UNCLASSIFIED

AD NUMBER
ADB005517
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; DEC 1974. Other requests shall be referred to Air Force Human Resources Lab., Williams AFB, AZ 85224.**
AUTHORITY
AFHRL ltr 18 Feb 1977

THIS PAGE IS UNCLASSIFIED

THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

AFHRL-TR-74-108(I)

AIR FORCE HUMAN RESOURCES LABORATORY

AD B005517

COMBAT-READY CREW PERFORMANCE MEASUREMENT SYSTEM: FINAL REPORT

By
Richard W. Obermayer
Donald Vreuls
Frederick A. Muckler
Ernest J. Conway

Manned Systems Sciences, Inc.
8949 Reseda Blvd
Northridge, California 91324

Joe A. Fitzgerald, Major, USAF

FLYING TRAINING DIVISION
Williams Air Force Base, Arizona 85224

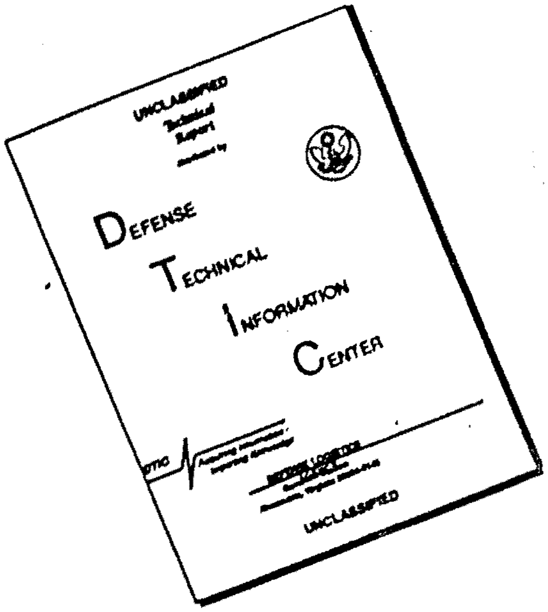
December 1974

DDC
JUL 31 1975
D

Distribution limited to U.S. Government Agencies only; Test and Evaluation; December 1974. Other requests for this document must be referred to AFHRL/FT, Williams AFB, AZ 85224.

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

NOTICE

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This final report was submitted by Manned Systems Sciences, Inc, 8949 Reseda Blvd, Suite 206, Northridge, California 91324, under contract F41609-71-C-0008 project 1123, with Flying Training Division, Air Force Human Resources Laboratory (AFSC), Williams Air Force Base, Arizona 85224.

Distribution limited to U.S. Government Agencies only; Test and Evaluation, December 1974. Other requests for this document must be referred to AFHRL/FT, Williams AFB, AZ 85224.

This technical report has been reviewed and is approved.

WILLIAM V. HAGIN, Technical Director
Flying Training Division

Approved for publication.

HAROLD E. FISCHER, Colonel, USAF
Commander

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFHRL-TR-74-108(I)	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): COMBAT-READY CREW PERFORMANCE MEASUREMENT SYSTEM. FINAL REPORT	5. TYPE OF REPORT & PERIOD COVERED: Final
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Richard W. Obermayer, Donald Vreuls, Frederick A. Muckler, Ernest J. Conway, Joe A. Fitzgerald	8. CONTRACT OR GRANT NUMBER(s): F41609-71-C-0008
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Manned Systems Sciences, Inc., 8949 Reseda Blvd, Suite 206, Northridge, California 91324	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62703F, 11230101
11. CONTROLLING OFFICE NAME AND ADDRESS: Hq Air Force Human Resources Laboratory (AFSC), Brooks AFB, Texas 78235	12. REPORT DATE: December 1974
	13. NUMBER OF PAGES: 72
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Flying Training Division, Air Force Human Resources Laboratory, Williams AFB, Arizona 85224	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to U.S. Government Agencies only; Test and Evaluation; December 1974. Other requests for this document must be referred to AFHRL/FT, Williams AFB, AZ 85224.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

D D C ... 1975

18. SUPPLEMENTARY NOTES

This report is the first of 7 volumes.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

performance measurement
flying training
measurement systems
data collection analysis systems

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Goals: To improve acquisition of training performance information through usable tools, this study was directed to: (1) Systematic definition of *performance measures* appropriate to combat-training needs. (2) Definition of a cost effective *measurement system* usable in combat-crew training environments to acquire and process needed training information.

Method: Definitions of needed performance measures were based on data derived from data collection trips to Castle AFB (B-52), Altus AFB (C-141), Dyess AFB (C-130), Davis-Monthan AFB (F-4), Tyndall AFB (F-106), Luke AFB

Item 20 (Continued)

(A-7), George AFB (F-4 crew), Norton AFB (C-141 crew), Nellis AFB (F-4 ACM). System criteria were based on an analysis of combat-crew training research procedures. Design studies were performed to provide data for tradeoffs between alternative system candidates. Finally, detailed system specifications and an implementation plan were prepared.

Performance Measures: Measurement was generated in the following steps: (1) The requirements of six aircraft were consolidated into a common framework of maneuvers: Transition, Instruments, Formation, Air Combat, Air Refueling, Ground Attack, Air Drop, Radar Navigation and Bombing; (2) For each maneuver, data collected from CCTS visits were formalized into measurement requirements; (3) Measurement parameters and (4) specifications were produced for hardware and software implications, respectively; and (5) Examination of crew interactions led to an analysis of communications measurement.

The Performance Measurement System: The performance measurement system consists of the following subsystems: (1) *Data Acquisition.* A hybrid audio/video/photo/digital recording system with programmed recording control was derived from system tradeoff analyses. A data playback station for combined manual and automatic processing is provided. (2) *Data Processing.* A general purpose digital computer with standard peripherals is required. In addition to executive and utility programs, specialized input, edit, measurement and analysis software is needed. (3) *Personnel.* A crew consisting of the following types (1) system director, (2) research personnel, (3) computer programmer, data clerks, engineers and technicians, and secretary, is needed to perform functions leading to research objectives. (4) *Facilities.* Two mobile-home trailers are recommended to house personnel and ground-based equipment.

SUMMARY

The organization of this report is intended to aid reading to the level of detail required for individual purposes. The following stages of increasing detail are pointed out to show the reader the various points at which he may stop if it suits his needs for information:

1. A one-page Abstract is included in this document.

2. Chapter I of this report constitutes a short summary of the entire program. An overview of the program and principal results are presented which may suffice for executive-level personnel, or as an initial reading for technical personnel.

3. The two major products of this study are (1) a definition of performance measures appropriate to combat-crew training needs, and (2) a definition of a cost-effective measurement system usable in combat-crew training environments. The chapters of this report, subsequent to Chapter I, amplify on these study products.

4. A number of detailed interim technical reports were prepared as working documents during the course of this contract, in the pursuit of a number of areas related to this study. Six of these are included as separate Volumes to this document. They are:

AFHRL-TR-74-108(II): Phase I. Measurement Requirements

AFHRL-TR-74-108(III): Phase II. Measurement System Requirements

AFHRL-TR-74-108 (IV): Phase IIIA. Crew Performance Measurement

AFHRL-TR-74-108(V): Phase IIIB. Aerial Combat Maneuvers Measurement

AFHRL-TR-74-108(VI): Phase IIIC. Design Studies

AFHRL-TR-74-108(VII): Phase IIID. Specifications and Implementation Plan

PREFACE

This is the Final Report of Contract F41609-71-C-0008, entitled, "Research on Operational Combat-Ready Proficiency Measurement." This contract was performed by Manned Systems Sciences, Inc., Northridge, California, for the Flying Training Division, Air Force Human Resources Laboratory (AFSC), Williams Air Force Base, Arizona. Major J. A. Fitzgerald, Chief, Combat-Crew Training Branch, was the Contract Monitor. Richard W. Obermayer served as the Principal Investigator.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

ABSTRACT

Goals

To improve acquisition of training performance information through usable tools, this study was directed to: (1) Systematic definition of performance measures appropriate to combat-training needs. (2) Definition of a cost effective measurement system usable in combat-crew training environments to acquire and process needed training information.

Method

Definitions of needed performance measures were based on data derived from data collection trips to Castle AFB (B-52), Altus AFB (C-141), Dyess AFB (C-130), Davis-Monthan AFB (F-4), Tyndall AFB (F-106), Luke AFB (A-7), George AFB (F-4 crew), Norton AFB (C-141 crew), Nellis AFB (F-4 ACM). System criteria were based on an analysis of combat-crew training research procedures. Design studies were performed to provide data for tradeoffs between alternative system candidates. Finally, detailed system specifications and an implementation plan were prepared.

Performance Measures

Measurement was generated in the following steps: (1) The requirements of six aircraft were consolidated into a common framework of maneuvers: Transition, Instruments, Formation, Air Combat, Air Refueling, Ground Attack, Air Drop, Radar Navigation and Bombing; (2) For each maneuver, data collected from CCTS visits were formalized into measurement requirements; (3) Measurement parameters and (4) specifications were produced for hardware and software implications, respectively; and (5) Examination of crew interactions led to an analysis of communications measurement.

The Performance Measurement System

The performance measurement system consists of the following subsystems: (1) Data Acquisition. A hybrid audio/video/photo/digital recording system with programmed recording control was derived from system tradeoff analyses. A data playback station for combined manual and automatic processing is provided. (2) Data Processing. A general purpose digital computer with standard peripherals is required. In addition to executive and utility programs, specialized input, edit, measurement and analysis software is needed. (3) Personnel. A crew consisting of the following types (1) system director, (2) research personnel, (3) computer programmer, data clerks, engineers and technicians, and secretary, is needed to perform functions leading to research objectives. (4) Facilities. Two mobile-home trailers are recommended to house personnel and ground-based equipment.

I. INTRODUCTION AND SUMMARY

Today, assessment of aircrew proficiency in those skills associated with advanced flying training depends largely on subjective evaluations by instructor pilots, supplemented by the more or less objective gunnery and bombing scores. In some areas, such as air combat maneuvering, combat-readiness determination is purely subjective, wholly without even the meager objective material available in other areas. An economically acceptable means of objectively measuring behavioral skills in the operational or crew training setting has been an elusive goal.

Interest in the problem has intensified in recent years because of the projected increase in costs of operating the newer weapons systems over the present generation of combat aircraft. Aircrew training costs currently absorb one quarter of the Air Force's budget and has, therefore, become an area of fiscal concern.

The key to significant cost savings lies in an approach directed to the reduction of flying hours during training, and the transfer, where possible, of such training to lower cost devices. Illustrative of the magnitude of the possible savings is a letter from the Commander of the Tactical Air Command to the CSAF[1], in which the TAC Commander describes an experimental aircrew training class in which a reduction of 35 flying hours per student would result in an estimated $700,000 cost savings.

The USAF is attempting to adapt modern Systems Approach to Training (SAT) techniques to aircrew training programs[2]. Inherent in the SAT concept is student advancement on individual proficiency rather than course length. For the more complex aircrew training objectives, the traditional subjective evaluative methods may prove insufficient.

Objectives

In an effort to improve training performance information, this study was directed to two objectives:

Goal 1. Systematic definition of performance measures appropriate to combat-crew training needs. Performance measures will include formal statements of methods of measuring flight

---

[1]Ltr, CC TAC to CSAF, 14 Mar 70, Subject: "Flying Training Efficiency."

[2]Ltr, CSAF to MAJCOMS, 2 Feb 70, Subject: "Flying Training Efficiency."

crew performance used during and at the end of combat-crew training, and, new measures meaningful to combat-crew training and useful as tools for training research.

Goal 2. Definition of a cost-effective measurement system, usable in combat-crew training environments to acquire and process needed training information. Specification of the recommended system includes all data acquisition devices and methods, data processing hardware and software, facilities, and personnel necessary for training research.

This study thus was an effort to describe usable measurement tools for utilization in combat-crew training research.

Instructional system development. Research studies directed toward performance measurement in combat-crew training are highly relevant today in view of USAF policy to employ a systems approach to flying training problems. The model for Instructional System Development (cf., Dept. of Air Force, 1970) contains the following basic steps:

1. Analyze system requirements.
2. Define education or training requirements.
3. Develop objectives and tests.
4. Plan, develop, and validate instruction.
5. Conduct and evaluate instruction.

In support of instructional system development, measures and a measurement system are necessary to (1) perform analyses of systems in their operational environments, (2) establish quantitative instructional standards, (3) provide an index of achievement for each behavioral objective, and (4) evaluate alternative instructional content, approaches, and training devices.

In particular, instructional system development requires that performance standards are identified so that the most efficient approach is used to train the needed skills and knowledge to the desired level of performance. Such performance standards imply performance measurement for both the determination of desirable approaches to training and for testing student performance.

A measurement system for the operational environment. It was required to develop measurement tools that would be usable in the operational environment under the constraints that such an environment implies. Within the context of this requirement, it was necessary to establish a list of parameters to be sensed, and the point-of-view taken was that the parameters should be derived from that information that the operational training personnel consider to be meaningful and significant.

An automated measurement system. An ancillary objective was to develop a measurement system that would relieve the instructor pilot, to a maximum extent, from the requirement of having to record a great deal of information manually on the basis that such activity degrades his ability to competently instruct his student. This does not imply that such a measurement system is an attempt at automated evaluation. The measurement system should certainly include means for transforming and analyzing performance information, but ultimately evaluation and decision for training control is a human function.

Measurement Based on Combat-Crew Training Information Needs

The strategy employed was to design a measurement system that could acquire that data identified as meaningful by training management and instructor personnel. On-site visits were made across a broad spectrum of combat-crew training programs to define these data.

The combat-crew training sites visited are listed in Table 1. The aircraft sample included heavy (inter- and intra-theatre cargo/transport, and bomber) and high-performance aircraft (one- and two-man interceptor and tactical fighter). An attempt was made to (1) consider measurement in the context of combat-crew training, (2) assess measurement already included as well as identify potential measurement indicated by combat-crew training personnel, and (3) assess the constraints placed by the environment on feasible, usable measurement systems.

Measurement System Criteria

While definition of measurement was based on training information needs, the criteria for the measurement system were based primarily on consideration of the use of measurement to achieve research goals. To achieve research goals, measurement must produce information in a timely and useful form during typical research activities.

Typical research sequence. A typical research sequence is shown in Figure 1.

(1) The test plan and measurement specification provides an initial statement of research crew activities in achieving specific data answering to the research problem.

(2) For the data to lead to meaningful measurement, the research crew must be very familiar with expected performance and difficulties which will be met; consequently, they must be aware of the goals of each mission as planned and accomplished, and all factors related to performance on each flight (mission briefing/debriefing and flight monitoring).

TABLE 1

DATA COLLECTION SITES

PLACE	AIRCRAFT
Castle AFB	B-52 F, G & H
Altus AFB	C-141A
Dyess AFB	C-130E
Davis-Monthan AFB	F-4 C, D & E
Tyndall AFB	F-106 A & B
Luke AFB	A-7D
*George AFB	F-4E
*Norton AFB	C-141A
**Nellis AFB	F-4E

*Special emphasis on crew-performance measurement.

**Special emphasis on air-combat maneuvers performance measurement.

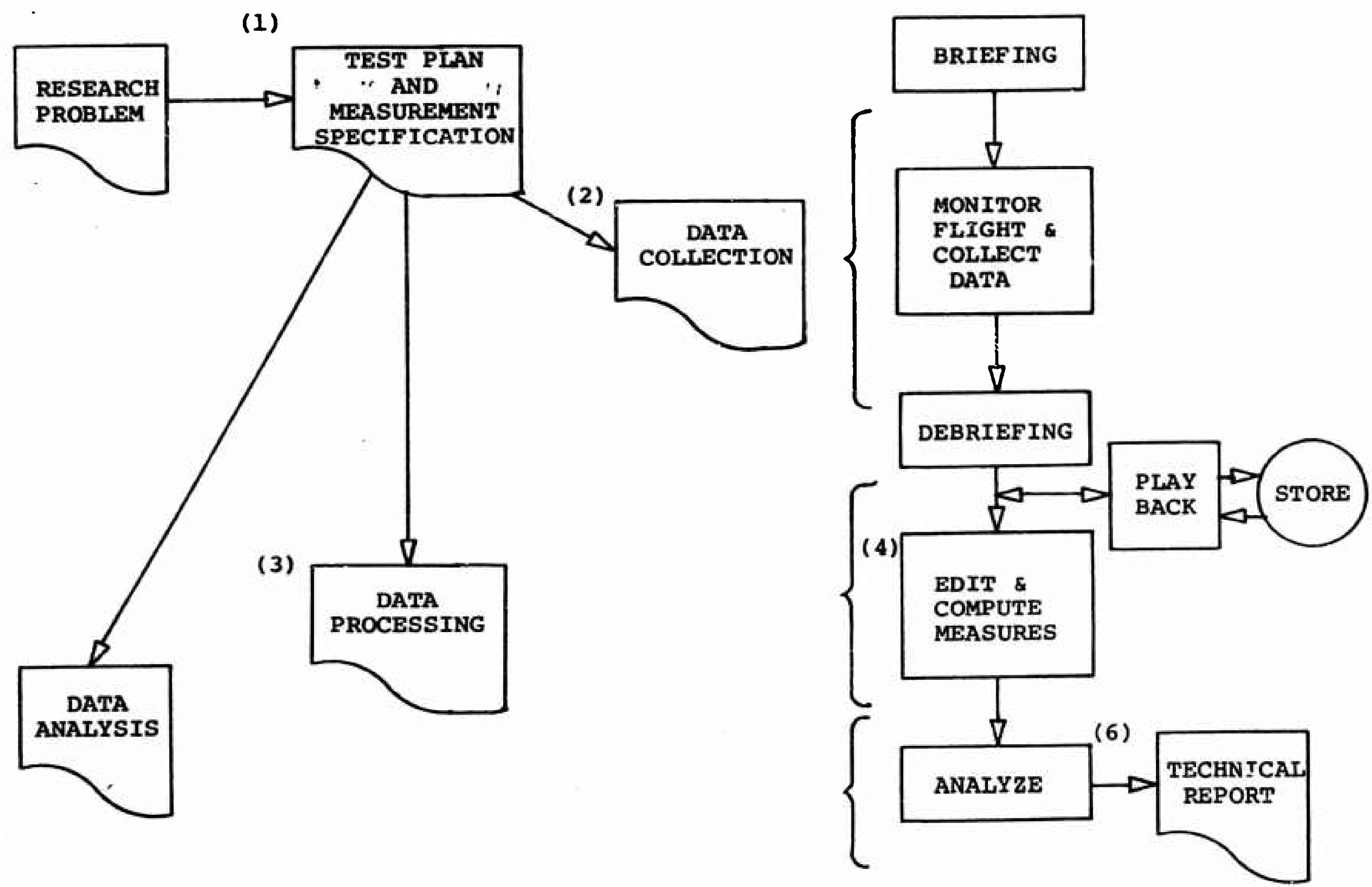


Figure 1. Typical Research Sequence.

