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MULTI-MODAL VIRTUAL ENVIRONMENT RESEARCH AT ARMSTRONG LABORATORY

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INTRODUCTION

One mission of the Paul M. Fitts Human Engineering Division is to improve the user interface for complex systems through user-centered exploratory development and research activities. In support of this goal, many current projects attempt to advance and exploit user-interface concepts made possible by so-called Virtual Reality (VR) technologies. Virtual environments may be used as a general purpose interface medium, an alternative display/control method, a data visualization and analysis tool, or a graphically based performance assessment tool. All of these uses of VR may be exploited in the development of new user-interface prototypes and supporting design tools. As a result, the Division has several active R&D efforts in these areas, as they pertain to user-machine interfaces.

The purpose of this presentation is to provide a brief overview of the range of R&D projects within the Division that involve VR technology. For the purpose of discussion, research projects are clustered into four categories:

- Prototype Interface Hardware/Software Development
- Integrated Interface Concept Development
- Interface Design and Evaluation Tool Development
- User and Mission Performance Evaluation Tool Development.

PROTOTYPE INTERFACE HARDWARE SOFTWARE DEVELOPMENT:
HELMET-MOUNTED DISPLAY SYSTEMS

The Division has been a pioneer in the development of visually coupled systems (VCS) technology which centers around the design of helmet-mounted display (HMD) devices. Beginning in 1966, a line of HMDs has been produced, ranging from small field-of-view (FOV) monocular systems to wide FOV stereoscopic ones. R&D activities address the development of high luminance miniature CRTs, relay optical systems, head gear, militarized image generators, trackers, and all technological and engineering aspects required to produce fully integrated systems for use in airborne platforms. The technical advancements made in this work over the years have provided the foundation from which the virtual reality industry has emerged. For example, the need for a method to reliably track head position without restricting operator movement or emergency egress stimulated the development of the magnetic tracking concept now used in many VR systems. The first successful implementation of such a device was sponsored by the Division and achieved in collaboration with our staff.

Current VCS development efforts are concentrated on:

- standardized, plug compatible VCS systems for integration into military platforms
- color CRT that can operate in high (luminance) ambient environments
- system and component performance measurement methods and standards
- psychophysical performance assessment .

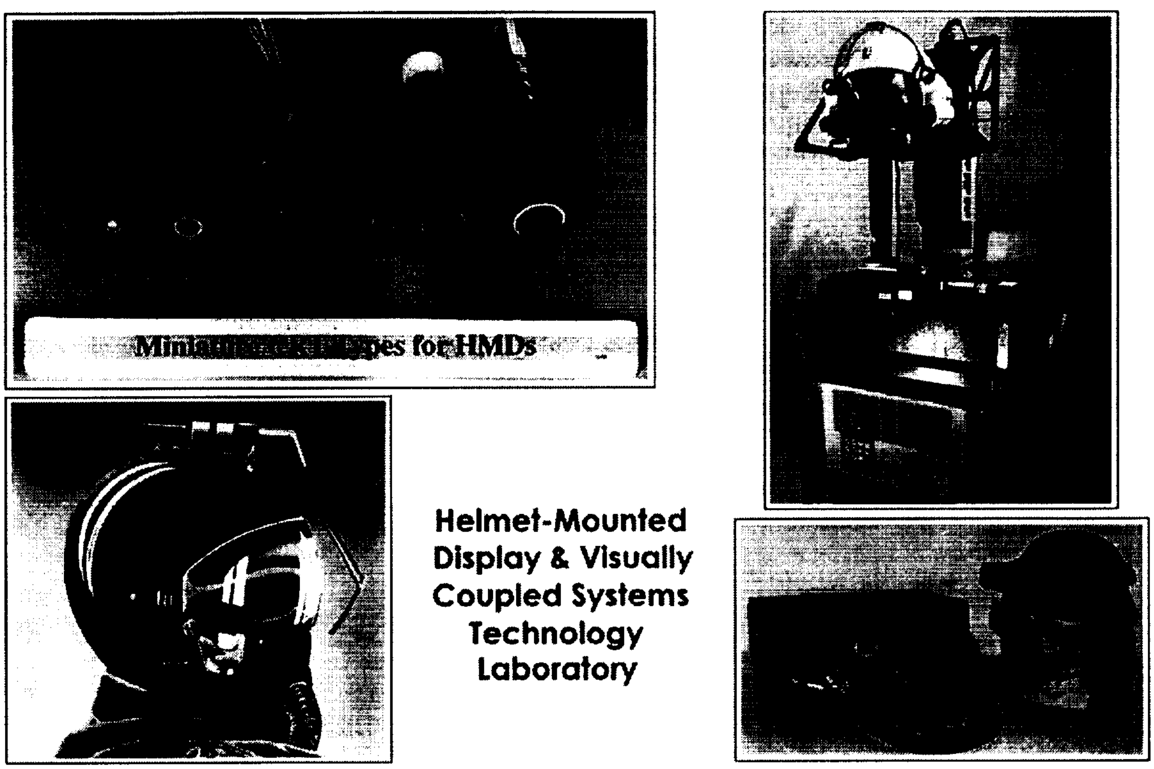


Figure 1

VCS CONTROL/DISPLAY CONCEPTS

In addition to developing the hardware and software technology infrastructure for the VCS system, we also develop advanced interface concepts around the technology. One example is the design of an interface device that supports head aiming (to select and track targets) and head-referenced instrument displays (flight and weapons) that are always available to the operator. This work involves the design of display formats, symbology, and control methods. It also includes a wide range of human performance research to insure compatibility of the concept to both the user and the expected real world task conditions. Several concepts have been developed and evaluated in simulated and actual flight tests.

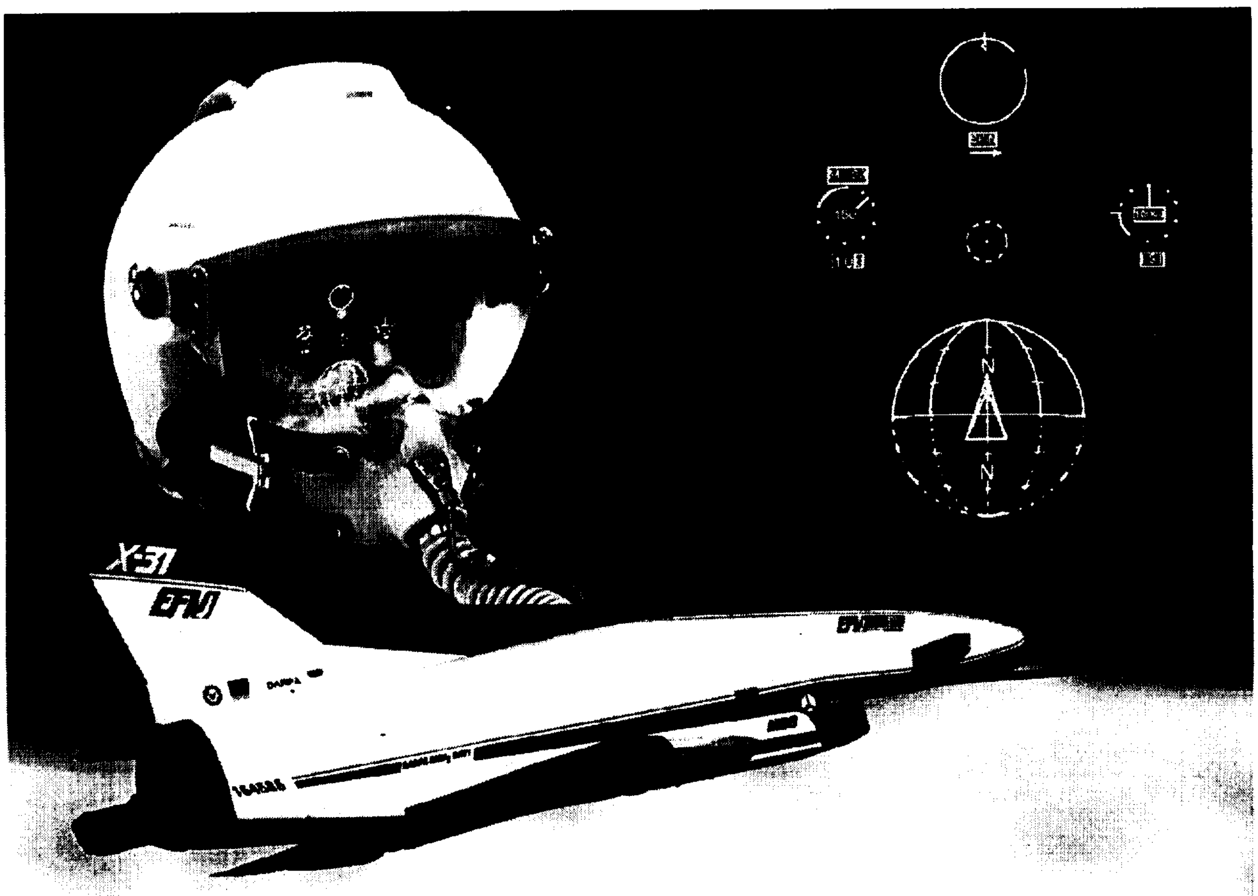


Figure 2

THREE-DIMENSIONAL AUDIO DISPLAYS

Similar to the VCS R&D efforts, Armstrong Laboratory has also been a leader in the development of 3-D audio systems, including hardware concepts, psychophysical analysis, application systems, and flight testing. Our first localized display was designed and fabricated in-house in the late 1980's. New systems compatible with operational avionics systems are being developed and evaluated.

The geodesic dome shown below is housed in an anechoic chamber located in the laboratory. This is the only available facility in the country that can support the full range of technical studies needed to advance this technology.

A study was recently completed that addressed target acquisition performance with and without the aid of a 3-D sound localizer. A summary of the results of that study is shown in the next two charts. Each graph depicts target search times as color zones (shown here as shapes of gray) over the search space defined in terms of azimuth and elevation angle. The first graph displays times when search was completed visually without the aid of localized sound cueing. The next graph shows the search time map when localize sound cueing was used. The improvement with sound cueing is obvious from visual inspection of the graphs.

