDRI contacted several major aircraft manufacturers to gain a better perspective on the current methods of predicting aircraft maintenance times. UDRI spoke with representatives of the aircraft companies' Maintainability Divisions to ascertain the current methods of predicting aircraft maintenance times, to present the current capabilities of CREW CHIEF, and to determine the desired capabilities of the Task Time Estimator. The five aircraft manufacturers visited to define requirements for the task time estimator were: Boeing Commercial Aircraft Co., Seattle, WA; Douglas Aircraft Co., Long Beach, CA; General Dynamics, Fort Worth, TX; Lockheed Aeronautical Sy[illegible] Corp., Burbank, CA; and Rockwell International, Lakewood, CA.

One of the key differences between the companies contacted was the fact that Boeing Commercial Aircraft Company develops commercial aircraft, whereas the other four companies develop military aircraft. In developing military aircraft, there are many Military Standards by which the companies must abide. In the commercial industry, the companies avoid mandatory restrictions in design but are faced with customizing the aircraft. Companies which develop military aircraft focus on the performance requirements of the aircraft, while commercial aircraft companies focus on maintainability and turn-around time. This difference can be seen in their approach to estimating maintenance time requirements. Boeing Commercial Aircraft Co. developed the Airplane Maintenance Engineered Time Standards (AMETS) computerized time system for work measurement and predicting maintenance times for new aircraft. AMETS is a direct application of the Navy's Elemental Standard Data (ESD) computerized for quick retrieval of task element times and reporting. The four military aircraft manufacturers rely on comparisons to existing systems, estimates from experienced maintainability engineers, time study from mock-ups, prototype and production aircraft, and historical data collected through AFM 66-1 programs (AFM 66-1 data are reported as gross time to complete a task, with no break down of time to separate the task elements).

In our discussions with representatives from the five aircraft manufacturers we found that in general, aircraft designers expressed a desire for a system which can be used to evaluate the degree of difficulty of maintaining a specific design, with the goal of determining if redesign is required to improve maintainability, while maintainability engineers expressed a need for a system which would provide an accurate estimation of task time. The following are the suggestions made by each of the aircraft companies contacted.

Boeing Commercial Aircraft Company showed great interest in the TTE providing a maintenance task time, and suggested that the maintenance tasks be coded by part number instead of by the elements since the designers know the part numbers. Boeing also mentioned a need for delay factors but were unsure of whether it should be incorporated into CREW CHIEF or left as a separate system.

General Dynamics expressed an interest in having the TTE predict the time per event of a task and also to provide a complexity factor. The maintainability engineers at General Dynamics wanted task time to take into account the limited arc for a wrench which causes "x" partial revolutions to secure a bolt with "y" threads. They also wanted a time so that the designers would understand the need for redesign. The complexity factor would provide a means of adjusting the task times to compensate for such things as ranges in personnel size, personnel strength, amount of interference, and design complexity. They would like the capability to predict a mean and maximum corrective task time based on the design characteristics and the physical characteristics of the human model.

Douglas Aircraft indicated an interest in a TTE program which would provide both a rating factor and a maintenance task time. Since their aircraft designers are not concerned with a maintenance time, they would require a rating factor to help them discover the need for redesign for ease of repair. The maintainability engineers would like a time prediction model that would provide them with a real time instead of the present estimated times.

Lockheed expressed an interest in the TTE providing (1) discrete predicted times for maintenance and (2) correction factors. The engineers in the Structures Group would like to predict task times down to the particular fastener used so they can find quantifiable design problems early. The maintainability engineers would like a combination of both task time and factors. They need correction factors for the environment so that they can adjust task times for other climates. They would also like correction factors for fatigue.

Rockwell International expressed an interest in the TTE providing task times and difficulty factors. The task times would be used for comparative purposes by the maintainability engineers. The main concern of the designers would be the level of difficulty of a task based on component design and location in the aircraft. Rockwell would like a set of delay factors which the designer could generate from the program for a particular task. The factors would tell the designer that the current design of a component will cause an increase in repair time by 3.5 times the ideal time, for example, due to the difficulty of the task.

2.1.3 Revise Development Plan

Throughout the development of the Task Time Estimator, UDRI continued to revise and update the TTE development plan as a result of experimentation and discussions with the Air Force, and our sub-contractors at Anthropology Research Project, and Texas Tech University. Development plans and revisions were presented to the Air Force during a Preliminary Design Review (PDR) {Attch 1, CDRL Sequence 3}, a Critical Design Review (CDR) {Attch 1, CDRL Sequence 3}, and the final Research Program Plan, Volume I {Attch 1, CDRL Sequence 5}.

Preliminary Design Review. As a result of discussions with the Air Force, representatives of aircraft manufacturers, and our sub-contractors at Anthropology Research Project, and Texas Tech University, UDRI developed three strategies for the development of the Task Time Estimator. These three strategies were presented to the Air Force during the Preliminary Design Review. At this point in the TTE development, laboratory methods for collecting maintenance task times and the basic structure of the TTE database had already been determined. The design problem which remained was how to determine the difficulty of aircraft maintenance tasks, and present it to the user. The three approaches for determining task difficulty presented at the CDR were 1) Difficulty Factors, 2) Hierarchical Elements, and 3) Difficulty Levels.

The Difficulty Factor approach was considered as a result of discussions with aircraft designers. They expressed a need for a numeric value which could be used to represent the relative difficulty of a task. With this approach a difficulty factor would be the result of a ratio between the time required to perform a task under normal conditions and the time required for the same task when difficult conditions are encountered. For example, if the time required to install a bolt under normal conditions is X seconds, and the time required when interference in encountered is Y seconds, the resulting difficulty factor is X/Y. The problem with this approach is that it requires all the information needed to determine the actual task times. It was decided that presenting the user with the actual task time for the condition under which it is performed is more desirable. The user would still have the ability to compute a difficulty factor, although, it may require the user to perform multiple analyses.

The Hierarchical Element approach was developed through input from our sub-contractor at Texas Tech University. In this approach all remove and replace tasks would be defined by eight elements at the top of the hierarchy. Each of these elements would be defined as a combination of task-hardware and task-method factors, each factor would be defined by variables, and each variable would be defined by levels. The difficulty of each element would be evaluated by making a decision at each step in the Element - Factor (both hardware and method) - Variable - Level hierarchy. The bottom level of the hierarchy would contain the task times. The problem with this approach is the amount of data it would require. In the simple example presented at the CDR, data for 61,803 different conditions would need to be collected.

The Difficulty Level Approach was developed from examination of the method used by the Navy for determining task difficulty in the development of their Elemental Standard Data (ESD). In this approach the difficulty of each task element is determined by three variables which affect the difficulty of the task, weight, distance, and control. Each of these variables are evaluated in terms of five levels of difficulty ranging from "very easy" to "very difficult." In addition, each variable is weighted according to its significance toward task difficulty. In the ESD system, data were developed from MTM-GPD for the first three levels of difficulty. The two most difficulty levels were extrapolated using a time/difficulty ratio equation. The ESD definition for each difficulty level for the variables weight and distance are discrete numeric values. However, difficulty for control is defined in subjective terms which requires expertise and experience on the part of the user. Furthermore, the variable control is the most significant in determining difficulty. For most of the ESD elements control accounts for 85% of task difficulty. The problem with this approach is the lack of empirical data for the variable "control."

Critical Design Review. Through consultation with the Air Force, and our sub-contractors, UDRI decided that a method similar to that used in the ESD difficulty level approach for determining task difficulty was the most feasible. However, instead of using five discrete levels of difficulty, a continuous scale would be used. This decision was supported by data collected in the Physical Ergonomics Lab. Comparison of laboratory data with ESD data was very favorable, supporting the validity of the method. UDRI presented the research finding, and proposed future research for the development of the TTE, to the Air Force at the Critical Design Review.

The proposed research concentrated on three major task categories most common to aircraft maintenance: plumbing, avionics electronic equipment, and mechanical components. The maintenance actions performed within each of these categories contain the majority of tasks required in aircraft maintenance.

Plumbing. Aircraft engine plumbing consists of tubing and fittings for fuel, oil, hydraulic fluid, and other fluids and gases. Maintenance of plumbing requires specific tools such as flare wrenches. The tools are used on fittings and couplings, whereby nuts and bolts are used infrequently. The objects handled are not usually heavy but often must be handled with care to prevent kinking or denting. It will only be necessary to test the removal and replacement of the plumbing as complete assemblies because the connections and fittings are installed on the tubing in the shops.

Avionics Equipment. Avionics equipment, commonly called black boxes, requires frequent removal and replacement for calibration and repair and, for this reason, is commonly designed to fit in easily accessed racks or compartments and is often held in place with captive fasteners. The components tend to be symmetrical and fairly easy to handle although some are quite heavy. The equipment is usually delicate and must be handled with care.

Mechanical Components. Mechanical components are the largest area of concern. They consist of aircraft items such as hydraulic and fuel pumps, generators, actuators, etc., and hardware such as brackets, bell cranks, and flight controls. Avionics equipment such as radomes and antennas also fall into this category. Mechanical components often have electrical and plumbing connections and are secured to the aircraft structure by nuts and bolts. They often are heavy, asymmetrical, and installed in areas of difficult access.

Task Time Estimator Research Program Plan. As a result of the Air Force's response to both the PDR and CDR, UDRI wrote the Research Program Plan for the Task Time Estimator and submitted it to the Air Force (Attch 1, CDRL Sequence 5). This document contains guidelines for the TTE development, results of time study research, description of proposed research, methods for developing the TTE databases, description of the TTE database structure, description of how the TTE will be implemented, and a plan for validating the time-to-repair estimated computed by the TTE.

2.1.4 Perform Research

Time Studies

A series of time studies were conducted to investigate the effects of numerous variables on the time required to disassemble and reassemble a flange-type pipe fitting. Critical elements included location of work area, accessibility of work area, types of tools and tool combinations for performing the task, and interference levels.

These studies utilized the same basic equipment and procedures, differing only in the specific variables and combination of variables. To simplify this report, the general experimental information that is common to all of the studies, will be described first. Information unique to the individual studies will be presented separately.

General Information

1. Apparatus:

   a. Test Equipment: The workstation simulated an aircraft maintenance task in which a technician must attach a flange-type pipe coupling (See Figure 1). This coupling was held together by four bolts with self-locking nuts and was attached to a flexible rubber hose that provided some resistance when aligning the coupling for bolt insertion. The workstation was equipped with an optional wall barrier that provided interference during the installation and removal of the bolts.

      The simulated workstation was mounted on a unistrut frame (8' w x 9' h x 4' d) that was adjustable in all three axes (height, fore and aft, and lateral). This allowed the workstation to be positioned at any reasonable location relative to the subject. The frame was equipped with a barrier that limited the subject's forward movements toward the workstation.

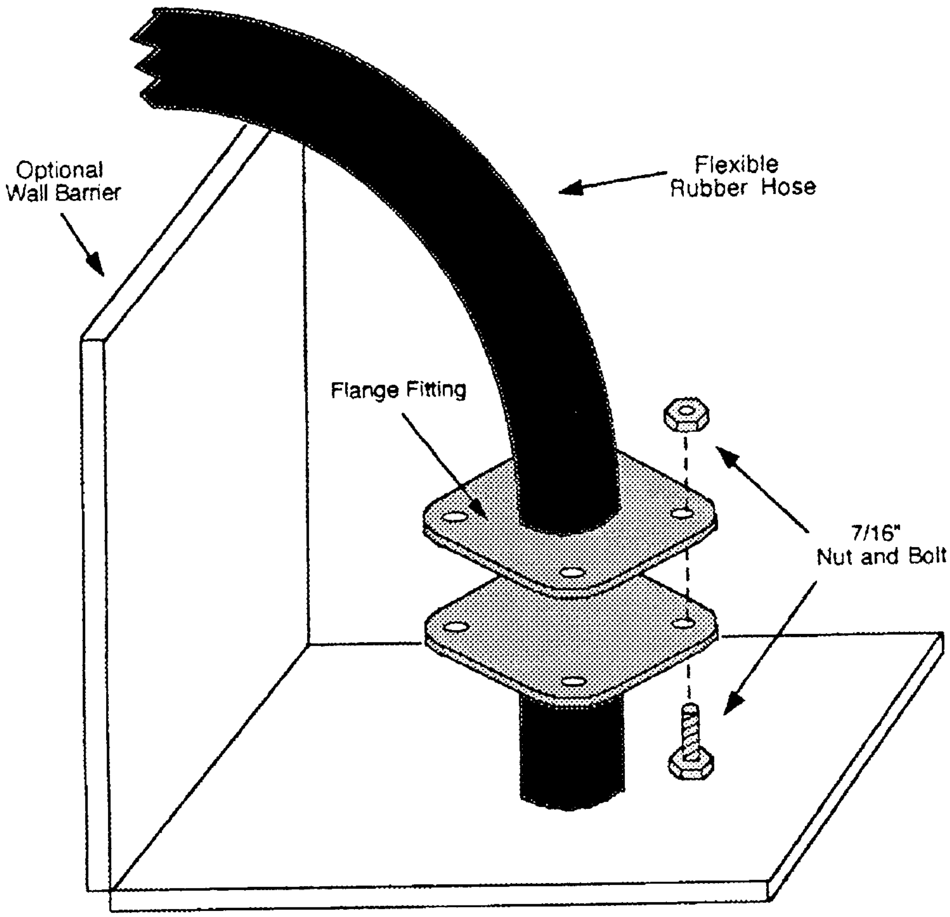


Figure 1. Simulated Flange Type Pipe Fitting

Three types of wrenches were used for the removal and installation of the coupling:

7/16" Ratchet wrench

7/16" Box-end wrench

7/16" Open-end wrench

All three types of tools were used on the bolt heads; however, the ratchet wrench was not used on the nut.

b. Data Collection System: A video recording system was the primary data collection equipment for this study. The system consisted of a camera, monitor, VCR, and an encoder/decoder. The encoder/decoder is a locally manufactured device that permits the experimenter to superimpose tones on the video tape with a hand-held switch. The tones correspond to event start and end times. After each data collection session, the tones were transferred from the video tape to a diskette via a computer program designed to decode the tones. If suspect results were encountered, the video tapes were reviewed and times were recorded with a hand-held stopwatch.

2. Procedures: All subjects were screened for health and physical fitness prior to acceptance. Eleven anthropometric measurements were taken on each subject. The subjects were then shown how to perform the task and were given a practice trial prior to actual data collection.

   The subjects were instructed to disassemble the flange type coupling, removing the bolts in a specific order. Time data for this portion of the task were broken into four elements corresponding to the complete removal of each nut and bolt. The reassembly required the subject install the nuts and bolts in the same order in which they were removed. This portion of the task was broken down into the following ten elements: 1-4, install each of the four nuts and bolts using the hands only; 5, obtain the wrenches and position them on the first nut and bolt; 6-9, tighten each of the nuts and bolts with the wrenches; and 10, lay wrenches aside.

Horizontal Time Studies

A. Time Study #5

"An Investigation of Time To Remove and Install Flange-Type Pipe Coupling with Various Wrenches and with Limited and Unlimited Workspace"

1. Objective: The objective of this study was to determine the effect of tool type and interference on the time required to remove and install a flange-type pipe coupling.

2. Apparatus: The access opening with which the subject had to reach through to perform the tasks was 19.5" x 19.5", which was large enough to accommodate the

95th percentile male reaching to shoulder depth with no visual obstruction (from MIL-STD 1472D). The workstation was equipped with an optional wall barrier that provided interference during the installation and removal of the bolts.

The height of the workstation and the lower edge of the opening was 49", which corresponds to the midpoint between the 5th percentile chest height for females and 95th percentile chest height for males. The workstation was 9" from the access opening and was situated directly in front of the subject.

3. Method:

a. Subjects: Forty-eight subjects (twenty-four male and twenty-four female), age 18 to 30, were used in this study. All subjects adequately represented the Air Force aircraft maintenance technician in body size (AFR 160-43) and weight lift capability (minimum of 40 pounds on the six-foot incremental weight lift test).

b. Variah' The variables for this study were as follows:

Dependent variables:

- Time to complete the installation or removal of each nut/bolt combination

Independent variables:

Task type

- Remove
- Install

Interference level

- No interference (no wall barrier)
- Interference (wall barrier 2" to the left of the pipe flange fitting)

Tool combination

- Ratchet on bolt, box-end on nut
- Box-end on bolt, box-end on nut
- Box-end on bolt, open-end on nut
- Open-end on bolt, box-end on nut
- Open-end on bolt, open-end on nut.

This created a 2 x 2 x 5 factorial consisting of 20 different combinations of the independent variables. Six groups of eight subjects were run through the different combinations of variables.

c. Results: Results for this study indicated the fastest times were produced with the tool combination of the Ratchet wrench and the box-end wrench. Time increased with the addition of the interference regardless of the tool combination. Table 1 presents the mean total task time for assembling and disassembling the flange type pipe fitting with each of the tool combinations and interference.

Table 1. Mean Total Task Times for Assembling and Disassembling the Flange Type Pipe Fitting with Each of the Tool Combinations and Interference

	Assemble		Disassemble	
Tool Type	No Interference	Interference	No Interference	Interference
Rat - Box	85.89	110.62	75.35	99.92
Box - Box	121.20	128.32	115.10	125.47
Box - Open	127.11	152.87	126.93	152.46
Open - Box	131.80	170.85	122.81	147.32
Open - Open	134.77	170.34	125.21	144.53

B Time Study #6

"An Investigation of Time To Remove and Install Flange-Type Pipe Coupling with Various Wrenches and with Limited and Unlimited Workspace"

1. Objective: The objective of this study was to determine the effect of tool type and interference on the time required to remove and install a flange-type pipe coupling. This study was a continuation of Time Study #5.

2. Apparatus: The access opening with which the subject had to reach through to perform the tasks was 8" x 5", which is the minimum access opening size allowed by MIL-STD 1472D for work requiring the use of two hands but with no visual access.

   The height of the workstation and the lower edge of the opening was 49", which corresponds to the midpoint between the 5th percentile chest height for females and 95th percentile chest height for males. The workstation was 9" from the access opening and was situated directly in front of the subject.

3. Method:

   a. Subjects: Forty-eight subjects (24 male and 24 female), age 18 to 30, were run in this study. All subjects adequately represented the Air Force aircraft maintenance technician in body size (AFR 160-43) and weight lift capability (minimum of 40 pounds on the six-foot incremental weight lift test).

   b. Variables: The variables for this study were as follows:

      Dependent variables:

      - Time to complete the installation or removal of each nut/bolt combination

      Independent variables:

      Task type

      - Remove
      - Install

      Interference level

      - No interference (no wall barrier)

- Interference (wall barrier 2" to the left of the pipe flange fitting)

Tool combination

- Ratchet on bolt, box-end on nut
- Box-end on bolt, box-end on nut
- Open-end on bolt, box-end on nut
- Box-end on bolt, open-end on nut
- Open-end on bolt, open-end on nut.

c. Results: Results indicated that significantly more time was required to complete the task with the 8" x 5" opening in place. Table 2 presents the mean total task time for assembling and disassembling the flange type pipe fitting with each of the tool combinations and interference.

Table 2. Mean Total Task Times for Assembling and Disassembling the Flange Type Pipe Fitting with Each of the Tool Combinations and Interference

	Assemble		Disassemble	
Tool Type	No Interference	Interference	No Interference	Interference
Rat - Box	121.10	150.24	120.09	137.42
Box - Box	165.38	198.01	170.23	196.61
Box - Open	161.59	175.22	148.37	172.00
Open - Box	200.77	254.53	178.12	217.06
Open - Open	195.55	240.97	193.29	225.59

Vertical Time Studies

A. Time Study #7

"An Investigation of Time to Remove and Install an Overhead Flange-Type Pipe Coupling with Various Wrenches with Limited and Unlimited Workspace"

1. Objective: The objective of this study was to determine the effect of tool type and interference on the time required to remove and install a flange-type pipe coupling.

   This study was a continuation of Time Studies 5 and 6. In those studies, the workstation with the flange-type pipe coupling was located at chest height, directly in front of the subject while in this study, the workstation was located overhead.

2. Apparatus: The workstation was mounted 80 inches above the floor and was accessible through a 19.5" x 19.5" access opening, which was large enough to accommodate the 95th percentile male reaching to shoulder depth with no visual obstruction (from MIL-STD 1472D).

3. Method:

   a. Subjects: Twenty-four subjects (12 male and 12 female), age 18 to 30, were run in this study. All subjects adequately represented the Air Force aircraft maintenance technician in body size (AFR 160-43) and weight lift capability (minimum of 40 pounds on the six-foot incremental weight lift test).

   b. Variables: The variables for this study were as follows:

      Dependent variables:
      - Time to complete the installation or removal of each nut/bolt combination

      Independent variables:
      Task type
      - Remove
      - Install

Interference level

- No interference (no wall barrier)
- Interference (wall barrier 2" to the left of the pipe flange fitting)

Tool combination

- Ratchet on bolt, box-end on nut
- Open-end on bolt, open-end on nut.

There were four groups of six subjects. Two of the groups were tested entirely with one of the tool combinations, performing three trials with each interference level. The remaining two groups used both tool combinations, based on interference level. One group used the ratchet-box combination without interference and the open-open combination with interference while the other group used the ratchet-box combination with interference and the open-open combination without interference.

c. Results: Table 3 presents the mean total task time for assembling and disassembling the flange type pipe fitting with each of the tool combinations and interference.

Table 3. Mean Total Task Times for Assemb[illegible] and Disassembling the Flange Type [illegible]pe Fitting with Each of the Tool Combinations and Interference.

	Assemble		Disassemble	
Tool Type	No Interference	Interference	No Interference	Interference
Rat - Box	107.00	124.54	100.02	120.19
Open - Open	156.07	204.87	140.92	173.97

B. Time Study #8

"An Investigation of Time to Remove and Install an Overhead Flange-Type Pipe Coupling with Various Wrenches with Limited and Unlimited Workspace"

1. Objective: The objective of this study was to determine the effect of tool type and interference on the time required to remove and install a flange-type pipe coupling.

   This study was a continuation of the previous time studies. In those studies, the workstation with the flange-type pipe coupling was located either at chest height, directly in front of the subject (Time Studies 5 and 6) or the workstation was located overhead unlimited access (Time Study 7). In the current study, the subjects performed an identical task while reaching overhead through and 8" x 5" access opening.

2. Apparatus: The workstation was mounted 80" above the floor and was accessible through an 8" x 5" access opening, which corresponds to the minimum width allowed by MIL-STD 1472D for reaching half arms-length (hand to elbows) with both arms. The access opening was cut in the center of a piece of plywood and placed 8" below the workstation, creating a ceiling of 72". The opening was centered on the task fixture and could be removed easily for installation and removal of the interference barrier.

3. Method:

   a. Subjects: Twenty-four subjects (12 male and 12 female), age 18 to 30, were run in this study. All subjects adequately represented the Air Force aircraft maintenance technician in body size (AFR 160-43) and weight lift capability (minimum of 40 pounds on the six-foot incremental weight lift test).

   b. Variables: The variables for this study were as follows:

      Dependent variables:
      - Time to complete the installation or removal of each nut/bolt combination

      Independent variables:
      - Task type
        - Remove
        - Install
      - Interference level
        - No interference (no wall barrier)

- Interference (wall barrier 2" to the left of the pipe flange fitting)

Tool combination

- Ratchet on bolt, box-end on nut
- Open-end on bolt, open-end on nut.

There were four groups of six subjects. Two of the groups were tested entirely with one of the tool combinations, performing three trials with each interference level. The remaining two groups used both tool combinations, based on interference level. One group used the ratchet-box combination without interference and the open-open combination with interference while the other group used the ratchet-box combination with interference and the open-open combination without interference.

c. Results: Table 4 presents the mean total task time for assembling and disassembling the flange type pipe fitting with each of the tool combinations and interference.

Table 4. Mean Total Task Time for Assembling and Disassembling the Flange Type Pipe Fitting with Each of the Tool Combinations and Interference

	Assemble		Disassemble	
Tool Type	No Interference	Interference	No Interference	Interference
Rat - Box	141.07	145.86	131.07	140.36
Open - Open	209.24	282.73	205.08	257.29

C. Time Study #9

"An Investigation of Time to Remove and Install an Overhead Flange-Type Pipe Coupling with Various Wrenches with Limited and Unlimited Workspace"

1. Objective: The objective of this study was to determine the effect of tool type and interference on the time required to remove and install a flange-type pipe coupling.

   This study was a continuation of the previous time studies. In those studies, the workstation with the flange-type pipe coupling was located either at chest height, directly in front of the subject (Time Studies 5 and 6), overhead with unlimited access (Time Study 7), or overhead with limited access (Time Study 8). In the current study, the subjects performed the identical task while reaching overhead with unlimited and limited access and at various ceiling heights.

2. Apparatus: The unistrut frame was adjusted to create six different ceiling heights (2', 3', 4', 5', and 18"). The workstation was mounted 8" above these heights and was accessible through both an 8" x 5" access opening (limited access), which corresponds to the minimum width allowed by MIL-STD 1472D for reaching half arms-length (hand to elbows) with both arms, and a 19.5" x 19.5" access opening which was large enough to accommodate the 95th percentile male reaching to shoulder depth with no visual obstruction (from MIL-STD 1472D). The 8" x 5" access opening was cut in the center of a piece of plywood and was centered on the task fixture.

3. Method:

   a. Subjects: Two hundred forty subjects (120 male and 120 female), age 18 to 30, were run in this study. Since each ceiling height was performed as a separate study, the subjects were divided into five groups of 48 (24 male and 24 female). All subjects adequately represented the Air Force aircraft maintenance technician in body size (AFR 160-43) and weight lift capability (minimum of 40 pounds on the six-foot incremental weight lift test).

   b. Variables: The variables for this study were as follows:

      Dependent variables:

      - Time to complete the installation or removal of each nut/bolt combination

      Independent variables:

      Access opening size

- Limited (8" x 5")
- Unlimited (19.5" x 19.5")

Interference level

- No interference (no wall barrier)
- Interference (wall barrier 2" to the left of the pipe flange fitting)

Tool combination

- Ratchet on bolt, box-end on nut
- Open-end on bolt, open-end on nut.

