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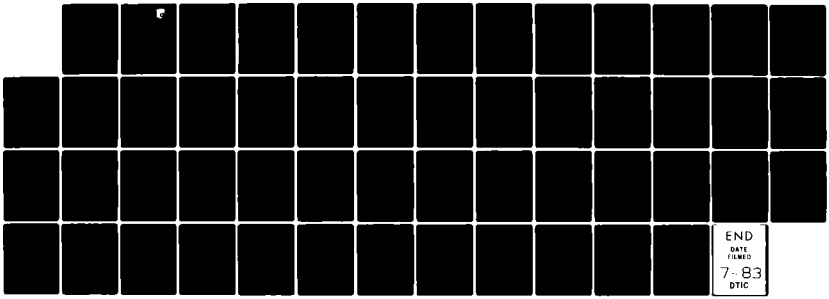

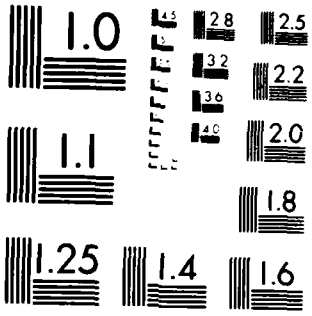

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COMPUTER-AIDED DESIGN AND EVALUATION TECHNIQUES (CADET)

James M. Richards
Michael A. Companion

Lockheed-Georgia Company
86 So. Cobb Drive
Marietta, Georgia 30063

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AIR FORCE SYSTEMS COMMAND
WRIGHT PATTERSON AIR FORCE BASE, OHIO 45433

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DANIEL D. BASEHORE, LT USAF
Aerospace Engineer
Crew Systems Development Branch
Flight Control Division

CHARLES R. GOSS, JR, LT COL USAF
Chief
Crew Systems Development Branch
Flight Control Division

FOR THE COMMANDER

H. [illegible] DAVIS
Assistant Chief
Flight Control Division

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This is the final report for the CADET program. It briefly discusses the approach taken and identifies criteria used to select recommended CADET. Potential Problems and their possible solutions are discussed. Recommended CADET are briefly described. Recommendations are made for future CADET program activities.

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SUMMARY

The Computer-Aided Design and Evaluation Techniques (CADET) program was initiated to identify and evaluate computer techniques that might be used in the design and evaluation of crew systems. Recommendations for future expansion and development of such techniques by the Flight Dynamics Laboratory (FDL) of the AF Wright Aeronautical Laboratories are included.

The original intent was to select those techniques that were compatible to computer hardware currently available at Wright-Patterson Air Force Base. Subsequent information indicated that future computer capacity made this constraint unnecessary.

Existing techniques identified as having potential to augment FDL's flight station design methodology include a CAD system, COMBIMAN, HOS, PLAID, SAINT, and WAM.

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PREFACE

This final report reviews computerized techniques that are applicable to flight station design and evaluation. It was prepared under Air Force contract F33615-81-C-3612 for the Flight Dynamics Laboratory of the Air Force Wright Aeronautical Laboratories, Wright-Patterson, AFB. The present study classifies current and previous work on computer aided techniques and evaluates the current state of the art. Observations and recommendations for future directions are provided in Section IV, Phase III.

The authors wish to acknowledge the helpful assistance of Commander Norman E. Lane, formerly associated with the Naval Air Development Center and now assigned to the Naval Training Equipment Center, for his guidance and review of existing CADET. Dr. James L. Lewis and Ms. Jerri Brown of the Johnson Space Center provided detailed information, current status, and a demonstration of the PLAID techniques. Valuable information on interfacing techniques and future applications was provided by Messrs. Don Kawamotto and Don Nichols of CADAM, Inc. a subsidiary of Lockheed Corporation.

The CADET Workshop sponsored by FDL and arranged by 1st Lt. D. D. Basehore, contract monitor, was extremely helpful in confirming the findings of the initial literature survey and in providing guidance in developing recommendations. While all participants provided useful information, special appreciation is offered to the attendees who represented agencies outside FDL. These included Dr. Alvah G. Bittner, Jr., U. S. Naval Biodynamics Laboratory; Dr. Floyd Glenn and Dr. Robert Wherry from Analytics; Dr. James L. Lewis, Johnson Space Center; Mr. John Kearns, ORLOC: and Dr. Joseph McDaniel and Arnold Mayer, Capt. Hollowell, and Mr. James Parker, all from other laboratories at Wright-Patterson AFB. Personnel from FDL who, in addition to their participation in the workshop, have contributed through their comments and suggestions include Lt. Basehore, Messrs. Larry Butterbaugh, David Frearson, Richard Moss, and Terry Emmerson.

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I. INTRODUCTION

The recent proliferation of computer graphics and rapid reductions in the cost of computer systems have caused government and industry to review the opportunities for cost-effective computer applications. Airframe manufacturers have made use of computer graphics and simulation techniques for structural and systems design and evaluation for some time. Extension of computer-aided design and evaluation techniques to the human interface in the flight station offers the potential to ensure that human capabilities and limitations are more thoroughly and effectively incorporated in the design process.

The Flight Dynamics Laboratory of the U.S. Air Force Wright Aeronautical Laboratories has had a long-standing interest in flight station development. Their approach to this development consists of a methodology intended to ensure full consideration of human limitations and capabilities. This methodology is essentially a problem-solving technique with three phases: Define the Problem, Solve the Problem, and Prove the Solution. The present three phase study was undertaken to determine what computerized techniques are available, or that could be developed, to enhance and compress the time cycle involved in the design, development, and evaluation of a flight station.

The initial phase of the CADET program, described in Section II, included a literature survey and a review of computer facilities at Wright-Patterson AFB. Reference 1 describes this phase and includes the bibliography that resulted from this search.

Section III provides an explanation of criteria used in evaluating the various Computer Aided Design and Evaluation Techniques CADET identified in Phase I. It also includes a brief description of those CADET that hold the most promise for current application or future development.

Recommendations for future implementation of CADET are presented in Section IV. The Phase III workshop findings are also summarized in this section.

II. PHASE I

The primary purpose of the Phase I effort was to identify existing CADET. To this end, an exhaustive literature search was undertaken. The details of this search and the resultant bibliography are documented in Reference 1.

SUMMARY OF APPROACH

The initial search was accomplished at Wright-Patterson AFB, using a Flight Dynamics Laboratory (FDL) remote-access terminal to query the Central Information and Retrieval Center (CIRC II) of the Aerospace Structures Information and Analysis Center (ASIAC). Additional searches were made at the Lockheed-Georgia Company Engineering Information Center of their Technical Information Department, using a variety of data bases including Lockheed's DIALOG, Engineering Index (COMPENDEX) and National Technical Information Service (NTIS).

A total of 648 titles and abstracts were reviewed. This number was reduced by excluding items published prior to 1970, unless they had historical significance. In general, unless a technique was applicable to the design and development of aircraft, it too was excluded. Also eliminated were techniques that had been superseded by more sophisticated work or discontinued because they were not cost-effective.

Using these ground rules for selection, 38 individual CADET were identified for further study during Phase II. These were classified according to the segment of the design methodology to which they might be applied. Figure 1 and Tables I and II from Reference 1, CADET Literature Survey, are included here for convenience. Figure 1 is a schematic diagram of the flight station design methodology with the segments affected by CADET identified with an "X". Table I provides a list of the 38 CADET initially identified. Table II is a glossary of CADET which decodes the acronyms and nomenclature associated with the various techniques.

The literature survey and discussions with persons cognizant of current activity related to CADET led to certain observations and findings, which are summarized in the next section of this report.