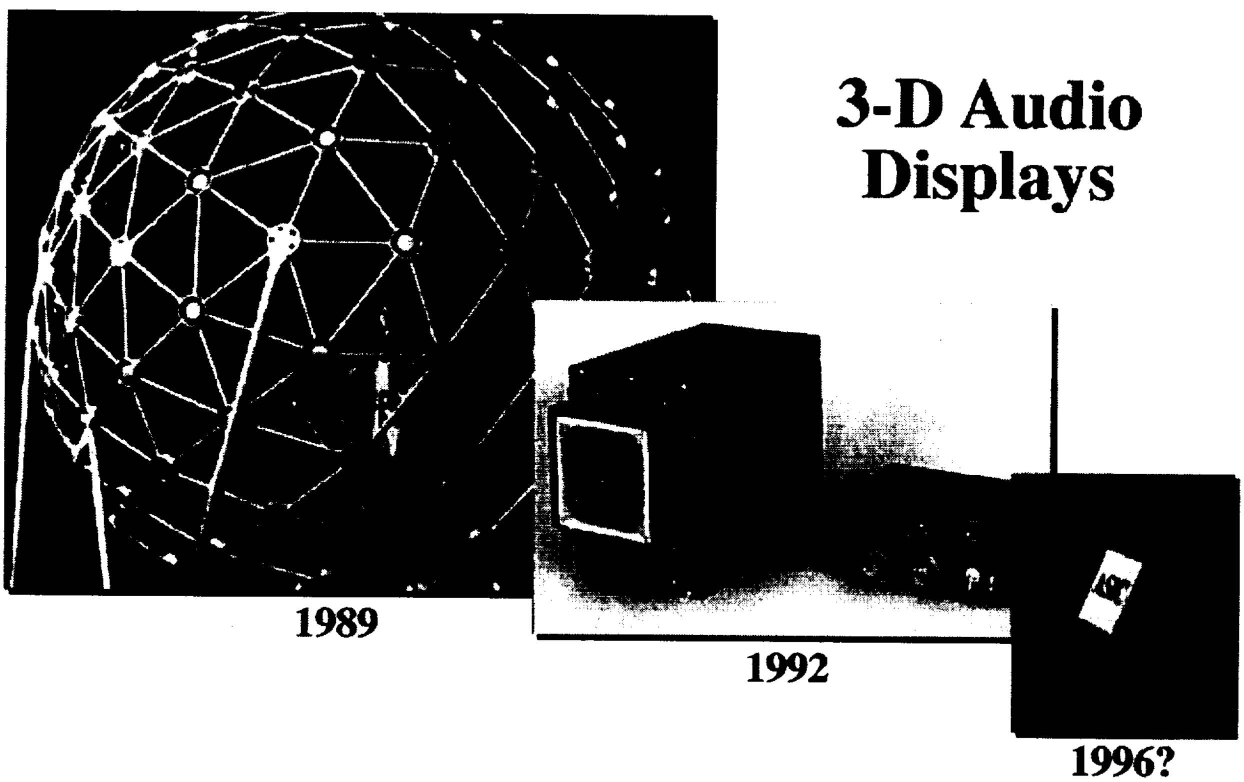


Figure 3

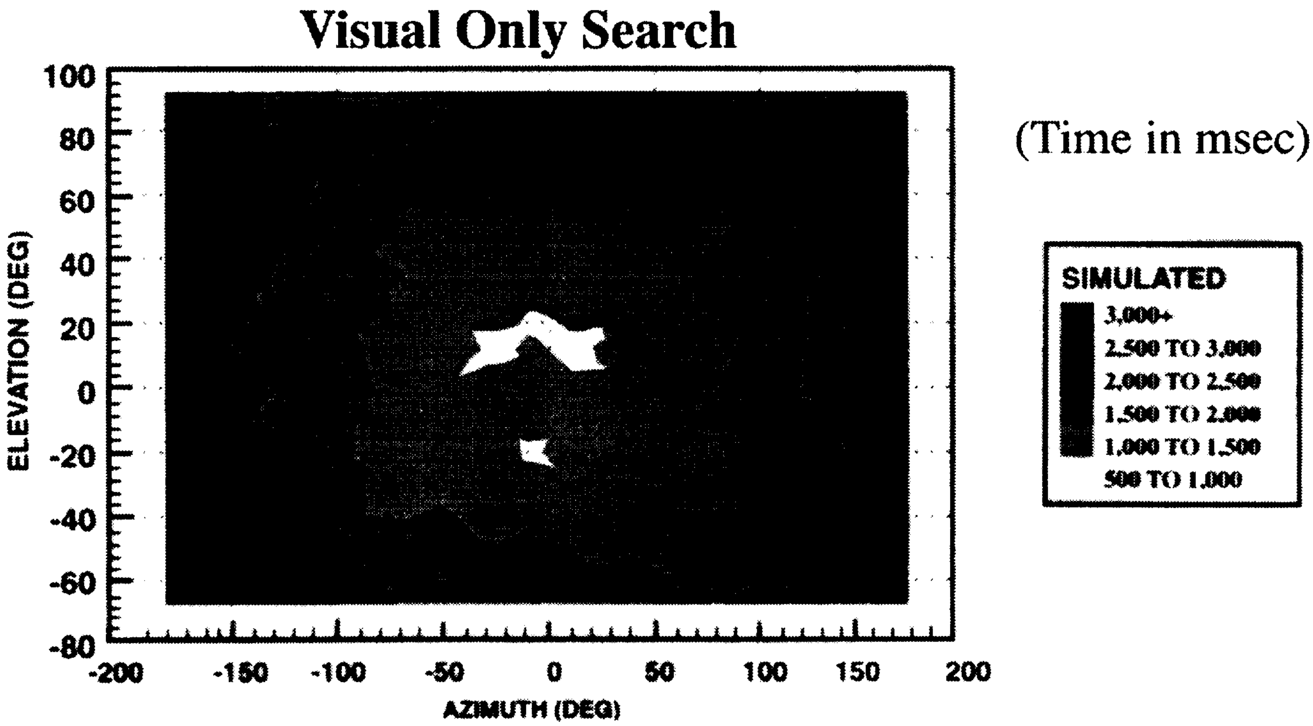


Figure 4

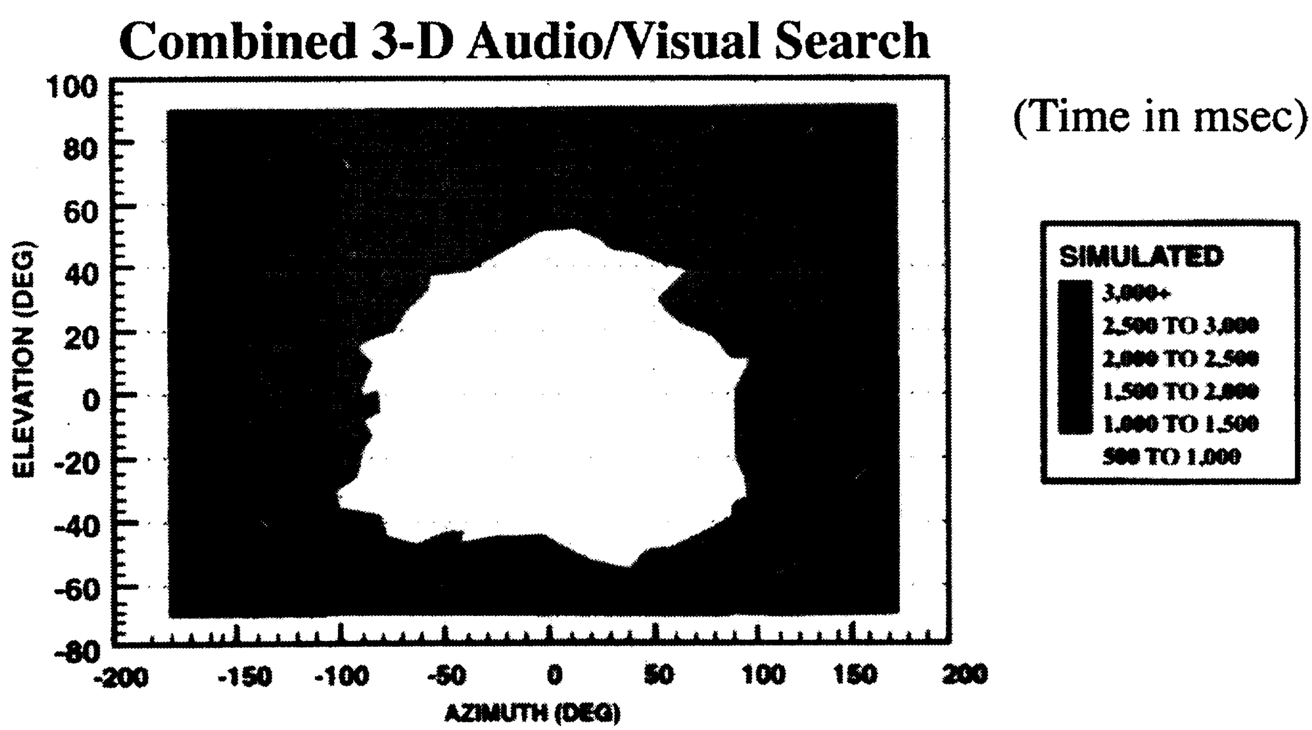


Figure 5

ALTERNATIVE CONTROL TECHNOLOGIES

Several projects in the Division are involved with developing and exploring the feasibility of novel interface methods as alternative I/O devices for use in a wide variety of application domains. These include the development of a gesture recognition system that combines a data glove which senses figure postures and gestures (coupled with a position/orientation tracker) with a neural net classifier. A demonstration system is being constructed that recognizes American sign language. The device may be used as an input mechanism to a system/computer or as a means to support nonverbal communication between people. The Veterans Administration has expressed interest in this work as an assistive technology.

A facial sensor testbed has been developed to determine if continuous speech recognition accuracy can be improved by "reading" facial expressions during speech. The basic idea is to use facial patterns as a basis for disambiguating classification uncertainties found with current hidden Markov model speech recognition systems.