Ceiling height (between-group variable)

- 60 inches
- 48 inches
- 36 inches
- 24 inches
- 15 inches

There were eight groups of six subjects for the 24 and 35 inch ceiling heights. Subjects in each group performed three trials each on two of the eight possible tool combinations (2), interference levels (2), and access opening size (2) conditions. The order of the six remove/install trials are counter balanced within each group. For the 15, 48 and 60 inch ceiling heights there were 3 groups of 6 subjects. Subjects in each of these groups performed three trials each on 2 of the 3 following experimental conditions: 1) Ratchet and boxed-end wrenches, unrestricted assess, and no interference, 2) Two open-end wrenches, restricted access, and No interference, and 3) Two open-end wrenches, restricted access, with interference.

c. Results: Table 5 presents the mean total task times for assembling and disassembling the flange type pipe fitting for each of the five ceiling heights.

Table 5. Mean Total Task Time for Assembling and Disassembling the Flange Type Pipe Fitting for Each of the Five Ceiling Heights

15 inch Ceiling

Tool Type	Interference	Opening Size	Install	Remove
Rat - Box	No	19.5 x 19.5	131.14	124.02
Open - Open	No	8 x 5	297.86	284.51
Open - Open	Yes	8 x 5	386.78	386.42

24 inch Ceiling

Tool Type	Interference	Opening Size	Install	Remove
Rat - Box	No	19.5 x 19.5	170.37	142.47
Rat - Box	Yes	19.5 x 19.5	195.21	179.49
Rat - Box	No	8 x 5	203.58	187.83
Rat - Box	Yes	8 x 5	254.95	213.86
Open - Open	No	19.5 x 19.5	315.93	316.14
Open - Open	Yes	19.5 x 19.5	325.46	325.02
Open - Open	No	8 x 5	396.86	377.48
Open - Open	Yes	8 x 5	493.89	369.46

36 inch Ceiling

Tool Type	Interference	Opening Size	Install	Remove
Rat - Box	No	19.5 x 19.5	112.87	103.37
Rat - Box	Yes	19.5 x 19.5	129.99	122.78
Rat - Box	No	8 x 5	186.88	171.02
Rat - Box	Yes	8 x 5	197.73	178.01
Open - Open	No	19.5 x 19.5	174.95	159.86
Open - Open	Yes	19.5 x 19.5	229.09	195.44
Open - Open	No	8 x 5	260.81	234.62
Open - Open	Yes	8 x 5	303.72	268.95

48 inch Ceiling

Tool Type	Interference	Opening Size	Install	Remove
Rat - Box	No	19.5 x 19.5	117.41	108.70
Open - Open	No	8 x 5	199.40	180.64
Open - Open	Yes	8 x 5	261.15	259.87

60 inch ceiling

Tool Type	Interference	Opening Size	Install	Remove
Rat - Box	No	19.5 x 19.5	134.20	119.50
Open - Open	No	8 x 5	310.12	274.15
Open - Open	Yes	8 x 5	332.58	352.17

Hand Clearance Studies

Two studies were performed to determine the effect of hand clearance and accessibility on the time to install and remove a fastener with the hands only. No tools were involved in this study. The studies were identical with the exception of the access opening size. For this reason, all of the general experimental information will be presented first, with the specific apparatus differences and results following. The two access openings tested were the unrestricted access (19.5" x 19.5" opening) and the restricted access (8" x 5").

1. Objective: The objective of this study was to determine the effect of nut size, bolt size, and hand clearance on the time to remove and install an individual nut or bolt.

2. Apparatus:

   a. Test Equipment: The workstation simulated an aircraft maintenance task in which a technician must install or remove a fastener by hand. Access to the work area was accomplished through either a 19.5" x 19.5" opening or an 8" x 5" opening. The installation point of the nut or bolt was located 8" from the opening.

   The workstation was mounted on a unistrut frame that had adjustments in all three axes (height, fore and aft, and lateral). This allowed the workstation to be positioned at any reasonable location relative to the subject. The fixture plate was oriented in six different directions in this study. The access opening was 49" above the floor and was centered directly in front of the work area.

The workstation was equipped with a movable wall barrier and a plate fixture onto which the nut or bolt was to be installed. The installation point of the fastener was centered on the plate, which required an additional 4.5" of reach.

b. Data Collection System: A video recording system was the primary data collection equipment for this study. The system consisted of a camera, monitor, VCR, and an encoder/decoder. The encoder/decoder is a locally manufactured device that permits the experimenter to superimpose tones on the video tape with a hand-held switch. The tones correspond to event start and end times. After each data collection session, the tones were transferred from the video tape to a diskette via a computer program designed to decode the tones. If suspect results were encountered, the video tapes were reviewed and times were recorded with a hand-held stopwatch.

c. Procedures: All subjects were screened for health and physical fitness prior to acceptance. Ten anthropometric measurements were t[illegible]n each subject. The subjects were then shown how to perform the task and were given a practice trial. The subjects were instructed to install the nut or bolt and then remove the fastener and were given several practice trials prior to beginning the test session.

Unrestricted Access Hand Clearance

3. Method:

a. Subjects: Sixty subjects (thirty male and thirty female), age 18 to 30, were run in this study. Since each task orientation was performed as a separate study, the subjects were divided into six groups of ten (five male and five female). All subjects adequately represented the Air Force aircraft maintenance technician in body size (AFR 160-43).

b. Variables: The variables for this study were as follows:

Dependent variables:

- Time to complete the installation or removal of each nut and bolt.

Independent variables:

Task Orientation

- Facing - Front
- Facing - Back
- Transverse - Right
- Transverse - Left
- Vertical - Top
- Vertical - Bottom

Fastener Type

- Bolt
- Nut

Fastener Size

- 1/4
- 1/2

Barrier Clearance

- 1 inch
- 1.5 inches
- 2 inches
- 3 inches

Task orientation was a between group, with ten subjects per group. Subjects in each group performed three trials of each sixteen possible conditions (2 fastener types , 2 fastener sizes, 4 barrier clearances).

c. Results: The means for all six groups were compared to determine whether differences existed between the six orientations tested in this study. The fastest times overall occurred in the removal of the 1/4" nut condition for all groups. The slowest times overall occurred in the installation of the 1/2" bolt conditions. For all groups and all conditions, there was no significant difference in performance times beyond the 2.0" clearance barrier level.

Performance times among the six orientations did not differ to a great extent; however, the slowest times appeared to occur in groups 5 and 6 (facing front and facing back). The remaining four groups (transverse left and right, vertical and down) did not show any substantial differences between the performance times in the various conditions.

For this reason, only groups 5 and 6 were selected to be tested in the follow-on restricted access opening study. Group 5 was tested first since this group produced the overall slowest times. The mean installation and removal times are presented in Table 6.

Table 6. Mean Installation and Removal Times for Unrestricted Access Hand Clearance

Group 1. Transverse Right Orientation

	Install				Remove			
	1.5"	2.0"	2.5"	3.0"	1.5"	2.0"	2.5"	3.0"
1/4 Nut	15.41	8.43	6.91	5.92	10.64.	6.63	6.15	5.59
1/4 Bolt	43.07	15.00	9.65	9.21	34.22	10.04	7.30	6.77
1/2 Nut	18.44	.84	7.21	6.86	15.19	10.34	8.60	8.23
1/2 Bolt	59.49	30.17	18.08	18.06	28.02	13.37	10.82	10.05

Group 2. Vertical Up Orientation

	Install				Remove			
	1.5"	2.0"	2.5"	3.0"	1.5"	2.0"	2.5"	3.0"
1/4 Nut	18.69	11.06	6.25	5.55	9.30	6.71	5.60	4.79
1/4 Bolt	30.33	15.44	9.74	8.43	34.27	9.86	7.33	7.07
1/2 Nut	16.21	9.67	6.52	6.12	13.87	9.69	8.28	6.99
1/2 Bolt	48.95	30.37	17.48	14.01	28.01	13.32	9.74	9.23

Group 3. Transverse [illegible] Orientation

	Install				Remove			
	1.5"	2.0"	2.5"	3.0"	1.5"	2.0"	2.5"	3.0"
1/4 Nut	20.59	12.36	6.87	6.88	12.24	9.01	7.77	7.29
1/4 Bolt	37.46	18.44	10.71	10.25	27.67	10.26	8.64	7.79
1/2 Nut	22.55	12.23	7.75	6.72	18.33	13.21	11.51	11.46
1/2 Bolt	81.41	69.62	25.10	23.36	21.55	13.11	11.10	11.13

Group 4. Vertical Down Orientation

	Install				Remove			
	1.5"	2.0"	2.5"	3.0"	1.5"	2.0"	2.5"	3.0"
1/4 Nut	26.13	16.31	8.24	7.69	11.01	7.29	5.45	5.32
1/4 Bolt	38.88	32.02	13.16	13.01	35.61	11.60	7.64	7.65
1/2 Nut	34.77	16.16	9.24	7.51	12.77	9.29	7.07	6.76
1/2 Bolt	51.37	31.09	20.20	17.54	33.11	15.40	9.86	9.59

Group 5. Facing Front Orientation

	Install				Remove			
	1.5"	2.0"	2.5"	3.0"	1.5"	2.0"	2.5"	3.0"
1/4 Nut	21.46	13.50	8.34	7.55	14.02	9.66	7.71	7.49
1/4 Bolt	47.64	24.56	17.27	13.26	46.19	15.30	13.70	11.76
1/2 Nut	22.97	12.59	8.29	8.37	23.76	15.99	13.55	12.17
1/2 Bolt	58.00	31.96	23.52	23.42	36.32	17.80	15.84	14.81

Group 6. Facing Away Orientation

	Install				Remove			
	1.5"	2.0"	2.5"	3.0"	1.5"	2.0"	2.5"	3.0"
1/4 Nut	22.24	17.59	10.44	8.31	14.58	10.12	8.49	8.18
1/4 Bolt	41.57	22.37	14.54	13.28	51.20	18.73	9.45	9.05
1/2 Nut					22.37	17.05	12.31	11.97
1/2 Bolt	49.91	26.15	19.84	16.96	34.67	16.99	12.12	11.41

Restricted Access Hand Clearance

This study was a follow-on to the unlimited access hand clearance study. The access opening was reduced to 8" x 5" to create a restricted access opening. Initially, only one group of subjects was tested to determine if it was going to be necessary to duplicate the entire study. Since the slowest performance times in the unrestricted access portion of the study were in the Facing Orientation, this group was tested first to determine if any significant differences existed between the large and small access openings. Analysis indicated significant differences in this group, suggesting the need to test the next slowest group from the unrestricted portion of the study. No significant differences between the two access opening times were evident in this group and further data collection was postponed.

a. Subjects: Twenty subjects (ten male and ten female), age 18 to 30, were run in this study. Since each task orientation was performed as a separate study, the subjects were divided into two groups of ten (five male and five female). All subjects adequately represented the Air Force aircraft maintenance technician in body size (AFR 160-43).

b. Variables: The variables for this study were as follows:

Dependent variables:

- Time to complete the installation or removal of each nut and bolt.

Independent variables:

Task Orientation

- Facing - Front
- Facing - Back

Fastener Type

- Bolt
- Nut

Fastener Size

- 1/4
- 1/2

Barrier Clearance

- 1 inch
- 1.5 inches
- 2 inches
- 3 inches

Task orientation was a between group, with ten subjects per group. Subjects in each group performed three trials of each sixteen possible conditions (two fastener types, two fastener sizes, and four barrier clearances).

d. Results: Analysis of Variance (ANOVA) were run on these data. Original analysis of the Group 5 data revealed a significant interaction of the "Study x Clearance" variables. However, an unexpected and unusual result prompted further investigation. This result indicated that the removal times for the unrestricted access conditions were an average of seven seconds slower than those in the restricted access conditions. Since this result was evident in only one condition (the 1.5" clearance level which was considered the most difficult), the raw data printouts and videotapes were studied to determine the circumstances of this result. The investigation revealed several anomalies with the data. The most serious was the inability to complete the 1.5" clearance conditions for 5 of the 10 subjects. It was determined that it would be necessary to run 5 additional subjects through all conditions.

Although performance times in the 1.5" clearance barrier condition were still higher for the Remove unrestricted conditions, these results were no longer significant. A graphic comparison of the means of these two groups shows the slowest performance times to occur in the 1/4" and 1/2" bolt conditions at the 1.5" clearance barrier level. This was also true for the installation performance times. ANOVA results indicated both bolt size conditions to be significantly different slower than the nut installation times.

ANOVA results for Group 6 (Facing Back) revealed a significant difference between the two access opening groups in the Remove conditions only. A significant interaction was also evident for "Study x Clearance" variables. A Tukey post hoc revealed the significant difference to occur between the two studies at the 1.5" clearance barrier only. These times were significantly different than all other times also (Restricted and Unrestricted at 2.0" , 2.5", and 3.0" clearance levels).

A comparison of the means revealed the slowest performance times to occur for both the 1/4" and 1/2" bolts at the 1.5" barrier clearance level in both the installation and removal tasks. Only minor differences in performance times were evident for the other conditions.

The mean installation and removal times are presented in Table 7.

Table 7. Mean Installation and Removal Times for Restricted Access Hand Clearance

Facing Front Orientation

	Install				Remove			
	1.5"	2.0"	2.5"	3.0"	1.5"	2.0"	2.5"	3.0"
1/4 Nut	40.89	16.16	10.21	10.37	15.17	10.99	9.78	9.28
1/4 Bolt	62.57	30.98	20.99	19.52	44.13	23.08	15.56	14.17

1/2 Nut	31.24	15.45	12.37	10.96	22.63	18.38	15.29	14.43
1/2 Bolt	63.51	32.69	26.94	26.75	34.91	21.80	18.21	16.64

Facing Away Orientation

	Install				Remove			
	1.5"	2.0"	2.5"	3.0"	1.5"	2.0"	2.5"	3.0"
1/4 Nut	28.22	17.57	11.11	10.60	17.04	11.26	9.53	8.92
1/4 Bolt	51.67	28.39	16.98	15.29	56.44	16.26	11.58	10.99
1/2 Nut	37.66	17.24	11.14	10.85	26.99	19.35	14.17	13.84
1/2 Bolt	62.54	30.31	22.27	20.07	50.47	19.[illegible]	14.67	13.88

Vision Study

The visibility of air crew and ground crew members can be limited by the head gear that they are required to wear during the performance of their duties. COMBIMAN displays visibility plots for air crews and CREW CHIEF displays visibility plots for ground crews. As new head gear is introduced into the Air Force, new studies are required so that visibility data can be modeled and included in the appropriate human model program.

Objective: The purpose of this study was to collect this visibility data to determine the peripheral vision limits of Air Force personnel while wearing the following equipment:

MCU-2/P Ground crew chemical defense mask

MBU-12/P Air crew respirator with HGU-153/P helmet

MBU-19/P Air crew chemical defense mask with HGU-153/P helmet

Apparatus:

1. Moving target with two degrees of freedom (azimuth and elevation). The target display was a single white flashing LED. The walls behind and around the target display were covered with a gray photographic background paper to reduce glare and provide a background void of any detail that might interfere with the subject's concentration on the target.

2. Adjustable chair with head rest. The chair could be adjusted horizontally and vertically, and the seat back angle could be adjusted. The head rest could be adjusted up and down and back and forth.

3. Non-elastic head band to secure the head to the head rest in the desired position.

4. Mechanical auditory signaling device, for subjects to use to signal the experimenter when the target was visible.

5. Head Gear: MCU-2/P Ground crew chemical defense mask, MBU-12/P Air crew respirator, MBU-19/P Air crew chemical defense mask, and HGU-153/P helmet.

Method:

Subjects. The subjects were ten males and ten females between the ages of 18 and 30. All subjects were required to have 20/40 vision, uncorrected.

Procedure. The subject is placed in the chair so that the sellion landmark (base of the nose, between the eyes) was 40.5 inches from the target. The subject's head was placed against the head rest with the frankfort plane (plane established by the three points of the sellion landmark and the two ear openings) parallel to the floor. The chair and head rest were positioned so that the subject's sellion landmark coincided with the intersection of the azimuth and elevation axes of the target. The head was secured to the head rest with a head band.

During each three hour test session, 56 data points were measured in each of the head gear conditions and in a baseline condition without head gear. Each point was measured twice; first by moving the flashing light into the field of view and then by moving the flashing light out of the field of view. The following points were measured:

Top:	From +80 to -80 degrees azimuth in 10 degree increments
Sides:	From +60 to -60 degrees elevation in 10 degree increments
Bottom:	From +60 to -60 degrees azimuth in 10 degree increments

Results: For each of the 56 coordinates that were measured in the subject's field of view, two measurements were taken. These points were averaged together for each subject and each condition. These data were then merged and averaged across all subjects and plotted, resulting in one average plot per condition. These data are illustrated in Figures 2 through 5. The average data were then converted to polar coordinates. For each condition, the points were averaged within angular coordinates of the field of view and moving averages were calculated.

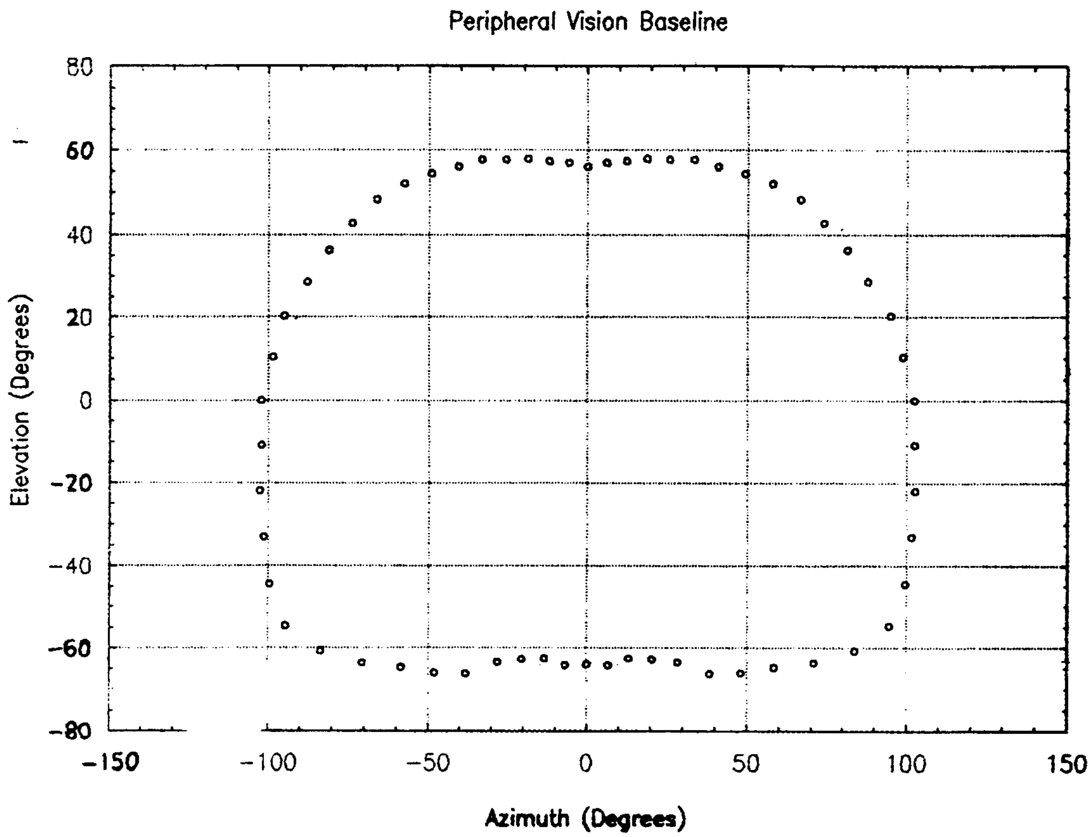


Figure 2. Peripheral Vision Baseline

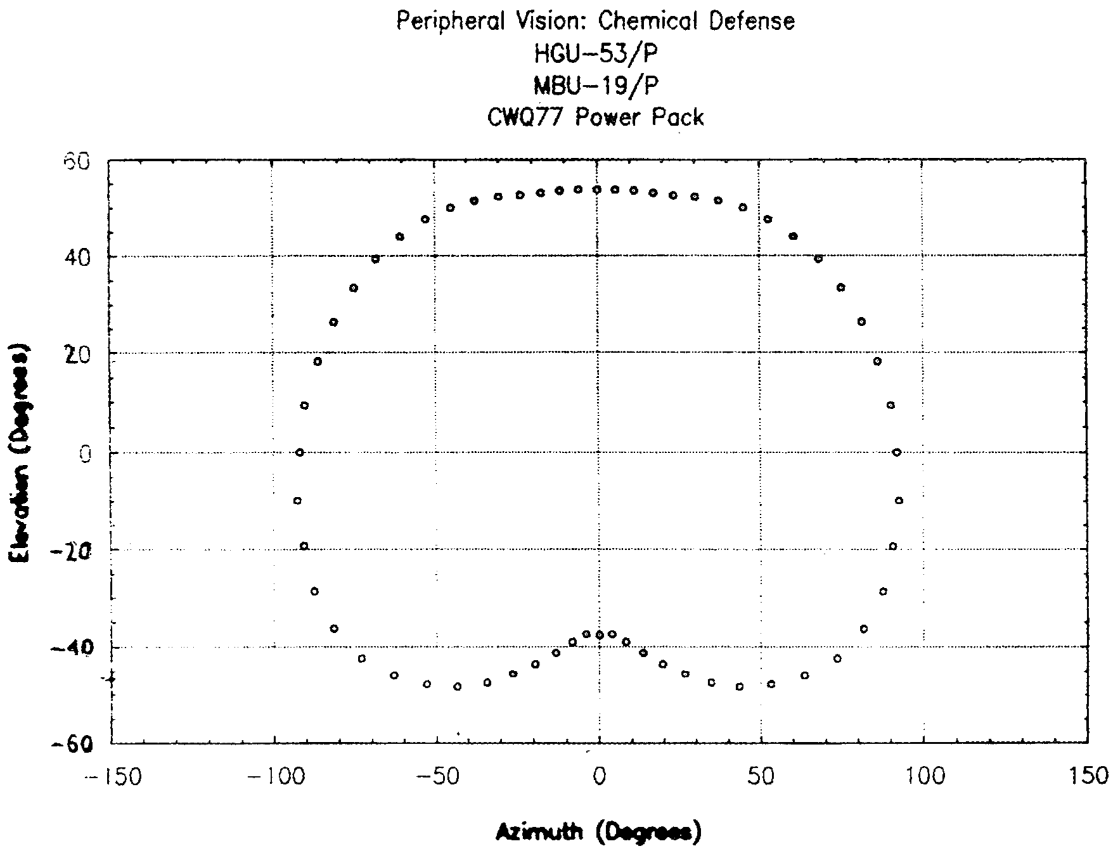


Figure 3.
Peripheral Vision: Chemical Defense

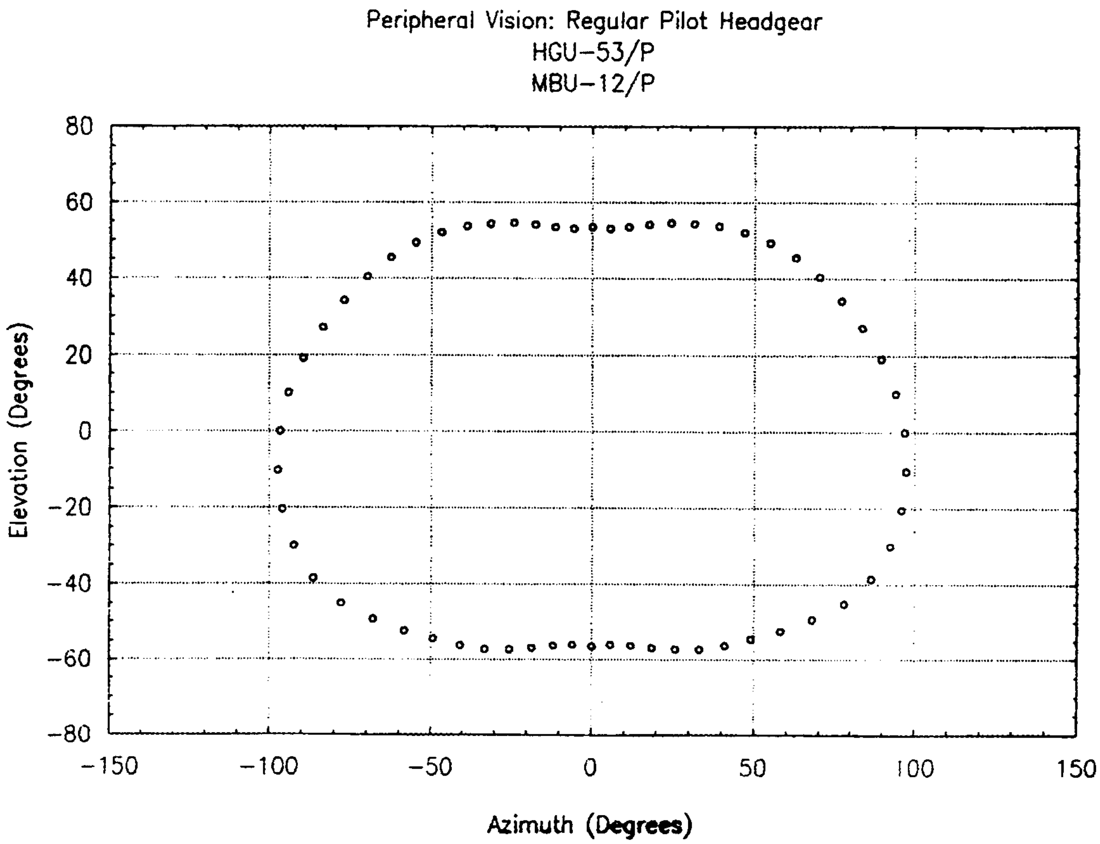


Figure 4. Peripheral Vision: Regular Pilot Headgear

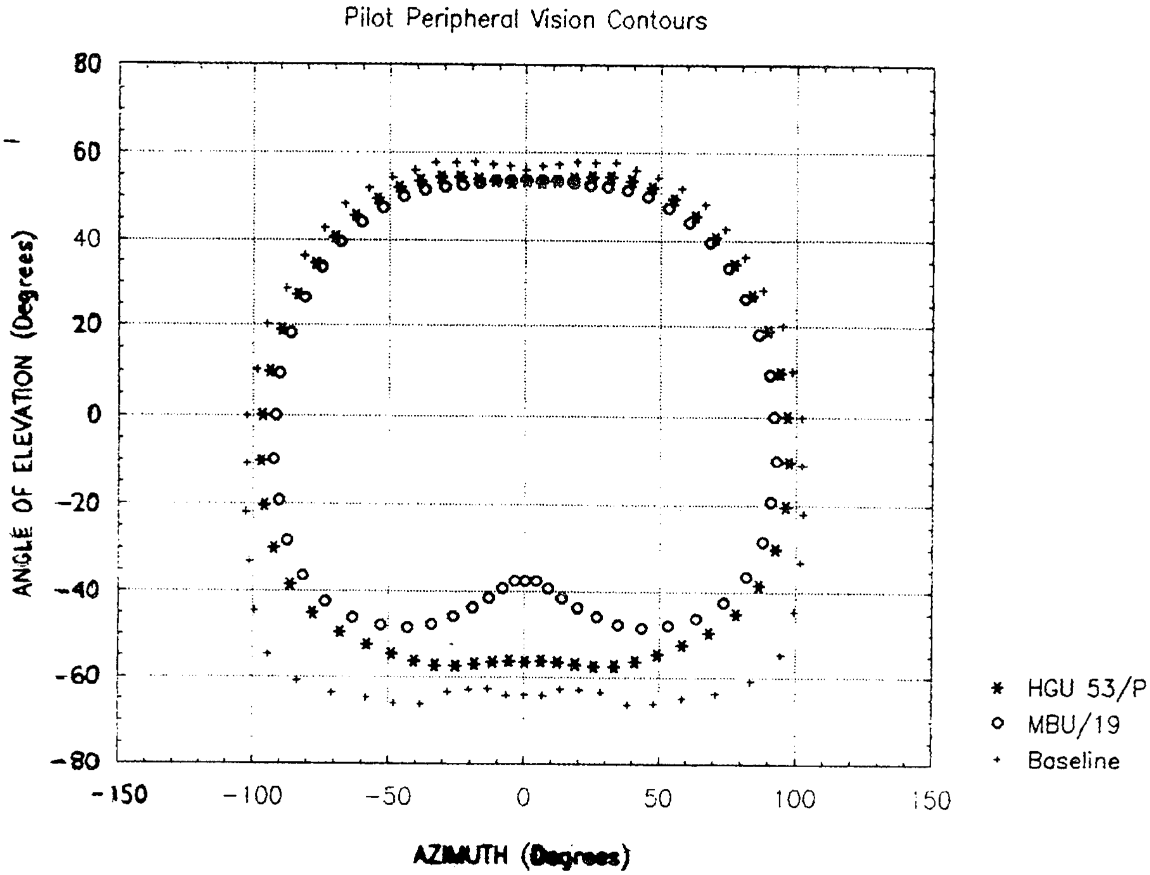


Figure 5. Pilot Peripheral Vision Contours

2.1.5 Develop TTE Capabilities

Paragraph 3.1.1.5 of the SOW required the developing of an enhancement to CREW CHIEF for computing time-to-repair.