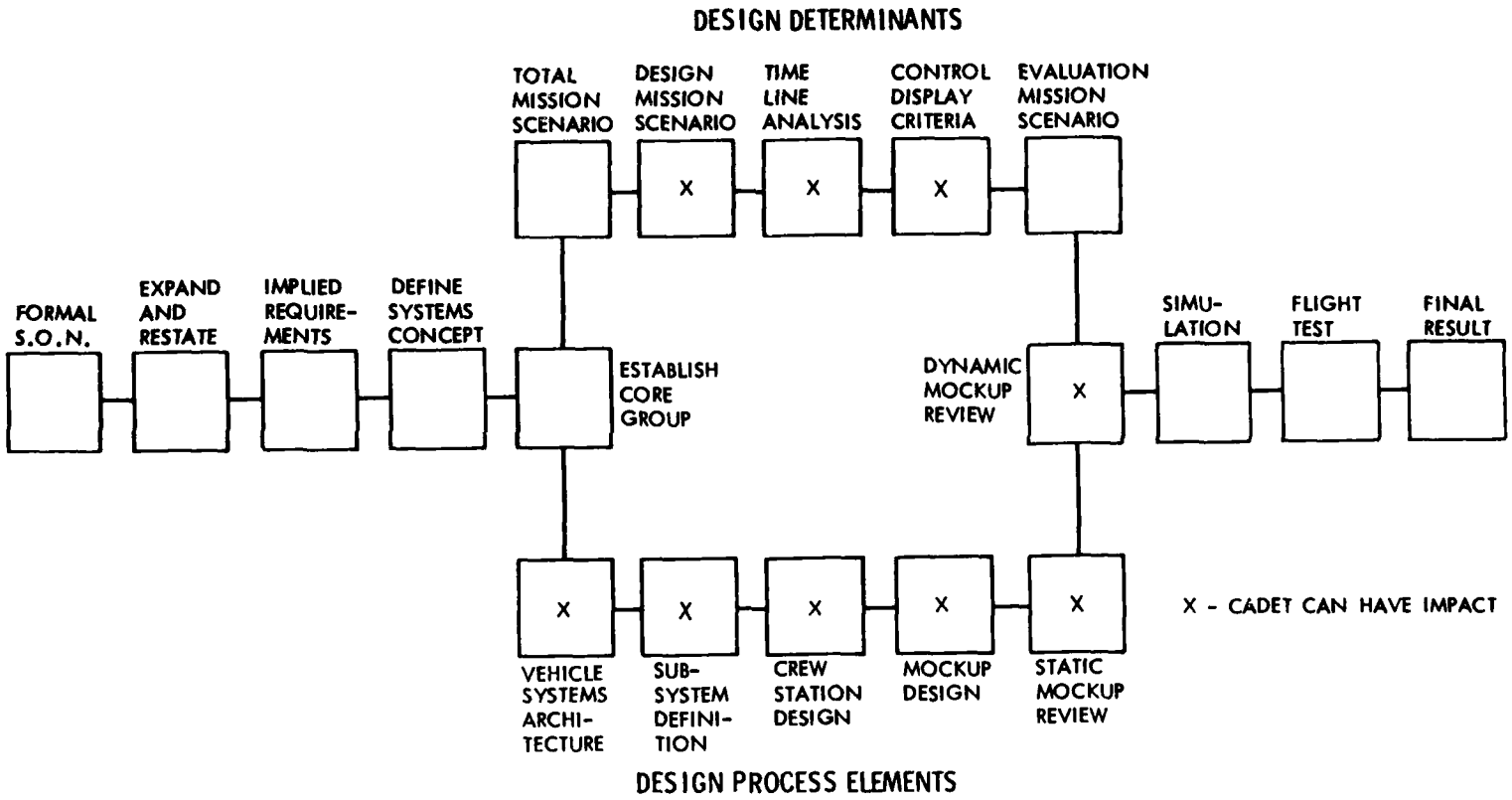

Figure 1. Potential CADET Impact on the Design Process

TABLE I DESIGN DEVELOPMENT SEGMENTS AND THEIR RELATED CADET

TECHNIQUE	TIME LINE ANALYSIS	CONTROL/DISPLAY CRITERIA	VEHICLE SYSTEMS ARCHITECTURE	SUBSYSTEM DEFINITION	CREW STATION DESIGN	MOCKUP DESIGN	STATIC MOCKUP REVIEW	DYNAMIC MOCKUP REVIEW
BOEMAN (CGE)					X		X	
BIOMAN					X		X	
BUBBLEMAN					X			
CAD (CAFES)					X			
CADAM			X		X	X	X	
CAFES	X		X		X		X	
CAPE					X		X	
CAR II					X		X	
CGE (CAFES)			X		X		X	
CISMS	X	X		X				
COMBIMAN					X		X	
CORELAP		X			X			
CRAFT		X			X			
CREVS			X		X		X	
CUBITS		X						
DMS (CAFES)	X							
DSM								X
FAM (CAFES)	X							
G-CIO	X							
GROUP								

TABLE I DESIGN DEVELOPMENT SEGMENTS AND THEIR RELATED CADET (CONT'D)

TECHNIQUE	TIME LINE ANALYSIS	CONTROL/DISPLAY CRITERIA	VEHICLE SYSTEMS ARCHITECTURE	SUBSYSTEM DEFINITION	CREW STATION DESIGN	MOCKUP DESIGN	STATIC MOCKUP REVIEW	DYNAMIC MOCKUP REVIEW
HOS	X	X						X
LAYGEN					X			
MMSS								X
ORACLE	X						X	
PANEL					X			
PLAID		X			X	X	X	
PSM								X
SAINT								X
SAMM	X							X
SAMMIE					X		X	
SBO	X							
SWAM	X							
TAS 033							X	
TEPPS	X						X	
TLA	X							
TX105	X				X			
WAM (CAFES)	X							
WOLAP					X			

TABLE II. GLOSSARY

BOEMAN	- Boeing Computerized Mathematical Human Model
BIOMAN	- (Computerized Anthropometric Model)
BUBBLEMAN	- (Computerized Anthropometric Model)
CAD (CAFES)	- Computer-Aided Design
CADAM	- Computer-Graphic Aided Design and Manufacturing
CAFES	- Computer-Aided Function Allocation and Evaluation System
CAPE	- Computerized Accommodated Percentage Evaluation
CAR II	- Crewstation Assessment of Reach
CGE (CAFES)	- Crewstation Geometry Evaluation
CISMS	- Cockpit Information Storage and Management System
COMBIMAN	- Computerized Biomechanical Man-Model
CORELAP	- Computerized Relationship Layout Planning
CRAFT	- Computerized Relative Allocation of Facilities
CREVS	- (Computerized External Visibility Simulation)
CUBITS	- Criticality/Utilization/Bits of Information
DMS (CAFES)	- Data Management System
DSM	- Digital Simulation Model
FAM (CAFES)	- Function Allocation Model
G-CIO	- (Calculate Hand and Eye Task Execution Times)
GROUP	- (Computerized Panel Layout Program)
HOS	- Human Operator Simulator
LAYGEN	- Layout Generator
MMSS	- Man Machine Stochastic Simulation
ORACLE	- Operator Research and Critical Link Evaluation
PANEL	- (Computerized Panel Layout Program)
PLAID	- Panel Layout Automated Interactive Design
PSM	- Pilot Simulation Model
SAINT	- Systems Analysis of Integrated Networks of Tasks
SAMM	- System Activity Modeling Methodology
SAMMIE	- System for Aiding Man-Machine Interaction Evaluation
SBO	- Specific Behavior Objects
SWAM	- Statistical Workload Assessment Model
TAS 033	- (Flight Deck Window Design Effectiveness)
TEPPS	- Technique for Establishing Personnel Performance Standards
TLA	- Time Line Analysis
TX-105	- (Control Cabin Design Evaluation)
WAM (CAFES)	- Workload Assessment Model
WOLAP	- Workspace Optimization and Layout Planning

Phase I also included a review of the computer capabilities at Wright-Patterson Air Force Base. The results of this review are not included in this final report because current and future needs are under extensive study, and any recommendations based upon current data would entail premature conjecture and might soon become obsolete. The situation with respect to hardware and software capabilities is discussed more thoroughly in Section IV, Phase III.

SUMMARY OF FINDINGS

The preliminary review of information gathered during the literature survey suggested some potential problem areas in the application of computer techniques to the crew station design methodology. Evaluation of CADET and analysis of the design methodology, supplemented by judgments of the participants in the CADET workshop, resulted in some general observations and specific recommendations. Potential problems and their possible impact on future activities are summarized below. The general observations and recommendations are presented in Section IV.

Batch vs. Interactive Technologies - The computer-aided graphics techniques associated with design are all interactive. Most of the modeling and analysis techniques that evaluate workload and suitability of design to human use are batch techniques. While there are sound technical reasons for this disparity, it provides a challenge to develop a means for effective data base management which will permit real-time design evaluation.

Basically, designers are attempting to design equipment or a system capable of fulfilling established functional requirements within certain constraints. From time to time they need information on these constraints or data that affect the ability of a design to meet these constraints. In this context, designers are seeking a specific response to a specific question. They require data bases capable of providing appropriate basic data or models already programmed to analyze available data to provide answers.

The human factors engineer, on the other hand, is generally concerned with a broader analysis of alternate system designs to determine their comparative suitability or to establish operational conditions that are

least demanding of a human operator. In effect, two separate CADET may be needed to meet the requirements of both effectively: a relatively direct interactive technique for use by design engineers and a more comprehensive analytical capability for the human factor engineer. This latter may tolerate batch loading and batch processing with an interactive capability for the review and analysis of model outputs.

Multi-purpose vs Specific Technologies - Many of the CADET developed to date are massive models or programs that require quantities of data and are capable of supplying a wide variety of statistical information, which in turn, must be analyzed to answer specific questions. As noted above, the system designer, using computer-aided graphics techniques, usually is seeking a single simple answer. The design process itself appears to require more system analysis to identify essential information requirements and data elements necessary to provide the analytical tools for design and evaluation by both designers and human factors engineers. It does not appear likely that all requirements can be efficiently provided by a single technique. This situation will be discussed further in Section IV.

Currency of Technology - The initial review of the literature and discussion with knowledgeable individuals indicated that, with one or two exceptions, work on CADET was at a standstill. This is not necessarily a problem but the question of "why?" certainly begs an answer.

It appears that the basic capabilities of the Siegel and Wolf model (Reference 2) have been fully exploited and the feasibility of the concepts established. However, as the various CADET were under development, computer technology advanced tremendously and the end result is that some of the previously developed CADET require adaptation to the capabilities of more recent equipment. This does not necessarily rule out their use, but it does require review of user requirements, equipment capabilities and an evaluation of the relative choice between adaptation of existing CADET or the development of new techniques.

Data Bases - Although there are increasing numbers of data bases available, there are still problems as to the ready availability of data bases that are appropriate in size, content, and statistical breakdown to the needs of a specific design or evaluation problem. The accuracy and currency of data in a given base may also be questionable. Currently,

there is also the problem of duplicating effort by building a new data base when somewhere a similar base exists.

