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COMPUTER-AIDED DESIGN MODELS TO SUPPORT ERGONOMICS

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FOR THE COMMANDER



CHARLES BATES, JR.
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19. ABSTRACT (Continue on reverse if necessary and identify by block number) This report describes a new computer-aided design (CAD) and evaluation model to simulate an aircraft maintenance worker called "Crew Chief". The model will interface to two or three CAD systems common in the aerospace industry. Crew Chief will generate a 3-D pictorial of either a male or female maintenance worker, accurate in size, clothing, mobility, accessibility, strength, and visual characteristics. The aircraft designer, working at the computerized drawing board, can superimpose the Crew Chief on the design and simulate the performance of maintenance activities. With this tool, the designer can verify that a system is maintainable before even a mockup is constructed. Because of its general purpose capability, the Crew Chief model will have application to nonaircraft design evaluations.					
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SUMMARY

The Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL) and the Air Force Human Resources Laboratory (AFHRL) are developing a computer-aided design (CAD) model of an aircraft maintenance technician. This model will interface to existing commercial CAD systems used by aerospace manufacturers and will be used by them to improve the maintainability and supportability of Air Force aircraft. By providing the designer with a computer simulation of a maintenance technician, maintainability analyses can be performed while the system is still on the computer-aided drawing board. Specifically, the model will simulate the physical characteristics and abilities of the maintenance technician: ability to reach into confined spaces, ability to use handtools, ability to handle objects (lifting, lowering, pushing, pulling, etc.), and ability to inspect or see into development of confined areas. This model will build on the technology used in the COMBIMAN model (Computerized Biomechanical Man) developed by AAMRL.



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PREFACE

The information in this paper was presented at the NATO Defense Research Group Panel VIII Workshop titled: "Applications of Systems Ergonomics to Weapon System Development", Panel II titled: "Operator/Maintainer Equipment Interface" on 9 - 13 April 1984 at the Royal Military College of Science, Shrivenham, England. This work was performed under Work Unit 71840831.

INTRODUCTION

Increasingly, aerospace firms are using computer-aided design (CAD) techniques. CAD replaces the conventional drawing board with a computer graphics terminal. The designer works with a keyboard, a lightpen, and a CRT display rather than with a pencil and paper. Lines are created in a data file in the computer and simultaneously displayed to the designer. The design process is accelerated by the ease with which the computer converts the designer's commands into digital form and with a degree of accuracy which cannot be achieved with a pencil. Once created, drawings can be dimensioned and plotted in seconds. Modifications and changes can be made with even greater efficiency. Changing a line length, for example, automatically results in concomitant changes in all other related lines and dimensions. The size of an object can be scaled up or down instantly. Once drawn on the CAD system, any object can be recalled, rescaled, and added to a new design without redrawing a single line. The new CAD systems also include a computer-aided manufacturing (CAM) capability which allows the designer to use the digitized drawing of an object to define the program for the digitally controlled machines which will manufacture the item, and to program the measuring tools which will inspect the finished items. Using the CAD technique, one designer can do the work of from four to sixteen traditional designers. There is no doubt that CAD is the way of the future and will totally replace traditional drawing boards in the aerospace industry by 1990. As it relates to the ergonomics design problem, CAD provides assistance by providing three-dimensional views of objects and assemblies, so that the CAD designer can better visualize access problems.

Despite the great capability of CAD in making the process more efficient, there are also many problems created by this technique which tend to increase the difficulty of the design

task. The environment of the CAD facility promotes work output and efficiency, but not thought and consideration. The CAD system is a very expensive workplace and designers must schedule time on the CAD system. Two and three shift utilization of CAD facilities is not uncommon. This situation does not promote long periods of contemplation such as designers traditionally have done while leaning on their drawing board. Also, a designer would rarely leave a CAD display running to go back to a desk to fetch a maintainability design reference manual. Rather the designer would make a note to look it up later and perhaps correct the problem at tomorrow's session. So, while the designer has a new tool of unprecedented power and capability, the designer is pressed by that same power to avoid the pauses associated with consideration. To overcome this problem, the CAD designer needs aids such as the Crew Chief Model to be provided by the CAD itself to assist with some of the more complex design issues.