The Task Time Estimation (TTE) function calculates the time required to remove and replace individual components and subsystems within a proposed design. This function takes into account such things as obstruction caused by other parts of the system, body posture, clothing, fatigue, and also the tools being used (if any). In addition, while the TTE does not directly calculate times for related tasks, such as setup, time spent retrieving spare parts, and troubleshooting, it does allow the user to enter these values into the TTE, which then uses these values in the final task time computations. Unlike other Predetermined Time Systems, which require the user to make subjective estimates of the difficulty of a task, the TTE objectively estimates task difficulty, and the times output reflect this difficulty.

Much of the data behind the TTE come from the Elemental Standard Data (ESD) database, and omni-level MTM database developed by the U.S. Navy. This database was expanded to take into account clothing, obstructions in the workplace, and other factors which affect task time in the workplace. The TTE function uses this database, along with user input and workplace geometry to calculate time for virtually all remove and replace tasks found in aircraft maintenance.

The user will define management tasks at three levels: User Element, Task, and Operation. A User Element is the lowest level maintenance element, and consists of several user elements performed in a specific sequence, and usually corresponds to a single, more complex activity, such as removing an access panel. An Operation consists of a series of tasks, performed in a specific sequence, and usually corresponds to a complete Remove and Replace maintenance activity.

The actual information input by the user will vary, depending on the level at which he is working. The user can begin defining a particular maintenance activity at any level, and any needed lower level information will be prompted for after the selected level is input.

A User Element corresponds to a simple, discrete maintenance activity, and is defined by the user through a series of prompts which detail the activity being performed. Through the answers to these prompts, the user will provide tool information, fastener information, object information, and human model positioning information.

Maintenance Tasks are defined by describing the exact sequence of User Elements which comprise the Task. Existing User Elements are displayed in a menu, and the user may pick from these. In addition, the user may key-in a new User Element name. After the definition of the Task is complete, the user will automatically be prompted to define any new User Elements keyed-in during the Task definition. Note that the order User Elements are defined will affect the overall time, so they must be defined in the same order as they would be performed on the flightline.

Maintenance Operations are defined by describing the exact sequence of maintenance tasks which comprise the Operation. Existing Tasks are displayed in a menu, and the user may pick from these. In addition, the user may key-in a new Task name. After the definition of the Operation is complete, the user will automatically be prompted to define any new Tasks keyed in during the Task definition. Note that the order Maintenance Tasks are defined will affect the overall time, so they must be defined in the same order as they would be performed on the flightline.

The Task Time Estimation Input/Output (TIO) subfunction accesses and/or updates the four databases needed to execute the Task Time Estimation (TTE) function. The TTE function calculates the time required to remove and replace individual components and subsystems within a proposed design.

The lowest level database is the Generic Element database. This database contains the basic times for various "types" of elements. Currently, the only type available is the threaded fastener (bolt/screw) type. Other types will be added to the database as data become available. The information to drive the element level of the user interface is contained in this database. The data in the database are based on the Elemental Standard Data (ESD) data and data collected in the local lab. The Generic Element database can only be accessed or read. This database will not be updated from TIO.

The User Element database contains element information d by the user. The elements correspond to a simple, discrete maintenance activity. The elements consist of tool information, fastener information, object information, and human modeling positioning. The TIO subfunction will access information concerning elements previously defined, or will add new user elements to the database. Information that will be updated or retrieved consists of number of elements in the database, names of the user elements, integers representing the variables used to define each user element and integers that identify the equation needed to define the time unit for a specific user element combination. Also a key code is output to this database that corresponds to a key code stored in the generic element database.

The Task database contains task information defined by the user. Each task corresponds to a sequence of user elements. Again, the TIO subfunction will access information concerning tasks previously defined, or will add new tasks to the database. Information that will be updated or retrieved consists of the number of tasks defined in the database, name of each task, number of elements that compose each task and identification numbers linking the elements defined in the User Element database to the tasks defined.

The final database is the Operations database which contains operation information defined by the user. Each operation corresponds to a sequence of tasks. This information consists of the number of operations defined in the database, name of each operation, number of tasks that compose each operation and identification numbers linking the tasks defined in the Task database to the operations defined. The TIO subfunction will access information concerning operations previously defined, or will add new operations to the Operation database.

The interface to any CAD system is done in the standard PROMPT, ACTION, RESULT format. The user is faced with the choice of defining an Operation, Task, or User Element. At the Operation level, the user is prompted to define tasks that make up this particular operation. The user can choose from existing tasks from the task database or can define new tasks. In the same manner, the user can define a task consisting of previously defined elements (from the User Element database) or can define new tasks. At the User Element level, the user defines the specifics of each User Element. These specifics include prompting the user to define tool information, fastener information, object information, and human model positioning information.

2.1.6 Validate the Task Time Estimator

UDRI performed time study research to validate existing data and developed a plan for validating the Task Time Estimator time-to-repair estimates.

Validation of Existing Data. Much of the research performed by UDRI was designed to validate data obtained from the ESD database, as well as provide additional data for the TTE database. The first of these studies was designed specifically to test the validity of the Navy's Elemental Standard Data database. The task studied was designed to exactly replicate the motions of the ESD data elements for installing and removing an object secured with four 3/8 inch bolts using a boxed end wrench. The ESD elements were decomposed onto their MTM-GPD components to ascertain the exact composition of the elements. The task was then engineered to replicate those elements. Element components such as the size and number of threads on the bolts, the number of threads turned by hand, the number of threads turned with the wrench, and the amount of swing on the wrench were made to correspond to the ESD elements.

The task involved positioning a 5 x 5 x 1.5 inch object on a mounting plate and securing it with four 3/8 inch bolts, using a boxed end wrench, and then removing it. The bolts were installed through holes, located in each corner of the objects, into threaded holes in the mounting plate. The variables in this study were the orientation of the mounting plate, the weight of the object and the distance between an access opening, through which the object was installed and removed, and the mounting plate. (The access opening was 19.5 x 19.5 inches and did not restrict access to the mounting plate, other than distance away.) Each experimental condition was performed five times including the practice trials. The subjects in this study were three males and two females recruited from the SRL subject pool.

It was not possible to draw any conclusions about the effects of distance and object weight. Shorter and weaker subjects reported being unable to perform the task at the far distance and/or with the heavier weight object. Therefore the task was modified to allow those subjects to complete it. However, it was the opinion of the experimenter that those subjects could have performed the tasks if they had been motivated to do so.

One interesting finding was obtained in this study through the experimenters observation of subjects performing the task using the heavy weight object. When the mounting plate was vertical, thus requiring the subject to support the weight with one hand, the subject's weight quicken. The subjects seemed to speed up their performance in order to avoid becoming overcome by fatigue.

The most important finding in this experiment was the close correspondence between the times obtained in this study and the times obtained from the ESD database. The task condition using the two pound object at the close distance was used for the comparison because that condition replicated the ESD elements. The following is a comparison of the time study results and ESD.

Table 8. ESD Analysis for Installation and Removal of a Component Secured with 4 Bolts

DESCRIPTION	CODE	TMU	OCC	TMU
A. Install				
1. Get and position component	OOH-PO-OA	120	0100	120
2. Install first bolt	OTF-SM-IB	1060	0100	1060
3. Install additional bolts	OTF-SM-XB	860	0300	2580

ESD ANALYSIS IN SEC. = 135.36

EXPERIMENTAL DATA IN SEC. = 135.70

DESCRIPTION	CODE	TMU	OCC	TMU
A. Remove				
1. Remove first bolt	OTF-SM-RB	1000	0100	1000
2. Remove additional bolts	OTF-SM-YB	820	0300	2460
3. Lay aside component	OMH-LA-OA	50	0100	50

ESD ANALYSIS IN SEC.	=	126.36
EXPERIMENTAL DATA IN SEC.	=	125.09

Note: Case B (easy) difficulty was used in the ESD analyses for bolt installation and removal due to the use of a boxed end wrench. Experimental data results are means of unedited raw data from the first five subjects, four test trials and one practice trial (N=25).

The next two experiments were designed to further examine the validity of the ESD database. As well as times for simple maintenance tasks, the ESD database also incorporates a system of determining the difficulty of a task and predicting the increased time required to accomplish it. These experiments were designed to investigate the validity of the ESD system for determining task difficulty and quantify the factors which cause the task to be difficult.

The ESD system uses five levels of difficulty ranging from "very easy" (level 1) to "very difficult" (level 5). The ESD difficulty levels are based on three variables which affect time; weight, distance, and control. The following are the ESD definitions of the variables for each of the five levels.

Weight	Level 1	0 to 3 pounds
	Level 2	over 3 to 10 pounds
	Level 3	over 10 to 25 pounds
	Level 4	over 25 to 50 pounds
	Level 5	over 50 pounds
Distance	Level 1	within an 18 inch radius
	Level 2	within a 30 inch radius
	Level 3	within a 4 foot radius
	Level 4	within a 6 foot radius
	Level 5	within an 8 foot radius
Control	Level 1	Accomplishment is unobstructed and object is clearly visible.
		Closeness of fit (where applicable) is loose and object is easy to handle.
		Maximum recoil is 1 inch.

Level 2 Accomplishment has SOME interference and object is visible, or there is no interference and object is PARTIALLY visible.

Closeness of fit (where applicable) is loose and object is difficult to handle.

Maximum recoil is 1 inch.

Level 3 Accomplishment contains interference and object is PARTIALLY visible.

Closeness of fit (where applicable) is close.

Maximum recoil is 5 inches.

Level 4 Accomplishment contains interference and object is NOT visible.

Closeness of fit (where applicable) is exact.

Recoil over 5 inches.

Level 5 Accomplishment is OBSTRUCTED and object is NOT visible.

Closeness of fit (where applicable) is exact with multiple and/or non-symmetrical, difficult positions.

It can be seen that ESD difficulty levels for the factors weight and distance can be easily determined. However, the level of control requires a subjective determination based on the amount of interference, visibility, and closeness of fit between mating parts. Furthermore, the ESD system does not assign equal importance to each of the three variables. The relative contribution to difficulty assigned to these variables is 5% for weight, 10% for distance, and 85% for control. Since, the difficulty levels for weight and distance can be objectively obtained and contribute relatively little to task difficulty, these studies were designed to validate and attempt to quantify the subjective factor of control.

The task used in these studies involved the disassembly and reassemble of a flange type pipe fitting. The simulated flange fitting was held together with four 1/4 inch bolts and self-locking nuts. A flexible rubber hose was attached to an end of the fitting, requiring the subject to position and align the two pieces of the fitting and hold them in place with one hand while the first bolt was inserted. The fitting was mounted horizontally to the subject with the bolt being inserted from the bottom and the nut on top.

The variables used in these studies were; tool type, tool interference, and access opening size. The task required the use of two tools, one on the nut and one on the bolt head. The 2 tool combinations used were as follows:

Tool on nut (top)	Tool on bolt head (bottom)
Ratchet wrench with socket	Boxed end wrench
Boxed end wrench	Boxed end wrench
Boxed end wrench	Open end wrench
Open end wrench	Open end wrench
Open end wrench	Open end wrench

Tool interference was accomplished by placing a vertical wall type barrier adjacent to one of the bolts at a distance of two inches. Two access opening sizes were used in the studies, a 19.5 x 19.5 inch opening and an 8 x 5 inch opening. The large opening represents the size necessary to accommodate a 95 percentile male working with both hands, through an opening up to the shoulders. This opening caused no physical or visual interference. The small opening represents the minimum size allowable by MIL-STD-1472D for two-handed work.

The first study employed 48 subjects divided into eight groups of six subjects each. Each subject performed three trials on two of the experimental conditions, for a total of six disassembly and reassembly trials. Subjects were also given the opportunity to practice the least and most restrictive conditions, up to a total of three trials. The order in which the task conditions were performed was counterbalanced within each group. The task conditions performed by each group were as follows.

WRENCH	INTERFERENCE	GROUP					
Ratchet/Boxend	Present	1					6
Ratchet/Boxend	Absent	1	2				
Boxend/Boxend	Present		2	3			
Boxend/Boxend	Absent			3	4		
Open/Boxend	Present				4	5	
Open/Boxend	Absent					5	6
Boxend/Open	Present	7					
Boxend/Open	Absent	7					
Open/Open	Present	8					
Open/Open	Absent	8					

Groups 7 and 8 were not included in the original experimental design. They were added after the study was in progress.

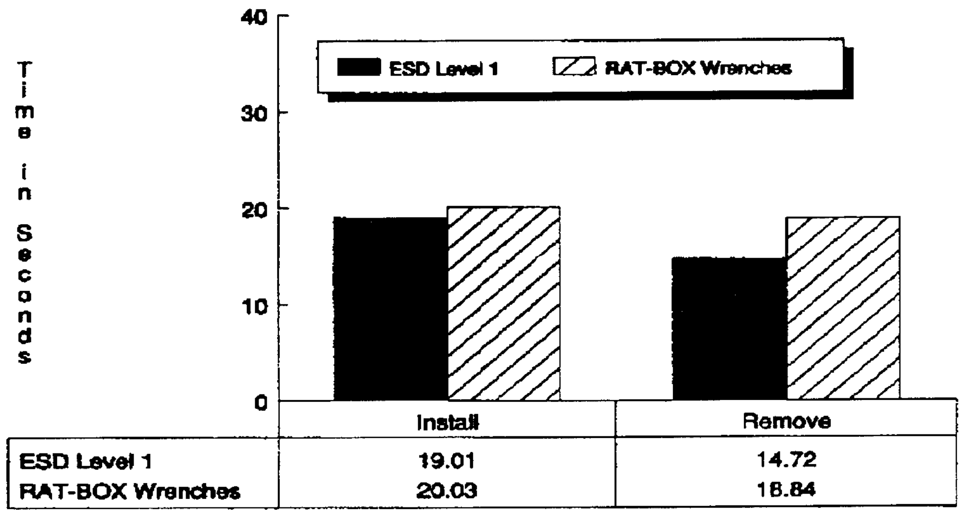
This experimental design was developed as an attempt to control for the effects of practice and transfer of training between experimental condition. Figure 6 shows the mean total task times for each trial across experimental condition. The figure shows that some learning did occur, however, the effect was minimal with only a 5.6% increase from first to third trial.

Figure 6. Mean Task Times for Each Trial
Across All Experimental Conditions

In the first study only the 19.5 x 19.5 inch access opening was used. The second study was a replication of the first using the 8 x 5 inch access opening. The second study employed 48 new subjects who did not participate in the first study.

According to the ESD definitions for control, Level 1 contr olves no interference and complete visibility. These conditions correspond to the Time study condition using the 19.5 x 19.5 inch access opening with no interference barrier present. It should be noted here that the use of two boxed end, open end, or combination wrenches constitutes Level 2 control in the ESD database. This is not obvious from the definitions, it was discovered by UDRI upon examination of the ESD database, and confirmed by the Navy's representative. The reason for this is the need to reposition one of the wrenches on every turn, requiring more control than a ratchet wrench or speed hand type tool. Therefore, the only experimental condition in our time study which conforms to the definition of Level 1 difficulty is that using the Ratchet wrench with socket and boxed end wrench (RAT-BOX). The mean time for installing and removing a bolt and nut with the RAT-BOX tools through the 19.5 x 19.5 inch opening with no interference barrier, is presented in Figure 7. Also, presented in the figure is the corresponding ESD element Times.

All ESD elements for installing and removing bolts, contain additional time for installing/removing washers. To keep the content of the ESD element consistent with the study, the MTM-GPD element times used to add the time for washers in the construction of the ESD elements were subtracted from the ESD element time. Also, note that the time study results shown are for Bolt #3. Since Bolt #3 was where the interference barrier was present, all results presented will be those obtained on Bolt #3.



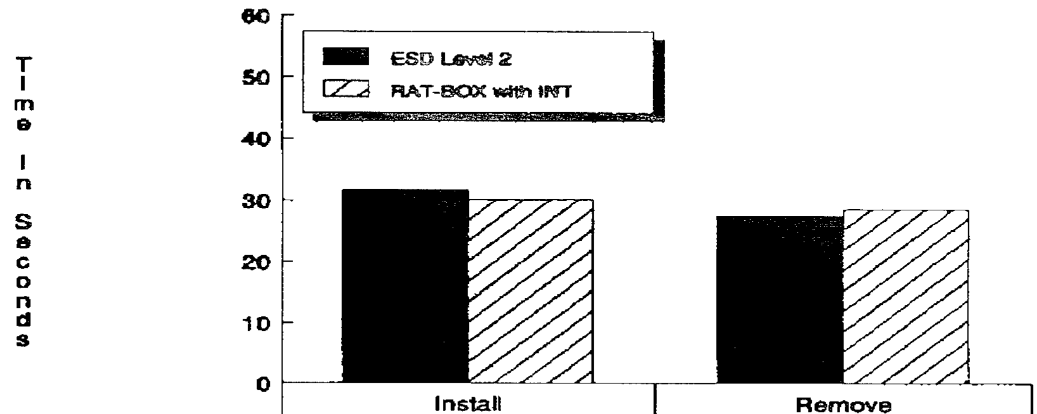
ESD elements OTF-BM-4A (install) and OTF-BM-9A (remove), minus the time for installing and removing washer.

Figure 7. Laboratory Time Study Data vs.
ESD Level 1 Data

It can be seen from the figure that the time study results conform very closely to the time predicted by the ESD element. Recall that the ESD definition of control stated that some interference constituted Level 2 control if the object is clearly visible. That condition corresponds to using the RAT-BOX tools through the large opening with the interference barrier in place. Figure 8 shows the results of that condition.

The ESD definitions of control also stated that impaired visibility of the object also constituted Level 2 control. That condition was simulated by the 8 x 5 inch access opening. Figure 9 shows the mean times for installing and removing a bolt and nut with the

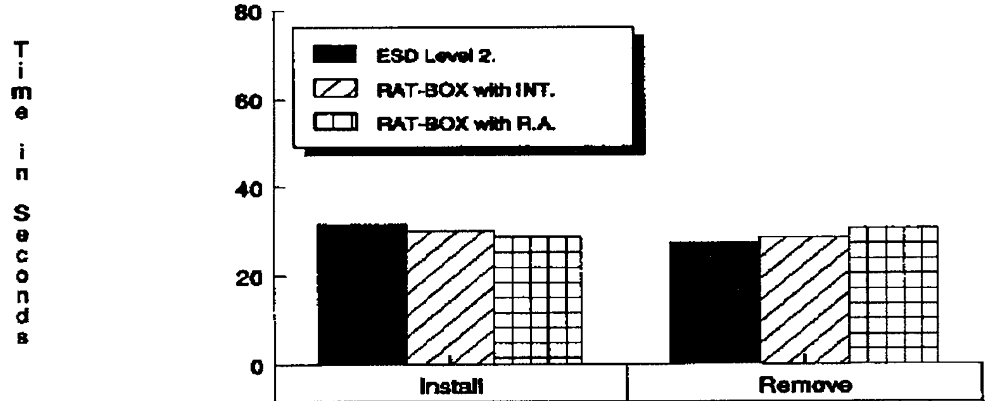
RAT-BOX tools with no interference barrier. Again, the ESD data compares very closely to the time study data.



	Install	Remove
ESD Level 2	31.68	27.47
RAT-BOX with INT	30.13	28.63

ESD elements OTF-BM-4B (install) and OTF-BM-9B (remove), minus the time for installing and removing washer.

Figure 8. The Effect of Interference on Laboratory Time Study Data vs. ESD Level 2 Data

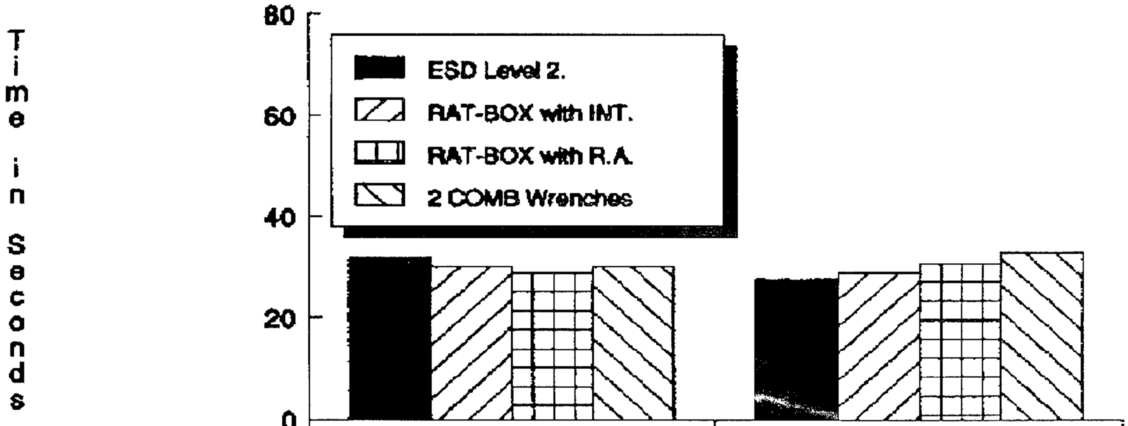


	Install	Remove
ESD Level 2.	31.68	27.47
RAT-BOX with INT.	30.13	28.63
RAT-BOX with R.A.	28.72	30.62

ESD elements OTF-BM-4B (install) and OTF-BM-9B (remove), minus the time for installing and removing washer.

Figure 9. The Effects of Interference and Restricted Access on Laboratory Time Study Data vs. ESD Level 2 Data

As mentioned earlier the use of two boxed, open, or combination wrenches constitutes Level 2 control. ESD does not differentiate between Boxed end wrenches, open end wrenches, and combination wrenches. The reason for this is that the MTM-GPD data upon which ESD is built do not differentiate between them. Therefore, the time study results presented for these tools are the mean times for all the tools combinations which used two boxed end wrenches, two open end wrenches, and one boxed end and one open end wrench; and will be referred to as combinations wrenches (COMB). Figure 10 shows the mean times for installing and removing a bolt and nut with two combination wrenches through the large opening with no interference barrier. It can be seen from the figure that all of the conditions which correspond to Level 2 control compare very favorably with the ESD Level 2 data element times.