(3) Data processing is ordinarily an iterative procedure, trying alternatives and adapting to performance characteristics, until the best data forms are achieved.

(4) All known data collection systems permit frequent errors, making data editing a major and important task which requires digital computer support.

(5) Data analysis, like measurement development, is an iterative process, searching for the best means to fully present experimental results; analytical tools involve large libraries of computer programs for statistical treatment.

(6) In general, the research crew will be responsible for using the facility described to produce a technical report answering to specific research objectives.

System criteria. The following criteria were used for tradeoff analysis of candidate measurement systems and to guide design of the selected approach.

(1) Provide needed information. If a measurement system is viewed as an information system it becomes apparent that the most important consideration is that it produce the information needed, i.e., primarily the information which was identified with the aid of combat-crew training personnel.

(2) Provide data in a useful form. Data should be provided in a useful form for (1) research objectives, and (2) combat-crew training.

(3) Short research cycle time. So that measurement is sufficiently timely, the measurement system must be set-up for operation as soon as possible after a research topic is identified, the system must be reliable to allow data collection to keep pace with training schedules, and, processed data must be available shortly after each flight to permit effective review (within one hour for debriefing purposes, within 12 hours for research review).

(4) Minimum initial/sustaining costs. Initial costs include modification of devices, installation, design and equipment purchases. Sustaining costs include personnel salaries, facility leases, supplies and services. These costs must be traded-off against the utility of the information derived.

(5) Minimum data distortion. Data distortion must be controlled so that missing and uninterpretable data do not render research meaningless.

(6) Compatible with different training devices. The measurement system should be able to support training and research which may take place with a wide range of existing or proposed training devices.

(7) Permit iterative design of valid measurement. Iterations in measurement design must be sufficiently convenient so that valid measurement appropriate to research needs may soon evolve.

(8) Minimum interference with training processes. A measurement system for training research should be inconspicuous, requiring little or no attention from the student or instructor.

(9) Permit correlation with data from external sources. For any given study, data from a number of such data sources may be collected, combined and correlated.

(10) Minimum space, weight, cooling and power requirements. Data acquisition equipment must be installable in aircraft of the present and future U.S. Air Force inventory, including fighter-type aircraft.

(11) Effective self-sufficient personnel/facility configuration. A proper mix of people, tools, supplies, facilities, and support are needed to successfully sustain and use a performance measurement system for training needs.

Product 1. Combat-Crew Performance Measurement

To a large extent, a common basis for measurement was established for the six aircraft included in the study; thus, allowing for a more or less modular approach. Allowance must be made for special aircraft characteristics; for example, the F-106 has no flaps and the B-52 has a quite complicated flap retraction routine compared to other aircraft. Measurement was treated for each of the following maneuvers:

(1) Takeoff and Climb
(2) Pattern, Land and Go-Around
(3) Instruments--General and Example
(4) Formation
(5) Air-Air Intercept
(6) Air Combat Maneuvers
(7) Air Refueling
(8) Ground Attack
(9) Air Drop and Air Drop Formation
(10) Radar Navigation and Bombing.

Prototype measurement. For each of these maneuvers, the data collected from combat-crew training site visits were compiled into the summary form shown in Figure 2. Since the blanks in the summary form of Figure 2 indicate needed information, and consequently items for measurement development, these forms were termed Prototype Measurement since they form a model after which measurement could be patterned.

TAKEOFF & CLIMB*

CONDITIONS:

Gross Wt: ____ Wing: ____/____ Runway: ____/____
Temp.: ____ Alt.Set.: ____ Field Elev. ____ Form Pos.: ____

TAKEOFF ROLL: (TO power until rotation)

Power Set: ____ Centerline Dev.: Min, Max, Av.
Reject Speed: Computed Heading: Min, Max, Av.
Time: ____ Dist: ____ Bank: R Max, L Max

ROTATION: (Nose gear off until pitch att. established)

Rot. Speed: ________ Stab. Trim: ________
Pitch: Rate: ________ Bank: ________
Final: ________ Centerline Dev.: ____
Overhsoot: ____ Heading: ________

LIFTOFF: (Pos. Vert. Vel.)

Unstick Speed: ____ Pitch: ____ Bank: ____ Hdg: ____
Vert. Vel. After: ____ Sec.: ____

GEAR-UP: (Handle up until gear-up & locked)

Gear-Up Speed: ____ V.V. Init.: ____ V.V. Final: ____
Pitch: ____ Bank: ____ Hdg: ____

FLAPS UP: (Start up to full up) Note: F106 has no flaps

Trim: ____
Pitch: ____ Bank: ____ Hdg: ____
A/S (INIT) ____ (FINAL) ____
VV (INIT) ____ (FINAL) ____
ALT (INIT) ____ (FINAL) ____

B-52 Only	IAS	PITCH	ALT	VV	TRIM
Start	x	x	x	x	x
1st Pos	x	x	x	x	x
2nd Pos	x	x	x	x	x
Full	x	x	x	x	x

CLIMB & LEVEL-OFF: (Depends on Flight Plan)

	PWR	A/S	MACH	INIT HDG	ALT	FINAL ALT	PITCH	TRIM
Accelerate	x	x	x	x	x	x	x	x
Climb A/S (#1) (#2)	x	x	x	x	x	x	x	x
Climb MACH	x	x	x	x	x	x	x	x
Level-Off (Alt-10% VV) (to Cruise)	x	x	x	x	x	x	x	x

---

*Also, mandatory communication & instances where A/C limits are exceeded.

Figure 2. Example of Prototype Measurement.

Measurement specifications. The parameters which must be sensed to permit measurement are not immediately evident from the information requirements (Prototype Measurement), since the measure specifies the output of a computation, and the computation itself must be known before the inputs to the computation (the parameters) can be determined.

For example, Figure 2 indicates that a measure of centerline deviations is desired during the takeoff roll. It is clear that the distance between the aircraft position on the runway and the runway centerline is a parameter needed for measurement. The desired measurement might be simply the average difference, or, conceivably, might involve the relationship between centerline deviation and heading (or lateral-G, or brake application) and thereby indicate the need for other parameters to execute the calculations for measurement. Further, the measurement calculations must be made (as indicated in Figure 2) from the application of takeoff power until rotation, implying the need for other parameters to indicate when the measurement interval starts and stops.

Consequently, in addition to basic obvious parameters, the following types of parameters may be needed for computation: (1) parameters for implementing logic to start and stop measurement computations, (2) information re ..ed to desired performance, and (3) error information derived fro the difference between actual and desired performance.

Therefore, using the Prototype Measurement as an initial point, the logic and computations to be used in measurement data processing were developed. The results of this step were presented in forms as shown in Figure 3. The data included in these forms either (1) constitutes a specification for computer software where automated processing is applicable, or (2) describes data clerk procedures where manual processing is employed.

Product 2. Performance Measurement System

A large portion of the design tradeoff analyses (Volume VI) were devoted to the comparison of video or photographic recording techniques with digital recording techniques. The ultimate conclusion was that neither application could fully satisfy all information requirements. A hybrid system was therefore recommended. However, since it was recognized that the full hybrid system would not be needed for all problems, and that such a system is costly, a modular hybrid system was specified. Depending on the specific nature of a given application, the full system could be used, or just the video/photo subsystem, or just the digital recording subsystem. Audio recording is provided with either modular subsystem.

A diagram of the performance measurement system ultimately recommended is depicted in Figure 4. A detailed description is presented in Chapter III of this report.

MANEUVER	MEASURE	FUNCTION	CONDITIONS	COMMENTS
TAKEOFF Roll	GMT	Value	At brake release.	
	Power Brakes	Average MC	From brake release to rotation.	Power, aircraft dependent; use fuel flow, TIT or N_2.
	Centerline Deviation	Average Minimum Maximum	From brake release to rotation.	Complex instrumentation . On ILS runways, use localizer deviation corrected for range. Range either ILS/DME or approximation using the integral of airspeed. . TACAN accuracy probably not sufficient. . Windscreen, HUD photography possible source with rotation. . Good inertial (commercial quality) also possible source.
	Heading	Average Minimum Maximum	Error from rnwy heading from brake release to rotation.	Insertion of rnwy heading required in processing.
	Roll	Minimum Maximum	From brake release to rotation.	Looking for maximum left and maximum right roll attitude.

Figure 3. Example Measurement Specification.

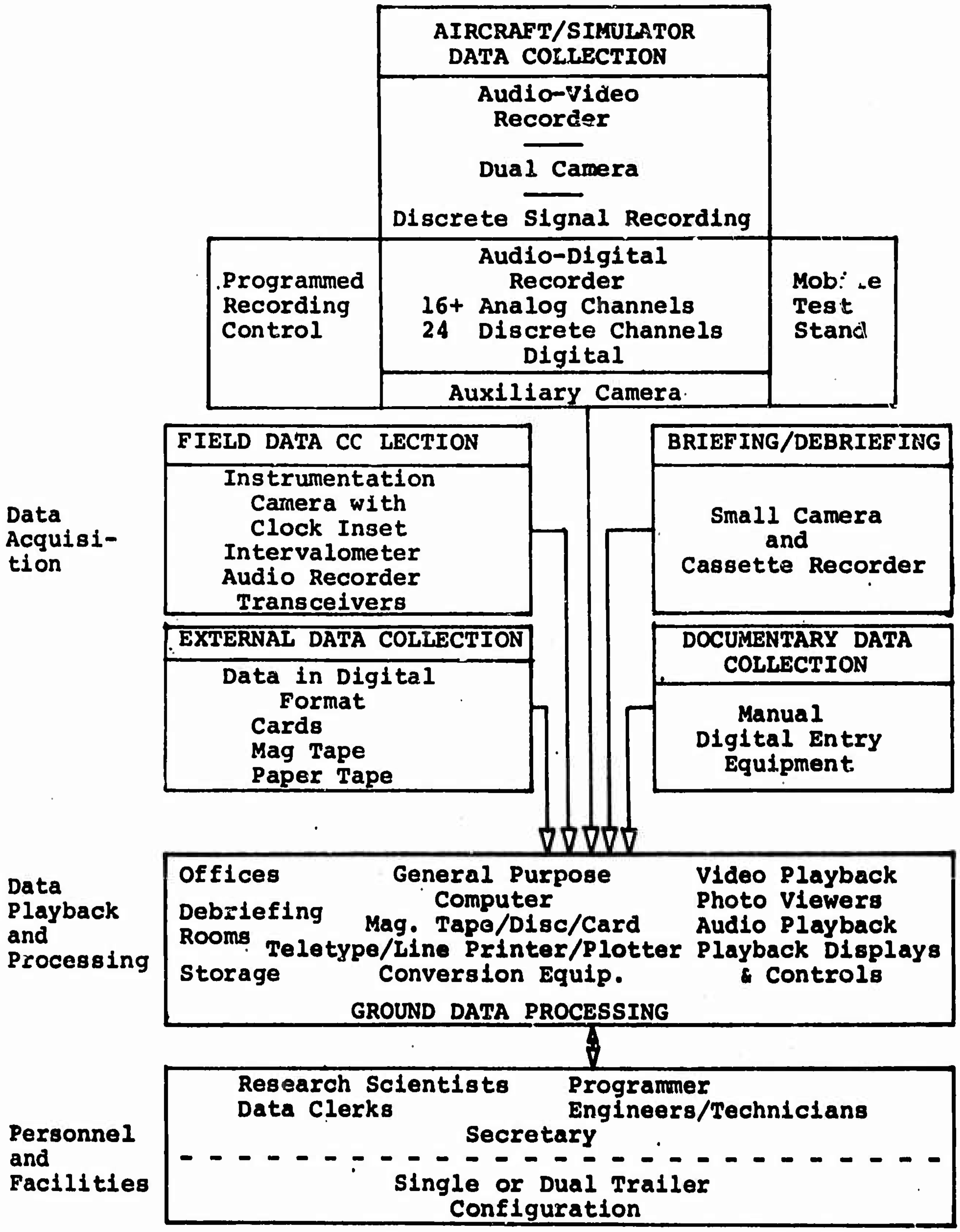


Figure 4. Mobile Combat-Crew Performance Measurement System.

Data acquisition. Data acquisition must provide for the following data sources: (1) aircraft and simulator, (2) field (e.g., runway or range), (3) briefing and debriefing, (4) external sources (e.g., other studies), and (5) documents. The major amount of data acquisition equipment is required for aircraft/simulator performance data. A hybrid audio/video/digital recording system was specified, including semi-automatic programmed recording control. An auxiliary camera is required for some mission types (e.g., air drop) and provided as a supplement for others. To reduce costs the digital recording capability was restricted, but sufficient capacity exists to provide stand-alone digital recording for many applications. The video recording equipment, which is the source of all pictorial or out-the-window information, is augmented with discrete recording channels (for events such as wheels-up, speed brakes out, weapon firing, etc.) to expand video recording capacity and permit rapid manual processing (by providing convenient stopping points used to key manual data reading).

Data playback and processing. It is clear that audio and video data recording requires manual processing, while digital recording permits use of a high degree of automation. Data processing must therefore provide for integrated manual and automated data playback. A general-purpose digital computer with many standard peripherals is needed to (1) input data, (2) edit data (man-computer interaction), (3) compute measures, and (4) perform data analyses. Standard executive software and user languages (FORTRAN IV) must be augmented with special measurement processing programs.

Personnel and facilities. The system is housed in either a single- or dual-trailer configuration, employing a structure used for mobile homes. In this fashion, the ground-based portion of the system is easily transported to a new data collection site and rapidly readied for use. Example layouts are shown in Figure 5.

An integrated research team capable of all research functions, starting with problem identification and following through with a technical report, is recommended. The personnel complement will include (1) Research Scientists, (2) Programmer, (3) Data Clerks, (4) Engineers and Technicians, and (5) Secretary. The crew conducting the research must possess a blend of skills and knowledge, including the following experience: (1) U.S. Air Force Combat flying, (2) training psychology, (3) experimental design, (4) field research, (5) statistical analyses, and (6) programming.

More Detailed Information

The remainder of this report expands upon the two principal study products: Chapter II. Combat-Crew Performance Measurement, and, Chapter III. A Mobile Combat-Crew Performance Measurement System. Chapter IV discusses implications for development of the system described.

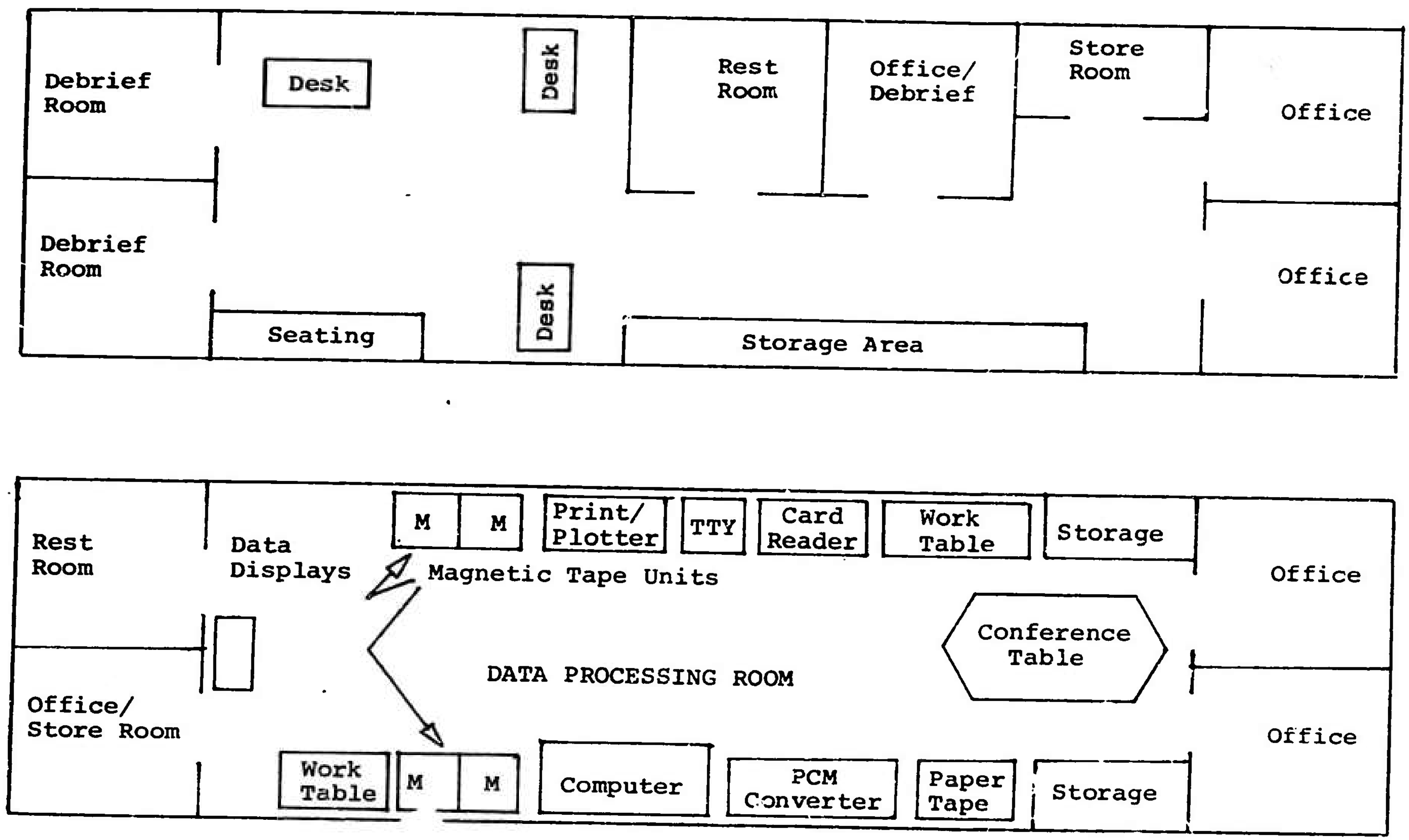


Figure 5. Example Mobile Measurement System Configuration (12' x 60' Trailers).

For further detail on the principal study products, as well as the analyses and methods used, reference should be made to:

AFHRL-TR-74-108(II): Phase I. Measurement Requirements

AFHRL-TR-74-108(III): Phase II. Measurement System Requirements

AFHRL-TR-74-108(IV): Phase IIIA. Crew Performance Measurement

AFHRL-TR-74-108(V): Phase IIIB. Aerial Combat Maneuvers Measurement (Secret)

AFHRL-TR-74-108(VI): Phase IIIC. Design Studies

AFHRL-TR-74-108(VII): Phase IIID. Specifications and Implementation Plan

II. DERIVATION OF COMBAT-CREW PERFORMANCE MEASUREMENT

One of the principal products of this study was the definition of performance measures appropriate to combat-crew training needs. Based on interviews with instructors and training management, measurement definitions evolved in the following steps:

(1) The varied requirements posed by the six aircraft and missions were consolidated into a common framework which permitted isolation of measurement modules (measurement commonality);

(2) Discussions of operational training information needs were formalized to indicate in a checklist fashion the measurement development needed (prototype measurement);

(3) Measurement parameters and (4) measurement specifications were produced together, but are presented separately for hardware and software implications, respectively;

(5) Measurement and analysis for crew communications recording were examined to provide means of examining crew interactions and individual contributions to total man-machine system performance.