PROBLEM

Approximately 35 percent of the lifetime cost of military systems is spent for maintenance. Because this is such a significant portion of the equipment related expenditures, every effort should be made to minimize that cost. Some maintenance costs are unavoidable. When a system breaks down, it must be repaired and restored to service. Experience shows that part of the time and effort required to repair a system is caused by a failure of the designer to adequately consider its maintenance. There are specialists employed by aerospace firms whose job it is to see that maintainability is considered in a design, but by the time a system is well enough defined that a maintainability engineer can identify problems, changes for the sake of efficient maintenance are often not feasible. If it cannot be proven that a particular maintenance activity is actually impossible, recommended changes are not made. And for the next twenty years the military maintenance technician will spend hours making a repair which could have been completed in minutes if accessibility to the site had been slightly improved.

Many are surprised to learn that simple problems of this type repeat themselves in modern design. Why are the lessons learned not being incorporated into the design process? The designer does not intentionally create a poor design, nor is the designer incompetent. There are a variety of reasons why designers are not designing for maintainability - some avoidable, and some not.

Among the unavoidable reasons for design-induced maintenance problems are the following:

- (1) Performance goals and characteristics have precedence over maintainability problems.
- (2) Program managers are typically faced with cost overruns and elect to pass on maintainability problems to

logistics to endure or correct as they choose.

- (3) The reliability of components sometimes turns out to be less than predicted at the time of the original design.

As a result, a presumably low-failure component is located in an inaccessible place. When the component fails frequently, the entire system may have to be disassembled repeatedly to get to the failed component.

Among the avoidable design-induced maintainability problems are the following:

- (1) Lack of feedback to the designer of previous maintainability problems.
- (2) Lack of three-dimensional representations of the assemblies so that the designer can visualize and analyze accessibility for maintenance tasks.
- (3) The designer's lack of experience with ergonomics problems, statistics, and combining factors.
- (4) Lack of applicable ergonomics data in a format the designer can use and understand.

These avoidable problems are the target of the Crew Chief Model.

BACKGROUND

Before describing Crew Chief, a few words should be said about his predecessor, COMBIMAN. This COMPUTERIZED Biomechanical MAN model simulates physical characteristics of an aircraft crew member in a real or conceptual aircraft or other seated workplace. The workplace itself is a digital representation of any seated workplace the designer cares to create. Working at a CRT display the designer can define the man-model by selecting a few key parameters and bring it into the crew station to perform human factors analyses of the design. The model can simulate variable body size, variable restraints (shoulder harness, lap belts, etc.), as well as crew member sight and reach capabilities. The model of the crew member and crew station are three dimensional, so that the designer can rotate the displayed image to see it from any angle. A zoom feature allows the designer to take a closer look at certain portions of the crew station to evaluate clearances and smaller details of controls and displays.

The heart of the COMBIMAN model is its ability to simulate the variability of human body size and proportions. The designer does not need to understand anthropometry or ergonomics to use the model. Algorithms within the model define the body size and proportions after the designer selects the critical dimension to be evaluated: sitting height, eye height, arm length, or leg length depending on the aspect of the design to be evaluated (head clearance, displays, hand control operability, or foot control operability). Having selected one of these, together with the desired percentile and population, the program provides a human model with the most probable size and proportions of all body segments. The designer has several populations to choose from; these include Air Force male pilots, Air Force female pilots, Air Force women, Army male pilots, Army women, or Navy male pilots, as well as a number of other populations. AAMRL has

anthropometric measures in its computerized data bank representing every available military survey and many civilian surveys as well. Having access to these data permits the development of the algorithms regression equations and the statistical descriptions to generate the human model.

AAMRL has also performed extensive research into the strength capabilities for operating aircraft controls and other controls found in seated workplaces. The strength characteristics are being incorporated into the COMBIMAN model. Extensive research into reach capability has been performed to define the effects of body size and the restrictions of clothing and harnessing on mobility and the ability to reach controls in the seated workplace. These data are also being converted into algorithms for the COMBIMAN.

Perhaps, the most valuable feature of the COMBIMAN is the ability to make hard-copy plots of the human model, the workplace, and the workplace as seen by the human model. The plots, to any desired scale, constitute a permanent record of an interactive analysis session at the CRT display station.

While COMBIMAN is an excellent tool for evaluating the physical accommodation of the crew member in a seated workplace, the COMBIMAN model would not be efficient in the design evaluation of maintenance activities because (1) the seated human model could represent only a small portion of the postures found in the maintenance activities and (2) the maintenance workplace is much larger and more complex than a crewstation, and it would not be feasible to convert into a second format for analysis purposes.