It can be anticipated that, with the advent of hierarchical computer networks, combined with improved data management techniques, it will become possible to identify appropriate data bases, selectively enter them, and load an operating program with the required data and proceed with the analysis.

Program Compatibility - Despite the fact that most of the existing CADET have been developed by, or under contract to, government, agencies, there is a variety of program languages and hardware requirements in the present techniques. This is not surprising, since they were, for the most part, developed independently with the resources of each agency guiding development decisions.

Complete compatibility is unlikely to occur. However, with current hardware and software technology, it is reasonable to assume that in the future it will be possible to translate and adapt programs and data bases sufficiently to permit effective interactive utilization.

SUMMARY

The overall status of computer-aided design and evaluation technologies appears to be that of a plateau or interregnum between large batch, multi-purpose, unit-based hardware or software, language-bound approaches, and interactive, single-purpose, versatile programs available on networks of interactive mainframe computer systems. The human task becomes one of developing procedures that can creatively and cost-effectively use such a system. The conversion from current to future systems may well be expensive, but the interactive nature of such a system will provide long-range savings.

Savings can be anticipated through the avoidance of duplication. A series of large data bases will be available to many users, thus requiring only one storage and a single maintenance capability for each base. Development costs will occur only once for both using programs and data bases. The addition and use of CADET and related data bases associated with the person-equipment interface should make current computer-graphics design

techniques more effective and, therefore, result in considerable cost savings in the long run.

III. PHASE II - RESULTS

The Phase I literature search reported in Reference 1 identified 38 CADET with varying potential for further consideration. During Phase II, each of these was reviewed for their potential for application to the FDL crew station design methodology. Several were eliminated because they were proprietary and, therefore, not cost-effective. A few were dropped because development had been discontinued. The remaining CADET were reviewed in greater depth, and their potential is discussed in the second section of this chapter.

The CADET workshop (Reference 3) provided information that resulted in the addition of three techniques and the deletion of three others. BUBBLEMAN and GROUP, both related to crew station design, and SAMM (Systems Activity Modeling Methodology), an approach to workload assessment, were added. HECAD was dropped because the development effort has been discontinued. SADT and THERP were dropped because they are not computerized.

CADET EVALUATION

In the review of CADET, several criteria were used to determine the overall utility and potential of each technique. The actual choices were subjective and were made on an overall basis; however, each criterion was considered in making an overall evaluation of each technique against others of similar capability.

The capability of a technique was of prime consideration: first in assigning it to a particular segment of the design cycle and, second, in how well it could perform the functions normally required for fulfilling the design requirements. Cost, in terms of acquisition, software maintenance and hardware requirements, was another consideration, as were currency and availability.

These latter two criteria were sometimes interrelated in that techniques which were not currently maintained tended not to be readily available; whereas those most readily available were the techniques which are current and up-to-date.

The flexibility of a technique was another important criterion. This criterion included the growth potential of the technique, its adaptability to other elements of the design process, and variety of applications.

The final criterion was ease of use: the complexity or friendliness of the software and the general acceptance of the technique. This latter included the number of known applications plus the judgement of individuals knowledgeable in the field of CADET.

In Phase II, the CADET identified in Phase I were first grouped by orientation or area of usage, such as techniques for anthropometric evaluation and techniques for workload evaluation.

The grouped techniques were then evaluated using the aforementioned criteria, and those techniques showing the highest potential to augment FDL's crew station design methodology were identified. Table III lists the high potential techniques by orientation. The selected CADET were then matched to the appropriate crew station design methodology phases to evaluate the overall impact of this matchup so summarized in Table IV.

The selection process is discussed in more detail below. A later section provides a summary description of the characteristics of those CADET that appear to have the greatest promise.

Anthropometry CADET - Of the seven anthropometry CADET, COMBIMAN and two segments of PLAID, BUBBLEMAN and CAR II, are considered the most viable current techniques.

The British developed SAMMIE has many of the features of COMBIMAN and appears to be useful in doing an anthropometric evaluation, but it is a proprietary technique with a high acquisition cost.

BOEMAN, BIOMAN, CAPE, and CGE each have features suitable to anthropometric evaluation; however, they lack the versatility of COMBIMAN and PLAID, and none of them are currently being used or undergoing further development. Both COMBIMAN and the PLAID elements, BUBBLEMAN and CAR II, provide a capability for anthroprometric evaluation, and they are readily available from the government agencies that sponsored their development. These techniques are currently in use with a potential for further growth and development.

Data Management CADET - The CISMS and DMS programs are identified as existing techniques. The nature of data management is so dependent on the

TABLE III. HIGH POTENTIAL CADET VERSUS DESIGN ORIENTATION

ANTHROPOMETRY CADET

- COMBIMAN
- PLAID
  - BUBBLEMAN
  - CAR II

DATA MANAGEMENT CADET

- NONE

DESIGN CADET

- CADAM
- ICAD

FUNCTION ALLOCATION CADET

- NONE

PANEL ARRANGEMENT CADET

- PLAID
  - CUBITS
  - GROUP
  - SLAM

SIMULATION CADET

- HOS
- SAINT

TASK TIME CADET

- HOS

WORKLOAD CADET

- HOS
- SAINT
- WAM

MISCELLANEOUS CADET

- CALSPAN 3-D CRASH SIMULATION

TABLE IV. HIGH-POTENTIAL CADET VERSUS DESIGN DEVELOPMENT SEGMENTS

TIME-LINE ANALYSIS

- HOS
- WAM

CONTROL/DISPLAY CRITERIA

- PLAID
  - CUBITS

VEHICLE SYSTEMS ARCHITECTURE

- CADAM/ICAD

SUBSYSTEM DEFINITION

- (SADT - MANUAL TECHNIQUE USED USUALLY WITH SAINT)

CREW STATION DESIGN

- CADAM/ICAD
- COMBIMAN
- HOS
- PLAID
  - CAR II
  - GROUP

MOCKUP DESIGN

- CADAM/ICAD
- PLAID

STATIC MOCKUP REVIEW

- CADAM/ICAD
- COMBIMAN
- PLAID
  - BUBBLEMAN
  - CAR II

DYNAMIC MOCKUP REVIEW

- HOS
- SAINT

nature of data bases available that data-base management should be tailored to the other techniques selected. A recommendation to this effect will be found in the discussion of Phase III.

Design CADET - In recent years there has been a major surge in the number and variety of computer-graphics design techniques. Most of these are suitable for the basic design task, especially for less-complex systems and subsystems. The four that were reviewed most thoroughly for the CADET program were the CAD portion of the Navy/Boeing CAFES program, the Lockheed Corporation CADAM, ICAD/ICAM developed for the AFWAL Material Laboratory, and the NASA Johnson Space Center PLAID. Of these, the CADAM is the most powerful and versatile. It is widely used and offers the greatest potential for long-term application. Such flexibility and power require relatively expensive hardware and may represent over-capacity for most projects envisioned for the CADET program. On the other hand, the ICAD/ICAM program may be readily available from the Material Laboratory at the AF Wright Aeronautical Laboratories. This program has the basic computer-graphics design capability required for flight station design, development, and evaluation.

Function Allocation CADET - The FAM segment of the Navy/Boeing CAFES program is the only computerized technique that addresses the problems of function allocation. The FAM program, requires extensive effort to develop the necessary inputs and the preparation of the inputs essentially accomplishes the decision making aspects of function allocation. Since much of the function allocation process is based on established state of the art or represents innovation by humans, it is very questionable whether computerization of this process is cost-effective.

Panel Arrangement CADET - Most computers with graphic capability can be used to arrange panels. CORELAP, LAYGEN, PANEL, PLAID, and WOLAP are all techniques that were developed specifically for panel arrangement. Of these, PLAID, with its sub-segments CUBITS, GROUP, and SLAM, provides the most versatile capability. Its current availability from NASA's Johnson Space Flight Center makes it a leading candidate for near-term implementation.

Simulation CADET - System simulation has become a popular analytic tool for evaluation prior to full-scale development. Models for human operators have, therefore, been a natural outgrowth of this trend. The

Digital Simulation Model (DSM), Man Machine Stochastic Simulation (MMSS), Pilot Simulation Model (PMS), and Human Operation Simulation (HOS) have all been developed as simulation models. The Systems Analysis of Integrated Network of Tasks (SAINT) has been developed more as a language which readily lends itself to modeling, both for simulation and for workload evaluation. It is this versatility, plus its ready availability, that makes SAINT, along with HOS, a prime candidate for use in these two areas. The SAINT technique is in widespread use and is readily available in its latest form (SAINT IV) from the Air Force Aerospace Medical Research Laboratory (AFAMRL).

Task Time CADET - There are only two techniques which relate to task times. The G-C10 calculates hand and eye task execution times and is thus restricted in its application. The HOS is capable of evaluating task times and has the added utility of being able to simulate and evaluate workload. It is available from the Naval Air Development Center. In general, however, task times can most efficiently be calculated by implementing existing or derived predictive functions on micro or minicomputers.

Workload CADET - Seven techniques related to workload analysis and/or evaluation were identified. Of these, CRAFT, ORACLE, SWAM, and TLA are either of limited utility or they are not readily available in useable form. The other three, HOS, SAINT, and WAM, have some potential to augment the FDL crew station design methodology. SAINT, as stated previously, is up to date, in wide use, and readily available from AMRL. WAM is available, through the Naval Air Development Center. HOS is available through the Naval Air Development Center or Analytics.