Measurement Commonality

Common measurement was desired to permit the design of one simple and practical measurement system, and eliminate the need for a totally unique measurement system for each aircraft.

Common training phases. As a first step to assessing commonality of measurement requirements, similar training phases were compared for each aircraft. Table 2 presents the training phases compared.

Not all maneuvers were taught at all sites visited. For example, the operational C-130 squadron visited did not explicitly train transition maneuvers; nevertheless, competent information was obtained for measurement. The F-106 air refueling modification had not been completed, and therefore was not trained. All combat maneuvers were not taught at the combat-crew training squadrons visited, but attempts were made to fill these gaps in data collection by cross-checking with other aircraft training where possible.

The following observations are indicative of the degree of commonality of training phases for the six aircraft:

(1) Transition (TR). Transition maneuvers occur in a common fashion, but the manner in which they are performed varies.

TABLE 2

COMMON TRAINING PHASES

MULTI HEAVY			HI PERF		
B-52	C-141	C-130	F-106	F-4	A-7
TR	TR	TR	TR	TR	TR
INST	INST	INST	INST	INST	INST
-	FORM	FORM	FORM	FORM	FORM/BFM[1]
			AA	AA	
				BFM/ACM	FORM/BFM[1]
AR			-	AR	AR
	AIR DROP	AIR DROP		GA	GA
HI LOW (BOMB)		BEACON DROP		GAR	RNB

LEGEND

TR: Transition
INST: Instruments
FORM: Formation
BFM: Basic Flight Maneuvers
AA: Air-Air Intercept
ACM: Air Combat Maneuvers
AR: Air Refueling
GA: Ground Attack
GAR: Ground Attack Radar
RNB: Radar Navigation Bombing
- : Data Not Available at Sites Visited

[1]Formation and Basic Flight Maneuvers are combined into one phase for A-7D training; therefore, a portion is similar to formation training on other aircraft, and a portion is similar to air-combat maneuvers training for the F-4 aircraft.

(2) Instruments (INST). Instrument maneuvers, and the external criteria which must be met, are essentially the same.

(3) Formation (FORM). Formation flight is performed by all six aircraft as a means to optimally employ composite flight and provide individual-ship effectiveness. However, a number of types of formation exist for specialized missions, each appropriate only to specific aircraft.

(4) Air-Air Intercept (AA). Air-to-air intercept and weapons delivery utilizing airborne radar is accomplished with only the F-4 and F-106 aircraft (rendezvous for air refueling is a different problem). While the F-4 and F-106 maneuvers and equipment differ, the same basic measurement requirements are presented.

(5) Basic Flight Maneuvers (BFM) and Air Combat Maneuvers (ACM). BFM and ACM are grouped together in F-4 training, while BFM and Formation are grouped together in A-7 training. The BFM/ACM grouping was maintained for purposes of measurement development, but formation was treated as a separate measurement problem.

(6) Air Refueling (AR). Air refueling can occur with four of the six aircraft, but is only considered a difficult maneuver for the B-52. Consequently, air refueling for the B-52 was emphasized.

(7) Ground Attack (GA) and Air Drop. A number of training phases are devoted to F-4 and A-7 ground attack (Day, Tactical, Night, with various weapons and delivery modes), but common measurement was judged to be appropriate.

Air Drop (Combat Airlift Mission) maneuvers for C-141 and C-130 training perhaps superficially resemble level-flight ground attack, but quite different measurement requirements are posed.

(8) Radar Navigation and Bombing (RNB). Navigation by use of radar, and subsequent delivery on target of either ordinance or cargo, occurs with most of the aircraft of the sample except the F-106, and compatible mission performance measurement is indicated.

Composite of training phases. From this examination, it is concluded that measurement can be directed to a composite of the training phases for the sample of six aircraft, as follows:

Transition
Instruments
Formation
Air-Air Intercept
Air Combat

Air Refueling
Ground Attack
Air Drop
Radar Navigation and Bombing

Of course, all of these training phases are not applicable to all aircraft of the sample, requiring only that the measurement subsequently developed be ignored where inappropriate. While there are differences in measurement requirements for specific aircraft within a given "common" training phase, these are slight compared to measurement differences across training phases.

Common Measurement

Each phase of flight, tentatively considered to permit common measurement, was examined for detailed measurement requirements. For each maneuver, measurement requirements were extracted from (1) interview notes with Instructors and Training Managers, (2) Aircraft Technical Orders, (3) Phase Manuals, (4) Instructor Guides, and (5) other specialized documents. In particular, important parameters, judging factors and common errors were noted for each maneuver. The information which an instructor pilot, or training manager, would consider important was especially stressed for translation into objective measurement.

For example, measurement requirements were noted for each aircraft during takeoff and climb-out maneuvers (Runway Roll, Rotation, Liftoff, Gear-Up, Flaps-Up, Climb and Level-Off). A matrix of measurement requirements was thus produced, allowing comparison across aircraft. It was noted that takeoff and climb-out are essentially the same for all aircraft, with the exception of the importance of some maneuvers (e.g., rotation is critical with the F-106), variations in aircraft design (e.g., F-106 has no flaps, B-52 involves a complicated flap schedule), and climb profiles depend on the specific mission and clearance.

While the similarities far outweighed the differences when comparing measurement requirements across aircraft, it was clear that a number of differences nevertheless did exist. On the other hand, it was apparent that the basic measurement components were the same, and a small number of specialized measures sufficed for unique aircraft requirements. In short, measurement could be derived from a relatively small number of building blocks for any aircraft and maneuver. Therefore, a modular approach to measurement was justified.

Prototype Measurement

As a logical extension of the considerations of measurement commonality, examples of the information required for training were developed in the form of formatted measurement outputs. That is, the information needs were expressed as example measurement, with blanks to indicate specific measures to be developed.

These forms were termed prototype measurement since they found a model after which measurement could be patterned. A full discussion of these prototype measures is presented in Volume II.

An example of prototype measurement is displayed in Figure 2 for takeoff and climb. Similar measurement was developed for each training phase; these are presented in Volume II. A blank or x in Figure 2 indicates one or more numerical entries to be determined as a result of measurement. Checking or mandatory communications, and other critical communications, is assumed in addition to other measures of performance in each of the prototype measurement forms.

(1) Transition. For convenience, transition was divided into (1) Takeoff and Climb, and (2) Pattern, Land or Go-around. As previously noted, measurement appropriate to the composite of six aircraft is indicated; the F-106 and B-52 require special treatment.

(2) Instruments. Measurement for instrument flight is treated as the sum of (1) basic aircraft control performance, and (2) navigation performance with respect to air traffic control requirements. While required measurement modules for each of these classes of measures can be specified, it is difficult to present detailed measurement except for specific clearances and published procedures.

(3) Formation. Measurement for formation flight is superimposed onto mission performance measurement, thus making formation measurement difficult to isolate. In particular, tactical formation performance was not clearly identified in this study in an objective quantitative fashion. It may be necessary to rely heavily on instructor subjective measurement (which may be quite satisfactory when the instructor is in a position to observe performance), except for measurement associated with join-up, close formation, and in-trail formation.

(4) Intercept. In order to be specific, intercept measurement was based primarily on the F-106, however, the intercept problem is essentially the same as the F-4. Of course, a two-man crew performs in the F-4 (crew performance measurement is discussed later).

(5) Air Combat Maneuvers. Prototype air combat maneuvering measurement dealt primarily with set-ups during initial training and for dart firing. A more extensive treatment is presented in Volume V. Measurement for more extensive air combat training is indicated in Table 3.

(6) Air Refueling. As Air Refueling is especially difficult in B-52 combat-crew training, the prototype measurement was tailored to the B-52 tasks and to Strategic Air Command requirements.

TABLE 3

CANDIDATE ACM MEASURES

BASIC AERODYNAMICS	MEASURES
DIHEDRAL EFFECT ADVERSE YAW LIFT AND DRAG	AOA, A/S, ALT, PITCH, ROLL, YAW/SIDE SLIP, RUDDER, STICK.
TURNING PERFORMANCE	MEASURES
HORIZ. & VERT. $G_R = \tan\phi$ $G_T{}^2 = G_R{}^2 + 1$ $G_T = G_R + \cos\theta$	ROLL G VELOCITY (ATTACKER) VELOCITY (DEFENDER) ANGLE OFF DISTANCE BETWEEN ACRFT
RADIUS & RATE OF TURN $R = V^2/G_{Rg}$ $\omega = G_{Rg}/V$ $R = V^2/g\ (G_T - \cos\theta)$	
PURSUIT CURVE $\omega = V_D\ (\sin(AO)/S)$ $\cos(\text{AO of Max G}) = V_A/2V_D$	
ENERGY MANEUVERABILITY	MEASURES
	ALT, A/S, M, FUEL, THROTTLE, G, VV, AOA or C_L, TURN RATE & RADIUS.
MANEUVERING SEQUENCES	MEASURES
OFFENSIVE/COUNTER-OFFENSIVE HI/LO PERF RANGE	ENERGY/AERO COND., FLIGHT PATH, VEH. ATT., THRUST, ANGLE-OFF, BEARING, G, ALT., VELOCITIES, CLOSURE, TRACKING ACCURACY, LAUNCH PARAMETERS, SET-UP.

(7) Ground Attack. Ground attack measurement was dictated by information needed for standard error analysis of weapons delivery accuracy and by ground attack procedures. Some of the measures are specially designed to apply to the A-7D heads-up display.

(8) Air Drop. Extensive prototype measurement was dictated for the Combat Airlift Mission since very detailed procedures are adhered to throughout the many portions of the mission. Crew performance is especially important in this mission.

(9) Radar Navigation and Bombing. Prototype measurement for Radar Navigation and Bombing is heavily dependent on the characteristics of the avionics used. As only the B-52 is equipped with low-level terrain avoidance radar (of the aircraft sampled in this study), measurement for these maneuvers has been tailored to this application.

Measurement Parameters

Measurement is the process of producing measures which are indices of performance such as the conditions existing at the time of weapon release during ground attack, deviations from the clearance during IFR flight, and flight conditions at liftoff. The measures are commonly computed from flight variables (e.g., altitude, airspeed, heading, etc.) and other raw information which must be recorded at some time; these are termed measurement parameters. The measurement parameters must be specified so that the required sensors and recording equipment can be determined. However, since the measures are the result of a computation, the details of the computation must be known so that the inputs to the computation (the parameters) can be established.

Figure 6 depicts the relationship between the specified measures, the computation, and the measurement parameters. The corresponding data processing is shown in Figure 7. It is assumed that the flight maneuvers will be divided into segments, so that different measures may be computed as appropriate for each segment (for example, different measures are required during takeoff roll than during climb-out). Consequently, it may be seen that the method of determining when to start and stop the computation of a specific measure may require the recording of measurement parameters in addition to those required during measure computation (e.g., the recording of weight-off-the-wheels to indicate liftoff).

In Figure 6, the output measures (O) correspond to the information requirements symbolized by the blanks in the prototype measurement forms; that is, if the prototype measurement forms indicated that a measure of centerline deviation is needed, then parameters must be recorded and computations developed which will answer the required measure, the following types of parameters may be needed in addition to the basic test parameters (M) (for example just mentioned, the basic test parameter would be a

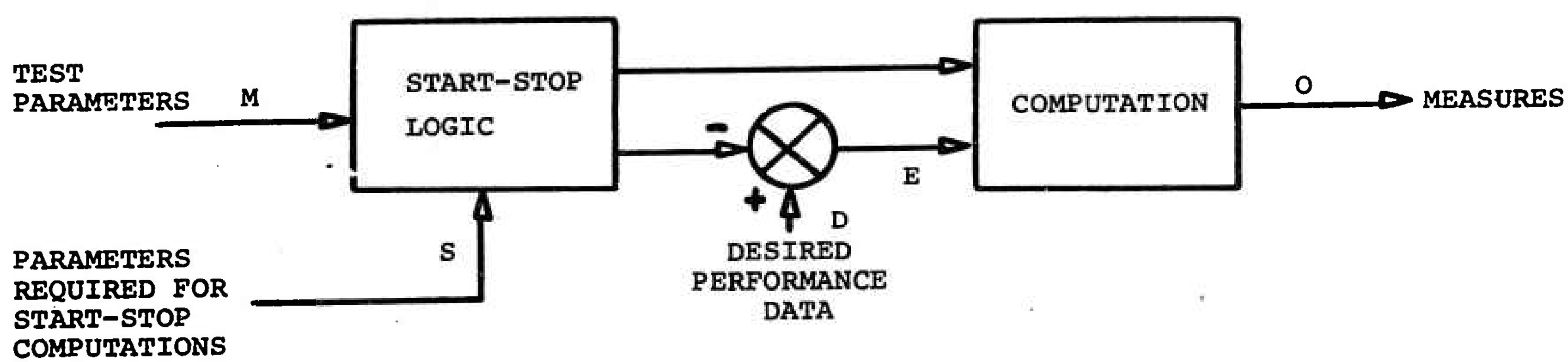


Figure 6. Identification of Measurement Parameters.

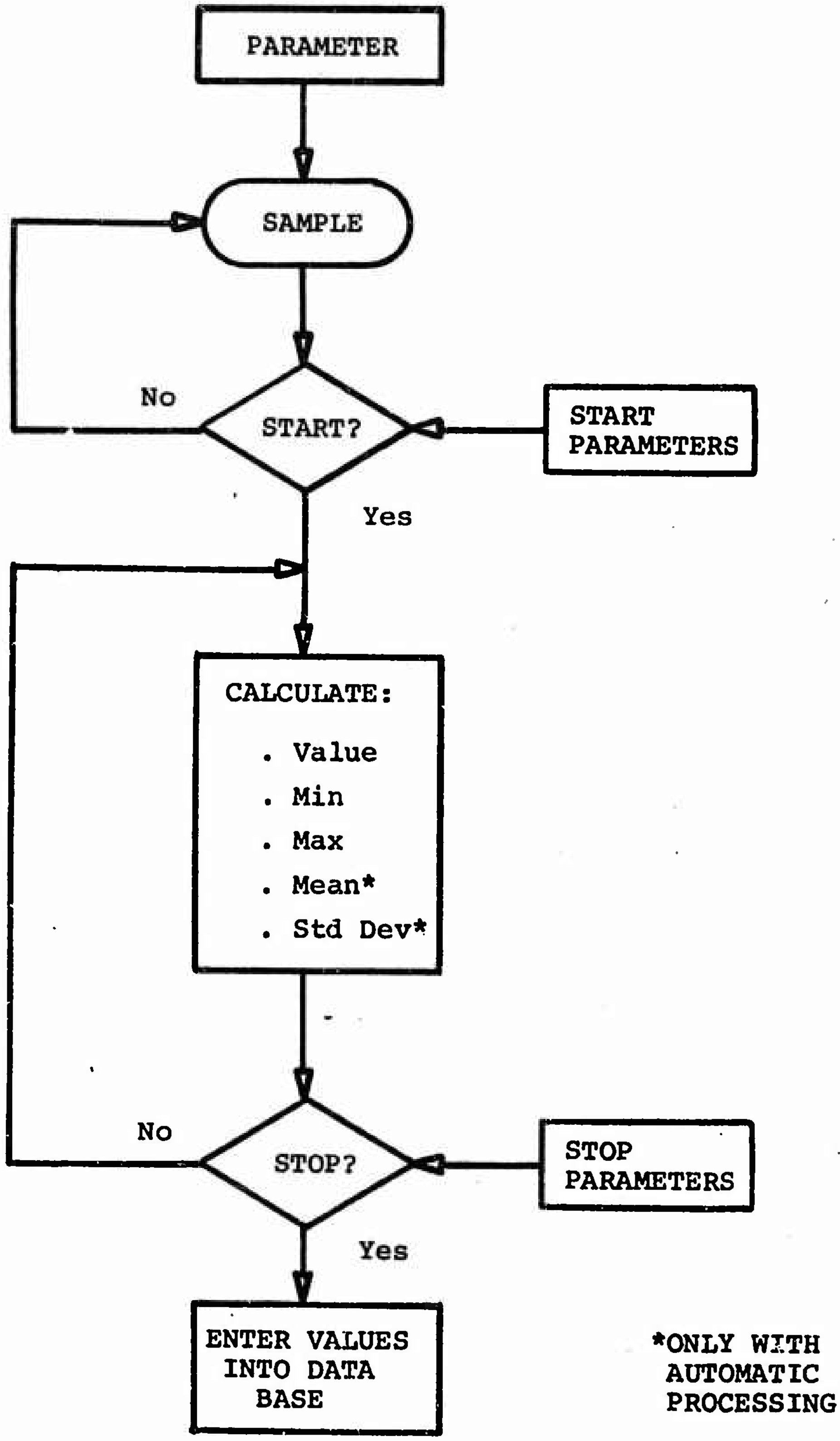


Figure 7. Example Raw Data Processing.

recording of the deviation from the runway centerline during takeoff roll): (1) parameters for implementing logic to start and stop measurement computations (S), (2) information related to desired performance (D), and (3) error information derived from the differences between actual and desired performance (E).

When a list of parameters was developed to show all the required sensors and recording needed for total measurement, it was seen that the resulting parameters could be placed in the following overlapping categories: (1) pictorial information (e.g., out-the-window radar), (2) analog information (e.g., time-varying quantitative, such as airspeed), (3) discrete information (e.g., weapon release), (4) audio information (e.g., communications), and (5) desired performance and existing conditions. These parameters were later assigned to alternative devices for data acquisition. After tradeoff analyses were conducted, a hybrid audio-video/photo-digital recording system was adopted. Although many parameters could be acquired by either video-photo or digital recording devices (to allow a partial system to have a stand-alone capability), tentative parameter allocations are listed in Tables 4 and 5. Audio recording will be accomplished with either video-photo or digital recording devices. Desired performance and conditions are manually derived from briefing/debriefing sessions and documents. Additionally, spatial coordinates (X-Y data) may be obtained if data are collected on an instrumental range including tracking-radar equipment, although equivalent information may be available from video-photo recording as shown in Table 6.

After detailed trade-off analyses, the use of video or photo techniques was emphasized due to lower costs, flexibility of application and simpler development compared to other all-electronic techniques; however, the problems associated with cockpit installation and an unfortunate tendency for loss of data should be noted, but it is believed necessary to accept these deficiencies for low-cost combat-crew training application (see Volume VI).