NEW MODEL

Crew Chief is a computer-aided design model of an aircraft maintenance technician currently under development. The crew chief model will give the designer using CAD the ability to simulate maintenance and other related human operator interactions with a system on the computer-aided drawing board. It will be able to represent the correct body size and proportions of the maintenance technician, the encumbrance of clothing and personal protective equipment (PPE), mobility limitations for simulating working postures, physical access for reaching into confined areas (with hands, tools, and objects), visual access (seeing around obstructions), and strength capability (for using hand tools and manual materials handling tasks). In summary, the model will provide a graphic representation of the physical characteristics of the maintenance technician.

The Crew Chief model user will be able to select from a range of useful body sizes and proportions for both male and female technicians. Size is important for several reasons. First, the designer tends to lose track of the scale of the hardware being designed on a CAD system. If the designer can superimpose an accurately defined Crew Chief model on the design, the perception of scale is instantly restored. Concern about the compatibility of the physical size of the maintenance technician with regard to the design, usually centers on individuals at the small and large ends of the size range. The current human factors military standards require that systems and equipment be designed to accommodate a range of users from the 5th percentile female to the 95th percentile male. Where safety or life-critical aspects are involved, the required range spans the 1st to 99th percentiles. So, if the designer suspects that a small female cannot reach high enough to accomplish a certain task, he or she can call up a model of a 5th percentile female maintenance

technician in the relevant posture and immediately see if she can perform the reach. Alternatively, a maintenance technician can be too large to accomplish a certain task. These cases usually involve access, but can likewise be evaluated by calling up a model of a large male maintenance technician and simulating the task.

The encumbrance of clothing and PPE is a very important limitation for the maintenance technician. A great deal of aircraft maintenance is performed outdoors on the flightline where the amount of clothing worn is dictated by the weather. If the maintenance technician must wear bulky clothing for protection against weather or against harmful substances (chemicals, fuels, liquid oxygen, etc.), the effective body size of the crew chief is increased and access problems arise where none existed before. While there are standards to design accesses for accommodation of bulky clothing, they cover only a few common situations. Much more research must be done before the Crew Chief model fully simulates the reduced mobility and access of bulky clothing.

With or without encumbering clothing, access in confined spaces is the single largest problem for the maintenance technician. More time is lost due to inadequate access to the objects being maintained than for any other reasons. The root of this problem lies in the need to keep the exterior volume of an aircraft as small as possible, while providing for the largest possible interior volume. As a result, the equipment which must be maintained is packed as closely together as possible, which, of course, limits accessibility for maintenance purposes. The airframe designer does not want large and numerous access openings in the design, because these reduce the structural strength of the design. This will be an even greater problem in the future with the increasing use of composite materials. So we see that the same goals that make an aircraft system efficient and sound also make it difficult to maintain. With this context,

however, the designer can do things to ease the accessibility problems if the designer is aware of them. Thus, the value of the Crew Chief model.

The designer can call up the model and simulate the accessibility of a box, fastener, or connector, for example. If there is an accessibility problem, the designer can deal with it then, before any decisions have been finalized. Access is a complex problem involving not only the limbs of the maintenance technician, but also the tools the technician must use and the room to manipulate the tool. It is not enough to be able to place a wrench on the head of a bolt if there is insufficient space to turn the wrench, or if there is insufficient mobility or strength in the maintenance technician's arm (in an awkward position) to turn the wrench. The maintenance technician must also manipulate objects in and out of confined places. In many cases, the task requires that the maintenance technician insert an object into an opening just large enough to accommodate it, raise it into a higher position, and then hold it there with one hand, while bolting it into place with the other hand.

Visual access is another problem. The maintenance technician may have to see the head of a screw in order to insert a screwdriver and remove the screw. This task requires simultaneous visual and physical access for the technician must position the screwdriver and see the screw head simultaneously. The designer must be able to see the task from the maintenance technician's viewpoint to determine if it can be accomplished. It may be discovered that even though the screw head is in plain sight of the access opening, when the maintenance technician's arm is inserted through the opening the arm fills the opening to the extent that visual access is obscured. The Crew Chief model will provide the designer with the capability to accomplish this accessibility evaluation so it can immediately be determined if a problem exists, and corrected if it does. Problems of this type usually are not discovered until a detailed hardware mock-up has

been constructed and the design has matured to the extent that "unnecessary" changes are no longer feasible. Regardless of the cost or time required, maintenance considerations are generally considered to be of low priority unless the particular task cannot be performed at all. The Crew Chief model will reduce the incidence of such problems by allowing the designer to perform maintainability analyses and correct design-related defects on the spot.