Miscellaneous CADET - The CALSPAN 3-D crash simulation model is particularly useful in estimating the effects of a crash on various parts of the human body. Developed primarily for use with automobiles, it could be used for aircraft, especially with ejection seats. Because of its specialized nature it did not receive further attention as a potential CADET.

Selected CADET for Design Process Segments - The FDL Crew Systems Design Methodology has been used as a guide in reviewing CADET. While not all segments are suitable for computerization, many of the activities can be more efficiently accomplished with computers. Figure 1 provides a guide to the interrelationship between CADET and design methodology segments.

CHARACTERISTICS OF SELECTED CADET

This section of the report provides summary descriptions of some of the more pertinent features of those CADET identified in the preceding section as having the greatest potential for further use and development.

CADAM - This is a basic design technique that was originally developed by the Lockheed-California Company for structural design. It is currently controlled by the recently formed CADAM, Inc., a wholly owned subsidiary of the Lockheed Corporation. The technique is in use with over 150 different organizations. Such widespread application assures its continued development and offers prospects of interchangeability as new capabilities are developed by user organizations. The system is based upon an IBM system which can be interfaced with IBM or ADAGE scopes. A color CADAM system which interfaces with a Spectrographics scope is under development.

The CADAM is a very powerful system that permits rapid incorporation of revisions or preparation of alternate designs. A relatively new, but very desirable, feature is the ability to develop a software interface capable of translating CADAM-developed formats into simulator-compatible software codes. The programmer needs only to add format dynamics.

CADAM can be used to design consoles, develop panel arrangements and design controls and display formats. These can be printed directly in full scale for use in soft mock-up development and evaluation. The color CADAM provides an opportunity for direct preliminary evaluation of color CRT formats.

The Air Force developed Integrated Computer Aided Manufacturing (ICAM) has an ICAD element that is similar to CADAM in its capabilities. This should be readily available as a basic technique that could be used as a core for future CADET development.

COMBIMAN - The COMBIMAN program is designed to make anthropometric evaluations and to define visibility contours. It is now in its fourth version and is readily available from Air Force Aeromedical Research Laboratory (AMRL). Dr. Joe McDaniel, AMRL/HEG, is the principal contact for this program.

COMBIMAN is written for an IBM computer with an IBM 2250-3 CRT interface. It can also be operated with an ADAGE 4250 scope, although not all

functions are operational with this equipment. The program has a standard Air Force anthropometric data base with the capability of accepting additional data bases. Coordinates for panels or controls are used as inputs to COMBIMAN. The outputs are pictorial reach analyses, either on the scope or plotter, and visibility analyses. For crew station design, COMBIMAN has a capacity of 250 panels and 150 controls.

In addition to the primary features identified above, COMBIMAN can be used with slumped or erect posture; side, front, top or oblique views; and with or without helmet, and with or without flight suit.

HOS - The Human Operator Simulator, or HOS, program was developed for the Naval Air Development Center (NADC) by Analytics, Inc. Dr. Robert Wherry or Dr. Floyd Glenn are knowledgeable contacts for this program. The HOS program is written in FORTRAN for a CDC 6600 computer and is applicable to panel arrangement and workload evaluation.

Based on analytical models, HOS simulates the following elements of human activity:

Information Absorption
Information Recall
Mental Computations
Decision Making
Anatomy Movements
Control Manipulations

To fulfill the requirements of the model, the following data are required:

Display and Control Locations
Display and Control Characteristics
Use of Each Display and Control
Operator's Mission
Operator Characteristics
Specific Problem Environment
Environmental/System Dynamics

The following information is derived by HOS and delivered as outputs:

Timeline Analysis
Channel Loading
Channel Activity Statistics
Devise Usage Time
Link Analysis (Transition Times)

While the HOS program appears to have some potential utility, a few limitations should be noted. First, it is a single-operator program that cannot currently be adapted to integrated crew activity. It also requires considerable analytical skills and is time-consuming to use.

PLAID - Although PLAID is still under development at the NASA Johnson Space Flight Center, it is current and appears to hold considerable potential for future applications. Dr. James Lewis or Ms. Jeri Brown at Johnson Space Flight Center are contact points for further information. This program is written in FORTRAN for use on a SEL 32/35, and the software is now being translated for operation on the VAX 11/780. NASA is currently using Tektronix 4081 and 4014. Plotter output is required for effective utilization of PLAID.

PLAID is comprised of several interactive subprograms: BUBBLEMAN, CAR II, GROUP, and CUBITS. Taken together, PLAID can be used for panel design and layout and for anthropometric evaluations. Reach and anthropometric evaluations are enhanced by a 3-D graphics package with an object rotation capability. Visibility evaluations can be made with PLAID through the use of selectable vision reference points. The outputs from PLAID are primarily visual through the use of either a CRT scope or a plotter.

PLAID development is currently behind schedule, but future plans include work on lighting simulation including reflectivity, color capability, shadowing effects, and additional anthropometric models. PLAID could be enhanced considerably by making it interactive with a CAD system such as CADAM or ICAD. This would appreciably speed-up graphics inputs.

SAINT - The SAINT system, which was developed for AMRL by Pritsker and Associates is not a model per se but a modeling system. Written in FORTRAN for use with an IBM computer, it is designed primarily for use in develop-

ing task simulation models. Mr. Robert Bachert of AMRL is the contact for the technique.

The following inputs are required to permit effective simulation:

Tasks
Resources needed for tasks
Task network
Task durations and distributions
Task branching
Task priorities
System attributes (optional)

Given these inputs, SAINT models will provide time statistics on selected tasks. These time statistics are presented as histograms and in tables of individual or average data. SAINT can be used to model multi-operator designs and is capable of modeling aircraft parameters and utilizing these parameters to modify and control pilot tasks.

SAINT can be rather time-consuming to use, particularly in developing and inserting the initial input data. However, it can be used with the Structural Analysis and Design Technique SADT data management system.

This technique has been implemented at numerous facilities with a wide variety of uses.

WAM - The Workload Assessment Model is a subprogram to the CAFES system developed for NADC by Boeing for use in developing timeline analyses and evaluating workload. It is written in FORTRAN for use with a KRONOS 2.1 operating system. WAM uses a timeline of mission tasks to identify areas of operator overload. WAM is available through NADC.

Essentially, WAM follows the early pattern of the FDL Crew Systems Design Methodology. It begins with the preparation of a mission profile and scenario, followed by the construction of a mission phase chart. For each phase, all the tasks to be performed are identified, with an estimate of performance time for each task. A timeline for each phase is then prepared. The human channels -- visual, manual, cognitive, auditory or verbal -- used for each task are identified. All of these data are then prepared for the WAM.

The following tabular and statistical summaries are delivered as WAM outputs:

Average workload for each channel
Average workload for combined channels
Sequence of task start time, duration time, and end time
Shifted tasks and length of time a task is shifted
System activity times
List of tasks contributing to overload
Standard deviation of workload for each channel
Standard deviation of workload for combined channels

INTEGRATION OF CADET INTO CSDM

Application of individual CADET to the crew station design methodology (CSDM) has the potential of reducing the design cycle time in developing a new crew station. It also permits evaluation of a wider variety of design options during a given time period. Initial development of a generic, i.e., fighter, bomber, transport, etc., flight station and entering the requisite data bases may be time consuming, but when fully implemented there should be savings in time.

Figure 1 has been repeated here to provide an orientation to the CSDM. The design elements that have related CADET have been numbered to correspond to numbers added to Tables III and IV, which are also presented again.

The following paragraphs go through the CSDM elements and explain how each element might be enhanced with the implementation of a specific CADET.

The initial development of statement of need with its expansion and development of implied requirements and systems concept definition are largely a matter of human judgment based upon knowledge of the problem and experience with the influencing factors. Human creativity and imagination are the primary ingredients and are not readily enhanced by computer techniques. Word processors with their flexibility for changing and adding text provide an increase in efficiency in developing these blocks of the CSDM. Similarly, the mission scenario can be developed and expanded on a word processor and graphically developed on computer graphics equipment.