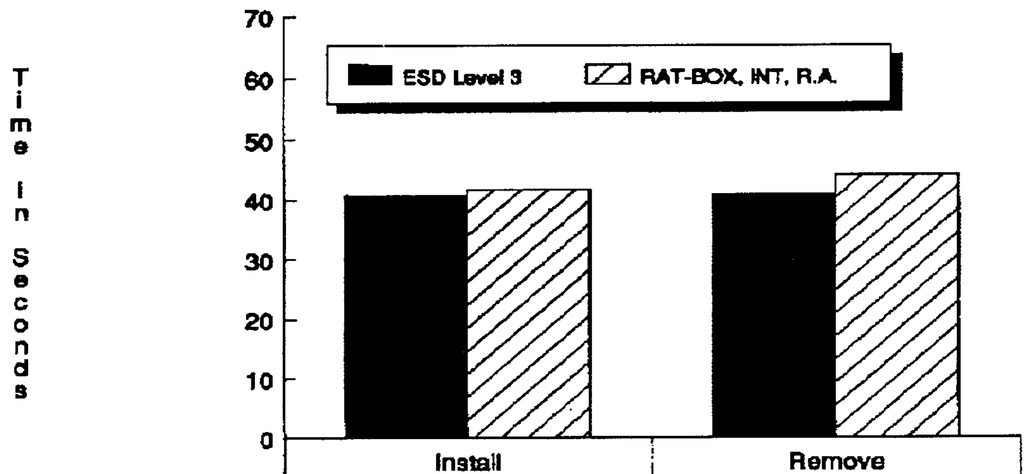
	Install	Remove
ESD Level 2.	31.68	27.47
RAT-BOX with INT.	30.13	28.63
RAT-BOX with R.A.	28.72	30.62
2 COMB Wrenches	30.02	32.78

ESD elements OTF-BM-4B (install) and OTF-BM-9B (remove), minus the time for installing and removing washer.

Figure 10. The Effects of Interference, Restricted Access, and Wrench Type on Laboratory Time Study Data vs. ESD Level 2 Data

Thus far, the results of the time studies have provided strong evidence that the ESD data valid for predicting times for task which correspond to their definition of Level 1 and Level 2 difficulty. Furthermore, the results have allowed the assignment of object, measurable task condition to the ESD subject definitions of control. It was found that an interference located at a distance less than the length of the wrench used and restricts movement of the wrench constitutes Level 2 control. Also, working through an opening which restricts vision constitutes Level 2 control. These are conditions which can be identified by the CREW CHIEF model for input into the TTE.

The ESD definition of Level 3 control states that, accomplishment contains interference and the object is partially visible. This corresponds to the experimental condition which uses RAT-BOX tool through the small access opening with the interference barrier present. Figure 11 presents the mean installation and removal times for that condition along with the ESD element times for Level 3 control. Inspection of the figure shows very close correspondence between the Time study data and the ESD Level 3 element times.

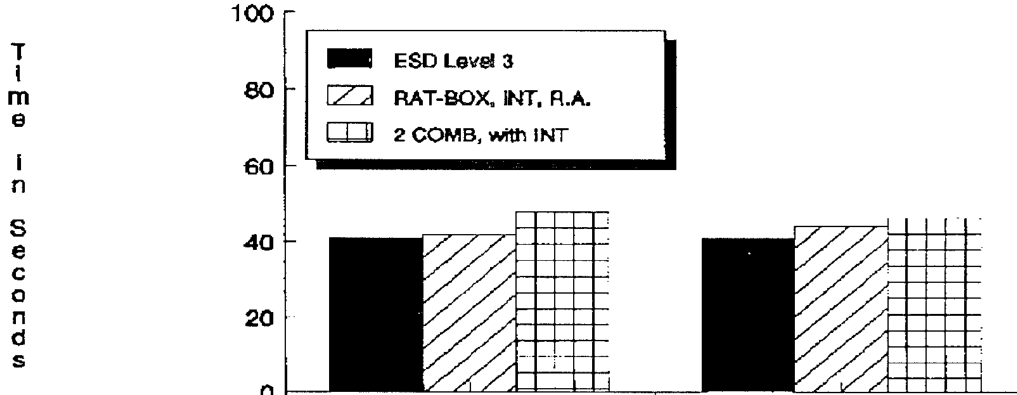


	Install	Remove
ESD Level 3	40.82	40.93
RAT-BOX, INT, R.A.	41.74	44.17

ESD elements OTF-BM-4C (install) and OTF-BM-9C (remove), minus the time for installing and removing washer.

Figure 11. The Combined Effect of Interference and Restricted Access on Laboratory Time Study Data vs. ESD Level 3 Data

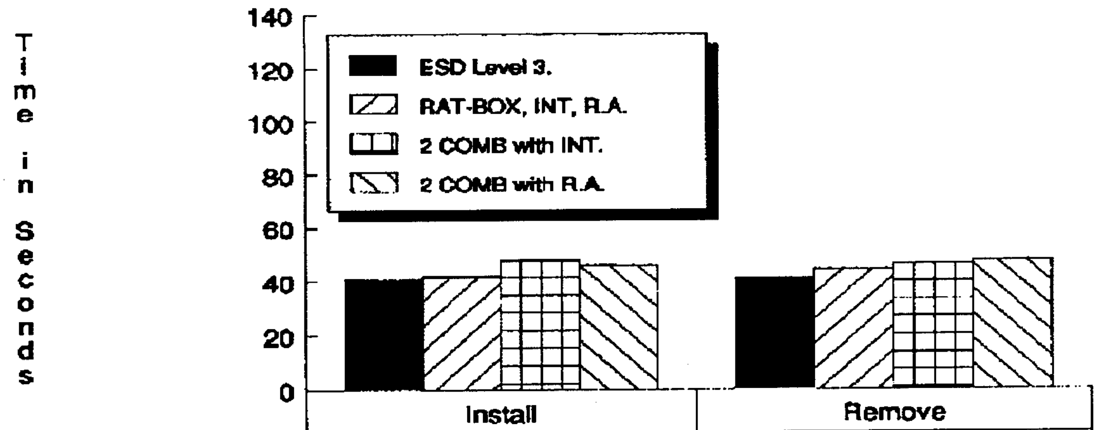
It was shown from the time study results that when interference was introduced into a Level 1 task condition, the time increased to approximately that of Level 2. The same was true when vision was restricted. What if those variables were introduced into a Level 2 task such as the installation and removal of a bolt and nut with two combination wrenches? Figures 12 and 13 show that the time increased to approximately that of Level 3.



	Install	Remove
ESD Level 3	40.82	40.93
RAT-BOX, INT, R.A.	41.74	44.17
2 COMB, with INT	47.75	46.23

ESD elements OTF-BM-4C (install) and OTF-BM-9C (remove), minus the time for installing and removing washer.

Figure 12. The Combined Effects of Interference and Restricted Access, and Interference and Tool Type on Laboratory Time Study Data vs. ESD Level 3 Data

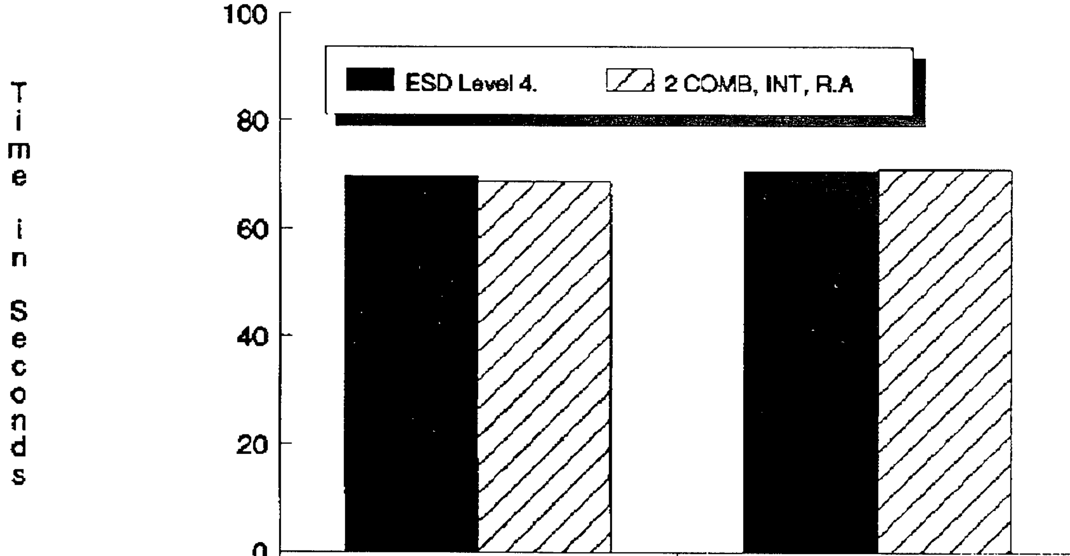


	Install	Remove
ESD Level 3.	40.82	40.93
RAT-BOX, INT, R.A.	41.74	44.17
2 COMB with INT.	47.75	46.23
2 COMB with R.A.	45.72	47.34

ESD elements OTF-BM-4C (install) and OTF-BM-9C (remove), minus the time for installing and removing washer.

Figure 13. The Combined Effects of Interference and Restricted Access, Tool Type and Interference, and Tool Type and Restricted Access on Laboratory Time Study Data vs. ESD Level 3 Data

To carry this logic one step further, if the task condition using two combination wrenches contained both interference and restricted access it would correspond to ESD level 4 difficulty. Figure 14 shows that this is indeed the case.



	Install	Remove
ESD Level 4.	69.67	70.85
2 COMB, INT, R.A	68.63	71.09

ESD elements were calulated using the
ESD time-difficulty ratio formula.

Figure 14. The Combined Effects of Tool Type, Interference, and Restricte Access on Laboratory Time Study Data vs. ESD Level 4 Data

Validation of TTE Time-To-Repair Estimates. UDRI has developed a plan to validate the task time computations produced by the TTE against Actual flightline maintenance. With the assistance of the Air Force, UDRI will schedule and obtain prior approval for visits to maintenance facilities in the vicinity of WPAFB to videotape maintenance tasks. The UDRI personnel who will be involved with this task have active security clearances, which is necessary for access to the flightline. The target facilities will include the Air National Guard at Springfield Municipal Airport, the 906th Fighter Group, and the 4950th Test Wing, both at WPAFB. To minimize the impact to and disruption of flightline activities, the task selected validation will be chosen from scheduled maintenance activities. This will also eliminate any additional aircraft downtime and maintenance man-hours, facilitate receiving Air Force approval, and (we hope) provide better cooperation from the technicians.

Once the tasks are videotaped, the tapes will be brought back to the Physical Ergonomics Laboratory for review. The times will be extracted using a stopwatch with any inappropriate delay times being removed from the data. These will include values that are plus or minus three standard deviations from the mean or times on tasks where interruptions occur. The difficulty of task elements will be determined from CREW CHIEF difficulty definitions. Once difficulty is established, the time-difficulty models will be applied to enable us to compare the actual flightline task times to the simulated laboratory task times for validation.

2.2 Develop Space Maintenance Model

In accordance with P00020 of this contract, this portion of the effort was deleted.

2.3 Rehost CREW CHIEF on other CAD Systems

The CREW CHIEF program has been rehosted on several additional CAD systems. CREW CHIEF interfaces are now available on four major CAD systems. These CAD systems run under eight different operating systems. There are two major factors for choosing the CAD systems and operating systems used for CREW CHIEF interfaces. The first factor is the availability of the hosts in the Computer Aided Workplace and Design Facility. The second factor is the survey of CREW CHIEF users. Survey results showed that 95% of CREW CHIEF users either had, or planned to acquire, at least one CREW CHIEF host system.

<u>CREW CHIEF Hosts</u>

<u>CADAM</u>

CREW CHIEF is interfaced to Version 21 of the CADAM CAD system running under the IBM MVS and VM operating systems. An interface to Pro CADAM running under the IBM AIX operating system is in progress.

<u>CATIA</u>

CREW CHIEF was interfaced to Version 3 of the CATIA CAD system running under the IBM MVS and AIX operating systems.

I-DEAS

CREW CHIEF was interfaced to level V of the I-DEAS CAD system running under the Silicon Graphics IRIX operating system. CREW CHIEF was also interfaced to level VI of the I-DEAS CAD system running under the Sun SUNOS operating system.

Unigraphics

CREW CHIEF is currently being interfaced to Version 9.0 of the Unigraphics CAD system running under the Sun SUNOS operating system.

2.3.1 Rehost CREW CHIEF on Other IBM CAD Systems

Under paragraph 3.1.3.1 of the SOW, UDRI was required to rehost CREW CHIEF on other IBM CAD systems. To satisfy these requirements, UDRI developed and released Versions 2 and 3 of CREW CHIEF with interfaces to CADAM 21 (under both VM and MVS operating systems) and CATIA (under VM, MVS, and the AIX operating systems). UDRI also made many of the changes to the CADAM 21 interface needed to make that interface compatible with ProCadam (under the AIX operating system), but due to the low number of requests for this interface and time constraints, this interface was delayed for further consideration.

The CADAM 21 interface was developed under the MVS operating system. UDRI developed the CADAM 21 interface using the Common User Interface (CUI) in conjunction with CADAM's Interactive User Exchange (IUE) module developed for CADAM software applications. Under CADAM IUE, UDRI developed icons which can be selected by the user to invoke CREW CHIEF function modules. For the MVS version of CREW CHIEF, UDRI separated each function into a separate module in order to save space in the mainframe's core memory. Each function module consisted of a set of FORTRAN routines for the core function software, a set of routines for the Common User Interface (CUI) software, and the software developed to drive the interface at the CAD level (in this case, the routines which used CADAM IUE routines for graphical input and output, menus, prompts, help tables, and icons). Since the core memory on the MVS system was small in comparison to what was needed for each function, every function had to have its own overlay structure to allow the system supervisor to load the appropriate chunks of code at function run time (i.e., when the user picks the icon representing a specific function). All of the CADAM 21 interface code was written in FORTRAN for compatibility with the CADAM IUE FORTRAN routines.

For the Version II interface, code and databases were updated mostly for ease of use considerations and for ridding the code of minor bugs. For example, the window settings were saved when the user entered a CREW CHIEF function (via an icon selection). This modification allowed the interface to present the user with a window which had all the geometry and text centered and scaled properly regardless of whether the user is making a menu selection, geometry pick, or an alphanumeric key-in. Previously CADAM had not allowed us access to the routines which read and set the window settings. Also, the number of icons available for selection along with the menu text increased to help the user visually determine what is actually defined by each menu pick. The help tables were also updated to accurately describe in detail what each menu, key-in, or geometry pick was actually defining. Finally, the wording of the prompts were all updated to make the interface easier to navigate through in an intelligible way. These changes were then tested fully one function at a time.

For the Version 3 interface, the Link Table and Grasp function interfaces were added using the Common User Interface (CUI) to parallel methods used for developing the Version II interface. These two function interfaces were integrated into the overall interface of CREW CHIEF and fully tested and validated. Note that during this time period, all of the CUI prompts were standardized and updated which forced full testing and validation of the previous 16 function interfaces already developed for CADAM 21 as well.

Once these interfaces were developed, UDRI cut and tested the distribution tapes and validated the installation directions. Then, the interface was ported over to the VM operation system by recompiling all the source code and writing the necessary procedures on the VM system to generate the executable modules and enable validation on the VM system. Then the VM distribution tapes were cut and master copies retained for subsequent tape copies as orders came in for this interface.

For the CATIA interface, UDRI used an interface developed by Boeing as a starting point in order to save time. Boeing started the interface by using the Function Structure Definition (FSD) language provided by CATIA to develop CATIA type functions. The FSD language is used to present the user with CATIA type menus and prompts. The menus are selected to invoke more menus or task subroutines (written in FORTRAN). UDRI (and

Boeing) developed several types of task subroutines for the CREW CHIEF interface to CATIA. Some of the task subroutines allow geometry selection (using the CATIA Data Input Manager (DIM) of the CATIA Graphics Interactive Interface (GII) module). Other task subroutines provide CATIA type panels (2-D windows with text) using the CATIA Graphics Interface (CATCGI) portion of CATIA's GII module. These panels were developed to allow the user to input data associated with the menu selected. UDRI stored all the data in the CREW CHIEF function control commons for use by the core when the final task for the selected function is invoked via menu selection. The final task is used to execute the selected function analysis and output the appropriate information to the user through the use of the CATIA supplied CATCGI portion of the GII module. In order to obtain geometric information from the CATIA drawing database, UDRI developed (and enhanced that which was already available from the Boeing partial interface to CATIA) the CREW CHIEF geometry input interface to CATIA. To accomplish this, UDRI used the CATIA FORTRAN routines provided by the Geometry Interface (CATGEO) module to access the CATIA data structures.

UDRI continued building on the partial interface developed by Boeing to produce a complete CATIA interface for Version II of CREW CHIEF. UDRI finished the interface by updating the FSD code, writing new FSD code, updating task subroutines, and developing new task subroutines for almost all of the CREW CHIEF functions. UDRI developed the entire Reposition function and redesigned most of the materials handling function interfaces to CATIA.

Once all the code for the tasks and menus was written, UDRI used the CATDCG utility provided by CATIA to compile the FSD code. Then UDRI used the LKFCAPI procedure to link the code with the CATIA geometry interface routines. Finally, UDRI integrated the executable code into CATIA using the CATIA Function Integration (CATFID) utility provided by CATIA. This final step allows CREW CHIEF to be selected as a menu item just like the rest of the CATIA functions.

For the Version 3 CREW CHIEF interface to CATIA, UDRI developed all the FSD code needed for the Link Table and Grasp function interfaces. This code was developed more modular than the FSD code generated for Version II. UDRI also developed all the FORTRAN routines needed for the task processing dictated by the menu trees developed in the FSD code for these function interfaces. UDRI also implemented geometry interface updates provided by Boeing periodically to allow for more CATIA elements to be processed for obstacle avoidance considerations. These updates allowed solids, dittos, and details to be processed as well as the drawing elements allowed for the Version II interface of CATIA.

Due to size constraints on the MVS development system, UDRI performed most of the CATIA interface development on the AIX operating system. All of the validation on the MVS operating system was performed by Boeing. The source code generated on the AIX system was loaded onto both the MVS and VM operating systems for compilation and linkage. Distribution tapes were cut for both of these systems. Since the AIX version of the CREW CHIEF interface to CATIA was relatively small once compressed, and since most IBM RS6000 workstations come with a 3.5 inch floppy drive, the distribution of the CREW CHIEF CATIA interface for the AIX system was performed using the 3.5 inch floppy disks.

2.3.2 Rehost CREW CHIEF on VAX Based CAD Systems

The SOW required the reprogramming of the CREW CHIEF model to operate on two CAD systems based on DEC VAX systems. Contract modification P00020, deleted this requirement from the contract.

2.3.3 Rehost on Other Platforms

The SOW requires that the CREW CHIEF model be rehosted on additional CAD systems. These CAD systems must be locally available and in use by major aerospace contractors. CREW CHIEF has been rehosted on I-DEAS Level V, I-DEAS Level VI and Unigraphics Version 9 CAD systems. These CAD systems reside on Silicon Graphics Iris workstations and Sun SPARCstations.

Silicon Graphics

The CREW CHIEF model has been rehosted on two CAD systems on a Silicon Graphics workstation. The CAD systems available to us on the Silicon Graphics platform are I-DEAS Level V and I-DEAS Level VI. The I-DEAS Level V rehosting took place on a Personal Iris system. The I-DEAS Level VI rehosting took place on an Iris 4-D system. Both I-DEAS interfaces use the CUI for the interface. These interfaces use the Director/Observer facility of the I-DEAS CAD system. Another critical part of these interfaces is the use of I-DEAS Universal files.

Sun SPARCstation

One of the two CAD systems on which the CREW CHIEF model was rehosted was I-DEAS VI on a Sun SPARCstation workstation. The I-DEAS rehosting uses the CUI for the interface. This interface uses the Director/Observer facility of the I-DEAS CAD system. Another critical part of this interface is the use of I-DEAS Universal files.

The other CAD system available on the Sun SPARCstation is Unigraphics Version 9. This rehosting uses the CUI for the interface. This interface uses the Unigraphics User Function facility.

2.4 Maintain CREW CHIEF Software and Documentation

Paragraph 3.1.4 required the CREW CHIEF software and documentation be maintained.

The official CREW CHIEF software is maintained on a SPARCStation, SUNOS. All notices of changes and updates are given to the software manager. The software manager updates the official software and then notifies all programmers of the updates. The software is then updated on each hardware platform by the person responsible for that specific platform.

Updates to CAD dependent software is handled a little differently. The CATIA interface was developed by Boeing and updates or modifications to this interface are sent to us from Boeing. We then update our version of the CATIA interface software. A CREW CHIEF/CATIA user's guide is available.

I-DEAS interface software is updated and tested on a SPARCStation. Once updates, modifications, or enhances have been fully tested, all programmers are informed of the changes. The ProCADAM interface is compatible with the CADAM 21 interface and therefore uses the same user's guide as the CREW CHIEF/CADAM 21 version.

The ProCADAM interface software is updated on a RS6000 system. Again, once updates, modifications, or enhancements have been fully tested, all programmers are informed of the changes. The ProCADAM interface is compatible with the CADAM 21 interface and therefore uses the same user's guide as the CREW CHIEF/CADAM 21 version.

CADAM 21 interface software is hosted on an MVS system. At present we do not have convenient access to a MVS system for updates. Previously we updated the interface software in the same manner as the previously mentioned CAD system interfaces to CREW CHIEF. A CREW CHIEF CADAM 21 user's guide is available.

Unigraphics interface software is hosted on the SPARCStation. This interface is still under development. At present there is no user's guide.

Also available is a CAD System Independent version of CREW CHIEF. This software is basically the official core software and is maintained on the SPARCStation. A CAD System Independent guide is available.

All user's guides are kept up-to-date. As enhancements are made to CREW CHIEF, the user's guides are updated. If new functions have been incorporated, the users' guides have been updated accordingly.

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SECTION 3 - ENHANCE AND UPDATE COMBIMAN

The contract SOW required three major areas of enhancement for COMBIMAN. First, UDRI was tasked to develop a host-independent version of COMBIMAN. As with CREW CHIEF, UDRI was tasked to rehost COMBIMAN on other CAD systems. Finally, UDRI was tasked to develop three seat models for use with COMBIMAN analyses. All relevant software and documentation had to be maintained too.

3.1 Develop Host-Independent COMBIMAN

COMBIMAN Version 8

The COMputerized BIomechanical huMAN model (COMBIMAN) is an interactive computer graphics engineering tool, that represents an operator in a crew station. Version 8 of COMBIMAN was a standalone system. The functions of COMBIMAN Version 8 can be classified as human model simulation and geometry manipulation. The geometry manipulation includes many typical CAD system functions. These functions include crew station manipulation, view manipulation and hard copy generation.

COMBIMAN Version 8 runs on an IBM system/370, 303x, 43xx, or equivalent computer. COMBIMAN requires an IBM 2250-III or equivalent display unit. The COMBIMAN Version 8 software has calls to the obsolete IBM Graphics Subroutine Package deeply embedded in the code.

COMBIMAN Version 9

Version 9 of COMBIMAN was structured into two distinct modules. This redesign has a graphics input and output module that allows a host CAD system, or other graphics package, to perform all graphics operations. The other module, in Version 9 COMBIMAN, performs the human model simulation. The new structure of COMBIMAN is the same as the CREW CHIEF program. COMBIMAN functions are shown in Figure 15. The following paragraphs describe the human model functions of COMBIMAN Version 9.

Generation Functions

Initialization

Regeneration

Head Orientation

Link Table

Reposition

Activity Analysis Functions

Reach

Strength

Reach Envelope

Visibility

Interference

Status Functions

Configuration

Figure 15. COMBIMAN Functions

Initialization Function

The Initialization function generates the COMBIMAN human model. The COMBIMAN program includes six built-in populations. The program has five methods to generate body size. COMBIMAN provides seven clothing types.

Regeneration Function

The Regeneration function regenerates the COMBIMAN model display. This function uses the enfleshment from the last successful positioning function. Positioning occurs during the Generation functions or during a Reach analysis.

Head Orientation Function

The Head Orientation function moves the COMBIMAN model's head toward some specified target point. The COMBIMAN model turns its head within the allowable mobility constraints. If the target point already lies within the model's view, the COMBIMAN model does not turn its head.

Link Table Function

The Link Table function allows changes to be made to the angles for selected links within the COMBIMAN model's link system. This function displays angles for 16 of the 36 links in COMBIMAN's link system. The user can enter phi, theta and psi values corresponding to the Euler angles for the selected links.

Reposition Function

The Reposition function is designed to augment the COMBIMAN positioning functions. This function allows the movement of peripheral body sections. Reposition allows movement of up to 12 body sections. Mobility constraints will still be enforced. Interference is not checked.

Reach Function

The Reach function allows evaluation of the aircrew member's capability to reach controls. Controls in this context are handles, rudder pedals and switches. A successful reach depends on clothing type, body mobility, control type and control location. Mobility limits and clothing type selection cause the COMBIMAN model to reach toward the designated location with realistic joint mobility.

Strength Function

The Strength function allows evaluation of the aircrew member's capability to reach and operate controls. Controls in this context are handles, rudder pedals, switches and ejection handles. A successful reach depends on clothing type, body mobility, control type and control location. Mobility limits and clothing type selection cause the COMBIMAN model to reach toward the designated location with realistic joint mobility. Strength capabilities are predicated on the assumption that force cannot be applied unless the control can be reached.

Reach Envelope Function

The Reach Envelope function determines if a control panel lies inside, intersects with, or lies outside the crew member's maximum arm-reach envelope. This evaluation is performed as a function of body size, clothing type, restraint type and control type. This function produces a reach envelope in 3-D space and then computes the intersection of that reach envelope with a user selected surface in the crew station.