Perhaps the most unusual alternative control technology under study is called Brain Actuated Control (BAC). As the name suggests, we are exploring ways brain states can be detected and used as a control decision which is then executed by the use of standard servomechanism principles in a closed-loop system. We have demonstrated reliable two-state based brain control, with the operator voluntarily enhancing and suppressing the magnitude of a certain EEG frequency. Continuous control has also been demonstrated through exploitation of a composite voluntarily produced EEG-EMG signal. This is another area where our work has spin-off potential for use with disadvantaged individuals.

Facial Sensor Test Bed **Hand Gesture Recognition**

Figure 6

Brain Actuated Flight Simulator

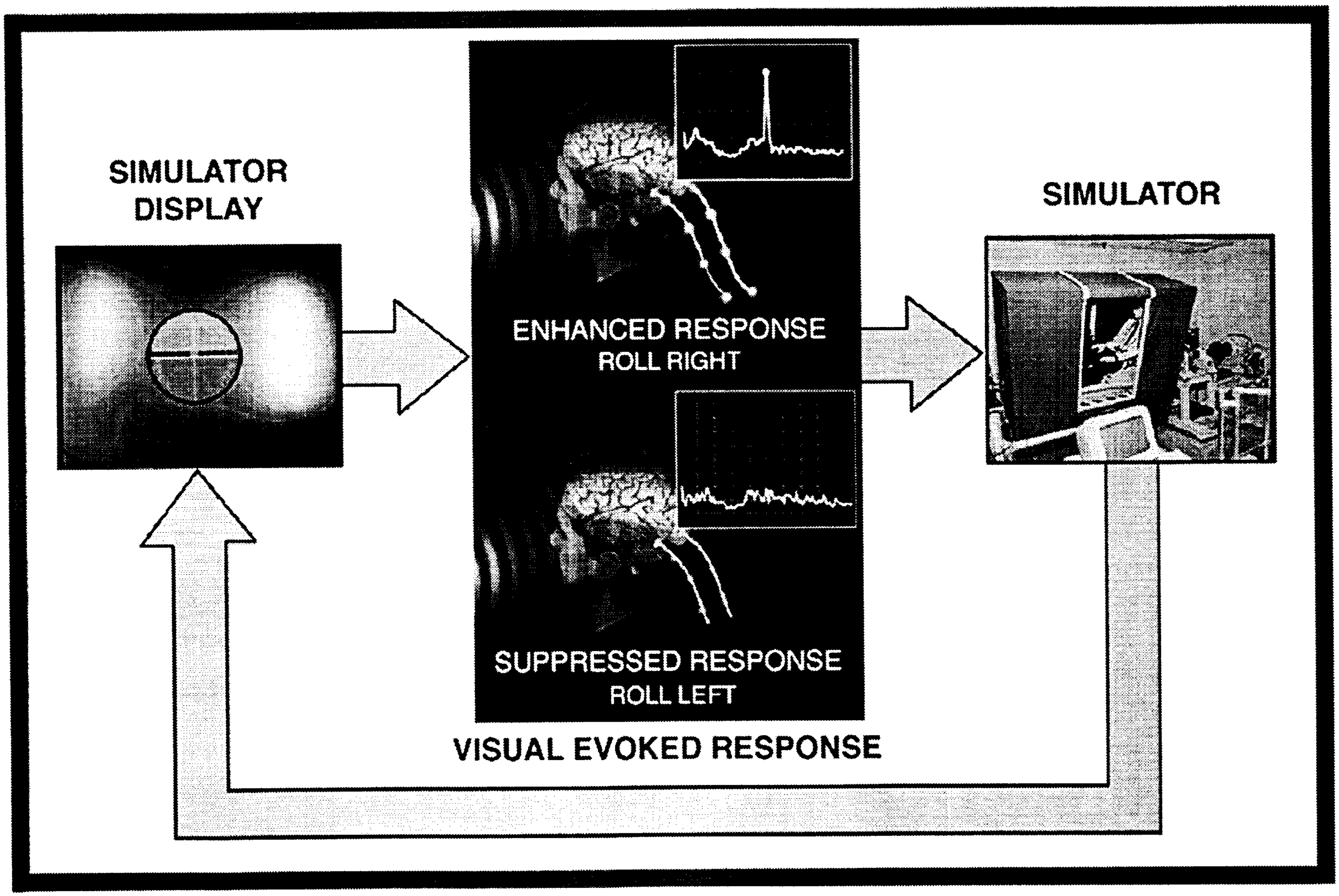


Figure 7

INTEGRATED INTERFACE CONCEPT DEVELOPMENT

Beginning with the Visually Coupled Airborne Simulation System (VCASS), which became operational in the early 1980's, we have had the ability to produce virtual interfaces or virtual cockpit concepts for investigation. This system probably marked the beginning of the new era of VCS technology that has become known as Virtual Reality, Virtual Environment, or Synthetic Environment technology. VCASS provides a 120 degree (horizontal) by 60 degree (vertical) instantaneous FOV in a head-mounted stereoscopic display system. We have coupled it over the years with data gloves, a simple force reflecting device, and 3-D audio to produce various forms of virtual cockpits. Unfortunately, limitations in computer graphics and system time delays have interfered with our ability to adequately assess the value of these innovative interfaces.

We have recently opened a new facility called the Synthesized Immersion Research Environment (SIRE), that provides a full capability immersive VR system. It integrates haptic displays with 3-D sound and VCS technology and also includes a large screen projection system. SIRE supports a wide range of human performance research, including investigations of augmented cockpit concepts which couple VR concepts and alternative control concepts with more conventional panel mounted displays.