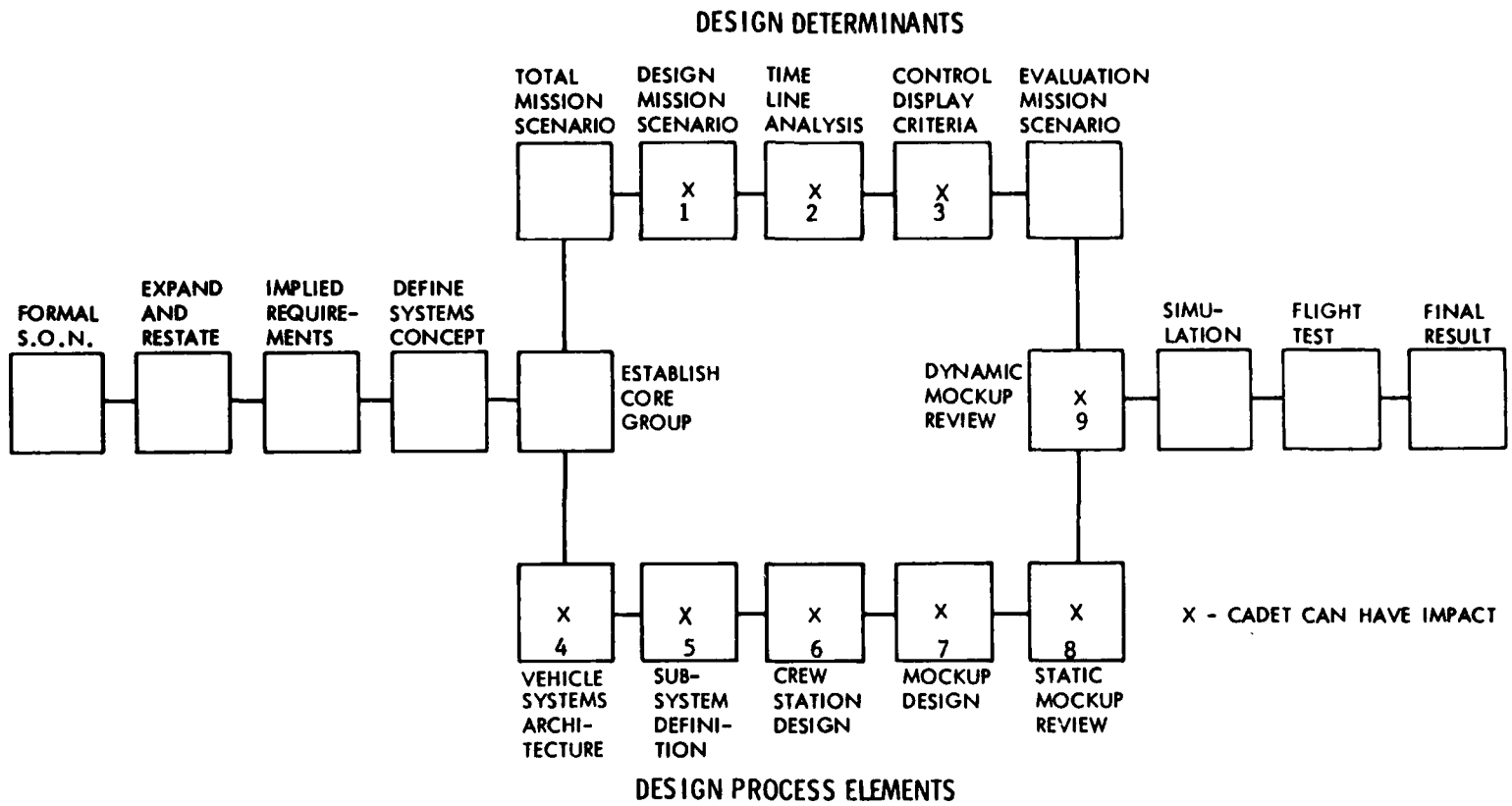

Figure 1. Potential CADET Impact on the Design Process

TABLE III. HIGH POTENTIAL CADET VERSUS DESIGN ORIENTATION

ANTHROPOMETRY CADET

- COMBIMAN
- PLAID
  - BUBBLEMAN
  - CAR II

DATA MANAGEMENT CADET

- NONE

DESIGN CADET

- CADAM
- ICAD

FUNCTION ALLOCATION CADET

- NONE

PANEL ARRANGEMENT CADET

- PLAID
  - CUBITS
  - GROUP
  - SLAM

SIMULATION CADET

- HOS
- SAINT

TASK TIME CADET

- HOS

WORKLOAD CADET

- HOS
- SAINT
- WAM

MISCELLANEOUS CADET

- CALSPAN 3-D CRASH SIMULATION

TABLE IV. HIGH-POTENTIAL CADET VERSUS DESIGN DEVELOPMENT SEGMENTS

2 TIME-LINE ANALYSIS

- HOS
- WAM

3 CONTROL/DISPLAY CRITERIA

- PLAID
  - CUBITS

4 VEHICLE SYSTEMS ARCHITECTURE

- CADAM/ICAD

5 SUBSYSTEM DEFINITION

- (SADT - MANUAL TECHNIQUE USED USUALLY WITH SAINT)

6 CREW STATION DESIGN

- CADAM/ICAD
- COMBIMAN
- HOS
- PLAID
  - CAR II
  - GROUP

7 MOCKUP DESIGN

- CADAM/ICAD
- PLAID

8 STATIC MOCKUP REVIEW

- CADAM/ICAD
- COMBIMAN
- PLAID
  - BUBBLEMAN
  - CAR II

9 DYNAMIC MOCKUP REVIEW

- HOS
- SAINT

Time Line Analysis - Current time line analysis techniques are tedious and laborious at best. They must be developed by or with a subject matter expert, either a skilled operator or an individual throughly familiar with the operating characteristics of each system. Various techniques are available for developing basic data such as movies or videotapes that are observed repeatedly or a tape cassette talk-through in a mockup might be used. In each approach, times must be allocated for each subtask and subsequently charted manually to provide a means of reviewing activities to identify modes of overlapping tasks that might represent overload conditions or require task sharing among crew members.

The CADET identified as potentially useful for Time Line Analysis were HOS and WAM with WAM preferred during the early part of the CSDM and HOS being more useful for iterative analysis later in the cycle. WAM supplements the initial TLA based on knowledge of tasks on existing systems which leads to a more precise early analysis of workload to be used as a basis for reallocation. Later in the CSDM HOS will supplement or do the final iterations, based on an actual layout, for evaluation and refinement.

Initial development of data for the WAM or HOS requires the same careful individual effort to identify tasks, sequences and times required for system operation. When completed and loaded into the computer program the WAM or HOS will create time line analyses which can be manually reviewed. The principle advantages of this computer capability is that system variations can be introduced and analyses performed without a complete manual redevelopment of all operator tasks. Alternate task sequences can also be evaluated.

Once the computer data bank is loaded, alternate configurations can be quickly evaluated with relatively minor additions to the basic data base. In addition, mission segments representing a variety of alternate mission capabilities can be considered without full reconstruction of all of the common mission segments. An end result is that a larger portion of time can be expended on analyses and evaluating and relatively less time establishing task data since it is possible to perform a wider variety of statistical compilations in a shorter or equal amount of time.

Control - Display Criteria - In traditional CSDM criteria for displays and controls are established by reference to military standards, handbooks

and established textbooks. Specifically, Military Standard, 1472 Human Engineering Design Criteria for Military Systems, Equipment and Facilities, and the AFSC Design Handbook (DH) 1-3, Human Factors Engineering, are standard references for control-display criteria. A design engineer must either have a thorough familiarity with the information in these documents or consult with a qualified human engineer.

In addition, the specific criteria or parameters for each control or display must be determined to assure that requisite information is provided in an acceptable form, and that a control device capable of activating, deactivating or alerting status of a system is available. The design engineer must select or develop devices capable of interacting with the human operator and assume that there are no "loose ends." The adequacy of integration, appropriateness of display/control relationships and the assurance of the logic and efficiency must all be determined by the engineer and/or his associates based upon their experience and personal knowledge of interacting systems.

The PLAID technique offers an opportunity to utilize computer memory and subroutines to provide assurance that control/display criteria are met. The subprograms in PLAID include criteria that can guide the early development of control and display panel layouts. These techniques permit the designer to manipulate his design and perform comparisons in an interactive fashion.

Again the primary advantage is in the time saved in using data stored in a computer versus manual investigations of system interactions. This time saving is coupled with the considerable convenience of a graphic interactive capability it readily presents to a designer the constraints which influence his design. While this is the reason so much time is saved it is also an easier more agreeable approach to designing crew stations.

Vehicle Systems Architecture - As the design development process continues, initial efforts require the identification of specific systems or subsystems capable of fulfilling the systems concept. Parametric studies with paper and pencil have long been replaced by computer analyses capable of matching hardware characteristics with design concepts. More recently, powerful computer graphics techniques such as CADAM and ICAD have made it possible to actually draw conceptual designs with the use of light

pens and touch panels. These techniques are also available to the electronic or mechanical engineer with a responsibility for developing equipment associated with subsystems e.g. hydraulic, fuel, navigation or even components within these subsystems.

The use of these computer graphics techniques saves a great amount of time over manual drawing. They also shorten the span of time between systems concept definition and tentative structural configurations and potential subsystem definition. Indeed, a variety of alternatives for each concept can be developed in less time than was previously possible for a single configuration with accompanying subsystem design. This flexibility, in turn, enables the crew station designer to compare alternates and investigate compatibility of crew stations with alternate design configurations.

When the vehicle systems architecture is available on a large computer graphic system such as CADAM the human factors engineer can extract those portions of the system which are of interest. This is especially true of information that provides the dimensions of the crew station or constrains basic crew station geometry. In a similar manner, wiring and control diagrams stored in computer memory can be readily indexed and retrieved for the identification of physical component interfaces which must be included in the pilot or co-pilot interface.

Subsystem Definition - The matching of specific equipment to the functional requirements of the system is largely a judgmental matter and for the most part will probably remain manual. The Structured Analysis and Design Technique (SADT) is essentially a manual technique but as used with SAINT in later phases offers an opportunity for workload comparisons and simulation evaluations. These comparisons can reveal which equipment is most efficient for flight station usage. If the SAINT model is already established this is a viable approach to subsystem definition. Otherwise it does not offer any great advantages over traditional approaches to equipment evaluation and selection.

Computer graphics capability can be useful in the development of block diagrams, however, only because it is a more efficient drafting technique.

Crew Station Design - This is the key element in crew station development. At this point the man-machine interface is defined. The neutral eye

reference point and associated seat reference point become the principal locators for establishing flight station geometry including visibility diagrams. Panel layout, including display/control location, is an important part of crew station design. Reach diagrams appropriate to human anthropometry are an important evaluation tool. Functional and sequential relationships must be taken into consideration along with any color or shape coding that can assist the human operator. Finally, display formats and specific control configurations that aid in overall flight station integration must be accomplished.