Accuracy requirements for measurement parameter sensing and recording are listed at the right-hand side of Table 4. These accuracies are referenced to the information displayed to the crew (for example, the required airspeed tolerance is ± 1% of the deviation between recorded values and those displayed to the pilot on his airspeed indicator) since the criterion given the crew is that they maintain vehicle parameters within specified tolerances referenced to their instruments (typically 5-10 knots for airspeed control). The tolerances listed in Table 4 are approximately 1/10th the tolerances required of the crew.

Measurement Descriptions

The gross operations involved in measurement computation are presented in the flow diagram in Figure 7. Each parameter must be sampled (at a sampling rate of 2, 10 or 20 times a second,

TABLE 4

PARAMETERS FOR DIGITAL DATA ACQUISITION

	TRANSITION	INSTRUMENTS	FORMATION	INTERCEPT	AIR REFUEL	AIR DROP	GROUND ATTACK	DART FIRE	AIR COMBAT	ACCURACY
AIRCRAFT PARAMETERS										
1. Pitch (Pitch Rate)	X	X		X		X	X	X	X	±1 degree
2. Roll	X	X		X		X	X	X	X	±1 degree
3. Heading	X	X	X	X		X	X	X	X	±1 degree
4. Airspeed	X	X	X		X	X	X	X	X	±1 knot
5. MACH	X			X					X	±.02 MACH
6. Altitude	X	X		X	X	X	X	X	X	±10 feet
7. Vert. Vel.	X	X		X	X	X	X	X	X	±50 fpm
8. Angle of Attack	X	X		X			X		X	±1 unit
9. Acceleration (G),	X			X			X		X	±.5G
10. Power (RPM, EPR, TIT, Fuel Flow)	X	X		X	X	X	X	X	X	±1% Full Scale
11. Fuel Quantity				X	X				X	±5% Full Scale
CONTROL PARAMETERS										
1. Stick (Pitch)			X		X				X	±5% Full Scale
2. Stick (Roll)			X		X				X	±5% Full Scale
3. Rudder									X	±5% Full Scale
4. Flap Position	X					X			X	±5% Full Scale
5. Stab Trim Position	X		X		X					±5% Full Scale
BINARY DISCRETE PARAMETERS										
1. Thrust Reverse	X									--
2. Speed Brakes	X	X			X				X	--
3,4. Main, Nose Gear Contact	X									--
5. Nose Steer Engaged	X									--
6. Gear Select	X									--
7. Drag Chute	X									--
8. Wheel Brakes	X					X				--
9,10. Red, Green Light						X				--
11. Weapon Release (Pickle).			X				X	X	X	--
12,16. Crewmember Voice Switch	X	X	X	X	X	X	X	X	X	--
17,19. Marker Beacon		X								--
20,24. Event Marker	X	X	X	X	X	X	X	X	X	--
TIME										
1. GMT (Range Time)	X	X	X	X	X	X	X	X	X	Hrs, Min, Sec, 1/100 Sec.

TABLE 5

PARAMETERS FOR VIDEO/PHOTO DATA ACQUISITION

PHASE	PARAMETERS
Transition	Runway Centerline Deviation, Lateral Drift, Threshold Crossing, Distance Down Runway, Ground Track.
Instruments	TACAN (Frequ., Course Set, Course Error, Bearing, DME); VOR (Frequ., Course Set, Course Error, Bearing); ILS (Frequ., Localizer Error, Glide Slope Error, Marker Beacon).
Intercept	Target use of ECM, Maneuvering Radar: Azimuth, Elevation, Range, Range Rate, Range Gate, Steering dot error, Firing Circle Radius, Lockon Pulse, IF Gain, Video Gain, Erase Intensity.
Refueling	Range to Tanker, Range Rate, Probe engagement, Centerline Displacement, Lights (Up, Down, Fore, Aft), Attitude Error.
Air Drop	Crosstrack Error, Groundspeed, Terrain Clearance, Range/Bearing/ΔAltitude from Lead Acrft, Red/Green Drop Lights, Actual Air Release Point.
Formation	Spacing: Range, Range Rate, Bearing, ΔAltitude.
Ground Attack	Target Slant Range, Aim Point Error, Bomb Fall Line, Flight Path Error, Spacing in Range Pattern.
Dart Firing	Range, Azimuth, Elevation, Hits.
Air Combat Maneuvers	Target Range, Range Rate, Aspect Angle, Heading Crossing Angle, Elevation.

TABLE 6. REQUIREMENTS FOR X-Y DATA

	PHASE	PARAMETER	OBTAINABLE WITH VIDEO/PHOTO ?
1	TRANSITION	GROUND TRACK	RA*
2		CENTERLINE DEV	RA
3		LAT. DRIFT	No
4		THRESHOLD	RA
5		DIST. DOWN RNWY	RA
6		SPACING	RA
7	INTERCEPT	TGT. AZIMUTH	No
8	(PRIOR TO LOCKON)	TGT. ELEVATION	No
9		TGT. RANGE	No
10		TGT. RANGE RATE	No
11		TGT. ASPECT ANGLE	No
12	AIR REFUELING	TANKER RANGE	RA
13		TANKER RANGE RATE	RA
14		CENTERLINE DISPL.	Yes
15		LIGHTS UP	Yes**
16		DOWN	Yes**
17		FORE	Yes**
18		AFT	Yes**
19		ALTITUDE ERROR	RA
20	AIR DROP	CROSS TRACK ERROR	No
21		POSITION ERROR	Yes
22		RANGE FROM LEAD	RA
23		BEARING FROM LEAD	RA
24		ΔALTITUDE FROM LEAD	RA
25		ACTUAL AIR RELEASE PT.	Yes
26	FORMATION	RANGE	RA
27		RANGE RATE	RA
28		BEARING	RA
29	GROUND ATTACK	TGT. SLANT RANGE	RA
30		AIM POINT ERROR	Yes
31		BOMB FALL LINE	Yes
32		FLIGHT PATH	RA
33		SPACING	RA
34	DART FIRING	RANGE	RA
35		AZIMUTH	RA
36		ELEVATION	Yes
37	AIR COMBAT	TGT. RANGE	RA
38		TGT. RANGE RATE	RA
39		TGT. ASPECT ANGLE	RA
40		TGT. HDG CROSS ANGLE	No
41		ELEVATION	RA
42		SPACE PATH	No

*RA = Reduced Accuracy.
**Obtainable with Video/Photo System, but not easily otherwise.

depending on the application) and tested to determine if conditions are appropriate to start measurement computation, and later to stop computation. During the measurement interval (or at specific conditions, e.g., flaps-up), one of the following statistics is calculated: (1) the value of a parameter, (2) minimum value, (3) maximum value, (4) mean, or (5) standard deviation. Thus, measurement is defined by specifying start/stop conditions and one of the five statistics.

An example of a measurement specification patterned in this fashion is shown in Figure 3. Measurement specifications were produced for each common training phase.

While these specifications initially assume automatic recording and computation, they can also be used to describe manual data processing procedures. If parameters are recorded which clearly identify start/stop conditions for automatic processing (e.g., a discrete signal indicating wheels-up)[1]. These parameters can also be used to start and stop manual processing such as scanning for out-of-tolerance conditions. During the measurement interval, the value, minimum or maximum of a parameter may be determined manually, but manual processing for computation of a mean or standard deviation is judged to be excessively laborious and time-consuming since a large number of data samples (at 2 or more times a second) is necessary. Consequently, the measurement specifications, as exemplified in Figure 3, are suitable for (1) defining software for digital computer measurement processing, or (2) manual processing procedures.

Communication Analysis

Measurement for crew performance overlays the system performance measurement thus far discussed. The performance demonstrated in A-7 or F-106 aircraft clearly involves only one man; however, the same missions may be flown by two men in the F-4 aircraft, requiring additional measurement to investigate crew interaction and diagnose individual performance contributions. The combat airlift mission in the C-130 and C-141 aircraft involves such close coordination of pilots, navigators, loadmasters and engineers that it is difficult to isolate an individual's performance (even the crewmembers themselves cannot be sure of the adequacy of their performance).

An individual's performance can be assessed by relating measurement at his workstation to overall system performance; this type of measurement is subsumed under the previous measurement discussion. However, the interaction between crewmembers

---

[1]Therefore, each recording device potentially requiring manual processing (e.g., video recording) should permit a means for discrete signal recording.

requires analysis of communications--presenting somewhat different requirements than system performance measurement. The following paragraphs present important topics related to crew performance measurement (see also Volume IV).

Communication measurement categories. Communications measurement must treat at least two gross types of crew interaction: (1) information is exchanged to aid another crewmember in performing his duties (e.g., when the F-4 Weapon System Officer acts as a good "copilot"), and (2) a crewmember provides a directive role in guiding another's performance (e.g., when the F-4 Weapon System Officer provides directive commentary to the Aircraft Commander in air-air intercept). In the latter case, direct links between auditory commands and system performance can be identified, allowing communication to be measured in terms of resulting performance changes.

Six categories of measurement related to information transfer were examined:

(1) Timing. Measures of information timing should relate to (1) jamming more important messages, (2) providing information at the wrong time, (3) delay in providing information, and (4) providing information at a rate not permitting effective response by another crewmember.

(2) Accuracy. Measures of accuracy require comparison of what is said in relation to the measured situation (e.g., was altitude reported correctly?).

(3) Brevity. As radio and interphone traffic often exceed channel capacity in combat, measurement should address communication duration and comparison to the standard vocabulary of the operational brevity code.

(4) Number and frequency. Also in relation to communication brevity, the number of communications and frequency of communications can be measured.

(5) Information content. Measures of information transmitted per unit time are quite important although usually practically difficult to obtain. Other measures such as time, number and frequency are often confounded since a crewmember may convey much information in short time or few transmissions, while another may say little in a long time or many transmissions; without knowledge of the information content it would be difficult to evaluate these situations.

(6) Performance changes. The performance changes of the vehicle, desired as a result of communicating, define measurement in terms of links between auditory data and system/mission performance data. For example, turning performance can be measured following a "hard-as-possible" direction to the pilot of an F-4 aircraft.

Auditory data processing. A computer-assisted manual auditory processing system is required since automatic voice decoding equipment is not available. Expert personnel are therefore required to identify complex performance and to structure processing rules for data clerks who reduce data to a form allowing input to a computer.

Three auditory data processing problems impose requirements for measurement system design:

(1) Identification. In spite of normal communications clutter, it is necessary to clearly identify who is talking, even if two transmissions are simultaneously made (jamming). Voice key circuitry is recommended to provide a digital signal indicating which crewmember is talking.

(2) Synchronization. Audio data must be synchronized with other data recording to permit relating auditory information to corresponding performance changes. Each recording device must therefore include an audio voice track.

(3) Data reduction. Manual functions in audio data processing are unavoidable, but can be minimized through computer-assistance. Audio data playback must be accompanied by display of performance parameters, especially the parameter of TIME, to allow computer correlation of manual audio-data entry with the digital data base. A convenient means for manual data entry is a desirable feature.

These data processing problems must be considered in the design of a combat-crew training measurement system.

III. THE PERFORMANCE MEASUREMENT SYSTEM

The second product of this study was the detailed description of a combat-crew performance measurement system. The measurement system description in this chapter includes (1) the data acquisition subsystem, (2) the data processing subsystem, (3) the personnel subsystem, and (4) facilities. The use of off-the-shelf equipment and proven techniques were emphasized to ensure that the system would be workable and attainable.

Of course, the principal objectives in measurement system design were to produce needed information, by available devices and techniques, in the combat-crew training environment, and at low cost. A large portion of the design tradeoff analyses were devoted to comparison of video or photographic recording techniques with digital recording techniques. The ultimate conclusion was that a hybrid system of video, photo, and digital devices should be assembled to allow use of the best features of each; however, the video/photo and digital subsystems were to have sufficient capability to allow separate deployment.

Separate deployment of the video/photo and digital subsystem was desired since either subsystem alone could suffice for a number of potential applications (i.e., for simplified measurement and specific combat-crew training phases). Therefore, a modular system was designed to allow either subsystem to be used separately where this is suitable, and used together as needed (in particular, both subsystems are needed where detailed measurement is required throughout the combat-crew training phases). Of course, the modular principle also permits separate procurement of subsystems at different times, where the immediate applications and available funding dictate this choice.

Even though a video/photo system would require a significant amount of manual data processing, a general-purpose computer is required to accept digital and manual inputs, edit and assemble data files, compute measurement, and perform research analyses. As data collection may take place at a number of training sites, the ground-based portions of the system are to be housed in trailers fashioned after mobile homes. These facilities will include debriefing features to interface with ongoing training, as well as a full complement of personnel capable of pursuing research goals.

System Criteria

As the measurement system is at least to be a tool for research and combat-crew training, the system criteria dealt mainly with the use of the tool and relevant constraints. The criteria were developed early, before any design considerations. Each requirement is discussed below in terms of tradeoffs considered (definitions and general discussion appear in Chapter I).

Provide needed information. Based on the investigations conducted, needed information will be provided if (1) necessary parameters are sensed, (2) sensors are available at each source of data, and (3) meaningful measures can be computed from the raw data.

(1) Sense necessary parameters. Sensors must be allocated to audio, pictorial, analog, discrete, and space-coordinate data to support combat-crew training information needs. Audio and space-coordinate data present special sensor problems, the remaining parameters are allocated to video/photo and digital data acquisition equipment. Of course, some information is also manually acquired and manually processed.

Audio recording of voice communications was found to be of value in all phases of combat-crew training. Audio recording must be synchronized with other recorded information; therefore, a voice track must be included with both video and digital recorders.

Space-coordinate recording (X-Y-Z data) requires the use of expensive multiple-target tracking radar for complete coverage with high accuracy. An analysis (see Table 6) fortunately indicated that satisfactory information could be obtained for many envisioned applications with video or photographic recording. Therefore, a tracking radar was not included in the system design, but an option remains to accept and process data from such a facility. Since comprehensive measurement of air combat maneuvering requires information on the space paths of combating aircraft, radar tracking data will be required for detailed measurement; one is otherwise limited to position information available through video/photo cameras only when the other aircraft is within the camera field-of-view.

Many kinds of out-the-window information can be obtained with video/photo recording which would otherwise be difficult and expensive to acquire, while at the same time allowing sampling of information from the cockpit instrument panel. The primary virtues of automatic digital recording are: (1) high-speed and accuracy, (2) ability to sense information which cannot be directly seen with a camera in the cockpit, and (3) automated computer processing permitting complex sophisticated measurement.

It was concluded that a hybrid system, including both video/photo and digital recording, is needed to attempt to provide a simple system sensing all combat-crew training measurement parameters; however, to allow flexibility in deployment, the video/photo and digital equipment are each expected to provide an independent capability for limited data acquisition (stand-alone capability). Due to considerations of cost, reliability and timely research execution, the complexity of the digital recording equipment was restrained, but with sufficient overlap with video/photo data acquisition to provide a digital stand-alone capability and enhance reliability of data collection with the hybrid system. On the other hand, discrete recording channels are required for the video/photo recording equipment to enhance the video/photo stand-alone capability and permit more efficient manual data processing. Figure 8 depicts the allocation of data acquisition responsibility to video/photo and digital recording devices.

(2) Sensors at each source of data. Combat-crew training performance information may come from a number of sources and through a variety of media. The data acquisition subsystem must acquire all forms of information and interface with manual and automatic means for compiling an integrated, correlated, common raw data base. Five categories of data sources must be treated: (1) aircraft and simulator, (2) field (e.g., range or runway), (3) briefing and debriefing, (4) external sources (e.g., other studies, tracking radar), and (5) documents. The data acquisition subsystem therefore must contain all the components of the block diagram shown in Figure 9.

(3) Compute meaningful measures. Although the raw data may be interpretable to a degree in its original form (such as, viewing a video playback monitor), the data take on more meaning when calculations are made using the raw data to provide comparable indices of performance. The hybrid system recommended requires a combination of manual and digital computer processing. Therefore, a manual data processing workstation and a general purpose digital computer are included in the recommended design.

Useful format. The superiority of formats depends on the use of the information. The video/photo format presents information in much the same way as the information is presented in flight; this should permit ease of interpretation by the instructor pilot and student, forming a framework to improve communication between each other, or between either of them and the research scientists. On the other hand, a quantitative presentation of information, in a much different form than that presented in the cockpit, promises hope for greater objectivity and the solution of problems which appear vague when discussed in terms of ordinary flight parameters. Both pictorial and numerical/graphical formats are therefore likely to be desired, and both are included in the recommended design.

Research cycle time. Measurement processing (exclusive of data analysis) consists of the following time periods: (1) aircraft or simulator modification, installation, and checkout, (2) equipment calibration and maintenance, (3) data collection, (4) data conversion and generation of quick-look data, and (5) measurement computation.

Equipment modification, installation and checkout introduce a significant time delay (T_1) before productive data collection can begin. Calibration and maintenance time (T_2) reduces the availability of equipment for productive use. As digital recording equipment has historically involved much time for both T_1 and T_2, its complexity was minimized.