INTEGRATED INTERFACE CONCEPT DEVELOPMENT

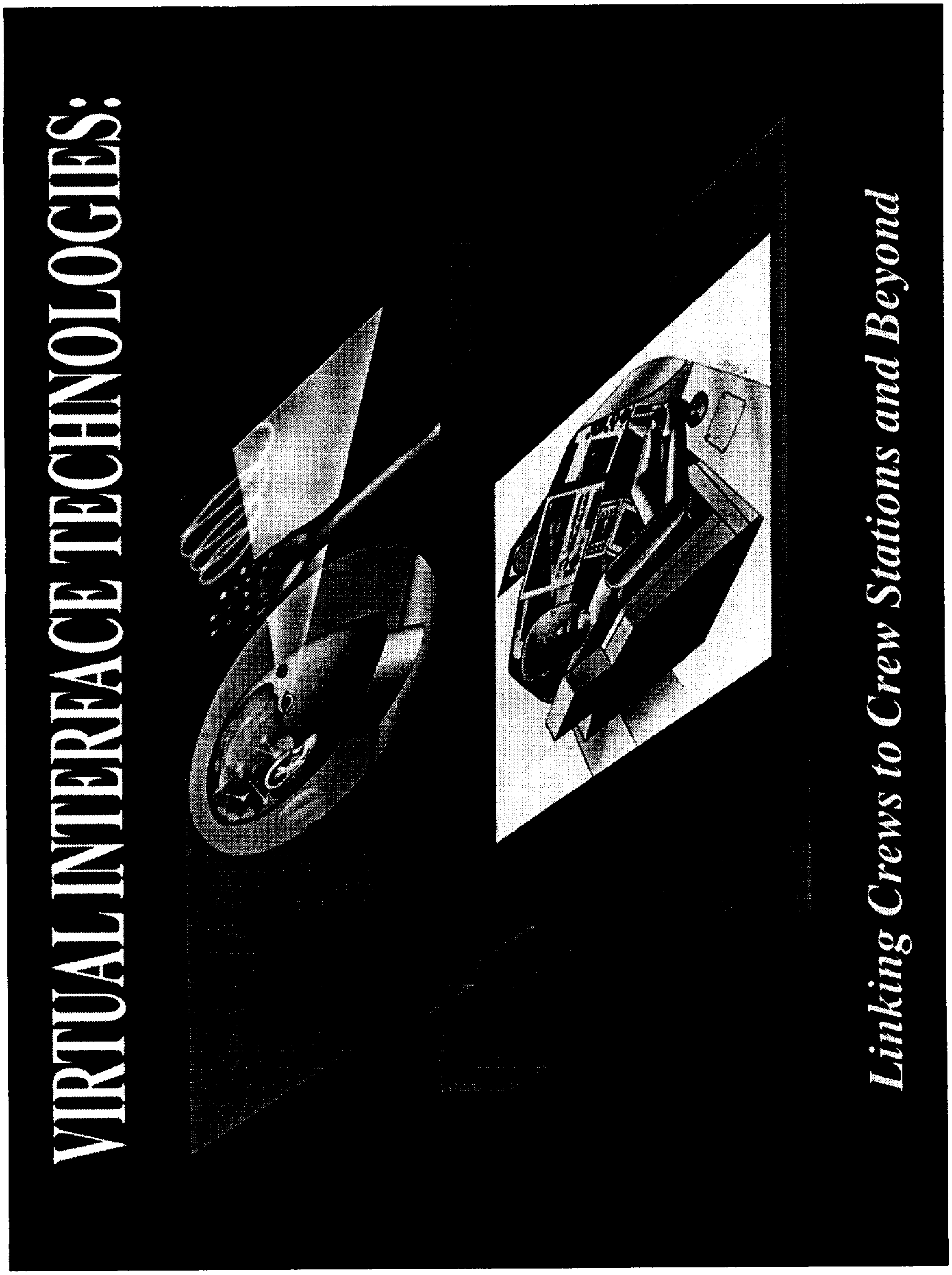


Figure 8

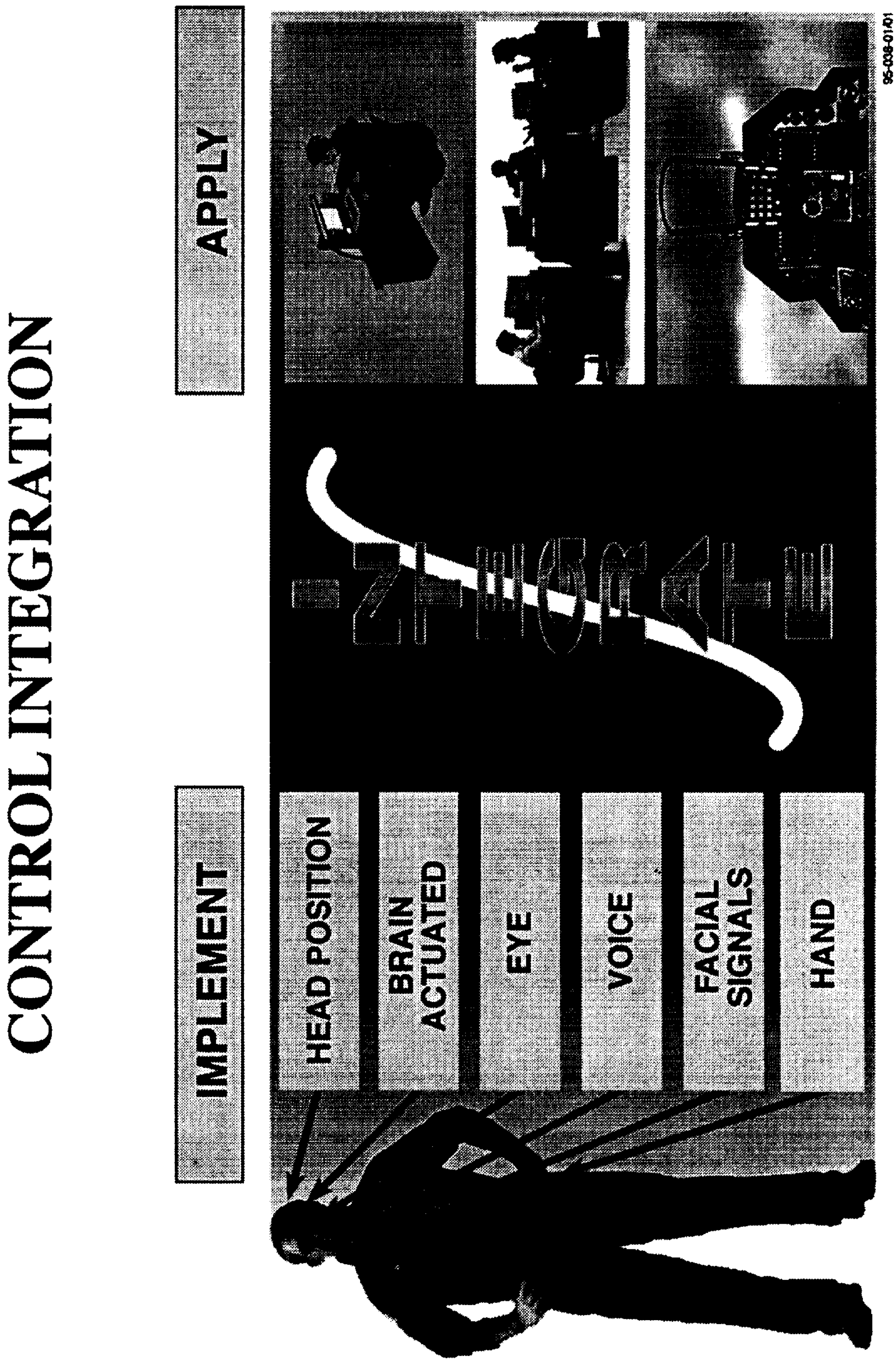

CONTROL INTEGRATION
IMPLEMENT
HEAD POSITION
BRAIN ACTUATED
EYE
VOICE
FACIAL SIGNALS
HAND
INTEGRATE
APPLY

Figure 9

INTEGRATED INTERFACE CONCEPT DEVELOPMENT

Figure 10

INTERFACE DESIGN AND EVALUATION TOOL DEVELOPMENT

Historically, it has often proven difficult to transition user-centered interface ideas and concepts into operational systems. There are many reasons for this breakdown in the development process. Most agree that one reason is the lack of adequate interface design and evaluation tools that fit properly into the systems engineering process used in advanced design of large-scale systems. In an effort to overcome this difficulty, we have been developing tools and concepts to support the design and evaluation process.

One area of research important to this goal is engineering anthropometry. In this area, we perform studies that allow us to develop relevant anthopometric data bases. For example, we assess the ability of different body types (size, strength, etc.) to perform different actions often required in maintenance tasks. Data bases like these have been combined with computer graphics systems to produce interactive visualization and analysis tools for assessing system designs (computer representations). VR has recently been used to allow the designer to assume different body sizes during the analysis.