In traditional design development the flight station must often await system and subsystem definition. This implies that the flight station design is determined by prior design decisions which receive priority over the limitations and capabilities of the human operator because any changes result in time consuming rework of drawings. The availability of CADET saves time and increases flexibility.

The various computer graphics techniques have similar characteristics and capabilities. Preferences and reasons for recommendations were provided in an earlier section on CADET Evaluation. The use of CADET for this element of the CSDM fulfills several functions each with an improvement over traditional manual drawing board methods.

The CADAM system, or a comparable computer graphics design aid, can take the gross vehicle architecture, extract flight station dimensions, location and basic geometry and then add preliminary consoles and panels; established seat location and neutral eye position and develop visibility diagrams.

The COMBIMAN program with its anthropometric data base can be used to develop reach diagrams and establish constraints associated with various seat positions and restraints conditions.

As with other CADET, the use of CADAM and COMBIMAN permit evaluation of a wide variety of potential layouts, panel locations and window locations (visibility diagrams) in a relatively short time.

In the evolving design, CADAM can be used to develop specific display formats. The relatively less complex PLAID technique is useful in the location of controls, control panel design and in panel layout. In either case iterations with variations can be readily accomplished so that

comparative evaluations can be made. The COMBIMAN technique can be utilized with each iteration to determine design adequacy with respect to reach.

Similarly, HOS can be used with time line data to evaluate workload for different design configurations. This technique is also used with each reiteration as the design is refined and retested.

Mock-up Design - The mock-up provides an opportunity to physically check dimensions and tasks with a full scale model of tentative crew station. Since the primary purpose of the mock-up is this opportunity for physical tryout, rather than analysis, a CADET is not generally used in evaluation. However, the design of the mock-up itself may be accomplished on the CADAM or with PLAID. The various candidate designs can come from CADET or PLAID layouts as described in the previous section.

Static Mock-up Review - The review of the static mock-up is, like the mock-up itself, an opportunity for individuals to personally satisfy themselves that a proposed flight station design is satisfactory and meets the constraints of various parameters, e.g. reach, visibility, workload, functional relationships, etc. This process can be aided considerably through the use of the CADAM/COMBIMAN or PLAID/BUBBLEMAN techniques.

This is particularly true where a reviewer may express preferences in layout or design that fit the reviewing individual but are unsuitable for the full anthropometric ranges. The interactive capabilities of the COMBIMAN or BUBBLEMAN techniques permit a rapid review of reach capabilities in different postures to demonstrate the adequacy or inadequacy of alternate arrangements.

Dynamic Mock-up Review - The purpose of the dynamic mock-up review is to provide a real life evaluation of a prospective design using experienced operational crews. This cannot be substituted for or replaced with computer techniques. It is, however, possible to prepare for or augment the dynamic review with a CADET such as HOS or SAINT.

A HOS or SAINT capability with an adequate data base permits study of a wider range of mission scenarios or system failures in a shorter period of time than would be possible with live crews. They also provide print-out data which can be analyzed in detail. This is in addition to any subjective, undocumented comments provided by live crews going through a

mock-up mission. The HOS or SAINT models can also pinpoint elements or segments which might be subject to more intense scrutiny when exercised by the operational crews.

Summary - The preceding section has provided a step by step description of the CSDM elements that might be facilitated by the use of CADET. In each affected step the specifically recommended CADET has been identified and a brief comparison made between the manual approach and the computerized method.

No attempt has been made to evaluate cost effectiveness since this is dependent on so many interactive elements such as availability of data bases, existing computer capabilities, and availability of appropriate software.

The next section describes some of the dynamics of computer applications to the CSDM and makes recommendations for future CADET program development.

Bearing in mind the continuing rapid change in microprocessor development and accompanying software capabilities, the ultimate application of CADET to CSDM must await a more clear cut picture of the computer revolution.

IV. PHASE III

The concluding section of this report provides a summary of the CADET Workshop held in February 1982 at Wright-Patterson Air Force Base. It also offers some general observations on the current state-of-the-art of CADET as gleaned from the earlier phases of this study and the workshop. Finally, it presents recommendations for future activities that would increase the utilization of CADET.

SUMMARY OF WORKSHOP

As part of the CADET program, a workshop was sponsored and arranged by the Flight Dynamics Laboratory. From the literature survey conducted in Phase I, a number of individuals were identified as authorities through their work in the development of CADET. These experts were invited to participate in a one-day workshop. There was good response to this invitation, and although many interested people were unable to attend, a representative number of people familiar with the various CADET were present at the workshop.

The workshop opened with a welcome and brief commentary by Col. Moore, Chief of the Flight Control Division of FDL. This was followed by a brief presentation on crew station design methodology by Mr. Richard Moss of FDL. Mr. Jim Richards, Lockheed-Georgia Company, discussed the progress of the CADET program, emphasizing the Phase I findings. The formal presentations were followed by structured, but free-flowing, discussions of CADET.

The workshop participants added three previously unidentified CADET and recommended deletion of two. There was general agreement with the findings of Phase I, which were summarized in Section II of this report. A few additional thoughts and concepts were added.

It was felt that the concept of a "friendly" system was probably more important than the question of batch versus interactive. In a similar vein, "modularity" or "building blocks" seemed more appropriate than "multi-purpose" versus "specific" techniques. The characteristic of "expandability" or "maintainability" was felt to be important, especially with respect to data bases.

The overall discussions were very productive, and the thinking expressed in the workshop has been incorporated in the evaluation of CADET found in Section II and in the later parts of this section. For a more detailed discussion of the CADET Workshop, the reader is directed to the Conference Minutes (Reference 3).

GENERAL OBSERVATIONS

The effort expended on the current study has provided an excellent opportunity for a review of the current state-of-the-art in CADET. It has also provided some insights that suggest opportunities that perhaps were not originally envisioned. The original intent was to provide a broad review of existing CADET, evaluate current computer capabilities at Wright-Patterson Air Force Base, and recommend a choice of CADET that were capable of fulfilling the requirements of the flight station design methodology and also compatible with the available computers. The information gained from the current study indicated that an even broader scope for the future might be more realistic.

System Interaction - The current study was confined to those computer-aided techniques related to human interaction with flight station equipment. There has been extensive work in a variety of disciplines to develop capabilities for evaluating a given design almost as soon as the designer has entered an idea into the computer. A design might be evaluated for conditions such as control requirements, weight, and fuel consumption, almost immediately. In other words, a whole series of mathematical models can be called upon in a very timely manner. Obviously, the constraints related to human performance, such as human anthropometry, information processing capabilities, workload capacity, and response characteristics, should also be available. Therefore, it became apparent that any CADET selected should have a potential for relatively direct use with an evolving design.

Central System - A second observation is the desirability of selecting, and perhaps adapting, CADET that can be tied to a specific computer-aided design (CAD) system. A number of CAD systems are in use throughout the country, most of which are extremely versatile and capable of greatly

increasing designer productivity. While the Lockheed CADAM system was recommended in Section III of this report, the important point is the desirability of identifying a single CAD system as the focus of the CADET system and adding the techniques related to human performance and flight station design to that central system, whatever it may be.

On-Base Hardware - The original work statement was directed toward identifying computer hardware currently available at Wright-Patterson Air Force Base and selecting CADET that would be compatible with the existing computers. It became apparent in early discussions that, within a relatively short period (approximately five years), computer capability and capacity would be greatly enhanced. Specifically, plans are underway for the development of a series of local computer capabilities that are tied in with a base local area network that is, in turn, tied to a national network. This means that an individual working at a terminal in his own laboratory will soon have access to computers, and related data bases, at remote sites all over the country. Hence, current on-base hardware is not a limiting factor in the choice of CADET.

Software Language - When computer technology began, the languages developed for communicating with computers were almost non-existent, i.e. being the computer's own binary and actual arithmetic. This gradually changed as computers become more versatile, higher order languages were introduced, and users became more sophisticated. A wide variety of software languages are now in use, and all but simpler computers perform in several languages. In the current state-of-the-art, there are a number of solutions to this potential handicap. A variety of operating systems are available which are capable of changing program languages, so that some computers can function with different languages. While there are still preferences under some circumstances, and there is a need for further standardization, it is not an oversimplification to state that the software language of a given CADET should not be a constraint against its use. The user may not have to use a language at all since it could be "user friendly" and menu driven, etc.

COMPUTERIZED CREW STATION DESIGN

With full implementation of CADET the CSDM will become much easier to exercise. It will be possible to consider a wider variety of mission scenarios, a more extensive number of flight station arrangements, a greater number of equipment candidates, and a fuller range of system anomalies that impact crew workload.

This improved approach to crew station design and evaluation will be the result of improved hardware with internetwork capabilities, more and larger data bases, more sophisticated software (CADET) capable of effectively utilizing the improved hardware and data bases.

The designer will be able to work at a single work station with one, or possibley two, computer interfaces. He will have an interactive capability to retrieve information related to any part of the design process and design or evaluate in real time. Many iterations of any or all portions of the design process will be possible in a relatively short time period. The following paragraphs describe in more detail a potential combination of modular CADET which will make possible the approach to design methodology described above.