Visibility Function

The Visibility function generates and plots a map of the angular line-of-sight to objects in a crew station. MIL-STD-850 (Aircrew Station Vision Requirements for Military Aircraft) requires visual angle maps be made of crew stations. MIL-STD-850 allows two formats. Aitoff's and Rectilinear projections. Both projections are available in COMBIMAN.

Interference Analysis Function

The Interference Analysis function checks for interference between the COMBIMAN model and drawing elements. Interference is displayed on the screen. Arrows indicate the points of interference.

Configuration Function

The Configuration function displays the parameters used to generate the human model. This function lists the anthropometric population, clothing type and seat reference point. All other definitions are included in the display.

A significant advantage of the new software structure for COMBIMAN, is that it can share modules with the CREW CHIEF program. Function modules that are identical for COMBIMAN and CREW CHIEF are Head Orientation, Interference, Regeneration, Reposition and Visibility. Subfunction modules that are identical for COMBIMAN and CREW CHIEF are Element Processing, Enfleshment Assembly, Head Orientation, Interference, Human Model Display, Reach and the Utility functions.

COMBIMAN Version 9 development began on two platforms. The Initialization function and prototype interface were developed on a MicroVAX system. The other COMBIMAN specific functions and subfunctions were developed on an IBM MVS system. The core and interface modules were combined and initial testing performed on a MicroVAX system. The development and testing of the COMBIMAN core modules then migrated to a Silicon Graphics Personal Iris workstation. Final phase of core module development and testing was completed on an IBM MVS system.

COMBIMAN Interface

The prototype interface for COMBIMAN Version 9 was developed on a MicroVAX system. The interface was written for the I-DEAS CAD system using the I-DEAS Ideal programming language. This prototype interface was not host-independent. When development of COMBIMAN migrated to a Silicon Graphics Personal Iris workstation, the prototype interface was converted to our Common User Interface (CUI).

3.2 Rehost COMBIMAN on Other Systems

UDRI was tasked to develop CAD-COMBIMAN interfaces for at least two additional CAD systems, taking into account the needs of the users. The CAD systems selected for interface were CATIA V3, I-DEAS level vi (under both IRIX and SUNOS), and CADAM V2R21.

3.2.1 Rehost COMBIMAN on CADAM V2 R21

COMBIMAN Version 9 and Version 10 were hosted on CADAM Version 2 R21 for both the MVS and VM operating systems. The interface was performed using the Interactive User Exit portion of the CADAM Access Module, and through COMBIMAN's Common User Interface module. The user interface featured icon-driven menus, on-line, context-sensitive HELP, and interaction with all surface and solid CADAM entities. Distribution tapes were developed for both the VM- and the MVS-based systems.

3.2.2 Rehost COMBIMAN on CATIA

COMBIMAN Version 9 and Version 10 were hosted on CATIA Version 3 R2, for both the MVS and AIX operating systems. The interface was performed using CATIA's Graphics Interactive Interface (GII), Function Structure Definition (FSD), and the CATIA Geometry Interface (CATGEO). The initial interfaces were performed by Boeing Computer Services, at no charge to the US Air Force, working in close cooperation with UDRI staff. After these initial interfaces were complete, Boeing transferred all source code to UDRI, and relinquished all rights to the software.

Once the interface software was received in-house, UDRI personnel compiled and linked the software, and performed extensive testing on the COMBIMAN-CATIA hosting. This testing included verifications of the user and geometry interfaces, as well as an evaluation of the user interface nomenclature and methods. UDRI corrected any errors discovered during verification, and made changes to the user interface to maintain nomenclature consistency and fidelity to the CATIA user interface.

The CATIA interface featured CATIA "panels" for menu processing, support for CATIA solids, and shaded image displays for the human model and the cockpit. The hosting supported 3-D curves, surfaces, and CSG-type solids.

3.2.3 Rehost COMBIMAN on I-DEAS

COMBIMAN Version 9 and Version 10 were hosted under I-DEAS Level VI, on both the IRIX (Silicon Graphics) and SUNOS (Sun) operating systems. The interface was performed using the I-DEAS Director/Observer and I-DEAS Universal Files (for geometry transfer). This interface was hampered by the limitations of the applications software interface capabilities of the I-DEAS CAD system. All data transfer had to be done in batch mode, and was executed immediately prior to running any CREW CHIEF functions. Menus were limited both in the length of each menu item descriptor, as well as the number of menu items allowed per menu.

3.3 Develop TWO Seat Models

During the course of this effort, UDRI developed two ACES II seat models, of ruse in COMBIMAN analyses. Data for creating these models were gleaned from various technical drawings, and created using the CATIA CAD system. One seat was created with a 15-degree seatpan angle; the other was created with a 30-degree seatpan angle. Using cockpit simulators located at WPAFB, UDRI measured relationships between a seated crew member and the seat, and used these data to manually manipulated the COMBIMAN link system so that these same relationships existed between COMBIMAN and the seat model.

During this contract period, UDRI developed several models for seat postures, a model for an ACES II seat, and a conform to seat capability. The posture databases were developed for the CAP, F16, and T38 workplace analyses. The ACESII seat was developed on CADAM and input into the COMBIMAN Version 8 crew station database format. The conform to seat capability was developed for Version 9 of COMBIMAN under the CATIA CAD system. These development efforts are consistent with the requirements listed in SOW paragraph 3.2.3.

The posture databases for CAP, F16, and T38 analyses were developed specifically for each analysis. These posture databases were required to allow the human model to reset to these postures when doing specific arms only type reaches under COMBIMAN. The postures were defined by using the Link Table function under COMBIMAN. By varying the link angles under the Link Table function, UDRI was able to determine the proper posture for each seat configuration. Then, by modifying the existing posture databases, UDRI created the new text input files needed to create a new posture database in direct access format. Subsequent arms only reaches then automatically set the posture to the proper orientation for the specific analyses being performed.

The ACES II seat was input into CADAM using an Air Force supplied drawing. The drawing was then used to input the ACES II seat into COMBIMAN Version 8 crew station database as a seat. This seat was created using CADAM line and spline functions to create a 3-D drawing from the 2-D drawings presented by the Air Force.

The conform to seat capability was also developed to satisfy the requirements of SOW paragraph 3.2.3.3. Several other capabilities must be developed before this capability can be incorporated into the core software of COMBIMAN The new capabilities needed are a temporary posture database which would be created during the initialization phase of COMBIMAN, and interface components which would define the seat back and seat pan relationships. Then the conform to seat capability can be used to a' `OMBIMAN to lie against the seat back and on the seat pan without a pre-defined posture database for each seat configuration. This capability was developed in subfunction form and allows hooks for compression data and allows the flexibility to have other limbs placed flush on planar surfaces.

3.3.1 Develop ACES II Seat Model

During the course of this effort, UDRI developed two ACES II seat models, of ruse in COMBIMAN analyses. Data for creating these models were gleaned from various technical drawings, and created using the CATIA CAD system. One seat was created with a 15-degree seatpan angle; the other was created with a 30-degree seatpan angle. Using cockpit simulators located at WPAFB, UDRI measured relationships between a seated crew member and the seat, and used these data to manually manipulate the COMBIMAN link system so that these same relationships existed between COMBIMAN and the seat model.

3.3.2 Conform to Seat Capability.

During this contract period, UDRI developed a subfunction to allow a body segment or set of body segments to conform to a planar surface or set of planar surfaces. UDRI developed this subfunction to satisfy the requirements of paragraph 3.2.3.3 of the SOW. UDRI developed this subfunction in stages. First, UDRI defined the subfunction requirements which include the subfunction input and output, any new data needed to implement the subfunction, and any new algorithms which need to be developed for the subfunction. UDRI then developed the mathematics for the new algorithms identified. Using the algorithm and subfunction requirements definition, UDRI then developed the core control common area and the core structure for the subfunction. Finally, UDRI developed the code to implement the algorithm developed for the subfunction, debugged the code, and tested the code.

In defining the subfunction requirements, UDRI found that this subfunction must perform three functions. First the function should be able to compress the enfleshment of a body segment which is to conform to a particular planar surface or surfaces. Second, the subfunction must have the ability to rotate the distal end of a compressed body segment onto a plane. Also, the subfunction must have the ability to place the proximal end of a body segment (usually the mid-hip region) in a fashion which would allow the compressed version of that body segment to be tangent to two intersecting planar surfaces.

UDRI then developed the algorithms needed to rotate the distal end of a body segment onto a plane and to place the proximal end of a body segment tangent to two intersecting planes. UDRI allowed for later development of a compression algorithm which will not be developed until applicable data are either gathered or found in existing literature. Both of the body segment placement algorithms use 3-D vector analysis, trigonometry, algebraic substitution, and quadratic equation solving techniques to determine the appropriate euler angles. The euler angles are then input into the euler angle common area and the body assembly is recalculated to get all the local and global link transformations needed for this body posture.

The algorithm placing the distal end of a body segment on a plane uses the enfleshment radii and the joint center offsets for enfleshment to determine the enfleshment point on the distal end which is closest to the plane on which the distal end is to rest. Now, the line between the center of enfleshment of the proximal end of the link and the enfleshment point closest to the plane on the distal end of the body segment can be projected onto the plane of conformity. Now using parametric equations, and noting that the original line can be rotated to force the enfleshment point to fall on the projected line, and thus on the plane. Once the parametric equations are developed, algebraic substitution was used, and the problem became a simple quadratic equation. The angle was then calculated and placed in the appropriate euler angle array element.

The algorithm placing the proximal end of a body segment tangent to two intersecting planes actually looks a bit simpler on the surface. Currently it is assumed that the only body segment which would be placed using this subfunction would be the mid-hip link. This allows the mid-hip to be tangent to both the seat back and the seat pan. The normal vectors are used to determine the seat pan and seat back directions. Then, using the enfleshment radii of the mid-hip ellipse, the theoretical mid-hip point is calculated. Then, the mid-hip link length was calculated as well as the euler angles. However, since the hip region is enfleshed using the right hip, left hip, and the lower spine links, this theoretical placement of the mid-hip center is only used to get the enfleshment close to being tangent to both planes of conformity. The next step UDRI used in developing the subfunction was to actually calculate the enfleshment around the hip, get the minimum and maximum values with respect to a theoretical seat coordinate system, and use these values to offset the hip center of enfleshment. The first pass is to get the hip center close to being tangent, the second pass gets the hip tangent since the angles do not change significantly after the second pass.

Using the algorithm and data requirements, UDRI then developed the core control common area and the structure for the subfunction code. The core common area contains two variables, two one dimensional arrays, and four two dimensional arrays. The structure allowed for development of eight new subroutines, one of which was to calculate compression which, as stated above, has not been developed.

The core control common variables supply the subfunction with the necessary input to calculate the requested euler angles. The first variable in the control common determine whether or not debug write statements are to be output. Next, the total number of body segments for which euler angles are to be calculated is input. Then, the link identifiers for each of these body segments is stored in an array as a list. The options for each link segment are then stored in the next array (i.e., compression only calculation, distal end placement, or proximal end placement). The next two arrays hold the normal vectors to the plane(s) on which the body segment is to be placed. The final two input arrays hold a point for each plane which is used with the previous normal vectors to fully define the plane on which the body segment(s) are to be placed.

The code structure was developed using a structure paralleling the structure of other COMBIMAN and CREW CHIEF subfunctions. The subfunction executive routine is used to drive the routines necessary to fulfill the requests found in the subfunction core control common area. The first routine simply checks the control common area for reasonable values. The next subroutine transfers necessary control common variables to subfunction common areas. Then the debug routine was developed to allow easy debugging when problems arose in development or use of the subfunction. UDRI put the hooks in for a subroutine to compress body segments before the routines that actually place the body segments (i.e., calculate the euler angles). Then the routine to place the proximal end of the body segment tangent to two intersecting planes is driven, if needed. Then, the routine to calculate the euler angles needed for placing the distal end of body segments tangent to a plane is driven, if needed. Finally, the hooks were put in for a routine which would output the euler angles to a temporary database for use by the reach subfunction. The euler angles are then used to calculate all the global and local transformations needed to determine link ends in local and global coordinate systems.

Finally, UDRI tested the subfunction by placing it in a temporary position in the COMBIMAN code. A temporary file is used to fill the control common areas since the interface for the initialization function does not currently gather the information necessary for the common area. The largest problem area was the hip center of enfleshment placement. This is due to the way the hip is enfleshed using the right hip, left hip, and the spine links. This problem was the reason the enfleshed points of the hip had to be used to calculate an adjustment vector and iterate over the algorithm twice. The other problem was the thigh link angles, the phi angles had to be adjusted to allow normal postures for the thighs. UDRI tested the subfunction for both the distal enfleshment rotation and the proximal enfleshment placement portions of the algorithms. The hooks for compression remain, however no data have been collected to model the compression during this contract period.

3.4 Maintain COMBIMAN Software

Paragraph 3.1.4 required the COMBIMAN software and documentation be maintained.

The official COMBIMAN software is maintained on a SPARCStation, SUNOS. All notices of changes and updates are given to the software manager. The software manager updates the official software and then notifies all programmers of the updates. The software is then updated on each hardware platform by the person responsible for that specific platform.

Updates to CAD dependent software is handled a little differently. The CATIA interface was developed by Boeing and updates or modifications to this interface are sent to us from Boeing. We then update our version of the CATIA interface software. A COMBIMAN/CATIA user's guide is available.

I-DEAS interface software is updated and tested on a SPARCStation. Once updates, modifications, or enhances have been fully tested, all programmers are informed of the changes. The ProCADAM interface is compatible with the CADAM 21 interface and therefore uses the same user's guide as the COMBIMAN/CADAM 21 version.

The ProCADAM interface software is updated on a RS6000 system. Again, once updates, modifications, or enhancements have been fully tested, all programmers are informed of the changes. The ProCADAM interface is compatible with the CADAM 21 interface and therefore uses the same user's guide as the COMBIMAN/CADAM 21 version.

CADAM 21 interface software is hosted on an MVS system. At present we do not have convenient access to a MVS system for updates. Previously we updated the interface software in the same manner as the previously mentioned CAD system interfaces to COMBIMAN. A COMBIMAN CADAM 21 user's guide is available.

Unigraphics interface software is hosted on the SPARCStation. This interface is still under development. At present there is no user's guide.

Also available is a CAD System Independent version of COMBIMAN. This software is basically the official core software and is maintained on the SPARCStation. A CAD System Independent guide is available.

All user's guides are kept up-to-date. As enhancements are made to COMBIMAN, the user's guides are updated. If new functions have been incorporated, the users' guides have been updated accordingly.

SECTION 4 - GENERAL SUPPORT TO SOFTWARE DEVELOPMENT

In addition to the enhancements discussed in Sections 2 and 3, this contract required many general support activities. This support included creating overview and training video tapes, demonstrating the COMBIMAN and CREW CHIEF programs for on-base visitors, and training novice users on how to use the programs. It also required providing design support by utilizing these physical ergonomics tools, additional general enhancements to the programs, and software distribution.

4.1 Make Video Tapes

The contract SOW required UDRI to produce two video tapes. The first video tape was supposed to be a ten-minute overview of the CREW CHIEF system of programs, including all major modeling and graphics capabilities. The second videotape was supposed to be about 30 minutes long, and was intended to be an instructional tape of new users of CREW CHIEF.

4.1.1 Overview Video Tape

An earlier video tape describing CREW CHIEF capabilities was produced under a previous contract. UDRI recommended, and the Air Force approved, the use of this earlier video tape as a basis for the new overview tape. The original script was edited to take into account the newer capabilities of CREW CHIEF. In addition, UDRI personnel created several new demo drawings depicting CREW CHIEF with many of its new capabilities. A film crew from the 1st Combat Camera Squadron (Det 2) was responsible for shooting new footage for the video tape.

Combat Camera was also responsible for the final editing of the tape. This included merging the new narrative with the new video footage. Some of the original, stock footage was retained, in order to reduce costs. Combat Camera also updated the credits and the CREW CHIEF introductory graphics.

4.1.2 Instructional Video Tape

In accordance with P00020 of this contract, this portion of the effort was deleted.

4.2 Apply COMBIMAN and CREW CHIEF PROGRAMS

During this contract, UDRI performed analyses of design problems based on reach, strength, and visibility as well as obstacle avoidance/interference. Analyses performed by UDRI included reach and visibility analyses on the T-38, Apache helicopter, C-141, and F-16. UDRI conducted strength analyses for available torque for boroscope plug removal. UDRI also performed visibility and reach analyses to evaluate workplace design for people confined to wheelchairs.

UDRI performed analyses on a T-38 cockpit to evaluate five potential locations for Control/Display Units (CDUs). First, UDRI had to put the T-38 into the CATIA drawing database. UDRI did this by taking the T-38 database in COMBIMAN Version 8 crew station database format and converting it to a CATIA drawing programmatically. Then UDRI made the final modifications needed for the analysis under CATIA. Then the five locations were evaluated for seven body sizes from the JPATS multi-variate anthropometry set with the seat adjusted according to body size to give visibility over the front panel. The locations on the left console and the left-side of the front instrument panel were evaluated for left-hand fingertip reach. The locations on the right console and the right side of the front instrument panel were evaluated for right-hand fingertip reach. The location in the center of the front instrument panel was evaluated for left and right hands. Miss distances were recorded to the corner points of any CDUs which were not entirely within reach. UDRI also evaluated visibility for each of the seven subjects to the CDU locations on each console (left, right, and center) with one hand reaching to the CDU and the other hand on the center stick.

UDRI also performed tandem reach curve and visibility analyses on the Apache helicopter. UDRI created CADAM drawing files from the drawings provided by the government. These CADAM drawings were then converted to COMBIMAN Version 8 crew station database format by using the CADCBM program. Then UDRI performed analyses for the 5th, 50th, and 95th percentile male Air Force pilots to determine the adequacy of proposed redesigns for both the pilot and co-pilot/gunner cockpits. This problem was evaluated because the pilots were not able to see around the gunner to land the plane. The analyses evaluated the seat location and its effect on this problem.

UDRI performed analysis on the C-141B SOLL II navigator station to determine navigator's ability to see the Forward-Looking Infrared Radar (FLIR) display while reaching to FLIR controls. UDRI first had to input the navigator station into CADAM from supplied drawings. Then, the CADAM drawing to COMBIMAN conversion program (CADCBM) was run to put the drawing into COMBIMAN Version 8 crew station database format. From the drawing it was seen that the navigators needed to reach to the center stick with their right hand and to controls overhead with the left hand. In this posture, they needed to look at the FLIR display which was located near the floor to their right. Several different alternatives to the current design were also analyzed and recommendations given to make the navigator station more efficient. Visibility analyses were made for both men and women flyers of smallest and largest body sizes for all suggested alternative designs and for the current design.

UDRI performed analysis on the F-16 to evaluate reach to selected panel controls. The subjects were 12 named subjects (six male, six female) whose dimensions were supplied by the customer. Reaches were performed to 38 different controls, with the left hand reaching to left-side panel and forward panel controls and right hand reaching to right panel controls. These reaches were either fingertip or functional depending on control type. Results were recorded (including miss distances). All reaches were performed with arm/shoulder mobility.

UDRI also analyzed the F-16 to evaluate co-pilot's field of view while landing. Again UDRI input the drawings into a CADAM drawing database and use the CADCBM program to convert the drawing to COMBIMAN Version 8 format. The pilot obstructed the view of the co-pilot during landing. Consequently, the co-pilot had to lean to the side to see around the pilot. The human model was leaned to the side as far as canopy clearance would allow, then visibility plots were made. Evaluations were performed for male Air Force pilots with the 10th, 20th, 50th, and 90th body size percentiles.

UDRI performed an analysis using CREW CHIEF which required the addition of a boroscope as a special tool under the CREW CHIEF Tool Analysis function. A boroscope was digitized into the CAD system using supplied dimensions. Analyses were made to evaluate access to the work area for tool reach. The minimum and maximum torque that could be applied on the boroscope plugs were also analyzed. The analyses were performed using 6- and 12-inch extensions and long and regular handles for a ratchet wrench with 3/8-inch and half-inch drives using both regular and reverse grips. The evaluations were performed for the 95th percentile male and 5th percentile female. In total, 96 reaches were performed.

UDRI performed analysis to evaluate candidate workplace configurations for people confined to wheelchairs. Two wheelchairs and two workplaces were digitized from supplied measurements, and COMBIMAN body size models were added for two subjects. Workplaces were analyzed for reach and visibility. Specific design problems were identified by the subjects. The individuals for whom the workplaces were being evaluated were present for most of the evaluation, thus, they were able to provide input for redesign possibilities. All furniture in the workplaces was modular and was entered on the CAD system to be separately movable pieces. The furniture was rearranged to provide several possible solutions, with each possible arrangement evaluated for physical accommodation using COMBIMAN. Reaches to bookshelves and keyboards, and knee clearance under desktops were evaluated. Visibility was evaluated for computer screens located in various locations throughout the workplace. Alternative configurations, constrained by space limitations and available furniture, were suggested after all the information from the analyses was digested.

4.3 Conduct Workshop

In accordance with P00020 of this contract, this portion of the effort was deleted.

4.4 Enhance Model Capabilities

Paragraph 3.3.6 of the SOW required UDRI to perform periodic surveys of CREW CHIEF and COMBIMAN users and record any complaints, deficiencies, and suggestions for enhancing the models. Additionally, UDRI was required to propose approaches for overcoming or correcting these deficiencies and present them to the Air Force. This section documents the work performed to satisfy these requirements.

UDRI performed the initial requirement of performing a survey of users shortly after commencement of the contract. Twenty-four users were contacted. Thirty-five percent of these users were still not installed either due to time, fiscal constraints, or lack of proper environment. At the time of this survey, 21% of the users were using CADAM as their CAD environment, 19% were using ComputerVision, 17% were using CATIA, and 14% were using UNIGRAPHICS. The enhancements suggested from this survey follow.

One request from the user survey was to make it easier to change parameters for similar CREW CHIEF runs. For example, if the user wants to check out the same lift task except for using a different arm during the lift, a method should be available to change only that variable and have all the other variables default to the last selected value. UDRI suggested what the user might like to see in the Critical Design Review on March 4, 1992. The user could choose whether or not complete definition of the function parameters is necessary or if only a partial definition of function parameters is necessary. Under the partial parameter definition scenario, UDRI suggested a shorter series of windows and menus which would allow the user to define only the function parameters needing redefinition. UDRI developed a plan to implement this remedy, including adding a CUI database to store current selections of functions. UDRI proposed this remedy to alleviate the user's exasperation of having to redefine all the parameters of function, but did not implement this remedy during the course of this contract.

Another CUI modification suggested from the user survey was the ability to have help and icon selections on every CAD system regardless of who writes the interface. UDRI suggested using a system independent graphical interface to allow different CAD systems to use icons, overlays, and help without doing all of the work to generate the icons for each particular CAD system. To accomplish this objective, UDRI suggested using a generic icon, overlay, and help database which would provide the interface programmer with all the necessary information to generate icon selections and help tables. The database would hold data for each graphical entity in a format which would allow PHIGS to draw such entities. Each graphical entity would be made up of a number of primitives, mainly lines and text, which would be stored in the database. The database would contain header block, a group data block, a help data block, a graphics data block, and a primitive data block.

The header block would contain the general information about the database. The CREW CHIEF version number and database version number would be the first pieces of information available to ensure the software available is matched to the database. Then the total number of graphical entity groups and the total number of help pages contained in the database would also be stored in the database header block. The final piece of information in the header block would be the pointers to the beginning of each graphical entity group and the pointers to the beginning of the help page data in the database.

The group data block would contain the information needed to display the icons and overlays. For the icons, the information stored in this block would be the number of icons in the group, the name of each icon in this group, a pointer to each icon's raw data, and the graphic transformation matrix for each icon in a particular group. The icon names allow the database to be updated quite easily for each individual group, and the raw data pointers allow the database to be more compact than a rigid format would allow. The graphic transformation matrix allows the same graphical entity to be used for different icons, even if they are not to be placed in the same area or orientation on the display window. The information stored for the overlays in this group would be the same information that was stored for the icons.

The help data block of this system independent graphics database will contain the help name and the help raw data pointers. The raw data pointers will be used to obtain the information necessary to write all the text and graphics associated with a particular help table. The help name will be used to make sure data are not repeated in the database just because the same information is used in different places in the program. Both of these features of the help block will allow the database to be as compact as possible with regards to the help information.

The graphics data block will contain all the graphical entities referenced from other portions of this database. The name of each graphical entity will be used to ensure entities are not unnecessarily repeated. The number of primitives for each graphical entity will also be contained in this block. The last piece of information will be the pivot point for each graphical entity. The pivot point helps place and orient the graphical entity.

The final block of data needed for the system independent graphics database is the primitive data block which is repeated for each primitive of the graphical entity. For each primitive, the primitive type, number of records needed to define the primitive, the attributes associated with the primitive, and the raw data for the primitive will be stored in this block. Note that one primitive can be used by more than one graphical entity, again saving space in the database and allowing easier creation of new graphical entities within the database.

Another request from the users was to allow for addition of more populations to the CREW CHIEF anthropometry database. UDRI proposed a series of modifications to the current anthropometric database maintenance programs to enable maximum flexibility in the implementation of this user request. The modifications involved were intended to accomplish the following:

- Eliminate hard coding of anthropometric regression equations.
- Streamline the program for calculating anthropometry (CALCANTH program).
- Incorporate use of the Anthropometry Regression database in CALCANTH.

- Eliminate the program that performed the final anthropometry conversion (CNVANTH program).
- Allow for processing of multiple populations.

UDRI implemented these modifications by developing three new programs which output the anthropometric data and regressions used as input by CALCANTH. The three programs UDRI created are AMPREG, VBLREG, and BLNREG. AMPREG was developed to create the anthropometry regression database which contains one or more populations, each consisting of ten basic regressions and anthropometric data (stature, weight, and arm length) for the ten percentiles of CREW CHIEF. VBLREG was developed to create the variable regression database containing sets of additional regressions required for construction of the man-model. Thus, different sets could be available for the different populations. BLNREG was developed to create a set of regressions to calculate body link lengths. These regressions are used for all populations.