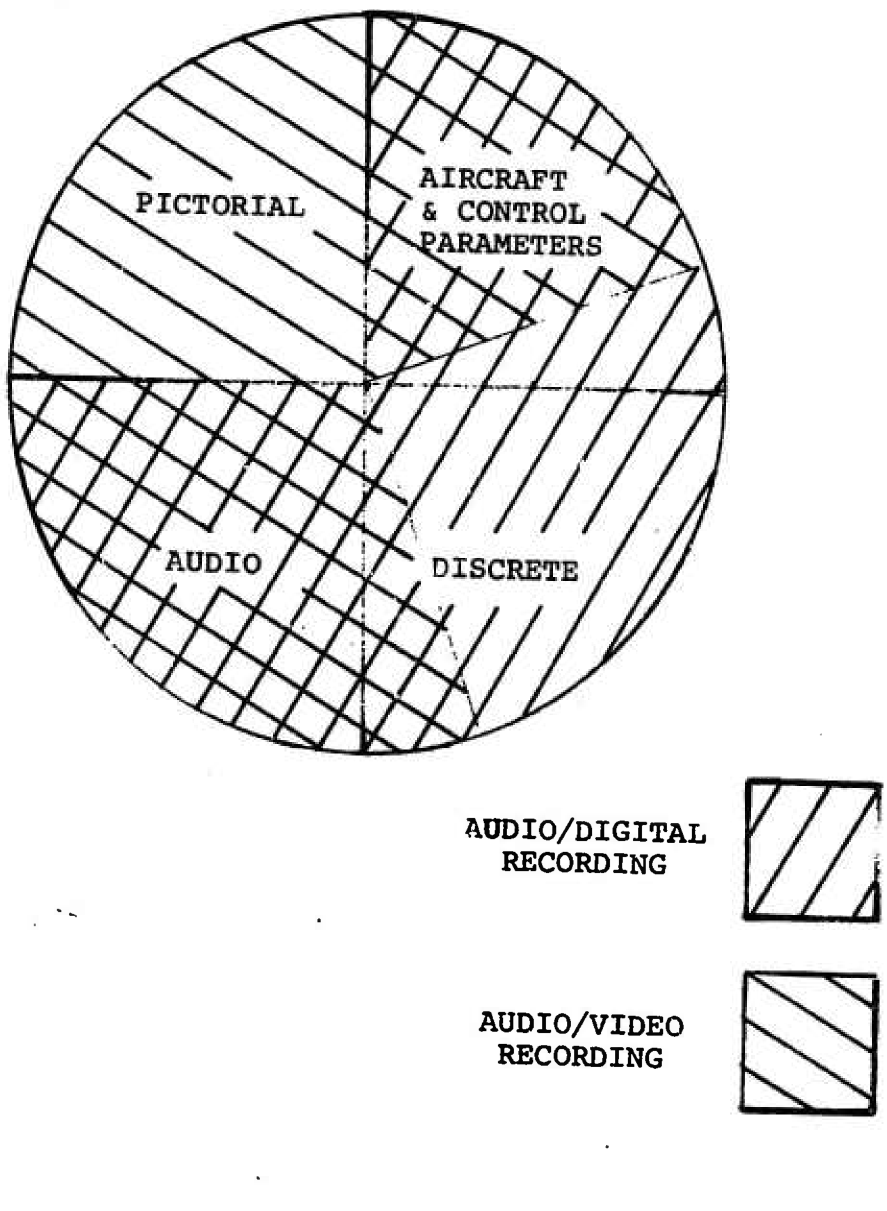


Figure 8. Distribution of Data Acquisition Between Audio/Digital Recording and Audio/Video Recording.

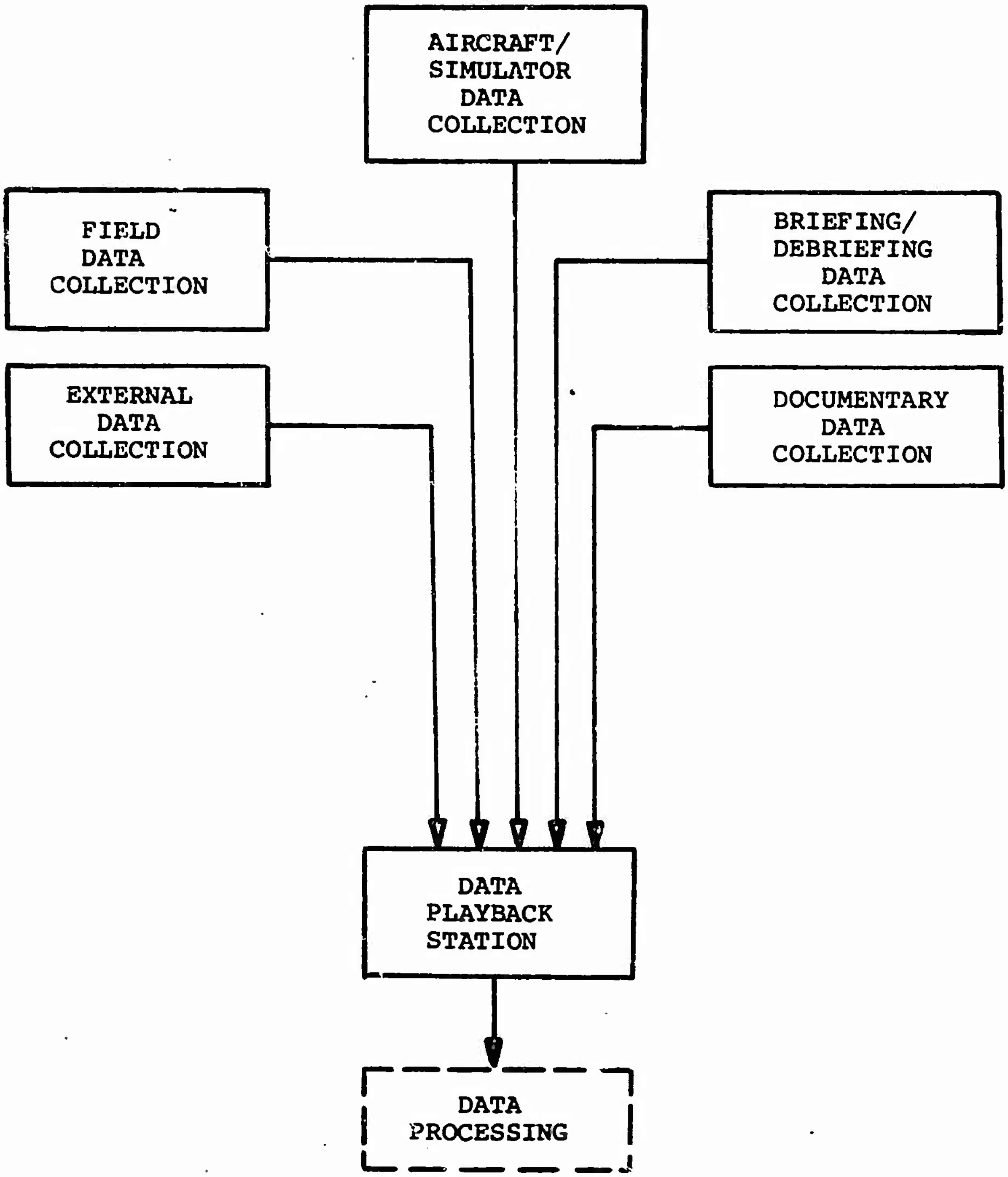


Figure 9. Data Acquisition Block Diagram.

Data collection is a critical period. It is probable that a concerted effort will be required to process measurement in pace with a training squadron schedule. Each airborne data collection system may be required for more than a flight a day for five days of the week. Inherent equipment reliability is needed to avoid large amounts of maintenance manpower, and associated recurring costs.

A form of quick-look data is required of each data acquisition device. Video recording permits rapid playback, but digital recording requires some form of conversion and digital computer processing, and photo processing requires ready access to speedy developing services.

Measurement computation time is not expected to be significant for digital recording once needed software is checked-out; however, manual processing of video/photo and audio data require efficient techniques and procedures (it is estimated that manual processing of 30-minutes of video recording can be accomplished in less than 1½ hours).

Costs. Both initial and recurring costs must be considered in system design tradeoffs. Use of off-the-shelf equipment reduces initial costs, although costs of modifications for airborne application must be considered.

A primary tradeoff consideration is the relatively-high cost of development and installation of a digital recording system in comparison with the relatively-costly and time-consuming manual data processing procedures associated with video/photo recording. The hybrid system selected provides a compromise moderate cost by (1) reducing the need for developing and installing a large digital system, and (2) permitting a significant amount of automated data processing. The total cost of the hybrid system is expected to be less than a system based entirely on digital or video/photo techniques (although neither technique can provide all needed information by itself). Gross estimates of costs for an all-digital system compared to an all-video system indicate that the all-digital system is 5-10 times more costly. The amount of manual data processing for an all-video/photo system is a f nction of the number of data collection flights per day, but is always undesirable and costly in comparison to semi-automatic processing for an all-digital system. The high costs of design, development, installation and test associated with an all-digital system loomed large in the tradeoff analyses, leading to a hybrid design minimizing the digital recording capability, yet providing full data coverage for the total system and allowing a digital stand-alone capability.

It should also be noted that, while video methods will be normally superior to photographic methods, total costs can be reduced by using photography, and that the lowest-cost useful system results from using only airborne instrumentation cameras with an audio recorder.

Manpower costs are the primary recurring costs. Design for high equipment reliability must be stressed to reduce engineering and technician labor, but other labor categories are difficult to reduce without impairing research-team effectiveness. The manloading depends on the manner in which digital and video/photo techniques are used, and on the number of flights to be flown for data collection each day. For four or more flights per day, the manloading is significantly greater for an all-digital system assuming equipment reliability demonstrated by current flight test efforts (see Volume VI, pp. 91-93).

Data distortion. While data distortion and losses are inevitable, they must be controlled to a minimum. Loss and distortion of data have been common in previous tests of video recording. Tests of video horizontal and vertical resolution are therefore recommended (it is estimated that resolution must exceed 400 lines). The data collected from any device must closely compare to the information presented to the crew and the errors involved must be small compared to the tolerances which the crewmember is expected to achieve (note accuracy requirements in Table 4).

Compatibility with training devices. Performance measurement will be desired in the simulator, or part-task trainer, as well as in the aircraft. Video/photo equipment permits easier adaptation to new installation than digital recording equipment as the latter requires extensive cabling and sensors. However, there is merit in using one system for all applications to provide a common output for efficient data processing, and thereby producing identical measurement for comparing performance between training device and aircraft.

Iterative measurement development. Iterative measurement development requires the ability to change measurement as a result of preliminary measurement tests. Video recording is particularly suited to trial-and-error measurement development since (1) desired new parameters may already be in the recorded field-of-view, and (2) new measures are obtainable through new instructions to data clerks. However, even with video data, new measurement transformations may be computed in the digital computer from the raw data bank; for this, flexible software under the control of the research scientists is needed.

Minimum training interference. Any measurement device interferes to some degree with the process being measured, but any amount is undesirable. Similarly, the measurement system interference with training must be minimized.

It is possible that the instructor or an airborne experimenter may be able to start and stop recording, and mark special events by entering a digital code; however, the recording sequence should be automatically controlled as much as is practical. For these reasons, programmed sequences of on/off control for recorders, and convenient manual recording control are recommended.

External data correlation. It may be necessary for data from a tracking radar station, subjective questionnaires, manuals, or other experiments, to be merged with video/photo or digital data. Merging of data will be performed in the data processing computer, except for small amounts of manual merging. As data from external sources may occur in many forms, the computer peripherals should include most standard forms of data input devices (e.g., magnetic tape, punched cards and paper tape).

Space, weight, cooling and power. Data acquisition devices must be suitable for installation in at least the sample of aircraft included in this study (i.e., B-52, C-130, C-141, F-106, F-4, A-7).

Effective personnel/facility. The personnel of the research team must be capable of performing all tasks needed to achieve research objectives, including (1) planning, (2) test, calibration and repair of equipment, (3) collection and processing of data, (4) preparation of computer programs, (5) interaction with training personnel, (6) improvement of measurement and research methods, and (7) analysis of data and presentation of findings. The facilities and equipment must support these activities. Since research may successively occur at different and remote sites, mobile trailers are recommended to house personnel and ground-based equipment.

Data Acquisition Subsystem

The Data Acquisition Subsystem consists of the equipment (as shown in Figure 9) for data recording for each source of information and devices for data playback. The specifications for the required equipment, presented in Volume VII, are summarized in this section.

Aircraft/simulator data collection. Although a hybrid system is recommended, it is also required that the video/photo and digital recording systems have a stand-alone capability; thus three data acquisition systems are defined: (1) a video/photo recording system, (2) a digital recording system, and (3) a hybrid recording system. Further, an option is available to replace video equipment with airborne photographic cameras if video resolution, size, weight and costs should appear unacceptable upon closer examination during system development.

The Aircraft/Simulator Data Collection Station, shown in Figure 10, consists of a dual-camera Audio/Video Recorder (AVR), an Auxiliary Camera (AC), an Audio/Digital Recorder (ADR), Recorder Controls/Displays (RCD), and an Interphone Interface (II).

Most pictorial information can be easily obtained only with video/photo techniques, but other avionics display information (e.g., radar, navigation and weapon control) will also be excluded from the AVR to reduce its complexity and associated costs. Aircraft and control parameters (e.g., airspeed, altitude) will be collected on the ADR and, redundantly, as many as possible

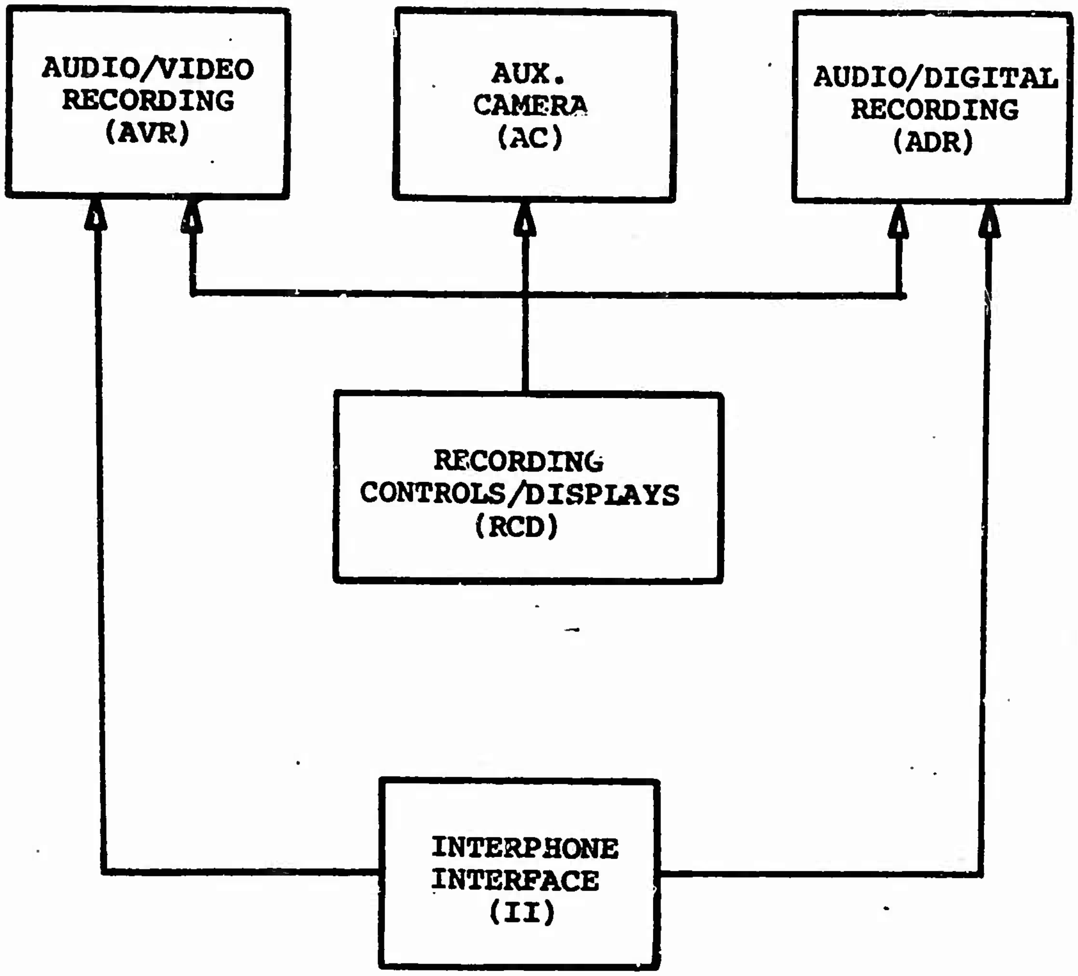


Figure 10. Aircraft/Simulator Data Collection Station.

within the field-of-view of the AVR. Similarly, discrete signals (e.g., wheels-up, speed brakes out) will be recorded on the ADR, but means are required to allow recording a small number of discrete parameters (e.g., weapons release) on the AVR to allow a stand-alone capability and to enhance manual measurement processing. An Auxiliary Camera (AC) is necessary to provide information where neither the ADR nor AVR is applicable (e.g., during air drop, pictures directly below over recognizable terrain and the drop zone). Recording Controls and Displays (RCD) provide manual and programmed switching of recorders, information for equipment set-up and for onboard-experimenter functions. Interface with the interphone system (II) completes the aircraft/simulator data collection station which is recommended for both aircraft and simulator environments.

The aircraft modification for measurement system installation must be consistent with space, weight and power availability, and not infringe upon aircrew safety. The amount of aircraft modification must be minimized. The installation must not impair crew vision and must be clear of seat ejection envelopes. Good human engineering practices and maintainability considerations are necessary for efficient inflight operation and for use in the environments encountered during combat-crew training.

(1) Audio/Video Recorder (AVR). Two video cameras are required together with suitable recording equipment. An option for connecting a special-purpose camera instead of one of the standard cameras is desired; for example, a helmet-mounted camera could provide unique information for some applications. Two complete images should be recorded, but in lieu of this extensive image control is required to allow freedom in combining the camera outputs into a composite picture. Audio recording of crew communications is needed, but the upper frequencies of the available bandwidth may be used for recording discrete parameters as audio-encoded signals. The audio/video recorder must permit remote control in synchronization with other recording devices.

Specifications for the recording and playback of video imagery are summarized in Table 7 (more detail is available in Volume VII). In particular, the principal problems noted in previous airborne video tests must be removed.

If it is necessary to combine the output of two video cameras into one composite picture (instead of recording two complete pictures), then image controls are desired to: (1) split the screen horizontally, one camera picture in the upper part, the other in the lower part, (2) split the screen vertically, (3) inset the picture from one camera onto the other, (4) alternate pictures at periodic intervals, (5) sequence between split screen and full screen, and (6) pan one camera at a selectable rate.

TABLE 7

AUDIO-VIDEO RECORDING AND PLAYBACK SPECIFICATIONS*

STANDARD AMERICAN TV

VIDEO QUALITY: Horiz. and vert. resolution, 500 lines desired, 400 lines minimum.
700-800% contrast, 8-10 shades of gray.
Greater than 40 DB signal-to-noise ratio.

LENSES: (1) Zoom type, (2) Fixed-outside viewing, (3) Fixed-outside viewing, very wide angle, (4) Fixed-cockpit viewing.

ILLUMINATION: 25-10,000 Foot-Candles; automatic sensitivity control over this range, less than approx. .1-second response time, rapid recovery from direct exposure to sun.

AUDIO: Frequency response 100-10,000 (min.) HZ; input from aircraft interphone system, earphone & speaker output.

INTERFERENCE: (Audio & Video) Low noise background for audio communication recording (filters for aircraft-induced noise required), negligible interference with either video or audio signals due to aircraft radio transmission, avionics, or weapons firing.

CONTROLS, LIGHTS, DISPLAYS: Operation with either hand in aircraft cockpit with full flight suit; lights adjustable for day and night operation; no restriction to crew visibility, mobility, or safety; amount of tape remaining indicator desired.

SIZE, WEIGHT, POWER, COOLING: Suitable for fighter aircraft installation; without significant cockpit modification, restriction of visibility, mobility, or safety; installation clear of crew ejection envelopes.

ENVIRONMENT: Dictated by normal combat-crew training (e.g., altitude to 50,000 ft. MSL, weapon firing, turbulence, maneuvering ± 8G).