Figure 1 and Tables III and IV are repeated to provide an outline of CSDM and to index current CADET that might become part of a future design and evaluation process. The crew station design block would be the keystone of the process with a basic CAD/CAM technique such as CADAM or ICAM would provide the interactive vehicle for system development. Other techniques would provide peripheral modules that could be accessed independently throughout the design process. The future CSDM utilizing CADET parallels the Integration of CADET into CSDM segment of Section III, Phase II - Results.

Because of the interactive nature between the "Design Determinants" and the "Design Process Elements" of Figure 1, as well as the interactive process envisioned in future CADET utilization, the sequence of describing potential applications is different from the sequence used in Section III. Design Mission Scenario and Time Line Analysis are described first, followed by Vehicle Systems Architecture and Subsystem Definition.

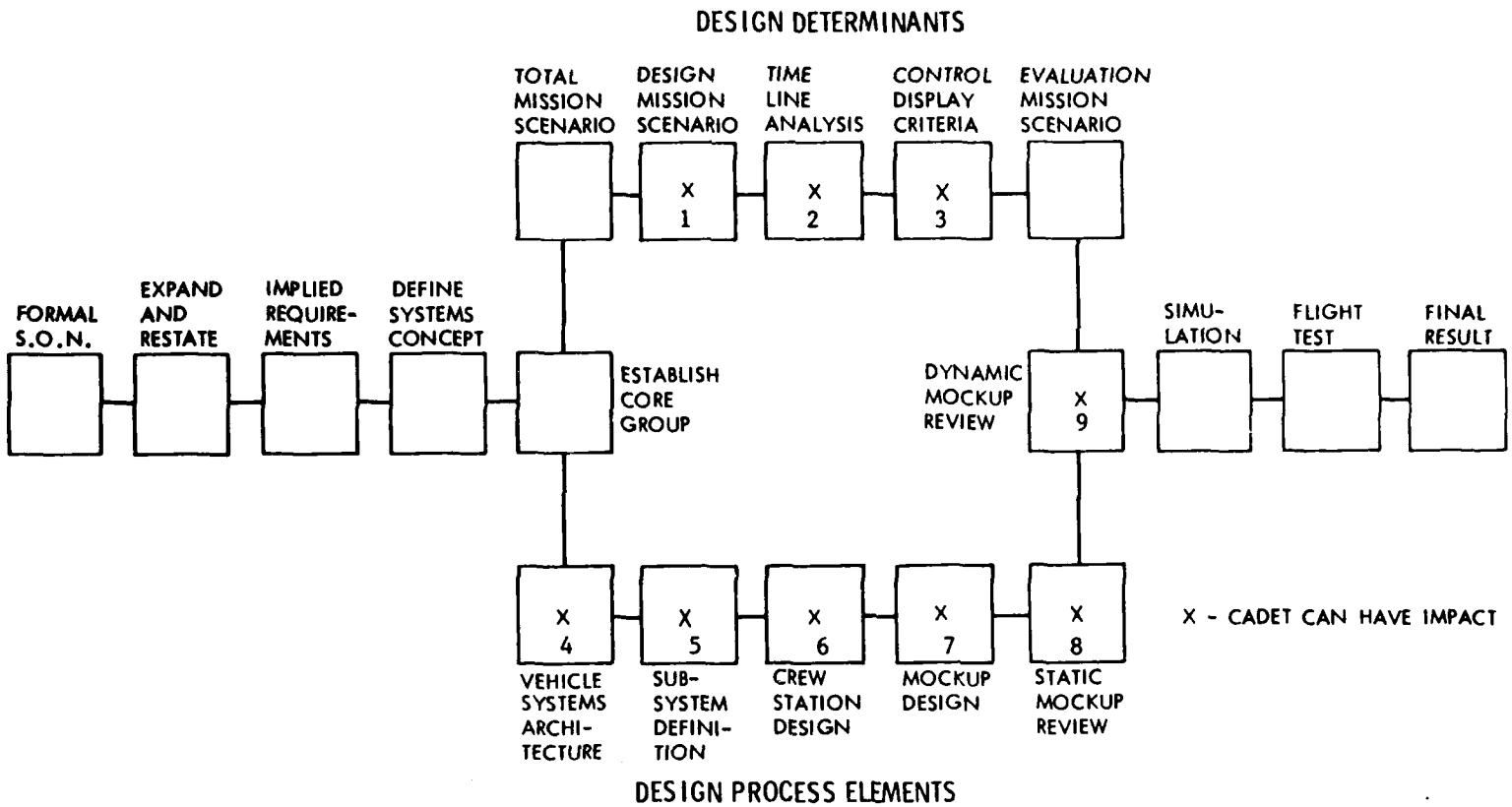

Figure 1. Potential CADET Impact on the Design Process

TABLE III. HIGH POTENTIAL CADET VERSUS DESIGN ORIENTATION

ANTHROPOMETRY CADET

- COMBIMAN
- PLAID
  - BUBBLEMAN
  - CAR II

DATA MANAGEMENT CADET

- NONE

DESIGN CADET

- CADAM
- ICAD

FUNCTION ALLOCATION CADET

- NONE

PANEL ARRANGEMENT CADET

- PLAID
  - CUBITS
  - GROUP
  - SLAM

SIMULATION CADET

- HOS
- SAINT

TASK TIME CADET

- HOS

WORKLOAD CADET

- HOS
- SAINT
- WAM

MISCELLANEOUS CADET

- CALSPAN 3-D CRASH SIMULATION

TABLE IV. HIGH-POTENTIAL CADET VERSUS DESIGN DEVELOPMENT SEGMENTS

2 TIME-LINE ANALYSIS

- HOS
- WAM

3 CONTROL/DISPLAY CRITERIA

- PLAID
  - CUBITS

4 VEHICLE SYSTEMS ARCHITECTURE

- CADAM/ICAD

5 SUBSYSTEM DEFINITION

- (SADT - MANUAL TECHNIQUE USED USUALLY WITH SAINT)

6 CREW STATION DESIGN

- CADAM/ICAD
- COMBIMAN
- HOS
- PLAID
  - CAR II
  - GROUP

7 MOCKUP DESIGN

- CADAM/ICAD
- PLAID

8 STATIC MOCKUP REVIEW

- CADAM/ICAD
- COMBIMAN
- PLAID
  - BUBBLEMAN
  - CAR II

9 DYNAMIC MOCKUP REVIEW

- HOS
- SAINT

Design Mission Scenario - As stated earlier there is no specific CADET appropriate to the design mission scenario, however, the use of a word processor provides a capability for storing a variety of mission segments for each type of aircraft, i.e. fighter, transport, bomber, etc. The existence of stored information will make it possible for a designer or system analyst to construct a series of missions with numerous contingencies in a relatively short period of time. These in turn are available to play against a variety of hardware designs and/or crew mixes to approach a design which can be optimized on selected parameters including the choice of specialized crew station equipment for certain unique mission segments.

Time Line Analysis (TLA) - The WAM technique with a large data base of tasks, time distributions and sequences permits an early evaluation of a variety of subsystems or equipment. Careful development of operator programmed limits or criteria will make it possible to identify high workload portions of whatever mission is selected.

This application of WAM avoids the manual development of the TLA which in itself is tedious. It also makes it unnecessary to review an entire TLA and requires study of only the high workload segments.

With this capability in place, alternate designs and/or various missions can be analyzed by computer with only the high workload portions extracted. This makes comparative analysis of design or mission alternatives relatively fast and easy compared to a manual development and review.

Vehicle Systems Architecture - Once the mission scenario has been established, parametric studies of prospective air vehicles can begin. Such things as size, range, speed and other operating characteristics are established and specific design concepts are defined. CADAM, ICAM or similar interactive computer graphic system provides a central or core system for developing vehicle systems architecture. Both color and 3-D capabilities are rapidly becoming available. These should greatly enhance the designer's ability to visualize, and also to communicate, his proposed solutions to the basic design problem.

As computer capabilities available to the crew station designer evolve it will be possible to access the structural design elements required for

crew station design without resort to paper blueprints. Subsystem designers will have similar access to systems architecture drawings and will be able to begin subsystem definition without re-drawing common elements essential to the finished design.

The principal advantage in the use of CADAM in systems architecture development is its effectiveness in increasing designer productivity. A collateral advantage for the crew station designer is the potential for improved communication with the system designer. With a CADAM type interactive capability the crew station designer can retrieve all pertinent system information, including dimensions, required to establish initial reference points in the crew station. It is also possible to rapidly consider alternate recommendations, discuss them with the designer, and readily make mutually agreeable changes.

Subsystem Definition - As mentioned in Section III there currently is only limited computerized capability in subsystem definition. It can be anticipated, however, that future development will produce some computerized aids to subsystem definition.

One development that might be anticipated is the establishment of extensive data banks on physical sizes and performance capabilities of equipment and components that might be used in a given subsystem. Ready access to such data banks should make it possible to establish requirements and have the computer identify all component candidates that meet the prerequisites. It would also be possible to develop a large number of potential alternate configurations for any particular subsystem.

Control Display Criteria - With the subsystem definition and time line analysis capability both available it is possible to establish control display criteria. Using a CADET such as the CUBITS portion of PLAID, each information requirement can be identified and the appropriate control modes established. Potential for integration of displays or automation of controls can be investigated. In a more advanced CADET it should be possible for the crew station designer to interactively explore alternate integration/automation schemes by inserting new criteria into the subsystem equipment data bank and/or accomplishing comparative time line analyses to evaluate workload.