UDRI developed this set of programs to allow populations to be entered through the Anthropometry Regression and Variable Regression databases. The populations are then automatically incorporated into CREW CHIEF's Posture Anthropometry database by running CALCANTH and INITDBAS.

To finish implementation of multiple populations, UDRI modified ANTEXE and the CREW CHIEF interface to allow access to the new populations, and INITDBAS was changed to create the final CREW CHIEF format of the initialization database. Then, UDRI added to new populations to the database and accessed all three populations from CREW CHIEF for verification. The new populations added were the Army population from the ANSUR 88 survey and the Air Force Officers population obtained from the subsets of the 1968 survey of Air Force women and the 1965 survey of Air Force men.

Another request from the users was addition of multiple technicians. Since the Air Force did not want UDRI to spend the time necessary for true addition of multiple technicians, UDRI simply suggested to the users that they save models into their drawings and then run another model for multiple technicians. This will at least allow the user to look at accessibility problems when using multiple technicians. However, it will not give them any indication of strength characteristics of multiple technicians or the effect one technician has on the other during a maintenance task. These characteristics would require a lot of new strength studies and would require a large amount of recoding to implement them even if the studies were completed.

One of the most frequently requested enhancements was the ability of CREW CHIEF to interact with solid models contained in drawings. UDRI has developed a plan to include solids processing in CREW CHIEF. The plan was developed for the CDR, and consisted of breaking the solids down to NURB (non-uniform rational b-spline) surfaces and then tessellating the surfaces into triangular facets. These facets could then be used by the CREW CHIEF interference algorithm instead of the linearization scheme currently used. This method would, however, require the user to run a function to generate a database with all the triangular facets needed to represent a particular drawing. Once this function has been run, then the user benefits from the use of triangular facets instead of lines which have holes between them that CREW CHIEF body parts may be able to sneak through in certain particular cases. Also, since no more linearization needs to take place during the interference analysis, and since the software no longer needs to interface with the CAD database, the interference function may actually take less time to perform its analysis even though the analysis will be more accurate with the tessellated surfaces.

Although UDRI has not implemented the CDR plan into CREW CHIEF yet, the plan was developed completely enough to add it in the future. Also, in the CATIA interface, a solids interface was developed by Boeing using the old linearization scheme, and that interface was implemented into the CATIA version of CREW CHIEF. UDRI also added solids processing into the UNIGRAPHICS and IDEAS versions of CREW CHIEF. These two versions were developed during this contract period by UDRI.

The IDEAS version of CREW CHIEF preprocesses the drawing at the beginning of the CREW CHIEF run. If you want to run CREW CHIEF with another drawing, it is necessary to start CREW CHIEF over again. UDRI used the software available from IDEAS to generate a tessellated version of the drawing database and stored the generated facets in a temporary database for future use by the obstacle avoidance subfunction and the Visibility function.

The UNIGRAPHICS version of CREW CHIEF uses the NURBS surface breakdown of the solid as the starting point for representing the solid in CREW CHIEF. Once the surface is in NURBS form, it is linearized and the line segments generated are passed to CREW CHIEF. For the surfaces in UINGRAPHICS, it was necessary to change the form of each surface to a NURBS form of the surface in order to be able to process the myriad of surfaces available in UNIGRAPHICS. This technique allowed UDRI to make the CAD database interface to UNIGRAPHICS one of the most complete CAD database interfaces CREW CHIEF has available. The technique parallels the technique developed for the CDR where tessellation will be used to break surfaces down to facets instead of line segments as done here.

The CATIA solids interface created by Boeing is also a linearization technique similar to the UNIGRAPHICS technique. UDRI implemented this solids interface to CREW CHIEF and also implemented later versions of Boeing's solids interface to CREW CHIEF. This interface still has some CATIA elements that are not passed to CREW CHIEF, since there is no easy way to transform the elements in the way that UNIGRAPHICS was done. However, most of the commonly used elements are now available for CREW CHIEF processing during interference and visibility analyses.

UDRI also presented the Air Force with another list of possible enhancements for CREW CHIEF during the PDR. The modifications UDRI suggested during this contract are the Input/Output Management (IOM) subfunction, a data restructure, the Link Table Function, the Grasp Function, database conversion programs, prompt standardization, Visibility Function enhancements, the Add User Defined Tool Function, CREW CHIEF reach enhancements, and mobility enhancements. Most of these suggestions have been designed, developed, and integrated into CREW CHIEF, however, some of these have not been integrated into CREW CHIEF during this contract.

The IOM subfunction was developed to control the flow of critical CREW CHIEF information. The first piece of information is the general human model information. This information contains the general characteristics, and the position, link system, and enfleshment information needed to fully define the human model. The tool information contains the general characteristics and the general, link system, enfleshment, reach, and other information needed to reconstruct the tool, and the enveloped information needed for performing the work envelope function. The last piece of information controlled by the subfunction is the object information for the Manual Materials Handling functions. Dimensions, orientation, and placement are the critical pieces of information saved by the IOM subfunction for the object. Currently, the IOM subfunction consists of two subroutines which are used separately to control the information described above. UDRI plans to combine these routines into a regular subfunction in the future, since the two routines are inextricably linked to one another.

Another in-house suggested enhancement to CREW CHIEF is the Grasp function. The Grasp function was developed as a function different from the Reach function in that the user is able to define the type of grasp the human model is to simulate. The Grasp function was developed in four phases. The first phase was the development of the Common User Interface (CUI) portion of the Grasp function (used as an interface between the software dependent on the CAD system and the core software to gather the function parameters from the user). The second phase of development was actually implementing the grasp algorithms as new core software. Since the Grasp function was being developed on the CADAM CAD system, icons, help pages, and overlays were also created for the Grasp function. The fourth and final phase of the Grasp function development was the testing and validation (and subsequent modifications to fix any software bugs found).

UDRI developed the CUI interface for the Grasp to allow an easy method to obtain the parameter definitions for the function. The code developed here simply defines the prompts, accepts the function parameters chosen by the user under the CAD dependent portion of the program, and passes these values to the core function software. The first couple of routines written for the CUI software for Grasp simply determine the number of arms and which arms are to be used during the analysis. The next routine was written to determine the type of object which is to be grasped (i.e., knob, edge, or handle). The next four routines developed were used to define the knob, handle, or object which is to be grasped. Then, finally, the general choices of mobility type, obstacle avoidance, and display type were called from the Grasp function's CUI driver routine. Then the Grasp function was called from the CUI routine and control passed to the core software.

Once the CUI software was developed, UDRI developed the core software for the Grasp function. The core algorithm first checks the parameters passed from the CUI. If all the parameters are correct, the core proceeds to transfer the control common variables to the appropriated core common blocks and then initializes any other variables needed for the Grasp (based on the control common variables input from CUI). Once all the variables are set, the reach subfunction is called and the defined reaches are attempted (along with interference if the user has selected obstacle avoidance). Then the variables set by the reach subfunction are processed to display to the user whether or not a successful grasp has been completed. If the grasp was unsuccessful, then the reasons for the model's inability to grasp are displayed. If the grasp is successful, then the human model is displayed in the final reach posture needed to perform the grasp.

The next phase of development for the Grasp function was to develop the icons, overlays, and help pages needed to give the user a graphical indication as to what each prompt is defining. The most important icons for the grasp are the icons which show the user what each type of grasp looks like. The other icons and help pages have been created for other functions, and only had to be incorporated into the Grasp function.

The final phase of the Grasp function development was the test and validation phase. Every path of prompts was tested to make sure all the information was being processed properly at both the CUI and core levels. This also tested all the CAD dependent routines which were used by the CUI for this function. Any bugs that were found were immediately corrected and any paths that the modification could have had an impact on were retested. Finally, after the model was fully tested with no errors, the Grasp function was incorporated into the Version 3 software of CREW CHIEF.

During this contract, UDRI also developed the Link Table function. The Link Table function was developed to enable the user total control over the orientation of a link with the only constraint being mobility limits for that link. Like the Grasp function, the Link Table function was developed in four phases. The first phase was the development of the Common User Interface (CUI) portion of the Link Table function. The second phase of development was implementing the Link Table algorithms as new core software. Again, like the Grasp function, the Link Table function was being developed on the CADAM CAD system, so icons, help pages, and overlays were also created for the Grasp function. The fourth and final phase of the Link Table function development was the testing and validation (and subsequent modifications to fix any software bugs found).

UDRI developed the CUI interface for the Link Table function to allow an easy method to obtain the parameter definitions for the function. UDRI only needed a few routines to develop the prompts and inputs needed for Link Table. The first prompt was the general choice of a display type used by many of the other functions in CREW CHIEF. UDRI then created several prompts which allow the user to choose which link to orient and how to orient that link by keying in the euler angles for the link. Then the Link Table function is called from the CUI routine and control is passed to the core software. When control is returned to CUI, the user may choose to save the new orientation, reject the new orientation, and resume or exit the Link Table function.

Once UDRI finished the CUI portion of the Link Table function, UDRI developed the core software for the Link Table function. UDRI developed core routines which check the range of the input common control variables passed from the CUI. Then UDRI developed the routine which transfers the core common control variables to the core common areas that will actually use the values set by the CUI. Then, UDRI developed the routines which used the Mobility subfunction to check the input euler angles to see if they were in the range of the human model's mobility. UDRI then developed the software which outputs the human model using the enfleshment and display subfunctions and also displays an arrow if the mobility bounds have been exceeded by the user's choice of euler angles. The final core developed by UDRI was the ability to save the link orientation changes made by the user, if the user decides to save the changes.

The next piece of development for the Link Table function by UDRI was the development of icons, overlays, and help pages for the CADAM version of CREW CHIEF. The main development here was the creation of the help tables to help the user understand how the euler angles they input would be used to change the orientation of the link to be moved. An overlay was generated for the menu determining which link to reorient. UDRI developed this overlay so it is easier to see which euler angles go with which link.

The final phase of the Link Table function development was the test and validation phase. Every path of prompts was tested to make sure all the information was being processed properly at both the CUI and core levels. This also tested all the CAD dependent routines which were used by the CUI for this function. Any bugs that were found were immediately corrected and any paths that the modification could have had an impact on were retested. Finally, after the model was fully tested with no errors, the Link Table function was incorporated into the Version 3 software of CREW CHIEF.

UDRI has made several enhancements to CREW CHIEF's Visibility function. UDRI has modified several routines to take care of plotting problems in Visibility. UDRI added the Aitoff projection as a choice of plot type (as opposed to the rectangular projection plot). Finally, UDRI added the ability to pick more than one overlay during an analysis so users are not forced to run the Initialization function several times to get the clothing overlays they need to analyze using the Visibility function.

UDRI found that when large elements in the CAD database are linearized in Visibility to allow for the distortion that takes place when converting rectangular coordinates into angle space, the FORTRAN array size limitations are such that the entire element cannot be plotted. For now, UDRI has allowed the processing to stop when the array bounds are exceeded, since this is a FORTRAN limitation that cannot be changed. UDRI has also devised a plan to create a database to store the workplace design geometry which would allow this problem to be eliminated. Due to time constraints, however, UDRI was not able to implement this design during the contract period.

UDRI also found some other software bugs in the Visibility function plot software. UDRI found that line segments were not displayed if they formed an angle of more than 90 degrees with the horizontal. Due to round-off error however, it was possible for some vertical lines to form an angle of more than 90 degrees (i.e., 90.20 degrees). UDRI removed this 90 degree restriction. Another bug was found in the clipping algorithm. The previous algorithm clipped an entire line segment even if it only lay partially outside the plot windows. This caused large line segments to be clipped totally out causing significant loss of geometry. UDRI modified this algorithm to clip only the portion of the line segment that lay outside the plot window.

UDRI added a new plot capability called the Aitoff's projection to the Visibility function. Military Standard 850 requires that visibility plots for cockpits be either rectilinear plots or Aitoff's equal area projection of a sphere. UDRI modified the user interface for Visibility to include selection of the desired type of visibility plot (rectilinear or Aitoff). Then, core routines were modified or added to calculate the Aitoff's projections under CREW CHIEF. UDRI also developed icons for this part of the user interface for the CADAM version of CREW CHIEF. The icons were used to show the user how the rectilinear and Aitoff projections would look. The icons were actually miniature rectilinear and Aitoff plots.

The final modification UDRI made to the Visibility function was the additional capability to select more than one overlay. Previously, users were forced to run Initialization if they wanted to get a different clothing overlay in the visibility function. Therefore, if the user needed several clothing overlays in visibility, one run of Initialization and one run of Visibility were necessary for each clothing type needed. UDRI modified the CUI software, the core software, and the Visibility database to allow the increased flexibility of being able to select multiple clothing overlays by running only one Visibility Analysis.

UDRI also enhanced the Reach subfunction during this contract period. UDRI modified this subfunction to allow trunk interference calculations in addition to the arm interference calculations. UDRI also added the ability to define the direction vector for a functional and a finger-tip reach. UDRI also modified the trunk positioning algorithm in the reach subfunction. In addition, UDRI performed some developmental work for a straight wrist algorithm.

UDRI modified the reach subfunction to allow trunk interference to correct problems occurring with the subfunction using arms only interference checking. CREW CHIEF was bending at the trunk to avoid arm interference, but at the expense of having the whole torso interfere with the workplace. To accomplish this additional checking, UDRI had to modify the interference subfunction also. The interference subfunction modifications allow the programmer the flexibility to check for interference with any body part(s). Then UDRI modified the reach subfunction to tell the interference subfunction to check for all the upper body segments. Then, the reach subfunction performs trunk positioning via a binary search for an unobstructed trunk position. If the trunk is pitched fully forward and interference is not found, then the trunk remains in that position. However, if interference is detected, then the trunk is positioned backward iteratively, each time moving the trunk half as much as the previous movement until an optimal trunk position is found, or until it is determined that interference cannot be avoided.

UDRI also modified the functional and finger-tip reach algorithms in the reach subfunction. The main thrust of this change was to allow the user to define the attach direction for the reach during functional and finger-tip reaches. UDRI modified the code to allow a consistent and precise grip when reaching to a knob or pushing a button. UDRI then test the code by performing reaches to knobs and buttons at different locations and orientations relative to the human model. UDRI found through this testing that reaches to nearby locations were mostly correct while reaches to some farther locations were not as precise. UDRI is still developing plans for integrating the new algorithm with the existing algorithm.

UDRI performed one other modification of the reach algorithm. UDRI noticed the wrist was bending when the natural reach would have been to keep the wrist straight. UDRI developed a prototype straight wrist reach by drastically modifying the reach algorithm relating to the wrist. Tests were performed using over fifty different reach scenarios. This included both right and left hand reaches in various locations around the human model. The tests included high, medium, and low reaches. In every instance the reach performed as desired and looked natural.

UDRI modified two areas of concern in the mobility subfunction. First, UDRI found problems with the upper arm abduction and adduction motions. Additionally, UDRI found problems with the upper arm rotations. UDRI modified the subfunction to correct these problems.

The problem with the upper arm abduction and adduction were traces to two specific causes. First, the angles allowed for arm movement in the four principal directions were not large enough. Also, Additional directional limits were required to model the upper arm joint motion accurately. UDRI expanded the model to include eight principal directions, with linear interpolation used to obtain intermediate angular limits.

UDRI also found a problem with the upper arm rotations. Typically, the rotations are given a continuous allowable range. Any joint angle whose twist falls outside this range is automatically reset to the closest boundary value. However, since inverse trigonometric functions are generally used to calculate these values, and these functions are single-valued within an interval of 2π, the specified rotational range of motion was limited to values within the interval $[-\pi\ \pi]$. New data proved this limitation was not valid, because some of the actual ranges crossed this boundary. Therefore, UDRI modified the software to account for multi-valued inverses.

UDRI also wrote and modified all of the database conversion programs for CREW CHIEF and COMBIMAN. CREW CHIEF databases often must be transferred from one system to another. In order to perform these transfers systematically, UDRI wrote programs to convert the direct access files to character files. These character files can then be transferred to the different systems. UDRI also wrote the programs to take the character files back to direct access files on the system to which the files have been transferred.

UDRI created a common area for these database conversion programs which holds the path name of the databases referenced by the conversion programs. Then an interactive procedure used to run the conversion programs was developed to allow conversions to be more user friendly and also give the user the option of running one database conversion at a time or all of the database conversions at once. All of the changes made to the database conversion programs were tested as well as the interactive procedure developed to run the conversion programs. These programs now exist as in house software to help alleviate the transition from one platform to another.

During this contract, UDRI also developed a more consistent prompt for the Common User Interface (CUI). UDRI found that many of the prompts were different between functions and, more noticeably, between CAD systems. In order to standardize the prompts, UDRI formed a committee whose task was to identify inconsistencies and resolve these inconsistencies in a fashion that would allow the most compatibility between CAD systems.

As a result, the UDRI committee determined the following must occur to give the most concise and uniform prompting between interfaces and functions:

- Use the phrase "human model" instead of "man-model."
- Use the key word "select" for all menu selection prompts.
- Use the word "pick" for all geometry selection prompts.
- Use the phrase "key" instead of "key-in."
- Use the key word "define" for prompts which call for identifying a point using any of the numerous methods supported by individual CAD systems.
- Shorten prompts, as much as possible, while maintaining comprehensibility.
- Prompts were changed to no longer be platform-specific in their wording.
- Place the most important information at the beginning of each prompt.

These recommendations were then implemented by changing all the prompts in the CUI source code. These changes were then thoroughly tested for all of the functions. Once testing was successfully completed, these changes became part of the official CUI source code.

Another set of enhancements UDRI implemented during this contract period were modifications to the Tool Analysis function and its interface. UDRI fixed invalid placement of a few sockets on the wrench, resolved inconsistencies between the Work Envelope and Tool Analysis Functions, and fixed the improper placement of the file in the workplace. UDRI also modified the Tool Analysis function interface to allow for a user selection of the User Defined Tool class. This last change consisted of making sure a tool class had tools in it before presenting it to the user for selection. UDRI also chained the tool database to allow CREW CHIEF to use a power grasp on all the wrenches to resolve discrepancies between how the strength data were collected and how CREW CHIEF represents the strength data.

4.5 Configuration Management of Software

UDRI managed the development of the COMBIMAN and CREW CHIEF programs by using a radical waterfall life cycle approach to software development. The waterfall life cycle approach to software development, see Figure 16, is broken into four steps. The four steps of this methodology are Analysis, Design, Code and Test. Analysis of the problem occurs during the Analysis step. The design of the solution occurs in the second step. Coding of the solution occurs in the third step. The final step is a rigorous testing of the software. In the classic waterfall life cycle, you must complete each step before the next step begins. In a radical approach to the waterfall life cycle software development, work on later steps can begin before work completes on earlier steps. The major benefit of a radical approach is that you can see intermediate results much sooner than in a conservative, or classical, waterfall life cycle approach. UDRI achieved a radical approach by using the waterfall life cycle for each module in the COMBIMAN and CREW CHIEF programs.

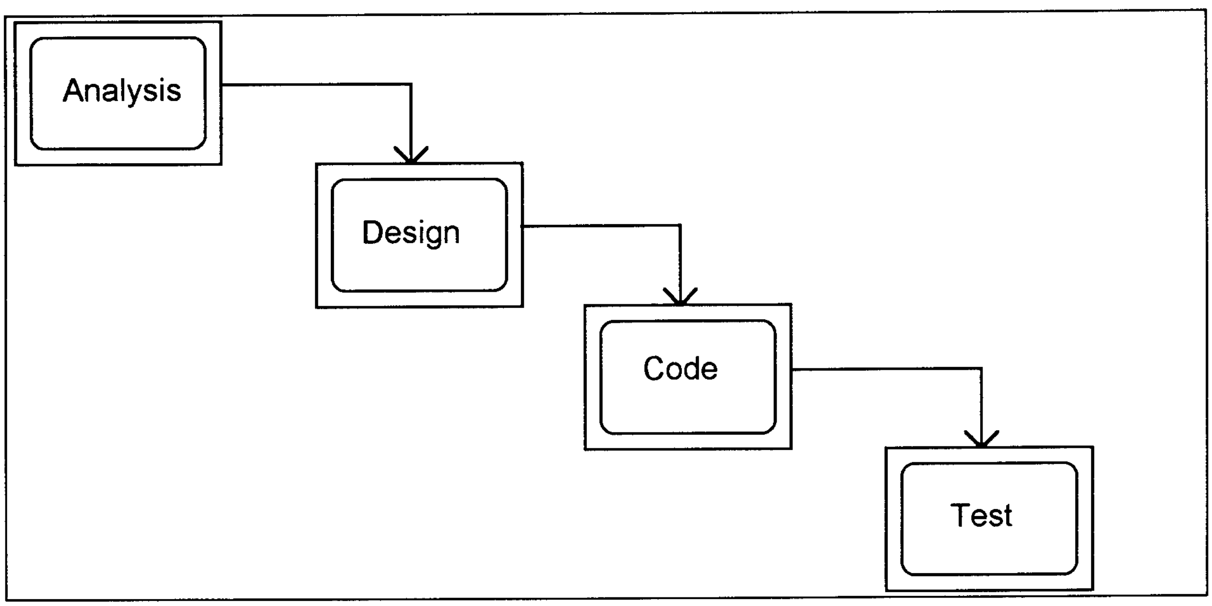

Figure 16. Waterfall Life Cycle Approach to Software Development

The waterfall life cycle was implemented through a series of 13 standing technical committees. Through the technical committees, and established programming standards, UDRI carried out a radical waterfall life cycle software development methodology. All of our programming personnel are involved as members of various committees. The standing technical committees are described in the following paragraphs.

Software Standards

The Software Standards committee is responsible for deciding the standards by which everyone should program. This includes the ways in which our modules interact. This committee also decides the structure of individual subroutines. The Software Standards committee must approve any violation of established standards.

Function Requirements

The Function Requirements committee must approve development plans for any new COMBIMAN or CREW CHIEF function or subfunction. This committee is responsible for ensuring that the proposed capabilities are applicable to address adequately the needs of the proposed module. Approval from this committee must be received before proceeding to any other committees.

Mathematical Models

The Mathematical Models committee must approve all mathematical models used in COMBIMAN and CREW CHIEF. Furthermore, this committee must also approve all statistical models used in COMBIMAN and CREW CHIEF. This committee does not need to approve candidate models that are undergoing testing. This committee must approve all final models.

Core Control Commons

The Core Controls Commons committee is responsible for approving FORTRAN COMMON BLOCKS. This committee must approve all of the function and subfunction Control Commons for COMBIMAN and CREW CHIEF. The Core Controls Commons committee is usually the second stop along the road to completing a new function or subfunction.

Core Structure and Nomenclature

The Core Structure and Nomenclature committee is responsible for maintaining the integrity of the modular structure of the programs. This committee is also responsible for maintaining the integrity of the naming conventions used in COMBIMAN and CREW CHIEF. Also, this committee approves subroutine titles and objectives.

Database Design

The Database Design committee is responsible for reviewing and approving all database designs for the COMBIMAN and CREW CHIEF programs. This includes any output to any FORTRAN logical unit, other than the Function Log and Diagnostic output units. Preliminary database designs also should go to this committee for discussion.

Common Areas Committee

The Common Areas committee is responsible for approving all non-control and final data common block variables. This includes function level and global variables. Also included are those variables that are COMBIMAN or CREW CHIEF specific.

Utility and Subfunction Modification

The Utility and Subfunction Modification committee must approve any additional utility subroutines. Also, this committee approves changes to existing subfunctions and utility subroutines. Note that this committee does not approve new subfunctions. New subfunctions must undergo the same approval as new functions.

Code Development

The Code Development committee is responsible for ensuring that all code written meets written programming standards.

User Interface Design

The User Interface Design committee is responsible for approving all user interface designs. User interfaces are some of the most important modules in the COMBIMAN and CREW CHIEF programs. Because of this, great care is taken to ensure that the user interface for each function is designed properly. Before implementation the contract monitor reviews each user interface.

CAD Dependent Routines

The CAD Dependent Routines committee is responsible for approving all new CAD dependent routines. This committee is also responsible for approving modifications to the argument lists for existing CAD dependent routines. CAD database input routines are also under the jurisdiction of this committee. This committee is not responsible for the coding of a subroutine for a particular interface. The CAD Dependent Routines committee functions to establish the standards by which the COMBIMAN and CREW CHIEF programs communicate with all CAD systems.

Function Testing and Validation

The Function Testing and Validation committee is responsible for ensuring that the COMBIMAN and CREW CHIEF programs are as bug free as possible.

CAD System Interfaces

The CAD System Interfaces committee must approve the basic development plan for all new CAD interfaces. Whenever possible the CUI is used as the method of interfacing to all CAD systems. This committee approves any deviation from the CUI.

In an attempt to increase the efficiency of documentation generation, some portions of the in-line documentation were automated. A computer aided Header Generator was developed, as well as a computer aided Hierarchy Chart Generator. The following paragraphs describe these automated documentation tools.

Computer Aided Header Generator

The Computer Aided Header Generator was developed to provide a simpler way of updating internal documentation for the COMBIMAN and CREW CHIEF programs. It also allows programmers to check the status of our internal documentation. This ensures us that the latest revisions are referenced. This program was developed in FORTRAN on an IBM mainframe running the MVS operating system. It provides a calls list, called by list, common area titles, subroutine titles, subroutine objectives, revision numbers and revision dates.

Computer Aided Hierarchy Chart Generator

Programmers, of COMBIMAN and CREW CHIEF, require hierarchy charts of the functions and subfunctions. A computer aided method for generating these charts was developed on an IBM mainframe running the MVS operating system. The program uses a list of called subroutines for every subroutine in COMBIMAN and CREW CHIEF. The charts were designed to show different symbols based on subroutine type. For example, hexagons enclose executive subroutines, circles enclose utility subroutines and rectangles enclose lower level subroutines.