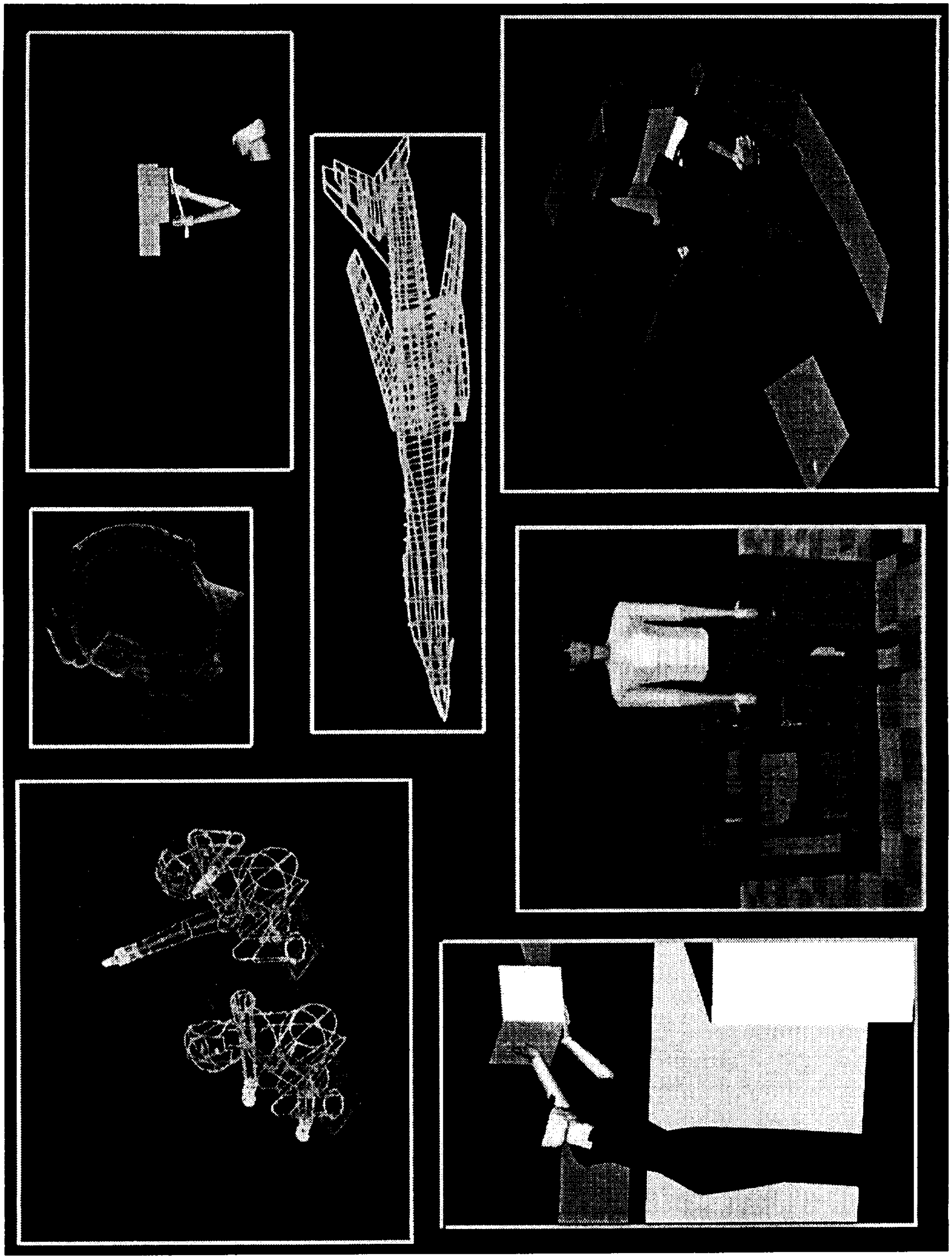


Figure 11

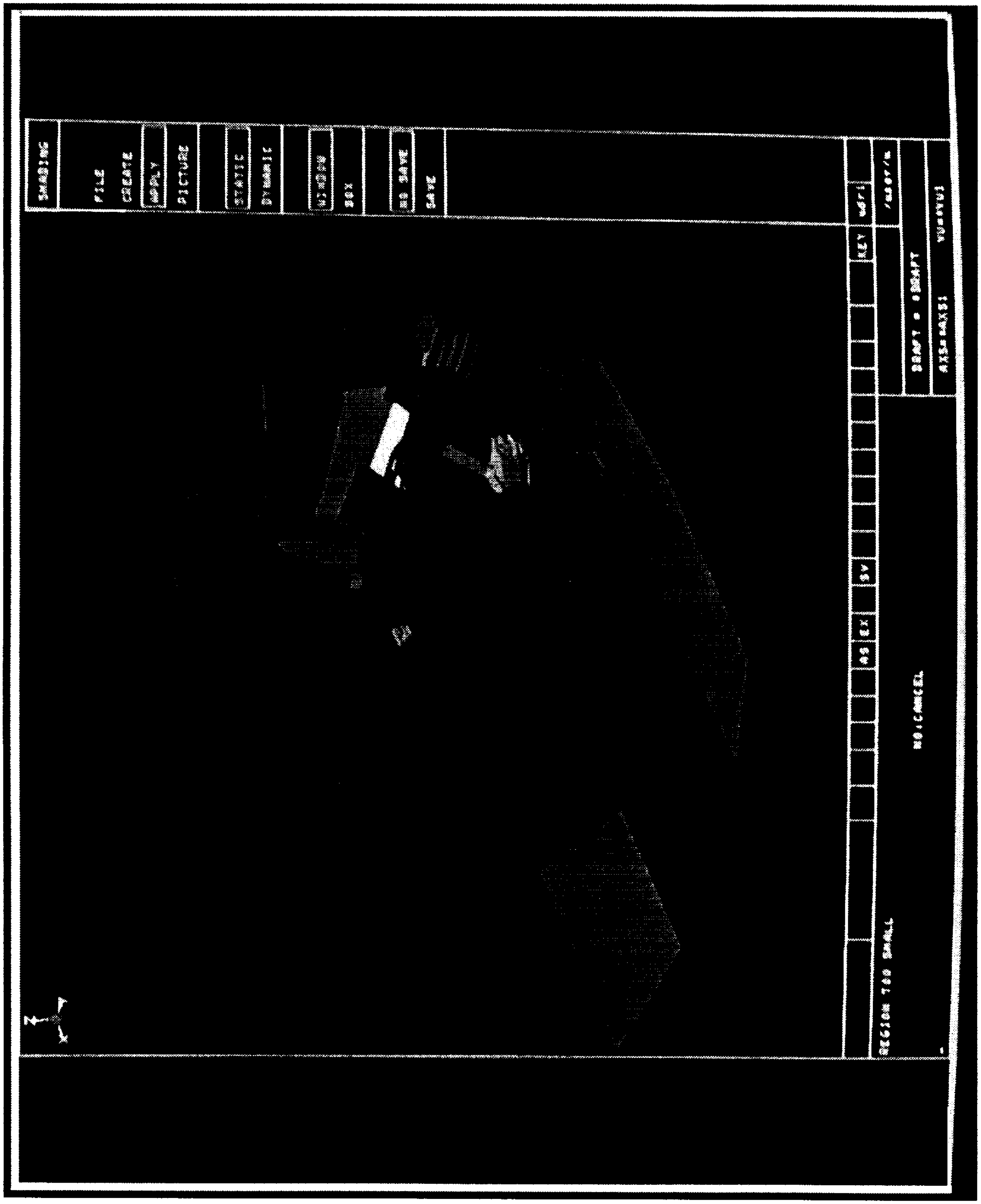

SHADING
FILE
CREATE
APPLY
PICTURE
STATIC
DYNAMIC
BOX
SAVE
KEY

Figure 12

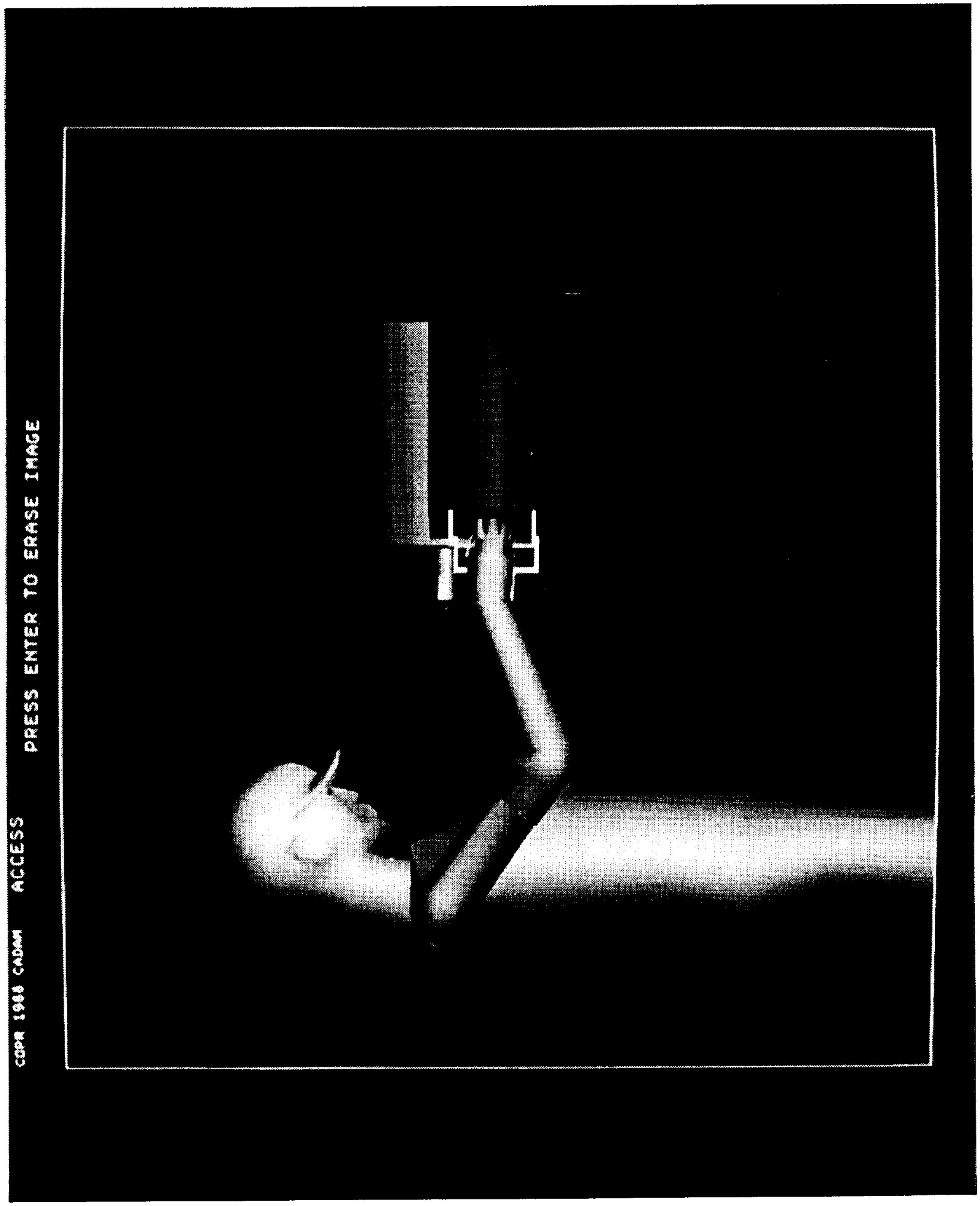


Figure 13

HUMAN CENTERED DESIGN ON THE CAD/CAE PIPELINE

Another effort has concentrated on the development of active information using multi-media technology. The goal is to be able to place human performance data into the CAD/CAE environment used in design. This research has addressed ways to improve access to information, ways to help the designer understand what questions they need to ask, and ways to facilitate opportunistic searches. In addition, we have invested in the production of a new tool called a perception and performance prototyper. This software product allows the designer to transition from equations and graphical presentations and analysis to experiential methods that allow the designer to experience the perceptual and performance consequences of their design decisions.