MAINTAINABILITY: Convenient access for maintenance and tape handling; provision for ground operation without aircraft power; set-up and test equipment to be included in system, including operations and maintenance documentation.

RECORDING TIME: 30-minutes minimum.

REMOTE CONTROL: On/off, start/stop controlled remotely in unison with other recording devices.

---

*The difficulties encountered in previous tests must be removed; i.e., specifically those in (1) TAC Test 69-4F, (2) TAC-TR-70A-113F, and (3) AFHRL(FT)-TRM-17.

A method must be developed to permit recording a minimum of 10 (24 desired) discrete parameters within the AVR. It is suggested that discrete information is encoded as audio tones within the available bandwidth above 3000 HERTZ. A selectable time bit derived from a time code generator must be recorded as one of the discrete signals to aid manual data processing (entire time code is recorded on the ADR).

(2) Audio/Digital Recorder (ADR). The parameters allocated to audio/digital recording are listed, along with accuracy requirements, in Table 4 for key training phases. A minimum of 24 discrete recording channels are needed in addition to those required for digital time code recording. Of course, an audio recording channel is necessary. Otherwise there are 16 channels which require analog-to-digital conversion; these normally must be sampled twice a second, but for some measurement a total of 10 channels must be sampled 10 times a second, and for still other cases, a total of 5 channels must be sampled 20 times a second. It is important to note that the accuracy specified for each parameter in Table 4 refers to deviations between recorded information and that indicated to the pilot by cockpit displays; otherwise, data collection anomalies may be attributed to pilot performance. Table 8 summarizes ADR specifications (more detail is available in Volume VII).

(3) Auxiliary Camera (AC). An auxiliary airborne camera is needed as a supplement to other equipment to record either displays in the cockpit or external views. External controls will be used to expose the film in either a motion-picture sequence, or as individual frames.

(4) Interphone Interface (II). The interphone interface must permit selection of communications from any crewmember, and generate a discrete signal identifying which crewmember is speaking. Since the available interphone system may be switched so that all crewmembers of interest are not recorded, an audio mixer is needed to combine the outputs desired for both AVR and ADR audio recording. Voice-operated switches installed at each microphone are suggested to generate a discrete signal whenever each crewmember speaks.

(5) Recording Controls/Displays (RCD). Recording controls and displays provide manual and programmed control of recorder functions, and information for set-up and data collection. The RCD is to include a time-code generator to be recorded on discrete channels of the ADR and AVR. Programmed recording control sequences will be initiated by a manual input (an event mark), an aircraft discrete parameter, or a specified time bit from the time-code generator. The following programmed sequence is desired: (1) recording is initiated by either event A or manually, (2) recording is stopped manually, at event B, or after a specified time, (3) recording is initiated manually, at event C, or after a specified time, and (4) recording is stopped again manually, at event D, or after a specified time.

TABLE 8

AUDIO/DIGITAL RECORDER SPECIFICATIONS

PARAMETERS/ACCURACY:	As indicated in Table 4 (minimum), growth capacity desired.
INTERFERENCE:	Controlled to achieve desired accuracy.
PARAMETER SAMPLING RATES:	Twice per second (16 + discretes + time), 10 times per second (10 + discretes + time), 20 times per second (5 + discretes + time).
AUDIO RECORDING CHANNEL:	Frequency response 100 - 10,000 (Min) HZ input from aircraft interphone system; earphone & speaker output; negligible background noise, low distortion.
TIME CODE RECORDING:	(Hrs, Min, Sec, 1/100 Sec.)
OUTPUT:	Through conversion equipment interface to general purpose digital computer. Audio output and digital display of digital time and discrete parameters during playback.
REMOTE CONTROL:	On/Off, Start-Stop, together with other recording devices.
RECORDING TIME:	30-minutes minimum.
CONTROLS/LIGHTS/DISPLAYS:	Operation with either hand in aircraft with full flight suit; lights adjustable for day and night operation; no restriction to crew visibility, mobility, or safety.
SIZE/WEIGHT/POWER/COOLING:	Suitable for fighter aircraft installation without significant cockpit modification, restriction of mobility, visibility or safety (installation clear of ejection envelope).
ENVIRONMENT:	Environment dictated by normal combat-crew training (e.g., altitude to 50,000 ft. MSL, weapon firing, maneuvering ±8G).
MAINTAINABILITY:	Convenient access for maintenance, calibration and tape handling; provision for ground operation without aircraft power; test stand to be provided (other than standard test equipment); minimum maintenance personnel requirements.

(6) Test Stand. Since maintenance ease with minimal personnel is so extremely important, the data acquisition subsystem must include a test stand including all equipment to permit checkout of recorder equipment and calibration of all channels of information prior to each data collection flight; the same equipment should facilitate diagnosis and repair.

Other data collection. Data will be collected in the field at remote places, at briefings and debriefings, from documents, and from external sources. Each of these must be considered in addition to aircraft/simulator data collection requirements.

(1) Field data collection. Simple portable equipment is required for data collection at remote sites such as at the runway, the weapons range, or a surveillance radar site. The major equipment items recommended are: (1) a camera with inset clock and an intervalometer for timed exposure, (2) a small hand-carried cassette-type audio recorder, and (3) transceivers for communicating with the data processing facility and for monitoring aircraft transmissions.

(2) Briefing/debriefing data collection. Much of the information presented during mission briefings relates to expected performance and appropriate performance measurement; information produced during debriefing can modify the briefed data, and can prove a source of subjective measurement for correlation with measured performance indicators. A small hand-carried cassette-type recorder may be necessary for recording for later transcription. A small camera may also be useful.

(3) Documentary data collection. Desired performance and measurement control parameters will also be obtained from documents such as the Dash-One Technical Order, Phase Manuals, and operation publications. No special equipment is believed necessary for this form of data collection, although manual digital entry equipment for computer processing is needed.

(4) External data collection. Data may also be produced by an external source which must be correlated with data collected by the data acquisition subsystem. However, under the assumption that these data must be provided in a form permitting processing with the available general purpose digital computer, no special equipment is needed for externally produced data.

Data playback. The data playback station, as shown in Figure 11, must permit the transformation of data collected through the five avenues shown in Figure 9 into a digital format appropriate to the general purpose computer. The digital magnetic tape requires only routine human operator activities to load the data into computer storage, although the audio recording portion is necessarily a manual processing task. All other types of information require manual processing, and eventually, typing of formatted data onto a punched paper tape.

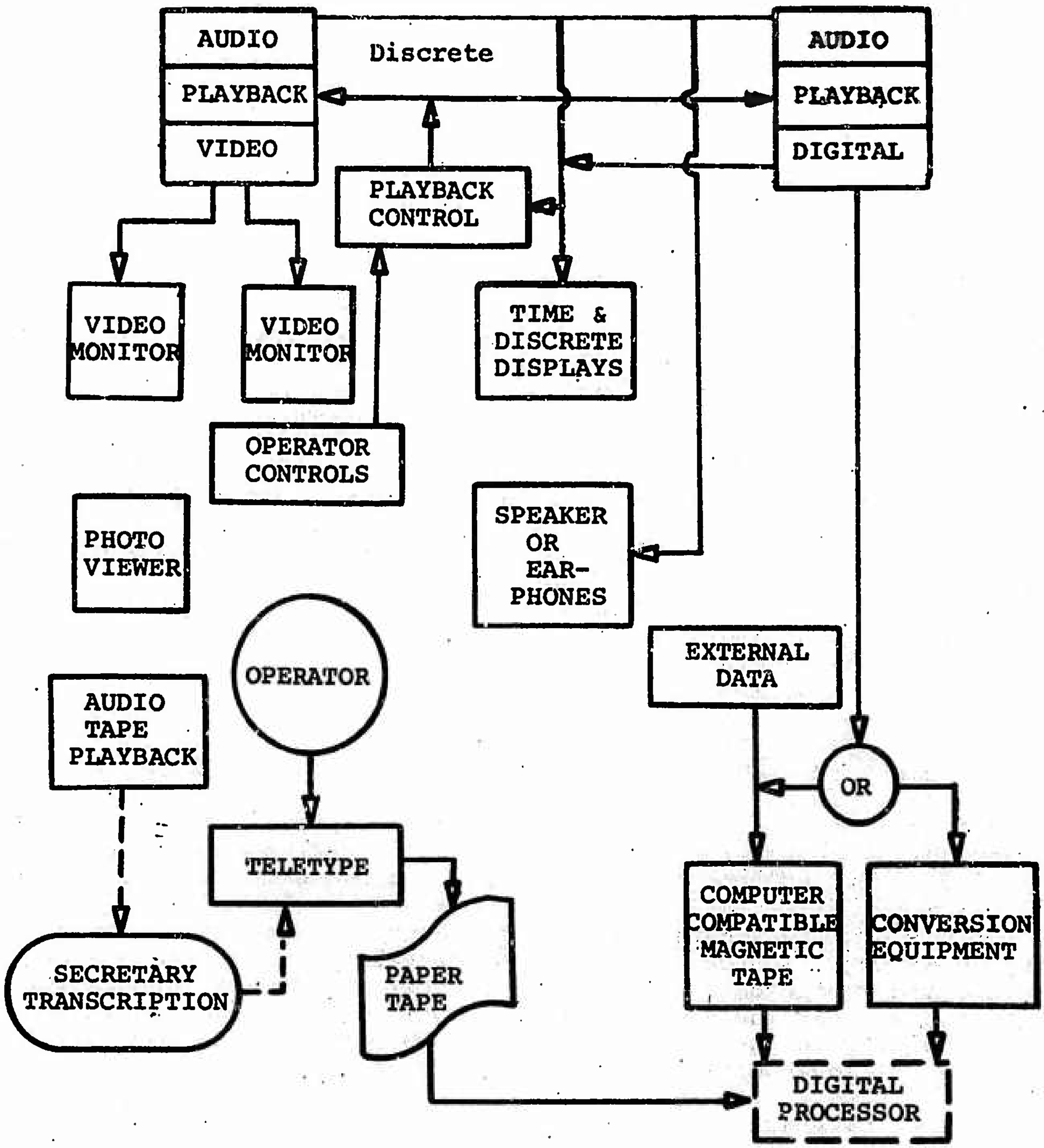


Figure 11. Data Playback Station.

(1) Video data processing. Video information will be reproduced through two video monitors if dual-channel recording is possible, otherwise, one will be used if split-screen merging of pictures is performed. Communications and the special discrete audio channels are reproduced simultaneously with the video information, thus the operator can ascertain who is talking, and the status of gear, speed brakes, etc. (if these are chosen for recording) while analyzing the video content.

The discrete information is also useful to aid searching for key events to initiate measurement activity sequences. Automatic measurement processing keys on clearly identifiable events whenever possible (i.e., discrete events). Unfortunately, these events often do not appear in the video picture. The human operator would then have to laboriously search the video tapes to infer from the cockpit instruments that an event has occurred which is important to measurement. The special discrete channels then provide the human operator with the advantage of the same information provided an automatic processor. Since it is normally desired that the situation at or near each event be analyzed, playback control features are required to stop the video tape at events occurring on specified discrete channels. (For example, set playback controls so that the tape will stop when weight is off the wheels, allowing conditions at lift-off to be recorded for computer entry.)

To further aid the human operator in sampling performance at constant time intervals, or just to advance the tape a known amount, it is required that the tape be advanced on command for a specified number of seconds. It was earlier specified that a time bit (1, 2, or 4 seconds) be recorded on one discrete channel so that these bits can be counted on playback for time control (i.e., the control requested is to advance N events on the time-bit discrete channel).

(2) Digital data entry. Digital data are expected to come from either external sources or the audio/digital recorder system.

External digital data should be acceptable in magnetic tape, punched card, or paper-tape form; any of these are directly read by the general purpose computer, although a magnetic tape copy may be made for high-speed re-reading.

Audio/digital recording can result in two acceptable forms: a digital magnetic tape which can be converted into a magnetic tape readable on standard computer magnetic tape units, and a digital magnetic tape which is read through special conversion equipment directly through an electrical interface into the general-purpose computer. The most cost-effective of these alternatives should be used. Neither method requires any significant manual processing activities to enter data into the computer data base.

(1) Audio data processing. Audio data processing is necessarily a manual task. The difference between audio data processing with audio/video playback and the audio/digital playback is the method of correlating the audio information with other performance parameters. With audio/video playback, the magnetic tape must be stopped at specific auditory events (e.g., commands), selected performance parameter values noted, and, auditory code and values punched on paper tape. With audio/digital playback, the magnetic tape must be stopped at specific auditory events, the time noted from a display of the digital time code, and, auditory code and time punched on paper tape so that the auditory information can be correlated with appropriate data samples read from the digital magnetic tape.

(4) Photo data processing. Photo data processing requires many of the same procedures as video data processing, although time-lapse photography is likely to be the primary mode. The resulting information must be coded onto punched paper tape, normally including time values to allow correlation with data from other sources.

Data Processing Subsystem

Processing of the training research measurement developed in this study requires appropriate hardware and software. The characteristics of these must be discussed to aid in equipment/software selection and specify new software development.

Data processing hardware. To support the volume of data anticipated it is necessary to have all measurement processing tools in a central location ready for use when they are needed. The equipment required in the dedicated processing facility is shown in Figure 12.

The heart of the measurement data processing facility is a general purpose digital computer (memory 16-32K words, word size 18-24 bit, cycle time 1-3 microseconds). However, much of the utility of the system for measurement and data analysis depends on the presence of the following peripheral equipment: (1) two magnetic tape units (7-9 track, variable density), (2) disc units (204 logical units), (3) line printer/plotter (minimum 300 lines per minute), (4) Teletype, (5) cathode-ray tube computer terminal, (6) paper tape reader and punch, and (7) card reader.

If both the data format and physical size of airborne magnetic recordings are the same as the magnetic tapes normally produced by the general purpose digital computer, then only the computer magnetic tape units will be needed to process them. However, since this is not likely, conversion equipment will be required to read the airborne magnetic tape and produce and input to the digital computer.

Software. Data processing system software requirements fall into two major categories: (1) the executive monitor, and (2) measurement processing.

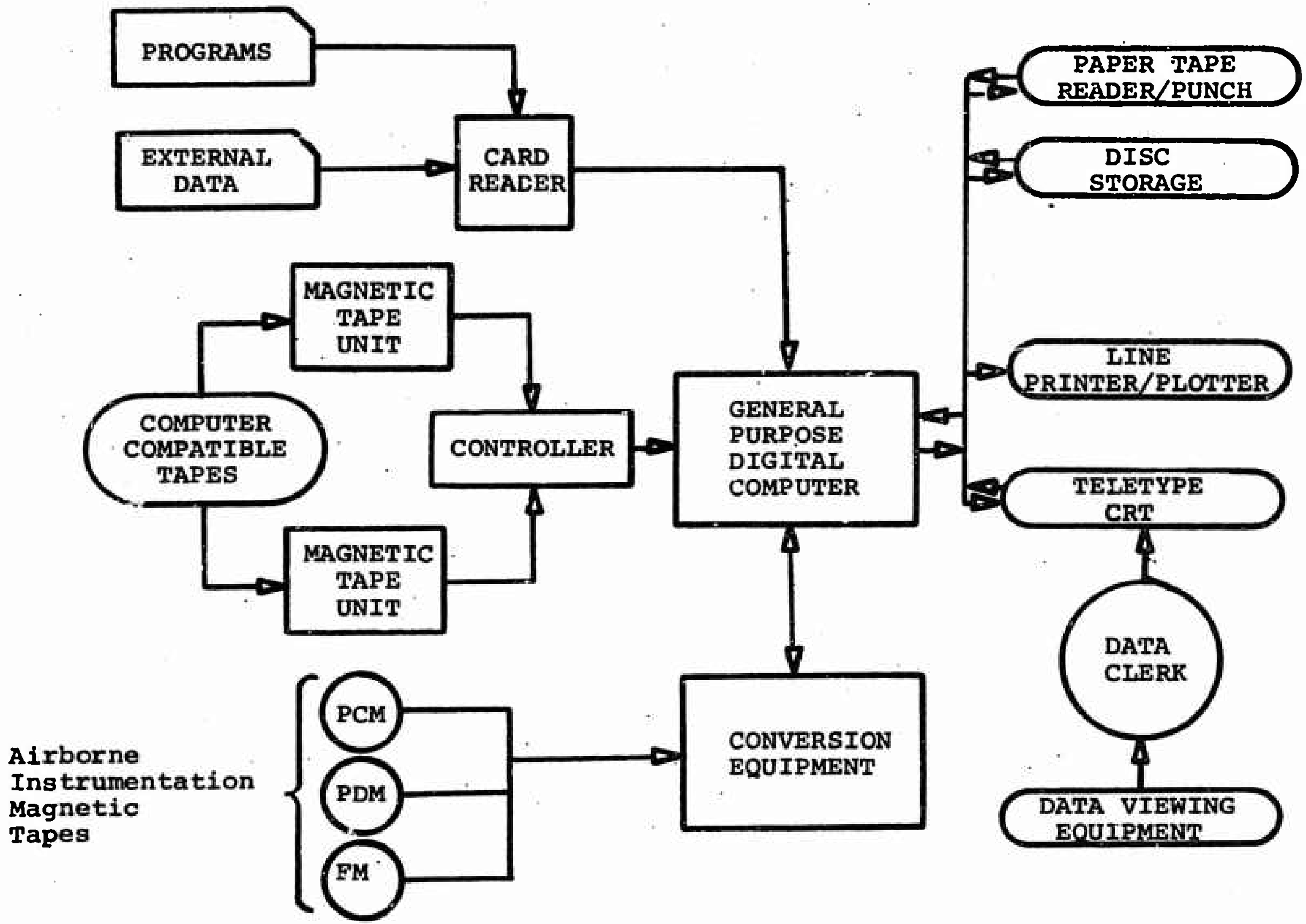


Figure 12. Dedicated Measurement Processing Facility.

(1) Executive Monitor. The Executive Monitor supervises all input/output and initiates all programs. In addition to its own operating system and housekeeping routines, the monitor should call at least seven utility programs: (1) the text editor is used to create or change files, (2) the file manipulator is used to perform file operations such as transfer, rename, segment, combine, delete, verify, and copy, (3) the FORTRAN IV compiler is used for the generation of most performance measurement programs, (4) the machine language assembler provides a machine-language capability for user programs, FORTRAN-callable subroutines, and special-purpose I/O operations, (5) the loader is commonly required to enter binary object programs into computer memory and start their execution, (6) the debug supervisor is used for the diagnosis and correction of new programs while they are executed, and (7) chain and execution features permit segmentation and execution of programs which would be otherwise too large to reside in computer core memory.