UDRI also developed a new file structure for the COMBIMAN and CREW CHIEF programs. We have implemented this file structure on all Unix platforms. The file structure is implemented in a tree structure with a root directory and subdirectories representing each major software module. The objective of this file system structure is to reflect the modular structure of the COMBIMAN and CREW CHIEF programs. Another goal of the file structure is to increase our ability to efficiently rehost our software on other Unix platforms. A final goal is to ease the sharing of software modules between COMBIMAN and CREW CHIEF. Figure 17 is a diagram of the Unix file structure.

The Unix "make" facility is used to control compiling and linking of the COMBIMAN and CREW CHIEF modules on all Unix systems. The "make" facility uses a series of description files (called Makefiles). The Makefiles describe the relationships among the program modules. These relationships, or dependencies, are used to ensure that all modules are current. This helps minimize errors and saves valuable programmer time.

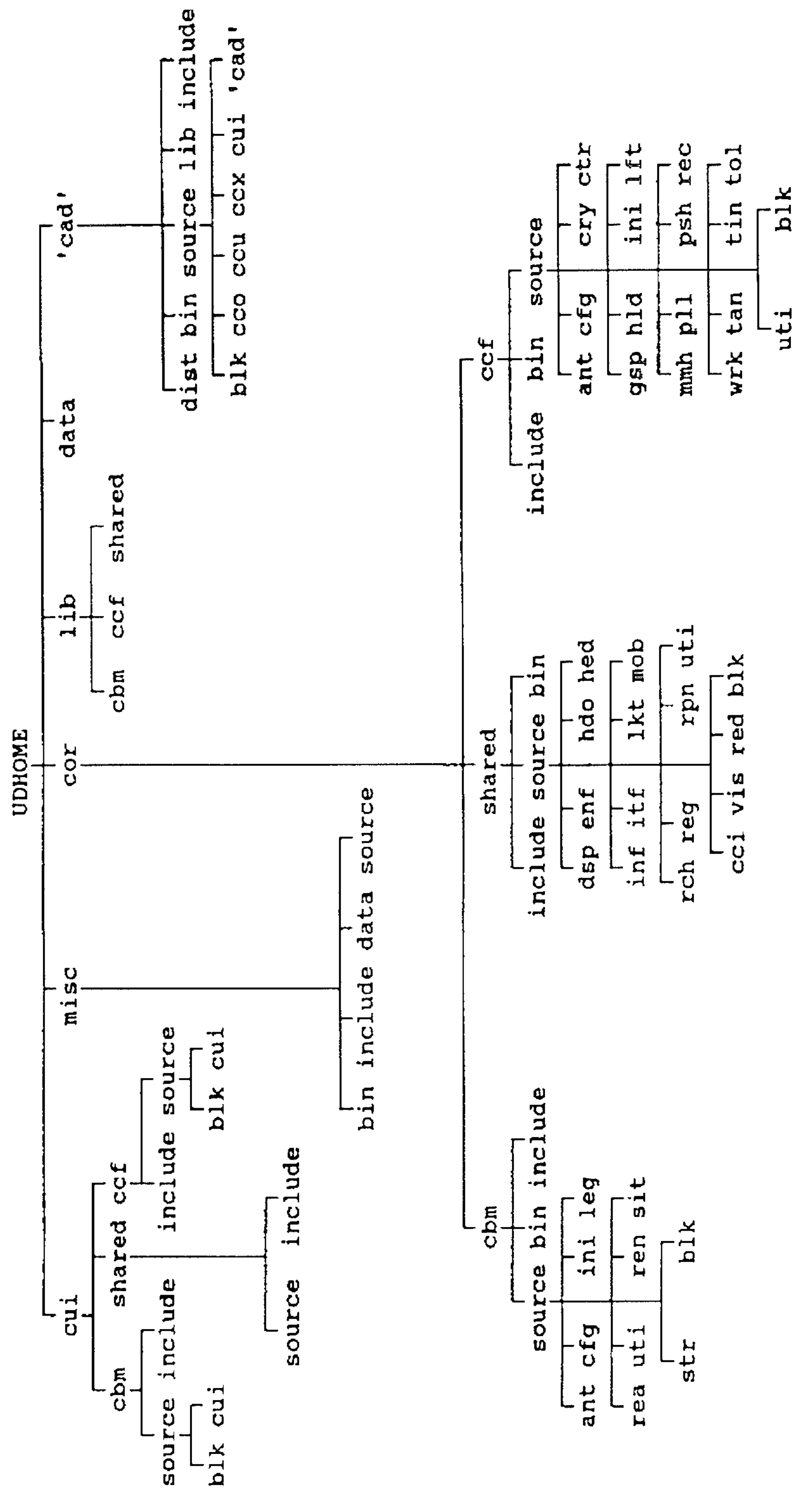

Figure 17. UNIX File Structure

4.5.1 Software Language

During software development efforts, UDRI used ANSI Standard FORTRAN 77 while coding CREW CHIEF and COMBIMAN core code and interface code. No nonstandard code was written. For in-house software, UDRI used software languages deemed most efficient for the particular development effort at hand.

4.5.2 Modular Structure for Software

The COMBIMAN and CREW CHIEF software consists of structured modules. There are several standing committees responsible for overseeing the modular structure. Each software module comprises many FORTRAN subroutines. The development of the underlying FORTRAN code followed documented in-house programming standards. The use of these standards ensures that program modules have very little dependency on the operation of the internal details of other modules.

Several standing committees exist to oversee the development of COMBIMAN and CREW CHIEF program modules. Adherence to the committee procedure ensures the development of modularized and standardized software. The following paragraphs give a brief description of the committees responsible for modular program development.

Software Standards

The Software Standards committee is responsible for deciding the standards by which everyone should program. This includes the ways in which our modules interact. This committee also decides the structure of individual subroutines. The Software Standards committee must approve any violation of established standards.

Function Requirements

The Function Requirements committee must approve development plans for any new COMBIMAN or CREW CHIEF function or subfunction. This committee is responsible for ensuring that the proposed capabilities are applicable to address adequately the needs of the proposed module. Approval from this committee must be received before proceeding to any other committees.

Core Control Commons

The Core Controls Commons committee is responsible for approving FORTRAN COMMON BLOCKS. This committee must approve all of the function and subfunction Control Commons for COMBIMAN and CREW CHIEF. The Core Control Commons committee is usually the second stop along the road to completing a new function or subfunction.

Core Structure and Nomenclature

The Core Structure and Nomenclature committee is responsible for maintaining the integrity of the modular structure of the programs. This committee is also responsible for maintaining the integrity of the naming conventions used in COMBIMAN and CREW CHIEF. Also, this committee approves subroutine titles and objectives.

Common Areas Committee

The Common Areas committee is responsible for approving all common blocks except control and final data common block variables. This includes function level and global variables. Also included are those variables that are COMBIMAN or CREW CHIEF specific.

Utility and Subfunction Modification

The Utility and Subfunction Modification committee must approve any additional utility subroutines. Also, this committee approves changes to existing subfunctions and utility subroutines. Note that this committee does not approve new subfunctions. New subfunctions must undergo the same approval as new functions.

Code Development

The Code Development committee is responsible for ensuring that all code written meets written programming standards.

The COMBIMAN and CREW CHIEF program modules (functions and subfunctions) contain many FORTRAN subroutines. While each function or subfunction is unique, there are many operations that are common among program modules. FORTRAN subroutines implement each of these common operations. The following paragraphs describe the most abundant of the common subroutines.

USR Subroutines

The USR subroutines are the core function entry points. These subroutines manage all processing within the core functions. The CUI accesses the USR subroutines. If required the CAD system interface software may access the USR subroutines directly. (Refer to the "CREW CHIEF CAD System Interface Guide" for more details.)

BUG Subroutines

The BUG subroutines output debug control variables. All COMBIMAN and CREW CHIEF functions and subfunctions receive control information through control common blocks. There are times when a programmer needs to produce an audit trail of the control variable values. The BUG subroutines send the control variables to the COMBIMAN or CREW CHIEF diagnostics log file.

CHK Subroutines

The CHK subroutines check interface control variables. These subroutines check the control variables passed to the core functions from the CAD interface to determine if the values are within acceptable ranges. The CHK subroutines will display any invalid value and the variable's acceptable range.

PRT Subroutines

The PRT subroutines print function parameters. The COMBIMAN and CREW CHIEF programs produce an audit trail containing all parameters selected by the user and function results. The PRT subroutines are responsible for printing the audit trail.

VIN Subroutines

The VIN subroutines are responsible for variable initialization. Our standards require that modules initialize their variables. Also, these routines initialize variables passed to subfunctions. The VIN subroutines do the initializations.

VXF Subroutines

The VXF subroutine control variable transfer. FORTRAN common blocks pass control variables to functions and subfunctions. Our standards require the moving of control data to the appropriate module level or global common area. It is the responsibility of the VXF subroutines to transfer module parameters.

EXE Subroutines

The EXE subroutines are the subfunction executive subroutines. These subroutines are the entry points for the subfunction modules. The EXE subroutines manage all processing within the subfunctions. Both function and subfunction level modules access these entry points.

SUC Subroutines

The SUC subroutines process successful reaches. These subroutines calculate and generate strength table values. The SUC subroutines also include human model display generation.

INT Subroutines

The INT subroutines process interference. These subroutines process the unavoidable interference information. This information includes the generation of interference arrows. The INT subroutines call the message generation subroutines.

MIS Subroutines

The MIS subroutines process missed distances. These subroutines output messages and the human model when a missed distance occurs. The MIS subroutines are part of functions that perform reaches.

POS Subroutines

The POS subroutines control posture initialization. These subroutines reset lower body posture for full body mobility. Push and Pull function use the POS subroutines.

TBL Subroutines

The TBL subroutines generate strength tables. These subroutines display tables of strength data. The data contain limits and predicted percentile values.

TXT Subroutines

The TXT subroutines generate strength table text. The TBL subroutines use the TXT subroutines to generate the text used in the strength tables.

LIM Subroutines

The LIM subroutines generate text for strength limits. These subroutines generate MIL-STD strength limits for Hold, Lift and Carry functions.

STR Subroutines

The STR subroutines calculate strength. These subroutines calculate strength values for percentile values. The STR subroutines send strength values to the SUC subroutines.

SRV Subroutines

The SRV subroutines set Reach subfunction variables. Functions that perforr reaches call the SRV subroutines.

BAR Subroutines

The BAR subroutines process bare handed reaches. These are materials handling subroutines. When reaching to an object without handles, the modules call the BAR subroutines.

HDL Subroutines

The HDL subroutines process reaches to handles. These are materials handling subroutines. The HDL subroutines calculate the variables needed to reach a handle.

The entire modular software structure is built upon FORTRAN source code. The development of the source code followed written programming standards. The programming standards include general appearance of the code. This covers cod ntation and a systematic way of labeling code and input/output statements. Our programming standards also cover the parameter passing among subroutines and modules. Our standards clearly define the use of FORTRAN common blocks, to store global and local information. Our standards extensively cover Source code documentation.

4.5.3 Embedded Comments

Paragraph 3.3.7 required the code to be self-explanatory with interval comments and in-line header block.

All sources require a header block which contains a title, objective, calls list, called by list, parameters passed (input vs output), and revision data. A Header Block program was created to extract this information from each source to be used in program documentation. This program reduced the time it took to do internal documentation of each subroutine.

The title of a subroutine is a short description of the functionality of a subroutine. It is intended to be a mnemonic aid to the programmer, and so should somehow reflect the three-letter descriptor at the end of each subroutine name. The objective of a subroutine is a more detailed description of its functionality. This description should include the names of any mathematical or algorithmic methods used, as well as any special considerations which should be taken into account when using the subroutine.

The called by and calls portion of the header list the name and title of each subroutine which is called by, or calls, the subroutine being described.

The parameters passed list should have a complete description of any variables passed into the subroutine through the parameter list. These descriptions should be concise and informative. Parameters should be divided into input and output parameters.

The common areas portion contains a list of all common areas and their titles, needed for the execution of the subroutine. Common areas should be titled to mneumonically reflect both the three-letter description and the contents of the common.

The revision data and number are used to track the history of a subroutine. The date listed here should be the date that the subroutine was last modified. The revision number indicates the total number of revisions the subroutine has undergone.

Programming standards have been incorporated, especially in documenting each subroutine internally. Comments within the body of the code should be clear and concise, and should be separated from FORTRAN statements by one blank comment describing what that block is doing. Within each block, every call, iterative loop, group of assignment statements, or branch should be commented immediately prior to the statement. In addition, the use of any constants within a subroutine should be documented immediately prior to their use. These statement-level comments should be easily distinguishable from the block-level comments, and should describe a low-level algorithm for the block of code.

Each database created contains a header block as the first record. This record gives the program number and name, database number and name, and a brief description of the records contained in the database.

4.5.4 Interaction with other Software

By using a modular structure, UDRI was able to separate software which was dependent upon a particular CAD system from the core modules of COMBIMAN and CREW CHIEF. The CAD routines were clearly identified and a user's guide was written for CAD interface programmers to follow when interfacing CREW CHIEF and COMBIMAN to a new CAD system. Specific system requirements were also identified as deemed necessary.

4.5.5 Modification to Existing Software

Tool Restructuring

The tool restructuring began with the creation of a new tool database. Before the new tool database, the CREW CHIEF program read tool data from four different files. The new tool database is a hierarchical schema set up in a single concise file. The new database makes it easier to add new tools to the database. Another advantage is that the new structure allows the building of the user interface from database information.

The development of the new tool database required the development of a new software module to read the database. The Tool Input (TIN) subfunction allows the CUI and core modules access to user prompts and tool data. Because the database contains the interface prompts and menus, we created new CUI subroutines.

The new CUI subroutines process tools without knowledge of the type or class of tool. This generic approach led to a more concise set of CUI subroutines. The need to put tool specific data in the CUI code no longer exists.

The original core tool modules (TAN and TOL) contained many instances of tool data residing in the source code. Many of these subroutines were rewritten due to the development of the new tool database. This eliminated most of the instances of hardcoded tool data.

Core Common Area Restructuring

UDRI is in the process of restructuring the core common areas. The main purpose is to allow the development of an Input/Output Manager (IOM) subfunction module. A pair of utility subroutines currently handle the functions of the IOM module. The size of the CREW CHIEF program, and the added complexity due to the development of Version 9 COMBIMAN, required the two utility subroutines evolve into a subfunction.

The elimination of structure violations is another purpose for common area restructuring. Software modules are only permitted to use common areas local to their modules or global common blocks. Some modules violate this structure. The Tool Input subfunction is the most notable culprit.

4.5.6 Software Structure

The COMBIMAN and CREW CHIEF programs comprise several modules. Each module performs a specific function or subfunction. A function module performs complete analysis or generation (Initialization, Tool Analysis, etc.). Subfunction modules perform specific, complex tasks, required for the completion of functions.

There are more than twenty functions making up the COMBIMAN and CREW CHIEF programs. There are four main types of functions Generation, COMBIMAN Activities, CREW CHIEF Tasks, and Accessibility, Visibility and Current Configuration. The following paragraphs briefly describe the functions.

Generation functions

The Generation functions are common to both COMBIMAN and CREW CHIEF. There are five generation functions. They are Initialization, Regeneration, Head Orientation, Link Table and Reposition.

Initialization

The Initialization function generates and displays the human model. The user selects the body size, clothing, posture and orientation. The human model, while placed in the user's drawing, is not a permanent part of the drawing. This prevents the programs from corrupting the user's drawing.

Regeneration

The Regeneration function regenerates the human model display. The programs use enfleshment data from the last successful positioning operation. The

Regeneration function provides the user the opportunity to change the model's display type and the user's viewpoint.

Head Orientation

The Head Orientation function lets the user specify where the human model will try to look. The human model will only turn its head as far as mobility constraints allow. Upon completion, the display shows the human model looking toward the selected location.

Link Table

The Link Table function allows the user to change the posture of the human model. The program presents the user with a table of angles for sixteen links in the human model's link system. The user changes the phi, theta and psi values to reposition the link system. The function checks each change to prevent the entering of unrealistic values and to ensure that the change is within joint mobility limits.

Reposition

The Reposition augments functions that position the human model. Sometimes the analysis requires that the program place the human model in an uncommon position, or a position requiring the movement of arms and legs. The reposition function allows the movement of up to twelve body segments. To protect from creating unrealistic positions, the function enforces mobility constraints.

COMBIMAN Activity Functions

The COMBIMAN activity functions are analysis functions that are used for a seated operator. There are three COMBIMAN Activity functions. They are Reach, Strength and Reach Envelope.

Reach

The COMBIMAN Reach function allows the evaluation of an aircrew member's capabilities to reach controls. Controls in this context consist of handles, rudder pedals, and toggle switches, rotary dials and push buttons. Because of mobility limits, the human model reaches toward the control location with realistic joint mobility.

Strength

The Strength function allows the evaluation of an aircrew member's capabilities to reach and operate controls. Controls in this context consist of handles, rudder pedals, and toggle switches, rotary dials and push buttons. Because of mobility limits, the human model reaches toward the control location with realistic joint mobility. This function assumes that a control is within the operator's reach before predicting strength capabilities.

Reach Envelope

The Reach Envelope function decides if a control panel lies inside, intersects with or lies outside a crew member's maximum arm-reach envelope. The evaluation depends on body size, clothing type, restraint type and control type (grip type). The Reach Envelope function produces a reach envelope in 3-D space and then computes the intersection of the reach envelope with the selected control panel(s).

CREW CHIEF Tasks

The CREW CHIEF tasks are functions that pertain to a maintenance technician. There are nine functions in this category. The functions are Tool analysis, Connector analysis and Manual Materials Handling (Carry, Hold, Lift, Push, Pull, Reach and Grasp).

Tool Analysis

The Tool analysis function evaluates the ability to reach with a tool. This includes the ability to reach around obstacles. This function displays strength capability (upon successful tool reach). The CREW CHIEF Tool Analysis function contains a 220-piece tool box. The types of tools included are wrenches with sockets, wrenches without sockets, screwdrivers, pliers and miscellaneous tools such as hammers.

Connector Analysis

The Connector analysis function evaluates the strength capability of a technician to secure an electrical connector at a specified location. The evaluation depends on the grip used and connector size. The results appear in a table of strength capabilities.

Materials Handling

The Materials Handling functions evaluate the capabilities of a technician to handle objects in the workplace. There are seven skills evaluated by this function. The skills are lift, push, pull, hold, carry, reach and grasp. Often the objects are the line replaceable units (LRUs). Strength data are available for carry, hold, lift, push and pull tasks.

Accessibility, Visibility and Configuration Functions

The Accessibility functions (Interference and Work Envelope) allow the user to analyze the interference between the human model and the drawing elements. The Visibility function allows the user to plot a projection of the workplace. The Configuration function displays information about the human model.

Interference Function

The Interference function checks interference between the human model and elements in the workplace. Interference checks the whole body or portions of the body. Interference checking works with or without a tool. Interference checking is performed using the current posture configuration and position of the human model. The function marks points of interference with 3-D arrows.

Work Envelope Function

The Work Envelope function presents a graphic display of the volume of space required to operate a tool. This function also shows the volume of space required for the movement of an object. Work Envelope is a quasi-dynamic interference check used only by the CREW CHIEF program.

Visibility Function

The Visibility function plots a projection of visual azimuth and elevation line-of-sight angles to elements in the drawing. The plot can be either a rectilinear or an Aitoff projection. The plot depicts the visual field as seen by the human model. This function has the option of a plot from a user defined viewpoint.

Current Configuration Function

The Current Configuration function displays the parameter values used in the execution of the COMBIMAN and CREW CHIEF programs.

Subfunctions

The COMBIMAN and CREW CHIEF functions rely upon the subfunction modules. These modules perform various complex tasks. Such tasks include interference calculation and enfleshment assembly. There are fifteen subfunction modules. The following paragraphs briefly describe the subfunctions.

ANT Subfunction

ANT is the anthropometry input subfunction. This subfunction reads and processes human model anthropometric data.

CCI Subfunction

CCI is the element processing subfunction. This subfunction inputs drawing elements into COMBIMAN and CREW CHIEF programs.

DSP Subfunction

DSP is the display human model subfunction. This subfunction produces graphical output data for human model enfleshment display.

ENF Subfunction

ENF is the enfleshment assembly subfunction. This subfunction positions the mesh file node data used to enflesh the human model.

HED Subfunction

HED is the head orientation subfunction. This subfunction controls head positioning for several COMBIMAN and CREW CHIEF functions.

INF Subfunction

INF is the interference subfunction. This subfunction finds the interference between the human model and the work place.

LEG Subfunction

LEG is the leg reach subfunction. This subfunction performs an iterated inverse kinematic reach.

MOB Subfunction

MOB is the mobility subfunction. This subfunction determines the range of motion for the human model link system.

MMH Subfunction

MMH is the Materials Handling subfunction. This subfunction performs operations common to the Materials Handling functions.

RCH Subfunction

RCH is the arm reach subfunction. This subfunction performs an iterated inverse kinematic reach.

RED Subfunction

RED is the read enfleshment subfunction. This subfunction initializes the mesh files used to enflesh the human model.

SIT Subfunction

SIT is the COMBIMAN initialization input subfunction. This subfunction reads the COMBIMAN posture, from the initialization database, based upon seat type.

TIN Subfunction

TIN is the tool input subfunction. This subfunction uses the tool database. The tool database contains tool sizing data and user interface information.

TOL Subfunction

TOL is the CREW CHIEF tool reach subfunction. This subfunction performs reaches with specified tools.

UTI Subfunction

The UTI module is a collection of utility subroutines. These subroutines perform operations that are required by many functions and subfunctions. For example, UTI subroutines perform matrix multiplication, gaussian elimination, etc.

CAD Interfaces

There are two ways to interface COMBIMAN and CREW CHIEF programs to CAD systems. The first method is for the interface to directly access the COMBIMAN and CREW CHIEF core functions, accomplished by passing parameters through FORTRAN common blocks. The second method is by using the Common User Interface (CUI). CUI is the outer shell of the COMBIMAN and CREW CHIEF host independent code. This shell contains the interface logic. CUI retrieves information from the user by calling a small set of CAD dependent subroutines. When the CAD system interface allows the use of the CUI, it is the preferred method of interfacing to COMBIMAN and CREW CHIEF. The following paragraphs briefly describe the COMBIMAN and CREW CHIEF CAD interfaces.

CATIA

This interface uses the CATIA Function Structure Definition (FSD) module to layout the menus. FSD prevents the use of CUI. The CATIA interface also uses the Graphics Interactive Interface and CATIA Geometry Interface modules. The COMBIMAN and CREW CHIEF CATIA interfaces run on IBM RS6000 workstations running the AIX operating system, IBM mainframe computers running the MVS operating system.

CADAM

This interface uses the CADAM Interactive User Exit (IUE) facility. IUE permits the use of CUI. The COMBIMAN and CREW CHIEF CADAM interfaces run on IBM RS6000 workstations running the AIX operating system, IBM mainframe computers running the MVS operating system and IBM minicomputers running the VM operating system.

I-DEAS

This interface uses the I-DEAS Director/Observer facility. Director/Observer permits the use of CUI. The COMBIMAN and CREW CHIEF interfaces to I-DEAS Level VI run on a Sun workstation running SUNOS operating system. The COMBIMAN interface to I-DEAS Level VI and the COMBIMAN and CREW CHIEF interfaces to I-DEAS Level V run on a Silicon Graphics workstation running the IRIX operating system.

Unigraphics

This interface uses the Unigraphics User Function interface facility. User Function permits the use of CUI. The COMBIMAN and CREW CHIEF CADAM interfaces to Unigraphics run on a Sun workstation running the SUNOS operating system.

Module Name	Function/Subfunction	Program
Initialization (INI)	Function	Both
Regeneration (REG)	Function	Both
Head Orientation (HDO)	Function	Both
Head Orientation (HED)	Subfunction	Both
Link Table (LKT)	Function	Both
Reposition (RPN)	Function	Both
Reach (REA)	Function	COMBIMAN
Reach (REC)	Function	CREW CHIEF
Reach (RCH)	Subfunction	Both
Strength (STR)	Function	COMBIMAN
Reach Envelope (REN)	Function	COMBIMAN
Tool (TAN)	Function	CREW CHIEF
Tool Reach (TOL)	Subfunction	CREW CHIEF

Module Name	Function/Subfunction	Program
Tool Input (TIN)	Subfunction	CREW CHIEF
Connector (CTR)	Function	CREW CHIEF
Materials Handling (MMH)	Subfunction	CREW CHIEF
Hold (HLD)	Function	CREW CHIEF
Pull (PLL)	Function	CREW CHIEF
Push (PSH)	Function	CREW CHIEF
Grasp (GSP)	Function	CREW CHIEF
Carry (CRY)	Function	CREW CHIEF
Lift (LFT)	Function	CREW CHIEF
Work Envelope (WRK)	Function	CREW CHIEF
Interference (ITF)	Function	Both
Interference (INF)	Subfunction	Both
Configuration (CFG)	Function	Both
Visibility (VIS)	Function	Both
Anthropometry Input (ANT)	Subfunction	Both
Leg Reach (LEG)	Subfunction	COMBIMAN
Seat Posture Initialization (SIT)	Subfunction	COMBIMAN

Display (DSP)	Subfunction	Both
Geometry Input (CCI)	Subfunction	Both
Enfleshment (ENF)	Subfunction	Both
Mobility (MOB)	Subfunction	Both
Enfleshment Input (RED)	Subfunction	Both

Figure 18. Function/Subfunction List

4.5.7 User-Computer Interface

Paragraph 3.3.7.7 of the SOW requires that all versions of CREW CHIEF and COMBIMAN software be in compliance with Paragraph 5.15 (User-Computer Interface) of MIL-STD-1472D.