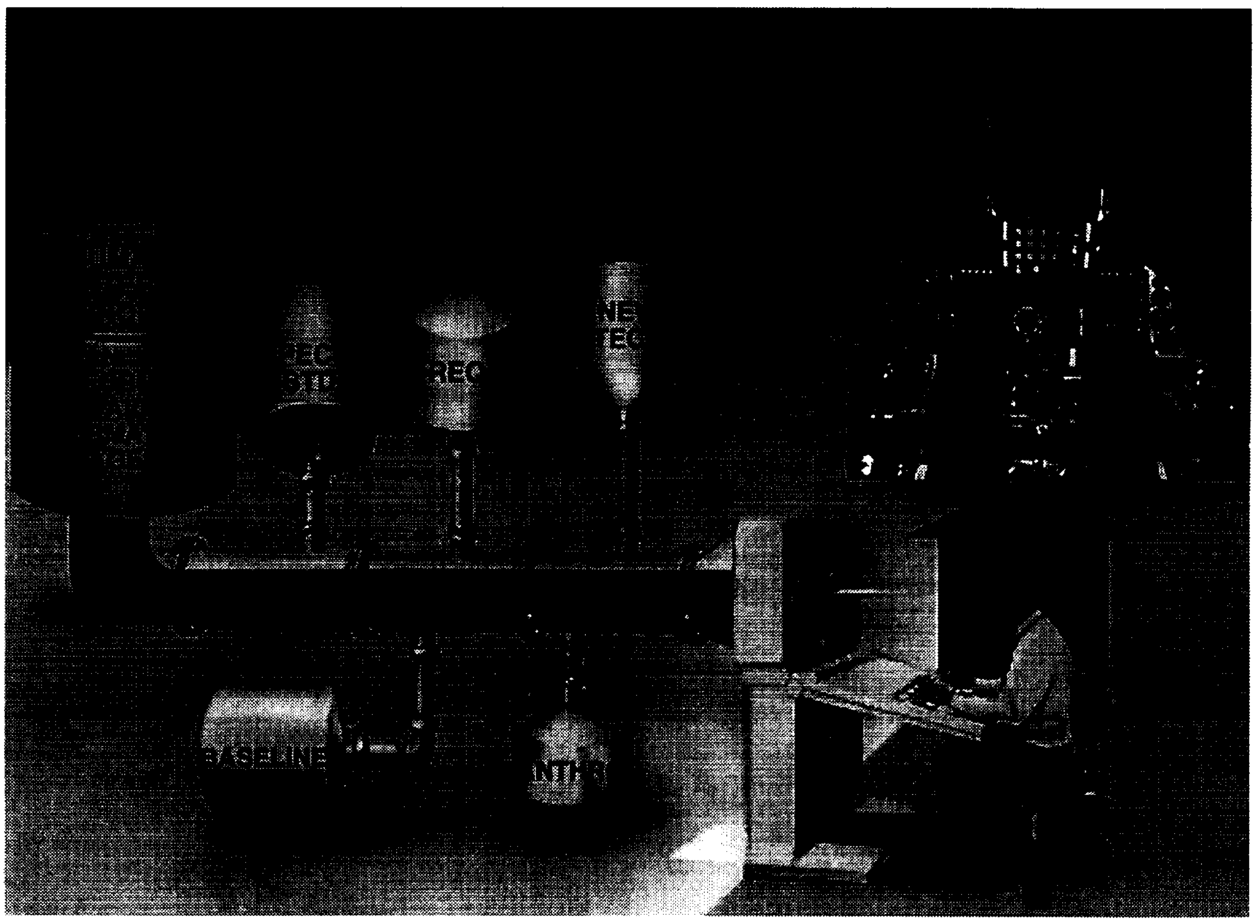


Figure 14

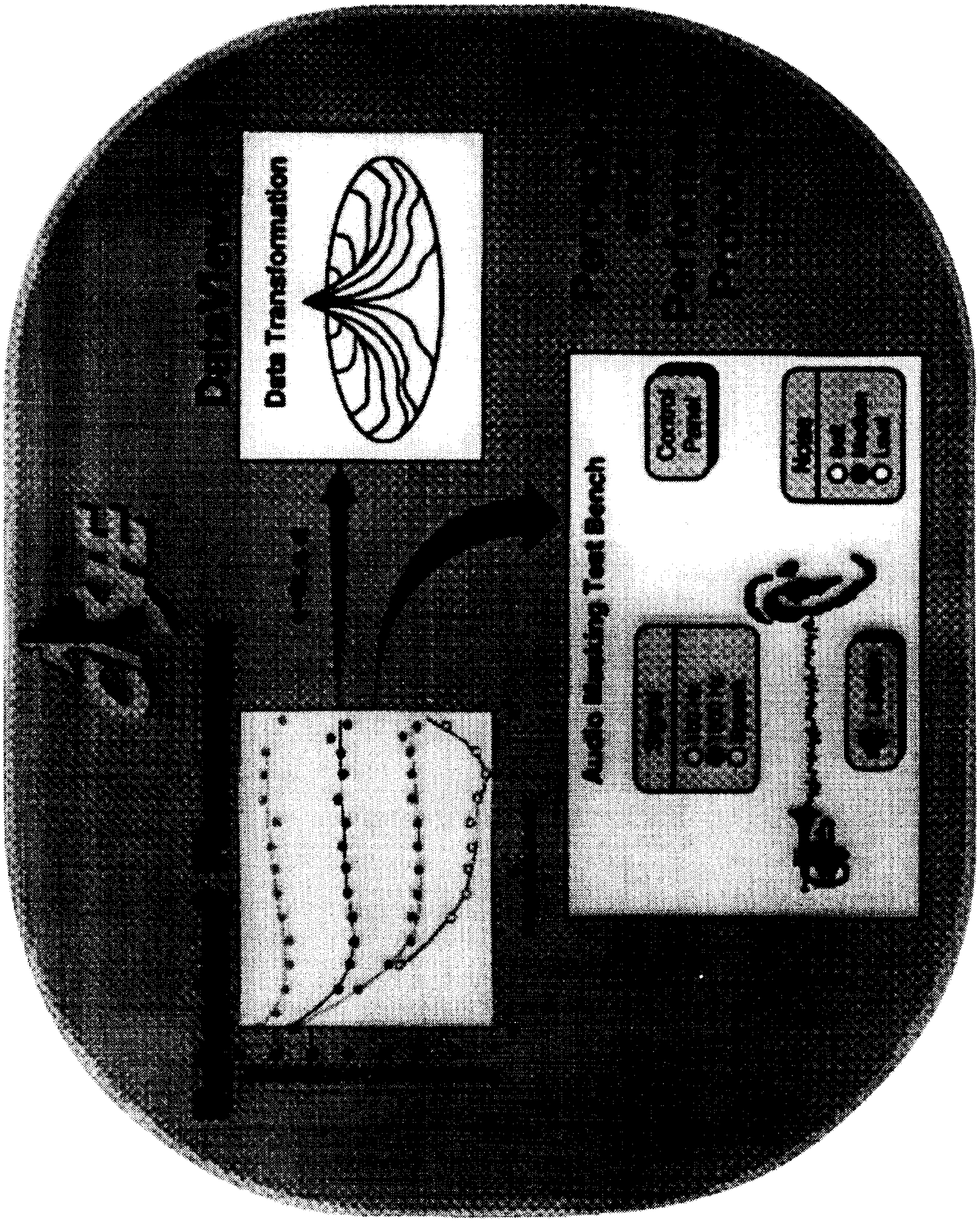

Data Transformation
Audio Masking Test Bench
Control Panel
Noise

Figure 15

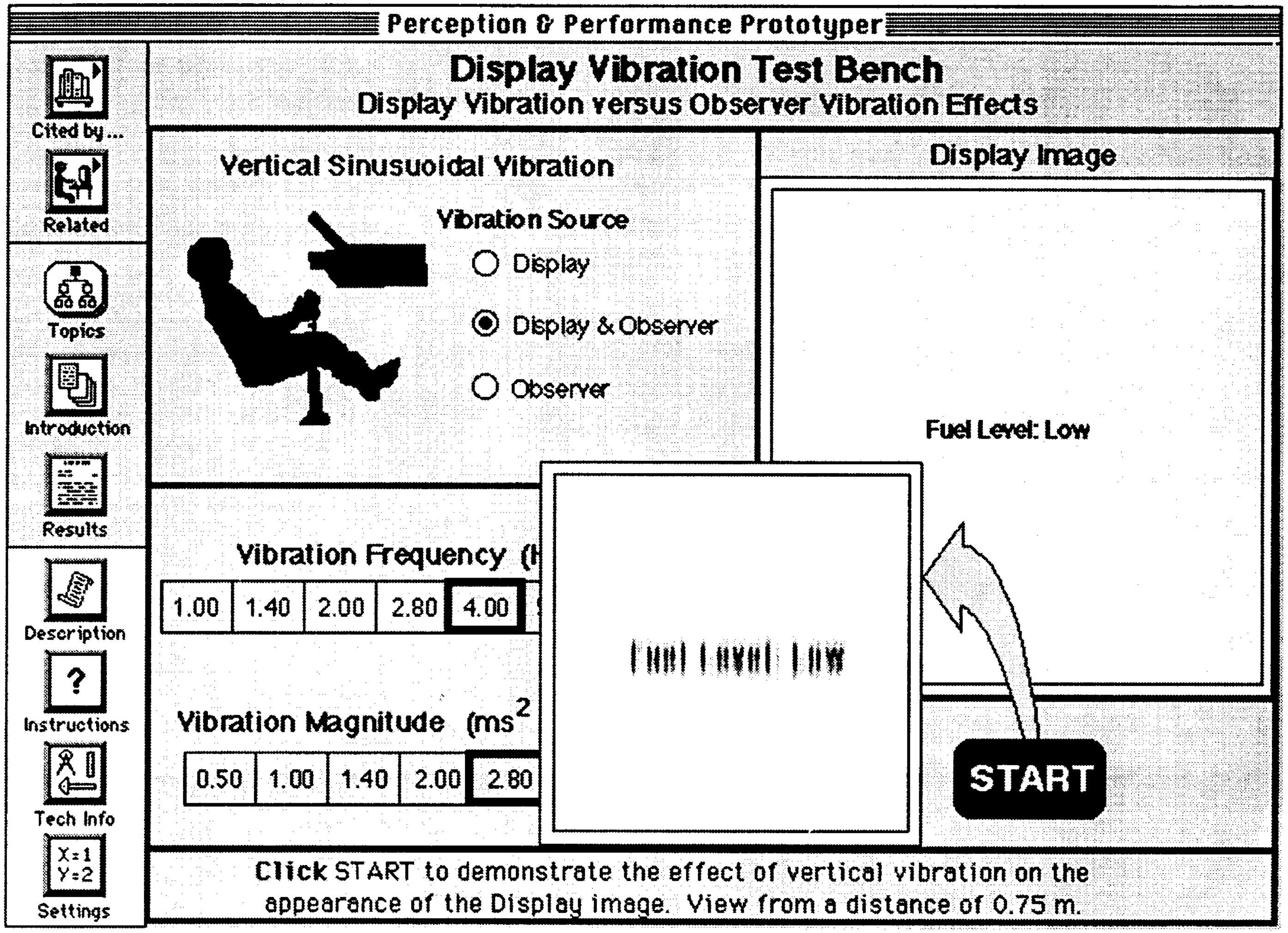

Perception & Performance Prototyper
Display Vibration Test Bench
Display Vibration versus Observer Vibration Effects
Cited by ...
Related
Topics
Introduction
Results
Description
Instructions
Tech Info
Settings
Vertical Sinusuoidal Vibration
Vibration Source
Display
Display & Observer
Observer
Display Image
Fuel Level: Low
Vibration Frequency
1.00 1.40 2.00 2.80 4.00
Vibration Magnitude (ms2
0.50 1.00 1.40 2.00 2.80
START
Click START to demonstrate the effect of vertical vibration on the appearance of the Display image. View from a distance of 0.75 m.

Figure 16

USER PERFORMANCE AND VIRTUAL SYSTEMS

It is clear that the potential applications for Virtual Technology are enormous. DoD, for example, is moving ahead with the use of this technology as both a tool and an end product in the development of advanced systems. Distributive Interactive Simulation (DIS) is being considered as a test bed to investigate advanced concepts under operational like conditions. Some of these systems may be virtual; others physical. In this and all other work involving VR technology, we suffer today from a lack of adequate understanding of how user performance interacts with properties of the VR technology itself. Without information like this we will not be able to determine to what degree user performance in, say, a DIS environment, reflects what can be expected in the real world, and what is due to characteristics of the VR simulations. Information of this nature is also needed to aid in design decision making, and to provide performance-based bench marks or requirements to guide VR technologists in advancing the state of the art.

We have undertaken a research project that focuses on this issue. One goal of this effort is to establish a quantitative relation between VR system properties and user performance. Our plan is to do this with a series of standardized bench mark tasks that cover a wide range of perception, perceptual-motor, and cognitive activities. To date we have completed studies that demonstrate the cost of VR system time delay on manual tracking and control and aimed movement control. The effects of several VR system variables on size-distance judgments in a virtual environment have also been studied.

The next chart depicts the fact that user performance based design data requires a link to be made between properties of user performance with properties of VR systems. The user performance properties must, in turn, be linked to specific application domains in order to map user performance to task performance. One goal of our research is to provide the desired user-performance data and the tools needed to complete the mapping to a wide variety of task domains.