(2) Measurement processing software. As shown in Figure 13 there are five stages of performance measurement processing: (1) ACQUIRE DATA, (2) INPUT, (3) EDIT, (4) MEASURE TRANSFORMATION, and (5) ANALYSIS. Each stage requires input control information and performance data (left-hand side of Figure 13), and produces needed output (right-hand side of Figure 13).

The ACQUIRE DATA stage reads paper tape into computer-controlled files (such as a test, auditory and video/photo data) and allows preliminary editing. A label file is created through the keyboard. The system test editor is used for this purpose.

INPUT arranges and labels the file records in standard form, scales and calibrates data, extracts magnetic tape control information from all files, and reads the external magnetic tapes into a file. All data files which will be subjected to numerical analysis will be formatted in a standard manner consisting of: (1) a label identifying the data and indicating the number of words of data to follow, and (2) a variable size data array.

Raw data files are tested for error in EDIT, where final corrections are made and data are placed into the data bank. EDIT should include the capability to correct (1) numeric data within a record, (2) labeling data within the label record, (3) record manipulations such as combining, splitting and deleting records from the file. EDIT is a man-computer interactive program which requires the operator to make data corrections on-line with the computer. For example, errors will be automatically flagged according to specified criteria, then upon a keyboard command one of the following options will be performed: (1) replace the number with the average of the preceding and following numbers, (2) replace the number with a linear fit of the preceding two numbers or the following two numbers, (3) type in a number, (4) delete the datum, or (5) delete the error flag indicating the datum is correct.

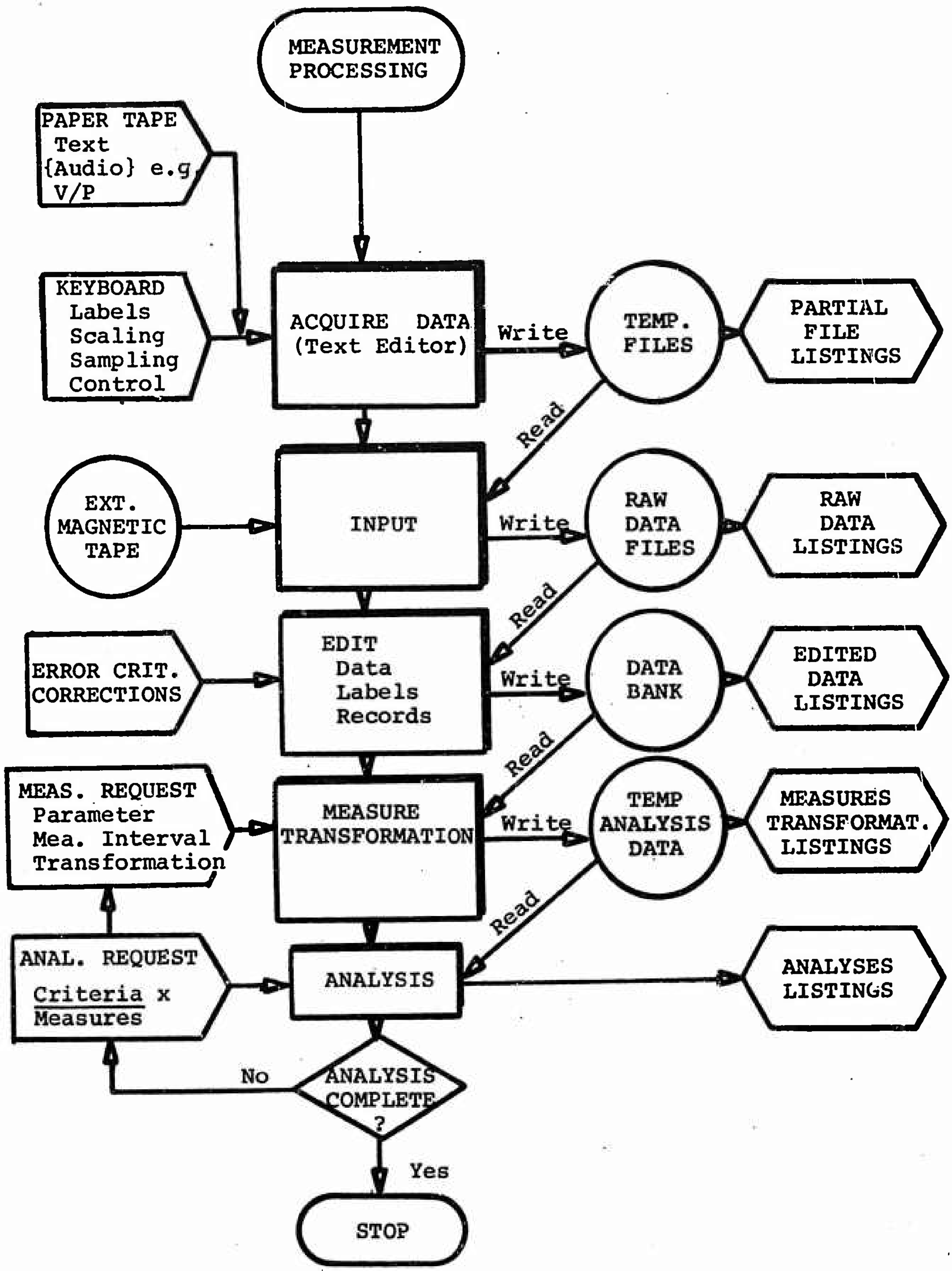


Figure 13. Measurement Processing Functions.

Following operator directions, measures are calculated in MEASURE TRANSFORM and placed into a temporary analysis file. Raw data is read from the data bank and converted into specific measures based on instructions contained in a measurement request file. The research scientists will formulate the measurement request file for trial data, receive preliminary output, and iteratively change the file until the desired transformations evolve.

ANALYSIS routines read the measures and perform operator-directed analyses. ANALYSIS is a library of statistical programs specially tailored to the research requirements; these are general purpose programs extensively modified for easy use in training research. (e.g., include tests of f-ratios, clear labeling of results, etc.)

Hard copy is available at each of the five stages of processing.

Personnel Subsystem

It is possible to identify six skill types needed for effective operation of the performance measurement system: (1) a system director, (2) research personnel, (3) a computer programmer, (4) data clerks, (5) engineers and technicians, and (6) a secretary. A general job description can be given for each of these skill classes.

System director. One individual must be responsible for management and supervision of the operating system. As the success of a system of this type depends to a very large extent upon careful planning and continuous control, much depends upon this individual. All levels of manloading contemplated require that this individual also serve as lead experimenter for data collection from one flight per day. Among other skills, this individual is expected to have knowledge and experience concerning (1) combat mission flying for all appropriate aircraft types, (2) military flight training procedures, (3) applied experimental design, (4) computer data processing, and (5) data analysis, interpretation, and report preparation.

Research personnel. Trained scientific personnel are necessary to support all phases of the performance measurement processing ranging from experimental planning, conduct of experimental studies, to final report preparation. During the actual conduct of experimental studies, the research specialist will be present at mission briefings to extract necessary information relevant to performance measurement. In some cases, he will be expected to serve as an inflight experimenter. The research specialist will be responsible for supervision of data processing for his assigned flights, and may perform measurement debriefings for instructor and student pilots. The research specialist is expected to be a graduate behavioral scientist with knowledge in depth of military missions and flight training as well as applied behavioral experimentation.

Computer programmer. The data processing subsystem recommended provides generalized software with the assumption that unique programming for each individual study will be required. This approach offers the greatest flexibility and overall effectiveness for performance measurement. It requires, however, the presence of a computer programmer both to set the specific study software and to insure that the data processing programs are running properly. For inflight and simulator experimentation, this skill type has consistently proven to be an essential member of the experimental team.

Data clerk. The data acquisition subsystem provides a heterogeneous set of input data which must be processed by data clerks. Personnel tasks are required for manual data processing of video, digital, audio, and photo raw data. With video, photo or audio data, the end product from the data clerks is a punched paper tape. In the actual procedure, two types of data clerks are assumed: (1) clerks for video, audio, and photo raw data extraction and (2) teletype operators to prepare the final punched tape.

Engineers and technicians. It is possible to identify three types of engineers and technicians necessary for equipment operation and maintenance tasks: (1) checkout, calibration, and maintenance of airborne (or simulator) data acquisition equipment, (2) operation and maintenance of ground data processing equipment, and (3) utilization of photo, video, and audio equipment in the mobile ground facilities.

Secretary. A secretary will be required for a myriad of support tasks such as scheduling, report typing, and assisting in data collection and processing when needed.

Estimated personnel requirements. Table 9 presents a summary of the estimated personnel requirements for the performance measurement system as a function of (1) skill types, (2) number of flights per day from one to four, and (3) two levels of data acquisition subsystem complexity. The full audio-video-photo-digital hybrid recording system has been assumed here as one case, and is termed the "complete system;" for purposes of comparison, a "minimal system" consisting of a single audio/video recording system, or a single cockpit camera plus audio recording, is also included.

These estimates only apply to the inflight experimentation case. A somewhat different pattern for personnel requirements develops for flight simulator performance measurement, and total personnel requirements are reduced as the number of flights per day increases to four. However, the availability of only one simulator is assumed, eliminating the possibility of simultaneous flights, but creating the same output for data processing.

TABLE 9

ESTIMATED PERSONNEL REQUIREMENTS

SKILL CATEGORY	COMPLETE SYSTEM: FLIGHTS/DAY				MINIMAL SYSTEM: FLIGHTS/DAY			
	1	2	3	4	1	2	3	4
System Director	1	1	1	1	1	1	1	1
Research Personnel	0	1	2	3	0	1	2	2
Programmer	0	0	0	1	0	0	0	1
Data Clerks								
(1) Data Transcription	1	1	2	2	1	1	1	1
(2) TTY Tape Punch	1	1	1	2	0	0	1	1
Engineer/Technician								
(1) A/B Engineer	1	1	2	2	0	0	0	0
A/B Technician	1	2	3	4	1	1	2	2
(2) Comp. Technician	1	1	1	1	1	1	1	1
(3) Equip. Technician	1	1	2	2	1	1	1	1
Secretary	1	1	2	2	1	1	1	1
Sum	7	9	15	19	5	6	10	11

Facilities

As the performance measurement system undoubtedly would be required to function at more than one combat-crew training site, and since the time for equipment set-up involves high costs and zero productivity in terms of research objectives, it is recommended that the performance measurement system be housed in a mobile facility. The mobile facility would be required to house: (1) post-flight debriefing rooms, (2) data processing equipment, (3) office space for technical personnel, (4) work area for equipment technicians, (5) work area for supporting personnel, (6) storage area for records and data, and (7) restroom facilities.

These facilities could be mounted in several truck-drawn trailers or in one or two large mobile-home trailers devoid of interior partitions and furnishings (with the exception of restroom facilities). The mobile home trailer, with reinforced floor, is recommended for flexibility of equipment configurations, personnel organization, and functional utilization of available space.

These facilities can be housed in either one 12-foot wide by 60-foot long mobile home type of vehicle, or, more advisedly, in two such vehicles. Figure 5 suggests a possible configuration for two vehicles; the one-trailer layout severely limits debriefing, office, storage and work space.

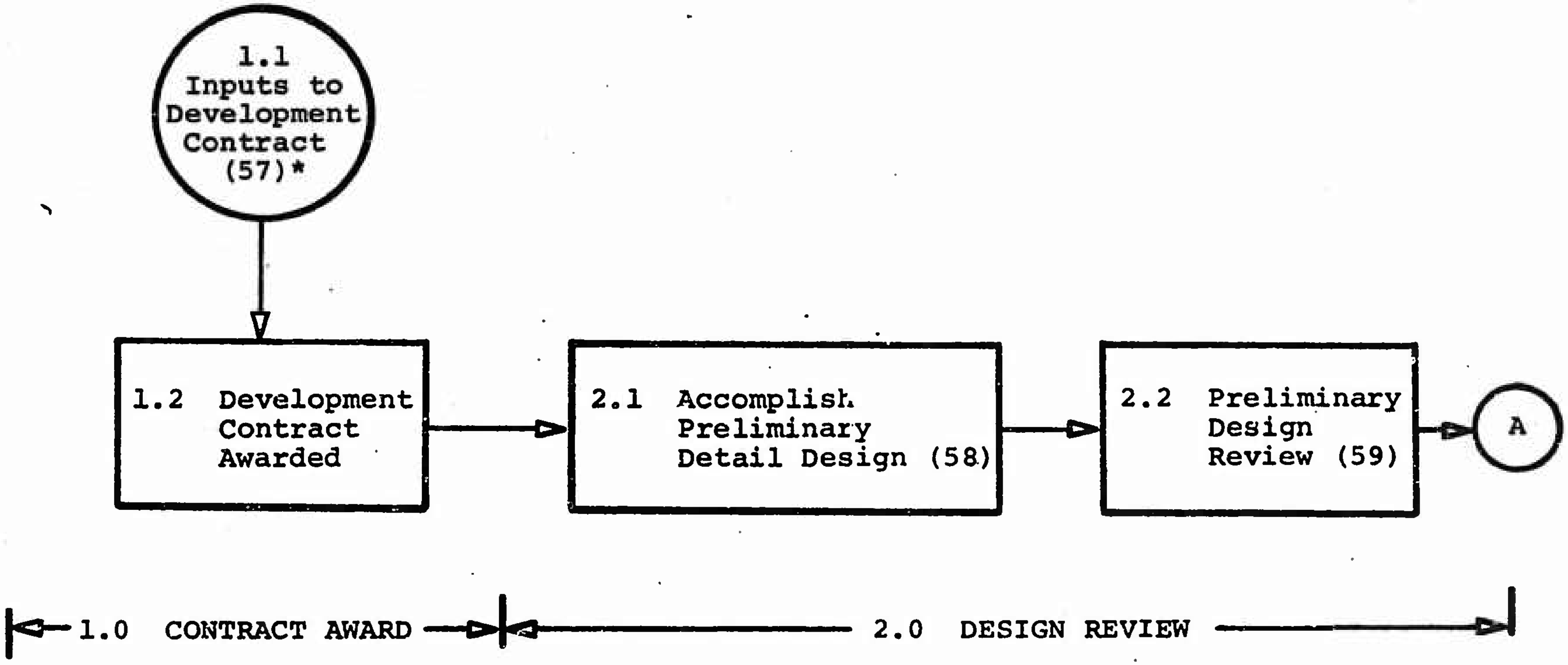
IV. FUTURE DEVELOPMENT OPPORTUNITIES

Opening a new flow of information can have a major influence on training technology. The execution of effective contemporary training, the development of new training devices, and the exploitation of powerful concepts such as adaptive training and learner-centered instruction, all depend on information available through performance measurement. Better performance information is also needed to realize the benefits of investments already made in other areas; for example, the fidelity of flight simulators has surged in the last decade, but performance measurement to convert the simulator into an effective training tool has not made corresponding advances. The role of performance measurement may be that of a causal input, a catalyst, or a weak link in a system chain, but the net effect of better performance measurement in any case is a positive and possibly revolutionary improvement.

What stands in the way of improvements through performance measurement? The major difficulty at present is that adequate performance measurement systems do not exist where needed. The present study has defined a blueprint for measurement in a manner permitting adaptation to specific needs and budgets. The opportunity for future performance measurement is, therefore, available. Recent developments indicate a change in the proper direction. For example, the Air Force is developing an Advanced Simulator for Undergraduate Pilot Training (ASUPT), and an Air Combat Maneuvering Range (ACMR). Both permit measurement on a large scale.

The status of combat-crew measurement and other areas of complex man-machine performance is reflected by the measurement analysis presented in this report (Chapter II). The measurement described here reflects the evident and critical dimensions of performance, and, corresponding to the initial study strategy, agrees with the measurement structure used by operational training personnel. Given this measurement capability a number of future advances are possible. First, use of this measurement will lead to efficient interim and immediately available measurement for training. Second, improvements in the generation of optimally efficient measurement sets may be expected. The clarification of the relationship between objective and subjective measurement should be possible. None of these results is going to occur without an acceptable performance measurement system and appropriate experimentation.

A number of avenues can be taken to the implementation of the measurement system described in this report. An especially effective and thorough method is shown in Figure 14 based on the methodological steps used for the acquisition of large weapon systems (AFSCM 375-5). This system management methodology is the result of extensive experience, and is generally as applicable to small systems as to large ones (in this case, scaled-down as appropriate).



*Parenthetical numbers refer to the applicable block numbers in the AFSCM 375-5 methodology.

Figure 14. Measurement System Implementation Plan.

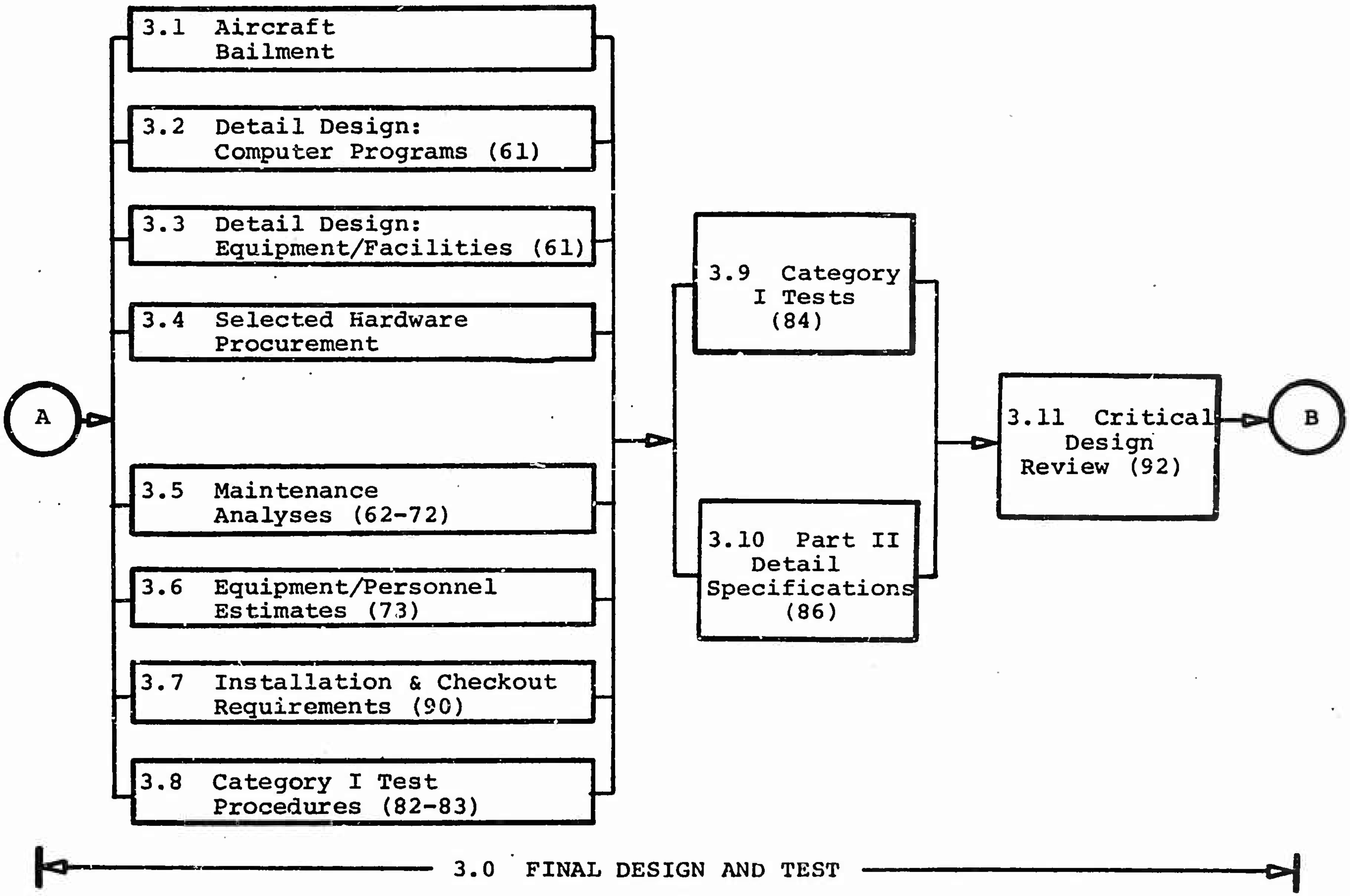


Figure 14 - (continued).