Once again, the increased flexibility and the ease of evaluating a number of alternate combinations is the factor that makes CADET attractive. Resultant criteria for displays and controls should assure that all required information is readily available and adequately presented and that the necessary controls are available and capable of effectively enhancing performance.

Crew Station Design - With the preceding steps of the CSDM accomplished, and an interactive capability established, the actual crew station design should not be too difficult. A basic CADAM, or equivalent, capability can be used for design, selecting station points from system architecture.

Actual panel layouts can be generated with PLAID. These layouts can then be evaluated for reach with the use of COMBIMAN or CAR II or analyzed for sequencing and workload evaluation with the use of HOS. Once again the interactive computerized capability makes it possible to compare a wide variety of alternate layouts with a minimum of time and effort. Similarly, a variety of potential constraints, e.g. reach, workload, sequence of activities, functional relationships, etc. can be readily evaluated. It also becomes possible to explore the interactions between these parameters in a way that permits design optimization according to the emphasis desired by the designer.

Mock-up Design - From the selected crew station design, a mock-up can be readily constructed. The CADAM or PLAID program can be used to design the necessary support structure if it is desired. With off-line color graphics capability, actual display formats for mock-up installation can be created expeditiously. This computer graphics approach combined with the usual flexibility of mock-ups shortens the time between crew station design and mock-up review. In point of fact, it practically eliminates the need for small scale mock-ups by making it possible to produce a full scale scale mock-up as readily as a small one. It is still possible, however, to select, develop and construct whatever size scale mock-up might be desired through proper computer instructions. Similarly, any changes or alterations desired can be made easily and within a minimum time span.

Static Mock-up Review - The static mock-up review will continue to be primarily a live personal review of a mock-up made by interested eval-

uators, e.g. pilots, designers, equipment engineers and various customer personnel. This review process can be enhanced with demonstrations utilizing the graphics capabilities of CADAM, PLAID or their equivalent along with a related COMBIMAN or BUBBLEMAN technique to demonstrate anthropometric compatibility, including reach. Off line printed diagrams can further supplement a static mock-up review.

Dymanic Mock-up Review - The use of the HOS or SAINT CADET in effect takes the place of the dynamic mock-up review since they make it possible to "fly" a given configuration through a variety of missions or mission segments. While there will always be a subjective preference for physically evaluating a full scale mock-up, the HOS and SAINT techniques, once appropriately modeled and supplied with the fulfilling data, can meet workload analysis requirements. With identification of control levels or limits the computer can make all requested runs, providing printouts for manual analysis only for situations which exceed established limits. Through shifting these limits, secondary or tertiary segments for closer review can be identified.

Alternate configurations, manning quantities, task or function allocations or mission profiles can be introduced into these programs. Once the software has been constructed any combination of the above alternate parameters can be readily analyzed within a relatively short time. Once programmed and run the detailed manual analysis or evaluation of potential problem areas can be reviewed with the computer graphics and potential solutions injected interactively for further iteration and evaluation.

Summary - The preceding subsection has reviewed potential future applications of current CADET to a fully computerized approach to CSDM. It is possible that some improved CADET will become available. Also additional work on some of the current techniques may make them more effective.

The following subsection provides RECOMMENDATIONS that should lead to enhancement of current CADET and speed the advent of the type of system outlined above.

RECOMMENDATIONS

This section identifies some specific actions that can be taken to improve current capabilities and enhance future competence in the utilization of CADET. Actions that could be taken in both the short-term and long-term are included.

Identify Existing Data Bases - Effective utilization of data is probably one of the great assets of computers. Data management (knowing where data is and how to get it) is one of the keys to more productive computer use. An early step toward enhancing CADET utilization would be to identify existing data bases and their availability for computer use. Many useful data bases are already loaded, ready to use, in some computer. Others have perhaps been compiled but never entered into a computer. Still other areas exist where a store of data would be useful, but for which no one has gathered the basic data. This problem could, and probably should, be addressed soon at a relatively modest cost.

Develop Specific Data Bases - A related and perhaps adjunct activity would be the underwriting of the development of specific data bases that are identified in the above recommended study. This could be an expensive undertaking, depending on the nature of the specific data base. On the other hand, if the need for a given data base is established, it is possible that it could be developed as a joint effort or might be accumulated as fallout from ongoing projects in a variety of areas. Approaches to systematic data base development need to be explored.

AMRL/HEA currently is involved in a program to develop an extensive human factors data base with the computerization of the data base as the eventual goal. The possibility and potential benefits of participating in the development of this data base should be explored.

Develop a Data Base Management Program - Existing techniques for data base management tend to be manual. It should be noted here that reference to "data base" may well imply a computer program as well as raw data, or a given program, model, or other technique may include data inherent to that technique. In these cases, the program or technique may itself be considered a data base. In any event, the problem of identifying, locating, and accessing a given data base exists and probably will continue for some

time. The above factors should not preclude the development of computerized data base management techniques. They do suggest that data management is a highly individual matter, and even though an existing technique is found, it will require adaptation to the needs of the individual user.

The early development of a systematic approach to data base management is important. It should include a built-in capacity for expansion. Activity in this area should be closely coordinated with the earlier recommendation concerning the identification of existing data bases.

Use On-base Programs - A quick and efficient method to initiate an active CADET program would be to utilize currently existing capabilities at Wright-Patterson Air Force Base. Specifically, the Aerospace Medical Research Laboratory (AMRL) was instrumental in developing both SAINT and COMBIMAN. Both of these techniques are found to meet the criteria for CADET and are worth further consideration. The ICAD program, available through the AFWAL Materials Laboratory, provides the basic requirements for a central design capability to which other elements could relate.

The use of currently available techniques should lead to an understanding of capabilities and limitations that will guide future developments.

Select a CAD/CAM Program - While the existing ICAD program may well meet immediate needs for a central computer graphics design capability, it should be reviewed with respect to future objectives and expectations and compared to other available techniques. Once the choice of a central design capability is established, additional modules for design and evaluation of flight stations can be considered.

Integrate with a Workload Model - The workload models, such as SAINT and HOS, offer the greatest challenge. Their importance to evaluation of the personnel-equipment interface cannot be overemphasized. On the other hand, loading, analyzing, and interpreting these models continue to be tedious tasks that are not greatly superior to manual methods. If workload models and their associated data bases can be deftly integrated with a basic CAD program, a very useful capability will be available. This capability appears to be within reach with existing hardware and software.

Expand a One-Person Model - Most of the existing workload models, e.g., HOS, are designed to determine the workload demands on a single operator given a specific set of tasks associated with fulfilling a function on a specified mission. In the real world, most functions are part of a coordinated effort of two or more people. Even though each member of a team may be functioning independently, it is important to review related effort for a possible reallocation of duties in case of overload and to identify the impact on workload of tasks which require multiple crew member actions. Therefore, it is highly desirable to expand one or more of the existing techniques to evaluate overall crew workload. The SAINT language currently has this capability, but it needs to be further exploited.

Participate in Efforts Toward Standardization - Among the longer-range and continuing efforts that should be undertaken is participation in work toward standardization. There is a need for determining data base requirements, not only in terms of subject area but also in terms of descriptive measures that should be included either in the raw data or as a statistical adjunct. Development of standard CADET would also aid the industrial/government community by permitting more direct comparisons of alternate design solutions on future programs.

Work Toward Software Specifications - In a similar vein, specifications for software are needed. Such specifications would aid in the standardization mentioned above. This would also ensure the quality of software, make it more transportable, and improve the "friendliness" of computer programs.

Join in Development of PLAID - The PLAID program and its associated CADET is a current active program under development by the NASA Johnson Space Flight Center in Houston. In all dimensions considered, it holds the most promise for future development and overall contribution to CADET. If the concept of CADET is to be actively pursued, it would seem appropriate to enter into some type of joint development agreement with the PLAID sponsors in Houston.

Develop Simulation Techniques - A final recommendation is that FDL work toward the development of simulation techniques. These may take the form of mathematical models that will permit the exercise of a given

mission with a proposed design to determine the human involvement in actual operation. These simulations could be implemented using SAINT.

Another activity could be the continued support of generic aircraft simulation where full-scale, high-fidelity flight stations can be "flown" on various missions, using alternate design configurations. Such a simulator could "fly" with different hardware or could be quickly reconfigured through software changes to provide an experimental platform for early evaluation of new design or procedural concepts.

CONCLUSION

The CADET study has identified approximately 40 different techniques that are pertinent to flight station development and evaluation. These have been reviewed, and those with the most potential for future development have been identified.

Computer hardware and software capabilities have been investigated to the point of determining that the current state-of-the-art is no longer limited by specific combinations. An overall recommendation is to proceed in developing an optimum CADET system without concern for hardware/software constraints.

A few specific near-term recommendations have been made, such as definition of data base requirements, identification of existing data bases, and choice of a central design capability. A further long-range recommendation of broad-scale involvement in the development of standards and specifications is intended to provide continuity in the effort toward a national network capable of meeting the goals of a long-range CADET program for crew systems development.

REFERENCES

1. Computer Aided Design and Evaluation Techniques (CADET): Technical Literature Review, Air Force Flight Dynamics Laboratory, Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, October 1981.

2. Siegal, A. and Wolf, J., "Techniques for Evaluating Operation Loading in Man-Machine Systems. A Description of a Model and the Results of Its First Application." Wayne, Pa., Applied Psychological Services, 1959.

3. Conference Minutes, CADET Workshop, Wright-Patterson Air Force Base, Feb. 25, 1982.

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