Figures 18 and 19 provide a brief summary of the results from some experiments that investigated simple aimed movement performance which was accomplished in a virtual environment (VE). In general, the data follow Fitts Law over an ID range of 2 to 6, but show departure from linearity around an ID of 7. In comparison with physical aimed movement, performance by highly practiced subjects was degraded by about 35-50% in a VE (see Fig. 19). Further, the effect of time delay in the VR system caused movement times to increase substantially under ID 5 conditions, somewhat for ID 6 conditions, and very little at other ID levels (see Fig. 19). Data like these provide the basis for constructing design trade-off nomographs like the example shown in Fig. 20.

A design trade-off nomograph (see Fig. 20) is a form of data representation that highlights the relation between a measure of user performance and two or more measures of VR system properties. This form of representation allows a VR system designer to easily see how user performance interacts with system properties. It can be used for defining system requirements and for performing trade-off analyses to select between alternative design options that can meet a requirement. Thus, it aids the designer in seeing the connection between user performance in a way that is clearly connected to system properties, but at the same time allows the designer to bring in technology risk, cost, and schedule factors in the process of deciding how to meet a performance goal.

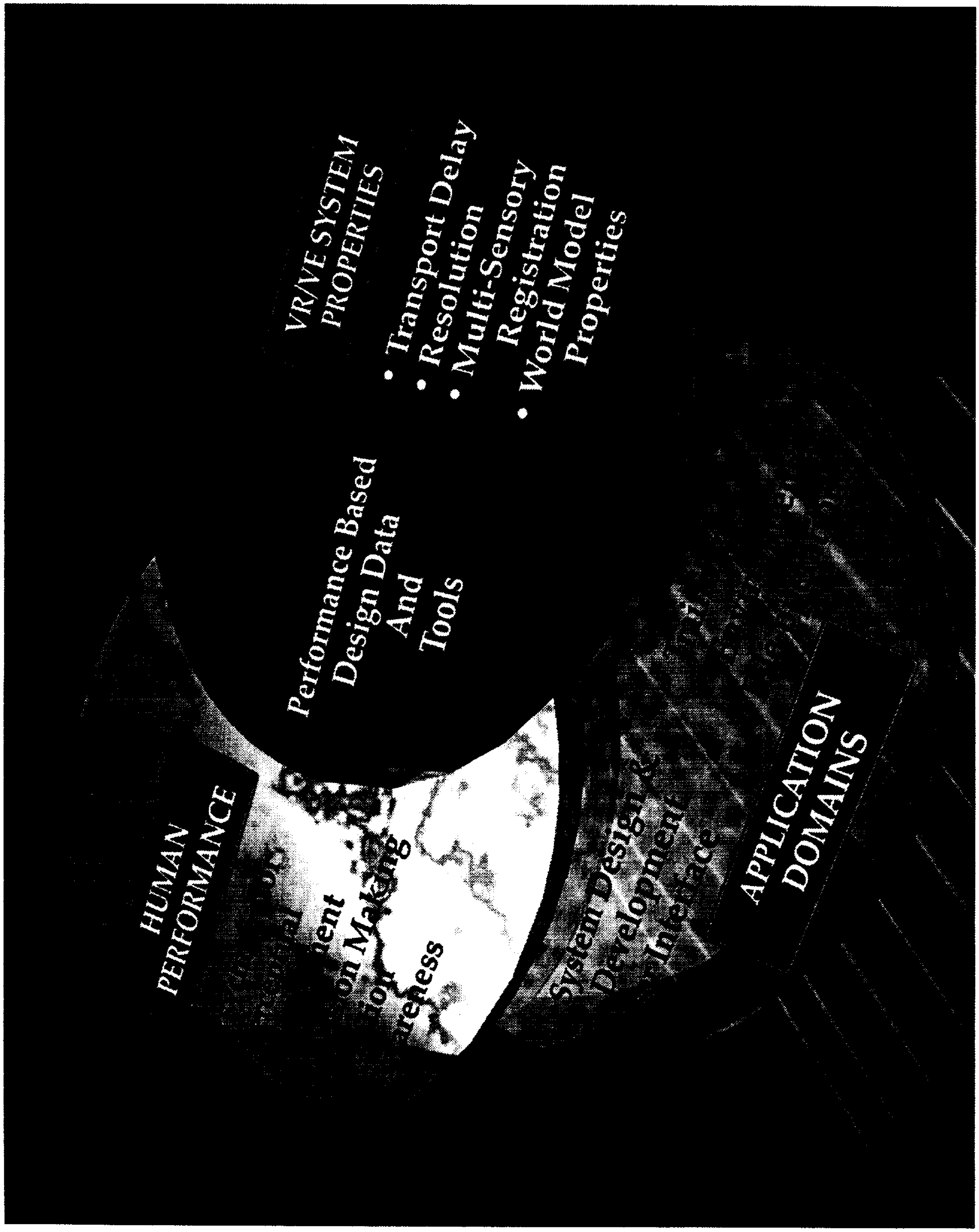

VR/VE SYSTEM PROPERTIES
• Transport Delay
• Resolution
• Multi-Sensory Registration
• World Model Properties
Performance Based Design Data And Tools
HUMAN PERFORMANCE
APPLICATION DOMAINS

Figure 17

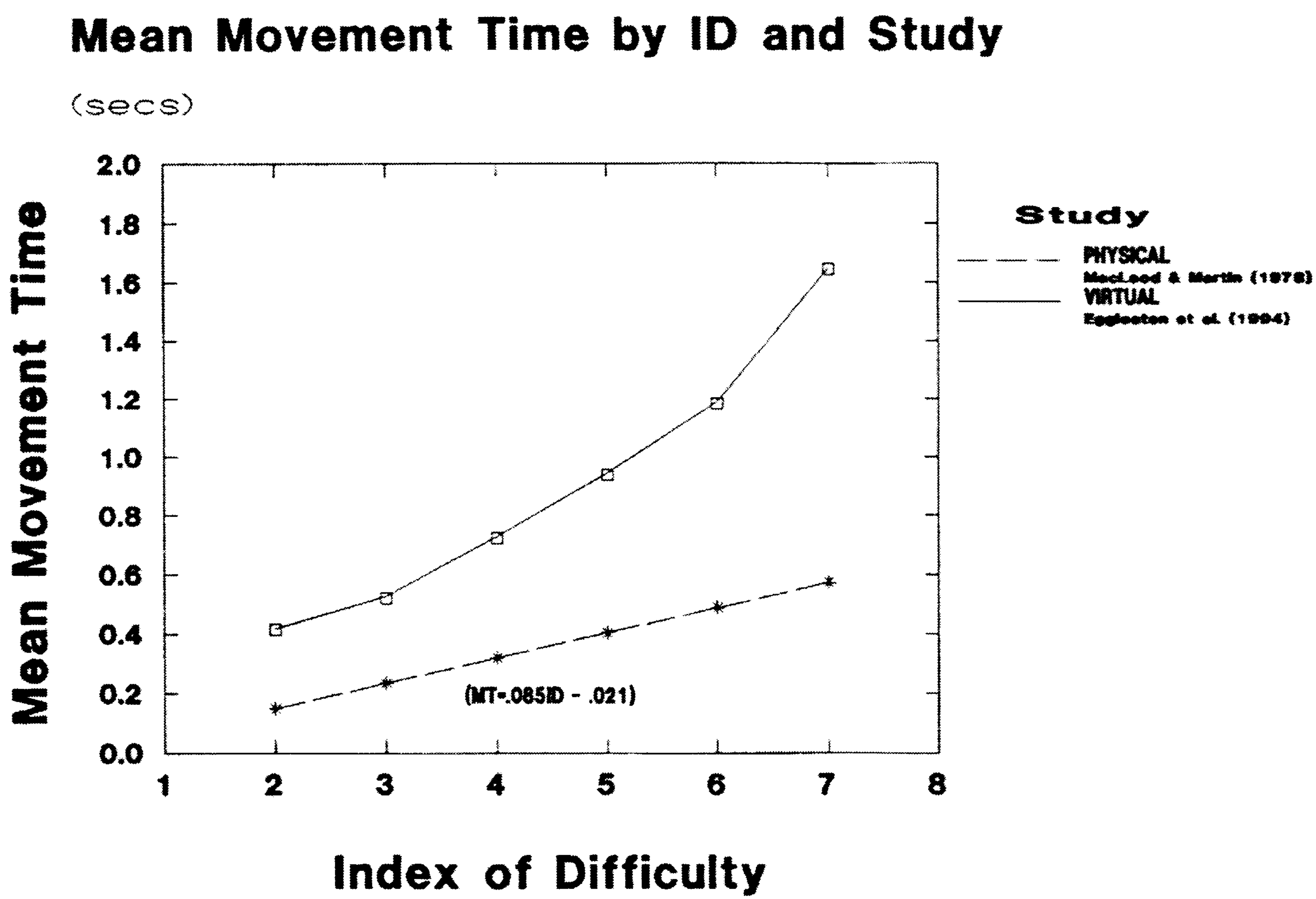

Mean Movement Time by ID and Study
(secs)
Mean Movement Time
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
5
6
7
8
Index of Difficulty
Study
PHYSICAL
VIRTUAL
(MT=.085ID - .021)