Posture is an important consideration in maintenance. Typical postures include standing, sitting, kneeling, stooping, squatting, bending, and lying on the stomach, back and side. The full range of activities are performed in each of these postures. Some of these postures reduce the mobility of the limbs and some limit the available strength to perform the task. For example, a maintenance technician may be fully capable of lifting an object while in an upright posture, but unable to lift the same weight while lying on his or her side. The lack of a comprehensive set of posture-related weight lift standards leads the designer to assume the maintenance technician has capabilities greater than he or she really has. The Air Force now has a large number of women working as maintenance technicians. These women are, on the average, less strong than the male technicians. The designer can try to accommodate all or most maintenance technicians, if just given the information on the human capabilities and limitations that must be accommodated. The Crew Chief model aims to achieve exactly that by providing a realistic simulation of a maintenance technician which the designer can effectively use for maintainability analyses.

APPROACH

There are three elements to the development of a computer-aided design model of an aircraft maintenance technician:

1. Definition of the computer graphics system interface.
2. Ergonomics data describing the physical capabilities of the maintenance technician.
3. The development of the computer model which will be the Crew Chief model.

The single most important decision in the program development is the definition and selection of the computer system on which the finished model is to operate. We want to learn from our previous efforts in developing the COMBIMAN model and avoid some of the limitations of that model. COMBIMAN required the user to digitize the crew station in a format unique to the COMBIMAN model. This approach is not feasible in the Crew Chief model because the data base is usually very large, and can include the entire aircraft. The Crew Chief model must be able to use the data base which the designer(s) has already developed at great cost and effort. The Crew Chief model must then interface to the designer's CAD system or the data base created on that CAD system. With this approach, the Crew Chief model will be software dependent but not hardware dependent, as was the COMBIMAN model. The software dependency is by far the lesser of the two because the major CAD programs operate on more than one graphics system. There are literally hundreds of firms providing CAD systems and software. (One recent forecaster said that if the trend continues, there will soon be as many CAD companies as there are CAD users.)

Our problems were somewhat simplified when we learned that the major aerospace firms use a small number of the major CAD

systems for mechanical and structural design. It further appears that by interfacing the Crew Chief model to as few as three CAD programs, the model will be useful and accessible to every major aerospace firm. Furthermore, because of the commonality of function among CAD systems, after the first conversion has been completed, conversions to additional CAD programs should not be difficult. Because these few CAD systems are popular in the mechanical design community, industry in general should have widespread access to the Crew Chief model, although the Air Force is developing the model for its own application. This approach allows the Crew Chief model to automatically gain access to new computer systems as the CAD software itself is expanded to new computer systems.

The largest single effort in the development of the Crew Chief model will be invested in the research needed to gather supplementary ergonomics data. One cannot make a model without relevant data. Many previous ergonomics models have failed to achieve their goals simply because the model developers assumed that all the required data was available. There is a wealth of data to be sure, but most of it is not suitable for the development of a general purpose model. Most data are limited in the range of variables, the sample size, the applicability of the population from which the sample was drawn, and the data itself, which are usually available only as statistical descriptions of the original data. Realizing this, developers of the Crew Chief model have programmed a large portion of their resources to gather ergonomics data. AAMRL has recently gathered data regarding manual materials handling for the standing posture, limitations of mobility due to harnessing in the seated posture, and maximum strength capability for operating manual controls for the seated posture. Additional data to support the development of a crew chief model will include the following:

1. Mobility requirements of handtools
2. Strength capabilities for using handtools

3. Manual materials handling capabilities in maintenance-related postures
4. Mobility when reaching around obstructions
5. Visibility limits of protective masks
6. Mobility due to bulky clothing

Work activities to be included in the model are: raising and lowering carrying, holding and positioning, reaching, moving, turning, grasping and gripping, inspecting, pushing and pulling. The handtools to be modeled include screwdrivers, socket wrenches, pliers, hammers, chisels, saws, wrenches (spanners), powered handtools (drills, riveters, etc.), files, and scrapers. The great quantity of data yet to be gathered would be prohibitive were it not for the computerized data collection systems and special purpose measuring transducers constructed for previous studies.

The development of the software will require detailed surveys of potential users to determine which functions and capabilities will be useful to the designer and how these functions are to be implemented so that the designer can use them without extensive training. During the validation phase of the model development, the model will be used by designers to determine if improvements are required to make the program useful to them. Another test in the validation phase will be the identification of known problems. Working with an old problem on an existing aircraft, a designer unfamiliar with the problem will use the Crew Chief model to try to discover the problem and its possible solution.

This development program will have by-products which will support the equipment design standards and provide a research data base describing the ergonomics attributes of the maintenance technician.

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