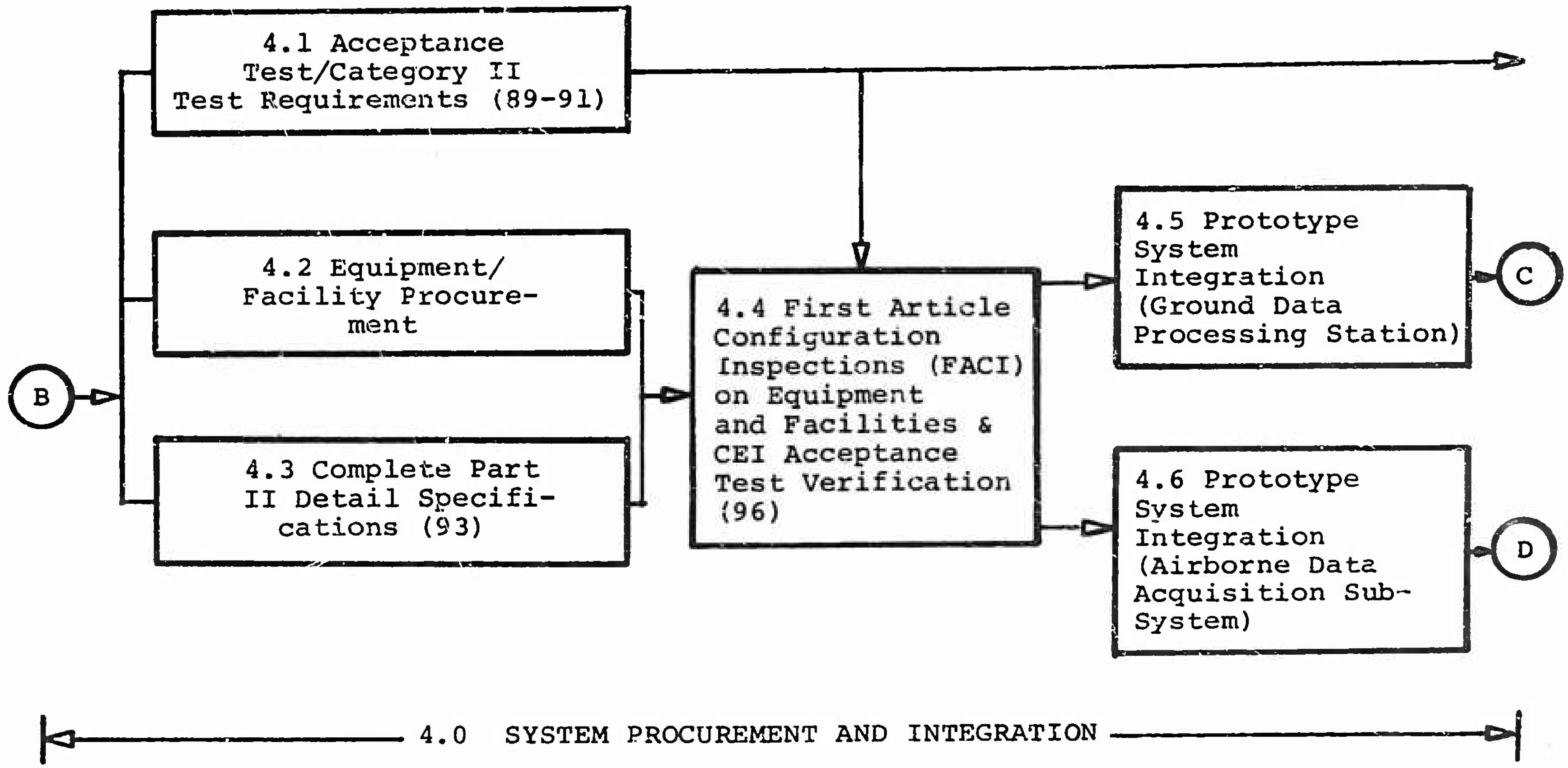


Figure 14 - (continued).

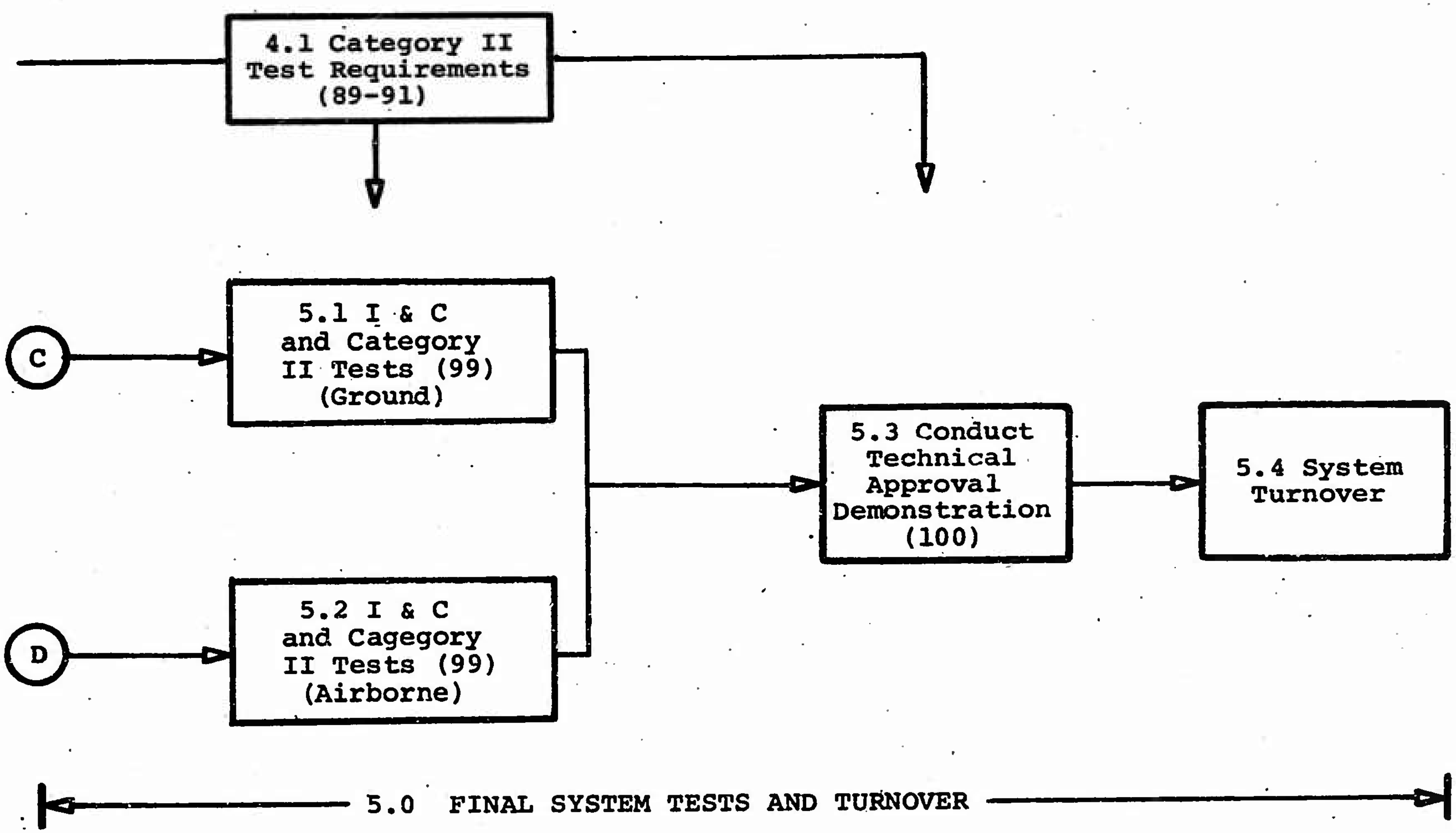


Figure 14 - (continued).

It is assumed that a system integration contractor is available to control system acquisition under the direction of the Air Force. The results of the present study may be used as the essential inputs for the development contract (Figure 14, Step 1.1). After selection of the system integration contractor, final detailed design is accomplished prior to hardware and software selection. The machinery exists, for example, to select tradeoff alternatives such as the most effective of the off-the-shelf video recording equipment. Large expenditures for hardware procurements can be avoided until critical design, analysis, and test information is available. A specific adaptation of the normal Category II tests can be achieved so that the tests can be performed while collecting research data in the combat-crew training environment and while personnel are trained to carry out the designated research mission.

A schedule for the acquisition, test, and development of a specific performance measurement system is presented in Figure 15. To exploit fully the benefits of the developmental framework recommended, a 28-month period is judged to be necessary.

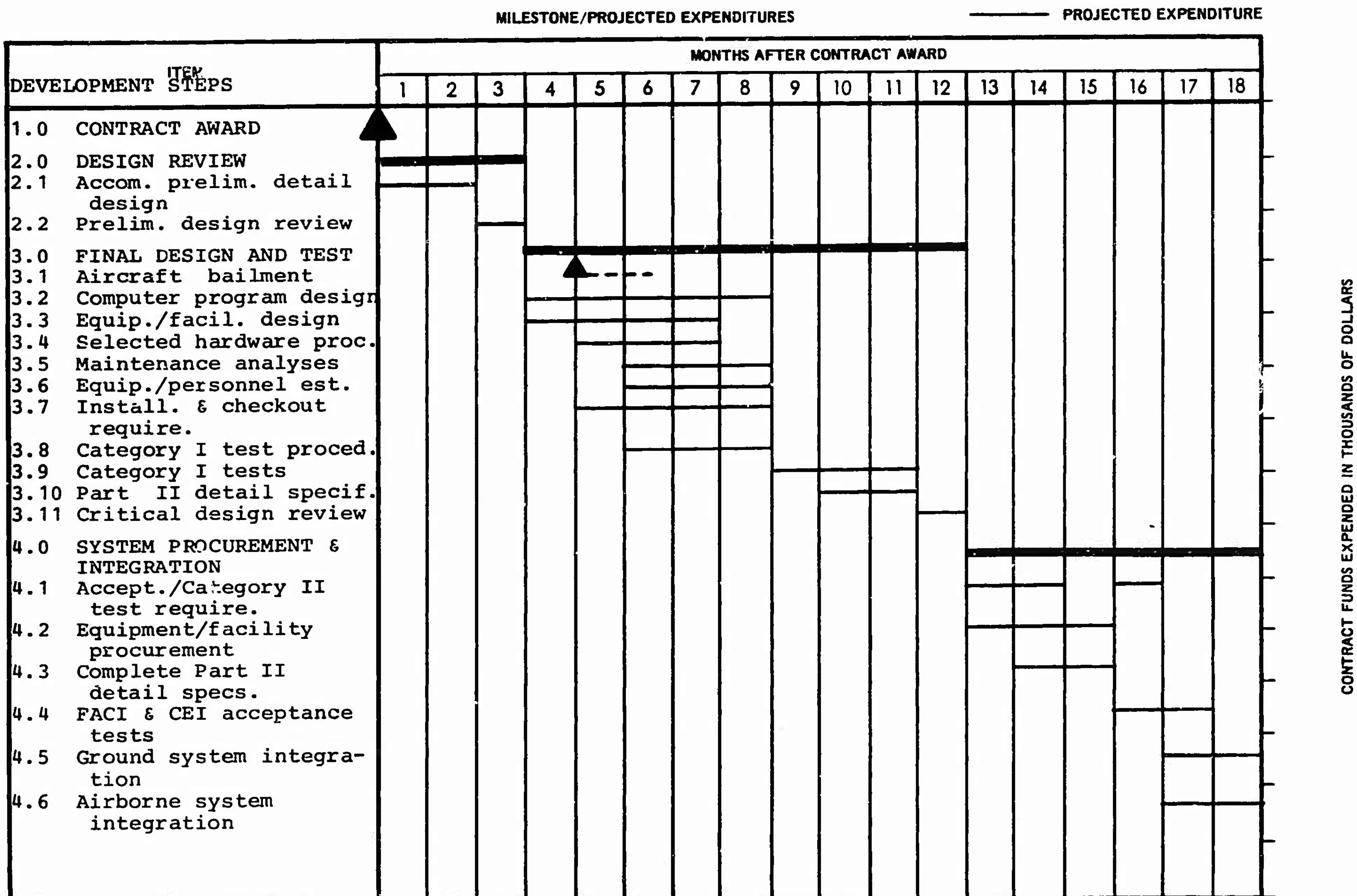


Figure 15. Measurement System Implementation Plan Schedule.

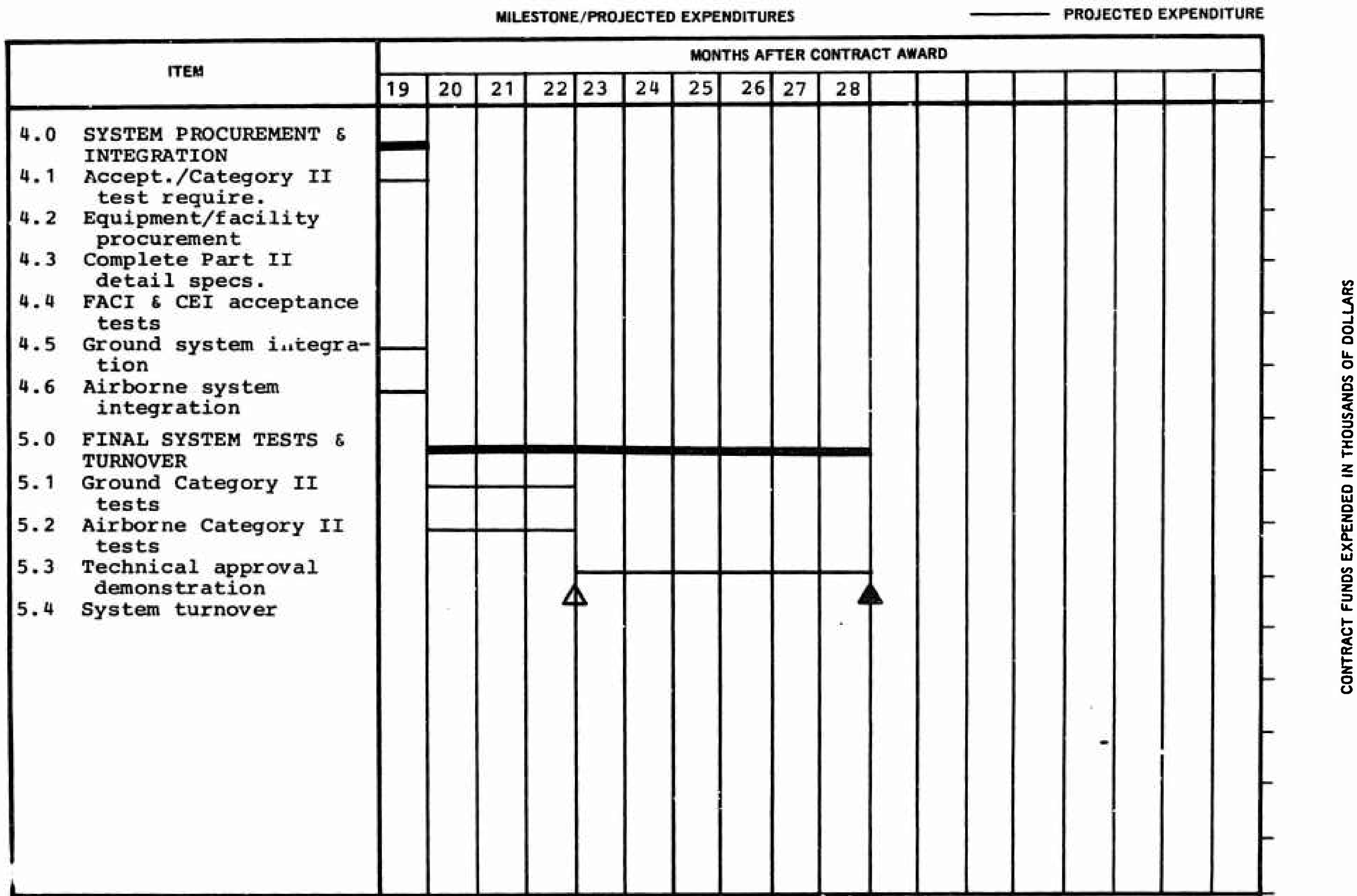


Figure 15 - continued.

REFERENCES

Department of the Air Force, Headquarters, USAF Tactical Fighter Weapons Center. TAC Test 69-4F, Audio-Video Recording System (AVRS). Headquarters, USAF Tactical Fighter Weapons Center, Nellis AFB, Nevada 89110, 23 September 1970.

Department of the Air Force, Headquarters, U.S. Air Force. Instructional System Development. A.F. Manual 50-2, Headquarters, U.S. Air Force, Washington, D.C., 31 Dec 1970.

Department of the Air Force, Headquarters, USAF Tactical Fighter Weapons Center. A-7D Airborne Video Recording System (AVRS). TAC-TR-70A-113F, USAF Tactical Fighter Weapons Center, Nellis AFB, Nevada 89110, February 1971.

Fitzgerald, J.A., and Moulton, D.L. Evaluation of Airborne Audio-Video Recording as a Tool for Training in the A-7D Tactical Fighter. AFHRL-TR-72-55, AD-744 041. Williams AFB, AZ.: Flying Training Division, Air Force Human Resources Laboratory, October 1971.

United States Air Force Systems Command Manual, "Systems Engineering Management Procedures," AFSCM 375-5, 10 March 1966.