Figure 18

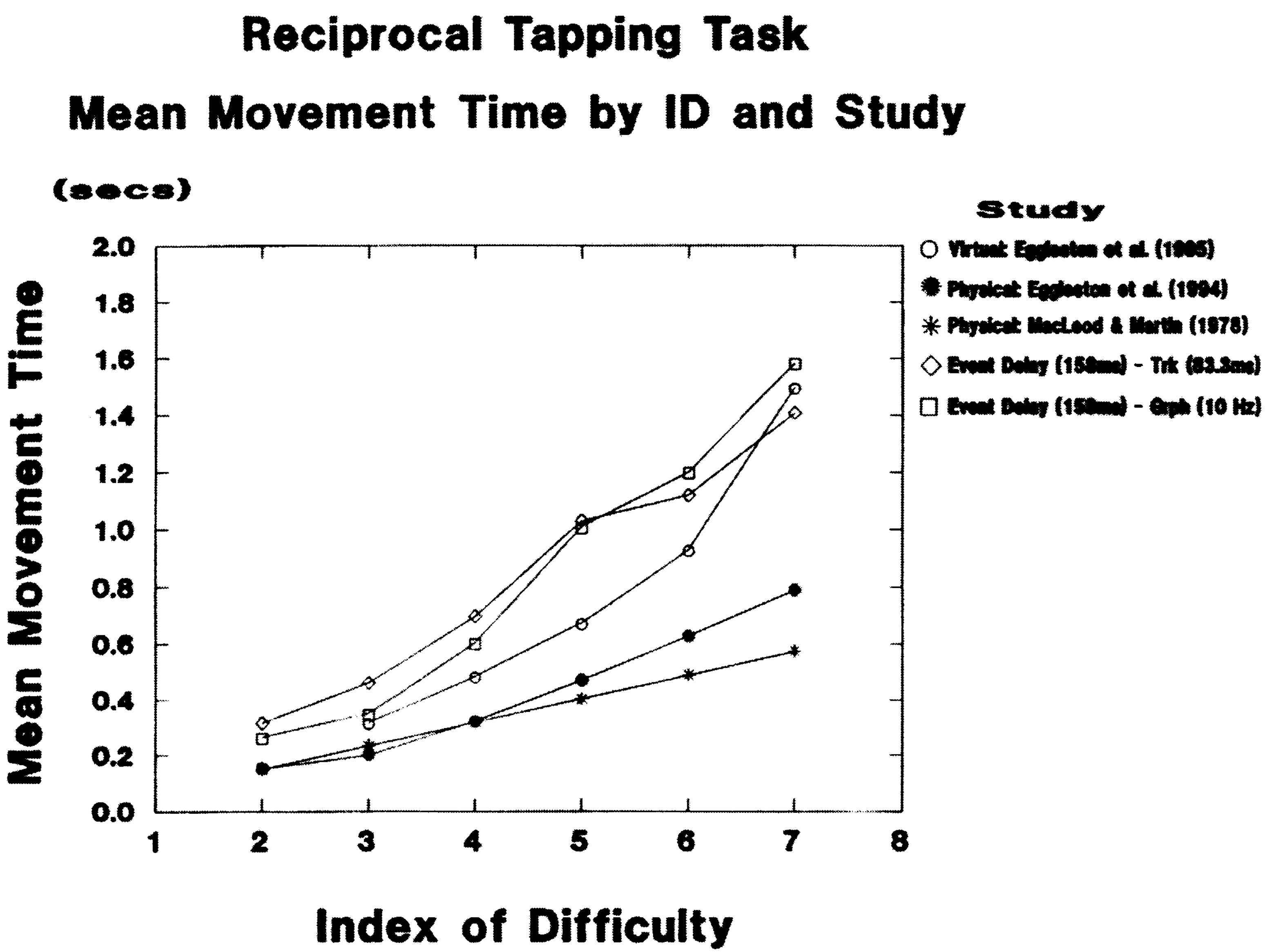

Reciprocal Tapping Task
Mean Movement Time by ID and Study
(secs)
Mean Movement Time
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
5
6
7
8
Index of Difficulty
Study
Physical: Eggleston et al. (1994)
Physical: MacLeod & Martin (1978)

Figure 19

USER PERFORMANCE AND VIRTUAL SYSTEMS

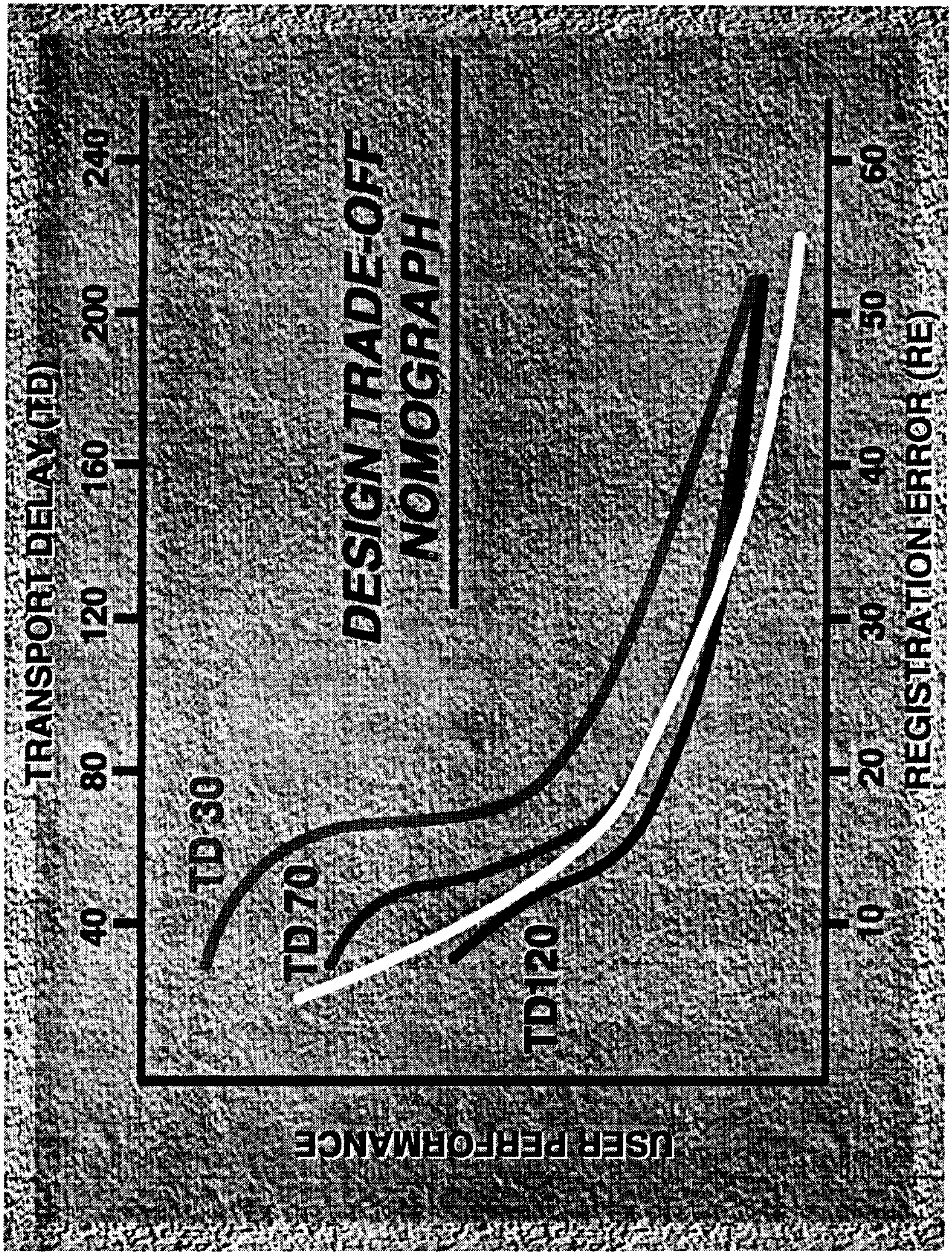
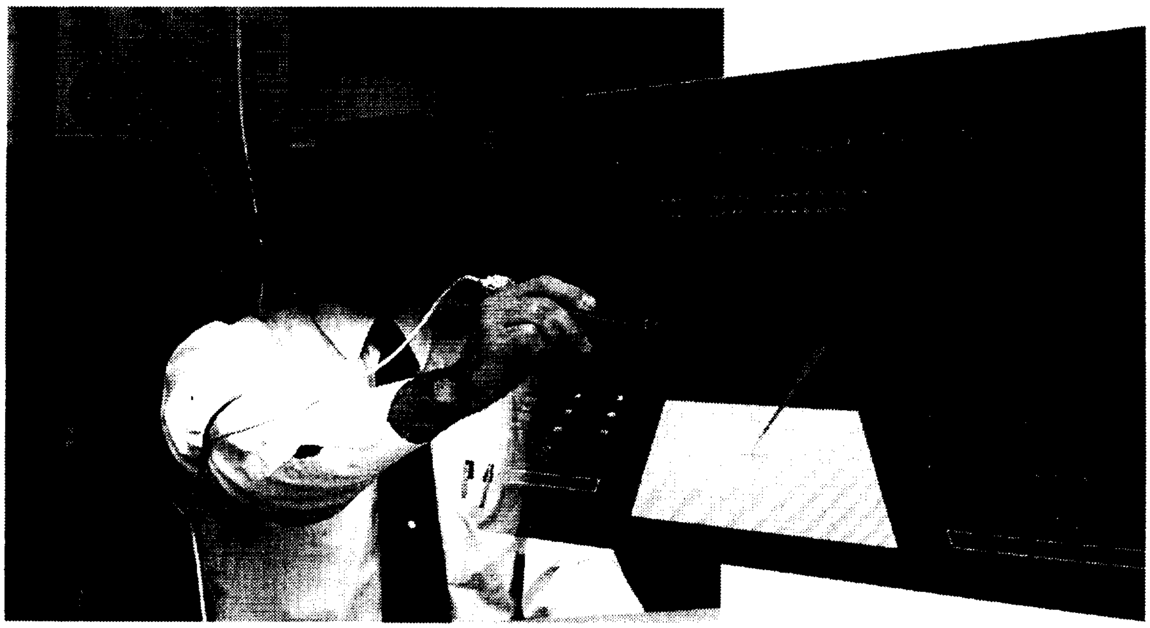


Figure 20

CLOSING REMARKS

As you can see, Armstrong Laboratory is engaged in a broad range of R&D research that involves both the development and exploitation of VR technology. We have a long history with the technology which has allowed us to achieve a high degree of understanding of the technical issues and challenges that need to be solved to insure its effective use in different application domains. We are very sensitive to the fact that VR technology by itself is neither desirable or undesirable. Rather, its value depends on how well we can unite it with the human user to produce successful products.



DETERMINING REQUIREMENTS AND CAPABILITIES OF VIRTUAL INTERFACES

Figure 21