Standard procedures for each user interface were followed. These procedures were set by UDRI and the Air Force. In defining the procedures, all prompts for CREW CHIEF and COMBIMAN were standardized. The terminology was set for key words in the prompts. These key words include DEFINE, KEY, PICK, and SELECT. Simple menus are used to simplify the use on each CAD system. Icons are used if possible. At present, the CADAM version of CREW CHIEF and COMBIMAN have icons incorporated into the interfaces.

On-line help is available on most of the CAD systems we have interfaced to. A user's guide is available for each CREW CHIEF and COMBIMAN interface to a specific CAD system. Each of the user's guides use a PROMPT, ACTION, RESULT format. The location of each prompt and menu on the screen is given for each CAD system.

4.6 Configure Software for Distribution

Paragraph 3.3.8 of the SOW requires that software be configured for distribution by customizing it to the recipient's configuration to the degree possible and that copies for distribution be produced. All configured distribution media were produced upon request from AL/CFHD or the CSERIAC program office. Each configured distribution media was delivered to AL/CFHD or the CSERIAC program office for distribution.

Distribution Configurations

One hundred twenty-three copies of COMBIMAN and CREW CHIEF were distributed during the course of this contract. COMBIMAN and CREW CHIEF have been delivered in 21 different configurations. The configurations comprise seven hardware platforms, nine CAD/graphics systems, three versions of COMBIMAN and three versions of CREW CHIEF. Thirteen of these configurations are obsolete and are no longer distributed.

Obsolete Configurations

Eleven of the COMBIMAN and CREW CHIEF configurations are no longer distributed because of obsolescence. The following table lists these configurations. The table shows the number of copies distributed on this contract. The last column of the table shows the obsolete feature.

Table 9. COMBIMAN and CREW CHIEF Obsolete Configurations

CREW CHIEF

Configuration	Number of Copies	Obsolete Feature
ComputerVision CADDStation	11	CREW CHIEF Version 1.1
ComputerVision CV4001	1	CREW CHIEF Version 1 and obsolete hardware
System Independent FORTRAN 77	6	CREW CHIEF Version 2
System Independent FORTRAN 66	1	CREW CHIEF Version 1
CADAM 20 - MVS	3	Obsolete CAD System
CADAM 21 - MVS	17	CREW CHIEF Version 2
CADAM 21 - VM/CMS	1	CREW CHIEF Version 1
CADAM 21 - VM/CMS	4	CREW CHIEF Version 2
CADAM 21 - VM/CMS CREW CHIEF V3	2	Obsolete hardware

COMBIMAN

Configuration	Number of Copies	Obsolete Feature
Standalone Version 7	1	Obsolete graphics software
Standalone Version 8	3	Obsolete graphics software

Current Configurations

CREW CHIEF

Currently, CREW CHIEF is available on five platforms. The interfaces represent three CAD systems on four hardware platforms. The CAD systems are CADAM, CATIA, and I-DEAS. The hardware platforms/operating systems are IBM 4341/MVS, IBM RS6000/AIX, Silicon Graphics Personal Iris/IRIX, and Sun 4/330 SPARCstation/SUNOS. The following table shows the CAD system, operating system, and total number of copies of CREW CHIEF V3 shipped.

Table 10. COMBIMAN and CREW CHIEF Current Configurations

OS	CAD System	Total Copies
MVS	CADAM 21	2
MVS	CATIA	9
AIX	CATIA	24
IRIX	I-DEAS LEVEL V	5
SUNOS	I-DEAS LEVEL VI	1

COMBIMAN

Currently, COMBIMAN is available on six platforms. The interfaces represent three CAD systems on four hardware platforms. The CAD systems are CADAM, CATIA, and I-DEAS. The hardware platforms/operating systems are IBM 4341/MVS, IBM RS6000/AIX, Silicon Graphics Personal Iris/IRIX, and Sun 4/330 SPARCstation/SUNOS. The following table shows the CAD system, operating system, and total number of copies of COMBIMAN V9 distributed.

OS	CAD System	Total Copies
MVS	CADAM 21	1
MVS	CATIA	7
AIX	CATIA	14
IRIX	I-DEAS Level V	4
IRIX	I-DEAS Level VI	2
SUNOS	I-DEAS Level VI	1

4.7 Develop User and Programmer Instructions

Because of the complexity of the CREW CHIEF and COMBIMAN systems of programs, comprehensible instructions for the user and the developer are critical. These instructions must be tailored to each individual CAD host, and must be updated and modified as newer versions of each program become available.

4.7.1 Develop Instructions for Users of CREW CHIEF and COMBIMAN

During this contract, UDRI submitted User's guides for COMBIMAN, Versions 9 and 10, and for CREW CHIEF, Versions 3 and 4. In addition, CAD-specific CREW CHIEF User's Guides were developed and submitted for CADAM V2R21, CATIA V3, and I-DEAS level V and VI. For COMBIMAN, CAD-specific user's guides were developed for CATIA V3 and I-DEAS level V.

The user's guide for CREW CHIEF Version 4 was re-designed to incorporate some of the suggestions of the CREW CHIEF users. It now comprises three volumes. Volume 1 provides the user with information on using CREW CHIEF on a particular CAD system (there will be several volume 1's-- one for each CAD host).

Volume 2 is in prompt-action-example-result format, and provides a full explanation of each possible execution option in the programs. Included in this format is a tutorial that allows the novice user to learn how to use most of the major analysis tools. The second half of this volume is a quick-reference guide.

Volume 3 contains descriptions of model development for every major computer model used in the programs. It explains the theoretical basis of each model, and contains usage notes which give the user instructions on when each analysis is appropriate, and when to select various options for a particular analysis.

4.7.2 Develop Instructions for Programmers of CREW CHIEF and COMBIMAN

The SOW required the expansion of the programmer instructions for COMBIMAN and CREW CHIEF for future contract programmers. Contract mc :ion P00020, deleted this requirement from the contract.

4.7.3 Enhance Instructions

UDRI enhanced the installation instructions for CREW CHIEF, to make them more comprehensible. A customer, Structural Dynamics Research Corporation (SDRC), reported a problem during CREW CHIEF installation. SDRC was attempting to install Version 3 CREW CHIEF for the I-DEAS Level VI CAD system on the SUNOS operating system. Consultation with SDRC personnel determined that the problem was due, in part, to a lack of clarity in the instructions. The enhancements to the installation instructions also reflect changes to the installation process.

SDRC encountered a problem installing CREW CHIEF. They installed CREW CHIEF on one of their Sun SPARCstations. The installation procedure completed without reporting an error. However, the CREW CHIEF program aborted when executed.

Upon receipt of the problem report, UDRI attempted to reproduce the problem. All attempts at installing CREW CHIEF on the local Sun SPARCstation were successful. UDRI then consulted with the SDRC engineer who had performed the CREW CHIEF installation. It was determined that the CREW CHIEF program was aborting, on SDRC's Sun, because it could not find the data files. The installation procedure was modified to avoid this problem.

During the investigation of the installation problem, it became apparent that the installation instructions made some incorrect assumptions about the Unix experience level of the installer. These assumptions include expecting the installer to have all necessary Unix commands in their search path, and to know how to use the Unix commands. UDRI changed the installation instructions to include step by step examples of every Unix command required by the installer. Also added were instructions detailing how to start the CREW CHIEF program, because many installers did not have access to the CREW CHIEF User's Guide.

4.8 Validation and Verification

A validation-Verification process was run for each modification or new function of COMBIMAN and CREW CHIEF. Depending on the type of modification, up to three areas of development may need to be validated or verified. In all cases, verification of the software was performed. Whenever a modification or enhancement could possibly affect the contents of a database, the effects of the modifications or enhancements on the database were specifically verified. Finally, if a modification or enhancement affected a mathematical or statistical model, or their associated software, the validity and output of these models were re-checked.

Software verification entails verifying all aspects of input and output. This includes exercising the user interface, as well as graphical and tabular output.

- User Input Processing

All possible combinations of user input for affected portions of the software were tested. This included verification of program interpretation (did the core receive the correct values for each control parameter?). It also included verification of processing for both non-sensical input, as well as input that fell outside the range of the models.

- Software Output

Both the graphical and tabular outputs were checked. This included consistency of the output with the databases, as well as consistency of the graphical output with the results of the analysis, including human model sizing, posture, and strength. It also included verification of the function log output.

Whenever a database or routines accessing a database were modified or creating, UDRI personnel performed verification testing on the output from the databases. In many cases, testing involved a 100% verification on the database and routines. For some of the larger databases, 100% verification was impractical, so only subsets were verified. The verification subset was selected to ensure that all code and database changes were fully exercised.

Any new or modifications to existing mathematical computer models were thoroughly verified and validated. Verification included testing the model for expected output, especially with regards to new portions of code. Proper handling of special cases in the underlying mathematical model was also verified.

Validation was performed on all new or modifications to existing mathematical computer models. Validation cases were gleaned from various sources, including experimentation and existing CAD drawings. Whenever possible, these cases were selected to ensure that the modifications or additions were specifically validated.

For each verification/validation effort, a specific plan was submitted to the Function Testing and Validation Committee for comment and approval. This plan included a description of the changes/modifications being tested, as well as a description of which conditions were being tested. This committee also had to give final approval on the test results.

4.9 Develop, Acquire, and Maintain Computer Hardware and Software

During the course of the contract UDRI was required to fabricate and modify various research equipment. The major items fabricated and/or modified are listed below.

- Designed and built two encoder/decoder systems for use in automated time study data collection.
- Horizontal Time Study test station, with multi-axis adjustment in locations and orientations of work, and with large and small access openings
- Task mounting plate and weighted boxes for use in the TTE experimentation
- Mounting plates and clearance barriers for use in the TTE experimentation
- Overhead time study test station, with multi-axis locations and orientations of work, with large and small access openings, and with adjustable ceiling heights.
- Tool clearance barriers for use in TTE experimentation
- Software development and modification to allow data collection and analysis for the time studies.

In addition, while this contract did not allow direct purchase of ADPE, UDRI personnel developed requirements and performed evaluations for several computer upgrades/acquisitions, including:

- Upgrade of the IBM mainframe in the HESS facility (now CWDEF).
- Replacement of the IBM mainframe in the HESS facility with an RS6000/580
- Acquisition of 4 X-terminals to be used for development of the human models
- Acquisition of an electromagnetic 3-D locating device called the Flock of Birds
- Acquisition of a low-cost head-mounted display for use in the prototype VR human model.
- Acquisition of a movie camera to be used as a low-cost RGB-NTSC scan convertor.
- Acquisition of a buffer plotter for use on the RS6000/580
- Acquisition of the RS6000/320 on-loan from IBM
- Acquisition of the Sun SPARCstation II on-loan from Sun Microsystems
- Acquisition of the SG Personal Iris on-loan from Silicon Graphics

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SECTION 5 - ERGONOMICS RESEARCH

The contract SOW requires UDRI to perform ergonomics research into human physical characteristics. Sometimes, these data exist in the literature, so UDRI must review existing literature for new data sources and, once found, acquire and catalog these data sources into the ergonomics research library maintained on-site. Because the ergonomics data often needed for CREW CHIEF and COMBIMAN are often non-existent or inappropriate, much of the data used in these models must be collected via experimentation. This experimentation must be well-planned to be both effective and safe for the subjects. And sometimes additional hardware and software must be acquired or fabricated.

5.1 Perform Ergonomics Research

During this contract period UDRI performed extensive research in support of the Task Time Estimator and the CREW CHIEF human model. The majority of the research studies conducted during this contract were time studies performed to collect data for the Task Time Estimator (TTE). UDRI also performed ergonomic research to collect body posture data to improve the fidelity of the CREW CHIEF human model in positioning the body during lifting and carrying task.

Time Study Research. UDRI planned and conducted numerous time and motion studies during this contract employing nearly 500 subjects logging over 1100 hours of actual data collection. Our time study research utilized simulated workstations which represent the uniqueness of aircraft maintenance, such as limitation on physical and visual accessibility, unusual and awkward postures, and the tools needed to accomplish aircraft maintenance tasks. UDRI's time studies involving the effects of physical accessibility on the time to remove and replace aircraft components, have included limitations due to access opening size, access opening location, limited hand clearance limited hand with tool clearance, interference from barriers, interference from the work object, and the location of work (this includes distance from access opening, angle in respect to access opening, and orientation of the object). UDRI's time and motion studies involving visual accessibility include visual obscurations due to access opening size, the work object, object and the workers hands and arms. UDRI has also studied the interaction between physical and visual access and how they are effected by awkward postures common to flightline maintenance (reaching overhead, reaching at arms length, hunched down, lying flat, and lying reaching up in a half sit-up posture). Our studies have included the use of hands alone, and all combination of one and two ratchet, box-end, and open end wrenches. We also studied the effects of object weight and the number of people performing a task. All studies involved both remove and replace activities. The focus of the time and motion research performed by UDRI thus far has been on the validation of the existing data and the collection of additional data for the development of time prediction equations to reflect flightline conditions. In addition to performing research on variables which effect maintenance time, UDRI has also performed several studies on the time study method itself. These studies involved the effects of practice and pace on time study results.

Physical Ergonomics Research. All of the physical ergonomics research involving human strength that was performed in the Physical Ergonomics Laboratory, also included the measurement of body posture during strength exertion via a 3-D sonic digitizing system. However, research performed offsite by our sub-contractors involving strength for lifting and carrying tasks did not include body posture data. The reason body posture data were not collected during these studies is the dynamic nature of lifting and carry task. The sonic digitizer used to measure body posture was not able to measure the body in motion. Therefore, during this contract period UDRI recreated the conditions under which the original research was performed and asked subjects to remain motionless at the beginning and end of the lifting and carrying tasks to allow the sonic digitizer to measure their body posture. During the body posture studies, subjects did not lift or carry objects of any significant weight. The objects were the same size as in the original studies but contained no weights. This was done to allow the subjects to remain motionless long enough to collect the necessary posture data, and to avoid possible injury to the subjects.

5.2 Develop and Acquire Laboratory Equipment

UDRI designed and fabricated, modified, and purchased several pieces of equipment to support the research conducted in the Physical Ergonomics Laboratory. Whenever possible we used the Air Force furnished shop facilities located in the Ergonomics laboratory to fabricate and modify research equipment. The pieces of equipment that were designed and fabricated were two Maintenance Task Simulators, and tone encoder/decoder devices used for task time data collection. Modifications were made to the Tool Torque Strength measuring device, the Push/Pull Static strength device, and the visual accessibility apparatus. Equipment purchases included a camcorder, a video cassette recorder, a video monitor, (and all the VR stuff).

Maintenance Task Simulators. UDRI designed and fabricated two Maintenance Task Simulators, one for task where the subjects assume a vertical posture, and one where subjects perform simulated maintenance task overhead. Both maintenance task simulators are used to simulate obstacles in the maintenance workplace for measuring the time required to perform remove/replace actions of varying physical demands. The vertical type apparatus consists of a unistrut framework 5.25 feet wide, 8.5 feet high, and 6 feet deep on a wooden platform 8 feet wide and 10.5 feet deep. The front of the framework is a plywood barrier with an opening through which the subject works with hand tools on simulated remove/replace tasks. The opening is of different sizes to vary the accessibility, from 19.5 inches square down to 8 by 5 inches square. Inside the framework (beyond the barrier) is an adjustable frame which creates vertical and/or horizontal obstacles around which the subject must reach while performing the task. Beyond the obstacle barrier is an adjustable mounting surface to which the experimental objects (of various kinds, sizes and weights) are attached, The mounting surface can be adjusted from 28 to 65 inches above the standing surface and 30 inches left or right of the opening of the plywood barrier, and can be oriented either vertically or horizontally. The plywood barrier extents to the floor and prevents tools or objects from striking the subject if the subject should accidentally drop any.

The overhead type is based on a wooden platform, 4 by 8 foot. It simulates maintenance actions as would be found working under a wing or under a fuselage. A unistrut structure sits above the platform. The height of the plywood ceiling can be adjusted from 12 inches to 6 feet above the platform. In the plywood ceiling there is a 19.5 by 19.5 inch opening. Another piece of plywood with a 5 by 8 inch opening in it can be placed over the larger opening to restrict access. Directly above the opening there is the mounting structure for the experimental object.

Each of the Maintenance Task Simulators have been modified several times to accommodate the experimental conditions and objects used to simulate the maintenance task being studied. Those modifications include the addition of interference barriers, nut plates with changeable self-locking nuts, and a flange type pipe fitting.

Tone Encoder/Decoder. UDRI designed and fabricated two tone encoder/decoder devices. This device was used in the time study research to automate the entry of task time data. The encoder/decoder permits the experimenter to superimpose tones onto the audio track of a video tape with a hand held switch. Four separately distinguishable tones can be placed on the tape to signal the beginning and end of task elements, and other task events defined for a particular study. Also connected to the encoder/decoder device is a start-stop button which the subject can use to place a tone on the tape signaling the beginning and end of each task. After data collection, the tape containing the tones is played back through encoder/decoder device into a personal computer. The computer calculates the time between the tones and differentiates between the 4 different tones. This data are then stored on disk for analysis.

Equipment Modifications. UDRI made some minor modifications to the Tool Torque Strength measuring device, the Push/Pull Static strength device, and the visual accessibility apparatus. Modifications to the Tool Torque Strength measuring device included using a programmable power supply to control the resistance of an electronic brake. Through a feedback loop programmed from a personal computer the tool torque device was able to simulate the tightening of a bolt, as the wrench was turned, the resistance increased. Another modification included the addition of simulated pieces of equipmer h are torqued by hand rather than by a wrench.

Modifications to the Push/Pull Static strength device included the installation of a shelf used in the lift posture studies, the installation of a ceiling height barrier used in the carry posture study, and the installation of anchors used to hold a gurney which subjects were required to reach over in a study to simulate patient handling in a hospital.

Modification to the visual accessibility apparatus included replacing the LED display with a constant light source. This modification was made for a study which measured peripheral vision.

Equipment Purchases. UDRI purchased a Sharp camcorder, a Sony video cassette recorder, and a Zenith video monitor. This equipment was used as part of the data collection and editing system in the task time studies.

5.3 Maintain Ergonomics Library

Reorganization of library

- The library was re-categorized.

  The library contains technical reports, text books, reference books, unpublished reports and software manuals from outside sources.

  - It was decided that to organize the library for more efficient use, different categories should be used. The document types were reviewed and the following categories were chosen: 000-099 COMBIMAN and CREW CHIEF TRs and Supporting Studies, 100-199 Anthropometry, 200-299 Standards and Regulations, 300-399 Human Modeling, 400-499 Computer Systems, 500-599 Space, 600-699 Human Factors, 700-799 Mathematics, and 800-999 Miscellaneous. The documents were divided into the various categories, but have not been renumbered (manually or in the computer).

- Before more effort is put into this endeavor, a decision needs to be made as to whether the existing library system is kept or other available systems are investigated. The current library system is Cardfile.

  Under Cardfile, there are seven fields to input information. They are title (225 characters), author(s) (35 characters per name), document type (5 characters), date (8 characters), report number (15 characters), library document number (15 characters), and key words (15 characters per word).

- If the decision is made to keep the present system, old documents need to be renumbered and input into the computer. When inputting into the computer, document summary information should include key words or subject matter. Numbers (stickers) need to be placed on the spine of each document.

  - New documents need to be numbered and input into the computer. These documents also need to be numbered by stickers. If check-out cards are used, they need to be typed and the card holders need to be attached to each document.

- A new check-out system needs to be established. Possibilities include 8-1/2 x 11 size folders with space for title, date of check out and person's name or a card system.

- Employees need to be informed of how to locate documents (on computer) in library. There should be a use and rules booklet, which includes instructions explaining how to search the library database for a specific item. Also included should be a description of library procedures on the check-out and return of items. The individual responsible for the library should be the only person with editing access to the program.

- A current listing of all documents in the library needs to be compiled and kept up-to-date. This listing should, if possible, be accessed by author name, title of document, or subject matter. A hard copy should be made available in the basement office and also in the library itself.

5.4 Plan Research Plan

The CREW CHIEF Research Program Plan contains four volumes each relating to a specific area of research and development for the enhancement of the CREW CHIEF human model capabilities. Volume 1 describes the plan for the development of the Task Time Estimator. Volume 2 describes the method for developing a space maintenance technician model. Volume 3 describes proposed enhancements to the human model interface. Volume 4 describes proposed program enhancements. The following is a brief summary of each of the four research program plan volumes.

Volume I: Task Time Estimator

The intended purpose of the CREW CHIEF Task Time Estimator (TTE) is to provide the aircraft designer and the maintainability engineer with a means of predicting the time for a maintenance task from a conceptual or developmental design. The development of this system requires research into a variety of elements. All factors that may significantly affect time to complete a REMOVE/REPLACE task must be identified. User interfaces must be developed for integrating a Task Time Estimator into CREW CHIEF and, further, a method must be devised for the program to determine different levels of physical accessibility. Finally, UDRI must determine the studies that will be required to build an appropriate database for the Task Time Estimator. The Task Time Estimator Research Program Plan contains guidelines for the TTE development, results of time study research, description of proposed research, methods for developing the TTE databases, description of the TTE database structure, description of how the TTE will be implemented, and a plan for validating the time-to-repair estimated computed by the TTE.

Volume 2: Space Maintenance Technician Model

The work outlined in the research program plan for the Space maintenance technician model is designed to study and define the maintenance tasks that are likely to be performed in a space environment, and to develop a practical Space Maintenance Technician Model with appropriate personal protective equipment and tools to perform the various tasks.

The program plan addresses the development of a plan to identify the specific data which must be gathered to support the model; the development of models of these data; the validation of models. tasks, space suits, and tools; a description of how these can be incorporated into CREW CHIEF; and the method to validate the enhanced capability. Also addressed is the development of preliminary models of the "shuttle space suit" and model descriptions of current "space tools" into the CREW CHIEF model.

Many of the techniques used in developing CREW CHIEF are directly transferable to the Space Maintenance Technician. The CREW CHIEF program code is structured in such a manner that it may be directly interfaced with virtually any CAD system available on the commercial market today. It was designed specifically with that purpose in mind, and performs all its modeling computations in a central core which is devoid of any CAD system dependency. All CAD system-dependent subroutines reside outside this core, and need merely to be replaced with their counterparts in a particular CAD system. This structure allows any aerospace manufacturer who employs a 3-D CAD system to use the CREW CHIEF system of programs.

Volume 3: Interface-Related Enhancements

The CAD industry is very volatile. New CAD systems are constantly being introduced into the market, while old CAD systems are updated and enhanced. User preferences on CAD systems also shift, as do even the types of geometric entities used for designing systems. And there are many enhancements to the CREW CHIEF-CAD interface that naturally arise as new techniques are developed, both in-house and in the literature.

This volume of the Research Program Plan deals with proposed enhancements to the CREW CHIEF-CAD interfaces. Some of these enhancements will be made to the user interface, and are included because they were suggested by current users, because they would greatly simplify the task of interfacing CREW CHIEF, or because they would significantly improve the usability of our programs. Other enhancements are related to the CAD entities processed by CREW CHIEF, and are a direct result of the typical aerospace CAD designer progressing from wireframe design techniques to using solids and surfaces as the basis for their designs.

The proposed enhancements to the user interface can be classified into one of two types: enhancements requested by CREW CHIEF users, and enhancements recommended in-house. One of the major suggestions received from CREW CHIEF users was to develop the ability to allow the user to repeat the execution of a CREW CHIEF function while changing only a few of the parameters needed to drive that function. Users also requested a batch version for the program which would allow users to perform several analyses on several candidate designs at once. Another suggested enhancement, this one from in-house, is the development of CAD independent help pages that could be used from CAD system to CAD system. The final enhancement, also in-house, is the development of a PHIGS (Programmer's Hierarchical Graphics Standard) interface to CREW CHIEF.

When the CREW CHIEF CAD Data Interface was first developed, the prevalent 3D entities used in design were wireframe in nature; almost no surfaces or solids were used. Consequently, CREW CHIEF was developed to process these types of entities, and only basic surface processing was performed. Today, however, designers make extensive use of solids and surfaces, ranging from simple primitive solids (cones, spheres, etc.) to complex Boundary Representation solid models. Consequently, the CREW CHIEF entity processing needs to be expanded to include full surface processing (for boundary representation models), as well as processing for any arbitrary type of solid.

Volume 4: Program Enhancements

Aside from the TTE and the Space Maintenance Model, UDRI was tasked to identify several other enhancements for the CREW CHIEF program. Suggestions were culled from users and from in-house, and the most requested enhancements still within the scope of the contract were selected. Some of these enhancements will be transparent to the CREW CHIEF user, because they deal with internal program structure and capabilities. Others, though, pertain directly to CREW CHIEF functionality, and thus will be readily apparent to the CREW CHIEF user.

1. GENERAL PROGRAM ENHANCEMENTS: These enhancements deal specifically with internal capabilities and structures, and relate to configuration management of the CREW CHIEF program. The first enhancement discussed is the development of a geometry input function, which will speed up program execution in general by preprocessing all the CAD conversions from complex geometric entities to simpler faceted surfaces, and is necessitated by the enhanced surface and solids processing discussed earlier. Because of early coding bias, as well as the large number of developers on the CREW CHIEF program, many modules are in need of overhauling so that other enhancements discussed in this plan can be implemented more easily. Finally, the set of subroutines which saves and restores the current human model data has grown large enough and complex enough to warrant the creation of a new subfunction module, the Input/Output Manager subfunction.

2. FUNCTION ENHANCEMENTS: CREW CHIEF users requested several enhancements to the analysis functions. Users requested two additional types of vision plot, a perspective plot and an orthographic plot. They also requested that the Head orientation be modified to allow direct line-of-sight viewing of the target point, in addition to the more natural orientation used currently. Yet another requested enhancement was the ability for the human model to use more than one tool at a time (such as holding a nut with an open -end wrench, while tightening the attached bolt with a ratchet wrench). The final area identified as highly desirable by users is animation, for visualization and training purposes.

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